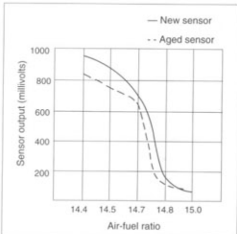
1988–1993

Ford Fuel Injection & Electronic Engine Control

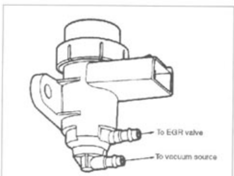
How to Understand, Service, and Modify

Identifying your engine's fuel injection and engine control systems—Chapter 1



How your engine control system works, and why it may not—Oxygen sensor: Chapter 4

Modifications to give your engine more power—Chapter 9



Component identification and location —Chapter 10

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Foreword

Author Charles O. Probst, SAE

Did you know that, in most Ford engine-control systems:

- The computer is continuously learning about how the engine is operating, and continuously adapting to the individual car and driver, the engine condition, the fuel in the tank, and the driving style.
- The computer keeps track of the small electric currents that control the engine, monitoring the signals to see they are operating properly. If any signal strays from the prescribed limits, the computer can guide diagnosis and troubleshooting of the problem.
- The control system can operate 120 times per second to manage the fuel injection and the ignition timing, sometimes modifying the control for each cylinder, all at 7200 rpm.

What does this mean to those who read this book?

For those of you who service the engine-control systems, it means satisfying your customers the first time, reducing costly come-backs. Knowing about the fundamentals and the operation of Ford systems, you will make sense of the trouble codes so you can troubleshoot with the least hassle.

For those of you who drive these cars, you will have more operating satisfaction and confidence. You will know how the engine operates under normal conditions. You will learn that the engine control system can handle minor failures until service; it can even "limp home" with most major failures.

As an automotive engineer who has spent most of my career in technical training, I write to simplify the explanations of these complex systems by providing considerable detail within a straightforward structure. I write with a wide range of experience including: showing Ford dealers how to detail a used car, showing the astronauts how to drive the Rover on the Moon, and developing service training for fuel-injection technicians.

Within the pages of this book I hope to tell you everything you always wanted to know about Ford EEC-III and EEC-IV Electronic Engine Control, so that you can get the most out of Ford systems.

Charles O. Probst

Glossary: 1993 and Later

To improve servicing, all manufacturers have worked with SAE (the Society of Automotive Engineers) to create common terms that apply to the same part from different manufacturers. Because of this, some of the terminology you see from 1993 on may differ from that used on 1988–92 vehicles. Where revised terminology is different it is listed under the column "Old Term." For a complete listing of 1988–1992 terminology see the inside front cover. This page lists Ford component and system terminology for 1993 models.

1993 and Later Terminology

Acronym	1993 and Later Term	Old Term
ACC	Air Conditioning Clutch	
ACD	Air Conditioning Demand	
ACON	Air Conditioning On	
AIR	Secondary Air Injection	AM, CT, MTA
AIRB	Secondary Air Injection Bypass	AM1, TAB
AIRD	Secondary Air Injection Diverter	AM2, TAD
BARO	Barometric Pressure	BP
B+	Battery Positive Voltage	BATT+
BOO	Brake On/Off	
BPA	Bypass Air	
CAC	Charge Air Cooler	Intercooler
CANP	Canister Purge	
CCD	Computer Control Dwell	DI
CCRM	Constant Control Relay Module	IRCM
CID	Cylinder Identification	
CKP	Crankshaft Position Sensor	CPS, VRS
DI	Distributor Ignition	CBD, TFI
DLC	Data Link Connector	Self-Test connector
DOHC	Dual Overhead Cam	
DOL	Data Output Line	
DPFE	Delta Pressure Feedback EGR	
DPI	Dual Plug Inhibit	
DRL	Daytime Running Lamps	
DTM	Diagnostic Test Mode	Self-Test mode
DTC	Diagnostic Trouble Code	Self-Test code
EAP	Electronic Air Pump	
ECT	Engine Coolant Temperature	
EEC	Electronic Engine Control	
EGR	Exhaust Gas Recirculation	
EGRT	EGR Temperature	
EI (low data rate, high data rate)	Electronic Ignition	DIS EDIS
EPT	EGR Pressure Transducer	
EVP	EGR Valve Position	
EVR	EGR Vacuum Regulator	
FC	Fan Control	EDF
FF sensor	Flexible Fuel sensor	
FFV	Flexible Fuel Vehicle	
FP	Fuel Pump	
FPM	Fuel Pump Monitor	
FPRC	Fuel Pressure Regulator Control	
GND	Ground	
HDL	Headlamp	
HFC	High Fan Control	HEDF
HFP	High Fuel Pump	
HO	High Output	
HO2S	Heated Oxygen Sensor	HEGO
HSC	High Swirl Combustion	
IAC	Inlet Air Control	ISC
IAC BPA	Idle Air Control Bypass Air	ISC-BPA
IAT	Intake Air Temperature	ACT
ICM	Ignition Control Module	DIS Module EDIS Module TFI Module
IDM	Ignition Diagnostic Monitor	
IFS switch	Inertia Fuel Shutoff Switch	IS
IMRC	Intake Manifold Runner Control	IAC

1993 and Later Terminology (cont'd)

Acronym	1993 and Later Term	Old Term
KAM	Keep Alive Memory	
KAPWR	Keep Alive Power	
KS	Knock Sensor	
LFC	Low Fan Control	EDF
LFP	Low Fuel Pump	
MAF	Mass Air Flow	
MAP	Manifold Absolute Pressure	
MECS	Mazda Engine Control System	
MFI	Multiport Fuel Injection	EFI
MIL	Malfunction Indicator Light	CEL
MLP	Manual Lever Position	
OC	Oxidation Catalytic Converter	COC
OCT ADJ	Octane Adjust	
OHC	Overhead Cam	
PAIR	Pulsed Secondary Air Injection	MPA, PA
PCM	Powertrain Control Module	ECA, ECM, ECU
PCV	Positive Crankcase Ventilation	
PFE	Pressure Feedback EGR	EPT
PIP	Profile Ignition Pickup	
PNP switch	Park/Neutral Position Switch	NDS NGS
PSOM	Programmable Speedometer/ Odometer Module	
PSP switch	Power Steering Pressure Switch	PSPS
PWR GND	Power Ground	
REDOX	Reduction Oxidation Catalytic Converter	
SC	Supercharger/Supercharged	
SD	Speed Density	
SFI	Sequential Multiport Fuel Injection	SEFI
SHO	Super High Output	
SIG RTN	Signal Return	
SIL	Shift Indicator Light	
SPOUT	Spark Output	SAW, SPOUT
SS	Shift Solenoid	
STI	Self-Test Input	
STO	Self-Test Output	
TB	Throttle Body	
TBI	Throttle Body Injection	CFI
TC	Turbocharger/Turbocharged	
TCC	Torque Converter Clutch	CCC, CCO
TCC solenoid	Torque Converter Clutch Solenoid	LUS, MLUS
TCM	Transmission Control Module	4EAT module
TCS	Transmission Control Switch	
TOT	Transmission Oil Temperature	
TP	Throttle Position	
TRD	Transmission Range Drive	
TROD	Transmission Range Overdrive	
TRL	Transmission Range Low	
TRR	Transmission Range Reverse	
TSS	Transmission Speed Sensor	TSS
TWC	Three-way Catalytic Converter	
VAF	Volume Air Flow	
VCRM	Variable Control Relay Module	IRCM
VPWR	Vehicle Power	
VREF	Voltage, Reference	
VSS	Vehicle Speed Sensor	
WOT	Wide Open Throttle	

Please read these warnings and cautions before proceeding with maintenance and repair work.

WARNING—

- Some repairs may be beyond your capability. If you lack the skills, tools and equipment, or a suitable workplace for any procedure described in this manual, we suggest you leave such repairs to an authorized dealer service department, or other qualified shop.

- Manufacturers are constantly improving their cars. Sometimes these changes, both in parts and specifications, are made applicable to earlier models. Therefore, before starting any major jobs or repairs to components on which passenger safety may depend, consult your authorized dealer about Technical Bulletins that may have been issued since the editorial closing of this book.

- Do not re-use any fasteners that are worn or deformed in normal use. Many fasteners are designed to be used only once and become unreliable and may fail when used a second time. This includes, but is not limited to, nuts, bolts, washers, self-locking nuts or bolts, circlips and cotter pins. Always replace these fasteners with new parts.

- Never work under a lifted car unless it is solidly supported on stands designed for the purpose. Do not support a car on cinder blocks, hollow tiles or other props that may crumble under continuous load. Never work under a car that is supported solely by a jack. Never work under the car while the engine is running.

- If you are going to work under a car on the ground, make sure that the ground is level. Block the wheels to keep the car from rolling. Disconnect the battery negative (–) terminal (ground strap) to prevent others from starting the car while you are under it.

- Never run the engine unless the work area is well ventilated. Carbon monoxide kills.

- Finger rings, bracelets and other jewelry should be removed so that they cannot cause electrical shorts, get caught in running machinery, or be crushed by heavy parts.

- Tie long hair behind your head. Do not wear a necktie, a scarf, loose clothing, or a necklace when you work near machine tools or running engines. If your hair, clothing, or jewelry were to get caught in the machinery, severe injury could result.

- Do not attempt to work on your car if you do not feel well. You increase the danger of injury to yourself and others if you are tired, upset or have taken medication or any other substance that may keep you from being fully alert.

- Illuminate your work area adequately but safely. Use a portable safety light for working inside or under the car. Make sure the bulb is enclosed by a wire cage. The hot filament of an accidentally broken bulb can ignite spilled fuel or oil.

- Catch draining fuel, oil, or brake fluid in suitable containers. Do not use food or beverage containers that might mislead someone into drinking from them. Store flammable fluids away from fire hazards. Wipe up spills at once, but do not store the oily rags, which can ignite and burn spontaneously.

- Always observe good workshop practices. Wear goggles when you operate machine tools or work with battery acid. Gloves or other protective clothing should be worn whenever the job requires working with harmful substances.

- Disconnect the battery negative (–) terminal (ground strap) whenever you work on the fuel system or the electrical system. Do not smoke or work near heaters or other fire hazards. Keep an approved fire extinguisher handy.

- Batteries give off explosive hydrogen gas during charging. Keep sparks, lighted matches and open flame away from the top of the battery. If hydrogen gas escaping from the cap vents is ignited, it will ignite gas trapped in the cells and cause the battery to explode.

- Connect and disconnect battery cables, jumper cables or a battery charger only with the ignition switched off, to prevent sparks. Do not disconnect the battery while the engine is running.

- Do not quick-charge the battery (for boost starting) for longer than one minute. Wait at least one minute before boosting the battery a second time.

- Do not allow battery charging voltage to exceed 16.5 volts. If the battery begins producing gas or boiling violently, reduce the charging rate. Boosting a sulfated battery at a high charging rate can cause an explosion.

- Some cars covered by this book may be equipped with a supplemental restraint system (SRS) that automatically deploys an airbag in the event of a frontal impact. The airbag is inflated by an explosive device. Handled improperly or without adequate safeguards, it can be accidently activated and cause serious injury.

- Greases, lubricants and other automotive chemicals contain toxic substances, many of which are absorbed directly through the skin. Read manufacturer's instructions and warnings carefully. Use hand and eye protection. Avoid direct skin contact.

CAUTION—

- Manufacturers offer extensive warranties, especially on components of fuel delivery and emission control systems. Therefore, before deciding to repair a car that may still be covered wholly or in part by any warranties issued by the manufacturers, consult your authorized dealer. You may find that he can make the repair for free, or at minimal cost.

- Part numbers listed in this manual are for identification purposes only, not for ordering. Always check with your authorized dealer to verify part numbers and availability before beginning service work that may require new parts.

- Before starting a job, make certain that you have all the necessary tools and parts on hand. Read all the instructions thoroughly, do not attempt shortcuts. Use tools appropriate to the work and use only replacement parts meeting manufacturer specifications. Makeshift tools, parts and procedures will not make good repairs.

- Use pneumatic and electric tools only to loosen threaded parts and fasteners. Never use these tools to tighten fasteners, especially on light alloy parts. Always use a torque wrench to tighten fasteners to the tightening torque specification listed.

- Be mindful of the environment and ecology. Before you drain the crankcase, find out the proper way to dispose of the oil. Do not pour oil onto the ground, down a drain, or into a stream, pond or lake. Consult local ordinances that govern the disposal of wastes.

- On cars equipped with anti-theft radios, make sure you know the correct radio activation code before disconnecting the battery or removing the radio. If the wrong code is entered into the radio when power is restored, that radio may lock up and be rendered inoperable, even if the correct code is then entered.

- Connect and disconnect a battery charger only with the battery charger switched off.

- Do not quick-charge the battery (for boost starting) for longer than one minute. Wait at least one minute before boosting the battery a second time.

- Sealed or "maintenance free" batteries should be slow-charged only, at an amperage rate that is approximately 10% of the battery's ampere-hour (Ah) rating.

- Do not allow battery charging voltage to exceed 16.5 volts. If the battery begins producing gas or boiling violently, reduce the charging rate. Boosting a sulfated battery at a high charging rate can cause an explosion.

Chapter 1

Ford Electronic Engine Control—An Overview

1

Contents

1. INTRODUCTION

Ford Motor Company was not the first U.S. company to offer fuel injection, but Ford is the first to go all the way, with virtually 100% fuel injection in passenger cars and trucks since 1987.

Did I say virtually 100%? Ford police cruisers with big 5.7 liter engines are the only carburetor cars in the recent Ford lineup. Ford Taurus police cruisers with 3.8L engines use electronically-controlled fuel injection.

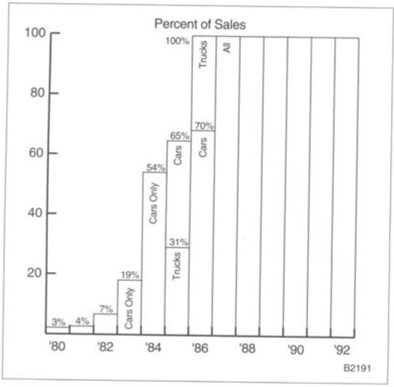

Fig. 1-1. Ford Motor Company is the first U.S. manufacturer to apply fuel injection to all cars and trucks, virtually 100% since 1987.

By 1988, most Ford engines inject the fuel to each individual cylinder intake-port, known as Multiport Fuel Injection (MFI). In this book, I'll concentrate on MFI. You'll find Ford references to this as EFI (Electronic Fuel Injection). I'll use "port injection" to refer to systems that inject at the intake port. Both Mazda Engine Control Systems (MECS), and Nissan Electronic Concentrated engine Control Systems (NECCS—used on the Villager) employ port injection. As late as 1989, a few small Ford engines were still using Central Fuel Injection (CFI), but these are not covered by this book.

1.1 What's in this book

Preview of Chapter 1—Overview

Chapter 1 introduces the idea of fuel injection and engine control, and tells you why Ford cars and trucks use fuel injection. I'll give you the broad picture of Ford fuel-injection systems, and the two main control systems, determined by where the powerplant is engineered:

Fig. 1-2. MFI (Multiport Fuel Injection) is often hidden by manifold runners (arrow).

Ford Electronic Engine Control	Mazda Engine Control System
EEC (say "eek")	MECS (say "mex")
NAAO—North American Auto Operations	Non-NAAO—Non-North American Auto Operations

A third system, Nissan Electronic Concentrated engine Control System (NECCS) operates beginning in the 1993 Mercury Villager. It has a relatively small population, but I'll mention the most significant differences.

All Ford systems include more than fuel metering. They control:

- Fuel injection
- Ignition timing (spark control)
- Some emission systems
- Idle rpm
- Intake air control
- Boost control

You'll also see the different types of fuel injection applied to Ford vehicles:

- MFI (Multiport Fuel Injection), also known as Electronic Fuel Injection (EFI)
- SFI (Sequential Multiport Fuel Injection), also known as Sequential Electronic Fuel Injection (SEFI)

- Mazda Engine Control Systems (MECS) applied to engines imported from Mazda. MECS-I used on 2.2L Probes, some Escorts and Tracers, Capris, and Festivas. "MECS-II" is my term for those 1993 and later engines with an advanced engine control system, closer to EEC

Preview of Chapter 2—Fundamentals

Chapter 2 will help you understand the fundamentals—the principles behind fuel injection and engine control. Some people regard fundamentals as dry theory, but I think you'll find this valuable if you are going to do even simple diagnostics and troubleshooting. Engine control systems are necessarily complex, and you cannot hope to perform successful troubleshooting if you only go by the numbers without understanding what they mean.

I'll discuss different engine needs to satisfy the driver for each driving condition—a broad picture of engine control. I'll discuss each operating mode and the different strategies of engine control. You'll see the intricate relationships among fuel metering, ignition timing, throttle-air bypass (idle-speed control), and emission controls. Different conditions are sensed as input to the computer, and output to the injectors and other actuators of the powertrain system.

Pressure is one of the most important factors in understanding fuel injection. I'll spend some time on the many different air pressures and fuel pressures in fuel injection, and the different units of measure that you will deal with and compare.

Preview of Chapter 3—Emissions and Alternate Fuels

Government standards for emissions and fuel economy are becoming increasingly important to save fuel and clean air, and to preserve the global environment. As you read this, Ford and other car makers are working to meet mandated fuel-economy standards and tighter emission limits for the 1990's. You'll see how computerized engine control is the only way to meet those needs while still providing good power and driveability. Alternate fuels may affect current engines, or Ford Flexible Fuel vehicles, or dedicated Alternate Fuel vehicles.

Preview of Chapters 4–7—The Different Parts Of The Systems

In Chapters 4, 5, 6, and 7 I'll show you how each part operates in the system. Many parts function similarly in EEC and MEC systems:

Sensors (Chapter 4) is the term generally applied to those parts that send signals to the computer, advising it of engine conditions, such as engine-coolant temperature.

Control Module (Chapter 5). Electronic Control Assembly (ECA) is the Ford term for the computer that receives and analyzes the input signals from the sensors, calculates the necessary commands to the engine, and sends control signals to the actuators.

Actuators (Chapter 6) is the term generally applied to those parts, such as fuel injectors, that are controlled by signals from the computer.

1

Fuel Delivery systems (Chapter 7) describes the different electric fuel pumps, filters, regulators and controls to get the pressurized fuel to the injectors.

If you don't really need to know the details of such things as a coolant-temperature sensor, use Chapters 3–7 for reference and move on.

Preview of Chapter 8—Strategies

In Chapter 8, I'll show how the complete engine control systems combine the components to satisfy the needs described in each mode of Chapter 2.

Specifically, I'll describe how each different engine condition—cruising, cranking, wide-open throttle—is monitored by the sensors, computed by the control module and is satisfied by the control signals to the injectors and other actuators.

Preview of Chapter 9—Tuning For Performance and Economy

In Chapter 9, for those who want more power from their engine-control system, I'll show you many different modifications for street-legal use or for off-road use. I'll discuss which ones are likely to work—and those probably not worth your time and dollars. I'll show you the excellent support available from Ford Special Vehicle Operations (SVO) for street-legal or for off-road racing. Most engine-control systems as installed Original Equipment (OE) by Ford are capable (without modification) of delivering extra fuel for engine modifications that increase performance, but I'll look at what you can do to modify the system delivered by the dealer.

For you owners who can tweak a Mustang carburetor by ear with a screwdriver on Saturday afternoon, this book will help you accept the performance of fuel injection as it takes away the need for your carburetor skills. Even so, you can do a lot more to your fuel-injected car than most people realize. When you understand fuel injection/engine control, you will have a better chance to remain street-legal while you stretch system performance.

Preview of Chapter 10—Diagnosis and Troubleshooting

In Chapter 10, I'll discuss Diagnosis and Troubleshooting of control system problems. I'll cover the simple diagnostic routines and testing for the average owner. Many tests can be done by counting blinks of the Check Engine light, or by swings of an analog voltmeter. I'll include some troubleshooting for technicians, such as with a scan tool.

Scan tool is a generic term for a hand-held unit that connects to the engine control system to read trouble codes. In later model cars, the tool can read signals to and from the computer. Ford calls its early scan tools Self-Test Automatic Readout (STAR) and its later tool, SuperSTAR, which has more capabilities. More on that in Chapter 10.

Fig. 1-3. Scan tool is plugged into diagnostic connector to read trouble codes. Analog voltmeter can also be used. Reading trouble codes is essential to troubleshooting electronic engine control.

In many cases, you can do simple diagnosis and testing using only simple tools, a volt-ohmmeter (VOM) and a fuel-pressure gauge. Some have complained that these modern engines mean the end of the shade-tree mechanic. "Hoo boy, I'll never touch that baby," I've heard owners say as they peer underhood. After you've read this book, you won't be saying that.

Preview of Chapter 11—Servicing

In Chapter 11, I'll show some of the specific procedures, still without specialized tools. Owners can improve your dialog with service technicians. Even if you don't want to do much of the work yourself, you'll still know enough about troubleshooting and repairs to communicate with the technician who may use special tools to service your car. Whether you're DIY (Do It Yourself), or PIY (Pay It Yourself), you'll find value in these pages.

Preview of Chapter 12—Service Data

In Chapter 12, you'll find the technical data you need to aid you in your diagnosis and service: trouble code definitions, electrical tests of major components, and wiring diagrams.

1.2 Terminology

Before I begin the first chapter, a word about terminology. Car makers and the Society of Automotive Engineers (SAE) have heard the complaints from service technicians: the use of different names for the same part in different cars is a servicing headache.

The push for common terminology came for emission control reasons, both from the Environmental Protection Agency (EPA), and from the California Air Resources Board (CARB). One reason for excessive in-use emissions is the inability of many technicians to properly service modern electronic-controlled engines. Technicians have a hard time applying the training we are developing to diagnose emission-control problems because the same part could be called by different names and acronyms (initials). And the same acronym could mean two different parts!

Beginning in 1991, Ford and most car companies cooperated with the SAE in developing a set of part names and acronyms that can become common to all cars. Beginning with 1991 cars, you'll find these SAE terms on the underhood decals, known as VECI (Vehicle Emission Control Information), and in 1993 and later manufacturers' service literature.

Examples of Acronyms, Names and Definitions from SAE Recommended Practice J1930:

- Multiport Fuel Injection:
  Ford term, EFI; J1930 term MFI
- Sequential Fuel Injection:
  Ford term, SEFI; J1930 term SFI
- EEC module:
  Ford term, Electronic Control Assembly (ECA); J1930 term, Powertrain Control Module (PCM)

NOTE —
Beginning about 1990, Ford refers to the module as PCM only when it controls both engine and transaxle. Beginning in 1993, PCM means all engine control modules.

To reduce confusion, I will use the SAE terms MFI for EFI and SFI for SEFI, but retain the Ford term for CFI. Other makers may call the engine-control module ECM (Electronic Control Module), or ECU (Electronic Control Unit). I'll usually call it the control module.

Before SAE and the manufacturers began to bring these terms together, I discussed the nomenclature problem with the head of service training at GM. He explained that parts get named in the Engineering Department at the time the part is originated. By the time they get to Training, perhaps two years later, he said, it's a done deal, a real mess to change them.

Beginning with 1993 models, manufacturers have responded, changing their terms and acronyms according to the SAE Recommended Practice, J1930. To help you refer to other

Consider some terms in current service literature and the opportunities for confusion:

For the air temperature sensor in the intake manifold:

- GM: MAT (Manifold Air Temperature)
- Ford: ACT (Air Charge Temperature)
- Chrysler: CTS (Charge Temperature Sensor); and to complicate the problem, at Chrysler, CTS also stands for Coolant Temperature Sensor!

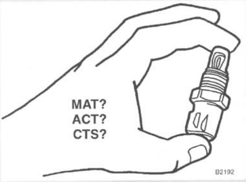

Fig. 1-4. Nomenclature can be a problem. Even within one company, Ford has different names for the same part. The name can change depending on where the engine-control system is engineered, Ford or Mazda, and even on the model year for the same engine.

Ford materials, I'll use Ford terms or generic terms, with occasional reference to SAE terms, but at the start of chapters where you might get confused I'll give you a brief list of terms and equivalents. Be sure to look in the glossaries for the terms that will be common to all cars.

Metrics

Did you know that virtually all modern cars are manufactured in the Metric system? Car components flow around the world in the global economy, in and out of the U.S., the only major country that still deals in pounds and ounces, feet and inches. Naturally, our cars must be made metric. For communicating with the service industry, only in the U.S., the metric dimensions must be converted into English units. (Canadians are already making the switch to metrics.)

Generally, I'll list both English and metric units. But I advise you, in the car business, the sooner you start thinking metric, the easier it will be for all of us.

I make it easier by making my conversions in "sensible metrics", so my values may not always match the Ford values. I avoid ridiculous conversions that make the metric system seem even more difficult.

Examples from a Ford Service Manual:

1. "Coolant level is specified as 0–2 inches (0–51 mm)." First, could the coolant level be read to an accuracy of 1 mm? Second, if it could, does 1 mm make any difference to the cooling system? Sensible metrics says, 0–2 in. (0–50 mm).
2. Pinion-bearing preload is specified as "the number of threads protruding from the front of the nut, 2.29–2.54 mm (0.90–1.00 inch)." Can you measure thread protrusion to 0.01 mm? Neither measurement makes sense. Try this: Threads should protrude about 1/10 of an inch (about 3 mm).

Any technician knows the difference between metric hand tools and English-unit tools. When a 10 mm wrench doesn't fit, it's easy to reach for an 11 mm. But if a 5/8 in. doesn't fit, you have to think to reach for an 11/16 in. wrench. Most gauges read both Metric and English units, so try the metric measurements; you'll find they're really easier.

2. Basics of Fuel Injection

Fig. 2-1. Electronic control of fuel injection and ignition helps clean up the tangle of underhood hoses that are necessary when vacuum circuits are used.

Today's cars are changing under the hood. The tangles of vacuum hoses—as well as emission-control miseries—are being replaced by the orderly installation of fuel-injection systems. But before we talk about specific Ford systems, you'll need to understand some basics about fuel injection.

Air-Fuel Mixtures

Internal-combustion engines create power by burning fuel mixed with air. In gasoline-fueled engines, the proportions of air and fuel—the air-fuel ratios or "mixtures"—are of critical importance to the quality of combustion and, therefore, to engine power output and running characteristics. Since the amount of air required by the engine varies with rpm and load, the required amount of fuel varies too.

The overall purpose of the engine-control systems covered by this book is to burn the fuel in the most efficient manner for the constantly changing engine-operating conditions.

What is Fuel Injection?

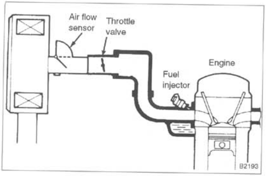

Fig. 2-2. Throttle controls the amount of air entering engine. Air flow sensor measures amount of air entering engine.

The throttle of an engine regulates air flow into the engine. The proportions of air and fuel are critical, but the throttle cannot meter the correct amount of fuel into the moving air. The fuel metering system responds to throttle changes and adjusts to continuously supply the engine with a combustible mixture of air and fuel. Fuel injection is an accurate and sophisticated type of fuel metering system.

Until the 1990s, there were two basic types of fuel metering systems in use, carburetors and fuel injection. These systems mix fuel and air, but in very different ways. To help you understand the differences in fuel injection, I'll review carburetors.

Contrast with Carburetors

Carburetors take advantage of the venturi principle: The Italian physicist, G. B. Venturi, discovered that the more air flows through an opening, the less pressure (I know, it would seem like more pressure, but in a venturi, it's less). Air flow through the carburetor throat, as determined by the throttle opening, creates a low pressure condition at the venturi, or throat. This reduced pressure pulls fuel into the intake air stream where it is vaporized to form a combustible air-fuel mixture. A wider throttle opening causes more air flow which results in more fuel flow. Fuel is "metered" more or less in proportion to air flow.

For many decades, a carburetor was a relatively simple way of metering fuel into the airstream entering the engine. But, beginning in the 1980s, drivers demanded more performance and more driveability; they would not accept the "stumbles" of the 70's. About the same time, the government demanded *tighter control of emissions and better fuel economy.* These demands require more precise control of fuel metering. Carburetors cannot provide the required precise fuel metering, especially under extreme operating conditions, even with their complex set of fuel circuits, jets, air bleeds, chokes and valves.

In 1980, a carburetor engineer, previously from Ford, worked with me to write the carburetor chapters of the MOTOR's 8th Edition of Auto Engines and Electrical Systems. He told me "The Ford 7200-VV variable-venturi feedback carburetor is a dream until it goes wrong; then it's a nightmare." About that time, my wife was ordering a Ford LTD. We specified the 5.7 engine with that electronically-controlled carburetor. The LTD was a dream. For years, starting and driveability were close to fuel-injection standards, but the 7200-VV became a nightmare, requiring three costly overhauls!

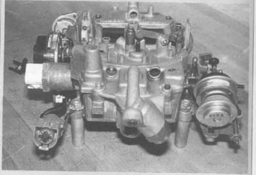

Fig. 2-3. The last major Ford carburetor, the 7200VV is in many ways more complex than most fuel-injection systems.

Fuel Injection

Fuel injection systems deliver fuel by forcing it under pressure into the incoming airstream. Fuel-injection systems directly or indirectly measure the amount of incoming air and deliver the fuel in precise amounts based on the amount of air. Because fuel is delivered to the airstream under pressure, the quantity of fuel delivered can be positively controlled. With this positive control, fuel metering can be more precisely managed to meet the special demands of many different operating conditions. This results in greater efficiency over a wider range of operation.

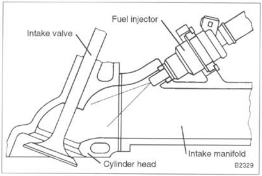

Fig. 2-4. Most Ford fuel injection systems inject fuel into incoming airstream near intake valve but outside the cylinder.

Benefits

Owners of fuel-injected cars experience better starting and driveability, especially when the engine is cold. In the 1990s, drivers demand an engine that starts on the turn of the key, handles cold acceleration without stumble, does not stall at the stoplight, and stops without run-on (dieseling).

For the manufacturer, fuel injection means better emission control and better fuel economy, both important in meeting increasingly-stringent government regulations. In an early paper to the SAE, Ford engineers listed the following advantages of fuel injection:

- Reduces air-fuel ratio variability
- Matches fuel delivery to specific operating requirements
- Prevents stalling caused by fuel-bowl wash during cornering
- Eliminates engine run-on (dieseling) when key is turned off

Until the 1980s, with looser emission limits in Europe, many European cars were built with fuel injection for delivery in the U.S., but with carburetors for delivery in Europe. In 1981 in Paris, I spoke with a chief engineer of one of the largest European manufacturers. He was reluctant to change his engines for export to the U.S. from carburetors to the more expensive fuel injection. He suggested that we in the U.S. were a little paranoid about clean air. Now, Europeans recognize the importance of clean air. "Green" is the term used to describe emission-controlled cars in Europe, derived from the Green Party in Germany, the initial force behind European Clean-Air legislation. In the 1990s, European manufacturers are rushing to replace carburetors with computer-controlled fuel-injection systems for cars sold in Europe. Now, many late-model European cars are sold in both the U.S. and Europe with the same fuel-injected engines using the same lead-free-fuel catalyst emission controls.

Cold-driveability of fuel injected engines is so good that you do not warm the idling engine in the driveway before drive-off ("for more than a few seconds", according to Ford owner's manuals). Those who care for their engine will drive off with moderate power for a few minutes, until the engine warms up and the oil flows freely. But if you live next to a freeway ramp, you can push your engine before it is ready—that's how good fuel-injection control is.

Background

Fuel injection is not new, particularly to racing. In 1965, Ford's 4-cam V-8s built for Indy racing used a simple Hilborn mechanical system injecting fuel continuously into each intake port. This was the basis for the Rochester mechanical system adapted for a few 1957 production Corvettes and Pontiacs. On the street, it was totally unsuccessful. Ford did not produce any fuel-injected cars for the market.

At Indianapolis, fuel-injection was the winner. By 1970, the Bendix RS-11 system took over at Indy in the Offenhausers and in the Ford engines. The fuel-injected Ford-powered car took first place in the 1970 Indy. It used a mass-airflow sensor, a way of measuring the mass, or weight of the air flowing into the engine. Based on the airflow, the system mechanically controlled fuel delivery to the intake ports. While well suited to near-constant high-speed operations of racing, it could not satisfy the changing needs of a street engine, which must start and run well from cold.

Electrojector—the Original EFI

Flashback to the mid 1950s, when a complete electronic fuel injection system was being developed in another Bendix Division in upstate New York. As defined, the electronic system used electronics to:

- Measure engine conditions
- Compute the amount of fuel needed
- Control fuel flow in proportion to air intake to satisfy engine conditions

The Electrojector system, as it was called, turned out to be ahead of its time—the first units used vacuum tubes for the electronics and took 30 seconds to warm up before the engine could be started! As transistors became available, the electronic warm-up problem disappeared, but the electronic system cost 20 times as much as a carburetor, and was less reliable. Manufacturers learned that using several carburetors was cheaper than one fuel-injection system. Bendix shelved the electronic system in 1961. In the U.S., it was to stay on the shelf for 12 years.

Bosch Influence

Beginning in 1937, in Germany, Robert Bosch GmbH had been adapting mechanical diesel-injection pumps to gasoline injection, in aircraft, in racing, and in the famous 1955 Mercedes 300SL. But, if the Bendix electronic system was expensive, the Bosch mechanical system was even more so, while lacking in metering accuracy, driveability, and, by the mid-1960s, new worry for the engineers, emission control.

It was emission-control concerns that drove Volkswagen to ask Bosch for an electronic system for the VW Type 3 air-cooled engine. In 1966, a cross-licensing agreement between Bosch and Bendix enabled Bosch to quickly adapt the Bendix system. In 1967, VW brought out the world's first production electronic fuel-injection system. It came to be known as Bosch D-Jetronic.

Bosch/Bendix/Cadillac

In a strange case of hands across the sea, some 1976–80 Cadillacs were built with an electronic fuel-injection system sharing features of the U.S. Bendix Electrojector and the German Bosch D-Jetronic. It was called EFI. Like the Bosch D-Jetronic, the analog computer controlled only fuel injection. It was an MFI system, like the D-Jetronic. One of the Cadillac engineers told me they had no technician training. They tested the system with an infamous "Blue Box." When the box failed, they started over, sometimes replacing the whole system.

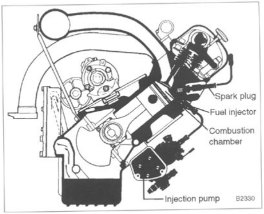

Fig. 2-5. Early Bosch mechanical fuel injection system used on Mercedes Benz 300 SL was adapted from Diesel injection system. Injection was directly into cylinder.

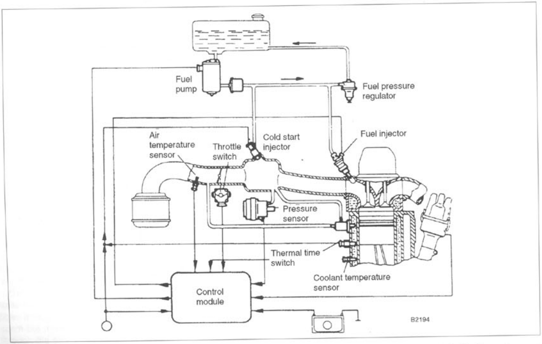

Fig. 2-6. First production electronic injection system was Bosch D-Jetronic, adapted from Bendix Electrojector for the 1967 Volkswagen Beetle to meet U.S. emission-control limits.

Some people say the engines that took the Wright brothers into the air in 1903 were fuel injected. I examined one of the first Wright engines on display at the Engineer's Club in their home town, Dayton, Ohio. True, it had no carburetor, also no fuel pump. Fuel fed by gravity from a small tank, 1 quart (1L), through a hand-set metering valve to a shallow chamber next to the cylinders. As warm air flowed over the surface, it vaporized some gasoline and carried it into the cylinders. A flywheel magneto supplied ignition current. Cold start delivered 16 horsepower, but after warm-up, the warmer air cut power back to 12. Crude, yes. Did it work? Yes. Fuel injection? No.

3. Ford Fuel Injection Types

3.1 Control Systems

Electronic Engine Control (EEC)

Ford-developed EEC systems are controlling most Ford engines around the world. They are generally based on Bosch principles, patent licenses, and in some cases, Bosch parts, but controlled by Ford EEC computers. Ford EEC-IV controls even racing engines such as the Ford Cosworth Indy Car.

Mazda Engine Control System (MECS)

Ford's partnership with Mazda in the late 1980s resulted in increased use of Mazda engines—with Mazda Engine Control (MEC) systems. MECS-I can be described as a Bosch-licensed "L-Motronic" system, made by NipponDenso. "L-Motronic" is my term for a traditional Bosch vane-type air-flow sensor fuel-injection system (Bosch-speak is "L-Jetronic"), combined with control of spark timing from the same computer (Bosch-speak is "Motronic").

MEC-I systems applications include:

- 1.3L engines in Festiva, manufactured by Mazda-owned Kia in Korea for Ford
- 1.6L engines with turbocharger and without, in 1991 and later Capri manufactured by Ford of Australia from Mazda 323 design
- 1.8L performance engines of some '91 and later Escorts and Mercury Tracers. This is the same engine Mazda builds for its own 323 and Protege
- 2.2L engines, with turbocharger and without, in 1988–92 Ford Probe cars built by Mazda in Michigan

NOTE —
Beginning in 1994, all 2.0L engine control is by Ford EEC instead of Mazda MECS, both MTX and C4DE.

MEC-II systems include:

- 2.5L V-6 engines in 1993 and later Probe cars
- 2.0L 4-cylinder 4EAT (Automatic Transaxle) 1993 only

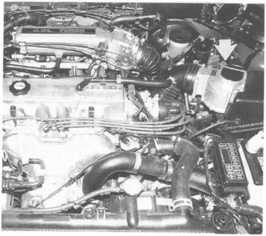

Fig. 3-1. MEC system in 1991 Ford Probe 2.2L Turbo engine. Look for the Vane Air Flow sensor (arrow), used in all MEC systems. Also used on EEC systems in earlier Ford 1.6 and 2.3L engines.

Ford sells Escort/Tracers made in Mexico and in Michigan. MECS controls 1.8L DOHC engine. EEC controls 1.9L SOHC Ford engine.

Ford sells Probe cars manufactured by Auto Alliance, a joint Ford/Mazda plant in Michigan. Four-cylinder Ford (Mazda) engines though 1992 are controlled by MEC systems. In the 1990–92 Probes, six-cylinder 3.0L Ford engines are fitted with Ford EEC. V-6 2.5L engines are fitted with MECS-II. The systems differ enough that I will describe them as: "MECS-I", 1988–92, and "MECS-II", 1993 and later. Look for EEC in 2.0L Probes, except 1993 with 4EAT that use Mecs-II

Fig. 3-2. MECS-II controls 2.5L V-6 in 1993 Probes. Also 2.0L 4-cylinder with automatic transmission (4EAT).

3.2 Injection Systems

All fuel-injection systems in U.S. Ford cars are electronic. All meter fuel in short pulses, delivered intermittently. Between 1980 and 1989, Ford systems are divided according to where the fuel is injected into the intake manifold.

Central Fuel Injection (CFI)

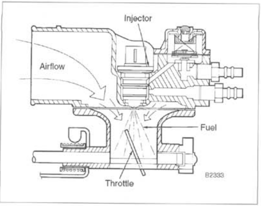

Fig. 3-3. CFI delivers fuel directly above throttle plate, similar to carburetor location. (Low-pressure shown.)

Central Fuel Injection (CFI) delivers fuel above the throttle plate, about where carburetor fuel is drawn into the airstream. As in carbureted engines, the manifold carries air-fuel mixture. Most CFI systems deliver with one injector, but some use two.

While CFI represents a few million of Ford fuel-injection car and truck production through 1987, CFI has been supplanted with the second type, Multiport Fuel Injection.

Multiport Fuel Injection (MFI)

Multiport Fuel Injection (MFI) systems look different from carburetor or CFI systems, with prominent intake manifolds leading to the cylinders. Usually you can see the injectors at each cylinder. Port systems deliver fuel at each intake port opposite the intake valve. That means the intake manifold delivers air instead of the air-fuel mixture, as in CFI or carburetors.

Ford MFI systems deliver fuel to multiple injectors, ganged in two banks of cylinders, 2 x 2 in four cylinders, left-bank/right bank in V-6 and V-8s.

Multiport systems usually deliver more power and better driveability than CFI systems for a number of reasons:

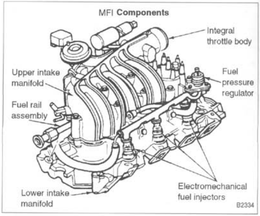

Fig. 3-4. Multiport Fuel Injection is used in all Ford systems in the 1990's; Ford CFI began in 1980.

- Greater power by avoiding venturi losses as in a carburetor. In addition, most Ford engines use tuned intake runners that help to ram in more air per stroke to improve torque characteristics
- Improved driveability by reducing the throttle-change lag which occurs while the fuel travels from the throttle body to the intake ports
- Increased fuel economy by avoiding condensation of fuel on interior walls of the intake manifold (manifold wetting)
- Simplified turbocharger and supercharger applications. The compressor need only handle air
- Improved power by operating with cooler, denser intake air

Sequential (Multiport) Fuel Injection (SFI)

Sequential Multiport Fuel Injection (SFI) systems deliver fuel to one injector at a time—each cylinder in firing order sequence. Hence the name "Sequential". Ford calls this SEFI. SFI systems look no different from MFI; the difference is in the computer.

Sequential systems provide less variation between cylinders for smoother idle and reduced emissions; SFI provides smoother acceleration and rpm limitation because fuel control is by individual cylinder rather than by banks as MFI.

Beginning in 1988, the advantages of multiport injection won out over CFI. SFI, first installed in 1986, is winning out over ganged MFI.

Fig. 3-5. Long intake runners, called ram manifolds, are widely used in Ford fuel injection.

4. TOTAL ENGINE CONTROL

Most people think of Fuel Injection as a replacement for a carburetor—a computer system controlling only the fuel delivered, as in the early Bosch systems. In contrast, Ford determined almost from the start that total engine control by computer had many advantages. Where other books treat fuel injection as a subject separate from engine control, I will stress that today, fuel injection is part of engine control.

Using many of the same signals needed for computer control of fuel delivery, Ford computers also control:

- Ignition, or spark-timing and dwell, eliminating most vacuum hoses and their servicing headaches
- Idle-air bypass to control idle rpm, and to manage air flow during deceleration
- Emission systems, improving driveability and again reducing the number of vacuum hoses
- Boost control in some engines

Ignition timing has always been important to power and economy, even when Henry Ford's Model A provided the driver with hand controls for timing and fuel. Later, a form of automatic control was provided by flyweights in the distributor that mechanically advanced timing for increasing rpm, and by vacuum diaphragms that retarded timing for increasing engine load.

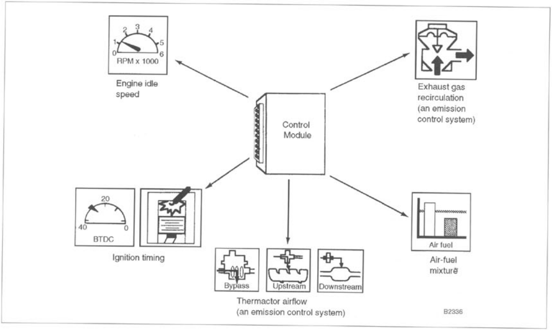

Fig. 4-1. Control module of EEC system controls more than fuel injection. It controls engine conditions in several ways.

From the 1931 Model A Book, paraphrased: "Before starting the engine, place the spark lever (left hand) at the top of the quadrant. This is the retard position. Always retard the spark lever when starting your engine. Starting the engine with the spark advanced may cause the engine to kick back and damage the starter parts. After the engine is started, advance the spark lever about half way down the quadrant. Only for high speeds should the spark lever be advanced all the way down the quadrant. When the engine is under heavy load as when climbing steep hills or driving through heavy sand, the spark lever should be retarded sufficiently to prevent a spark knock." Now do you wish to return to the "good ole days"?

Fig. 4-2. Ford Model A driver controlled spark timing and fuel directly. EEC systems control timing and fuel to satisfy many requirements, many times per second.

Spark Timing

The correct timing of spark-plug firing depends on many of the same variables that control fuel metering, including engine speed, engine temperature, altitude and, in some cases, whether the engine is knocking. Electronic ignition control uses these variables to compute the spark timing point. The control module refers to a timing map, a set of data points in the Control module memory that give the best timing point for all conditions.

In addition to controlling timing, in Ford supercharged engines, electronic systems control the boost.

Idle-Air Bypass—Closed Throttle

Control of idle-air for controlling idle speed contributes to fuel economy and reduced emissions. Using many of the same variables already input, the control module adjusts idle rpm by varying the amount of air that enters the engine when the driver's foot is off the accelerator.

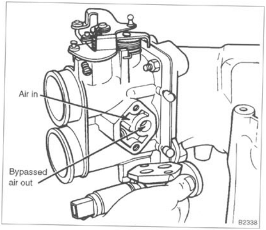

Fig. 4-3. Idle-air bypass controls air flow around throttle plate. It includes Idle Speed Control (ISC), but also functions during more engine operating conditions than just idle.

Control of air passing the throttle-body is also important to operations during deceleration from cruise or Wide Open Throttle (WOT). When you take your foot off the accelerator, the control unit allows extra air intake. This reduces emissions during deceleration, and prevents engine stalling.

NOTE —
I don't like the traditional nomenclature of Idle Speed Control (ISC). Because of its importance to deceleration control (indeed the engine may be slowing from 7500 rpm!), I will use the term Idle-Air Bypass (ISC). This is close enough to the Ford term Idle Speed Control-ByPass Air (ISC-BPA) while describing accurately the purpose of this important system: more than just idle-speed control.

Emission Control

Emission-control functions are usually included in the engine control unit functions. For example, I'll describe those Ford electronic systems that control:

- Secondary air (air injected into the exhaust stream)
- Opening and closing of the fuel-vapor charcoal canister purge valve
- Flow of EGR (Exhaust Gas Recirculation). More on Emission Control in Chapter 3

5. APPLICATIONS

In this brief run-through of Ford's fuel-injection/engine control systems, you may follow the patterns of application and see where your car fits in.

5.1 Systems

NOTE —
In this book, I do not cover the early fuel-injection systems, used 1980–87. I list them only to show the background of Ford Electronic Engine Control.

1978: EEC-I is Ford's first application of Electronic Engine Control. Beginning in a small way, Ford introduces EEC-I in 5.0L V-8 engines in Lincoln Versailles for the purpose of reducing emissions. EEC-I controls spark timing and emissions, EGR flow, and secondary air—Thermactor as Ford calls it. No fuel injection, in fact, no control of fuel, even in carburetors.

1979: EEC-II is Ford's first electronic control of fuel—in carburetors, adding to control of ignition timing, idle rpm, and emissions. It starts first in California with its stricter limits. First use: Full-size cars with 5.8L engines, Ford, California only, and Mercury, 50 states.

1980: MCU—Microprocessor Control Unit is a simplified system of fuel control in carburetors. It begins in California 2.3L engines and continues through 1985 in several cars and the 4.9L light truck. MCU controls carburetor air-fuel ratio and the Thermactor, but does not control ignition timing.

Mid-year 1980: EEC-III signals an industry-milestone year of tighter emission-control limits in all cars. Ford began fitting EEC-III CFI fuel injection to Lincoln 5.0L V-8's.

1981–83: EEC-III CFI expands to 5.0L engines in Lincoln/-Mark VI, Continental, full-size Ford/Mercury, and T'Bird/Cougar. Idle Speed Control (ISC) is added in 1981, knock control in '82.

1983: EEC-IV begins with the 1.6L MFI engines in Escort and Lynx and EXP/LN7. Also in 2.3L MFI turbocharged engines in T'Bird/Cougar. From 1985 through 1988, MFI spreads to 5.0L, 3.8L, 3.0L, and 1.9L, and to 2.3L in trucks. Ford's first MFI engines include expanded diagnostics. Turbo engines include individual-cylinder knock control, and turbo-boost control.

1985–87: EEC-IV controls CFI in 3.8L, 2.5L, 2.3L, and 1.9L engines; and MFI, as carburetors are gradually eliminated. The first Sequential (SFI) systems appear on T'Bird/Cougar 3.8L. Truck engines get MFI beginning in 1986.

1988: MEC systems begin with the 1.6L Mazda engine in the Mercury Tracer, followed by the 1989 2.2L Probe engine, and continue on 1.3L engines in Festiva. All car and truck engines are port-injected with minor exceptions.

1993: Second-generation MECS (I call it "MECS-II") in Probe 6-cylinder 2.5L, and 4-cylinder 2.0L 4EAT(automatic transaxle) only. Watch for 2.0L MTX (manual transaxle). It uses EEC-IV. In the shop, this could catch you by surprise.

1994: First EEC-*V* cars with the Thunderbird/Cougar and Mustang. EEC-V is faster, with more memory and with Flash EEPROM (computer chip reprogrammable in the shop) and advanced systems, known as On-Board Diagnostics II (OBD-II). Thunderbird/Cougar: 4.6L engine from the Lincoln/Crown Victoria/Grand Marquis. Mustang: 240-horsepower engine from the Cobra, and 3.8L V-6 standard engine to replace 2.3L. Aspire: new name for slightly lager Festiva.

1995: (Mid 1994) Ford Contour and Mercury Mystique CDW-27 world car (Mondeo in Europe) replace Tempo/Topaz. Four-cylinder 2.0L Zeta engine, 16-valve DOHC, SFI/DIS. V-6 2.5L 24-valve DOHC SFI/DIS. Dual-stage Intake Manifold Runner Control (IMRC) similar to Mark VIII.

5.2 Vehicles

In this book, I'll cover production Ford and Mazda fuel injection/engine control installed since 1988.

Table a. Ford Platforms and Families

Platform	Ford	Mercury	Lincoln
BT17	Festiva		
CT20	Escort '92+	Tracer	
Erika	Escort to '91	Lynx	
DN5	Taurus	Sable	
FN9			Continental
Fox	Mustang		
LS			Mark VII & VIII
Panther	Crown Victoria	Grand Marquis	Town Car
MN12	T'Bird	Cougar	
Topaz	Tempo	Topaz	
ST16	Probe		
SA30		Capri	

Some engines are optional in some lines.

Abbreviations

Table b on the following pages uses these abbreviations:

AXODE: Automatic Transaxle, OverDrive (4-speed), Electronic
DIS: Distributorless Ignition Systems (J1930:Electronic Ignition, Low Data Rate)
EDIS: Electronic Distributorless Ignition Systems (J1930: Electronic Ignition, High Data Rate)
EEC: Ford Electronic Engine Control
MAF: Mass Airflow sensor
MECS: Mazda Electronic Control System
MFI: Multiport Fuel Injection (Ford: EFI)
NECCS: Nissan Electronic Concentrated engine Control System
SFI: Sequential (Multiport) Fuel Injection (Ford: SEFI)

NOTE —
Unless otherwise noted, all engines listed use EEC engine control, distributor ignition, and MAP (speed-density) airflow measurement

Table b. Applications

Engine family	Model	Engine control system and fuel injection type
1993 Passenger Cars		
1.3L	Festiva (Mazda)	MECS-MFI
1.6L	Capri (Mazda)	MECS-MFI
1.6L Turbo	Capri (Mazda)	MECS-MFI
1.8L	Escort / Tracer	MECS-MFI
1.9L	Escort / Tracer	SFI-MAF-DIS
2.0L	Probe–MTX	EEC-SFI-MAF
2.0L	Probe–4EAT (Mazda)	MECS-SFI-MAF
2.3L OHC	Mustang	MFI-MAF/DIS
2.3L HSC	Tempo/Topaz	SFI-MAF
2.5L	Probe (Mazda)	MECS-SFI-VAF-SC
3.0L	Tempo / Topaz	SFI-MAF
3.0L	Taurus/Sable	SFI-MAF
3.0L	Taurus FFV	SFI-MAF/DIS
3.0L	Taurus SHO M/T	SFI-MAF/DIS
3.2L	Taurus SHO A/T	SFI-MAF/DIS
3.8L	Taurus / Sable /Police	SFI-MAF
3.8L	Continental	SFI-MAF
3.8L	T'Bird/Cougar	SFI-MAF
3.8L SC	T'Bird	SFI-MAF/DIS
4.6L	Town Car, Crown Vic. / Grand Marquis	SFI-MAF/EDIS
4.6L -4V	Mark VIII	SFI-MAF/EDIS
5.0L HO	T'Bird / Cougar, Mustang	SFI-MAF
1993 Light Trucks		
2.3L OHC	Ranger	MFI-MAF/DIS
3.0L V-6	Ranger	SFI-MAF
3.0L	Aerostar	SFI-MAF
3.0L	Mercury Villager	NECCS-SFI-MAF
4.0L	Aerostar / Explorer / Ranger—49 state	MFI-MAF/EDIS
4.0L	Aerostar / Explorer / Ranger—CA	SFI-MAF/EDIS
4.9L	E/F-Series, Bronco	MFI
5.0L	E/F-Series, Bronco	MFI
5.0L	E-series—CA	SFI
5.8L	E/F-Series, Bronco	MFI

Table b. Applications (continued)

Engine family	Model	Engine control system and fuel injection type
1992 Passenger Cars		
1.3L	Festiva (Mazda)	MECS-MFI
1.6L	Capri (Mazda)	MECS-MFI
1.6L Turbo	Capri (Mazda)	MECS-MFI
1.8L	Escort / Tracer (Mazda)	MECS-MFI
1.9L	Escort / Tracer Integrated 4EAT	EEC- SFI-MAF
2.2L	Probe (Mazda)	MECS-MFI
2.2L Turbo	Probe GT (Mazda)	MECS-MFI
2.3L OHC	Mustang	MFI-MAF/DIS
2.3L HSC	Tempo / Topaz	SFI-MAF
3.0L	Tempo / Topaz	SFI-MAF+AXODE
3.0L	Taurus SHO	SFI-MAF/DIS
3.0L	Taurus / Sable	SFI-MAF
3.0L	Probe	EEC-MFI
3.8L	Taurus / Sable /Police	SFI-MAF
3.8L	Continental	SFI-MAF
3.8L	T'Bird/Cougar	SFI-MAF
3.8L SC	T'Bird	SFI-MAF/DIS
4.6L	Town Car, Crown Vic. / Grand Marquis	SFI-MAF/EDIS
5.0L HO	T'Bird / Cougar, Mustang	SFI-MAF
5.0L HO	Mark VII	SFI
1992 Light Trucks		
2.3L OHC	Ranger	MFI-MAF/DIS
2.9L	Ranger	MFI
3.0L	Aerostar	SFI-MAF
4.0L	Aerostar /Explorer / Ranger	MFI-MAF/EDIS
4.9L	E/F-Series, Bronco	MFI
5.0L	E/F-Series, Bronco	MFI
5.8L	E/F-Series, Bronco	MFI

continued on next page

Table b. Applications (continued)

Engine family	Model	Engine control system and fuel injection type
1991 Passenger Cars		
1.3L	Festiva (Mazda)	MECS-MFI
1.6L	Capri (Mazda)	MECS-MFI
1.6L Turbo	Capri (Mazda)	MECS-MFI
1.8L	Escort / Tracer (Mazda)	MECS-MFI
1.9L	Escort / Tracer	EEC-SFI-MAF/EDIS
2.2L	Probe (Mazda)	MECS-MFI
2.2L Turbo	Probe GT (Mazda)	MECS-MFI
2.3L OHC	Mustang	EEC-MFI-MAF/DPDIS
2.3L HSC	Tempo / Topaz	MFI
2.5L HSC	Taurus	SFI-MAF+AXODE
3.0L	Probe	MFI
3.0L	Taurus / Sable	SFI-MAF+AXODE
3.0L SHO	Taurus	SFI-MAF/DIS
3.8L SC	T'Bird	SFI-MAF/DIS
3.8L	T'Bird / Cougar	SFI-MAF
3.8L	Continental, Taurus / Sable	SFI-MAF+AXODE
4.6L	Lincoln Town Car	SFI-MAF/EDIS
5.0L	Crown Victoria / Grand Marquis	SFI
5.0L HO	T'Bird / Cougar, Mustang	SFI-MAF
5.0L	Mark VII	SFI
1991 Light Trucks		
2.3L OHC	Ranger	SFI-MAF/DIS-DP
2.9L	Ranger	MFI
3.0L	Aerostar	MFI-MAF
4.0L	Aerostar / Explorer / Ranger	MFI-MAF/EDIS
4.9L	E/F-Series, Bronco	MFI
5.0L	E/F-Series, Bronco	MFI
5.8L	E/F-Series, Bronco	MFI

Table b. Applications (continued)

Engine family	Model	Engine control system and fuel injection type
1990 Passenger Cars		
1.3L	Festiva A/T (Mazda)	MECS-MFI
1.9L	Escort	MFI-MAF
1.9L HO	Escort	MFI
2.2L	Probe (Mazda)	MECS-MFI
2.2L Turbo	Probe GT (Mazda)	MECS-MFI
2.3L OHC	Mustang	MFI (MAF in CA)
2.3L HSC	Tempo / Topaz	MFI
2.5L HSC	Taurus	CFI
3.0L	Probe	MFI
3.0L	Taurus / Sable	MFI
3.0L SHO	Taurus	SFI-MAF/DIS
3.8L	T'Bird / Cougar	SFI
3.8L	Continental, Taurus / Sable	SFI
5.0L	Lincoln Town Car	SFI
5.0L	Crown Victoria / Grand Marquis	SFI (MAF in CA sedans)
5.0L HO	Mustang	SFI-MAF
5.0L	Mark VII	SFI
1990 Light Trucks		
2.3LOHC	Ranger	MFI/DIS
2.9L	Ranger / Bronco II	MFI-MAF/EDIS
3.0L	Aerostar	MFI
4.0L	Aerostar / Explorer / Ranger	MFI-MAF/EDIS
4.9L	E/F-Series, Bronco	MFI
5.0L	E/F-Series, Bronco	MFI
5.8L	E/F-Series, Bronco	MFI

continued on next page

Table b. Applications (continued)

Engine family	Model	Engine control system and fuel injection type
1989 Passenger Cars		
1.6L	Tracer (Mazda)	MECS-MFI
1.9L HO	Escort	MFI
2.2L	Probe (Mazda)	MECS-MFI
2.2L Turbo	Probe GT (Mazda)	MECS-MFI
2.3L OHC	Mustang	MFI
2.3L OHC Turbo	Merkur	MFI
2.3L HSC	Tempo / Topaz	MFI
2.3L HSO+	Tempo / Topaz 4wd	MFI
2.5L HSC	Taurus	CFI
3.0L	Taurus	MFI
3.0L SHO	Taurus	SFI-MAF/DIS
3.8L SC	T'Bird / Cougar	SFI-MAF/DIS
3.8L	T'Bird / Cougar; Cont; Taurus / Sable	SFI
5.0L	Crown Victoria / Grand Marquis, Town Car	SFI
5.0L HO	Mustang	SFI-MAF
5.0L HO	Mark VII	SFI
1989 Light Trucks		
2.3L OHC	Ranger	MFI-DIS
2.9L	Ranger / Bronco II	MFI
3.0L	Aerostar	MFI
4.9L	E/F-Series, Bronco	MFI
5.0L	E/F-Series, Bronco	MFI
5.8L	E/F-Series Bronco	MFI

Table b. Applications (continued)

Engine family	Model	Engine control system and fuel injection type
1988 Passenger Cars		
1.6L	Tracer (Mazda)	MECS-MFI
1.9L	Escort	CFI
1.9L HO	Escort	MFI
2.2L	Probe (Mazda)	MECS-MFI
2.2L GT	Probe (Mazda)	MECS-MFI
2.3LOHC	Mustang	MFI
2.3L Turbo	Mustang, Merkur	MFI
2.3L HSC	Tempo / Topaz	CFI
2.3L HSO+	Tempo / Topaz	CFI
2.5L HSC	Taurus	CFI
3.0L	Taurus	MFI
3.8L	T'Bird / Cougar	MFI
3.8L	Continental, Taurus / Sable	MFI
5.0L	Cr own Vic / Grand Marquis, Town Car	SFI
5.0L HO	Mustang	SFI-MAF
5.0L	Mark VII	SFI
1988 Light Trucks		
2.3LOHC	Ranger	MFI
2.9L	Ranger / Bronco II	MFI
3.0L	Aerostar	MFI
4.9L	E/F-Series, Bronco	MFI
5.0L	E/F-Series, Bronco	MFI
5.8L	E/F-Series, Bronco	MFI

Chapter 2

Engine Control Fundamentals

Contents

1. Introduction

In this chapter, I'll review some basic factors about fuel injection and engine control that apply to just about every engine.

- How the air-fuel ratio, spark timing, and idle-air bypass can be controlled to improve driveability and control exhaust emissions with little sacrifice of power
- The necessity for emission control and fuel economy
- The concepts of feed-back and feed-forward in engine control
- Why various engine operating modes demand different control strategies—different air-fuel mixtures, different spark timing, and different idle-air bypass

You need a clear understanding of the requirements of engine control under different conditions. This will help you to understand the operation of the sensors that send signals to the control module, and to understand the actuators that are controlled by the control-module output signals. I do it this way for two reasons:

- In spite of the different systems for different cars and trucks, these systems are more alike than they are different
- When you know what's behind these systems, you'll be much better equipped to go inside the system for service or for high performance

2. Basic Factors

2.1 Air-Fuel Ratios

The main job of any fuel metering system is to mix fuel with the incoming air in the proper ratio. Small variations in air-fuel ratio can have major effects on power output, fuel consumption, and exhaust emissions. In your engine, the throttle controls the amount of air the engine takes in, but has no direct effect on the fuel metering.

The Basic Combustible Mixture

Surprising as it may seem, liquid gasoline will not burn! Combustion of gasoline requires that the particles be small enough. Also, the particles must reach the correct amount of oxygen in proportion to the amount of fuel. In internal combustion engines, the fuel is atomized into tiny droplets, and metered in correct proportion to the intake air. In round numbers, it takes about 14 parts of air to support complete combustion of 1 part of fuel—in other words, an air-fuel ratio of about 14:1.

Gasoline air-fuel ratios that are higher or lower than about 14:1 will still burn, but such combustion usually raises emissions and produces other side effects. As you read further into this chapter, you'll see what those are, and why precise control of the air-fuel ratio has become so important. You'll need to understand the relationship between air-fuel mixture and exhaust gas oxygen to relate to the electronic control of emissions. Alternate fuels, such as Methanol blends, will require different air-fuel ratios.

Throughout this book, I'll follow generally accepted practice and discuss air-fuel ratios primarily in terms of mass. "Mass Air-Flow Sensor" is an input sensor you'll hear about in the newer Ford EEC systems. You'll see carburetor flowrates expressed as volume, such as xx cubic feet per minute. Engines burn mass, such as xx pounds of air per minute. In Earth gravity, mass is about the same as weight. The combustion takes place in terms of mass, or weight, not volume. Think of weight, or mass as the simplest and best way to understand the basic factors governing fuel delivery and combustion.

Fig. 2-1. The mass of one ounce of gasoline, as in a shot glass, burns with the mass of the air in a car trunk, about 14 ounces. Yet the volume of the liquid gasoline is much, much smaller than the volume of air in the trunk. It is the mass that determines the air-fuel ratio, not the volume.

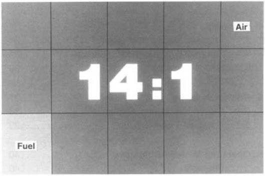

Fig. 2-2. It takes about 14 parts of air by mass to support complete combustion of 1 part of gasoline fuel. Once upon a time, an air-fuel ratio somewhere close to 14:1 was good enough.

Rich and Lean Mixtures

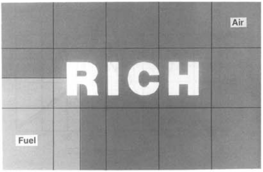

Fig. 2-3. A rich mixture burns almost all the oxygen, so exhaust gas is low in oxygen content. Exhaust gas has much unburned fuel.

You've probably heard the terms "rich" and "lean" as used to describe mixtures. A rich mixture is one with a lower air-fuel ratio. It has insufficient air (oxygen) to support complete combustion of the fuel. Rich mixtures increase fuel consumption and emissions of hydrocarbons (HC) and carbon monoxide (CO)—the products of incompletely burned gasoline. They tend to reduce power, increase carbon deposits and, in the extreme case, foul spark plugs and dilute the engine oil.

"Enrichment" is the process of metering more fuel for a given amount of air to produce a richer mixture.

If the air-fuel mixture in the combustion chamber gets richer than about 10:1 for steady running, the engine loses power, and unburned fuel pours out the exhaust pipe in black smoke.

Fig. 2-4. A lean mixture burns almost all the fuel, so exhaust gas contains leftover oxygen, and very little unburned gasoline.

A lean mixture is one with a higher air-fuel ratio. After complete combustion of the fuel, the exhaust contains leftover air. The fuel will burn completely, but more slowly and at a higher combustion temperature. Lean mixtures reduce power, elevate engine temperature, and increase emissions of oxides of nitrogen (NO_x)—a product of combustion at excessively high temperature. They also cause driveability problems. In the extreme case, the high temperatures resulting from lean combustion will cause pre-ignition—violent combustion of the mixture that can cause serious engine damage.

If the air-fuel mixture gets leaner than about 17:1, misfiring in the cylinder can lead to loss of power and backfiring.

The way the air-fuel mixture affects the exhaust gas is fundamental to engine control. Remember:

- **Rich** air-fuel mixtures produce exhaust gases with little or no oxygen
- **Lean** air-fuel mixtures produce exhaust gases with extra oxygen

Stoichiometric (Ideal) Ratio

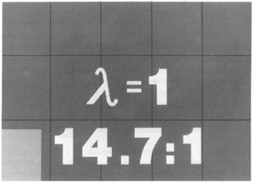

Fig. 2-5. For a warm engine, running on gasoline at part throttle, the ideal or "stoichiometric" air-fuel ratio—when there is just enough air to burn all the fuel—is 14.7:1.

"Stoichiometric" is a fancy word that roughly means "measuring the elements." A stoichiometric ratio is neither too rich nor too lean. It contains just enough fuel to burn all the oxygen in the mixture. It is the air-fuel ratio that provides the proper exhaust gas to operate the catalytic converter. More on that later. For a warm engine, running at part throttle, stoichiometric is a so-called "ideal" ratio—the one that offers the best compromise between best power and best economy.

Engines operate most of the time at part throttle at the ideal air-fuel ratio, 14.7:1 for gasoline. But conditions can change, in a fraction of a second, and over a long period of time. To handle these changes in condition, engine control must change air-fuel ratios and spark timing with great speed and accuracy.

When "gas was cheap and the air was dirty," carburetors usually delivered mixtures richer than 14:1, perhaps with an air-fuel ratio as low as 12:1. As the car aged and a little excess air leaked in around the gaskets of the carburetor or the intake manifold, the engine still got a good combustible mixture. Also, a richer *mixture was some compensation for unequal fuel distribution* with the carburetor farther from the end cylinders than from the middle ones. 1970 Ford specifications for carburetor idle air-fuel ratios were usually in the 13s, but ran as low as 12:1.

For the first emission controls, in 1968, lean mixtures reduced hydrocarbons (HC) and Carbon Monoxide (CO). More on Emission Controls in Chapter 3.

Fig. 2-6 shows another reason for setting up carbureted engines to run a little rich. Air-fuel mixture was less precise, and some variations were to be expected. Variations in a rich mixture have only a small effect on power, while variations in a lean mixture affect power dramatically.

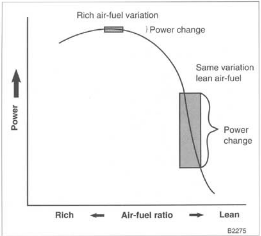

Fig. 2-6. Variation in a rich air-fuel ratio makes much less difference in power than the same variation in a lean air-fuel ratio.

2.2 Spark Timing (Ignition)

Precise control of spark timing is also important to engine control for emissions and economy, and for driveability. As the spark jumps across the plug gap, on the average, it takes about 2 ms (milliseconds—thousandths of a second) to ignite the air-fuel mixture. The spark must fire at the proper millisecond so the combustion pressure peaks just after the piston reaches TDC (Top Dead Center), shown as 0 in Fig. 2-7.

Line b shows the spark timing is too early—too advanced. Cylinder pressure builds as the piston is travelling upward. An advanced spark ignites the mixture so that it "crashes" into the

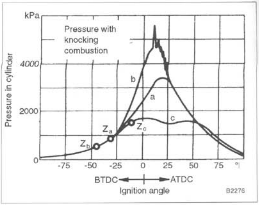

Fig. 2-7. Pressure in the combustion chamber varies according to spark timing advance.

piston. That can cause knocking in the combustion chamber, and that costs power.

NOTE —
The pressure-build that causes knocking depends on the octane rating of the fuel—less tendency to knock with high octane fuels because they burn more slowly.

Line c shows it's too late—retarded. The piston is already travelling downward and again, that costs power.

Line a shows the proper timing, producing maximum pressure shortly after the piston reaches TDC.

Spark timing is usually measured from TDC, considered as 0 degrees of crankshaft travel. When the spark is timed before the piston reaches the top, we say it fires BTDC (Before TDC):

- Point Za, the proper spark timing is about -30, or 30 degrees BTDC
- Point Zb, the advanced timing is about 45 degrees BTDC
- Point Zc, the retarded timing is about 10 degrees BTDC

The two most important factors affecting spark timing for power and economy are engine speed and engine load.

Engine Speed/Spark Timing

During maximum rpm operation, the piston may travel ten times as fast as during its slowest rpm. But the spark doesn't jump any faster, or ignite the mixture any faster. To build combustion pressure according to the TDC, spark timing must be advanced more as the engine rpm increases. Before the days of engine control, spark timing was advanced by a set of centrifugal weights.

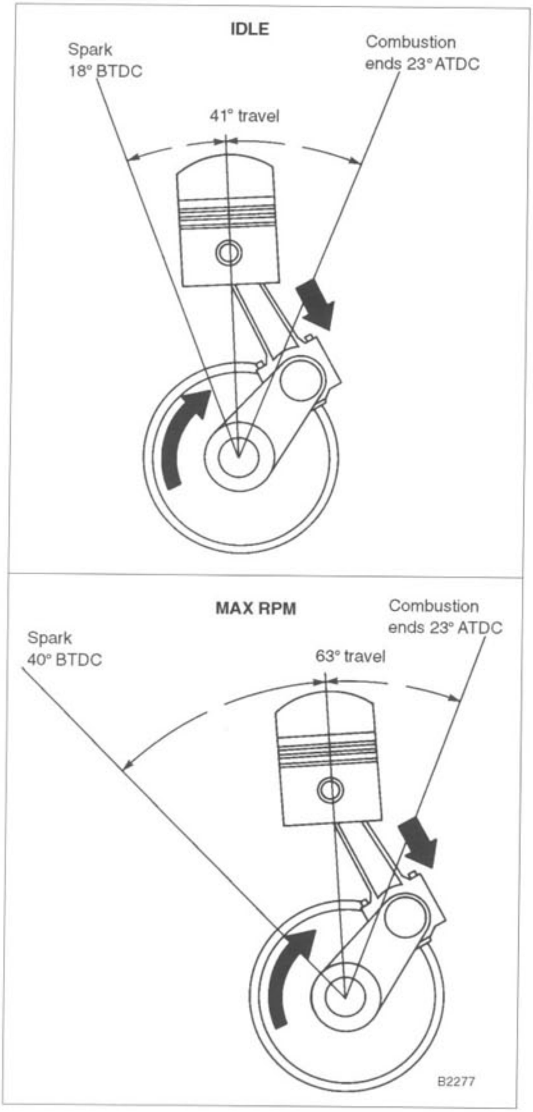

Fig. 2-8. Spark timing for idle, compared to spark timing for max rpm.

Engine Load/Spark Timing

During part-load operation, the air-fuel mixture is throttled, so there is less mixture in the combustion chamber, and it burns more slowly. Therefore, under part load, spark timing must be advanced. Before the days of engine control, spark timing was advanced by vacuum-advance diaphragms.

Engine control must also consider the effect of spark timing on emissions. Naturally, emissions are related to the air-fuel ratio, and how that will burn according to different spark timings. For more on Emission Control, see Chapter 3.

Spark timing can change power. As shown in Fig. 2-9, advancing spark timing to about 50 degrees BTDC can improve power.

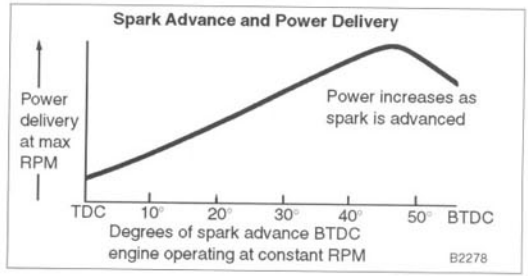

Fig. 2-9. Effect of spark timing on power.

Variations in Spark Timing

All the above is based on that old qualifier, "All other things being equal." But variations exist cylinder-to-cylinder because of variations in manifolding and in injectors, even in engines in good condition. Those variations increase with engine wear, and other factors such as carbon buildup in the cylinders, and valve seating and stem clearances. Other factors could be variations in injector clogging and intake-valve deposits, and, in SFI, variations in individual sequential injectors.

Some changes in operating conditions occur over long times, measured in years. Others over shorter times, such as warm-up time. Others occur almost instantaneously, time measured in milliseconds:

- Acceleration
- Deceleration
- Starting

Engine control of spark timing must consider all these factors, as well as idle smoothness and driveability.

Dwell Control

Dwell control refers to the instant the primary circuit is closed, beginning the saturation of the primary coil windings. Spark timing refers to the instant the primary circuit is opened, causing the coil to develop the voltage to fire the spark plug.

Today's high-compression engines, particularly turbo/supercharged require high-energy ignition systems. Yet, in the interests of coil life and reliability, the dwell period must begin at the right millisecond. The coil must be charged just enough and no more to satisfy the plug firing requirement. That means the engine control system must control dwell.

Push Starting

Late-model ('93) control systems provide spark control for push starting. When the engine is being turned at low rpm with no Crank signal from the key, the control module recognizes a push start. The battery is probably low voltage so the push-start system provides increased dwell (coil ON time). For details, see Chapter 8.

2.3 Air Flow, Fuel Metering and Engine Load

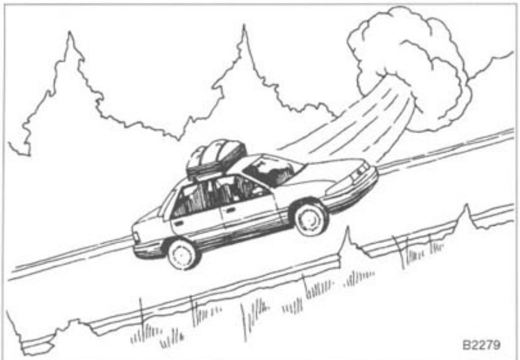

Fig. 2-10. Load changes as a result of hill, head wind, trailer, truck load, also under-inflated tires, open windows, dragging brakes, luggage/ski racks, etc.

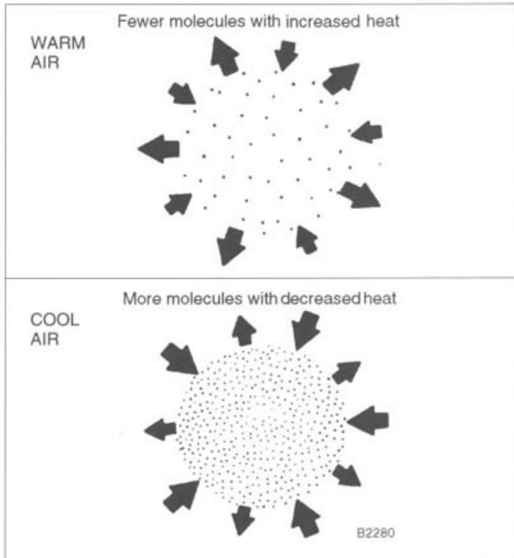

Fig. 2-11. Warm air has less density than cool air, and so, for the same volume, needs less fuel injected.

Measuring the engine load is an important need for good engine control. The load indicates how hard the engine is working. Load tends to relate to how hard you are pressing the accelerator. Load increases with increasing speed, also for climbing hills, increasing head winds, trailer towing, increased load in the truck bed. Load measurement is most important for determining the amount of fuel to be injected, but also for spark timing. Indirectly, load is important for emission control and for control of closed-throttle air passage.

When the control module needs load measurements, it's really asking, "How much air are we burning?" Or more specifically, "What is the weight of the air we are burning? To deliver the correct air-fuel ratio, I will calculate the weight of fuel to be injected."

Load relates to the weight or mass of air intake. The control module calculates the weight of air and then calculates the weight of fuel to be injected so the air-fuel ratio is correct for the operating conditions. Control module calculations must consider that the air changes its density (pounds per cubic foot) under two influences:

- Temperature—the same volume of warm air weighs less than cool air, and so needs less fuel injected
- Pressure—at higher altitudes, the same volume of air weighs less than at sea level. So too, the same volume weighs less when there is low pressure than when there is high pressure

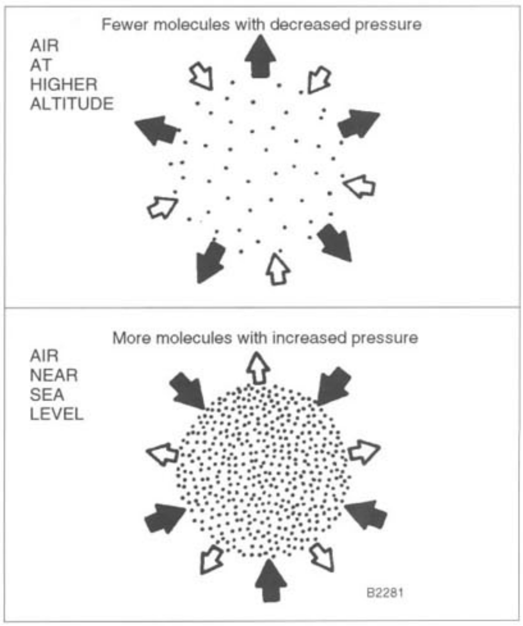

Fig. 2-12. Air at reduced pressure, such as at high altitude, or in low-pressure weather conditions, has less density than sea-level air. So, for the same volume of air needs less fuel.

3. Controlling Air Intake

You know that air is drawn into the engine with each intake stroke of each piston. The piston moving down on its intake stroke increases cylinder volume and lowers pressure in the cylinder. With the intake valve open, air and fuel rush in from the intake manifold to fill the cylinder. The amount of fuel necessary to create a burnable mixture depends on how much air fills the cylinder, as well as other conditions such as temperature. For turbo or supercharged engines, manifold pressure under boost is greater than atmospheric, packing in more air-fuel mixture than naturally-aspirated engines, as in most Fords.

3.1 Throttle

The throttle valve restricts intake air flow. Opening the throttle increases manifold pressure. In simplest terms, intake air flows into the cylinder because manifold pressure is higher than the pressure in the cylinder. Air rushes in during the intake stroke, trying to equalize the pressure. So the amount of air that rushes in on the intake stroke depends on the pressure difference—the difference between the pressure in the intake manifold and the pressure in the cylinder.

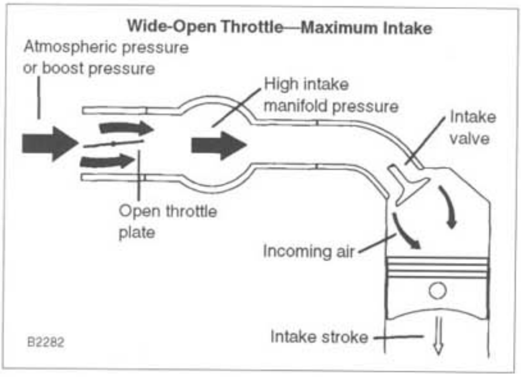

Fig. 3-1. When the throttle is open, manifold pressure is greater than pressure in the cylinders, so more air-fuel mixture moves into the cylinder as the intake valve opens. Boost increases air intake.

Pressure in the intake manifold depends on throttle opening. The greatest intake air flow occurs when the throttle valve is fully open. The throttle valve causes almost no restriction, and full atmospheric pressure (or boost pressure) is admitted to the intake manifold. This creates the greatest possible difference between manifold pressure and reduced pressure in the cylinder during the intake stroke, and the greatest intake air flow.

The least intake air flow occurs when the throttle is nearly closed. The restriction of the throttle valve limits the effect of atmospheric pressure. Air flow is low because of the small difference between manifold pressure and the pressure in the cylinders.

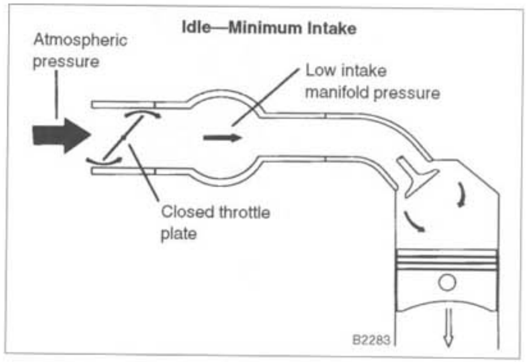

Fig. 3-2. With throttle closed, atmospheric pressure has little effect on manifold pressure. Low pressure-differential between manifold and cylinders results in little air flow. Of course, there is no boost.

Fuel metering requirements depend on how much work you are asking the engine to do—on how much of a "load" you are placing on it. To accelerate, you step down harder on the accelerator. This opens the throttle valve, increasing manifold pressure. The greater pressure difference between the manifold and the cylinders increases intake air flow, and therefore fuel flow, to increase power and accelerate the car.

Driving down a level road, you can cruise along comfortably and maintain a desired speed with a relatively small throttle opening. When you come to a hill, it is necessary to press farther down on the accelerator to maintain the same speed, even though engine rpm is unchanged. The hill has demanded more work from the engine—created a higher load—and the engine has demanded more air and fuel to match that load.

Regardless of engine speed, the air-flow and fuel-delivery demands of the engine depend on the load being placed upon it. That load, and the resulting throttle opening, directly affect manifold pressure. Manifold pressure in turn affects air flow and thus fuel requirements.

The overall air intake is directly related to the air flow, and indirectly related to the manifold pressure. The amount of air that enters each cylinder for each opening of the intake valve(s) is affected largely by the pressure at the intake valve(s).

When you see manifold pressure as on a manifold pressure gauge, or on a vacuum gauge, it may seem constant for a given engine condition. In fact, manifold pressure changes rapidly by the millisecond as the intake valves open and close, as shown in Fig. 3-3.

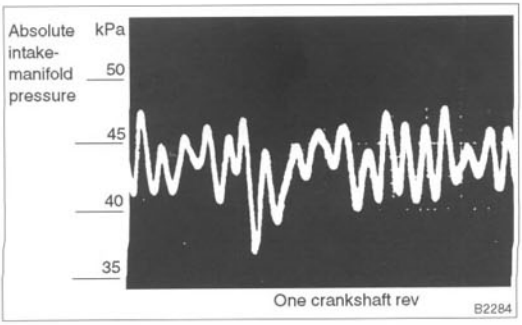

Fig. 3-3. Manifold pressure fluctuates rapidly (as much as 10%) as a result of intake valves opening and closing. This can cause changes in fuel-injection requirements.

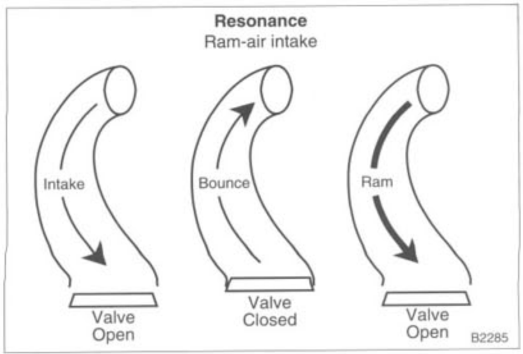

Fig. 3-4. Resonance of air column as it moves in intake runner helps ram air into cylinder.

You'll see an increasing number of Ford engines with two intake valves, four valves per cylinder. These begin with the 1989 SHO (Super High Output) 3.0L, and the 1.8L DOHC (Dual Overhead Cam) Escort/Tracer engine, first seen in 1991. DOHC 4.6L engines began with the 1993 Lincoln Mark VIII. Two intake valves provide a larger total inlet area than a single valve. Plus, each valve is lighter and can operate at a higher rpm.

3.2 Ramming Intake Air

The cylinder air intake—the mass of air that enters the engine—affects engine power. Getting more air-fuel mixture into the cylinders *per stroke* is the same as having a larger engine (more power).

With fuel injection, the intake runners carry only air instead of air-fuel mixture. The intake system can therefore ram intake air to improve engine efficiency without regard to fuel-puddling in the runners or boost limitations (typical carburetor problems).

Each column of air resonates or "bounces" back and forth in its runner. See Fig. 3-4. We say the air column has "inertia" as it moves back and forth. If the air column is bouncing toward the intake valve just as it opens, the increased pressure "rams" in extra air through each valve opening. The pressure also resists back flow caused by the rising piston on the first part of the compression stroke, while the intake valve is still open. The natural resonance depends on the length of the intake runner—longer runners take longer for the air to bounce back and forth. "Ram air intake" refers to the technique of ramming more air into the cylinders.

In general, long runners tend to improve low-speed torque and fuel economy, while shorter runners improve high-speed torque and power at a slight expense of economy.

Ford engine control involves three variations to increase intake air flow, depending on the engine:

- Fixed tuned intake-manifold runners
- Variable-length tuned intake-manifold runners
- Turbocharger or supercharger

Tuned Intake Runners

The first method of influencing intake air flow is tuning the intake manifold runners to a fixed length to take advantage of the natural inertia of the column of air. See Fig. 3-5. Ford engines use a surge tank or chamber just downstream of the throttle to dampen the effect of one cylinder on its neighbors.

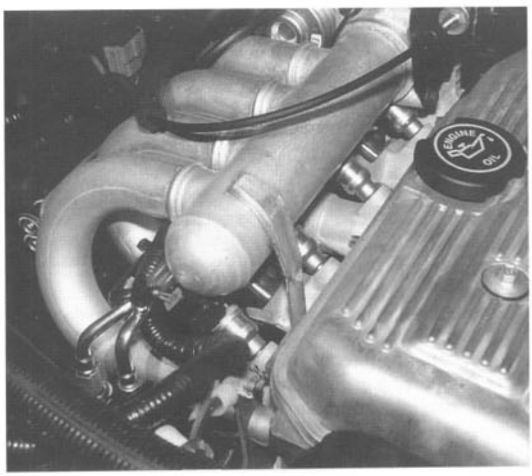

Fig. 3-5. Most Ford engines have tuned surge tank and intake runners. Objective is to use pulsations in runners to ram in more air per intake valve opening.

This separates the air column for each intake valve in its own intake runner.

It doesn't take a rocket scientist to figure that, for a fixed-length runner, this natural resonance, or inertia effect, has a fixed rate while the rate of intake valve-opening changes with rpm. In other words, the length is tuned for a highest efficiency within a relatively small range of rpm, according to the probable use of the vehicle.

Intake Air Control (IAC)

The second method of influencing intake air flow is to actively change the length of the intake runners as the engine changes speed. Ford uses a few different systems:

- Intake Air Control (IAC) on Ford Taurus SHO (Super High Output) 3.0/3.2L engines
- High-Speed Inlet Air (HSIA) control, also called Variable Inertia Charging System (VICS), on 1991and later Ford (Mazda) 1.8L DOHC engines in some Escorts and Tracers
- Variable Resonance Induction System (VRIS), similar to VICS, used on 1993 Ford Probe (Mazda) 2.5L V-6

Changing the effective length of the runners changes the tuning to match rpm. See Fig. 3-6. At lower rpm, the length of the intake runners is longer so the air column takes longer to bounce or resonate between the surge tank and the intake valve. The slower ram effect is timed to the slower rate of intake-valve opening. As rpm increases, the control module activates valves in the intake manifolds to shorten the effective lengths of the runners. The shorter air columns bounce faster to resonate with the intake valves, ramming in more air at higher rpm.

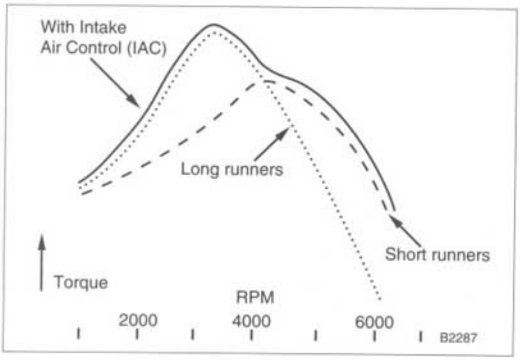

Fig. 3-6. Long runners increase torque at lower rpm. Short runners increase torque at higher rpm. With Intake Air Control, overall torque curve is better.

Turbocharging/Supercharging

The third method of influencing intake air flow is actively ramming air by turbocharging/supercharging, seen on three families of engines in the years since 1988:

- 1988–92: 2.2L Turbo 4-cylinder Mazda engines in Probe
- 1991 and later: 1.6L Turbo Mazda engine in Mercury Capri
- 1989 and later: 3.8L Supercharged V-6 in T-Bird SC/Cougar XR-7

The turbocharger mounts on the exhaust manifold to use the flow of exhaust gasses to spin a turbine. On the same short shaft, a compressor develops pressure in the intake system. Turbine speeds over 100,000 rpm are common. In these engines, Ford limits boost pressures to about 7 to 8 psi. Turbos tend to build boost pressures at higher engine rpm, increasing maximum power output, but delivering relatively little power increase at lower rpm.

Fig. 3-7. Engine exhaust drives the turbocharger (arrow). Ford uses turbochargers on some 1988 and later and some MECS engines.

The supercharger compresses air with two rotors. It is driven by the engine crankshaft through a poly V-belt at 2.6 times crankshaft speed, up to a rotor speed of about 15,000 rpm. Boost pressures of 12 psi are reached at about 4,000 engine rpm, so low-speed torque is a benefit of the supercharger over the turbocharger. The ordinary engine throttle controls boost pressures, controlling inlet to the supercharger so no wastegate control is needed.

NOTE —
Ford has dropped turbochargers from recent engines for emissions reasons. Hot exhaust is necessary for the catalytic converrter to operate most efficiently. The energy used to turn the turbo cools the exhaust. Cooler exhaust means the car may fail an emissions test.

Fig. 3-8. Engine-driven supercharger in 3.8L Ford delivers better low-speed torque than exhaust-driven turbocharger.

There are some problems with supercharging/turbocharging. At maximum power, the supercharger draws about 60 horsepower from the engine. The 3.8L engine without supercharger is rated at 140 horsepower. With the supercharger, the engine is rated at 210 horsepower net, so the gross horsepower is 270. For most operation, supercharger output is bypassed, reducing the supercharger draw to about ½ horsepower.

Also, when superchargers or turbochargers pack extra air into the cylinders, in effect they raise the compression ratio. One rule of thumb is that compression ratio rises by 1 for each 3.7 psi boost. That has two consequences:

- Some charged engines have lower compression ratios than their uncharged counterparts
- Knock sensing becomes important, even critical

Finally, the compression of ramming the intake air heats it. Remember from earlier that hot air has less mass, and therefore can burn less fuel (less power). To cool the air after compression, supercharged models have an intercooler (Charge Air Cooler) between the supercharger and the intake manifold. The cooler air—with more mass—provides increased power.

Volumetric Efficiency

Engineers use the term "Volumetric Efficiency" to describe the efficiency of taking air into the cylinders. Taking 5.0L of air into a 5.0L engine is described as 100% volumetric efficiency. Most engines run Wide Open Throttle (WOT) in the 70–80% range. With a turbo/supercharger, compressing the intake air can raise it to over 100%.

> Working with a new scan tool, I was surprised to find a read-out for volumetric efficiency. Of course that's no problem for the engine-control computer: It knows the cylinder capacity, say 5.0L. Reading the rpm, it counts 2 crankshaft revolutions (intake filling of all cylinders). Reading the Mass Air-Flow sensor, it knows the air-mass intake. (Knowing the air temperature, it calculates the volume). If the intake volume calculates to 4.0L every 2 revolutions, volumetric efficiency is 80%. Why would technicians want to read volumetric efficiency, I asked myself. Well, that could be a troubleshooting clue to a clogged air filter, or deposits in the intake passages. Further, it's a guide to the effectiveness of performance modifications such as intake porting and polishing, increased valve lift, and camshaft changes.

4. Pressure

Fuel injection means fuel under pressure. In most Ford engines, injectors operate at a relative fuel pressure of 270 kPa (39 psi). Relative pressure means pressure above the Manifold Absolute Pressure (MAP). More on that later.

When pressurized fuel is injected into the airstream, it vaporizes and mixes with the air into a good burnable mixture. Picture how a liquid is vaporized when you spray it under pressure from an aerosol can.

Fuel in a carburetor is normally at atmospheric pressure. Vacuum at the tip pulls gasoline from the fuel jets. I'm talking about vacuum, or the pressure difference between:

- Air pressure on the fuel in the carburetor bowl, and
- Air pressure in the venturi chamber

That difference is usually small. Fuel moves into the airstream because the moving air in the venturi of the carburetor is at reduced pressure, aided by the piston pumping actions. For a cold start, the carburetor choke restricts the air entering the venturi, acting to further reduce the air pressure to pull in more fuel.

4.1 Pressure Measurement

As I get into the specific functional details of fuel-injection systems, you'll see that many functions and relationships are defined in terms of pressure. They may be fuel-pressure values in the fuel system, manifold pressure in the air intake system, or atmospheric pressure. I may be talking about a differential pressure—the difference between two opposing pressure values somewhere in the system.

Barometric (Atmospheric) Pressure

If you watch the local TV weatherperson, you'll hear talk of "highs" and "lows." They're talking about barometric pressure readings used to describe atmospheric pressure changes.

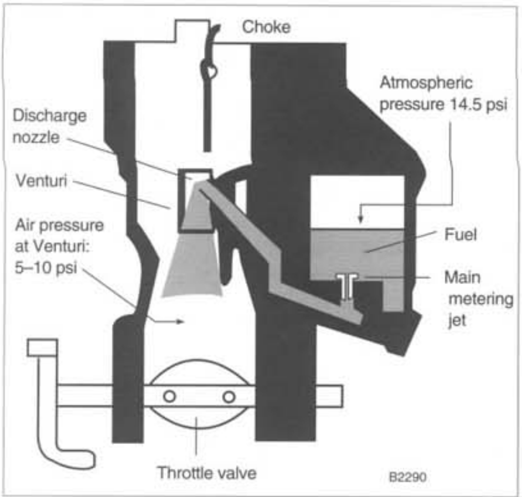

Fig. 4-1. Fuel-metering part of a carburetor operates with small differences in pressure. Atmospheric pressure on fuel in bowl moves fuel into reduced pressure at the discharge nozzle in venturi.

Changing atmospheric pressure changes the density of the air. Denser intake air can slightly alter the air-fuel ratio and may affect how your engine operates. Some Ford engine-control systems have features that allow the system to compensate for variations in air density.

Barometric pressure is the result of air pressing down (and in all directions). Typical "standard day" pressures are 101 kPa, (14.7 psi, or 29.92 in.Hg). I round off to 100 kPa because that's within day-to-day variations from standard, and besides, 100 kPa corresponds to about 500 feet above sea level. Few vehicles operate exactly at sea level.

Barometric pressure is hard to understand because we don't feel it. We live in this "ocean of air" with atmosphere pressing on all sides of us. But it's inside too, so it balances out and we don't feel it. But our engines do. When the engine pumps air in the intake strokes, it reduces the absolute pressure below atmospheric and creates what we call "vacuum." The engine control system must "feel" the barometric pressure and the manifold absolute pressure and adjust accordingly.

In any case, you'll find pressure values expressed in one or more of the following units or terms. With the appropriate conversion factors, all are interchangeable.

Wait a minute, 14.7 is the ideal air-fuel ratio, and 14.7 psi is barometric pressure at sea level! How's that again? Pure coincidence, but that makes it easier to remember those two important numbers in engine control, particularly in U.S. measuring units.

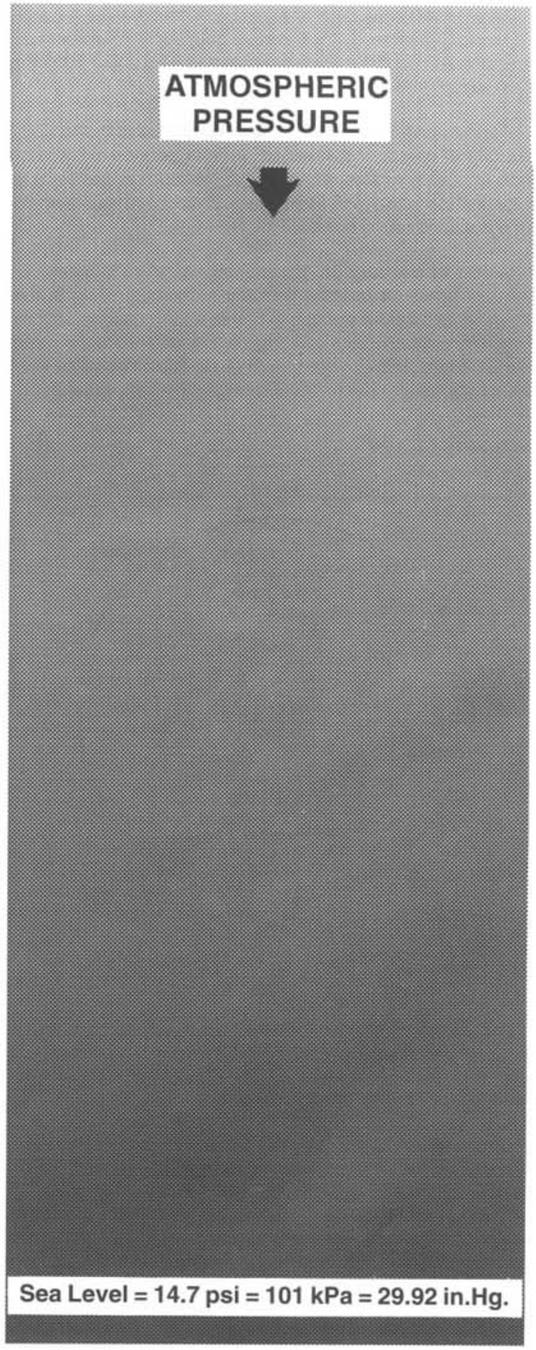

Fig. 4-2. Pressure at sea level is weight of air pressing down.

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kiloPascal (kPa). SAE and most auto makers use the metric unit for pressure. Some pressure gauges now read both psi and kPa. Atmospheric pressure at sea level is about 100 kPa, easy to remember.

Pounds-per-Square Inch (psi). Widely used in the U.S., the unit of pressure defined as force in pounds, divided by area in square inches. Atmospheric pressure at sea level is approximately 14.7 psi. Most of us drive above sea level so 14.5 is a good round number.

Inches of Mercury (in. Hg.). Originally refers to measurement of pressure using a mercury manometer. (Hg is the chemical symbol for mercury.) This is a term used to specify manifold vacuum. 29.92 in. Hg. is the difference between standard atmospheric pressure at sea level and absolute vacuum. Indy racers refer to boost in terms of in.Hg., absolute.

Gauge Pressure

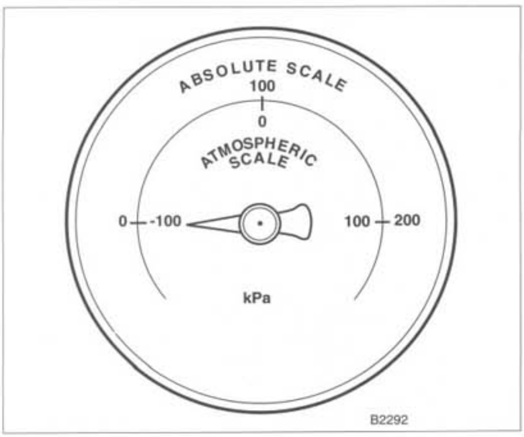

Fig. 4-3. Calibration of pressure gauge influences how you interpret pressure readings.

I've described engine intake-airflow and load in terms of manifold pressure, and I've discussed the units of measure used to describe pressure. Now it is important that you understand exactly what you are measuring.

For many years, people have traditionally thought about engine air flow and load in terms of vacuum—the "vacuum" created in the intake manifold by the intake strokes. Using atmospheric pressure as a baseline, as zero, the lower manifold pressure is expressed as a negative value—vacuum. That was convenient because carburetors worked on "vacuum."

By the 1980s, the automotive industry had moved away from thinking in terms of vacuum. Widespread use of fuel injection under pressure called for positive thinking—in terms of the manifold absolute pressure (MAP), measuring from absolute zero. During part-throttle operation, or coasting, manifold pressure reads positive, from zero. During supercharging and turbocharging, manifold pressure also reads positive, from zero. In the world of fuel injection, and particularly, boosted systems, vacuum measurements are confusing.

Using absolute pressure as the reference point, the piston on its intake stroke is creating a low pressure in the cylinder —approaching zero absolute pressure. The absolute pressure in the intake manifold (MAP) is higher and always a positive number. Atmospheric pressure outside the engine is higher still. Your throttle controls its influence on manifold pressure. The turbocharger provides pressure above atmospheric pressure.

You must understand how barometric pressure relates to gauges you may work with:

- Vacuum gauges are referenced to barometric pressure, reading 0 when there is no vacuum
- Most pressure gauges are vented to or referenced to barometric pressure, reading zero when there is no pressure above atmospheric
- Boost gauge of turbo engine is referenced to barometric pressure. Read vacuum in in. Hg. less than barometric, boost in psi above barometric
- Absolute pressure gauges are sealed, referenced to zero pressure. With the engine off, they read absolute atmospheric pressure. In the engine control, the Manifold Absolute Pressure (MAP) sensor reads absolute pressure, always positive whether below atmospheric, as in idle or part throttle, or above atmospheric, as in boost

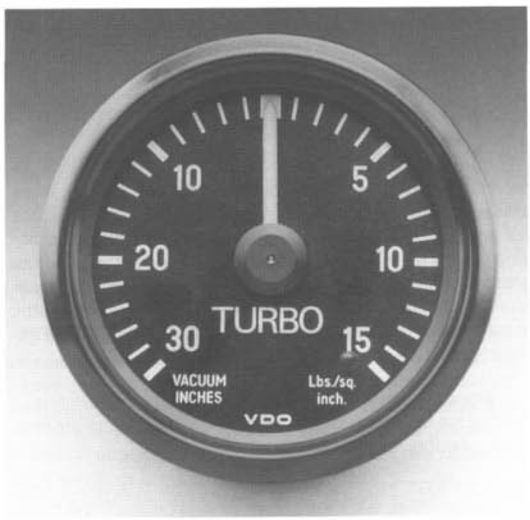

Fig. 4-4. Turbo boost gauge reads vacuum in inches of mercury, but reads boost in psi. That's like adding apples and oranges. Indy race drivers read absolute gauges, 0-60 in. Hg.

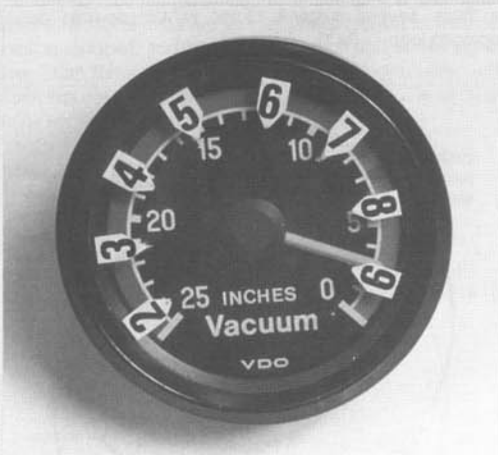

Fig. 4-5. When you open throttle for increased load, you increase MAP (Manifold Absolute Pressure). Reading a vacuum gauge, WOT decreases manifold vacuum. If you think positive—increased MAP for increased load, it's easier to understand fuel-injection control.

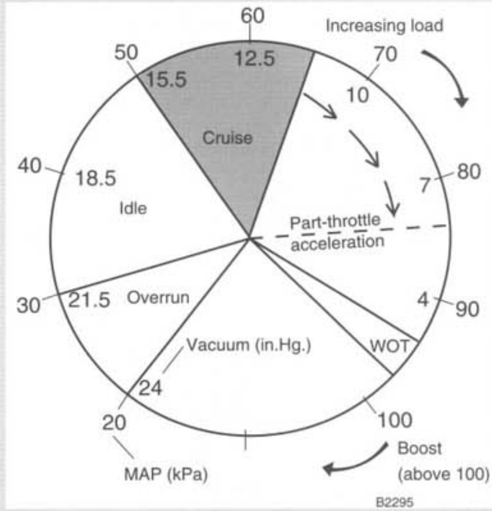

Fig. 4-6. Increasing load increases MAP. Typical OVERRUN is 20–30 kPa, IDLE, 35 kPa, CRUISE, 50–65 kPa, WOT of unboosted engine, near 100 kPa, MAX BOOST 180 kPa.

I've been driving with a vacuum gauge connected to the intake manifold of each of my last 9 cars. The gauge comes calibrated in terms of vacuum, so at Wide Open Throttle (WOT) it reads close to zero. Notice this gauge has zero on the right so increasing manifold pressure (as a measure of engine load) increases clockwise, just the same as the tachometer. I have marked my gauges to read positive manifold pressure. At or near sea level, that's close to MAP. At WOT (near zero vacuum), my gauge reads about 9 on the homemade MAP scale, as shown in Fig. 4-5. Multiply by 10 to read pressure in kPa (90 kPa). The important point is that the numbers increase as the load and power increase. Fig. 4-6 shows approximate range of gauge values for various driving conditions and throttle positions. By coincidence, 65 mph cruise reads about 65 kPa.

On a turbocharged or supercharged car, boost will read above 100 kPa (atmospheric) on the MAP scale. In Ford engines, MAP changes continuously from about 20 kPa during overrun (coasting with closed throttle) to perhaps 180 kPa at maximum boost. When we discuss the importance of manifold pressure to fuel injection, you will find it an advantage to think in terms of the positive MAP values (from absolute zero) rather than vacuum.

Vacuum is related to MAP, but differs from MAP in two ways:

- MAP increases with engine load while vacuum decreases
- MAP measures load referenced to absolute zero pressure, while vacuum is referenced to barometric pressure

5. Control Systems

By now, you are aware that control plays an overwhelmingly important part in maintaining the acceptable balance of power, fuel economy, emission control, and driveability. Ford electronic engine control systems, by responding to measured inputs and precisely metering the appropriate amount of fuel for the conditions, offer unparalleled control.

Control systems may operate one-way or "open-loop." Under limited engine operating conditions, they take the information about operating conditions received from various sensors, or from computer memories and then use that information to determine signals to the actuators:

- Injector pulse time
- Spark advance time
- Idle-air bypass opening

Accuracy of the open-loop air-fuel ratio, spark advance, and idle rpm depends mainly on how well the system can predict the engine's needs based on its "knowledge" of operating conditions.

Most of the time, Ford engine-control systems operate "closed-loop." While they try still to predict the engine needs based on operating conditions, they also measure the results of their fuel metering and use that information as an input to achieve ever more precise control.

5.1 Closed-loop Control Systems

In a closed-loop control system, information about whatever is being controlled is continuously fed back to the system as an input. There's an unfortunate tendency in our business to associate closed-loop only with air-fuel ratios. But, as I'll show you here, several systems in the vehicle operate closed loop/open loop.

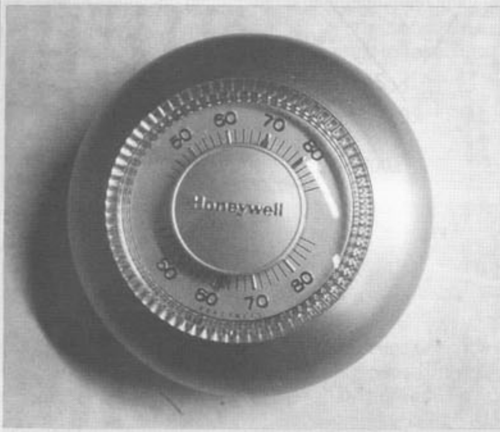

Fig. 5-1. Home thermostat is closed-loop system, using feedback from the thermometer (sensor) to control the furnace or air-conditioner (actuator).

The operation of a thermostat in an automatic heating system is an example of closed-loop control. You set a target temperature—what you want the automatic heating (or cooling) system to deliver. As the temperature falls from the target, the thermostat senses lower temperature and automatically signals the furnace to add heat. As soon as the temperature rises to the target setting, the thermostat senses the results of its own control action. The heat produced by the furnace automatically signals the furnace to cut back the heat, a closed-loop system.

An open-loop system may, for example, sense low temperature and simply turn on the heat for a predetermined amount of time, with no feedback of the results of turning on the heat. However, closed-loop control is automatic. Temperature stays relatively constant, reducing energy consumption. In all, the result is better, more precise control.

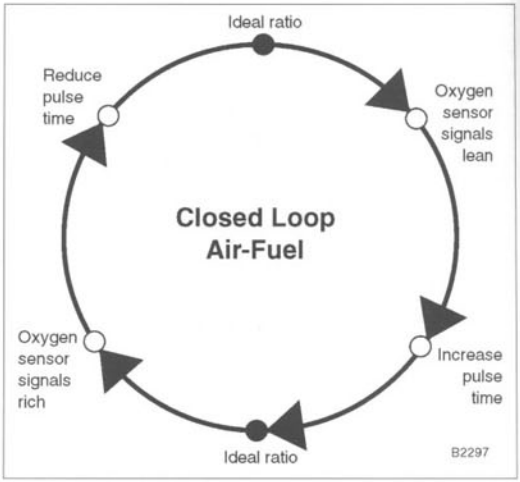

Fig. 5-2. Air-fuel ratio is controlled closed-loop by sensing oxygen in exhaust (an indirect measurement of air-fuel ratio), and changing injector pulse time.

Air-fuel ratio control operates closed-loop, comparing the actual air-fuel ratio to the desired. Measurement is indirect, based on the oxygen sensor signal to the control module. The control modules varies injector pulse time to maintain the target air-fuel ratio (oxygen content). When open loop, injector pulse times are independent of oxygen sensor input. More in Chapter 4.

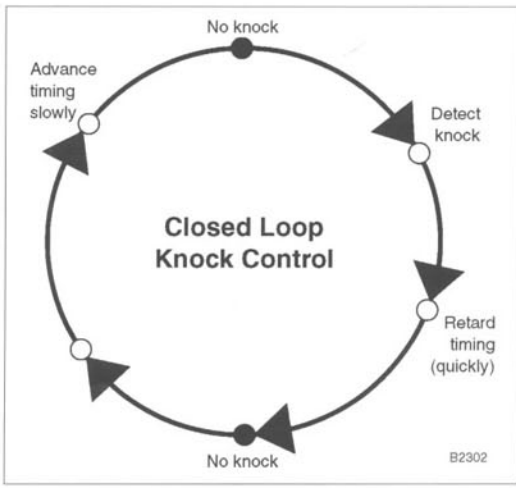

Fig. 5-3. Knock feed-back signals relate to engine detonation (spark knock) and therefore spark timing.

Knock control operates closed loop, sensing knock-sensor signals. When signals are sensed, spark timing is retarded, boost is reduced, and injectors are cut off until knock signals stop. Then the actuators return to normal—gradually—until knock signals are sensed again. To prevent engine damage, knock sensors are never operated open loop.

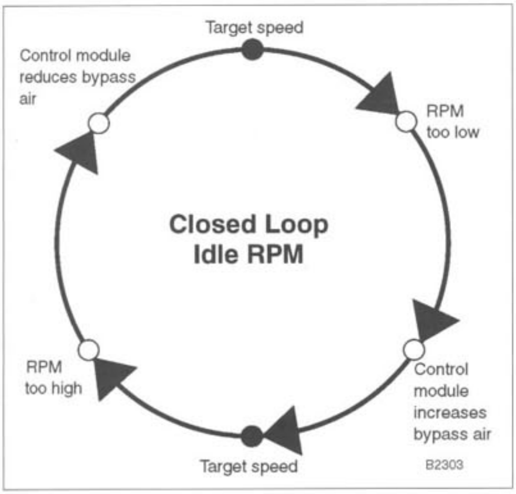

Fig. 5-4. RPM feedback signals relate to engine speed, and therefore to idle speed control (idle air bypass).

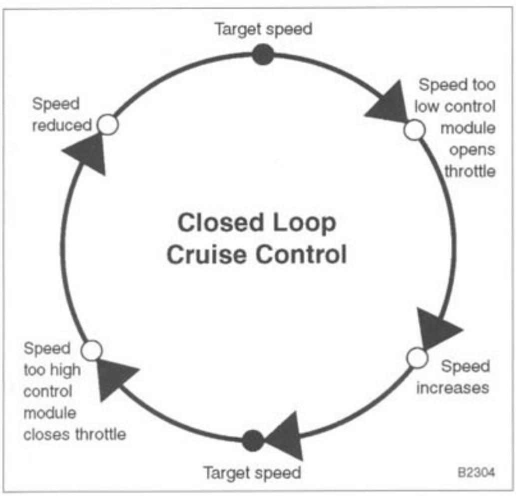

Fig. 5-5. Cruise Control operates closed loop, comparing target speed (from memory) with actual speed (sensor). Control module actuates cruise-control motor to maintain target speed. When cruise control is off, system operates open loop.

> Unfortunately, closed-loop electronic engine controls occasionally add to pollution in a strange way. One EPA engineer told me that they find what they call "gross emitter" fuel-injected cars with the driver unaware that he is so far from "green". In one worst case, one car was emitting 321 g/mi, almost 100 times the limit. The engine-control system was so flexible that the car was still driveable. If a carburetor car were running that dirty, it would be a pig to drive and the owner would be more likely to take it in for repair.

2

Idle rpm control operates closed loop, comparing idle rpm to target rpm. When rpm is too low, idle-air bypass is increased to prevent stalling. When idle rpm is too high, idle-air bypass is decreased.

Cruise Control, when engaged, operates closed loop. The computer compares the target speed with the actual speed, and sends signals to the cruise-control motor, opening or closing the throttle to automatically deliver the target vehicle speed. When disengaged, cruise control operates open loop, with the driver operating the throttle.

I like to describe closed-loop as the equivalent of having a skilled technician riding under the hood, continually tuning the mixture, adjusting spark timing and other engine operations for the best operation under the current conditions.

5.2 Feedback/Feedforward

Feedback is the term applied to the measurement signal to the system. It looks back to monitor the results and feeds those back to the computer—a sort of "How am I doing?" Several systems feed back measurement signals:

- Exhaust-gas feedback signals relate to the air-fuel ratio, and therefore the injector pulse-time
- Knock feedback signals relate to the detonation in the engine, and therefore to the spark timing
- RPM feedback signals relate to engine speed, and therefore to the idle-air bypass

Feedforward is a relatively new term, the counterpart of feedback. It looks ahead and feeds signals to the computer that anticipate changes about to happen—a sort of "What should I be doing?" Several systems feed forward signals that anticipate changes in engine control:

- Engine accessories feed forward signals relating to engine idle rpm, and therefore to the idle-air bypass Examples: air conditioning, power steering pressures, even the increased alternator load caused by heated rear-window or windshield
- Idle rpm is maintained to a target engine speed by the closed-loop feedback system. But the feedforward signals anticipate rpm drop caused by load, and prevent it, instead of reacting to it. The result is a smoother engine idle

6. Operating Modes—Strategies

If I were talking about the requirements of a stationary industrial engine, I'd expect it to operate under fixed conditions: constant rpm, constant load, nearly constant temperature, limited stops and starts, no acceleration, and no heavy-footed driver. Such an engine would operate quite nicely at a fixed air-fuel ratio, and fixed spark timing. It could be easily tuned to maximize fuel economy and emission control, and would require only the simplest of engine control systems.

Cars and trucks, however, are a different story. We expect them to perform under the widest possible variety of operating conditions. And we have given "performance" a new definition: it is not only impressive horsepower and torque, but also maximum fuel economy, and controlled exhaust emissions.

As if these performance demands were not enough, we also expect the car to meet these demands effortlessly, at any time, under any conditions, and at the turn of a key. We expect "driveability"—the ability of the vehicle to provide smooth, trouble-free performance under virtually any condition.

Driveability is a term that evolved out of the early days of strict emission control and the '70s energy-crisis concerns over fuel economy. The carburetor technology of the time dictated an approach to both problems that often resulted in the engine running too lean. Running too lean robbed power and contributed to rough idle, poor throttle response, stumbling and stalling, as well as destructive underhood temperatures. It also increased some emissions! Retarded timing reduced some emissions, and robbed engines of their power, economy, and driveability. By 1974, the cures for emissions were almost worse than the disease. Fuel economy ratings hit a disastrous low. Since the 1980s, fuel injection and engine-control systems offer the precise control and flexibility necessary to meet modern performance requirements.

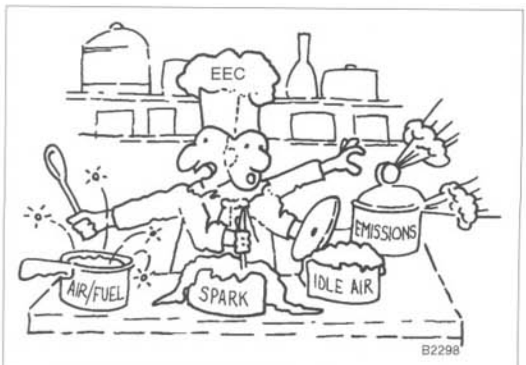

Fig. 6-1. Ford engine control systems have to watch many systems at one time.

One reason Ford engine control can seem complicated is that it has so many things to manage, perhaps something like a solitary chef keeping several dishes cooking at the same time:

- Air-fuel ratio
- Ignition timing
- Idle-rpm
- Emission control (Exhaust Gas Recirculation, Secondary Air to manifold or catalytic converter, Evaporative emissions (fuel vapors)

While you're at it, manage:

- Automatic transmission, or signal the A/T control unit
- Engine-cooling fan and engine temperature
- Air-conditioner operation
- Engine diagnostics (remember any fault codes)
- In later model engines, keep a running count of serial data (sensor and actuator data) to play back to advanced scan tools

Be sure to send information to:

- Keep Alive Memory (KAM)
- Malfunction Indicator Light (MIL) "Check Engine"
- Trip computer

Oh, yes, remember the "short-term" corrections you are making and adapt the engine control on a "long-term" basis.

Strategies

Ford uses the term "strategy" to describe the plan of the engineers' design of the engine-control system. In this chapter, I'll describe nine strategies as they relate to different engine operating conditions. I'll show how those strategies relate to the four parts of engine control: air-fuel ratio, spark timing, idle-air, and emission controls. In chapters 4–7, I'll discuss the parts of the engine control system—the sensors, the actuators, and the control module. I'll put it all together in Chapter 8—how each of the Ford systems operate to satisfy the goals of each strategy under different conditions.

6.1 Normal (Warm) Cruise Strategy # 1

I'll start with warm cruise because it is probably the simplest job for the engine management system.

Normal cruising at light load with the engine fully warmed up is the baseline operating condition. The basic engine control strategy meets the need for the proper air-fuel ratio, the proper spark timing, and the proper emission control under these simple cruising conditions. You may add power on a hill or to pass another car, or cut back power to slow down, but fuel management, timing and emission control are still relatively simple.

> Ford uses the term "warm" during the first three minutes after Cold Start at room temperature. After that, it is "hot." I prefer to consider the engine "warm" when it is at normal operating temperatures, and "hot" when it is overheating. After all, "H" on your temperature gauge means too warm, "Hot!" All depends on how you look at, or how you feel it.

When you are cruising down the interstate on a level road, the engine is operating under relatively constant normal conditions. The fuel quality may vary from one tank fill to the next, weather and outside temperature may change, it may be dry or it may be damp. The ideal air-fuel ratio and timing may be different for each of these conditions. An engine-control system can adjust to these changing conditions with little challenge. It can maintain air-fuel delivery near the ideal ratio of 14.7:1. It can maintain timing slightly below the knock levels to satisfy the most important considerations of fuel economy and low exhaust emissions. Normally, the systems operate closed-loop during warm cruise.

Control Emission Systems

Warm Cruise conditions are right for emission control. Further, most of the engine operating hours are at warm cruise so emission control has the greatest total effect on emitted gasses. EEC controls emission systems such as Exhaust Gas Recirculation (EGR), Canister Vapor Purge, and Three-Way Catalytic Converter on two bases:

- When is it right for the engine? For example, the engine does not run well if exhaust gas is recirculated when the engine is cold. The engine loses maximum power if EGR is on at Wide Open Throttle
- When is it right for the system? For example, pumping air into a cold catalytic converter prevents the converter warm-up that is necessary

Control Torque Converter

For cruising economy, the strategy calls for control of the torque converter lock-up clutch most of the time, according to engine operating conditions.

Continuous Test

During all normal operation, the control module continuously tests inputs. One at a time, each individual circuit is tested for shorts and opens. Additionally, the control module notes illogical readings—an Engine Coolant Temperature Sensor changing from warm to cold to warm. The first time an error is observed, it is counted but not registered because the system does not store errors that are not repeated. After an error occurs several times, it is stored as a Trouble Code in the memory—in the Keep Alive Memory (KAM).

Provide Diagnostic Codes

For troubleshooting, strategies include signalling a malfunction to the driver, and storing EEC trouble codes of malfunctions for later readout by a voltmeter or by a hand-held tester. This applies to all strategies, even crank, signalling the possible cause of no-start.

Provide Deceleration Control

Although the engine is not idling, cruising strategy calls for providing enough airflow around the throttle plates to act as a "dashpot" in the event of sudden throttle closing.

Intake Air Control

The engine is operating at light load unless you are climbing a hill—I'm talking road horsepowers in the region of 10 to 20. The Intake air controls are operating at light load. The turbo, or the engine-driven supercharger, is coasting.

6.2 Engine Crank—Strategy #2

As an owner, you expect the engine to start instantly when cranked by the starter, unaffected by

- Temperature, whether at sub-zero temperatures or parked in the desert, too hot to touch
- Time, whether it's been sitting for five minutes at the store or for five weeks in the garage

Cold Engine

Cold crank means the engine is cold. That is, it probably hasn't run for at least 12 hours. The temperature needle is at the low end of the gauge. The engine temperature might be:

- Minus 30°C (-20°F), sometimes called cold-cold
- Plus 45°C (115°F), sometimes called warm-cold

In either case, the engine is still cold compared to its normal operating temperature of about 90°C (195°F).

In most parts of the country, you may need to start under cold-cold cranking conditions, the most challenging of all. Gasoline is less likely to vaporize when it is cold. Even if it is adequately vaporized, some fuel condenses on the cold parts of the engine before it can be burned. The engine requires extra fuel for starting so that, in spite of vaporization and condensation problems, the engine still receives a combustible air-fuel mixture.

What constitutes a combustible mixture depends on air temperature, the volatility of the gasoline, altitude, barometric pressure and humidity. While a carburetor relies on a relatively crude choke mechanism to enrich the mixture for cold starting, fuel injection compensates for many of these factors. Temperature is the most important.

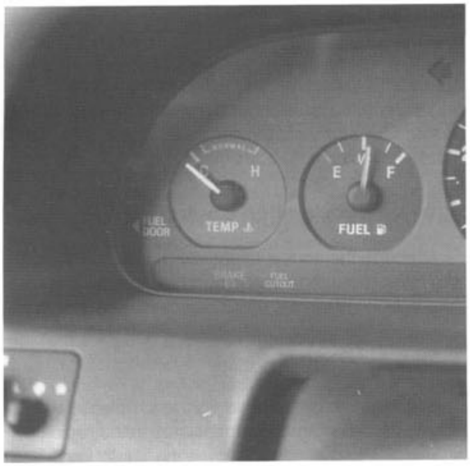

Fig. 6-2. Engine-cold temperature varies according to outside temperature. Cold start means engine has not run for several hours.

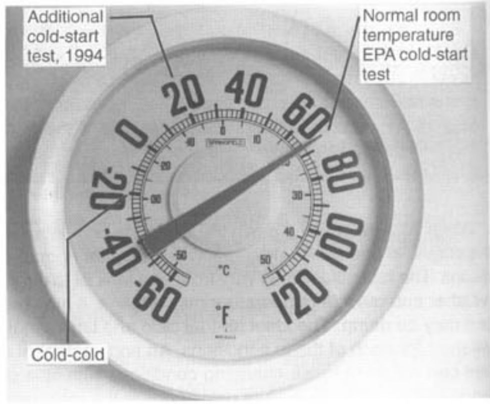

Fig. 6-3. Fuel requirement for engine starting varies according to outside air temperature: cold-cold or warm-cold. These temperatures are both cold compared to normal engine operating temperatures.

To understand the distinctions I've made in cold-start temperature, consider the Environmental Protection Agency (EPA) definition of cold start. For EPA testing, cold is room temperature, about 20°C (68°F). All vehicles are tested on dynamometers inside the lab. The engine must cold-soak at 20°C in the lab next to the dynamometer for 12 hours before the test. Technicians push vehicles onto the dynamometer for the cold-start test. As it happens, 20°C is close to actual cold-start temperatures in Southern California and much of southern U.S. Engine temperature affects the driveability of your engine, which may be much colder than an EPA cold engine. For scientific comparison testing, and for the regulatory aspects of EPA testing for emissions and fuel economy, testing to a single set of standard conditions for uniformity is the most important factor. Cold-start emissions are so important to the total pollution effect that, beginning in 1994, EPA will test engine starts at –8°C (20°F). This will certainly affect engine control systems, and probably, your driveability.

Cranking vs. Starting

In defining strategies, Ford makes a distinction between cranking and starting. Cranking needs its own strategy because the engine-control computer cannot depend on the usual signals from the sensors to compute fuel injection, spark timing, or idle rpm. The computer can distinguish cranking from starting because the cranking rpm is slow and irregular. The most important considerations:

- Programmed rich mixture, with fixed air-fuel ratios:
  12:1 for a warm crank
  2:1 for a cold-cold crank
- Fixed spark timing
- Wide-open idle-air bypass to start without requiring driver's foot on the accelerator
- Withhold any emission control such as EGR, secondary air, or canister purge

Cranking enrichment quickly becomes a problem if the engine does not start right away due to a marginal battery, ignition components in poor condition, or whatever. Enrichment during cranking must be cut back after 20 seconds. If it goes on too long, the air-fuel mixture will be too rich to ignite. The spark plugs may become fuel-fouled, particularly when they are cold, and the engine will not start.

Cold cranking also needs help in terms of intake air flow. A closed throttle at slow cranking speeds does not allow enough air for starting.

De-Choking

Under some conditions, cranking may "flood" the engine in spite of the best efforts of the engine control system. "De-choking" provides for cranking without fuel to dry out the plugs and the cylinders. Cranking with the accelerator held full down signals the system to de-choke.

6.3 Cold Start—Strategy #3

Starting strategy begins after engine crank when the engine computer receives signals indicating a steady crankshaft rpm. Depending on engine temperature and intake-air temperature, the engine control calls for:

- Programmed rich mixture, probably less rich than cranking
- Advanced spark timing, cool engines are less likely to detonate
- Reduced idle-air bypass, only enough to maintain cold idle rpm
- Emission control is still cut off

Drivers of carbureted cars develop intricate starting procedures: depress the accelerator to the floor, release, then hold the throttle about 1/3 open (for example). The first depression is necessary to set the carburetor choke and fast-idle cams. The second is to open the throttle and make sure the engine is getting enough air. And, after start, some of us would keep kicking the throttle, trying to get it off the fast-idle cam to reduce the racing idle speed.

Ford fuel-injection systems can control the air by bypassing the closed throttle, admitting more air when cold without any effort or attention from the driver. In the Owners' Manual, you'll see "No-Touch" starting: "Do not depress accelerator until the engine starts."

Warm-up

Cold start includes the beginning of warm up. Enough good signals are coming from the sensors so that the engine can be controlled on the basis of temperatures.

- Mixture enrichment cut back
- Spark timing retarded from its cold advance
- Idle rpm reduced
- Emission control limited to secondary air into the intake manifold to help burn the rich mixture delivering some raw fuel into the exhaust. This helps heat up the unheated oxygen sensor and the catalytic converter so they can begin operating sooner. Exception: not when engine is colder than 13°C (55°F). Emission control cuts back air injection after 3 minutes.

One of the joys of driving cars with fuel-injected engines is the freedom from a too-fast idle that can jar the vehicle when an automatic transmission is shifted into Drive or Reverse. Most Ford cold-idle specs are slightly more than 1000 rpm.

6.4 Cold Driveaway—Strategy #4

Cold driveaway strategy must prevent cold stall caused by:

- Shifting automatic transaxle into Drive or Reverse or releasing clutch of manual transaxle vehicle
- Opening the throttle

Cold driveaway strategy includes control to:

- Enrich fuel to provide burnable mixtures with added intake air
- Advance spark timing to provide smooth acceleration

For those accustomed to warm-up in the driveway, let me urge a "cold driveaway." Ford manuals use the phrase, "after a few seconds." Driveway warm-up is a bad habit carried over from carbureted vehicles that usually required restart if not allowed to warm up before driving. Today, both Ford and EPA encourage cold driveaway in the interests of economy and emissions. Of course,I discourage full-bore on the freeway until the engine warms enough for good oil circulation.

6.5 Warm Driveaway—Strategy # 5

- Programmed fuel injection still richer than normal, needs enrichment during throttle opening
- Spark timing is advanced, but less than cold driveaway, controlled by several factors, engine rpm, load, and temperature
- Emission control may include EGR as the engine warms

6.6 Part Throttle Acceleration, Warm—Strategy # 6

This strategy follows Warm Cruise, closed loop operation, with all emission controls operating. This strategy considers that you want to increase vehicle speed, but you're still interested in economy and emission control:

- Fuel-injection is enriched during the brief interval of opening the throttle and reaction by the air flow sensor
- Spark timing is advanced, but less than Warm Driveaway
- Emission control continues, with secondary air oxidizing in the catalytic converter

6.7 Full Throttle Acceleration, Warm—Strategy # 7

This strategy, sometimes called WOT for Wide Open Throttle, operates to provide full power, without regard to economy or emission control. Closed loop operation switches to open loop.

- Fuel injection is enriched as long as the throttle is full open
- Spark timing is advanced to increase power. With the rich mixture, extra advance can be programmed with less risk of detonation
- Emission control stops (EGR, air injection)
- Air conditioning compressor and cooling fans are turned off for 10 seconds

As soon as the throttle moves from WOT, strategy switches to Part Throttle, #6.

6.8 Deceleration, Closed Throttle—Strategy # 8

This strategy saves fuel, and prevents engine stalling by sudden cut-off of intake air. Remember, I said in Warm Cruise, or any Part-Throttle Operation, the Idle Air Bypass is always part way open, to act as an electronic dashpot.

- Closed throttle at any rpm above idle means deceleration or coasting, so fuel is cut off, and air flow is maintained to keep the engine from stalling
- Closed throttle at idle rpm means idle, requiring idle fuel and idle air flow

This strategy provides a smooth transition between deceleration, when engine braking is desired, and idle, when engine power is needed to keep the engine turning, with various loads, as in Strategy #9.

6.9 Warm Idle—Strategy # 9

Our vehicles spend much time idling, so a smooth idle is important to driver comfort and emission control. The main requirements of a warm engine running at idle speed are smoothness, and smooth response once the throttle is opened. Some engines require a richer mixture at idle for smooth running, and to ensure good off-idle response.

In general, the engine should idle at the lowest speed at which the engine will still run smoothly enough to satisfy the driver. Reducing idle speed to a minimum reduces noise and fuel consumption.

The biggest obstacle to low idle speeds is the variation in load on the engine at idle. At idle, small changes have big consequences. Friction loads change with temperature. The power required to operate the charging system varies with electrical load (headlights, for example). Air conditioning compressors switch on and off. On vehicles with automatic transmission, shifting into Drive or Reverse at idle increases the load.

With engine control monitoring and constantly correcting idle speed, it is not necessary to maintain a high idle to handle variations in engine performance, changing of loads, and similar causes of stalling from idle.

Idle-Speed Stabilization

Advanced idle-speed stabilization systems satisfy some sophisticated requirements, particularly on vehicles with air conditioning (A/C) and automatic transmission:

Condition	Transmission	Idle Speed
A/C Off PS load normal	In Neutral/Park	Lowest rpm required for engine smoothness
	In Drive/Reverse	Lowest rpm for minimum creep
A/C On PS load normal	In Neutral/Park	Increase rpm for A/C compressor load
	In Drive/Reverse	Increase rpm, but less, for creep
A/C Switch On, or hard PS turn	In Neutral/Park	Increase rpm during switch On to prevent stall
	In Drive/Reverse	Delay increase to avoid surge
Hot ECT (110° C)	In Neutral/Park	Increase rpm to cool engine
	In Drive/Reverse	Delay increase to avoid surge

Modern fuel-injection/engine control systems manage much more than fuel delivery. Chief among the extra capabilities of an engine-control system is simultaneous control of fuel delivery, spark timing, idle-air, and emissions. Controlling all these factors opens up new possibilities for power and driveability improvements while maintaining tight control of exhaust emissions and fuel economy.

Recent question to an auto editor of a Silicon Valley (CA) newspaper. "I have a Mazda MX-6 [Ed. note: same engine control as a Ford Probe]. I notice a strange change in my idle under these conditions: night, lights on, idling at stop light, turn signal blinking. Every time the turn signals are on, the engine seems to speed up slightly; when they're off, the engine seems to relax -- not enough to see on the tach, but I feel it."

And the wise auto editor understood Idle Speed Stabilization. "with the headlights on, when the turn signal lights blink on, that causes the line voltage to drop, so the alternator must increase output. The idle-air bypass opens slightly to increase engine output. As the lights go off, the alternator load reduces and the engine can relax."

7. Changes in Engine Conditions

Automatic control of air-fuel ratio continuously adjusts the amount of fuel injected to correspond to oxygen in the engine exhaust. This feedback system provides a fine tuning of the air-fuel ratios called for by the computer. For example, as the engine mechanical condition changes with time, the feedback system can accommodate, changing the air-fuel ratio to match changing engine conditions. Perhaps a leaking valve is causing a change in combustion, so a bit more fuel is required in the cylinder. The closed-loop system will tend to accommodate this change. It will also accommodate certain changes in fuel quality that may affect combustion.

7.1 Adaptive Control

Adaptive control means the computer can be programmed to "learn" the way the closed-loop control is operating. Suppose, for example, the system were continually driving slightly toward rich compared to the open-loop values stored in the memory, perhaps to counter a small vacuum leak. The computer might memorize this correction. At the same time, the engine may be operating at a high altitude that causes it to run rich. These two conditions do not cancel each other because the leakage affects the air-fuel ratio at low loads, while the altitude affects the air-fuel ratio at high loads.

Adaptive control operates to lean the mixture at low loads, and enrich the mixture at high loads until the computer memory has *stored open-loop values the same as closed-loop.* Then, when the system is operating open-loop, the computer would use a similar correction factor to the air-fuel ratios stored in its open-loop memory. With adaptive control, the system can often operate without a separate sensor for barometric pressure because the system will learn how to operate best at each altitude.

You may never notice the effect of adaptive control because the learning changes are smooth and gradual. On the other hand, you may notice it when you lose it, such as when the battery terminal is disconnected to clear a trouble-code stored in the memory, to install some electrical accessory, or to service that has nothing to do with the engine.

Disconnecting usually means loss of the memory that is storing the adaptive learning.

After disconnection, the learning process must begin all over. Vehicle performance may change. After the disconnection, with the engine warm, drive around: at part throttle, in "crowd", a little push above steady cruise, and let it idle. How long does it take to re-learn? Usually about 5 minutes. If the computer were programmed to take longer, operation could be unsatisfactory. If it were programmed to relearn in 1 or 2 minutes, the computer could be adjusting itself for short-term changes that do not count.

From a recent Ford Owner's Manual: "If you ever disconnect the battery, install a new battery, or experience a dead battery, you must allow the computer to relearn its idle conditions before your vehicle will idle at its best. . . . Start the vehicle. Let the engine idle for at least one minute. (Engine must be warm in order to learn.) Also, allow approximately 10 miles (16 km) of stop and go traffic for your engine to completely relearn its idle. . . . Your vehicle will eventually relearn its idle while you drive it, but it takes much longer than if you use the procedure above."

8. Diagnosis

Trouble codes are stored in one of the computer memories. This memory is known as a volatile memory. Another term is RAM, Random Access Memory. That means it is not permanent, but rather can be erased after it has served its purpose.

Sometimes there can be an engine control problem but the *computer is programmed to make do until repairs can be* made. The memory can include acceptable range values from each sensor. An input signal outside that range may cause a "Check Engine" signal from the computer, and a storage of the proper trouble code. The engine operates on a fixed "limp-home" warm temperature until the sensor can be serviced.

That means coolant-temperature-sensor failure may not even be noticed in engine operation. The engine will operate quite well so long as conditions do not change. You will have a hard start if it cools off, and as you know, with fuel injection, no amount of accelerator pumping will change that. The stored trouble code will lead to proper replacement of the sensor or its wiring harness or connector.

But look what else that means: If you try to play games with the sensor inputs, you better know what you are doing because the computer may be programmed to detect improper sensor input signals. More on this in Chapter 9.

Chapter 3

Emission Control and Alternate Fuels

Contents

3

1. Introduction

In Chapter 2 you saw how controlling emissions is one of the four main concerns of engine-control strategies. Emission control is becoming a larger and larger factor in engine design. In this chapter, you will learn:

- How engine emissions form
- How engine controls operate to reduce emissions while meeting economy standards
- How engine emissions form smog according to climatic conditions
- How your cars and trucks on the road today will respond to coming changes in fuels—starting, fuel economy, driveability
- How your cars and trucks will be tested for emissions, particularly in the roughly 100 areas that are not attaining Clean Air standards as of 1993
- How alternate fuels affect the cars and trucks you're driving now, and how fuels will affect future vehicles

Green

"Green" is the worldwide term for an increasing concern for clean air and clean environment. Green will affect the cars and trucks you buy, beginning in the early '90s. Green is important enough that I will emphasize emissions and economy in this book, even in modifications for performance in Chapter 9. In Chapter 10, you'll understand how Inspection and Maintenance (I&M) for emissions depend on diagnostic systems of fuel injection/engine control for the troubleshooting.

I'll start with traditional emission control as it has defined electronic engine control and engine design.

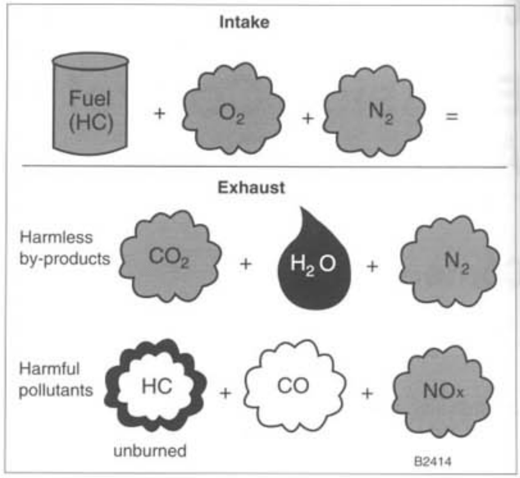

Fig. 2-1. The emission equation: Engine takes in fuel, oxygen, and nitrogen (top). Combustion produces harmless by-products: carbon dioxide, water, and nitrogen (middle); and harmful pollutants: unburned hydrocarbons, carbon monoxide, and oxides of nitrogen.

2. Emission Control

The development of today's fuel-injection and engine control systems links closely with the increasing demand for control of harmful exhaust emissions.

- Exhaust emission-control could not have been accomplished without fuel injection/engine control
- Fuel injection/engine control would not have been so successful and widely used without the challenges of meeting emission-control regulations

With changing legislation and tougher regulatory standards, engine-control systems have undergone significant changes. Emission standards have tightened, but modern engine control provides the driveability demanded by owners. Fuel-economy standards have tightened, generally requiring smaller engines, but fuel injection/engine control has added power.

2.1 Combustion By-products

Combustion of the air-fuel mixture in the engine cylinders creates gaseous by-products that make up the exhaust. Some of these are relatively harmless, and some are known to be harmful. Traditionally three exhaust gasses have been controlled as the most harmful ones:

- Hydrocarbons (HC)
- Carbon monoxide (CO)
- Oxides of nitrogen (NO_x)

Emission of these three gasses is regulated by the Federal Clean Air Act of 1970. As revised in 1990, the regulations require reduced emissions beginning in 1994 and gradually tightening through the year 2000. Two new developments affect engine controls and the fuels you will be burning. 1) Better control of current regulated gasses is needed, as well as regulation of other polluting gasses, because of more vehicles being driven more miles. 2) Emissions depend on the motor-vehicle system—the powertrain/controls, and the fuel being burned. More on that later.

The exhaust gasses are normally colorless and invisible. Every television story concerning vehicle pollution shows pictures of smoking tailpipes, but I want to set you straight: A clear tailpipe is not the sure sign of a clean-burning engine; it may be pumping out invisible pollutants.

According to a recent report I reviewed, EPA studied 50 high-mileage gross polluters, all running closed-loop engine control. All failed the I&M test, some with ten times the allowable emissions. None of these gross-polluting vehicles showed blue smoke at the tailpipe.

Sometimes TV stories on pollution show pictures as in Fig. 2-2. They're not showing pollution, but steam.

Fig. 2-2. Tailpipe steam is visible when natural water vapor, H_2O, condenses in cold air. Pollution is normally not visible, and what's visible is not necessarily pollution.

Each engine family is certified under the Federal Test Procedure (FTP) to operate within the defined limits of HC, CO, and NO_x, as measured by the exhaust output during a controlled set of driving cycles.

Fig. 2-3. Every car and light truck engine is certified to meet EPA emissions standards, and from those measurements, standards for fuel economy. Drivers follow exact driving pattern. Dynamometer rolls load engine according to inertia weight and resistance to movement, including friction, tire rolling resistance, and aerodynamic drag.

Harmful Emissions—Controlled

Hydrocarbons (HC): Gasoline is a mixture of many compounds composed of hydrogen and carbon. In the combustion process, these elements combine with oxygen to form the by-products of water (H_2O) and carbon dioxide (CO_2). HC in the exhaust is unburned gasoline, the result of incomplete combustion.

Carbon Monoxide (CO): CO, a poisonous gas, is another result of incomplete combustion. When gasoline burns completely, the carbon exits the exhaust pipe as CO_2.

Oxides of Nitrogen (NO_x): NO_x refers to several kinds of nitrogen oxide which result from chemically combining nitrogen and oxygen during combustion. Nitrogen and oxygen are normal parts of air, but they exist in air as separate elements. As long as the combustion temperature stays below about 1300°C (2400°F), the nitrogen and oxygen do not combine. The nitrogen passes out the exhaust pipe just as it came in, separate and harmless. However, if combustion temperatures rise only slightly higher, the two elements combine chemically into various forms of of gasses that become NO_x, a key element of smog.

Harmless Emissions—Not Controlled

Carbon Dioxide (CO_2) (Greenhouse Effect): Until recently, carbon dioxide (CO_2) was considered a harmless emission. But now consider the "greenhouse" effect. Recent studies show that CO_2 is accumulating in the upper atmosphere, trapping global heat much as glass traps heat in a greenhouse.

Other greenhouse gasses include CFC (Freon—being phased out of air conditioners), NO_x, and CH_4 (methane, not Methanol). Most experts consider that global warming of only a few degrees would have disastrous worldwide results. The probable results are rises in global temperatures, successive heat waves, and iceberg melting, which could raise ocean levels to flood seaside properties worldwide.

The amount of CO_2 coming from our exhaust pipes is astonishing, even if invisible. See Fig. 2-4. The numbers work out like this:

- For 1 lb. of fuel = 3.2 lb. of CO_2
- For 1 gal. of fuel = 20 lb. of CO_2
- For 1 gal. of fuel = about 750 cu.ft. of CO_2, or twice the volume of a typical car

Any burning of fossil fuels such as oil, gasoline, and coal produces CO_2. Automobiles are a significant source. Unlike the other combustion by-products, we can't treat CO_2 to eliminate its effects. Reduction requires reducing the amount of fuel burned. That is the basis of the so-called "carbon tax."

What can we do in driving to reduce CO_2? Avoid unnecessary idling, for one thing. Turn off your engine when parked, even if it means less heating or air conditioning. Choose vehicles that burn less fuel with lighter, more efficient, smaller engines, because CO_2 increases with fuel burned. Impose your own restrictions on driving. Car pool, combine your trips, use public transit, walk.

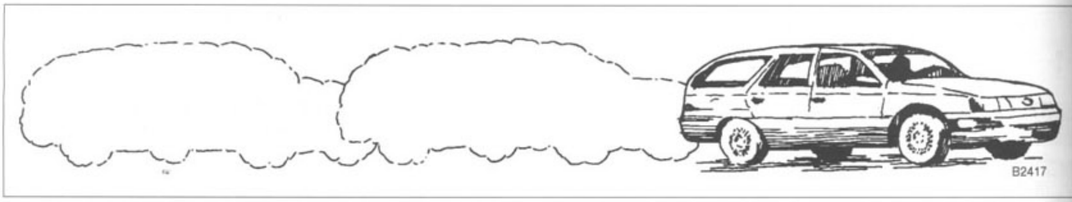

Fig. 2-4. For each gallon of gas burned, we leave behind a cloud of invisible CO_2 equal to twice the volume of a typical car.

Emission Limits

Why do government agencies keep tightening limits on cars and trucks? Haven't we done our share? Compared to pre-control, our 1980–90 cars emit 86% less HC, 92–96% less CO, and 76% less NO_x.

That's true, but we have more vehicles on the road, and we're driving more. Vehicle Miles Traveled (VMT) is increasing about 3% per year. Compounded, 3% a year is almost 35% more VMT in 10 years, double the VMT in the 33 years from the first emission control to the year 2000.

Tightening HC, CO and NO_x limits may be better for us than restrictions on driving, such as Mexico City, where "Each car must stay off the road one day a week." And, of course, we don't hear that much about controls imposed on other sources of pollution, such as refineries, powerplants, dry cleaners, bakeries (honest—gasses from the yeast rising in the dough!).

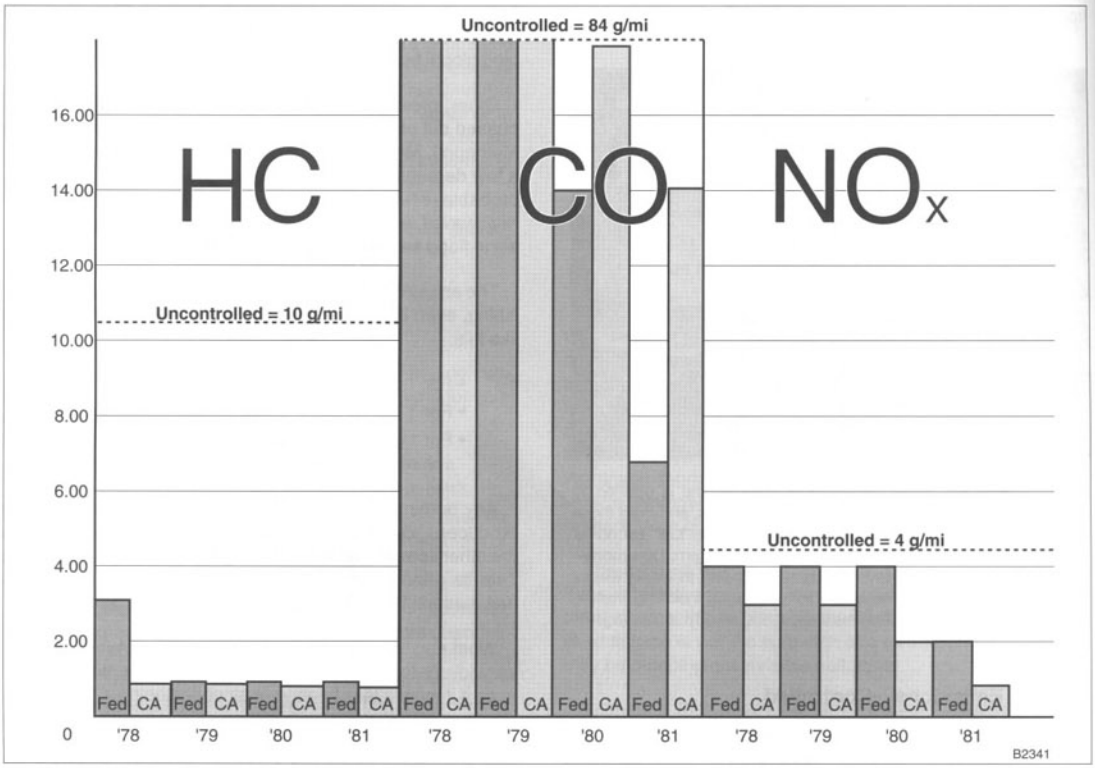

Fig. 2-5. Emission limits tightened from 1979–81, stayed level for rest of 1980s. Fuel injection became increasingly necessary to meet standards. Note '81 California CO limit was higher than Federal because California Air Resources Board (CARB) determined NO_x reductions were more important to smog control, and CO and NO_x are interrelated.

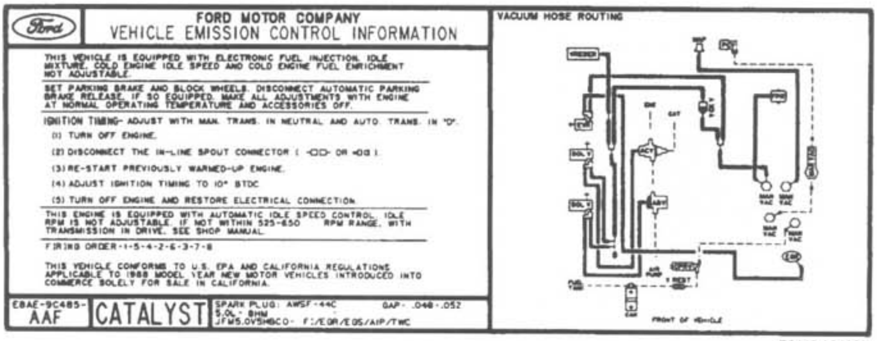

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Fig. 2-6. Underhood labels identify the limit of the limits (50-state label shown). 49-state (Federal) vehicles cannot be registered new in California (registering less than 7,500 miles on the odometer).

Doing Better than the Limits

As emission limits tighten (**Table a**), governments encourage manufacturers to do better than the limits by allowing them pollution credits against future-year pollution excesses. The 1993 Ford Escort/Mercury Tracer sold in California meets the 1997 limits, four years ahead of schedule. HC is cut by over 50%, with a loss in fuel economy of one mpg. A larger catalytic converter is mounted closer to the engine, designed to heat up sooner. The oxygen sensor also heats up sooner, aided by an electric heater. The law also allows CAFE credits for beating CAFE, and for using alternate fuels.

"50-state cars," "49-state cars," "California cars," can there be different cars for different states? Yes. And why not a New Jersey car? The answers are simple, and yet they are not. In Southern California, the warm climate and the terrain, an open bowl facing the ocean breezes, turned out to be "ideal" to discover how vehicle engines contribute to smog. Californians operate about 1 out of 7 vehicles in the U.S., so you understand why the state began pollution control in 1966, before the rest of the U.S. followed in 1968. When the first Federal limits were legislated, California insisted on tighter limits for itself. Congress agreed, but decreed that any other state that wanted tighter limits for itself could only adopt California limits.

- 50-state car qualifies to Federal and CA limits
- 49-state car is OK to Federal limits, but not to CA. Some 49-state cars are identical to CA cars, but are labeled 49-state to qualify for the shorter Federal warranty requirements. A 49-state car may not be licensed in CA with less than 7,500 miles on the odometer
- A California car qualifies only in CA and may not be sold outside the state

It's bad enough that the world's car makers must build two quite different cars for the U.S., but to build 50 different sets of limits for one country, requiring 50 different engine controls! New York, Massachusetts and several other states (mainly North-Eastern) with their own serious smog problems are passing legislation requiring cars sold in their states to conform to California limits. So perhaps we're headed for something like "10-state" and "40-state" cars.

Table a. Changing Limits—Grams/Mile

	Through 1992		1993–1996	
	FED	CA	FED	CA
HC	0.41	0.39	0.25 NMHC	0.25 NMHC*
CO	3.4	7.0	3.4	3.4
NO_x	1.0	0.4–0.7	0.4	0.4–0.7

*Beginning 1994, California requires that NMOG be measured instead of NMHC. This has the effect of requiring fuel of less volatility. Each manufacturer must *average* 0.25 NMOG for its fleet, with no vehicle higher than 0.39 g/mi. Each year, these NMOG limits tighten, gradually reducing NMOG to 25% of the 1994 standards. Also, HC limits tighten beginning 1994. Manufacturers must certify these limits for the first 50,000 mi. of operation, and are allowed slightly greater HC and CO to 100,000 mi. After that, the owner is responsible for meeting the applicable limits.

As the new limits phase in, a greater percentage of cars are required to meet the limits each successive year (sooner in California). For example, as shown in **Table b**, by model year 1995, 100% of each maker's passenger cars and light duty trucks sold in California must meet the new limits, but in the other 49 states only 80% need to meet the limits.

Table b. Phase In of New Emission Limits

	1993	1994	1995	1996
California	40%	80%	100%	100%
Federal	–	40%	80%	100%

2.2 Smog Formation

Smog is a fact of life that has been affecting our cars and trucks since the late 1960s. Increasingly, it will affect our driving and indeed, what we can do to our vehicles. Its impact on our environment, our health, indeed our lives are so important that governments and industry are working together to reduce its effects and to improve the quality of our lives. Those of us who love cars and who love to drive are coming to recognize what we can do to be responsible motorists.

Fig. 2-7. The real costs of smog—health, vegetation, property—are recognized as greater than costs of reducing air pollution.

The word "Smog" came in with cars, right? Well, cars and trucks have made smog serious worldwide, but the word appears in the 1905 Oxford English language dictionary. Smoke from coal heating, plus fog in London—they called it "smog."

Today, Smog refers to a "soup" of many gasses, principally ground-level ozone, cooked in the sunlight from gasses emitted from motor vehicles. Besides smog, vehicle air pollution includes carbon monoxide (CO), and oxides of Nitrogen (NO_x) from industry, plus dust and particulate matter.

In high concentrations, ground-level ozone is hazardous to people and growing things, such as trees and plants. Ozone (O_3) is poisonous because it contains an extra atom as compared to good oxygen (O_2). You may hear also of upper-level ozone that protects the Earth from ultraviolet rays from the Sun. Formed by different processes, upper-level ozone is good; ground-level ozone is bad.

Effect of Climate

As air pollution has increased and spread to more cities, new measurements show that it varies with the seasons and the climate. The seasonal effects are so important that fuel blends sold in different areas of the country are tailored to the season. How the different fuels are handled by your engine-control system can affect starting, driveability, performance and economy.

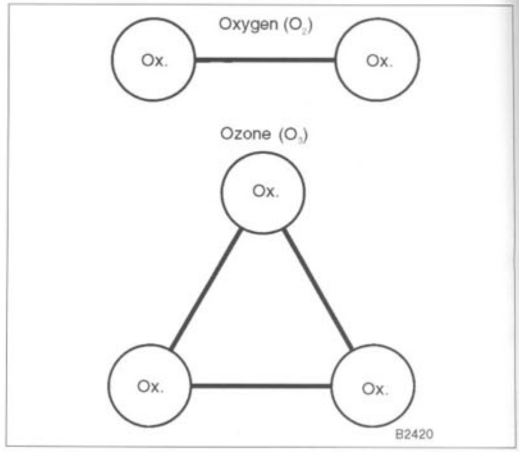


Fig. 2-8. Ozone is O_3, an extra atom of oxygen attached to an ordinary oxygen molecule, O_2. In summer, ozone is most important threat from smog. In longer, hotter, sunny hours, smog increases, resulting from more cooking of the "soup".

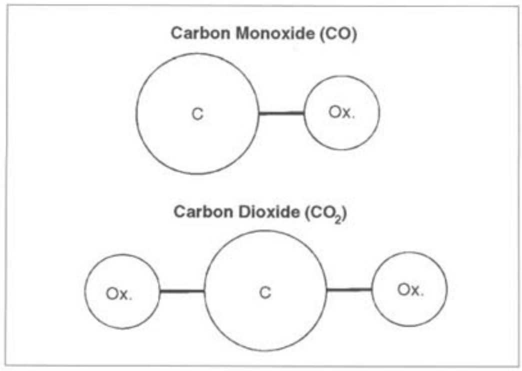


Fig. 2-9. Carbon Monoxide (CO) combines one atom of carbon with one atom of oxygen. In winter, (CO) is most important air pollution threat. CO increases because 1) more cold starts with more cold-start emissions, and 2) temperature inversions and weather concentrate pollutants in lower atmosphere.

Non-attainment Areas

Air quality worsens according to climate, number of vehicles, miles traveled, vehicle condition, and traffic idling. Based on summation of daily monitoring by EPA, most major cities reach or exceed dangerous levels of ozone and/or CO on at least several days a year. They fail to "attain" Federal air quality standards. **Table c** lists the worst offenders. You may notice different engine operation (driveability, cold-starting, fuel

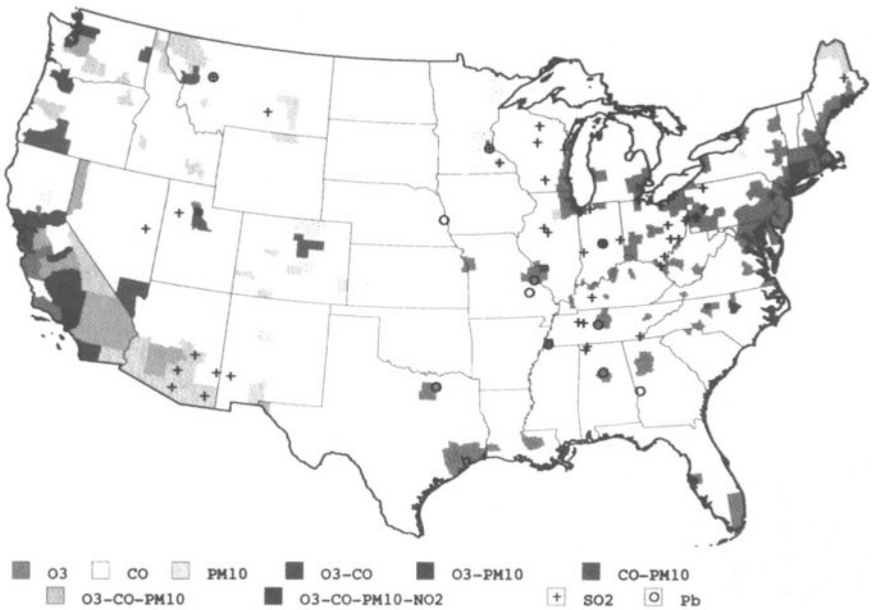


Fig. 2-10. EPA monitoring stations measure air quality to determine when areas do not meet air-quality standards. "PM-10" is dust and soot suspended in air.

economy) depending on your part of the country—depending on if you drive in a "non-attainment" area. In non-attainment areas, two things may change your vehicle operation:

- Fuel may be modified to reduce emissions
- More Inspection and Maintenance (I&M) may be required for licensing

Table c. Top Smog Cities

Ozone Metropolitan Areas	Ozone Days	CO Cities	CO Days
1. Los Angeles Anaheim/Riverside CA	137	1. Los Angeles CA	71
2. Bakersfield CA	44	2. Spokane WA	37
3. Fresno CA	24	3. Oshkosh WI	32
4. New York/New Jersey/Connecticut	17	4. Steubenville OH, Weirton WV	31
5. Sacramento CA	16	5. Las Vegas NV	26
6.Chicago IL/Indiana/ Wisconsin	13	6. New York City	26
7. San Diego CA	12		

NOTE —
Five of the big 7 ozone areas are in sunny California. No wonder California has taken the lead in pollution controls. New York City & Chicago represent largest vehicle concentrations. San Diego claims (with good reason) that one-third of their ozone pollution is blown down the coast from Los Angeles. The complete list includes about 100—varying from year to year.

Other Gasses Emitted

We have improved our ability to measure low levels of the traditional exhaust gasses. Recent research shows that some other emitted may increase smog formation at ground level, while other emitted gasses may decrease smog formation. And some gasses in the stratosphere affect global warming, adding to our smog vocabulary:

Formaldehyde: A compound of hydrogen, carbon and oxygen, HCHO. Produced in trace quantities from combustion of alcohol-based fuels, it irritates eyes, nose and throat, for some people even at minimal levels. May increase cancer risk.

Methane: A particular form of hydrocarbon, CH_4, found in natural gas. Methane does not react to form smog. A Greenhouse gas, it contributes to global warming, along with CO_2.

NMHC: Non-Methane Hydrocarbon, a Federal (EPA) standard of measure. NMHC is measured instead of HC because methane is stable and does not react to form ground-level ozone.

NMOG: Non-Methane Organic Gas, a California standard of measure beginning in 1993. These include hydrocarbons, alcohols, aldehydes, ketones and ethers.

VOC: Volatile Organic Compounds, a broad category including the hydrocarbons, NMHC, and NMOG that vaporize at ambient temperatures (volatile), and are carbon-based (organic).

Also added to our vocabulary are Oxygenates—fuels or fuel additives containing oxygen that burn with less oxygen, forming less Carbon Monoxide (CO):

- Methanol, 50% oxygen by weight
- Ethanol, 35% oxygen by weight
- MTBE, 18% oxygen by weight—an additive
- ETBE, 16% oxygen by weight—an additive

Ozone-forming Potential

Reactivity Adjustment Factor (RAF) is a measure of the ozone-forming potential of any Volatile Organic Compound (VOC). California (and states following CA limits) measures the combined effect on smog of the vehicle and the fuel it burns. After the emitted gasses are measured, they are multiplied by the RAF. So, the cleaner the fuel the vehicle is designed to operate on, the less restrictive the emission controls.

The basis for the new approach to emission control is ozone-forming potential. As it turns out, this is affected by the ratio of Volatile Organic Compounds (VOC) to NO_x. The strategies to reduce smog may vary in different parts of the country, and in different seasons:

- With low VOC ratio (VOC less than 10 times NO_x), control VOC more than NO_x
- With high VOC ratio (VOC more than 20 times NO_x), control NO_x more than VOC.

Controlling NO_x means measuring emissions under load, unlike most emission testing in the early '90s. Emission testing under load affects how vehicles are "smog-checked."

Why Green?

Emission control can get pretty complicated and you may be asking, Why Green? Health impacts, for one thing. Ozone can cause burning sensations in your lungs and can aggravate asthma, making it harder to breathe. (Besides attacking humans, ozone attacks plants, plastics, rubber.) Other smog pollutants irritate your eyes. CO can reduce oxygen flow to your brain, impairing your motor coordination. CO interferes with your heart's delivery of oxygen to your body, aggravating chest pains, angina.

Acid pollution for another. The formation of nitric acid and sulfuric acid turns into acid rain. In Los Angeles, the fog can be as acidic as lemon juice—imagine that in your lungs. Trees die; the Greens party in Germany calls it "Waldsterben" or forest death. Lakes and streams become too acidic to support fish. Buildings are eaten away, especially marble.

Now that you know some of the combustion by-products and the importance of controlling them, I will discuss how electronic engine controls operate to reduce them.

2.3 Effects of Air-fuel Ratios on Pollutants

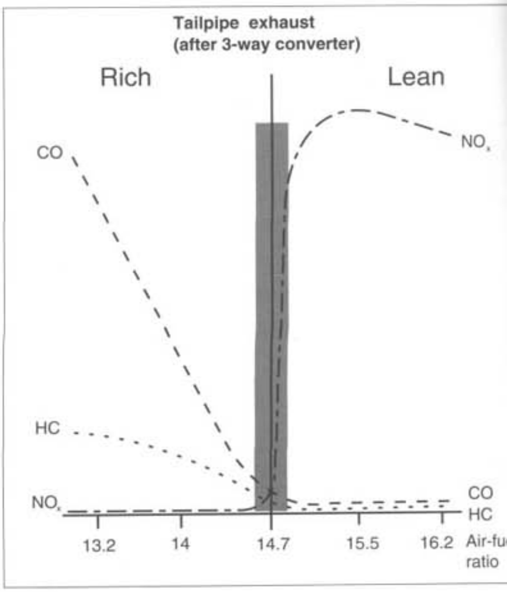


Fig. 2-11. Tailpipe exhaust after converter shows least emission of controlled gasses when air-fuel ratio changes back and forth in narrow range around ideal or stoichiometric 14.7.

Just as variations in the air-fuel ratio change power output and fuel consumption, they also change exhaust emissions. As I described, the air-fuel ratio is a key to complete combustion of the fuel. It also affects combustion temperature that, in turn, affects the formation of pollutants. What's more, the air-fuel ratio changes exhaust-gas oxygen levels, and that affects the operation of the catalytic converter.

- Too rich (too little air), then the fuel will not burn completely. The unburned fuel comes from the engine as higher HC and CO
- Too lean (too much air), then lean misfire increases HC (raw fuel), and elevated combustion temperature increases NO_x
- When the mixture is ideal, 14.7, the catalytic converter can treat the exhaust-gas mixture to deliver the least emissions from the tailpipe

When flying piston-engine aircraft, emissions are not as important as engine temperature affected by air-fuel ratio. I adjust for a rich air-fuel mixture during high-power climbs to keep the engine cool. (The effect in a car will reduce NO_x.) Then, during cruise, I lean the mixture for economy, knowing it will increase engine temperature. If the needle on the engine temperature gauge starts to rise above the green arc, I know I have leaned the mixture too much. If you install an exhaust gas temperature (EGT) gauge on your vehicle engine, you can make similar observations (though the mixture is not usually cockpit-adjustable).

2.4 Effects of Spark Timing on Pollutants

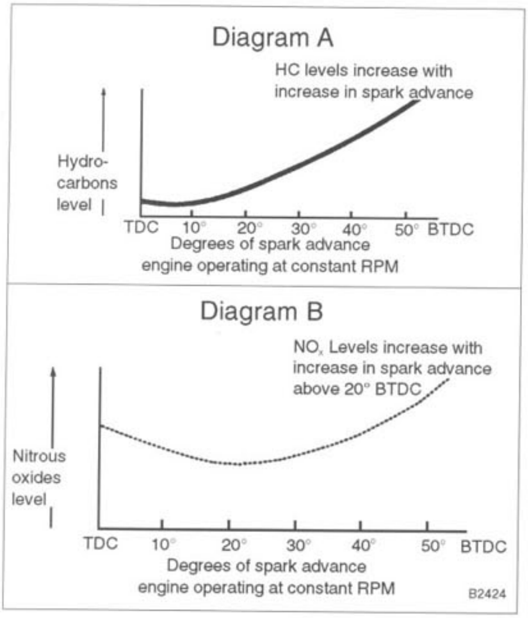


Fig. 2-12. Lowest HC (HydroCarbon) emissions result from spark timing near TDC. As timing is advanced, say to 50 degrees, HC emissions more than double. Emission of NO_x (Nitrogen Oxides) increases with spark advance above about 20 deg. BTDC.

2.5 Exhaust Gas Treatment

So far, we have been talking about the effects of air-fuel ratio and spark timing on engine-out exhaust.

Some Ford engines (generally the larger) use Exhaust Gas Recirculation (EGR) to reduce the formation of NO_x. Some engines, again the larger, use Air Injection (thermactor) to oxidize (burn) HC and CO in the manifolds and in the catalytic converter.

Exhaust Gas Recirculation (EGR)

Exhaust Gas Recirculation (EGR) is a technique for reducing the formation of oxides of nitrogen (NO_x). The EGR valve routes a small amount of exhaust gas (5 to 15%) into the intake manifold and back into the combustion chambers. This dilution of the air-fuel mixture lowers combustion temperature. You'll remember that excessive combustion temperature is the cause of NO_x formation.

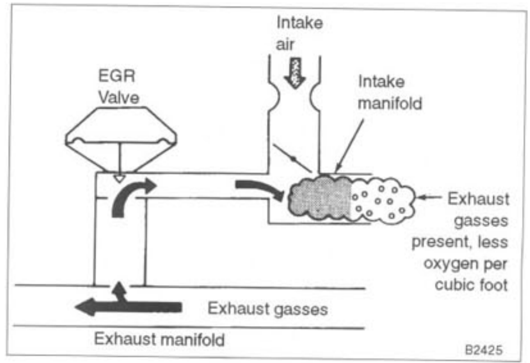


Fig. 2-13. Exhaust gas is admitted from the exhaust manifold into the intake manifold (operating at a lower pressure) through a control valve.

Air Injection

One of the early approaches to reduce emissions was air injection. An engine-driven air-injection pump, commonly referred to as a "smog pump," can deliver air into the exhaust manifold. Adding air during warm-up tends to burn HC and CO resulting from the rich starting mixtures, reducing emissions. Not incidentally, this increases underhood heat. Exhaust-manifold burning has the additional advantage of heating the Exhaust Gas Oxygen Sensor, and the catalytic converter, both of which must be hot to operate.

Pulse-Air is another way to add air to the engine exhaust. Pulse-Air allows air to be drawn from the air cleaner through a set of reed-valves. The natural pulsations in the exhaust pressure operate the reed-valve. It opens to allow air into the exhaust stream when the pressure is lower, and closes to prevent backflow when the pressure is higher.

With electronic engine control, air can be added to the oxidation converter part of the catalytic converter, described below. This can come from the Air Injection pump, or from the Pulse Air Valves to burn the HC and CO in the catalytic converter instead of in the exhaust manifold. Ford refers to air injection as Thermactor systems. In the '90s, few Ford engines

Fig. 2-14. Many larger Ford engines use smog pumps, engine-driven air pumps, to deliver oxygen (air) into exhaust system, either eat xhaust manifold or at catalytic converter.

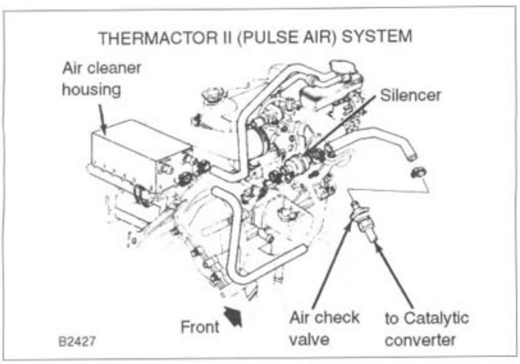


Fig. 2-15. For engines up to about 2.3 liters, pulse-air systems eliminate smog pump by using "pumping" action of pressure changes in exhaust system.

use air injection. You'll find air pumps only on engines larger than 4.9L, and pulse-air systems only on the 2.3L HSC.

Catalytic Converters

Catalytic converters form part of the exhaust system, located between the exhaust manifold and the tailpipe. The catalytic converter contains special materials, called catalysts. Catalysts promote additional chemical reactions with the pollutants in the exhaust gas and convert them into less harmful substances. The term "catalytic" means the conversions take place

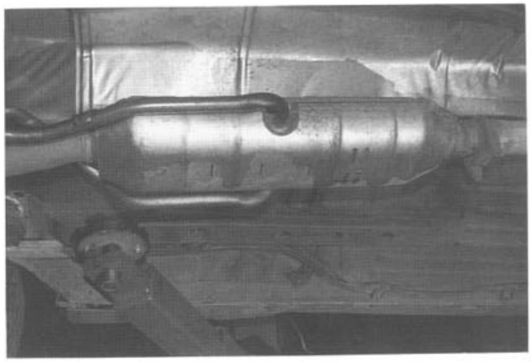


Fig. 2-16. Catalytic converter treatment of exhaust generates heat. Converter heat shield protects vehicle and anything combustible under the vehicle. Many Ford cars and trucks use two converters.

without affecting the catalyst itself, usually small amounts of rare metals such as platinum, pallaium, and rhodium.

Oxidation Catalysts (OC) make use of air supplied by an air pump or Pulse Air Valve. Oxygen in the air converts CO to CO_2 and converts HC to H_2O. In early years, Ford engine control used OC in combination with Three-Way catalysts (TWC).

Three-Way catalysts reduce NO_x as well as oxidize CO and HC. The combination of a Three-Way Catalyst and an oxidation catalyst in one housing—a dual-bed catalyst—produces a series of chemical reactions that reduce all three pollutants. A disadvantage of dual-bed catalysts is that they rely on a slightly rich air-fuel ratio that increases fuel consumption. In later years, you'll find only TWC, or two TWC on engines larger than 3.0L.

To work most efficiently, a converter must be hot enough to begin the conversion of exhaust gasses. Conversion further raises the temperature of the converter, increasing its efficiency. For this reason, it is placed in the exhaust system as near to the engine as possible. Most catalytic converters require heat shields to prevent combustion of something under the vehicle.

A series of misfires in a cylinder can deliver raw fuel into the converter, making it too hot. Too hot for too long can permanently damage the converter, so don't drive with a bad plug or wire.

Remember that, in complete combustion, $HC + O_2 + N_2 = CO_2 + H_2O + N_2$. Incomplete combustion produces CO instead of CO_2 and high temperature combustion, as from a lean mixture, combines $N_2 + O_2$ to form NO_x. See earlier Fig. 2-1.

In the three-way catalytic converter, we want to 1) add oxygen to oxidize the HC and CO to make H_2O and CO_2, and 2) take away oxygen to reduce NO_x, separate it into N and O_2.

You might think it's as simple as taking the oxygen away from the NO_x and giving it to the CO. Stated simply, that is what happens in some three-way catalytic converters.

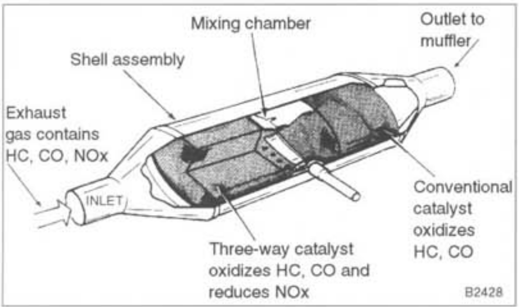


Fig. 2-17. Dual-bed catalytic converter combines three-way catalytic converter (TWC) with oxidation catalyst (OC).

The catalytic material in the converter helps these chemical reactions take place. For reduction (taking away oxygen from NO_x) to match oxidation (adding oxygen to CO and HC), the proportion of the gasses in the engine exhaust must be controlled very closely. That means the intake air-fuel ratio must always be in the narrow range near stoichiometric—an air-fuel ratio of 14.7 parts of air to one part of fuel. In some Ford three-way converters, air (oxygen) is pumped in after the reduction to further enhance oxidation.

> The story of emission control, three-way catalytic converters, carburetors, fuel injection and oxygen sensors is a fascinating story of worldwide development. I had the good fortune to be there at the beginning.
>
> In 1971, I was writing technical films for a corporation with a new development—one of the first catalytic converters. In the lab, they showed me good control by the converter, but only if the engine had precise control of air-fuel ratios. With 1971 carburetors, they couldn't even control air-fuel mixtures adequately on one car in the lab, let alone in quantity production.
>
> About the same time I was working with engineers in the Bendix Research Labs on another project. They showed me their system for electronic fuel injection that could provide the kind of precise control needed, using a feedback system (closed loop). By 1974 Bendix demonstrated the system to Cadillac. Cadillac adopted Bendix MPI without the feedback, apparently satisfied they could meet 1976 emission limits without it. They called the system EFI. It followed 9 years after the Bosch EFI introduced in 1967 by VW, and operated much the same.
>
> Under the cross-licensing agreement, in Europe Bosch pushed ahead, adapting the oxygen sensor to the L-Jetronic EFI system. In 1978, Volvo and Saab introduced Bosch feedback EFI systems to meet California emission limits. Also in 1978, Ford and other U.S. manufacturers introduced some electronically-controlled feedback carburetors to solve the same emission problems.

Earlier Fig. 2-11 illustrates the degree of emission control afforded by a three-way catalyst on an engine running very near the stoichiometric ratio. You can see that if the air-fuel mixture strays from 14.7:1, the proportion of exhaust gasses (HC, CO, & NO_x) exiting the converter changes. As the air-fuel ratio becomes leaner, hotter combustion temperature causes increased production of NO_x. A rich mixture will produce an excess of HC and CO.

With the air-fuel ratio maintained at 14.7:1, the converter can reduce the emission of all three pollutants to very low levels. Precise control, however, is very important to the successful operation of three-way converters. Any significant deviation from 14.7:1 upsets the balance of the chemical reactions in the converter and the level of one or more pollutants increases dramatically. Development of three-way catalytic converters has been accompanied by development of more sophisticated systems for the fine control of air-fuel ratio.

Canister Purge—Evaporative Fuel Vapor

Unburned hydrocarbons can pollute the atmosphere another way unless they are contained. Canisters under the hood contain fuel vapors forming over the liquid fuel in the tank. Yet the tank must not be sealed, otherwise, the fuel pump could not draw fuel for the engine.

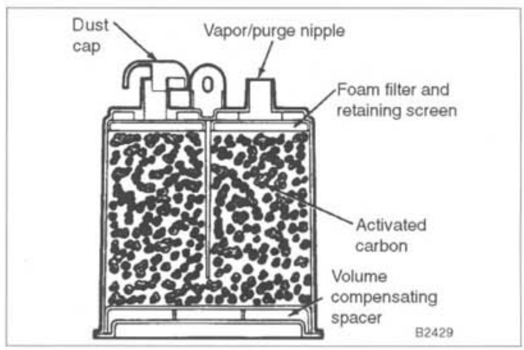


Fig. 2-18. Carbon canister stores fuel vapors from tank and engine. Canister is purged by drawing fuel vapor into engine, under control of the control module.

The canister is purged by drawing the fuel vapors into the engine but only under certain engine conditions, as discussed in Chapter 8. Purging must be controlled by a valve so the vapors do not disturb the proper air-fuel ratio.

The more you know something about emissions and the limits placed on them by legislation, the more you'll understand how fuel-injection and engine-management systems work.

Some Ford fuel-injected vehicles reduce the amount of emitted gasses by improved engine design. These engines are able to eliminate some types of emission control that interfere with driveability, including Exhaust Gas Recirculation (EGR) and air pumps.

Table d. 1992–'93 Engines Meeting Limits Without Some Emission Control Systems

Model	EGR	Secondary Air
Festiva 1.3L	No	No
Capri 1.6L	No	No
Escort/Tracer 1.8L	No	No
Escort/Tracer 1.9L	Yes	No
Probe 2.0L	Yes	No
Probe 2.2L	Yes	No
Mustang 2.3L OHC	Yes	No
Probe 2.5L V6	Yes	No
Probe 3.0L Taurus SHO 3.0\3.2L	No, (Y CA) Y (3.2L)	No
Taurus/Sable 3.0L	Yes	No
T'Bird 3.8L SC	Yes	No
T'Bird/Cougar/ 3.8L Continental/ Taurus/Sable-Police	Yes	No
Crown Victoria/ Grand Marquis 4.6L Mark VIII 4.6L-4V	Yes	No
Ranger 2.3L OHC Truck	No except M/T	No
Ranger 2.9L Truck	No	No
Aerostar 3.0L Van	No	No
Ranger/Explorer/ Aerostar 4.0L	No	No

2.6 Conflicting Demands on Engine Control

I've described engine needs for a combustible mixture of air and fuel, and how variations in mixture influence performance. And I've described engine needs for variable spark timing. While power is always a requirement, modern engine control systems face additional demands:

- Fuel economy, due to legislation and increasing concern over cost and availability of gasoline
- Exhaust emissions, due to environmental concerns and resulting legislation
- Driveability, due to drivers' demands for quick starting and smooth, trouble-free performance under any operating conditions

In designing an engine and its control system, two regulation factors must have priority: emissions and economy. Unless it meets standards for both emissions and economy, the vehicle is not street-legal to sell in the U.S. That may seem tough, but think about this—Indy cars racing at 220 miles per hour must also consider fuel economy. Each car is limited to 278 gallons of pure methanol, total fuel for the race. If they don't get 1.8 miles per gallon, they don't cross the finish line. For comparison, that's equivalent to over 3 miles per gallon on gasoline (higher gasoline energy content). Indy drivers don't worry about emissions, but they adjust the electronic controls from the cockpit to enrich the mixture to increase power when necessary, and to lean the mixture for economy if necessary to finish. You better believe those drivers watch fuel economy as it trades off with performance.

Each of these factors places different demands on the engine-control system, and the design engineer must consider tradeoffs. Adjusting the system for maximum power also means increasing fuel consumption. Minimizing fuel consumption means sacrificing power and driveability. Choosing either maximum power or minimum fuel consumption may mean increased exhaust emissions. The modern fuel delivery system must be able to maintain strict control of air-fuel ratio to achieve the best compromises and meet these conflicting demands in the most acceptable way. This means slight sacrifices of power and fuel economy in exchange for optimum emission control.

Fuel injection can maintain the air-fuel ratio within closer tolerances than carburetor systems. For the manufacturer, fuel-injection means better emission control and better fuel economy, both important in meeting increasingly stringent government regulation. For the owner, fuel-injection means achieving fuel economy and emission control while preserving driveability and maximum power.

Fuel Economy—CAFE

CAFE (pronounced "cafay") stands for Corporate Average Fuel Economy. Each corporation must meet rated fuel economy averaged for all domestic or import cars or trucks produced in a model year, or pay a stiff fine.

Ford and each other manufacturer must meet the CAFE standards for its domestic fleet, and separately for its import fleet. For purposes of the law, the economy figure is the rated test miles per gallon, calculated 55% CITY rating, and 45% HIGHWAY rating. As most people know, the ratings are made under controlled conditions for comparison of all vehicles, and to conform to legislated limits. The ratings do not represent what mileage you will "get."

While some customers of the 1990s rate power and reliability higher on the list than economy, other customers choose their vehicles for economy as they face rising oil prices and increased taxation. Ford must consider both customer de-

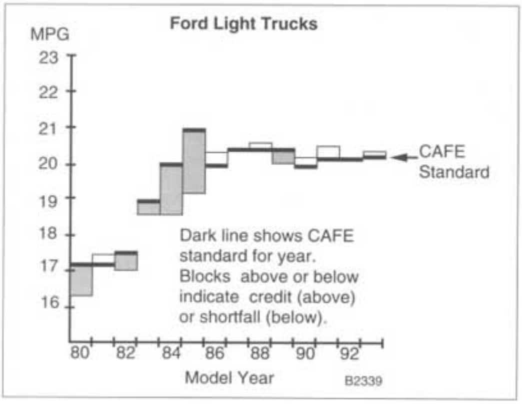


Fig. 2-19. Light truck fuel economy (CAFE) standards.

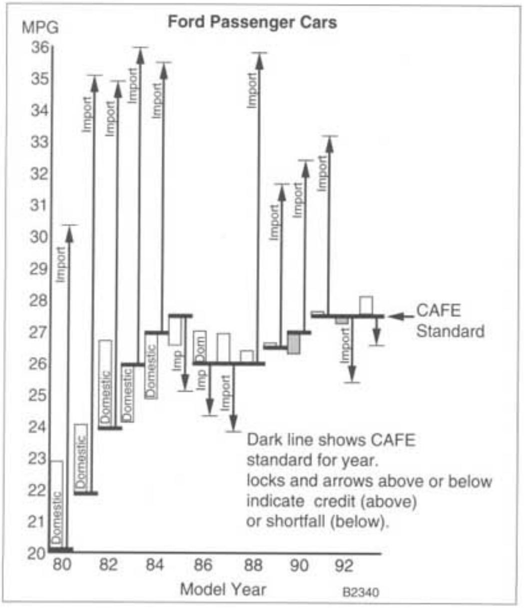


Fig. 2-20. Domestic passenger car fuel economy (CAFE) standards are averaged separately from imports.

mands, and CAFE standards. Higher standards are legislated in the interests of reducing emissions and global warming, and in reducing the U.S. dependence on imported oil.

The industry trend in composite (55/45) rated miles per gallon (mpg) turned upward beginning in 1975, as catalytic converters replaced engine de-tuning as a means of emission control. Government legislation established average mpg standards to apply to the total passenger car fleet and to the truck fleet each manufacturer delivers each year. Imports are averaged separately. Further, the car target mpg standard raised each year, starting at 18 mpg in 1978, and rising to 27.5 mpg in 1985. After a brief cut back in 1986 to 26 mpg, federal standards were again raised to 27.5.

Originally, trucks were exempt from legislation limiting emissions and fuel consumption. But, beginning in 1980, light truck standards were established. This is in part recognition of the increasing use of light trucks, including vans, such as Mercury Villager and Ford Aerostar, as passenger cars.

Credits are allowed to offset CAFE shortfalls, carried forward or backward for 3 years. Notice how 1992 model year import MPG drops when large cars (Crown Victoria and Grand Marquis) are rated as imports instead of domestics.

3. ALTERNATE FUELS

Gasoline, refined from petroleum, is one of the most concentrated forms of energy. Yet its worldwide use contributes to air pollution and greenhouse gases, and increases U.S. import of what could become a scarce resource.

I've discussed how emission control requires changes in engine hardware. But it's important to consider the engine/fuel combination. Beginning 1995–96, in all states, fuels are changing to help reduce auto pollution. I'll start with the ways new gasoline fuels affect your regular Ford emissions.

To encourage the development and sale of alcohol-based fuels, EPA modifies the fuel economy rating, counting only the gasoline burned, according to design intent. Thus, an M-85 vehicle, rated at 15 mpg, is designed to burn 15% (15/100) gasoline. It scores the same as a 100 mpg car. That does good things for the manufacturer's CAFE.

Beginning in 1993 in California, Ford and others began selling Flexible Fuel Vehicles. Based on driving such a vehicle, I can report that the system is "transparent"—you don't notice any difference, except the need to fill up more often. You may notice the instrument-panel readout from the fuel sensor. Mine read "83", or 83% methanol, M-83. Actually, it was telling me that a little gasoline, M-0, was mixed with mostly M-85. Of course, that changes as a result of fill-ups.

How do alternate fuels affect engines you're now driving, and how do alternate fuels affect future Ford powerplants?

3.1 Dedication and the Future

Any consideration of alternate fuels looks at the cars and trucks on the road, and at the fuel distribution network. You

> Changing engine hardware affects new cars and trucks being built and sold, but it takes up to 20 years to turn over 95% of the fleet
>
> Changing fuel affects almost all vehicles on the road immediately

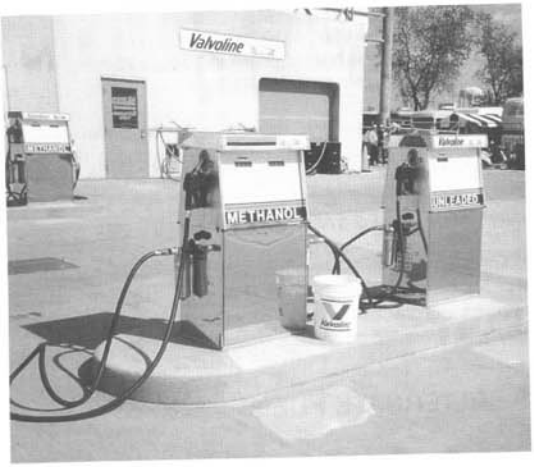


Fig. 3-1. Indy race cars are fueled by Methanol to help increase power, but they can't burn pump gasoline—they are "dedicated" vehicles.

can expect to see three classes of vehicles, 1) Existing, 2) Dedicated, and 3) Transition. Ford fuel injection/engine control systems are involved in all three:

1. Existing vehicles, the 170 million on the road today (and most of those being built in the near future) must operate on what can be distributed widely. Any change to the fuel must satisfy existing engines and fuel systems.
2. Dedicated vehicles operate only on a specific alternate fuel. The advantage is a no-compromise design that takes advantage of the strengths of the alternate fuel. For example, the anti-knock rating of pure methanol allows higher compression ratios and more power. The disadvantage is fewer filling stations.
3. Transition vehicles, also known as Flexible Fuel Vehicles (FFV), operate on alternate fuels, and also on existing fuels, including any mix. Advantage—fill up anywhere, but lose the benefits of high compression because the engine and its control system must still operate with gasoline. Transition vehicles emit less CO and reduce dependence on foreign oil. They also help to establish the distribution network for alternate fuels. But, because of the necessary compromises, transition vehicles can cost more and satisfy less.

3.2 Fuels You May Be Burning—Existing Vehicles

In general, the objectives of providing cleaner gasolines are:

- Reduce smog-forming emissions by reducing aromatic HC
- Reduce cancer-causing benzene
- Maintain catalytic converter efficiency by reducing sulfur

In addition to the familiar Regular (87 Octane), and Premium (91 Octane), you can now burn Mid-Grade (89 Octane), depending on instructions in your Owners Manual. Some aromatics, such as Toluene, increase octane, but refineries juggle other compositions to maintain the normal ratings. Octane ratings are not considered part of emission control.

> **NOTE —**
> If you're considering adding lead to your fuel, be aware that, since 1996, it is illegal to burn leaded fuel in any vehicle on U.S. public roads. Manganese additives, such as MMT, have been illegal in California since 1977.

Beyond Octane ratings, you have little or no choice in the pump gas you burn. Rather, your fuel depends on your part of the country—the smog problems as measured, daily, by:

- Non-attainment of Ozone standards
- Non-attainment of CO standards

The solutions to Ozone are different from solutions to CO, and if you have both Ozone and CO, that's different again.

Those measurements are affected by (not necessarily in this order):

- Local weather, temperature inversions--warm air above cool air
- Prevailing winds and terrain
- Pollution "transported" by prevailing winds from upwind sources
- Concentration of vehicles and traffic congestion

One at a time, I'll look at what you'll be burning in the foreseeable future, depending on where you're driving:

1. Conventional gasoline
2. Winter oxygenated gasoline
3. Reformulated gasoline, Federal RFG, Phase I
4. Reformulated gasoline, Federal RFG, Phase II
5. California RFG, Phase II

In some parts of the country, there's controversy about these new fuels, but tests by several industry groups and by several government agencies agree on a number of things when comparing new fuels to previous fuels:

- No engine changes required, such as tune up
- No meaningful difference in performance or acceleration
- No effect on vehicle warranties
- Some slight loss in mileage

Conventional Gasoline

Conventional gasoline is sold in parts of most states (not California) where air quality is satisfactory, with few "non-attainment" days, and in most of the nation's "open-space" ar-

> As of 1997, if you drive coast-to-coast, or even cross-country, you might be burning several different kinds of gasoline. All of these are different from the fuels of the early 1990s, including what was then called "Reformulated Gas." And some fuels you burn in 1997 will probably change by the year 1998, and again by 2000. In most parts of the country, summer fuels differ from winter fuels. During spring changeover, summer fuels may cause longer crank times on a real cold day. Why? Lower vapor pressures, but fuel-injected engines are less affected than carbureted.

eas, but not most of the nation's cars. The differences from most previous gasolines:

- Lower vapor pressure (volatility) to reduce HC emissions
- Additives (detergents) to reduce engine deposits
- Fuel economy losses expected: about 1% in the summer, with usual winter weather losses

Winter Oxygenated Gasoline

Winter oxygenated gasoline is used where CO measures too high. It is used in most states (not California), and is required where air-quality measurements show significant CO non-attainment days. It is generally sold during four to five "high CO" months (such as October through May), with the exception of being sold year 'round in the Minneapolis/St. Paul area. The differences from most previous oxygenated gasolines:

- Added oxygenates, usually MTBE (Methyl Tertiary Butyl Ether); also Ethanol (grain alcohol). SInce Oxygenates reduce energy in the fuel, MTBE has 2.8% less energy. Ethanol has 3.4% less energy
- Increased vapor pressure to assist Open Loop operation: cold starts, warm-up, W.O.T. acceleration (winter vapor pressures more than summer, but less than previous winter vapor pressures)
- Fuel economy losses of 2 to 3%, plus usual winter losses of 5 to 15%, but remember that famous line: "your mileage may vary."

Reformulated Federal Gasoline, Phase I RFG

Phase I RFG will be sold year 'round until the year 2000 in parts of most states (not California). It is required where air-quality measurements show significant Ozone non-attainment days. The differences from most previous gasolines:

- Reduced toxic chemicals—some cancer-causing—including Benzene, a cancer-causing aromatic, and other aromatics
- Reduced sulfur; sulfur-dioxide with moisture makes sulfuric acid that damages lung tissues and also vehicle smog-control equipment
- Oxygenates used all year (required by federal law), principally important during Open-Loop operation such as cold start/warm-up; mostly MTBE, and some Ethanol
- Reduced Summer Vapor Pressure to reduce VOC in refueling, in tailpipe emissions and EVAP system losses; compare to 9.0 psi previous:
  - 7.1 psi Southern states (VOC control region 1)
  - 8.0 psi Northern states (VOC control region 2)
- Increased deposit-control additives to reduce deposits on injectors and valves
- Expect economy losses of 2 to 3%, plus the usual winter-weather losses of 5 to 15%
- Emission reductions:
  - CO about 11%
  - VOC (NMHC), tailpipe and EVAP, about 9%
  - NOx about 4%
- Expect increased prices at the pump, based on increased refinery costs of 2 to 5 cents/gallon

Reformulated Gasoline, Federal RFG, Phase II

Phase II RFG will be sold year 'round beginning in 2000 in parts of most states (not California). Compared to 1990 gasoline, further limitations of polluting elements of gasoline will reduce:

- VOC by 27% in Southern states, and 29% in Northern states
- Toxics by 21%
- NOx by 6.8%

California Reformulated Gas (RFG), Phase 2

You've already seen that California has significantly more vehicle pollution than other states. Its fuels are different, and are required for sale in the entire state and only in California. The differences from other gasolines (limits by volume):

- Reduced toxic chemicals—some cancer-causing
  - Benzene, a cancer-causing aromatic (1.2%)
  - Other aromatics (30%)
  - Olefins (10%) to reduce the reactivity of EVAP losses, and reduce NOx
- Reduced sulfur (80%); sulfur-dioxide makes sulfuric acid that damages lung tissues and also catalytic converters
- Oxygenates added all year (1.8–2.7% in winter; 0–2.7% in summer); mostly MTBE, with some Ethanol. This has limited effectiveness in reducing tailpipe or evaporative VOC, except in Open-Loop, but is federal requirement
- Reduced Summer Vapor Pressure—limit 7.0 psi—to reduce VOC in refueling, in tailpipe emissions and EVAP system losses, compare to previous California limit of 7.8 psi
- Increased deposit-control additives to reduce deposits on injectors and valves

- Expect economy losses of 1% compared to previous California winter gas, plus usual winter losses of 5-15% (oxygenates have less energy than gasoline)
- Some cold starting problems on exceptionally cold Spring days, due to early distribution of Summer fuel; less likely with these 1988+ fuel-injected engines than with carbureted engines
- Emission reductions:
  - CO, greater than 11%
  - VOC (NMHC), tailpipe and EVAP, greater than 17%
  - NOx, greater than 11%
  - Sulfur dioxide, greater than 80%
  - Total toxic emissions, greater than 44% (potency weighted)
- Increased prices at the pump, based on increased refinery costs of 5 to 15 cents/gallon

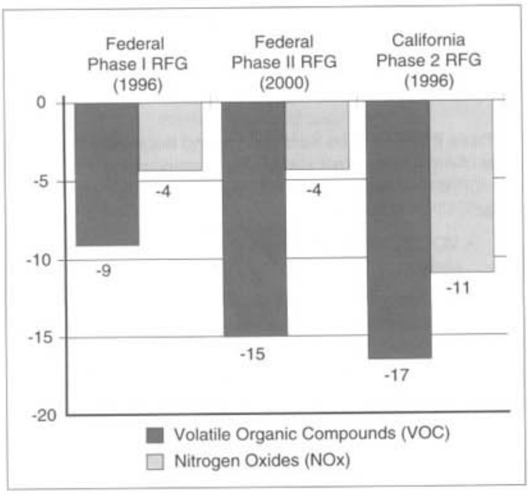


Fig. 3-2. Comparing Smog-forming emissions of new fuels, reference 1994 California conventional gasoline.

What's the bottom line? Ford approves their use. Automakers have participated in tests of the new fuels. Fuel Recommendations in your Owners Manual refer to fuels sold then, and this is now. These fuels did not exist when most of those manuals were written.

- With high mileages, greater than 100,000, you can expect deterioration of some flexible fuel lines—about 3%. That is no different from deterioration factors with old fuels.
- Fuels do vary from one refinery to the next, even as they meet the new specifications. If you have trouble, change brands or change stations

3.3 Advanced Technologies for Dedicated Vehicles

Some proposed fuels demonstrate greater advantages when the engines and their control systems can be designed for their exclusive use. Dedicated vehicles do not operate on existing supplies such as gasoline-based fuels.

Methanol—M-85

Pure methanol (M-100) is an attractive fuel for several reasons:

- It burns more cleanly
- Its high pump-octane rating, 110, improves engine power and economy
- It is cheap, widely available, and reduces our dependency on foreign oil. However, pure methanol presents problems, including cold-start vaporization

M-85 is the most promising fuel, a blend of 85% methanol and 15% gasoline. The gasoline in the M-85 helps solve the cold-starting problem of M-100. Dedicated vehicles using M-85 need special high-flow injectors, including a cold-start injector, similar to most Bosch systems. M-85 also needs modifications to the fuel system to solve the corrosion problem. Because of the low relative energy, M-85 fuel tanks must be about twice the normal size, or you have to stop and fill up twice as often. And methanol is toxic, poisonous to swallow, dangerous on your skin.

M-85 is quite different from an M-5 gasoline blend. In dedicated vehicles, the 102 pump-octane rating of the M-85 blend allows use of high compression ratios and advanced spark timing without knocking. M-85's increased cooling effect increases the density of intake air, improving power slightly. An engine dedicated to M-85 can deliver more power and economy than if it were designed to run on gasoline. Because methane is non-reactive in the atmosphere, its ozone-forming potential is much smaller than gasoline. But the formation of formaldehyde may be a serious pollution threat.

Special oil is needed to counteract more severe wear in the cylinder walls and to neutralize the formation of special acids. Additives are needed to prevent the forming of emulsions—methanol is not soluble in oil as gasoline is.

M-85 reduces the fire hazard in collisions. (Gasoline ignited in 180,000 vehicles in 1986, and caused about 760 deaths.) Methanol vaporizes less and is less likely to burn. Methanol fire releases a small fraction of heat compared to a gasoline fire. EPA estimates methanol could save 95 lives out of 100 compared to a gasoline fire. However, using water on an M-85 fire could cause separation of the gasoline from the alcohol, a floating gasoline flame and an invisible methanol flame.

Natural Gas (NG) Vehicles

Natural Gas (NG) is an excellent motor fuel. It has an octane rating of 130 and costs about half as much as gasoline. NG-dedicated vehicles need no gasoline fuel-injection system, and much simpler control for spark and bypass air-idle. NG burns cleanly, less HC and CO, but burns hotter in the cylinders, so NO_x may need more control. It is safer than gasoline (no vehicle fires on record).

The fuel is stored as a compressed gas under pressure of about 3,000 psi (21,000 kPa). NG enters the engine as a gas, prolonging the life of the plugs and the lubricating oil, "500,000-mile engine life" is predicted. And the U.S. supply is plentiful. This is the same fuel that we burn in our houses for cooking, home heating, water heating and clothes-drying.

If it's that good, why are we still burning gasoline? One simple answer is: There are few NG vehicles because there are few NG filling stations because there are few NG vehicles because there are few NG filling stations. . . . The stimulus for increasing use of NG will come from government agencies responsible for reducing smog in critical areas, beginning with California. Already, you're seeing early usage in fleets operating shorter runs in urban areas, and utilizing central fueling facilities. NG offers much promise for cleaner air, and energy independence. With the wide distribution of low-pressure natural gas to businesses for heating, the major requirement is for a compressor to fill vehicle tanks.

Fig. 3-3. Experimental NG fuel pumps provide fill-ups, but must supply fuel through special fittings under pressure as high as 3,000 psi (21,000 kPa).

Fig. 3-4. NG first usage is more likely on trucks because NG tanks are bulky.

The driver of a vehicle dedicated to alternate fuel operation can feel mighty lonely as he watches his fuel supply dwindle, passing service stations selling only gasoline. I remember the feeling, driving one of the early passenger-car diesels.

3.4 Transition Vehicles—FFV (Flexible Fuel Vehicles)

M-85 to Gasoline

Until we have a nationwide supply of M-85, most alternate-fuel engines must operate on both gasoline and the alternate fuel. They must have regular compression ratios suitable for gasoline and cannot take full advantage of the properties of M-85.

Considering the scarcity of M-85 stations, the engine must operate on any mixture between M-85 and gasoline, depending on whether gasoline or M-85 is added to the fuel mixture already in the tank. The EEC system includes a Flexible Fuel (FF) sensor in the fuel line that signals the control module about the fuel mixture, causing changes in injected fuel pulse-times, and spark timing.

The FF sensor calculates the percentage of methanol in the system by sensing electrical properties and temperature of the fuel. The sensor signals the control module to adjust the air-fuel ratio and the spark timing. Final mixture adjustments are modified according to exhaust-gas signals from the oxygen sensor.

Flexible-fuel systems require special tanks, lines, pumps, sender, and filter. Injectors are special, also exhaust-gas oxygen sensor, catalytic converter, and the control module.

On 1993 models, additional fuel is delivered to assist cold starting below 15˚C (60˚F) because methanol does not vaporize as well as gasoline. The control module determines the delivery of fuel based on temperature. The Flexible Fuel Cold-start Adapter is a 10-inch spray bar that mounts in the intake manifold plenum chamber.

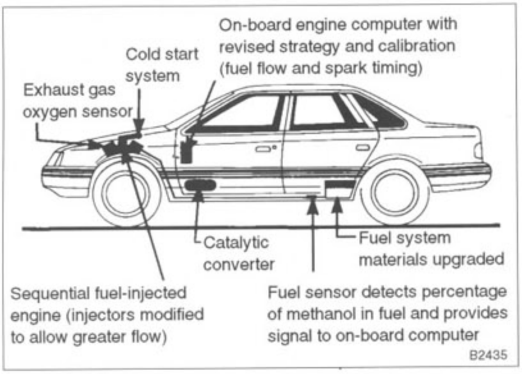


Fig. 3-5. M-85 Flexible-Fuel Ford automatically selects fuel metering and spark timing to match fuel delivered to engine.

Natural Gas (NG) Dual Fuel Vehicle

Ford is experimenting with answers to NG problems. When I examined a Ford Taurus converted to burn NG, I could see that the bulky storage tanks occupied most of the trunk. The engineer demonstrating the car told me:

- The tanks in the NG demonstration Ford will carry it about the same distance as the gasoline in the normal tank
- The fill-up sources for compressed gas are rare. NG must be compressed to about 3,000 psi, using the natural gas that is delivered at about 0.4 psi into homes and businesses

In most cases conversion is not recommended. Ford is delivering some factory-modified light trucks to utilities. Filler fittings are being standardized. Quick-fill is possible in about the same time as liquid fuel at your service station. Overnight fill-up is also available, using a local compressor.

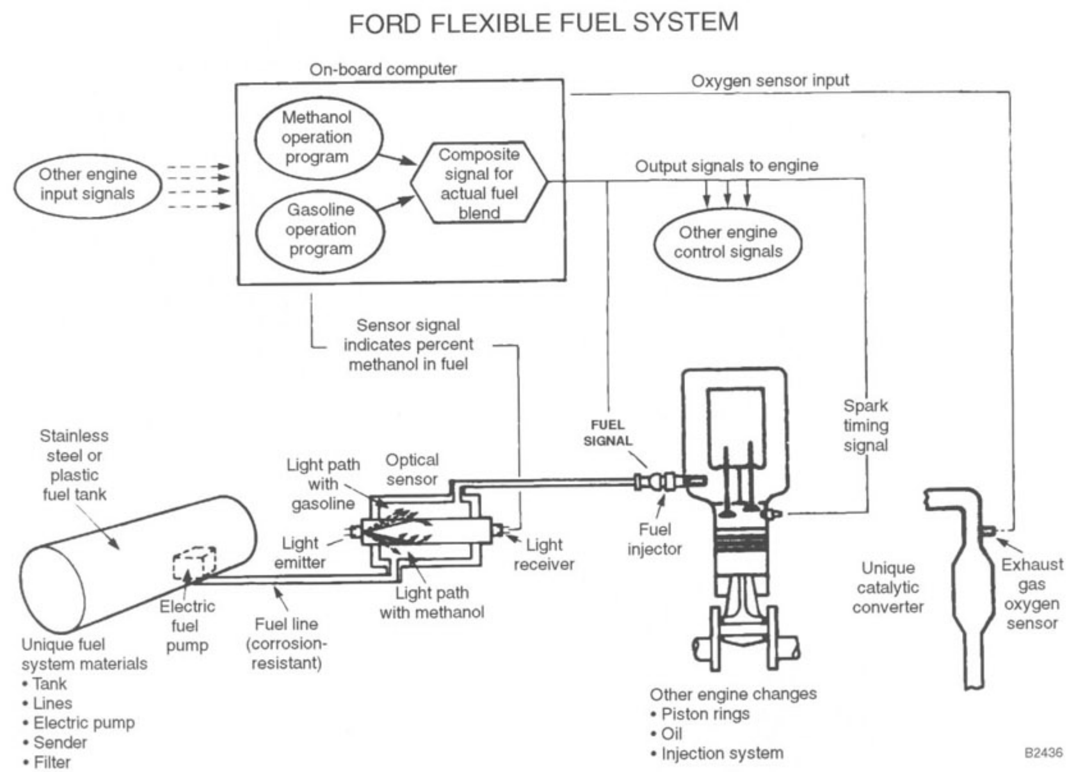


Fig. 3-6. M-85 flexible fuel sensor signals changes in fuel optical properties for different mixtures between M-85 and pure gasoline (M-0).

Fig. 3-7. Ford Taurus converted to dual fuel, capable of operating on NG (Natural Gas) without fuel injection, or gasoline.

For the average driver, there are few fill-up stations. The engine must operate dual-fuel. That means it must retain its compression ratio and spark timing for gasoline so it cannot take advantage of the high-octane of NG.

Fleet owners will be the first filling stations for private owners, again probably trucks and utility vehicles at first. And as more vehicles are converted to NG, you'll see private filling stations. With those, more dedicated NG vehicles can be manufactured, generally at much less cost than vehicles operating dual fuel. Such engines will still use electronic engine control, but will need no fuel injection, reducing cost still further.

Summary/Conclusion

How does it all add up? The new fuels are helping to clean the air and to reduce our dependence on imported oil. Within the limits described above, they are satisfactory for use in current vehicles designed to run on gasoline. If you notice any difference from pure gasoline, the engine may knock less because of the higher octane of the blends, and the gas mileage may be reduced slightly because of the lower energy content of the blends.

According to a recent study by the California Energy Commission, comparative costs in the year 2000 show a slight increase in cost for M-85 FFV, and a significant saving for M-85, Dedicated and NG, FFV. For dedicated NG, expect even more savings, plus better range and 0-60 times. To encourage use of cleaner fuels, these may be skewed by government tax advantages. See **Table e**.

Table e. Relative Cost/Performance of Driving 100,000 Miles

Fuel	Cost per 100,000 mi. (compared to gasoline)	Range: miles per 15 gal.	0–60 times, in sec.	Refuel time, min.
Gasoline	$5,000 (100%)	510	12	2
Methanol (M-85) Flexible	$5,200 (104%)	300	11	2
Methanol (M-85) Dedicated	$4,460 (90%)	350	10	2
NG FFV	$3,000 (60%)	125	12	5
Electricity	$2,100 (42%)	100	20	360

For ecology reasons, you may be buying one of Ford's Flexible Fuel Vehicles as the vehicles become more available, and as M-85 fuel pumps become more convenient. As M-85 fuel availability improves, you may be driving vehicles with M-85 dedicated engines, with much higher compression ratios, and advanced fuel-injection systems. The engine will operate much more fuel efficiently, compensating in part for the lower energy in each gallon of M-85. It will also decrease HC emissions by another 50%. But if you're committed to M-85, your friendly gasoline pump is not for your vehicle. Even if the engine runs on gasoline, the engine knock could be destructive.

If you're driving an NG Ford, it may be a dual-fuel type so you can fill with gasoline if the NG tank is empty. The engine can be switched over to operate on the EEC fuel-injection system. If the truck is a dedicated NG, end of story—no fuel injection; EEC for spark control. All you've got are low emissions, great starting in cold weather, high octane compression ratios, the cleanest engines inside, and short range.

The alternate-fuels story begins in California. California currently registers 1 out of 7 vehicles in the U.S., and drives them more VMT than the rest of the country. If you live there, and especially in smoggy Southern California, I can promise you one thing, you will be among the first to enjoy the benefits, and to experience the challenges of alternate fuels. The California bellwether often points to what's ahead in the other 49 states. Stay tuned because the fuel picture is changing even as I write.

Chapter 4

Sensors—Determining Engine Operating Conditions

Contents

TABLES

4

1. Introduction

You've seen the fundamentals, enough to understand that engine control systems must manage several basic factors to satisfy many different operating conditions:

- Injected fuel
- Spark timing
- Idle rpm, and closed-throttle air
- Emissions
- Intake manifold runners (some)

To control a modern, fuel-injected engine, you need three activities, and so the parts of Ford engine control systems are divided into three categories:

- Input signals—sensors that signal information about engine operating conditions
- Computation—a control module or computer that calculates output signals based on the input
- Actuation—action or movement based on output signals from the computer. Another way to think of this is Control, based on output from the computer

Sensors send input signals, generally about "how much" of something is happening—how hot is the coolant—or "when"—when did a crankshaft reach a TDC reference point. A form of sensor is a switch that signals "yes," or "no."

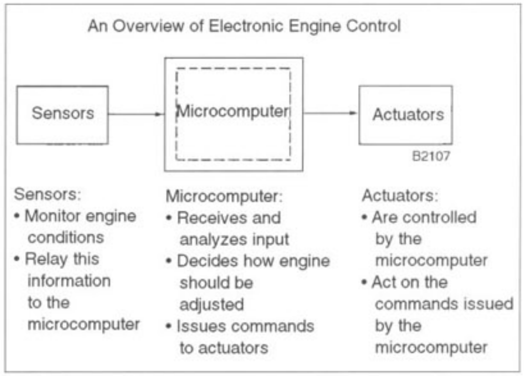


Fig. 1-1. Electronic Engine Control depends on input signals from many sensors to control module. Control module acts on these input signals and sends output signals to actuators.

You will find different combinations of sensors and actuators in different engines, depending on the model and the year. You've already seen how engines use 4, 6, or 8 injectors, one for each cylinder, injecting at the intake port.

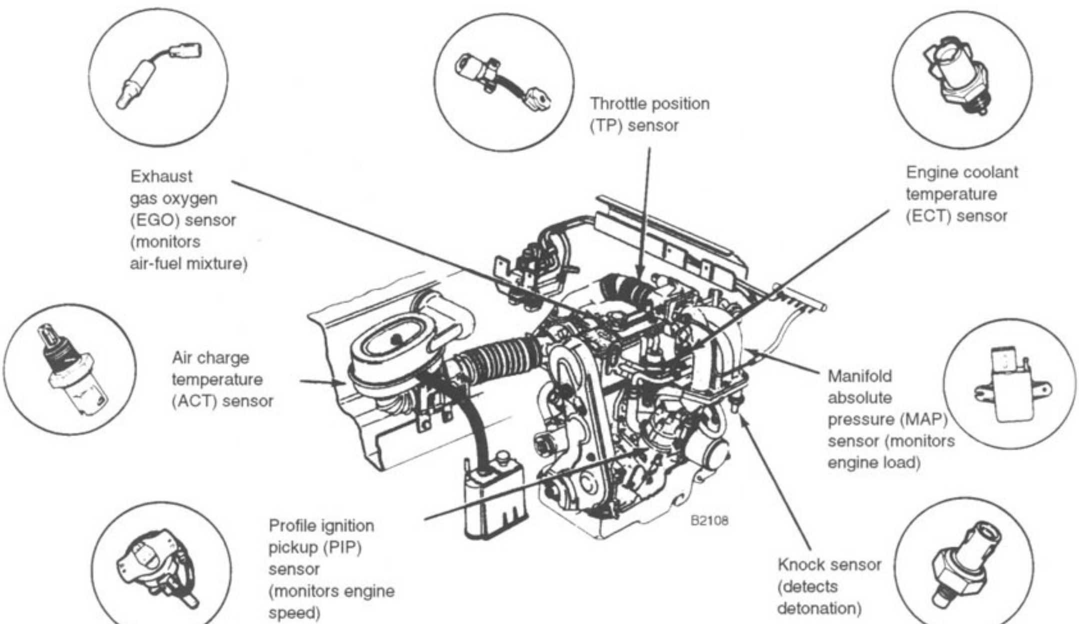


Fig. 1-2. Sensors supply input signals based on engine conditions.

Some sensors send input signals that are important to the control of many outputs or actuators in several engine subsystems. For example, the Engine Coolant Temperature (ECT) sensor is important to the control of fuel, spark timing, idle rpm, and emission control. It is also important during several operating conditions, including cranking, warm-up, cruise, idle, and acceleration.

In this chapter, I'll show you the sensors. In Chapter 5, I'll discuss control modules. In Chapter 6, you'll see the result of all this—the actuators used for engine control. In Chapter 7, I'll discuss Fuel Delivery Systems. Then, when you read Chapter 8, you'll see how these parts work together as a system to satisfy the operating conditions described in Chapter 2.

I'll concentrate on EEC systems, applicable to most Ford cars and all trucks with electronic engine control/fuel injection. I'll describe the differences you'll find in Ford/Mercury cars operating with Mazda Electronic Control Systems (MECS).

The MECS are designed to do the same things for the Mazda engines as the EEC systems do for the Ford engines. MECS-I are quite similar to Bosch L-Jetronic, or L-Motronic, controlling fuel injection (air-fuel ratio), spark timing, throttle air bypass, and emissions, as well as turbo boost.

You may see another engine control system in the 1993 Mercury Villager, a Ford/Nissan joint minivan project (also sold as the Nissan Quest). Because of the small number of vehicles involved, I won't spend much time on Nissan engine control in the Villager, but I'll summarize the differences in Sensors at the end of this chapter and Actuators at the end of Chapter 6.

When you finish this chapter, you'll know what each sensor looks like and how it operates. You'll understand the different kinds of input signals that different sensors send to the computer, and their importance under different operating conditions. First, I'll talk about generic types of sensors and switches. Then I'll discuss sensors in detail according to their purpose.

1.1 Terminology

Beginning in 1993, some of the names for the sensors were changed to comply with the SAE standard J1930 to provide common terms for the same general part throughout the automotive industry. For more information on terminology changes, see Chapter 1. This chapter uses the terminology applicable for the years 1988–1992. For reference, **Table a** lists those terms and their equivalents that changed in 1993.

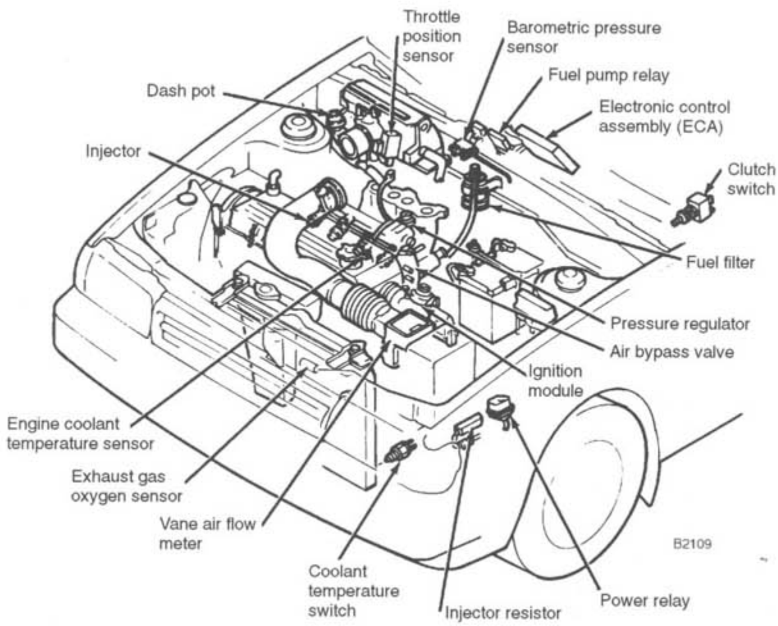


Fig. 1-3. 1988 Mercury Tracer 1.6L shows typical MECS-I. Most operate similar to those in a typical Ford EEC system. Differences include ignition coil (rpm signal for some engines), Vane Air Flow sensor (VAF) with Vane Air Temperature sensor (VAT), Electrical Load Unit (ELU), Idle Switch. Engines with Electronic Spark Advance (ESA) operate on electronic timing signals from distributor.

Why do I give you all this information about how these sensors operate? To help you understand for diagnostic purposes. Think of the sensors as the nerves of the system. Sensor signals don't take much power so sensor currents are measured in milliamps (mA). That means input signals are sensitive to the effects of corrosion, particularly at connectors.

In contrast, actuators are the muscles of the system. To do the work, output actuator currents can be a thousand times greater, up to 2 amperes. That means you can expect large voltage drops if extra resistances are involved. In both sensors and actuators, the grounds in the system are important.

In this chapter, I'll highlight **Opens & Grounds** to help you interpret readings from your DVOM or scan tool.

Table a. 1993 and Later J1930 Terminology

1988–1992 Term	1993 Equivalent
Air Charge Temperature (ACT)	Intake Air Temperature (IAT)
Barometric Pressure (BP)	BARO
Crankshaft Position (CPS)	CKP
Cylinder Identification (CID)	CID
Heated Exhaust Gas Oxygen (HEGO)	Heated Oxygen Sensor (HO2S)
Profile Ignition Pickup (PIP)	CKP/PIP
Vane Air Temperature (VAT)	IAT
Variable Reluctance (VRS)	CKP

1.2 Types Of Sensors

Six types of sensors send signals to the control module.

Thermistors are temperature-sensitive variable resistors. They operate on a reference voltage (VREF), supplied by the control module. Resistance changes with temperature, changing the signal voltage to the control module.

Potentiometers are mechanically-variable resistors, also operating on VREF. Signal voltage changes with position or rotation.

Signal Generators create a changing signal directly, without VREF. Some sensors send voltage signals; others send frequency signals.

Hall Effect Devices generate a signal that can be processed to create a digital pulse, a frequency signal changing as the shaft rotates.

Hot-wire Sensors create a voltage signal changing as the mass of the air intake changes.

Magnetic Pick Ups create an AC signal changing as a tooth passes a stationary magnet.

Table b. Sensor Type and System Affected

Sensor Type	Sensor	System Affected
Thermistor	Engine Coolant Temperature (ECT) Air Charge Temperature (ACT) Vane Air Temperature (VAT)	EGR, timing, canister purge, thermactor, idle speed, air-fuel ratio Timing, air-fuel, turbo boost Timing, air-fuel
Potentiometer	EGR Valve Position (EVP) Vane Air Flow (VAF) Throttle Position (TP) Pressure Feedback EGR (PFE)	EGR, timing, air-fuel Timing, air-fuel EGR, timing, canister purge, thermactor, air-fuel EGR, timing, air-fuel
Signal generators	Exhaust Gas Oxygen (EGO/HEGO) Knock Sensor (KS) Manifold Absolute Pressure (MAP) Barometric Pressure (BP)	Air-fuel Timing (retard) EGR, timing, air-fuel, idle speed
Hall effect devices	Profile Ignition Pickup (PIP) (also CID)	Timing, air-fuel, idle speed, fuel pump, EGR
Hot wire	Mass Air Flow (MAF)	Air-fuel ratio, timing
Magnetic pick up	Variable Reluctance Sensor (VRS) Vehicle Speed Sensor (VSS)	Timing, air-fuel Idle speed, cruise control, engine fan

1.3 Types Of Switches

Three types of switches also say "yes" or "no" to the control module about conditions that could affect the engine.

Table c. Switch Type and System Affected

Switch Type	System Affected
Grounding-type	Transmission Temperature Switch (TTS) Neutral Drive Switch (NDS) Neutral Pressure Switch (NPS) Transaxle Hydraulic Switch 3–2 (THS 3–2) Transaxle Hydraulic Switch 4–3 (THS 4–3) Clutch Engaged Switch (CES) Neutral Gear Switch (NGS) Power Steering Pressure Switch (PSPS) Idle Tracking Switch (ITS)
Voltage-input type	A/C Clutch Compressor (ACC) A/C Clutch Cycling Switch (ACCS) A/C Demand (ACD) Brake On/Off (BOO) Speed Control Command Switches (SCCS)
Electrical input signals	Ignition Diagnostic Monitor (IDM) Key Power (Key On Input) Self-Test Input (STI)

Grounding switches ground a circuit to signal the control module, either a 12 v. battery voltage or VREF (5v). See Fig. 1-4. A fixed current-limiting resistor reduces current flow to the control module. A typical 2K ohm resistor reduces current flow to a tiny 6mA (milliamps). 12v. ÷ 2,000Ω (ohms) = 0.006A, or 6mA.

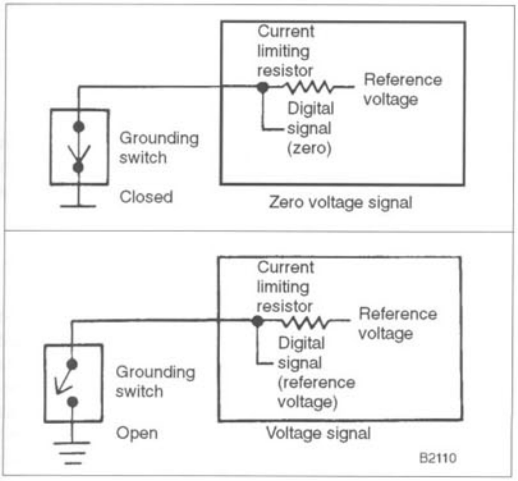


Fig. 1-4. Through a grounding switch, VREF is supplied through a current-limiting resistor. Grounded switch produces a zero signal. Open switch signals VREF at very low amps.

Voltage-input switches send a 12v. signal to the control module. See Fig. 1-5.

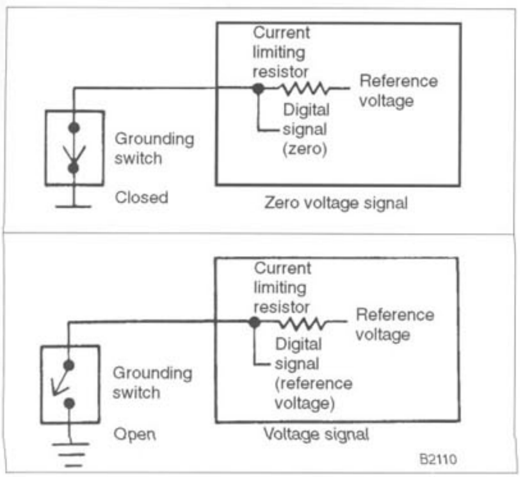


Fig. 1-5. Battery voltage (B+) is sent to control module when voltage input switch is closed.

Electrical Input switches send special signals to the control module, such as that the ignition key is ON.

2. Engine RPM, Crankshaft Position and Cylinder Identification

RPM, Crankshaft Position Sensor (CPS) and Cylinder Identification sensor (CID) signals are important to fuel injection, spark timing, idle rpm, and emission control. The engine rpm sensor is probably the most important of all the sensors. Without this, the engine will not run. On the other hand, with this one sensor, rpm input signals will usually allow limp home even if signals are lost from all the other sensors.

As engine controls grew more precise, the control module needed more information than just how fast the crankshaft is turning (rpm). Now the control module needs to know the *position* of the crankshaft, relating piston to TDC, and including rpm information, and to know when No.1 cylinder is coming up on TDC on its compression stroke (CID), to decide which injector is next in sequence to be fired, and which plug gets the spark, and when.

I'll show you five different sensors used by different 1988–93 Ford engines to signal the following:

- RPM—how fast is the crankshaft turning?
- CPS—what is the crankshaft position?
- CID—Cylinder I.D. or identification—when is #1 cylinder on its power stroke?

Of the five, the important EEC-IV technologies are the Profile Ignition Pickup (PIP) and the Variable Reluctance Sensor (VRS).

Profile Ignition Pickup (PIP)—Hall Effect

You'll find Profile Ignition Pickup (PIP) sensors in EEC-IV and MECS systems, based on a Hall-effect element. A Hall-effect device employs a rotary cup with tabs (sometimes called vanes). See Fig. 2-1. During rotation, each vane passes between a permanent magnet and a semiconductor device known as a Hall-effect element. Each vane acts as a shield,

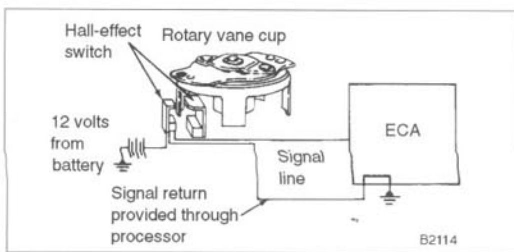


Fig. 2-1. Rotary vane cup passes through Hall-effect switch. Switch receives battery voltage. Vane passing switch signals control module. Frequency of pulses signals rpm. Timing of pulses signals crankshaft position.

> A Hall-effect device takes its name from a Dr. Hall, who discovered a way to accurately switch a small current flow with no contacts and, therefore, no wear. The idea is to interfere with a magnetic field to prevent current flow through the device.

interrupting the magnetic field, which allows the Hall element to pass a small current to the control module. See Fig. 2-2. The turn-on and turn-off are very sharp, almost like a digital signal.

- Hall element sees magnetic field = Hall signal
- Magnetic field blocked = No Hall signal

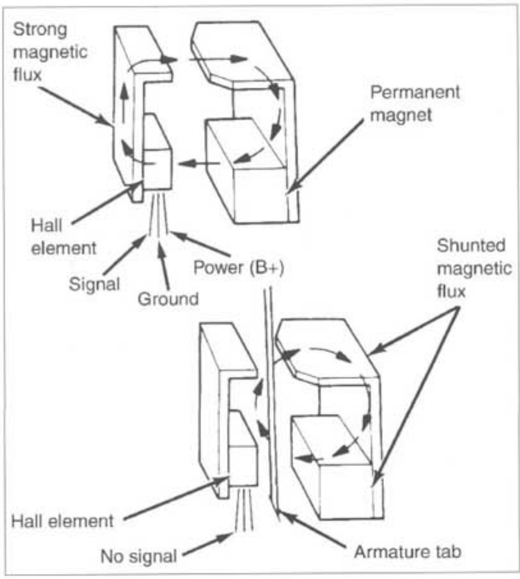


Fig. 2-2. Hall element operates on battery voltage through two of the leads, B+ and ground. Upper: When the element operates in a strong magnetic flux, as from the permanent magnet, it sends a signal through the third lead. Bottom: When the magnetic field is shunted, or cut off from the element by the tab, the signal is cut off. Magnetic field = signal; no magnetic field = no signal.

In the Ford PIP, the output of the Hall-effect device is processed—amplified and shaped. And here's what can be confusing: the signal becomes *inverted* in the process. So when the Hall element generates voltage, as when there is a window, the PIP sends no signal. And when the vane cuts off the Hall-effect voltage, the PIP sensor sends a signal. (No wonder it can be confusing!) The output from Ford PIP sensor seems to be the opposite of the signal from other manufacturers' Hall-effect sensors. And it *is*:

- Window = Hall voltage = no PIP signal
- Vane = No Hall voltage = PIP signal

A Schmitt trigger shapes the wavy output of the Hall device into square digital pulses. Square pulses are more useful to the control module because they are more precise than the Hall wave output (or of the previously-used CPS).

2.1 Distributor Mount PIP

For many Ford engines, rpm is sensed with the PIP located in the distributor, about where the centrifugal flyweights used to be. See Fig. 2-3. Signals from the Hall-effect device in the PIP are sent through the Ignition Module to the control module, corresponding to a base spark timing of 10 degrees BTDC (Before Top Dead Center). Turning at the speed of the distributor (and the camshaft), the PIP cup has one vane per cylinder. For a 4-cylinder engine, the PIP with four tabs sends four pulses for each revolution of the distributor shaft; that's two pulses per crankshaft revolution.

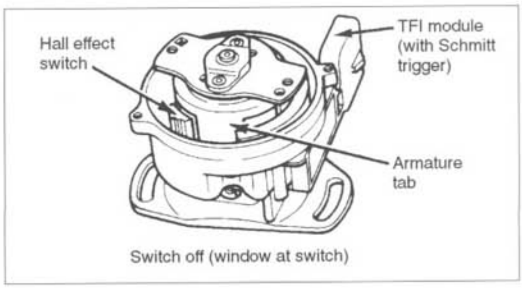


Fig. 2-3. Distributor carries TFI module. Hall-effect armature (cup) rotates on shaft where flyweights were.

The control module computes rpm by counting the pulses, and timing by when the pulses begin. At low rpm, the pulses are low frequency. The faster the engine turns, the higher the frequency of these digital pulses. If you played these pulses through your audio amplifier, starting from idle, you would hear a low growl, rising in frequency as the rpm increased.

Signature PIP is a variation used on engines with Sequential MFI. See Fig. 2-4. It provides a cylinder-identification signal to time the firing of individual injectors. With one segment narrower than the others, it sends a different signal for that segment. This provides the control module with information about which cylinder is next to open its intake valve.

When the PIP is located in the distributor bowl, it is easy to reach if it's necessary to adjust base timing. Its job is to sense crankshaft rpm and position; however, it is separated from the

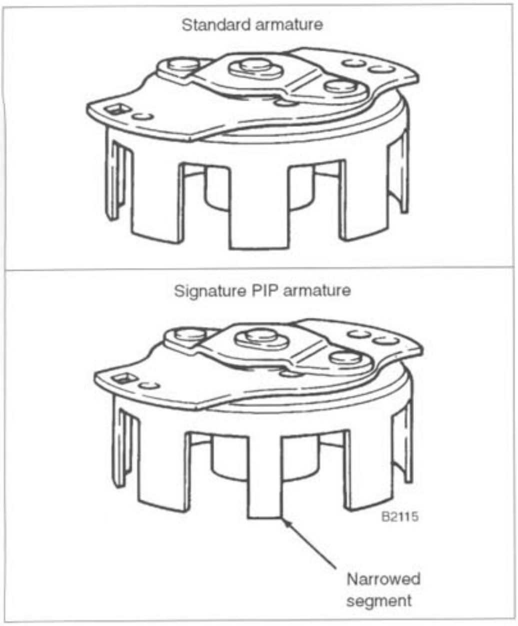


Fig. 2-4. Signal from narrowed segment, or vane of Signature PIP "looks different" to control module, providing a form of cylinder identification.

crankshaft by the timing belt and the drive gears of the distributor. Depending on the belt tension, this could introduce inaccuracies in the measurement, particularly of crankshaft position.

2.2 Distributorless Systems

To improve fuel economy, reduce emissions, and increase timing accuracy, sensor signals need greater precision. This led Ford to Distributorless Ignition Systems (DIS). DIS uses either Hall-effect devices or Variable Reluctance Sensors (VRS).

Depending on the engine, the Hall-effect devices are in different locations:

- 3.8L SC engine: CID sensor is mounted in the normal distributor location, driven by the camshaft. Timing accuracy is determined by the PIP on the crankshaft
- 3.0L & 3.2L SHO engines: the CID sensor is driven directly from the end of the rear overhead camshaft
- 4-cylinder Dual-Plug Distributorless Ignition System (DPDIS) dual-Hall sensor is driven off the crankshaft for both PIP and CID

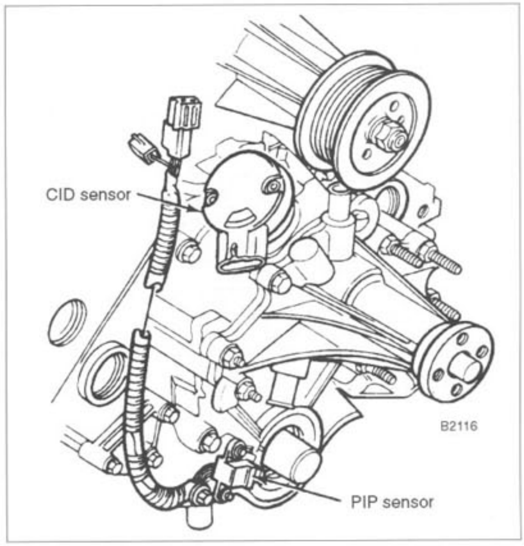


Fig. 2-5. 3.8L SC V-6 engine drives PIP Sensor directly off crankshaft. CID (Cylinder Identification sensor) is driven by camshaft through bevel gears in distributor location. On 3.0 and 3.2 SHO engines, CID is driven directly off of rear camshaft.

For the V-6 engines, the PIP sensor is mounted on the crankshaft for greatest timing accuracy, but the Cylinder Identification (CID) sensor is driven by the camshaft.

The crankshaft sensor uses three vanes turning at crankshaft speed to generate the PIP signal for the firing of the three Distributorless Ignition (DIS) coils for each crankshaft revolution. Spark timing accuracy is determined directly by crankshaft position.

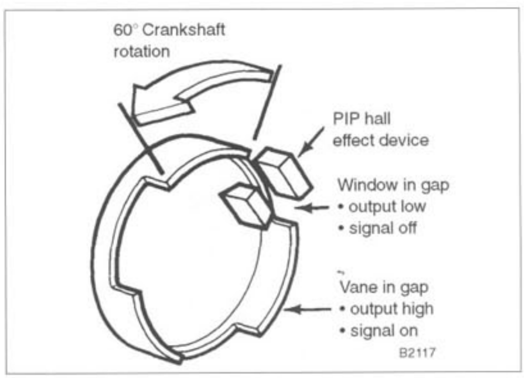


Fig. 2-6. 6-cylinder PIP on crankshaft turns twice as fast as distributor (or camshaft-driven) so it operates with half as many vanes as cylinders, here 3.

Each 6-cylinder PIP signal from the crankshaft is 60 degrees on with 60 degrees off (three for each crankshaft revolution. To look at it another way, 6 vanes pass the Hall-effect device for each two revolutions of the crankshaft (one camshaft revolution) for six cylinders.

The camshaft Cylinder Identification (CID) sensor operates with only one vane and one window, turning at camshaft speed. See Fig. 2-7. Its job is to identify the cylinder. Spark timing accuracy is not affected by the inaccuracies of the camshaft drive because the crankshaft PIP determines timing. The CID only determines which coil to fire. The CID signal also identifies which cylinder is on compression stroke for the sequential injection of fuel to that cylinder.

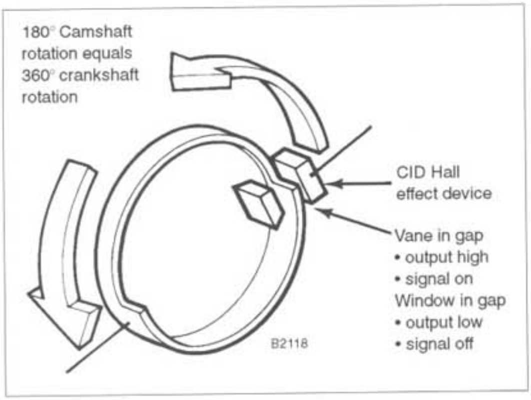


Fig. 2-7. Camshaft CID signal is on for 180 degrees of camshaft rotation, or for 360 degrees of crankshaft rotation.

Dual-Hall Crankshaft Sensor

You'll find some 4-cylinder models with Dual-Plug Distributorless Ignition System (DPDIS). Look for one crankshaft-mounted sensor signalling both PIP and CID. See Fig. 2-8. This sensor is a Dual-Hall sensor.

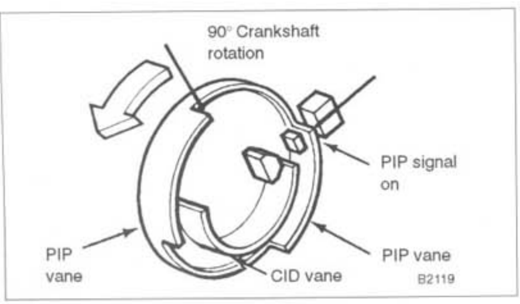


Fig. 2-8. In Dual-Hall Crankshaft Sensor, outside sensor operates as PIP to signal rpm and Crankshaft Position. Inside Hall sensor operates as CID to identify which coil should be fired.

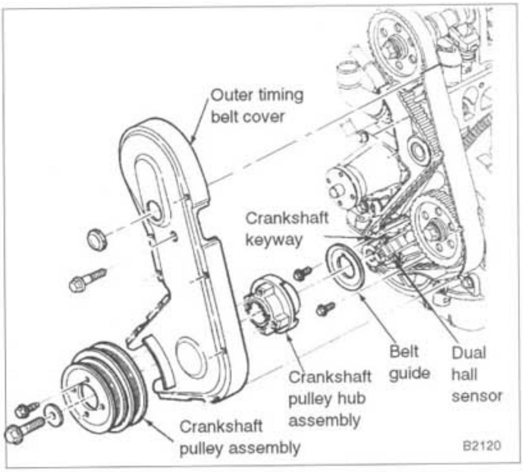


Fig. 2-9. Dual Hall sensor is located on the crankshaft under the outer timing belt cover—2.3L DP. Two rotary vane cups are mounted on the damper, one for each of the two Hall-effect sensors.

The DPDIS Dual-Hall sensor is located on the front of the crankshaft, as in the original CPS, where it can sense even small changes in crankshaft rotation rate.

PIP cup, with two vanes on the crankshaft, turns at twice the rpm of a PIP in the distributor. Two vanes send the proper signal rate for four cylinders, two for each crankshaft revolution.

CID has one vane, 180 degrees around. While the CID vane is passing the second Hall-effect device, it sends voltage, identifying the coils for cylinders 2 and 3. When the vane is clear, the lack of battery voltage signal from CID identifies cylinders 1 and 4.

Variable Reluctance Sensor (VRS)

On models with Electronic Distributorless Ignition System (EDIS) you'll find a single crankshaft sensor known as the Variable Reluctance Sensor (VRS). Applications include:

- 1990 and later 1.9L 4-cylinder Escort
- 4.0L V-6 Ranger/Bronco/Aerostar
- 4.6L V-8 in 1991 and later Lincoln Town Car, 1992 and later Ford Crown Victoria/Mercury Grand Marquis, and the 1993 and later Mark VIII

The VRS is a passive electromagnetic device that generates AC voltage using a a stationary sensor and a toothed wheel mounted on the front of the crankshaft. See Fig. 2-10. As teeth pass through the sensor's magnetic field, they generate a voltage signal that increases with engine rpm. The wheel has a tooth every 10°, with one tooth missing (35 teeth). Using the signal difference caused by the missing tooth,

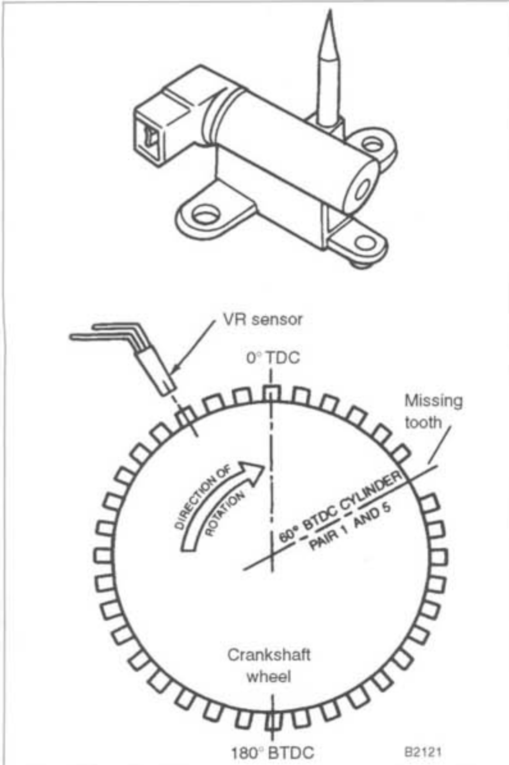


Fig. 2-10. Variable Reluctance Sensor (VRS) senses movement of toothed wheel past point of sensor. 36-minus-one toothed wheel signals 60 degrees BTDC. (V-8 shown)

this one sensor can supply the signals for the control module to compute rpm, crankshaft position, and cylinder identification. One tooth is missing so control module can identify which cylinder is coming up to be fired.

But wait a minute. In Fig. 2-10, the missing tooth corresponds to two cylinders. How does the module make cylinder identification? By a 1-revolution trial and error. During crank, the control module tries to fire cylinder #1. If that doesn't start the engine, it tries cylinder #5 on the next revolution. Then the control module notes which of the two cylinder pairs worked, and remembers for as long as the engine runs. Of course, if it knows the 1-5 pair, it knows the other cylinder pairs. For the next engine start, the module makes another trial.

Opens & Grounds

An open between Hall device and control module results in constant 5v. signal at control module. A short-to-Ground in same circuit results in constant 0v. signal at control module.

2.3 Mazda Engine Control Systems (MECS) PIP, CID, CPS

I've shown you two different types of sensors, Hall-effect and Variable Reluctance, used by EEC-IV to signal rpm, crankshaft position, and cylinder identification. Some MECS-II engines also use Hall-effect devices. Other MECS systems may use one or more of these three different sensors:

- Old-fashioned breaker points
- Magnetic sensor pickup coils
- Optical sensor with slotted disc

Mazda Engine Control Systems (MECS) differ significantly from the EEC systems. And the 1993 and later MECS-II differs from the MECS-I used in 1988–92 models. MECS-II is used in '93 and later V-6, also '93 2.0L with automatic (4EAT). Remember, EEC-IV is on '93 2.0L manual transmission, and all '94 and later 2.0L.

MECS-I 2.2L non-turbo engines in the Probe and 1.6L engines in Capri use the outmoded ignition timing called Distributor-Mounted Ignition Module with Vacuum Advance (DMIVA)! The ignition coil lead senses rpm, with ignition timing varied by the flyweights and vacuum advance.

In other MECS-I engines, you'll find Electronic Spark Advance (ESA). In the distributors, you'll find a Crankshaft Position Sensor (CPS) and two Cylinder Identification Sensors (CID).

MECS-I RPM Signal

On 2.2L turbo models, the Crankshaft Position Sensor (CPS) in the ESA distributor base uses a magnetic sensor pickup coil next to a wheel with 24 teeth. See Fig. 2-11. This generates 24 pulses every rotation of the distributor shaft (every two revolutions of the crankshaft). Turning 720 degrees in two crankshaft revolutions, 24 teeth (720 ÷ 24) = 30 crankshaft degrees per pulse.

MECS-I Cylinder Identification

In 2.2L turbo engines, a separate rotor for the two Cylinder Identification Sensors (CID) rotates on the same distributor shaft. In Fig. 2-11, you can see the CID rotor, looking like a twisted teardrop. One pickup, shown on top, signals TDC for cylinder #1. The other pickup, shown below, signals TDC for cylinder #4. Recall that cylinder #1 rises to TDC on its compression stroke at the same time #4 rises on its exhaust stroke. With signals from these two sensors, the computer identifies which cylinder gets the spark timing, and which gang of two injectors gets the injection pulse.

1.8L and 1.3L engines use a slotted disc. A Light Emitting Diode (LED) shines through the slots to a photo sensor. This is sometimes called an optical system. See Fig. 2-12. The disc has one inner CID slot that generates 1 pulse for every two revolutions of the crankshaft. Another LED shines through the CID slot to a CPS photo sensor. On a disc that rotates once for

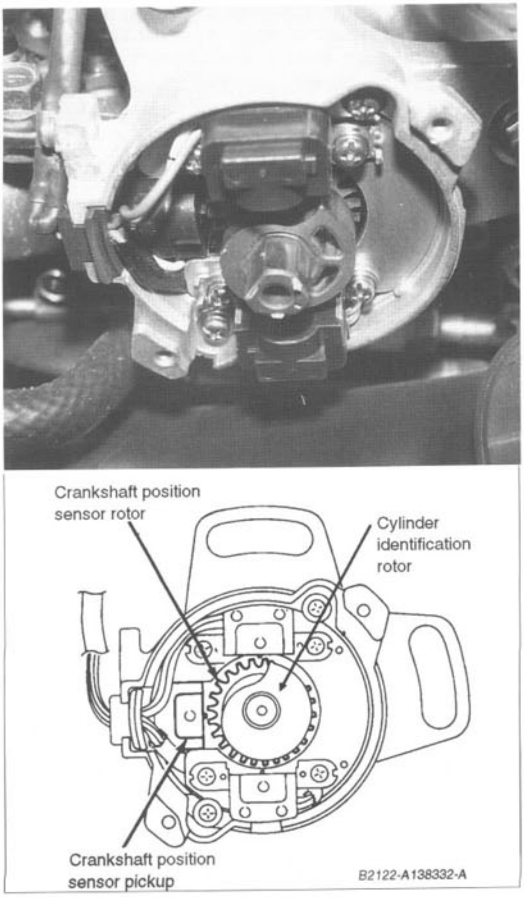


Fig. 2-11. MECS-I 2.2L Turbo ESA distributor includes sensors for CPS and CID.

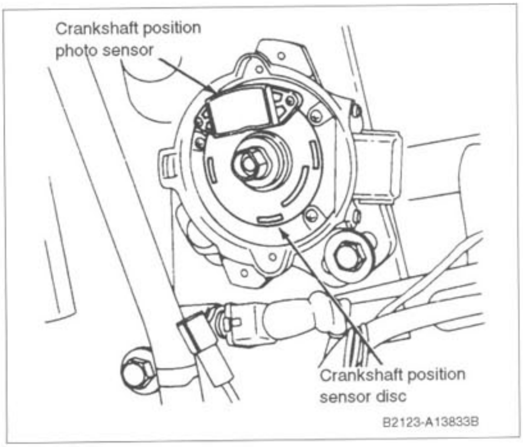


Fig. 2-12. MECS-I 2.2L/T, 1.3L and 1.8L ESA distributor includes sensors for CPS and CID.

each two crankshaft revolutions, it takes only one CID signal to signal TDC of #1 cylinder.

- 1.3L and 1.8L engines use Transistorized Ignition Module 3-pin type, TI3, that relays spark timing from the ECA to the coil
- 2.2L turbo uses 5 pin, TI5, that relays spark timing, grounds the coil negative and returns feedback signal to the ECA

MECS-II

To provide the timing necessary for sequential fuel injection (SFI), '93 and later MECS-II provides improved crankshaft position and cylinder-identification signals to the control module.

V-6 2.5L engines use two sensors, one in the distributor, and the other on the rear of the crankshaft pulley.

On 2.0L MTX, the EEC-IV distributor drives an optical disc with four equally-spaced outer slots. These slots generate 4 pulses for every turn of the distributor shaft (two revolutions of the crankshaft). See Fig. 2-13.

On 2.0L 4EAT, the MECS-II distributor uses a 4-vane Hall-effect sensor, similar to PIP in EEC.

On 2.5L MTX and 4EAT, the MECS-II distributor uses a 6-vane Hall-effect sensor, similar to PIP in EEC. Call it Crankshaft Position (CKP1) sensor. The second Crankshaft Position sensor (CKP2) mounts directly on the crankshaft. See Fig. 2-14.

CKP2 is particularly valuable at the higher rpm's of this little V-6, over 100 revs every second. Avoiding the camshaft belt that drives the distributor, CKP2 accurately signals crankshaft position. CKP1, in the distributor, sends backup crankshaft position signals, and also CID signals of cylinder #1 compression TDC.

CKP2 provides increased accuracy at higher rpms. This increased accuracy increases torque about 3% above 5,000 rpm. CKP2 detects changes in crankshaft rotation rate during acceleration, improving the accuracy of ignition timing.

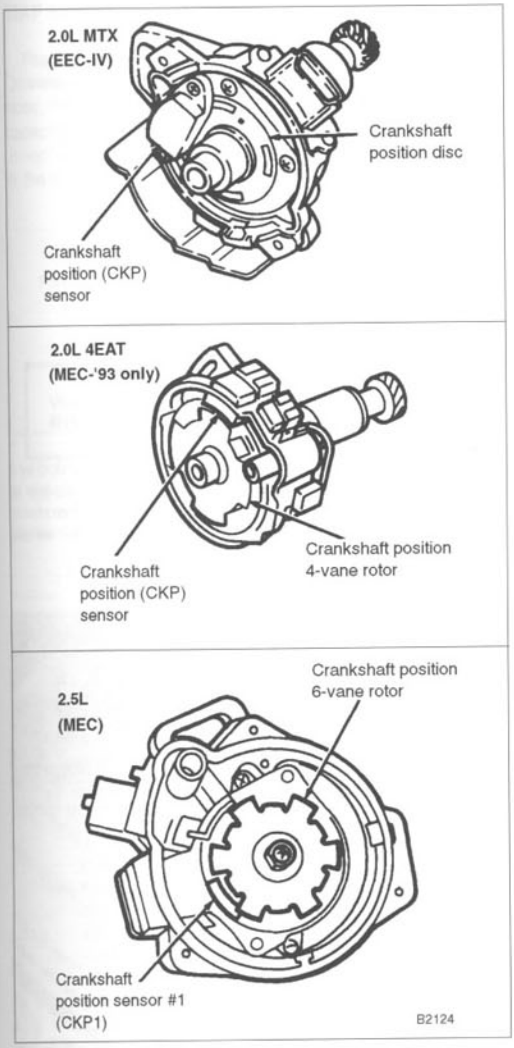


Fig. 2-13. Compare different 1993 Mazda Crankshaft Position (CKP) sensors: 2.0L MTX slotted disc for light signals, similar to 1.3L and 1.8L; '93 2.0L 4EAT MECS 4-vane rotor for Hall effect; 2.5L 6-vane rotor for Hall-effect.

Cylinder identification signals are sent by a second Hall-effect sensor. A single blade, under the CKP cup, rotates at camshaft speed, similar to the CID sensor in 3.8L EEC systems.

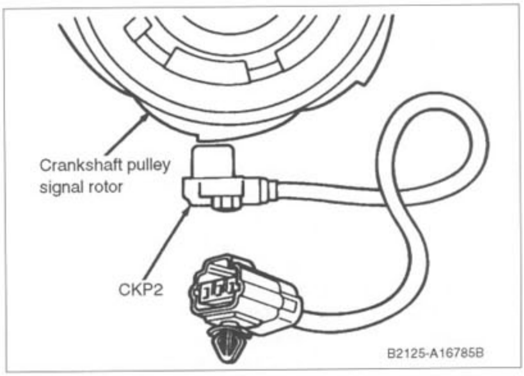


Fig. 2-14. 1993 and later 2.5L V-6 uses two crankshaft position sensors, CKP1 and CKP2. CKP2 sends accurate signals of compression TDC of each cylinder.

2.4 Summary—RPM, PIP, CID

In summary, in 1988–93 Ford vehicles, different Ford engines use different combinations of sensors to signal for computation of crankshaft rpm and position, and cylinder identification.

1. Hall-effect devices operate a rotary cup with one or more vane and windows:
   - When a vane interrupts a magnetic field from a permanent magnet, the Hall switch (or element) closes, sending a current signal
   - When a vane passes, a window allows the field to reach the Hall switch, opening it and preventing current flow
2. Distributor-mounted Hall-effect devices use a rotary cup with one vane for each cylinder. Ford calls it Profile Ignition Pickup (PIP).
3. Distributorless systems (DIS and EDIS) use Hall-effect devices directly on the crankshaft:
   - V-6 engines provide Cylinder Identification (CID) signals from a separate Hall-effect device, driven at camshaft speed
   - 4-cylinder DPDIS dual-vane Hall-effect cups are driven directly from the crankshaft. The PIP cup supplies crankshaft speed. The CID cup supplies cylinder identification
4. Variable Reluctance Sensors (VRS) are used on EDIS systems. A crankshaft-mounted missing-tooth wheel signals pulses. The control module can use these signals to compute rpm, crankshaft position, and cylinder identification.

5. MECS engine-rpm sensors
   - Distributor Mounted Ignition, Vacuum Advance (DMIVA), rpm signal from coil
   - Electronic Spark Advance (ESA), distributor signals, CPS from rotor and coil, CID from teardrop rotor and two coils
   - ESA, distributor signals from disc and LED/photo sensor, CPS from four slots, and CID from a single slot
   - ESA, CKP & CID PIP signals from Hall-effect sensors in distributor
   - ESA, CKP signal from crankshaft position sensor (#1), and from distributor Hall-effect sensors, one for CID and the other for backup CKP.

3. Engine Load

To measure engine load, 1988–93 Fords use three different load sensors relying on three different measurements:

1. Manifold Absolute Pressure (MAP) sensor—Speed-density. Refers to measuring engine speed and measuring air pressure in the manifold by sensing MAP.
2. Mass Air Flow (MAF) sensor—Air mass. Refers to measuring the mass or weight of intake air by the MAF.
3. Volume Air Flow (VAF) sensor—Air volume. Refers to measuring the volume of intake air by the Vane Air Flow (VAF) sensor, or by the Measuring Core Volume Air-Flow Sensor (MC-VAF).

MAP is the simplest and the most indirect measurement. It is being phased out, virtually all supplanted by the MAF, first seen on the 1989 3.0L SHO engine. MAF is probably the most accurate measurement of engine load, and is also on '93 Probe 4-cylinder with MECS.

3.1 Manifold Absolute Pressure (MAP) Sensor

The Manifold Absolute Pressure (MAP) sensor measures the positive increase in manifold pressure from absolute zero to barometric. (Remember what I said in Chapter 2 about thinking positive instead of negative, i.e., vacuum.) The MAP sensor is usually mounted on the engine bulkhead away from the vibration of the engine.

The MAP sensor is connected to the manifold in a manner similar to a vacuum gauge. But if you think in terms of negative pressure (vacuum measured as less than atmospheric), you'll have trouble understanding engine load and boost. Think positive, absolute pressure from zero:

- At idle and deceleration, MAP is least, typically 30 kPa
- At WOT, MAP is close to barometric, typically 95 kPa

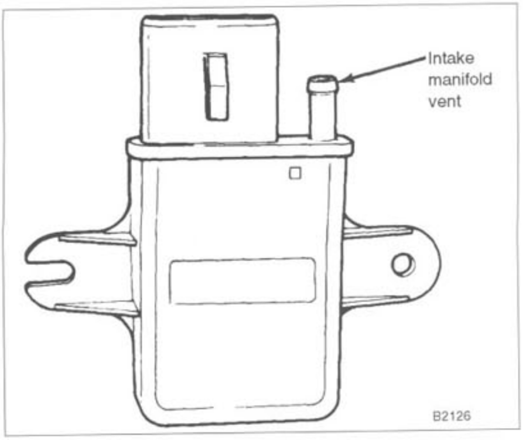


Fig. 3-1. MAP sensor is connected to intake manifold by a hose. MAP sensor may also be switched over to measure barometric pressure, or barometric pressure may be measured by a similar sensor, called BP or BARO.

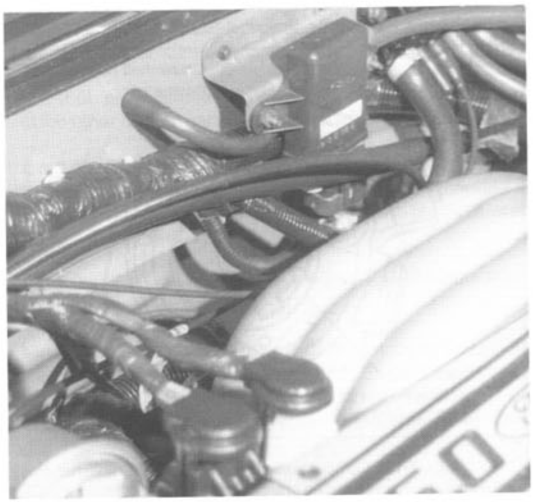


Fig. 3-2. MAP/BP sensor installation on 5.0L high output engine senses barometric pressure.

> Those of you familiar with Bosch systems will recall their term "map". That is not MAP. A Bosch map refers to their visualization of a three-dimensional map of data points in the memory, what Ford calls "Look Up Tables"—more about that in Chapter 8.

MAP Sensor Design and Operation

The MAP sensor is a pressure-sensitive disc capacitor. One side of the disc is connected to the intake manifold by a hose. As manifold pressure is applied to the disc, it changes capacitance. These electrical capacitance signals are "conditioned" to be translated into changing frequencies. The greater the manifold pressure, the faster the frequency.

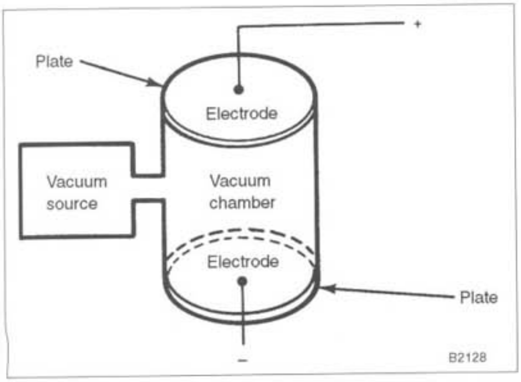


Fig. 3-3. Variable capacitor in MAP or BP sensor changes capacitance as pressure varies between two electrodes, or plates.

In the MAP or BP sensor, changing capacitance is converted by a frequency generator into a series of digital pulses, changing from reference voltage to zero. The greater the pressure, the faster the frequency.

> ***CAUTION —***
> *Ford MAP and BP sensors measure frequency—the signal is digital pulses of reference voltage. That's different from pressure sensors in most other cars. You cannot measure frequency with a voltmeter. Do not test for resistance with an ohmmeter. You may damage the sensor.*

Speed Density

When you hear the term "speed-density," that's one way an engineer refers to the basic factors that determine the output of the engine, and therefore the amount of fuel injected at any moment.

Speed is, of course, engine speed, or rpm. The higher the rpm, the more times per minute the cylinders fill with air-fuel mixture.

Density refers to the pounds of air that move into the cylinders per intake stroke. Density relates to Manifold Absolute Pressure (MAP), and also to temperature of the intake air. (Performance-oriented people know that cold air = more density = more pounds = more fuel needed = more power!)

MAP/BP Opens & Grounds

An open or short to ground between the MAP or BP and the control module results in a constant zero v. signal at the control module.

A poor connection between the sensor and control module results in a weak signal that cannot be recognized by the computer frequency-to-voltage converter.

3.2 Mass Air Flow (MAF) Sensor

The Mass Air Flow (MAF) sensor is the most direct method of measuring engine load because it measures the mass of air intake without needing corrections for temperature or pressure. Although you'll see Speed-Density on most Ford engines of the 1980s, MAF is the choice in Ford engines of the '90s, and in performance modifications (see Chapter 9).

MAF depends on the measurement of current flowing through heated wires to measure air flow. It is also known to Bosch guys as the "hot-wire" sensor because of its heated-wire design. It has several advantages over vane-type air-flow sensors.

1. It measures air mass, or weight, so it requires no air-fuel-mixture ratio correction for changes in density due to temperature or altitude. Measuring mass reduces correcting computations in the control unit.
2. It has no moving parts. That means mechanical simplification. Measurements follow changes in air mass in 1 to 3 milliseconds.
3. It offers insignificant resistance to the passage of air. Even at maximum air flow, drag force on the wire is measured in milligrams.

MAF Sensor Design and Operation

Between the air cleaner and the manifold, you'll see a simple cylinder with an electronic box, as shown in Fig. 3-4 and Fig. 3-5.

The EEC-IV hot-wire system depends on measurement of the cooling effect of the intake air moving across the heated wires. Suppose you had a fan blowing across an electric heater. With a small movement of air past the heated wires, the cooling effect is small. With more air moving past the heated wires, the cooling effect is greater.

MAF control circuits use this effect to measure how much air passes the hot wire. The hot wire is heated to a specific temperature *differential* of 200° Celsius above the incoming air. That's twice the temperature differential of the Bosch hot wire of 100°C. Notice I did not say it was heated to 200°C, but rather to 200°C above the temperature of the intake air. I'm going to offer a rough approximation of the 200°C hot-wire temperature differential as 360° Fahrenheit, but you'll understand the principle better if I stay with a single unit of measurement, Celsius.

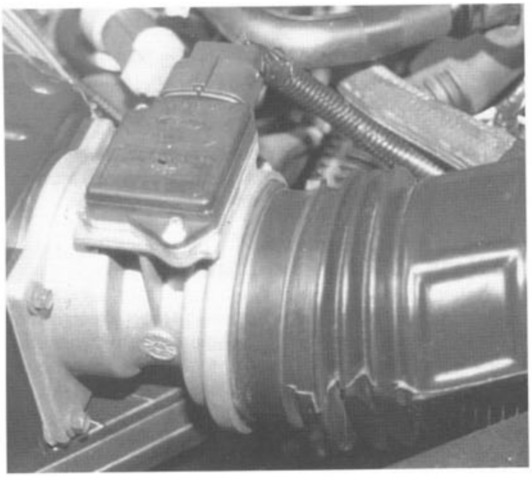


Fig. 3-4. Mass Air Flow (MAF) sensor mounts between air cleaner and intake manifold. 4.0L Explorer shown.

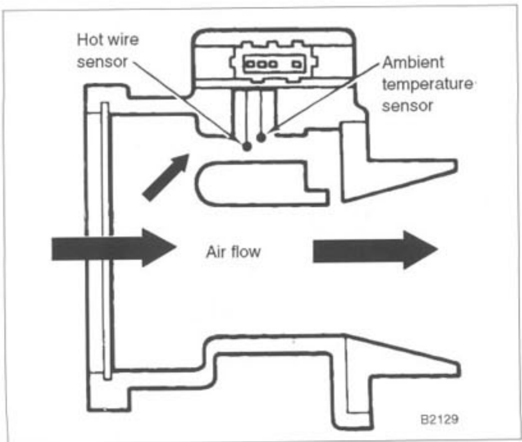


Fig. 3-5. MAF sensor uses a hot-wire system to signal mass of air intake.

Two wires are exposed to a proportion of the airflow:

- The Ambient Temperature Wire is also called the "Cold Wire" because it is not heated. Ambient means "surrounding", so the cold wire operates at the temperature of the surrounding air. The cold wire serves as a reference temperature
- The Hot Wire is heated by the MAF control circuits to be 200°C above the ambient air. If it is freezing outside, 0°C, the hot wire will be heated to 200° hotter, or 200°C. If it is a hot day out, say 40°C, the hot wire will be heated to 240°C

Think about it, 40°C temperature is about 100°F, so the Cold Wire is "cold" only because it is unheated. We call it cold only because it is 200°C colder than the hot wire.

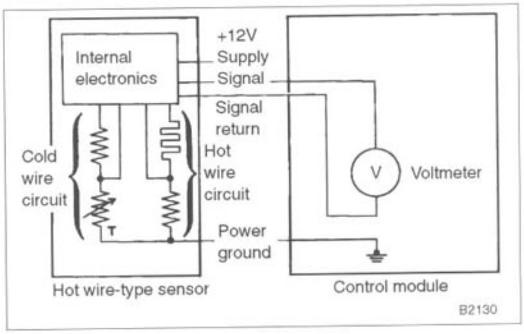


Fig. 3-6. By comparing voltage drop across hot-wire element to voltage drop across cold-wire element, sensor electronics send a DC voltage signal directly proportional to mass of air flow through sensor. Vehicle power, 12v. is supplied, not VREF. Output is much less.

As soon as air flows over the wire, both wires are cooled. The control circuits then apply more voltage to keep the hot wire at the original temperature differential, 200°C. This creates a voltage signal monitored by the control unit. The greater the air flow and wire cooling, the greater the signal. Cooling depends on the mass of the intake air and on its temperature so no additional corrections are needed. MAF input signals to control module are directly related to intake air mass.

The typical voltage output, increasing as speed increases are 0.20v, idling to 1.5v. max, engine running, or 0.70v. max, KOEO (Key On, Engine Off).

If you're familiar with the Bosch Hot-Wire Sensor of LH-Jetronic/Motronic systems, you'll notice a major difference in the Ford sensor. Ford measurement takes place in a separate bypass above the main flow, while the Bosch measurement takes place in a centrally-mounted set of wires. What does this mean to you?

- The air flowing through the Ford bypass, past the measuring wires must be closely proportional to the total intake air flow, otherwise the measurements will be false, distorting the air-fuel mixture. In the design of the sensor and its ducting, Ford considers the delivery of air into the sensor to be even-flow, "laminar" is the term. If you plan any rework of the sensor mounting or its duct work, consider the importance of the even flow of intake air.

- With the measurement wires separated from the main flow, they are less likely to collect dirt. The Ford sensor does not require the Bosch circuitry for hot-wire cleaning at shut-off.

MECS-II MAF Sensor

Mazda Engine Control Systems (MECS-II) for 1993 4-cylinder 2.0L with automatic transmission (4EAT) use a MAF different from the EEC-IV MAF. The '93 2.0L Manual Transaxle (MTX) and all '94 and later 2.0L use a regular EEC-IV MAF.

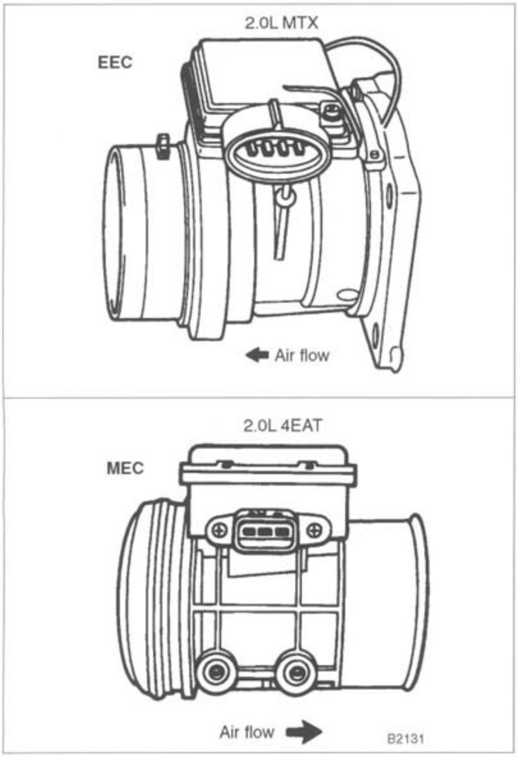


Fig. 3-7. Compare MAF for EEC-IV system on Probe 2.0L Manual transmission (MTX) with MAF for Probe 2.0L Automatic Transmission (4EAT). Contrast appearance to insure that you are using proper data for working on engine.

This MECS-II MAF mounts the heated resistor plate in a central passage, a location similar to most Bosch "hot-wire" AFS. In contrast, Ford EEC-IV MAF measures the air flow through a hot wire in a side bypass. The MECS-II sensor also differs from the FORD EEC-IV MAF in using a heated-resistor plate instead of a fine wire.

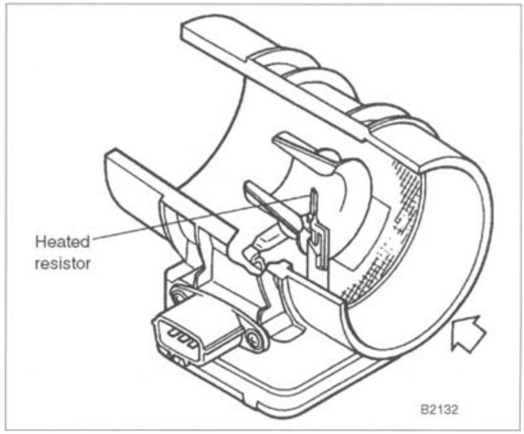


Fig. 3-8. Heated-resistor plate (not wire) measures air mass flowing through central passage. 1993 and later Probe 2.0L 4EAT engine.

3.3 Vane Air Flow (VAF) Sensor

Some early Ford engines and the 1988–92 Mazda Engine Control System (MECS-I) engines use the Vane Air Flow (VAF) sensor. See Fig. 3-9.

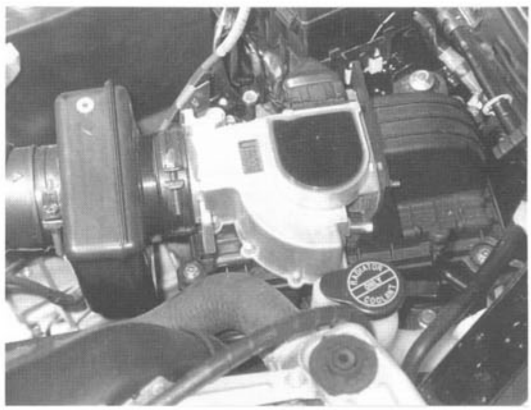


Fig. 3-9. Vane Air Flow (VAF) sensor in this 1.8L engine is a Bosch air flow sensor, as used in L-Jetronic or Motronic.

The VAF sensor is called a vane-type because its internal vane moves as air is drawn into the engine. The sensor measures the air volume controlled by the regular throttle valve. (Its new name is Volume Air Flow sensor, still VAF.) The sensor does not regulate the air flow. The air vane, also called an air flap, is lightly spring-loaded, and pivots by the force of the air flow as the throttle opens to admit more air.

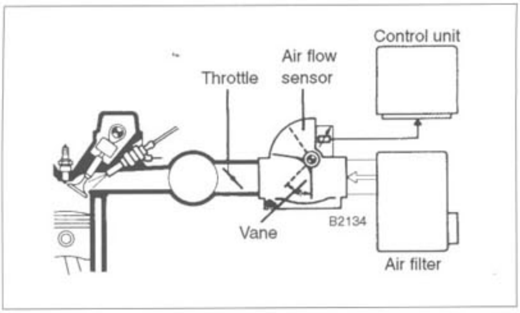


Fig. 3-10. Air flow sensor air vane/flap measures intake air; throttle controls intake air.

VAF Sensor Design and Operation

If you could remove the cover of the air flow sensor, you would see the air vane and the damper flap. See Fig. 3-11. The air vane is pushed by the incoming air. In the curved portion of the housing, and mounted on the same shaft as the air vane, the damper flap operates to dampen, or cushion the movement of the air vane by pressing against the air in the chamber. The damper reduces flutter caused by manifold pressure variations from the opening and closing of the intake valves.

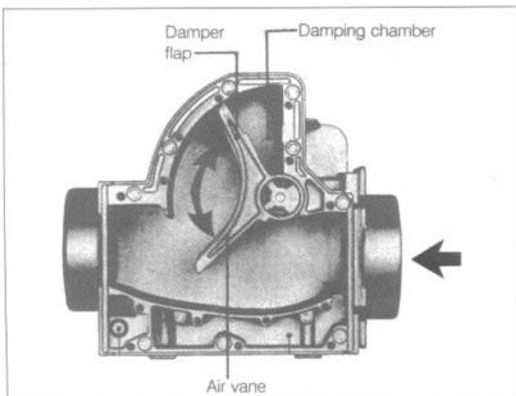


Fig. 3-11. Backfires and pulsations cancel out as opposite forces on the air vane.

During sudden throttle openings, the air vane assembly will rotate clockwise rapidly, but its final movement will be cushioned by the damper flap as it squeezes the air in the damping chamber.

The shape of the housing surface opposite the end of the air vane is calculated so the relation between the air passing through and the angle of the flap is logarithmic. That is, a doubling of the air vane angle indicates that air flow has increased 10 times. That means that the most sensitive measurements are at low air flows; at low speeds, measurements are more critical. Maximum air flow is 30 times the minimum.

A moving electrical contact called a wiper is mounted on the same shaft as the air vane. As the vane rotates, the wiper also rotates, crossing a series of resistors and conductor straps on a ceramic base, increasing resistance. See Fig. 3-12.

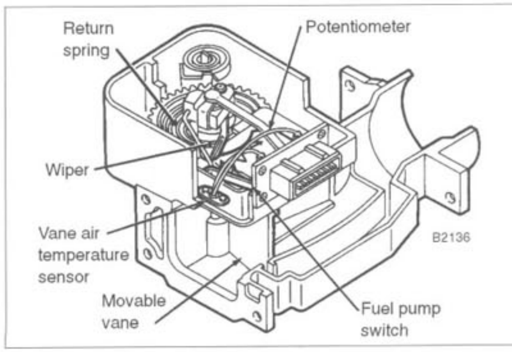


Fig. 3-12. VAF meter includes vane sensor and potentiometer, Vane Air Temperature (VAT) sensor, and fuel pump switch. Potentiometer wiper rotates on wiper track. Signal is based on VREF of 5 v. from control module.

Most VAF signals increase in voltage as vane opens. See Fig. 3-13. Exception: 1.8L voltage falls as vane opens. This is similar to early L-Jetronic AFS (Air Flow Sensor).

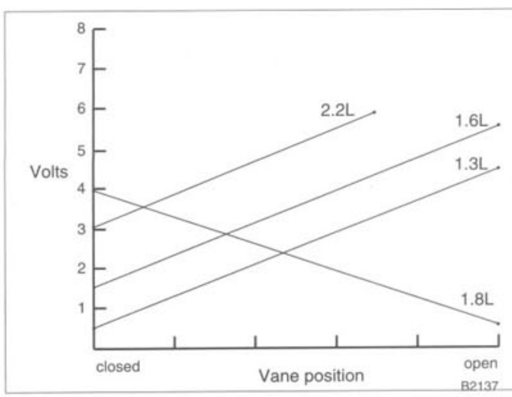


Fig. 3-13. VAF voltage changes as vane opens and closes.

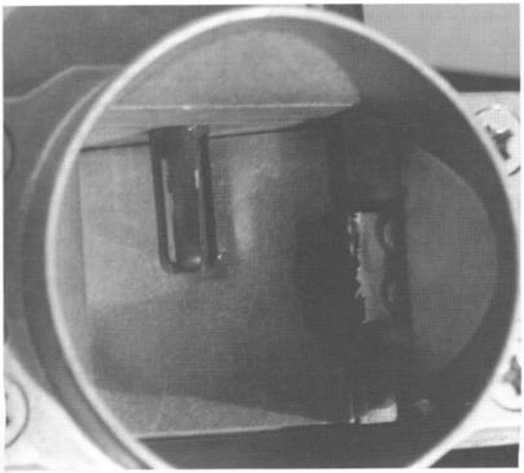


Fig. 3-14. Air Charge Temperature (ACT) sensor in VAF signals temperature of incoming air. Together with pressure signals from BP, these measurements can be combined in control module to calculate air mass.

The vane can be damaged by backfires. The best advice to help prevent this damage when starting the engine, is to keep your foot off the accelerator. Ford calls this "No-Touch Starting."

When you put all these signals together, VAF + ACT + BP, the control module can calculate a mass air flow number. But it takes more computing time—time that is valuable during changing conditions such as stomping on the accelerator. The computer: "Let's see, this much air flow volume, corrected for this much air temperature, corrected for this much barometric pressure—Oops, the measurements just changed; start over!"

MECS-I Vane Air Flow Sensor

MECS-I VAF sensors differ from previous Ford VAF in two ways:

- Non-turbo engines use a closed-vane switch to open the fuel pump relay power and stop the pump if the engine stops. During deceleration, a charged condenser supplies power momentarily to the relay to keep the pump running as the vane closes. Turbo engines signal the control module with ignition pulses as a sign the engine is running
- 2.2L Turbo engines use a full-open vane switch to signal the control module about excess engine speed and load. When the control module detects an unsafe combination of air flow, rpm, and boost, it sounds a warning chime for the driver. If excess conditions continue, the control module cuts back fuel injection

MECS-II Measuring-Core Volume Air Flow (MC-VAF) Sensor

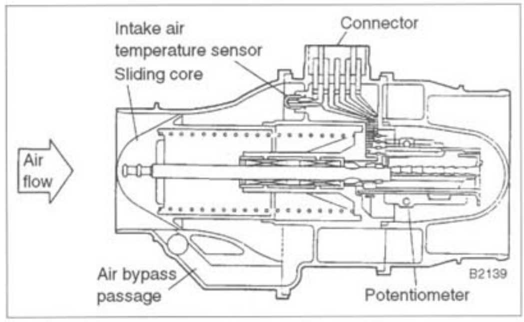


Fig. 3-15. Measuring-Core VAF (MC-VAF) measures air volume flowing through sensor. Used beginning 1993 Probe V-6.

The 1993 V-6 2.5L uses the Measuring-Core VAF (MC-VAF), also known as Sliding-Core AFS. The measuring-core sensor measures air volume by the movement of the sliding core under pressure from the intake air. You might say, MC-VAF substitutes the sliding core for the vane in the Volume Air Flow sensor. In the diagram, notice the bullet-shaped core piece. As the air enters, it pushes the core straight back, compressing the long spring. The core moves in a curved cone, curving out to increase its size. Just as in the vane meter, this increases sensitivity with a relatively large motion at lower speeds where the measurement is more critical, and relatively less motion at high speeds and greater air flow.

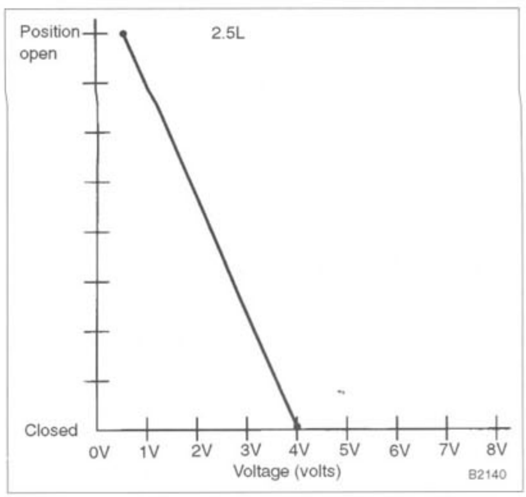


Fig. 3-16. Output curve shows that MC-VAF sensor signal is 4.0v. when closed, falling in straight line to 0.35v. when open.

In the rear of the sensor, motion is translated by a potentiometer into changing resistances. Beginning with a fixed reference voltage, (VREF), this sensor signals the computer with a voltage drop, increasing as the air volume increases.

The Intake Air Temperature (IAT) Sensor signals the computer, permitting calculations to convert air volume into air mass, as in VAF.

The MC-VAF is made largely of plastic, smaller and much lighter than the vane-type VAF sensor.

3.4 Summary—Engine Load

So you've seen three types of sensors used in 1988–93 EEC-IV and MECS Fords to measure engine load:

- Manifold Absolute Pressure (MAP) sensor—EEC-IV Fords only. Sensing MAP and rpm to then calculate air mass intake, corrected for temperature with ACT, corrected for pressure with BP
- Mass Air Flow (MAF) sensor—Both EEC-IV and MECS. Directly sensing the mass of intake air with MAF sensor. MECS MAF (2.0L 4EAT) uses different air mass measurement method
- Volume Air Flow (VAF) sensor—Sensing the volume of intake air with a moving vane or core, correcting it to air mass with input signals from ACT and BP. Early EEC-IV Fords use a Vane Air Flow sensor, with a moving vane. MECS Fords use a Vane Air Flow Sensor and a Measuring Core VAF, sensing volume with a moving core

4. Air Charge Temperature (ACT)

Temperature is an important factor in air density. As I discussed in Chapter 2, air density affects air-fuel ratios. The control module uses temperature signals, along with pressure signals, to help calculate air mass. The Air Charge Temperature (ACT) sensor signals the control module about the air temperature. The ACT is usually located in the intake manifold, but may also be in the air cleaner. See Fig. 4-1. MECS ACT is usually in the air flow sensor.

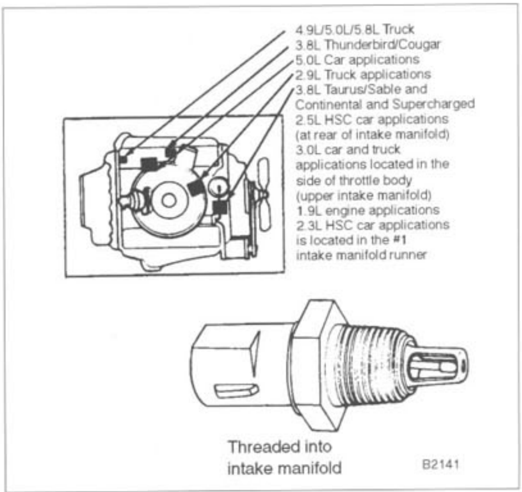


Fig. 4-1. Air Charge Temperature (ACT) sensor mounts in manifold or in air cleaner. It holds a thermistor, a solid-state thermal transistor.

The ACT is a thermistor, a thermal transistor. As a solid-state device, it has less resistance when warm than when cold. That is the opposite of most resistors that increase resistance when warmer, and so you may hear Bosch guys refer to the thermistor as "NTC" (Negative Temperature Coefficient). See Fig. 4-2.

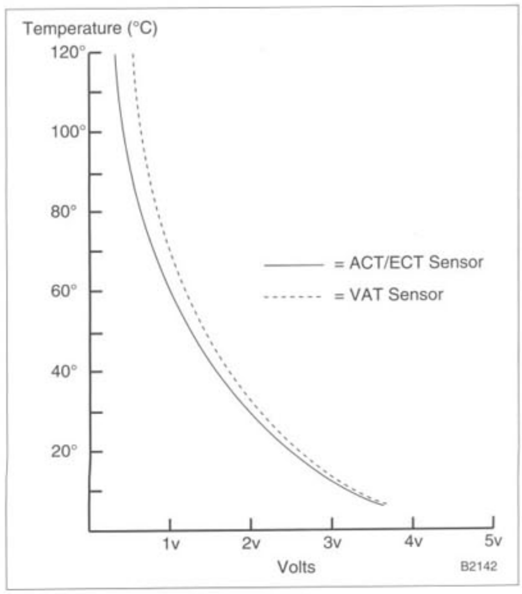


Fig. 4-2. As temperature increases, ACT thermistor resistance decreases. Based on VREF of 5v., at shop temperature, 20°C (70°F), resistance will measure about 37Kohms, which will give voltage readings of about 3v.

When I first looked at thermistor graphs like this, I said, "Wait a minute. is this Ohm's Law in reverse? When the thermistor is warm, resistance is less, and voltage is less. How can that be? I'd think, with less resistance, voltage should be more!" What they don't tell you, but I will, is that the thermistor circuit includes a fixed resistor in series. The voltage signal is the VREF minus the voltage drop across the resistor and the thermistor. The voltage drop is proportional to the resistance, so as the resistance changes, that changes the signal. See Fig. 4-3.

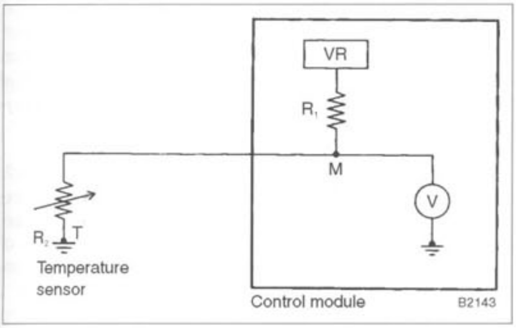


Fig. 4-3. Thermistor circuit includes a fixed resistor in series. The voltage signal is VREF minus the voltage drop across the resistor and the thermistor.

ACT Opens & Grounds

An open between thermistor and control module results in constant 5v. signal at control module.

A short-to-ground in the same circuit results in near-zero v. signal at control module.

Extra resistance in the circuit, such as corrosion at the connectors results in higher-then-normal voltage because the signal is based on voltage drop. Extra resistance could cause hard cold starts.

5. Engine Coolant Temperature (ECT)

Engine temperature is one of the most important modifiers to the calculations of engine speed and load. It affects air-fuel ratio, spark timing, idle rpm, and emission control. You'll find the Engine Coolant Temperature (ECT) sensor usually in the heater outlet fitting of the engine, as shown in Fig. 5-1.

The ECT is similar to the ACT, a thermistor in a housing, operating from Voltage Reference (VREF) of 5v.

ECT resistance decreases as it gets warmer so the voltage-drop signal decreases as it gets warmer. If you measure the resistance by measuring the voltage drop at shop temperature, say 20°C, a typical voltage reading would be 3 v., while at normal engine temperatures, say 90°C, it might be 0.6v. See the description of the Air Charge Temperature sensor for an explanation of what seems like Ohm's Law in reverse.

ECT Opens & Grounds

An open between thermistor and control module results in constant 5v. signal at control module.

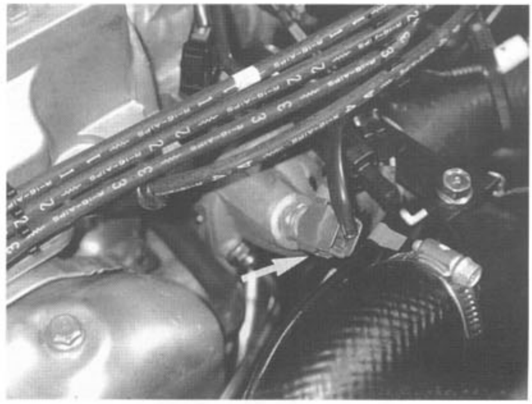


Fig. 5-1. Engine Coolant Temperature (ECT) sensor is located in coolant system in heater outlet fitting, near flywheel in 2.3L, and 3.8L Taurus/Sable and Continental; opposite flywheel in others.

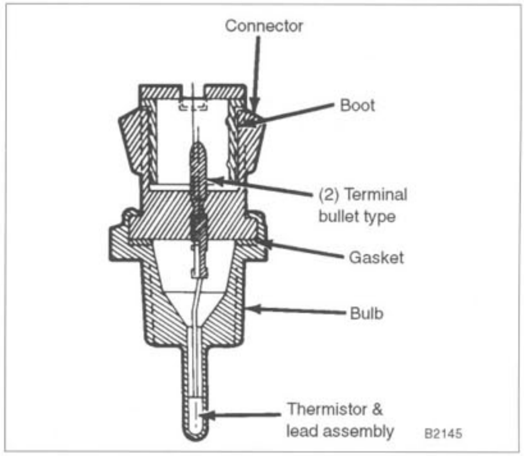


Fig. 5-2. ECT sensor is a thermistor in a housing, similar to ACT. ECT is important to air-fuel ratio, spark timing, idle rpm, emission control.

A short-to-ground in same circuit results in near-zero v. signal at control module.

Extra resistance in the circuit, such as corrosion at the connectors results in higher-then-normal voltage because the signal is based on voltage drop. Extra resistance could cause hard cold starts.Low coolant level causes a false rich signal, leading to a warm stumble.

Low coolant level causes a false rich signal, leading to a warm stumble.

6. Exhaust Gas Oxygen (EGO)— Oxygen Sensor

You'll remember from Chapter 2 the discussion of the ideal air-fuel ratio and its relation to emissions. The air-fuel ratio for best emission control is achieved by sensing the oxygen content of the exhaust gas. The oxygen sensor signal is monitored by the control module so it can adjust pulse time to maintain the ideal air-fuel ratio. The system operates closed-loop. The oxygen sensor affects emissions but has no effect on spark timing or idle-rpm control.

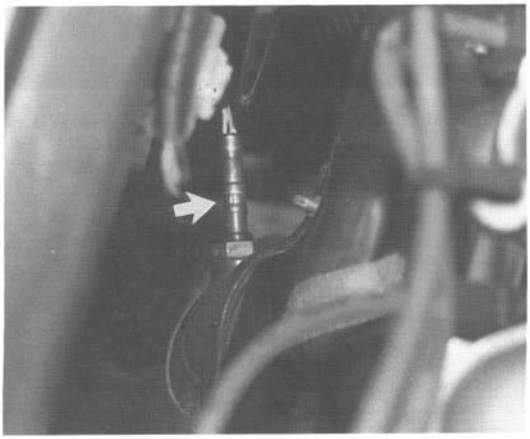


Fig. 6-1. Oxygen sensor generates its own voltage when air-fuel ratio is rich, but only when sensor is hot. Oxygen sensor threads into exhaust manifold where it samples oxygen content in hot exhaust gasses.

Oxygen Sensor Design

The oxygen sensor is something like a small battery. When it's hot, it generates a voltage signal based on the differential between the oxygen content of the exhaust gas, and the oxygen content of the ambient air.

A cutaway view of the oxygen sensor is shown in Fig. 6-2. On the right, the tip of the sensor that protrudes into the exhaust gas is hollow, so that the interior of the tip can be exposed to the ambient air, coming from outside. Both sides of the ceramic tip of the sensor are covered with metal conductive layers.

The ceramic sensor body is a solid electrolyte that generates a voltage only if the ambient air has a higher oxygen content than the exhaust. The ceramic material must be hotter than about 300°C (570°F). On a cold engine, it may take 90 to 120 seconds for an unheated oxygen sensor to get hot enough to start generating voltage.

In most 1988–93 EEC systems, and beginning with '93 MECS, you'll find electrically-heated oxygen sensors to improve emission control. During engine warm up, mixtures are rich because the system is operating open loop, not controlled closed-loop. The sooner the oxygen sensor becomes hot enough to send proper signals, the sooner the engine can operate closed loop for better control. A heated sensor may be

> Ford has been the only manufacturer to call the oxygen sensor "EGO". The Ford Heated Exhaust Gas Oxygen sensor was "HEGO". Bosch-speak is "Lambda" sensor, from the Greek letter L, the German "Luft", referring to the "air" in the exhaust. New term O_2S from the chemical symbol for oxygen, O_2. The Heated Oxygen Sensor is "HO_2S".

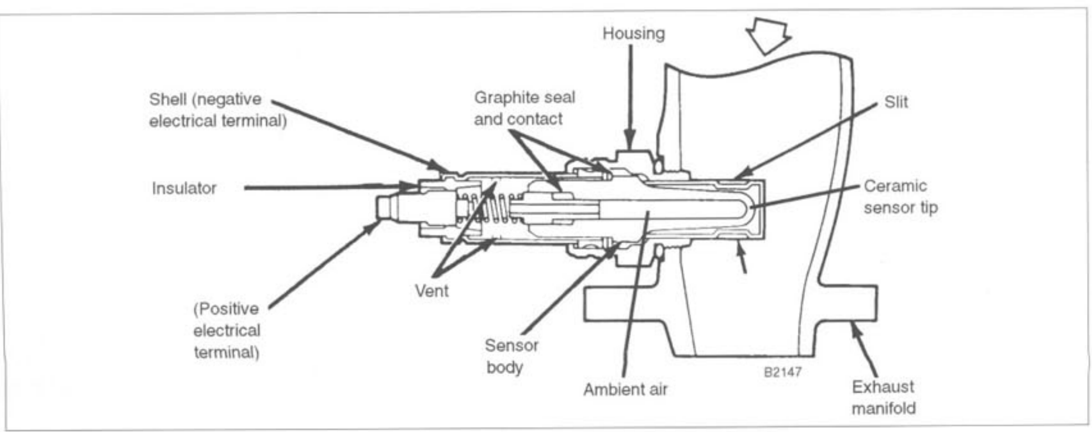


Fig. 6-2. Cutaway view of oxygen sensor. Oxygen sensor generates voltage when oxygen content of ambient air inside center tube is greater than oxygen content in exhaust gasses outside.

hot enough after 10 to 15 seconds. V-type engines usually have two oxygen sensors, one for each bank.

Oxygen Sensor Operation

- Oxygen in the exhaust is a sign of a lean mixture because the exhaust has excess air—air is left over after all the fuel is burned
- Lack of oxygen in the exhaust is a sign of a rich mixture because all the oxygen was burned with fuel—fuel is left over

When the air-fuel mixture is lean, the exhaust gas has oxygen, about the same amount of oxygen as in the ambient air, so the oxygen sensor will generate less than 400mv. Remember, lean = less voltage.

When the mixture is rich, there's less oxygen in the exhaust than in the ambient air so voltage is generated between the two sides of the tip. The voltage is greater than 600mv. Remember rich = more voltage.

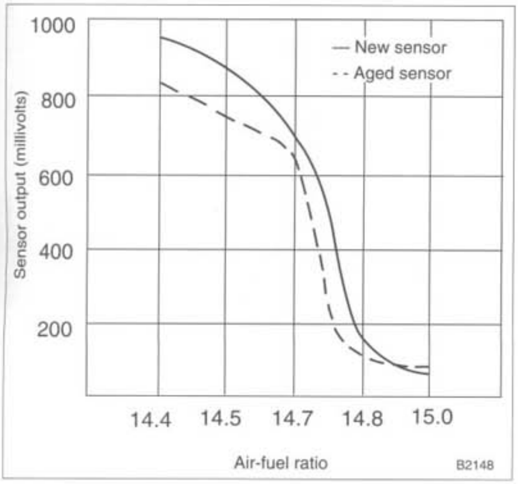


Fig. 6-3. Air-fuel ratio changes oxygen sensor voltage signal. Rich mixture and low content of oxygen in exhaust causes voltage output from oxygen sensor. Remember, rich = voltage. As oxygen sensor ages, its voltage changes are less.

Here's a tip: the newer the sensor, the more the voltage changes, swinging from as low as 0.1v. to as much as 0.9v. As an oxygen sensor ages, the voltage changes get smaller and slower—the voltage change lags behind the change in exhaust gas oxygen.

Because the oxygen sensor generates its own voltage, never apply voltage, and never measure resistance of the sensor circuit. To measure voltage signals, use an analog voltmeter with high input impedance, at least 10 Megohms. Remember, a digital voltmeter will average a changing voltage.

EGO Opens & Grounds

An open or a short-to-ground between the sensor and the control module results in a 0v. signal, similar to a lean mixture signal, so the engine runs rich.

A poor connection increases the resistance, dropping the voltage signal to the computer, with a similar lean signal, rich-running condition.

Failure of the oxygen sensor or its circuit is the leading cause of failure to pass emission tests.

6.1 Closed-Loop Control

In Chapter 2, I discussed open-loop/closed-loop systems. The oxygen sensor and the control module form the air-fuel ratio closed-loop system that continually adjusts the mixture by changing fuel-injector pulse time. In normal warm operation, the oxygen sensor generates a higher voltage because the mixture is rich, so the control module reduces pulse time to lean the mixture. Oxygen sensor voltage falls, so the control module increases pulse time to enrich the mixture. Sensor voltage increases, and so on....

The oxygen sensor voltage is always fluctuating as shown in Fig. 6-4, so it is hard to maintain the exact point at which the air-fuel ratio is ideal. Instead, the ratio tends to oscillate to either side of the ideal ratio. The oscillation is so fine—about 0.1 total oscillation around 14.72, that is 14.67 to 14.77—that it is not noticeable in engine performance.

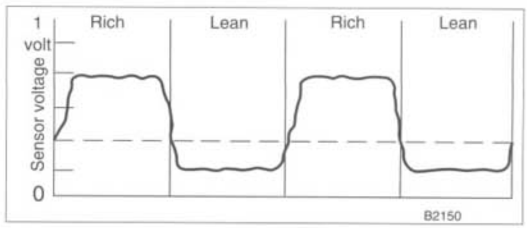


Fig. 6-4. Closed-loop oxygen sensor voltage cycles back and forth from slightly rich to slightly lean. Cycling increases with engine rpm and sensor temperature.

The rate of the air-fuel ratio oscillation, from lean to rich and back (sometimes referred to as "cross-counts") is related to how much exhaust passes a sensor. At idle, the cycle may take about 1 second. At cruising speed, the cycle may happen several times a second. Cycling is fastest when an oxygen sensor is hot, and new; cycling slows down as a sensor ages from mileage and/or time, or by coatings deposited by fuel.

Closed-loop air-fuel ratio control operation is known as "short-term" trim. It must operate quickly and continuously to maintain air-fuel ratios as close as possible to the stoichiometric. Later, I'll discuss "long-term" air-fuel ratio control, known

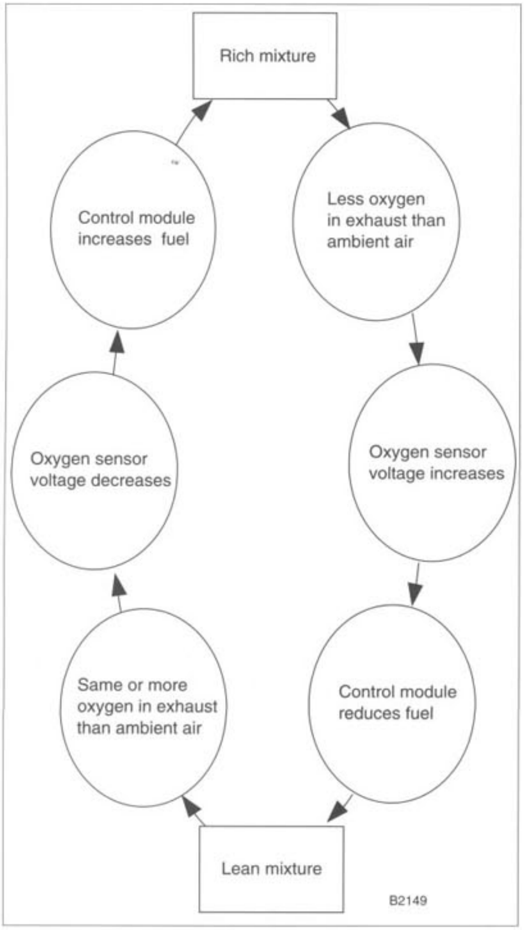


Fig. 6-5. Ford engine controls operate closed-loop most of the time.

as adaptive strategy. Ford uses Adaptive strategy in all vehicles since 1986.

This closed-loop system can adapt to compensate to some degree for changes in the engine over time. For example, if a valve is leaking slightly, or if there is an intake air leak, the oxygen sensor senses the change in combustion and brings the system back within its design limits. Changes beyond the system's range, though, can still lead to driveability problems.

Before the oxygen sensor is heated enough to generate a proper voltage signal, the control module is programmed to operate open-loop at programmed injection rates. While it's cool, even while the engine is warm, the oxygen sensor voltage signals are meaningless and the control module is programmed to ignore them, operating the system open loop. The same thing happens if you disconnect or cut the oxygen sensor wire, or if the sensor is fouled by leaded gasoline. This becomes important when you are trying to make closed-loop adjustments at idle, and the unheated sensor cools off because not enough exhaust is passing it. Many service procedures depend on closed-loop operation, so remember that the oxygen sensor has to be warm enough.

7. Throttle Position (TP) Sensor

The Throttle Position (TP) sensor signals the control module about intentions of the driver (or throttle actions as actuated by the Cruise Control). The TP sensor mounts directly on the throttle body, and rotates with throttle shaft to signal the position of the throttle plate.

Fig. 7-1. Throttle Position (TP) sensor (arrow) sends a feed-forward signal to control module of just what you would expect—throttle position. Movement signals what driver expects engine to do.

Movement causes feed-forward signals. For example, when you step on the accelerator, the TP signal increases before the manifold air pressure or the air flow increases. In a way, it contributes to the calculations about load, signalled by other sensors I've described earlier, the MAP for Speed Density, the MAF for Mass Air Flow, and the VAF for Volume Air Flow. The TP signal can cause enriched mixture as the throttle opens, something like the accelerator pump of a carburetor. The control module interprets signals from the TP in six ways:

1. Amount of throttle opening—how far is accelerator depressed? Amount is important to Cruise Strategy.
2. Rate of throttle opening—how fast is the accelerator being depressed? Rate is important to Acceleration Strategy.
3. Closed-throttle position—idle or deceleration.
4. Wide-Open Throttle position—acceleration enrichment, A/C cutout, de-choke on crank.

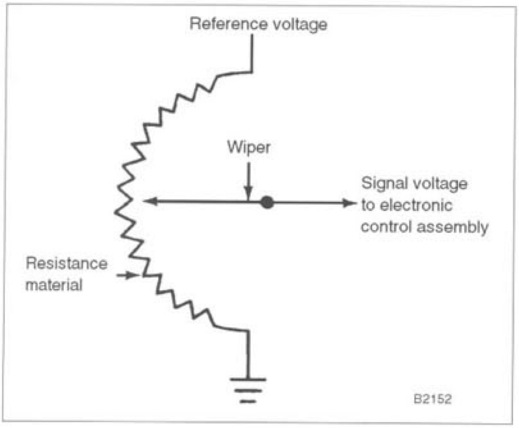


Fig. 7-2. TP operation: VREF is supplied to grounded resistor. As wiper turns on its shaft, a variable voltage signals control module about shaft position.

5. Failure of MAF signal—TP helps control module to calculate air intake based on throttle opening and rpm.
6. Transmission-shift signals for electronic automatic transmissions (transaxles).

The TP potentiometer operates from VREF of 5v. The TP signals affect injected fuel, spark timing, idle rpm, and emissions. The TP sensor is an important sensor.

Recent Ford systems, all EEC since 1988, use a Rotary TP. The potentiometer increases resistance as the throttle shaft rotates. It is not adjustable, but the control-module programming compensates for any differences in sensors, readjusting to a base voltage when the throttle is closed.

The TP sensor signal voltage increases directly with rotation of the throttle shaft. Actual values vary with engine application and are given in specs. Fig. 7-3 is a typical signal curve.

TP Opens & Grounds

An open results in a 0v. signal if there is a fault in one of the following: a) VREF; b) signal return; c) sensor itself; d) VREF side of wiper

An open results in a 5v. signal if the open is in the ground line, or on the ground side of the wiper.

A short-to-ground in either VREF or signal return results in 0v. signal.

Higher than normal resistance in VREF results in lower voltage input, tending to cause lean mixtures and misfire.

Higher than normal resistance in the ground results in higher voltage input, tending to cause rich mixtures.

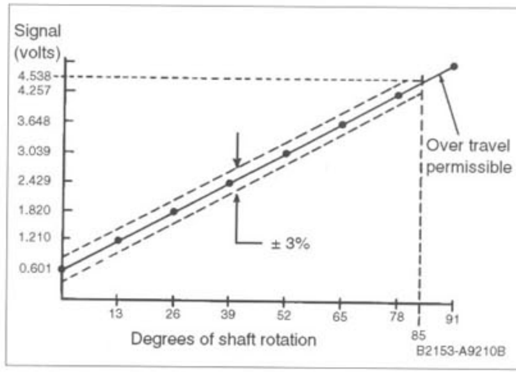


Fig. 7-3. As throttle shaft rotates, signal voltage increases in straight line. Values vary according to application so do not apply these numbers to a specific engine.

MECS Throttle Sensors and Switches (TP)

Some MECS Throttle Position sensors are quite similar to the EEC TP sensor. The potentiometers signal the full range of throttle plate movement. In addition, the control module in most MECS systems depends on a separate signal that the throttle is closed. Although referred to as Idle, the closed-throttle signal is also important to deceleration, when the engine is far from idle. I find it less confusing to refer to it as a closed-throttle switch. In this book, I'll say CTS (idle).

In the 1.8L Automatic Transaxle (ATX) and 1.3L, the CTS (idle) switch is integrated with the potentiometer in the TP sensor. See Fig. 7-4. In the 2.2L engines, the CTS (idle) switch is separate. See Fig. 7-5. The switch is closed when the throttle

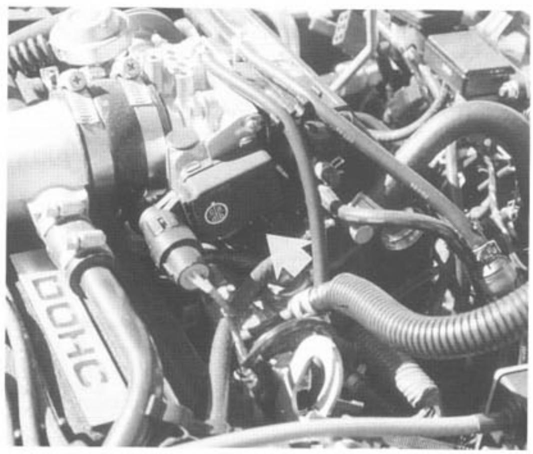


Fig. 7-4. MECS 1.8L and 1.3L style TP.

4

plates are closed. For good engine control, it is important that the switch open as soon as the primary throttle plates open.

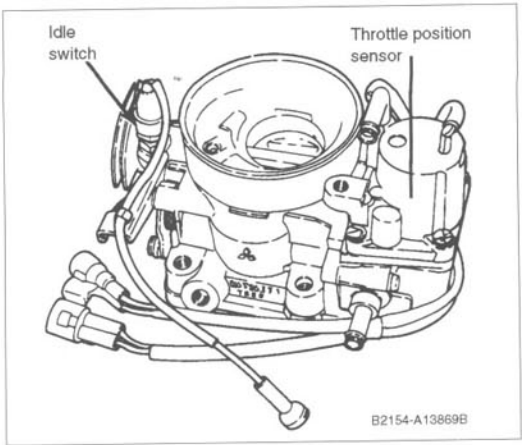


Fig. 7-5. Some MECS Throttle Position (TP) sensors have so-called Idle Switch. "Idle" Switch is separate from the TP sensor in 2.2L engines.

In the '93 and later 2.5L V-6, the throttle body carries the TP sensor on the main shaft. The TP sensor includes a potentiometer and an integral CTS (idle) switch. See Fig. 7-6.

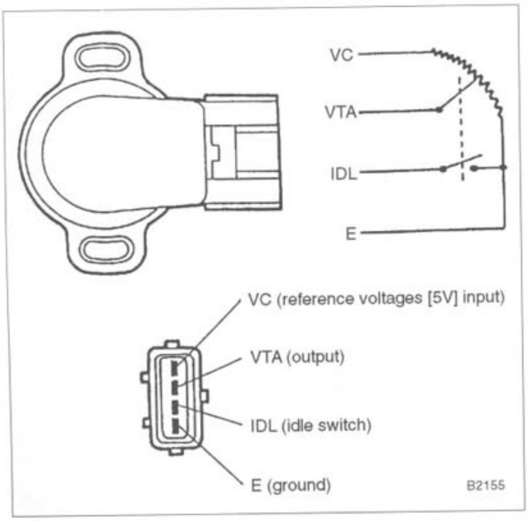


Fig. 7-6. In 1993 and later 2.5L V-6, TP sensor mounts directly on throttle shaft, with no dashpot.

In the '93 2.0L system, the TP sensor signals potentiometer voltage drop as throttle is opened. This TP sensor lacks an CTS (idle) switch, differing from the '93 2.5L V-6. The TP sensor helps the control module calculate intake air if the MAF sensor fails.

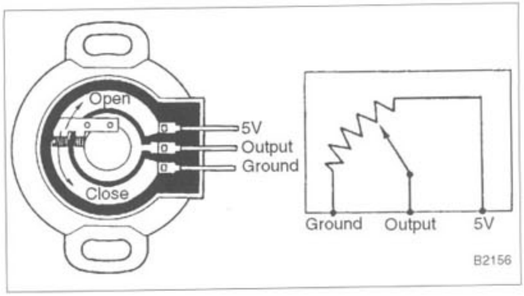


Fig. 7-7. TP sensor of '93 2.0L includes potentiometer but no CTS (idle) switch. TP sensor is not adjustable.

In the other MECS systems, the 1.8L Manual Transaxle (MTX), the 1.6L and 1.3L engines, two switches signal closed (idle) and Wide Open Throttle (WOT). This is described as integrated with the TP sensor. However, with no potentiometer, the idea of "integrated" stretches the definition of a Throttle Position Switch. In signalling only closed and WOT, the two-position switch is similar to early Bosch fuel-injection control.

8. KNOCK SENSOR (KS)

The Knock Sensor (KS) is a feedback signal used for control of spark timing and wastegate, not for fuel injection, idle rpm, or emission control. You might think of the KS as an insurance policy, allowing the spark timing to be more advanced with less concern that harmful knocking will destroy the engine. In other words, the engine designer is reasonably sure he can protect against engine destruction from knocking. As a result, he can program more timing advance than if he had to provide a cushion against the possibility of uncontrolled destructive knocking. Some V-type engines use a separate knock sensor on each bank. Check the wiring schematics in Chapter 12.

KS Design and Operation

The KS is a tuned vibration sensor accelerometer mounted on the engine block. The KS is something like a tuning fork that vibrates most at a certain narrow band of frequencies. When the KS vibrates, its crystal generates a small voltage (about 1v.) that changes with the frequency of the engine vibrations.

Depending on the engine, knock may be signalled at frequencies of about 6 Khz—5450, 5700, 6000, 6150, and 6400

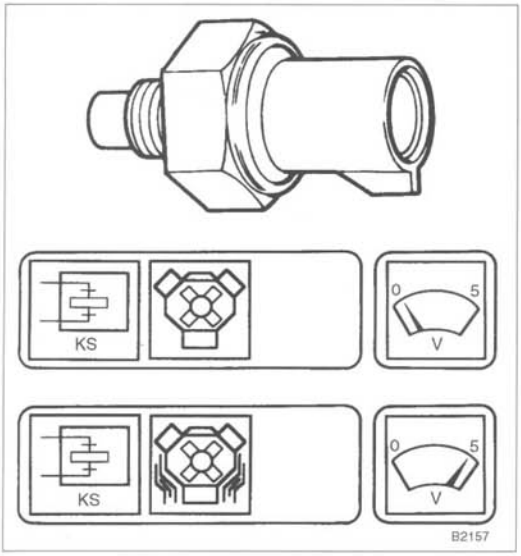


Fig. 8-1. Knock Sensor (KS) converts engine vibrations directly into a signal for control module to control spark timing.

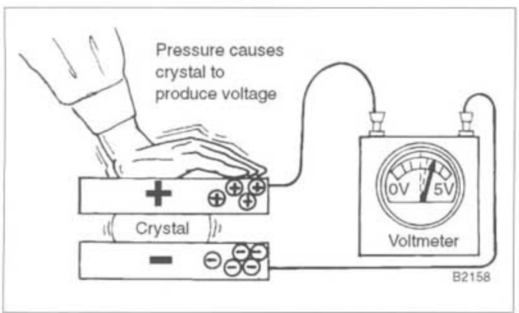


Fig. 8-2. Engine-knock vibrations force KS crystal to vibrate, generating voltage signals.

Hz (cycles per second). Some engines require a different knock sensor because they have a different resonant frequency—9,500 Hz for some 4.9L, 5.0L, 5.0L Econoline/Broncos. Those would be pretty high musical notes. Based on engine dynamometer tests, those specific vibrations are chosen because they are known to indicate engine knocking. The control module can be programmed to ignore other vibrations.

When knocking occurs, the KS signals in the design frequency range cause the control module to retard the timing. If that reduces or eliminates the knock, then after a few seconds the control module again advances timing. If knocking continues, the control module opens the wastegate to reduce boost.

You can see that the KS supplies a feedback signal for timing, similar to the EGO feedback signal for fuel injection. That means the KS operates closed-loop. With input signals from cylinder-identification sensors, the control module can identify the individual cylinder that is knocking (one cylinder usually starts knocking before the others). EEC-IV has the computing power for individual-cylinder knock control, retarding the spark only for the knocking cylinder(s).

In some engines, the KS acts as a limited-range automatic octane selector, advancing timing for increased power when the engine is burning fuels with higher anti-knock index. With lower octane fuel, timing is automatically retarded, with corresponding lower power outputs.

For years, drivers have known that using higher-octane fuel did not add to engine power unless spark timing was adjusted at the distributor to take advantage of the improved anti-knock index. Now, with knock sensors and closed-loop spark-advance control, power output can depend on the anti-knock index of the fuel being burned. I have even seen engine-power specifications include the anti-knock index of the fuel to be used.

It may even be less than desirable to use fuel with a higher octane rating than called for in the owner's manual. Recent advancements in emission control may depend on so-called "fast-burn" to reduce emissions. If you burn 92 RON when the engine is designed for 87 RON, the higher octane fuel burns slower, and may add deposits to the combustion chamber.

With precise control of spark timing and turbo boost, engines can be designed with higher compression ratios for greater power output. On all engines, the knocking limits depend on many factors:

- Intake air temperature
- Engine temperature
- Engine deposits
- Combustion chamber form
- Mixture composition—air-fuel ratio, and stratification
- Fuel quality
- Air density, altitude and weather

MECS Knock Sensor (KS) and Knock Control Unit (KCU)

The MECS-I Knock Sensor (KS) is similar to that of the EEC systems. The principle difference is the Knock Control Unit (KCU). Where the EEC control module receives and calculates knock signals directly, the MECS-I KCU filters the vibrations and signals the control module only when the vibrations indicate engine knocking and not just engine vibrations.

In 1993 2.5L V-6, the knock sensor sends vibration signals directly to the engine computer, eliminating the Knock Control Unit. The 2.5L engine computer determines if the vibrations are knocking signals. The engine computer can retard timing up to 6 degrees, depending on the severity of the knock. This

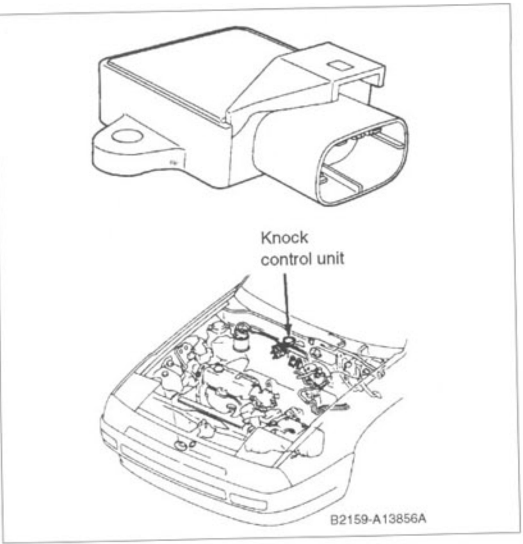


Fig. 8-3. MECS-I KCU (Knock Control Unit) filters engine vibrations and signals control module when vibrations indicate engine knocking. 2.2L turbo shown, 1.6L turbo similar.

KS operates between 750 and 5500 rpm, but its torque improvement is greatest below 3000.

KS Opens & Grounds

An open or short-to-ground results in a 0v. signal to the control module.

Poor connection between sensor and control module may drop the signal voltage to hide the knock.

9. OTHER SENSORS

9.1 Octane Switch

The Octane Switch in some engines adds a feed-forward signal for spark timing and turbo boost. When the Octane Switch is in place in the underhood socket, it shorts the contacts in a circuit to the control module for normal spark timing. If the engine is knocking with the fuel being used, you can change to a higher octane fuel, or you can remove the switch from the socket to retard the timing by about 3 degrees, and reduce the maximum boost.

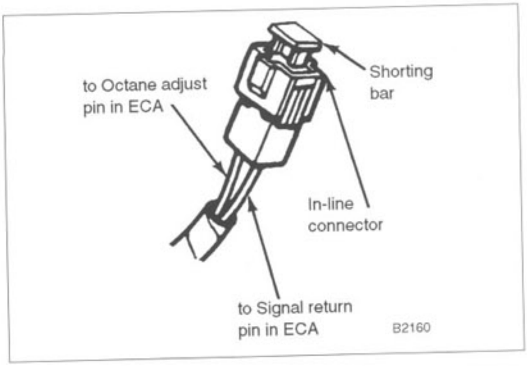


Fig. 9-1. Octane Switch shorting bar closes a circuit to control module providing normal spark advance for fuels of recommended octane. Removing shorting bar signals control module to retard spark about 3 degrees to handle fuels of lower octane.

Bob Stelmaszczak of Ford SVO (Special Vehicle Operations) told me of the beginnings of the Octane Switch. In qualifying the Ford original 2.3L turbo to California regulations, he ran up against a requirement that the engine control provide for operation on regular fuel. The turbo engine was set up for premium, and it was pretty late to change the engine control. Simple solution: The Octane Switch, which continues in current applications.

9.2 Barometric Pressure (BP)

The Barometric Pressure (BP) sensor generates a frequency signal that changes with pressure. It looks and operates like the MAP. The only difference is that the MAP is connected to the manifold, while the BP is vented directly to the atmosphere, or barometric pressure. See earlier Fig. 3-2.

The BP is used by the control module as part of control of fuel injection, spark timing and emission control. The BP is most important when the vehicle is driven at altitudes significantly above sea level.

- In some engines, BP (Barometric Pressure) is measured by the MAP sensor, switched over during conditions of engine-off and Wide Open Throttle
- In other engines, BP is measured by a separate similar sensor open to the atmosphere. It may be called BAP or BARO. Look for a separate BP on MAF engines

MECS Barometric Pressure (BP)

Most MECS employ Barometric Pressure (BP) sensors to help in controlling air/fuel ratio and idle speed. In most systems, the BP sensor is integrated into the ECA. The exception is the 1.6L engine with its separate BP sensor. Late model MECS do not use BP sensors.

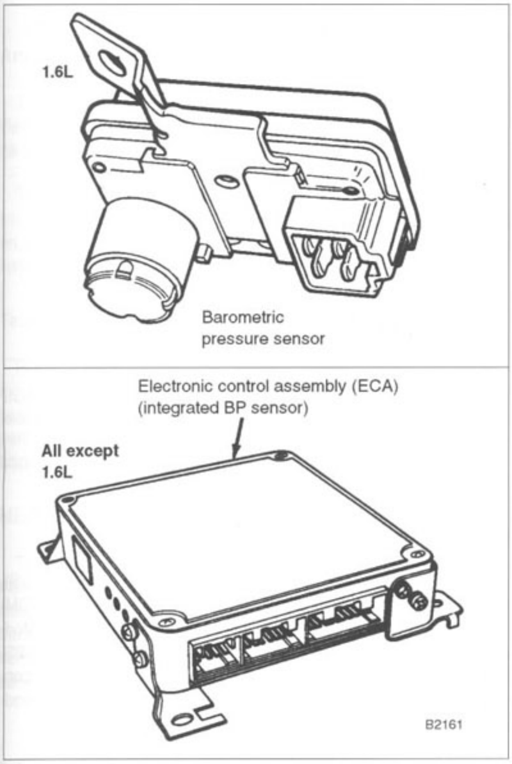


Fig. 9-2. Most MECS mount BP in control module for direct input. 1.6L systems mount a separate BP sensor on cowl.

9.3 EGR Feedback

The EEC system receives feedback signals about the exhaust gasses that are diluting the air-fuel mixture flowing into the combustion chambers. EGR feedback changes the air-fuel mixture calculations and the resulting injection pulse times. Ford has used several different types of monitors, but in the latest vehicles, you'll want to know about these three.

Pressure Feedback EGR (PFE)

Pressure Feedback EGR (PFE) is a closed-loop EGR system that senses the pressure drop across an orifice or opening in the EGR passage to determine EGR flow. See Fig. 9-3. The PFE transducer senses a controlled pressure input and signals the EEC module. The module sends a duty-cycle signal to the EGR Vacuum regulator(EVR), controlling the intake vacuum that operates the EGR valve. By regulating the pressures that control the EGR valve, PFE balances the changing pressures in the intake manifold and the exhaust manifold so the EEC module can compute the proper EGR flow rate.

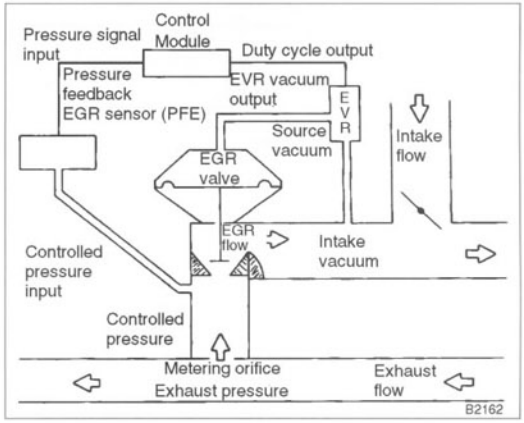


Fig. 9-3. Pressure Feedback EGR (PFE) system controls EGR flow rate by monitoring pressure drop across metering orifice.

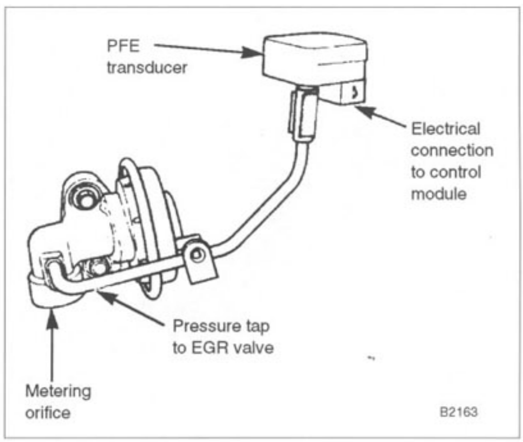


Fig. 9-4. PFE transducer senses exhaust pressure, converts that to an analog voltage signal to EEC module.

Delta Pressure Feedback EGR (DPFE) sensor

Delta is the engineering term for "difference", from the Greek letter "delta". DPFE is similar to PFE except that it measures the difference between the exhaust pressure in the exhaust system and the pressure at the EGR metering orifice. DPFE is applied to the newer engines beginning in 1991.

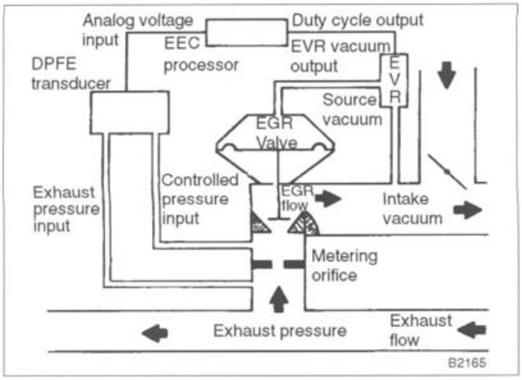


Fig. 9-5. Delta Pressure Feedback Electronic (DPFE) EGR system controls EGR flow rate by monitoring difference between exhaust pressure and pressure drop across metering orifice.

EGR Valve Position (EVP) sensor for Electronic EGR (EEGR)

The EGR Valve Position (EVP) sensor signals the position of the EGR pintle valve. See Fig. 9-6. The Electronic EGR (EEGR) system operates the EGR valve by a duty-cycle output to the EGR valve-regulator solenoid (EVR).

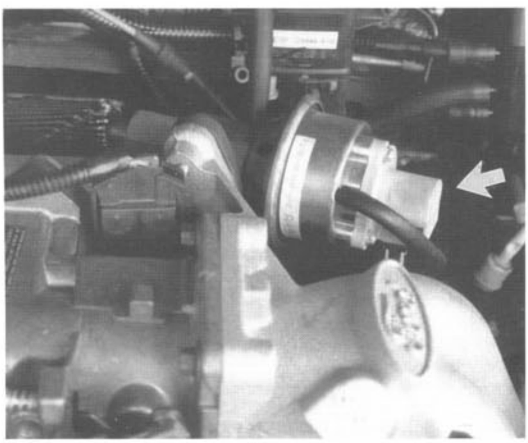


Fig. 9-6. EGR Valve Position (EVP) sensor on EGR valve signals EGR valve movement to EEC module.

9.4 Vehicle Speed Sensor (VSS)

The Vehicle Speed Sensor (VSS) uses a magnetic pickup, usually mounted on the transaxle, to signal the control module about the vehicle speed. The VSS is important for control of speed (Cruise) control, idle-air bypass, transmission torque-converter lock-up, and engine cooling fan (Ford cars cut off the electric fan at about 45 mph).

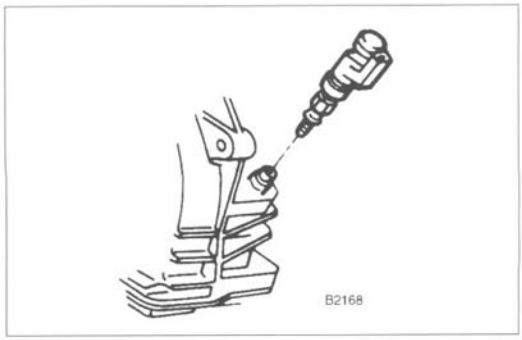


Fig. 9-7. The VSS (Vehicle Speed Sensor) is driven from the transmission to signal the control module about vehicle speed.

Programmable Speedometer/Odometer Module (PSOM)

On EEC-IV vehicles with Anti-Lock Brake Systems (ABS), the Programmable Speedometer/Odometer Module (PSOM) delivers vehicle speed signals to the Powertrain Control Module. PSOM uses the same toothed-wheel sensor as the ABS. In addition to providing vehicle speed data for powertrain control, PSOM also sends vehicle speed signals to the speed-speed control (Cruise Control).

MECS vehicle speed is signalled by a sensor (VSS) located in the speedometer of the instrument panel.

9.5 Feed-forward Switches

Feed-forward switches signal the control module to anticipate that a load will be added to the engine. Feed-forward switches are the opposite of feedback sensors, which signal the control module what has happened. Generally, feed-forward switches are important to control of idle rpm. You'll remember from Chapter 2 that idling at the lowest rpm is important for fuel economy and emissions, so feed-forward switches prevent stalling when load is added.

Following are examples of feed-forward switches, most of them designed to prevent engine stall at idle, not all found on all cars.

Control of idle-air bypass for control of idle rpm depends on the loads carried by the idling engine. I divide those into three categories:

- Drive loads, such as A/T in a drive gear, or M/T applying power
- Continuing accessory loads such as air conditioning
- Other temporary loads, such as power steering during parking

Accessory Loads

The Air Conditioner Clutch (ACC) feed-forward signal advises the control module when the AC clutch is about to be engaged, anticipating adding load to the engine.

The Heated Rear Window switches and Heated Windshield switches are feed-forward signals to the control module, when on, to anticipate idle-rpm drop from the extra load on the alternator.

Temporary Loads

Power Steering Pressure Switch (PSPS) signals the control module when the power steering system is operating at high-pressure—above 400–600 psi such as during a sharp turn in parking, usually with engine idling. When PSPS closes, it anticipates the PS load and calls for idle rpm increase.

MECS Electrical Load Unit (ELU)

The Electrical Load Unit (ELU) collects signals of the electrical load to assist in control of Idle RPM. When any of these loads is added to the electrical system, the additional drag of the alternator could drop idle rpm to unstable or rough conditions. To prevent this, the ELU signals the ECA to call for additional bypass air to maintain the target idle rpm.

- Rear defroster
- Engine Cooling Fan
- Heater/Air Conditioner Blower
- HeadlampsYou can appreciate that the smaller *MECS engines would be more affected by these* electrical loads than, say a 5.0L engine.

See **Table c** at the beginning of this chapter for additional switch types and systems.

Brake On/Off Switch

The Brake On/Off (BOO) signal comes from the stoplamp switch. When the brakes are applied, the BOO signal to the control module can cause:

- Short-time brake application—3 to 5 seconds cut off of AC compressor circuit and engine cooling fan
- Longtime brake application—idle cut-off of AC compressor circuit; also increased idle rpm

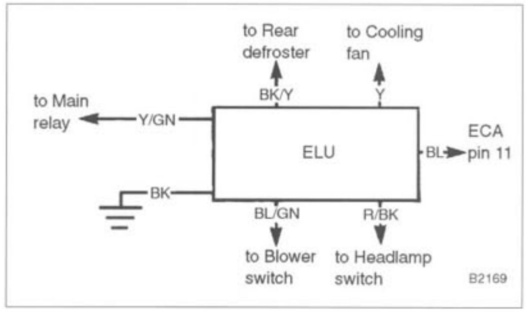


Fig. 9-8. Electrical Load Unit (ELU) collects signals relating to electrical load for input to the ECA.

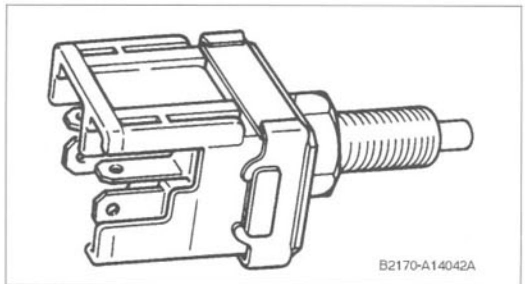


Fig. 9-9. Brake On/Off (BOO) switch signal to control module can affect air conditioning and engine cooling fan.

This is one of those "gotchas" because a burned out stoplamp bulb, or open circuit can cause engine control problems. And you would never think to check that circuit, would you? When they called this the BOO switch, someone at Ford had a sense of humor.

Drive Loads

The Automatic/Transaxle Neutral Drive Switch (NDS) signals when the transaxle is in Neutral or Park, a no-load condition. A shift out of P or N sends feed-forward signals to the control module to anticipate a drive load on the idling engine.

In manual transmissions (M/T), the Clutch Engaged Switch (CES) and the Neutral Gear Switch (NGS) work together to sense load on the engine. If transaxle is in any drive gear (other than N), and if clutch is engaged, that feed-forward signal anticipates that the engine is being loaded.

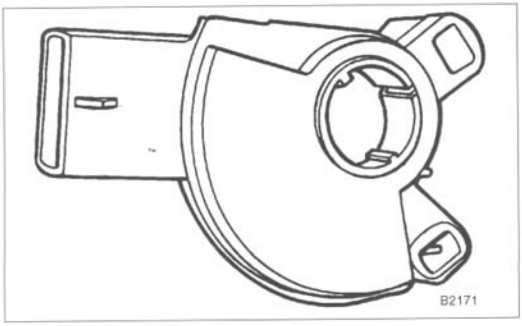


Fig. 9-10. Neutral-Drive Switch sends feed-forward signals to control module, anticipating when automatic transmission will load the engine. This prevents a drop in idle rpm which could stall engine.

10. POWERTRAIN

10.1 Automatic Transmission/Engine Control

I want to mention the interactions between electronic engine control and the electronic control of automatic transaxle and transmissions. I will not cover the control of the transaxle, but rather show how much engine and transaxle depend on each other. Look for increasing use of what Ford calls AXODE (Electronically Controlled Automatic Overdrive Transaxle) in Ford-engine cars, and EAT (Electronic Automatic Transaxle) in Mazda-engine cars. In some vehicles, electronic control of both engine and transaxle is in the same computer whose name is now Powertrain Control Module (PCM). In others, control is in two computers that communicate with each other.

The following transaxle signals are important to engine control:

- Manual Lever Position Switch (MLPS)—engine can crank only if in Neutral or Park
  - increased throttle-air bypass to increase idle rpm for engine load if in Neutral or Park
  - in most vehicles, a variable-resistance rotary-switch, mounted on the shift linkage, indicates shift lever position to the ECA
  - in Escort/Tracer EAT, the shift lever positions OD, D, L, R, N or P are signaled to the EEC-IV computer by a series of switches. Similar for MEC cars with EAT
  - several vehicles have electronic control of shifting: rear-drive Crown Vic/Grand Marquis/Town Car (AOD-E); front-drive Taurus/Sable/Continental (AXOD-E); E/F Series/Bronco (E4OD). These signal position through a single lead, MLP.
- Vehicle Speed Sensor (VSS)
- Transmission Speed Sensor (TSS)
- Transaxle Oil Temperature (TOT)
- Forcing downshift or unlocking Torque Converter Clutch if transaxle is overheating

The following engine signals are important to transaxle control:

- Throttle Position (TP)—Downshift when driver wants more power
- Engine Coolant Temperature (ECT)—Restrict Torque Converter Lockup until engine is warm

In addition, a Powertrain Control Module (in distinction from Engine Control) signals the automatic transaxle (ATX) to upshift according to several factors including engine temperature, throttle position, and vehicle speed.

In advanced powertrain controls, the electronic engine control (EEC) operates with the ATX control to reduce the load during shift. Whether the operation is one computer or two linked computers, it works like this:

1. ATX computer determines proper time to shift, advises EEC that transaxle is about to shift.
2. EEC retards spark for about 20 milliseconds, just enough to reduce power briefly. EEC advises ATX computer that it has retarded spark. NOTE, if engine is cold, EEC will not retard and will not signal ATX.
3. ATX shifts during power reduction.
4. EEC advances spark timing to normal. Driver experiences a smooth shift. ATX experiences less load on clutches, extending transaxle life.

11. CONCLUSION

You've seen six types of sensors that monitor conditions and send input signals to the control module. Many of these are returned as signals referenced to VREF = 5v. You've seen typical switches, many of them feed-forward switches that signal the control module to anticipate engine loads that would cause the idling engine to stall.

When you look at the electrical schematic in Fig. 11-1, or at the large number of pins in the connector to the control module, you begin to appreciate the large number of sensor signals going to the computer. In the next chapter, I'll discuss what happens to those signals in the control module.

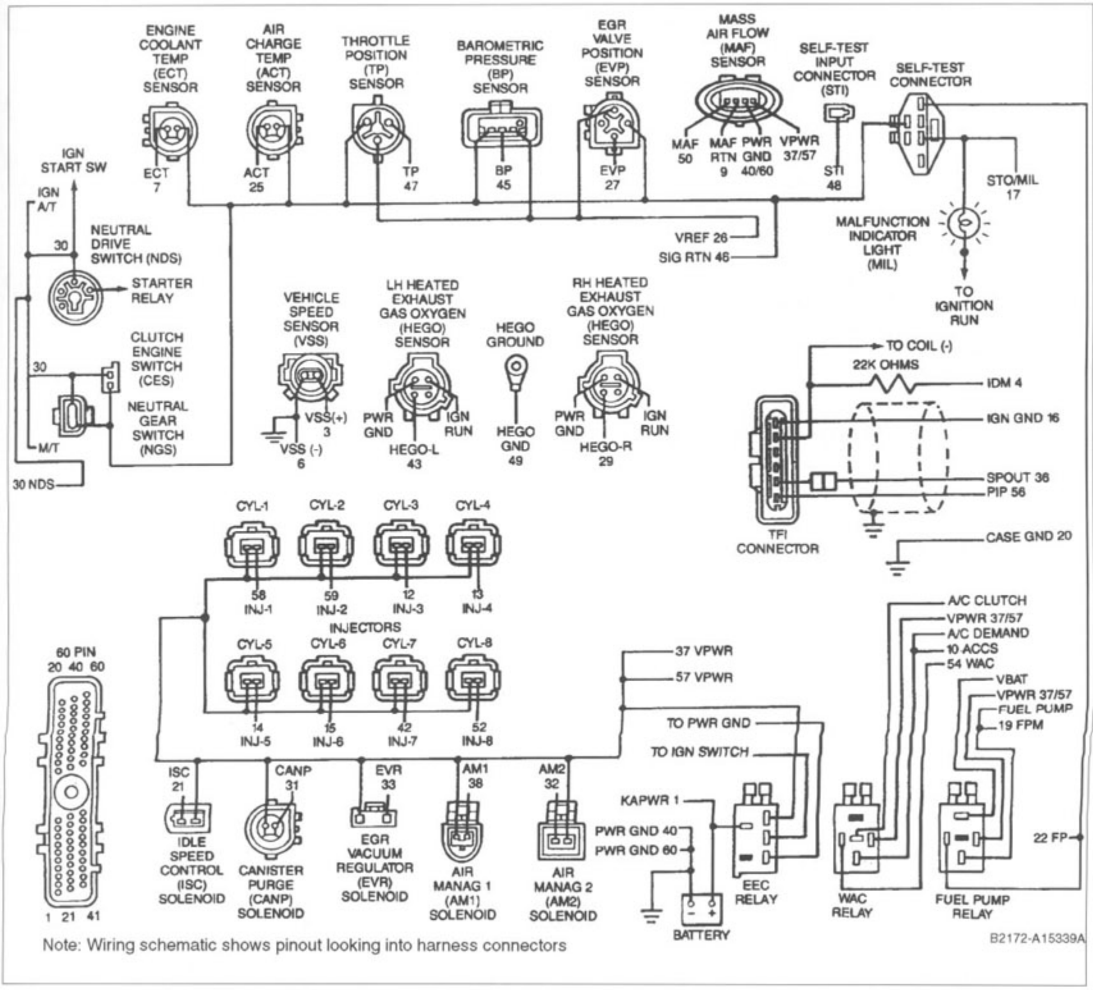


Fig. 11-1. Typical wiring diagram shows number of sensors with input signals to control module. (Outputs shown at lower left.)

4

12. Nissan Electronic Concentrated Engine Control System (NECCS) ('93 Mercury Villager)

The sensors of this 3.0L Nissan engine in the Mercury Villager are quite similar to those in Ford EEC systems. The major exception is the Crankshaft Position sensor (CKP).

The Crankshaft Position (CKP) sensor uses light pulses passing through slits in a rotor plate in the distributor. With one set of 360 slits in the outside of the plate, engine speed is measured once for each degree of distributor rotation—2 degrees of crankshaft rotation. This signals the control module with great frequency, ensuring rapid response to acceleration—changes in engine speed.

A second set of six slits signals once for each cylinder to assist in timing of spark and sequential injection. One of these slits is oversize, signalling the timing of cylinder #1.

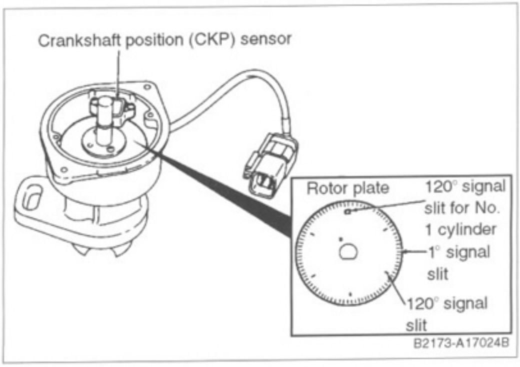


Fig. 12-1. NECCS Crankshaft Position (CKP) sensor in distributor housing uses Light Emitting Diodes (LED) and photo diode to count slits in rotor plate.

Chapter 5

Control Module—Computing Engine Operation

Contents

TABLES

5

1. INTRODUCTION

In Chapter 4, you've seen the sensors that provide the input of information, monitoring conditions in the engine. In this chapter you'll see how the engine control module does the following:

1. Input Conditioning—how the control module processes the different kinds of analog and digital input-signals.
2. Central Processing—how the Central Processing Unit (CPU) in the control module uses information from the sensors and from its memories to calculate output signals.
3. Output Drivers—how the control module signals actuators in different ways to operate the engine.

When you finish the chapter, you'll be able to explain in simple terms what happens in the control modules—so they are no longer the mysterious "black box."

In 1980, EEC-III was the first Ford control module to control fuel injection. Its predecessors were EEC-I in 1978 for controlling emissions, and EEC-II in 1980 controlling a feedback carburetor. Since 1983, EEC-IV has grown in capabilities to improve power and driveability while meeting economy standards and emission limits. In many cases, improvements in EEC-IV computing functions met tighter limits while eliminating emission control hardware such as air pumps and EGR.

Control Module

The engine control module is a *digital* processor, a cousin of the Personal Computer. Like your PC, the Central Processing Unit (CPU) of the control module operates with a chip, a microprocessor that does the calculating and the memorizing. Like your PC, it has memories. But, instead of delivering output to a screen or a printer, it delivers outputs to the engine actuators. Instead of getting input from a keyboard, it receives inputs from the sensors. See Fig. 1-1.

Transmission Control

Increasingly, computers control electronic automatic transaxles/transmissions. In some Fords, they are separate from engine control modules, and they're called Transmission Control Modules (TCM). In later models, one control module controls both engine and transaxle/transmission. In this book, I'm concentrating on engine controls, but you should recognize the close link between engine control and transmission control. Examples:

- Signals needed for transmission control come from many of the sensors sending input signals for engine control, including throttle position and barometric pressure
- Fuel cutoff (for several milliseconds) during upshift reduces torque for smoother shifting and reduced load on the clutches of the automatic transmission

Table a. EEC-III and EEC-IV Control Capabilities

1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
EEC-III			EEC-IV											
Central Fuel Injection (CFI)														
			Multiport Fuel Injection (MFI)											
						Sequential Fuel Injection (SFI)								
	Idle Speed Control (ISC)													
		Knock Sensor (KS)												
			Knock Sensor—Individual Cylinder											
			Turbo Boost											
				Decel Fuel Shut-off										
				Wide Open Throttle (WOT) A/C Cut-off										
				Data Link										
					Transmission Control									
						Cruise Control								
								Mass Air Flow (MAF)						
									Additional Transmission Control					
										CA mandatory	On-Board Diagnostics-I (OBD-I)			
													Flash EEPROMS	
														OBD-II*
													Full transmission control	PCM

*OBD-II phase-in: 10% in 1994, rising to 100% by 1996

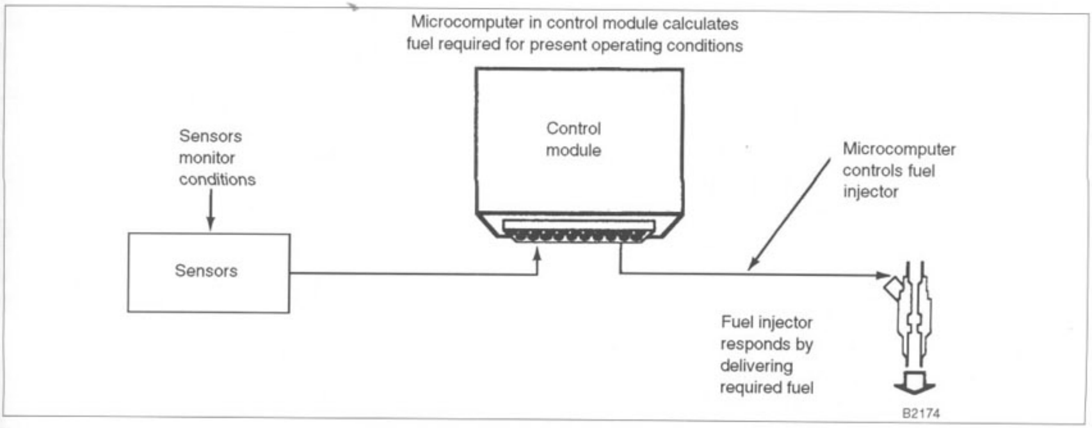


Fig. 1-1. Sensors monitor engine conditions, signal control module. Microcomputer calculates necessary operations and signals actuators. Fuel injector is actuator we think of first.

- *Ignition-timing retard (for several milliseconds) during* downshift again provides smoother shifts and reduces load on the automatic clutches

The new terminology, Powertrain Control Module (PCM) suggests that the control module controls both engine and transaxle/transmission, but you'll find PCM used for a computer limited to engine control. You may also find such a module labeled PCM-E.

Many of the ideas you'll gather from this chapter apply to other control units in cars and trucks, including: anti-lock brake systems, climate control, steering and suspension controls, and a list that will increasingly control our vehicles.

> I studied "Computers" at a Communication Cybernetics seminar of the Air Force Office of Scientific Research. In 1963, computers were room-sized mysteries operated in an air-conditioned clean environment by computer specialists. When we needed computer output, we brought our input data, knocked on the door, and waited a day for the outputs. No PC's, and no engine computers. At the seminar, one of the scientists challenged us, "Do you think you could live without your computer? How many of you would pull the plug tomorrow?" No one volunteered. Today, solid-state electronics and computer chips operate in all factories and businesses, in many offices and homes, in the watch on your wrist, and in all cars. I drive a car with nine of them. We would not pull the plug.

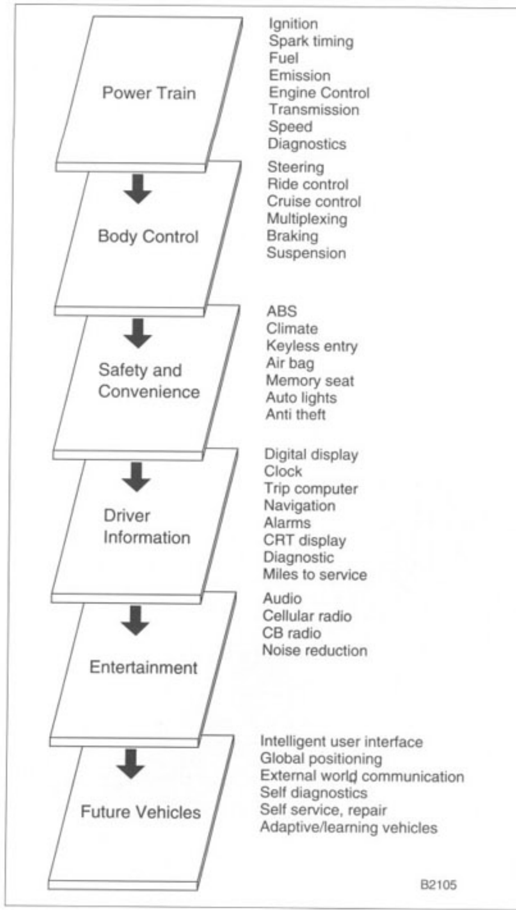


Fig. 1-2. EEC-IV engine control module is only beginning of applications to automotive systems.

What a Control Module Does

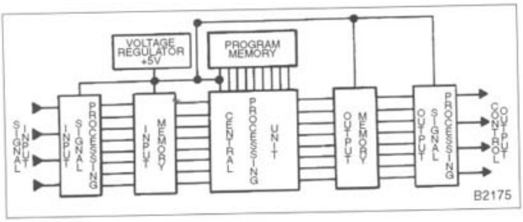


Fig. 1-3. Within control module, seven different functions are performed, from processing input signals to processing output signals.

In the block diagram above, you can see the seven parts of the control module that do seven different jobs:

- Regulate voltage
- Process input signals
- Store input memory
- Process the information
- Store program memory
- Store output memory
- Process output signals

The control module is about the size and weight of a hardcover book, usually located in the passenger compartment. When you hold it in your hand, it doesn't seem like much. It doesn't seem as if it should cost as much as it does, almost more than the entire first Ford V-8 car in 1932. Without it, our cars would have far less performance, driveability, economy, and emission control. If you think you'd like to go back to the "good ole" days before computers, you're remembering only the good side of those pre-computer engines.

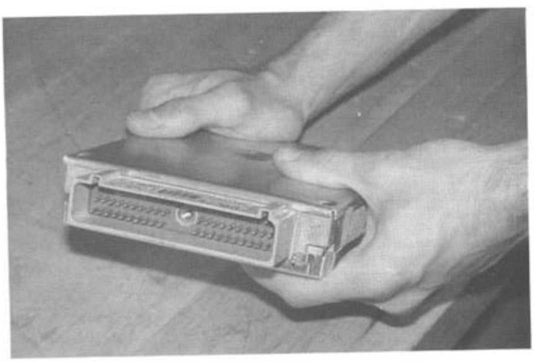


Fig. 1-4. Control module is heart of Ford EEC. Ford and auto industry have made more computers than IBM.

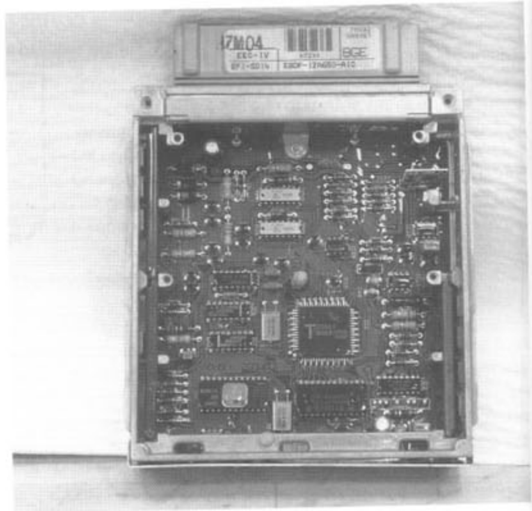


Fig. 1-5. Don't do this: Opening the EEC control module to make modifications (such as the installation of performance chips) can at the very least violate EPA regulations, and at the worst cause your engine to run poorly or ruin the control module.

2. INPUT CONDITIONING

In Chapter 3, you saw some of the sensors that send analog signals to the control module. Most of these input signals must be prepared or conditioned before the microprocessor can calculate. Some people refer to this conditioning as a process of "translating from one language to another". But be careful, we're not talking about computer languages.

2.1 Analog/Digital Signals

Analog/digital, what's the difference? Sometimes you use a digital VOM. You know it reads in digital numbers. The older analog VOM reads with a swinging needle. "Numbers" and "needles," is that the difference between analog and digital? Don't you believe it. It's important to know the real difference.

Analog measures continuously; an analog display changes in direct proportion to the input, such as an ordinary odometer. If you've gone two-thirds of a mile since it measured an even mile, the tenths digit will read about two-thirds. On the other hand, digital measures in steps. The digital clock shows exact steps, nothing in between as shown in Fig. 2-1. Each step can be extremely accurate, and does not change with wear or aging factors. Digital is "Yes" or "No," "1" or "zero," nothing in between. That might mean, "Is it 3:27?" Yes. "Is it 3:28?" No.

Fig. 2-1. Analog measures continuously; digital measures in steps, and each step is exact.

Digital Steps/Analog–Continuous Change

The important difference is: steps versus continuous change. See Fig. 2-2. Analog accuracy is limited, as indicated by the curved line measuring the signal of the straight line. But analog measurement can be more accurate than digital measurement that uses large steps. For example, most digital clocks read in steps of one minute. They read no more accurately than the step of a minute. By increasing the number of steps, digital accuracy is usually greater than analog, such as seconds, or hundredths of a second. But, for engine control, the most important benefit of digital signals is that they are less likely to be affected by changes in current flow through the harnesses and connectors.

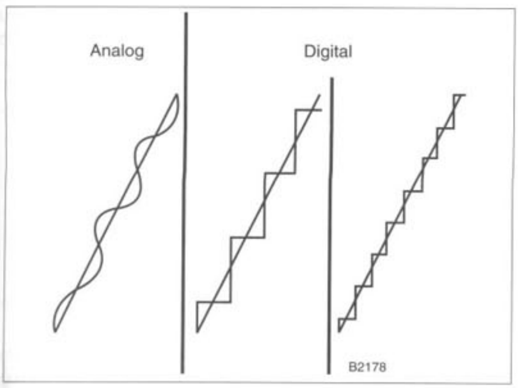


Fig. 2-2. Analog accuracy is limited by many variables. Digital is limited by number of steps.

2.2 Conversion and Amplification

Many input signals are analog voltage signals. These include:

- Variable resistor, ECT and ACT—temperature sensors
- Potentiometer, such as TP sensor

The Analog to Digital (A/D) Converter in the control module converts these analog signals to digital pulses.

Some input signals are small analog voltage signals. The oxygen sensor, a signal generator, is an example. These small signals must be amplified and then converted in an A/D Converter. Other signals are digital as frequency outputs from Signal Generators, or from switches. Digital signals need no conversion.

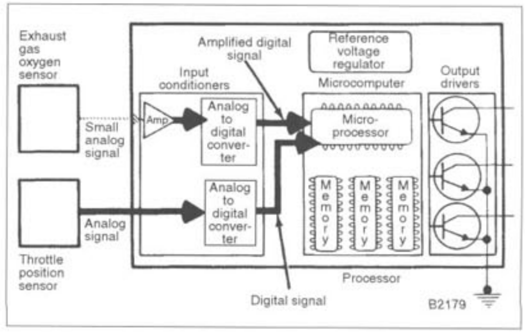


Fig. 2-3. Input conditioning. Input signals, from oxygen sensor, must be amplified and then converted Analog to Digital. Signals from ECT and ACT need A/D conversion. Also signals from TP.

Some sensors, such as PIP and the DIS Module contain *their own conditioning to send the proper digital signals. In future* engine-control systems, you'll see more of sensors that condition their own signals; they're called "smart sensors."

3. CENTRAL PROCESSING UNIT (CPU)

The Central Processing Unit (CPU) is the heart of the control module. It includes the microprocessors, two "chips" such as you've probably heard about that are smaller than your key. See Fig. 3-1. Each is an LSI—Large Scale Integrated circuit with many transistors. With all the different Ford engines, and all the different car models and transmissions/transaxles, one of the chips is specific to each application.

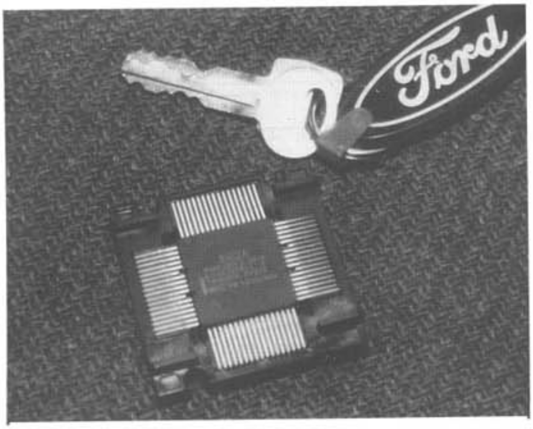


Fig. 3-1. Intel 8061 chip, a 16-bit microprocessor. Memory chip 8361 is similar. Each chip is an LSI—Large Scale Integrated circuit.

The microprocessor makes decisions about engine control by referring to three sources of information:

- Sensors—what's happening to the engine?
- System Strategy—what is the engine supposed to be doing under this condition?
- Look-Up Tables—what did the engineers advise about the air-fuel ratio, spark timing, throttle-air bypass (ISC) and emission control of this engine model for this strategy?

For you techies, Ford and Intel jointly designed the two chips. The 16-bit microprocessor with 70,000 transistors is called the 8061. The custom memory chip with 85,000 transistors is called the 8361. Using n-channel High-performance Metal Oxide Semi-Conductor (HMOS), these chips provide maximum circuit density, function, and speed—15MHz crystal frequency. Typical time to execute an instruction averages 1 to 2 µs; that's microsecond—I'm talking millionth of a second! Beginning in 1994, EEC-V chips operate 20% faster, at 18 MHz instead of 15.

Processing Speed

Consider the processing speed required. A 6-cylinder SFI engine at 6,000 rpm injects fuel to a cylinder and fires a plug 300 times per second, or once every 3.3 ms.

- 6000 rev/min ÷ 60 sec. per min. = 100 rev/second
- 1 rev fires three cylinders in 0.01 sec., or 10 ms
- 10 ms ÷ 3 cyl. = inject and fire one cylinder every 3.3 ms

Under transient, or changing conditions, the chip may calculate individual cylinder-injection times and individual cylinder spark-timing in 2.5 ms. In 2.5 milliseconds, the chip senses the inputs, processes and calculates, and delivers the outputs, leaving 0.8 ms of the 3.3 ms for other computation.

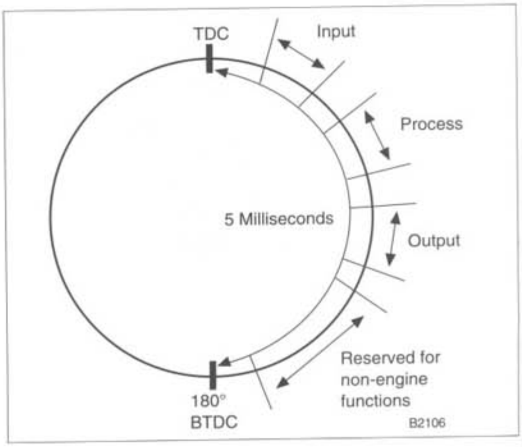


Fig. 3-2. For an SFI V-6 engine running 6,000 rpm, microprocessor must sense, process, and output individual-cylinder injection times and spark timing every 3.3 milliseconds.

Fortunately, the engine runs under transient conditions only some of the time. At other times, the chip has a few milliseconds to tend to other matters such as idle rpm, emission control, diagnostics, relation to the transmission, vehicle speed and trip computer. And it must deliver that kind of processing for 3,000 to 5,000 engine-running hours.

Interrupts

The 8061 chip provides for interrupting the less time-critical events to tend to fuel injection and spark timing. When you stomp on the accelerator, or release it suddenly, the chip quickly responds to the dynamic changes. Of the eight possible interrupt sources, the chip determines the most important. Temporarily, it stores the program it was working on in memory while it tends to the more important transient matters.

Memories

The control module contains three kinds of memories:

- Read Only Memory (ROM)—Long Term: the main body of data the engineers want the control module to remember about how the engine control operates
- Random Access Memory (RAM)—Short Term: data to be used and then forgotten, a scratch pad, something like when you look up a telephone number, use it, and forget it. Some RAM lasts until you turn off the key, when all RAM is erased
- Keep-Alive Memory (KAM)—Mid Term: data to be remembered for a while, then forgotten or erased. For example, diagnostic trouble codes remain in memory even with the key off. Disconnecting the battery erases the KAM

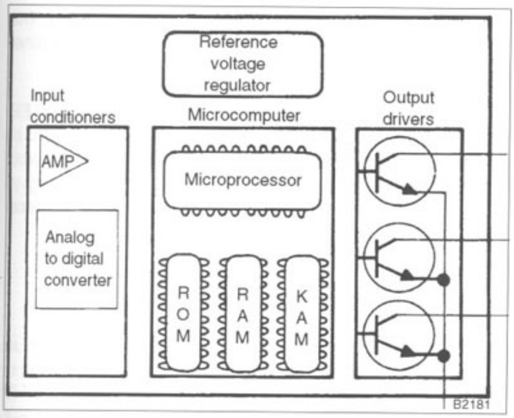


Fig. 3-. Three kinds of memory: 1) ROM—permanent engine data, 2) RAM—temporary storage, 3) KAM—stored semi-permanently, even with key off, lost when battery is disconnected.

3.1 Read Only Memory (ROM)

Strategy

Strategy, a long-term memory in ROM, holds plans created by engine designers for the timing and control of EEC systems. For example, normal fuel control strategy is to maintain stoichiometric air-fuel ratios, while cold cranking fuel-control strategy is to enrich the mixture. More on Strategies in Chapter 8.

Look-Up Tables

Look-Up Tables are long-term memories in ROM, holding calibrations and specifications about how this particular engine-type should perform under different strategies, including air-fuel ratios, spark timing, idle rpm, and emission control.

To determine precise timing-advance requirements, engineers test each family of engines. They determine the best air-fuel ratio and spark timing for each condition of speed, load, and other variables in heat and cold, on the dynamometer and in the mountains. They look for many different values of the air-fuel ratio and spark timing for best power, for best economy, all the while meeting emission limits.

The result of these tests is a series of data Look-Up Tables, as shown in Fig. 3-4. The Look-Up Tables of the ROM store thousands of data points for readout during engine operation. For any combination of engine load and rpm, the control unit

5

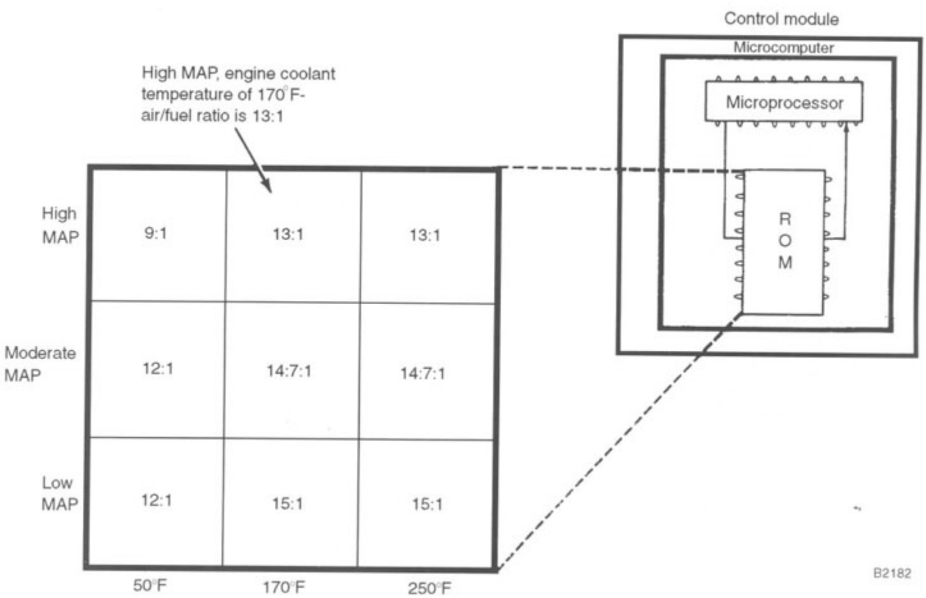


Fig. 3-4. ROM Look-Up Table of air-fuel ratio data for different conditions of MAP and ECT. Control module can interpolate: If ECT is 110°F (halfway between 50 and 170), control module determines that air-fuel ratio at high MAP should be 11:1 (halfway between 9:1 and 13:1. ROM includes many look-up tables for spark timing and other data.

can supply the best air-fuel ratio and the best spark timing. A LookUp Table is about the same thing Bosch calls a "map," not to be confused with MAP (Manifold Absolute Pressure).

Interpolation

Let's take an example, an rpm-input signal of 2050 rpm, at an engine-load signalled by the input sensor, whether MAF, MAP, VAF. The control module looks up the timing advance angle, let's say it should be 22 degrees BTDC. Is that it? No, control is even more precise. Suppose the rpm is 2050, and the memory contains only data points for 2000 and 2100. The control module looks up both 2000 = 22 degrees BTDC, and 2100 = 24 degrees BTDC, and interpolates. It calculates an advance for the 50 rpm difference between 2000 and 2050, and outputs timing of 23 degrees BTDC. The control unit computes timing so fast that EEC can adjust timing for every firing of each spark plug!

What a memory the control module has!

Non-Volatile ROM (PROM)

As I said, ROM is Read-Only Memory; it is also non-volatile. ROM remains intact even without battery power. On the other hand, RAM is volatile. When it is no longer powered, it loses its memory. Usually ROM is not erasable. Computer guys say it is not programmable. But recent developments offer several ways to reprogram ROM, that is to change the values stored in the memory without changing the chip. The reasons for reprogramming in the vehicle extend beyond hot-rodding the engine:

- Adapt to a new sensor introduced in production as a running change
- Selection of features according to customer options
- Improve maintainability or emission control based on field experience

You'll hear a lot of talk about PROM—that's Programmable ROM. Start with the PROM in your Ford control module, containing all the values described above, burned into the chip at the manufacturer. The trend is toward Erasable PROMs of three kinds, with the lowest cost ROM being the least flexible.

EPROM (Erasable PROM) means the whole chip can be erased by exposing it to ultra-violet light (UV). Put away your ideas of removing the chip and hitting it with your suntan lamps, guys. This means Start-Over City, and you have no idea how much work this is for an individual, re-creating all the maps and strategies.

Flash EEPROM (Flash Electronically Erasable PROM) means the whole chip can be bulk-erased electronically, while still in the control module. This means starting over, but this can be done in 15 seconds, feeding it stored data from a CD-ROM (Compact-Disc—Read Only Memory). We'll see more of Flash EEPROMs so the engines can be reprogrammed in-use based on new data, a sort of active Technical Service Bulletin (TSB).

EEPROM can be erased selectively—"byte erasable". That means most of the millions of bytes of data can be retained while changing only selected portions of the maps.

Both Ford and the government are interested in Flash EEPROMs with the proper safeguards built in. They want to be sure the authorized service facility can reprogram within proper engine control and emission limits, while performance guys cannot. Sorry, but performance mods take second precedence to clean air and reduction of global warming.

3.2 Random Access Memory (RAM)

Random Access Memory (RAM) stores information as needed for short term, which may be for a few milliseconds, or for several hours until the key is turned off. Earlier EEC-IV RAM store 32kB (kiloBytes) of information. Beginning in 1993, EEC-IV RAM stores 56kB. It could store this chapter, which measures 51kB. This book measures several million kB.

RAM stores information:

- From sensors
- Results of calculations
- Other data which is subject to change

Example: when you turn on the ignition, the control module takes a few milliseconds to collect the BP pressure signal and store it in RAM. See Fig. 3-5. It may update that BP data occasionally, collecting and storing new BP data. When you turn off the key, RAM says, "Forget it. Don't store that old data because the barometric pressure changes with the weather. I'll store new data when the engine is restarted."

3.3 Keep Alive Memory (KAM)

You can think of KAM as a special kind of Keep-Alive RAM, powered directly from the battery instead of from the ignition key. KAM's main purpose is to store Service Codes, also known as diagnostic trouble codes. KAM also stores adaptive corrections.

3.4 Voltage Reference (VREF)

When you apply your Volt-OhmMeter (VOM) to make diagnostic tests, you're going to run into Voltage Reference (VREF). One job of the control module is to step down battery voltage to a reliable fixed reference voltage supplied to certain sensors. See Fig. 3-6. EEC-IV VREF is 5v. above Signal Return. For the necessary precision to govern input signals, the control module must compare sensor signals to a stable reference level. As you may know, battery voltage can change from 9 v. during cold cranking to over 14 v. while the alternator is charging.

VREF is especially important for three-wire sensors that depend on resistance division in a potentiometer. These include the TP, and the VAF, and sensors that translate sensor changes into voltage input signals, such as the MAP, and the MAF.

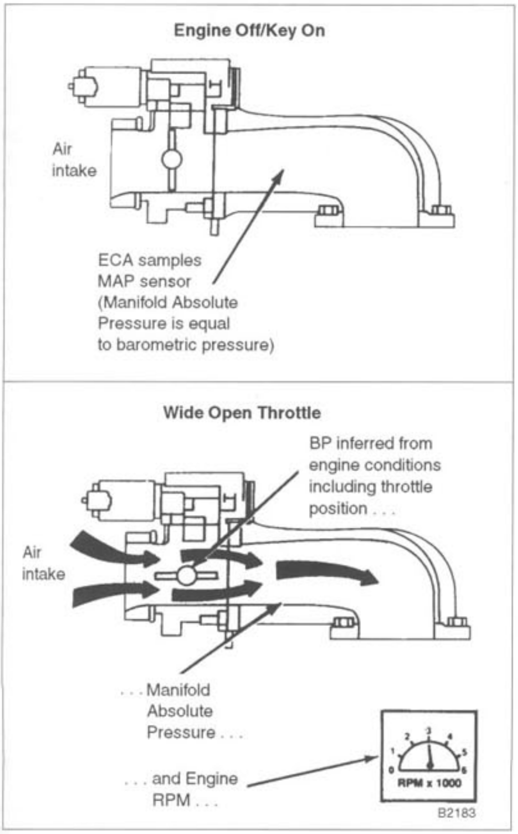


Fig. 3-5. In some engines, control module collects BP in RAM under two conditions: Key ON, engine OFF; WOT (Wide Open Throttle).

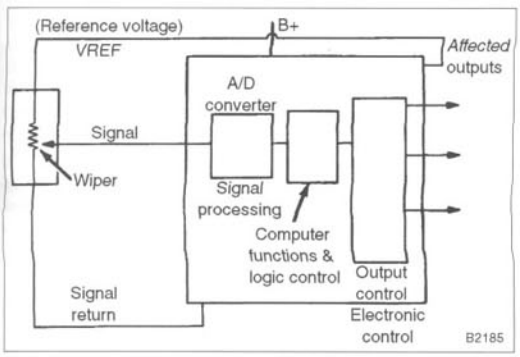


Fig. 3-6. For accuracy, some sensors require a steady fixed voltage input generated in the control module as Voltage Reference (VREF). EEC-IV VREF is 5v.

3.5 Signal Return (SIG RTN)

Most sensors are two-wire connected, with an input signal and a Signal Return (SIG RTN). SIG RTN is a sort of EEC-special ground, rather than depending on vehicle ground, as in most electrical circuits. The input signal is the result of the control module comparing the input voltage to the SIG RTN ground, and is based on VREF of 5v. See Fig. 3-6 above. Some oxygen sensors have no SIG RTN. As a voltage generator, the oxygen sensor is grounded to the exhaust manifold, and so to the chassis. The heated oxygen sensor has a three-wire circuit, but two of those are for the heating circuit and its ground. The latest oxygen sensors have SIG RTN.

4. Output Control

Output control is necessary to handle relatively large current circuits controlled by very small-current control module signals. The control module inputs deal in milliamps, but it takes full-size amperes to drive some solenoids and injectors. It will help you in your diagnosis if you keep this difference in mind:

- Small currents—milliamps for *in*put
- Large currents—amperes for *out*put

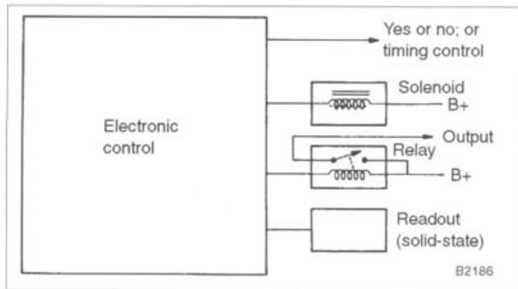


Fig. 4-1. Control module outputs are usually digital: yes/on = voltage, *or no/off = no voltage. Output can operate* a solenoid, a relay, or a solid-state readout.

4.1 Output Drivers

Output drivers deliver output signals that control actuators. When you look at a wiring diagram, you'll see that most actuators are powered from the battery by the Vehicle Power (VPWR) circuit whenever the key is turned to ON or START. The control module provides a ground circuit for the actuators. Small voltages from the control module cause the transistor output drivers to open or close the ground circuit of the actuator.

When the output driver closes the ground circuit to an injector, it grounds VPWR supplied to the injector. That causes fuel to be injected. When the output driver opens the circuit, the injector closes. Varying the time-closed of the driver

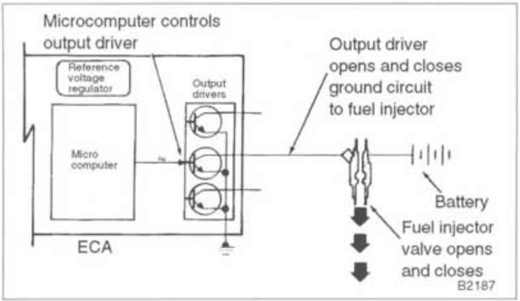


Fig. 4-2. Each output driver opens and closes ground circuit to its fuel injector. Each injector is supplied Vehicle Power (VPWR) from battery.

(injector-open time) varies the amount of fuel injected. You can measure this time to show how the circuit is operating. Remember, this may be happening as fast as every few ms.

4.2 Duty Cycle

When you hear someone speak of duty cycle, or dwell, they're talking about digital pulses from the output drivers. The control unit varies the pulses in their ON-time/OFF-time (duty cycle) to control the position of a motor such as in the Idle-Air Bypass. When you measure the on-off ratio, you measure the percentage of time the current is on. If the pulses are on 50% of the time, the circuit is passing 50% of the current that it would pass with a closed circuit. With a battery current of 12 v., 50% duty cycle would average out on a VOM to read 6 v. This seems to be a tough idea to comprehend. People have asked me, "How can a DVOM read duty cycle?" The answer is, by averaging the voltage-on, voltage-off times.

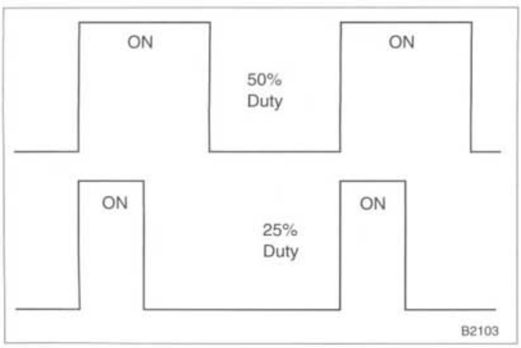


Fig. 4-3. If pulses are on 50% of time, circuit is passing 50% of current that it would with a closed circuit, 100%. A digital voltmeter will average input voltage. 50% duty cycle would read 6 v. from a 12 v. input source. 25%, 3V

5. Adaptive Strategy

You'll hear a lot about Strategies in Ford EEC systems. While we're in the control module, let's look at Adaptive Strategies. The control module is adaptive when it stores in memory how this driver is driving this car. Every 10 minutes or so, the adaptive system "learns" those modifications to the control. I'm talking about an intelligent car that adjusts itself to its own need, and the driver's need. Some 1985 Ford engine controls were adaptive. All since 1986 are adaptive.

Adaptive strategy continually shifts the base calibration to compensate for changes in barometric pressure, intake air temperature, fuel composition, small drifts in sensors or actuators. "Wait a minute," you say, "EEC is already measuring those." Yes, but the strategies stored in the ROM are based on how the *test* engine responded to sensor inputs. Adaptive strategy looks at how *this* engine is currently responding—and further, how this engine is responding to how this driver drives.

Long-term Correction

Adaptive strategy is a long-term correction based on repeated short-term corrections. Example: suppose the oxygen sensor keeps sending rich mixture (go-to-lean) signals as short-term correction under certain rpm/load signals. The control module notes these repeated short-term corrections, and shifts the base calibration for that rpm/load combination toward lean. The control module has "learned" that this engine needs less fuel than the test engine under the same conditions.

Short-term Correction

Basic feedback from the oxygen sensor is relatively slow - perhaps 100—1000 milliseconds (and must be for stability reasons). Basic feedback corrects for steady-state errors caused by aging and failures. Adaptive Strategy can apply corrective factors learned during a few milliseconds of transition during acceleration and deceleration to correct for dynamic changes and driver differences. Limiting adaptive strategy in its correction prevents shifting calibrations to unsafe or improper fuel injection or spark timing.

In one Ford development test, an EEC-IV system was calibrated properly for CO emission of 3.4 g/mi., then set 20% rich from open-loop fuel injection. At 20% rich, the CO emission was over 60 g/mi., 17 times the limit. Within one hour's driving (long-term) with many accelerations and decelerations, as during normal urban driving, the control module had adapted. It had "learned" well enough to reduce CO even below the 3.4 limit, to almost zero. See Fig. 5-1.

When I first learned of Adaptive Strategies, I talked with one of GM's trainers. I asked why I could find nothing about "learning adaptation" in GM training. "Not yet," he said, "we're worried it will blow their minds." These days, GM teaches it as "Block Learn." Ford describes it in their training, but some of what I'll tell you here comes from deep inside SAE technical papers.

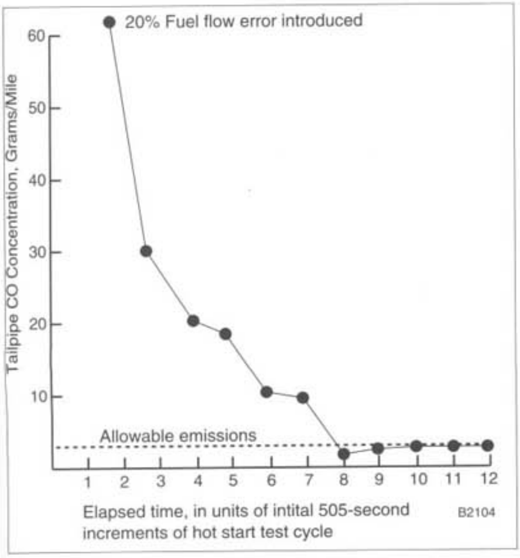


Fig. 5-1. In Ford test, control module Adaptive Strategy corrects an engine purposely set 20% rich, from over 60 g/mi. CO tailpipe emissions (about 17 times normal) to allowable, 3.4 g/mi. or less.

> Drivers who drive their adaptive-system cars to the drag strip are often puzzled about their high Elapsed Times. The system adapts to street driving. When they run the strip a few times, the control module re-adapts to the strip, and their E.T.s improve.

KAM Storage

KAM stores Adaptive Strategies. That means the EEC adapts to your engine and your driving—but only as long as no one disconnects the battery. If the car is serviced, or loses battery power during installation of a theft alarm or cellular car phone, look out. You can expect the system to lose the Adaptive KAM, along with the settings for the electronic radio and the clock. To prevent this, some technicians plug in an auxiliary power supply. After disconnecting a battery, good technicians often drive the car for about 10 minutes to restore the adaptive values in the KAM.

If the car drives strangely after being serviced electrically, the engine has lost its adaptive memory in KAM. Adaptive strategy needs time to work after replacement of any part of the EEC system, and when the car is new. For normal conditions, Adaptive systems should get itself to normal in about 10 minutes of driving.

6. Failure Strategies

6.1 System Self-Test (Trouble Codes)

One of the programs stored in the ROM is called a Self-Test program. Almost continuously, this program samples various input and output signals, comparing them to normal ranges. When it senses a signal that is improper, it stores a Service Code, also called a Diagnostic Trouble Code (DTC), or Trouble Code.

- If the indicated trouble is not serious, a Soft Code stores for later readout, but does not signal the driver
- More serious trouble stores a Hard Code and turns on the Malfunction Indicator Light (MIL) (Check Engine)

You can read these codes several different ways, as described in Chapter 10, Diagnosis and Troubleshooting.

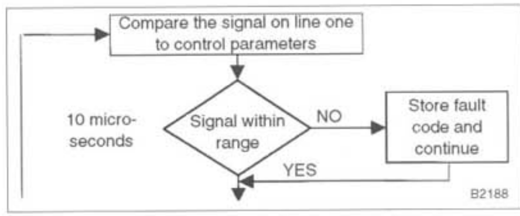


Fig. 6-1. Diagnostic-Test samples one signal at a time. Even at the blinding speed of microprocessor, this can take up to 10 microseconds (10 millionths of a second).

The Self-Test can sample only one signal at a time. While this can be very quick, usually about 10 microseconds (10 *millionths* of a second), Self-Test looks at many signals, one at a time.

In Fig. 6-2, if a fault occurred in the first signal as the control module was sampling the second signal, and did not last for the time required to cycle back to the first signal, the fault would not be stored. That is one basis for the infamous intermittent symptom that does not store a trouble code. Another basis is the nature of the Self-Test program that it does not store a service code until the same fault has happened several consecutive times. That prevents false trouble codes. The result: The vehicle has a driveability problem but the system reports "Code 11—No Service Codes".

> When trouble codes first appeared, scoffers said, "Whoa, how can they ask a control module to check itself? What if the control module itself is in trouble?" It turned out: 1) that the control module was checking the sensors, and 2) that the control module did not fail as often as people expected, or as often as sensors, connectors and harnesses. Do not expect to service these engine-control systems without trouble codes.

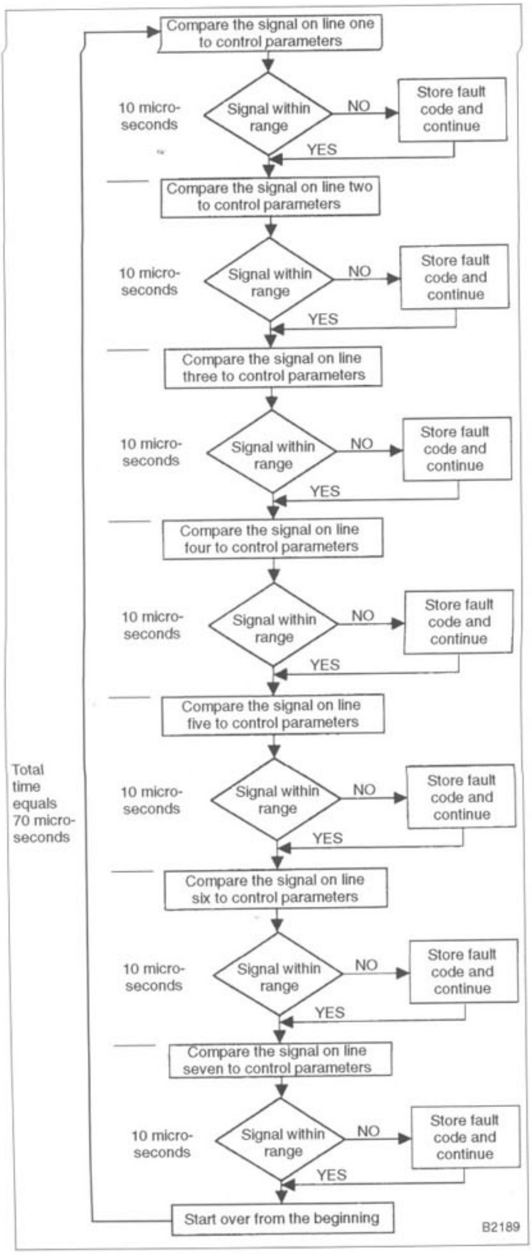


Fig. 6-2. Sampling just seven signals takes 70 microseconds. Ford control modules sample many times seven signals.

Ford EEC systems provide several strategies for various kinds of failure. Diagnostics began as simple storage in RAM of service codes. When a sensor signal that is outside preset limits enters the control module, that triggers the Self-Test Output (STO) circuit, turning on the Malfunction Indicator Light (MIL). On the instrument panel, the MIL could read "Check Engine" or "Service Engine Soon." At the same time, this stores a service code for that sensor.

Limits of Sensor Inputs

Chapter 12 lists the limits of each sensor. When a "Check Engine" light appears, you begin by reading the service code, through a scan tool, with an analog VOM, or even by observing the flashing of the Check Engine light. You can probe the indicated circuit with your VOM, based on those limits. You can determine what caused the trouble, a sensor, a connector, an open or short in the circuit, or some other problem. More of that in Chapter 10 and Chapter 11.

On-Board Diagnostics (OBD)

Beginning in 1989, Fords in California include On-Board Diagnostics (OBD) in the control module monitors more components. The OBD regularly monitors the control module, the sensors and the actuators. When OBD detects a fault, it stores a trouble code and lights the Check Engine light. After repair, OBD verifies that the fault is cured.

Beginning in 1994, the second generation of On-Board Diagnostics (OBD-II) stores much more information to assist in diagnostics, particularly for intermittent faults. **Table b** shows OBD applications.

Table b. On-Board Diagnostic (OBD) System Monitoring

System Monitored	OBD-I, 1989-on (CA)	OBD-II, 1994-on
Control Module	Yes	Yes
Fuel Metering	Yes	Yes
EGR	Yes	Yes
Oxygen Sensor	Yes	Yes
Catalyst	No	Yes
Engine misfire	No	Yes
Thermactor	No	Yes
EVAP	No	Yes

How does OBD operate on Ford cars and light trucks?

Control module: OBD checks the internal memories, RAM and ROM, and checks the bit pattern of the signals. It uses a "watch-dog" circuit to monitor any runaway program.

Fuel metering: OBD monitors the injectors indirectly by observing signals from the oxygen sensor(s).

EGR: OBD momentarily activates EGR when it should be off (or deactivates it when it should be on), measuring engine rpm or fuel-injection corrections. OBD-1 in California measures the EGR passage temperature, so that's why California vehicles have an added sensor, EGR temperature.

Sensors: OBD checks sensors for acceptable outputs as well as for electrical continuity.

Oxygen sensor: OBD checks sensor output voltages and switching frequencies. If voltage is continuously low, the mixture is lean. If voltage is continuously high, the mixture is rich. That could indicate a defective sensor, a fuel-system fault, or an intake-system fault (vacuum leak). If the switching frequency is low, the sensor has deteriorated or is defective. Some people call this a "lazy" oxygen sensor. OBD also checks the sensor heating element for continuity.

Catalytic converter: OBD II checks operation by double oxygen sensors. Comparing the oxygen content of the exhaust gas entering the converter with the oxygen content of the exhaust gas leaving the converter reports conversion activity.

Engine misfire: OBD II senses engine misfire if there is a momentary and unusual change in crankshaft rotation, within just a few degrees. Forces vary as the cylinders fire, but they vary in a pattern. Cylinder misfire changes the pattern. On-the-road misfires can be a significant factor in excess emissions.

Thermactor: OBD II activates air injection when it should normally be off, then observes changes in oxygen sensor voltage.

To minimize improper fault codes, OBD may repeat a test every few minutes, storing a fault code only if the test results are the same for a certain number of successive tests.

6.2 Failure Mode Effects Management (FMEM)

Failure Mode Effects Management (FMEM) shifts calibration in the event the Diagnostics program senses failure of one or more parts. For example, if the ECT suddenly signals an infinite resistance, as in an open, the control module ignores this input, which would otherwise drive the air-fuel ratio very rich. In effect, the control module program says, "I know the limits of a signal from the ECT, so if it's outside those limits, something is wrong." In that case, the FMEM switches to a fixed resistance value for the ECT, allowing the warm engine to operate as a warm engine.

At the same time, the control module turns on the "Check Engine" light warning you to seek service. Do not expect a cold engine to start properly with a fixed warm FMEM signal for a cold engine. Each sensor has a separate FMEM fixed value. In another logic, FMEM is programmed to remember the ECT signal just before the failure and continue at that input value.

6.3 Limited Operational Strategy (LOS)

Limited Operational Startegy (LOS) provides for loss of just about all signals. LOS is a limp-home strategy, barring complete failure. For example, under LOS, the PIP signal of 10 degrees before TDC becomes the basic timing signal for ignition, without correction for temperature or any other condition. The warm engine will probably get you home or to the shop, but it won't start cold. Ford is considering eliminating LOS. "It just doesn't happen that often that we lose all signals", one Powertrain engineer told me.

Ford uses EEC-IV worldwide, controlling most Ford engines in Europe. Modified EEC-IV computers control racing engines in Formula I cars in Europe and, beginning in 1993, Indycars.

7. MECS Electronic Control Unit

Mazda Engine Control System (MECS-I) control modules, also known as Electronic Control Units (ECU) handle fewer engine functions than their EEC counterparts. The memories are different in the storage of service codes. Unlike EEC-IV, Self-Test Mode does not exercise sensors or switches. Intermittent codes are stored permanently until erased.

Several engine control units exchange information with the 4-speed Electronically Controlled Automatic Transaxles (4EAT). These transaxles are controlled by a "Standalone" processor. Some MECS control units also handle the 4-speed Electronically Controlled Automatic Transaxles (4EAT). This combination of control unit is called "Integrated" 4EAT Powertrain Control Module (PCM) on the following models:

- 1991–92 2.2L non-turbo
- 1993 2.0 L
- 1993 2.5L

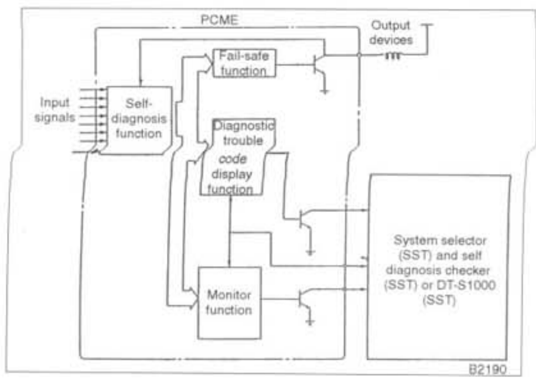


Fig. 7-1. MECS-II Diagnostic Test Mode (DTM) includes fail-safe function, similar to EEC Failure Mode Effects Management, with Code Display, and Code readout by scan tool.

Chapter 6

Actuators—Implementing Control Strategies

Contents

TABLES

1. Introduction

Actuators are what it's all about—the reason we have sensors and computers is to control actuators for air-fuel ratio, spark timing, idle rpm (bypass air), and emissions. See Fig. 1-1.

When you finish this chapter, you'll be able to tell what happens to each actuator as it receives output signals from the control module. Another term for actuators is "control". As you'll remember from Chapter 5, outputs to the actuators are generally digital:

- Yes/no, or simply timing control modified in the control module
- Solenoid operation, controlling flow
- Grounding an actuator that is on battery power
- Readout to a solid-state display such as scan tool or dashboard indicator

Table a lists the EEC-IV, MECS-I and MECS-II actuators controlled by the control module. These are the familiar terms used up through 1992.

Table a. Control Module Outputs to Actuators

Air-Fuel Control	Fuel Injectors Intake Air Control (IAC) Intake Manifold Runner Control (IMRC) High Speed Inlet Air (HSIA) Variable Resonance Induction (VRIS) Turbo Boost Control (TBC)
Timing/Spark Control	Thick Film Integrated-IV (TFI-IV) Ignition Distributorless Ignition (DIS) Electronic Distributorless Ignition (EDIS) Electronic Spark Advance (ESA)
Throttle Bypass Air	Idle-Speed Control—Bypass Air (ISC-BPA) Idle-Up solenoids
Emission Control	Exhaust Gas Recirculation (EGR): Pressure Feedback (PFE) Electronic (EEGR) Thermactor (TAB/TAD) Canister Purge (CANP)
Relay/Information	Shift Indicator Light Data Output (DOL) Check engine light (MIL) Self-Test Output (STO) Fuel Pump Relay (FPR) Controller Modules A/C & Fan (WAC, EDF, HEDF) Lock-Up Solenoid (LUS)

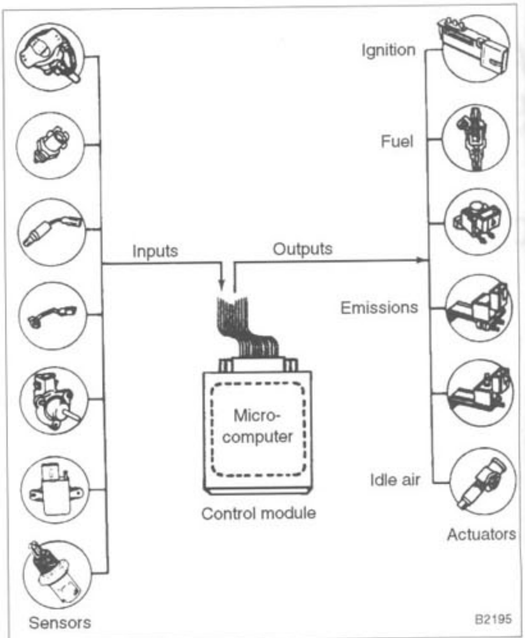


Fig. 1-1. Sensor inputs to control module are for control of air-fuel ratio, spark timing, throttle Bypass Air (BPA), emissions.

1.1 Terminology

Beginning in 1993, a number of the names for the actuators were changed to comply with the SAE standard J1930 to provide common terms for the same general part throughout the automotive industry. For more information on terminology changes, see Chapter 1. This chapter uses the terminology applicable for the years 1988–1992. For reference, **Table b** lists those terms and their equivalents that changed in 1993. Especially note the changes of Intake Air Control and Idle Speed Control.

Refresh your memory about the different Ford fuel injection systems, as they were applied in time sequence:

- 1980, Central Fuel Injection (CFI)
- 1983, first MultiPort Fuel Injection (MFI); Ford called it EFI. By 1988, virtually all Ford engines are MultiPort
- 1986, the first Sequential (MultiPort) Fuel Injection (SFI), Ford-speak = SEFI. I'll use the term "port injectors" when I mean both MFI and SFI
- 1989, Mass Air Flow (MAF-SFI). By 1992, MAF is almost universal in EEC systems
- 1988, MECS MultiPort applied to 1.6L Tracer, 2.2L Probe; later to 1.3L Festiva and 1.8L Escort/Tracer
- *1993 MECS-II SFI with MAF and SC-VAF applied* to Probe

Table b. 1993 and Later J1930 Terminology

1988–1992 Term	1993 Equivalent
Converter Clutch Control (CCC)	Torque Converter Clutch (TCC)
Distributorless Ignition System (DIS)	Electronic Ignition (EI)—Low Data Rate
DIS / EDIS / TFI Module	Ignition Control Module (ICM)
Electronic Distributorless Ignition (EDIS)	Electronic Ignition (EI)—High Data Rate
Electro-Drive Fan (EDF)	Low Fan Control (LFC)
High-Speed Fan (HEDF)	High Fan Control (HFC)
Idle Speed Control (ISC)	Idle Air Control (IAC)
Inertia Switch (IS)	Inertia Fuel Shut-Off Switch (IFS)
Intake Air Control (IAC)	Intake Manifold Runner Control (IMRC)
Integrated Relay Control Module (IRCM)	Constant Control Relay Module (CCRM)
Lock-Up Solenoid (LUS)	Torque Converter Clutch Solenoid (TCC)
Self-Test Connector (STC)	Data Output Line (DOL)
Self-Test Output (STO)	Data Link Connector (DLC)
Spark Angle Word (SAW)	Spark Output (SPOUT)
TFI-IV/DIS/EDIS Module	Ignition Control Module (ICM)
Thermactor Air–Bypass (TAB)	Air Injection Reaction Bypass (AIRB)
Thermactor Air–Diverter (TAD)	Air Injection Reaction Diverter (AIRD)
Thick Film Integrated-IV (TFI-IV) Ignition	Distributor Ignition (DI)

2. Actuators for Air-Fuel Ratio

2.1 Injectors

The actuators that control the air-fuel ratio are the injectors. Injectors are solenoid valves. They are electrically-hot all the time the fuel-pump relay is closed. For fuel delivery, the final stage of the control module grounds the injectors. The grounding in the control module completes the circuit, signalling the injector to open.

Each injector opens as a result of the electrical signal from the control module, and closes by spring force when that signal stops. See Fig. 2-1. When current flows through the winding, electromagnetic force lifts the solenoid, and the injector delivers fuel. When the needle valve is closed by the spring, no fuel flows.

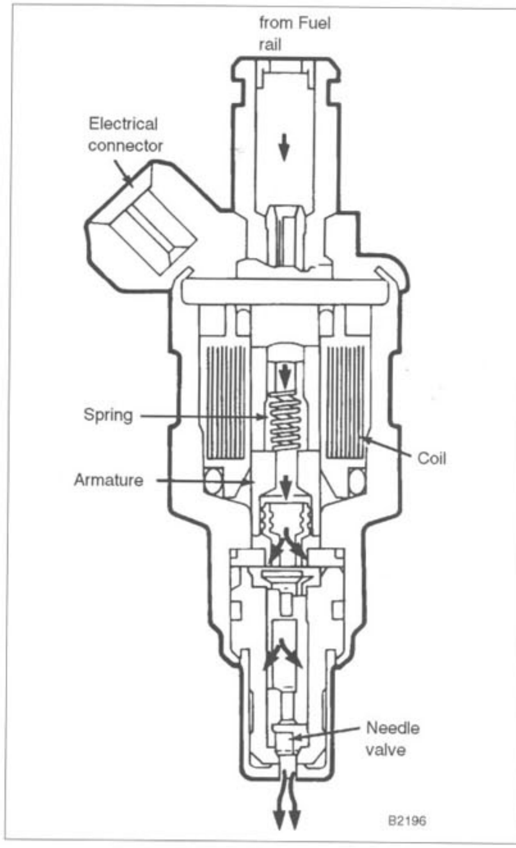


Fig. 2-1. High-pressure injector is about size and shape of a spark plug.

Looking at the cross-section of the high-pressure injector you can see the main parts:

- Top feed, with an integral filter
- Electrical connector, both VPWR and ground
- Coil and armature of the solenoid
- Stainless-steel body
- Stainless-steel needle, lifted by the solenoid
- Needle valve with pintle (See Fig. 2-2)

Since 1988, Ford has standardized on high-pressure injectors located in the intake ports, one for each cylinder. See Fig. 2-3. Note that the 1988–89 2.5L Taurus uses low-pressure injectors located in the central charging assembly.

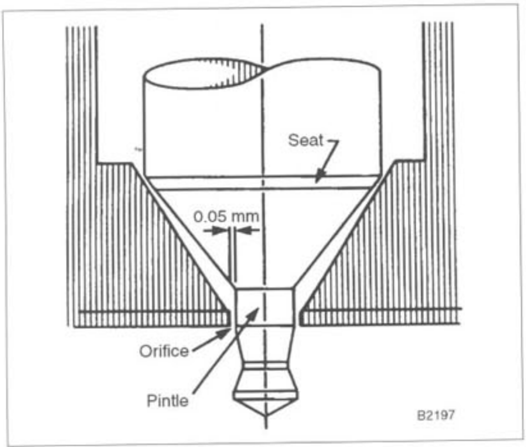


Fig. 2-2. Valve seats on conical body. Pintle has very small precise clearances to body. Pintle tip shape atomizes and distributes fuel.

Most Ford high-pressure injectors operate at relative fuel pressures of about 270 kPa (39 psi). Remember, port injectors operate downstream of the throttle in the changing pressures of the intake manifold so the regulator needs to keep the relative pressure the same.

Port injectors are held in the intake manifold ports with O-rings that tend to insulate the injectors from engine heat and vibration. If the O-rings crack, false air enters, leans the mixture and may increase idle rpm.

Fig. 2-3. Port injectors are mounted in manifolds at intake ports.

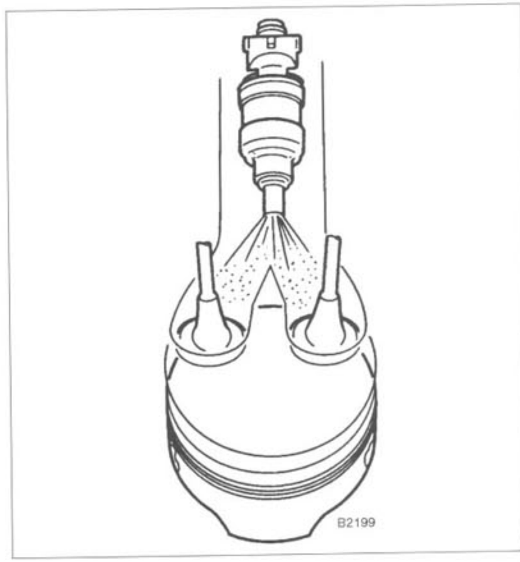


Fig. 2-4. Divided-spray injector delivers separate spray of fuel into each intake port of DOHC engines.

Metering Fuel Injection

Two factors affect the amount of fuel delivered by the electronic fuel injectors:

- Pressure—the greater the pressure, the greater the delivery
- *Time—the longer the injector is open, the greater the* fuel delivery

That may seem obvious, but variations in those two factors, pressure and time are important to your understanding of electronic fuel injection.

In electronic fuel injection, metering takes place at the tip of each injector as a needle lifts a tiny amount, for a short time, and delivers a small amount of fuel. The amount of lift is about 0.15mm (0.006 in.), about the thickness of two pieces of paper. The lift is fixed, the same every time. The amount of fuel injected depends on the time the injector is open. It also depends on the fuel pressure. For port injection, actual fuel pressure in the system depends on the fuel-pressure differential *between the injector tip and the manifold.*

Suppose you want to add more fuel than the original engine. Perhaps you've cleaned up the intakes to admit more air. Remember, the engine is measuring the air flow and injecting fuel to match. So, for street cars, the control module will usually increase fuel injection with no modification on your part.

Perhaps you want to run richer for off-road. Then you increase the fuel-pressure, or you increase the injector-open times. You must consider the injection time—how long the injectors are open under different conditions, and the pulse-period—how much time is available in the engine cycle for injector delivery.

Time Factors

I said that the signal from the control module to the injectors is a pulse that changes to vary the amount of fuel injected. Injection time—the pulse time that delivers the amount of fuel required—may be as short as one millisecond or as long as 15 milliseconds. A millisecond, that's one-thousandth part of a second, written ms. Some wit has defined a millisecond: "That's the time between the light changing green and the guy behind honking." We'll say it's a very short piece of time.

Injection Time, sometimes called pulse-width, is the open time of each injector, from the instant it receives the open signal until it receives the close signal. The injector is delivering fuel the whole time. It takes about 1ms to open, that is counted in the injection time. The closing time is not counted, but it averages out: pulse-width is effective injector-open time.

Operation

MFI injectors are grounded by the control module in banks. See Fig. 2-5.

- V-6 and V-8 by separate left and right banks
- In-line 4- and 6-cylinder engines in two groups (referred to in circuit diagrams as "bank 1" and "bank 2", even though the cylinders are in line, all in one bank)

Sequential Fuel Injection (SFI) controls each injector individually in firing order for better control of individual cylinders. See Fig. 2-6. This requires more computing power, but extra computing power was designed into EEC-IV from the beginning. By 1992, most Ford engines are SFI.

Does each sequential injector fire at the time its intake valve is open? That easy assumption is not always true.

- In some engines, depending on the intake porting, injectors are timed to fire through the open valve
- In other engines, firing through the intake valve can produce undesirable variations in the in-cylinder mixture. In these engines, firing the injector against the closed, hot intake valve just before it opens improves fuel vaporization and reduces emissions.

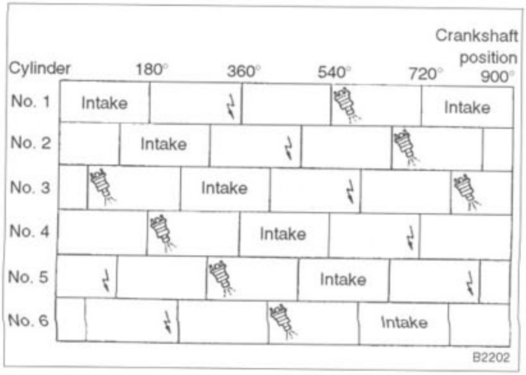


Fig. 2-6. Sequential injection timing on 1993 and later Probe 2.5L V-6 shows delivery during exhaust stroke, before intake valve opens.

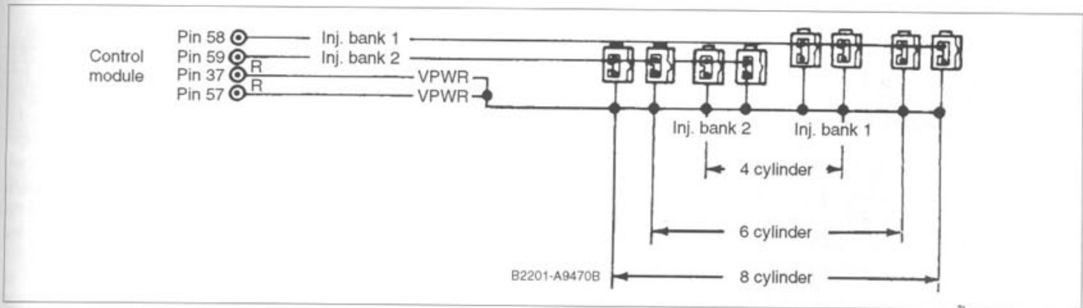


Fig. 2-5. MFI injectors (shown) are grounded in banks, L-R for V-type, and two cylinders at a time for 4 and 6-cylinder engines. SFI injectors are grounded by control module individually in firing order. V-6 and V-8 are similar.

Deposit-Resistant Injectors (DRI)

Port injectors are more prone to deposits than Central Fuel injectors because port injectors meter at the injector tip near the hot intake valve, where the temperatures are higher.

Beginning in 1990 models, look for Deposit-Resistant Injectors (DRI) in most engines. DRI resist the tendency of injectors to clog with deposits from certain fuels under certain operating conditions. See Chapter 11 for information on un-clogging earlier injectors.

Injectors identified as DRI resist deposits in two ways:

- Some have a director/metering plate to shield the tip from excess temperatures
- Others meter most of the fuel in the center of the injector, away from the heat at the tip

On the 1993 and later 2.5L V-6 Probe, side-feed injectors mount in the fuel distributor or rail. See Fig. 2-7. As fuel flows through the injector, some fuel is delivered to the intake passage during injector open-time. But other fuel flowing through carries away fuel vapor that might interfere with hot starting.

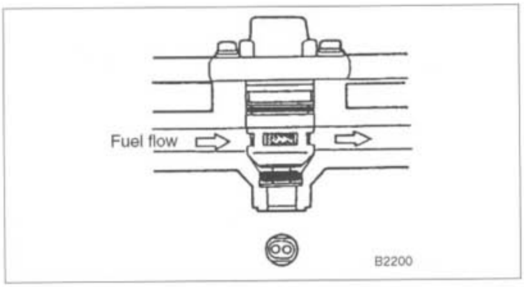


Fig. 2-7. Side-feed injector on 2.5L V-6 circulates fuel through injector. Fuel flow carries away vapor caused by engine heat, improving hot starting.

2.2 Inlet Air Control

Remember the discussion in Chapter 2, where intake runner length is a factor affecting engine performance. I'll describe several inlet air controls, all designed to get more air into the cylinders for more power. These include: Intake Air Control (IAC) on SHO 3.0L/3.2L engines, Intake Manifold Runner Control (IMRC) on 4.6L-4V engines, Variable Resonance Induction System (VRIS) in the MECS 2.5L V-6, and turbo control on MECS 2.2L turbo engines.

Intake Air Control (IAC)

Intake Air Control (IAC) on SHO 3.0L/3.2L engines varies the length of the air intake passages to increase power output over a greater range of rpm. See Fig. 2-8. IAC controls valves in the variable-intake manifolding. When you look at a SHO engine, the long tuned runners seem to overwhelm the entire engine, but they are important to that 220 hp. at 6200 rpm.

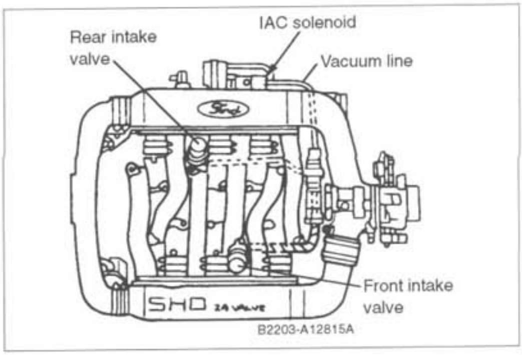


Fig. 2-8. Intake Air Control (IAC) valves on SHO 3.0/3.2L intake manifolds are operated by vacuum from IAC solenoid valve controlled by control module. IAC valves change intake passages for increased power over greater range of rpm.

IAC changes the air intake flow so the air passages are longer at lower rpm, and shorter at higher rpm. Do not confuse the manifold intake valves with the traditional cylinder-head intake valves. The manifold valves are like throttle-valve plates.

In the manifolds, the front Intake Valve and the rear Intake Valve are vacuum-operated. The control module controls operation of the IAC solenoid actuator. At higher rpm, control-module signal voltage to the solenoid closes the IAC valves by vacuum operation. This has the effect of shortening the intake manifold runners and increasing the ram effect.

Intake Manifold Runner Control (IMRC)

Intake Manifold Runner Control (IMRC) manages air delivered to the dual intake valves of the 4.6L-4V V-8. See Fig. 2-9. IMRC differs from the IAC "resonance" control in the SHO engines and the other Ford DOHC engines. In the 4.6L-4V, IMRC closes off one set of intake manifold runners at low rpm (below about 3,000). So, even though all intake valves open, the engine operates through the primary intake runners as a single-valve (per cylinder) engine. With no air delivered to the secondary intake vales, economy and emissions are improved at low speed, low load.

"Resonance" is the term describing the back and forth movement of air in the short and long intake runners of the SHO engine, and some MECS engines. The purpose is to increase power over a broad band of engine speeds. Do not confuse this resonance with the passive resonance chambers of the intake system. Their purpose is to reduce intake noise. They are not part of engine control.

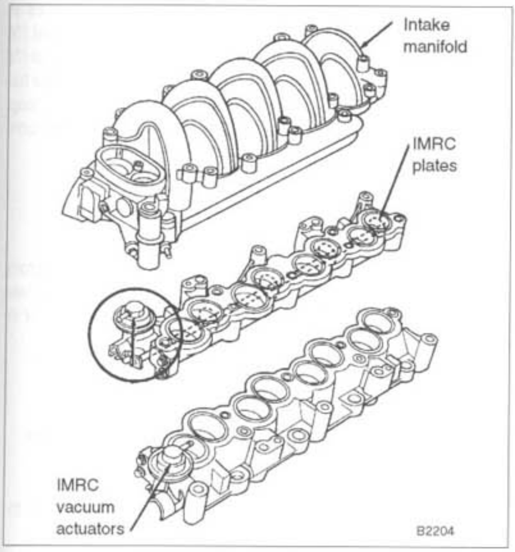


Fig. 2-9. Intake Manifold Runner Control (IMRC) on 4.6L-4V delivers intake air to one manifold runner (primary) and intake valve for each cylinder. Above about 3,000 rpm, IMRC valves open to deliver air to both intake valves.

As rpm rises, the control module signals the IMRC vacuum solenoid to vent the two IMRC Vacuum Actuators (one for each cylinder bank). The eight spring-loaded secondary valve plates (one for each cylinder secondary-intake-runner) open. With intake air delivered to both intake valves of each cylinder, more power is available on demand. On the camshafts, each secondary intake-cam lobe opens the secondary intake valve slightly later than the primary intake valve, promoting swirl in each cylinder.

The driver's foot (or cruise control) controls power of this 4.6L-4V engine by the mechanical throttle in the throttle body. In contrast, electronic control (IMRC) of the valve plates in the secondary intake runners improves power output in the higher ranges.

MECS High Speed Inlet Air (HSIA) Control

In High-Speed Inlet Air (HSIA), different kinds of manifold valves control the length of the intake runners in 1991 and later 1.8L DOHC engines. See Fig. 2-10. The HSIA control operates for the same purpose as the Intake Air Control (IAC) of the SHO engines. You'll also find the nomenclature Variable Inertia Charging System (VICS), and Variable Resonance Induction System (VRIS).

Below 5,000 rpm, the HSIA solenoid is actuated by a signal from the control module. The solenoid applies vacuum to actuate the four Shutter Valves, closing the shorter inlet air passages. Intake air must flow through the longer passages that have a longer-time inertia or "ram" effect to match the lower range of rpms. (See Chapter 2 for more discussion of the inertia effect.)

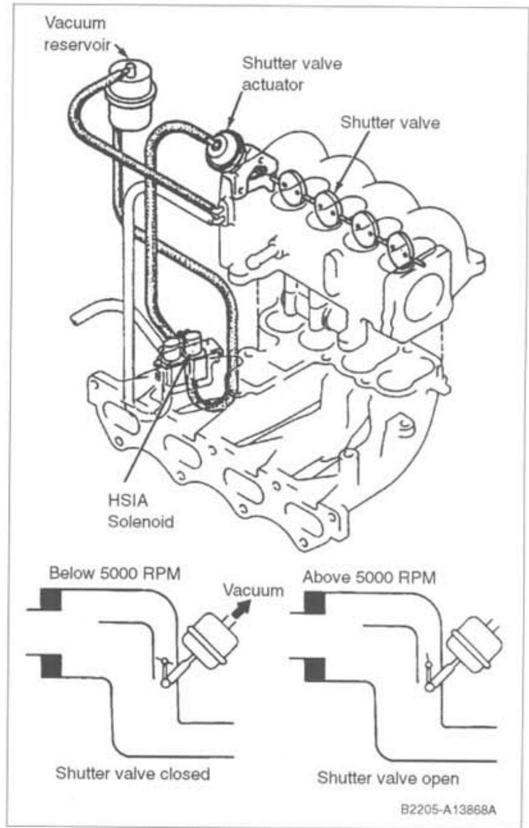


Fig. 2-10. Above 5,000 rpm, HSIA solenoid opens shutter valve actuator to atmosphere, opening four shutter valves to shorter passages. Vacuum reservoir insures power to actuate even at full-throttle.

Above 5,000 rpm, the control module signals the solenoid to vent the actuator, opening the four Shutter Valves to the shorter high speed ports for the faster inertia "ram" effects. There's no need to close the longer paths. When both sets of passages are open, the intake air naturally flows through the shorter, easier passages. The Vacuum Reservoir insures that the actuator will operate even at low-rpm full-throttle conditions.

Variable Resonance Induction System (VRIS)

The Variable Resonance Induction System (VRIS) in the 2.5L V-6 of the 1993 and later Probe improves the ram effect of the intake air at low rpm, through medium rpm, and to higher rpm. Three shutter valves are vacuum operated according to engine rpm and throttle opening angle (TPS). See Fig. 2-11.

- Shutter valve 1 (VRIS-1) opens at about 3,000 rpm, changing the resonance path from long to medium
- Two shutter valves (VRIS-2) on a shaft near the main throttle open at about 4,000 rpm. With VRIS-1 and VRIS-2 open, the resonance paths are shortest, directly to the cylinders
- Above about 6,000 rpm, VRIS-1 and VRIS-2 close again, providing best resonance path for high rpm

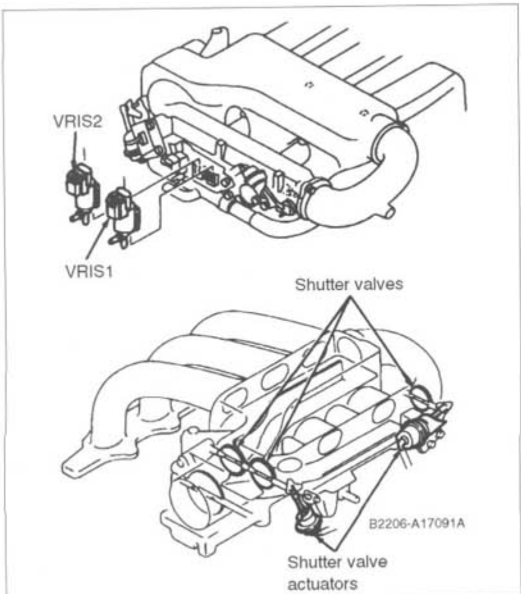


Fig. 2-11. Variable Resonance Induction System (VRIS) in 1993 and later Probe 2.5L V-6 operates similar to the IAC of Taurus SHO V-6.

MECS Turbo Boost Control (TBC)

MECS Turbo Boost Control (TBC) controls the wastegate to protect the engine from overboost, and from engine damage due to knocking.

In 2.2L engines, TBC operates the same as in EEC, with the control module controlling the wastegate. The control module limits boost to a maximum pressure of 8.7 psi (60 kPa). In overboost condition, the wide-open VAF switch will signal the control module, sounding a warning chime for the driver and cutting off fuel injection. If the KS indicates knocking even after spark timing retard, the control module will control boost to 6.5 psi (45 kPa).

In 1.6L engines, wastegate control is mechanical, based on boost pressure. Boost is limited to a maximum of 8.1 psi (56 kPa). If the Boost Pressure Switch (BPS) indicates 11 psi (76 kPa) boost, the control module cuts off fuel injection. Your turbo-boost gauge will be in the red. If the KS indicates knocking, the control retards spark timing up to 15 degrees, but the control module cannot reduce boost.

2.3 Summary

So the actuators controlling air-fuel ratio are the injectors, and, in multi-valve engines (4-valves per cylinder), the intake manifold air controls. Some engines use the resonance or inertia effect to pack in more air:

- In SHO engines, IAC solenoid controls intake air passages
- In 1.8L DOHC, HSIA controls intake air passages
- In 2.5L V-6, VRIS controls intake air passages
- In the 4.6L-4V, IMRC electronically controls secondary throttles to increase intake air delivery to engine secondary-intake valves.

3. SPARK TIMING

All Ford EEC systems handle spark timing electronically in the control module, and therefore need no centrifugal weights or vacuum diaphragms. Through the 1980s most EEC systems use distributors. Through the 90s, the control module handles both timing and distribution, eliminating distributors.

3.1 Thick-Film Integrated-IV (TFI-IV) Ignition

Thick-Film Integrated-IV (TFI-IV) is an electronic distributor-type system using an integrated ignition module. "Thick film" refers to the manufacture of the solid-state trigger and power units in the module. It has no service meaning except that TFI is different from Duraspark. TFI-IV ignition systems began with the first EEC-IV systems in 1983.

The EEC control module uses the Profile Ignition Pickup (PIP) and Cylinder Identification (CID) signals to determine the proper point to fire the coil. See Fig 3-1. The control module sends the Spark Output (SPOUT) signal to the TFI module to turn the coil on and off. The TFI module also generates the Ignition Diagnostic Monitor (IDM) signal so that the EEC module can check TFI operation. Operation of the PIP and CID sensors is covered in Chapter 4.

TFI Module

The TFI module acts as an electrical switch controlling the flow of electricity to the coil. See Fig. 3-2. TFI circuits calculate the best coil-charging time between SPOUT pulses. The TFI module is usually mounted on the distributor, except on models with Closed Bowl distributor, as described below.

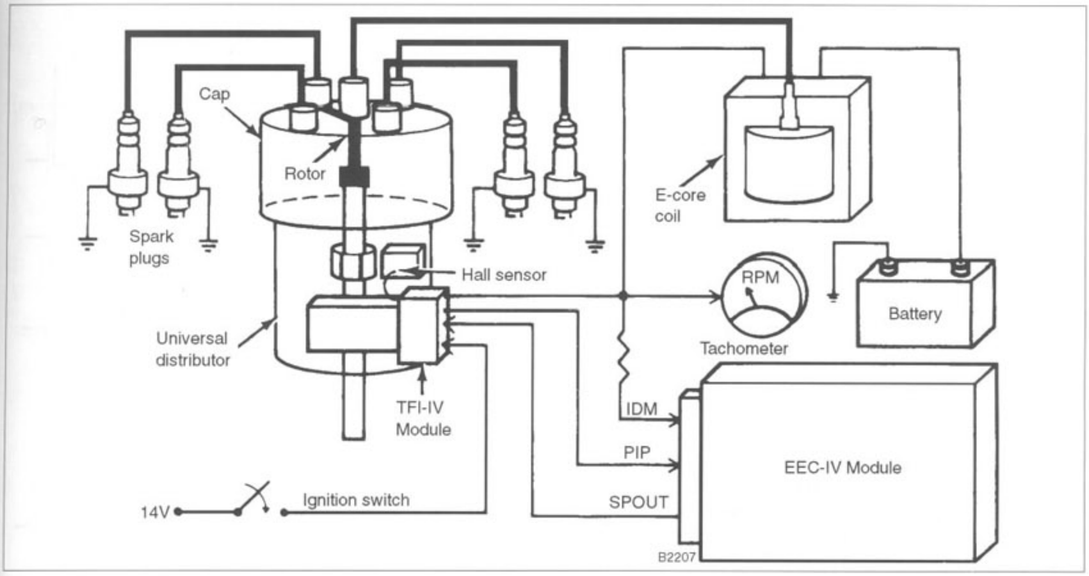


Fig. 3-1. EEC-IV ignition system is slightly different from other makers' systems. Thick Film Ignition (TFI) module is switch for spark timing, as controlled by EEC module.

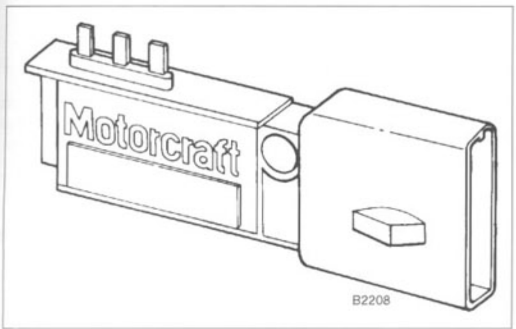


Fig. 3-2. TFI Module is solid-state unit that calculates timing and switches flow of electricity through ignition coil.

Spark Output (SPOUT)

The signal controlling ignition is the Spark Output (SPOUT) from the control module to the TFI module. The SPOUT signal determines the ignition timing of the next plug in firing order. It differs slightly according to the type of ignition. As shown in Fig. 3-3, spark timing goes through TFI Module twice:

- The PIP signal goes through the TFI module to the control module for advance or retard adjustments
- The SPOUT signal from the control module goes back to the TFI module
- The TFI module opens the primary circuit to control spark timing, and switches primary closed
- If the TFI module does not receive a SPOUT signal, it times the ignition directly from the PIP signal

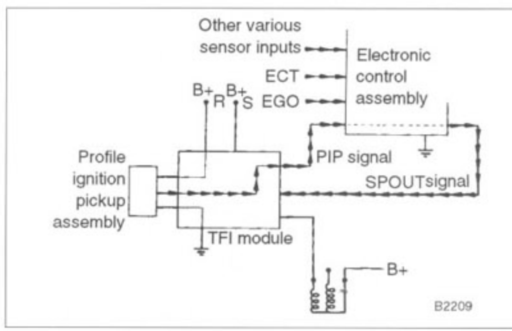


Fig. 3-3. Control module modifies PIP signal to change ignition timing according to other sensor inputs. Control module sends SPOUT signal to TFI Module. TFI module uses SPOUT or PIP to fire ignition coil at proper timing.

In Chapter 5, you saw a typical Look-Up Table for spark advance. The control module determines that for certain conditions, say 33 kPa Manifold Absolute Pressure and 2000 rpm, spark advance should be 32 deg. before TDC.

The PIP input signals the control module about rpm and the basic crankshaft position of 10 deg. BTDC. Using other sensor inputs, such as ECT and EGO, the control module calculates the timing for 32 deg. BTDC, and sends an output signal to the TFI. TFI compares SPOUT and PIP for timing to open the primary circuit for the coil, causing firing of one plug as selected by the distributor rotor.

Ignition Diagnostic Monitor (IDM)

Ignition Diagnostic Monitor (IDM) signal is sent from the TFI Module to the control module as a check of ignition function. This uses the same pin that sends the signal to the coil and to the tachometer. The control module compares the IDM with the SPOUT to verify that the coil signal from the TFI module matches the SPOUT signal from the control module. If they are not the same, the ignition system probably has some fault.

The control module will turn on the "Check Engine" Light and store the proper trouble code in its memory. If the fault is serious, *the control module will switch over to Failure Mode Effects Management* (FMEM) so you can drive home or to the shop. Ford has described this checking as "SPOUT is the shout, IDM is the echo."

Push Starting

For push starting, output of the control module is modified for stronger spark under conditions of low battery. The control module recognizes push-starting condition as a relatively low rpm signal, as if cranking, but no START signal, as if cranking with the starter. Push starting mode provides longer dwell for greater coil ON time. See Fig. 3-4.

Compare the waveforms of the Ignition Control Module (ICM), the upper showing push-start mode, and the lower, regular Computer-Controlled Dwell (CCD). In each set of waveforms, the top set of lines shows the spark firing lines as you would see them on the scope.

- Push start: the coil is fired (turned off) by the rising edge of a SPOUT signal. This provides the longest coil ON time for maximum charging of the coil Charging time is not controlled by SPOUT signal.
- CCD: SPOUT signal rising edge fires the coil. Falling edge turns coil ON, just long enough to charge coil

TFI-IV With Closed-Bowl Distributor (CBD)

TFI-IV Closed Bowl identifies a distributor design in 1988–90 3.8L engines. The distributor bowl is closed, and the TFI module is remotely mounted. One PIP signal (PIP-B) is sent to the TFI module. A second PIP signal (PIP-A) is sent to the control module, along with the ignition ground, along with the

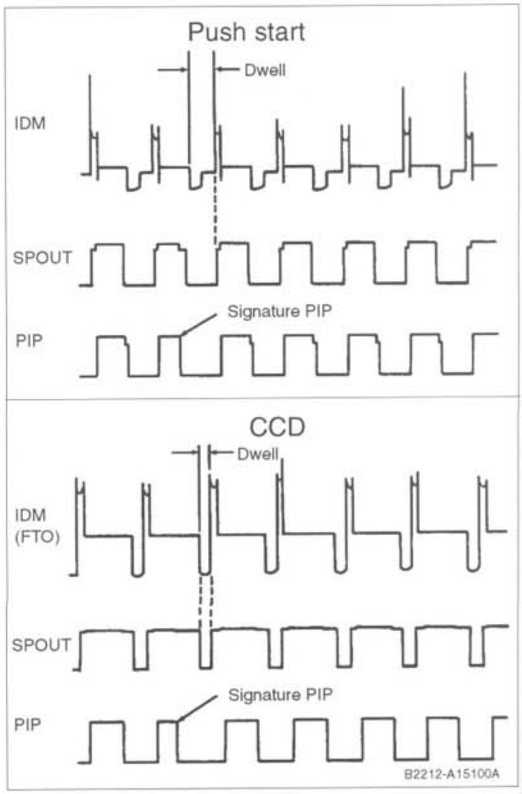


Fig. 3-4. Push-start spark signals, upper, fire plugs when ignition is ON, PIP signals are low rate, and START signal is missing. Compare to Computer-Controlled Dwell (CCD), lower.

SPOUT signal from the TFI. See Fig. 3-5. These show in the wiring diagram *as passing through a grounded shield.*

TFI With Computer-Controlled Dwell (TFI-CCD)

TFI Computer-Controlled Dwell (TFI-CCD) is used on some Ford engines, beginning with the 1989 3.0L in California. By 1992, most Ford systems control dwell, the minimum time necessary to charge the coil before the next firing, either TFI or DIS/EDIS (see following).

CCD computes the timing of closing the primary circuit. See Fig. 3-6. In effect, CCD answers the question, "When must TFI close the primary circuit for the next firing (which keeps changing its timing) so the coil primary current can rise to the proper level just at the moment of opening the primary circuit?" For example, the higher the rpm, the sooner the primary circuit must close to allow enough time to charge the coil, so CCD includes inputs from PIP. CCD delivers less energy into the coil to reduce overheating.

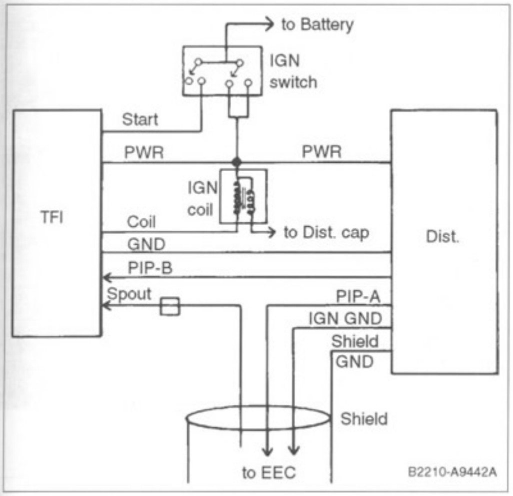


Fig. 3-5. TFI-IV Closed Bowl Distributor mounts TFI module remote from distributor. PIP-B signals go to TFI, while PIP-A signals go to control module.

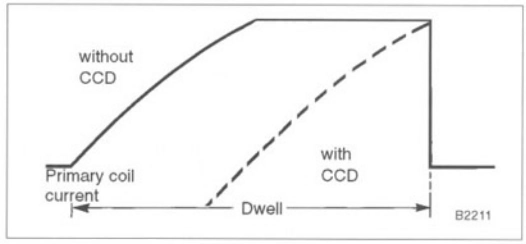


Fig. 3-6. Without CCD, primary coil current must be turned on well before firing timing. With CCD, primary coil current is turned on so primary coil current reaches proper level just at turn-off for spark timing.

3.2 Distributorless Ignition System (DIS)

You already know how computer-controlled ignition systems eliminated points to switch the coil current. Distributorless Ignition Systems (DIS) eliminate the rotor and cap to distribute the high-voltage current directly from the coils to each plug.

6

The DIS module, Fig. 3-7, uses the Profile Ignition Pickup (PIP) sensor signal, Cylinder Identification (CID) sensor signal, and the Spark Output (SPOUT) signal from the EEC mod-

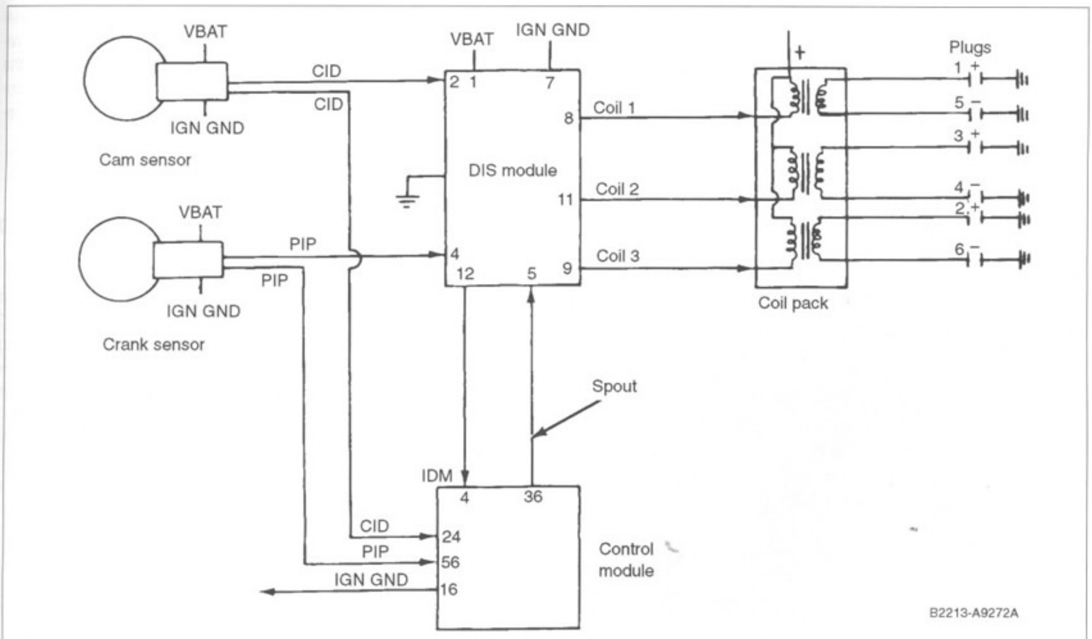


Fig. 3-7. DIS module receives SPOUT signal from control module. Comparing it to PIP and CID, module calculates timing and determines which coil to fire.

ule to determine coil turn on and turn off. PIP and CID sensors used on different DIS models are covered in Chapter 4.

In place of the distributor and coil, look for one or two box-shaped coil-packs. See Fig. 3-8.

- For most 4-cylinder engines, the coil pack handles two pairs of 2 cylinders. (Exception: Dual-Plug DIS uses two coil packs
- For a 6-cylinder, the coil pack handles three pairs of two cylinders
- In the 4.6L V-8, two four-cylinder coil packs handle the four pairs—8 cylinders

DIS Module

The DIS module replaces the TFI module. See Fig. 3-9. DIS receives input from both PIP and CID Hall-effect sensors. Most DIS engines use a single set of plugs, while Dual-Plug DIS (DPDIS) on some 2.3L engines uses dual plugs. I'll concentrate in single-plug DIS, first used on 3.0L engines including SHO, and 3.8L engines.

SPOUT signals are sent by the control module to the DIS module. Comparing SPOUT to PIP and CID, the DIS module determines when to fire a coil, and decides which coil to fire. During cranking, CID determines which coil to fire. During running, CID also determines sequential fuel injection (SFI).

DIS includes CCD—Computer Controlled Dwell. In Fig. 3-10, you can see the SPOUT signals, a series of digital pulses.

- The first signal, SPOUT off, closes the primary of 1 coil so the current increases, charging the coil
- The second signal, SPOUT on, opens the primary of 1 coil so the current falls, firing two plugs, Power and Waste

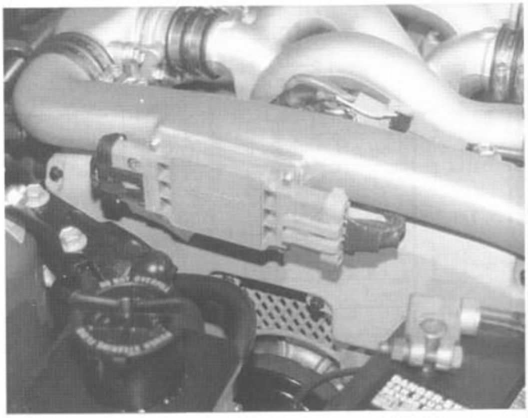
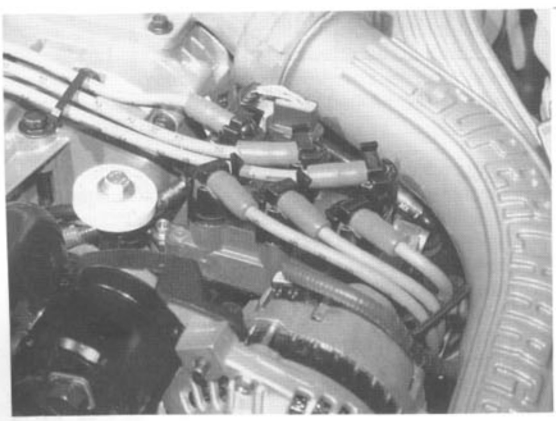


Fig. 3-9. DIS module on 3.0L SHO engine.

The difference between the first (on) and the second (off) signals is dwell. By changing the on-time to be just right for the off-time, the DIS module uses the length of the SPOUT signal to control the dwell. See Fig. 3-11.

At engine start, coil 2 always fires first. In the V-6, cylinder 3 is rising on compression stroke while cylinder 4 is rising on the exhaust stroke. Coil 2 fires two sparks at the same time. In cranking, during the next crankshaft revolution, the CID signal causes 3 and 4 to exchange. Cyl 4 on compression stroke receives the power spark; Cyl 3 on exhaust stroke receives the waste spark. Each coil fires in the order 2-3-1, firing synchronized with compression strokes. The coils continue in this relation to the firing order.



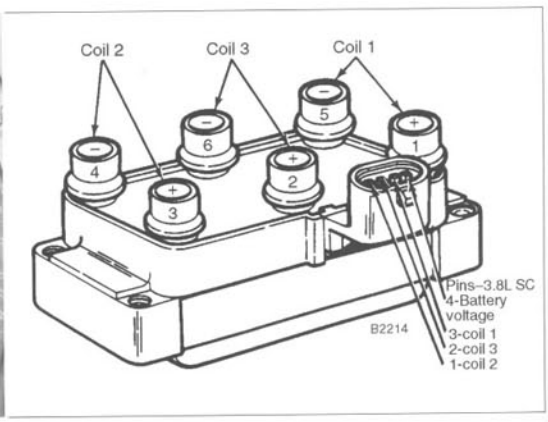


Fig. 3-8. DIS coil pack replaces distributor and coil. Three coils fire six cylinders of 3.0L and 3.8L engines.

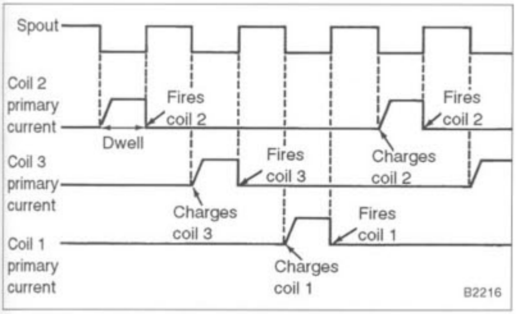


Fig. 3-10. When SPOUT signals on, DIS module closes primary—current increases. When SPOUT signals off, primary opens, firing coil, determined by timing needs. Dwell is difference between off and on.

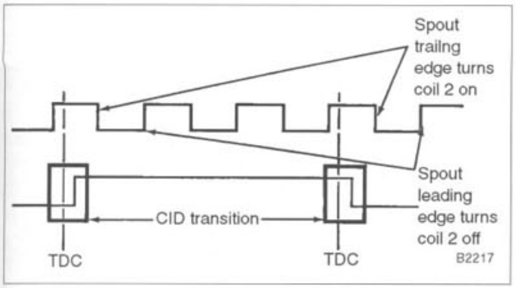


Fig. 3-11. SPOUT signals and CID signals combine to choose which coil to fire. They control coil turn-on and turn-off, firing two plugs.

Cylinder Pairs

Each coil fires a pair of two cylinders at the same time, the two cylinders that rise toward TDC at the same time. See Fig. 3-12. I'll call them "A" and "B." Cylinder A is rising on the compression stroke, ready to fire. A gets most of the coil energy in what is called the "power spark." As B is rising on its exhaust stroke, B gets a little of the coil energy in what is called the "waste spark." On the next rotation of the crankshaft, when B rises on its compression stroke, B gets the power spark and A gets the waste spark. The big question is: "how does the coil know?" (See sidebar, page 126.)

At first, it may seem impossible to fire two cylinders with one coil. In fact, a few engines (not Ford) provide a separate coil for each cylinder, four for the Saab 4, and 8 for the Lexus V-8. If you don't care how Ford fires two plugs with one coil so the

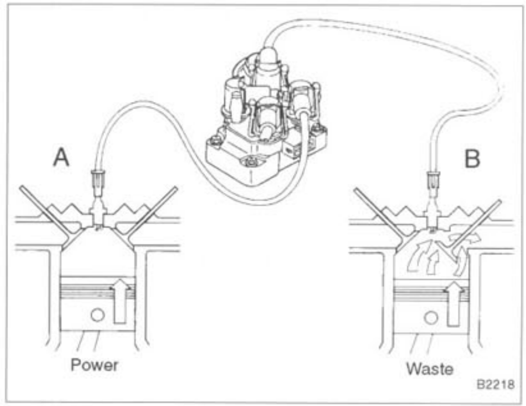


Fig. 3-12. Two plugs fire in pairs from each coil. When plug A is on its compression stroke, A gets power spark, most of coil energy. Plug B is on its exhaust stroke, so it gets waste spark. On next rotation of crankshaft, B gets power spark and A gets waste spark.

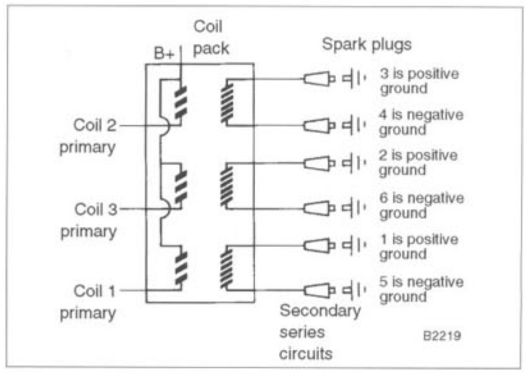


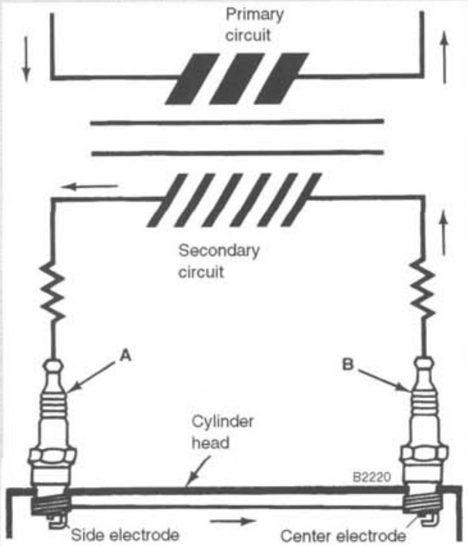
Fig. 3-13. Each coil fires a pair of plugs. Coil 2 fires both plugs 3, positive ground, and 4, negative ground.

proper cylinder gets the proper spark, skip the side-bar on the next page.

On the 4.6L V-8s, you see one DIS coil pack at the end of each cylinder bank. See Fig. 3-14. You may wonder why each pack doesn't just handle the plugs in that bank. Why do the plug wires cross-over to the other bank? Then you realize that each coil handles two cylinders in pairs depending on their sequence in the firing order. An "A" cylinder in one bank pairs with a "B" cylinder in the opposite bank.

How does the coil know?

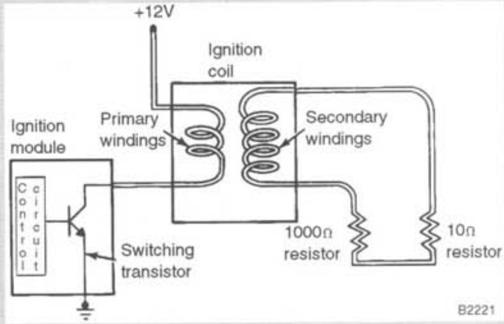
I will tell you, beware of misinformation about why the power spark delivers high voltage to the cylinder on the compression stroke. Even some Ford factory manuals are confused about this. Let's see if we can figure it out.



Each end of secondary connects in series to one plug, with circuit completed through cylinder head.

From the coil secondary, current flows through the plug cable to plug A and jumps from the center electrode to the side electrode. Crossing through the head to plug B, the current jumps from the side electrode to the center electrode, completing the series circuit through the plug cable to the coil. The amount of current flow is the same throughout the series circuit. What differs between the two plugs is voltage.

- In A, on its compression stroke, the cylinder pressure is high, requiring higher voltage to overcome the resistance of the air-fuel mixture to fire the spark.



Consider two spark plugs as resistors with same current flowing through a series circuit. Plug with lower resistance (~10Ω) (exhaust stroke) has lower voltage drop, and lower energy (waste spark). Plug with higher resistance (compression stroke) gets power spark.

- In B, on its exhaust stroke, the cylinder pressure is low so the waste spark fires at low voltage.

The power spark goes to the proper cylinder (under compression) and the waste spark goes to the cylinder during exhaust based on cylinder pressure and the associated resistance. *With two cylinder pairs connected in series to each coil, the current flow must be the same.*

- When A is beginning its power stroke with high compression pressure, it will require high voltage to jump the spark gap, say 10 kv. Power is proportional to voltage, so A gets the power spark
- B gets the low voltage waste spark, say less than 2-3 kv., because it is firing into the exhaust gases at low cylinder pressure. The waste spark has no effect on emissions or power

To see DIS on the engine analyzer scope, select secondary display for a two-cylinder engine, and place the secondary pick-up on each plug lead one at a time. Look for the high voltage of the power spark in cylinder A, plus the alternate firing of the high voltage of the power spark in cylinder B. The usual display adds them on the screen—A, then B, then A, until they appear to be simultaneous. In between, you'll see a little noise from another coil for another cylinder pair.

Dual Plug DIS (DPDIS)

Dual Plug DIS (DPDIS) provides dual ignition in each cylinder to improve the burning of the air-fuel mixture, increasing power and reducing emissions. See Fig. 3-15. DPDIS operates on PIP and CID signals from the Dual Hall sensor described in Chapter 4. On the left side of the engine, you'll find the DIS Module, the four left-side plugs, and the left coil pack. On the right side, you'll find another set of four plugs and another coil pack.

Dual-Plug Inhibit (DPI)

Both left and right-side plugs fire at the same time when the engine is running. When it is cranking, however, only the right set of plugs fires. During cranking, the control module signals the DIS Module through the Dual-Plug Inhibit (DPI) circuit to inhibit or restrict the left set of plugs from firing.

Fig. 3-14. Coil pack on each cylinder bank of 4.6L V-8 shows plug wires crossing to other bank, necessary to fire cylinders in proper pairs.

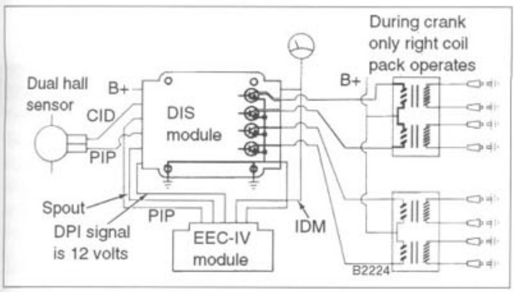


Fig. 3-15. DPDIS module fires two coils under control of control module. During crank, DPI signal from control module to DIS module acts to inhibit (shut off) left set of plugs.

3.3 Electronic Distributorless Ignition System (EDIS)

The Electronic Distributorless Ignition System (EDIS) simplifies the earlier DIS by using a single crankshaft-mounted Variable Reluctance Sensor (VRS) in place of the PIP and CID sensors. VRS generates a more complex signal, and provides more accurate spark timing, both steady state and transient (acceleration).

EDIS uses dual coil packs similar to DIS coils, and also uses two plugs, one firing on the power stroke while the other fires on the exhaust (waste) stroke. See Fig. 3-12 above. The EDIS module (Fig. 3-16) uses the PIP and CID signals from the VRS, and the Spark Angle Word (SAW) signal from the EEC module, to determine coil turn on and turn off. See Fig. 3-17. See Chapter 4 for more information on VRS operation.

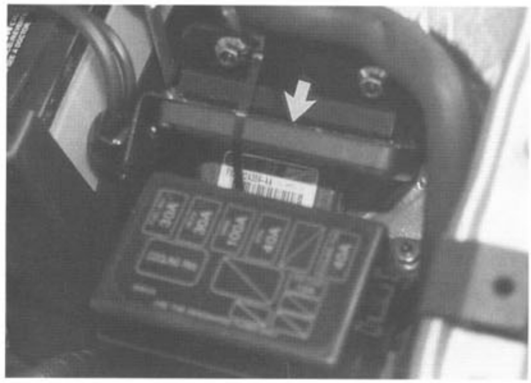


Fig. 3-16. EDIS Module calculates spark timing and coil firing. It selects proper coil and turns it on and off with a coil driver. It is usually located on a fender apron.

Electronic Distributorless Ignition Systems (EDIS) first appeared in:

- 1990 1.9L 4-cylinder engine in Escort/Tracer
- 1990 4.0L V-6 engine in Ranger, Bronco II, and Aerostar
- 1991 4.6L V-8 engine in Lincoln Town Car

Spark Angle Word (SAW)

Spark Angle Word (SAW) is the response by the control module to the EDIS module after the control module does its usual job of calculating the advance or retard of spark timing. In EDIS, SAW is the same kind of signal as SPOUT is to TFI-IV and DIS.

In the EDIS Module, the microprocessor decides which coil to fire at what millisecond—coil selection and spark timing. In addition to the coil-driver outputs, the EDIS Module confirms its timing by sending the IDM signal to the control module, a signal that also operates the tachometer.

Repetitive Spark (1.8L Escort/Tracer)

Repetitive Spark fires each plug with a series of sparks for each ignition during operation under 1,000 rpm. This tends to smooth the idle. You'd never know the difference except:

- Your external tach will probably misread actual rpm
- You can see the extra spark pulses on a scope

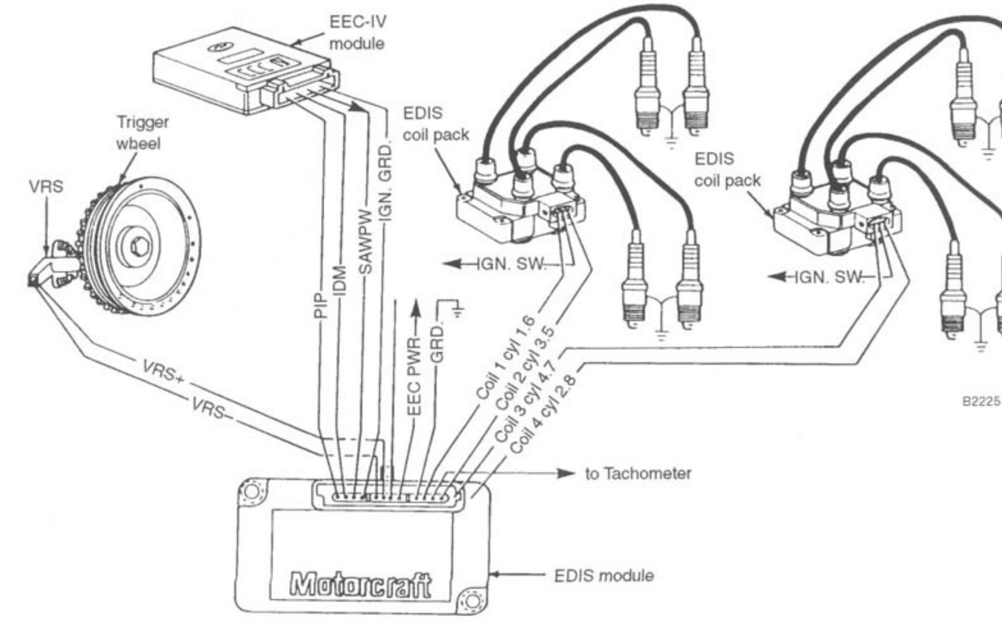


Fig. 3-17. EDIS on 4.6L engine uses two sets of two EDIS coil-packs, each firing two cylinders. Firing cylinder-pairs, two wires cross over from each set of coil packs to opposite bank of cylinders. EDIS Module has own ground to the battery negative post.

Delay Start

On some EDIS engines, Delay Start allows crank without ignition for about half a second. The purposes:

- Insure oil flow to the bearings before starting loads
- Insure full revolution of the crankshaft for better timing signals from the VRS

3.4 MECS Spark Timing

As of 1993, all MECS ignition systems operate with a distributor; none are DIS. Several operate with mechanical-advance flyweights and vacuum-operated diaphragms! Mazda-speak: "Distributor-Mounted Ignition Module with Vacuum Advance (DMIVA)". Forget it—I'm talking primitive electronic ignition as we knew it in 1975. The engines include the 2.2 L non-turbo, 1.6L turbo and non-turbo. Look for the vacuum hoses running to the distributor.

Other MECS engines are more modern, controlling spark timing as determined by the engine-control module, similar to EEC systems.

MECS Electronic Spark Advance (ESA) controls spark timing based on input signals from many sensors, as shown in Fig 3-18. The control module calculates timing and signals the igniter to generate the high voltage for the coil.

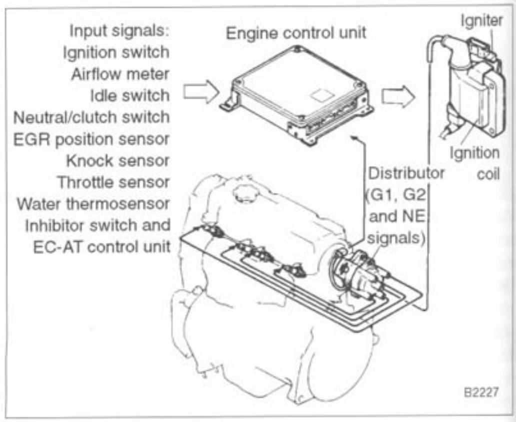


Fig. 3-18. MECS Electronic Spark Advance (ESA) operates in similar manner to Ford EEC systems. Igniter generates high voltage to coil.

4. THROTTLE BYPASS AIR—IDLE SPEED CONTROL (ISC)

The Throttle Bypass Air—ISC performs three functions:

- Controls idle speed according to a variety of engine loads and conditions
- Acts as an electronic dashpot during deceleration, preventing engine stalling, and preventing too-low manifold pressure that causes excess emissions
- Provides additional air during starting, bypassing the closed throttle

These roles are reflected in the new terminology under SAE J1930 in 1993, with the term "Idle Air Control." This throttle bypass does more than most people realize since the functions of deceleration control and emission control are hidden by the name. I'm talking about the amount of air that enters the engine when the driver's foot is off the accelerator. In engineering terms, an engine operating at "no-load" is at idle, regardless of the rpm. So the name change helps us understand this control.

Beginning with 1988 models, all Ford EEC systems use Idle Speed Control—ByPass-Air (ISC-BPA) Valve Assembly. ISC-BPA bypasses air around the closed throttle plate(s). Although they are sometimes described by the same name, the EEC ISC-BPA is quite different from the MECS-I ISC-BPA described below. The EEC unit uses only electronic control, while most MECS units use a combination of electronic control and mechanical coolant-control. Exception: 1993 and later Probe 2.5L V-6 idle air is controlled by Powertrain Control Module as in EEC, but not the '93 and later Probe 2.0L.

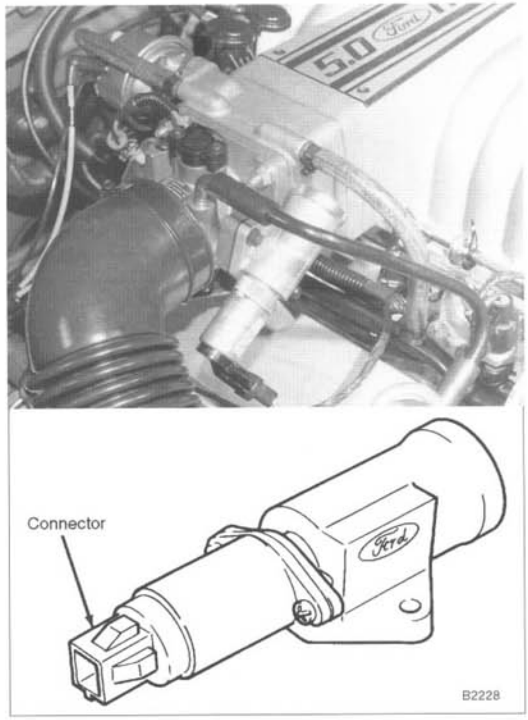


Fig. 4-1. Throttle-Bypass Air (ISC) valve usually mounts on throttle body to provide a passage around throttle plate.

4.1 Bypass Air Valve Assembly (ISC-BPA)

The Throttle-Bypass Air valve is usually mounted on the throttle body. See Fig. 4-1. In normal operation, it allows controlled air to bypass the closed throttle plate(s). This bypass air must not lean the air/fuel ratio of the mixture. The air flowing through the bypass usually comes from directly upstream of the throttle so it is measured air.

- For VAF or MAF systems, the increased bypass air flow increases the air flow signal, automatically adding fuel to compensate
- For the MAP systems, the bypass air increases the measured MAP. The calculated increased air flow signal automatically adds fuel to compensate

A few Ford engines draw bypass air from the air cleaner. This is unmeasured air. The control module calculates the increased air flow according to the bypass air signal, and adds fuel to compensate. You can tell those engines by the air hose from the air cleaner to the Bypass Air valve.

Duty Cycle

The Throttle-Bypass Air valve is positioned by a solenoid, controlled by output ISC signals from the control module. Supplied with Vehicle Power (VPWR), the solenoid is grounded in the control module. The solenoid receives a series of digital pulses. The more pulses, the greater the opening. See Fig. 4-3.

- With 100% duty cycle pulses, the solenoid receives maximum current and opens the valve fully.
- With 0% duty cycle (no pulses), the valve is closed

In normal engine-idle operation, the valve is held partly open, allowing some air to bypass the throttle. It closes as necessary to reduce idle speed, and opens to increase idle speed.

In "dashpot" mode, it allows bypass air to flow during deceleration to prevent engine stall. Of course, as the engine speed reduces, bypass air must be cut off to allow engine braking and to prevent fast idle.

100% duty cycle is the normal setting for CRANK, providing what Ford calls "no-touch" starting.

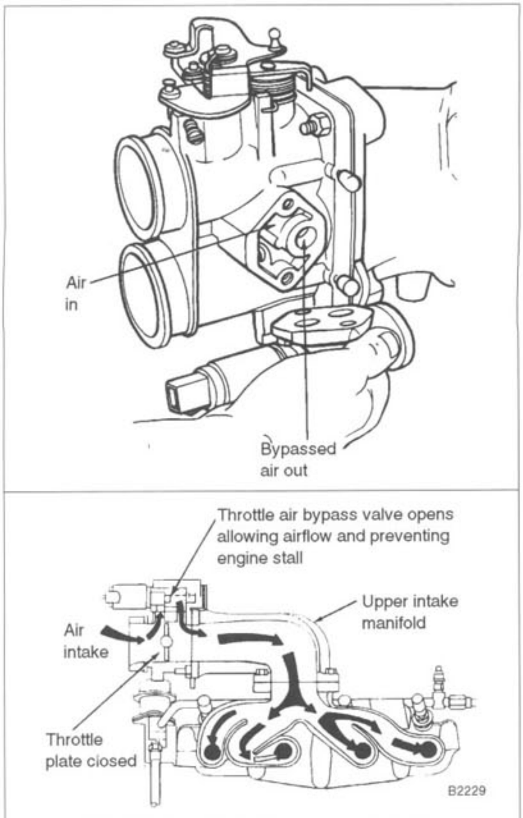


Fig. 4-2. Throttle Bypass Air is normally part way open allowing barometric air to bypass a closed throttle into the area of reduced MAP.

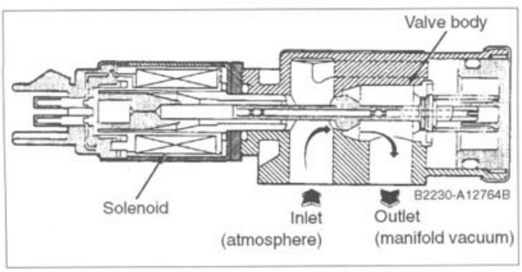


Fig. 4-3. Opening of plunger in ISC-BPA valve is controlled by solenoid, in response to signals from control module.

You may find three types of BPA valves on late model EEC systems. The first is a Hitachi model, shown in Fig. 4-1 above. When clogged with fuel sludge, the valves can be cleaned. A second Hitachi valve has a vent and filter (used to equalize pressure in the valve, not to pass air). This type cannot be cleaned. See Fig. 4-4. A third type is made by Nippondenso, and also cannot be cleaned. See Fig. 4-5.

Fig. 4-4. If you see vent filter (arrow), you know this is a different Hitachi unit that cannot be cleaned.

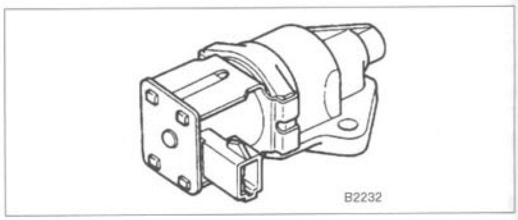


Fig. 4-5. If you see a black plastic housing, do not use cleaning solvent on this Nippondenso valve.

4.2 MECS Throttle-Bypass Air

Most Mazda Engine Control (MEC) engines control Throttle-Bypass Air in a combination of electronic Idle Speed Control (ISC) and mechanical ByPass Air (BPA). This is known as Bypass Air Control (BAC), where incoming air can bypass the closed throttle through two separate passages. Depending on the engine, there may be a single ISC-BPA valve (also known as a BAC valve) or two separate valves.

Electronic Control

The ISC valve is electronically controlled by duty-cycle signals from the control module, controlling bypass air according to engine rpm and load signals. See Fig. 4-7. The air valve is normally half open. Increased duty-cycle signals cause increased air flow to increase or maintain engine rpm, or to control air flow during deceleration. The ISC operates at all temperatures.

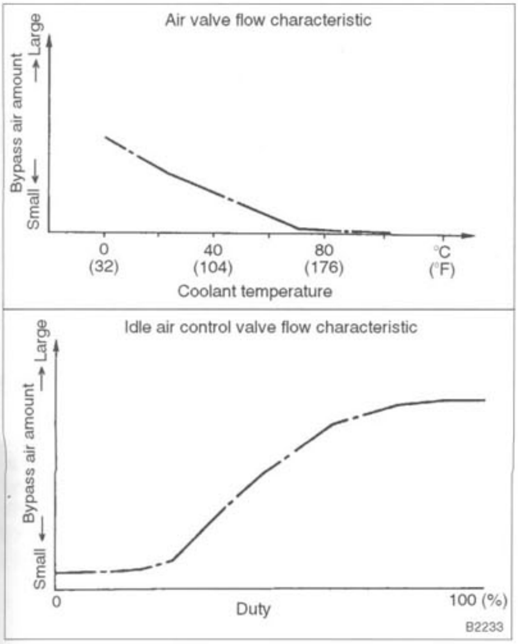


Fig. 4-6. Upper curve shows amount of bypass air controlled by coolant temperature. Lower curve shows amount of bypass air controlled by duty cycle of ISC linear solenoid valve.

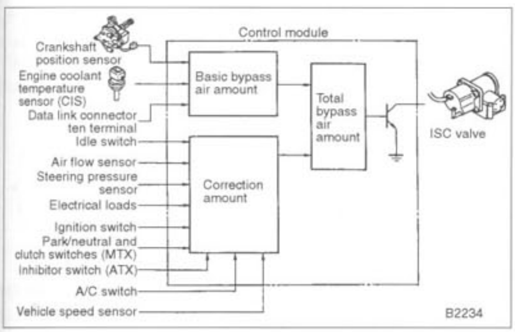


Fig. 4-7. Electronic control of ISC valve depends on sensor inputs of rpm and coolant temperature. Additional control is based on many additional sensor inputs.

Coolant Control

The BPA valve is directly controlled by coolant flow through the valve, bypassing more air when coolant temperature is lower. See Fig. 4-8. Think of it as a thermostat for intake air.

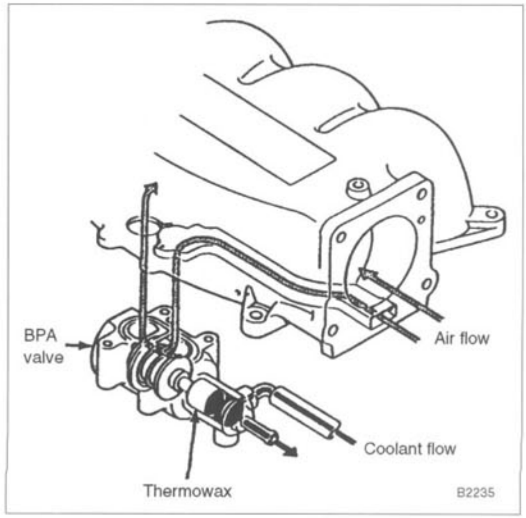


Fig. 4-8. Dark arrows indicate coolant flow through BPA, bypassing throttle plate(s). Gray arrows indicate passage of air.

The colder the coolant, the greater the bypass air through this passage. Below about 50°C (about 120°F), cold coolant flow causes the thermowax material to contract, increasing air flow. Above those coolant temperatures, the BPA is closed and has no effect on bypass air.

> **NOTE —**
> The 1.6L Capri engine needs a bit more air when cool. It bypasses intake air until coolant temperatures above 60°C (about 140°F).

The electronically-controlled ISC and the coolant-controlled BPA are usually combined in a single unit. See Fig. 4-9 and Fig. 4-10. Look for the ISC-BPA on the throttle body. Exception: ISC-BPA for early 1.3L and 1.6L mounts on the bulkhead. In later 1.3L and 1.6L engines, look for the ISC-BPA on the side of the intake manifold.

Intake air bypasses the throttle plates through the ISC valve and through the BPA valve, returning to the intake manifold. Coolant flows through the BPA valve to add air flow when the engine is cool. The same coolant flow passes through the ISC valve to cool the solenoid. The coolant has no control function in the ISC.

Look for a different ISC and BPA on the 1.8L engine in the late model Escort/Tracer. Look for the BPA valve on the intake plenum, separate from the ISC valve, mounted on the throttle body.

The coolant-controlled idle-air bypass continues in the '93 and later Probe 2.0L because the Idle Air Solenoid is more limited than the others.

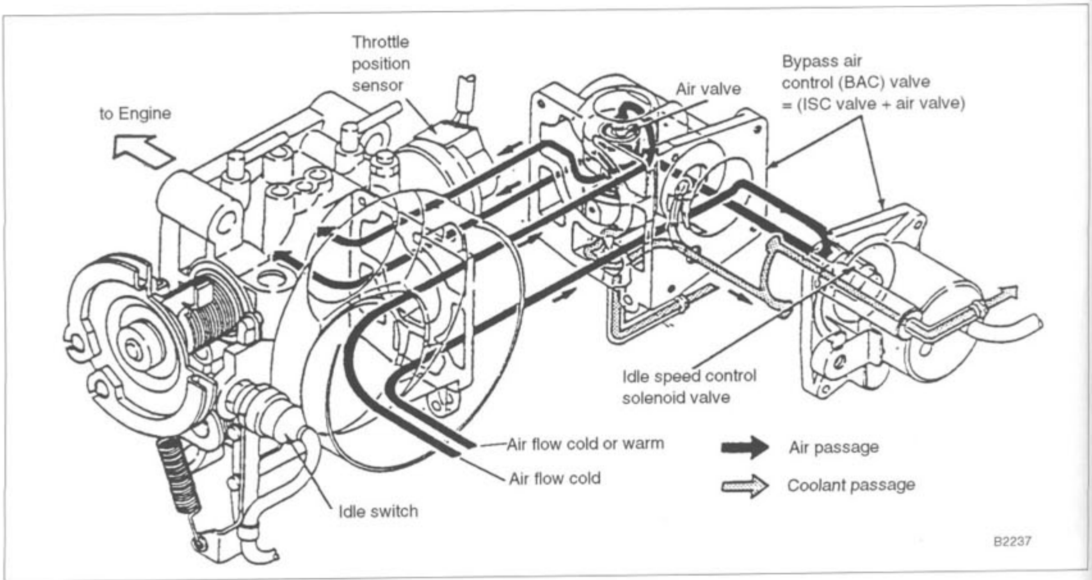


Fig. 4-9. Exploded view of combination ISC-BPA.

Fig. 4-10. Combination ISC-BPA (arrow) on 1.8L engine.

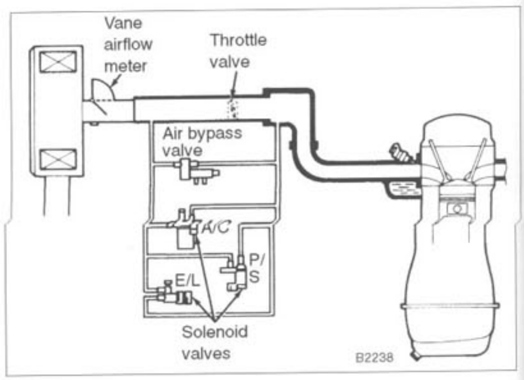


Fig. 4-11. Idle-Up system on 1.6L Tracer engine uses four throttle bypasses, generally directly controlled by electrical circuits and not by control module.

Idle-Up Solenoid Valves

Earlier MEC 1.6L engines (1988–90 Tracer) use three separate solenoid valves to operate a primitive throttle-Bypass Air known as Idle-Up, with four separate passages around the closed throttle. See Fig. 4-11.

1. The Bypass Air valve is a Bosch-type Auxiliary Air Valve, complete with both coolant flow for long-term engine temperature influence and an electric heating coil for warm-up.
2. The Air/Conditioning solenoid bypass valve is opened by power from the A/C compressor clutch circuit.
3. The Power Steering solenoid bypass valve is opened by the P/S pressure switch.

4. The Electrical Load (E/L) solenoid bypass valve is opened by a separate control module based on electrical load of headlights, blower motor, engine cooling fan, and rear-window defroster. The E/L solenoid is also energized through its control unit by the control module under two conditions:
   - During deceleration to reduce exhaust emissions on sudden throttle closing
   - At high altitudes to stabilize idle rpm

Clearly, in this Idle-Up system, idle speed is not stabilized by rpm feedback, but simply boosted as needed by feed-forward signals.

5. Emission Control Actuators

Emissions are controlled in part by engine design—by the valve design and valve timing, by the swirl of the incoming air-fuel mixture around the combustion chamber, and by many other factors. Emission control includes many systems. Some, such as PCV, are not under control by the control module so I'll deal only with those involving the EEC system:

- Exhaust Gas Recirculation (EGR)
- Secondary Air—Thermactor (TAB/TAD)
- Evaporative Emissions—Canister Purge (CANP)

5.1 Exhaust Gas Recirculation (EGR)

EGR recirculates a small amount of exhaust gas into the engine through the intake manifold. This lowers combustion chamber temperatures to minimize the emission of Nitrogen Oxides (NO_x) at part throttle. See Chapter 3 for more information on EGR.

- EGR is shut off at idle and during warm up: NO_x formation is minimal and EGR could cause rough idle
- EGR is shut off during Wide Open Throttle (WOT) operation because it causes loss of power (WOT is usually for short periods.)

Because EGR causes some loss of power, the control module changes the engine calibration (fuel injected) and the spark timing. The control module operates the EGR valve only when it receives all the following input signals:

- Warm engine signal from the ECT
- Part-throttle signal from the TPS
- Part-load signal from the MAF or MAP
- Time since start, from the timer in the control module

EGR Control

In most Ford systems, the EGR valve is vacuum operated under control of the EEC control module. Look for the EGR assembly mounted on the exhaust manifold, or near the throttle body, with the EGR sensor on top. Two Ford EGR systems control flow by monitoring pressures, or back-pressures at the EGR valve. A third, known as Electronic EGR (EEGR), controls flow by monitoring valve-position.

When the EGR system delivers exhaust gas into the intake manifold, the control module gets EGR feedback signals to reduce the fuel injection accordingly. The engine needs less fuel because there's less oxygen to burn in the recirculated exhaust gas.

Pressure Feedback EGR

Pressure-Feedback EGR systems control flow rate by monitoring pressure drop across a special metering orifice. See Fig. 5-1. These systems are known as Pressure-Feedback EGR (PFE) and Delta-Pressure Feedback (DPFE). (Delta is

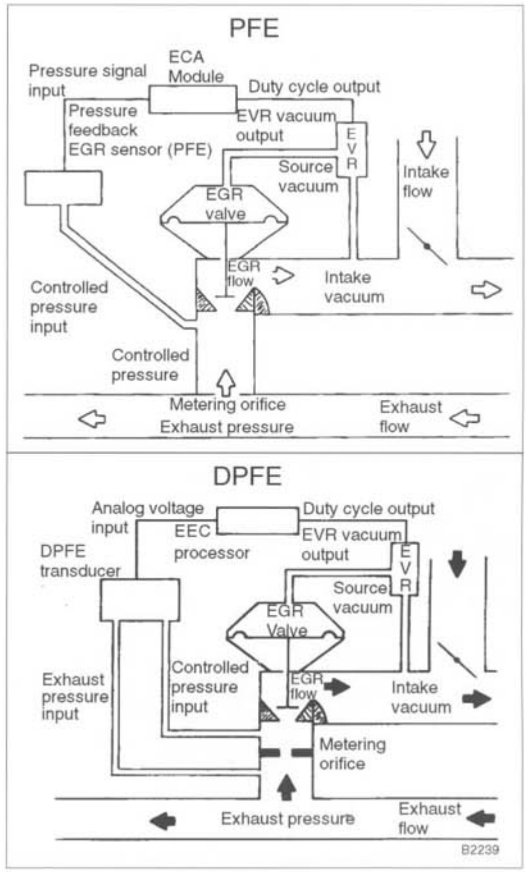


Fig. 5-1. Pressure Feedback EGR (PFE) measures exhaust pressure downstream of metering orifice. Delta PFE measures between that controlled pressure input and exhaust-pressure input. DPFE gives a more accurate measure of EGR requirements.

engineer-speak for difference.) The control module calculates the desired flow based on pressure drop beyond the metering orifice of the EGR valve. With pressure feedback from the transducer, the duty-cycle signal from the control module controls how much the EGR Vacuum Regulator (EVR) opens the EGR valve to achieve the desired pressure drop. A duty-cycle output of 50% would hold the EVR half open.

Electronic EGR (EEGR)

Electronic EGR (EEGR) monitors the position of the EGR *valve pintle. See Fig. 5-2 and Fig. 5-3.*

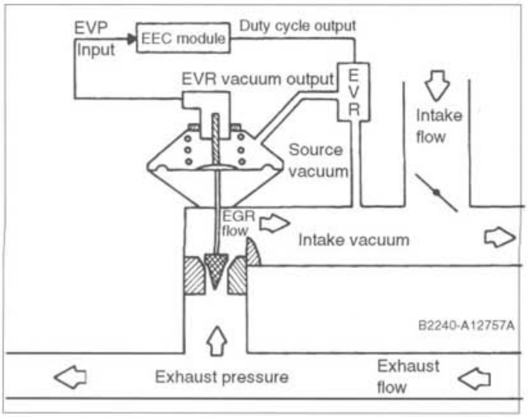


Fig. 5-2. Electronic EGR (EEGR) controls flow rate by using EGR Valve Position (EVP) sensor to monitor position of EGR valve pintle.

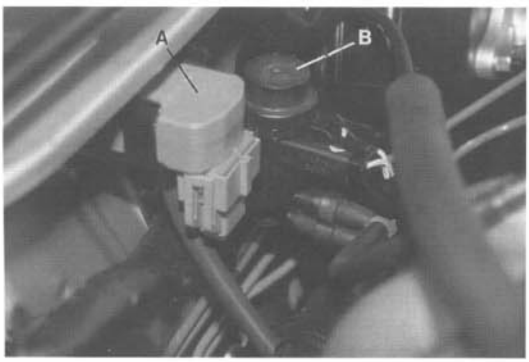


Fig. 5-3. Installed position of PFE Sensor (**A**) and EVR (**B**).

The control module calculates the desired flow and the corresponding lift of the EEGR pintle valve. The EGR Valve Position (EVP) sensor sends a feedback signal so the control module duty-cycle signal can control how much the EGR Vacuum Regulator (EVR) opens the EGR valve. A duty-cycle output of 50% would hold the EVR half open. Although PFE and EEGR are electronically-controlled, EEGR gets the name Electronic because it relies on more electronic processing in the control module.

EVP is a linear potentiometer sensor, operating on VREF of 5v. As the sensor follows the EGR valve pintle, it signals a changing voltage to the control module between:

- 0.2v., minimum EGR flow
- 4.9v., maximum EGR flow

Backpressure Variable Transducer (BVT)

The Backpressure Variable Transducer (BVT) regulates EGR on 1988 1.9L Escort engines. The EEC-controlled solenoid determines when EGR is applied. The BVT determines how much. The BVT operates on two back pressures, one from the exhaust manifold, and the other from the EGR Control Chamber. The signal from the control chamber to the BVT could be positive pressure or it could be vacuum because this chamber connects to the intake manifold when the EGR valve is open.

MECS EGR Control

EGR control in 2.2L non-turbo engines is the same as the BVT control described above. See Fig. 5-4. 2.2L turbo-engine EGR control is by twin solenoids in one unit, one to apply vacuum, the other to vent vacuum. See Fig. 5-5. This is similar to the Dual EGR solenoid valve assembly used on some 2.3L Mustang engines. No EGR is required on other MECS engines, 1.8L, 1.6L, and 1.3L.

EGR is applied and regulated by the engine control module.

- One solenoid opens the vacuum side to admit vacuum to the EGR control valve
- Other solenoid opens the vent side to vent vacuum from the valve

The two valves work together to control vacuum, operating the EGR valve. Both solenoid valves receive variable duty-cycle signals from the control module according to EGR requirements. The solenoid valves are called "dithering valves." They dither, or move back and forth to balance the vacuum control and the vacuum vent to deliver just the proper EGR flow for the engine conditions.

5.2 Secondary Air—Managed Thermactor Air (MTA)

Secondary air is delivered into the exhaust gasses to reduce emissions of HC and CO. This additional air supplies oxygen to combine with unburned fuel coming from the combustion chamber. In Managed Thermactor Air (MTA) under EEC control, sometimes identified as Conventional Ther-

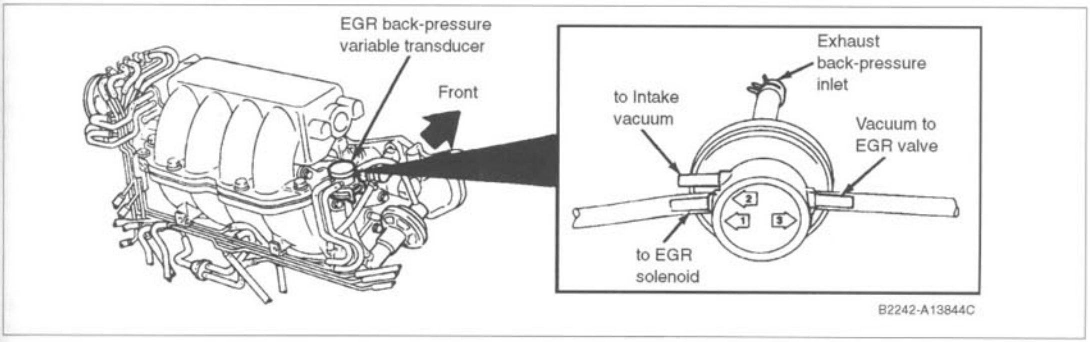


Fig. 5-4. MECS EGR Backpressure Variable Transducer (BVT) senses engine vacuum and exhaust backpressure to control vacuum to EGR valve.

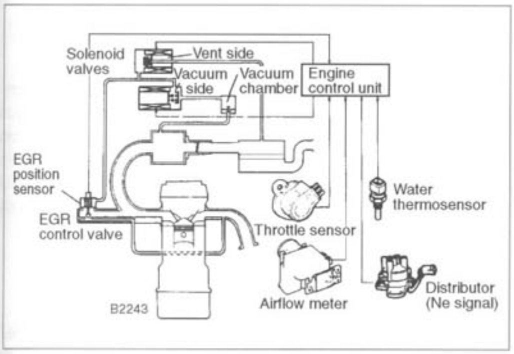


Fig. 5-5. Solenoid valves regulate MECS EGR control valve. One solenoid applies vacuum, other vents vacuum.

mactor (CT), secondary air from the engine-driven air pump is directed to one of three outlets:

- Upstream—meaning upstream of the catalytic converter. Upstream air is diverted to the exhaust manifold
- Downstream—meaning downstream of the three-way section of the catalytic converter, into the mid-bed air port
- Dumped—meaning vented or "dumped" into the atmosphere

Since 1988, most Ford engines operate without secondary air injection. You'll find it on the larger engines—1988-90 3.8L engines, and most 4.9L and above. No MECS engines require secondary air injection.

In some smaller EEC engines, secondary air is provided by a Pulse Air system. This operates on natural pressure changes in the manifolds and has no electronic controls.

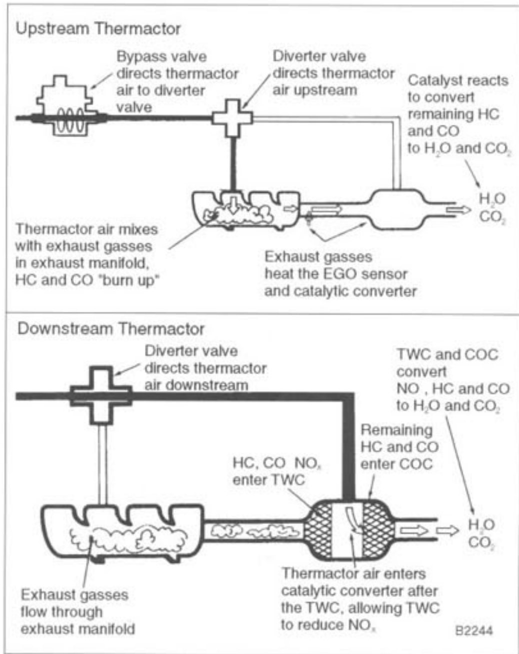


Fig. 5-6. Thermactor operation showing bypass valve (TAB) and diverter valve (TAD).

The control of secondary air by the control module depends on engine temperature and time since engine start.

The easiest way to keep Thermactor Air actuators straight is to think of two valves in series. I think the problem arises because Ford named one TAB and the other TAD. Vacuum to *each valve is controlled by a solenoid controlled by the control* module.

- Thermactor Bypass Air (TAB) controls bypass of secondary air when none is needed. When secondary air is needed, TAB sends it to TAD
- Thermactor Air Diverter (TAD) diverts the secondary air either upstream to the exhaust manifold or sends it downstream to the catalytic converter

The secondary air system is called Managed Air Thermactor. The TAB valve is called AMT-1, and the TAD valve is called AMT-2.

5.3 Canister Purge (CANP)

Canister Purge (CANP) controls the purging of the canister containing fuel vapors. The control module determines the proper engine operation for purging, usually warm-engine cruising. When the Canister Purge Regulator Valve receives a signal, the solenoid valve opens passage from the canister to the intake manifold.

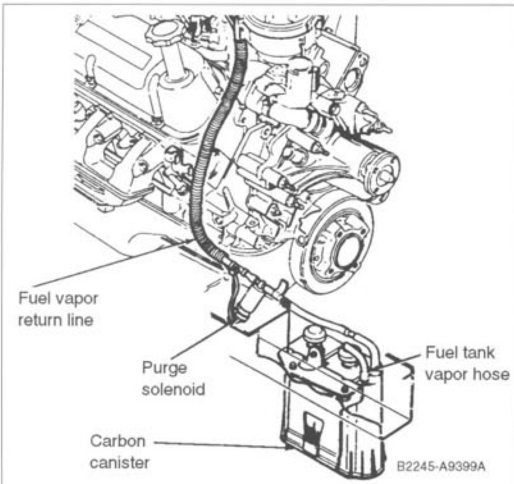


Fig. 5-7. Canister Purge Solenoid Valve opens on signal from control module, passing fuel vapors from carbon canister into intake manifold.

6. *Information Signals*

Much information, or data, flows inside the EEC system. The system also sends information out to advise the driver, to assist the technician in diagnostics, and to control other systems.

6.1 Driver Information

Shift Indicator Light (SIL)

Shift Indicator Light (SIL) signals the driver of a manual-transmission car to upshift. The SIL illuminates when the combination of higher rpm and light loads suggests the driver is racing the engine. Shifting to a higher gear will improve economy and emissions. The engine must be warm so the control module combines input from ECT, MAP, and rpm to determine when to light the SIL.

Data Output Line (DOL)

Data Output Line (DOL) supplies information for trip computers. Pulse-time signals to the injectors can be computed as gallons per hour fuel flow. Vehicle Speed Signals (VSS) can be read as miles per hour. Each can display metric for liters per 100 kilometers. Combining these two provides signals of instantaneous and trip fuel economy that can be displayed on the trip computer.

Malfunction Indicator Light (MIL)

Malfunction Indicator Light (MIL) could read "Check Engine," "Service Engine Soon," "Check DCL" (Data Communications Link). In addition to advising the driver, the system helps technician diagnostics by flashing the MIL. On some cars and trucks, the DCL sends trouble codes and operating data.

6.2 Self-Test Output (STO)

For Self-Test Output (STO), the DCL relates to the Self-Test Connector. STO was first conceived to check out engines at the end of the factory assembly line. Now, the industry recognizes the importance of output signals to service diagnosis in the field. DCL provides for:

- Self-Test Input (STI) to the control module for purposes of signalling the individual actuators, monitoring their responses, and looking for trouble codes in the memory
- Self-Test Output (STO) delivers vehicle information, operating conditions, and diagnostic information. STO trouble-code signals turn on the MIL and store the data in the KAM. More on that in Chapter 10. For accuracy, STO data is referenced to Signal Return voltage

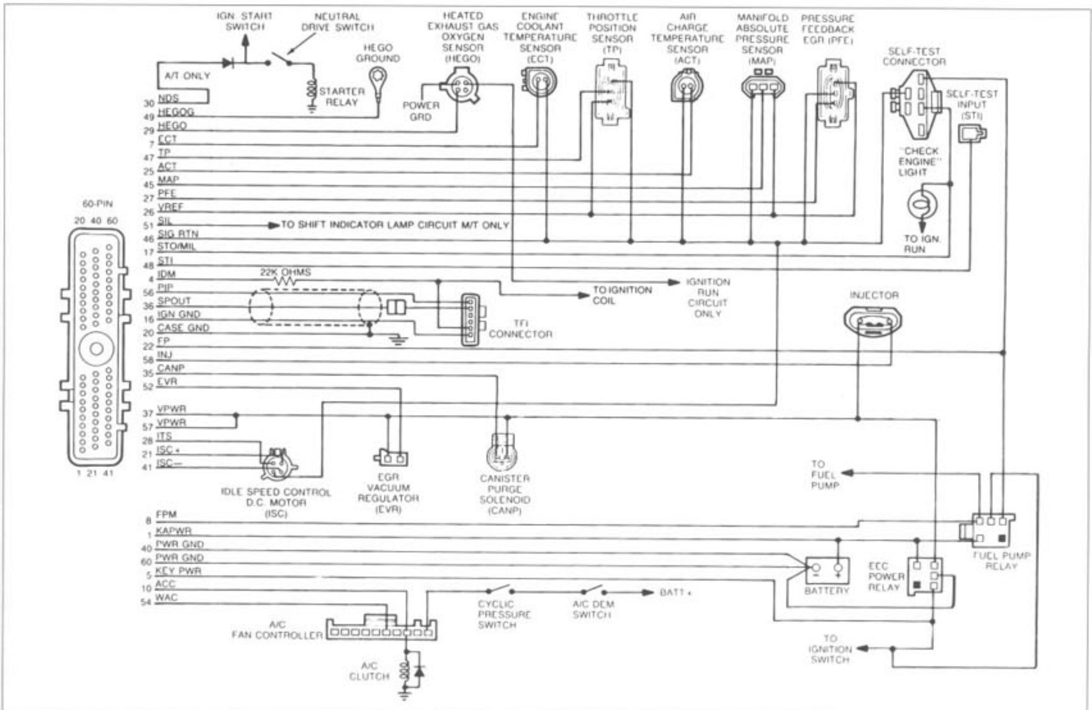


Fig. 6-1. Self-Test Connector provides Self-Test Input (STI) circuit to control module to initiate Self-Test, and Self-Test Output (STO) to read diagnostic information. STO can turn on "Check Engine" light and store trouble code in KAM.

MECS-I reads out only those diagnostic faults that are present during the test. It does not store intermittent faults. See Chapter 10. MECS-II stores and reads out codes similar to EEC.

6.3 Other Information Signals

Engine Temperature (ECT) and Vehicle Speed (VSS) information is sent to several other systems not directly related to engine control:

- Automatic Transmission/Transaxle uses data on vehicle speed, engine speed, temperature, and BOO to influence lock-up of the converter clutch, and, in some vehicles, the shift points
- Automatic Adjustable Shock Absorber Control (ACL) and other electronic ride controls use VSS data

7. Relays and Controls

Several other output signals are sent by the control module. See Fig.6-1 for a typical wiring diagram. The key energizes the EEC power relay and, in most vehicles, a separate fuel-pump relay.

7.1 Fuel-Pump Relay (FPR)

The Fuel-Pump Relay turns on the fuel pump as signalled by the control module. See Fig. 7-1. When the vehicle has 2 fuel pumps, it has also 2 relays. See Chapter 7 for more information.

7.2 Vehicle-Speed Control

The Vehicle-Speed Control (cruise control) system uses vehicle speed (VSS) to compare the actual speed with the set speed. The control module controls speed by controlling the actuator vacuum through the Speed Control Vacuum Solenoid

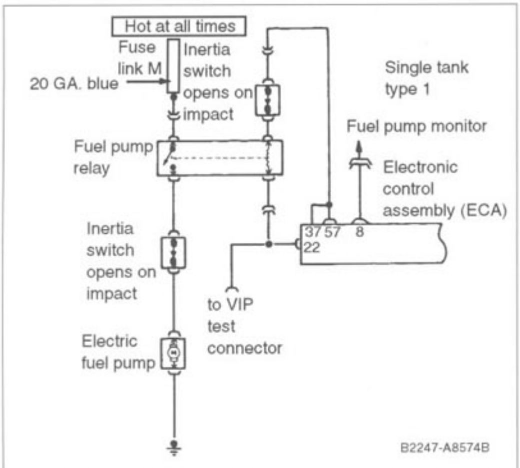


Fig. 7-1. Fuel pump relay controls power to fuel pump to insure fuel delivery during cranking and running, but to cut off if engine stops, even with key ON.

(SCVAC) and the Vent Solenoid (SCVNT). The control module controls the Speed Control Command Switch (SCCS) to cut off cruise control when the speed is below minimum control speed, or when the driver operates the Brake On/Off (BOO) switch.

7.3 Wide-Open Throttle A/C Shutoff Relay (WAC)

The Wide-Open Throttle Air Conditioner (WAC) Shutoff Relay receives EEC signals to briefly cut off the air-conditioner under full-throttle conditions, or under prolonged idle.

7.4 Electro-Drive Cooling Fan (EDF)

The Electro-Drive Cooling Fan (EDF) Relay receives EEC signals based on coolant temperature and vehicle speed to supply power to operate the fan. On vehicles with A/C, a second relay controls the second fan, High-Speed Electro-Drive FAN (HEDF).

7.5 Controller Modules

In some vehicles, the separate relays operate together in Controller Modules.

Integrated Relay Control Module (IRCM)

The Integrated Relay Control Module IRCM combines several relays into one module, replacing several separate relays found in earlier model-year cars. As shown in Fig. 7-3, the IRCM operates with Vehicle Power (VPWR) and the key switch (KPWR) under control module control to switch several circuits:

- Fuel pump(s)
- Control module power
- EDF and HEDF for engine cooling
- A/C solid-state Relay

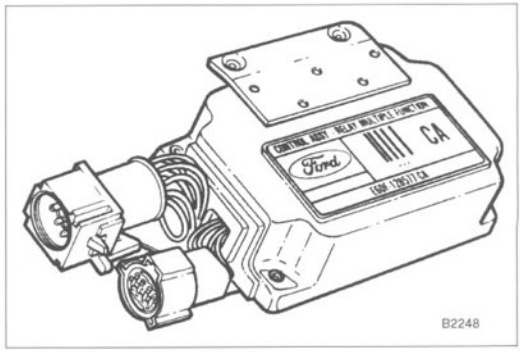


Fig. 7-2. Integrated Relay Controller Module combines several relays controlled by control module. It includes a diode to protect EEC system from reverse polarity, as in mis-connected jump-start cables.

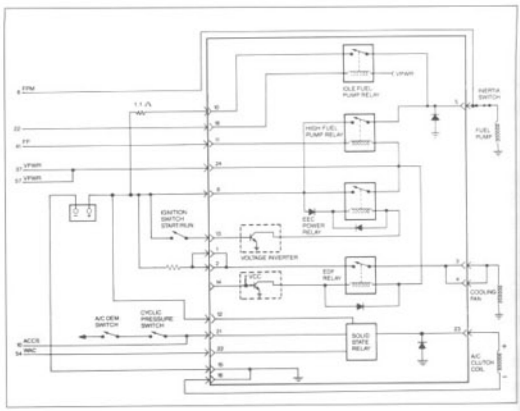


Fig. 7-3. Integrated Relay Control Module switches fuel pump(s), control module power, cooling fan(s), and Air Conditioner.

On newer models, the IRCM is called the Constant Control Relay Module (CCRM). Do not confuse IRCM with the new J1930 term for Intake Manifold Runner Control (IMRC).

Air-Conditioner and Cooling-Fan Controller Module (ACCM)

In some vehicles, you'll find the A/C relays combined in one Air-Conditioner and Cooling Fan Module. Under control of the control module, based on signals from ECT, VSS, and BOO, it provides:

- A/C cut-off briefly at Wide Open Throttle (WOT)
- EDF/HEDF cuts off briefly at WOT, provided the engine temperature is below limits
- Both A/C and EDF/HEDF cut off for a few seconds *when the BOO switch indicates Brake ON*
- EDF/HEDF cuts off when vehicle speed is above 50 mph (80 kph)

Variable Control Relay Module (VCRM)

The Variable Control Relay Module (VCRM), first used on Mark VIII 4.6L-4V, brings together several control functions and self-diagnosis. VCRM controls:

- Vehicle power to EEC and Powertrain Control Module
- Fuel pump
- Engine cooling fan
- Air-conditioner clutch

In addition, any failure detected by VCRM is sent to the Powertrain Control Module and stored as Diagnostic Trouble Codes (DTC).

Fuel Pump Control

Through VCRM, the two-speed fuel pump on the Mark VIII normally operates on less than battery voltage, reduced by a VCRM resistor. The pump is sized to deliver normal quantity fuel at low voltage, running quieter and lasting longer.

At higher loads and rpm, VCRM receives a signal from the Powertrain Control Module to bypass the resistor, sending full battery voltage to the pump. This delivers extra fuel for maximum power output.

Engine Cooling Fan Control

Through VCRM, the engine cooling fan operates at the required speed, rather than On/Off as in most fan controls. Engine cooling fan needs are determined in the Powertrain Control Module based on inputs from sensors: coolant temperature, vehicle speed, air-conditioner demand, A/C head pressure. Receiving fan-speed requirement signals from the Powertrain Control Module, the VCRM adjusts fan speed by varying battery-voltage pulses in a duty cycle.

Air-Conditioner Head Pressure Control

VCRM can turn off the Air-Conditioner pump clutch if head pressure rises near the safe limits of the system.

7.6 Other Fuel-pump Cut-off Switches

Inertia Switch (IS)

Ford is one of the few manufacturers using an inertia switch in all fuel-injected cars as a safety switch to interrupt power to the fuel-pump relay in the event of an accident. Few people think of it as a control item to be checked in a No-Start condition, when the fuel pump should run but does not. You'll find the Inertia switch located in the trunk of passenger cars. After checking to be sure that you do not smell or see gasoline, push the reset button in to restore the pump circuit.

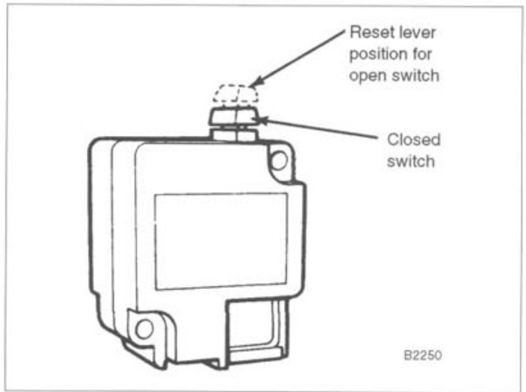


Fig. 7-4. Typical inertia switch interrupts fuel-pump control *circuit in accident.*

> ***WARNING —***
> *If you see or smell gasoline, do not reset inertia switch.*

Anti-Theft Switch

In vehicles with an anti-theft system, a switch interrupts power to the fuel-pump relay if the system detects evidence of break-in. Troubleshooting a NO START engine may include checking the anti-theft circuit, if fitted.

7.7 Lock-Up Solenoid (LUS)

The lock-up signal from the control module to the automatic transmission torque converter requires the following:

- Warm engine
- Part-throttle
- Calibrated engine rpm

When the solenoid is energized, transmission fluid flows to the torque converter, locking the clutch. The LUS will be unlocked by stepping on the brake pedal (BOO switch), or planting your foot on the accelerator (WOT). Do not confuse LUS with LOS, "Loss of Signal."

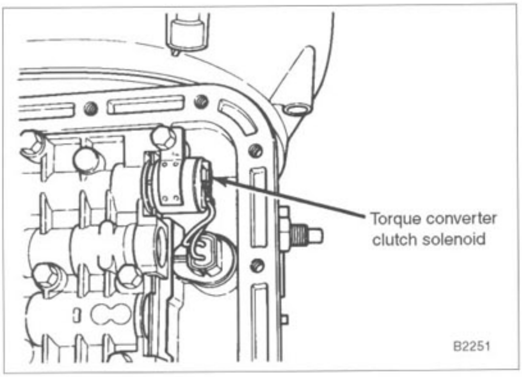


Fig. 7-5. Lock-Up Solenoid (LUS) receives output signal from control module to lock torque-converter clutch.

7.8 MECS Relays

You'll find two kinds of relays to control the fuel pump and the A/C clutch through the control module.

1. Fuel Pump Relay (FPR) (2.2L turbo). The control module grounds the FPR wire to turn on the fuel pump during start and during deceleration.
   - In 2.2L turbos, the VAF sensor cuts off the pump when closed, and this relay keeps it running during deceleration
   - Other MECS engines control the fuel pump by the VAF-closed switch
2. Wide-Open Throttle Air Conditioning (WAC). The control module opens ground to cut off the A/C clutch during start and during Wide Open Throttle (WOT)
   - Smaller engines, 1.3L, 1.6L, 1.8L—WAC Relay
   - 2.2L engines—Condenser Fan Relay (CFR)

In 1993 and later Probe engines, a relay cuts off the A/C relay under several conditions:

- WOT
- After engine start, 3–4 seconds
- Acceleration from idle, 2 sec.—2.0L
- High coolant temperature, above about 115°C (240°F)

8. Nissan Engine Control System—Mercury Villager

Bypass Air Valve (BPA)

Villager Bypass air is controlled in the old-fashioned Bosch way. A rotary valve in a bypass around the closed throttle is controlled by a bi-metal strip. When the strip is warm, it bends to close the valve. When cold, the strip opens the valve. The strip temperature depends on the engine temperature—contact with the cylinder head, and on the electric heater wound around the strip. The control module supplies electrical power at start up, but it does not modulate the bypass air. In other words, no coolant temperature input, no calculations. The only job of the control module is to feed power to the electrical heater.

Fast Idle Control (FIC)—Air Conditioner

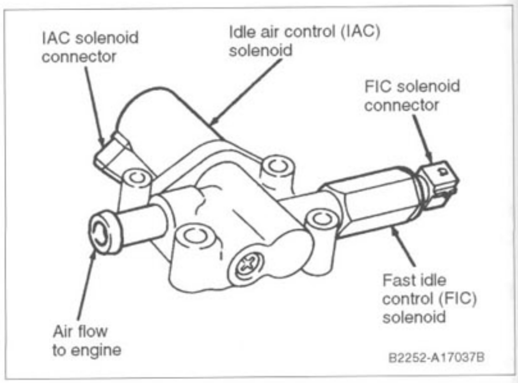


Fig. 8-1. Villager Fast Idle Control (FIC) Solenoid bypasses additional air during operation of air conditioner compressor to handle additional load during idle.

Villager Fast Idle Control (FIC) provides additional bypass air to prevent idle stall during air-conditioner operation. The FIC solenoid operates on signal from the control module, opening when the engine control module signals operation of the A/C. Although FIC and BPA are both mounted in the throttle bypass, they are separate—FIC compensates for air-conditioner load; BPA compensates for cold engine.

Chapter 7

Fuel Delivery Systems

Contents

1. Introduction

The fuel system delivers clean fuel under pressure to the injectors. It regulates pressure at the injectors to ensure precise control of amount injected. It provides for sensing fuel pressure. This discussion covers delivery of fuel from the tank to the injectors. Chapters 4–6 cover control of the amount of injection. Electric fuel pumps require relays and safety circuits to ensure that the pumps stop when the engine stops.

The fuel tank(s) are usually pressurized at 7–14 kPa (1–2 psi), controlled by a relief valve in the filler cap. Vapor lock is virtually eliminated because:

- The fuel is cooled by constant recirculation
- The fuel in the delivery lines is pressurized, usually at about 270 kPa (39 psi)

2. Pumps

Ford systems deliver fuel with two kinds of pump systems:

- One high-pressure in-tank pump (passenger cars and Aerostar)
- Low-pressure supply pump in tank, working with high-pressure in-line pump (larger light trucks have two tanks, each with a low-pressure pump)

All pumps are roller-cell type, where the motor operates in the fuel in the pump housing. It may seem dangerous, an electric motor running in gasoline, but it is safe because the housing never contains an ignitable mixture. There are those who, fearing a burnable mixture, say "never run out of gas with a fuel-injected car." But thirty years of electric pump experience shows they just don't catch fire that way. However, operating in gasoline is important—it cools the pump. So if you do run out of gas, just don't crank a long time or you may ruin the pump.

2.1 High-Pressure In-Tank Pump

In most EEC systems, you'll find an in-tank fuel pump assembly with an internal pressure regulator and the fuel gauge sender. The high-pressure pump in the tank pressurizes the fuel lines to reduce vapor lock, and improve hot starting. See Fig. 2-1.

In the larger light trucks, E/F-series and Bronco, the high-pressure pump is part of an In-Tank Reservoir (ITR) assembly in the fuel tank. Beginning in 1992, it is known as the Fuel Delivery Module (FDM). By either name, the assembly includes the pump, a reservoir, a fine mesh filter, a pump pressure regulator, and a fuel level sender. See Fig. 2-2.

In most vehicles, the high-pressure pump can deliver 60 liters (16 gal.) of fuel per hour—just about a whole tankful in one hour! At cruise, the engine might burn 2–3 gal/hr, so you can see that most of the fuel recirculates. That serves to cool the pump and the system. Larger engines may use a larger pump. Some deliver 80 L/hr, or 100 L/hr (21 or 26 gal/hr), and some deliver twice the standard, 120 liters (32 gal) per hour.

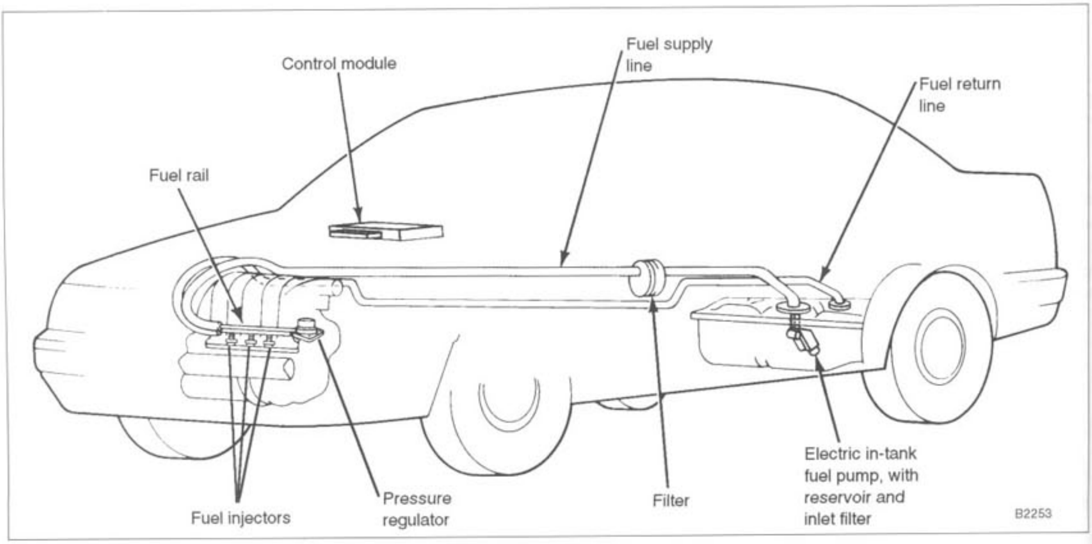


Fig. 1-1. In typical fuel delivery system, fuel is drawn from tank by an in-tank pump, filtered, and delivered to a fuel rail. A return line circulates fuel.

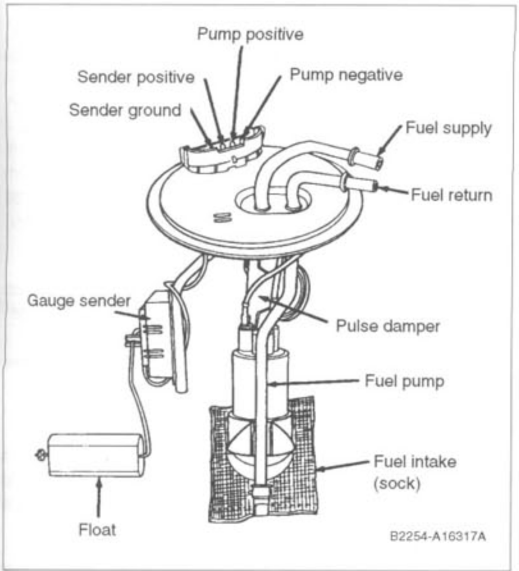


Fig. 2-1. High-pressure pump can supply 60 liters per hour (16 gal/hr) at working pressure of 270 kPa (39 psi). Check valve retains fuel pressure after shutdown.

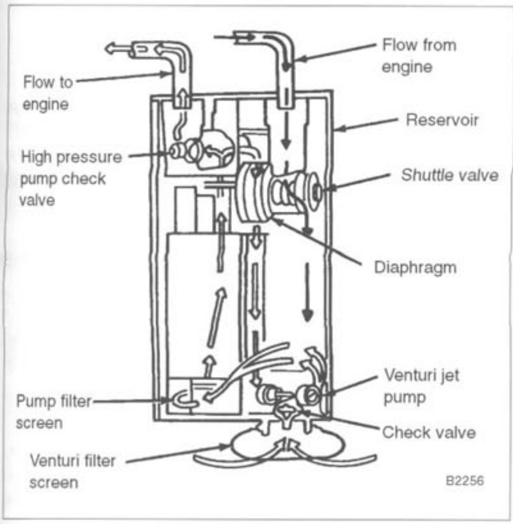


Fig. 2-2. Fuel Delivery Module (FDM) in tank includes high-pressure pump with check valve, fuel filters and reservoirs. Look for two FDM's in trucks with dual fuel tanks.

Fuel pumps on some cars vary fuel delivery according to demand by varying the voltage to the pump. The Variable Control Relay Module (VCRM) on Mark VIII and on Flexible Fuel (FF) 3.0L Taurus normally operates the pump through a high resistance wire. This reduces pump speed for quieter operation. At higher engine speeds/loads, the control module and the VCRM bypass the resistance with the high-speed fuel-pump relay. The pump runs faster, delivering more fuel. The need for the two-speed pump control differs in the two applications:

- 4.6L-4V peak output of 280 horsepower requires peak delivery of fuel. During idle and other low-demand operations, the pump operates more quietly while still delivering enough fuel
- The 3.0L Flexible Fuel Vehicle (FF) may operate on M-85 methanol-based fuel. Even though its peak output of 140 horsepower is the same with gasoline and with M-85, more gallons of M-85 must be burned because of M-85's lower energy content. The FF vehicle pump runs slower for normal cruise, and faster for full power output

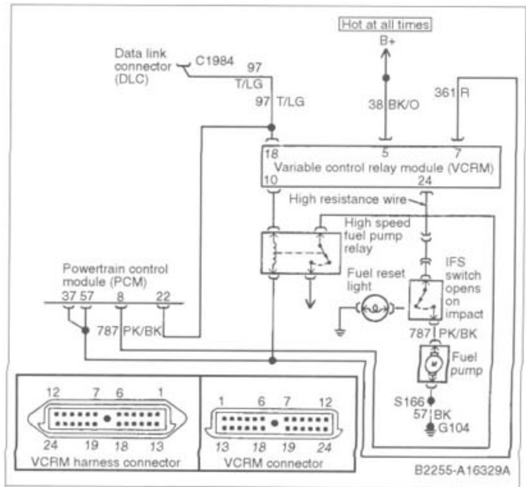


Fig. 2-3. On Mark VIII 4.6L and 1993 FF 3.0L, fuel-pump voltage control operates pump at lower speeds for normal, shifting to full voltage, higher speeds for higher fuel demand.

A check valve at the pump retains fuel pressure in the line after the pump shuts off. An internal pressure relief valve releases fuel into the tank if pump pressure exceeds 850 kPa (125 psi) because of a clogged filter or line.

2.2 High-pressure In-line Pump with Low-pressure In-tank Pump

Some 1988 and later Ford light trucks use two kinds of pumps. The low-pressure pump(s), often called the supply pump, in the tank(s) delivers fuel to a fuel reservoir. The high-pressure pump in the line delivers pressurized fuel to the injectors. See Fig. 2-4. The reservoir carries enough fuel to meet extra demands such as wide open throttle running. Line pumps operate at deliveries and pressures similar to those of high-pressure pumps in the tank. See Fig. 2-5.

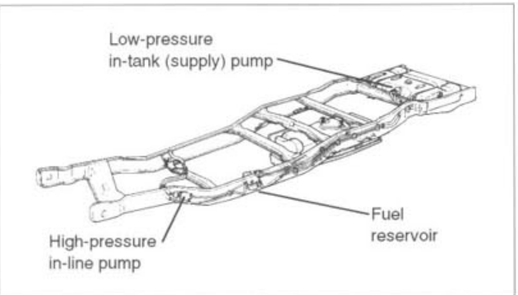


Fig. 2-4. Some light truck fuel systems operate low-pressure pump(s) in the tank(s) to supply the reservoir for the high-pressure pump in the line.

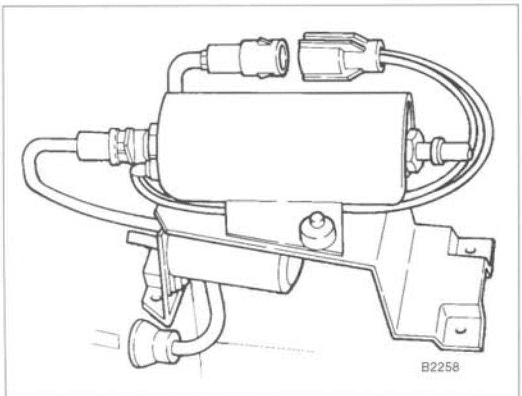


Fig. 2-5. High-pressure in-line pumps can deliver 60–100 L/hr (16–26 gal/hr) at working pressures of 270 kPa (39 psi), with relief valve set at 850 kPa (125 psi).

2.3 Pump Control by the Control Module

The control module runs the pump(s) for one second when it receives an IGNITION-ON signal. It also runs the pumps as long as it receives a CRANK signal from the ignition switch. When it receives a PIP signal from the Hall-effect devices, it continues pump operation even after the key is released from START. If the PIP signal falls below 120 rpm, the control module cuts off the signal to the Fuel Pump Relay, or the Integrated Relay Control Module. The pump will also run when the terminals of the fuel-pump test connector are jumped.

- The control module signals the pump when it receives a CRANK signal, and when the control module gets PIP signals that the engine is running;
- The pump does not run if the PIP indicates the engine is not running, even with ignition ON (except for that first one second).

MECS-I fuel-pump relays are normally controlled by a switch in the Volume Air Flow Sensor (VAF). This is similar to early Bosch systems. During cranking, the control module grounds the circuit to the fuel-pump relay.

During rapid deceleration, with closed throttle, air flow falls to near zero. The VAF flap closes, sending a false "shut-off" signal to the fuel pump relay. MECS uses two methods to keep the engine from stalling during deceleration:

- On 2.2L turbo engines, the ECA grounds the fuel-pump relay during deceleration to keep the pump running
- On 1.6L engines, a resistor and capacitor in the fuel-relay supply current into the pump relay coil

MECS-II (1993 Probe 2.0L and 2.5L V-6) fuel-pump relays operate just like EEC system relays, running with the START position of the ignition key, or by the rpm signals from the crankshaft position sensor(s).

3. Pressure Regulator

The fuel pressure regulator, shown in Fig. 3-1, is important to the precise metering of fuel from the injectors. To ensure that fuel delivery varies only with changes in injector open time, relative fuel pressure at the injector must be kept constant.

Relative fuel pressure is the difference between fuel pressure pushing the fuel out of the injector, and manifold pressure pushing back at the tip. See Fig. 3-2 and 3-3. As you'll see, for each millisecond of injector pulse time, the amount of fuel delivered through the injector tip depends on the relative pressure.

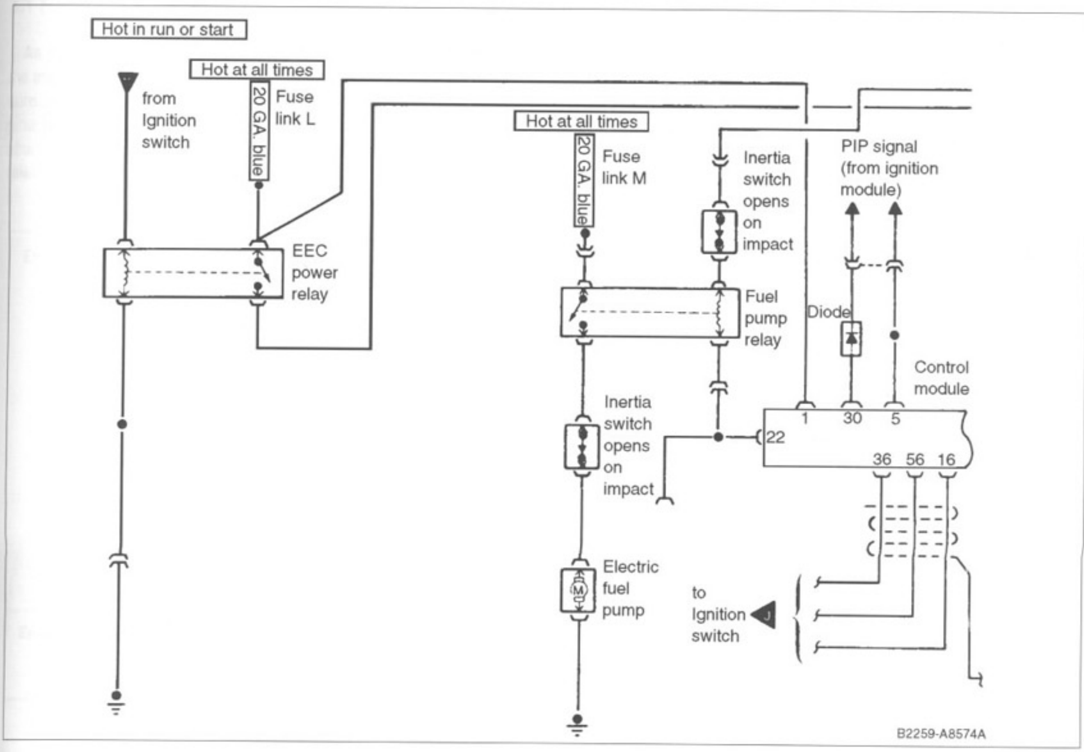


Fig. 2-6. Control Module grounds Fuel Pump Relay to run fuel pump. Control based on input signals from ignition switch in CRANK, and from PIP indicating crankshaft revs of over 120.

Fig. 3-1. Pressure regulator (arrow) at end of fuel rail controls fuel pressure by controlling fuel return flow to tank. Hose connection leads to intake manifold.

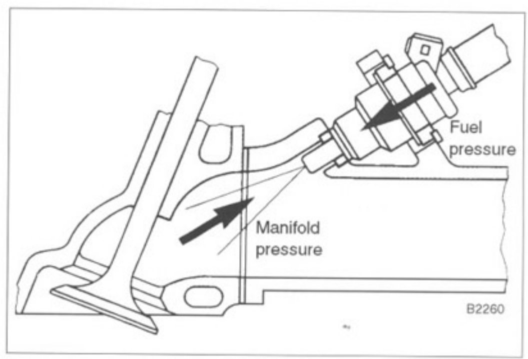


Fig. 3-2. Precise delivery depends on relative pressure—the difference between fuel pressure in the injector, and Manifold Absolute Pressure (MAP) pushing back.

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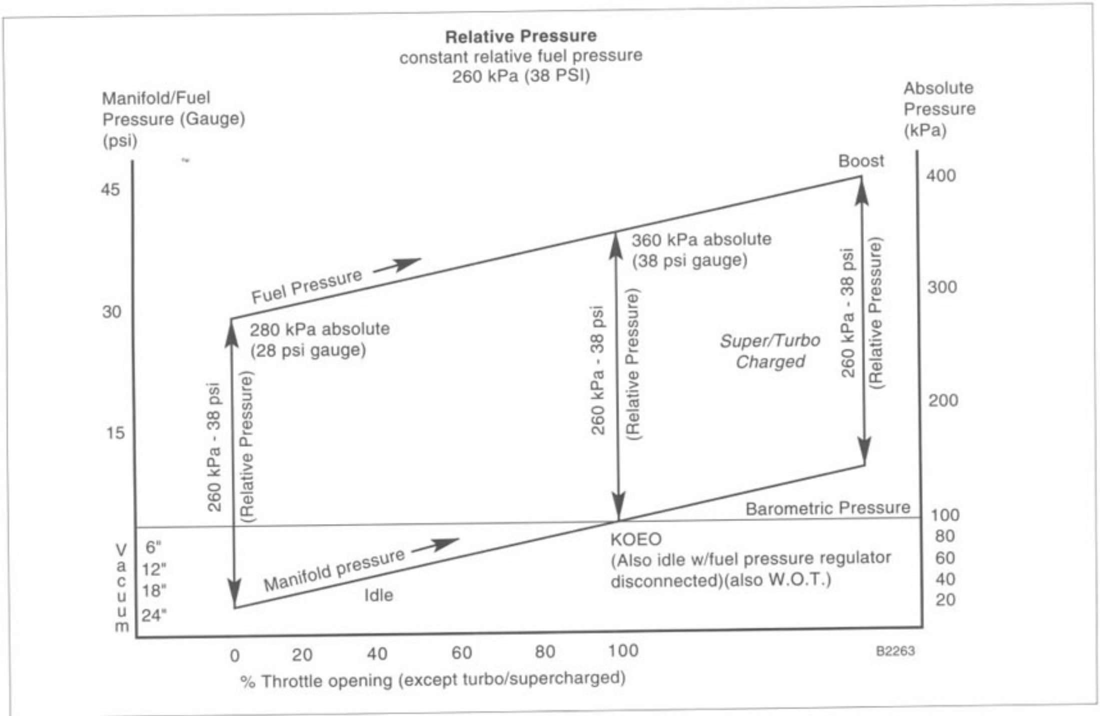


Fig. 3-3. Fuel pressure regulator keeps fuel pressure 260 kPa above pressure at the injector tips. As manifold pressure rises, fuel pressure rises. Absolute measurement is 100 kPa (barometric pressure) above gauge measurement.

The pressure regulator, usually mounted on the fuel rail, holds relative fuel pressure constant. See Fig. 3-4. All fuel from the fuel pump flows into the fuel rail at one end, then through the pressure regulator valve and back to the tank. A spring presses down on the regulator diaphragm so the valve restricts return flow to the tank. Pump pressure pushes on the diaphragm and spring until the valve opens at a set pressure. Spring pressure determines basic fuel pressure. Air pressure from the intake manifold affects the spring pressure (and therefore fuel pressure) via the diaphragm. When the engine is off, spring pressure keeps the regulator valve closed, maintaining pressure in the system.

Most Ford systems operate (engine Off, pump On) at a nominal 270 kPa (39 psi) gauge pressure—that is, pressure above barometric. Exceptions:

- Higher pressure in some engines, such as the 4.9L and 1993 and later 2.3L HSC, with more tendency to boil fuel in the rails, operate at 380 kPa (55psi)
- Lower pressures in the SHO engines, with greater range of rpms and therefore different injectors, operate at 210 kPa (31 psi)

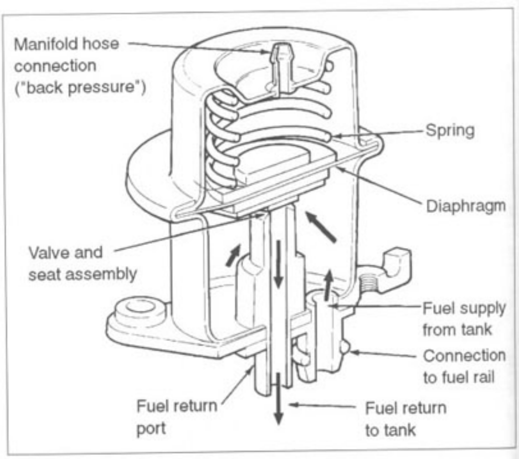
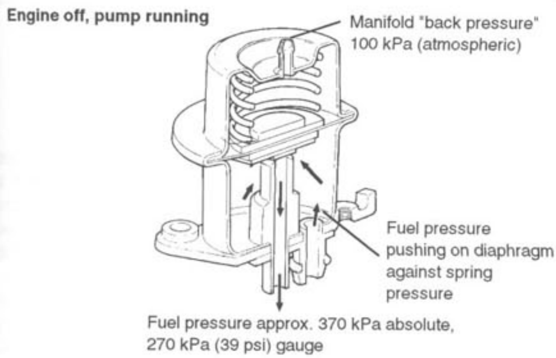


Fig. 3-4. Fuel pressure regulator with pump running. Fuel pressure enters from fuel rail, raises diaphragm against spring and manifold air pressure. Excess fuel is returned to tank.

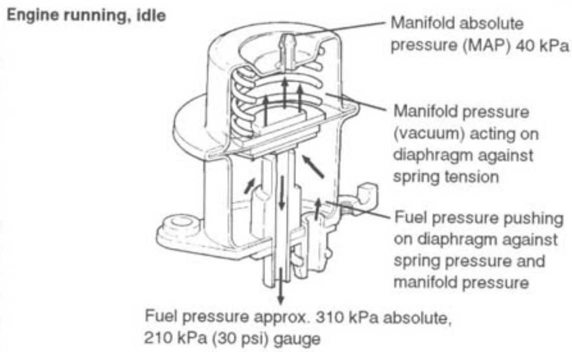
3.1 Relative Fuel Pressure and Fuel Delivery

As you know, manifold pressure and therefore pressure at the injector tip changes with throttle opening. If the fuel pressure were constant for all manifold pressures, then at low engine loads, with the throttle partly closed, reduced manifold absolute pressure would increase fuel delivery. To keep that relative pressure constant as the throttle is opened and closed, the fuel-pressure regulator is connected to the intake manifold by a hose. Manifold pressure acts on the diaphragm to hold the relative pressure constant. See Fig. 3-5.

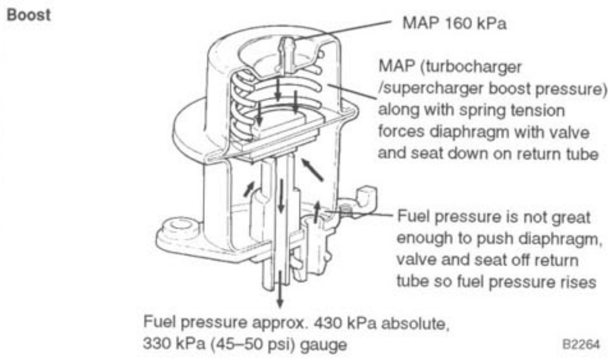
Remember back in Chapter 2, I told you fuel injection is easier to understand when you think positive, also when you keep in mind the difference between barometric pressure and absolute pressure, usually about 100 kPa at or near sea level. Your



- With engine off, pump running and barometric pressure 100 kPa, fuel pressure is 370 kPa, absolute. Fuel pressure would be about the same at Wide Open Throttle (WOT) when the throttle allows MAP to approach barometric pressure. Pressure would also be the same with the engine idling with vacuum hose to regulator disconnected. Relative pressure at the injector tips is 270 kPa (370 minus 100).



- With engine idle, MAP is 40 kPa, so fuel pressure is regulated to be about 310 kPa absolute. The MAP pushing the pressure-regulator diaphragm is only 40 kPa instead of 100. The reduced MAP on the diaphragm allows it to move away from the opening, returning more fuel to the tank. Gauge fuel pressure drops to about 210 kPa. The relative pressure at the injector tip is still 270 kPa (310 absolute minus 40).



- At boost of 160 kPa MAP (about 10 psi gauge), fuel pressure is regulated to be 430 kPa absolute. The MAP pushing the pressure-regulator diaphragm is 160 kPa. The increased MAP on the diaphragm forces it toward the opening, returning less fuel to the tank. Gauge fuel pressure increases to about 330 kPa. The relative pressure at the injector tip is still 270 kPa (430 absolute minus 160).

Fig. 3-5. Relation of fuel pressure, absolute and gauge, to manifold absolute pressure (MAP).

fuel pressure gauge reads "gauge pressure"—that is, fuel pressure above barometric; or fuel pressure, gauge. This relates to a fuel pressure regulator set for 260 kPa. (Some engines differ, but follow an example of a system operating at relative fuel pressure of "260kPa (38psi)".)

Now perhaps you see the importance of the fuel pressure regulator. Its job is to insure that fuel delivery per injection is not affected by changes in manifold pressure. When you understand this principle of relative fuel pressure, injection pressure versus manifold pressure, you'll understand the checking of fuel pressures. You'll also understand how greater delivery for off-road performance operation may be increased by increasing fuel pressures.

Fuel Pressure Regulator Control

On some engines, EEC and MECS, you'll find a Fuel Pressure Regulator Control (FPRC) system. See Fig. 3-6. It prevents percolation of the fuel during idle after restarting a warm engine. Some FPRCs operate to raise fuel pressure during crank, idle, neutral, and wide open throttle (WOT), depending on input signals to the Powertrain Control Module.

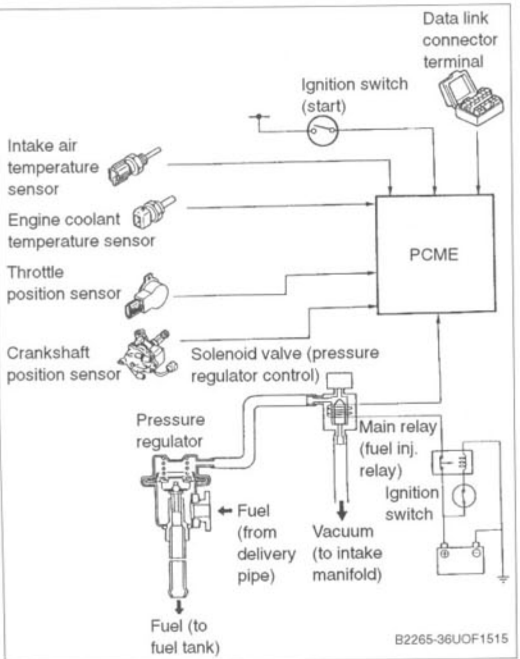


Fig. 3-6. MECS Fuel Pressure Regulator Control (FPRC) solenoid valve closes passage from pressure regulator to manifold when engine is warm, raising idling fuel pressure to prevent percolation.

Coolant temperature signals, or intake air temperature signals cause the engine control module to ground a circuit from the main relay. The solenoid valve closes the line connecting the pressure regulator to the manifold, and vents the pressure regulator to atmosphere. This has the effect of raising the fuel pressure of a warm engine from a normal idle pressure of 33 psi (230 kPa) to 41 psi (280 kPa). A timer in the control module releases the solenoid after a measured time, (10 to 120 seconds, depending on the engine). This returns the fuel pressure regulation to normal. In most controls, the TPS must signal closed throttle, CKP signal low rpm, and Clutch or Park/Neutral signal engine not driving car.

4. Fuel Filters

The fuel-injection fuel filter is much larger than the usual carburetor fuel filter because clean fuel is so important to fuel-injection systems. Also, in contrast to carburetor-engine pumps, fuel-injection pumps deliver more fuel than is burned, so the filter handles up to 10 times the actual fuel consumption. Fuel-injection filters are also finer. Replace the filter as a complete unit, not as an insert. In most high-pressure fuel-injected cars, look for the fuel filter next to the fuel pump. In some trucks, check in the fuel reservoir. When the truck has in-tank high-pressure pumps, look for the filter on the frame near the fuel tank.

For most vehicles, including MECS, look for the fuel filter under the hood. If it's not there, look for it next to the external high-pressure fuel pump, or in the line between the tank and the engine.

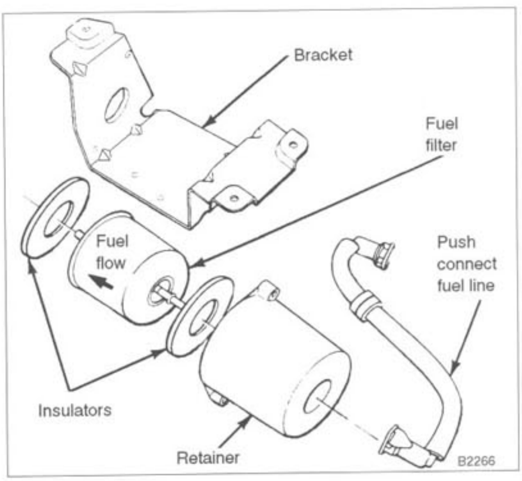


Fig. 4-1. Fuel filter for high-pressure in-tank pumps is usually located under car near fuel tank.

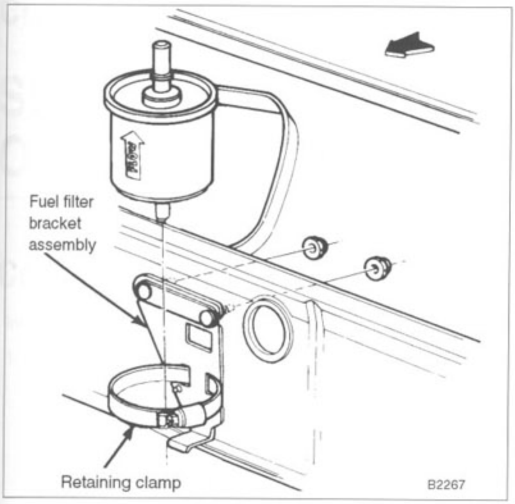


Fig. 4-2. Fuel filter for Escort, MECS, and other vehicles is located under hood.

5. Fuel Rail

The fuel rail serves two purposes:

- Delivers fuel to the injectors
- Stabilizes fuel pressure at the injectors

The relatively large fuel supply in the fuel rail helps to minimize pressure changes or pulsations that could cause uneven fuel injection, leading to rough idle. Fuel pressures change rapidly in the fuel rail as the injectors pop open and closed. Pressure change is noticeable when two, three or four injectors open at the same time, as in ganged port injection. The pressure changes less when individual injectors open and close one at a time, as in SFI. V-6 and V-8 engines have two rails, each one feeding the injectors of that bank.

5.1 Pressure Test Point

Ford EEC systems provide a pressure test point on the fuel rail. You can read fuel pressure directly from this point by connecting a gauge, without the need to bleed the pressure and open the system.

MECS systems do not provide a pressure test point. You must release pressure before installing a pressure gauge. And, after removing the gauge and closing the system, you must prime the fuel system before starting to avoid excess cranking. More in Chapter 10 and Chapter 11.

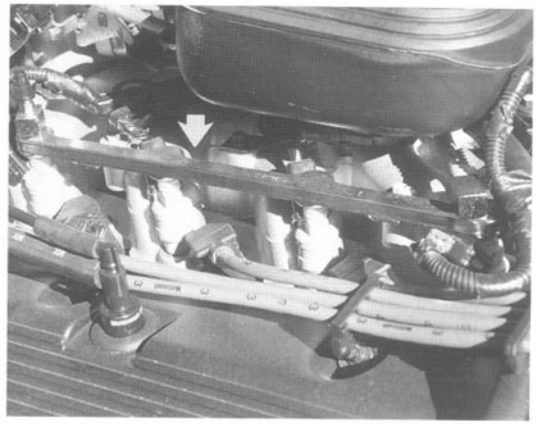


Fig. 5-1. Fuel rail (arrow) provides fuel supply to injectors and helps damp fuel pressure pulsations.

Fig. 5-2. Fuel-pressure test point provides direct access for reading of fuel pressure. System does not need to be bled and opened.

Chapter 8

Strategies—Responding to Operating Conditions

Contents

8

INTRODUCTION

In this chapter I bring it all together. I'll describe how the sensors, control module and actuators operate during each of the nine engine strategies I outlined in Chapter 2. I'll discuss the systems that control the three basics of engine control, fuel, spark timing, and intake air, concentrating on the active sensors.

Rather than confuse by describing all the engines in all strategies, I'll discuss typical strategies of an SFI (MAF-SFI) 6-cylinder engine.

I'll look at the fuel injection, spark timing and throttle-by-pass-air for each of the strategies. While most recent Ford engines operate with reduced emission controls (compared to the early '80s), I'll discuss emission-control considerations in general, and you can apply them to the specific engines depending on the specific emission controls. And I'll discuss some MECS differences. The Nissan 3.0L engine in the 1993 Mercury Villager is a completely different engine from the Ford 3.0L, and its strategies differ somewhat from EEC.

1. WARM CRUISE—STRATEGY #1

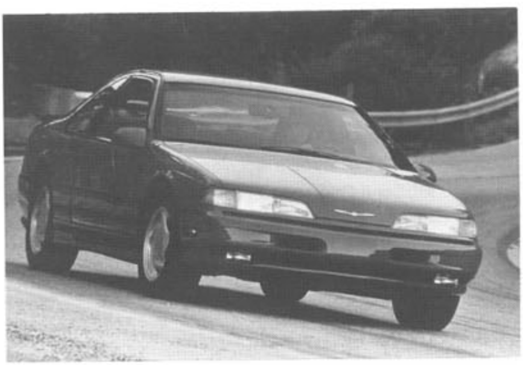


Fig. 1-1. Warm cruise is simplest of engine control strategies.

In some ways, Warm Cruise is the simplest of strategies because conditions are relatively stable, and because the engine operates without some of the special control actions applied to a cold engine. The engine operates more time in Warm Cruise than in any other strategy. As I described in Chapter 2, Warm Cruise strategy is designed for moderate power, maximum fuel economy, and minimum emissions. Level cruise generally draws 15–30 horsepower, a fraction of maximum engine output.

1.1 Active Sensors

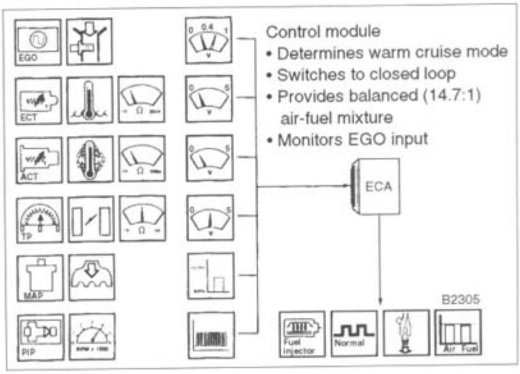


Fig. 1-2. In Warm Cruise, some sensors are active, sending operating signals. Other sensors, such as EVP are advising control module of conditions that might determine change of strategy.

All the sensors are operating, but some have no control effect on engine operations. So, for each strategy, I'll concentrate on the active sensors. Examples: Selection of Warm Cruise Strategy is based on:

- PIP is active, signalling engine rpm. For each two revolutions of the crankshaft, each sequential injector opens and closes once. At 2,000 rpm, each injector fires 16 times per second. For six injectors, a total of 96 pulses per second (Note: PIP and MAF indicate engine load)
- TPS is active, signalling throttle position. TPS signals Part Throttle, less than Wide Open Throttle (WOT), and more than Closed Throttle
- Engine coolant temperature (ECT) is normal so the control module is not active—does not add to the fuel-injection base pulse
- Delta Pressure Feedback EEGR Sensor (DPFE) signals indicate EGR pressures related to EGR flow. (Note: EGR sensors vary with different engines.)

1.2 Fuel Control

All those input signals match the values stored in the memories for Warm Cruise Strategy so the control module oper-

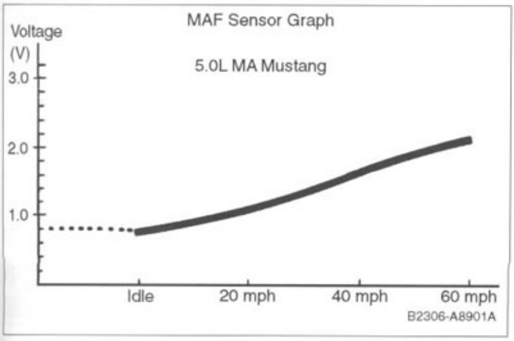


Fig. 1-3. MAF signals Mass Air Flow.

ates in a closed-loop mode. Each fuel injector receives a pulse signal of about 7–10 ms (milliseconds). The base injector pulse signal is calculated from the amount of air flow into the cylinders for a burning at the ideal (stoichiometric) ratio of 14.7:1.

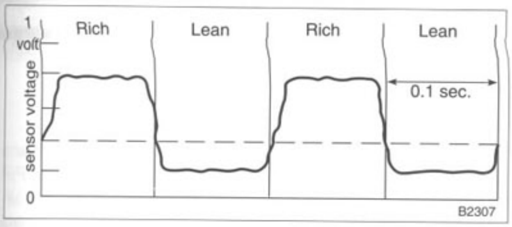


Fig. 1-4. Oxygen sensors (HEGO) signal exhaust gas oxygen.

Table a. Typical SFI Engine Warm Cruise Operation at 60 mph

Warm Cruise 60 mph	Per minute	Per second
Air burned	3 lb (1.4kg)	0.05 lb (.02kg)
Fuel burned—6 inj.	0.2 lb (0.1kg)	0.003 lb (.0015kg)
Six injectors	6,000 pulses	100 pulses
Each injector	1,000 pulses	16 pulses
Each injection	0.00003 lb (0.000015kg, 0.015 grams)!	

We're talking a fraction of a drop per SFI injection pulse! In comparison, MFI injectors may fire four times as often as SFI, and deliver 1/4 as much fuel per pulse for the same rpm/load conditions.

The amount of fuel injected is continuously fine-tuned by signals from the oxygen sensors. The signals advise the control module of the oxygen content of the exhaust. Remember:

- When the sensor observes oxygen in the exhaust, it generates low voltage (between 0.1–0.4v.). That indicates lean mixture. The control module adds fuel by slightly increasing injection pulse time
- When the sensor observes little or no oxygen in the exhaust, it generates higher voltage (between 0.6–0.9v.). That indicates rich mixture. The control module slightly decreases injection pulse time

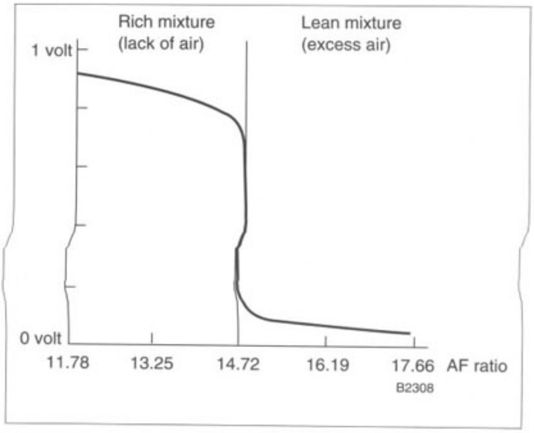


Fig. 1-5. Oxygen sensor output varies sharply on either side of ideal ratio.

By cycling back and forth between slightly rich and slightly lean, the computer controls the air-fuel ratio very close to 14.7:1, minimizing the output of emissions. Typical cruise cycles are 10–20 times per second.

SFI allows control of injection pulse times of each individual cylinder. Under some engine conditions, the control unit program calculates the individual cylinder air-fuel ratio by reading the oxygen sensor, knowing the time required for the exhaust gas from that cylinder to reach the sensor at that rpm. In V-type engines, two oxygen sensors are used, one for each bank. Metering is improved in what Ford Electronics engineers call "Stereo Hego".

1.3 Emission Control

EGR

All of these three sensors must signal in the proper range before the control module turns on EGR:

- ECT is neither too cool nor too hot
- TPS is part throttle
- PIP is between minimum rpm and maximum rpm

EGR affects Warm Cruise fuel injection. The formation of NO_x is controlled by the EGR Vacuum Regulator (EVR) solenoid. The EGR valve is opened the proper amount to recirculate exhaust gas into the intake manifold, minimizing the output of NO_x.

The Delta Pressure Feedback (DPFE) sensor sends feedback signals to the control module, verifying that the EGR valve is open the proper amount for these engine operating conditions. Calculations in the control module subtract the EGR flow (as unburnable) from the fresh air intake and reduce the fuel injection pulses accordingly.

Canister Purge

Canister purge during Warm Cruise affects fuel injection. Fuel vapors stored in the canister are being purged—drawn through the open Canister Purge valve (CANP) into the intake manifold to be burned in the engine. The look-up tables for fuel injection consider this flow during Warm Cruise. Fuel-injection pulse times are slightly shorter than they would be without canister purge. This delivers the ideal air-fuel mixture.

Secondary Air—Thermactor

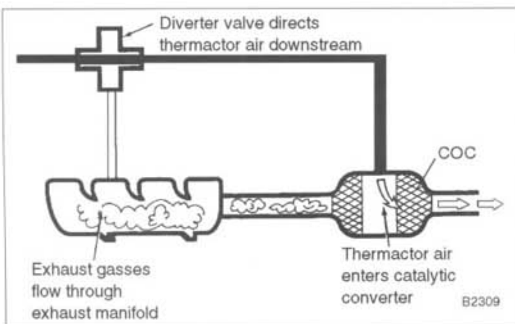


Fig. 1-6. Warm Cruise thermactor air flow.

On Thermactor-equipped engines (4.9L and larger) in Warm Cruise strategy, the control module closes the Thermactor Air Diverter (TAD), and opens the Thermactor Air Bypass (TAB). During Warm Cruise, the Thermactor system delivers secondary air to the Conventional Oxidation Converter (COC) to assist in oxidizing the HC and CO.

1.4 Spark Timing

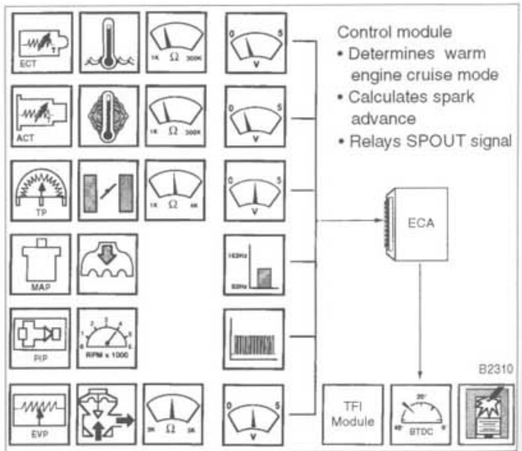


Fig. 1-7. Warm Cruise timing control.

Spark timing is determined by the look-up tables for Warm Cruise. Remember that, at a base timing of 10° BTDC, the PIP signal comes to the TFI 10° BTDC. In Warm Cruise, the air-fuel ratio allows for relatively slower burning, so the control module SPOUT signal advances timing to about 30° BTDC. This advance increases fuel economy; it also increases HC and NO_x engine-out emissions, but the tradeoffs favor the advance.

Effect of Exhaust Gas Recirculation

EGR flow during Warm Cruise affects Spark Timing because the EGR slows the burning of the air-fuel mixture. Using the DPFE signal, the control module changes the SPOUT signal to advance the spark timing by a few degrees to ignite the fuel earlier, allowing for the effect of the EGR.

1.5 Throttle Air Bypass (ISC)

From its original name of Idle Speed Control (ISC-BPA), the Throttle Air Bypass would seem to be operative only at idle. But no. The Warm Cruise bypass signals are 100% duty cycle to drive the bypass full open. Full open bypass flow prepares for deceleration. It's ready to close slowly like a dashpot to reduce emissions. When fully closed, it provides engine braking, and, at low engine speeds, it opens to prevent engine stalling.

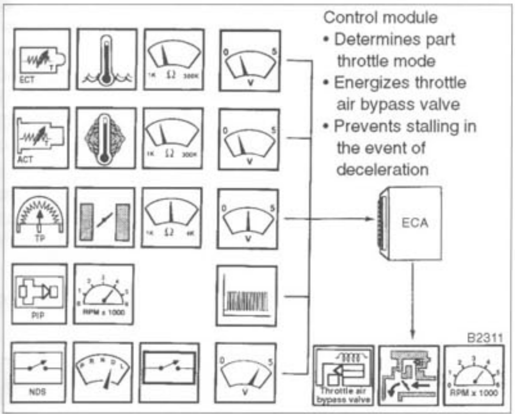


Fig. 1-8. Warm Cruise idle air bypass control.

You can see that even in the relatively stable conditions of Warm Cruise, the control module must keep track of several foreground operations with considerable interaction. In between, the control module must keep track of several background conditions, such as adaptive fuel corrections.

1.6 Mazda Engine Control Systems (MECS)

MEC systems generally operate quite similarly to those of EEC systems. Their strategies are generally simpler. I'll describe the principle differences.

MECS Warm Cruise

In Warm Cruise, the engine operates closed loop, with fuel control, EGR, and canister purge similar to EEC. Below 5000 rpm, on 1.8L engines, the High-Speed Intake Air (HSIA) valves are closed. For most engines, Electronic Spark Advance (ESA) spark timing is by control module. Exceptions: 1.6L and 2.2L non-turbo engines modify advance by centrifugal weights and vacuum diaphragm. With Automatic Transaxles, at vehicle speeds above about 40 mph, the control module signals the 4EAT module to lock up the torque converter.

For most MECS-I cruising, each bank of two injectors fires once every other revolution. In effect, the manifold receives injected fuel once per revolution. When Warm Cruise exceeds 4500 rpm, control switches over to one pulse per cycle (every two crankshaft revolutions). With half the number of pulses, pulse time is doubled to deliver the same amount of fuel per revolution.

Output device \ Engine condition		Cranking (cold engine)	Warming (during idle)	Medium load: Cold	Medium load: Warm	Acceleration	Heavy load	Deceleration	Idle	IG: on (engine not running)	Remark
Injector	Fuel injection amount	Rich			Normal	Rich		Fuel cut*	Normal	No injection	* Engine speed: above 1,500 rpm
Fuel pump relay		On								Off	
Igniter		Fixed at BTDC 6°	Advanced: depends on engine condition								
Solenoid valve	Purge control	Off			On (purge)			Off			
Solenoid valve	EGR	Off			On*			Off			* Engine speed: 1,300–4,500 rpm
Solenoid valve	PRC	Off (vacuum to pressure regulator)							On*	Off	* During hot start only
BAC valve	IACV	On (closed loop duty)		On (fixed duty)					On (closed loop duty)	Off	
BAC valve	Air valve	Open			Closed					—	
A/C relay		Off (a/c cut)	On			Off (a/c cut)	On			Off	

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Fig. 1-9. MECS outputs also vary according to Strategy (engine condition).

MECS-II differences:

- 2.0L 4-cylinder & 2.5L V-6—Sequential injection fires each injector on that cylinder exhaust-stroke, just before the intake valve opens. If malfunction of CID signal or control module, control switches to simultaneous injection (MPI)—all cylinders, once every two revolutions. On the '93 2.5L V-6 the MECS-II Variable Resonance Induction System (VRIS) valves close below 3250 rpm, and also above 6250 rpm. VRIS #1 is open from 3250 to 6250 rpm, VRIS #2 is open from 4250 to 6250 rpm. See Fig. 2-2.

1.7 Warm Cruise Summary

- Fuel injection controlled to match engine rpm and load
- Spark timing controlled to match engine rpm and load
- Closed loop (oxygen sensor signal)
- Throttle-Bypass Air is full open
- Emission controls: EGR, secondary air (large engines only), Canister Purge

2. Engine Crank—Strategy # 2

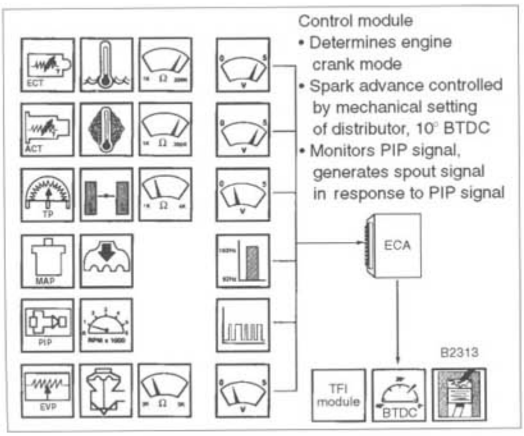


Fig. 2-1. Engine Crank strategy. Note irregular PIP signals.

The normal condition for Engine Crank is a cold engine. Remember, I'm talking about engine cold, and that could be as cold to you as 20-below zero or as warm to you as +100°F *(In Celsius, minus 30° to +35°C). It's still engine-cold.* The sensors advise the control module to operate under Engine Crank strategy.

Turning the key to ON causes the fuel pump to run for one second to pressurize the system. To reduce load on the starter, the control module shuts off the Air Conditioning compressor clutch during cranking, cold or hot.

Sensor input signals

- PIP is slow and irregular
- MAF is low and irregular
- ECT is low
- ACT is low
- TPS is low, for closed throttle
- Oxygen sensor signals are near zero

All those signals match the Engine Crank values stored in the memory. The system operates open loop. No controls are energized for emission control.

2.1 Fuel Control

Pulse times are based solely on temperatures. From its Engine Crank look-up tables, the control module finds the base injection pulse times for rich mixtures. Then the control module adds to the pulse times, adding more:

- When the ECT signal indicates lower coolant temperature
- When the ACT signal indicates colder intake air

No fuel is delivered until the engine starts to turn. Injection timing is synchronized with the PIP signal, 10° BTDC.

SFI injectors are fired sequentially, once during each two crankshaft revolutions. MFI injectors are double fired in gangs, twice every crankshaft revolution (that's once for each PIP signal). Ford gasoline systems do not use the Cold Start Injector common to Bosch systems and to some General Motors systems. You'll find a Bosch-type cold-start injector in EEC Flexible Fuel Vehicles to improve starting with methanol mixtures of fuel.

The control module also starts the timer. After 20 seconds, if the engine has not fired, the control unit reduces injector pulse times to prevent flooding.

Engine control shuts off EGR during Engine Crank. Control bypasses Thermactor air to prevent exhaust manifold explosions from the rich mixture. This also improves engine start by relieving the starter loading by the air pump.

If you flood the engine, you can clear the cylinders by cranking with the accelerator pressed to the floor. This Wide Open Throttle TPS signal cuts off fuel *injection so the incoming air can* sweep out some of the raw fuel and dilute the rest enough to fire.

2.2 Spark Timing

Spark timing during Engine Crank is set by the distributor. Distributor mechanical setting is the base timing of 10° BTDC. The control module receives the PIP signal and generates the SPOUT signal without modifying PIP. On some EDIS engines, the spark signal is delayed for about one-half second. This insures oil flow to the bearings before the starting loads. Delay also insures full crankshaft revolution of the VRS for better timing signals. MECS fixed spark timing during Crank is 6° BTDC. MECS-II fixed timing is 7° BTDC.

Push-Start Timing

New provisions for Push-Start change the spark output signals. When the control module sees low-rpm PIP signals (Ignition ON) but no START signal, it provides spark timing for push starts.

Compared to Computer-Controlled Dwell (CCD), Push-Start Waveforms show a longer dwell and a corresponding shorter SPOUT signal. See Chapter 6 for more information.

2.3 Throttle Air ByPass (ISC)

The Throttle Air Bypass is full open during Engine Crank, operating with 100% duty cycle. With the throttle plate closed ("No Touch" starting), the bypass supplies the air to start the engine.

2.4 Cold/Warm Differences

Warm Engine Crank strategy is the same Cold Engine, but the ECT and ACT signals cause the control module to signal shorter fuel-injection pulses.

2.5 MECS Engine Crank

Bypass air is full open with the cold thermowax element. The valve begins to open with warm coolant temperatures: 40–50° C (105–125°F), except the 1.6L in the Capri—60°C (140°F). Control shuts off the Air Conditioning compressor clutch during cranking. It stays off during the first 5 seconds after start. Establishing the initial idle is more important than cooling the passengers, at least for 5 seconds.

MECS-II

On the 2.0L 4-cylinder, for Engine Crank there are simultaneous injections, two per crankshaft revolution (four per cycle), each injector. See Fig. 2-2. On the 2.5L V-6, there are sequential injections, the same as during engine running.

2.6 Engine Crank Summary

- Fuel-injection pulse times from look-up tables, corrected for ECT and ACT. MAF signals ignored
- Spark timing directly from PIP, 10°BTDC. No SPOUT
- Throttle-Bypass Air full open, bypassing closed throttle
- Open Loop
- No emission controls operating

8

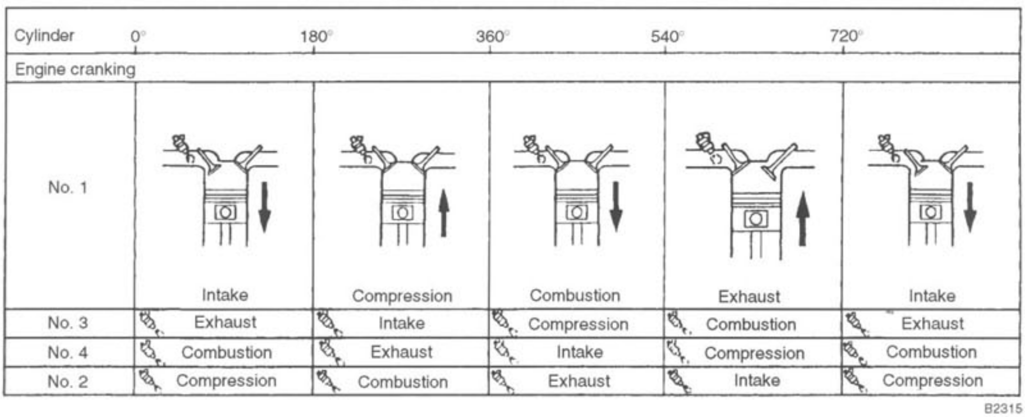


Fig. 2-2. MECS 2.0L Engine Crank strategy: simultaneous injection, twice per crankshaft revolution.

3. Cold Start/Warm-Up—Strategy # 3

Fig. 3-1. Engine Cold/Warm-Up strategy depends on engine temperature.

The control module changes over from Engine Crank Strategy to Cold Start/Warm-Up when it observes the signs of engine running:

- PIP input indicates a steady rpm signal, higher than cranking
- MAF signals become regular, indicating low load
- TPS remains low, closed throttle

3.1 Fuel Control

Cold Start/Warm-Up strategy changes fuel-control look-up tables to reduce basic injection pulse time by half. To this, pulse time is added because the ECT signals cold engine, but that gradually reduces as the engine warms up. Air-temperature input signals add fuel-injection pulse time as needed, depending on the temperature of the intake manifold. Warm-up Strategy looks for a balance in enrichment:

- On one hand, a richer mixture means better combustion in cold cylinders, improving cold idle and reducing the chances of a cold stall. Further, extra fuel delivered to the catalytic converter burns sooner and heats up the converter for earlier action
- On the other hand, a leaner mixture means the engine will more likely pass its qualification emission test. Many engines fail during the first minute, the cold warm-up period

3.2 Emission Control

Emission control is important during Cold Start/Warm-Up. It must be handled by the fuel control for the air-fuel mixture in the combustion chamber because none of the emission systems can be engaged immediately after cold start.

During warm starting, on engines with Thermactor, when ECT signals warmer than 12°C (55°F), the control module signals the bypass valve (TAB) to close. This sends the secondary air through the diverter valve (TAD) upstream to the exhaust manifold. The control module timer limits upstream delivery to about 3 minutes.

Remember, diverting the secondary air upstream to the exhaust manifold burns "leftover" HC and CO gasses from the rich air-fuel mixtures of warm ups, providing three results:

1. Less warm-up pollution—with the addition of air containing oxygen, HC and CO from the air-fuel mixtures tend to be burned or oxidized into H_2O and CO_2.
2. The hot exhaust gasses resulting from the burning air-fuel mixtures in the exhaust manifold help to heat the catalytic converter. HEGOs are warming electrically.
3. The Thermactor air (mostly oxygen) increases the oxygen content of the exhaust gasses flowing past the oxygen sensor. Because it is sensing extra oxygen, it signals low voltage, inaccurately indicating lean mixture. The control module ignores any oxygen sensor readings while the Thermactor is diverted to upstream.

3.3 Spark Timing

Cold Start/Warm-Up strategy changes Spark-timing look-up tables to advance base spark timing according to PIP and MAF inputs. The base timing is advanced further depending on the cold-engine ECT signals. The control-module timer causes further advance after a calibrated time. Spark-timing advance increases combustion chamber temperatures, warming the catalytic converter.

Cold Start/Warm-Up timing is also changed according to the engine load, depending on the transaxle status. Cranking can only be done in Neutral or Park, indicated by the NDS switch (or the indications of neutral or clutch disengaged in manual transaxles). After start, shifting the Transaxle into Drive or Reverse signals the control module to adjust the spark timing for adequate power and a smooth idle.

3.4 Throttle Air Bypass (ISC)

As the engine warms up, the Throttle-Air Bypass closes more for a normal idle rpm. The control module signals a reduced duty cycle to the Bypass Air for a smaller opening, so-called fast idle. For colder ECT and air-temperature signals, idle rpm is higher. Without the fast-idle cam of carburetors, you do not need to kick it off the cam. Notice too that Warm-up cold-idle rpm is much lower with fuel injection than with carburetors.

Transaxle-load status helps to determine throttle bypass-air to control rpm. *Neutral load allows the bypass to close, maintaining* the desired lower Warm-up rpm. Shifting to any drive mode causes the bypass to open, carrying the load of the transaxle. To reduce creep, Drive rpm is lower than Neutral or Park.

Idle rpm receives several feed-forward signals related to electrical loads affecting the alternator drag, or power-steering pump drag:

- Heated rear window (backlight to Ford), or heated windshield (special option on some luxury Fords). The control module increases bypass air to anticipate the drop in idle rpm caused by the increased alternator load. Higher idle rpm also increases alternator rpm for greater output rate to carry the electrical load
- Air conditioner. Receiving a signal from the A/C compressor clutch, the control module signals to increase bypass air to anticipate the load of the compressor
- Power steering. Turning the steering wheel while still at standstill puts the greatest load on the power-steering system. If the pump pressures rise above 400–600 psi (2700–4100 kPa), the control module signals to increase bypass air to anticipate the power-steering pump load, preventing engine stalling
- Headlamps ON increases alternator load. (Daytime Running Lamps in Canada)
- Heater blower on position 3 or 4

Idle rpm is controlled in a closed-loop mode. The computer compares the PIP signal to each different target idle rpm from the control module computations and modifies output signals to maintain the target idle rpm.

3.5 MECS Cold Start/Warm-Up

Fuel and spark timing are similar to EEC systems except for the 1.6L engines and the 2.2L non-turbo engines, with vacuum-controlled advance retard. Spark timing operates independently of the control module, using port vacuum.

Bypass air is increased through two passages: 1) direct temperature control through the thermowax pellet of the Air Valve, and 2) through the control module actuator signals to the Idle-Speed Control Solenoid. As the engine warms past 40–50°C (100–120°F) (Capri 1.6L and Probe 2.0L and 2.5L slightly warmer), the wax pellet expands and closes that passage. The other passage, the ECA-controlled bypass, operates at all temperatures.

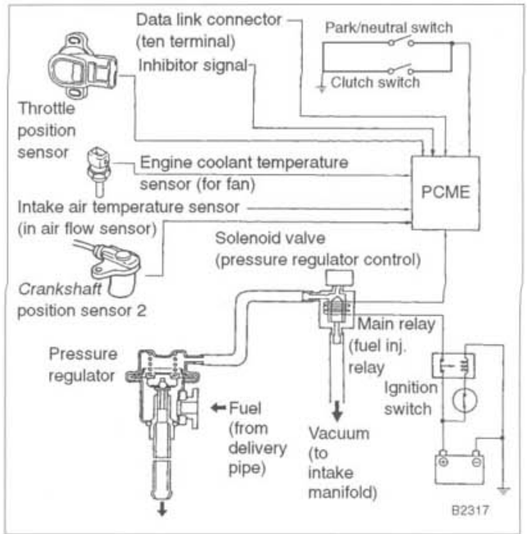


Fig. 3-2. MECS increases fuel pressure after hot start by venting pressure regulator to atmosphere instead of to intake manifold. Venting determined by high coolant temperature or high intake air temperature.

To prevent fuel boiling in the injectors or fuel rail after a hot start, MECS solenoid valve vents the fuel pressure regulator. When the fuel-pressure regulator is open to the atmosphere, it raises the fuel pressure to about 41 psi (280 kPa). After about 2 minutes, or if the engine is loaded by driveaway, the solenoid closes the vent, resuming normal relative fuel pressure of 33 psi (230 kPa).

MECS-II delays Air-conditioning power for 3–4 seconds after start to prevent stalling.

3.6 Cold Start/Warm-Up Summary

- Fuel injection controlled by PIP and MAF, corrected for ECT and intake-air temperature. Emission controls delayed, EGR, Canister Purge; Secondary air as ECT signals warm-up
- Spark timing controlled by PIP and MAF, corrected for ECT and air temperature, also for transaxle status; advanced by timer
- Open Loop based on seconds since start, ignoring first signals from HEGO
- Throttle Air Bypass operates closed loop, opening and closing the passage to maintain target rpm—higher for cold temperatures, modified by feed-forward signals from various loads on alternator and power-steering pump

COLD START/WARM-UP— STRATEGY # 3

4. Cold Driveaway—Strategy # 4

Cold Driveaway probably happens within one minute. The active sensors are:

- PIP signals increase in rpm
- MAF signals increase in air flow
- TPS signals increase in amount of throttle opening, and rate of throttle opening
- ECT and ACT signal cold temperatures

4.1 Fuel Control

Cold Driveaway uses fuel-injection look-up tables for the changing PIP (rpm) and MAF (load). To these base pulse times, the control module adds pulse time for the TPS signals of amount and rate of throttle opening. Control further adds pulse time according to the ECT signals of the cool engine. ACT signals also add pulse time as needed. As ECT and intake-air temperature rise, the cold enrichments gradually reduce.

During Cold Driveaway, based on ECT signals greater than 77°C (170°F), or on elapsed time greater than 3 minutes, the control module opens the diverter (TAD) valve. If the secondary air were not diverted from the exhaust manifold, continued burning of excess fuel would overheat the manifold. The open Diverter Valve sends the secondary air downstream of the exhaust manifold and the oxygen sensor. The oxygen in the air helps to burn the HC and CO in the oxidation section of the catalytic converter (OC), reducing tailpipe emissions.

For engines with EGR, during Cold Driveaway, the control module signals keep the EGR valve closed. Exhaust gas would interfere with the engine operation. At the low engine temperatures, little NO_x is forming in the combustion chambers.

During Cold Driveaway, control shuts off Canister Purge (CANP) to prevent interfering with the air-fuel ratio during warm up.

4.2 Spark Timing

Cold Driveaway uses Part-Throttle spark-timing look-up tables for the changing PIP (rpm) and MAF (load). Base spark timing increases with increases in the PIP signal rpm. With a cool ECT signal, spark timing is advanced from base timing.

4.3 Throttle Air Bypass (ISC)

Cold Driveaway continues the increased duty-cycle signal that keeps the air bypass partly open. While the bypass air is reduced with further warm up, the control-module signal continues to keep some bypass air flowing. If the throttle is suddenly closed, the bypass air prevents engine stall.

4.4 Cold Driveaway Summary

- Fuel injection cuts back as engine warms. EGR and Canister Purge still shut off. Secondary air to catalytic converter
- Spark timing advances with rpm and retards as engine warms
- Throttle Air Bypass partly open, reducing with warm-up.

5. Warm Driveaway—Strategy # 5

The important Warm Driveaway sensors are:

- PIP signals increasing engine rpm
- MAF signals increasing mass air flow
- ECT and ACT signal engine temperatures approaching warm
- TPS signals cause mixture enrichment as throttle is opened (as accelerator pump). Enrichment increases with lower ECT and ACT, and with increases in MAP (load)
- DPFE signals indicate EGR backpressures as exhaust gas begins to circulate, about one minute after starting
- From operating Open Loop, the oxygen sensor warms enough to begin sending good (fluctuating) signals so the control module can begin Closed Loop operation.

5.1 Fuel Control

Warm Driveaway fuel control is based on the base fuel-injection pulse times from the PIP and MAF signals. Extra fuel is provided for acceleration. ECT is warm enough that no added fuel pulse times are needed, but ACT may signal cold air in the intake system, requiring extra fuel pulse time to be added.

- DPFE signals indicate EGR backpressures as exhaust gas begins to recirculate, and PFE signals indicate EGR pressure drop
- Early in this warm up in Open Loop (as quickly as 10 seconds), the heated oxygen sensor warms enough so its signals begin fluctuating. As permitted by the timer, the control module signals closed-loop operation

The Canister Purge valve remains closed until ECT signals indicate that the engine is fully warmed up, ready to receive fuel vapors into the incoming air-fuel mixture.

5.2 Spark Timing/EGR Flow

Warm Driveaway base spark timing is taken from a part-throttle look-up table. Timing may be advanced if the control module is receiving low ECT signals. As the engine warms, the control unit cuts back the temperature-based timing advance.

As EGR begins to flow, the control module adds advance to the base timing:

- The EGR-diluted air-fuel mixture takes longer to burn, so the spark timing must be advanced
- The EGR-diluted air-fuel mixture is less likely to detonate so the spark timing can be advanced

Advanced timing tends to burn the mixture more completely, reducing HC and CO. Spark timing is proportional to EGR flow rate—the more flow, the more advance.

Spark-timing/Automatic Transmissions

Spark timing is retarded during some shifts of later model automatic transmissions such as E4OD, AXODE, and 4EAT to provide smoother shifts. The strategy reduces the torque for about 50 milliseconds during the shift.

- When the A/T control unit is ready to shift, it signals the engine control unit. Under certain load conditions, if the engine control unit is warm, it signals the A/T control unit, something like, "OK shift"
- During the shift, the control module retards the timing briefly (20–30 ms), then resumes normal timing
- If the engine is cold, the control module may signal that it is not going to retard timing. "Shift, but under continued torque conditions"
- The A/T increases hydraulic pressure during the shift to handle continuing torque

Later models combine control of engine and automatic transmission (transaxle) into a single EEC-IV or MECS control unit.

5.3 Throttle Air Bypass (ISC)

Quite similar to Cold Driveaway.

5.4 MECS Part Throttle Acceleration

When you press the accelerator, the TPS signals throttle position and rate of movement on 2.2L and 1.8.L with automatic transaxle (ATX), also on 1993 and later 2.0L and 2.5L. But on the other MECS engines, control calculates acceleration when it senses larger-than-normal air flow signals from the VAF for the current crankshaft speed.

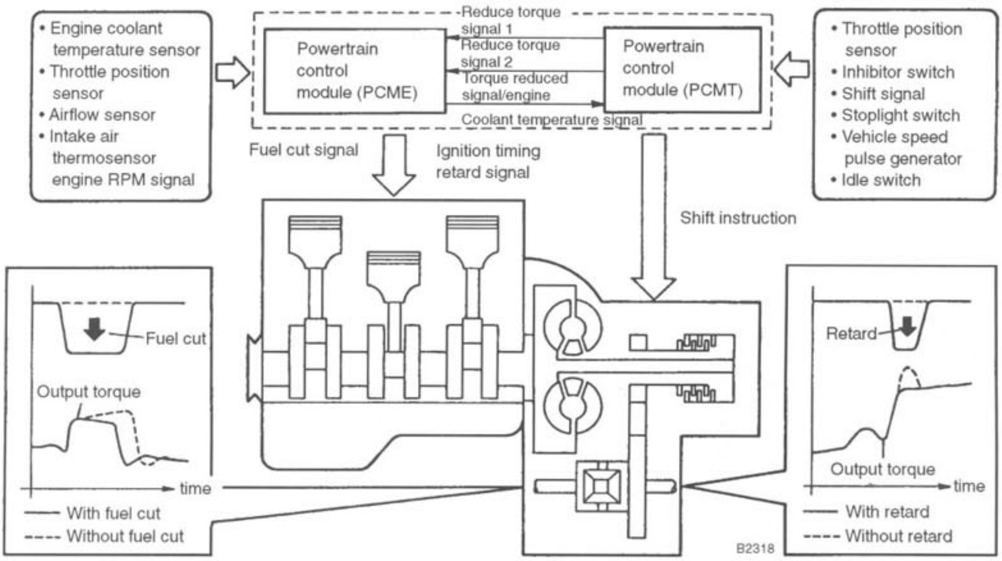


Fig. 5-1. Engine control module (PCME) and Transaxle Control Module (PCMT) trade signals for torque reduction—fuel cut during some upshifts, spark timing retard during most downshifts.

Torque Reduction

The 2.5L V-6 Engine Control Unit receives signals from the A/T Control Unit to provide smoother shifting, and to reduce load on the automatic transaxle shifting mechanism.

- Upshifting-1>2, and 2>3—when the transaxle is ready to shift, it signals the control module. If the coolant is warm, > 60°C (140°F), the control module sends "reduce torque signal #1" to cut fuel injection for about 50 milliseconds: if TPS signals throttle more than half-open, cut 1/2 the cylinders and, If TPS signals more than 3/4 open, cut all cylinders
- Downshifting (except OD>3)—when the transaxle is ready to downshift, it signals the control module. If warm, the control module sends "reduce torque signal #2" to retard timing for about 50 milliseconds

The 4-cylinder 2.0L Engine Control Unit also controls Automatic Transaxle similarly but in a single control unit for torque reduction during upshifts and downshifts.

5.5 Warm Driveaway Summary

- Fuel injection switches to Closed Loop in about one minute
- Spark timing considers rpm, temperature, EGR flow
- Secondary air to converter, Canister Purge off

6. Part-Throttle Acceleration—Strategy #6

Part-Throttle Acceleration considers that you want to increase car speed, but are still interested in good fuel economy and good emission control. To do this, engine control must remain closed loop, with emission controls operating. The most important sensor is the TPS, signalling less than Wide Open Throttle (WOT).

> If you are driving for economy, you may wonder how far to push the accelerator to increase speed. Some energy conservationists advise drivers to operate the accelerator as if an egg were on the accelerator pedal. During an earlier fuel crisis, BMW ran tests showing that the egg-on-the-accelerator concept did not save fuel. Indeed with fuel injection, accelerating briskly to the desired speed is more economical because the acceleration-enrichment time is shorter. I accelerate "briskly" at about 90%, "90kPa" on my manifold-pressure gauge. I want to avoid sending a Wide Open Throttle (WOT) signal to the computer because that changes all the rules of acceleration. I suspect the egg-on-the-accelerator bit is a leftover from carburetor days, avoiding that extra squirt from the accelerator pump that carburetors needed to prevent engine stumble.

6.1 Fuel Control

Part-Throttle Acceleration base injection pulse time is taken from the Part-Throttle look-up tables according to the PIP (rpm) and the MAF (load) signals. Pulse times are increased according to the TPS signal, indicating amount and rate of throttle opening. The rate signal, indicating how fast you depressed the accelerator, adds pulse time during the throttle movement, usually less than one second. Then control reduces enrichment to the proper pulse time for that throttle position.

Pulse time is also increased according to the ACT and ECT sensors, greater when the incoming air and/or the engine is colder. Control calculates the base pulse time and the additional fuel necessary to handle the increased air flow while maintaining the ideal air-fuel ratio. Oxygen sensor signals continue from the exhaust gas, and the system operates closed loop. Emission Control EGR, Thermactor, and Canister Purge continue as in Warm Cruise.

Acceleration that can cause a downshift of the automatic transmission may call for fuel cut or spark-timing retard to reduce torque loading during the shift. When the engine is warm, fuel may be cut from some injectors briefly—in milliseconds.

6.2 Spark Timing

Part-Throttle Acceleration spark timing continues from the Part-Throttle look-up tables, as in Warm Cruise, determined by rpm, load, and modified by ECT, and air temperature.

6.3 Throttle Air Bypass

Part-Throttle Acceleration Air Bypass continues as in Warm Cruise.

6.4 Intake Manifold Runner Control (IMRC)

During acceleration—part throttle or full throttle, as rpm increases above 3200—the control module opens the secondary throttle valves. This delivers air to the secondary intake valves, providing a smooth transition from low-speed low-load operation.

7. Full-Throttle Acceleration—Strategy # 7

Full-Throttle Acceleration is also defined as Wide Open Throttle (WOT). When the TPS signals WOT, that changes all the rules. You are indicating to the control system that you want full power. You are willing to sacrifice economy and emission control during that WOT acceleration.

7.1 Fuel Control

With the TPS signalling WOT, the control module shifts to Full-Throttle look-up tables. From those tables, the PIP and MAF signals to the control module determine a new set of base pulse times. Control provides extra enrichment during the throttle opening to handle the sudden rush of air. ECT and ACT add pulse times as necessary for lower temperatures.

The oxygen-sensor signals indicate rich mixture, but the control module ignores the oxygen sensor: "I know, I know, it's rich—and I want it that way!" Full-Throttle Acceleration causes the control module to shut off emission controls: Canister Purge valve closed; EGR valve closed; Thermactor Air diverted or dumped.

Wide-Open Throttle Air Conditioning (WAC) cuts out for 5–10 seconds after the WOT. In the Integrated Relay Control Module (IRCM), power is cut from the Air Conditioning Clutch for 10 seconds. The A/C compressor interruption is so short that you will probably never notice any change in air temperature. In some smaller engines, WOT control turns off the cooling fans for 10 seconds to reduce alternator drag. Again, the interruption will not be noticed.

7.2 RPM/Vehicle Speed Limitation

Some Ford engines with superchargers are easily capable of exceeding rpm limitations of the engine. To prevent engine destruction, rpm limitation operates from PIP signals to reduce fuel injection gradually to limit engine rpm.

The 3.8L SC engine in T'Bird/Cougars cuts back fuel injection if the coolant temperature or the oil temperature signals overheat when running above 100 mph for extended periods of time. If the engine rpm is too high for third gear, the T'Bird will illuminate the Shift Indicator Light and sound a chime. This warns the driver to upshift or slow down, otherwise, fuel will be cut back.

The SHO engine is rev-limited by the control module to 7300 rpm to prevent over-revving the accessories. If the pulley diameters are changed to under-drive accessories, engineers say the engine is safe to 8500 rpm.

7.3 Spark Timing

Full-Throttle Acceleration shifts spark timing to a different set of look-up tables that provide advanced spark timing for maximum power without regard to emission control. With a richer mixture that is less likely to detonate, spark timing increases, perhaps from 20° BTDC to 30°. The Knock Sensor (KS) monitors engine vibrations and retards spark if it detects detonation. KS operates closed loop, retarding to reduce knocking, and advancing slowly as knock signals disappear. See Figure 7-1.

Full-Throttle Acceleration often causes downshift of the automatic transmission. When engine conditions permit (warm), ignition timing is retarded for a fraction of a second, just long enough for the shift. This improves shift smoothness, and also increases life of the shift clutches.

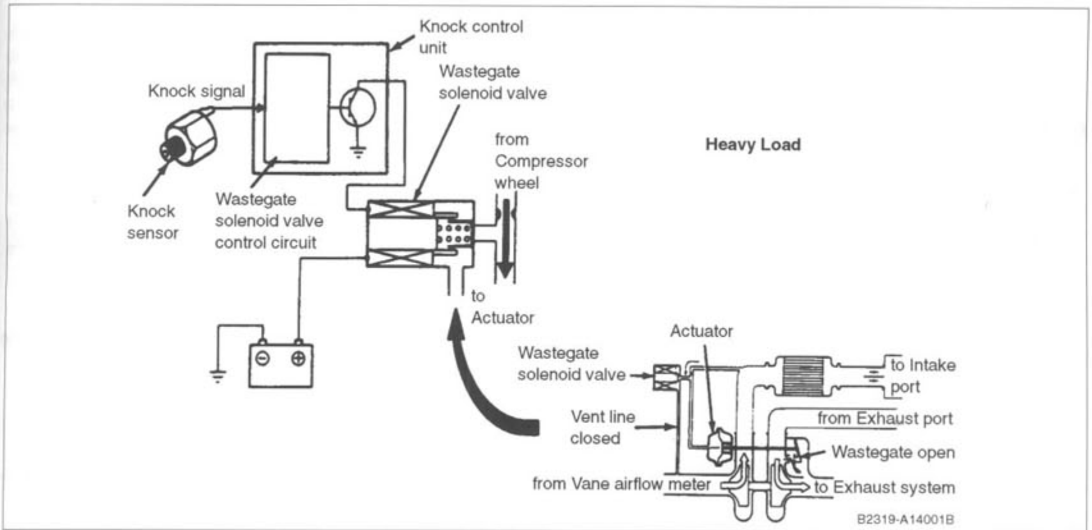


Fig. 7-1. Under heavy load, knock signals to Knock Control Unit (KCU) cause wastegate solenoid valve to open bypass, reducing turbo boost.

7.4 Throttle Air Bypass (ISC)

No change from the 100% duty cycle of Warm Cruise. Passing extra air around the wide-open throttle has the effect of fitting a larger throttle body. At the same time, if WOT is snapped shut without drive connection, (Neutral or clutch disengaged), the Throttle Air Bypass keeps the engine from stalling.

7.5 MECS Full-throttle Acceleration

The TPS signals WOT to the control module. Fuel enrichment begins and emission control (EGR and canister purge) cuts off. Turbo engines build boost, with knock protection:

- 2.2L computer-controlled spark retard and wastegate opening
- 1.6L computer-controlled spark retard, and mechanical control of wastegate opening

MECS-II Overspeed Protection

- 2.0L 4-cylinder cuts fuel supply over 6800 rpm, and over 5500 rpm if engine is cold—ECT below −15°C (5°F)
- 2.5L V-6 cuts fuel over 7500 rpm, and over 5500 rpm if engine is cold—ECT below −15°C (5°F)

7.6 Full-Throttle Acceleration Summary

- Fuel injection rich, Open Loop. Emission controls off (EGR, Secondary Air, Canister Purge), Speed limitation cuts fuel to limit overspeed
- Spark timing for max power. Knock signals retard timing and cut back boost, closed loop
- Throttle bypass wide open for added air/power

8. DECELERATION—STRATEGY # 8

Strangely enough, Deceleration closed-throttle operation presents some problems. The control module recognizes this operation by the signal from the Vehicle Speed Sensor (VSS) and by the closed-throttle signal from the Throttle Position Sensor (TPS). The strategy calls for reducing fuel flow (fuel is being wasted) while still controlling emissions that result from too-lean burning.

8.1 Fuel Control

Deceleration injector pulse times become shorter. When pulse times are less than 2 milliseconds and rpm is greater than 1500, control shuts off the injectors. In some engines, the oxygen sensor continues to switch voltages, calling for closed-loop operation to maintain ideal air-fuel ratio; in others, the mixture goes lean and the system operates open loop.

From shut-off, the control module resumes normal injection pulses:

- As engine speed decreases to 1200 rpm, sooner if ECT signals indicate cold engine
- As you step on the accelerator

Emission control does not function. Signals cut off EGR and Thermactor.

8.2 Spark Timing

Deceleration spark timing comes from a Closed-Throttle look-up table. With low air flow signals, there is little chance of detonation so spark timing is advanced.

8.3 Throttle Air Bypass (ISC)

Deceleration Throttle Air Bypass is complex, depending on PIP and VSS signals. Control-module signals drive the Bypass:

- Part-way closed when the TPS first signals closed throttle. The bypass acts as a throttle dashpot to prevent an over-rich mixture
- Full closed a few seconds later, to increase engine braking
- Partly open again as rpm approaches idle, to prevent engine stall

8.4 MECS Deceleration

MECS 1.3L, 1.6L and 1.8L engines use a mechanical dashpot to limit sudden throttle closing. The dashpot prevents stalling and excess emissions from too-rich operation. Full closing of the vane in the VAF normally cuts off the fuel-pump safety switch in the VAF, cutting off the fuel pump. MECS-I uses two different methods to prevent this fuel-pump shut off:

- In 2.2L turbo engines, the control module completes the circuit to the fuel pump relay during deceleration
- In 1.6L engines, a capacitor discharges current to the fuel-pump relay during deceleration, keeping the pump running

Deceleration fuel is cut off from the injectors above 2200 rpm.

MECS-II

The Throttle Bypass-Air prevents cut-off of air flow, eliminating the need for a dashpot.

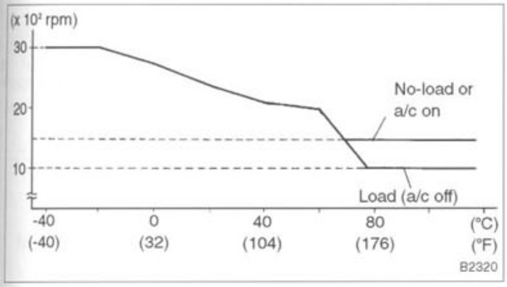


Fig. 8-1. Fuel cut-off ends as engine rpm drops, depending on ECT, AC, or engine load.

8.5 Deceleration Summary

- Fuel injection reduced, or cut off in most engines, resuming at lower rpm to prevent stalling
- Spark timing advanced
- Throttle Air Bypass closes partway as dashpot, then fully for engine braking, then open to prevent stalling

9. Warm Idle—Strategy # 9

9.1 Fuel Control

The control module recognizes Warm Idle strategy when the TPS indicates closed throttle, VSS indicates zero vehicle speed, and ECT signals warm engine. The control module switches to Closed Throttle look-up tables. Injection pulses are short because the engine needs to deliver only enough power to keep itself running.

Usually, the oxygen sensor continues to deliver switching voltages, so the engine operates closed loop. If the control module sees no change in the switching voltage for 15 seconds, it goes to open loop. Then if it sees two exhaust-gas oxygen variations, the control module switches back to closed loop.

The control module shuts off the EGR. The Thermactor will continue to divert downstream, but if idle continues for several minutes, the Thermactor will bypass to avoid overheating the catalytic converter.

9.2 Spark Timing

Warm Idle allows the exhaust gasses to cool. If prolonged, Warm Idle increases emissions of HC and CO. Ford Warm Idle strategy increases the temperature of the exhaust gasses for better emission control. Spark timing is retarded gradually about 5° after 1 minute of Warm Idle. Spark retard is combined with increased Throttle Air Bypass.

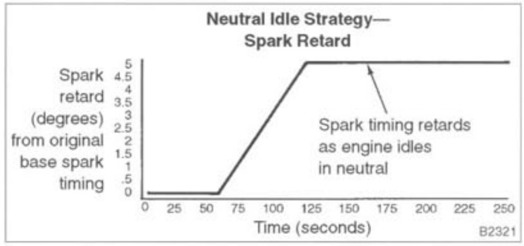


Fig. 9-1. After about 1 minute of warm idle, control module gradually retards spark about 5°.

9.3 Throttle Air Bypass (ISC)

Warm Idle Throttle Air Bypass increases gradually after 1 minute. This maintains idle rpm even with spark-timing retard. After 4 minutes, the throttle-air bypass opens slightly to increase engine speed about 80 rpm. But this rpm increase is limited unless the A/T is in Neutral or Park to prevent automatic-transmission creep.

Warm Idle can turn into hot idle, and the control module includes a strategy to reduce overheating:

- If coolant rises above 105°C (225°F), the control module signals the Throttle Air Bypass to increase Warm Idle engine speed about 100 rpm. It does this only if A/T is in Neutral or Park
- If the intake-air temperature is above 105°C (225°F), the control module signals the Throttle Air Bypass to increase Warm Idle engine speed about 25 rpm. It does this only if A/T is in Neutral or Park

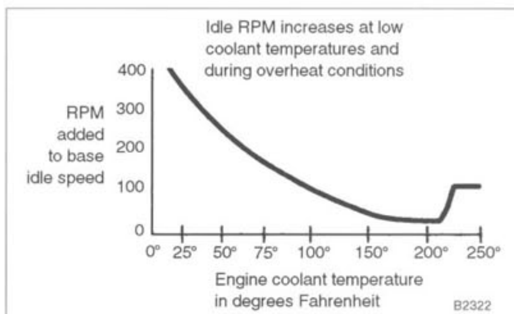


Fig. 9-2. High engine coolant temperatures (ECT—above 225°F) will cause control module to increase idle rpm about 100 rpm.

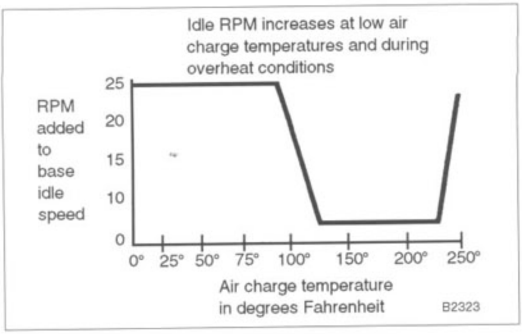


Fig. 9-3. In some engines, high intake air temperatures will cause control module to increase idle rpm about 25 rpm.

9.4 MECS Warm Idle

MECS engines do not operate on Warm Idle strategy as EEC engines. Control does not command advance in spark timing or rpm with high coolant temperatures or high air charge temperatures.

9.5 Warm Idle Summary

- Fuel injection, Closed Loop. Emission Controls off
- Spark timing gradually retards
- Throttle Bypass Air increases after time to reduce emissions or to reduce engine overheat

Table b. EEC-IV Control Strategies

Strategy Number	Fuel Control	Spark Timing	Bypass Air	Emission Control	Active Sensors
1. Warm Cruise	Closed loop, ideal	Advance, 30° BTDC	Full open (100% duty cycle)	EGR, canister purge, secondary air	PIP, MAF, HEGO, DPFE
2. Engine Crank	Open loop, rich	Fixed, 10° BTDC	Full open (100% duty cycle)	None (some secondary air)	PIP, ECT, ACT
3. Cold Start/Warm Up	Open loop, rich	Base, plus advance for load, rpm, time, ECT	Closed loop, feed forward signals, gradual close	Secondary air diverted	PIP, MAF, TPS, ECT, ACT, NDS
4. Cold Driveaway	Open loop, rich, gradually leaning	Base, plus advance for load, rpm, time	Full open (100% duty cycle)	Secondary air diverted	PIP, MAF, TPS, ECT, ACT, NDS
5. Warm Driveaway	Open loop, quick switch to closed loop	Base, plus advance for load, rpm, time, ECT, EGR flow	Full open (100% duty cycle	EGR, secondary air diverted, canister purge	PIP, MAF, TPS, ECT, ACT, NDS, DPFE
6. Part-throttle Acceleration	Closed loop, enrich for acceleration	Base, plus advance for load, rpm, time, ECT, EGR flow	Full open (100% duty cycle)	EGR, secondary air diverted, canister purge	PIP, MAF, TPS, ECT, ACT, DPFE
7. Full-throttle Acceleration	Open loop, rich, WOT look-up tables	Special advance look-up tables, KS	Full open (100% duty cycle)	None	PIP, MAF, TPS, ECT, ACT
8. Deceleration	Open loop, lean, some closed loop, some fuel cut	Advanced, special look-up tables	Dashpot, then engine braking, then open to avoid stall	Canister purge	PIP, TPS, ECT, VSS
9. Warm Idle	Closed loop unless no EGO switch	Gradual retard, after 1 minute of idle	Closed loop control, feed forward signals	Secondary air diverted, then switch to bypass	PIP, MAF, TPS, ECT, VSS, NDS

WARM IDLE—STRATEGY # 9

Table c. MECS-I Control Strategies

Strategy Number	Fuel Control	Spark Timing	Bypass Air	Emission Control	Active Sensors
1. Warm Cruise	Closed loop, ideal, 1.8L HISA valves close below 5000 rpm	Advance, 30° BTDC	Bypass closed, ISC valve open slightly	EGR, canister purge	CKP, VAF, HEGO
2. Engine Crank	Open loop, rich	Fixed, 6° BTDC (7° BTDC MECS-II)	Bypass full open, ISC open	None	CKP, ECT, ACT
3. Cold Start/Warm-Up	Open loop, rich	Base, plus advance for load, rpm, time, ECT	Bypass full open, ISC open, gradual close	None	CKP, VAF, TPS, ECT, ACT, NDS
4. Cold Driveaway	Open loop, rich, gradually leaning	Base, plus advance for load, rpm, time	Bypass full open, ISC open, gradual close	None	CKP, VAF, TPS, ECT, ACT, NDS
5. Warm Driveaway	Open loop, quick switch to closed loop	Base, plus advance for load, rpm, time, ECT, EGR flow	Bypass closed, ISC valve open slightly	EGR, canister purge	CKP, VAF, TPS, ECT, ACT, NDS
6. Part-throttle Acceleration	Closed loop, enrich for acceleration	Base, plus advance for load, rpm, time, ECT, EGR flow	Bypass closed, ISC valve open slightly	EGR, canister purge	CKP, VAF, TPS, ECT, ACT, DPFE
7. Full-throttle Acceleration	Open loop, rich, WOT look-up tables	Special advance look-up tables, KS	Bypass closed, ISC valve open slightly	None	CKP, VAF, TPS, ECT, ACT
8. Deceleration	Open loop, lean, some closed loop, some fuel cut	Advanced	Bypass closed, ISC valve open slightly	None	CKP, VAF, ECT, VSS
9. Warm Idle	Closed loop unless no EGO switch	Advanced according to rpm	Bypass closed, ISC valve open slightly, feed forward signals	None	CKP, VAF, TPS, ECT, VSS, NDS

Chapter 9

Tuning for Performance and Economy

Contents

9

1. INTRODUCTION

In the previous chapters, I explained the detailed workings of Ford fuel injection and engine control systems. Now I will take a look at the enthusiast's obvious next step—modifying electronic engine-control systems for high performance.

You know enough about the various ways that Ford systems meter fuel. We'll look at what Special Vehicle Operations (SVO), the factory performance group, and the aftermarket *tuners and parts suppliers offer you. We'll consider what features* of the stock system you might have to give up. You'll know enough to ask questions and to understand the tradeoffs that usually accompany fuel-system modifications.

I'll describe legal issues (some new as of 1993), emissions, and warranties. I'll describe some of the decisions you'll be making, the payoffs and the give-ups of performance mods. After covering some of the basics as they affect performance, I'll describe specific parts, kits, and add-ons available from Ford Special Vehicle Operations (SVO), and from aftermarket suppliers.

Many Ford owners show an intense interest in performance mods. Some devote their energies and their dollars to knock off another tenth of a second. They support several independent monthly Ford buff magazines and dozens of aftermarket suppliers. And Ford Motor Company supports them with the Special Vehicle Operations. You can do a lot at your friendly Ford dealer, buying performance parts and even ready-to-run street-legal performance vehicles such as Ford's Special Vehicle Team (SVT) Mustang Cobra and F-150 Lightning. Look also for aftermarket-created Mustangs such as Steeda Mustang, and SAAC Mustang, complete with warranties.

You'll find many roads to improving the performance of your car, van or truck. Those of you familiar with Bosch fuel injection have a head start. You can tell there's a touch of Bosch in most Ford vehicles: injectors, fuel pumps, fuel-pressure regulators, fuel rails, even Volume Air Flow sensors. In addition, truck and van owners, Mercury and, yes, even Lincoln owners have several possible performance options.

> I know you'll find carbureted Fords laying down rubber and winning NASCAR events, but that's another subject. Here, I'll concentrate on performance relating to fuel injection/engine control. Also, I know you can do a lot with heads, headers, cams, pistons, not to mention suspensions and brakes, but that is another book. And don't forget that when you're considering engine mods and their effect on performance, remember what I said about the effects of temperature and humidity on engine power. SVO advises *that your elapsed times can vary by 0.2 seconds or more depending on the local weather conditions.*

Fig. 1-1. Ford Mustang Cobra shows Ford's path to modifying 5.0L engines: larger intake and exhaust ports, revised intake manifold, high-flow fuel pump, and recalibrated EEC-IV control module.

Fig. 1-2. SVO Performance Parts Catalog shows many ways to improve the performance (and appearance) of your Ford car or truck.

2. Ford and Performance

Ford owners are fortunate. While there's still a lot of Ford carburetor muscle out there, there's also a lot of advanced electronic fuel injection/engine control. Our aim is to wring more performance out of the system.

Race on Sunday, Sell on Monday

Ford is a performance-oriented company. After a recent Ford President experienced track training at a high-performance driving school, he insisted his top executives do the same. That's changed top-down attitudes. Since then, Ford cars have shown improved performance and handling.

Ford builds some performance engines with knock sensors (5.0L trucks but not 5.0L passenger cars), and some with Octane Selectors. With a knock sensor, you can improve full-throttle performance by burning premium, higher octane fuel.

Fig. 2-1. 5.0L H.O. (High Output) version of long-time favorite small block V-8, also known as the 302, found in Mustang GT and Mark VII LSC.

Under the label Motorsport, Ford SVO operates with 23 people. They provide strong support to aftermarket performance shops and owners for track and for street. Sales of performance mods totalled $30 million in a recent year.

SVO develops special EEC-IV for Formula One cars in Europe, and Indy cars, beginning in 1993. See Fig. 2-2 and 2-3. When I examined these EEC-IV units at Ford, I could see they differed from stock EEC-IV so you can't fit one to your Ford. They have military connectors for reliability; they are packaged to get rid of the extra heat caused by rpm up to 14,000 and longer injector pulse-times, and they are sealed against moisture. "Formula One runs in the rain," SVO reminded me. Yet the basic EEC-IV module corresponds to the millions of engine-control units made by Ford for street use. SVO experience feeds back into the production line electronics. For example, Ford SVO was able to cause improvements in production coolant-temperature sensors to be suitable for both production and racing.

Ford competes in CART, Formula One, IMSA, off-road truck racing, and SCCA Trans-Am. SVO philosophy: "We race what we sell, and we sell what we race."

Ford Mustangs are strong runners on the track. The 5.0L fuel-injected engine is well suited to hop-up for the strip. Its large production volumes attract many aftermarket suppliers of performance gear.

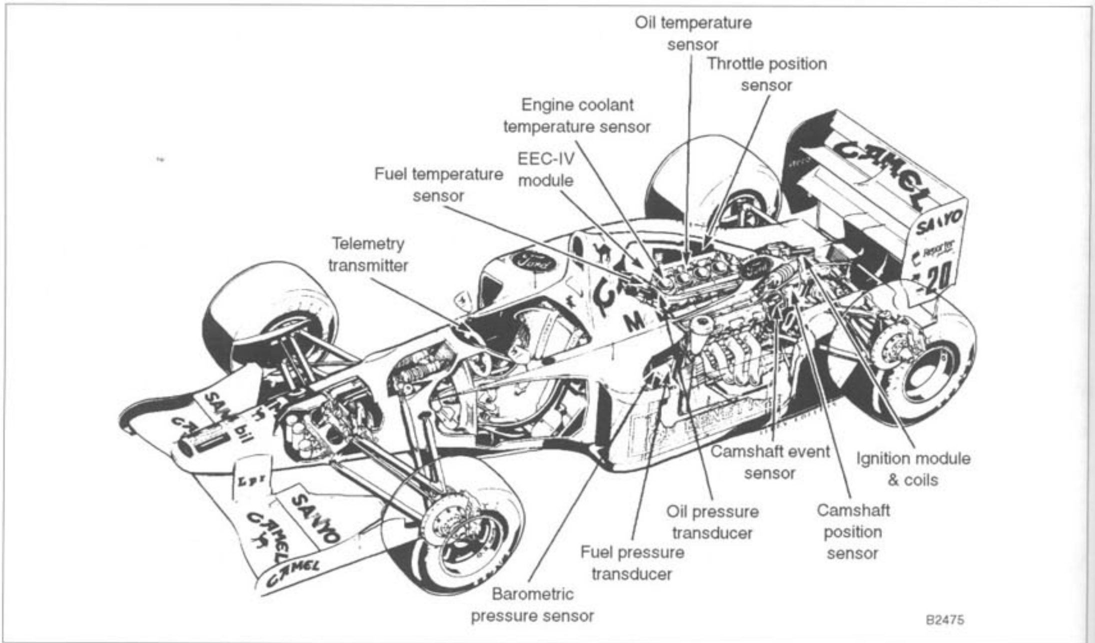


Fig. 2-2. Ford F1 engine uses EEC-IV engine control. Control module is similar to one used on production cars.

Fig. 2-3. F1 EEC-IV module can be tapped into right at track. Note MAP/BP sensor to right of module, and fuel rail and pressure regulator.

SHO (Super High Output Taurus)

Finally, there's SHO (Super High Output) production Taurus sedans, streetable of course, with performance versions of the 3.0L V-6 (M/T) and 3.2L (AXODE), jointly developed by Ford and Yamaha. You can appreciate EEC-IV when you realize how little the engine-control system had to be changed while bumping the output of the V-6 engines more than 50%. What you have here is a "Q-ship," a four-door sedan that can excite the driver without exciting the police. Word on the track is, Ford and Yamaha have done such a great job with it that you don't need to tamper with it.

> "Q-ship" is a term from World War II, when German submarines threatened shipping lanes. The Allied Navies fitted innocent-looking merchant vessels with high-power hidden armament, hoping for a challenge from a U-boat. When the enemy surfaced and approached for the kill, the Q-ship unleashed its power, the big guns came out, and the kill went the other way. In Europe today, autobahn Q-ship cars are usually black and carry no badges indicating the engine size. Consider our U.S. speed limits and the price of tickets—cash, license points, and insurance premiums—you may have more highway fun in an innocent-looking Q-ship such as the Taurus SHO than in a red Fer-

Fig. 2-4. SHO 3.0L engine in 5-speed transaxle (M/T) Taurus delivers 220 horsepower from 3.0L. Beginning '93, SHO 3.2L 220 bhp comes with automatic transaxle, E4OD.

Other fuel-injected engines adaptable to performance include:

- 1.6L turbo four (MECS-I) Capri
- 1.8L DOHC four (MECS-I) Escort/Tracer
- 2.0L DOHC four (EEC/MTX) Probe
- 2.2L four (MECS-I) Probe
- 2.3L Turbo OHC four (EEC) T'Bird/Merkur
- 2.5L DOHC V-6 (MECS-II) Probe
- 3.8L S/C V-6 (EEC) T'Bird/Cougar
- 5.8L V-8 351W (EEC) trucks
- 7.5L V-8 460 (EEC) trucks

Ford has built hundreds of thousands of fuel-injected 5.0L V-8s, with the potential of substantial power gains from modifying the engine under the stock fuel-injection system. In some cases (1987 California, 1988 and earlier 49-state), modification of the engine-control system is necessary to realize the full benefits of other engine work such as radical camshafts, rocker arms, cylinder head porting, or forced induction.

3. The Legal Issues

OK, this subject is not the most fun, but it is realistic and must be faced in today's green climate. Before you modify your engine, consider the issues of warranty, and the issues of tampering.

3.1 Warranties

On most cars, the emission-control system (and that includes most of the fuel injection/engine control) carries a warranty of 5 years or 50,000 miles. As of 1993, manufacturers warrant systems for 3 years/36,000 miles. But for 7 years/70,000 miles, manufacturers must replace under warranty any emission-control parts costing more than $300.

Be sure you read the fine print where it says "under normal use." As soon as you bolt on performance equipment, you may give the dealer and the manufacturer a legal claim to void the warranty if they can show that your modifications interfere with the performance or reliability of the original equipment. In one extreme case, a manufacturer (not Ford) voided warranty coverage after installation of an aftermarket car phone. It seems the installer had inadvertently drilled through a circuit in the Anti-lock Brake System (ABS). What can I say? Before you grab for performance, know what you might be giving up.

This catalog lists primarily special, competition parts and is intended only as a supplement to the published service manuals and parts catalogs of Ford Motor Company. Buyers of competition parts are warned that many of these parts are for off-highway use only and that special warranty provisions apply.

OFF-HIGHWAY OR RACING USE

Because U.S., Canadian, state or provincial laws and regulations may prohibit removal or modification of components that were installed on vehicles by Ford Motor Company to meet emission requirements or to comply with motor vehicle safety regulations applicable to vehicles manufactured for use on public roads, Ford Motor Company recommends that vehicles equipped with parts designated "for off-highway use" not be operated on the public roads and offers such parts only for track or off-highway competitive or performance use. Such parts have a special "warning" label which reads:

WARNING:

This part has been designed and is intended for off-highway application only. Installation on a vehicle intended for use on public roads may violate U.S., Canadian, state or provincial laws and regulations including those relating to emission requirements and motor vehicle safety standards. (NOTE: In California this part may legally be used only on a racing vehicle which will never be operated on public roads.) In addition, installation of this part may adversely affect the warranty coverage on your vehicle.

NOTE — CALIFORNIA ONLY

The emission laws and regulations of the State of California apply to all non-racing vehicles. Consequently, those parts marked in this catalog with an asterisk and appropriately marked on their packaging may legally be used in California only on a racing vehicle which will never be operated on public roads.

NO PARTS WARRANTY

*Competition parts are sold "**as is**" without any warranty whatsoever. **Implied warranties, including warranties of merchantability or fitness for a particular purpose, are excluded.** The entire risk as to quality and performance of such parts is with the buyer. Should such parts prove defective following their purchase, the buyer and not the manufacturer, distributor or retailer, assumes the entire cost of all necessary servicing or repair.*

Ford Motor Company vehicle and parts warranties are voided if the vehicle or part is used for competition or if they fail as a result of modification.

B2379

Fig. 3-1. Ford Motorsport spells it out. Some performance parts are for "off-highway or racing." The parts are not warranted, and may adversely affect warranty coverage on your vehicle.

Ford SVO sells competition parts "as is," without any warranty whatsoever. If you really get a defective SVO part, don't go back to your friendly Ford dealer under the vehicle warranty. SVO will listen to you on a case-by-case basis, but they're covered in writing: "Entire risk...is with the buyer."

3.2 Tampering

For emission-controlled cars—and that includes all Ford vehicles I'm talking about in this book—fuel injection systems are considered to be part of emission-control equipment. Modifying the fuel injection system is, therefore, modifying the emission controls, and that raises some questions relating to federal laws of the U.S. and Canada, as well as state and provincial laws.

You may have heard that only the professional technician is subject to a fine if he alters emission-control equipment but the owner was exempt from such restrictions. That was before the 1990 Amendments to the Clean Air Act. Now the $2500 fine extends to owners and individuals. Regardless of who does it, tampering is a Federal offense. In effect, future performance mods fall in two classes:

- Strictly for the track, never to be driven on public roads
- Exempted by the state or federal government as not affecting emissions

"What is street-legal?" It's a rapidly changing picture. One of the important movers and shakers in performance mods is Specialty Equipment Market Association (SEMA). Frank Bohanon, SEMA Director of Technical Affairs, told me of the new emphasis on performance products: "There's room for performance mods to go beyond the Original Equipment Manufacturer (OEM), who had to design and build to meet the needs of his total market. It is possible to modify these vehicles, and when you use these products as directed, you can get higher performance, still meeting the applicable guidelines and laws"

SEMA has created a voluntary parts-labelling system:

- Green #1 = 50-state legal
- *Blue #2 = 49-state legal, not California*
- Amber #3 = Race only, not legal for use on highway (this also applies to "non pollution-controlled vehicles", but <u>all EEC</u> engines are now pollution controlled.

SEMA prepares a monthly update of CARB E.O.s (Exemption Orders). Frank Bohanon said that you can obtain this list by writing, SEMA, address on p. 437. Or check with manufacturer regarding the status of their product. My only caution: some manufacturers seem more anxious to sell you their mods than in helping to keep our vehicles on the street "street-legal".

To help toward Clean Air, 1991 and later California cars and trucks have first generation On-Board Diagnostics (OBD-1) in the engine control unit. By 1994, 10% of each manufacturer's nationwide must have second-generation diagnostics (OBD-II), and by 1996, 100% of vehicles must have OBD-II. OBD-I and II keep a closer look at sensors and inputs to the control unit that could affect emissions. "They reduce our options," says Bob Stelmaszczak of Ford SVO (see later in this chapter). "On the other hand, we'll be looking at ways to improve performance of vehicles with alternate fuels, even Natural Gas (NG)!"

Practically speaking, if the car is to be registered and driven on public roads, the laws in your state and the legality of your modifications are more important than ultimate performance.

3.3 Modifications and Future Legislation

Tom Wilson, Editor of Super Ford magazine, told me where we're headed:

- Cars will be one or the other—really street-legal, or track, nothing in between. No more "street legal" (wink, wink). The fine print ("for use only off-road" or "not legal for sale or use in pollution-controlled vehicles") will get larger and be enforced. Note: All Ford fuel-injected vehicles are considered pollution-controlled
- Less exchanging of chips. Ford now solders chips to the board. But you'll see more electronic changing, under control, and street legal. (See Chapter 5 for information on FLASH and EEPROM)
- Less changing of cams, rockers, pistons, heads on newer engines
- Less need to change cams, rockers, pistons as manufacturers reach for better performance while remaining clean and economical. The new Ford "modular" engines, beginning with the 4.6L V-8, have greatly increased power outputs, but do not modify easily. As we go to press, parts are not available
- Increased certification of turbos, superchargers, and Nitrous bottles. NOS mods do not affect the engine control and they may run only about 10 miles in *50,000, and mainly at full throttle*
- Continued Ford support of performance enthusiasts, both street-legal and track

The early '90s are a time of change concerning exemption certificates. I'll indicate which mods are exempt as of time of writing, but that does not mean they are not "green." After all, no smog test is run at Wide Open Throttle.

Several aftermarket suppliers and tuners tell me their mods will pass emission tests but the paperwork and cost of exemption is discouraging. They are saying, "We think we're clean but it costs too much to prove it." California Air Resources Board (CARB) is saying, "We'll make it easier to exempt, but some of the mods have been completely careless about emissions. From now on, let's agree that your mods test clean. With an Exemption Order, we don't have a problem with tampering."

See the Appendix for a listing of the modifications as we went to press.

4. Street or Track?

I talked street or track at Ford SVO in Allen Park, Michigan, just down the road from Ford World Headquarters in Dearborn. Bob Stelmaszczak, SVT engineer, is one of the reasons Ford owners have such a rich supply of performance parts. Bob breathes Ford performance and has been responsible for more than a little of the street-legal performance and handling built into the production lines.

Even more so, he and other Ford engineers have designed and tested performance parts on the tracks. They have arranged for manufacture and distribution of the bolt-ons and major mods that support racing. John Vermeersch runs the Motorsport Tech Hot line, and publishes answers to common questions. SVO sheds new light on performance in the '90s in the time of serious movement toward clean air.

Word From the Top at SVO

Probst: At Ford SVO, you look at all the elements of improving performance, but let me ask you specifically about the engine-control systems.

Stelmaszczak: Before I explain control systems, let me give you an overview of Ford SVO and its place in Ford Motor Company structure. Ford SVO is organized in two departments: 1) Motorsport Department administers its motor racing business; 2) Performance Equipment Parts Department provides the Ford enthusiast with a source of high-performance and racing goods.

Through this Performance Equipment Parts Department, we can provide customers with a catalog of unique aftermarket items that are especially engineered for Ford vehicles. This includes engine "hard-core" parts, such as cylinder heads, manifolds, cams, and engine electronics, all designed to improve vehicle performance. The key word here is "designed." Our product offerings are engineered, built by quality suppliers (many of whom manufacture our standard production parts), and then undergo rigorous laboratory and vehicle testing.

These design elements are included in our production engine-control systems. The electronics must meet a number of specifications, the most notable of which are emission regulations. The Clean Air Act of 1970 and the 1990 Amendments legislate very stringent tailpipe standards. To us at SVO, that means absolutely no tampering with street vehicles. That's why some of our products are for off-road use only. The decision our customers must make is whether the modifications are easily reversible, or of the more permanent nature.

So don't let what you do for racing or off-road contribute to air pollution on the highways. We label our competition parts and do not encourage evading the laws, whether California, 49-state or Canadian.

P: OK, we can improve performance on the highway and still stay legal, or we can run off-highway. Where do we start?

S: There are ways of improving performance, and then again, there's "just being foolish." Don't just jump in and start increasing fuel pressure and installing larger injectors. And don't look for the magic chip. Unlock the performance of your engine one step at a time.

P: It's not like changing carburetor jets. What's the first step?

S: I think the first step is getting more air into the engine, particularly the 5.0L. Sometimes simple modifications can make quite a difference. Larger throttle bodies, low-restriction MAF (Mass Air Flow) sensors, increased-flow manifolds. Many times, these modifications work well within the reserve of the stock EEC-IV control system. That means you still have properly matched fuel flow and spark timing.

P: What would you change in the EEC system?

S: Convert the speed density to MAF. Ford SVO offers a Mass Air conversion kit for the early EEC-IV Mustang 5.0L, and it's no challenge to install in about an hour. You'll see a real improvement in the idle quality and low-speed driveability. As a result, you can do more for the high end with camshafts, aluminum cylinder heads, ported heads, headers and so forth while still maintaining driveability. This kit includes a new EEC-IV processor with better fuel flows and spark timing for stock and modified engines. We are offering a new MAF that handles increased air flows with less pressure drop.

Fig. 4-1. Mass Air Flow (MAF) kit converts Manifold-Absolute Pressure (MAP) system from indirect sensing of air-flow to direct sensing for performance mods. Includes new EEC-IV control unit.

Fig. 4-2. Ford Motorsport Explorer.

P: With more air flow, sometimes you really do need a lot more fuel flow, right?

S: Right, you may get some enrichment with stock injectors and elevated fuel pressures. Or use larger injectors with a high-capacity fuel pump from our catalog.

P: What about replacing the chip? What does that buy you?

S: Generally speaking, replacing the chip will buy you a lot of trouble unless you have the resources to perform an entire engine calibration. Up to 1992, Ford EEC-IV systems are not designed to be reprogrammed. Therefore, changing the chip is not an option. If you purchase an aftermarket stand alone engine-control system, you may need an engine dynamometer, a qualified electronic technician, and most of all, a lot of patience. After all, you will be trying to duplicate the resources of the Ford Motor Company to re-map the engine. This includes all fuel flow and spark-timing values, during cold start, hot start, and all normal off-road engine operating conditions.

P: How can you tell a good aftermarket control system?

S: Look for signs of quality engineering and production. Look for clear instructions and a phone number for service and assistance—you'll probably be calling it for help during your installation.

P: What can you tell about quality from seeing the system, or talking with the supplier, or studying his literature?

S: First, look for quality electrical connectors. They're the source of many problems. Ford Performance Equipment Products electrical connectors are so well-sealed they will work even under water. Second, look for built-in diagnostics. You can't guess about what's happening in these engines. (As described in this book) Ford EEC-IV will alert the driver or the technician to faults with sensors, actuators and systems. Third, ask the supplier if his control system will work alongside other aftermarket equipment, such as CD ignitions, CB radios, and cellular phones. All these create Radio Frequency Interference (RFI), or electronic noise problems. We're dealing with tiny current flows to control these engines and it doesn't take much to bother them.

P: What can you tell from the supplier's literature?

S: Can the supplier demonstrate broad-based improvement, or does he cut your ET's but leave you unable to start cold or in wet weather? Does he try to sell you with a few glowing testimonials and anecdotes, or does he show you some real measured improvements?

P: How does an owner find a good performance shop?

S: Well, to start, no single performance shop is able to answer all questions. But there is a way, the Ford Motorsport Performance Equipment catalog. We list several hundred of our worldwide distributors by name, address, and phone number. (See also the Appendix) I've found they are an invaluable source of information, and they are willing to help. They are also great for obtaining references to other experts in the field. Also, you can talk to us here at Ford Motorsport. Our technical-assistance hot-line (313) 337-1356 gives customers direct access to some of Ford's SVO technical experts with answers to really tough problems.

P: Your Motorsport Department works with many different kinds of racing from dirt track to Formula One. "Race on Sunday, sell on Monday," right? But does racing really improve the breed?

S: You bet! At Ford Motor Company, we improve the breed several ways. As I explained earlier, we deliver our performance parts with production quality through our engineering staff, our testing labs, and many of our Q1 suppliers (Q1 is Ford's name for Quality is Job One.) We're committed to this level of quality assurance in the aftermarket.

In our racing and motorsport involvements, feedback is bi-directional. I mean, the engineering flows freely from the race track to the production environment literally on a daily basis.

P: Such as?

S: We use aerodynamic test data from Ford NASCAR teams to improve air-flow management on production-vehicle sheet metal. Conversely, Formula One race engines and off-road racing engines in Ford cars and trucks use many of the same EEC-IV sensors designed, engineered and developed for use in production cars. There are many more examples, but I think you see what I mean.

P: Since the first Ford flat-head V-8s, when I was learning to drive, Ford cars have always attracted the performance aftermarket.

S: Right, and you can bet Ford will continue to meet the performance enthusiasts with more new products into the 1990s.

SVO Tips

Bob passed on a couple of other tips, particularly applicable to the 2.3L SVO turbo.

- Many control modules include two separate memory maps for different-octane fuels. Switchover occurs when you change the Octane Switch from Regular Unleaded to Premium.
- Be careful if you consider bypassing the boost-limiter. That's a no-no unless you have an intercooler.

4.1 Parts, Kits, and Factory Performance Cars

If you look closely at Ford performance cars such as Cobra and Sport Truck, and even at independents such as Saleen and SAAC Mustangs, you'll notice they are street-legal even though they use parts listed as not street legal. It seemed strange to me until SVO explained the difference between certified-legal cars or packages and certified-legal parts.

- Changing one part, such as a 65mm throttle body, or a 77mm MAF kit may be street legal depending on the camshaft timing and many other factors, including the transmission, or it may not.
- Changing one part without considering the rest of the engine and its control system could damage the converter, or ruin idle quality.
- You can buy a street-legal complete engine, or a complete car with performance mods that individually are not street legal because SVO or the modifier, and the government (EPA, CARB) has certified the complete system. They have demonstrated that the modifications work properly with each other.

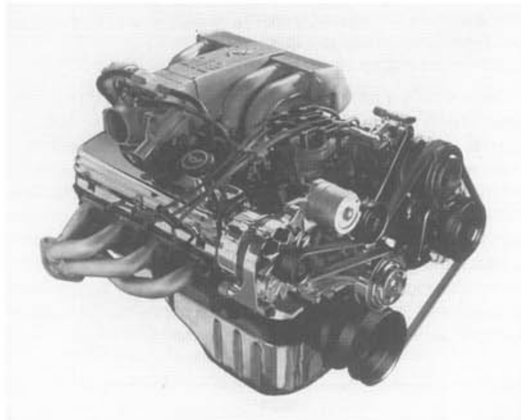


Fig. 4-3. You can buy street-legal GT-40 complete engine or car with same, delivering 285 hp, but some individual parts are not certified as street-legal because separately they might increase emissions beyond limits.

4.2 Modifications and Emissions

As I write, at least 37 states require some sort of inspection program; so do over 100 non-attainment areas. Unless waivered or equipped with exempt parts (CARB/EPA), the car is ineligible for use on public roads if it is found to be modified, or if it fails to pass an exhaust emissions test.

California regulations are especially tough, defining illegal tampering as "missing, modified, or disconnected smog-control systems or parts." No matter how clean your exhaust is, passing a Smog Check in California includes passing a visual inspection. Any missing or modified parts must be restored to their original, functioning condition. The cost incurred by the owner to bring a non-tampered engine into compliance is limited by law. For 1990 and later cars, the limit is $300, $175 for 1989-1980 cars (those years include Ford cars with fuel injection/engine control). California cars may come under the new

Federal limit of $450. But if the inspection reveals evidence of *tampering, there is no limit; the owner must bring the engine* into compliance whatever the cost.

Vehicle Age	Limit
1971 & older	$50
1972–74	$90
1975–79	$125
1980–89	$175
1990 & newer	$300

Fig. 4-4. Just to be sure we get the message: this is a typical list of repair-cost limits to pass a smog test without evidence of tampering. Such a list comes from DMV with each application to renew registration in California.

Several tuners say their mods are clean, based on passing an emission test. In California, it's officially "smog check," but in most states, and in Federal-speak, it's called Inspection & Maintenance (I&M). Passing such a test is not the same as certifying performance mods; in most states and provinces, that's not good enough. I expect more suppliers will comply with certification, so I advise you to check any source you plan to use. If the government says you cannot operate your vehicle on the highway, and won't issue plates for it, you have stepped over the line. You must make it compliant, using government-approved (CARB/EPA) parts or engine swap.

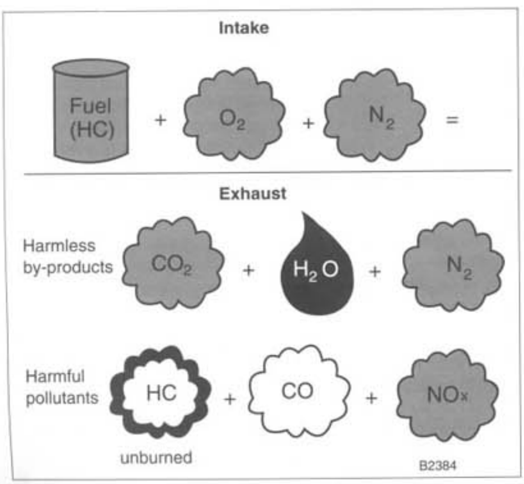


Fig. 4-5. Three exhaust pollutants are controlled by the Federal and California test procedures. NO_x is not measured at decentralized Smog Test stations. Increasingly in the '90s, centralized testing with a dynamometer loads the engine, testing all three.

"Mind your appearance," say tuners in California, where the *Bureau of Auto Repair* (BAR) operates the Smog Check program. Pay attention to the appearance of your mods. When they are properly and neatly installed, clean, and look like stock, your vehicle is more likely to pass the inspector or the referee. If your modified engine looks like a rat's nest, forget it.

Another tip, beyond street-legal and clean air. Consider what the mod means to your maintenance. If you need to pull the mods to get at the plugs or change the filter, at least realize the built-in extra price of the mod.

The matter of emissions and their effect on health and the environment is becoming increasingly serious, and increasingly legislated by Federal and state governments in response to public demand. It's called "Going Green." New York, Massachusetts and other states are moving toward the standards set by California. If you want to keep up with a fast-changing set of standards, call your local EPA office, listed under government agencies in your phone book. Regardless of state regulations, clean air is everyone's responsibility.

Fig. 4-6. Check state or community laws before making any fuel-system modifications.

4.3 Planning for Performance

At first glance, it may seem that I'm out to discourage fuel-injection system modifications, but that is hardly the case. Time spent under the hood, investigating and experimenting with fuel-injection modifications is fascinating and educational. My intent is simply to help you:

- Avoid wasting time and money
- Avoid some of the more common and costly mistakes

You need basic knowledge to build the best running fuel-injected engine for your needs. For many applications, the stock fuel system is generally the best system, so my recommendation is to keep your changes to a minimum.

Of course, in the presence of the "tree," or a waving green flag, the whole scene changes. Some exciting examples of Ford fuel injection can be found on many tracks.

If you're going to haul your car to the track, legality is only an issue in terms of the applicable rule book. Emissions are not usually a factor at all in racing. Especially in production-based racing classes, the rules governing fuel-injected cars will usually include some distinctions between modifications that are allowed and those which are not. The best advice is to study the rule book carefully before modifying the fuel-injection system. If possible, consult someone who is knowledgeable about race-preparation of cars in your particular class.

If the moral argument isn't convincing, then consider this: Before automotive fuel injection ever found its way into a passenger car, it was used in racing cars by manufacturers seeking a more controllable and more efficient alternative to carburetors. Later, the first passenger car applications began on high-performance models. The point is this: Precise control of fuel delivery results in more complete combustion and a more efficient engine. Efficiency is the one basic building block for optimum horsepower, clean exhaust, and maximum fuel economy.

4.4 Driveability

One of the most significant advances that fuel-injection systems offer over carburetors is improved driveability. Driveability is the delivery of smooth-running performance under a wide variety of operating conditions. A fuel-injection system measures many of the factors that affect driveability—engine temperature for example—and compensates for different conditions to deliver the appropriate air-fuel mixture.

Any stock fuel-injection system is a compromise design that balances power output against concerns of driveability, fuel economy, and exhaust emission control. When you plan to modify fuel injection to deliver more performance, or to match engine modifications, you will be making tradeoffs. Many people overlook just what the tradeoffs are. The important point is this: Not all modifications will retain the driveability or fuel economy of the original, unmodified system.

Fuel-injection driveability concerns are quite different from those with carburetors. For example, if the camming is too aggressive, fuel injection can be a total pain. Extreme fluctuations in manifold air flow and manifold pressure can send false signals to the engine control module.

4.5 You Have To Decide

I'll discuss the details of some of these modifications later in this chapter. For now, just remember that any set-up is a compromise. Part-throttle responsiveness, fuel economy, and low-speed torque are all balanced against power at wide open throttle. Most high-performance enthusiasts are willing to put up with some sort of driveability problem in exchange for increased power. That is something you have to decide for yourself. If the car has to start and run in cold weather, idle, and run smoothly in stop-and-go traffic, carefully consider the driveability tradeoffs.

5. High Performance Basics

In a practical sense, fuel injection/engine control is one system of the engine, and all the systems must work together in a balanced way to achieve peak performance and efficiency. So, before getting into the nuts and bolts of fuel injection modification, I'll run through a quick review of internal-combustion engine basics. I'll begin by discussing the basics of high-performance, and some of the good and not-so-good ideas. For street use, I'll describe the general implications of feedback control found on all fuel-injected Fords, and what happens when you modify these systems that all use an oxygen sensor and catalytic converter.

5.1 Air Flow and Volumetric Efficiency

Keep in mind that an internal-combustion engine is an air pump. A piston, traveling downward on its intake stroke, creates a pressure lower than barometric (sometimes called vacuum) in the cylinder. Pushed in by barometric pressure, the air mixes with fuel and burns to produce power. When you increase the air flow through the engine, the injection system is programmed to add more fuel and produce more power.

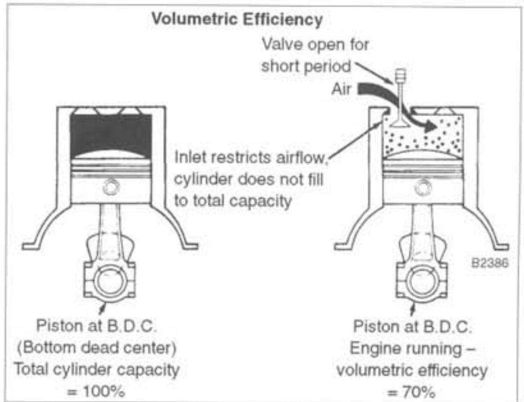


Fig. 5-1. Volumetric efficiency is measured as a percentage of total cylinder volume. If cylinder takes in only 70% of its capacity, V.E. is 70%.

In theory, the amount of air that is taken in by an engine is determined by displacement and rpm. In practice, two factors reduce the theoretical maximum:

- Valve timing and valve lift limit the amount of air that can be taken in on the intake stroke or pumped out on the exhaust stroke. The term used to describe how well the engine pumps air—the true value as compared to the theoretical 100%—is "volumetric efficiency." The best tuning can raise it above 100%, taking advantage of ram-effect manifold runners

- In the real world, automotive engines are not very efficient air pumps. The free flow of air into the combustion chamber is reduced on the intake side by the air filter, the air-flow sensor, the throttle valve, the EGR spacer, and the intake manifold and ports. Volumetric efficiency is further reduced by the restrictions of the exhaust system—exhaust manifolds, catalytic converters, mufflers and tailpipes. (See Chapter 10 for discussion of volumetric efficiency and its readout on some scan tools)

With these things in mind, it is easy to see that nearly all the hot-rodder's or racer's horsepower tricks have one common goal: to increase air flow through the engine by increasing volumetric efficiency at one part of the power curve (at the expense of other parts). The gains may be tailored to the middle rpm range to improve torque, or to the high rpm range to maximize peak horsepower, but the idea is the same. Higher lift and longer duration camshafts, larger valves, ported cylinder heads, aftermarket intake manifolds, low-restriction exhaust headers, and even dual exhaust systems all have the same job. They reduce air-flow restriction and allow atmospheric pressure to push more air into and through the engine. Superchargers and turbochargers have the same purpose, except that their job is to *force* more air through.

5.2 Fuel Metering

Naturally, when engine improvements allow increased air flow through the engine, the fuel system must compensate. It must deliver a proportionally greater amount of fuel to maintain the proper air-fuel ratio, or the engine will run lean.

The air flow and fuel delivery capabilities of the stock fuel-injection system have been chosen to correspond to the performance demands of the engine, including its volumetric efficiency. Modifying the engine changes the engine-volumetric efficiency and, therefore, the demands being placed on the original fuel-injection system.

In practice, this may or may not be a problem. Some of the stock Ford systems are quite flexible, able to compensate for some impressive flow increases. More on that later in this chapter.

For now, just keep in mind this fundamental question: When you modify the engine, does the increased air flow and increased demand for fuel exceed the limits of the stock fuel-injection system? If so, some fuel injection modifications may be necessary and worthwhile. Another question for owners of MAP systems—when you increase the intake air flow, does the EEC system know enough about the increased flow to add fuel properly? The answer to that is: seldom.

As for stock or only slightly modified engines, modifying the injection system to get more power is a different story. This is where significant power gains are elusive, and where it is easy to do more harm than good. Even the earliest, most basic Ford fuel-injection systems are precise and highly optimized, especially when compared to carburetors.

Higher system fuel pressure may also be a safety concern. With fuel lines and connections subjected to higher pressure, you have an increased risk of leaks or outright failure. To ensure reliability, the standard Ford parts are rated for pressures well above the normal operating range, but significantly higher fuel pressures may be a source of problems. This may be a problem if the pump is expected to operate above its designed delivery pressure.

Just "twiddling the knobs" on the injection system stands a good chance of reducing power—or fuel economy—and threatening exhaust emissions. Only after you get significantly more air into the engine will the fuel-injection system really require major modifications, or be able to benefit from engine mods.

5.3 Air-Fuel Ratio and Performance

In practice, the best set-up for clean exhaust and the best set-up for maximum power are slightly different. I'll discuss the differences in detail later in this chapter. For now, just remember that maximum power output demands a slightly richer air-fuel mixture—more fuel for a given amount of air.

Adjustments to fuel mixture would, at first glance, seem to be one aspect of fuel injection that is perfect for fine-tuning to increase power output. To some extent, Ford is already ahead of you. Ford fuel-injection and engine-management systems recognize full-throttle operation as a special condition with special requirements. Under normal, part-throttle running conditions, these systems precisely adjust the air-fuel mixture for good performance with minimum exhaust emissions. Then, at wide-open throttle, they provide a richer mixture—more fuel—to meet the brief demand for maximum power. Emissions increase at wide-open throttle, but the tradeoff is acceptable because of the short periods of time spent at full throttle.

As discussed in Chapter 2, all engines need a proper mix of air and fuel to achieve complete combustion. For a warm gasoline engine at part throttle, the ideal (stoichiometric) air-fuel ratio is about 14.7:1—approximately 14.7 kg of air are required for complete combustion of 1 kg of gasoline. The ratio is the same whether you're talking kilograms or pounds.

The stoichiometric ratio, however, is not necessarily the optimum ratio for peak power or for minimum fuel consumption. The graph in Fig. 5-3 shows the relationships between power, fuel consumption, and air-fuel mixture. Peak power is achieved with a slightly richer air-fuel mixture, approximately 13:1. Minimum specific fuel consumption is achieved with a slightly leaner mixture, about 15:1. In boosted engines at full throttle, where extra fuel is injected for cooling, air-fuel ratios can be as rich as 10.3:1 to 10.9:1.

At part-throttle, the fuel-injection system operates in a narrow range around what is approximately the stoichiometric air-fuel ratio, 14.7:1. As the graph in Fig. 5-3 shows, this provides the best compromise between maximum power output and minimum fuel consumption. Operating in this narrow range is essential for minimizing exhaust emissions.

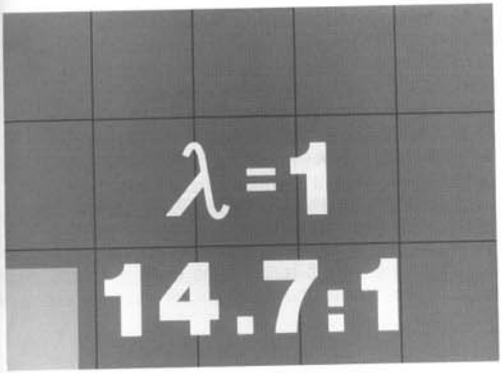


Fig. 5-2. For warm gasoline-fueled engines at part throttle, most complete combustion occurs at ideal ((stoichiometric) air-fuel ratio of about 14.7:1—approximately 14 kg air for every 1 kg fuel.

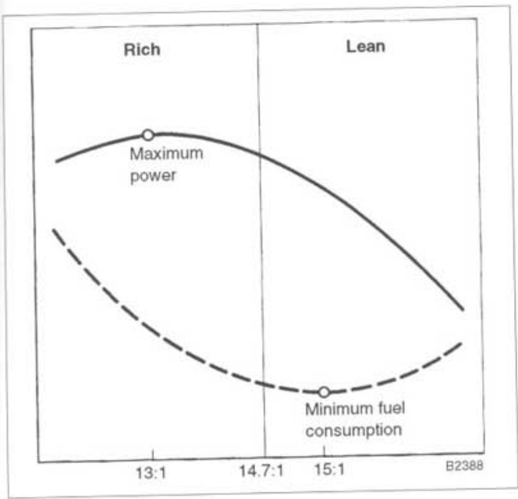


Fig. 5-3. Power and specific fuel consumption both vary as a function of air-fuel ratio

5.4 Add More Fuel?

In theory, it is possible to fine-tune the air-fuel mixture, either to maximize power or to minimize fuel consumption. This is tempting, of course, but take a closer look.

First, as I said, most systems already provide some kind of mixture enrichment at full throttle, so some of what you could hope to gain by optimizing the mixture for maximum power is already there.

Second, reconsider the curves on the graph. In the areas of interest—near the maximum power point and the minimum fuel consumption point—those curves are relatively flat. Even if the system can be adjusted to deliver the perfect mixture (just at the point of maximum power), the gain promises to be pretty small. There are no huge amounts of horsepower to be unlocked here! And if you miss and go too rich, its easy to end up de-tuning instead of improving! Of all the methods that try to optimize the air-fuel mixture for peak power, the ones that provide more gain than pain are likely to have extensive dynamometer testing and road testing behind them.

5.5 Closed-Loop Systems with Oxygen Sensors and Catalytic Converters

All Ford fuel-injected cars and trucks are equipped with one, or even two oxygen sensors and catalytic converters. The relatively clean exhaust resulting from combustion at the stoichiometric ratio is necessary for proper operation of the catalytic converter. For all cars, any significant deviation from 14.7:1 increases engine exhaust emissions dramatically because the catalytic converter cannot convert. As the mixture becomes rich, hydrocarbons (HC) and carbon monoxide (CO) go up. As the mixture becomes lean, oxides of nitrogen (NO_x) increase very rapidly. See Fig. 5-4.

Remove the Converter?

All Ford fuel-injected street-driven cars are originally equipped with oxygen sensors and catalytic converters. At the track, you might remove the converter to reduce back pressure. But never remove the oxygen sensor. At the track, I've watched them tune the mixture for the race, using the oxygen sensor. Some people report the 5.0L converter back-pressure is important for better low-speed torque for the launch. Before you pull the converter, remember the whole system is tuned for that back pressure. Removing the converter may add speed but increase your ETs.

On the street, you retain the converter for reasons of emissions and inspection. In addition, these feedback systems provide driveability and fuel economy advantages—their ability to continuously fine-tune the air-fuel mixture to match different conditions, even different fuels. What's more, the computer maps of air-fuel ratios and timing are set for the exhaust-system back-pressure of the stock exhaust with its converters.

I've covered the functional details of these systems in other parts of this book. In the context of high-performance modifications, however, here are some important things to remember.

The original fuel-injection system meters fuel to air in the best proportions possible, based on its various inputs. In closed-loop operation, the oxygen-sensor feedback system monitors the exhaust and continuously makes additional fine adjustments to the air-fuel mixture. The exceptions (open loop operation) occur principally at two times. One, the engine operates open loop during warm-up when the oxygen sensor is not yet up to operating temperatures. Two, more important for performance, it goes open loop at full throttle when oxygen sensor control is bypassed in favor of a slightly enriched mixture.

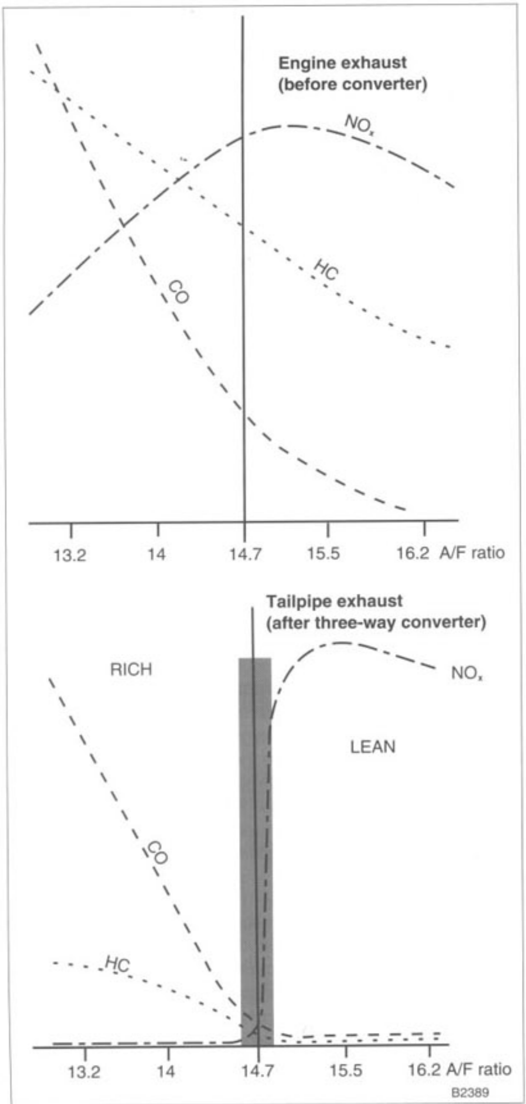


Fig. 5-4. Stoichiometric air-fuel ratio, 14.7:1, results in most complete combustion and minimizes harmful exhaust emissions when engine has a catalytic converter. Notice inevitable increase in exhaust emissions as mixture deviates from 14.7:1.

Remember, even if you modify the system to make it capable of providing more fuel, in most part-throttle operation, the oxygen-sensor system will still do just what it was designed to do. It continuously adjusts the air-fuel mixture to approach the stoichiometric ratio, the narrow range around 14.7:1. In short, no gain, except (maybe) in open-loop operation at full throttle.

Normally, this self-correcting capability—automatically keeping the mixture near the perfect stoichiometric ratio—is very desirable. Minor system modifications may make the mixture a little too rich at low and mid-range rpm. The oxygen-sensor system in closed-loop operation will tend to correct back to the stoichiometric ratio and preserve driveability, exhaust emissions control, and fuel economy.

The problems come when fuel system modifications force the system to the limits of its normal range of adjustment. The system constantly senses an over-rich mixture. When it tries to adjust more lean, it reaches the limits of its adjustment range. In such a case, the modifications and the resulting rich

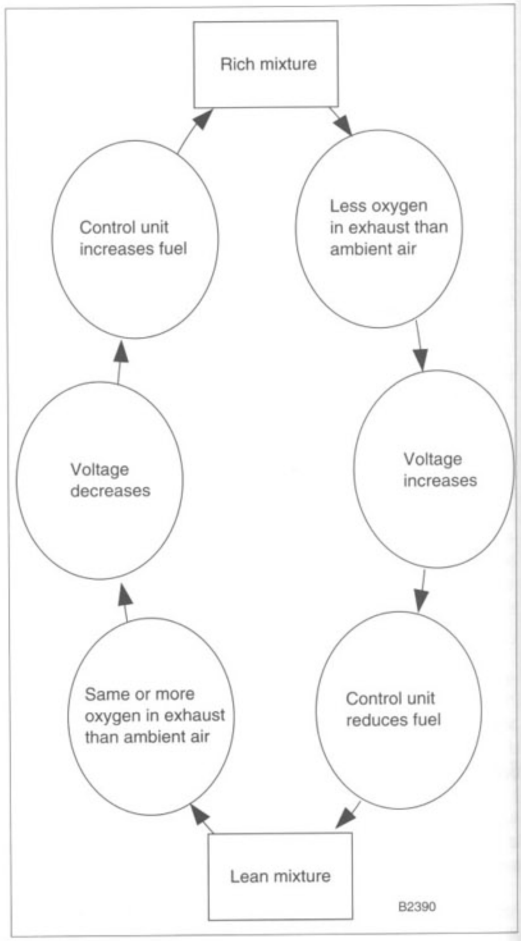


Fig. 5-5. In closed-loop operation at part throttle, engine control system will continuously try to correct air-fuel mixture to a stoichiometric value—no matter what modifications have been made to increase fuel delivery.

mixture will override the oxygen sensor's ability to correct, and will wreak havoc on fuel economy, driveability, and exhaust emissions. It may even hurt performance.

This situation can affect the performance and driveability of unmodified engines with high mileage and wear. Mixture control is addressed in 1986 and later Ford fuel injection/engine control systems with adaptive control. Instead of working within a fixed range of feedback control parameters, adaptive systems are able to accumulate data during operation. They adjust the center of their operating range according to the needs of the individual car, to this individual driver, even to the fuel of this fill-up.

5.6 Ignition

Ignition timing is another performance factor that goes hand-in-hand with fuel delivery. As you know, all Ford EEC systems and most MEC systems control fuel delivery and ignition timing in one electronic control unit. Conservative fuel-mixture control in the name of low exhaust emissions may also be accompanied by conservative ignition timing curves, primarily because of the manufacturer's concerns over the quality of available gasoline. Many tuners of fuel-injected cars usually advocate revised ignition timing specifications to further unlock the performance potential of revised fuel control. With 92-octane premium fuel, try advancing base timing to 12 to 14 degrees BTDC. Do not try higher-octane racing fuels to advance timing further. These fuels burn too slowly and may actually reduce power and increase carbon build-up.

As I described previously, some Ford ignition systems provide an Octane Switch so you can advance or retard ignition timing by a few degrees. With or without an Octane Switch, two other options are available: 1) advance base timing, 2) modify with an aftermarket ignition system.

For those engines with knock sensors, neither EEC-IV nor MECS engine controls advance spark timing toward the early limits of knock sensing. (Some European engine-control systems do that kind of advance).

Fuel and Spark Timing

It's to your advantage to use the lowest octane fuel that does not provoke pinging in your engine. If you've pushed the timing and the engine control toward pinging, consider your options:

- Pump gas with higher octane. If 92 octane premium unleaded sells for about 20 cents a gallon more than 87 octane regular unleaded, you gain about 5 octane points at a cost of about 4 cents per octane/gallon
- Octane Enhancers. Generally alcohol-based, they can raise the octane rating of premium fuel by as little as 0.1, and as much as 2.2. Some enhancers take advantage of the methanol pump-octane rating of 101. But recall from Chapter 3 that methanol additions of over 10% can lead to real trouble with fuel system corrosion as well as engine-control system problems. And excess octane slows burning to lose power

> Too often, we limit our thinking of modifications to the Mustang tire-burner on the street or on the track. But many of these mods will help the owner of a Bronco, Explorer, Aerostar or an E/F series light truck increase power for trailer pulling.

6. Bolt-ons and Modifications

Each of the Ford fuel-injection systems you've already read about in this manual has its own unique features and characteristics. I'm considering only fuel-injected engines. Most of the available modifications apply to 5.0L engines, some to the 2.3L turbo, and some to the Mazda engines in the Probe, and the 1.6L Mazda engine in the '91 and later Capri.

I'll describe the most popular fuel injection/ignition system modifications, and give a cross-section of the methods employed by experienced tuners. In line with the legal and the moral "green" aspects of the '90s, I'll identify those mods that are certified street-legal as we go to press.

The efforts of tuners are not only interesting and exciting. They also provide valuable insight into how the experts think about the problems, and how they approach solving them. These insights, combined with your knowledge of the system basics, should help you to decide which modifications hold promise for your application.

Some of these modifications are well-known and well-tested. I can give you a fairly accurate idea of the results, if any, that you might expect. For many others, the results are much less certain. I've described these modifications and the theories by which they are supposed to work. I make no recommendations.

6.1 Mass Air Flow Conversion

Mass Air Flow (MAF) sensors are stock in most late-model Ford cars and trucks. Interestingly, MAF began with the 1988 California 5.0L H.O. engines. But Manifold Absolute Pressure (MAP) sensors were stock in 1988 49-state 5.0L and in many other Ford engines between 1988 and 1992. The MAP system (also known as Speed-Density) is quite different from MAF, in spite of the similarity of the initials. MAF is generally superior for street and for track, so most tuners will begin by recommending changeover from Speed-Density to MAF. If you had to do it from scratch, it would be a major mod. But Ford Motorsport has seen the need and provided a complete kit.

SVO Kits

Fig. 6-1. MAF kit for F-series truck includes jumper wire harness to convert gang (bank) injection to sequential (SFI), and new EEC-IV control unit. Not street-legal in California as we go to press.

Ford Motorsport kits include the MAF sensor, a matching computer, the hoses, and the harness. You can order one of four kits:

- '88 49-state Mustang, Manual transmission
- '88 49-state Mustang, Automatic transmission
- '88 and later F-series 5.0L truck, Manual transmission
- '88 and later F-series 5.0L truck, Automatic transmission

Each is a neat bolt-on, available from most Motorsport dealers and tuners. Truck kits include a special overlay wire harness that converts your two-bank ganged injectors into sequential (SFI). Not street-legal in California.

Compared to Speed-Density, this MAF Conversion kit provides two benefits:

1. Better idle quality and overall vehicle performance. Even if you don't change anything else, it can react faster and more accurately to the changes in air flow as you accelerate and decelerate.
2. Versatility required when your performance mods change the air flow. Without changing the engine control or the fuel pressure, you can expect to handle up to 320 horsepower. Then the injector dwell is 100%—they're open all the time. You can expect good driveability even as you change the mass of air drawn into the engine for each stroke by changing:

- Camshaft
- Cylinder heads
- Throttle bodies
- Intake manifolds
- Headers
- Exhaust systems
- Axle ratios
- Turbo/supercharger

> Speed-density systems do not measure air flow directly. Instead, the computer looks at the speed signal (rpm from TFI) and the calculated air density (MAP and Air Charge Temperature (ACT) and barometric pressure (BARO), plus data from its memory) to calculate the air flow. More on this in Chapter 4. Many performance mods—not only to the engine, but to the exhaust and even the axle ratios—defeat the accuracy of those calculations. They change the real air flow to be different from the calculated air flow. MAF measures the real air flow.

6.2 Increasing the Air Flow

One logical place to start is where the air comes in, the air filter. Suppliers like K&N Engineering and Hypertech offer replacement low-resistance air filters. See Fig. 6-2. They're widely used, reducing the obvious restriction of the original air ducting and filter. They're easy to add (5 minute installation) and they're certified street-legal. They claim horsepower increases up to 15.

Fig. 6-2. Low-resistance air filter (here coupled with larger Mass Air Flow sensor) increases air flow. Filter requires cleaning and oiling at regular intervals.

Among the hot Mustangs, most increase air flow from the stock 60mm throttle body, following Motorsport options of larger MAF sensor, throttle bodies, and EGR spacer plates. Among your options:

- 77mm MAF sensor with high-capacity air filter from Motorsport increases air flow without degrading idle quality. For max performance mods. Not recommended for stock unmodified engines. Certified, E.O. #D-242
- 65mm Throttle body. See Fig. 6-3

- 67mm EGR Spacer is machined to be compatible with 65mm Throttle body. It is compatible with stock manifolds or Motorsport manifolds.
- Motorsport Upper and Lower Intake Manifolds. They must be used together.

The intake manifolds add to the effect of your enlarged MAF sensor, throttle body and EGR spacer. Each tubular runner is 42mm (1.65 in.) in diameter. You can use production fuel rails, sensors and wiring harnesses. You'll gain power, and look good underhood, too.

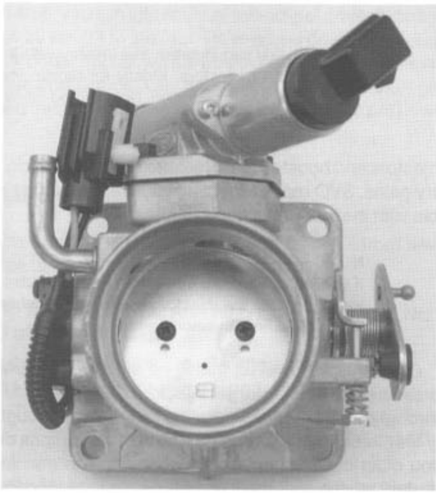


Fig. 6-3. 65mm Throttle body "High Flow Hi Po" from Motorsport flows about 10% more air than a production 60mm. Comes complete with TPS and Throttle Air Bypass–ISC valve. Not certified for street use.

Saleen offers an upper intake manifold to increase the flow. Saleen represents you'll have no problem passing a smog test. In fact, if you buy this intake manifold installed in a modified Saleen Mustang, available from selected Ford dealers, the car is EPA Certified as passing complete Federal/California tests.

For other intake manifolds, look to BBK, Edelbrock, and several others.

Charlie Bruno of Charlie's Mustang in Silicon Valley is one of several tuners I talked to. His "50 horsepower" conversion increases air flow in several ways:

- MAF conversion from Speed-Density
- Enlarged EGR and upper manifold to 70mm with polished runners

Fig. 6-4. GT-40 intake manifold (here with 65mm throttle body) can mean big horsepower gains. By them selves they are not street-legal, but Ford sells a full GT-40 kit (including valve train components, heads and ring and pinion set) that is 49-state legal.

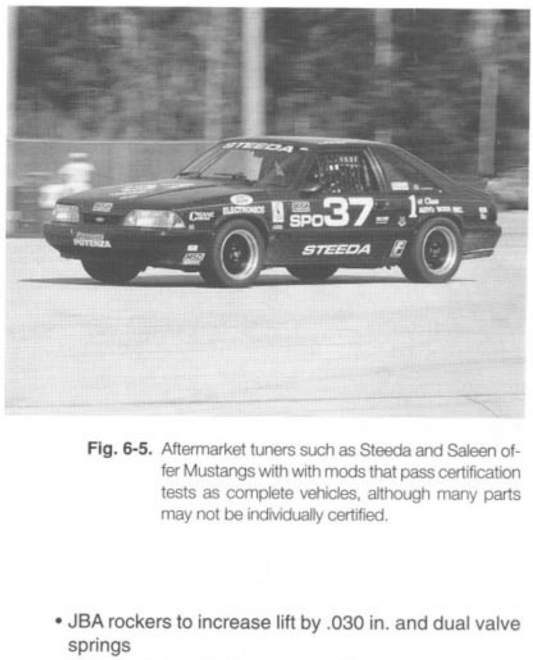


Fig. 6-5. Aftermarket tuners such as Steeda and Saleen offer Mustangs with with mods that pass certification tests as complete vehicles, although many parts may not be individually certified.

- JBA rockers to increase lift by .030 in. and dual valve springs
- JBA shorty headers
- No change to injectors or to control module

Doug Baker of JBA (J. Bittle American) of San Diego, told me he doesn't touch the control module, or the injectors. The stock settings seem to handle the increased air flow. As Doug put it, "The 5.0L is very production—you can really improve the engine to build performance into the many compromises of the production engine."

For your 5.0L engine, JBA offers roller rocker arms, headers and other goodies beyond this book. Most are for track so check to verify which are certified street legal.

You can see that increasing air flow has many dimensions, and your considerations are interrelated. How much horsepower can you get from:

- What size MAF?
- What size throttle body?
- What manifold?
- How about smoothing the manifold? Porting?
- Supercharger? Turbocharger?

6.3 Increasing the Fuel Injected

The Ford Motorsport high-flow fuel pump replaces the stock in-tank pump. It includes the in-tank filter, the internal pressure-relief valve, and the discharge check valve. It delivers up to 110 liters (28 gal) per hour against the standard regulator pressure of 39 psi (270 kPa). This pump increases delivery, not fuel pressure. I advise safety considerations in working with the fuel tank. This is not a user-friendly job.

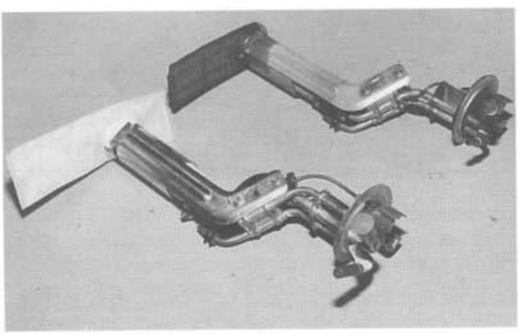


Fig. 6-6. High-Flow fuel pump (lower) from Ford Motorsport increases delivery from 88 to 110 liters/hr to eliminate high-end fuel starvation in modified 5.0L H.O. engines. Not recommended for use with Nitrous Oxide. CARB No. D-308. Street Legal.

For race applications, you may want increased fuel delivery at mid-range to high rpm. Try the SVO kit of high-flow injectors, delivering 25 lb/hr. These work best with revised MAF sensors, trimmed for high flow rates. Stock injectors at normal fuel pressure can deliver 19 lb/hr. That calculates to 320 horsepower, maximum.

To achieve significant fuel delivery increases without extremely high fuel pressures, you may also want to install larger injectors. At near-stock fuel pressures, poorer fuel atomization from larger injectors is a drawback, but a combination of larger

Fig. 6-7. You can increase fuel delivery with this kit of 24 lb/hr injectors. Strictly for racing. Require MAF special calibration. Not certified for street use.

injectors and boosted fuel pressure can produce big fuel delivery gains. SVO replacement injectors are electrically compatible with the stock injection system.

> **NOTE —**
> If you install injectors other than Ford-manufactured, be sure the injector impedance matches the original Ford injectors.

Once more, however, this is no simple fix. Increasing fuel pressure or installing larger injectors will increase fuel delivery throughout the engine-operating range, even though it is really only needed at high rpm. So, with modifications of this type, you must make a corresponding change to maintain correct air-fuel mixtures at the low and middle rpm ranges. You may: 1) alter the inputs to the computer, 2) reprogram the computer, or 3) alter its outputs.

6.4 Turbocharging/Supercharging

Increasing the air flow by turbo/supercharging falls in two categories:

1. Are you adding a turbo or supercharger to a non-turbo engine? For those engines that breathe naturally, you may hear the term "Naturally-Aspirated."
2. Are you increasing the flow from a factory-installed turbo/supercharger? Ford has delivered thousands of Original Equipment (OE) turbos. Ford introduced domestic superchargers in the T'Bird Super Coupe (SC).

Boosting a Non-turbo Engine

Bob Stelmaszczak of Ford told me that it's not as simple as some people say. The boost system must complement the engine and the fuel-delivery system. You might increase the high-end power, then wonder what happened to your power around town. You might fire up the engine, then wonder why it starves at high outputs.

According to George Spears of Spearco, the stock fuel pump delivers enough fuel at zero boost to maintain 350 horsepower at an air-fuel ratio of 12:1. But at 7 psi boost (45 in. Hg MAP), the pump delivers only enough fuel for 320 hp. That's because the pump is delivering against the higher regulated fuel pressure, raised by the regulator to inject against the higher MAP.

Even if you dramatically increase the engine power output (and you can), you must consider how long your drivetrain will last unless you modify that—clutch, transmission, final drive.

Further, you must get the power to the road. After you can smoke the tires, you run into limits of two-wheel drive. Acceleration transfers weight to the rear. Rear-wheel drive, as in Mustangs and T'Birds, puts down the power better than front drive, as in Probes and Capris. OK, add horsepower, and then get ready to add traction bars, slicks, shocks, and stuff to put down the power.

Turbo Add-ons

Turbo kits and add-on accessories are available from several sources (addresses listed in the Appendix):

- Car-Tech, Dallas TX. Also high-flow fuel pumps. Not certified for street use
- Spearco, Panorama City CA offers intercooler kits and accessories for many Ford factory turbo/supercharged engines (2.3L, 3.8L) as well as for use with aftermarket superchargers such as from Vortech (described below). See Fig. 6-8.
- Turbo Technology of Tacoma WA offers a TurboNetics T04 water-cooled turbo with special wastegate and an intercooler for the 5.0L. See Fig. 6-9. Not certified for street use

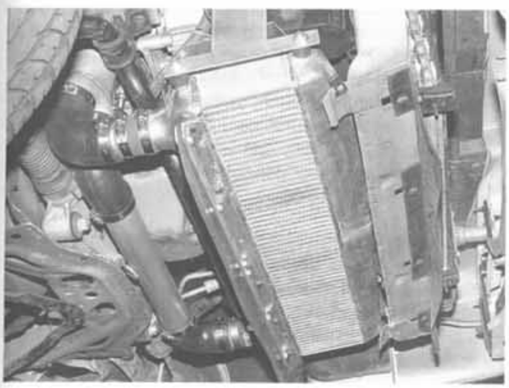


Fig. 6-8. Intercooler from Spearco is designed to work with 5.0L Supercharger kit from Vortech.

Fig. 6-9. Turbo Technology T04 water-cooled turbo.

Remember that forced-air induction raises the intake air temperature, reducing the air-fuel mixture density and the available power. Any turbo system will benefit from intercooling to reduce the intake air temperature, and Spearco offers a number of options depending on whether you want to intercool an OE turbo system or an aftermarket or custom system.

In most cases, intercooling will reduce the temperature of the air charge by a minimum of 100°F, with only about 1 psi of pressure drop. On one system designed for the factory 2.3L Turbo Thunderbird/Cougar, Spearco claims an air charge temperature reduction of 130°F and a horsepower increase of 18–20%. This system was originally designed for Ford SVO.

Supercharger (aftermarket)

Best known are the Paxton blowers from Paxton Superchargers in Santa Monica CA. They are street legal, CARB Exemption # D-195-8, P/N 10018, and kits are designed for the 5.0L engine in Mustang, Mark VII, Bronco, and F-150 (also 5.8L and 7.5L). You can also bolt on the Paxton supercharger kit for the 4.0L V-6 in the Explorer, Ranger, or Mazda Navaho. See Fig. 6-10.

As engine displacement increases, supercharger requirements also increase. In most cases it may be easier to fit dual turbochargers instead of one large unit. Paxton has a twin-supercharger kit for the big 7.5L engines as shown in Fig. 6-11.

Vortech V-1 Gearcharger turns up to 63,000 impeller rpm for 6 psi boost to add 100 horsepower, if your drivetrain can take it. Kit includes special Fuel Pressure Regulator to increase fuel pressure according to boost. Vortech Gearcharger at 8 psi boost delivers 317 hp, and 418 ft lbs torque. You'll need a new pulley, fuel pump, ignition retard, high-flow air filter. Both are street legal, CARB certified for 50 states.

Fig. 6-10. Paxton centrifugal supercharger is belt driven. Adds up to 45 horsepower to 5.0L Mustangs. Street legal. CARB # D-195-8.

Fig. 6-11. Paxton twin-supercharger kit for large-displacement engines provides over twice the volume of air over single 5.0L unit. Kit pending CARB exemption.

Fig. 6-12. Vortech belt-driven centrifugal supercharger. Street legal. CARB # D-213-1. Also available for 5.8L.

Adding Performance to Your OE Turbo/Supercharger

Consider changing the supercharger on your Thunderbird 3.8L Super Coupe (SC) or Cougar XR-7. Ford Motorsport offers a high-flow supercharger that clips 1/4 mile times and increases speed.

Two major improvements increase flow, about 7% volumetric efficiency with less heating of the air:

- A smaller drive pulley spins the rotors faster while reducing inlet temperature
- The Teflon-coated rotors can be made with tighter tolerances because they seat themselves in the casing. One SAE engineer told me this: If you keep reducing tolerances of metal rotors in a metal casing, pretty soon they touch, and at those speeds, they fuse. But when Teflon-coated rotors touch, the Teflon wears down quickly and soon there are much closer tolerances without danger of metal-to-metal contact

6.5 Nitrous Oxide (N_2O)

Nitrous Oxide injection is popular because it is a blast, and it is cost effective. Nitrous Oxide (N_2O) is a simple gas of 2 Nitrogen atoms combined with 1 Oxygen atom. N_2O is compressed to a liquid under high pressure. During operation, it is released as a gas at the throttle body. N_2O systems provide extra oxygen and add extra fuel to combine with the oxygen, with little or no effect on the fuel-injection system or the control module.

Normally operated only at full-throttle, and only for a few seconds at a time, it has little or no effect on emissions, driveability, or long-term fuel economy. For the short term, you'll burn lots of fuel to make lots of power. Tom Wilson of *Super Ford* advises, "Nitrous makes it too easy to destroy your engine with too much power. Stay with a small system unless you plan some serious engineering."

N_2O can be jetted to deliver all the power your drivetrain can handle, all the power you can put to the road through the tires. For a few seconds, your car or truck will "leap tall buildings in a single bound."

The instantaneous blast of power results from two ways of increasing power:

- Added oxygen is like adding extra air flow, like a turbo or supercharger. If you add N_2O to a turbo/supercharger, it's like having two of them in series. What's more, adding extra oxygen and fuel just as the throttle goes full open tends to reduce turbo lag
- When the compressed N_2O liquid at 800 psi (5500 kPa) changes to a gas at the throttle body, it cools the incoming air by as much as 60 degrees, increasing the air mass. Remember, the engine burns pounds of air, not cubic feet

Nitrous Oxide Systems Inc. in Cypress CA offers systems for the Ford 5.0L and the 2.3L fuel-injected engines, including the #5115 Stage II kit shown in Fig. 6-13. This system can be made 50-state legal with an additional kit, #0015 (CARB EO #D-266), that includes a special Wide Open Throttle module that senses throttle position and releases a progressive charge of N_2O.

A fogger nozzle delivers extra fuel to the throttle body combining the N_2O and the fuel in a gaseous vapor. An actuating solenoid controls the flow of Nitrous Oxide. A separate solenoid controls fuel flow. A full-throttle switch actuates both solenoids after being armed by a cockpit switch. "Armed" is a good word because the N_2O injection can seem like some kind of explosion somewhere behind you, and on your pistons.

Installation of a kit can be relatively simple. The extra fuel is drawn from the fuel rail through a fitting installed in the pressure-test port under regulated pressure, normally 39 psi (270 kPa). If you install an aftermarket system, be sure you mount it down stream of the air-flow sensors (MAF or VAF). N_2O can damage either sensor.

Several different kits are available for the 5.0L from The Nitrous Works. The simplest is calibrated to gain 125 hp, working with either the stock throttle body or the Ford Motorsport 65 mm throttle body. No vehicle or fuel system modifications are required. An adjustable kit provides up to a claimed 175-hp gain, with a larger fuel pump. A dual-staged kit is claimed to give gains up to 250 hp. See Fig. 6-14

Some cautions:

- Be aware of the results of adding this kind of power; operating at high cylinder pressures, engine detonation is a real possibility: is it protected by a knock sensor? Does it need retard of base spark timing? Usually yes. Does it need a high-output ignition system? Yes
- Avoid grease or oil near the bottle, fittings and solenoids; the oxygen in N_2O could make a nasty fire
- Upgrade your clutch, or prepare to replace it

Fig. 6-13. Nitrous Oxide Systems claim up to 150 additional horsepower with their Kit #5115. Addition of special Kit #0015 can make installation 50-state legal.

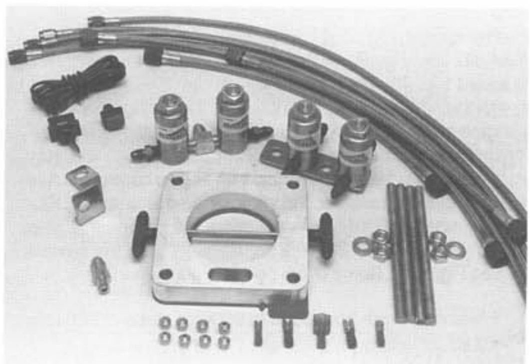


Fig. 6-14. The Nitrous Works kit #13025 is claimed to give horsepower gains of up to 250.

6.6 Engine Control Modification

You'll find plenty of offers from aftermarket chip changers for chips to plug into your EEC control module. This is not the way to modify EEC control. Opening the EEC module to change the chip is now in most cases against EPA regulations. It's also a good way to make your engine run worse or even ruin it. The only Ford Motor Co.-accepted way to modify the engine controller is by interfacing with the EEC harness, not the control module. Rather than changing the chip, you use a special harness and an additional control module that modifies EEC output.

Some more evidence that plug-in chips are a bad idea: A recent report by CARB (California Air Resources Board) estimates installation of at least 100,000 performance chips in that state alone. In a recent SAE paper, EPA reported tests of several Aftermarket Programmable Read Only Memory (APROM) chips in performance cars and in light trucks. All increased emissions, some seriously so: HC up to 27%, CO up to 59%, NO_x up to 53%; fuel economy down slightly. Performance chips may (or may not) improve your performance, but they are such a threat to air quality that Ford soldered the chip in place beginning in 1985. I hear talk that future Emission Testing may learn from your own engine control module if you have removed your performance chip module just to pass the Smog Test. When I asked CARB engineers about this, they nodded and said, "Not yet, but we're working on it." Be aware of so-called "street-legal" chips, unless they include a CARB exemption order.

The control module is designed to give you performance, economy, driveability, emission control, and more. It provides air/fuel ratios to prevent destructive detonation, and limits engine speed to 6250 rpm to help prevent other kinds of damage. But, with the right kind of know-how, and the willingness to risk the engine or the drivetrain, you may be one of those enthusiasts who can push beyond the built-in boundaries. You may want to explore an "extender," an add-on engine control module that simply plugs in between the vehicle harness and the EEC-IV control module: Ford SVO now offers the Extender, a chip module that allows you to make adjustments from the driver's seat. See Fig. 6-15. Some of the possible adjustments are:

- Maximum rpm from 6500 to 9300, in steps of 200 rpm
- Air-fuel ratio from 9.5:1 to 14:1, at engine speeds above 4200 rpm

The Extender is designed to work with 5.0L MAF systems only (49-state). As we go to publication, Ford is working on a

Fig. 6-15. SVO Extender is extra control module that installs between EEC-IV module and wiring harness to give additional air-fuel ratio control and redline adjustment.

CARB Exemption Order, but don't see it as a problem since air-fuel ratio is affected only above 4200 rpm. That's well above the speed at which emission tests are done.

The Extender is a simple plug-in installation, with two knobs on it for mixture and redline adjustments. Note that the Extender does not affect ignition timing, so it is not recommended for use with turbo or nitrous modifications.

Some chips may give you a greater kick in the back, with a great power surge as the turbo spools up. It feels good, but you can expect drivetrain problems down the line. The programming of the stock chip makes the power come on quickly, as fast as the drivetrain can handle over time. Keeping the stock torque-curve flat may reduce the exhilaration factor, but may keep your car running longer. And it may be just as fast as the hop-up chip. What's your decision?

Unfortunately, it is difficult to hold a computer chip-module or "black box" in your hand and be able to tell what it can and cannot do, or what the tradeoffs or undesirable effects might be. The word is that some chips are "smoke and mirrors." There is plenty of opportunity for a small gain in one area—full-throttle acceleration, for example—at the expense of driveability, fuel economy, and exhaust emissions. Try to find out as much as possible about the product. It's real results that count.

Ford SVO Extreme Performance Engine Control (EPEC) System

Ford SVO recently released a new system intended to maximize engine performance. The Extreme Performance Engine Control (EPEC) System allows the owner to recalibrate *all* engine parameters, from air-fuel ratio, to spark timing, to add-on nitrous systems and engine speed limiters. The EPEC system installs in the EEC-IV wiring harness and is controlled by a laptop computer (owner-supplied) running Windows software. The system also has a data-acquisition feature to check the effects of recalibrations.

Fig. 6-16. Ford EPEC system installs between EEC-IV module and wiring harness and interfaces with a laptop computer to give total control over the calibration of air-fuel ratio, spark, and other parameters.

Fig. 6-17. This 1989 Mustang GT hatchback pulls an 11.94 quarter mile at 113.26 mph. Modifications include GT-40 intake with 65mm throttle body and the stock MAF sensor ported to 61mm.

The EPEC System puts an unprecendented amount of control in a tuner's hands—Ford warns that destroying an engine is possible if the system is not used carefully. Currently the EPEC system is available for many MAF sensor controlled models (such as 1988–93 Mustangs), with plans to offer a MAP sensor (speed-density) version in the future.

6.7 Ignition System Mods

When you talk ignition system mods, start with "MSD," for Multiple Spark Discharge. Autotronics Controls Corporation of El Paso TX makes all sorts of ignition goodies for the aftermarket. Glen Grissom, formerly of MSD, tells me they work closely with Ford Motorsport for ignition-system mods. MSD builds the SVO racing ignitions under the Ford label.

The CD unit (CD in this case stands for Capacitive Discharge) draws battery power, steps it to 300 to 450 volts, then stores the raised-voltage energy in a capacitor. When the spark signal arrives, the capacitor energy is delivered to the coil where it is transformed into several-thousand volts to fire the plug.

The CD ignition tends to pay off for serious engine mods, delivering a reliable spark:

- Higher compression ratios
- Richer air-fuel mixtures
- Higher cylinder pressures resulting from supercharging/turbocharging
- Nitrous Oxide injection

The multiple sparks show up more at lower revs so you're likely to see the results in better starting, reduced plug fouling, better fuel economy, and lower emissions.

Autotronics offers just about every ignition mod up to and including a system for a Land Speed Record (LSR) holder. I'll concentrate on those parts for Ford fuel-injected engines, both street and track: ignition control, rev control, timing control, boost retard, knock sensors and alerts.

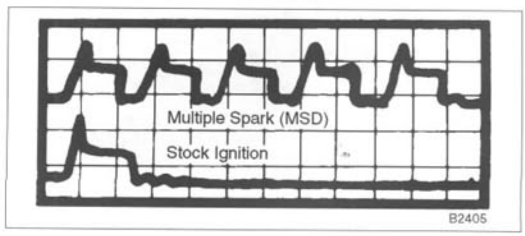


Fig. 6-18. MSD is a capacitive discharge (CD) system, producing sparks over 20 degrees of crankshaft rotation. At low rpm, that means multiple sparks.

The Ford Motorsport MSD kit provides improved capability to fire wet, fouled plugs. See Fig. 6-19. It is recommended for competition and all-out racing. With the ignition coil and wiring harness, it connects directly to all Ford TFI-IV (Thick-Film Ignition—EEC) systems. It does not apply to DIS (Distributorless Ignition Systems).

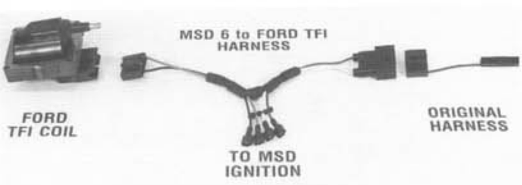


Fig. 6-19. Motorsport MSD kit provides simple installation of control unit to Ford TFI coil.

The Rev Control protects your engine from overspeed caused by a missed shift or loss of traction. The Soft-Touch gets its name because it limits revs smoothly to the selected rpm without backfires or engine roughness. When the limit is reached, it drops one cylinder at a time, then fires that cylinder the next revolution, dropping another cylinder. You adjust the rpm limit with a plug-in module, such as 6,000, 7,000, 8,000, but the Rev Control will not extend the rev limit already in the EEC control module. Some ignition controls provide a built-in rev control.

The MSD Adjustable Timing Control allows dashboard control to advance timing toward the ping point, and to retard timing for bad gas, or for extra heavy loads in your truck.

You may be able to hear the ping, or other noises may cover it—wind, road, engine noises. Or your car may have noise insulation between you and the engine. If so, you may need an Engine Knock Monitor, with a knock sensor to bolt to your engine. On the dashboard readout, you'll see green for light knock, yellow for moderate and red for "Back off, bud!" Remember, light knock is probably the point of maximum engine efficiency so a monitor can be a real help. You will need to use the sensitivity adjustment to tune the sensor to match your engine.

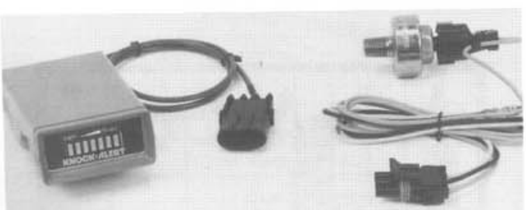


Fig. 6-20. Engine-knock monitor kit provides a readout of knock vibrations picked up by knock sensor you attach to engine block.

If you are using this Engine Knock Alert timing control to adjust according to the indicated knock, you are operating "open loop." You must recognize the difference between this and a closed-loop system that, sensing the detonation, retards the spark timing in milliseconds. I have yet to find an aftermarket knock sensor kit that operates closed loop.

Within that limitation, the ignition system can be set up so that maximum spark advance is close to the most efficient power point. The timing adjustment does not need the fudge factors and retarded timing that may be required when you must depend on your ears to hear the knock, and your fingers to react quickly enough.

With a knock-sensor system, preferably original equipment (closed loop), there is some advantage to buying higher octane gasoline. The better fuel is more resistant to detonation, and the knock-sensor system will allow more spark advance for more power.

7. QUESTIONABLE TRICKS

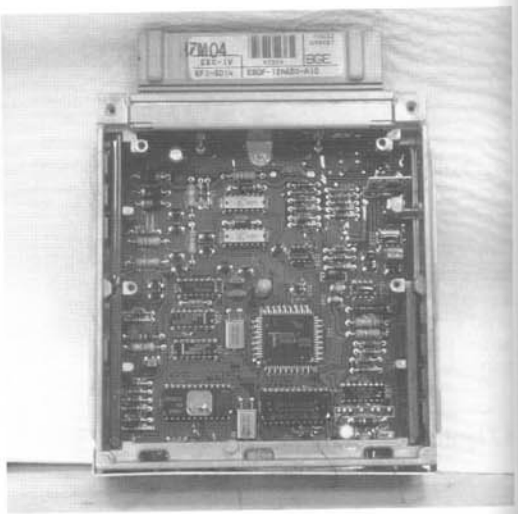


Fig. 7-1. Don't do this: Opening the EEC control module to make modifications (such as the installation of performance chips) can at the very least violate EPA regulations, and at the worst cause your engine to run poorly or ruin the control module. Stay away from modifications that have you open the control module.

Modifications that attempt to trick the electronic control module by manipulating its input signals may produce some performance gains under full-throttle acceleration. But these modifications might also result in less-than-perfect air-fuel mixtures under other operating conditions.

Wolfgang Hustedt, Bosch Motorsport Manager, told me, "Don't try to fool the computer. Can you enrich by playing games with the sensors? That's kid stuff that seldom gets results. The effect of the sensors on the enrichment is usually linear, so if you want rich at speed, you'll probably get too much rich at lower speeds." *In other words, any marginal improvement* may well be accompanied by problems elsewhere.

Steve Dinan, President of Dinan Engineering, an aftermarket tuning firm in Mountain View, California, told me, "...power gain is elusive. Somebody can show you tests with more power at one point on the curve, but you don't know that you are losing somewhere else. You might gain peak power, but driveability glitches can develop, such as poor idle, loss of low-end torque, and high HC (hydrocarbon exhaust emissions). Some of the most involved work we do is trying to restore driveability to a (car) that has been fooled with for a little gain at one point of the curve."

7.1 Fool the Coolant-Temperature Sensor?

As you have seen, the variable resistance of the coolant-temperature sensor is an input to the computer. At lower temperatures, the higher resistance signals the computer to call for more fuel. They'll tell you that adding resistance to this circuit will trick the computer into thinking the engine is cold, so enrichment is added. I don't see any professional Ford tuners trying this old trick.

Here is the problem. Computers are programmed to operate within a certain band of resistance values of the coolant-temperature-sensor circuit. Instead of enriching the mixture, a radical change in resistance might cause the computer to revert to Failure Mode Effects Management (FMEM), lighting your Check Engine light. Some systems simply operate based on the last "normal" temperature signal. This won't work closed loop.

Even if it worked open loop, it would be a bad trick. Over an extended period, the extra fuel could cause wear of the rings and cylinder walls. The big caution in a set-up like this is to watch for too much enrichment on cars equipped with catalytic converters. Too much fuel will send converter temperatures soaring—in some circumstances high enough to light the car on fire!

7.2 Install Lower-Temperature Thermostat?

Some tuners recommend low-temperature thermostats. It's true that a cooler engine takes in cooler air—more pounds for more power. Sounds good, but lower coolant temperatures do not lower the temperature of intake air by the same amount.

There is one possible gain from a cooler thermostat: lowering head temperature may reduce probability of detonation. That means you can advance the spark timing for increased power. Except for the track, this is not one of your better ideas.

Most engines are designed to operate with a coolant temperature of around 95°C (200°F). Unfortunately, lower coolant temperature will increase cylinder wall wear and, in cold climates, affect driveability. What's more, the cooling system operates with greater efficiency at the stock 200-degree temperature. So the lower-temperature thermostat could lead to overheating at high powers.

When I investigated this some time past, the Eveready engineers told me *some NASCAR racers run 100% glycol in the* cooling system so they can run the engine at higher temperatures. And in Europe, Honda found its racing engines operated more efficiently if they raised the air temperature. Something about lean-burn efficiency. How about that! Pass on cool thermostats.

7.3 Disconnect Fuel-Pressure-Regulator Vacuum Line?

This is one of the worse ideas, trying to improve performance by defeating the line that modifies fuel pressure according to manifold pressure. As you know, the system is designed to operate with constant relative fuel pressure. At WOT, the regulator will give you maximum fuel pressure, even with the vacuum line connected. At less than WOT, the injector pulse times are calibrated for properly-reduced fuel pressures. Disconnecting the vacuum line causes rich running only at part throttle. What a scheme to foul plugs!

7.4 Convert from MAF to MAP?

Unfortunately, some tuners want to change your Mass Air Flow (MAF) sensor to a Speed-Density system, operating from MAP. Apparently, they cannot stand the thought of the restriction of the stock MAF, a reduction of air flow that is so small it is measured in milligrams. They forget that Ford, once committed to Speed-Density, has almost completely changed engine control to MAF. Motorsport offers a kit for your aftermarket changeover to MAF.

The Speed-Density conversion is usually bad news. Because the MAF sensor signals control of fuel and ignition, some converters find the engine will not run at all; others find detonation and poor driveability. Check this out all the way before you try converting MAF to MAP.

7.5 Remove EGR (Exhaust Gas Recirculation)?

If you're tempted to block off the EGR flow, hold it. I know, dumping partly-burned gasses back through the combustion chamber seems a power-robbing game. When EGR first appeared in 1974, blocking off the EGR was probably the only thing that kept some engines running. But today, in these fuel-injected engines, people who know don't do it for two reasons:

- The engine-control already shuts off EGR under high-performance conditions, also at idle and during cold operation
- The rate of fuel injected and the spark advance are calculated for EGR under part-throttle conditions. If you block off EGR, you stand of good chance of experiencing knock and wasting fuel. You might even reduce your power output, and you are dirtying the air

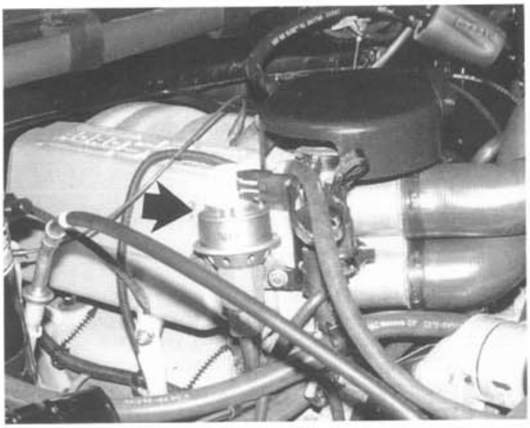


Fig. 7-2. Disabling EGR valve (arrow) control may lead to engine knock and poor fuel economy.

7.6 Add-On Injectors?

One approach to providing needed fuel enrichment to modified engines is to leave the existing fuel system untouched and add a separate system with the capability to meter additional fuel. See Fig. 7-3. The controller considers input signals of rpm and MAP to determine the activation point. Tuning is required to determine the gain, the percentage of injector capacity to be used. Unfortunately, some controllers do not correct for coolant or air temperature, so the air-fuel ratio may be off. In my opinion, you're asking for driveability problems, particularly in northern climates, if you add injector(s) that do not provide for temperature compensation.

Fig. 7-3. Add-on fuel injector (arrow) can supply fuel for high demand situations, but precise control of air-fuel ratio is difficult .

8. MAZDA ENGINE CONTROL SYSTEM (MECS)

HKS of Torrance CA, and of Shizuoka, Japan, specializes in performance mods for Japanese engines, including the turbo 1.6L in the 1991 and later Capri, and the turbo 2.2L in the Ford Probe. These include: fuel-system components, boost controls, air induction and exhaust systems, intercoolers and ignition systems. Systems come in several stages of tune. Those that are Smog Legal show "EC" (Environmentally Conscious) in the Part #. Typical power boosts from stock Probe GT with 2.2L turbo:

Street			
	HP	Boost (psi)	Mods
Stock	145	10	—
Legal 1	159	10.5	Intake and exhaust upgrades
Legal 2	164	10.5	Above, plus intercooler upgrade
Off-Road			
Stage 1	169	11	Intake and exhaust upgrades
Stage 2	178	12	Above, plus wastegate control
Stage 3	187	12	Above, plus intercooler upgrade
Stage 4	222	15.5	Above, plus power-chip module

The HKS power-chip module, known as a Programmed Fuel Computer, Stage IV Off-Road, really adds horsepower, based on serious engine mods. It is adjustable with internal dipswitch, and can even be cockpit controlled with an additional mod, the Graphic Control Computer.

The HKS Electronic Valve Controller (EVC) manages the wastegate to increase the time at max boost without increasing the max boost pressure. The electronic control maintains closer control over the wastegate than an air-operated boost control. We're talking Stage II, Off Road.

In addition, the dashboard controller allows boost increases over stock to 150%, 200%, 300%. I hope your engine and your drivetrain can handle that.

One simple mod improves air flow, using a low-resistance air filter as described earlier.

Another simple mod improves power by changing the exhaust. The HKS High-Flow Turbo Exhaust system is certified street legal. What's more, it does not affect engine timing, fuel enrichment or emissions because the engine-control module compensates for any changes. Reducing the back pressure at the turbo increases the pressure across the nozzle so the turbo winds up more quickly, reducing turbo lag. It might raise the max boost.

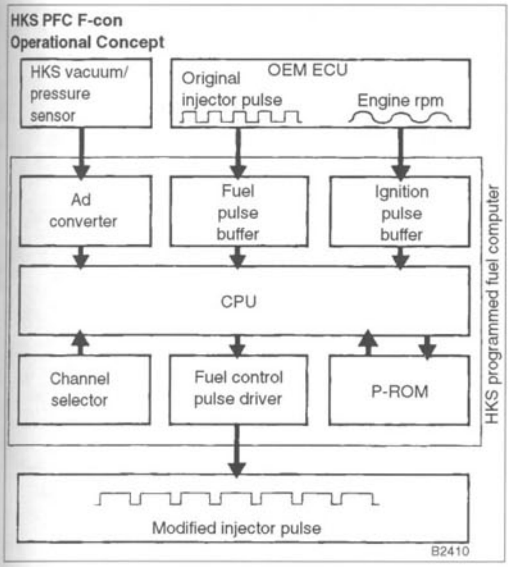


Fig. 8-1. HKS power-chip module reads OEM (Original Equipment Manufacturer) control module, modifying injector pulse times. Not Certified as street-legal.

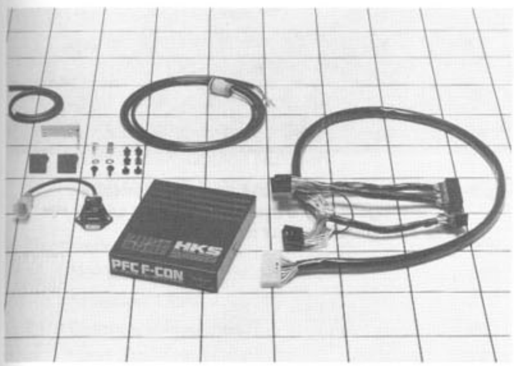


Fig. 8-2. HKS power chip module monitors Ford control module and modifies injector pulse times. Not certified for street use.

You can replace the stock intercooler with the upgrade intercooler for modest horsepower increases for both Probe and '91 and later Capri. With more cooling, you'll increase the peak horsepower (Probe about 6 hp, Capri about 8 hp), but with increased volume of the intercooler, you'll increase turbo lag. Street legal, CARB #D-186-1.

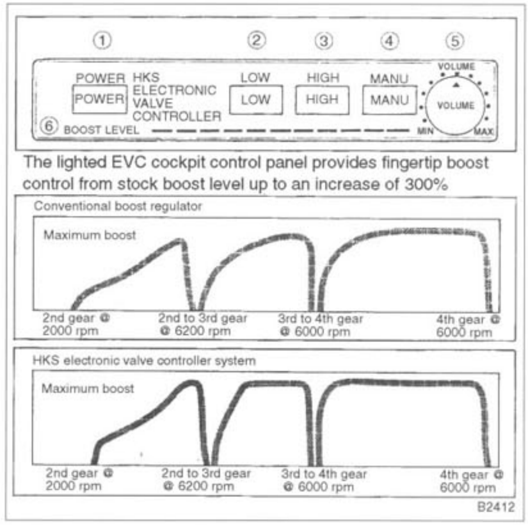


Fig. 8-3. Electronic monitoring of wastegate provides more time at max boost without increasing max boost pressure.

To improve low-speed driveability and throttle response, try the HKS Twin-Power Capacitive Discharge (CD) Ignition Amplifier. You may find an improvement in high-end misfire, particularly if you're increasing the boost.

Recalibrating the Volume Air Flow (VAF) Sensor

The Bosch Volume Air Flow (VAF) sensor is used in MECS-I engines, including 1991 and later 1.6L Capri, some 1.8L DOHC Escorts and Tracers, and 1989 and later 2.2L Probes.

From the factory, the relationship between the air-flow sensor mechanism (the flap) and the signal to the computer is precisely calibrated. But, you can recalibrate the mechanism by tightening or loosening the return-spring tension on the air-flow sensor flap to alter this relationship. Adjusting the spring tension will change the sensor-flap position for any given intake air flow. This produces a greater or lesser signal and, therefore, a leaner or richer mixture—in the range up to about 4000 rpm where the air-flow sensor is fully open.

Some very knowledgeable independent tuners have had success with this method, but remember that the VAF sensor is a sensitive, delicate device. Without knowing what you are doing, it is easy to do more harm than good. You must check the fine adjustments and their effects on mixture with an engine exhaust analyzer. Ford does not recommend or endorse any kind of internal VAF adjustment.

9. CONCLUSION

In this chapter I have presented a broad spectrum of ideas on the high-performance application of fuel-injection systems in Ford cars and trucks and on modification of those systems. The subjects have ranged from inexpensive modifications to street cars to extremely expensive custom electronic controls made for racing.

The fundamental messages of the chapter are these:

1. In the quest for more power, increased efficiency, or better fuel economy, the stock fuel-injection system is not necessarily the weak link. Sometimes the stock system is the best system, considering the limitations of the engine and the needs of the driver.
2. There are no "demon tweaks," no magic chip that can miraculously unlock vast amounts of horsepower. The need for fuel-injection system modifications depends directly on the needs of the engine. It all comes down to whether the needs of the engine exceed the capabilities of the injection system.
3. There is no substitute for knowledge—knowledge of the engine's requirements, knowledge of the engine control system's limitations, and an understanding of the real effects of modifications. I've devoted the first eight chapters to describing the detailed functions of each Ford fuel-injection system. Thorough understanding of these functions will be the first and most important step in figuring out what adjustments and modifications will pay off for your car and your individual needs.

NOTE —
See appendix for CARB Exemption Order List

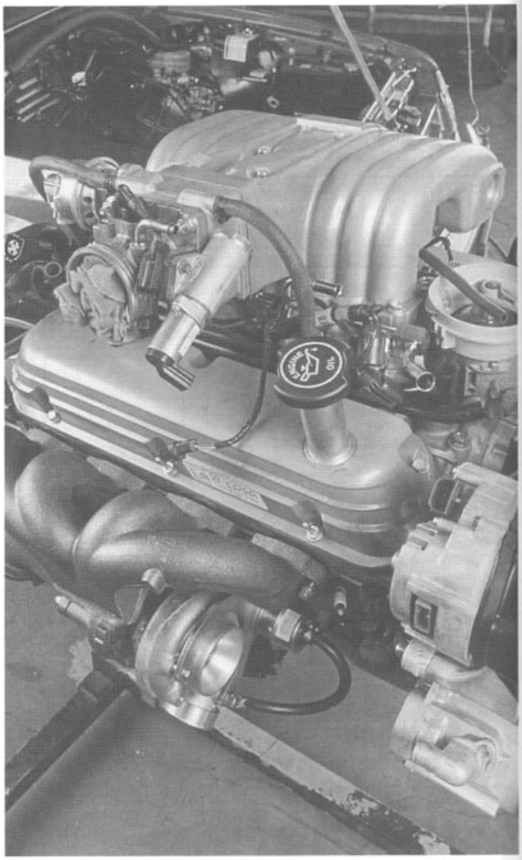


Fig. 9-1. All it takes for successful tuning is a thorough knowledge of engine management basics as well as the trade-offs of your modifications.

Chapter 10

Diagnosis and Troubleshooting

Contents

TABLES

1. INTRODUCTION

In this chapter you'll see the diagnostic and troubleshooting procedures that apply to fuel-injection and engine-control systems in Ford cars and trucks, both EEC and MECS. Troubleshooting and diagnosis is the most important part of service today. In the early days of fuel injection, a mechanic (and I use the word "mechanic" instead of "technician" advisedly) would wet his finger and prescribe, "You need a new control module." That didn't cut it then, and it won't cut it now.

This chapter will guide you to the source of problems. Section **2. Diagnosis and Troubleshooting Basics**, gives you some troubleshooting tips and general information you should know before beginning. Section **3. Diagnostic Routines**, gives you the specific troubleshooting steps. Later sections expand on the basic procedures. In all cases, the results of your troubleshooting will indicate specific components that need further testing or replacement. Look for this information in Chapter 11.

If you're an owner, troubleshooting your own car, you'll need to recognize there's a limit to how far you can "wade into this pool." But you'll be way ahead of those who have said to me, "When I raise the hood on these fuel-injected cars, I'm afraid to touch anything."

If you're servicing professionally, you have more tools and you can "wade in farther." I think you'll be pleasantly surprised how much you can find out, using this book.

By this point in this book, you should know:

- Fundamentals—what the system is supposed to do
- Operation of the sensors, the control module, the actuators and systems
- Strategies and how the control system deals with various operating conditions
- The differences between Ford EEC systems and Ford MEC systems:

Ford Electronic Engine Control	Mazda Engine Control System
EEC (say "eek")	MECS (say "mex")
NAAO—North American Auto Operations	Non-NAAO—Non-North American Auto Operations

If you've turned to this chapter without going through the previous chapters, you're going to be troubleshooting by the numbers with little understanding of what you are doing. For example, do you know what the BOO switch is? (If you don't, look it up, using the Index.) You will use the BOO switch in troubleshooting. Today's engine controls are too complicated and too interrelated to service by the numbers. Believe me, you can't afford the time or the dollars to try the old routine of "substitute a known good part." When you try that, you're flying blind.

When you finish these chapters, you'll know how to deal with diagnostics and troubleshooting and with the real problems. You'll know how to:

- Perform specific diagnostic checks to narrow the list of tests you will make for specific complaints
- Run a series of general tests that use the control module to lead you to specific service procedures

Fig. 1-1. Engine compartments are laid out with a great deal of logic to help you troubleshoot and repair fuel-injection/engine-control problems.

1.1 Terminology

Beginning in 1993, some of the names of the engine-control components were changed to comply with the SAE standardization J1930, in order to provide common terms for the same general part throughout the automotive industry. For more information on terminology changes, see Chapter 1. This chapter uses the terminology applicable for the years 1988–1992. For reference, **Table a** lists those terms and their equivalents that changed in 1993.

Table a. 1993 and Later J1930 Terms

1988–1992 Term	1993 Equivalent
Air Charge Temperature (ACT)	Intake Air Temperature (IAT)
Barometric Pressure (BP)	BARO
Check Engine Light (CEL)	Malfunction Indicator Light (MIL)
Control Module/Electronic Control Assembly (ECA)	Powertrain Control Module (PCM)

continued on next page

Table a. 1993 and Later J1930 Terms (cont'd)

1988–1992 Term	1993 Equivalent
Distributorless Ignition System (DIS)	Electronic Ignition (EI)—Low *Data Rate*
DIS / EDIS / TFI Module	Ignition Control Module (ICM)
Electronic Distributorless Ignition (EDIS)	Electronic Ignition (EI)—High Data Rate
Heated Exhaust Gas Oxygen (HEGO)	Heated Oxygen Sensor (HO2S)
Idle Speed Control (ISC)	Idle Air Control (IAC)
Inertia Switch (IS)	Inertia Fuel Shut-off Switch (IFS)
Intake Air Control (IAC)	Intake Manifold Runner Control (IMRC)
Integrated Relay Control Module (IRCM)	Constant Control Relay Module (CCRM)
Profile Ignition Pickup (PIP)	Crankshaft Position (CKP)
Self-Test Connector (STC)	Data Output Line (DOL)
Self-Test Output (STO)	Data Link Connector (DLC)
Spark Angle Word (SAW)	Spark Output (SPOUT)
Thermactor Air–Bypass (TAB)	Air Injection Reaction Bypass (AIRB)
Thermactor Air–Diverter (TAD)	Air Injection Reaction Diverter (AIRD)
Thick Film Integrated-IV (TFI-IV) Ignition	Distributor Ignition (DI)
Vane Air Temperature (VAT)	Intake Air Temperature (IAT)
Variable Reluctance (VRS)	Crankshaft Position (CKP)

2. Diagnosis and Troubleshooting Basics

2.1 Tips

Don't expect all the details for all cars to be in the book you're reading now. Ford Customer Service Division needs several thousand pages to cover all Ford fuel-injection and engine-control systems. But to help you with basic troubleshooting information and test values, you'll find a comprehensive set of wiring diagrams and specifications in Chapter 12.

What Parts Cause Trouble

I will tell you some of the more likely causes of problems, and some of the things often blamed but seldom guilty. If you know from experience what's most likely to go wrong, then it makes sense to start your troubleshooting there before going to the diagnostic routines.

- Ignition modules have given Ford more than its share of problems, particularly in the earlier TFI-IV systems
- Early model Throttle Position (TP) sensors can develop "glitch areas". The wiper track develops drop-outs, particularly where the TP sits for cruise control
- The inertia switch, a feature of Ford EEC and some MEC systems not generally found in other cars, can cause a No-Start, and I'll tell you why
- *Carbon build-up on the EGR valve seat on on the* pintle can cause the valve to remain open, setting a fault code
- The port injectors on early models can foul, and the intake passages can collect deposits
- Cracked or loose fan blades can cause a rough idle, easily blamed on the engine-control system
- Connectors have been a problem, particularly before it was realized how even small amounts of corrosion can interfere with the milliamps of current in the signal circuits. Ford devotes considerable attention to reliable links between sensors, actuators and control module. So should you in your troubleshooting
- Non-resistor spark plugs can introduce stray electrical noise in the sensor circuits—known as "spark echo." The low-amperage engine-control current flows can be skewed by spark echo, resulting in incorrect air-fuel ratios, spark timing, and even idle air
- Quick-check for No-start on MAP sensor equipped vehicles: Disconnect the MAP sensor and crank the engine. The Failure Mode Effects Management will substitute a fixed value. If the engine starts, then you know you probably have a MAP sensor problem. Don't forget to clear the trouble code when finished

Fig. 2-1. Connectors, harnesses and grounds are common trouble spots in electronic engine-control systems. Make sure connections are clean and tight. In earlier systems, cleaning corrosion from connectors will often fix problems without replacing components.

Corrosion in Wiring

Corrosion in wiring harnesses can change the resistances and induce current leakage, affecting the signals from sensors. Once upon a time, we wrapped a splice to insure no contact with another lead or with ground. Now it's important to prevent moisture from entering connectors and conduits.

If water and salts enter, they can move along the harness, propelled by temperature changes, vibration, and wicking. Protect every point of entry into the harness from intrusion of moisture and dirt. If you find crystalline residues, white and blue green in color, clean off the corrosion damage and look for the points where moisture could enter. An old-fashioned tape splice may hide the source of your problem. Puncturing insulation to DVOM-measure a circuit may save the time and cost of a breakout box; but that pin-prick opening may haunt you in time ahead. If you find any pinholes in wiring, always seal them with a dab of silicone sealant.

Road Testing

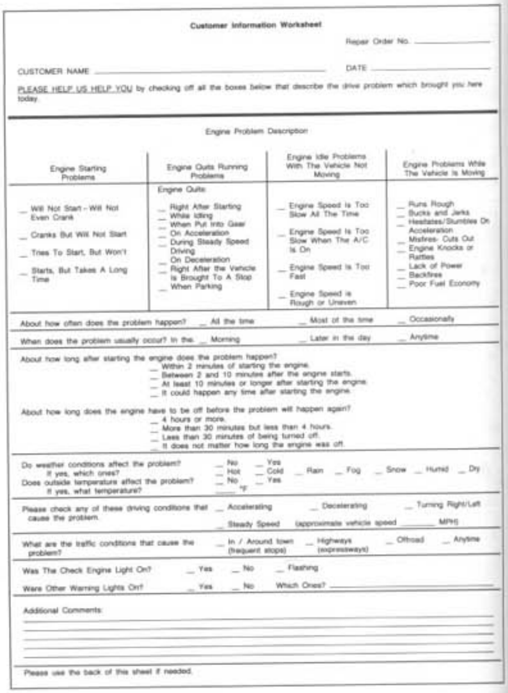
Whether you are servicing your own car or someone else's, begin by road testing, observing with your best analytical eyes and ears. As you drive the vehicle, listen and feel for the specific signs that verify the complaint and lead you to focus your troubleshooting.

In my experience, one of the toughest diagnostics, short of sudden failure, is analyzing your own car. Driving it day-to-day, you may fail to recognize changes that have occurred gradually. Day 365 doesn't seem much different from day 360, but it really is different from day 1.

Two suggestions that I've found valuable:

1. Ride as a passenger. With someone else driving and telling you what they are doing with the accelerator, you can better concentrate on the engine response to changing conditions.
2. Follow the car under test. Again, you need to know what the other driver is doing, but consider this, for example: If he suddenly closes the accelerator and you see a brief puff of blue smoke, you'll probably find worn valve guides. It's not likely the driver of the test car would see the blue smoke puff so he might blame the high HC emissions on the engine-control system.

Another helpful tip is something Ford service people use when they write up a repair: a customer information sheet. See Fig. 2-2. When you fill it out yourself, you may define the problem.



Customer Information Worksheet

Repair Order No. ________

CUSTOMER NAME ________ DATE ________

PLEASE HELP US HELP YOU by checking off all the boxes below that describe the drive problem which brought you here today.

Engine Problem Description

Engine Starting Problems	Engine Quits Running Problems	Engine Idle Problems With The Vehicle Not Moving	Engine Problems While The Vehicle Is Moving
_ Will Not Start – Will Not Even Crank _ Cranks But Will Not Start _ Tries To Start, But Won't _ Starts, But Takes A Long Time	Engine Quits: _ Right After Starting _ While Idling _ When Put Into Gear _ On Acceleration _ During Steady Speed Driving _ On Deceleration _ Right After the Vehicle is Brought To A Stop _ When Parking	_ Engine Speed Is Too Slow All The Time _ Engine Speed Is Too Slow When The A/C Is On _ Engine Speed Is Too Fast _ Engine Speed Is Rough or Uneven	_ Runs Rough _ Bucks and Jerks _ Hesitates/Stumbles On Acceleration _ Misfires- Cuts Out _ Engine Knocks or Rattles _ Lack of Power _ Backfires _ Poor Fuel Economy

About how often does the problem happen? _ All the time _ Most of the time _ Occasionally

When does the problem usually occur? In the _ Morning _ Later in the day _ Anytime

About how long after starting the engine does the problem happen?
_ Within 2 minutes of starting the engine.
_ Between 2 and 10 minutes after the engine starts.
_ At least 10 minutes or longer after starting the engine.
_ It could happen any time after starting the engine.

About how long does the engine have to be off before the problem will happen again?
_ 4 hours or more.
_ More than 30 minutes but less than 4 hours.
_ Less than 30 minutes of being turned off.
_ It does not matter how long the engine was off.

Do weather conditions affect the problem? _ No _ Yes
If yes, which ones? _ Hot _ Cold _ Rain _ Fog _ Snow _ Humid _ Dry
Does outside temperature affect the problem? _ No _ Yes
If yes, what temperature? ____ °F

Please check any of these driving conditions that cause the problem. _ Accelerating _ Decelerating _ Turning Right/Left _ Steady Speed (approximate vehicle speed ____ MPH)

What are the traffic conditions that cause the problem? _ In / Around town (frequent stops) _ Highways (expressways) _ Offroad _ Anytime

Was The Check Engine Light On? _ Yes _ No _ Flashing

Were Other Warning Lights On? _ Yes _ No Which Ones? ________

Additional Comments:

Please use the back of this sheet if needed.

Fig. 2-2. Sample customer information worksheet.

Engine Condition

It's easy to jump from a complaint to "a quick answer" for the problem. To some who are familiar with carburetors or points and condensers, electronic engine-control systems are still a new technology. So, often they blame the fuel injection or the control module first.

It's better to follow a definite troubleshooting procedure without skipping around. We used to teach the necessity of checking basic engine condition first. We said, when the vehicle is older or has higher mileage, be sure your troubleshooting is not fooled by poor compression, leaking valves, and deposits on the injectors or in the intake passages. That's still true of some driveability complaints. But, as it turns out, with the longevity built into today's engines, you are more likely to cure the bad emitter of pollution by first checking the engine-control system.

One of my favorite troubleshooting stories, from Gus's Garage in Popular Science, long ago:

LOL (Little Old Lady): "Gus, sometimes my car does not start."

GUS: "What do you mean, 'Sometimes?'"

LOL: "Well, when I drive to the ice-cream store and buy vanilla ice cream, it starts OK, but when I buy peppermint-stick candy ice cream, it won't start."

GUS: "Well, let's drive your car down to the ice-cream store and buy some ice cream." (You can tell this is a troubleshooting story from way back when garage owners had time to do this kind of thing. Either that, or this customer drives a Rolls-Royce).

Gus and LOL drive to the store, enter. Gus orders a pint of vanilla and a pint of peppermint-stick candy. Without delay, the clerk reaches into the freezer and hands Gus a pre-packed pint of vanilla. He then goes in the back room and returns in about 10 minutes with a custom-packed pint of peppermint-stick candy ice cream. Gus immediately troubleshoots the problem. What do you think?

LOL's car has a hard hot-start problem. During the ten minutes it takes to pack the peppermint-stick candy ice cream, the fuel is boiling in the lines. The engine has a vapor lock and so, a hard hot start. When she buys vanilla, she restarts the engine soon, before the fuel has time to boil. Imagine a shop troubleshooting a Repair Order: "Customer complains car will not start after she purchases peppermint-stick candy ice cream"!

Discussing diagnostics, I told this story to some engineers from Germany. One turned to the other and said triumphantly, "You see, I told you we could not program the diagnostic computer for all troubleshooting."

No, it takes knowing how the engine and its control system operate.

In a 1992 SAE paper, EPA reported testing some 245 four-cylinder cars, averaging about 50,000 miles on the odometer. All had failed an Inspection & Maintenance (I&M) test. EPA and vehicle manufacturers found that HC and CO emissions could be reduced by repair to the system, regardless of whether the vehicle had low or high cylinder compression. Of course, NOx formation is reduced with lower compression. Conclusion: "Reasonable emission levels can be achieved with proper repairs to the emission control system even on vehicles with internal engine problems."

On the other hand, don't overlook the basics. For example, you'd be barking up the wrong tree if you replace an Engine Coolant Temperature Sensor based solely on a scan-tool readout. The problem may really be caused by low coolant level that doesn't reach the sensor.

Two engine problems seem to crop up regularly on high mileage cars:

1. EGR valve clogged with carbon buildup. This can make the valve stick open or cut off EGR flow completely.
2. Buildup of fuel gum and crankcase blowby sludge in the throttle housing and around the throttle plate. This will affect air flow at all engine speeds, but especially idle.

Ford Service Engineering learns from these lessons: Most late-model engines are designed to meet emission limits without an EGR system. And most late-model throttle bodies (91+) are coated to resist sludge and gum.

Finally, let me suggest a few other basics often overlooked:

- Fuel—enough in the tank, and good quality
- Ignition—general condition of wires, moisture contamination, cracks in the distributor cap, damage
- Battery and starter—circuits, system grounds
- Vacuum hoses—cracked or disconnected (Fortunately, you have fewer vacuum hoses with EEC and MECS)

Use the Control Module

Ford engine control systems test themselves to give you a lot of help troubleshooting. These Self-Tests are designed into the system to:

1. Test major subsystem elements.
2. Display test results with minimum test equipment.
3. Reduce time required for diagnostics.
   - Keep-Alive Memory (KAM) stores diagnostic routines and fault memories in the control module
   - KAM stores adaptive corrections
   - Failure Mode Effects Management (FMEM) improves the ability of the engine to run even with the failure of some component, while retaining information about the failure in the memory

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In the Diagnostic Routines section of this chapter I'll show you how to use the control module to guide you to the problem. You'll find three kinds of Self-Test:

1. Continuous: tests during normal operation, all the time you're driving.
2. Key On, Engine Off: tests static sensor readings.
3. Engine Running: tests outputs by forcing various conditions and looking for responses.

See Fig. 2-3. These are also called Quick Tests, or On-Demand Tests. You demand the tests through the Self-Test Input (STI), and see the results through the Self-Test Output (STO). See **3. Diagnostic Routines**.

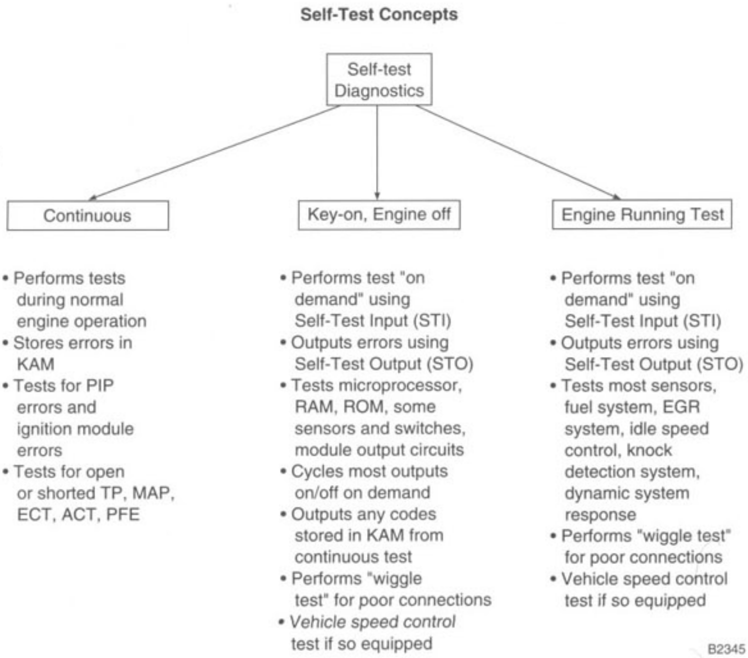

Fig. 2-3. Flow chart showing different types of Self-Tests made by control module.

2.2 Tools

Let's start with your need for a basic selection of good quality tools: wrenches, sockets, screwdrivers, pliers, and a timing light. You will also need a few specialized tools and some others will be helpful, even if not required.

You'll need a shop tachometer to read engine rpm. Don't depend on the dash instrument, particularly for reading small rpm changes.

A vacuum pump was more necessary when many systems operated by vacuum signals or vacuum power. You may need one for certain engine controls, particularly older MY systems or larger displacement engines. You might need a vacuum gauge with a range of 0-30 in-Hg. (0-100 kPa). You can also use the gauge on the vacuum pump.

You'll need a fuel pressure gauge, such as the one shown in Fig. 2-4, for fuel pressure tests. Most Ford systems operate at high pressure so be sure your gauge has the proper scale.

For ignition testing, you'll need a timing light to observe timing marks, and a Spark Tester to check ignition quality. A tester is available as special tool. See Fig. 2-5.

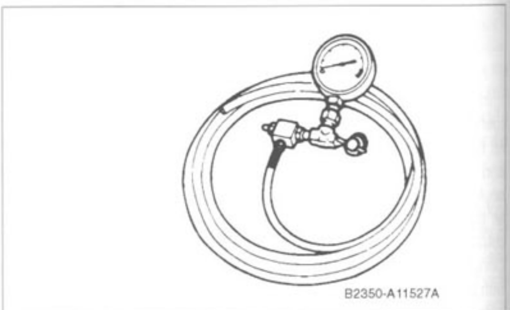

Fig. 2-4. Fuel pressure gauge.

Volt-Ohmmeter

Many of the electrical tests in this book call for the measurement of resistance (ohms) or voltage signal of sensitive electronic components. A DVOM (Digital Volt-Ohm Meter) with high-input impedance registers millivolts and milliamps, and does not overload electronic components.

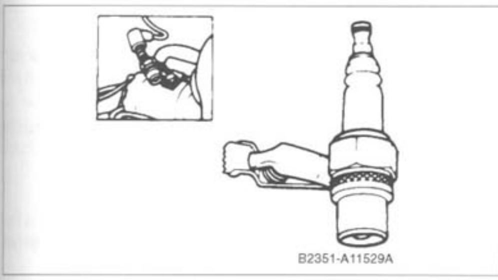

Fig. 2-5. Spark tester.

NOTE —
When making AC voltage readings, use a "standard" VOM. Do not use a "true" RMS-type meter because the readings will be incorrect.

You can use an analog voltmeter to read trouble codes, but it takes longer than a scan tool and needs more interpretation on your part.

Scan Tools

Any extended troubleshooting requires a scan tool to plug into the Self-Test Connector. The Ford tools are known as:

- STAR (Self-Test Automatic Readout)
- Super STAR II
- NGS (New Generation Star)

NGS reads serial data—that is, actual values to and from the sensors and actuators. This serial data is available when you are driving, so it really can help you troubleshoot problems that occur only on the road.

Generic scan tools help troubleshoot Ford vehicles as well as other makes. Some offer additional capabilities. The Fluke Scope meter combines a multimeter with a small scope display. The Snap-On Scanner combines a four-line LCD readout with replaceable cartridges to update vehicle-specific data.

> If you drive with a scan tool on the road, take a helper. I've driven with a diagnostic tester while I designed and produced a video training program on a scan tool. The data stream can be so fascinating as to be dangerously diverting. Reminds me of the description of a tachometer in the first how-to-drive book I read when I was 12. It was a British book, written before the days of synchromesh transmissions. "TACHOMETER—OBSERVE THE INSTRUMENT CAREFULLY AND YOU WILL BE ABLE TO ENGAGE GEARS WITHOUT A SOUND EXCEPT FOR THE CRASH OF THAT LARGE PLATE GLASS WINDOW YOU DRIVE THROUGH." Ah, British humor. You watch the scan tool while your helper drives.

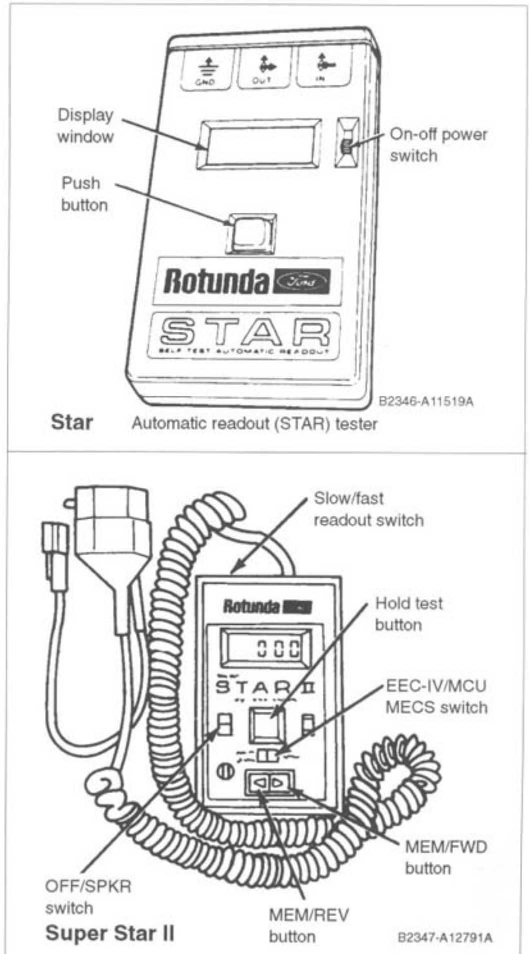

Fig. 2-6. MEC systems do not display in STAR; use Super STAR II.

If you don't use a scan tool, you'll need a test light to indicate current flow. For component protection it should not have an incandescent bulb, but should be of the high-input-impedance type, such as an LED (Light Emitting Diode) test light.

BreakOut Box

For more advanced troubleshooting, some shops use a BreakOut Box, commonly known as BOB. See Fig. 2-8. This fits between the connector and the control module, providing access for measuring signals in individual circuits during operation.

Some techs say they don't need a breakout box. They insert a fine probe into a connector from the back to read circuit volt-

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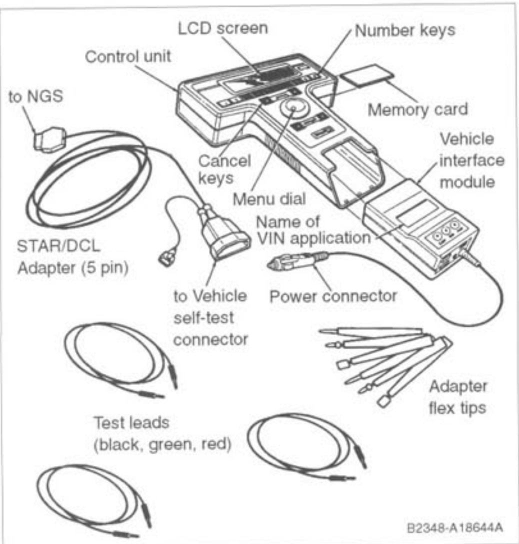


Fig. 2-7. New Generation STAR (NGS) adapts to different model years with a replaceable memory card. It reads data from Self-Test Connector and displays on LCD screen.

Fig. 2-8. BreakOut Box (BOB) installs between control unit connector and control unit to provide testing of signals as engine operates.

ages/resistances. This is sometimes called "backprobing". But be very careful. Do not insert probes from the front of the connector. This can cause pin damage and later lead to problems.

EEC-IV Monitor

The Rotunda (Ford trade name) EEC-IV Monitor is also used by shops servicing Ford vehicles. It's self contained and actually easier to use than a BOB. In the service bay or on the road, it measures the sensors and actuators and translates their operation into understandable terms. Aftermarket monitors are available.

The Monitor saves time when you're chasing problems that are intermittent, that don't generate service codes, or generate too many codes.

The Monitor helps you locate non-electronic failures because it shows you the same information seen by the control unit as the vehicle operates, and how the processor reacts to this information.

Engine Analyzer

Finally, if you're doing lots of troubleshooting, you'll need access to an engine analyzer to supplement your scan tool; they make a good troubleshooting team.

- When the scan tool points to the problem, the analyzer scope patterns help you to concentrate your troubleshooting on specific sensor/actuator signals
- Your problem may show up in the scope patterns on the analyzer even if the scan tool shows no problem

A modern engine analyzer will show much more than the traditional ignition patterns. You can see clues that lead you to the troubleshooting answers:

- Whether the problem is in one or two cylinders, or in all cylinders
- The effects of different air-fuel mixtures in one or more cylinders
- Injector patterns, and even patterns from some sensors

2.3 Precautions

Before performing any work, read the general Warnings and Cautions at the beginning of this book, and follow basic safety rules, as well as those specific to fuel injection and ignition systems.

WARNING —
• Gasoline fuel is one of the most concentrated sources of energy around. Keep any spilled fuel away from hot engine parts. Do not smoke or create sparks when fuel is present, and always have a fire extinguisher handy. Work in a well-ventilated area.

• Fuel injection systems operate under pressures much higher than other fuel systems. See Fig. 2-9. Confine the fuel spray during any injector testing or opening of fuel lines to minimize the chance of a fire.

WARNING —

• Remove jewelry, metal watches, and watchbands. If one of those shorts a circuit, you may wear the scar the rest of your life.

• An engine has the power to crush you. If you run the engine of a car with an automatic transmission while testing, do not trust your life to the PARK position of the lever. Set the parking brake and chock the drive wheels. Avoid working in front of the bumper whenever possible.

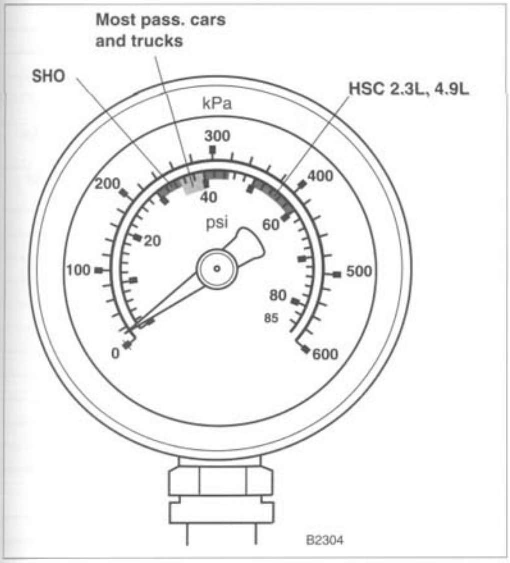


Fig. 2-9. Most Ford fuel injection systems operate at high pressures. Key On Engine Off values shown.

CAUTION —

• For many tests, such as compression checks or cylinder balance checks, either disable the fuel injection system or keep the duration of the test short. Cranking a fuel-injected engine without starting it can deliver raw fuel into the cylinders, and from there into the exhaust system. This may cause the catalytic converter to overheat and melt down when the engine is restarted.

• Avoid the use of high-voltage battery boosters or chargers. Anything greater than 16 volts is potentially harmful. Be aware that some service stations use 24-volt boosters to turn over engines in sub-zero weather.

• Turn off the key and isolate both ends of a circuit when checking for shorts or continuity.

CAUTION —

• Disconnect solenoids and switches from the harness before measuring for continuity, resistance, or before energizing.

• Any time you disconnect a connector, inspect for damaged or pushed out pins, loose wires, corrosion. Take care not to damage terminals when testing. When assembling the connector, make sure the connection is tight.

• Do not disconnect or reconnect the wiring harness connector to the control unit with ignition ON. This can send a damaging voltage spike through the control unit.

• Dirt is the first enemy of fuel injection systems. Even minute particles can clog the small orifices of the components. Before you open a fuel fitting, wipe it clean with a solvent.

• If the system is open, avoid using compressed air, and don't move the car unless necessary. If you leave the job unfinished, cover removed parts and system openings with plastic, not cloth. When installing new parts, unwrap them just before installation.

Only perform electrical tests(what Ford calls "Pinpoint Tests") when directed by the Quick Test procedures. Otherwise, the incorrect results may lead you to replace good components.

Avoid excess voltage or voltage spikes to the control unit. Ford fuel-injection/engine-control systems are protected from surge and overvoltage, but watch for the following conditions which may damage any system:

- Check for disconnected or loose battery connections. Alternator output goes up as the voltage regulator senses low battery voltage. An open battery circuit will cause the alternator to deliver excess voltage that could damage the control unit as well as the wiring harnesses.
- Before you disconnect a booster or charger with the engine running make sure you have an electrical load. You want to avoid a voltage spike. I'm suggesting you add load just for the moment it takes to disconnect the cables. Turn on the lights and blower or rear window heater. As soon as the booster cables are disconnected, you can turn everything off again.

2.4 Vehicle Identification

Before you begin any work or troubleshooting you need to know just what engine and engine-control systems are installed on the vehicle.

Engine and Model Year (MY)

First, determine the engine and its EEC or MECS system. Start with the Vehicle Emission Control Information (VECI) decal under the hood. See Fig. 2-10. You'll see the engine-control system and what's adjustable, and what's not. You may need to verify whether this is a 49-state car, a California car, or a 50-state car. Those differences can be important. You'll see the Model Year (MY), which can be trickier than you think. Some 1991 MY cars were introduced as early as March 1990.

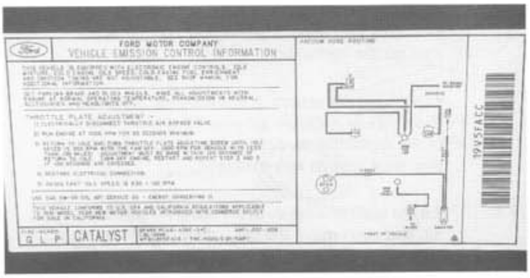


Fig. 2-10. VECI decal for 1991 1.8L Escort.

Vehicle Identification Number

Learn to read the VIN and what it can tell you about the Engine Code and MY. Look for it inside the lower windshield frame ahead of the driver. Look for it also on the plate inside the door frame showing the VIN and the build-date. See Fig. 2-11. You'll need to know the VIN to use the STAR or other scan tools, to choose the wiring diagrams, and to apply service bulletin information. What looks like the same engine may have a different Engine Code, even if it is the same capacity, and it may differ according to the MY. Do not guess.

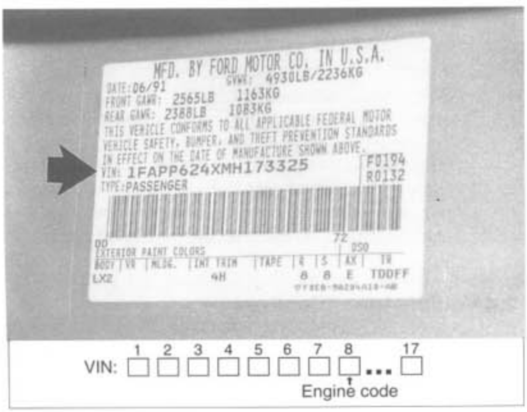


Fig. 2-11. Vehicle Identification Number (VIN) on door jamb. Look at eighth digit to determine engine code.

Engine	VIN Code	Transmission
EEC-IV Passenger Cars		
5.0L MAF-SFI (1988–93)	E	
5.0L MAP-SFI (1988–92)	E	
4.6L 4V MAF-SFI (1993)	V	AODE
4.6L MAF-SFI (1991–93)	W	AOD (AODE '93)
3.8L MAF-SFI SC (1989–93)	R (C early)	
3.8L MAF-SFI (1988–93)	4	AXODE some
3.2L MAF-SFI (1993)	P	AXODE
3.0L FF (Flexible Fuel Vehicle)	1	AXODE
3.0L MAF-SFI (1988–93 SHO)	Y	
3.0L MAF-SFI (1988–93)	U	AXODE
3.0L MAP (1988–92)	U	
2.3L MAF-SFI (1988–92) HSC	A	
2.3L MAP (1988–91) HSC	A	
2.3L MAF-SFI (1988–93) OHC	S	
2.3L MAP (1988–90) OHC	S	
2.0L MAF-SFI (1993 Probe)	A	(See MECS for '93 4EAT)
1.9L MAF-SFI (1990–93)	J	See MECS for 1.8L Escort
1.9L VAF (1988–89)	X	
Nissan Engine Control		
3.0L MAF-SFI (Villager)	W	4F20E
EEC-IV Light Trucks		
5.8L MAP (1988–93)	H	
5.0L MAF-SFI (1993)	N	AODE
5.0L MAP (1988–93)	N	
4.9L MAP (1988–93)	Y	
4.0L MAF-SFI (1993 CA)	X	
4.0L MAF-SFI (1990–93)	X	
4.0L MAF (1990–93)	X	
3.0L MAF-SFI (1992–93)	U	
3.0L MAF (1991)	U	
3.0L MAP (1988–91)	U	
2.9L (1992)	T	
2.9L MAP/MAF (1988–91)	T	
2.3L OHC MAF (1988–93)	A	
Mazda Engine Control Systems (MECS)		
2.5L V-6 MC-VAF-SFI	B	
2.2L Turbo	L	
2.2L Non-Turbo	C	
2.0L (automatic only)	A	4EAT (See EEC for MTX)
1.8L	8	
1.6L Turbo	6	
1.6L Non-Turbo	Z	
1.3L	H	

Fig. 2-12. Engine VIN identification codes for vehicles covered by this book. Firing Order & Cylinder #1

The VECI decal usually supersedes what you might read in a shop manual. Some VECI decals may be pasted over the original for an engine-control system modified for a recall. Also, be on the lookout for such oddities as non-stock engine-control modifications made for performance. If the car is not yours, or if you bought it used, try to find out as much about the car's history as possible. Beginning in 1991, VECI decals use the new terminology recommended in SAE J1930. See Chapter 1 for more information.

Firing Order and Cylinder #1

Here's a special tip for checking Ford engines: learn to identify the cylinder numbers and the firing orders. I know that sounds weird, but we've got three problems:

1. What is the firing order? Although they look alike outside, most Ford 5.0L engines fire 1-5-4-2-6-3-7-8, while the 5.0L HO fires 1-3-7-2-6-5-4-8. See Fig. 2-13.
2. Where is cylinder #1? Most diagrams show cylinder #1 next to the fan. But with transverse engines (across the engine bay) the electric fan is next to the radiator and useless as a clue. On Ford engines, cylinder #1 is farthest from the flywheel or the transaxle. On V-type engines, it's on the cylinder bank to your right when facing the engine. On transverse V-type engines, it's on the cylinder bank closest to the firewall.

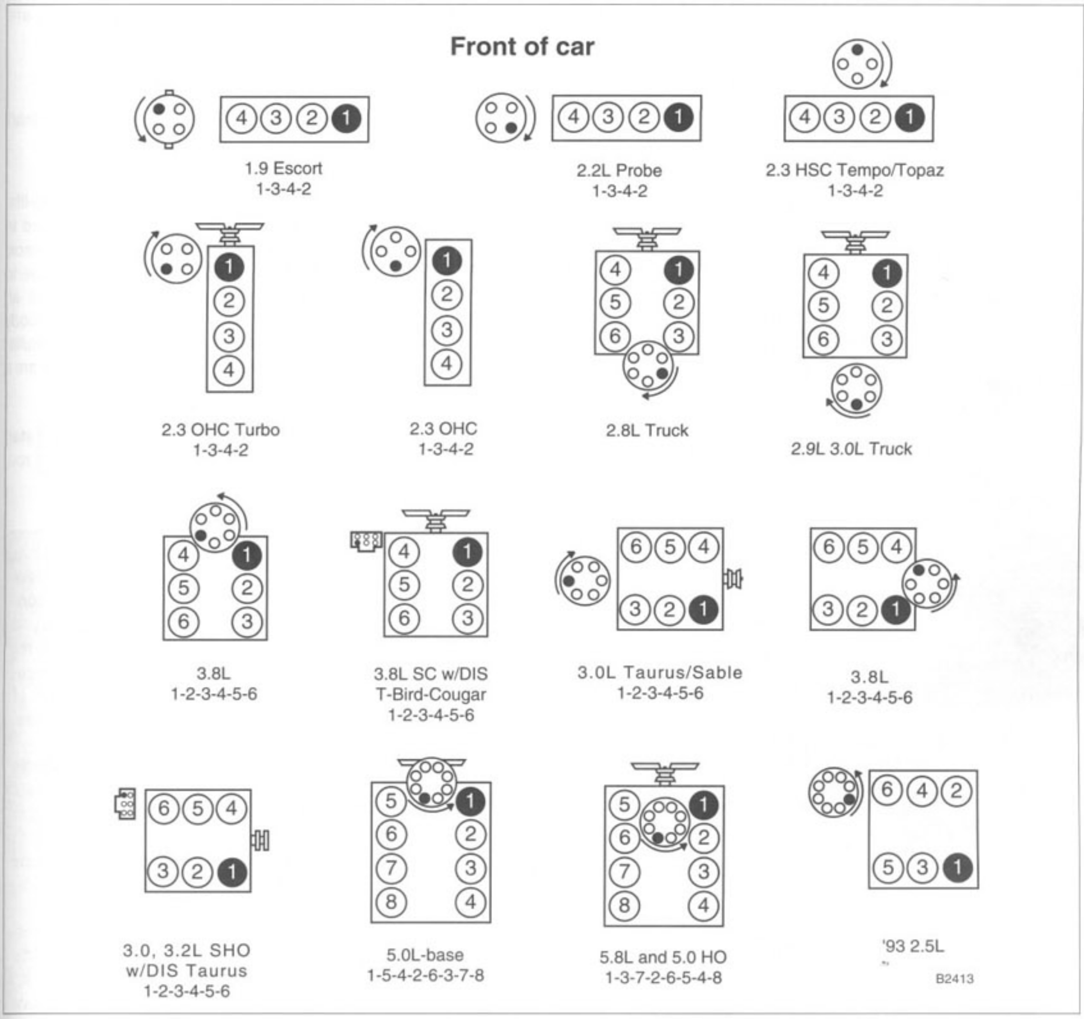


Fig. 2-13. Ford numbers cylinders differently from most other makers. Ford firing orders differ even on engines seemingly the same. Most Ford 5.0L engines fire 1-5-4-2-6-3-7-8, while the 5.0L H.O. fires 1-3-7-2-6-5-4-8. Notice how '93 Probe 2.5L numbering differs from Ford V-type engines.

3. Where is cylinder #2 in a V-type engine, next to #1 or across in the other bank? Ford has its own way of numbering cylinders that can fool you on a V-type, particularly transverse as in Taurus/Sable and recent Continentals. For U.S. transverse V-type engines, the right bank is the rear bank. Ford engines number consecutively along each bank. Begin 1-2-3 along the right bank, looking from the driver side, then 4-5-6 on the left bank. That's different from the 1993 Probe 2.5L V-6: #1 in right bank (closest to bulkhead, and alternating across, 1R, 2L, 3R, 4L, 5R, 6L. Most other V-type engines also alternate, beginning the other way: usually 1L, 2R, 3L, 4R, 5L, 6R.

Fig. 2-14. Ford identifies cylinder numbers differently from other manufacturers. It pays to check the diagrams or the cylinder number identifiers on the plug wires of late-model engines.

3. DIAGNOSTIC ROUTINES

For any complaint, the possible causes are many. If you just troubleshoot randomly you could be at it for hours before you find the source of the problem. I've already given you some basic tips about how to begin your troubleshooting, now let's take it one step further.

To make troubleshooting easier and faster, Ford has developed Diagnostic Routines. These charts list the best order to check systems and components for specific problems. The routines are based on years of technician experience, and have been developed considering three factors:

1. Probability—how likely is this to be the cause?
2. Ease of accomplishment—how easy is it to check this?
3. Accessibility—how easy is it to get at the part?

For example, if the engine is fitted with long-life, platinum-tipped spark plugs, and some of them are hard to reach, those are likely to be lower on the list of things to check. On Ford vehicles, intake air leaks are less common due to component mounting locations. So checking for intake air leaks or bad gaskets at the intake manifold or throttle body mounting is also lower on the list. If you're one who is familiar with many Bosch systems, you know that intake air leaks are a common problem due to long ducting.

The moral of this is that if you want to save time, don't start hooking up your testers until you follow the diagnostic routines.

> Control modules are often blamed unfairly. It is true that many early troubleshooting charts ended at the control module, saying something like, "Check every sensor, connector, cable, and actuator. We don't know how to tell you to check the control module so if everything else is OK, replace the control module." I've heard that Ford had a warehouse full of modules returned under warranty, most of which tested OK. Bosch told me of similar experiences. These days, that's less true for at least three reasons:
>
> 1. Shops are finding that modules are more reliable than expected. Control modules are complex but have nothing mechanical to wear out. They're checked out on the assembly line and they don't leave the factory if they're not good. One general electronics rule of thumb: if it's going to fail, it will be within the first hours or days of operation.
> 2. In the control module, improved On-Board Diagnostics (OBD) increase your chances to find the real problem instead of blaming the module by default.
> 3. Troubleshooting charts no longer end with "Replace the control module".
>
> In other words, control modules have gotten smarter and so have we.

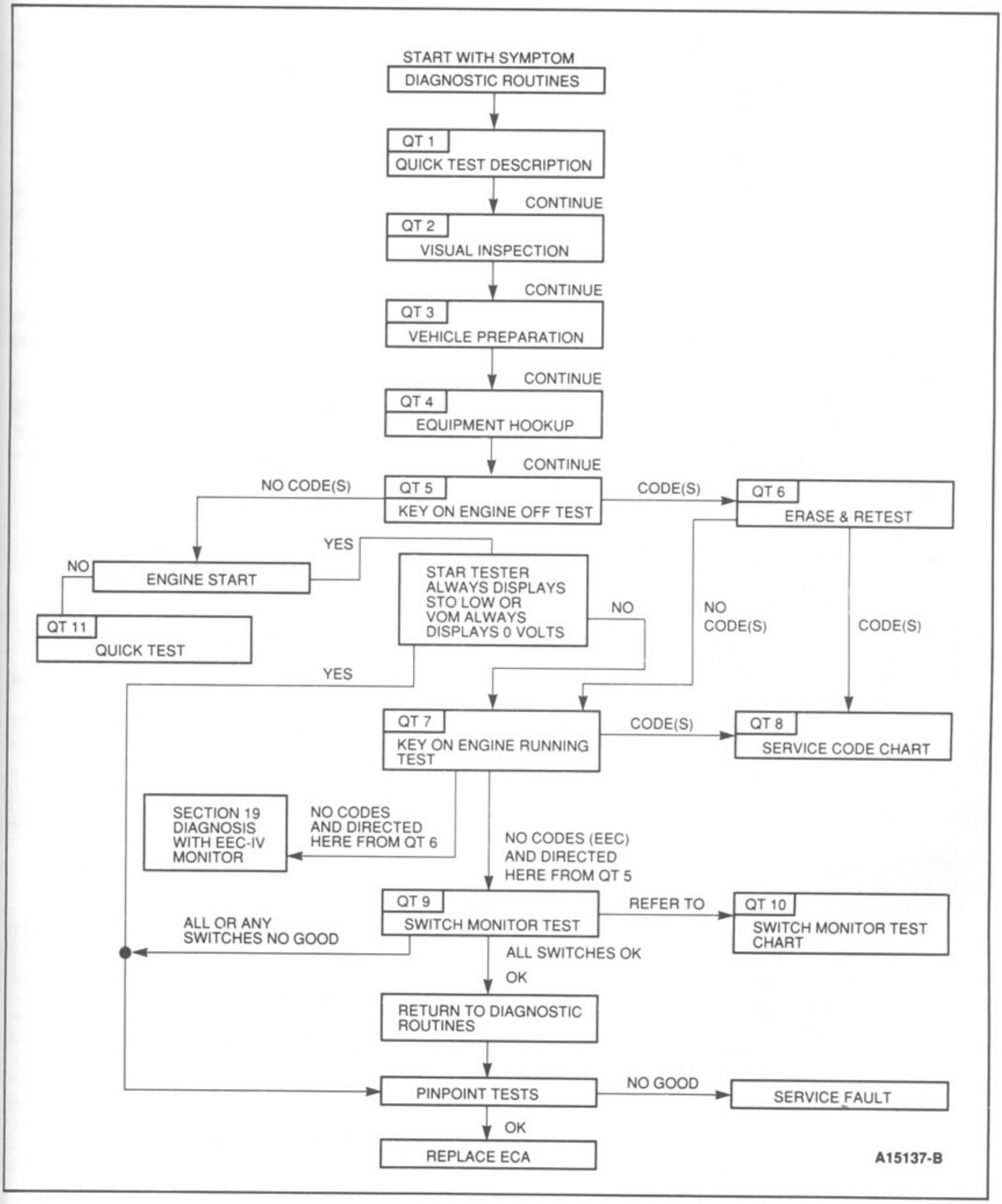


Fig. 3-1. Example of Diagnostic Routines Flow Chart for *Mazda Engine Control System (MECS) equipped* vehicles.

No-Crank

Before we go to the routine charts, let's talk about a No-Crank condition. You've checked the battery, the starter relay, the Neutral Drive/Clutch switch, the starter and the key switch. But turning the key to START produces nothing, not even a groan. What does the control system have to do with cranking? Let me suggest two possibilities:

1. The inertia switch cuts off power to the Fuel Pump Relay. If it opens, you have a No-Start. That open circuit can happen with a vigorous slam of the trunk lid or hatch. Beginning in some 1991 vehicles, a dash warning lamp signals "FUEL CUTOUT" if the inertia switch opens the fuel pump circuit.
2. There's one strange item that's not on Ford's list for a No-Crank condition: Check for an Anti-Theft device. Be especially wary of an aftermarket anti-theft with an ignition and/or starter cut-off. If triggered, it cuts off the ignition and the starter.

> No-Start was a condition that gave our younger son problems when he bought a used 1980 Fiat Spyder (with Fiat's first use of Bosch L-Jetronic fuel injection). He would phone from across the country, "The mechanic says I need a new air box. What do you think?" I'd say, "Did he say why? Find another mechanic," Another mechanic said it would need a new control module. Son found a diagnostic technician who reported the correct fix: Previous owner had installed an aftermarket anti-theft system that cut off power to the fuel pump. Any jostle of the car was causing the anti-theft to open the fuel pump circuit. When he reset the anti-theft switch, son cured his No-Start condition, without a new airbox, or a new control module.

Emission Tests

Studies by EPA and manufacturers have shown the parts most likely required to repair cars that failed emission tests. According to recent studies reported to the SAE, for example, these parts are more likely to need replacement to pass the idle-emission test for hydrocarbons (HC):

- Oxygen sensor: 50 to 70% of the cars
- Catalytic converter: 20%
- Computer: 5 to 8%

To pass the Carbon Monoxide (CO) test:

- Oxygen sensor: 80 to 95%

NOTE —
While it is important for the engine to be at normal operating temperature before idle testing emissions, extended idling causes EEC-IV to change timing and increase rpm. If your engine idles extensively before testing, you may have to shut the engine off and restart to reset normal idle before testing.

The diagnostic routines give possible causes for test failure, but let's consider the problem first. With proper conditioning, any Ford vehicle with fuel injection in good condition is designed to pass these idle tests with room to spare. Just remember a couple of things before you let them test your vehicle.

NOTE —
The following applies to no-load emission tests for HC and CO, both at idle and 2500 rpm. In the coming years though, you'll see more emission tests required under loaded conditions on a dynamometer, testing NOx as well as HC and CO. Engines operating under no-load conditions produce little or no NOx, so that emission gas is not tested under current Inspection & Maintenance (I&M) tests.

- The engine temperature must be warm and stabilized before the test
- The vehicle must not be tested immediately after idling too long in the line awaiting the test. If the test is preceded by a long period of idling, run the engine at about 2500–3500 rpm for 15 to 30 seconds before the test

Make sure the test operator checks the following:

- Verifies normal operating temperature
- Verifies all accessories OFF
- Reads idle emissions
- Revs engine to about 2500 rpm (2200 to 2800) and reads 2500 rpm emissions within 30 seconds
- Again reads idle emissions within 30 seconds of idle

If the operator of the Emission Idle Test facility does not follow these steps, the test may not reflect the emission condition of the vehicle.

Knowing what you know about KAM (Keep Alive Memory), if you replace any emission components, be sure to clear the KAM before re-running any emission tests.

> A word of warning for the chip changers: I hear talk that future Emission Testing may learn from your own engine control module if you have removed your performance chip module just to pass the Smog Test. A recent report by CARB (California Air Resources Board) estimates installation of at least 100,000 performance chips in California alone. Performance chips modules may (or may not) improve your performance, but they are such a threat to air quality that Ford now solders the chip. When I asked CARB engineers about this, they smiled and said, "Not yet, but we're working on it." That probably applies to 1993 and later cars and trucks with new diagnostics, but be aware of so-called "street-legal" chips. (See Chapter 9)

3.1 Diagnostic Routines

The following tables list the diagnostic routines for EEC-IV and MECS cars. When you see a reference in the routines to a specific component, that means go to that component and check it. Ford calls these Pinpoint Tests. There are also references in the routines to Quick Test, checking fuel supply, and the ignition system. Full diagnostic procedures for the fuel supply system, ignition system, and other Pinpoint Tests are described in detail in Chapter 11 and in Chapter 12. Quick Test, which uses the control module to help you diagnose problems, is described in the next section. Tempting as it may be to start with Quick Test, be guided by the diagnostic routine charts.

The charts are arranged in order of what component/system to check first. The numbers in the first two columns indicate where to start, depending on the engine control system. For example, for a Hard Start on EEC-IV systems, you'd look at the ignition system first. On Mazda Engine Control Systems (MECS) cars you'd start at the air intake system, since vacuum leaks are more likely to cause problems on these cars.

Table 1. Hard Start/Long Crank

EEC-IV	MECS	System	Component
1	3	Ignition	Scope engine for: Spark Plugs Coil Secondary Ignition Wires Spark Plugs Fouled TFI IV: Distributor Cap, Adapter and Rotor DIS/EDIS: Single or Dual Hall Crankshaft Sensors Hall Camshaft Sensor DIS/EDIS Ignition Module Coil Pack(s)
2	2	Engine Control	Quick Test
3	4, 5	Fuel/ Throttle Body	Filter Pump Pump Switch (in VAF meter) Water/Dirt/Rust Contamination in Fuel Fuel Lines Fuel Pressure Regulator Sender Filter Injectors Improper Fuel Idle Air flow (ISC-BPA)
4	10	Exhaust	Component (restricted)
5	1, 7	Air Intake and Vacuum Distribution	Vacuum Leaks Air Cleaner Element Restricted VAF meter binding
6	8	Cooling	Electric Fan (Hot Start Only)
7	6	EGR	Valve
8	—	PCV	Valve
9	—	EVAP	Components
—	9	Basic engine	Compression, camshaft and valve train

Table 2. No Crank

System	Component
Starting	Battery Starter Relay Starter Neutral Drive Switch/Clutch Switch Brake Interlock Switch Ignition Switch Transmission Linkage Adjustment
Control System	Neutral Drive Switch /Clutch Switch
Base Engine	Flywheel Engine Seized
Fuel/Throttle Body	Injectors (hydro-lock)
Ignition	Harness (START wire short to GND)

Table 3. No Start/Normal Crank

EEC-IV	MECS	System	Component
1	3	Engine Control	Quick Test
2	2	Ignition	Electrical Connections Secondary Ignition Wires Spark Plugs Fouled Ignition Switch TFI IV: Ignition Coil Ignition Module Rotor Alignment Distributor Cap, Adapter, Rotor and Stator DIS/EDIS: Single and Dual Hall Crankshaft Sensors Hall Camshaft Sensor DIS/EDIS Ignition Module Coil Pack(s)
3	8	Fuel/ Throttle Body	Fuel Filter Fuel Pump Pump Switch (in VAF meter) Water/Dirt/Rust Contamination in Fuel Fuel Lines Tank (Fuel Supply) Fuel Sender Filter Fuel Pressure Regulator Injectors Inertia Switch
4	4	Base Engine	Compression, Camshaft Timing
5	6	EGR	Valve
6	7	Exhaust (Turbocharger, where app.)	Component (Restricted)
7	5	Air Intake	Air Tube, VAF meter binding
—	1	Engine Electrical	Fuses, Power Relays

Table 4. Stalls After Start, Stalls or Quits at Idle

EEC-IV	MECS	System	Component
1	2	Engine Control	Quick Test
2	3, 4	Fuel/ Throttle Body	Idle Air flow (ISC-BPA) Electrical and Vacuum Connections Fuel Filter Fuel Pump Pump Switch (in VAF meter) Water/Dirt/Rust Contamination in Fuel Fuel Lines Tank (Fuel Supply) Sender Filter Fuel Pressure Regulator Injectors Improper Fuel
3	1	Vacuum Distribution	Vacuum Leaks
4	11	Ignition	Electrical Connections Secondary Ignition Wires Ignition Switch TFI IV: Ignition Coil Ignition Module Rotor Alignment Distributor Cap, Adapter, Rotor and Stator Ballast Resistor DIS (Thunderbird SC only): Hall Camshaft Sensor (CID)
5	7	Exhaust (Turbo charger, where app.)	Component (restricted)
6	5	EGR	Valve
7	6	Air Intake System	Air Tube Intercooler Tube (Thunderbird SC) VAF meter binding
8	9, 10	Base Engine	Camshaft and Valve Train
—	8	PCV	Valve

Table 5. Fast Idle, Diesels

EEC-IV	MECS	System	Component
1	3	Fuel/ Throttle Body	Idle Air flow (ISC-BPA) Throttle Plate and Linkage Speed Control Chain
2	1	Vacuum Distribution	Vacuum Leaks
3	6	Engine Control	Quick Test
4	2	Air Intake System	Air Tube Intake Manifold Gasket VAF meter binding
5	4	Cooling	Overheating
6	—	Air Conditioning	A/C Clutch A/C Demand A/C Cyclic Pressure Switch A/C Refrigerant Charge
—	5	Ignition	Base timing plus advance and retard
—	7	EVAP	Components

Table 6. Rolling Idle, Rough Idle

EEC-IV	MECS	System	Component
1	3	Ignition	Scope Engine For: Spark Plug, Coil, Secondary Ignition Wires, Distributor Cap, Adapter and Rotor, Ignition Timing
2	5	Engine Control	Quick Test
3	2,4	Fuel/Throttle Body	Idle Air flow (ISC-BPA) Electrical and Vacuum Connections Fuel Pressure Regulator Injectors Fuel Rail Fuel Lines
4	1	Vacuum Distribution	Vacuum Leaks
5	—	Cooling	Thermostat Fan (loose or cracked)
6	6	EGR	Valve
7	10	Base Engine	Compression Valve Train Camshaft Intake Manifold Gaskets
8	8	PCV	Valve
9	—	EVAP	Components
10	7	Air Intake System	Air Tube Intercooler Tube (Thunderbird SC) VAF meter
11	—	Charging System	Components
12	9	Exhaust (Turbo charger, where app.)	Components
13	—	Thermactor	Thermactor System Components

Table 7. Low Idle Stalls or Quits on Deceleration

EEC-IV	MECS	System	Component
1	1, 2	Fuel/ Throttle Body	Idle Air flow (ISC-BPA) Electrical and Vacuum Connections
2	4	Engine Control	Quick Test
3	—	EGR	Valve
4	—	Base Transmission (A/T with overdrive)	Transmission Oil Level Converter Clutch Control Solenoid Modulated Converter Clutch Control Solenoid
—	3	Fuel Delivery	Pump Switch in VAF Meter

Table 8. Stalls/Quits on Acceleration or Cruise, Bucks/Jerks, Hesitates/Stumbles, Surges

EEC-IV	MECS	System	Component
1	2	Engine Control	Quick Test
2	3	Ignition	Scope engine for: Spark Plug, Coil, Secondary Wires, Distributor Cap and Rotor, Crossed Wires Ignition Timing
3	4	Fuel/Throttle Body	Idle Air flow (ISC-BPA) Fuel Filter Fuel Pump Water/Dirt/Rust Contamination in Fuel Fuel Lines Fuel Pressure Regulator Sender Filter Injectors
4	—	Vacuum Distribution	Vacuum Leaks
5	5	Air Intake Systems	Air Cleaner, Air Duct Intercooler Tube (Thunderbird SC)
6	6	EGR	Valve
7	—	PCV	Valve
8	9	Exhaust	Restriction (with Backpressure EGR system (PFE))
9	7	Base Transmission (A/T with Overdrive)	Converter Clutch Control Solenoid Converter Clutch Override Converter Clutch Modulated Converter Clutch Control Solenoid
10	8	Base Engine	Components
—	1	Bypass air control	ISC-BPA

Table 9. Runs Rough on Acceleration or Cruise, Misses

EEC-IV	MECS	System	Component
1	1	Ignition	Scope engine for: Spark Plug, Coil, Secondary Wires, Distributor Cap, Adapter and Rotor Ignition Timing
2	2	Engine Control	Quick Test
3	3	Fuel/Throttle Body	Fuel Filter Fuel Pump Fuel Lines Fuel Pressure Regulator Sender Filter Injectors
4	5	EGR	Valve
5	—	Vacuum Distribution	Vacuum Leaks
6	—	Base Engine	Components
—	4	Bypass air control	ISC-BPA

Table 10. Surges on Cruise

EEC-IV	MECS	System	Component
1	5	Engine Control	Quick Test
2	4	Fuel/Throttle Body	Filter Pump Lines Fuel Pressure Regulator Sender Filter Octane Idle Air flow
3	2	Ignition	Scope engine for: Spark Plugs, Wires, Coil, Secondary Ignition Wires Timing
4	1	Vacuum Distribution	Vacuum Leaks
5	6	EGR	Valve
6	7	Air Intake System	Air Intake Components
7	8	EVAP	Components
8	—	Base Engine	Valve Train and Camshaft Intake Manifold and Gaskets
9	—	Thermactor	Thermactor System Components
10	—	Supercharger	Assembly
11	—	Base Transmission (A/T with Overdrive)	Converter Clutch Control Components
—	3	Bypass Air Control	ISC-BPA
—	9	Turbocharger	Components

Table 11. Backfires

EEC-IV	MECS	System	Component
1	2	Ignition	Scope engine for: Spark Plugs, Wires, Coil, Crossed Wires, Ignition Timing
2	1	Vacuum Distribution	Vacuum Hoses, Connections
3	4	Engine Control	Quick Test
4	—	Thermactor	Thermactor System Components
5	3	Base Engine	Intake Manifold Gaskets Compression Checks Camshaft Valves
6	5	Exhaust	Components (restricted)
7	6	Fuel/Throttle Body	Filter Pump Water/Dirt/Rust/ Contamination in Fuel Lines Fuel Pressure Regulator Injectors Sender Filter Octane

Table 12. Lack/Loss of Power

EEC-IV	MECS	System	Component
1	2	Ignition	Scope engine for: Spark Plugs, Wires, Coil, Timing
2	6	Engine Control	Quick Test
3	3	Fuel/Throttle Body	Filter Pump Lines Fuel Pressure Regulator Fuel Sender Filter Injectors Idle Air flow
4	7	Exhaust	Component (restricted)
5	—	Cooling	Thermostat
6	—	Vacuum Distribution	Vacuum Leaks
7	1	Air Intake Systems	Air Cleaner Duct and Element Throttle plates and linkage Electrical and Vacuum connections VAF Meter
8	4	EGR	Valve
9	5	Base Engine	Compression Check Camshaft Valves
10	9	Drivetrain	Clutch, Automatic Transmission, Brakes
11	—	Supercharger	Assembly
—	8	Turbocharger	Components

Table 13. Spark Knock

EEC-IV	MECS	System	Component
1	1	Ignition	Timing
2	4	Engine Control	Quick Test
3	5	Cooling	Overheating
4	—	Base Engine	Oil Level Compression Check Intake Manifold Gasket
5	—	Fuel/Throttle Body	Filter Pump Lines Fuel Pressure Regulator Sender Filter Injectors
6	—	PCV	Valve
7	3	EGR	Verify Correct Application, then Diagnose
8	—	Air Intake System	Air Cleaner Duct and Element
9	—	Thermactor	Thermactor System Components
10	—	Base Transmission (E4OD, AODE, AXOD-E)	Transmission Controls
—	2	Vacuum distribution	Vacuum leaks, Delay Valve, Vacuum Reservoir
—	6	Turbocharger	Components

Table 14. Poor Fuel Economy

EEC-IV	MECS	System	Component
1	4	Fuel/Throttle Body	Fuel Pressure Regulator Fuel Return Line Blocked
2	3	Air Intake System	Air Cleaner Duct and Element, VAF Meter
3	2	Ignition	Scope engine for: Spark Plugs, Wires, Coil, Secondary Wires, Distributor Cap, Timing
4	5	Engine Control	Quick Test
5	7	Cooling	Thermostat
6	8	Factors External to the Engine	Tire Pressure Clutch Operation Converter Clutch Override Automatic Transmission Shift Pattern, Fluid Level Brake Drag Exhaust System Speedometer/Odometer Gear Ratio Axle Ratio Vehicle Load Road and Weather Conditions Aftermarket Add Ons
7	—	Base Transmission (A/T with Overdrive)	Converter Clutch Control Components Modulated Converter Clutch Control Solenoid
8	6	EGR	Valve Operation
—	1	Vacuum distribution	Vacuum leaks
—	9	Base Engine	Compression, Camshaft, Intake Manifold Gasket

Table 15. Emissions Compliance, Idle Test

EEC-IV	MECS	System	Component
1	2	Engine Control	Quick Test
2	4	Ignition	Scope engine for: Spark Plugs, Wires, Coil, Timing
3	6	Vacuum Distribution	Vacuum Leaks/Blockage
4	3	Fuel/Throttle Body	Idle Air flow Injectors Fuel Rail Fuel Pressure
5	1	EGR	Valve Vacuum Regulator
6	8	PCV	Valve
7	7	EVAP	Valve
8	—	Thermactor	Thermactor System Components
9	9	Exhaust	Pipes, Muffler, Catalysts, Resonator, etc.
10	10	Cooling	Unstabilized Engine Temperature
11	12	Base Engine	Scheduled Maintenance Compression Valve Train Camshaft Intake Manifold Leaks
—	5	Inlet air control	Throttle plates of linkage, Air Cleaner and Duct
—	11	Turbocharger	Components

4. QUICK TEST

This section explains the part of the diagnostic routines known as Quick Test. You can perform Quick Test on any EEC-IV (or MECS) vehicle. Although it is quicker to use special equipment, you can perform a full Quick Test with just an analog VOM. Generally, you'll perform Quick Test for two reasons:

1. When directed to by the diagnostic routines.
2. If the dash warning light is on. This is known as the Malfunction Indicator Light (MIL). Depending on the vehicle, it can read CHECK ENGINE, or SERVICE ENGINE SOON.

Quick Test results depend on proper operation of the engine itself. While engines have grown increasingly sturdy and reliable, all the things that went wrong with engines before electronic controls can still go wrong to cause driveability problems. Just because you know all about electronic control systems after reading this book, don't automatically assume that all problems start with the electronics. You'll save time if you perform the prescribed diagnostic routines in order.

What Is Quick Test?

Quick Test means using the built-in diagnostic capabilities of the engine control module to find faults in the fuel-injection and engine-control systems.

If you've done troubleshooting in the traditional way, isolating each circuit or sensor, and measuring resistance, you know it can take hours. When you perform Quick Test, you'll appreciate how much diagnostic capability you have in the control module to help you find a problem—and why it's called Quick Test. Running Quick Test helps you to do three things:

1. Look inside the control module memory for stored information about specific system faults.
2. Use the control module to qualify sensors and actuators—to see if they are working within operating ranges.
3. Direct you to specific diagnostics of certain sensors, actuators and circuits (Pinpoint Tests).

A SERVICE ENGINE SOON message is often considered less threatening than CHECK ENGINE. Some owners, seeing the red CHECK ENGINE light immediately stop the car and have it towed. But that's not necessarily so. The message of either light is just to take the car in for service as soon as possible.

Trouble Codes

When the control module tests the system and finds faults, it makes a record of the fault in the form of a trouble code. Trouble codes are a series of digital pulses that represent numbers. See Fig. 4-1. During Quick Test, the control module will read out one or more codes. You then compare the trouble code numbers to a chart to lead you to specific tests to identify the fault. You'll find trouble code charts in Chapter 12.

4.1 Quick Test and Trouble Codes

You will perform Quick Test Key ON Engine OFF (KOEO) and Engine Running (ER). You may also see reference to KOER (Key On, Engine Running), but I prefer the simpler ER—it's easier to keep it separate from KOEO, and you don't need KOER because the key must be ON if the engine is running. In both those steps you read a number of different codes.

Codes for KOEO:

1. **Self-Test codes**. These are the results of the system testing itself during Quick Test and detecting faults. Self-Test verifies control module memory integrity and processing capability. It also verifies that sensors and actuators are connected and operating properly. These codes are known as HARD faults. They are also sometimes called On-Demand codes.
2. **Separator Pulse codes**. These are issued 6 to 9 seconds after the last Self-Test code. This separates Self-Test codes from Continuous Memory codes.
3. **Continuous Memory codes**. The Continuous Self-Test program in the control module creates these codes. It continually checks the system as you drive and stores fault codes in KAM. These codes can indicate chronic and intermittent problems. They include SOFT codes, intermittent faults that happened in the past but are not now present. KAM does not store these soft codes indefinitely. If the engine warms up 80 times (40 times on a few engines) without the fault re-occurring, the module assumes that the fault was a fluke, and "forgets" it—erases the soft fault code.
4. **Fast codes**. They contain the same information as the regular codes but are transmitted 100 times faster. The manufacturer uses special instruments to read these during the building of the car. You can read these by Super STAR II. Three-digit trouble codes show only in fast codes, so you can't use a START tool.

Codes for ER:

1. **I.D. Pulse codes**. They identify the type of engine in the vehicle. They also verify that the proper control module is installed and that Self-Test has been entered.
2. **Dynamic Response code**. This may appear to signal additional checks of wide open throttle during the ER portion of Quick Test. It is not on all vehicles.
3. **Self-Test codes**. The same type of codes as during KOEO.

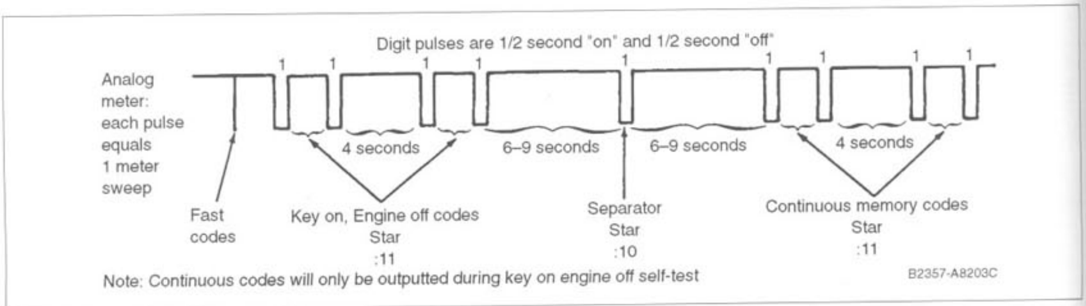


Fig. 4-1. EEC-IV trouble code output format. Digital pulses indicate numbers. 2-digit codes shown. MECS codes are similar.

4.2 Code Generation

Continuous Memory codes: As you drive, the control module continuously checks sensors and even its own Central Processing Unit (CPU) to determine the signals being sent. For example, in Fig. 4-2, the Continuous Test samples the Engine Coolant Temperature (ECT) signal. ECT signal should range between 91% of VREF (Reference Voltage = 5v.) and 4% VREF. If ECT rises above 91% VREF (4.55v) for between 50 and 300 milliseconds (ms), the Keep Alive Memory (KAM) starts counting. If the error repeats several times, KAM stores Service Code 51. If ECT falls below 4% of VREF (0.20v) several times, KAM stores Service Code 61. Follow those examples through on the above chart and you'll understand Continuous Memory Codes for ACT, TPS, MAP or MAF or VAF, EGR sensor, EGO (Exhaust Gas Oxygen), and each other input tested.

OBD SYSTEM DESCRIPTION

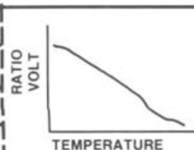
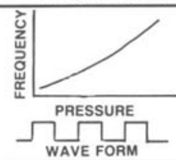
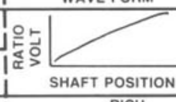
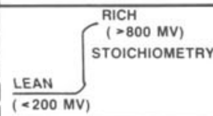
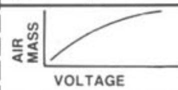
SENSED PARAMETERS	SERVICE CODES	MINIMUM TIME	SIGNAL RANGE	SIGNAL DESCRIPTION
(ACT)/(VAT) AIR CHARGE TEMPERATURE	54	50-300 MSEC	>91% VREF	 NON-PULSATING THERMISTOR RESISTANCE THAT VARIES NON-LINEARLY AND INVERSELY WITH RESPECT TO TEMPERATURE
	64	"	<4% VREF	
(ECT) ENGINE COOLANT TEMPERATURE	51	"	>91% VREF	
	61	"	<4% VREF	
(TPS) THROTTLE POSITION	53	"	>97% VREF	 NON-PULSATING POTENTIOMETER RESISTIVE ELEMENT THAT VARIES LINEARLY AND IS DIRECTLY PROPORTIONAL TO THROTTLE PLATE MOVEMENT
	63	"	<4% VREF	
(MAP) MANIFOLD PRESSURE	22	150-300 MSEC	<8 Hz	 PULSATING RECTANGULAR FREQUENCY SIGNAL THAT IS PROPORTIONAL TO PRESSURE
(BP) BAROMETER PRESSURE	22	150-300 MSEC	<16 in. H.g.	
EGR SENSOR	31	50-300 MSEC	<4% VREF	 NON-PULSATING POTENTIOMETER RESISTIVE ELEMENT THAT VARIES LINEARLY WITH SHAFT DISPLACEMENT
	35	"	>96% VREF	
EGO	41	MUST REGISTER EIGHT EGO SWITCHES WITHIN FOUR MINUTES OF REACHING NORMAL OPERATING TEMPERATURE		 SWITCHING, SELF-GENERATING VOLTAGE SIGNAL THAT INDICATES WHETHER THE A/F RATIO IS LEAN OR RICH COMPARED TO STOICHIOMETERY
STEREO EGO	91			
(VAF)/(MAF) AIR FLOW SENSOR	56	50-300 MSEC	>98% VREF	 NON-PULSATING POTENTIOMETER WHICH THE ANALOG VOLTAGE OUTPUT HAS A LOGARITHMIC RELATIONSHIP TO VOLUMETRIC AIR FLOW
	66	"	<3% VREF	
CPU OK	11	11-17 MSEC	TIME SINCE LAST CPU-OK PULSE >14 ± 3 MSEC. SIGNAL IS INTERNAL TO THE PROCESSOR.	
D.C. MOTOR	13	50-300 MSEC	RATIONALITY CHECK-USES TPS FEEDBACK	OUTPUT
(ITS) IDLE TRACKING SWITCH	71	MONITORED AT KEY-OFF AND DISPLAYED DURING ENGINE RUNNING		LEVEL (ON/OFF) INPUT

Fig. 4-2. Example Self-Test mode diagnostic procedures in the control module.

Continuous Memory codes are stored for each sensor that falls out of range as indicated. But if the engine starts and warms up 80 (40 on some vehicles) times without that fault repeating, KAM erases it. Otherwise, the Service Code waits in the KAM for you to read it in the Self-Test.

KOEO (Key ON Engine Off) codes: To see what happens when you activate KOEO Self-Test, follow the flow chart in Fig. 4-3. From Self-Test Output (STO) OFF, the sequence begins with Microprocessor instruction-execution test.

- If that fails, it turns STO on continuously and exits test
- If that passes, it proceeds to RAM/KAM test
- Test ROM, setting memory code if that fails
- Test Analog to Digital (A/D) inputs for proper range, and switch for proper state - open or closed, setting memory codes for those that fail

The chart shows how the control module tests system circuits KOEO, from the top A to the bottom A, setting memory codes for those that fail.

Now the control module sends the stored memory codes, as described below. First the codes for the KOEO test, faults in the system at this time. Then the Continuous codes, faults that may have existed in the past, but are not present now (intermittent faults).

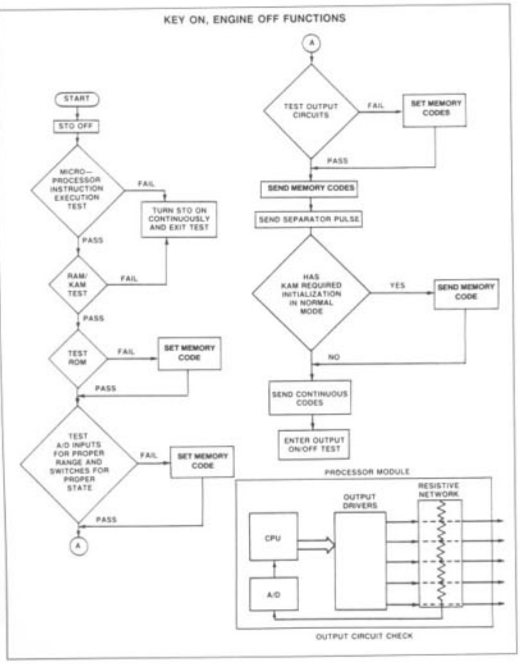


Fig. 4-3. Key On Engine Off (KOEO) Self-Test.

ER (Engine Running): To see what happens when you start the engine in Self-Test, follow the flow chart Fig. 4-4. With the engine running, the control module tests sensors for proper range, tests switches for proper state. Those that fail set memory codes.

- The control module ramps the fuel lean—that is, it cuts back on fuel-injection pulse times until the mixture is too lean, looks at the oxygen sensor to see if it reports a lean mixture. If EGO does not, KAM sets an error code
- The module ramps the fuel rich, increasing pulse times to see if the oxygen sensor reports rich mixture

Follow A to A on the next line. The control module checks that the EGR is in proper range, then signals to increase the EGR, looking to see if the rpm drops when EGR increases.

The control module checks that the Idle Speed Control rpm is in the proper range.

Then it stores several idle values for comparison, and sets the spark for the "goose" test. When it signals for dynamic response, you briefly press Wide Open Throttle (WOT). The control module looks for a knock (if Knock Sensor fitted), then looks to see if the signals changed as they should ("Delta" means difference). It sends any stored codes. And finally, fixes the spark for two minutes so you can perform a timing check. Whew!

As you read this, it may sound complicated. But follow it through, and try it with a scan tool. You'll be surprised how

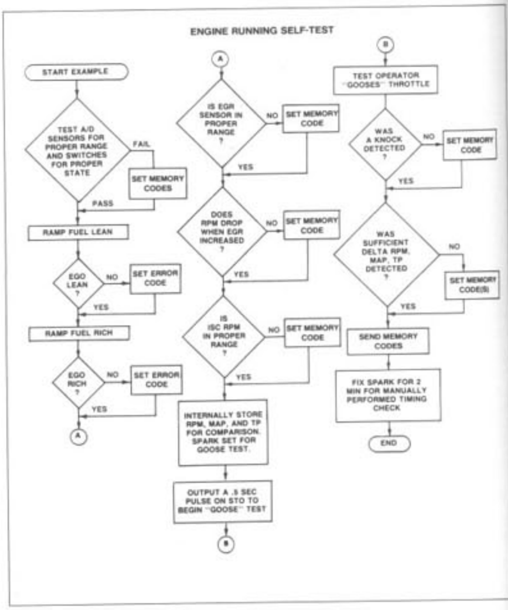


Fig. 4-4. Engine Running (ER) Self-Test.

much time this saves, and how much work it would be to do all this manually, one sensor and actuator at a time.

Reading Trouble Codes

The control module sends the trouble code pulse signal to two places, the Self-Test Output (STO) wiring connector and the Malfunction Indicator Light (MIL). When you ground the Self-Test Input (STI), the control module starts sending codes.

Look for STO under the hood, usually near the cowl. The MIL is in the instrument cluster. The STI is the single-wire connector next to the STO connector.

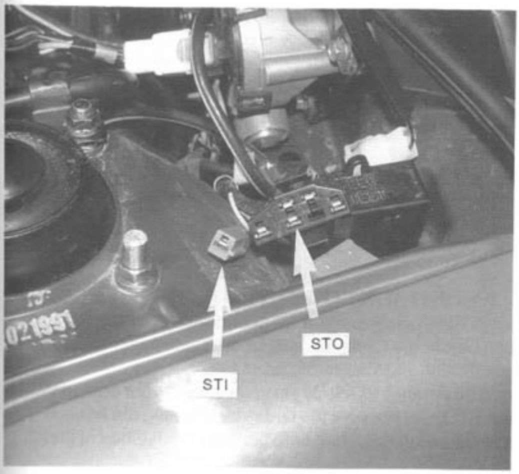


Fig. 4-5. Look for Self-Test Output (STO) and Self-Test Input (STI) connectors under hood, near cowl.

You can read the codes in several different ways, depending on your equipment. From the simplest to the most expensive these include: MIL, analog voltmeter, STAR (EEC system, but not MECS-I), scan tool, Super STAR II or New Generation STAR (NGS).

WARNING —
Do not use a device that draws more than 0.5 amps to read trouble codes. Hooking a high current draw device to the STO may damage the control module.

With the MIL or voltmeter, you see and count the pulses. A scan tool such as STAR translates those pulses into specific numbers. Some scan tools even display the English language interpretation of those numbers so you don't have to refer to the tables. In Fig. 4-6, the two "pulse, pulse" signals are read by the STAR as 11-11, the code for SYSTEM PASS. The separator pulse is read as 10. The Continuous Memory Codes are read as 11 (SYSTEM PASS). That does not mean you're done. It does not tell you, for example, if the intake passage deposits are causing a problem. It means the engine-control system passes and the problem is somewhere outside the fuel-injection/engine-control system.

In the Engine Running part of Quick Test, the I.D. pulse code identifies the number of cylinders that fire on one turn of the crankshaft. 2, read by STAR as 20, means 4-cylinder engine. 3 means 6-cylinder. 4 means 8-cylinder. I'll discuss the other ER codes during the test procedure, below.

With MIL: With the MIL, you read codes by counting light flashes. It may seem difficult, but once you've tried it, it's not so hard. See Fig. 4-7.

Each code is usually two digits, sometimes three. Look for a 2-second pause between digits.

- To display the number or digit 2, the MIL flashes, waits 2 seconds, then flashes again. Flash, flash.
- To display 23, the MIL goes flash, flash, waits 2 seconds, then flash, flash, flash.

When the control module memory has more than one code, the display pauses 4 seconds between codes.

Suppose you had a 23 and a 53, you'd see:

- flash, flash PAUSE flash, flash, flash (23)
- 4 second pause
- flash, flash, flash, flash, flash PAUSE flash, flash, flash (53)

10

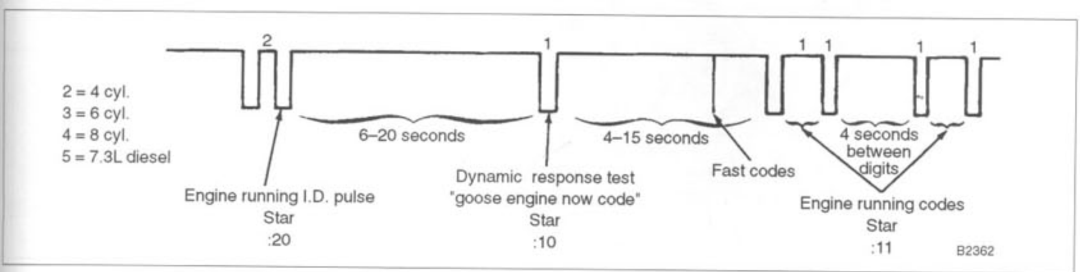


Fig. 4-6. Engine Running (ER) Self-Test code format.

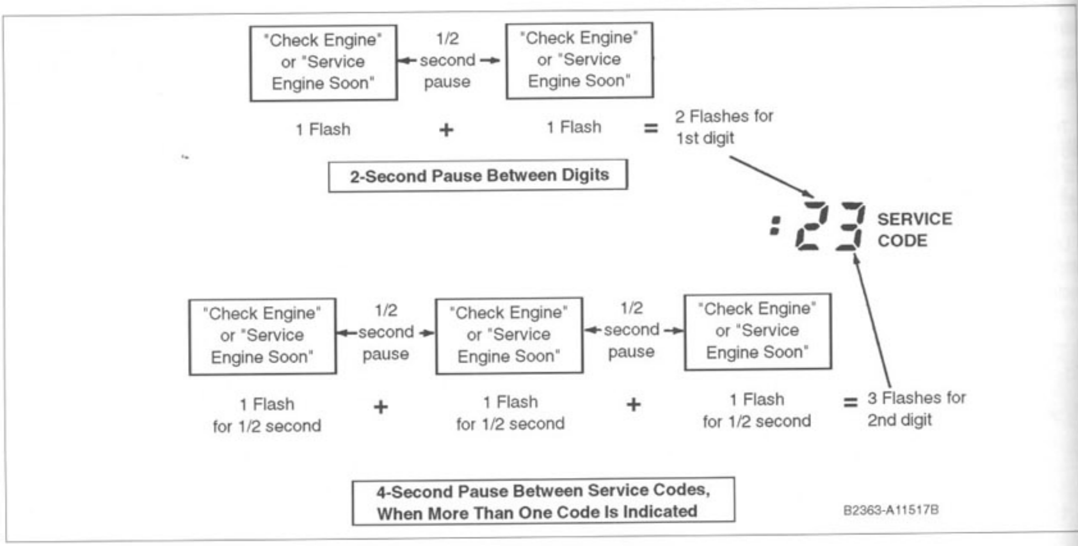


Fig. 4-7. MIL trouble code output format.

Questions you might ask about the MIL:

1. If the MIL is ON because there's a problem, how can it flash to tell me the code? Simple. When you activate Quick Test, the MIL changes to code mode.
2. How do I know the MIL is working at all? Also simple. The MIL should light each time you turn the key to START. If it's FLASHING during driving, that's a sign of an intermittent problem.

After the last KOEO code, you'll notice a 6-second delay, a single flash, and another 6-second delay. This is the separation before the Continuous Memory Codes.

With Analog VOM: When you connect your analog VOM to the STO, you observe the codes by counting the sweeps of the needle, using the same time basis as the flashes of the MIL.

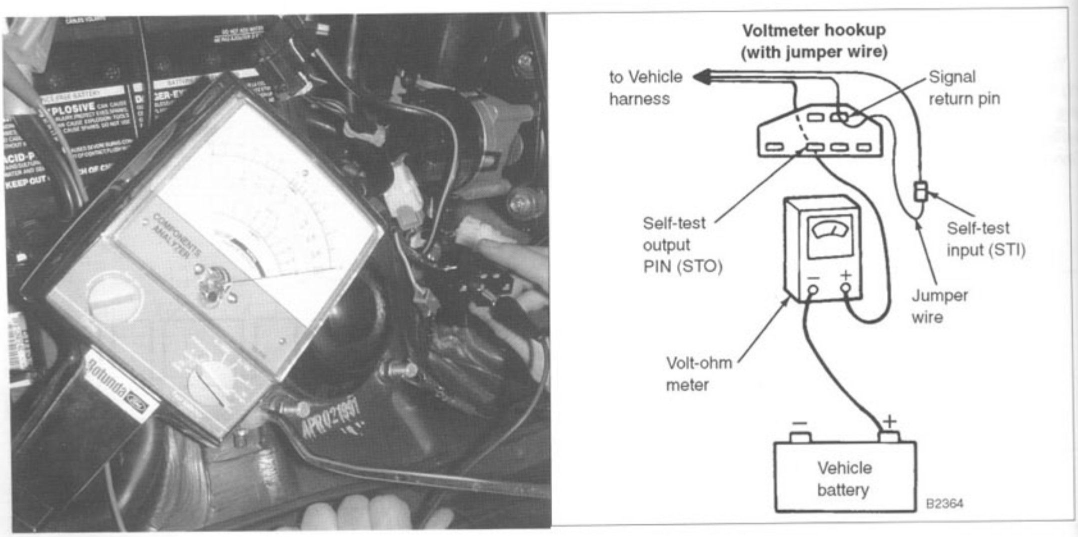


Fig. 4-8. Volt-Ohmmeter (VOM) connection for reading trouble codes.

23: sweep, sweep PAUSE sweep, sweep, sweep. See Fig. 4-9.

With STAR Tester: The STAR tester reads 88 during its display check, and 00 when it's ready to start the Self-Test. During the tests, codes will display directly as numbers, rather than as flashes. See Fig. 4-10 and Fig. 4-11.

With Super STAR II: Super STAR II reads fast codes and slow codes. You must set to it to fast-code mode to read out three-digit codes used in some later model cars. It reads the STI circuit used to initiate the test, as well as the STO.

Super STAR II first displays 888, lights all the prompts on the left side, and beeps the speaker. When the tester is ready, you'll see STI-LO and STO-LO, but the readout will be blank until you turn the key ON

For most MECS, slide the adapter switch to MEC, but for 1.8L and 2.0L MTX engines, slide the adapter switch to EEC. See Fig. 4-12.

Fig. 4-10. STAR tester hookup to read trouble codes.

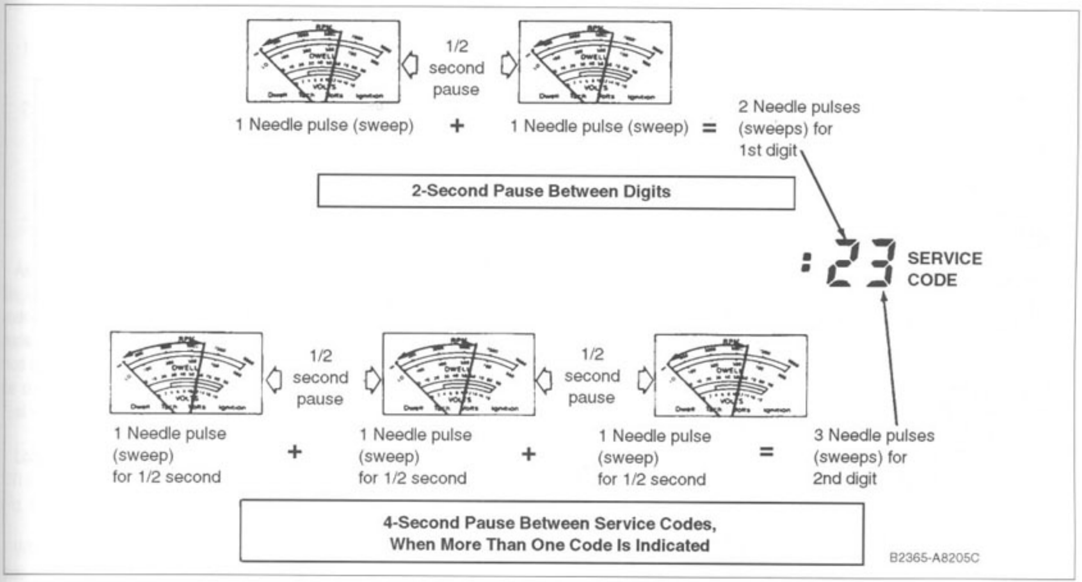


Fig. 4-9. VOM trouble code output format.

10

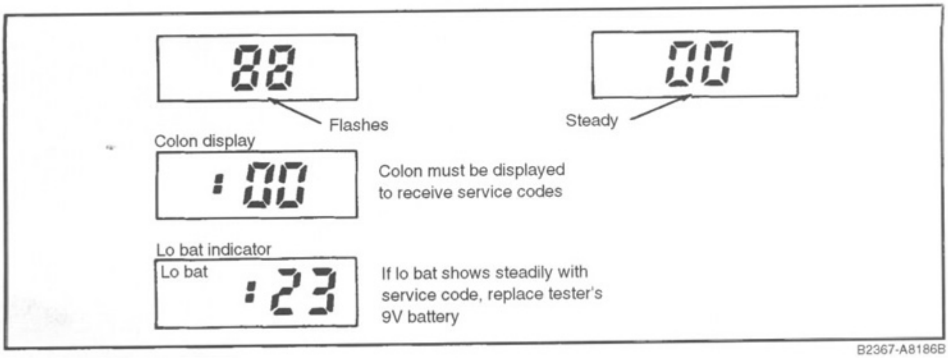


Fig. 4-11. STAR tester trouble code output.

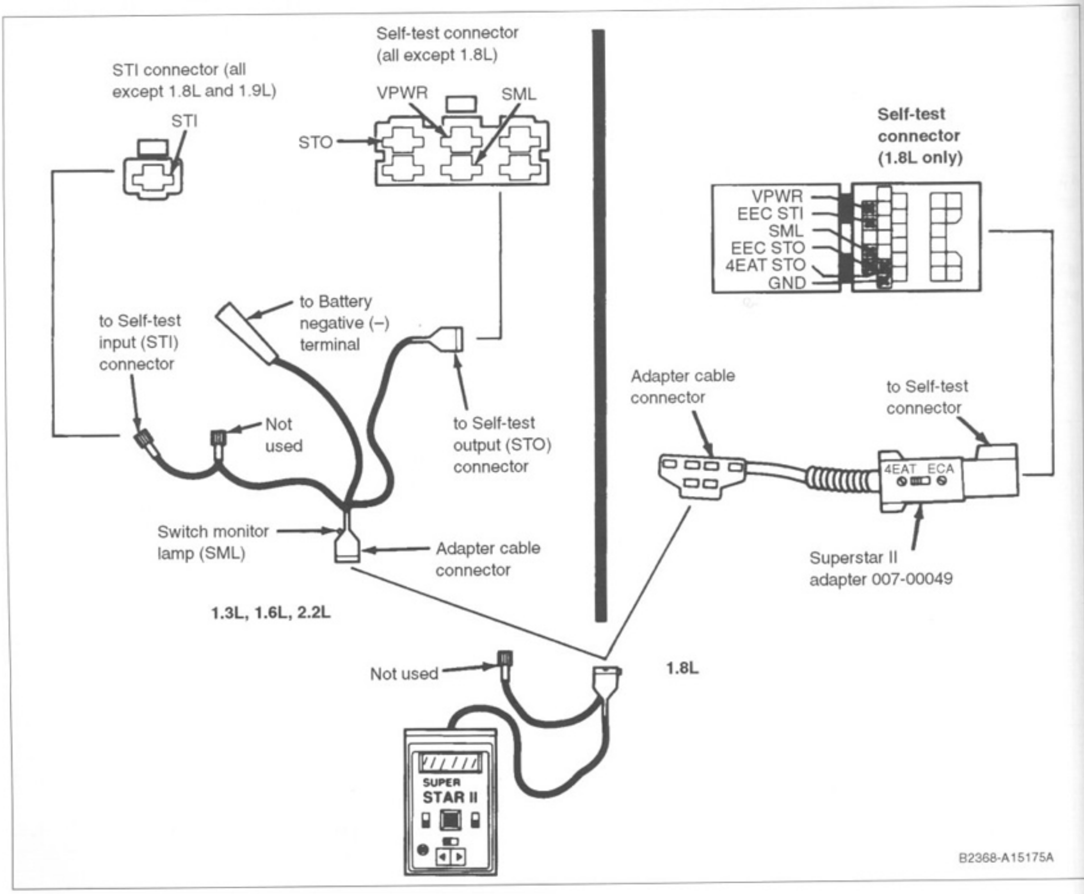


Fig. 4-12. Super STAR II hookup for reading trouble codes on MECS-equipped vehicles.

If you're checking a late model Continental, you'll find codes displayed in the Message Center.

1. Jumper STI to SIG RTN at the Self-Test connectors, or connect the STAR tester and latch center button in the down position. (TIP from the field: Listen for the sound of solenoids clicking when you ground STI, or latch the STAR button.)
2. While pressing all three buttons, Select, Reset, System Check, turn the key ON. Release buttons. 4255 indicates Self-Test has been entered successfully. Observe and record codes. Service code output will be the right three digits. 4011 means PASS.
3. While pressing all three buttons, start engine. Release buttons. 4030 indicates engine ID code (3 for 6 cylinders), and that Self-Test has been entered successfully. Observe and record codes.
4. Ignition OFF, and remove jumper, or unlatch STAR tester.

4.3 Running Quick Test

This section gives the steps for running Quick Test. In summary:

1. Hook up your VOM or scan tool to the control module Self-Test Output (STO) terminal.
2. Signal the control module to begin Quick Test.
   - With MIL or VOM, you send the signal by grounding another wire, the Self-Test Input (STI)
   - With a STAR tester, you latch the center button down
3. Record any trouble codes.

As I said before, there are two parts to Quick Test, Key On Engine Off (KOEO), and Engine Running (ER) to read all codes. If you read more than one code, start servicing the first code received. Proceed to the electrical tests indicated to service each succeeding code. After completing electrical tests, be sure all components are reconnected. Then rerun Quick Test or verify that the complaint is fixed.

Look for the STO in the 6-pin self-test connector; look for the STI in the small connector next to the larger connector. See Fig. 4-13.

When you see the instruction "activate Self-Test", that means either ground the STI terminal or latch the tester button. Deactivate means remove the ground/unlatch the button. Look for Trouble code tables and typical Self-Test values in Chapter 12. Before beginning Quick Test check the vacuum hoses, the wiring harness and all connectors for faults or looseness.

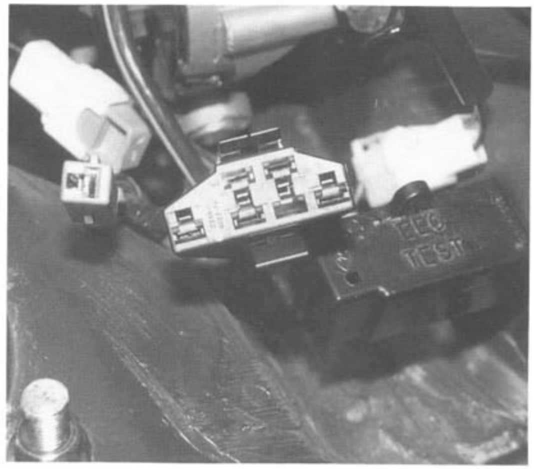


Fig. 4-13. Self-Test Input terminal is located in small connector next to 6-pin self-test connector. Ground terminal by inserting a grounded lead into STI.

To Quick Test (EEC-IV, all except Super STAR II):

1. Parking brake ON, Shift lever in PARK (Neutral in M/T vehicles). Block drive wheels and turn off all electrical loads. Warm engine to normal operating temperature.
2. Perform KOEO to read codes:
   - turn key OFF for 10 seconds
   - activate Self-Test (ground STI/latch button)
   - key ON, do not start engine
   - record all Self-Test and Continuous Memory codes

   NOTE —
   If no codes are displayed, skip Step 3 (below) and go to Step 4. If PASS (11) is displayed, but MIL is ON, check Continuous Memory code charts. If PASS is displayed on an MPI or SFI engine that runs or idles rough, check Throttle Air Bypass ISC. Disconnect it and check to be sure it operates properly for idle rpm drop or stall. If PASS is displayed on a DIS or EDIS engine that runs or idles rough, check for Continuous Memory codes # 45, 46, 48.
3. Check computed timing:
   - key OFF, wait 10 seconds
   - activate Engine Running Self-Test (ground STI/latch button)
   - start engine
   - with timing light, check computed timing to be base timing, plus about 20 (17 to 23) degrees

10

NOTE —
Timing will vary until the last ER code, then will remain fixed for 2 minutes unless you disconnect STI ground. Base timing is usually 10 degrees BTDC. Check VECI decal for correct base timing. Adjust if necessary, following procedures on VECI.

4. Perform ER (Engine Running) test:
   - deactivate Self-Test
   - be sure engine is at operating temperature
   - run engine at 2500 rpm. With the unheated oxygen sensor, run for at least 2 minutes
   - engine OFF for 10 seconds
   - activate Self-Test (ground STI/latch button)
   - start engine

After the I.D. code:

- within 1-2 seconds, turn power-steering wheel at least one-half turn and release
- if equipped with BOO, depress brake pedal and release
- if equipped with manual transmission, depress clutch pedal
- if equipped with E4OD, cycle OCS (Overdrive Cancel Switch)
- record all Self-Test codes
- if a Dynamic Response code shows, briefly press Wide Open Throttle

NOTE —
If PASS (code 11) is displayed, and you received pass codes in KOEO, you've completed diagnostic testing of EEC-IV. If you've still got a problem, it's elsewhere in the powertrain. If codes are displayed, perform electrical tests. If no codes are displayed, either PASS or otherwise, you may have a problem with the Self-Test circuits. See **4.8 No Codes Displayed**.

To Quick Test (EEC-IV, with Super STAR II):

1. Parking brake ON, Shift lever in PARK (Neutral in M/T vehicles). Block drive wheels and turn off all electrical loads. Warm engine to normal operating temperature.
2. Plug in both connectors of the tester. Set switch to EEC-IV. Select FAST CODE or SLOW CODE. Turn tester power ON.
3. Perform KOEO (Key ON, Engine OFF) to read codes:
   - press test button to activate Self-Test
   - turn ignition ON
   - record Self-Test and Continuous Memory codes
4. Perform ER (Engine Running) test:
   - engine at normal operating temperature
   - turn engine OFF
   - press test button to activate Self-Test
   - restart the engine

For vehicles with 2-digit service codes, look for:

- engine I.D. code
- Dynamic Response code (some vehicles)
- Self-Test codes

For vehicles with 3-digit service codes, look for:

- Dynamic Response Indicator, but no D.R. code
- Self-Test codes

NOTE —
If PASS (code 11 or 111) is displayed, and you received pass codes in KOEO, you've completed diagnostic testing of EEC-IV. If you've still got a problem, it's elsewhere in the powertrain. If codes are displayed, perform pinpoint tests in the trouble code charts. If no codes are displayed, either PASS or otherwise, you may have a problem with the Self-Test circuits. See **4.8 No Codes Displayed**.

To Quick Test (MECS):

NOTE —
On MEC systems, use MIL, VOM, Super STAR II, or NGS for Quick Test.

1. Parking brake ON, Shift lever in PARK (Neutral in M/T vehicles). Block drive wheels and turn off all electrical loads. Warm engine to normal operating temperature.
2. Plug in both connectors of the tester. Set switch to MECS. Select SLOW CODE. Turn tester power ON.
3. Perform KOEO to read codes:
   - turn key OFF for 10 seconds
   - activate Self-Test (ground STI/latch button, turn on Super Star II)
   - key ON, do not start engine
   - on Super Star II only, unlatch then latch button
   - record all codes

NOTE —
If codes are displayed, do not go to electrical tests. Go to step 3. If no codes are displayed, go to the ER test below.

4. Erase codes and retest KOEO:
   - deactivate Self-Test (remove STI ground/unlatch button and turn off Super Star II)
   - disconnect negative battery cable
   - depress brake pedal for 5 to 10 seconds
   - reconnect battery cable and rerun KOEO test
   - record all codes

NOTE —
If codes recorded the first time do not reappear, tap sensors and components, wiggle harnesses, or drive the car to induce a fault.

5. Perform ER (Engine Running) test:
   - deactivate Self-Test
   - be sure engine is at operating temperature
   - run engine at 2000 rpm for at least 3 minutes
   - activate Self-Test (ground STI/latch button)
   - engine OFF
   - start engine and run at idle
   - on Super Star II only, unlatch then latch button
   - record all codes

NOTE —
If PASS (code 11) is displayed, and you received pass codes in KOEO, you've completed diagnostic testing. If you've still got a problem, it's elsewhere in the powertrain. If codes are displayed, perform electrical tests in the trouble code charts. If no codes are displayed, either PASS or otherwise, you may have a problem with the Self-Test circuits. See **4.4 No Codes Displayed**.

4.4 Continuous Monitor Test (Wiggle Test) (EEC-IV only)

The Continuous Monitor Test can help you to find the cause of an intermittent fault. The test is sometimes called the "wiggle test" because you attempt to recreate the fault by wiggling wiring and connectors under Self-Test conditions. Use the Wiggle Test only if a Quick Test indicates that a such a pinpoint test is necessary for an intermittent fault.

To wiggle test (KOEO):

1. If using STAR tester or VOM, hook it up.
2. Key ON, do not start engine.
3. Activate Self-Test for 10 seconds (ground STI/latch button), then deactivate and activate again. The system is in Continuous Monitor mode.
4. Locate the suspected sensor or harness. Wiggle, tap, and move. Look for indication of fault stored in memory:
   - STAR—Red LED lights and/or continuous tone
   - MIL—CHECK ENGINE light
   - VOM—needle sweeps

To wiggle test (ER):

1. If using a STAR tester or VOM, hook it up.
2. If the KOEO test was just done, turn the key OFF for at least 10 seconds.
3. Start engine.

Fig. 4-14. In Continuous Monitor Test (EEC-IV only) you attempt to recreate fault while checking for codes. For example, tap MAF sensor while watching STAR tester.

4. Activate Self-Test for 10 seconds, then deactivate and activate again. The system is in Continuous Monitor mode. Keep engine running.
5. As in KOEO, locate the suspected sensor or harness. Wiggle, tap, and move. Look for indication of fault stored in memory:
   - STAR—Red LED lights and/or continuous tone
   - MIL—CHECK ENGINE light
   - VOM—needle sweeps

4.5 Switch Monitor Tests (MECS only)

The Switch Monitor test checks the input signals from each individual switch to the control module. You will activate each switch, one at a time, and observe the signal that tells how that switch is signalling the condition shown in Fig. 4-15, the Switch Monitor Test Chart.

- SML (Switch Monitor Lamp), an LED on the Adapter cable of the Super STAR II tester (see Fig. 4-12 above)
- Voltage on the VOM

To switch monitor test:

1. Engine off, allow to cool, all accessories OFF, transaxle in P or Neutral, foot off brake.
2. Deactivate Self-Test. Remove the STI ground or unlatch center button and turn OFF Super STAR II.

QT 10	Switch Monitor Test Chart					
Switch	**1.3L**	**1.6L**	**1.8L**	**2.2L**	**2.2L Turbo**	**Super Star II Tester LED or Analog VOM Indications**
Clutch Engage Switch/Neutral Gear Switch (CES/NGS) (MTX only)	X	X	X	X	X	LED on or less than 1.5V in gear and clutch pedal released
Manual Lever Position Switch (MLP) (ATX only)	X	X	X	X	X	LED on or less than 1.5V in P or N
Idle Switch (IDL)	X	X	X	X	X	LED on or less than 1.5V with accelerator pedal depressed
Brake On-Off Switch (BOO)	X	X	X MTX	X	X	LED on or less than 1.5V with brake pedal depressed (not fully)
Headlamps Switch (HLDT)	X	X	X	X	X	LED on or less than 1.5V with headlamp switch on
Blower Motor Switch (BLMT)	X	X	X	X	X	LED on or less than 1.5V with blower switch at 2nd or above position
A/C Switch (ACS)	X	X	X	X	X	LED on or less than 1.5V with A/C switch on and blower on
Defrost Switch (DEF)	X	X	X	X	X	LED on or less than 1.5V with defrost switch on
Coolant Temperature Switch (CTS)	X	X	X	X	X	LED on or less than 1.5V with cooling fan on
Wide Open Throttle Switch (WOT)	X		X			LED off or 0V with accelerator pedal fully depressed
Knock Control (KC)					X	LED on or less than 1.5V while tapping on engine

Fig. 4-15. MECS Switch Monitor Test chart.

3. Key ON.
4. Activate Self-Test. Ground the STI or turn ON Super STAR II, latch center button.
5. One at a time, activate a switch. For example, press the brake pedal. Look for:
   - LED ON, or
   - VOM less than 1.5v

4.6 Adaptive Mixture Self-Test Codes (EEC-IV only, 1991-on)

On some 1991 and later vehicles, during Quick Test you'll see Continuous Memory codes that identify signals from the oxygen sensor. These give you information about how the engine control system is regulating the air-fuel mixture and adapting to changes in engine condition (Ford calls it Adaptive Fuel).

Those of you familiar with Bosch procedures will see that this is another approach to testing the system's ability to adapt quickly to extreme variations in the air-fuel mixture. Where the Bosch tests often depend on reading engine-out exhaust with an exhaust gas analyzer, the Ford tests are built into the control module, reading exhaust gas through the oxygen sensor.

Look for two sets of codes that can alert you to problems of poor air-fuel mixtures.

1. Adaptive fuel offset at the rich limit: "This engine is still running lean even though I've shifted as far rich as I can go."
2. Lean limit: "This engine is still running rich even though I've shifted as far lean as I can go."

Most V-type engines have two oxygen sensors, one for each bank. Finding the signal in both sensors indicates the problem is common to all cylinders. If you find the signal in just one oxygen sensor, that narrows your troubleshooting to that bank of cylinders.

If you see adaptive fuel codes, the first question you want to ask is if the problem is in all cylinders or only one. With rich limit codes on SFI systems you can run a cylinder balance Self-Test to determine which cylinder is not getting fuel. Obviously, you cannot run this test with MPI, where several injectors are fired by the same control module signal.

To check for causes of lean limits on SFI systems, or for MPI systems see Causes of Limits below.

4.7 Cylinder Balance Self-Test (SFI only)

This Self-Test is automatically operated by the control module. It is much simpler than running cylinder balance manually, or even with an engine analyzer. It does not even require a tachometer.

To run a cylinder balance test, press and release the throttle within 2 minutes of the last ER Self-Test code. In the following 2 to 3 minutes with no action required by you, the control module does the following:

1. Commands a fixed duty cycle to the Throttle Air Bypass ISC, so that the ISC does not attempt to correct for changes in idle rpm, then stores this idle rpm figure for comparison purposes.
2. Shuts off fuel flow to one injector and stores the rpm figure for all cylinders minus that injector, then calculates the rpm drop for that cylinder.
3. Turns first injector back on, waits until the idle rpm steadies, and repeats the process for each other injector.
4. Determines from its memory the maximum drop of any cylinder.
5. Calculates the allowable tolerance between cylinders by taking a percentage (depends on the engine model) of the max rpm drop recorded. Example: Max rpm drop of 150 x 65% = 98 rpm. If all cylinders drop at least 98 rpm, they are all considered to be delivering equal power. You'll see code 90, PASS.
6. If one cylinder drops less than 98 rpm, that cylinder is weak, not contributing to the engine power. The code indicates the weak cylinder. Number 30 means cylinder #3. 10 means #1. 80 means #8.

You can repeat the cylinder balance test by pressing and releasing the accelerator within 2 minutes of the last code output. This time, the control module will use a smaller percentage to calculate the cylinder differences, further separating the weaker cylinders. Example: Max rpm drop of 150 rpm x 43% = 65 rpm.

- If all the rpm drops are greater than 65 rpm, code 90 indicates PASS.
- If #3 fails the first test and passes the second, it is firing, but weak, possibly caused by a clogged injector or injector/wiring harness resistance out of spec.

If you press and release the accelerator again as above, the third cylinder balance test will re-calculate at a lower percentage as the minimum rpm drop for any cylinder to pass this test. Example: Max rpm drop of 150 x 20% = 30 rpm.

- If code 30 shows with all three tests, #3 is probably dead.

> **NOTE —**
> The cylinder-balance test cannot find a bad injector because it looks for differences. It will not point to an injector that is not flowing any fuel. Check the appearance of the plug in the cylinder of a suspect injector. If it looks cleaner than the other plugs, the injector is probably not opening.

If the cylinder balance test reads code 90, PASS, a lean mixture is not the result of inadequate individual-cylinder injection of an SFI system. You need to check for other causes of a lean limit. See Fig. 4-16.

Checking for Cause of Limits

Based on the limit codes observed earlier under Self-Test for all systems, whether MFI or SFI, the following could be causes of adaptive fuel reaching limits. You'll see in Chapter 11 how to check these.

Self-Test Steps				
1st test	**2nd test**	**3rd test**	**Indication**	**Possible Causes**
90	X	X	Indicates a pass, all cylinders contributing equally	
30	90	X	Indicates a weak cylinder. Cylinder is firing, but not contributing as much as the others	• Partially clogged injector • Injector/harness resistance out of specification
30	30	90	Same as above, but more severe	• Same as above, but more severe
30	30	30	Very weak or dead cylinder	• Open or shorted circuit • Loss of injector drive signal • Fully clogged injector

Fig. 4-16. Typical cylinder balance Self-Test code outputs.

Causes of rich limit (engine running too lean):

1. Vacuum leaks: false air reaching cylinders with no matching fuel injection.
   - air induction system (the air-flow sensor, the soft rubber ducting to the throttle body, the throttle body itself, the intake manifold and gasket)
   - vacuum system (hoses for fuel pressure regulator, brake booster, Thermactor solenoid valves, Canister purge—all places indicated by the vacuum diagram on the VECI decal)
2. Low fuel pressure
3. MAP/BP sensor out of spec (Speed-density system)
4. Low VPWR voltage supplied to injectors
5. Canister-Purge solenoid stuck closed
6. Upstream air leak in Thermactor system

Causes of lean limit (engine running too rich):

1. Excess fuel pressure
2. Canister Purge will not hold vacuum for 20 seconds
3. MAP/BP sensor is out of spec (Speed density system)
4. Oxygen sensor fault: heater circuit or sensor contamination
5. Cooling, ignition, EGR if applicable
6. Injector flow test
7. Cylinder compression

4.8 No Codes Displayed

What if you do not see any codes at all? When you have nothing on the MIL or on the scan tool, you have a problem with the readout from the control module memory. This is rare, so I'll summarize the tests.

Perform this series of Tests. Refer to the proper circuit schematic and electrical test in **Chapter 12**. Check the following:

1. VREF voltage at Self-Test Connector to be 5v.
2. STI circuit continuity, using an ohmmeter across the two ends of the lead.
3. STO circuit continuity.
4. STO circuit for short to ground.
5. Power Relay always ON.
6. VPWR circuit for short to power.
7. MIL for always ON, or always OFF.

Fix any faults. Replace all connections and rerun Quick Test.

4.9 Clearing Memory Codes

After you've fixed faults and rerun your Quick Test, clear the Memory Codes. You might have been told that it's simple, just remove the negative battery cable, but wait. First, decide whether you want to clear Continuous Memory codes, or clear the KAM.

To clear EEC-IV Continuous Memory codes:

1. Run KOEO Self-Test as described previously.
2. When the codes begin to show, deactivate Self-Test (remove STI ground/unlatch button). Codes will be erased without erasing KAM.

To erase MECS-I Continuous Memory codes:

1. Disconnect battery cable and press brake for 5-10 seconds.

To clear the KAM:

1. Disconnect the negative battery cable for at least 5 minutes. This removes power from the control module and allows the KAM memory to decay. Do this after you have replaced some component of the system.

NOTE —
KAM stores the adaptive values for various components. Let's say a particular vehicle has adapted to tolerances in EGR, oxygen sensor, injectors, MAP/BP, TPS, MAF, and VAF. After clearing the KAM, you can expect driveability problems while the control module adapts—for 10 miles or more depending on the vehicle.

4.10 Checking Output State (EEC-IV only)

You can use this test to help you service actuators. You tell the control module to energize and de-energize most of the actuators, not one at a time, but all at once. Then you can check to see if, for example, the EVAP canister purge opens and closes correctly, or if the thermactor diverter works. If not, then you know you have to go further to check wiring or the component.

Check output states after you've observed all codes from KOEO and Continuous Memory. The engine is not running, and all code output has ended.

To test output state:

1. If not in Self-Test, activate it (ground STI/latch tester button).
2. Briefly press the throttle wide open and release. This energizes or sends signals to most of the actuators. This may also reveal some codes that didn't show before.

NOTE —
I know, I know, with a carburetor, you would never mash the throttle, engine off, to avoid pumping raw gas into the cylinders. But remember: fuel-injection systems have no accelerator pump, so you don't have to worry.

3. Again briefly press the throttle wide open and release. Now you have de-energized most of the actuators. Again, that may reveal some codes that didn't show before.

4.11 MECS-II

MECS-II ('93+) Engine Control Module provides considerably more diagnostic capabilities than MECS-I. The control module runs continuous checks of input signals. But it checks outputs only for three seconds when you request the check:

- Ignition ON
- Ground STI terminal of data-link connector

"00" indicates No Trouble Codes. Read codes by scan tool, Analog VOM, or flashing MIL on dash

4.12 4EAT Codes

Diagnostic Trouble Codes can usually be read by counting flashes of the Malfunction Indicator Light (MIL) when the control module is in Diagnostic Test Mode, 1991 and later 1.8L 4EAT and 1993 and later 2.0L 4EAT. To indicate trouble codes, some cars flash other dash indicator lamps:

- '93 and later 2.5L 4EAT - Overdrive Off Lamp (ODL)
- '91 and later 1.6L 4EAT - Manual Shift Lamp (MSL)

5. CONCLUSION

In this chapter, you've seen troubleshooting and diagnostics covering most Ford cars and trucks. Beginning with a series of Diagnostic Routines, you've seen how to use Quick Tests and other diagnostic procedures to track down problems in less time. You've seen the built-in test capabilities of the EEC and MECS-II systems. To see how to perform pinpoint tests and make further tests of fuel and ignition, go to the next chapter.

Chapter 11

Servicing

Contents

1. INTRODUCTION

In the previous chapter you've seen how to use tools such as scan tools to look for trouble codes and to run a Quick Test of the engine control system. In this chapter you'll see how to:

- Check specifics on the fuel system, ignition system and idle-air system
- Run typical specific tests of components that are indicated by trouble codes or Quick Test
- Observe and measure details of sensors and actuators, so that you can apply this using the electrical tests in Chapter 12

When testing components, owners and shops without the necessary BreakOut Box (BOB), may choose to backprobe. Backprobers push a straight pin in through the back of a connector, probing for a contact that allows making an electrical test (voltage/ground/resistance) on that circuit.

CAUTION —
• Be very careful when backprobing connectors. Backprobing can destroy the waterproofing of a connector. Moisture entering the opening can corrode the contacts inside the connector. If in doubt, don't backprobe.

• When backprobing connectors, insert pins from the harness side.

• Never force the probe into a female connector. On the male pin side, probe the pin. Be sure you do not short between the pins.

Fig. 1-1. Backprobing gives you access to circuit signals without breakout box. Checking VPWR to Mass Air Flow (MAF) sensor shown. Take care not to damage connector or terminals.

CAUTION —
• Connect or disconnect multiple connectors and test leads only with the ignition off. Switch multimeter functions or measurement ranges only with the test leads disconnected.

• Do not use a test lamp that has a normal incandescent bulb to test circuits containing electronic components. Use only an LED (light emitting diode) test lamp.

• Do not use an analog (swing-needle) meter to check circuit resistance or continuity on electronic (solid state) components. Use only a high quality digital multimeter having high input impedance (at least 10 megohm).

1.1 Electrical Troubleshooting

Four things are required for current to flow in any electrical circuit: a voltage source, wires or connections to transport the voltage, a consumer or device that uses the electricity, and a connection to ground.

For trouble-free operation of the engine control systems, the ground connections, including the negative battery cable and the body ground strap, must remain clean and free from corrosion. Most problems can be found using only a multimeter (volt/ohm/amp meter) to check for voltage, for resistance, for breaks in the wiring (infinite resistance/no continuity), or for a path to ground that completes the circuit.

Electric current is logical in its flow, always moving from the voltage source toward ground. Keeping this in mind, electrical faults can be located through a process of elimination. When troubleshooting a complex circuit, separate the circuit into smaller parts. The general tests outlined here may be helpful in finding electrical problems. The information is most helpful when used with the electrical tests and wiring diagrams provided in **Chapter 12**.

Testing for Voltage and Ground

The most useful and fundamental electrical troubleshooting technique is checking for voltage and ground. A voltmeter or a test light should be used for this test. For example, for a code 74/536 Brake On/Off (BOO) circuit failure, checking for voltage will determine if the problem is in the circuit or the switch. See Fig. 1-2 and Fig. 1-3.

NOTE —
A test light only determines if voltage or ground is present. It does not determine how much voltage or how good the path to ground is. If the voltage reading is important, use a digital voltmeter. To check the condition of the ground connection, check voltage drop on the suspected connection as described below.

To check for positive (+) battery voltage using a test light, connect the test light wire to a clean, unpainted metal part of

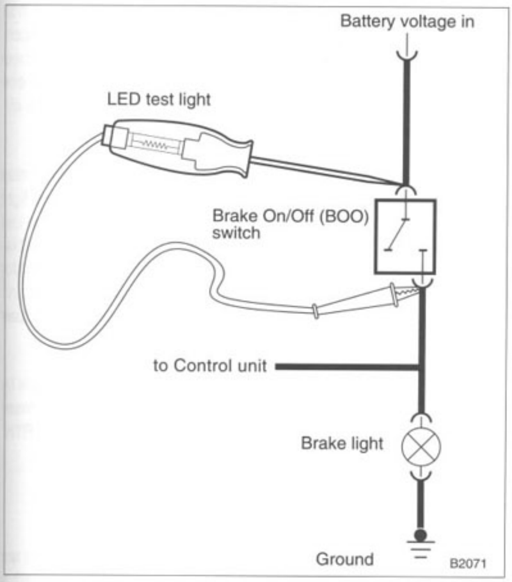


Fig. 1-2. How to use a test light for checking voltage in BOO circuit. A test light is the quickest way to check for voltage and ground.

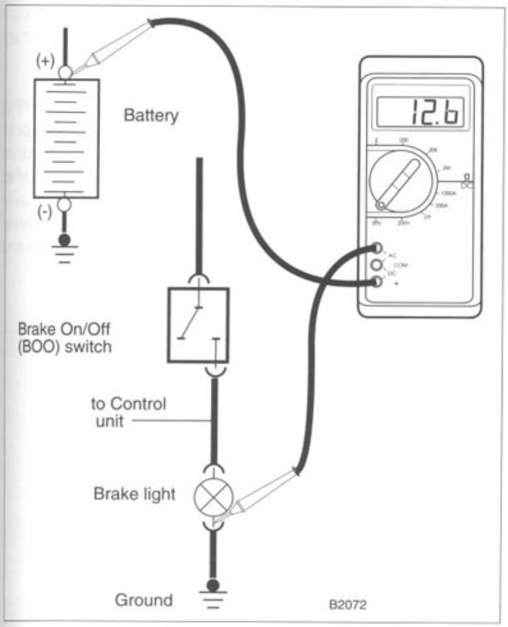


Fig. 1-3. How to use a voltmeter to check for ground.

the car or a known good ground. Use the pointed end of the light to probe the positive (+) connector or socket. To check for continuity to ground, connect the test light wire to the positive (+) battery post or a battery source. Use the pointed end of the light to probe the connector or socket leading to ground. In either case, the test light should light up.

To check for voltage using a voltmeter, set the meter to the correct scale. Connect the negative (–) test lead to the negative (–) battery terminal or known good ground. Touch the positive (+) test lead to the positive wire or connector. To check for ground, connect the positive (+) test lead to the positive (+) battery terminal or voltage source. Touch the negative (–) test lead to the wire leading to ground. The meter should read battery voltage.

Continuity Test

The continuity test can be used to check a circuit or switch. Because most automotive circuits are designed to have little or no resistance, a circuit can be easily checked for faults using an ohmmeter. An open circuit or a circuit with high resistance will not allow current to flow. A circuit with little or no resistance allows current to flow easily. See Fig. 1-4.

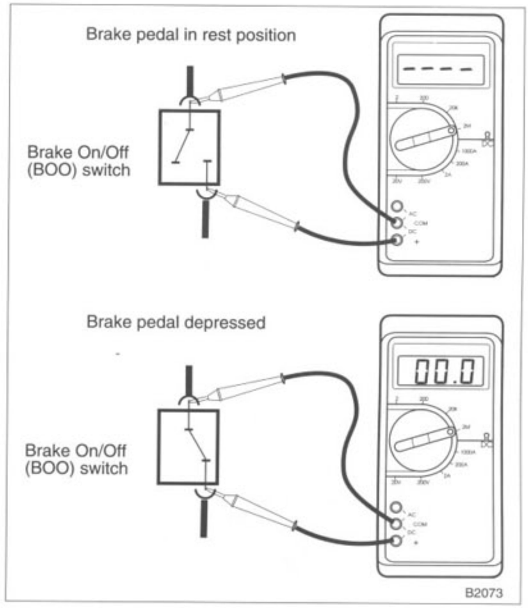


Fig. 1-4. How to test BOO switch for continuity. With brake pedal in rest position (switch open) there is no continuity. With brake pedal depressed (switch closed) there is continuity.

When checking continuity, keep the ignition off. On circuits that are powered at all times, disconnect the battery. Using the appropriate wiring diagram, you can test a circuit for faulty connections, wires, switches, relays, and engine sensors by checking for continuity.

On the BOO code, for example, you could check wiring continuity from the battery to the switch, from the switch to ground, or from the switch to the control module. You could also check continuity across the switch.

Short Circuit Test

A short circuit is exactly what the name implies. The circuit takes a shorter path than it was designed to take. The most common short that causes problems is a short to ground where the insulation on a positive (+) wire wears away and the metal wire is exposed. If the exposed wire is live (positive battery voltage), a fuse will blow and the circuit may possibly be damaged.

> ***CAUTION —***
> *On circuits protected with large fuses (25 amp and greater), the wires or circuit components may be damaged before the fuse blows. Always check for damage before replacing fuses of this rating. Always use replacement fuses of the same rating.*

Shorts to ground can be located with a voltmeter, a test light, or an ohmmeter. Short circuits are often difficult to locate. Therefore, it is important that the correct wiring diagram is available. Short circuits can be found using a logical approach based on the current path. See Fig. 1-5.

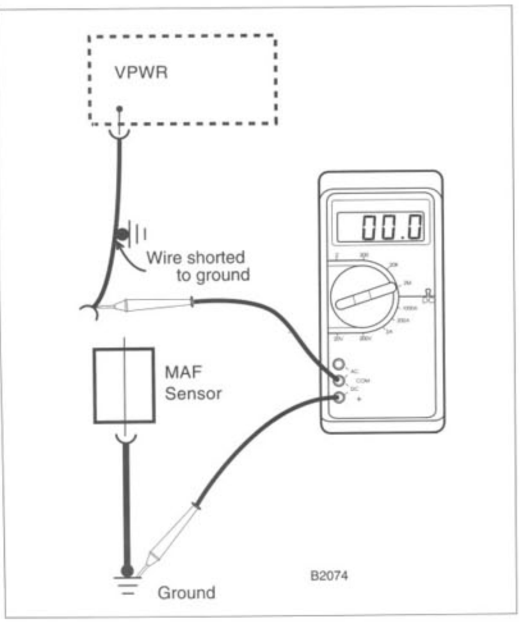


Fig. 1-5. How to use an ohmmeter to check for short circuit to ground On Mass Air Flow (MAF) sensor power supply.

To check for a short circuit to ground, disconnect the harness connector from the circuit's load or consumer. If necessary, remove the blown fuse from the circuit and disconnect the cables from the battery. Using an ohmmeter, connect one test lead to the load side terminal (terminal leading to the circuit) and the other test lead to ground.

Working from the wire harness nearest to the fuse/relay panel, move or wiggle the wires while observing the test light or the meter. Continue to move down the harness until the test light blinks or the meter displays a reading. This is the location of the short. Visually inspect the wire harness at this point for any faults. If no faults are visible, carefully slice open the harness cover or the wire insulation for further inspection. Repair any faults found.

You can also check for a short circuit to the control module by disconnecting both the component and control module harness connectors and probing two terminals, say MAF and MAF RTN. If there is continuity, then there is a short in the harness.

Voltage Drop Test

The wires, connectors, and switches that carry current are designed with very low resistance so that current flows with a minimum loss of voltage. A voltage drop is caused by higher than normal resistance in a circuit. This additional resistance actually decreases or stops the flow of current. A voltage drop can be noticed by problems ranging from dim headlights to rough running. Some common sources of voltage drops are faulty wires or switches, dirty or corroded connections or contacts, and loose or corroded ground wires and ground connections.

Voltage drop can only be checked when current is running through the circuit, such as by operating the starter motor or turning on the ignition. Making a voltage drop test requires measuring the voltage in the circuit and comparing it to what the voltage should be. Since these measurements are usually small, a digital voltmeter should be used to ensure accurate readings. If a voltage drop is suspected, turn the circuit on and measure the voltage at the circuit's load.

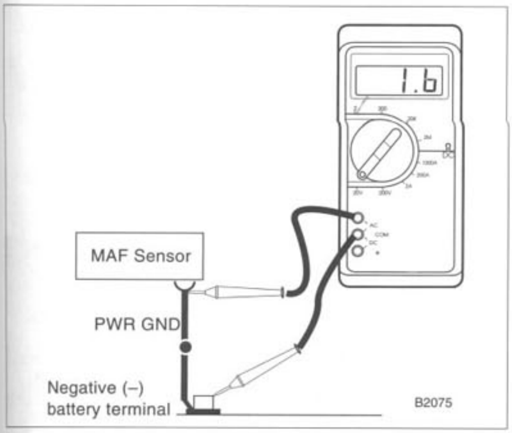


Fig. 1-6. How to test voltage drop on MAF sensor ground. Voltmeter showed 1.6-volt drop between PWR GND at MAF connector and battery ground. After removing and cleaning battery ground, voltage drop returned to normal.

NOTE —

- A voltage drop test is generally more accurate than a simple resistance check because the resistances involved are often too small to measure with most ohmmeters. For example, a resistance as small as 0.02 ohms results in a 3 volt drop in a typical 150 amp starter circuit. (150 amps x 0.02 ohms = 3 volts).

- Keep in mind that voltage with the key on and voltage with the engine running are not the same. With the ignition on and the engine off, battery voltage should be approximately 12.6 volts. With the engine running (charging voltage), voltage should be approximately 14.5 volts. Measure voltage at the battery with the ignition on and then with the engine running to get exact measurements.

- The maximum voltage drop, as recommended by the Society of Automotive Engineers (SAE), is: 0 volt for small wire connections; 0.1 volt for high-current connections; 0.2 volt for high-current cables; and 0.3 volt for switch or solenoid contacts. On longer wires or cables, the drop may be slightly higher. In any case, a voltage drop of more than 1.0 volt usually indicates a problem.

2. CHECKING FUEL SYSTEM

You may have noticed that codes do not show when the fuel system is not operating properly. The engine does not have a sensor for low fuel pressure or fuel flow. But your Diagnostic Routines often consider fuel delivery as a possible cause of a driving complaint.

If you've come to this section from the Diagnostic Routines, you're specifically looking for a problem that would cause fuel flow through the injectors to be incorrect. Your fuel delivery checks will look for answers to four questions:

1. Is the pressure regulator controlling the pressure?
2. Is the fuel pump creating enough pressure?
3. Is the fuel pump delivering enough volume?
4. Are the injectors operating correctly?

If you suspect fuel system problems, first listen to make sure the pump runs when you turn on the ignition. If not, check the system relay, the fuel pump relay, (or the Integrated Relay Control Module if fitted), the inertia switch, and the anti-theft system. You'll be looking for power to the relay, ground from the relay, and relay switching when power is applied.

Also make sure the control module is receiving the signal indicating the engine is turning over. On EEC systems (and on MECS-II), it comes from the ignition system (PIP signal). On most MECS-I, this comes from the air-flow sensor. If the pump runs, continue to check basic system pressures, fuel delivery, and operation of the fuel injectors.

WARNING —

- *Remember that Ford port-injection systems operate at high pressures, typically about 40 psi (270kPa).*

- *Fuel lines are usually pressurized even when the engine is not running. If you open a line under pressure, that can spray gasoline which is a severe fire hazard.*

2.1 Pre-checks

Start by checking over the complete fuel-delivery system. You're looking for leakage in fuel lines or at fuel line connections, loose wiring connectors, cracks, pinching, kinking, corrosion, grounding abrasion. Check around all components:

- Fuel tank
- Filter
- Pump(s)
- Injectors and fuel rail
- Pressure regulator

Check that the battery is fully charged and the fuel tank has fuel. (I know, that's an oldie, but it's easy to overlook an empty tank.) Check the fuses controlling the fuel-delivery system.

2.2 Pressure Tests

Excess fuel pressure may enrichen the mixture, while insufficient pressure may lean the mixture. Why? Because injection times are calculated on the basis of specified fuel pressure. *You'll be checking three pressures:*

- Engine off, to check pump pressure
- Engine running, to check pressure-regulator response to manifold pressure
- Rest (or residual) pressure to check leakage in the system

To check engine off/engine running fuel pressure (all except MECS systems):

1. Attach the fuel-pressure gauge. Look for a fitting on the fuel rail. See Fig. 2-1. Be sure to tighten the gauge onto the valve.

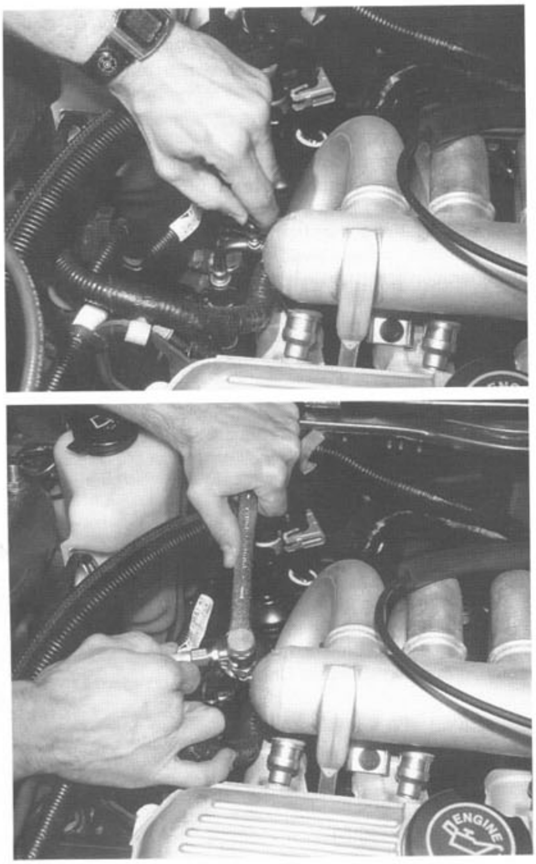


Fig. 2-1. Fuel pressure gauge attachment to EEC systems is easy. Look for Schrader valve fitting on fuel rail. Attach gauge to fitting and tighten.

2. With the key OFF, ground the fuel pump (FP) lead of the Self-Test Connector (STC). See Fig. 2-2.

NOTE —
For short tests without grounding the fuel-pump lead in the STC connector, you can build engine-OFF fuel pressure by turning the key ON several times. This runs the pump for about one second at a time until pressure builds.

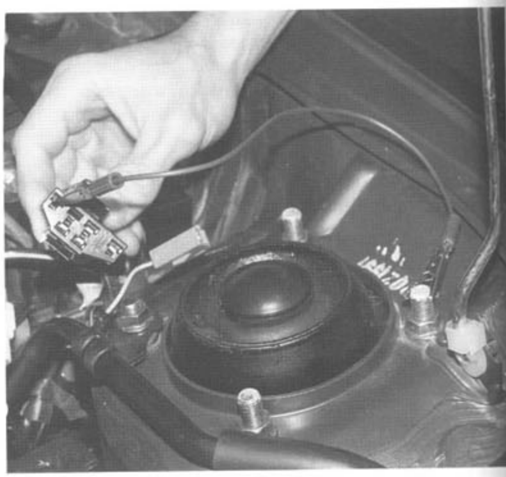


Fig. 2-2. Grounding Fuel Pump (FP) lead of Self-Test Connector to run fuel pump with engine off.

3. Turn the key ON to run pump (Do not start the engine).
4. Check the Engine Off fuel pressure according to the specifications. See **Table a** or **Table b**. Turn the key OFF and remove the jumper wire when done.
5. Start the engine and check Engine Running pressure.

To check engine off/engine running fuel pressure (MECS systems):

1. Relieve the fuel pressure, open the supply line and with an adapter, T-in the gauge. Here's how:
   - With engine idling, remove fuel-pump relay
   - After engine stalls, turn ignition OFF
   - Install fuel-pump relay
   - Use rag when opening fittings to prevent spray
   - Install gauge with hose clamps
2. After fuel-pressure release, prime the pump before starting the engine:
   - Ground pump at test connector
   - Ignition ON for 10 seconds
   - Check for leaks
   - Ignition OFF
   - Remove jumper wire

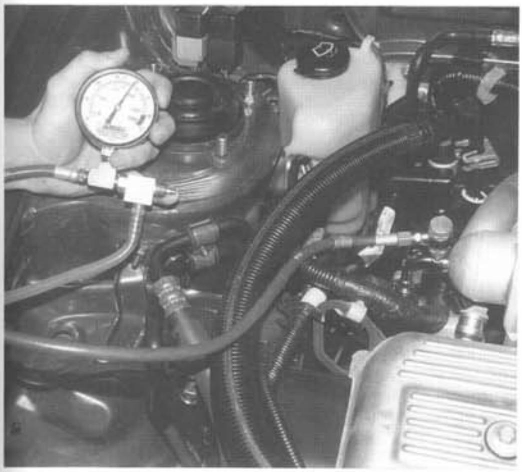


Fig. 2-3. Fuel pressure, pump running, engine off. See tables below for correct values.

Table a. EEC-IV Fuel Pressure Specifications

	Key On Engine Off		Engine Running (ER) Idle	
Engine	**psi**	**kPa**	**psi**	**kPa**
1.9L, 2.3L OHC, 2.9L 3.0L, 3.8L, 5.0L	35–45	240–310	30–45	210–310
2.3L HSC, 4.9L	50–60	345–415	45–60	310–415
SHO and other cars not listed	30–45	210–310	28–33	193–227
3.8L SC	35–40	240–280	30–40	210–280
4.6L	35–40	240–280	30–45	210–310
Trucks not listed	35–45	240–310	30–45	210–310

Table b. MECS Fuel Pressure Specifications

	Key On Engine Off		Engine Running (ER) Idle	
Engine	**psi**	**kPa**	**psi**	**kPa**
1.3L	35–40	240–280	25–31	175–215
1.6L	37–41	255–290	28–31	195–215
1.8L	38–45	265–315	30–37	205–255
2.2L	34–40	235–275	27–33	185–225
'93 2.0L	37–46	260–320	30–38	210–260
'93 2.5L	37–46	260–320	30–36	210–250

To check leakdown pressure (residual):

1. Begin with the engine idling, with the fuel-pressure gauge connected, as above. Get ready to time the leakdown.
2. Turn off engine, then turn Key ON, but do not start. Observe the KOEO pressure.
3. Turn the key OFF and measure pressure for one minute after turning key off.
4. At the end of that time, fuel pressure should hold within the KOEO specification.

If the car passes, but still has a start problem, recheck to a tighter limit—say, it should lose no more than 2 psi per hour. Incorrect fuel pressures indicate a problem either with fuel delivery from the pump, with the pressure regulator or with the fuel lines.

Checking for Causes of Incorrect Fuel Pressures

If KOEO pressure is too low, first check for a clogged fuel filter. Also check for a bad pump, or a bad pressure regulator. Why? These parts affect how much fuel reaches the pressure gauge. If reduced, you'll see less gauge pressure.

If KOEO pressure is too high, the problem is either a clogged return-line or a faulty regulator. Why? These parts affect how much fuel returns to the tank. If return is reduced, you'll see more gauge pressure.

Low residual pressure could be caused by leakage at the fuel-pump check valve or the fuel pressure regulator. Or look for leaking injectors. See **2.6 Checking Injectors** for more information.

If there is no change in ER pressure, check the vacuum supply and hose to the pressure regulator. Fix if faulty. If the vacuum and hose are OK, then the regulator is probably faulty.

On port-injected engines, notice the difference between the Key On, Engine Off (KOEO) pressure and the Engine Running (ER) pressures. With the engine OFF, Manifold Absolute Pressure (MAP) is higher than it would be with the engine running. See Chapter 7 for additional information.

- ER, idle fuel pressure is lower than KOEO because the fuel pressure regulator compensates for the lower MAP.
- ER, wide-open-throttle fuel pressure is usually about the same as KOEO because MAP is about the same as it would be Engine OFF.
- ER, idle fuel pressure with the vacuum hose removed from the fuel pressure regulator is also the same as KOEO. (Fuel-pressure gauge is operating at barometric pressure, both cases.)

To check for causes of low fuel pressure:

1. Check voltage and ground at the high-pressure fuel-pump terminals. Voltage should be within 0.5v. of battery voltage. Continuity to ground should be less than 1 ohm. If not, check the wiring and check for corrosion.
2. Remember, some Ford trucks use a low-pressure pump in the tank and a high-pressure pump in the line. Verify low-pressure pump operation by listening at the fuel tank through the open filler pipe. You may have to check delivery of the low-pressure pump.
3. On MECS-I, verify operation of the VAF fuel-pump switch and VAF ground. See **Chapter 12**.
4. Check fuel volume delivery as described below.
5. If all of the above ar O.K., then the fuel pressure regulator is probably faulty.

To check for causes of excess fuel pressure:

1. Remove the fuel return line from the regulator. Attach a hose and direct the fuel return into an unbreakable container. See Fig. 2-4.

> ***WARNING —***
> *This test delivers gasoline into the open, with attendant vapors. Know what you are doing and be extra careful. You can expect fuel to leak or gush out. Do not smoke or cause sparks. Have an approved fire extinguisher handy.*

Fig. 2-4. Check return flow from regulator. Fuel-pressure gauge fitted to Schrader valve has drain valve.

2. Re-run the fuel-system pressure test. If pressures are now within spec, clean or replace the fuel return line. If pressures are still high, replace the regulator.

To check leakage in the regulator or at the pump:

1. Disconnect the fuel-return line from the engine. Plug it.
2. Build up normal fuel pressure by cycling key ON and OFF.
3. In 30 seconds, fuel-pressure drop should be less than 5 psi (34 kPa).

If the drop is still more than spec, fuel is probably leaking past the fuel-pump check valve. Why? Because with the return line plugged, the regulator could not be causing the drop in pressure. If the drop is now in spec, a faulty pressure regulator caused the drop you observed in the first test. Why? Because blocking off the regulator cured the pressure drop.

To check pressure regulator diaphragm:

1. Start the engine and run for about 10 seconds.
2. Stop the engine for about 10 seconds.
3. Run the engine for another 10 seconds. Stop the engine.
4. Remove the vacuum hose from the regulator. See Fig. 2-5. If the diaphragm is leaking, you will see evidence of fuel at the vacuum port. Replace the regulator.

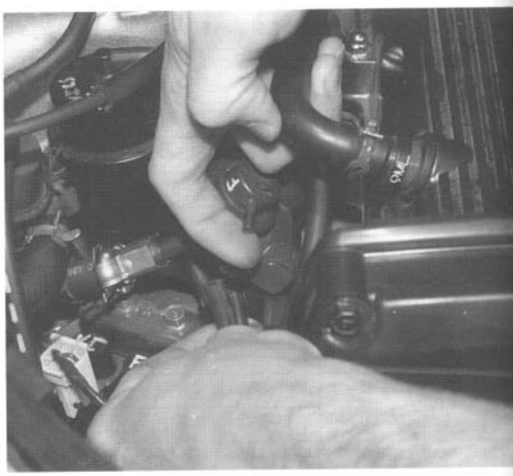


Fig. 2-5. Check for evidence of fuel at regulator vacuum port. If it is dry, the diaphragm is not leaking.

2.3 Fuel Volume Delivered

The latest service manuals do not call for this test, relying on other checks to verify proper operation of the fuel system. On the other hand, if you are faced with loss of power at high revs or if there seems to be no other reason for low fuel pressure, this test could verify if pump delivery as the problem.

> **NOTE —**
> If you wonder why you check fuel delivery from the return line instead of the supply line, I did too, at first. Then I learned that what counts is the delivery amount against the regulated pressure, and that measuring the supply line against zero pressure gives a higher, misleading delivery volume.

To measure delivery:

1. Disconnect the fuel-return line at the engine.
2. Slip a hose over the return line and place the other end in a container holding about 1 qt. (1 L). Use a plastic or metal container; if a glass container breaks, the spilled gasoline would be a real fire hazard. See Fig. 2-4 above.
3. Connect a jumper to the FP lead of the STC. See Fig. 2-2 above.
4. Get ready to measure time as you turn ignition ON for just 10 seconds. **Table c** gives delivery specs.

Table c. Fuel Delivery Specifications

System	Time	Fuel Delivered
EEC-IV	10 sec	170 ml (5oz.)
MECS 1.8L	10 sec	170 ml (5oz.)
MECS other	10 sec	220-380 ml (7.5–13 oz.)

If fuel delivery is low, replace the filter, and blow air through the supply line to be sure it is open. If delivery is still low, check voltage and ground at the high-pressure fuel-pump terminals. See Fig. 2-6. Voltage should be within 0.5v. of battery voltage. Continuity to ground should be less than 1 ohm. If not, check the wiring and check for corrosion. If there is no other problem and the pump electricals are OK, replace the pump.

2.4 Relieving Fuel Pressure

The fuel system is under pressure even when the engine is not running. The fuel-pump check valve holds pressure in the system for many hours after the engine is turned off. To prevent fuel from spraying over yourself and the engine when opening a fuel line, always relieve pressure in the lines.

Fig. 2-6. Check voltage at fuel-pump relay. On the '91 1.9L Escort, it is under the center console.

First, remove the gas tank cap. Why? Although most people don't realize it, gasoline vapor-pressure builds in fuel tanks. If you open a fuel-return line with the gas-tank cap in place, the small pressure can force fuel out of the line. Normal tank pressure is controlled by the valve in the cap at about 1.6 psi (11 kPa).

Fig. 2-7. Ford sets relief valve in the fuel tank cap at 1.6 psi (11 kPa). That small pressure can force fuel out of an open return line.

Next, release the pressure in the lines. The old way was to wrap the fuel fitting in a shop cloth and loosen it, but that can be messy and dangerous if a lot of fuel is spilled. I'm going to tell you two ways applicable to Ford engines.

1. EEC engines: With the fuel-pressure gauge attached to the Schrader valve as shown previously, gradually open the drain valve and catch the pressurized fuel in a container.
2. EEC or MECS engines: Open the inertia switch reset button (or disconnect the inertia switch connector) to disable the fuel-pump circuit. See Fig. 2-8. Run the engine until it stalls. Using a rag, disconnect the hose as necessary. Be sure to reset inertia switch.

Fig. 2-8. Inertia switch in trunk.

On MECS engines there's a third way. Disconnect power to the fuel pump, then crank/run the engine dry. On all except the 2.2L Turbo engine, disconnect the VAF connector to cut pump power. On the 2.2L Turbo, remove fuel-pump relay. After the engine stops, reconnect the circuit.

2.5 Opening EEC Fuel Lines

Generally, Ford fuel line connections use special couplings. See Fig. 2-9. Although you can make fuel connections simply by pushing them together, you'll need a special tool to open the fuel lines. In most engines, a $\frac{1}{2}$" tool opens the larger supply lines. A $\frac{3}{8}$" tool opens the return lines. See Fig. 2-10.

Here are four special points to remember:

1. Relieve fuel pressure before separating the spring-clip connectors. Twist the fittings to aid their release.
2. Use only the specified O-rings, made of special material for these couplings. Other O-rings may leak later, even if they seem at first to seal.
3. In reassembly, lubricate O-rings and both fittings with clean engine oil.
4. The color of the safety clip identifies the type. The larger, black clip identifies the supply line; the smaller, gray clip identifies the return line.

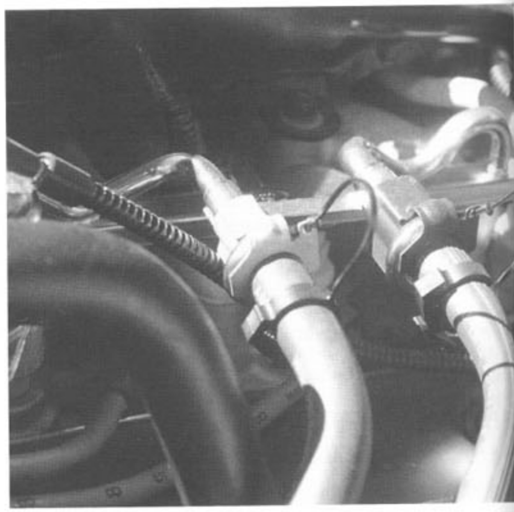


Fig. 2-9. A garter spring inside a circular cage holds safety-clip push-connect fittings with push-lock couplings together.

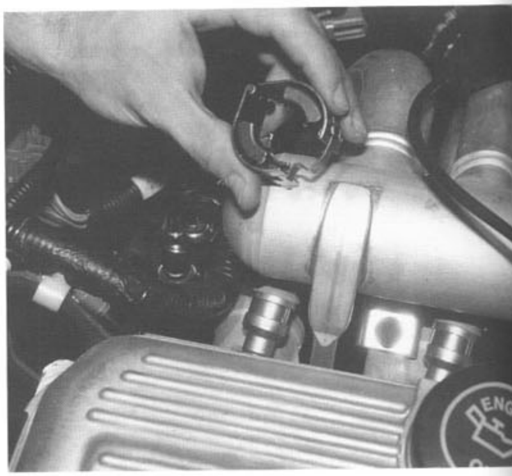


Fig. 2-10. You'll need special Ford tool to open fuel lines.

Whatever the coupling, always use new gaskets, O-rings and seals when reconnecting lines or installing components. Many of these seals crush on tightening. If a crushed seal is reused, it may leak immediately, or worse, it may develop a leak later as you drive.

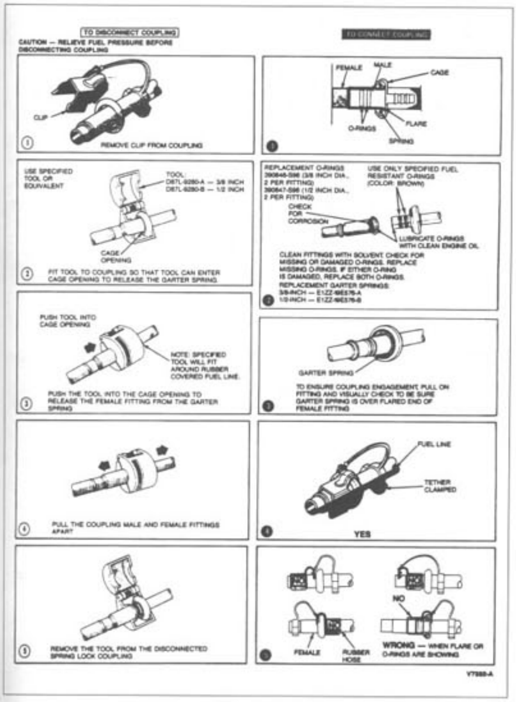


Fig. 2-11. Fuel line disconnect and connect procedure.

2.6 Checking Injectors

You have several methods to check the operation of the fuel injectors. In addition to those listed here, don't forget to check wiring continuity to the control module. Note: while the injectors may appear to be operating correctly, even a small amount of injector clogging can affect engine performance. This can lead to hard starting, rough idle, stumbles and surges, and gas smell from leaking.

> ***CAUTION —***
> *Do not apply voltage to the fuel injectors in an attempt to test them. Remember, injectors receive voltage from the computer and are grounded by the computer. Excessive voltage will burn out the injectors.*

Injector Operation

You can usually check injector operation by the vibration—indicating that they are opening and closing—while the engine is idling. If they're too hot to touch with your fingertips, use a mechanic's stethoscope or a screwdriver as shown in Fig. 2-12. You should hear a buzzing or clicking sound. Remember that each SFI injector fires individually once every two crankshaft-revolutions, a rate only half as fast as MFI injectors, which fire in gangs every crankshaft revolution.

Fig. 2-12. You can check injector operation with a stethoscope or by placing screwdriver tip against injector body and listening for clicking sound.

No vibration indicates a bad injector or harness. A different pitch of vibration in one versus the others can also indicate a bad injector or injector clogging. Interchange injectors (MFI on the same circuit). If the same injector is still faulty, then replace the injector. If the injector now works, check the wiring.

Injector Electrical Tests

To check resistance of an individual injector, disconnect the harness connector and use an ohmmeter across the injector terminals. See Fig. 2-13. See **Table d** for specifications.

Fig. 2-13. Checking injector resistance.

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Table d. Single Injector Resistances

Engine	Ohms
Most Late Model Engines	13.0–16.0
2.3L OHC & 3.0L	15.0–18.0
up to '90 1.9L MFI	2.0–2.7
1.9L & 2.5L CFI	1.0–2.0
2.3L TC MFI	2.0–3.0
5.0L SFI	13.5–19.0
'89 TRUCK	13.5–18.0
MECS-I (except 2.2L T)	12.0–16.0
MECS 2.2L Turbo	11.0–15.0
MECS-II 2.0L	12.0–17.0
MECS-II 2.5L V-6	12.0–16.0

For MECS 2.5L V-6, measure resistance of individual injectors at the harness terminals as shown in Fig. 2-14 .

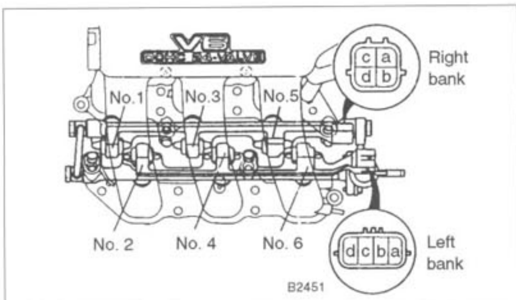

Fig. 2-14. MECS 2.5L V-6: Measure individual injector resistances at the connectors. Use the terminals shown in the table below.

Harness	Terminals	Injector No.
Right bank	a—b	1
	a—c	5
	a—d	3
Left bank	d—c	2
	d—b	4
	d—a	6

Notice the real differences in resistances of some injectors. Substituting a low-resistance injector for a high-resistance one (or vice versa) would cause real trouble.

To check the signal from the control module, use an LED test light across the harness connector terminals. Special injector test lights that plug into the connector are available from auto supply stores. When the engine is cranked the test light should flash. If it doesn't, there's a problem with either the wiring or the power and ground circuit from the control module. Remember,

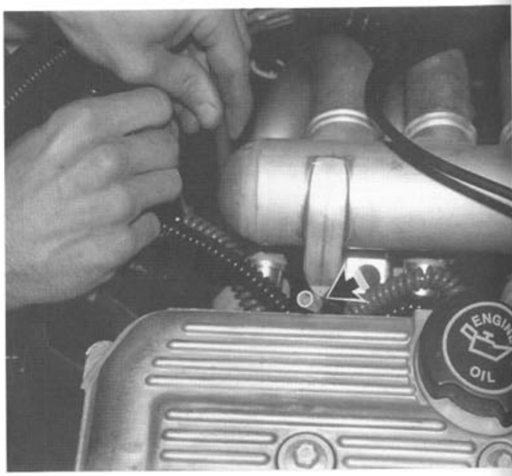

Fig. 2-15. Checking injector triggering by control module using a Light Emitting Diode (LED) test light (arrow).

the injectors are supplied power with the key on, and the control module grounds the circuit to open the injectors.

RPM Drop Test

Sometimes you can identify an injector that is not carrying its load by looking for rpm drop as you disconnect, one at a time. Disable idle speed control by removing the connector. With the engine idling, and with a shop tach connected (the instrument-panel tach is not adequate), disconnect each injector by pulling its connector.

If any injector does not cause a drop of about 100 rpm, pull the injector and check it out. Check its circuit also. Remember, for SFI engines, the computer Quick Test does the RPM Drop Test for you.

Injector Leakage

Fuel injector leaks can occur at the seams around the fuel injector body and bleed off residual fuel pressure. Clean off the injector and look closely. Injectors usually leak most when they are cold. Replace an injector that leaks this way.

Also check the injector pintle for leakage. On some port systems, you can remove the fuel rail with the injectors and fuel *lines still attached, then build up fuel pressure as in the pres*sure test and watch the injector(s) for drips. If you see more than 1 drop in two minutes, clean and retest. If not OK, replace the injector.

WARNING —
A leaking injector may spray vaporized gasoline, the most hazardous form. Keep a fire extinguisher handy.

Injector Clogging

Symptoms of a clogged fuel injector are a rough idle, a stumble or hesitation during acceleration, or a failed emissions test. A buildup of carbon and other deposits on the injector pintle causes fuel-injector clogging. This reduces the flow of gasoline through the injectors and results in a poor spray pattern. See Fig. 2-16.

> **NOTE —**
> Injector clogging is seldom a problem with side-feed injectors used in MECS 2.5L V-6, or in deposit-resistant injectors, used in most late-model EEC systems.

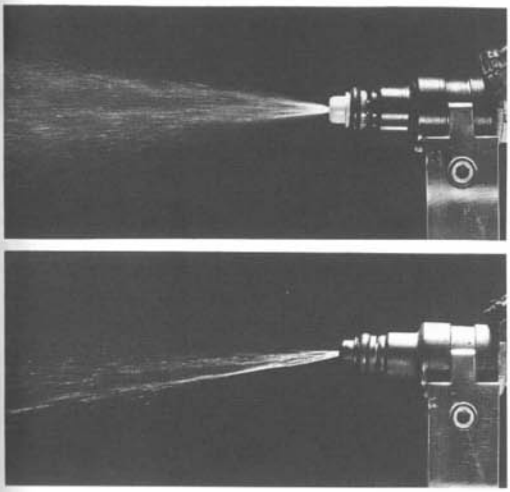

Fig. 2-16. New injector (top) has good spray pattern. Clogged injector (bottom) has poor pattern and flow rate of 50% less.

Causes of Clogging

Clogging is the result of the combination of a number of factors:

- High underhood temperatures on smaller cars
- Fuel being metered at the tip of the port injector
- Short driving cycles followed by hot-soak periods
- Low-detergent fuels with a high carbon content and low hydrogen content

The worst clogging seems to occur with driving cycles where the car is driven for at least 15 minutes, ensuring full warm-up, then parking for about 45 minutes or more. While the engine runs, the fuel flow cools the injector tips. After shut-down the engine acts as a heat sink and temperatures climb, particularly at the valves and manifolds. Injector-tip temperature climbs equally high, and the small amount of fuel that is in the tip of the injector breaks down and causes the deposit. Considering the small quantities of fuel that the injector meters, and the tiny orifice of the injector tip, it doesn't take much to restrict the flow, as shown in Fig. 2-17.

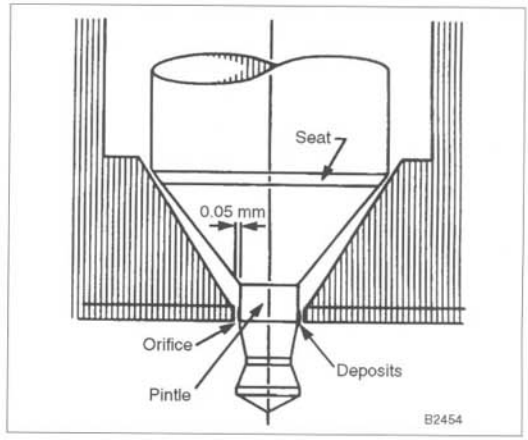

Fig. 2-17. Very small amounts of deposits will affect engine performance.

Normally, one injector clogs before the others, reducing its delivery so that one cylinder runs lean. The oxygen sensor compensates by enriching the mixture for other cylinders, which is in turn too rich for the cylinders with unclogged injectors. The result is a rough idle. The engine will most likely fail an emission test, and will send you to the gas pump more often, because it can lose as much as 25% fuel economy.

Solving the Clogging Problem

The first step towards solving the problem of fuel injector clogging is to determine whether one or more injectors are indeed clogged. You may use the special Ford Rotunda tester that checks the flow of each injector without removing them.

> **NOTE —**
> Test all multi-port injectors at 40 psi (270 kPa) regardless of the operating pressure specified for the vehicle.

Without the tester there are other ways to check for clogging. On SFI systems you can run a Cylinder Balance Test as described in Chapter 10. On other MFI systems, you can try an rpm drop test as described above.

Here's a tip from the field: read the plugs. If one looks OK and the others read rich, what could cause that? The OK plug is from the clogged injector. The other plugs are dark because the control module is adding extra fuel to compensate for the lean-mixture signal from the oxygen sensor. You can also read the plugs on a scope firing line. The plugged-injector cylinder will read normal, while the others will read low.

The tendency to form injector deposits varies considerably depending on the fuel. Many cases of injector clogging can be cured by using premium fuels advertised as containing more detergent additive. Most regular unleaded fuels probably have enough detergent to keep unclogged injectors clean, but they probably won't dissolve deposits on clogged injectors.

Pour a separate additive in your gas tank to clean injectors in a short time as shown in Fig. 2-18. In some cases, this may free other deposits that can clog the fuel system. Be aware that some gasoline additives that cure clogging can cause carbon deposits on the intake valves. These fluffy deposits absorb fuel and cause rough idle and hesitation, especially in cold running conditions. Check with your dealer for a recommended gasoline or additive.

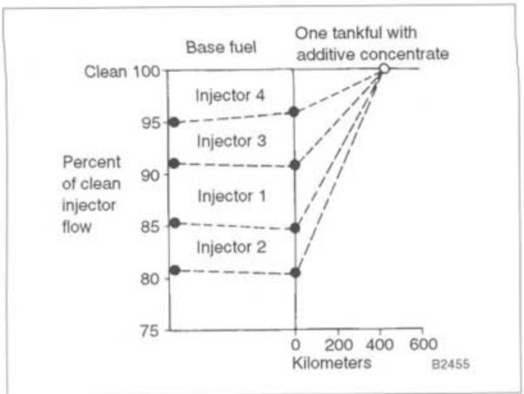

Fig. 2-18. Effect of adding fuel-injector cleaning additive to one tank of gas.

Change your driving cycle if you still get clogged injectors with all fuels. If you can't get good fuel, or if you want the best protection, it may be possible to install deposit-resistant injectors. Check with your dealer.

Cleaning Injectors

There are a number of special repair kits available that hook up to the fuel system to flush out deposits. Often they attach to the pressure test fitting. Ford dealers test and clean injectors with the Rotunda tester. I'll briefly list the steps. In any case, I suggest you follow the instructions of the specific cleaner you use.

- Install the tester/cleaner to the fuel lines
- Run the engine on gasoline/solvent mixture
- Reinstall fuel lines and check for leaks

Many cars may need to have their injectors cleaned on a regular basis. But with widespread distribution of fuels of increased quality, the great injector-clogging problem may pass into history.

3. Air Flow (Load) Measurement

Here are four different basic procedures for making Pinpoint tests of the components that measure air flow into the engine. Generally, you would make these when you see trouble codes during Quick Test (for example: codes 08, 22, 26, or 159). See also the electrical tests in Chapter 12 for terminal identification, tests specifications, and wiring diagrams.

> ***CAUTION —***
> *Check your DVOM for compatibility. Do not use a True DVOM for these measurements. See the Caution at the beginning of Chapter 12.*

> **NOTE —**
> These electrical tests are called for by the Trouble Codes from Quick Test. That indicates the sensor is out of self-test range. Ordinarily, these sensors do not call for routine checking.

3.1 Mass Air Flow (MAF) Sensor

The MAF signal may be affected by the air-cleaner element, the inlet air duct and the throttle body. In addition, it can be affected by the service garage-ventilation system. If you get a code signal, rerun the Self-Test vented to the outside atmosphere. The following procedure gives the basic steps for troubleshooting a code.

> **NOTE —**
> With 2-digit trouble codes, look for 66 in memory, indicating a MAF sensor problem. This is the only signal like this.

To check MAF sensor:

1. Check power and ground to MAF:
   - Key OFF
   - Disconnect MAF sensor
   - DVOM on 20v. scale
   - Key ON
   - Measure between VPWR and PWR GND at the MAF sensor connector
   - Look for: 10.5v. or more

   > **NOTE —**
   > This test can also be made with the harness connector connected. See Fig. 1-1 earlier.

2. If not OK, there is a fault either with the VPWR circuit or with the ground circuit to the battery. Check wiring continuity. Check VPWR as described in Chapter 12.
3. Next check MAF circuit output. With the MAF sensor reconnected, backprobe connector as shown in Fig. 3-1.
   - DVOM on 20v. scale, Start engine
   - Look for: 0.2 to 1.5v. MAF sensor output varies with engine load, also with temperature. See Chapter 12 for full specs

Fig. 3-1. Checking Mass Air Flow (MAF) sensor output with engine running.

4. If not OK then either there is a problem with the wiring to the control module, the control module, or the MAF sensor. Go to the next step.
5. Check wiring continuity from the control module to the MAF sensor connector.
   - Backprobe at the control module connector as shown in Fig. 3-2. See the wiring diagrams in Chapter 12 for connector terminal identification
   - DVOM on resistance scale
   - Look for: 5.0 ohms or less in each test
   - If not, fix wiring faults

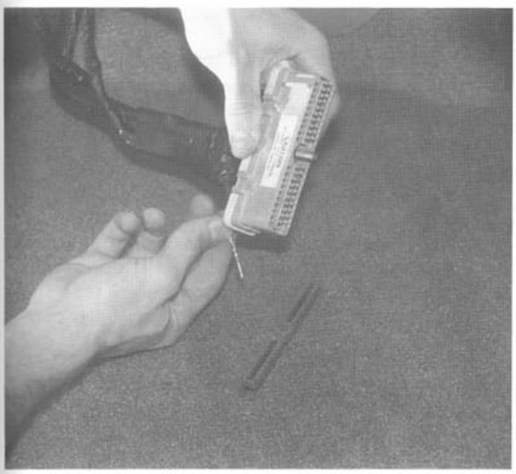

Fig. 3-2. Control module harness connector being backprobed to test pins (or use BreakOut Box).

6. Check the control module for an internal short.
   - Control module connector connected
   - MAF connector disconnected
   - DVOM on resistance scale
   - Check resistance between MAF SIG and MAF RTN, and between MAF SIG and PWR GND
   - Look for: 10,000 ohms or greater
   - If not, then the control module is probably faulty
7. If the wiring and the control module are OK, then the MAF sensor is most likely faulty.

3.2 Manifold Absolute Pressure (MAP) Sensor

Recall that the Manifold Absolute Pressure (MAP) sensor outputs a frequency signal. That does not show on your DVOM. There are four ways to measure MAP output:

1. BreakOut box (BOB) to read SIGRTN, MAP/BP SIG, and VREF.
2. Ford MAP/BP Tester, shown in Fig. 3-3.
3. Oscilloscope voltage pattern.
4. MAP frequency using a frequency tester. See Chapter 12.

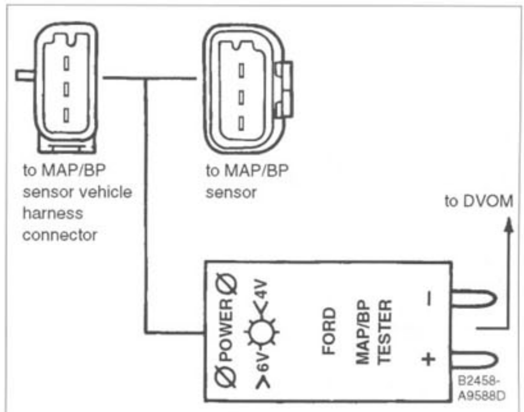

Fig. 3-3. Measure MAP/BP voltages at the BreakOut Box, or at the plugs of the Ford MAP/BP tester.

The following tests are for when you receive a typical MAP trouble code during Quick Test. For example: 22, 29, 126 or 129.

> **NOTE —**
> Engine Running (ER) trouble codes generated during ER Self-Test may be due to a faulty vacuum hose or to excess EGR flow. The latter causes the sensor to "see" pressure beyond its normal compensation. Continuous memory codes may be due to a MAP sensor leak.

To check MAP/BP sensor with MAP/BP tester:

1. With Key OFF, disconnect MAP/BP sensor.
2. Connect tester between vehicle harness connector and sensor.
3. Insert tester plugs into DVOM, set to 20v. scale.
4. Key ON.
   - Look for: Green light
   - If not, red light indicates VREF is either too high or too low
   - Disconnect MAP/BP sensor
   - Look for: green light. If yes, replace MAP/BP sensor. If not, check wiring to control module, and check VREF circuit as described in Chapter 12, then retest
5. If green light in Step 4 above indicates VREF OK, test sensor output. Voltage output changes with altitude as shown in chart below. See also Chapter 12.

Table e. MAP/BP Output

Approx. Altitude	Output v.
Sea level	1.55–1.63
1,000 ft. (300m)	1.52–1.60
2,000 ft. (600m)	1.49–1.57
3,000 ft. (900m)	1.46–1.54
4,000 ft. (1200m)	1.43–1.51
5,000 ft. (1500m)	1.40–1.48

If MAP sensor voltage is OK but a trouble code is still generated, check the wiring to the control module for continuity and for shorts to ground or power. If the wiring is OK, the control module may be faulty.

To check MAP/BP sensor with oscilloscope:

1. Connect center wire to scope, set scope to "Voltage Pattern"
2. Apply vacuum to sensor port with vacuum pump.
   - Look for: time from one square wave pattern to the next
   - With 1000 ms in one second, dividing the time of one pulse will tell you the frequency of the pulses—how many per second
   - No vacuum: 6.25ms; 1000 divided by 6.25 = about 155 Hz frequency
   - Full vacuum: 10.8ms; 1000 divided by 10.8 = about 93 Hz frequency

If necessary, correct readings for altitude above sea level. Remember, other factors can cause faulty MAP output. If excess EGR is delivered into the intake manifold the sensor "sees" pressure beyond its normal compensation.

> **NOTE —**
> Tip from the field: This is the only place where "try a known good part" may diagnose a bad MAP sensor. They're almost interchangeable. Try a replacement if the MAP tests OK but the problem persists.

3.3 Volume Air Flow (VAF) Sensor

Be particularly aware of "false air," unmeasured air that enters the engine without passing through the VAF, causing lean mixtures. Check ducting between the VAF and the throttle body, vacuum leaks from vacuum-operated devices, and engine sealing, PCV, CANP, valve-cover seal, even the seating of the dipstick. The following procedure gives the basic steps for troubleshooting a code. See also Chapter 12.

To check VAF sensor:

1. Key OFF, wait 10 seconds.
2. Remove the air cleaner ducting so you can see the VAF inlet.
3. Press on the vane with your finger, full open and release slowly to close.
   - Look for: smooth free movement, with just a light touch. Your fingertip will sense if the vane is binding
   - If the interior is dirty, spray carburetor cleaner on a cloth and pass it through the VAF to remove oily film buildup. Do not spray carb cleaner in the VAF. Retest for freedom of movement. If you still feel binding, replace the VAF
4. Check VAF Output.
   - Backprobe or install BOB and connect control module
   - Place a unsharpened pencil as shown in Fig. 3-4
   - DVOM on 20 scale
   - Key ON. Do not run engine
   - Measure voltage between VAF and SIG RTN
   - Look for: 2.8 to 3.7v
5. If not, check VAF connector pins and VREF to sensor. If still not OK, replace VAF.

Fig. 3-4. Place a pencil through the VAF to deflect the vane. Measure the voltage output. Shown is 2.2L Turbo.

3.4 Measuring-Core Volume Air Flow (MC-VAF) Sensor (2.5L V-6)

To check MC-VAF sensor:

1. Check the sensor for cracks and damage.
2. Gently push back the sliding core; verify smooth motion.
3. Measure resistance across terminals shown in Fig. 3-5. See **Table f** for test values.

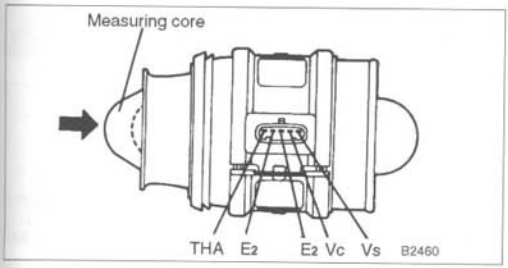

Fig. 3-5. Measuring-core air flow sensor. Measure resistance values at about room temperature, 70°F.

Table f. MC-VAF Sensor Test Values

Terminals	Resistance (Ohms)
E_2 and Vs	20–600 Closed 20–1,000 Open
E_2 and Vc	200–400 Open or Closed
E_2 and THA (Intake Air Temp)	2,000–3,000 at room temp.

4. Checking Ignition System

With electronic ignitions such as Thick Film Ignition (TFI), we got rid of points and condensers. With Distributorless and Electronic Distributorless Ignition Systems (DIS/EDIS), we got rid of distributors. With fewer moving parts and virtually nothing to wear or change tolerances, these ignition systems give less trouble.

That doesn't mean that things don't go wrong. Early TFI-IV modules fail. DIS and EDIS Hall magnets break when the vane strikes the magnet. DIS modules loosen and vibrate in the mounting. A few EDIS modules and VRS have been known to break. On EDIS engines, water can get into the connector and short the pins, the VRS can become disconnected or dislodged, or the module can fail.

In addition, some traditional parts need routine checking, such as ignition coil resistance, or replacement, such as plug wires, or the distributor cap and rotor (TFI-IV only). And there can be occasional problems with the other system components. So just in case, I'll show you examples of several troubleshooting tests for Ford systems. Additional diagnostics tests are given in Chapter 12.

On the Vehicle Emission Control Information (VECI) decal, you'll read about the list of items not adjustable, including ignition timing. But the VECI decal will list the base, or initial timing. In troubleshooting, you can check initial timing and computed timing advance to see if timing is responsible for a complaint, and what you should replace if it is.

4.1 Pre-checks

Your first job is to verify which system is on the car you are servicing.

- Most Ford EEC systems of the 1980's use the TFI-IV, and many of those use Computer-Controlled Dwell (CCD). I'll describe two simple tests for TFI-CCD
- Beginning recently, you'll find coil packs on EEC engines but no distributor. These are classed as DIS
- Beginning in the '90s, in the newer engines, you'll find EDIS

11

Begin with a visual inspection. Check that all plug wires are properly routed and secure. Be sure plug wires are not lying directly together but are separate and secure in their clamps.

Check spark plug condition. If you have one or more wet plugs, in addition to checking for leaking injectors, check spark quality. Hook up your spark tester or engine analyzer/scope.

Check wiring harnesses and connectors for insulation damage, loose connections, burned or broken connectors. Check that the battery charge indicator shows OK. All accessories OFF, engine at normal temperature, Transmission in P (automatic) or N.

4.2 Thick Film Ignition (TFI-IV)

If you receive trouble codes relating to the TFI-IV ignition system, basic questions you might want to ask are:

- Is the Hall sender in the distributor generating a Profile Ignition Pickup (PIP) signal? See Fig. 4-1. If not, check that the Hall sender in the distributor has power and ground. If so, then the sender is probably faulty
- Is the control module receiving the PIP signal? Check for wiring continuity from the TFI module to the control module
- Is the control module generating the correct Spark Output (SPOUT) signal to control ignition timing? If not, then either the wiring or the control module is likely faulty

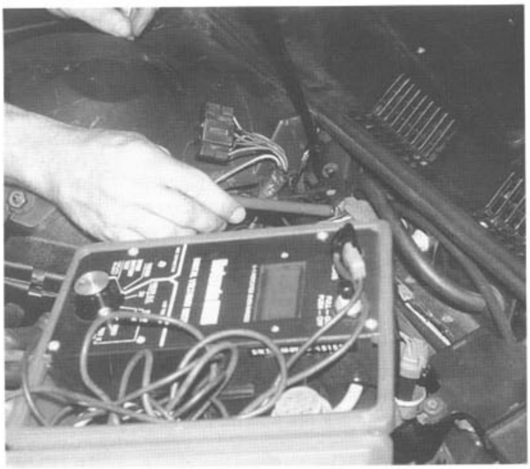

Fig. 4-1. Check for cranking and running PIP signal at the TFI-IV module (some modules are mounted on the distributor, some are mounted on the engine cowl).

The tests below check basic timing and timing advance control by the EEC module (SPOUT). See Chapter 12 for additional TFI-IV electrical tests of PIP, SPOUT, and the TFI module.

To check initial timing:

1. Connect a timing light.
2. Disconnect the in-line SPOUT connector near the TFI module.
3. Check initial timing using a timing light. It should be within 3 degrees of base timing value on the VECI decal. If base timing is specified as 10 deg. BTDC, 7 to 13 is OK.
4. If not, adjust timing of TFI-IV distributor:
   - Loosen distributor mounting-bolts
   - Rotate distributor to correct timing
   - Tighten bolts

To check spark-timing advance:

1. Key OFF.
2. Disconnect the in-line SPOUT connector near the TFI module.
3. Attach negative (–) lead of VOM to the distributor base.
4. Start the engine.
5. Measure battery voltage with engine running.
6. Measure voltage on test-pin side of the in-line TFI connector. See Fig. 4-2.
   - Look for: voltage 30–60 percent (4.2–8.4v) of battery voltage measured in previous step

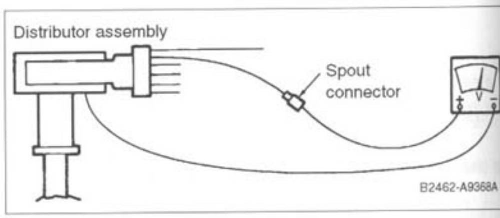

Fig. 4-2. Checking TFI-IV timing signal at SPOUT connector.

7. If not, check the wiring to the TFI module. See Fig. 4-3.
   - Look for: less than 5 ohms indicating wiring is OK
   - If not, fix wiring and retest
   - If wiring OK, the TFI module is internally damaged

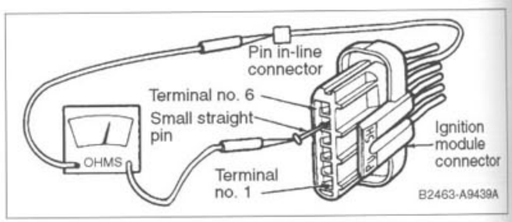

Fig. 4-3. Checking wiring continuity of SPOUT circuit.

To check computed timing in Self-Test:

1. If code 18/213 appears in ER Self-Test, SPOUT circuit is open.

NOTE —
Self-Test locks computed timing at base timing plus about 20 (17 to 23) degrees for 2 minutes after last code output. During those 2 minutes, check computed timing with timing light.

2. Disconnect in-line SPOUT/SAW connector.
3. Engine idling. Reconnect SPOUT/SAW connector.
   - Look for: Timing change when connection is replaced
   - If not, then either the wiring or the control module is faulty

4.3 Distributorless Ignition System (DIS/EDIS)

Procedures for checking DIS timing are similar to TFI. Use the right coil pack, on the exhaust side of the engine. Locate the Spark Output/Spark Angle Word (SPOUT/SAW) disconnect next to the Ignition Diagnostic Monitor (IDM) at the coil.

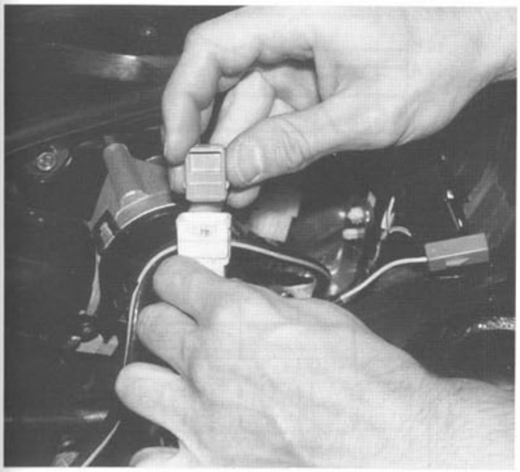

Fig. 4-4. Spark Output/Spark Angle Word (SPOUT/SAW) connector for DIS/EDIS) is located near the coil.

If you receive trouble codes relating to DIS ignition, basic questions you might want to ask are:

- Is the crankshaft sensor generating a Profile Ignition Pickup (PIP) signal? If not, check that the sensor has power and ground. If so, then the sensor is probably faulty
- Is the control module receiving the PIP signal? Check for wiring continuity from the crankshaft sensor to the control module. See Fig. 4-5
- Is the control module generating the correct Spark Output (SPOUT) signal to control ignition timing? If not, then either the wiring or the control module is likely faulty
- Is the control module receiving the IDM signal? If not, then either the DIS module or the wiring is faulty
- Does the DIS module have power and ground?
- Is the DIS module providing power to the ignition coil(s)?

For example, Code 18 Engine Running or 18/212 Continuous indicates a SPOUT/SAW failure (IDM circuit failure or SPOUT circuit grounded). Basically, the control module is indicating that it lost IDM input. Possible causes are: open circuit, shorted circuit, damaged DIS/EDIS module, or a damaged control module.

See Chapter 12 for DIS/EDIS electrical tests of PIP, SPOUT, IDM and the DIS/EDIS module.

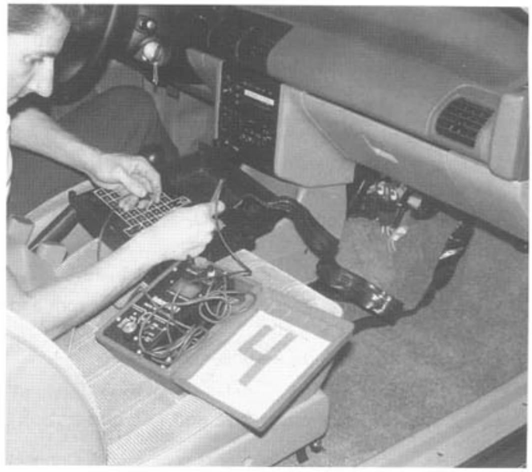

Fig. 4-5. Check DIS/EDIS inputs to EEC control module (PIP, IDM) at control module connector using BreakOut Box (BOB).

4.4 Mazda Engine Control System (MECS) Ignition

Mazda Engine Control System (MECS) equipped vehicles use an ignition system similar to TFI-IV. On some models, advance is handled by flyweights and a vacuum diaphragm at the distributor.

If you receive trouble codes relating to the MECS ignition system, basic questions you might want to ask are:

- Is the Crankshaft Position Sender in the distributor generating a Profile Ignition Pickup (PIP) signal? If not, check that the sender in the distributor has power and ground. If so, then the sender is probably faulty
- Is the control module receiving the PIP signal? Check for wiring continuity from the ignition module to the control module

- Is the control module generating the correct Spark Output (SPOUT) signal to the ignition module (not all models)? If not, then either the wiring or the control module is likely faulty

The tests below check basic timing and timing advance control. See Chapter 12 for additional MECS electrical tests of PIP, SPOUT, and IDM.

2.2L Non-Turbo and 1.6L Turbo and Non-Turbo

To check timing:

1. Check vacuum supply. Remove vacuum-delay valve. Apply 25 in.Hg. to green side.
   - Look for: vacuum-delay valve holds vacuum for 10–20 seconds. If not, replace valve
2. Check base timing.
   - Plug vacuum hoses
   - Ground STI connector.
   - At idle, all loads OFF, check base timing
   - Look for: 2.2L turbo 5–7° BTDC, 1.6L non-turbo 1–3° BTDC 1.6L turbo 11–13° BTDC
3. Check centrifugal advance. Slowly advance rpm and note timing per Fig. 4-6.
   - If not OK, centrifugal weights may be faulty

To check vacuum diaphragm (2.2L and 1.6L non-turbo):

1. Check vacuum advance/retard, engine idle. Connect vacuum tester to vacuum diaphragm. Apply vacuum to Chamber A, and note timing. See Fig. 4-7.
2. Apply vacuum to Chamber B, and note timing.
   - If not OK, replace vacuum diaphragm

To check vacuum diaphragm (1.6L Turbo):

1. Apply vacuum to advance diaphragm and note timing. See Fig. 4-8.
2. Apply pressure (10 psi MAX) to advance diaphragm and note timing.

If not OK, replace vacuum diaphragm.

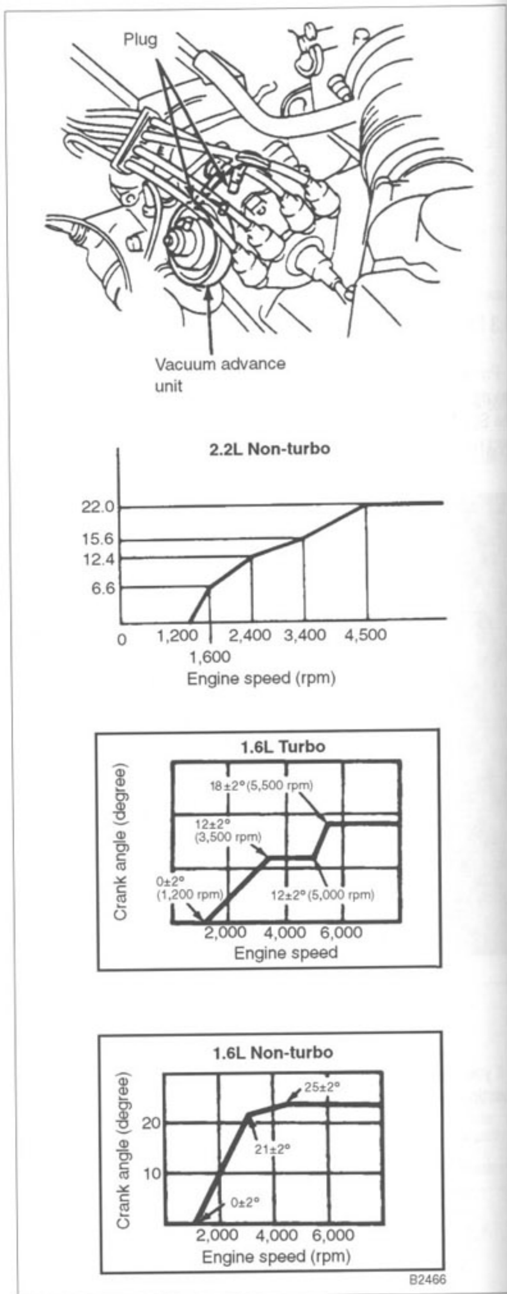

Fig. 4-6. Check centrifugal advance.

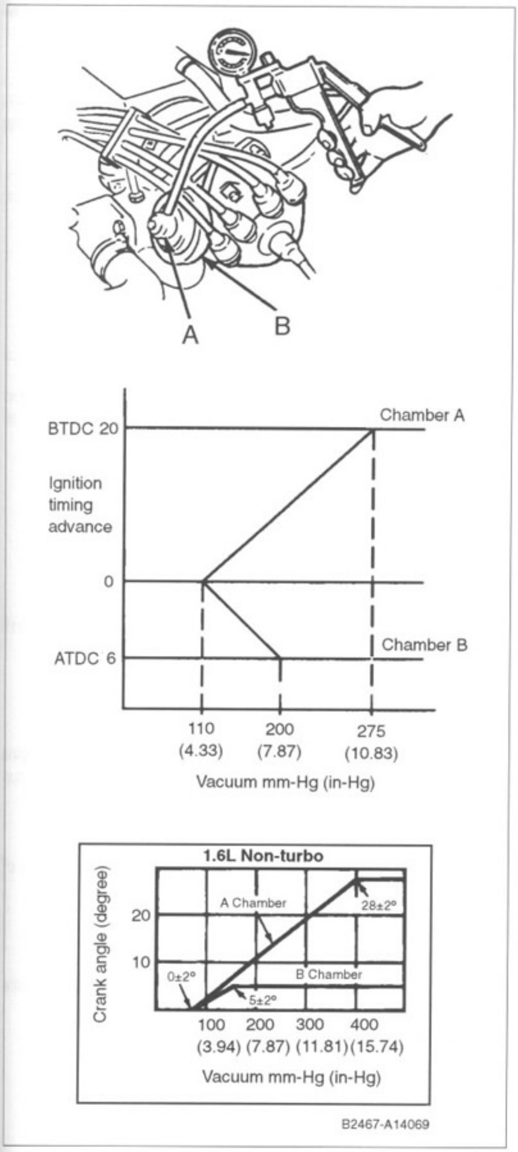

Fig. 4-7. Check vacuum diaphragm, 2.2L Turbo and non-Turbo, 1.6L non-Turbo.

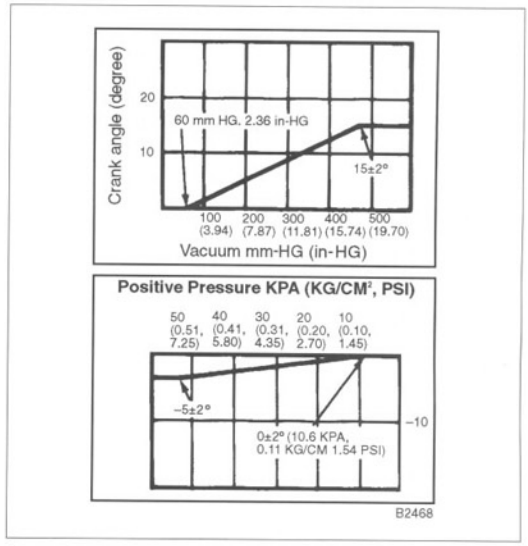

Fig. 4-8. Check vacuum diaphragm, 1.6L Turbo.

1.3L, 1.8L, 2.2L Turbo

These MECS engines feature Electronic Spark Advance (ESA) controlled by the computer.

To check base timing:

1. Warm engine, idle.
2. Ground Self-Test Input (STI) connector. See Chapter 10 for location.
   - Look for: base timing 9–11°, except 2.2L Turbo, 8–10°

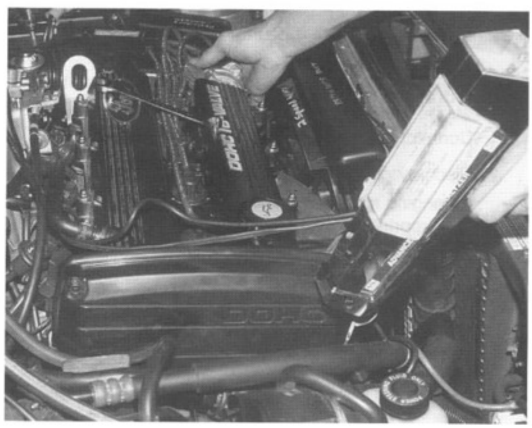

Fig. 4-9. Check timing on MECS 1.8L with Electronic Spark Advance (ESA).

5. Checking Idle RPM (Throttle-Air Bypass–ISC)

Idle rpm is controlled by a bypass valve that allows air to bypass the closed throttle plate. See Chapter 12 for additional Idle Speed Control (ISC) tests.

5.1 Idle Speed (EEC-IV)

Pre-checks

Improper idle rpm can be the result of non-EEC problems, including: Engine cool, or too hot, A/C input, throttle sticking, linkage binding, Speed Control linkage.

The following Throttle-Air Bypass Pinpoint tests will help diagnose:

- RPM in Self-Test
- ISC solenoid
- Harness circuits, ISC and VPWR
- Control module

Self-Test RPM Limit Codes

An Upper Limit trouble code (12/412) indicates that engine rpm could not be controlled within the Self-Test upper limit during ER test. Possible causes include:

- Open or shorted circuit
- Throttle linkage binding
- Improper idle set
- Contamination of throttle body or bypass–ISC (throttle body sludge)
- Faulty ISC solenoid
- Faulty control module

Begin checking with an rpm drop test.

To rpm drop test:

1. Connect a shop tachometer and start the engine.
2. Disconnect the ISC-BPA harness connector.
   - If engine rpm drops, check for EGR codes, and run appropriate tests by symptom
   - If engine rpm does not drop, and no EGR codes, check for other EEC codes, and see appropriate tests by symptom
   - If no EGR or EEC codes, see Step 3
3. Measure ISC-BPA solenoid resistance as shown in Fig. 5-1.
   - Look for: 7–13 ohms
   - If not, replace the ISC-BPA
   - If OK, continue with additional checks outlined below

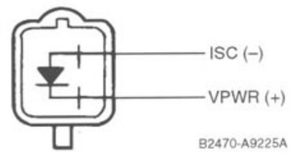

Fig. 5-1. Check ISC-BPA solenoid resistance. Solenoid has a diode, so measurement should be as shown, with DVOM (+) lead on VPWR pin.

4. Check for internal short to ISC solenoid case.
5. Check VPWR circuit voltage.
6. Check ISC circuit continuity.
7. Check ISC circuit for short to ground.
8. Check ISC circuit for short to power.
9. Check for ISC signal from the control module.
10. Check base idle as described below.

A Lower Limit trouble code (13/411) indicates that engine rpm could not be controlled within the Self-Test lower limit during ER test. Possible causes include:

- Improper idle set
- Vacuum leaks
- Throttle linkage binding
- Throttle plates open
- Improper ignition timing (TFI vehicles)
- Contamination of throttle body or bypass-ISC (throttle body sludge)
- ISC circuit short to ground
- Faulty ISC solenoid

Tests for this condition include:

1. Check idle rpm.
2. Check for internal short to ISC solenoid case.
3. Check ISC circuit for short to ground.
4. Check control module output signal.

Setting Idle Speed (EEC-IV)

Under normal use, the idle speed will not need adjustment. If, as a result of parts replacement, idle rpm is out of spec, the idle-speed stop screw may need adjustment. You may also be setting idle speed from a diagnosis of rough idle, or fast idle.

Remember that idle rpm can be affected by several factors outside the EEC system:

- Contamination within throttle bore, or within Throttle-Air Bypass-ISC (sludge)
- Oxygen sensor
- Throttle sticking
- Vacuum leaks
- Ignition timing

> **NOTE —**
> To reduce intake sludge in the throttle body, a sealant/coating covers the inside of the throttle bore and the throttle plate(s) on all '92 and later vehicles and some previous models. Look for the black/yellow attention sticker. DO NOT CLEAN inside a coated throttle body. The ByPass Air valve is not coated and may need cleaning.

Pre-checks

- Engine warm, transmission in P or neutral
- Parking brake applied and wheels chocked
- Heater and all accessories off
- Throttle lever resting on the throttle-plate stop screw
- Quick Test, all codes serviced
- KAM cleared: disconnect battery for 5 minutes

To check idle speed:

1. Idle engine 2 minutes.
2. Goose engine, return to idle.
3. Gently press accelerator and release.

> **NOTE —**
> If electric cooling fan comes on, wait until it shuts off; otherwise, the generator load may affect the idle rpm.

- Look for: idle rpm to spec as shown on Vehicle Emission Control Information (VECI) decal
- If engine does not idle properly, follow procedures according to vehicle model

> **NOTE —**
> - Some vehicles have provisions for Self-Test Idle-Speed check. These include: 2.3L car, 3.0L (except SHO), 3.8L, 3.8L SC, 4.0L, 4.6L, 4.9L, 5.0L E4OD, 5.0L HO (T-Bird or Cougar), 5.8L. For these, your scan-tool output will guide you to the need to adjust base rpm. See Procedure A for typical steps.
>
> - Some vehicles have no provision for Self-Test Idle-Speed Check. These include: 2.3L truck, 2.9L, 3.0L SHO, 3.2L SHO, 3.0L truck, 5.0L non-E4OD, 5.0L Mustang or Mark VII. See Procedure B for typical steps.

- In some vehicles, idle rpm is not adjustable. These include: 1.9L SFI Escort/Tracer (730–830 rpm), 3.2L SFI Taurus SHO (720–780 rpm), 4.0L MFI Aerostar/Ranger/Explorer, 4.6L 4V Mark VIII.

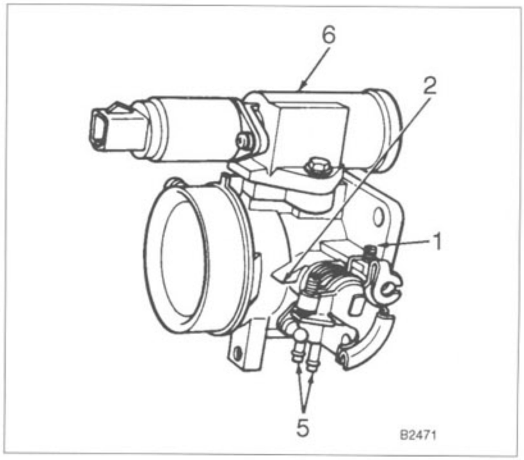

Fig. 5-2. Typical throttle body showing idle speed adjustment screw (**1**).

The following is the typical procedure for setting idle speed using a scan tool. The procedure for a specific engine may differ slightly.

To set base idle speed (Procedure A):

1. Using your scan tool, activate Engine Running Self-Test as described in Chapter 10.
2. After code 11 is displayed, quickly (within 4 seconds) latch and unlatch the tester button.
   - Look for: constant tone/solid light/STO LO indicating base idle OK

3. If not OK, check for problems listed under **Self-Test RPM Limit Codes** above.
4. Next, adjust idle speed by turning the throttle stop screw shown in Fig. 5-2 above until tone/light/STO LO is correct.
5. Open throttle to 1500 rpm for 10 seconds, then recheck base idle speed.

To set idle speed (Procedure B):

Below is the typical procedure for a 5.0L HO Mustang or Mark VII (idle speed specified to be 625–725 rpm). The procedure for other engines may differ slightly.

> ***CAUTION —***
> *Do not use this procedure with 5.0L HO in Thunderbird or Cougar.*

1. Disconnect the negative battery terminal for 5 minutes to clear KAM, then reconnect.
2. With engine OFF, install feeler gauge 0.025" between the throttle plate idle stop-screw and the throttle lever. See Fig. 5-2 above.
3. Run engine at 2500 for about 30 seconds.
   - If rpm too low, check for plate orifice-plug
   - If plug in from previous service, remove plug
4. Turn screw to adjust to 650–700 rpm.
   - If rpm too high, turn engine off and disconnect air-cleaner hose
5. Block off orifice in throttle plate. See Fig. 5-3.
   - If no plug, reattach hose from MAF and recheck rpm
   - If engine stalls, crack open plate with stop screw
   - If throttle plate has orifice plug, remove the plate and install plug with proper color code, depending on orifice size

> **NOTE —**
> Select the proper plug by using the Go/NoGo gauge pegs in the service kit FOPZ-9F652-A.

6. Recheck rpm to 650–700 rpm. Turn plate stop screw only clockwise. If you turn counterclockwise, throttle plate may stick at idle.
7. Remove feeler gauge. Key OFF, restart, Idle for 2 minutes.
8. Engine off. Disconnect battery for 10 minutes.
9. Run KOEO Self-Test for proper TPS output code.
10. Start engine. Run 2 minutes. Goose engine, return to idle. Gently press accelerator. Return to idle. Recheck to verify that idle problem is cured, and rpm is within spec.

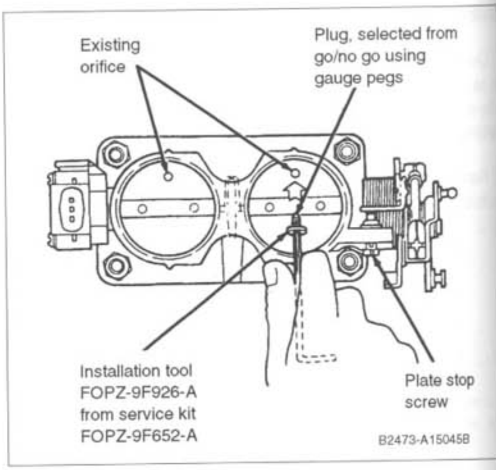

Fig. 5-3. If necessary, install plug in throttle plate orifice. (Dual throttle plates shown.) Notice plate stop-screw.

This should result in proper EEC operation for idle rpm; if not, check other causes listed above. If rpm is not within limits, Neutral, A/C OFF, look for other possible causes. If none, replace the throttle body.

5.2 Idle Speed (MECS)

Remember, Mazda Engine Control (MEC) systems increase idle rpm with two bypasses: one "warm-up" bypass is directly dependent on engine coolant temperature. The other "engine-load" ISC bypass is computer-controlled for engine load changes that affect idle rpm. Checking improper idle rpm is a two-part process. I'll look first at the BPA that functions for warm-up. It is controlled only by coolant flow so you will not see trouble codes. The BPA valve is packaged with the ISC valve, except on 1.8L engines, where it is separate. See also Chapter 12 for additional ISC electrical tests.

Coolant-Controlled BPA

Consider three possibilities that could cause idle problems:

1. The cold engine starts hard, then stalls, but runs OK once warm. The BPA coolant-controlled valve could be stuck closed.
2. The warm engine races at idle. The valve could be stuck open, or the warm coolant flow could be clogged.
3. The cold engine stalls and the warm engine races. The valve could be stuck in the middle.

First, visually inspect the coolant and air hoses. Be sure the engine warms up. Check the base-idle speed as described in the VECI decal.

To check for cold-engine stall:

1. Remove the BPA valve; If it is warm from the engine, cool it in cold water.
2. Blow through the air passage.
   - If you cannot blow through, the valve is stuck closed. Replace the valve

To check for warm-engine fast-idle:

1. Remove the BPA valve, and cool it in cold water, if necessary.
2. Blow through the air passage.
   - If you can blow through, the valve is not stuck closed. But it may be stuck part-way open
3. Run hot water through the coolant passages, at least 55°C (130°F).
4. Blow through the air passages.
   - If it's easier to blow through warm than cold, the valve is not stuck. If the valve is not stuck, check the ISC solenoid

ISC Valve Solenoid

1. Disconnect the ISC valve connector.
2. Measure the resistance of the solenoid.
   - Look for: resistance between 6.3–9.9 ohms
   - If not, replace the solenoid
   - If OK, the problem is probably incorrect input from a temperature sensor. It may also be incorrect processing in the control module

Setting Idle Speed (MECS)

To set idle speed:

1. Warm engine. All accessories off. Connect tachometer.
2. Check ignition timing to spec, 11–13° BTDC.
3. Ground Self-Test Input (STI) (TEN pin on engines with Data Link Connector).
   - Look for: 650–750 rpm
   - If not, adjust by turning air-adjusting screw, as in Fig. 5-4

NOTE —
Adjustment screw for 2.2L trims air flow rather than acting as adjustable hard stop.

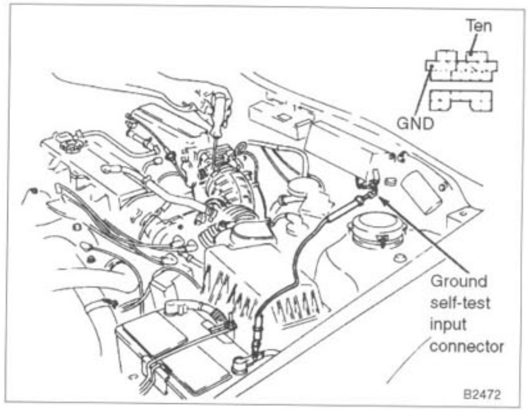

Fig. 5-4. Adjust MECS idle by turning adjusting screw next to throttle body. 2.2L shown; others similar.

6. Checking Temperature Sensors

Engine Coolant Temperature (ECT), Air Charge Temperature (ACT), and Vane Air Temperature (VAT) sensors provide an important input for calculation of the air-fuel mixture. If they're out of whack, you may have serious driveability, or even starting problems in cold weather. These thermistor sensors are quite similar and can be tested the same way. With this test, I'll show you the typical way to check the sensors, the harness circuit and the control module. Full specifications are given in Chapter 12.

Pre-checks

Be sure you have an engine control problem, indicated by Quick-Test trouble codes. Codes usually mean the sensor is outside its Self-Test range, normally 0.3 to 3.7 v.

Remember that the problem may not be with the sensor. You may get a code because of engine underheat/overheat. Don't forget to check engine coolant level, engine temperature, and the thermostats.

You would think you could just measure the resistance at any temperature. But Ford wants you to check these things reasonably warm:

- ACT or VAT in the KOEO test, more than 10°C (50°F)
- ECT in the KOEO test, more than 10°C (50°F)
- ECT in the ER test, more than 85°C (180°F)

The ACT and ECT temperature sensors connect through a common SIG RTN.

Check VREF Voltage

One of the first possibilities to consider is that the sensor is not supplied with the proper reference voltage (VREF). A convenient place to check is the Throttle Position Sensor (TPS).

1. After the key has been OFF at least 10 seconds, disconnect the TPS.
2. Key ON, measure voltage between VREF and SIG RTN at the TPS connector. See Chapter 12 for specifications.

Check Resistance—Engine Off

ECT/ACT resistances vary with temperature. Calculated from Ford specs, allow 15% variation for sensors.

1. After the key has been OFF for at least 10 seconds, disconnect the sensor you think is the problem.
2. Measure the resistance between the sensor signal circuit and SIG RTN. See Chapter 12 for Specifications.
   - If sensor is out of spec, replace the sensor. Reconnect the harness and re-run the Quick Test
   - If sensor is in spec for KOEO, check resistance with Engine Running

Check Resistance—Engine Running

Remember, coolant temp above 85°C (180°F).

1. With suspect sensor disconnected, run engine for 2 minutes at 2000 rpm.
2. Measure resistance as in step 2 above.
   - If sensor is out of spec, replace the sensor
   - If sensor is in spec, check wiring continuity to the control module. If the wiring is OK, replace the control module and re-run Quick Test

Chapter 12

Trouble Codes, Electrical Tests, and Wiring Diagrams

Contents

1. Introduction

These electrical tests and wiring diagrams will help you in your diagnosis and troubleshooting. Use them along with the diagnosis and troubleshooting procedures detailed in Chapter 10 and Chapter 11.

The information can help you answer the question, when there is a trouble code, whether the component, the wiring, or the control unit is at fault.

For example, let's say that during diagnosis, you run Quick Test and get a trouble code 21 or 116. This means that there is a fault in the Engine Coolant Temperature (ECT) circuit. Using the electrical tests and the wiring diagrams, you can check ECT resistance, you can check voltage in the circuit with Key On Engine Off (KOEO), and you can check wiring harness continuity from the ECT to the control unit. See Fig. 1.

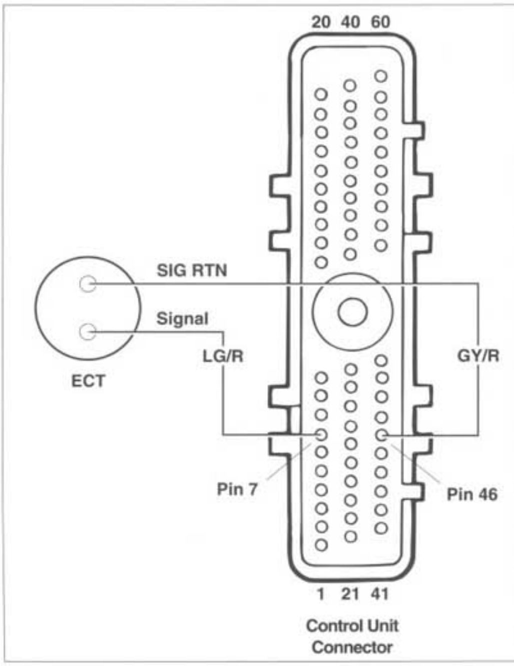

Fig. 1-1. Schematic diagram of a typical Engine Coolant Temperature (ECT) sensor circuit. Disconnect harness connector from sensor to test sensor resistance. Disconnect control unit connector to check wiring continuity to sensor connector.

CAUTION —
Do not probe harness connectors from the front. The connector sockets may be damaged by the probe. Test only by using an appropriate breakout box (BOB) or by backprobing the connector.

The electrical tests and wiring diagrams are divided into two parts, by engine control system. As I've discussed, most Ford/Lincoln-Mercury vehicles operate with Ford EEC-IV systems, while most Probes, Escort/Tracers with 1.8L engines, Capri and Festiva use MECS. The first part is for all 1988 and later Ford and Lincoln-Mercury vehicles employing EEC-IV electronic engine control systems. The second part is for all 1989 and later Ford vehicles employing Mazda Engine Control System (MECS).

1.1 Terminology

Beginning in 1993, some of the names of the engine-control components were changed to comply with the SAE standardization J1930, in order to provide common terms for the same general part throughout the automotive industry. For more information on terminology changes, see Chapter 1. This chapter uses the terminology applicable for the years 1988–1992. For reference, **Table a** lists those terms and their equivalents that changed in 1993.

Table a. 1993 and Later J1930 Terms

1988–1992 Term	1993 Equivalent
Air Charge Temperature (ACT)	Intake Air Temperature (IAT)
Barometric Pressure (BP)	BARO
Check Engine Light (CEL)	Malfunction Indicator Light (MIL)
Control Module/Electronic Control Assembly (ECA)	Powertrain Control Module (PCM)
Crankshaft Position Sensor (CPS)	CKP
Distributorless Ignition System (DIS)	Electronic Ignition (EI)—Low Data Rate
DIS / EDIS / TFI Module	Ignition Control Module (ICM)
Electro-drive Fan (EDF)	Low Fan Control (LFC)
Electronic Distributorless Ignition (EDIS)	Electronic Ignition (EI)—High Data Rate
Heated Exhaust Gas Oxygen (HEGO)	Heated Oxygen Sensor (HO2S)
High-speed Electro-drive Fan (HEDF)	High Fan Control (HFC)
Idle Speed Control (ISC)	Idle Air Control (IAC)
Inertia Switch (IS)	Inertia Fuel Shut-Off Switch (IFS)
Intake Air Control (IAC)	Intake Manifold Runner Control (IMRC)
Integrated Relay Control Module (IRCM)	Constant Control Relay Module (CCRM)
Profile Ignition Pickup (PIP)	CKP
Self-Test Connector (STC)	Data Output Line (DOL)
Self-Test Output (STO)	Data Link Connector (DLC)

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Table a. 1993 and Later J1930 Terms (cont'd)

1988–1992 Term	1993 Equivalent
Spark Angle Word (SAW)	Spark Output (SPOUT)
Thermactor Air–Bypass (TAB)	Air Injection Reaction Bypass (AIRB)
Thermactor Air–Diverter (TAD)	Air Injection Reaction Diverter (AIRD)
Thick Film Integrated-IV (TFI-IV) Ignition	Distributor Ignition (DI)
Vane Air Temperature (VAT)	Intake Air Temperature (IAT)
Variable Reluctance (VRIS)	Crankshaft Position (CKP)

1.2 Using the Trouble Code Tables

As you saw in Chapter 10, all Ford vehicles store and read out trouble codes—numerical representations of faults detected in the engine control system. The trouble code tables will tell you what the numbers mean.

For example, a 2-digit numerical code **21** indicates that when the control module tested the Engine Coolant Temperature sensor (ECT), it found that ECT resistance was not what was expected (out of Self-Test range).

Earlier Ford vehicles with EEC-IV engine control systems have 2-digit trouble codes. More current EEC-IV systems have more complex engine controls. They need 3-digit codes to cover all of the complexities. All Ford vehicles with Mazda Engine Control Systems (MECS) have 2-digit trouble codes.

1.3 Using the Electrical Tests

The electrical tests are arranged in alphabetical order, by component or system repair group acronym. Thus for a trouble code indicating an ECT circuit fault, you would turn to the electrical test repair group with the head **ECT**.

Each electrical test repair group contains information on circuit operation, troubleshooting, component location, wire color, and electrical test results (voltage or resistance). For pin out numbers (the control unit terminals where the wires lead), see the applicable wiring diagram for the engine.

1.4 Using the Wiring Diagrams

The wiring diagrams are arranged by engine family and year, with model differences noted where applicable. Vehicle Identification Number (VIN) codes help you further determine which is the correct diagram for your engine. Where engines may be the same from one year to the next, they are covered by one diagram.

Remember that Ford engines with a similar displacement may have a different air flow sensor type, either Mass Air Flow (MAF) or Manifold Air Pressure (MAP). The MAF sensor is clearly visible, while the MAP sensor is usually on the bulkhead. Some engines are also Sequential Fuel Injection (SFI), but you cannot tell sequential-injection engine controls from the outside. To know whether the engine is SFI you must check the VIN code. The VIN check digit is usually the **8th** digit. See Fig 1-2.

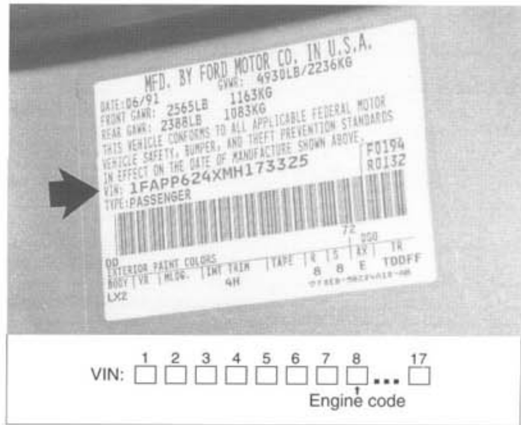

Fig. 1-2. VIN, shown here on door jamb, will help you identify engine in your car. Look for eighth digit in VIN.

In a few cases, the installation of Automatic Transmissions or Transaxles makes a difference. Look for Automatic Transaxle OverDrive Electronic (AXODE), Electronic 4-speed OverDrive (E4OD), and 4-speed Electronic Automatic Transaxle (4EAT). All of these differences are noted in the wiring diagram header.

For 1988-92 Mazda Engine Control System (MECS) vehicles, look for the Vane Air Flow (VAF) sensor. I caution you again that on the 1993 and later Probe 2.0L with automatic transaxle (4EAT) you'll find MECS, while with manual (MTX) you'll find EEC-IV.

Notice the form of the wiring diagrams differs slightly. Beginning in 1992, diagrams are simplified, eliminating the wires to the connectors, but all pin outs are still numbered to help you in your troubleshooting.

Finally, remember that engines that look the same outside can operate with different engine controls. They can even be different displacements, as with 3.8L and 3.0L, so be sure of the engine size and fuel injection type in your vehicle before you begin any servicing.

2-Digit Trouble Codes (EEC-IV)

EEC-IV 2-Digit Trouble Codes

Code	Conditions			Definition
11	O	R	C	System PASS
12		R		Cannot control rpm during ER Self-Test high rpm check
13		R		Cannot control rpm during ER Self-Test low rpm check
14			C	PIP circuit failure
15	O			EEC [PCM*] Read Only Memory (ROM) test failed
			C	EEC [PCM*] Keep Alive Memory (KAM) test failed
16	O			Ignition Diagnostic Monitor (IDM) signal not received
		R		RPM too low to perform HEGO [H02S*] test
17		R		RPM below Self-Test limit with ISC off
18		R		SPOUT circuit open or Spark Angle Word (SAW) circuit failure
			C	Loss of tach input / IDM circuit failure / SPOUT circuit grounded
19	O			Failure in EEC [PCM*] internal voltage
		R		RPM erratic, dropped too low during test
			C	Cylinder Identification (CID) circuit failure
21	O	R		ECT out of Self-Test range
22	O	R	C	MAP/BP [BARO*] out of Self-Test range
23	O	R	C	TP out of Self-Test range
24	O	R		ACT [IAT*] or VAT input out of Self-Test range
25		R		KS signal is not sensed in Dynamic Response Test
26	O	R		MAF or VAF input out of Self-Test range Transmission Oil Temperature (TOT) sensor out of Self-Test range (4.9L, 5.0L truck)
28	O	R		VAT sensor out of Self-Test range
			C	Loss of primary tach (IDM)—right side
29			C	Insufficient input from the Vehicle Speed Sensor (VSS)
31	O	R	C	EVP or PFE circuit below minimum voltage
32		R		EGR not controlling (2.3L MAP)
		R	C	EGR valve not seated
	O	R	C	EVP voltage below closed limit (SONIC) / EPT circuit voltage low (PFE)
33		R	C	EGR valve opening not detected
34		R		EGR valve opening not detected (2.3L MAP)
	O	R	C	Insufficient EGR flow / Excessive exhaust back pressure; or EVP voltage above closed limit (SONIC) / PFE sensor voltage high or out-of-range
KEY: O = Key On Engine Off (KOEO), R = Engine Running (ER), C = Continuous Memory				

*1993 and later terminology

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2-Digit Trouble Codes (EEC-IV)

EEC-IV 2-Digit Trouble Codes (continued)

Code	Conditions			Definition
35		R		RPM too low for EGR test (2.3L MAP)
	O	R	C	EVP / PFE circuit above maximum voltage
39			C	AXOD converter bypass clutch not applying properly
41		R		HEGO [H02S*] circuit indicates system lean (right H02S)
			C	No HEGO [H02S*] switch detected—always lean (right H02S)
42		R		HEGO [H02S*] circuit indicates system rich (right H02S)
			C	No HEGO [H02S*] switch detected—always rich
43			C	HEGO [H02S*] lean at wide open throttle
44		R		Secondary Air Injection system inoperative (right side)
45		R		Secondary Air Injection upstream during Self-Test
			C	DIS coil pack 3 circuit failure or Coil 1 primary circuit failure
46		R		Secondary Air Injection not bypassed during Self-Test
			C	DIS coil pack 1 circuit failure or Coil 2 primary circuit failure
47	O			4 x 4 switch is closed (E4OD)
		R		Measured air flow low at base idle
48		R		Measured air flow high at base idle
			C	DIS coil pack 2 circuit failure or loss of secondary tach (IDM)—left side; Coil 3 primary circuit failure
49			C	SPOUT signal defaulted to 10 degrees BTDC or 1-2 shift error (E4OD)
51	O		C	ECT sensor fault or circuit open
52	O			PSPS [PSP*] circuit is open
		R		PSPS always staying open or closed
53	O		C	TP circuit above maximum voltage
54	O		C	ACT [IAT*] or VAT sensor fault, circuit open
55		R		Key power input to processor is open
56	O		C	MAF or VAF circuit above maximum voltage TOT sensor failure or circuit grounded (4.9L truck)
57	O			Octane Adjust service pin in use / circuit grounded
			C	AXOD Neutral Pressure Switch NPS circuit failed open
58	O		C	VAT indicated -40° F/ circuit open (1.9L VAF)
59	O			AXOD 4/3 pressure switch circuit failed closed or Idle adjust service pin in use (2.9L MAP)
	C		C	AXOD 4/3 pressure switch circuit failed open or 2-3 shift error (E4OD)
	O		C	Low speed fuel pump circuit failure

KEY: O = Key On Engine Off (KOEO), R = Engine Running (ER), C = Continuous Memory

*1993 and later terminology

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2-Digit Trouble Codes (EEC-IV)

EEC-IV 2-Digit Trouble Codes (continued)

Code	Conditions			Definition
61	O		C	ECT sensor fault, or circuit grounded
62	O			AXOD 4/3 or 3/2 pressure switch circuit failed closed
			C	Converter clutch error (E4OD)
63	O		C	TP circuit below minimum voltage
64	O		C	ACT [IAT*] or VAT sensor fault, or circuit grounded
65		R		Overdrive Cancel Switch (OCS) not changing state (E4OD)
			C	Never went to closed loop fuel
66		R	C	MAF or VAF circuit below minimum voltage
	O		C	TOT sensor input is less than Self-Test minimum or VAF circuit below minimum voltage (E4OD)
67	O			Neutral Pressure Switch (NPS) circuit open (3.0L MAP, 3.0L MAF-SFI, 3.8L SFI)
			C	Clutch switch circuit failure
	O	R		Neutral Drive Switch (NDS) circuit open; A/C input high
	O		C	Manual Lever Position (MLP) sensor out of range; A/C input high (4.9L MAP, 5.8L MAP)
68	O		C	VAT circuit grounded
	O	R	C	AXOD Transmission Temperature Switch (TTS) failed open
69	O			AXOD 4/3 or 3/2 pressure switch circuit failed closed
			C	AXOD 4/3 or 3/2 pressure switch circuit failed open; 3-4 shift error (E4OD)
70			C	EEC-IV data transmission circuit failed (DCL)
71			C	Software re-initialization detected or Cluster Control Assembly (CCA) circuit failed
72			C	Power interrupt detected or Message Center Control Assembly (MCCA) circuit failed
		R		Insufficient MAP / BP or MAF output change during Dynamic Response Test
73	O			Insufficient throttle position change
		R		Insufficient TP output change during Dynamic Response Test
74		R		BOO brake on/off circuit failure--not actuated during test
75		R		BOO brake on/off circuit closed--always high
76		R		Insufficient VAF output change during Dynamic Response Test
77		R		Brief WOT not sensed during Self-Test / Operator error
79	O			A/C on / Defrost on during Self-Test
81	O			Insufficient Idle Air Solenoid (IAS) output voltage change when activated (3.0L MAF-SFI) Secondary Air Injection Diverter AM2 [AIRD*] solenoid circuit failure
82	O			Secondary Air Injection Bypass AM1 [AIRB*] solenoid circuit failure Supercharger bypass circuit failure (3.8L MAF-SFI SC)
KEY: O = Key On Engine Off (KOEO), R = Engine Running (ER), C = Continuous Memory				

*1993 and later terminology

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2-Digit Trouble Codes (EEC-IV)

EEC-IV 2-Digit Trouble Codes (continued)

Code	Conditions			Definition
83	O			EGRC solenoid circuit failure (2.3L MAP)
	O			High speed electro-drive fan HEDF [HFC*]circuit failure
	O		C	Low speed fuel pump relay circuit open (3.0L MAF-SFI)
84	O	R		EGR Vacuum Regulator (EVR) circuit failure
85			C	Adaptive fuel lean limit reached
	O	R		Canister Purge (CANP) circuit failure
86			C	Adaptive fuel rich limit reached
	O			Adaptive fuel limit reached or 3-4 Shift Solenoid circuit failure
87	O	R	C	Fuel pump primary circuit failure
88	O			Electro-drive fan EDF [FC*] circuit failure
			C	Loss of dual plug input control
89	O			AXOD Lock-Up Solenoid LUS circuit failed or Clutch Converter Override (CCO) circuit failure
91	O			Shift Solenoid 1 (SS1) circuit failure
		R		HEGO [H02S*] circuit indicates system lean (left H02S)
			C	No HEGO [H02S*] switching detected (left H02S)
92	O			Shift Solenoid 2 (SS2) circuit failure
		R		HEGO [H02S*] circuit indicates system rich (left H02S)
93	O			TP sensor input low at maximum D.C. motor extension Coast Clutch Solenoid (CCS) circuit failure (E4OD)
94	O			Converter Clutch Control (CCC) solenoid circuit failure
		R		Secondary Air Injection system inoperative (left side)
95	O		C	Fuel pump secondary circuit failure
96	O		C	High speed fuel pump relay circuit open; Fuel pump secondary circuit failure
97	O			Overdrive Cancel Indicator Light (OCIL) circuit failure
98	O			Electronic Pressure Control (EPC) driver failure in processor
		R		Hard fault is present - FMEM mode
99	O		C	Electronic Pressure Control (EPC) circuit failure
		R		EEC system has not learned to control idle
No Codes				Unable to initiate Self-Test or unable to output code
Codes Not Listed				Codes displayed are not applicable to the vehicle being tested
KEY: O = Key On Engine Off (KOEO), R = Engine Running (ER), C = Continuous Memory				

*1993 and later terminology

3-Digit Trouble Codes (EEC-IV)

EEC-IV 3-Digit Trouble Codes

Code	Conditions			Definition
111	O	R	C	System Pass
112	O		C	Air Charge Temp ACT [IAT*] Sensor circuit below minimum voltage/ 254°F indicated
113	O		C	Air Charge Temp ACT [IAT*] Sensor circuit above maximum voltage/ -40°F indicated
114	O	R		Air Charge Temp ACT [IAT*] higher or lower than expected during KOEO, ER
116	O	R		Engine Coolant Temp (ECT) higher or lower than expected during KOEO, ER
117	O		C	Engine Coolant Temp (ECT) Sensor circuit below minimum voltage/ 254°F indicated
118	O		C	Engine Coolant Temp (ECT) Sensor circuit above maximum voltage/ -40°F indicated
121	O	R	C	Closed Throttle Voltage higher or lower than expected
122	O		C	Throttle Position (TP) Sensor circuit below minimum voltage
123	O		C	Throttle Position (TP) Sensor circuit above maximum voltage
124			C	Throttle Position (TP) Sensor voltage higher than expected
125			C	Throttle Position (TP) Sensor voltage lower than expected
126	O	R	C	MAP or BP [BARO*] Sensor higher or lower than expected
128		R		MAP vacuum circuit failure
129		R		Insufficient Mass Air Flow (MAF) change during Dynamic Response Test
136		R		HEGO [HO2S-2*] sensor circuit indicates system always lean
137		R		HEGO [HO2S-2*] sensor circuit indicates system always rich
139			C	No Oxygen Sensor (HEGO) [HO2S-2*] Switches detected
144			C	No Oxygen Sensor (HEGO) [HO2S-1*] Switches detected
157			C	Mass Air Flow (MAF) Sensor circuit below minimum voltage
158	O		C	Mass Air Flow (MAF) Sensor circuit above maximum voltage
159	O	R		Mass Air Flow (MAF), higher or lower than expected during KOEO, ER
167		R		Insufficient Throttle Position change during Dynamic Response Test
171			C	Fuel system at adaptive limits, Oxygen Sensor (HEGO) [HO2S-1*] unable to switch
172		R	C	Lack of Oxygen Sensor (HEGO) [HO2S-1*] Switches, indicates lean
173		R	C	Lack of Oxygen Sensor (HEGO) [HO2S-1*] Switches, indicates rich
174			C	HEGO switching time is slow
175			C	Lack of Oxygen Sensor (HEGO) [HO2S-2*] switching, fuel system at adaptive limits (front side)
176			C	HEGO [HO2S-2*] sensor circuit indicates system always lean (Front side)
177			C	HEGO [HO2S-2*] sensor circuit indicates system always rich (Front side)
178			C	HEGO switching time is slow
179			C	Fuel system at lean adaptive limit at part throttle, system rich
KEY: O - Key On Engine Off (KOEO) R = Engine Running (ER) C = Continuous Memory				

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3-Digit Trouble Codes (EEC-IV)

EEC-IV 3-Digit Trouble Codes (continued)

Code	Conditions			Definition
181			C	Fuel system at rich adaptive limit at part throttle, system lean
182			C	Fuel system at lean adaptive limit at idle, system rich
183			C	Fuel system at rich adaptive limit at idle, system lean
184			C	Mass Air Flow (MAF) higher than expected
185			C	Mass Air Flow (MAF) lower than expected
186			C	Injector pulse width higher than expected
187			C	Injector pulse width lower than expected
188			C	Fuel system at part throttle lean adaptive limit, system rich
189			C	Fuel system at part throttle rich adaptive limit, system lean
191			C	Fuel system at idle lean adaptive limit, system rich
192			C	Fuel system at idle rich adaptive limit, system lean
211			C	Profile Ignition Pickup (PIP) circuit failure
212			C	Loss of Ignition Diagnostic Monitor (IDM) input to ECA/ SPOUT circuit grounded
213		R		SPOUT circuit open
214			C	Cylinder Identification (CID) circuit failure
215			C	EEC [PCM*] Processor detected Coil 1 primary circuit failure
216			C	EEC [PCM*] Processor detected Coil 2 primary circuit failure
217			C	EEC [PCM*] Processor detected Coil 3 primary circuit failure
218			C	Loss of Ignition Diagnostic Monitor (IDM) signal-left side
219			C	SPOUT signal defaulted to 10 degrees BTDC/SPOUT circuit open
222			C	Loss of Ignition Diagnostic Monitor (IDM) signal-right side
223			C	Loss of Dual Plug Inhibit (DPI) control
224			C	Erratic Ignition Diagnostic Monitor (IDM) input to processor
225		R		Knock not sensed during Dynamic Response Test
226	O			Ignition Diagnostic Monitor (IDM) signal not received
311		R		Thermactor [AIR*] air system inoperative (right side)
312		R		Thermactor [AIR*] air upstream during Self-Test
313		R		Thermactor [AIR*] air not bypassed during Self-Test
314		R		Thermactor [AIR*] air system inoperative (left side)
326		R	C	PFE/DPFE [EGR*] sensor circuit voltage lower than expected
327	O	R	C	PFE/DPFE [EGR*] circuit below minimum voltage
328	O	R	C	EGR closed valve voltage lower than expected

KEY: O - Key On Engine Off (KOEO) R = Engine Running (ER) C = Continuous Memory

*1993 and later terminology

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3-Digit Trouble Codes (EEC-IV)

EEC-IV 3-Digit Trouble Codes (continued)

Code	Conditions			Definition
332		R	C	Insufficient EGR flow detected
334	O	R	C	EGR closed-valve voltage higher than expected
335	O			PFE/DPFE [EGR*] sensor voltage out of Self-Test range
336		R	C	PFE [EGR*] sensor circuit voltage higher than expected
337	O	R	C	PFE/DPFE [EGR*] circuit above maximum voltage
338			C	Engine coolant temperature [ECT*] lower than normal
339			C	Engine coolant temperature [ECT*] higher than normal
341	O			Octane Adjust Service Pin in use or circuit open
411		R		Cannot control rpm during ER low rpm check
412		R		Cannot control rpm during ER high rpm check
452			C	Insufficient input from Vehicle Speed Sensor (VSS)
511	O			EEC [PCM*] Processor Read Only Memory (ROM) test failure
512			C	EEC [PCM*] Processor Keep Alive Memory (KAM) test failure
513			C	Failure in EEC [PCM*] processor internal voltage
519	O			Power Steering Pressure Switch PSPS [PSP*] circuit open
521		R		Power Steering Pressure Switch PSPS [PSP*] circuit did not change states
522	O			Vehicle not in PARK or NEUTRAL [PNP*] during KOEO
524	O		C	Low speed fuel pump circuit open (battery to ECA)
525	O			Vehicle was either in gear or AC was on during Self-Test
526	O			Neutral Pressure Switch NPS [PNP*] circuit closed; A/C on
527	O			Neutral Drive Switch NDS [PNP*] circuit open/ A/C on
528			C	Clutch Switch Circuit failure
529			C	Data Communications Link DCL or EEC [PCM*] processor circuit failure
533			C	Data Communications Link DCL or Electronics Instrument Cluster (EIC) circuit failure
536		R	C	Brake On/Off (BOO) circuit failure / not actuated during ER
538		R		Insufficient RPM change during ER Dynamic Response Test or operator error
539	O			AC On/Defrost ON during KOEO
542	O		C	Fuel Pump secondary circuit failure
543	O		C	Fuel Pump secondary circuit failure
551	O			IAS [IAC*] circuit failure
552	O			Air management 1 AM1 [AIRB*] circuit failure
553	O			Air management 2 AM2 [AIRB*] circuit failure

KEY: O - Key On Engine Off (KOEO) R = Engine Running (ER) C = Continuous Memory

*1993 and later terminology

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3-Digit Trouble Codes (EEC-IV)

EEC-IV 3-Digit Trouble Codes (continued)

Code	Conditions			Definition
554	O			Fuel Pressure Regulator Control (FPRC) solenoid circuit failure
556	O		C	Fuel Pump Relay primary circuit failure
557	O		C	Fuel Pump primary circuit failure
558	O			EGR Vacuum Regulator (EVR) circuit failure
559	O			Air Conditioning ON (ACON) relay circuit failure
563	O			High Speed Electro-Drive Fan HEDF [HFC*] circuit failure
564	O			Electro-Drive Fan EDF [FC*] circuit failure
565	O			Canister Purge (CANP) circuit failure
566	O			3-4 Shift Solenoid circuit failure
617			C	1-2 shift error (E40D)
618			C	2-3 shift error (E40D)
619			C	3-4 shift error (E40D)
621	O			Shift Solenoid #1 (SS1) circuit failure
622	O			Shift Solenoid #2 (SS2) circuit failure
624	O		C	Electronic Pressure Control (EPC) solenoid or driver circuit failure
625	O			Electronic Pressure Control (EPC) driver open in ECA
626	O			Coast Clutch Solenoid (CCS) circuit failure (E40D)
627	O		C	Converter Clutch Control solenoid circuit failure
628	O		C	Lock-Up Solenoid (LUS) failure, excessive clutch slippage
629	O			Converter Clutch Control circuit failure or Lock-Up Solenoid (LUS) circuit failure
631	O			Overdrive Cancel Indicator Light (OCIL) circuit failure
632		R		Overdrive Cancel Switch (OCS) not changing state (E40D)
633	O			4 x 4 switch is closed (E40D)
634			C	Manual Lever Position (MLP) sensor voltage out of Self-Test range or A/C on (E40D)
636	O	R		Transmission Oil Temperature (TOT) sensor voltage out of Self-Test range
637	O		C	Transmission Oil Temperature (TOT) sensor voltage out of Self-Test maximum
638	O		C	Transmission Oil Temperature (TOT) sensor voltage below Self-Test minimum
639		R	C	Insufficient input from the Transmission Speed Sensor (TSS)
641	O			Shift solenoid #3 (SS3) circuit failure
643	O		C	Converter Clutch Control (CCC) circuit failure
645			C	Incorrect gear ratio obtained for first gear
646			C	Incorrect gear ratio obtained for second gear
KEY: O - Key On Engine Off (KOEO) R = Engine Running (ER) C = Continuous Memory				

*1993 and later terminology

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3-Digit Trouble Codes (EEC-IV)

EEC-IV 3-Digit Trouble Codes (continued)

Code	Conditions			Definition
647			C	Incorrect gear ratio obtained for third gear
648			C	Incorrect gear ratio obtained for fourth gear
649			C	Electronic Pressure Control (EPC) range failure
651			C	Electronic Pressure Control (EPC) circuit failure
652	O			Modulated Converter Clutch Control (MCCC) solenoid output circuit error
654				MLP sensor not in Park position
656				Converter Clutch Control (CCC) continuous slip error detected
998 r				Hard fault present (FMEM mode)
NO CODES				Unable to initiate Self-Test or unable to output Self-Test codes
CODES NOT LISTED				Service codes displayed are not applicable to the vehicle being tested
KEY: O - Key On Engine Off (KOEO) R = Engine Running (ER) C = Continuous Memory				

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MECS Trouble Codes

MECS Trouble Codes

Code	Definition
01	Ignition Diagnostic Monitor (IDM) or Crankshaft Position Sensor (CKP)
02	Crankshaft Position Sensor #2 (CKP2)
03	Cylinder Identification (CID) Sensor
04	Crankshaft Position Sensor #1 (CKP1)
05	Knock Sensor (KS)
06	Vehicle Speed Sensor (VSS)
08	Volume Air Flow (VAF) or Measuring Core Volume Air Flow (MC-VAF) Sensor
09	Engine Coolant Temperature (ECT) Sensor
10	Intake Air Temperature (IAT) Sensor
12	Throttle Position (TP) Sensor
14	Barometric Pressure (BARO) Sensor
15	(Left) Heated Oxygen Sensor (LHO2S) Voltage Always Below 0.55V
16	EGR Valve Position (EVP) Sensor
17	(Left) Heated Oxygen Sensor (LHO2S) Voltage Does Not Change
23	Right Heated Oxygen Sensor (RHO2S) Voltage Always Below 0.55V
24	Right Heated Oxygen Sensor (RHO2S) Voltage Does Not Change
25	Fuel Pressure Regulator Control (FPRC) Solenoid
26	Canister Purge (CANP) Solenoid
28	EGR Control (EGRC) Solenoid
29	EGR Vent (EGRV) Solenoid
34	Idle Air Control (IAC) Solenoid
41	Variable Resonance Induction System (VRIS) Solenoid #1 or High Speed Inlet Air (HSIA) solenoid
42	Turbocharger Boost Control Solenoid (BOOST)
46	Variable Resonance Induction System (VRIS) Solenoid #2
55	Pulse Shift Generator (PSG)
56	Transmission Oil Temperature (TOT) sensor
57	Reduce Torque Signal #1 (RTS1) (to PCM)
58	Reduce Torque Signal #2 (RTS2) (to PCM)
59	Torque Reduce / Engine Coolant Temperature Signal (TRS) (from PCM)
60	1-2 Shift Solenoid (SS1)
61	2-3 Shift Solenoid (SS2)
62	3-4 Shift Solenoid (SS3)
63	Torque Converter Clutch Control (TCCC) Solenoid

*1993 and later terminology

continued on next page

MECS Trouble Codes

MECS Trouble Codes (continued)

Code	Definition
64	Downshift Solenoid (DSS)
65	Torque Converter Clutch (TCC) Solenoid
66	Line Pressure Solenoid (LPS)
67	Low Cooling Fan (LFAN) Relay
69	Cooling Fan Engine Coolant Temperature (ECTF) Sensor
STO LO always ON	Not able to initiate diagnostic test mode
STO LO always ON and no codes (Blank SUPER STAR II)	Pass Code

ACT (EEC-IV)

Circuit Description

Air Charge Temperature (ACT*) sensor provides information about intake air temperature. It is a thermistor, in series with a fixed resistor in the control unit. Its resistance changes with temperature. Voltage in the circuit is equal to VREF minus the voltage drop across the fixed resistor and the ACT. For more information see Chapter 4.

An open between the ACT and the control module will result in a constant 5.0 volt signal. A short will result in approximately 0 volts in the circuit. Corrosion in the circuit at terminal connections results in higher-than-normal voltage due to the voltage drop.

ACT Circuit Wire Color

	1988	1989	1990	1991	1992	1993–On
Engine Family	**Wire color**					
Car						
1.9L MA SFI	—	—	W/GR	W/GR	W/GR	W/GR
2.0L MA SFI	—	—	—	—	W/LG	W/LG
2.3L OHC MFI	LG/P	LG/R	LG/R	GY	GY	GY
2.3L MA MFI	—	—	L/GR	—	—	—
2.3L MFI TURBO	PK/BK	—	—	—	—	—
2.3L HSC MFI	LG/P	LG/P	LG/P	LG/P	GY	GY
2.5L AXODE SFI	—	—	—	LG/P	—	—
2.9L MFI	—	—	BR/Y	—	—	—
3.0L MFI	LG/P	LG/P	Probe Y all others LG/P	Y	Y	—
3.0L MA SFI	—	—	—	—	GY	GY
3.0L AXODE SFI	—	—	—	LG/P	LG/P	GY
3.0L SHO SFI	—	LG/P	LG/P	LG/P	GY	GY
3.2L SHO SFI	—	—	—	—	—	GY
3.8L MFI AXOD	LG/P	LG/P	LG/P	Taurus/Sable LG/P Continental GY	Taurus/Sable LG/P Continental GY	GY
3.8L RWD MFI	LG/P	LG/P	LG/P	LG/P	LG/P	GY
3.8L SC SFI	—	LG/P	LG/P	LG/P	LG/P	GY
4.6L SFI	—	—	—	LG/P	Crown Victoria/ Marquis LG/P Town Car GY	GY
4.6L 4V	—	—	—	—	—	GY
5.0L SFI	LG/P	LG/P	LG/P	LG/P	GY	
5.0L MAF SFI	LG/P	LG/P	LG/P	Mustang GY all others LG/P	GY	GY
Truck						
2.3L MFI	Y/R	Y/R	Y/R	GY	GY	GY
2.9L MFI	LG/P	LG/P	LG/P	GY	GY	GY
2.9L MAF MFI	—	—	LG/P	—		—
3.0L MFI	LG/P	LG/P	LG/P	LG/P		—
3.0L MAF MFI	—	—	—	GY	GY	GY
4.0L MAF MFI	—	—	LG/P	Aerostar LG/P Ranger/Exp. GY	GY	GY GY
4.9L MFI	Y/R	Y/R	F-series, Bronco G/Y E-series Y/R	F-series, Bronco G/Y E-series Y/R	GY	GY
Wiring Color Code	BK–Black, BL–Blue, BR–Brown, DB–Dark Blue, DG–Dark Green, GR–Green, GY–Gray, LB–Light Blue, LG–Light Green, N–Natural, O–Orange, P–Purple, PK–Pink, R–Red, T–Tan, W–White, Y–Yellow					

continued on next page

*1993 and later called IAT—see glossary

ACT (EEC-IV)

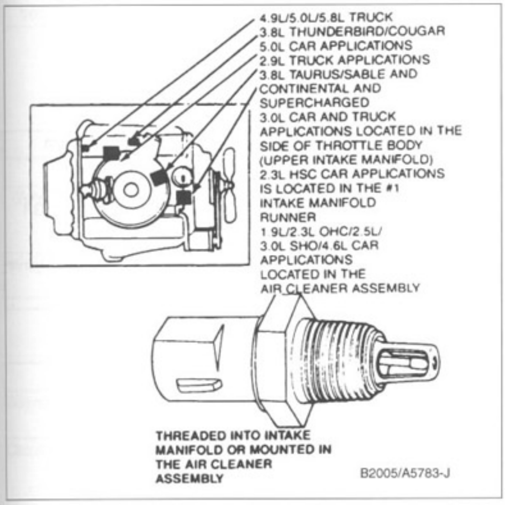
ACT Circuit Wire Color (continued)

	1988	1989	1990	1991	1992	1993–On
Engine Family	**Wire color**					
5.0L MFI	Y/R	Y/R	F-series, Bronco G/Y E-series Y/R	F-series, Bronco G/Y E-series Y/R	GY	GY
5.8L MFI	Y/R	Y/R	F-series, Bronco G/Y E-series Y/R	F-series, Bronco G/Y E-series Y/R	GY	GY
Wiring Color Code	BK–Black, BL–Blue, BR–Brown, DB–Dark Blue, DG–Dark Green, GR–Green, GY–Gray, LB–Light Blue, LG–Light Green, N–Natural, O–Orange, P–Purple, PK–Pink, R–Red, T–Tan, W–White, Y–Yellow					

ACT Sensor Tests

Test	Conditions	Test Results	If Not
Sensor resistance	–Disconnect sensor connector –Measure across sensor terminals	See table below	Sensor may be faulty
Circuit voltage	–Sensor connected –KOEO	See table below	Wiring to control unit or control unit faulty

Component Locator



Test Data

ACT SENSOR DATA

Voltage values calculated for VREF = 5.0v
(These values may vary ± 15% due to sensor and VREF variations)

TEMPERATURE °F	°C	VOLTAGE Volts	RESISTANCE K ohms
248	120	0.28	1.18
230	110	0.36	1.55
212	100	.47	2.07
194	90	.61	2.80
176	80	.80	3.84
158	70	1.04	5.37
140	60	1.35	7.60
122	50	1.72	10.97
104	40	2.16	16.15
86	30	2.62	24.27
68	20	3.06	37.30
50	10	3.52	58.75

B2006/A12843-A

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*1993 and later called ACT—see glossary

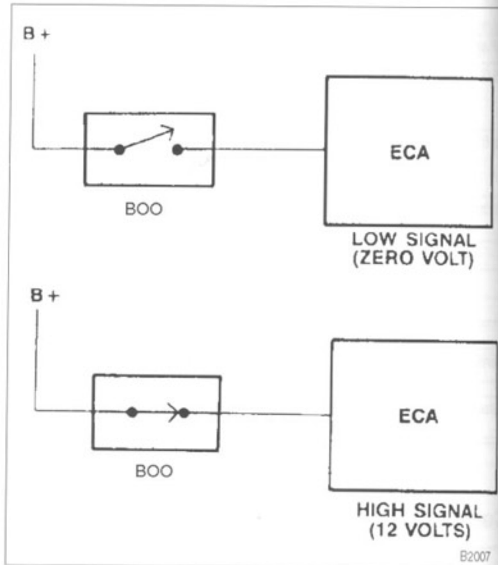
BOO (EEC-IV)

Circuit Description

Brake On/Off (BOO) switch provides a 12 volt signal to the control unit when the switch is closed. It is wired to the stoplamp circuit. The BOO input is used primarily by the Torque Converter Clutch lock/unlock strategy. For more information see Chapter 4.

When troubleshooting the BOO switch, check the brake lights and their ground. The circuit receives a secondary ground through the stop light bulbs.

Test Data



BOO Signal Wire Color

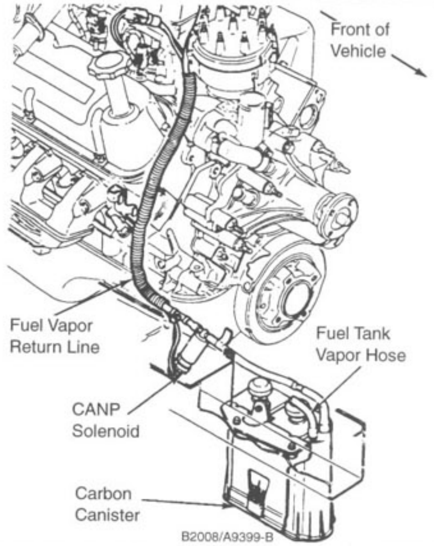
1988	1989	1990	1991	1992	1993–On
Mustang (2.3L OHC), Taurus/Sable, Aerostar: R/LG All others: LG	Mustang (2.3L OHC), Taurus/Sable, Aerostar: R/LG All others: LG	Mustang, Taurus/Sable, Aerostar: R/LG Town Car: DG/W All others: LG	Taurus/Sable, Aerostar: R/LG All others: LG	Taurus/Sable, Aerostar: R/LG Escort/Tracer: GR All others: LG	Taurus/Sable, Aerostar: R/LG Escort/Tracer: GR All others: LG
Wiring Color Code	BK–Black, BL–Blue, BR–Brown, DB–Dark Blue, DG–Dark Green, GR–Green, GY–Gray, LB–Light Blue, LG–Light Green, N–Natural, O–Orange, P–Purple, PK–Pink, R–Red, T–Tan, W–White, Y–Yellow				

CANP (EEC-IV)

Circuit Description

Canister Purge (CANP) valve and solenoid are controlled by the PCM to regulate the flow of fuel vapors from the EVAP canister to the fuel system. The canister is normally closed. When the control unit energizes the solenoid it opens, allowing fuel vapors to be drawn into the engine. For more information see Chapter 4.

Component Locator



Typical location of CANP solenoid.

CANP Circuit Wire Color

1988	1989	1990	1991	1992	1993–On
GY/Y	GY/Y	Probe: W/BK All others: GY/Y	Probe: W/BK All others: GY/Y	1.9L MAF SFI: O/W 3.0L MFI: W/BK All others: GY/Y	1.9L MAF SFI: O/W All others: GY/Y
Wiring Color Code	BK–Black, BL–Blue, BR–Brown, DB–Dark Blue, DG–Dark Green, GR–Green, GY–Gray, LB–Light Blue, LG–Light Green, N–Natural, O–Orange, P–Purple, PK–Pink, R–Red, T–Tan, W–White, Y–Yellow				

CANP Solenoid Tests

Test	Conditions	Test Result	If Not
Solenoid resistance	–Disconnect solenoid connector –Measure across solenoid terminals	40 to 90 ohms	Solenoid may be faulty
Circuit voltage	–Disconnect solenoid connector –Measure between VPWR at harness connector and battery ground –KOEO	10.5 volts or greater	Power circuit or wiring faulty
Solenoid integrity	–Disconnect solenoid connector –KOEO –Apply 16 inHg. (53 kPa) of vacuum to manifold side of solenoid	Holds vacuum for at least 20 seconds	Solenoid may be faulty
EEC control	–Disconnect solenoid connector –Connect DVOM across harness connector: positive lead to VPWR, negative to CANP –KOEO –Depress and release throttle several times	CANP circuit cycles 0.5 volts or greater	Circuit wiring or control unit faulty

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DIS (EEC-IV)

Circuit Description

Distributorless Ignition System (DIS*) consists of a crankshaft mounted Hall sensor providing a PIP signal, a coil pack or coil packs, a Hall cylinder identification sensor providing a CID signal, and a DIS control module.

When troubleshooting, note that both PIP and CID are digital signals. They should switch between VBAT and GND as the engine turns. Using an LED test lamp is a quick way to see that the sensors are generating a signal. Also note that proper operation of the DIS system depends on good grounds. The DIS module IGN GND is internal through the mounting screws. Always check the mounting screws for tightness and make sure there is no corrosion.

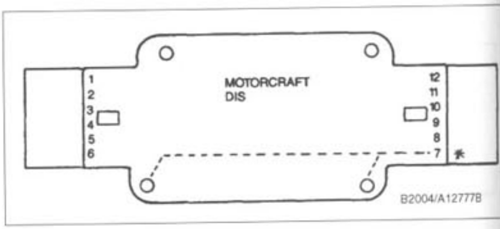
DIS Module Inputs/Outputs

Signal*	DIS Module Terminal
VBAT	1
CID	2
PIP to EEC	3
PIP	4
SPOUT	5
DPI	6
IGN GROUND	7 (internal via mounting holes)
COIL	8
COIL	9
COIL	10
COIL	11
IDM	12
*=where applicable	

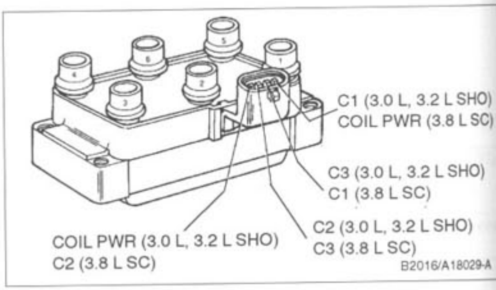
WARNING —
The DIS ignition system is a high-energy system operating in a dangerous voltage range which could prove to be fatal if exposed terminals or live parts are contacted. Use extreme caution when working on a vehicle with the ignition on or the engine running.

CAUTION —
Do not use an incandescent test lamp to test electronic components. Use only an LED test lamp.

DIS Module



DIS 6 Cylinder Coil



DIS Electrical Tests

Test	Conditions	Test Results	If Not
PIP to control unit	–Connect DMM or LED test light between PIP wire and negative (–) battery terminal –Crank engine	3 to 7 volts or Test light blinks	Crank sensor, crank sensor power or ground, or wiring faulty
SPOUT to DIS module	–PIP signal OK –Connect DMM or LED test light between SPOUT wire and negative (–) battery terminal –Crank engine	3 to 7 volts or Test light blinks	Control unit or wiring faulty
IDM to control unit	–Connect DMM or LED test light between IDM wire and negative (–) battery terminal –Crank engine	3 to 7 volts or Test light blinks	DIS module or wiring faulty
CID at sensor	–Connect LED test light between CID CS wire and negative (–) battery terminal –Crank engine	Test light blinks	CID sensor or wiring faulty
COIL PWR	–Connect LED test light between COIL PWR (VBAT) wire and negative (–) battery terminal –Key on	Test light on	COIL PWR wiring faulty

*1993 and later called EI—see glossary

EEC-IV DISTRIBUTORLESS IGNITION SYSTEM (DIS)

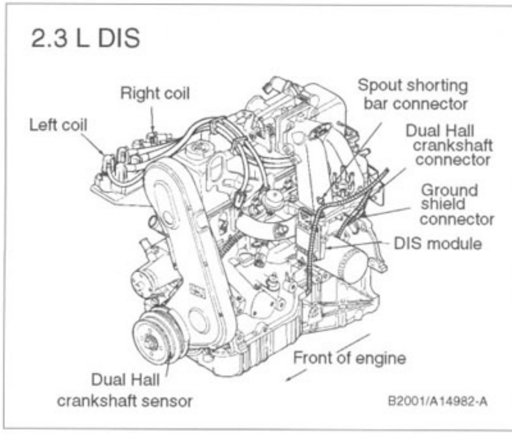
DIS (EEC-IV)

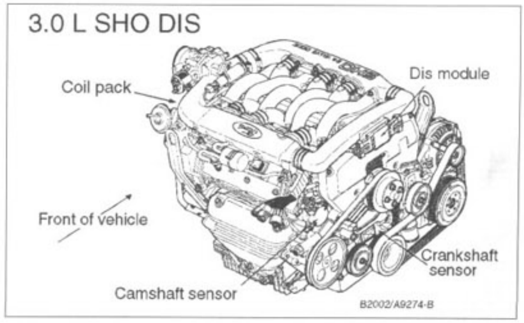
DIS Signal Wire Colors

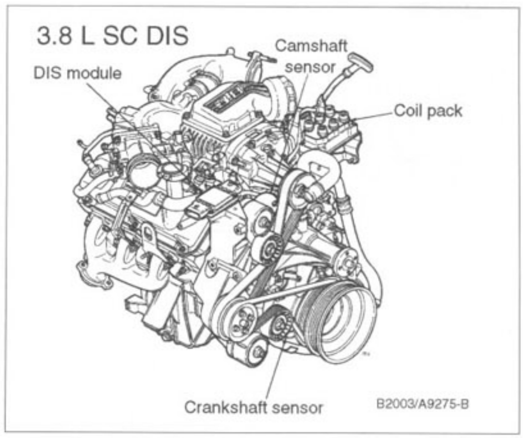
Signal	Wire color
Car:	
2.3 L	
PIP	GY/O
SPOUT	PK
CID	DB/O
IDM	T/Y
IGN GND	O/R
3.0, 3.2L SHO SFI	
PIP	DB
SPOUT	Y/LG
CID	DG
IDM	GY/O
IGN GND	BK/O
3.8 L SC SFI	
PIP	DB
SPOUT	Y/LG
CID	DG
IDM	DG/Y T/Y 1992–On
IGN GND	LB
Truck:	
2.3 L	
PIP	DB 1989–90 GY/O 1991–)n
SPOUT	Y/LG 1989–90 PK 1991–On
CID	GY 1993 only
IDM	LG/P 1989 DG/Y 1990 T/Y 1991–On
IGN GND	BK/O 1989–90 O/R 1991–On

Wiring Color Code: BK–Black, BL–Blue, BR–Brown, DB–Dark Blue, DG–Dark Green, GY–Gray, LB–Light Blue, LG–Light Green, N–Natural, O–Orange, P–Purple, PK–Pink, R–Red, T–Tan, W–White, Y–Yellow

Component Locator







ECT (EEC-IV)

Circuit Description

Engine Coolant Temperature (ECT) sensor provides information about engine temperature by changing resistance. The change in resistance changes voltage flow in the circuit. The sensor resistance decreases as the surrounding temperature increases.

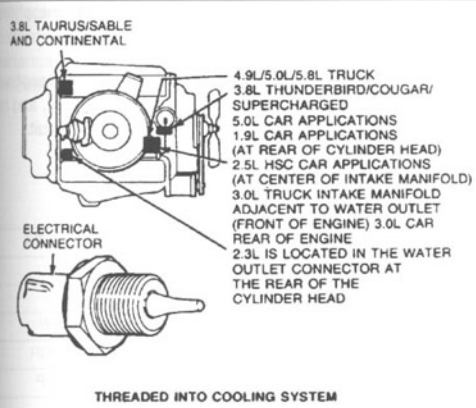
A short will result in approximately 0 volts in the circuit. Corrosion in the circuit at terminal connections results in higher-than-normal voltage due to the voltage drop at the connection.

ECT Circuit Wire Color

Engine Family	1988	1989	1990	1991	1992	1993–On
Car:			Wire color			
1.9L MA SFI	LG/Y	LG/Y	BL/W	BL/W	BL/W	BL/W
2.0L MA SFI	—	—	—	—	Y/BK	Y/BK
2.3L OHC MFI	LG/Y	LG/Y	LG/Y	LG/R	LG/R	LG/R
2.3L MA MFI	—	—	LG/Y	—	—	—
2.3L MFI TURBO	LG/Y	LG/Y	—	—	—	—
2.3L HSC MFI	LG/Y	LG/Y	LG/Y	LG/R	LG/R	LG/R
2.5L AXODE SFI	—	—	—	LG/R	—	—
2.9L MFI	—	—	BR/GN	—	—	—
3.0L MFI	LG/Y	LG/Y	Probe YR all others LG/Y	Y/R	Y/R	—
3.0L MA SFI	—	—	—	—	LG/R	LG/R
3.0L AXOD SFI	—	—	—	LG/R	LG/R	LG/R
3.0L SHO SFI	—	LG/Y	LG/Y	LG/Y	LG/R	LG/R
3.2L SHO SFI	—	—	—	—	—	LG/R
3.8L MFI AXOD	LG/Y	LG/Y	LG/Y	LG/R	LG/R	LG/R
3.8L RWD MFI	LG/Y	LG/Y	LG/Y	LG/Y	LG/R	LG/R
3.8L SC SFI	—	LG/Y	LG/Y	LG/Y	LG/R	LG/R
4.6L SFI	—	—	—	LG/R	LG/R	LG/R
5.0L SFI	LG/Y	LG/Y	LG/Y	LG/R	LG/R	—
5.0L MAF SFI	LG/Y	LG/Y	LG/Y	Thunderbird/ Cougar LG/Y all others LG/R	LG/R	LG/R
Truck:						
2.3L MFI	LG/Y	LG/Y	LG/Y	LG/R	LG/R	LG/R
2.9L MFI	LG/Y	LG/Y	LG/Y	LG/R	LG/R	LG/R
2.9L MAF MFI	—	—	LG/Y	—	-	
3.0L MFI	LG/Y	LG/Y	LG/Y	LG/R	-	
3.0L MAF MFI	—	—	—	LG/R	LG/R	LG/R
4.0L MAF MFI	—	—	LG/Y	LG/R	LG/R	LG/R
4.9L MFI	LG/Y	LG/Y	F-series, Bronco LG/B E-series LG/Y	F-series, Bronco LG/R E-series LG/P	LG/R	LG/R
5.0L MFI	LG/Y	LG/Y	F-series, Bronco LG/R E-series LG/Y	LG/R	LG/R	LG/R
5.8L MFI	Y/R	LG/Y	F-series, Bronco LG/R E-series LG/Y	LG/R	GY	LG/R
Wiring Color Code	BK–Black, BL–Blue, BR–Brown, DB–Dark Blue, DG–Dark Green, GR–Green, GY–Gray, LB–Light Blue, LG–Light Green, N–Natural, O–Orange, P–Purple, PK–Pink, R–Red, T–Tan, W–White, Y–Yellow					

ECT (EEC-IV)

Component Locator

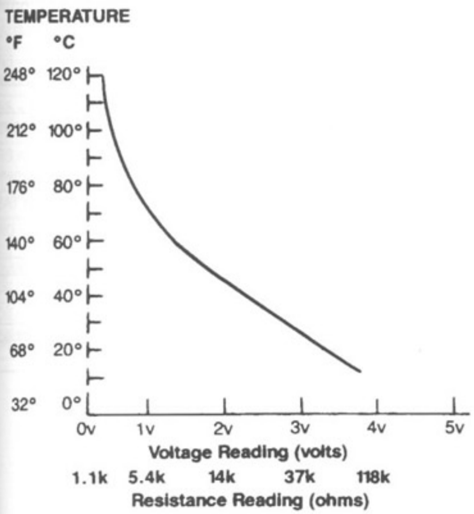


ECT Sensor Tests

Test	Conditions	Test Results	If Not
Sensor resistance	–Disconnect sensor connector –Measure across sensor terminals	See table below	Sensor may be faulty
Circuit voltage	–Sensor connected –KOEO	See table below	Wiring to control unit or control unit faulty

Test Data

ECT Sensor Graph



ECT SENSOR DATA * Voltage values calculated for VREF=5.0v (These values may vary ± 15% due to sensor and VREF variations).

TEMPERATURE °F	°C	VOLTAGE* Volts	RESISTANCE K ohms
248	120	0.28	1.18
230	110	0.36	1.55
212	100	.47	2.07
194	90	.61	2.80
176	80	.80	3.84
158	70	1.04	5.37
140	60	1.35	7.60
122	50	1.72	10.97
104	40	2.16	16.15
86	30	2.62	24.27
68	20	3.06	37.30
50	10	3.52	58.75

EDF (EEC-IV)

Circuit Description

Electro-Drive Fan (EDF*) control turns the low speed (primary) fan on and off.

On the 1.9L and 2.0L MAF SFI engines, the EDF fan relay is a separate relay. The EEC-IV control unit turns on the fan by grounding the EDF pin to energize (close) the relay.

On all except the 1.9L and 2.0L MAF SFI engines, the EDF fan relay is part of the Integrated Relay Control Module (IRCM). The EEC-IV control unit turns on the fan by applying voltage to the EDF pin to energize (close) the relay.

Troubleshoot the circuit by checking the signal wire continuity from the EEC-IV control unit to the relay or IRCM, and by checking power, ground, and continuity in the fan circuit.

EEC-IV EDF Signal Wire Color

	1988	1989	1990	1991	1992	1993-On
Engine Family	**Wire color**					
Car						
1.9L MA SFI	—	—	Y/W	Y/W	Y/W	Y/W
2.0L MA SFI	—	—	—	—	BK/GR	BK/GR
2.3L OHC MFI	—	—	—	LG/P	LG/P	LG/P
2.3L MFI TURBO	T/O	—	—	—	—	—
2.3L HSC MFI	—	—	—	—	T/O	T/O
2.5L AXODE SFI	—	—	—	T/O	—	—
3.0L MFI	T/O	T/O	Probe Y/GR all others T/O	Y/GR	Y/GR	—
3.0L MA SFI	—	—	—	—	T/O	T/O
3.0L AXODE SFI	—	—	—	T/O	T/O	T/O
3.0L SHO SFI	—	T/O	T/O	T/O	T/O	T/O
3.2L SHO SFI	—	—	—	—	—	T/O
3.8L MFI AXOD	T/O	T/O	T/O	Taurus/Sable T/O Continental DB	Taurus/Sable T/O Continental DB	Taurus/Sable T/O Continental DB
3.8L SC SFI	—	T/O	T/O	T/O	T/O	T/O
Wiring Color Code	BK–Black, BL–Blue, BR–Brown, DB–Dark Blue, DG–Dark Green, GR–Green, GY–Gray, LB–Light Blue, LG–Light Green, N–Natural, O–Orange, P–Purple, PK–Pink, R–Red, T–Tan, W–White, Y–Yellow					

EDF Electrical Tests

Test	Conditions	Test Result	If Not
With IRCM IRCM/Fan circuit	–Key off, disconnect IRCM connector –KOEO –3.0L SHO: Measure between pins: 1,2 and ground –3.8L: Measure between pins: 3,4 and ground –All other models: Measure between pins: 1,2,6,7 and ground	10.5 volts or greater	Check for open in battery power circuit
With IRCM Low speed fan circuit	–Key off, disconnect IRCM connector –Disconnect cooling fan, jumper pins 1 and 3 at IRCM connector	Battery voltage at cooling fan connector	Check power to IRCM, check wiring to cooling fan
Without IRCM Low speed fan circuit	–Key off, disconnect cooling fan connector –KOEO	Battery voltage at cooling fan connector	Check power to EDF fan relay, check wiring to cooling fan

*1993 and later called FC or LFC—see glossary

EDIS (EEC-IV)

Circuit Description

Electronic Distributorless Ignition System (EDIS*) consists of a crankshaft mounted toothed wheel and a variable reluctance sensor, a coil pack or coil packs, and an EDIS control module.

> ***WARNING —***
> *The EDIS ignition system is a high-energy system operating in a dangerous voltage range which could prove to be fatal if exposed terminals or live parts are contacted. Use extreme caution when working on a vehicle with the ignition on or the engine running.*

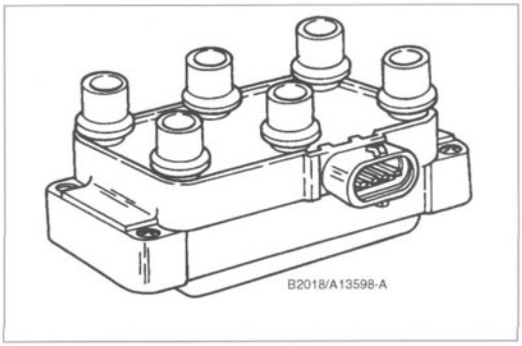
> ***CAUTION —***
> *Do not use an incandescent test lamp to test electronic components. Use only an LED test lamp.*

When troubleshooting, note that PIP should switch between VBAT and GND as the engine turns. Using an LED test lamp is a quick way to see that the sensors are generating a signal. Also note that proper operation of the EDIS system depends on good grounds. Always check the module for a good ground and make sure there is no corrosion at the terminals.

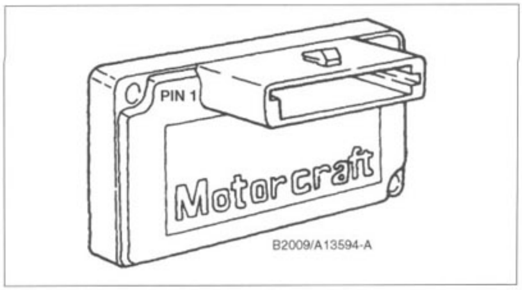
EDIS Module Inputs/Outputs

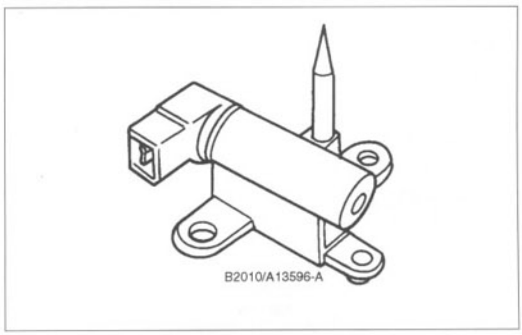
Signal[1]	EDIS Module Terminal
PIP (EDIS output signal)	1
IDM (diagnostic signal to EEC-IV)	2
SAW (EEC spark control signal)	3
IGN GND	4
VRS – (variable reluctance sensor negative)	5
VRS + (variable reluctance sensor positive)	6
VRS shield (variable reluctance sensor shield)	7
VBAT (battery positive)	8
GND (battery negative)	9
COIL (coil drive)	10
COIL/IDM	11
COIL (coil drive)	12
[1]=where applicable	

EDIS Coil



EDIS Module and VRS Sensor





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*1993 and later called EI—see glossary

EDIS (EEC-IV)

EDIS module wire colors

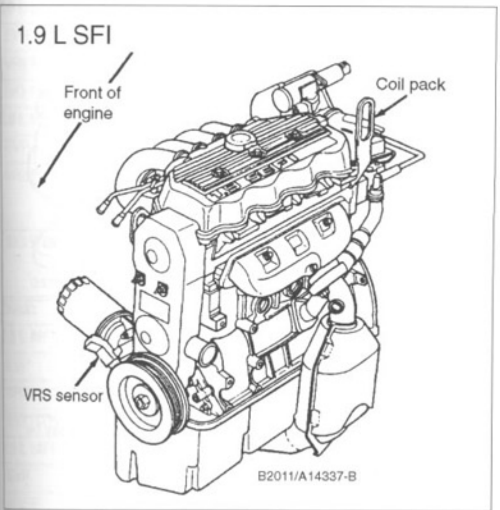
	1990	1991	1992	1993-On
Engine Family	**Wire color**			
Car:				
1.9 L SFI				
PIP	GR/W	GR/W	GR/W	GR/W
IDM	R	R	R	R
SAW	LG/W	LG/W	LG/W	LG/W
IGN GND	R/BL	R/BL	R/BL	R/BL
VBAT (VPWR)	W/R	W/R	W/R	W/R
4.6 L				
PIP	—	GY/O	GY/O	GY/O
IDM	—	T/Y	T/Y	T/Y
SAW	—	PK	PK	PK
IGN GND	—	O	O/R	O/R
Truck:				
4.0 L				
PIP	Aerostar: DB Ranger/Bronco II: BK/LB	Aerostar: DB Ranger/Explorer: GY/O	GY/O	GY/O
IDM	Aerostar: BK/Y Ranger/Bronco II: DG/Y	T/Y	T/Y	T/Y
SAW	Y/LG	Aerostar: Y/LG Ranger/Bronco II: PK	Aerostar: Y/LG Ranger/Bronco II: PK	PK
IGN GND	BK/O	O/R	O/R	O/R
VBAT (VPWR)	–	–	–	R
Wiring Color Code	BK–Black, BL–Blue, BR–Brown, DB–Dark Blue, DG–Dark Green, GR–Green, GY–Gray, LB–Light Blue, LG–Light Green, N–Natural, O–Orange, P–Purple, PK–Pink, R–Red, T–Tan, W–White, Y–Yellow			

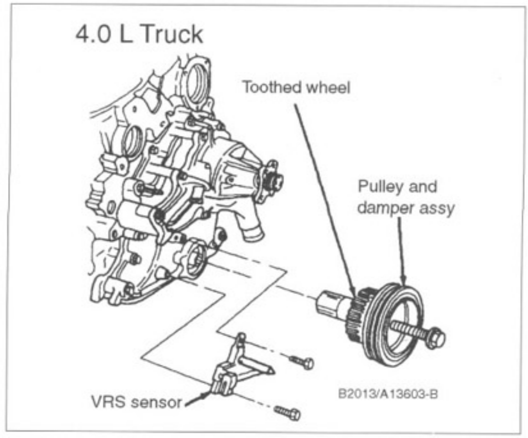
EDIS Electrical Tests

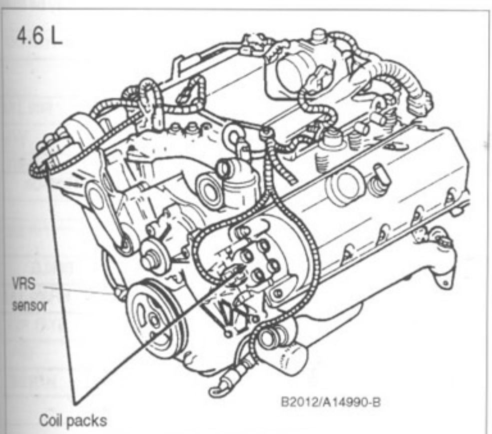
Test	Conditions	Test Results	If Not
PIP to control unit	–Connect DMM or LED test light between PIP wire and negative (–) battery terminal –Crank engine	Test light blinks	Crank sensor, crank sensor power or ground, EDIS module or wiring faulty
VRS at EDIS module	–Connect DMM between VRS (+) and VRS (–) at EDIS module –Crank engine	Greater than 1 volt AC	VRS sensor or sensor wiring may be faulty
VRS bias at EDIS module	–Connect DMM between VRS (+) and ground at EDIS module –Key on	1 to 2 volts DC	EDIS module may be faulty
VRS at sensor	–Disconnect VRS engine harness –Connect DMM at VRS (+) and VRS (–) sensor output –Crank engine	Greater than 1 volt AC	VRS sensor or sensor wiring may be faulty
VRS (+)	–Connect DMM at VRS (+) and VRS (–) –Key on, engine running	4 to 6 volts AC	VRS sensor or sensor wiring may be faulty

EDIS (EEC-IV)

Component Locator





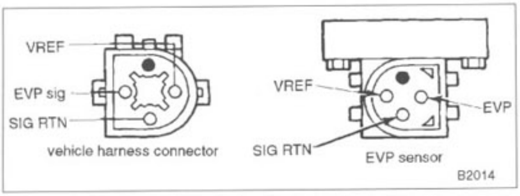


EVP (EEC-IV)

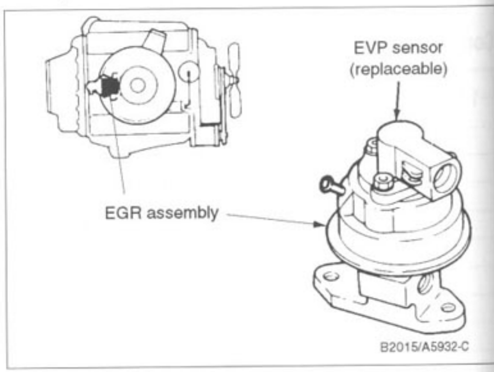
Circuit Description

EGR Valve Position (EVP) sensor is attached to the EGR valve to provide the EEC-IV system with a signal indicating the valve position. It is serviceable as a separate unit.

EVP Sensor Connectors



Component Locator



EVP Sensor Electrical Tests

Test	Conditions	Test Results	If Not
EVP resistance	–Key off, disconnect EVP sensor connector –Connect ohmmeter to connector at EVP SIG and VREF –Disconnect vacuum line to EGR –Connect vacuum pump, increase vacuum	5500 ohms to 100 ohms as vacuum increases to 33 kPa (10 in. Hg.)	EGR valve or EVP sensor may be faulty
VREF at EVP sensor	–Key off, disconnect EVP sensor connector –Key on, measure voltage at vehicle side of harness between VREF and SIG RTN	4 to 6 volts dc	Wiring or EEC-IV module may be faulty

EVP Circuit Wire Colors

Engine Family	1988	1989	1990	1991	1992	1993-On
Car:	Wire color					
2.3 L OHC MFI						
EVP	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG
VREF	O/W	O/W	O/W	BR/W	BR/W	BR/W
SIG RTN	BK/W	BK/W	BK/W	GY/W	GY/R	GY/R
2.3 L MA MFI						
EVP	–	–	BR/LG	–	–	–
VREF	–	–	O/W	–	–	–
SIG RTN	–	–	BK/W	–	–	–
2.3 L HSC SFI						
EVP	–	–	–	–	BR/LG	–
VREF	–	–	–	–	BR/W	–
SIG RTN	–	–	–	–	GY/R	–
Wiring Color Code	BK–Black, BL–Blue, BR–Brown, DB–Dark Blue, DG–Dark Green, GR–Green, GY–Gray, LB–Light Blue, LG–Light Green, N–Natural, O–Orange, P–Purple, PK–Pink, R–Red, T–Tan, W–White, Y–Yellow					

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EVP (EEC-IV)

EVP Circuit Wire Colors (continued)

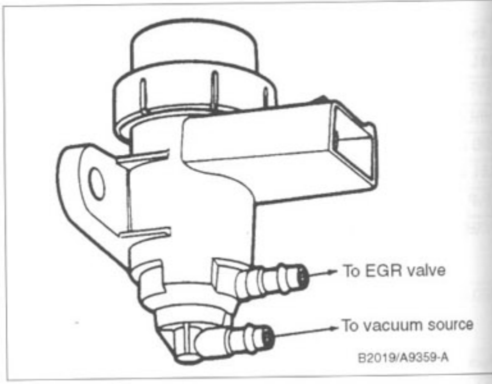
Engine Family	1988	1989	1990	1991	1992	1993-On
5.0 L SFI						
EVP	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG
VREF	O/W	O/W	O/W	BR/W	BR/W	BR/W
SIG RTN	BK/W	BK/W	BK/W	GY/R	GY/R	GY/R
5.0 L MA SFI						
EVP	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG
VREF	O/W	O/W	O/W	Thunderbird/ Cougar: O/W all others: BR/W	BR/W	BR/W
SIG RTN	BG/W	BK/W	BK/W	Thunderbird/ Cougar: BK/W all others: GY/R	GY/R	GY/R
Truck:						
2.3 L MFI						
EVP	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG
VREF	O/W	O/W	O/W	BR/W	BR/W	BR/W
SIG RTN	BK/W	BK/W	BK/W	GY/R	GY/R	GY/R
4.9 L MFI						
EVP	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG
VREF	O/W	O/W	F-series, Bronco: BR/W E-series: O/W	BR/W	BR/W	BR/W
SIG RTN	BK/W	BK/W	F-series, Bronco: GY/R E-series: BK/W	GY/R	GY/R	GY/R
5.0 L MFI						
EVP	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG
VREF	O/W	O/W	F-series, Bronco: BR/W E-series: O/W	BR/W	BR/W	BR/W
SIG RTN	F-series, Bronco: BK/W Econoline: BR/W	BK/W	F-series, Bronco: GY/R E-series: BK/W	GY/R	GY/R	GY/R
5.8 L MFI						
EVP	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG	BR/LG
VREF	O/W	O/W	BR/W	BR/W	BR/W	BR/W
SIG RTN	F-series, Bronco: BK/W Econoline: BR/W	BK/W	F-series, Bronco: GY/R E-series: BK/W	GY/R	GY/R	GY/R
Wiring Color Code	BK–Black, BL–Blue, BR–Brown, DB–Dark Blue, DG–Dark Green, GR–Green, GY–Gray, LB–Light Blue, LG–Light Green, N–Natural, O–Orange, P–Purple, PK–Pink, R–Red, T–Tan, W–White, Y–Yellow					

EVR (EEC-IV)

Circuit Description

EGR Vacuum Regulator (EVR) is an electromagnetic device that controls vacuum to the EGR valve. An electric current to the regulator's coil opens and closes a disc allowing more or less vacuum to reach the EGR valve.

EVR Solenoid



EVR Solenoid Electrical Tests

Test	Conditions	Test Results	If Not
EVR resistance	–Key off, wait 10 seconds –Disconnect EVR solenoid harness –Connect ohmmeter to solenoid	**4.9 L and 5.8 L**: 20 to 45 ohms **all others**: 20 to 70 ohms	EVR solenoid may be faulty
VPWR at EVR solenoid	–Key off, disconnect EVR solenoid harness –KOEO, measure voltage at EVR vehicle harness connector between VPWR and battery negative (–) terminal	Voltage greater than 10.5 volts dc	Wiring or EEC-IV module may be faulty

EVR Solenoid Wire Colors

Engine Family	Wire color
Car:	
1.9 L MA SFI	
EVR	W/BL
VPWR	W/R
2.0 L MA SFI	
EVR	W/BL
VPWR	W/R
2.3 L MA MFI	
EVR	DG
VPWR	R
2.3 L OHC MFI	
EVR	BR/PK
VPWR	R
2.3 L HSC MFI	
EVR	Y
VPWR	R
2.5 L AXODE SFI	
EVR	1991: BR/PK 1992: W
VPWR	1991: R 1992: R/BK

EVR Solenoid Wire Colors (continued)

Engine Family	Wire color
2.9 L MFI	
EVR	DG
VPWR	BK
3.0 L MFI	
EVR	1988–89: DG 1990: Probe: W, all others: DG 1991–92: W
VPWR	1988–89: R 1990 Probe: R/BK all others: R 1991–92: R/BK
3.0 L MA SFI	
EVR	Y
VPWR	R
3.0 L AXODE SFI	
EVR	BR/PK
VPWR	R
3.0 L SHO SFI	
EVR	1989–91: DG 1992–On: BR/PK
VPWR	R

continued on next page

EVR (EEC-IV)

EVR Solenoid Wire Colors (continued)

Engine Family	Wire color
3.2 L SHO SFI	
EVR	BR/PK
VPWR	R
3.8 L MFI AXOD	
EVR	1988–90: DG 1991–On: BR/PK
VPWR	R
3.8 L RWD MFI	
EVR	1988–91: DG 1992–On: BR/PK
VPWR	1988: BK/Y 1989–On: R
3.8 L SC SFI	
EVR	1989: Y 1990: DG
VPWR	R
4.6 L SFI	
EVR	BR/PK
VPWR	R
5.0 L SFI	
EVR	1988–90: DG 1991–On: BR/PK
VPWR	1988 Thunderbird/Cougar: BK/Y all others: R
5.0 L MA SFI	
EVR	1988–90 and '91TBird/Coug: DG 1991–On: BR/PK

EVR Solenoid Wire Colors (continued)

Engine Family	Wire color
VPWR	R
Truck:	
2.3 L MFI	
EVR	1989–90:DG 1991–On: BR/PK
VPWR	R
2.9 L MFI	
EVR	BR/PK
VPWR	R
4.0 L MA SFI	
EVR	BR/PK
VPWR	R
4.9 L MFI	
EVR	1988–89 all, and '90 E-Series: DG 1990 F-Series, Bronco: BR/PK 1991–On: BR/PK
VPWR	R
5.0 L MFI	
EVR	1988–89 all and '90 E-Series: DG 1990 F-Series, Bronco: BR/PK 1991–On: BR/PK
VPWR	R
5.8 L MFI	
EVR	1988–89 all and '90 E-Series: DG 1990 F-Series, Bronco: BR/PK 1991–On: BR/PK
VPWR	R
Wiring Color Code BK–Black, BL–Blue, BR–Brown, DB–Dark Blue, DG–Dark Green, GR–Green, GY–Gray, LB–Light Blue, LG–Light Green, N–Natural, O–Orange, P–Purple, PK–Pink, R–Red, T–Tan, W–White, Y–Yellow	

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HEDF (EEC-IV)

Circuit Description

High-speed Electro-Drive Fan (HEDF*) control turns the high speed (secondary) fan on and off.

On the 1.9 L and 2.0 L MAF SFI engines, the HEDF fan relay is a separate relay. The EEC-IV control unit turns on the fan by grounding the HEDF pin to energize (close) the relay.

On all except the 1.9 L and 2.0 L MAF SFI engines, the HEDF fan relay is part of the Integrated Relay Control Module (IRCM). The EEC-IV control unit turns on the fan by applying voltage to the HEDF pin to energize (close) the relay.

Troubleshoot the circuit by checking the signal wire continuity from the EEC-IV control unit to the relay or IRCM, and by checking power, ground, and continuity in the fan circuit.

HEDF Electrical Tests

Test	Conditions	Test Result	If Not
With IRCM IRCM/Fan circuit	–Key off, disconnect IRCM connector –KOEO –3.0L SHO: Measure between pins: 1,2 and ground –3.8L: Measure between pins: 3,4 and ground –All other models: Measure between pins: 1,2,6,7 and ground	10.5 volts or greater	Check for open in battery power circuit
With IRCM High speed fan circuit	–Key off, disconnect IRCM connector –Disconnect cooling fan, jumper pins 1 and 3 at IRCM connector	Battery voltage at cooling fan connector	Check power to IRCM, check wiring to cooling fan
Without IRCM High speed fan circuit	–Key off, disconnect cooling fan connector –KOEO	Battery voltage at cooling fan connector	Check power to HEDF fan relay, check wiring to cooling fan

EEC-IV HEDF Signal Wire Color

Engine Family	Wire color
Car	
1.9L MA SFI	R/BK
2.0L MA SFI	BL/GR
2.3L OHC MFI	LG/P
2.3L MFI TURBO	PK
2.3L HSC MFI	PK
2.5L AXODE SFI	LG/P
3.0L MFI	PK
3.0L MA SFI	LB
3.0L AXODE SFI	LG/P
3.0L SHO SFI	PK
3.2L SHO SFI	LG/P
3.8L MFI AXOD	1988–90:PK 1991–On: LG/P
3.8L SC SFI	1989–91: PK 1992–On: LG/P
Wiring Color Code BK–Black, BL–Blue, BR–Brown, DB–Dark Blue, DG–Dark Green, GR–Green, GY–Gray, LB–Light Blue, LG–Light Green, N–Natural, O–Orange, P–Purple, PK–Pink, R–Red, T–Tan, W–White, Y–Yellow	

*1993 and later called HFC—see glossary

HEGO (EEC-IV)

Circuit Description

Heated Exhaust Gas Oxygen (HEGO*) sensor detects oxygen content in the exhaust gasses. It sends a voltage signal to the EEC-IV control module. The sensor is electrically heated so the sensor output signal stabilizes more quickly. Some engines have two HEGO sensors: HEGOR and HEGOL.

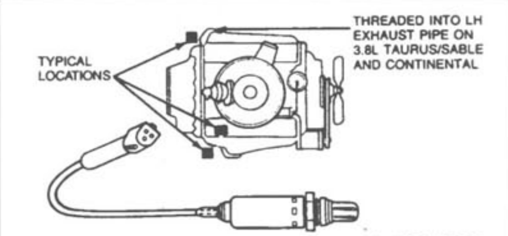
HEGO Inputs/Outputs

Signal[1]	Description
HEGO SIGNAL	Oxygen sensor output
HEGO GND	Oxygen sensor ground
KEY POWER	Power input for heating element
POWER GROUND	Heating element ground
[1]=where applicable	

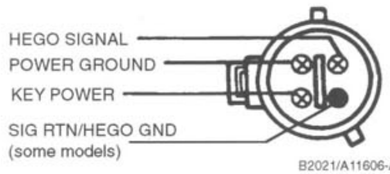
CAUTION —
Do not get any anti-seize compound or RTV sealer on the sensor tip or in the sensor slits. These chemicals will quickly foul the sensor element and render the sensor inoperative.

When troubleshooting, note that the HEGO signal should only be measured after the engine has run for several minutes. Fuel contaminated engine oil can affect HEGO readings. Always change the oil and oil filter if contamination is suspected. The HEGO heating element in the sensor can be tested using an ohmmeter.

HEGO Sensor



HEGO Connector (HEGO side)



HEGO Electrical Tests

Test	Conditions	Test Results	If Not
HEGO SIGNAL	–Key off, disconnect HEGO sensor connector –Connect DMM between HEGO SIGNAL and negative (–) battery terminal –Run engine for 2 minutes at 2000 rpm	0.5 volts or greater	HEGO sensor may be faulty
HEGO response to exhaust	–Key off, disconnect HEGO sensor connector –Connect DMM between HEGO SIGNAL and negative (–) battery terminal –Run engine for 2 minutes at 2000 rpm –Create vacuum leak (disconnect vacuum hose to intake manifold)	Voltage drops and fluctuates	HEGO sensor may be faulty
HEGO heater element	–Key off, disconnect HEGO sensor connector –Connect DMM between KEY POWER and POWER GROUND at sensor connector	2 to 5 ohms at room temperature	HEGO heater element faulty
KEY POWER	–Key off, disconnect HEGO sensor connector –Connect DMM between KEY POWER and POWER GROUND at vehicle connector –Key On	10.5 volts or greater	Check harness wiring and grounds

*1993 and later called HO2S—see glossary

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ISC-BPA (EEC-IV)

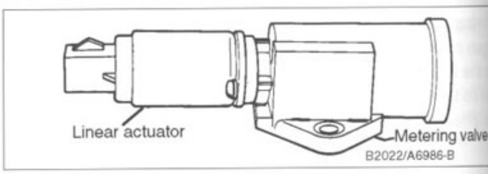
Circuit Description

Idle Speed Control-Bypass Air (ISC-BPA*) solenoid is an actuator that allows air to pass around the throttle plate. Principle job is to control idle RPM. Secondary jobs: prevent engine stall - electronic dashpot, and provide air for engine start. The ISC-BPA is controlled by the EEC-IV control unit. When troubleshooting the ISC-BPA circuit, always begin by checking for air leaks in the intake system, and check fuel injector O-rings for cracking and sealing. Note that unmetered air can also cause idle problems. Perform the electrical tests in order.

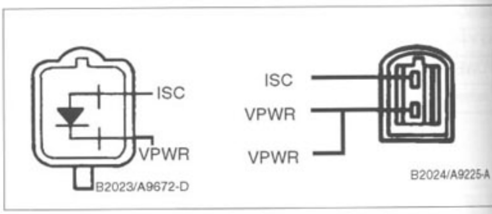
ISC-BPA Inputs/Outputs

Signal	Description
ISC	Input to solenoid from EEC-IV
VPWR	Input to solenoid

ISC-BPA Solenoid



ISC Solenoid Connector and Vehicle Harness Connector



ISC-BPA Electrical Tests

Test	Conditions	Test Results	If Not
ISC-BPA Solenoid	–Key off –Connect engine tachometer –Start engine, disconnect ISC-BPA solenoid	rpm drops or engine stalls	ISC-BPA solenoid may be faulty
ISC-BPA Solenoid resistance	–Key off, disconnect ISC-BPA solenoid connector –Connect DMM (+) lead to solenoid VPWR pin, DMM (–) lead to solenoid ISC pin	7 to 13 ohms	ISC-BPA solenoid may be faulty
VPWR circuit to ISC-BPA	–Key off, disconnect ISC-BPA solenoid connector –Connect DMM between VPWR at vehicle harness connector, and battery ground terminal –KOEO	10.5 volts or greater	VPWR circuit wiring faulty
ISC-BPA signal from EEC-IV module	–ISC-BPA solenoid connected –Key off, backprobe with DMM between ISC wire at vehicle harness connector and battery ground terminal –ER, slowly increase and decrease rpm	Voltage varies between 3 and 11.5 volts	EEC-IV module or wiring may be faulty

*1993 and later called IAC-BPA—see glossary

KS (EEC-IV)

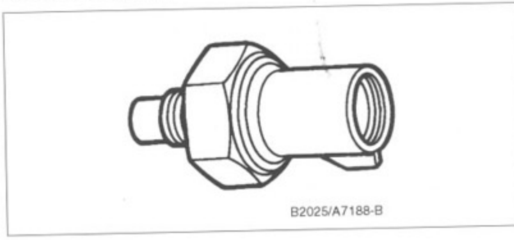
Circuit Description

Knock Sensor (KS) is a sensor that detects engine detonation (spark knock). When knock occurs, a voltage signal is sent to the EEC-IV module which retards spark timing. On some engines, two knock sensors are used. The knock sensor is color coded to indicate frequencies for that particular engine, and should be replaced with one having the same color code. When troubleshooting the knock sensor circuitry, begin by checking the fuel quality, ignition timing, and altitude at which test is being performed.

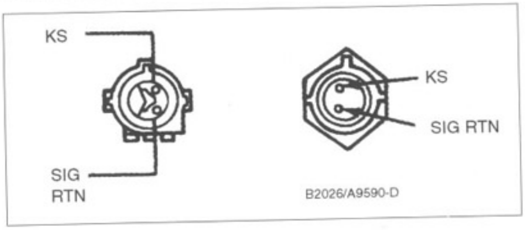
KS Inputs/Outputs

Signal	Description
KS	Input to EEC-IV module
SIG RTN	Signal return

Knock Sensor



Knock Sensor Vehicle Harness Connector and Knock Sensor Connector



KS Electrical Tests

Test	Conditions	Test Results	If Not
Knock Sensor Circuit Voltage	–Key off, wait 10 seconds –Disconnect knock sensor connector –KOEO, measure voltage between KS and SIG RTN at vehicle harness connector	1 to 4 volts dc	EEC-IV module or wiring may be faulty
Knock Sensor Operation	–ER, knock sensor connected –DMM on VAC scale, backprobe connector –Slowly raise engine speed to 3000 rpm	AC Voltage reading increases	Knock Sensor may be faulty
Knock Sensor Operation	–ER, knock sensor connected –DMM on VAC scale, backprobe connector –Tap exhaust manifold with 4 oz. hammer	AC Voltage reading fluctuates	Knock Sensor may be faulty

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MAF (EEC-IV)

Circuit Description

Mass Air Flow (MAF) sensor measures the mass of the air flowing into the engine. The sensor output is a DC signal ranging from about 0.5 to 5.0 volts, used by the EEC-IV module to vary fuel injector opening time. Power to the MAF sensor is controlled by the EEC-IV module. Ground is through the PWR GND circuit to the battery negative (–) terminal. The unit cannot be repaired. When troubleshooting the MAF sensor always begin by checking for air leaks in the intake system and repair as necessary.

> NOTE —
> Trouble code 26/159 can be generated by a high concentration of ambient exhaust gas—for example in an unvented or poorly vented garage.

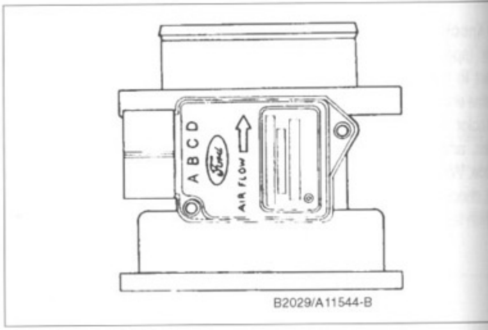
MAF Inputs/Outputs

Signal	Description
MAF SIG	Signal to EEC-IV module
MAF RTN	Signal return
VPWR	Vehicle power
PWR GND	Vehicle power ground

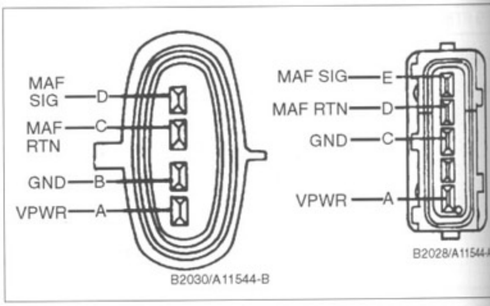
Typical* MAF Sensor Test Values

Speed	MAF Signal Voltage
Idle	0.6
20 mph	1.10
40 mph	1.70
60 mph	2.10
* values may vary based on vehicle load, temperature, and equipment	

Mass Air Flow Sensor



Mass Air Flow Sensor Connectors



MAF (EEC-IV)

MAF Electrical Tests

Test	Conditions	Test Results	If Not
VPWR and Ground	–Key off, disconnect MAF connector –Connect DVOM between VPWR and GND at vehicle harness connector –KOEO	10.5 volts or greater	Fault in VPWR circuit or in GND circuit to battery
MAF Circuit Short To Ground	–Key off, disconnect MAF connector –Connect DVOM between MAF SIG and MAF RTN, and MAF SIG and GND at vehicle harness connector	10,000 ohms or greater	Fault in wiring to control unit or faulty control unit
MAF Sensor Voltage	–MAF sensor connected –Backprobe MAF sensor connector between MAF and battery negative (–) terminal –ER	0.2 to 1.5 volts dc	MAF sensor may be faulty

MAP/BP (EEC-IV)

Circuit Description

Manifold Absolute Pressure (MAP) sensor measures the intake manifold pressure and sends a frequency signal to the EEC-IV module. The MAP sensor frequency decreases as vacuum increases. **Manifold Absolute Pressure/Barometric Pressure** (MAP/BP*) sensor is used to also sense barometric pressure allowing the EEC-IV module to compensate for changes in altitude.

When troubleshooting the MAP or MAP/BP sensor always begin by checking for air leaks in the intake system and vacuum system. Repair as necessary. The sensor can be checked using a frequency meter and a hand held vacuum pump with gauge. Begin by checking that the sensor holds vacuum.

If VREF and the MAP/BP sensor test OK, then either the wiring to the control unit or the control unit itself is faulty.

NOTE —
- Engine Running (ER) trouble codes generated during ER Self-Test may be due to a faulty vacuum hose or to excess EGR flow.
- Continuous memory codes may be due to a MAP sensor leak.

MAP Inputs/Outputs

Signal	Description
MAP or MAP/BP	Signal to EEC-IV module
SIG RTN	Signal return
VREF	Reference voltage input

MAP Sensor Test Values[1]

Manifold Vacuum		MAP Frequency
in-Hg	kPa	Hz
0	0	159
3	10.2	150
6	20.3	141
9	30.5	133
12	40.6	125
15	50.8	117
18	61.0	109
21	71.1	102
24	81.3	95
27	91.5	88
30	101.6	80

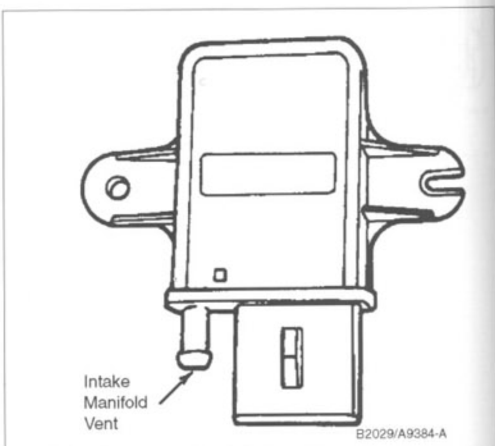
[1] based on barometric pressure of 30 in-Hg. Note: values may vary approximately ± 3 Hz

MAP/BP Sensor Test Values

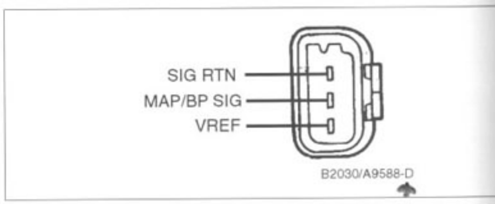
Barometric Pressure		MAP/BP Frequency
in-Hg	kPa	Hz
17.1	58	122.4
18.3	62	125.5
19.5	66	128.7
20.7	70	131.9
21.8	74	135.1
23.0	78	138.3
24.2	82	141.8
25.4	86	145.4
26.6	90	148.9
27.7	94	152.5
28.9	98	156.1
30.1	102	159.6
31	105	162.4

Note: values may vary approximately ± 3 Hz

MAP Sensor



MAP Sensor Terminals



*1993 and later called BARO—see glossary

MAP/BP (EEC-IV)

MAP and MAP/BP Electrical Tests

Test	Conditions	Test Results	If Not
VREF	–Key off, disconnect MAP/BP connector –Measure voltage between VREF and SIG RTN at vehicle harness connector –KOEO	4 to 6 volts dc (VREF)	Check VREF circuit
MAP Sensor	–Connect MAP connector –Backprobe MAP connector between MAP wire and battery negative (–) terminal –Vary vacuum using pump –ER	See table above	MAP sensor may be faulty
MAP/BP Sensor	–Connect MAP/BP connector –Backprobe MAP/BP connector between MAP wire and battery negative (–) terminal –Vary vacuum using pump –ER	See table above	MAP/BP sensor may be faulty

PFE (EEC-IV)

Circuit Description

Pressure Feedback (PFE)/**Delta PFE** (DPFE) EGR sensor converts a varying exhaust gas pressure value into an analog voltage which is sent to the EEC-IV module. The EEC-IV module uses this information to compute the optimal EGR flow. The PFE sensor can be tested using a vacuum pump and gauge. Begin by checking the pressure input hose to the sensor for blockage and correct as necessary.

> ***CAUTION —***
> *To avoid possible sensor damage, do not exceed pressure/vacuum range shown below when testing.*

> **NOTE —**
> Trouble code 34/335 could be due to a lack of exhaust system pressure, caused by shop exhaust extraction equipment.

PFE/DPFE Inputs/Outputs

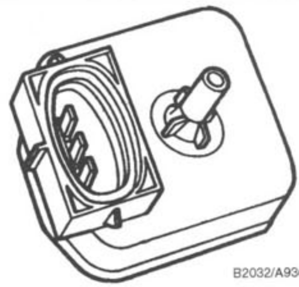
Signal	Description
PFE/DPFE SIG	Signal to EEC-IV module
SIG RTN	Signal return
VREF	Reference voltage input

PFE Sensor Test Values

Pressure/Vacuum			PFE Voltage
psi	in-Hg.	kPa	Volts
1.82	3.70	12.5	4.75
1.36	2.79	9.42	4.38
0.91	1.85	6.25	4.0
0.46	0.94	3.17	3.63
0	0	0	3.25
–2.47	–5.03	–17.0	1.22
–3.63	–7.40	–25.0	0.25

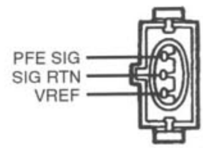
Note: values may vary ± 15 percent due to sensor and VREF variations

PFE Sensor



B2032/A9363-A

PFE/DPFE Sensor Connector



B2031/A9596-D

DPFE Sensor Test Values

Pressure/Vacuum			DPFE Voltage
psi	in-Hg.	kPa	Volts
4.34	8.83	29.81	4.56
3.25	6.62	22.36	3.54
2.17	4.41	14.90	2.51
1.08	2.21	7.46	1.48
0	0	0	0.45

Note: values may vary ± 15 percent due to sensor and VREF variations

PFE/DPFE Electrical Tests

Test	Conditions	Test Results	If Not
For Code 31/327 (PFE/DPFE signal less than 0.2 volts)	–Key off, disconnect PFE/DPFE sensor connector –Jumper PFE/DPFE circuit to VREF at harness connector –Perform KOEO Self-Test	Code 35/337 generated (ignore other codes)	–No codes at all: internal short in wiring to control unit, or control unit faulty –If 35/337 generated, replace PFE/DPFE sensor –If 35/337 not generated, check VREF
For code 35/337 (PFE/DPFE signal more than 4.8 volts)	–Key off, disconnect PFE/DPFE sensor connector –Perform KOEO Self-Test	Code 31/327 generated (ignore other codes)	–If 31/327 generated, replace PFE/DPFE sensor –If 31/327 not generated, either internal short in wiring to control unit, or control unit faulty
VREF	–Key off, disconnect PFE/DPFE connector –KOEO, measure voltage between VREF and SIG RTN at vehicle harness connector	4 to 6 volts dc (VREF)	Check VREF circuit
PFE/DPFE Sensor	–Connect PFE/DPFE connector –Connect DVOM (backprobe or BOB) between PFE wire and SIG RTN –ER, vary vacuum using pump	See table above	PFE/DPFE sensor may be faulty

TAB/TAD (EEC-IV)

Circuit Description

Thermactor Air Bypass/Thermactor Air Diverter (TAB/TAD*) solenoids (also known as AM1/AM2) direct secondary air to either the engine or exhaust manifold and catalytic converter. Opening and closing of the solenoids is controlled by the control module.

TAB Signal Wire Color

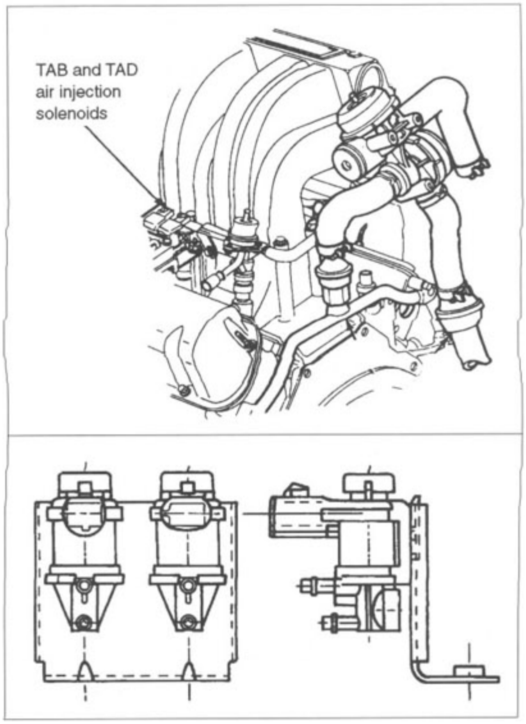
Engine Family	Wire color
Car:	
2.3L HSC MFI	W/R
5.0L SFI	W/R
5.0L MA SFI	*1992–On Mustang: W/Y* all others: W/R
Truck:	
4.9L MFI	1988–89: W/R 1991 E-series: O all other 1990–On: W/O
5.0L MFI	1988–89: W/R 1990 E-series: W/R *all other 1990–On:* W/O
5.8L MFI	1988–89: W/R 1990–91 F-series: W/O 1990–91 E-series: W/R 1992–On: W/O

TAD Signal Wire Colors

Engine Family	Wire color
Car:	
5.0L SFI	1990 Town Car: O all others: LG/BK
5.0L MA SFI	1988–90 all other: LG/BK 1990 Town Car: O 1991–On: W/LG
Truck:	
4.9L MFI	1988–90: W/BK 1990 E-series: W/BK 1991–On: B/R
5.0L MFI	1988–90: W/BK 1990 F-series, Bronco: B/R 1990 E-series: W/BK 1991–On: B/R
5.8L MFI	1988–90: W/BK 1990 F-series, Bronco: B/R 1990 E-series: W/BK 1991–On: B/R

Wiring Color Code BK–Black, BL–Blue, BR–Brown, DB–Dark Blue, DG–Dark Green, GR–Green, GY–Gray, LB–Light Blue, LG–Light Green, N–Natural, O–Orange, P–Purple, PK–Pink, R–Red, T–Tan, W–White, Y–Yellow

Component Locator



Typical location of TAB and TAD. Engine shown is F-series, Bronco 5.0 L.

Test Data

Check the TAB/TAD solenoids for internal vacuum leaks by connecting a vacuum pump to the supply port and a vacuum gauge to the output port of one solenoid. Apply a vacuum of 15 in-Hg. (51 kPa) and observe gauge. Gauge reading should hold for each solenoid.

Check for VPWR with the key on, engine off (KOEO) after disconnecting the solenoid connector. VPWR should be 10.5 *volts or greater. If not, check wiring for continuity or corrosion.*

Solenoid resistance at solenoid terminals should be 51–108 ohms. If not replace the solenoid.

If solenoid operates and wiring to the control unit is OK, then the control unit may be faulty.

*1993 and later called AIRB/AIRD—see glossary

TFI-IV (EEC-IV)

Circuit Description

Thick Film Ignition-IV (TFI-IV*) and **Thick Film Ignition** with **Computer Controlled Dwell** (TFI-CCD*) are ignition systems that use solid state integrated circuits. A Hall sender in the distributor creates a signal (PIP) indicating crankshaft position for the EEC control module. The EEC control module triggers the TFI module with a signal (SPOUT) to fire the ignition coil. On models with Closed-Bowl Distributor, two PIP signals are sent, one to the TFI module and one to the EEC module.

Remember that a no-spark condition may also be caused by a fault in power to the coil, or by a faulty coil. Always begin by checking the power supply and ground to the module.

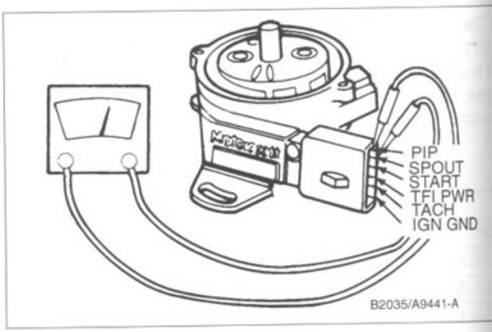
On TFI-IV and TFI-CCD, if there is no PIP signal but the module has power and ground and there is continuity in the module (PIP IN to PIP) then the Hall sender is probably faulty. On TFI with closed-bowl distributor, if there is no PIP signal but the Hall sender has power and ground, then the Hall sender is probably faulty. Perform the tests in the order shown below.

> ***WARNING —***
> *The TFI-IV ignition system is a high-energy system operating in a dangerous voltage range which could prove to be fatal if exposed terminals or live parts are contacted. Use extreme caution when working on a vehicle with the ignition on or the engine running.*

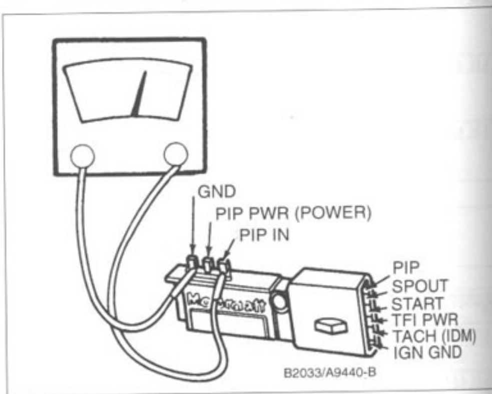
TFI-IV Inputs/Outputs

Signal	Description
START	Battery voltage input with ignition switch in start position
RUN (TFI PWR)	Battery voltage input with ignition switch in run position
COIL (TACH)	Switched output to ignition coil
PIP	PIP signal output to EEC-IV
IGN GND	Ignition ground
SPOUT	Spark out signal from EEC-IV
FTO	Filtered Tach Output signal
PIP IN	PIP signal from Hall sender
PIP PWR	Power to Hall sender

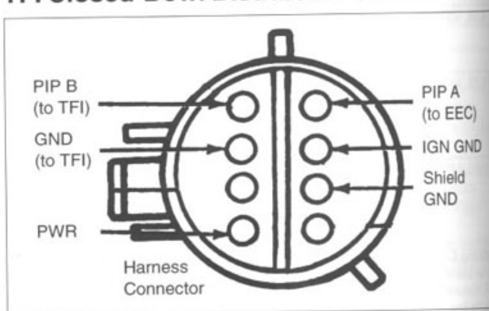
TFI-IV Module (Testing)



TFI-IV Module (Hall sender connector)



TFI Closed-Bowl Distributor Connector



*1993 and later called DI—see glossary

TFI-IV (EEC-IV)

TFI-IV Electrical Tests

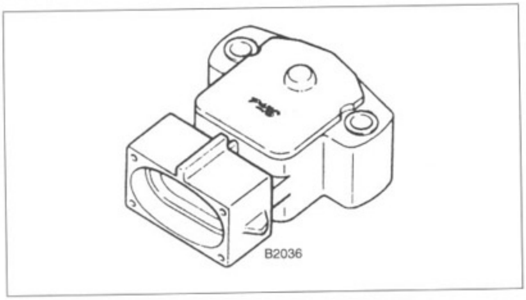
Test	Conditions	Test Results	If Not
Distributor ground	–Connect DVOM between distributor base and engine block	Continuity (less than 2 ohms)	Fault in distributor ground, check distributor mounting
Power to TFI module or closed-bowl distributor, engine run	–Key off, disconnect TFI-IV/distributor connector –Measure voltage at vehicle harness connector between TFI PWR/PWR and distributor base (ground) –KOEO	Battery voltage	Fault in power circuit from ignition switch
Power to TFI module, engine crank	–Key off, disconnect TFI-IV connector –Measure voltage at vehicle harness connector between START and distributor base (ground) –Engine Crank	8 to 10 volts	Fault in power circuit from ignition switch
Power to Hall sender (closed-bowl distributor)	–Key off, disconnect distributor connector –Measure voltage between PWR at harness connector and distributor base (ground) –KOEO	Battery voltage	Fault in power circuit from ignition switch
PIP signal (TFI, TFI-CCD)	–TFI connector connected –Backprobe TFI connector at PIP with DVOM or LED test lamp –Engine Crank	3 to 6 volts, or LED test lamp blinks	If TFI module tests OK as shown below then Hall sender is faulty
PIP signal (TFI with closed-bowl distributor)	–Distributor connector connected –Backprobe distributor connector at PIP A/B with DVOM or LED test lamp –Engine Crank	3 to 6 volts, or LED test lamp blinks	Hall sender faulty
SPOUT	–TFI connector connected –Backprobe TFI connector at SPOUT with DVOM or LED test lamp –Engine Crank	3 to 6 volts or LED test lamp blinks	Check wiring to control module. If OK, control module may be faulty
TFI Module tests (See illustration above, **TFI Module (Hall sender connector)**			
GND to PIP IN	–Remove distributor from engine –Remove TFI module from distributor –Probe with ohmmeter at Hall sensor connector	Greater than 500 Ohms	TFI module faulty
PIP PWR to PIP IN	–Probe with ohmmeter at Hall sensor connector	Less than 2000 Ohms	TFI module faulty
PIP PWR to TFI PWR	–Probe with ohmmeter at Hall sensor connector	Less than 200 Ohms	TFI module faulty
GND to IGN GND	–Probe between TFI module connectors	Less than 2 Ohms	TFI module faulty
PIP IN to PIP	–Probe between TFI module connectors	Less than 200 Ohms	TFI module faulty

TPS (EEC-IV)

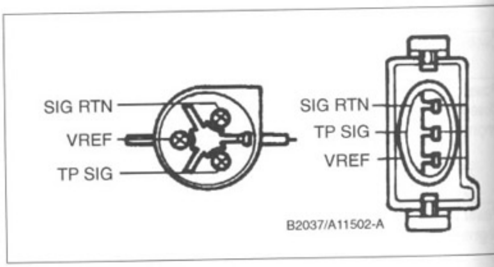
Circuit Description

Throttle Position Sensor (TPS) is a sensor that provides the EEC-IV module with a variable voltage that represents the position of the throttle. This information is used to control air-fuel ratio, timing, fuel shut-off, and EGR and A/C functions. When the throttle is closed the TPS voltage is approximately 0.6 volts. When the throttle is fully open the TPS voltage is approximately 4.5 volts. The TPS is a sealed unit and cannot be repaired. The TPS is located in the throttle housing.

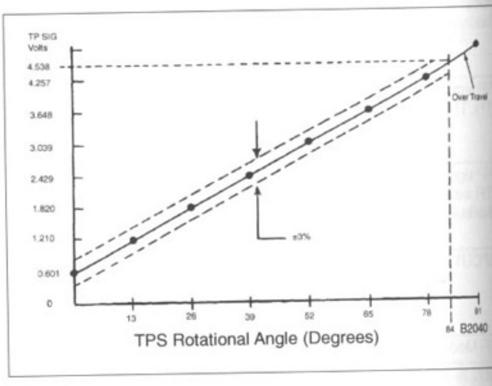
Throttle Position Sensor (Rotary type)



Throttle Position Sensor Vehicle Harness Connectors



Throttle Position Sensor Output Voltage



TPS Inputs/Outputs

Signal	Description
TP SIG	Variable voltage from approximately 0 to 5 volts
VREF	Reference voltage
SIG RTN	Signal return

TPS Electrical Tests

Test	Conditions	Test Results	If Not
VREF	–Key off, wait 10 seconds –Disconnect TPS connector –Probe between VREF and SIG RTN at TPS vehicle harness connector –KOEO	4 to 6 volts	Check VREF circuitry and wiring
TP SIG	–Backprobe TPS connector between TPS and SIG RTN –KOEO –Move throttle through entire range	–Variable voltage from 0 to 5 volts without any breaks as throttle is moved through range	Faulty TPS

VAF/VAT (EEC-IV)

Circuit Description

Vane Airflow Sensor (VAF*) is a sensor that provides the EEC-IV module with a voltage signal that represents the amount of air flowing into the engine. The VAF sensor consists of an air vane that is attached to a potentiometer. The air vane moves as the intake air volume changes, changing the voltage. When troubleshooting the VAF sensor, begin by checking for air leaks in the intake system that cause unmetered air to enter. Check that the VAF sensor is not binding or sticking and remove all residue and intake deposits using a cleaner. The VAF sensor cannot be repaired. The VAF sensor is located in the vane air meter in the throttle housing.

Vane Air Temperature (VAT*) sensor provides the EEC-IV module with a voltage that changes with ambient temperature. The VAT sensor is similar in operation to the ACT sensor. The VAT sensor is in the vane air meter and is not replaceable. It can be tested using an ohmmeter using the values shown below.

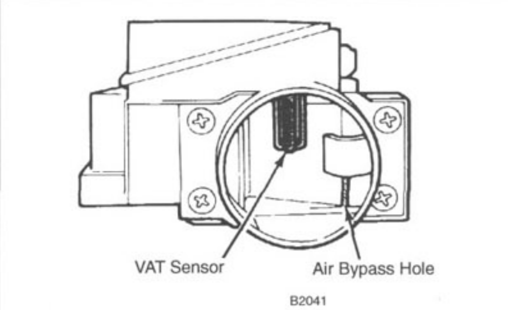
VAF/VAT Inputs/Outputs

Signal	Description
VAF SIG	Variable voltage to EEC-IV module
VAT SIG	Variable voltage to EEC-IV module
VREF	Reference voltage
SIG RTN	Signal return

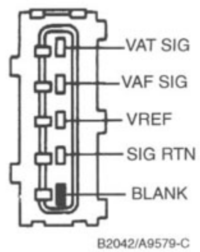
VAT Sensor Values

Temperature	Resistance
32° F	5800 ohms
65° F	2700 ohms
185° F	300 ohms
220° F	180 ohms
240° F	125 ohms

Vane Air Meter



VAF/VAT Sensor Connector



VAF/VAT Electrical Tests

Test	Conditions	Test Results	If Not
VREF	–Key off, wait 10 seconds –Disconnect VAF connector –Probe between VREF and SIG RTN at VAF vehicle harness connector –KOEO	4 to 6 volts	Check VREF circuitry and wiring
VAF SIG	–Key off, wait 10 seconds –Backprobe VAF connector between VAF and SIG RTN with DMM –KOEO –Move air vane meter through entire range	–Variable voltage from 1 to 5 volts without any breaks as vane is moved through range	Faulty Vane Air Meter
VAT SIG	–Key off, wait 10 seconds –Disconnect VAF connector –Probe VAF connector between VAT SIG and SIG RTN with DMM	–Resistance value as specified at a particular temperature (See table above)	Faulty Vane Air Meter

*1993 and later called VAF/IAT—see glossary

VPWR (EEC-IV)

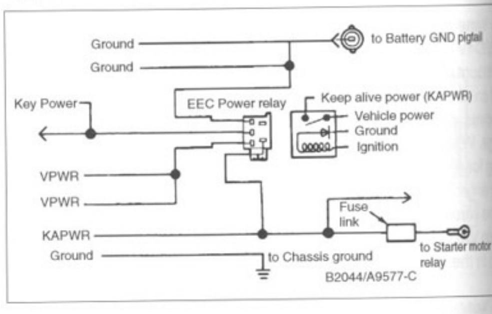
Circuit Description

Vehicle Power (VPWR) is battery voltage distribution to certain output actuators when the key is on. The EEC Power Relay located in the IRCM supplies VPWR to these various electrical components. A failure in the VPWR circuit will result in a no start condition.

VPWR Inputs/Outputs

Signal	EEC-IV Module Pin	Description
VPWR	37, 57	Power distribution
KEY POWER		Ignition key input to EEC power relay in IRCM
KAPWR		Battery voltage at all times
GND or PWR GND	40, 60	Ground

Typical VPWR Circuit



VPWR Electrical Tests

Test	Conditions	Test Results	If Not
VPWR	–Key On or Key in Crank position –Measure voltage with DMM between VPWR and battery negative (–) terminal	10.5 volts or greater	–Check for open or short in VPWR circuit –Check EEC Power Relay in IRCM, ground wiring, and key power circuit –Check continuity of VPWR wiring from IRCM to EEC-IV module
KEY POWER	–Key On, Engine Off –Engine Running	10.5 volts or greater	–Check ignition switch and wiring
GROUND	*–Measure continuity to battery negative (–)* terminal	*5 Ohms or less*	*Check ground cable and straps*
KAPWR		10.5 volts or greater	Check battery positive (+) cable and battery

VREF (EEC-IV)

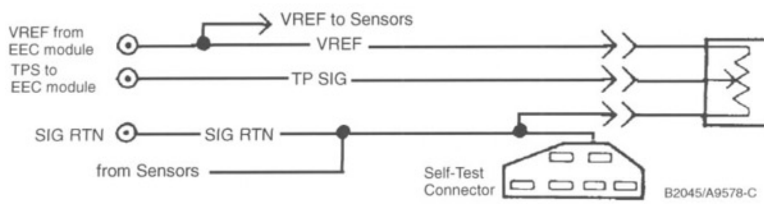
Circuit Description

Reference Voltage (VREF) is a voltage supply used for various sensors such as TPS, EVP/PFE, MAP, 4EAT and VAF. The VREF voltage should be 5 volts, with just a small variance (± 0.1v.) an acceptable range. The VREF supply is generated internally by the EEC-IV module. Always begin troubleshooting by checking for VPWR and GND to the EEC-IV module. To isolate problems with sensors that use VREF, disconnect one sensor at a time and re-measure VREF.

VREF Inputs/Outputs

Signal	EEC-IV Module Pin	Description
VREF	26	Reference voltage of 4 to 6 volts from EEC-IV module
SIG RTN	46	Signal return (ground) for VREF
VPWR	37, 57	Battery voltage with key on or key in crank position
GND or PWR GND	40, 60	Ground

Typical VREF Circuit



VREF Electrical Tests

Test	Conditions	Test Results	If Not
VREF	–Key on or Key in crank position –Measure voltage with DMM between VREF and SIG RTN –Note: measure VREF and TPS	5 ± 0.1 volts	–Check for power and ground to EEC-IV module –Check for open or short in VREF circuit –Check for faulty sensor connected to VREF, check continuity of wiring
VPWR	–Key On, Engine Off –Key On, Engine Running	10.5 volts or greater	–Check EEC Power Relay in IRCM
KEY POWER	–Key On, Engine Off –Key On, Engine Running	10.5 volts or greater	–Check ignition switch and wiring
GROUND	–Measure continuity to battery negative (–) terminal	5 Ohms or less	Check ground cable and straps
SIG RTN	–Measure continuity between SIG RTN and battery negative (–) terminal	5 Ohms or less	Check wiring to EEC-IV module

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BP (MECS)

Circuit Description

Barometric Pressure (BP*) sensor is used to sense barometric pressure so the control module can compensate for changes in altitude. The sensor can be checked using a volt meter and a hand-held vacuum pump with gauge. Begin by checking that the sensor holds vacuum.

> **NOTE —**
> On all except 1.6L engines, if a trouble code 14 exists and it cannot be erased, the control module must be replaced. The BP sensor is integral with the module and cannot be replaced separately.

BP Sensor Inputs/Outputs

Signal	Description
BP SIG	Signal to EEC-IV module
SIG RTN	Signal return
VREF	Reference voltage input

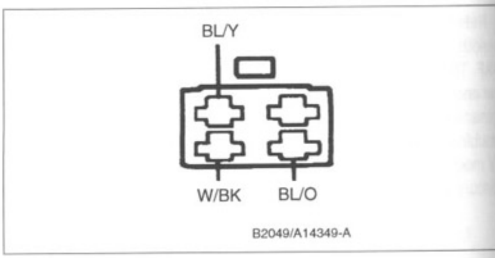
BP Sensor Test Values (all except '93 and later 2.0 L EAT)

Volts (±15%)	Vacuum	
	in-Hg.	kPa
3.26 to 4.42	0	0
2.86 to 3.86	5	16.7
2.26 to 3.06	10	33.7
1.64 to 2.22	15	50.7
1.07 to 1.45	20	67.7
0.49 to 0.67	25	84.7

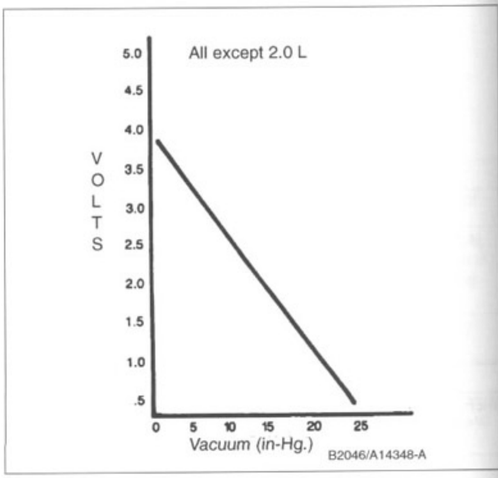
BP Sensor Test Values ('93 and later 2.0 L EAT)

Volts (±15%)	Vacuum	
	in-Hg.	kPa
3.9	0	0
3.6	3.94	10.0
3.1	7.87	20.0
2.5	11.81	30.0
2.0	15.75	40.0
1.5	19.69	50.0
0.9	23.62	60.0
0.4	27.56	70.0

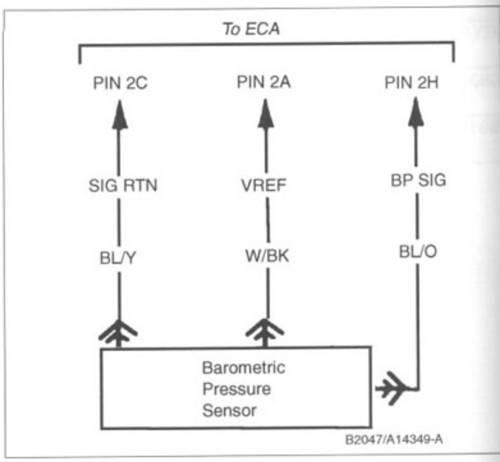
BP Sensor Harness Connector



BP Sensor Test Data



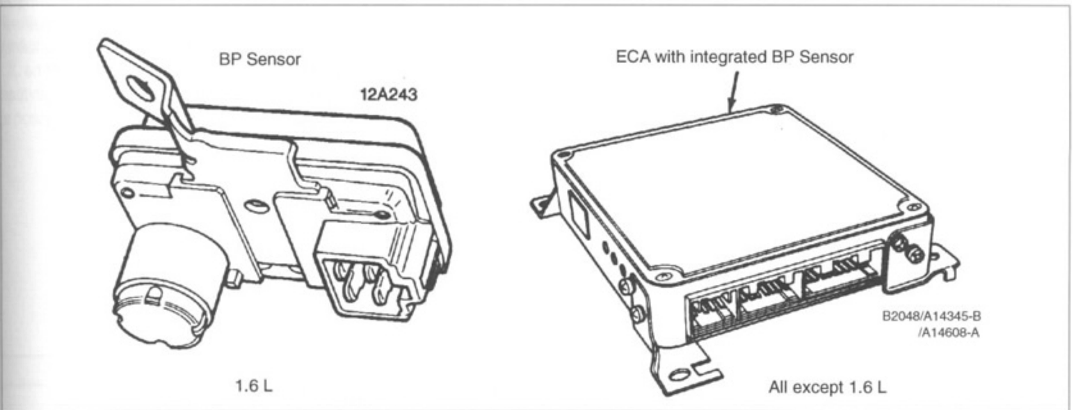
BP Sensor Schematic



*1993 and later called BARO—see glossary

BP (MECS)

BP Sensor



BP Sensor Electrical Tests

Test	Conditions	Test Results	If Not
BP SIG	–Using a DMM, backprobe between BP SIG wire and SIG RTN wire at the sensor connector –Remove dust cover from BP sensor –Apply vacuum as shown in table –KOEO	See **BP Sensor Test Values** for test results	BP sensor may be faulty
VREF	–Disconnect BP sensor connector –DMM connected between VREF wire and SIG RTN wire –KOEO	4.5 to 5.5 volts	–Check wiring to control module, check VPWR and ground to module –Possible faulty control module
SIG RTN		Continuity to ground	Check wiring to control module

CANP (MECS)

Circuit Description

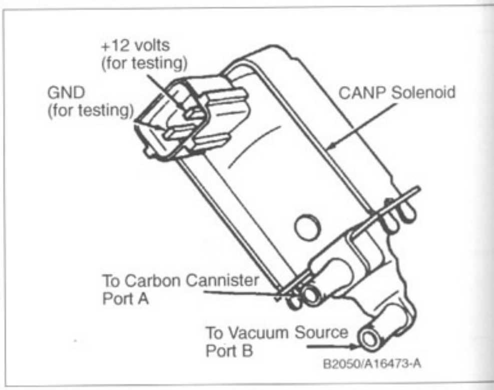
Canister Purge (CANP) solenoid is controlled by the control module to regulate the flow of fuel vapors from the EVAP canister to the intake system. The solenoid is normally closed. When the control unit energizes the solenoid to open, the fuel vapors are drawn into the engine using vacuum. The CANP solenoid is located near the center of the cowl panel. If the solenoid checks out OK and there are no wiring faults to the control module, then the control module may be faulty.

> **NOTE —**
> Excessive fuel tank pressure could be caused by the fuel cap and does not necessarily indicate a problem with the CANP solenoid or canister.

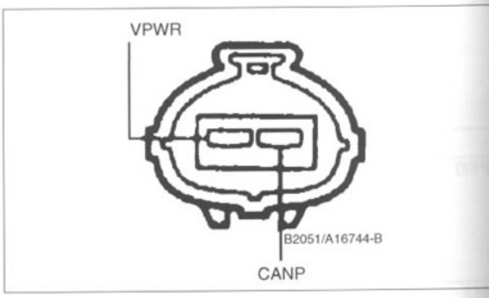
CANP Inputs/Outputs

CANP	Input to solenoid from control module
VPWR	Vehicle power

CANP Solenoid



CANP Solenoid Connector



CANP Solenoid Tests

Test	Conditions	Test Result	If Not
CANP solenoid	–Disconnect solenoid connector –Disconnect vacuum hoses A and B –Blow air through port A	No air flows from port B	Replace CANP solenoid
	–Disconnect solenoid connector –Disconnect vacuum hoses A and B –Apply 12 volts and ground as shown above –Blow air through port A	Air flows from port B	Replace CANP solenoid

CID (MECS)

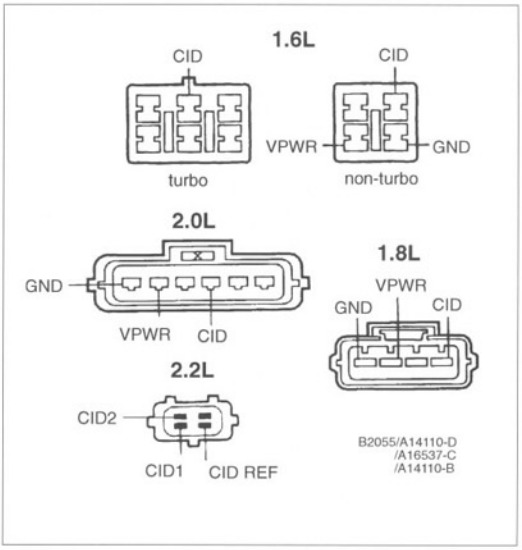
Circuit Description

Cylinder Identification (CID) sensor employs a distributor mounted rotor and sensor. The CID sensor provides accurate crankshaft position information to the control module. The 2.2L engine has two sensors, CID1 and CID2. When troubleshooting the CID sensor, begin by checking for VPWR (vehicle power) and GND (ground) at the distributor connector.

> ***WARNING —***
> *The ignition system is a high-energy system operating in a dangerous voltage range which could prove to be fatal if exposed terminals or live parts are contacted. Use extreme caution when working on a vehicle with the ignition on or the engine running.*

Engine	CID Sensor
1.6L turbo 1.6L non-turbo	Detects cylinder no.1 top dead center
1.8L, 2.0L	Detects cylinder no.1 on compression stroke
2.2L	Detects cylinder no.1 and cylinder no.4 using two magnetic pickups (CID1 and CID2)

Distributor Harness Connectors



CID Sensor Tests

Test	Conditions	Test Result	If Not
CID (except 2.2L)	–Key off –Backprobe between CID wire and GND wire at distributor connector –Crank engine	Voltage alternates between 0 and 5 volts or LED test light blinks	–Check VPWR and GND to distributor –CID sensor may be faulty
CID1 (2.2L engines)	–Key off –Backprobe CID1 wire and CID REF wire at distributor connector –Crank engine	0.6 to 0.8 volts	–Check VPWR and GND to distributor –CID1 sensor or wiring may be faulty
CID2 (2.2L engines)	–Key off –Backprobe CID2 wire and CID REF wire at distributor connector –Crank engine	0.6 to 0.8 volts	–Check VPWR and GND to distributor –CID2 sensor or wiring may be faulty

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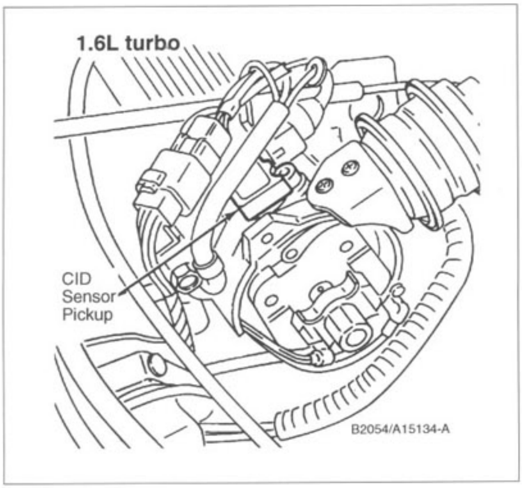
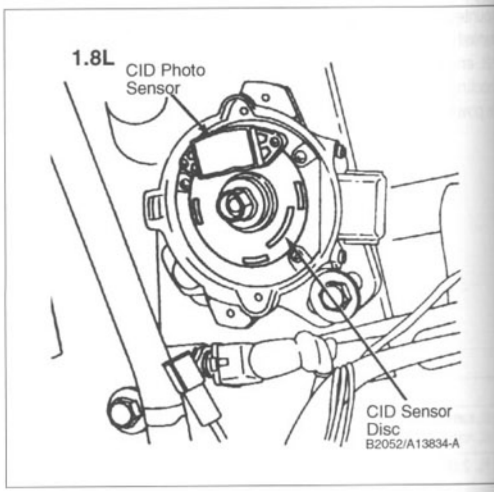
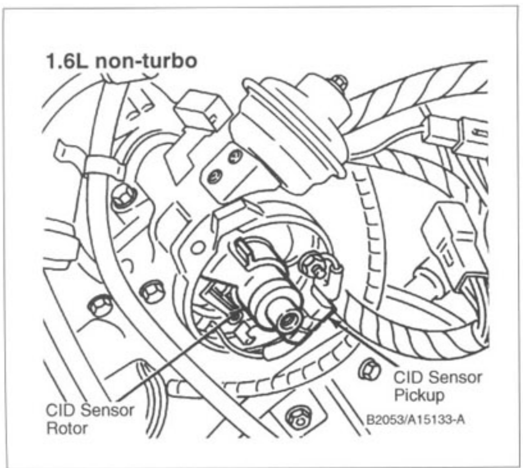
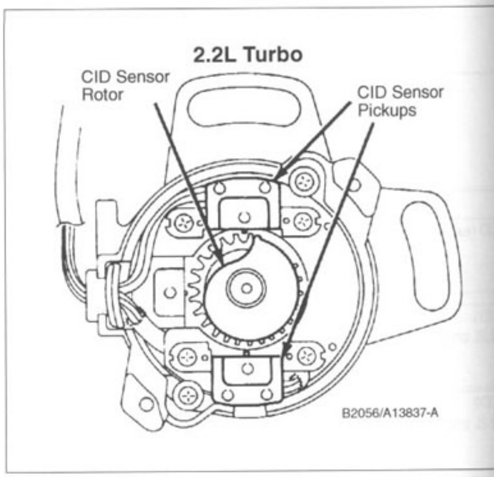
CID (MECS)

Component Locator









CPS (MECS)

Circuit Description

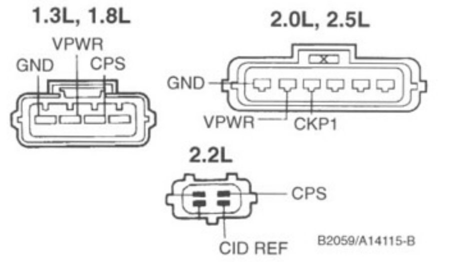
Crankshaft Position Sensor (CPS*) is a distributor mounted rotor and sensor. The rotor has slots or teeth that pass through the sensor to generate a signal. The CPS provides accurate engine speed information for the control module. When troubleshooting the CPS, begin by checking for VPWR (vehicle power) and GND (ground) at the distributor connector, and correct any faults found.

> ***WARNING —***
> *The ignition system is a high-energy system operating in a dangerous voltage range which could prove to be fatal if exposed terminals or live parts are contacted. Use extreme caution when working on a vehicle with the ignition on or the engine running.*

CPS Inputs/Outputs[1]

Signal	Description
CPS	Engine speed signal to ECA
CKP1	Engine speed signal to ECA
VPWR	Vehicle power
GND	*Ground*
CID REF **2.2 L engines**	Signal reference (ground)
[1] where applicable	

Distributor Harness Connector



CPS Tests

Test	Conditions	Test Result	If Not
CKP1 **2.0 L and 2.5 L engines**	–Key off –Backprobe between CKP1 wire and CID REF wire at distributor connector –Crank engine	Voltage alternates between 0 and 5 volts or LED test light blinks	–Check VPWR and GND to distributor –CKP1 sensor may be faulty
CPS **all other engines**	–Key off –Backprobe between CPS wire and GND wire at distributor connector –Crank engine	Voltage alternates between 0 and 5 volts or LED test light blinks	–Check VPWR and GND to distributor –CPS sensor may be faulty
VPWR	–Key off –Backprobe VPWR wire and GND wire at distributor connector –KOEO	10 volts or greater	–Check VPWR and GND to distributor, –Check wiring to ECA and IRCM
GND		Continuity	Check wiring to battery negative (–) terminal

*1993 and later called CKP—see glossary

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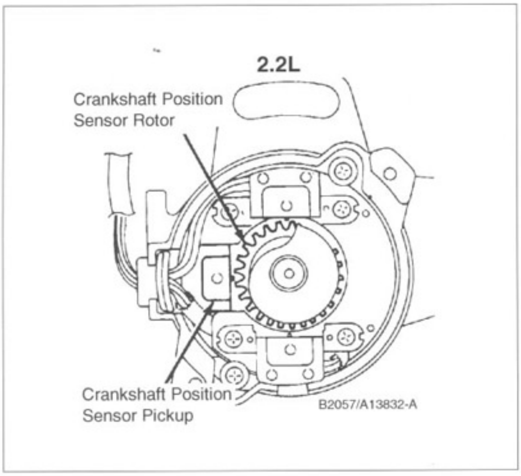
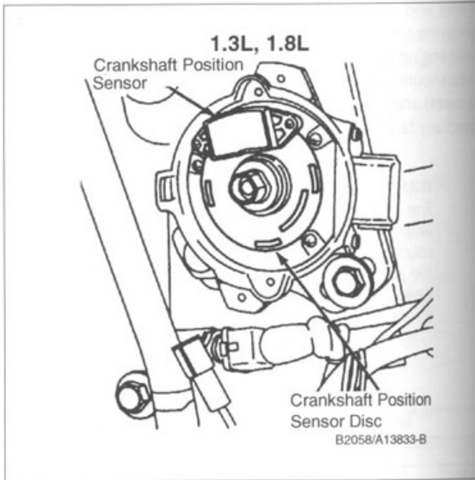
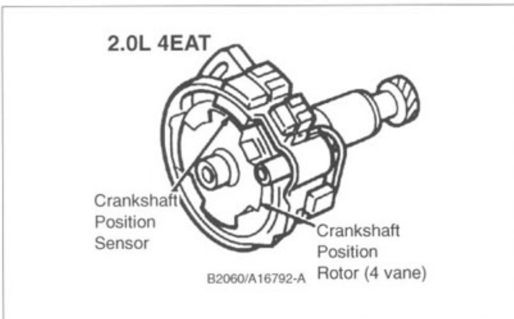
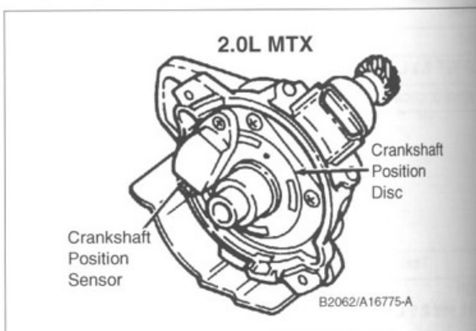
CPS (MECS)

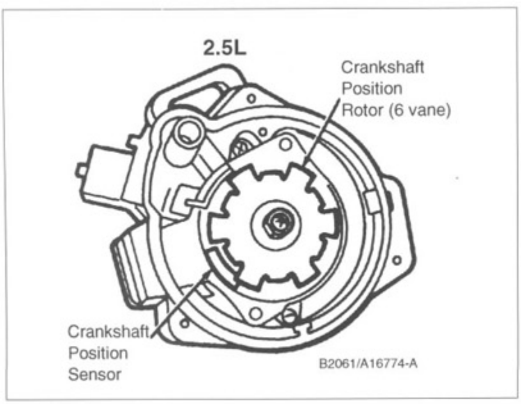
Component Locator











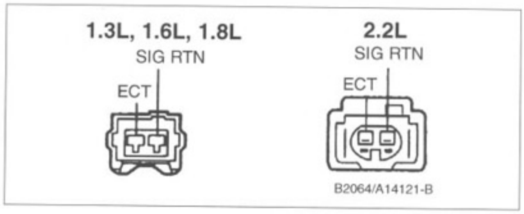
ECT (MECS)

Circuit Description

Engine Coolant Temperature (ECT) sensor provides information about engine temperature by changing resistance. The change in resistance changes voltage in the circuit. The sensor resistance decreases as the surrounding temperature increases.

A short will result in approximately 0 volts in the circuit. Corrosion in the circuit at terminal connections results in higher-than-normal voltage due to the voltage drop at the connection.

ECT Harness Connector



ECT Sensor Location

Engine	ECT Location
1.3 L	Threaded into top of intake manifold
1.6 L	Threaded into underside of intake manifold
1.8 L	Threaded into engine near thermostat housing
2.0 L	Threaded into the coolant temperature sensor housing on the left side of engine
2.5 L	Threaded into the coolant elbow on the right side of engine

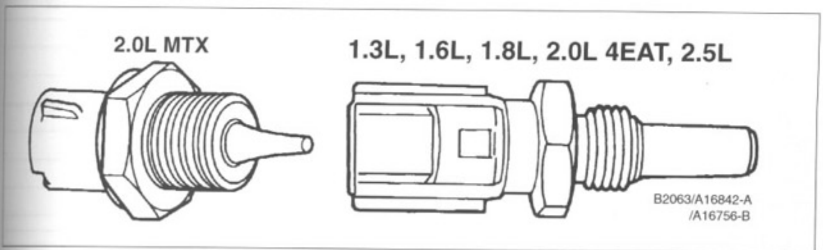
ECT Sensor Test Data

Coolant Temperature		ECT Sensor Resistance
°C	°F	Ohms
–20	–4	14600 to 17800
20	68	2200 to 2700
40	104	1000 to 1300
60	140	500 to 650
80	176	290 to 350

ECT Sensor Tests

Test	Conditions	Test Results	If Not
Sensor resistance	*–Disconnect sensor connector* –Measure across sensor terminals	See table above	Sensor may be faulty

ECT Sensors



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EGO (MECS)

Circuit Description

Exhaust Gas Oxygen Sensor (EGO*) is a sensor that detects oxygen content in the exhaust gasses and sends a voltage signal to the control module. The sensor is threaded into the exhaust manifold or connecting pipe. On some engines, the sensor is electrically heated so the sensor output signal stabilizes more quickly.

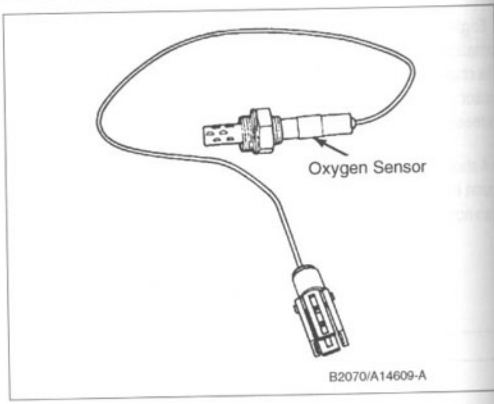
EGO/HEGO Inputs/Outputs

Signal[1]	Description
EGO/HEGO SIGNAL	Oxygen sensor output
SIG RTN	Heated oxygen sensor ground
PWR	Power input for heating element
GND	Heating element ground
[1]=where applicable	

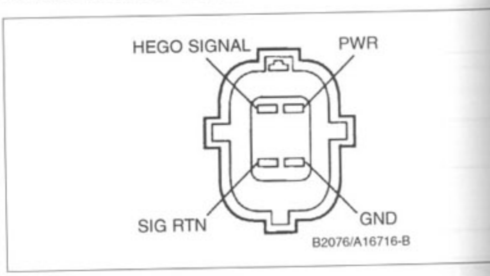
> ***CAUTION —***
> *Do not get any anti-seize compound or RTV sealer on the sensor tip or in the sensor slits. These chemicals will quickly foul the sensor element and render the sensor inoperative.*

When troubleshooting, note that the EGO/HEGO signal should only be measured after the engine has run for several minutes. Fuel-contaminated engine oil can affect EGO readings. Always change the oil and oil filter if contamination is suspected.

EGO Sensor



HEGO Sensor Terminals



EGO/HEGO Electrical Tests

Test	Conditions	Test Results	If Not
EGO/HEGO SIGNAL to control unit	–Key off, disconnect EGO sensor connector –Connect DMM between EGO SIGNAL wire and negative (–) battery terminal –Engine at normal operating temperature	Approximately 0.55 volts	EGO sensor may be faulty
EGO/HEGO SIGNAL to control unit	–Key off, disconnect EGO sensor connector –Connect DMM between EGO SIGNAL wire and negative (–) battery terminal –Engine at normal operating temperature –Create vacuum leak (disconnect vacuum hose to intake manifold)	Voltage drops and fluctuates	EGO sensor may be faulty
HEGO heater element	–Key off, disconnect HEGO sensor connector –Connect DMM between KEY POWER wire and POWER GROUND at sensor connector	Approximately 6 ohms at room temperature	HEGO heater element faulty
PWR	–Key off, disconnect HEGO sensor connector –Connect DMM between PWR wire and GROUND at vehicle connector –Key On	10 volts or greater	Check harness wiring and grounds

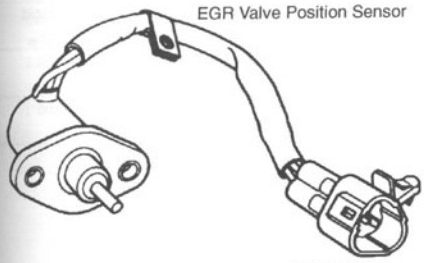
*1993 and later called O2S/HO2S—see glossary

EGR (MECS)

Circuit Description

Exhaust Gas Recirculation (EGR) system is controlled by the control module using a solenoid(s) to port vacuum to an EGR valve. Two types of EGR systems are used. Begin checking the EGR system by inspecting the vacuum hoses for cracks and replace as necessary. The EVP sensor (where applicable) can be tested using a hand held vacuum pump and gauge. The EGR solenoids can be tested by applying voltage to the solenoid and blowing through either ports.

Component Locator



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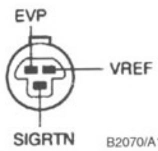
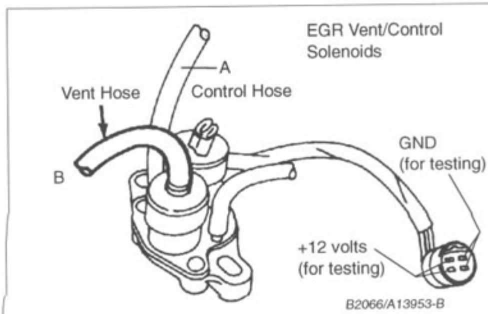


B2070/A14151-A

EVP Test Values

Vacuum (in-Hg.)	Volts ±15%
0	0.867
1	0.893
2	0.923
3	1.434
4	1.84
5	2.09
6	3.86
7	4.93
8	4.93

Component Locator



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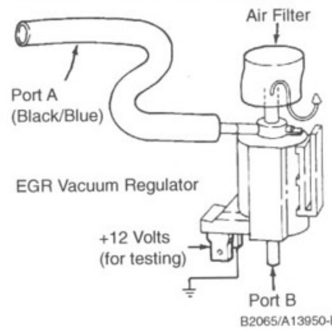

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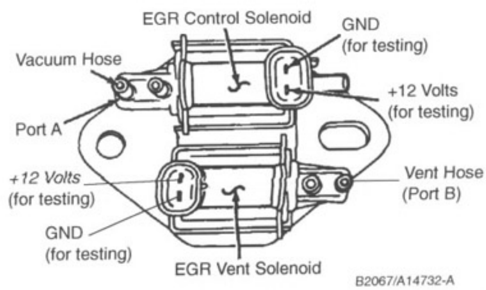

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EGR (MECS)

EGR Component Electrical Tests

Test	Conditions	Test Results	If Not
EVP Sensor	–Connect vacuum pump to EGR valve –Backprobe EVP Sensor between EVP wire and SIG RTN wire –KOEO	See Test Values	–EVP sensor faulty –VREF not 4.5 to 5.5 volts –Faulty wiring between sensor and control module
EGR Vacuum Regulator Solenoid	–Disconnect hose at port B –Blow through Black/Blue hose at port A	Air flow from port B	EGR Vacuum Regulator faulty
EGR Vacuum Regulator Solenoid	–Disconnect hose at port B –Apply +12 volts and ground as shown above –Blow through Black/Blue hose at port A	Air flows from air filter	EGR Vacuum Regulator faulty
EGR Control Solenoid	–Blow through hose A	No air flow through solenoid	Replace EGR Control Solenoid
EGR Control Solenoid	–Apply +12 volts and ground as shown above –Blow through hose A	Air flows through solenoid	Replace EGR Control Solenoid
EGR Vent Solenoid	–Blow through hose B	No air flow through solenoid	Replace EGR Vent Solenoid
EGR Vent Solenoid	–Apply +12 volts and ground as shown above –Blow through hose B	Air flows through solenoid	Replace EGR Vent Solenoid

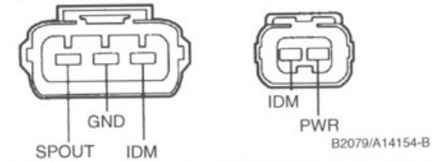
IDM (MECS)

Circuit Description

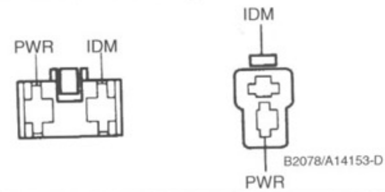
Ignition Diagnostic Monitor (IDM) is an input signal to the control module that detects malfunctions in the ignition system. The IDM signal consists of a single pulse for each successful ignition firing. If the IDM signal is not present there is either an intermittent or malfunction in the ignition system. Begin testing the IDM circuit by checking for a spark at the ignition coil using a spark tester.

> ***WARNING —***
> *The ignition system is a high-energy system operating in a dangerous voltage range which could prove to be fatal if exposed terminals or live parts are contacted. Use extreme caution when working on a vehicle with the ignition on or the engine running.*

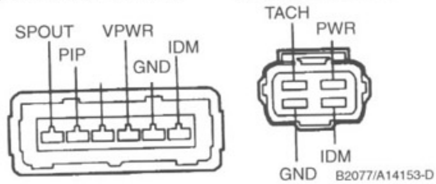
1.3L and 1.8L



1.6L turbo and non-turbo, 2.2L non-turbo



2.2L turbo



IDM Electrical Tests

Test	Conditions	Test Results	If Not
IDM SIGNAL to control unit	–Key off, disconnect ECA connector –Connect LED test light between IDM SIGNAL wire and VPWR (battery voltage) –Crank engine	LED test light flashes	IDM circuit may be faulty
Power to Ignition Control Module	–Key off, disconnect Ignition Module connector –Connect DMM between PWR wire or VPWR wire and ground –Key On	10 volts or greater	–Ignition Module may be faulty –Check wiring to Ignition Module
PIP	–Key off, disconnect Ignition Module connector –Connect LED test light between PIP wire and ground –Crank engine	LED test light blinks	–PIP circuit wiring from ECA faulty –ECA faulty –Crank position sensor faulty
PWR	–Key off, disconnect coil connector –Connect DMM between PWR wire and GROUND at connector –Key On	10 volts or greater	Check harness wiring and grounds

ISC (MECS)

Circuit Description

Idle Speed Control-Bypass Air (ISC-BPA*) solenoid is an actuator that controls engine idle speed by allowing air to pass around the throttle plate. The ISC-BPA is controlled by the control module and by coolant temperature. When troubleshooting the ISC-BPA circuit, always begin by checking for air leaks in the intake system, and check fuel injector O-rings for cracking and sealing. Note that unmetered air can also cause idle problems. The Bypass Air Valve must be replaced if faulty. On 1.8L engines, the ISC and BPA are separate units. Perform the electrical tests in order.

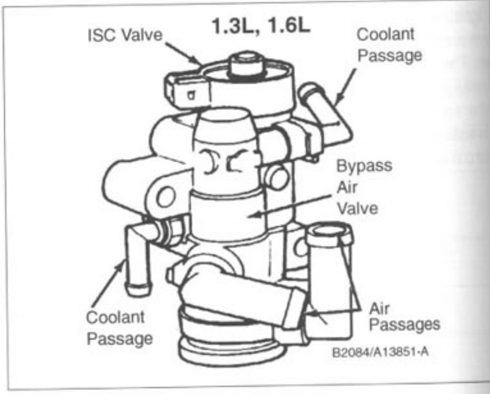
ISC-BPA Inputs/Outputs

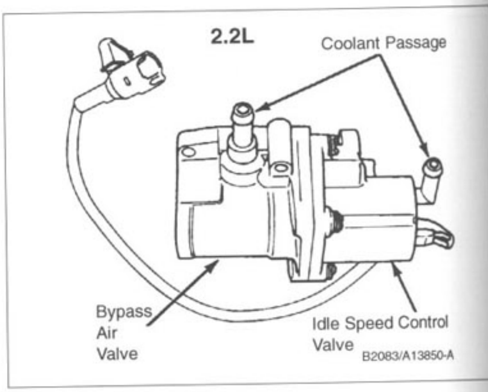
Signal	Description
ISC	Input to solenoid from ECA
VPWR	Input to solenoid

ISC-BPA Solenoid Test Values

Engine	Resistance
1.3L	6 to 14 Ohms
1.6L	6 to 14 Ohms
1.8L	6 to 14 Ohms
2.0L	7.7 to 9.3 Ohms @23°C (73°F)
2.5L	10.7 to 12.3 Ohms @20°C (68°F)
all others	6.3 to 9.9 Ohms

ISC-BPA Solenoid





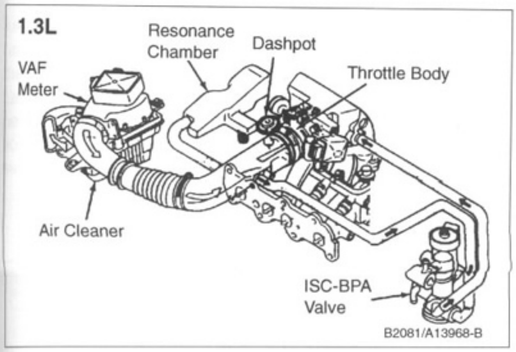
ISC-BPA Electrical Tests

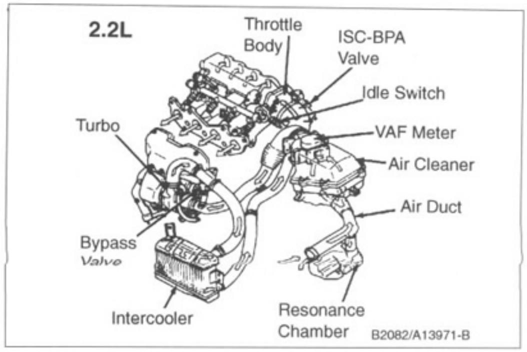
Test	Conditions	Test Results	If Not
ISC-BPA Solenoid	–Engine running	ISC-BPA Solenoid clicking	ISC-BPA solenoid may be faulty
ISC-BPA Solenoid resistance	–Key off, disconnect ISC-BPA solenoid connector –Connect DMM leads to ISC solenoid wires	See test values above	ISC-BPA solenoid may be faulty
VPWR circuit to ISC-BPA	–Key off, disconnect ISC-BPA solenoid connector –Connect DMM between VPWR wire at vehicle harness connector, and battery ground terminal –Key On	10.5 volts or greater	VPWR circuit wiring faulty

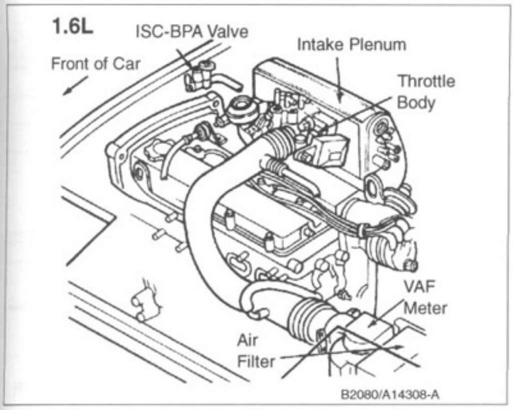
*1993 and later called IAC—see glossary

ISC (MECS)

Component Locator







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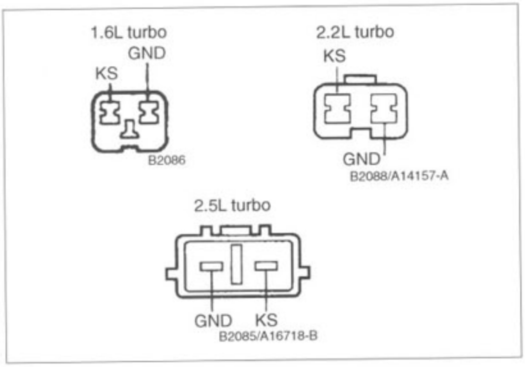
KS (MECS)

Circuit Description

Knock Sensor (KS) detects engine detonation (spark knock). The Knock Sensor threads into the side of the engine block and is used on turbo engines only. When knock occurs, the sensor sends a voltage signal to the Knock Control Unit. The Knock Control Unit then signals the control module, which sends a signal to the Ignition Control Unit to retard spark timing. When troubleshooting the knock sensor circuitry, begin by checking the fuel quality, ignition timing, and altitude at which test is being performed.

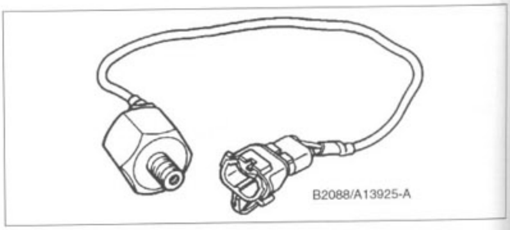
Knock Sensor Harness Connector



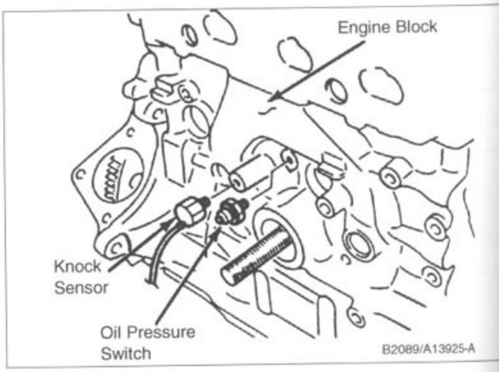
KS Inputs/Outputs

Signal	Description
KS	Input to Knock Control Unit from sensor
KC	Signal from Knock Control Unit to control module
VPWR	Battery power to Knock Control Unit
GND	Signal return

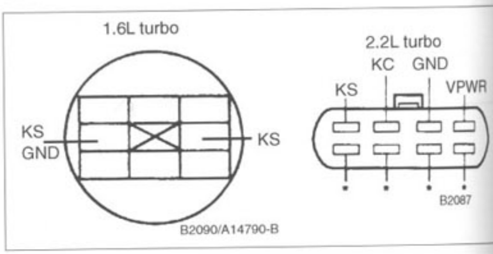
Knock Sensor



Component Locator



Knock Control Unit Connector



KS Electrical Tests

Test	Conditions	Test Results	If Not
Knock Sensor (2.2L turbo)	–Key off, wait 10 seconds –Disconnect knock sensor connector –Measure voltage between KS wire and GND at sensor harness connector	30 mV (0.030 volts) or greater	Knock Sensor faulty
Knock Sensor (all others)	–Timing light connected –Disconnect distributor vacuum hose –Engine running, knock sensor connected –Tap intake plenum with plastic hammer	Ignition timing retards	–Knock Sensor may be faulty –Knock Control Unit or wiring faulty
VPWR (all)	–DMM connected to VPWR wire and ground at Knock Control Unit –KOEO	10 volts or greater	Check wiring to Knock Control Unit

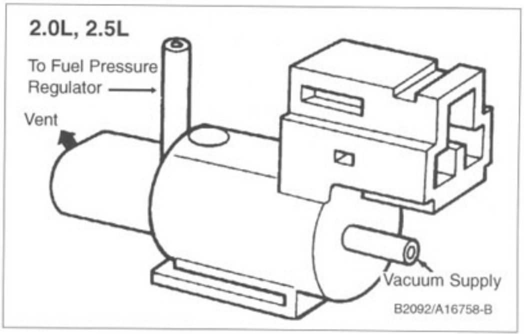
PRC (MECS)

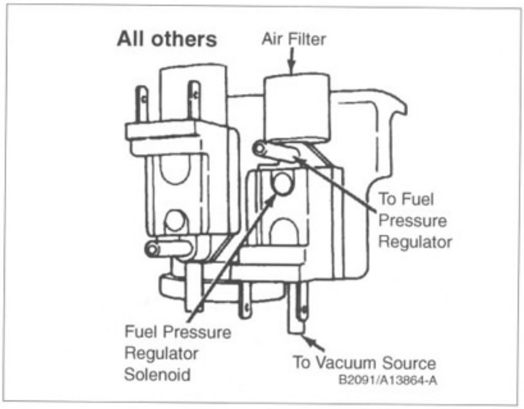
Circuit Description

Pressure Regulator Control (PRC) controls vacuum to the fuel pressure regulator. The solenoid is normally open, but on hot start, the control module activates the solenoid, venting the fuel-pressure regulator to the atmosphere. Vacuum to the fuel regulator is reduced to increase fuel pressure. This action helps to avoid hot start problems. Troubleshooting the PRC solenoid should also take into consideration a basic fuel pressure test and fuel pump electrical tests.

> ***WARNING —***
> *When working on the fuel system, do not smoke or work near heaters or other fire hazards. Keep an approved fire extinguisher nearby.*

Pressure Regulator Control Solenoid





PRC Solenoid Inputs/Outputs

Signal	Description
PRC	Input to solenoid from ECA
VPWR	Vehicle power

PRC Solenoid Location

Engine	Location
1.6L (all)	Mounted on firewall next to CANP solenoid
1.8L	Mounted on engine below Fuel Pressure Regulator
2.0L	Mounted on lower righthand side of intake manifold
2.2L non turbo	Mounted on firewall between CANP and EGR Solenoids
2.2L turbo	Mounted on firewall next to CANP solenoid
2.5L	Mounted on VAF meter housing

PRC Solenoid Electrical Tests

Test	Conditions	Test Results	If Not
VPWR	–Backprobe VPWR wire at PRC solenoid –Key On	10 volts or greater	Check VPWR wiring from ECA
PRC	–Key Off –Measure continuity with ohmmeter from PRC wire at solenoid to control module	Continuity	PRC wiring faulty

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TPS (MECS)

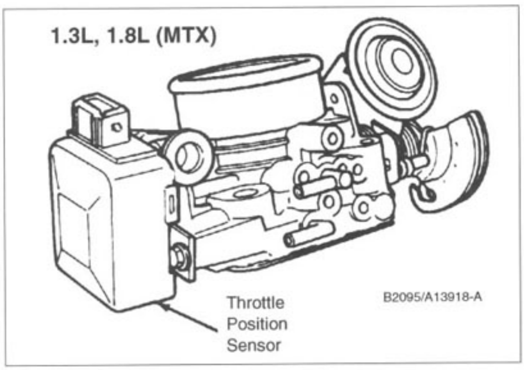
Circuit Description

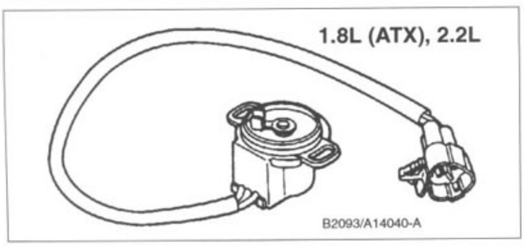
Throttle Position Sensor (TPS) Most provide the control module with a variable voltage that represents the position of the throttle. This information is used to control air-fuel ratio, timing, fuel shut-off, and EGR and A/C functions. The TPS is a sealed unit and cannot be repaired. On the 1.8L (ATX) engine, the TPS combines an idle switch and a potentiometer. On the 1.3L, 1.6L, and 1.8L (MTX) engines the TPS is two switches that sense idle (IDL) and wide open throttle (WOT). All other engines use a potentiometer.

TPS Inputs/Outputs

Signal	Description
TP SIG	Variable voltage from approximately 0 to 5 volts
VREF	Reference voltage
SIG RTN	Signal return

Component Locator





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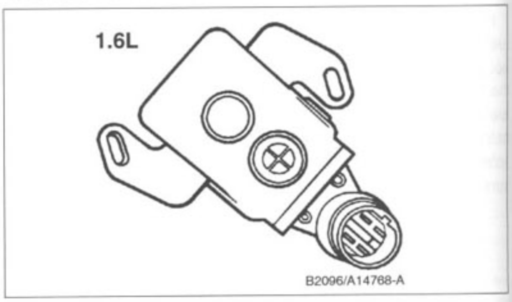
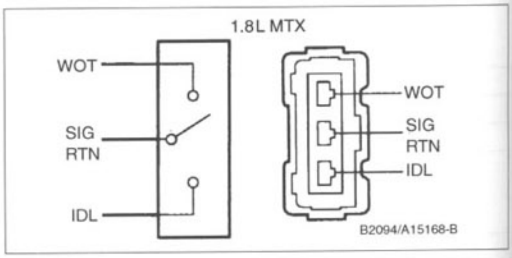
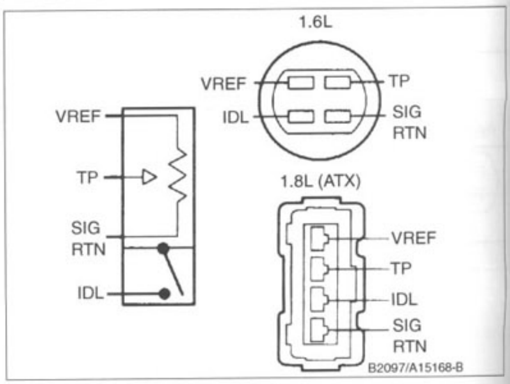
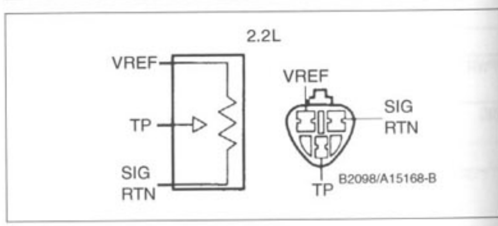


TPS Harness Connector Terminals







TPS (MECS)

TPS Potentiometer Test Values*

Throttle Position	Volts
1/8	0.998
2/8	1.60
3/8	2.37
4/8	2.74
5/8	3.15
6/8	3.43
7/8	3.60
8/8	4.02

* test values are ±15%

TPS Potentiometer Electrical Tests

Test	Conditions	Test Results	If Not
VREF	–Key off, wait 10 seconds –Disconnect TPS connector –Probe between VREF wire and SIG RTN at TPS vehicle harness connector –KOEO	4 to 6 volts	Check VREF circuitry and wiring
TP SIG	–Backprobe TPS connector between TPS and SIG RTN –KOEO –Move throttle through entire range	Variable voltage (see **Test Values** above) without any breaks as throttle is moved through range	Faulty TPS
IDL	–Throttle in rest position	Continuity with SIG RTN	Faulty TPS or wiring
WOT	–Throttle fully open	Continuity with SIG RTN	Faulty TPS or wiring

TPS Switch Tests (MTX - 1.3L, 1.6L, 1.8L)

Test	Conditions	Test Results	If Not
IDL	–Backprobe IDL and SIG RTN –KOEO	4 to 6 volts	Faulty VREF or wiring
	–Move throttle just off idle	0 to 0.5 volts	Faulty TPS
WOT	–Backprobe WOT and SIG RTN –KOEO –Throttle closed	0 to 0.5 volts	Faulty VREF or wiring
	–Move throttle wide open	4 to 6 volts	Faulty TPS

VAF/VAT (MECS)

Circuit Description

Vane Air Flow (VAF*) sensor provides the control module with a voltage signal that represents the amount of air flowing into the engine. The VAF sensor consists of an air vane that is attached to a potentiometer. The air vane moves as the throttle is opened changing the voltage. When troubleshooting the VAF sensor, begin by checking for air leaks in the intake system that cause unmetered air to enter. Check that the VAF sensor is not binding or sticking and remove all residue and intake deposits using a cloth. The VAF sensor cannot be repaired. The VAF sensor is located in the vane air meter in the throttle housing.

Vane Air Temperature (VAT*) sensor provides the control module with a voltage that changes with ambient temperature. The VAT sensor is similar in operation to the ACT sensor. The VAT sensor is in the vane air meter and is not replaceable. It can be tested using an ohmmeter using the values shown below.

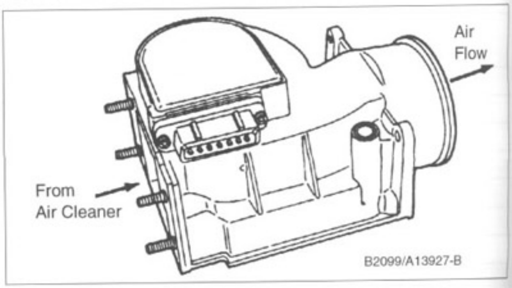
VAF/VAT Inputs/Outputs

Signal	Description
VAF SIG	Variable voltage to control module
VAT SIG	Variable voltage to control module
VMREF	Reference voltage
VREF	Reference voltage
VPWR	Battery voltage
SIG RTN	Signal return

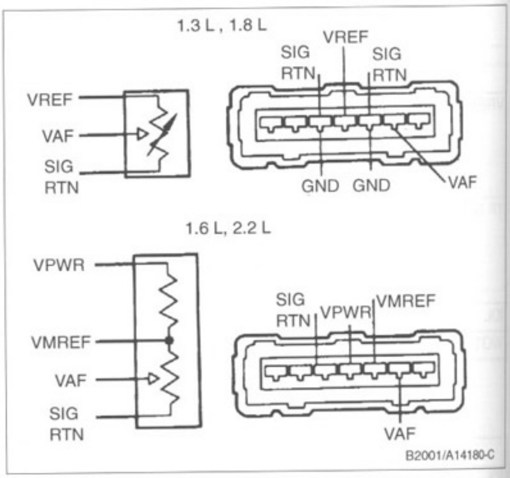
VAT Sensor Values

Temperature	Resistance
32° F	5200 ohms
68° F	2500 ohms
104° F	1100 ohms
140° F	600 ohms
176° F	300 ohms

Vane Air Meter



VAF/VAT Harness Connector Terminals



*1993 and later called VAF/IAT—see glossary

VAF/VAT (MECS)

VAF/VAT Electrical Tests

Test	Conditions	Test Results	If Not
VREF	–Key off, wait 10 seconds –Disconnect VAF connector –Probe between VREF wire and SIG RTN wire at VAF vehicle harness connector –KOEO	4.5 to 5.5 volts	Check VREF circuitry and wiring
VMREF	–Key off, wait 10 seconds –Disconnect VAF connector –Probe between VREF wire and SIG RTN wire at VAF vehicle harness connector –KOEO	7 to 9 volts	Check VMREF circuitry and wiring
VPWR	–Key off, wait 10 seconds –Disconnect VAF connector –Probe between VREF wire and SIG RTN wire at VAF vehicle harness connector –KOEO	10 volts or greater	Check VPWR circuitry and wiring
VAF SIG	–Key off, wait 10 seconds –Backprobe VAF connector between VAF wire and SIG RTN with DMM –KOEO –Move air vane meter through entire range	Variable voltage from 1 to 5 volts without any breaks as throttle is moved through range	Faulty Vane Air Meter
VAT SIG	–Key off, wait 10 seconds –Disconnect VAF connector –Probe VAF connector between VAT SIG wire and SIG RTN with DMM	Resistance value as specified at a particular temperature (See table above)	Faulty Vane Air Meter

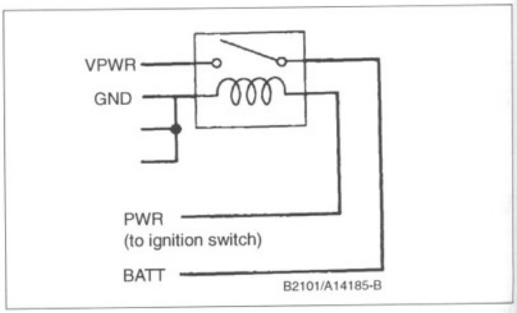
12

VPWR (MECS)

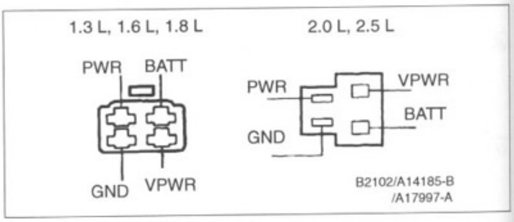
Circuit Description

Vehicle Power (VPWR) is battery voltage distribution to certain output actuators when the key is on. VPWR is distributed from the main relay. A failure in the VPWR circuit will result in a no-start condition.

Main Relay



Main Relay Harness Connector Terminals



VPWR Inputs/Outputs

Signal	Engine	ECA Pin	Description
VPWR	1.3L 1.6L 1.8L 2.0L 2.2L 2.5L	1B 3I 1B 1B, 1U 1B 1B	Power distribution
PWR or KEY POWER			Ignition key input to main relay
BATT			Battery voltage at all times
GND or PWR GND	1.3L 1.6L 1.8L 2.0L 2.2L non-turbo (MTX) 2.2L (4EAT) 2.2L turbo 2.5L	2A, 2B, 2C 2R, 3A, 3G 2A, 2B, 2C 3A, 3B, 3C 2A, 2B, 2C 3A, 3B, 3C 3A, 3B, 3C 3A, 3B, 3C, 3D	Ground

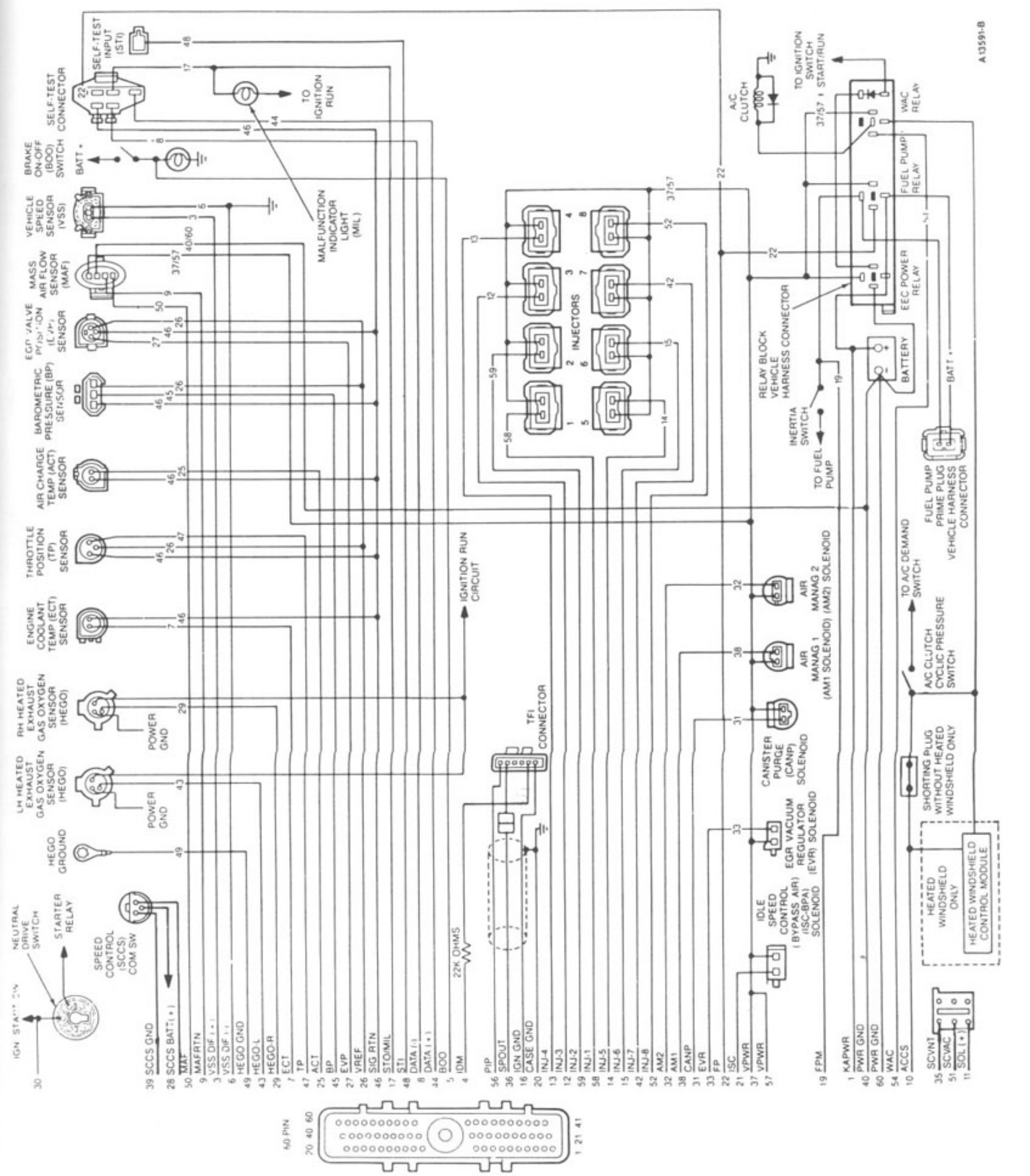
VPWR Electrical Tests

Test	Conditions	Test Results	If Not
VPWR	–Key on or Key in crank position –Measure voltage with DMM between VPWR and battery negative (–) terminal	10.5 volts or greater	–Check for open or short in VPWR circuit –Check Power Relay, ground wiring, and key power circuit –Check continuity of VPWR wiring from power relay to control module
KEY POWER	–KOEO –ER	10.5 volts or greater	–Check ignition switch and wiring
GROUND	–Measure continuity to battery negative (–) terminal	5 Ohms or less	Check ground cable and straps
BATT		10.5 volts or greater	Check battery positive (+) cable and battery

1991 Crown Victoria, Grand Marquis (CA)

5.0L MAF-SFI
(VIN Code E)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

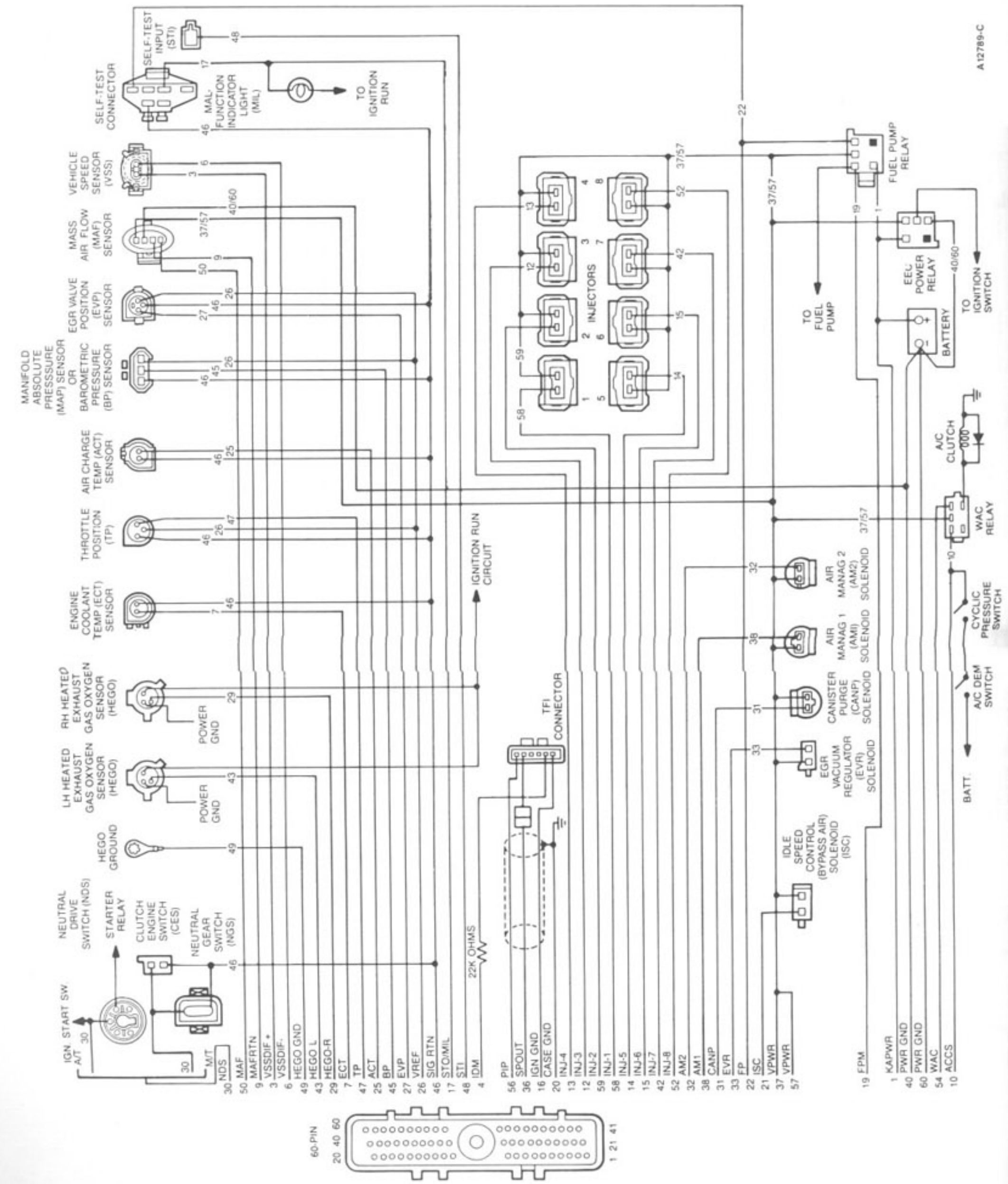


12

5.0L MAF-SFI
(VIN Code E)

1988–1991
Mustang

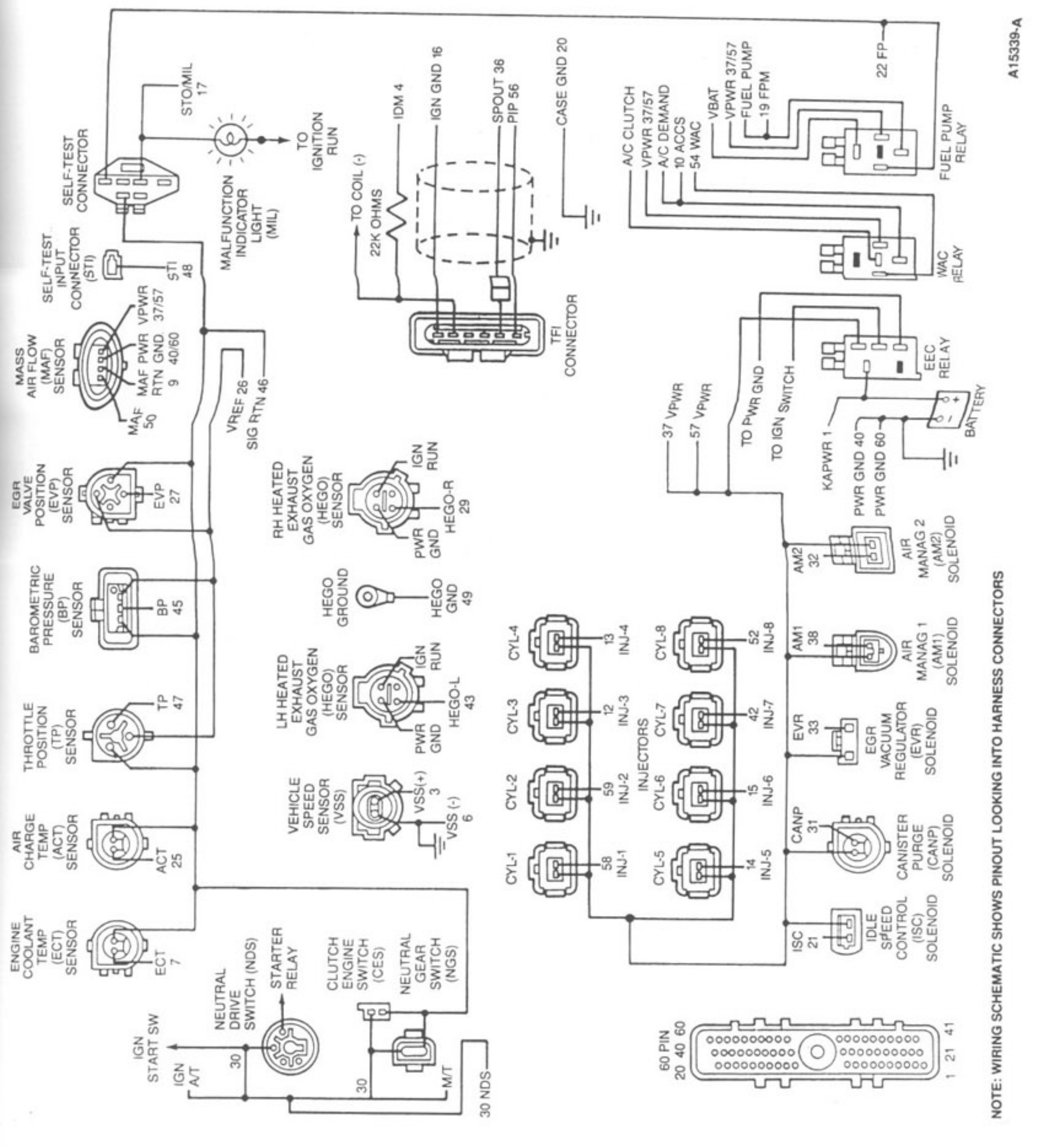
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



1992–1993 Mustang HO

5.0L MAF-SFI
(VIN Code E)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

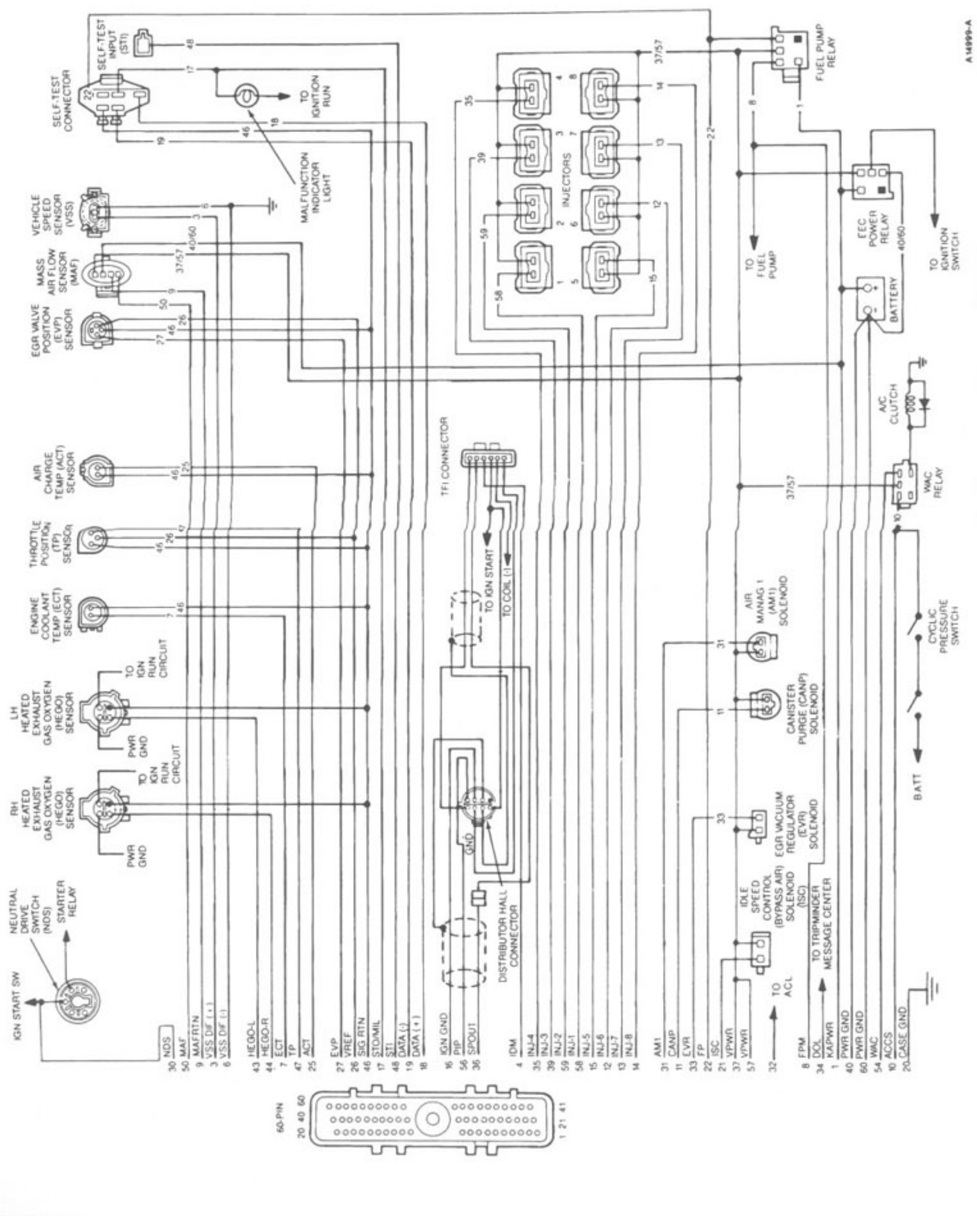


12

5.0L MAF-SFI
(VIN Code E)

1991
T-Bird, Cougar

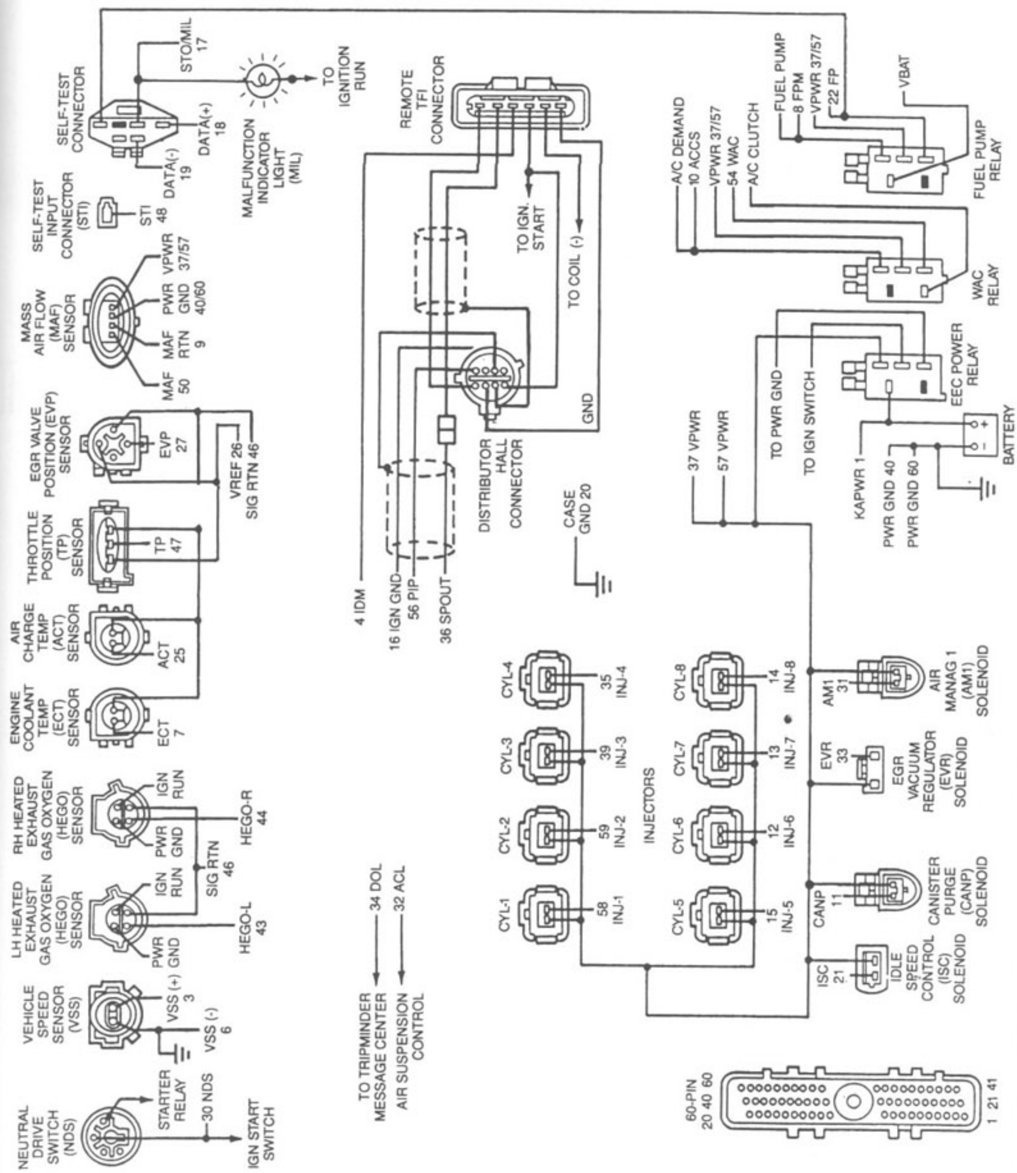
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



1992–1993 T-Bird, Cougar

5.0L MAF-SFI
(VIN Code E)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



A15340-A

NOTE: WIRING SCHEMATIC SHOWS PINOUT LOOKING INTO HARNESS CONNECTORS

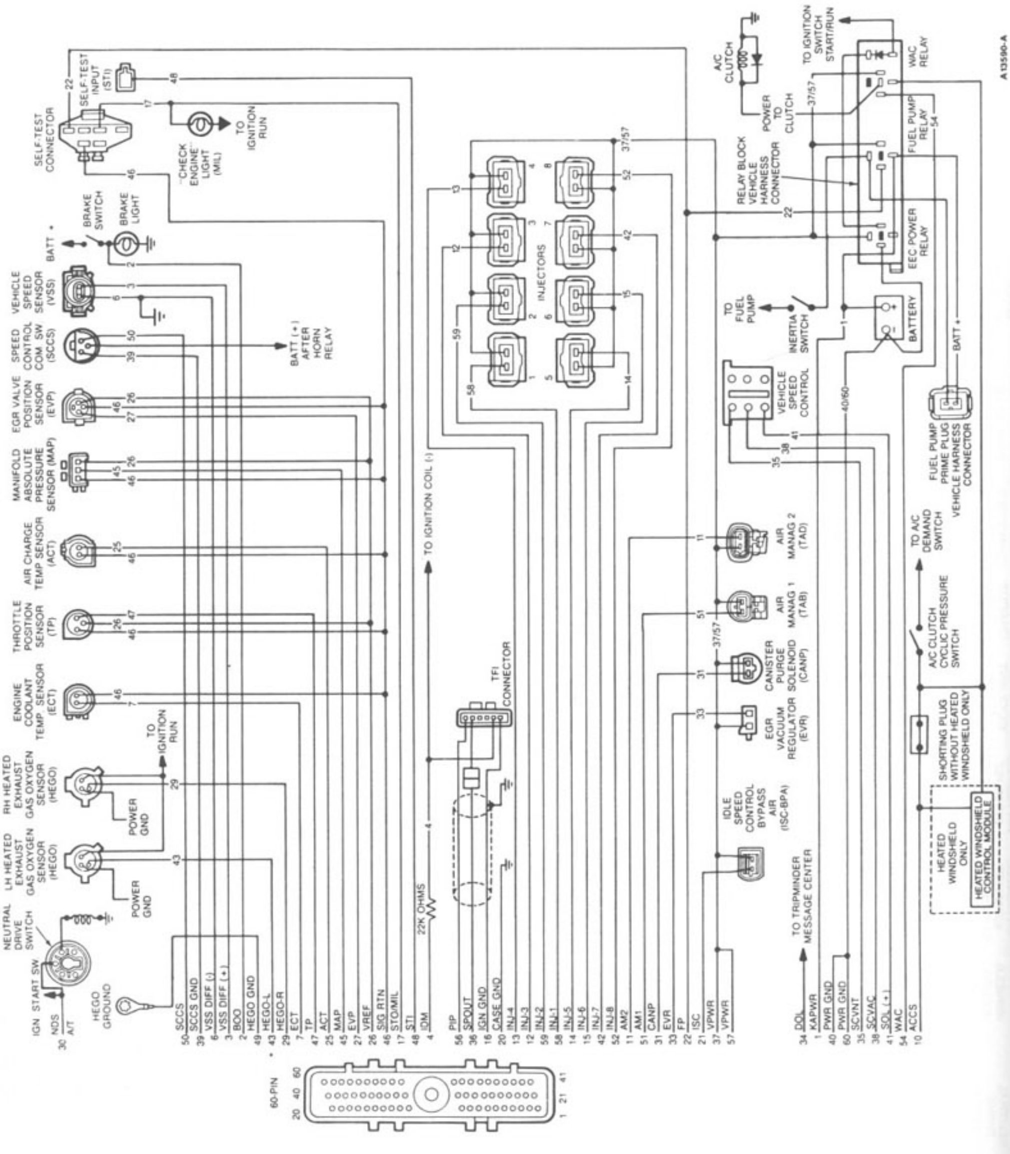
12

5.0L MAP-SFI
(VIN Code E)

1988–1989
Crown Victoria, Grand Marquis

VIN: 1 2 3 4 5 6 7 8 ... 17

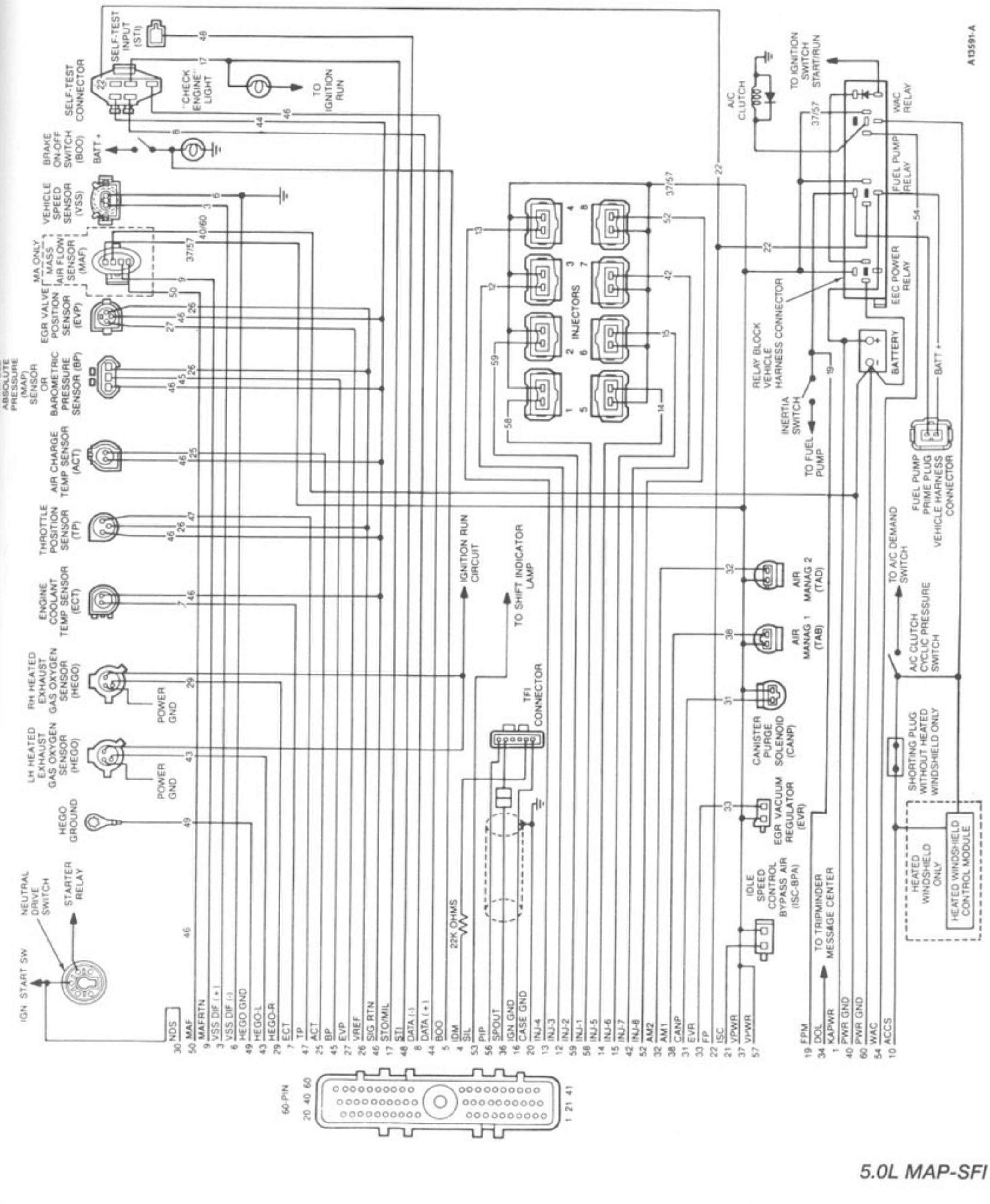
Engine code



1990–1991
Crown Victoria, Grand Marquis, Town Car

5.0L
MAP-SFI
(VIN Code E)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

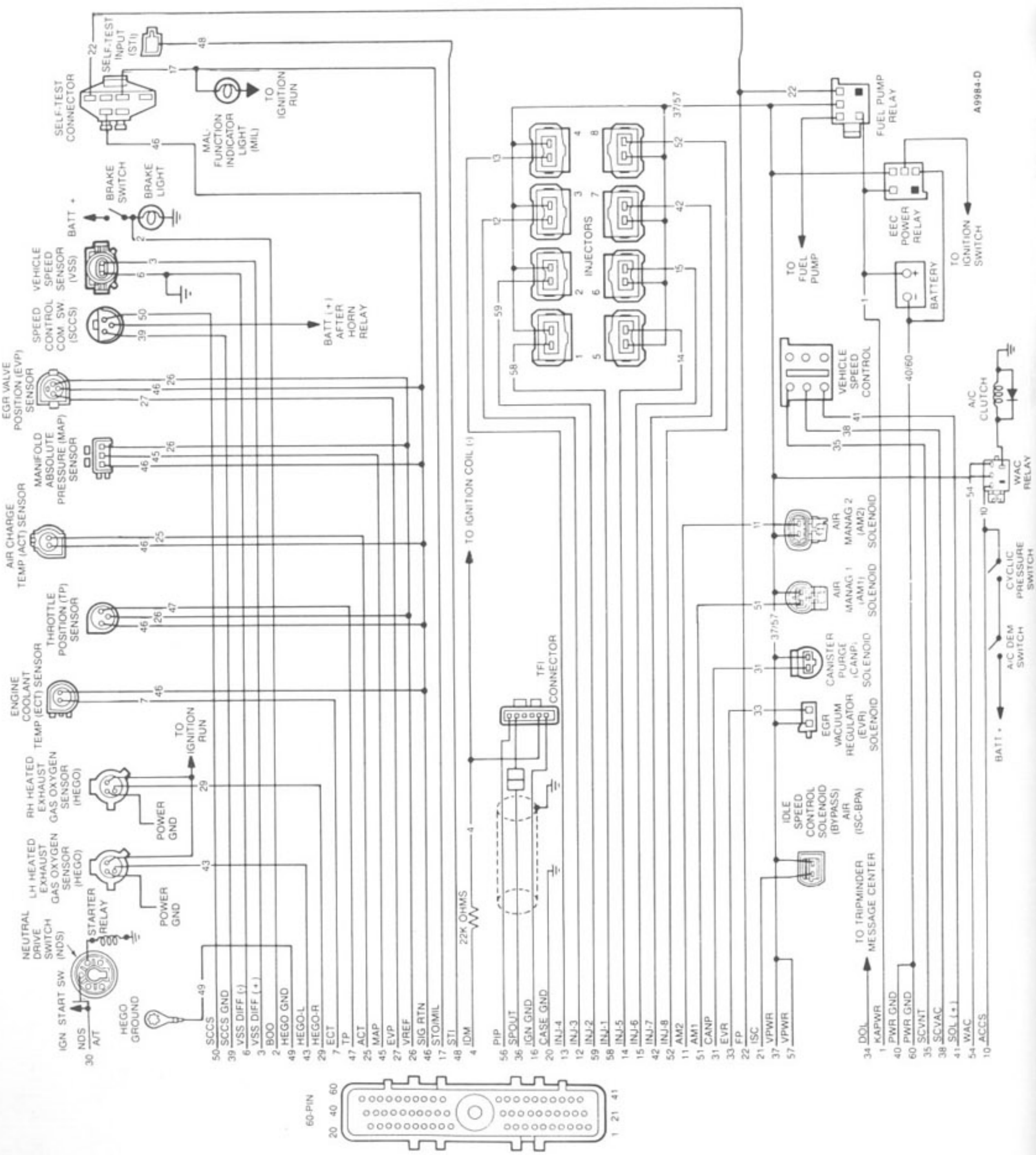


12

5.0L MAP-SFI
(VIN Code E)

1988–1991
Mark VII

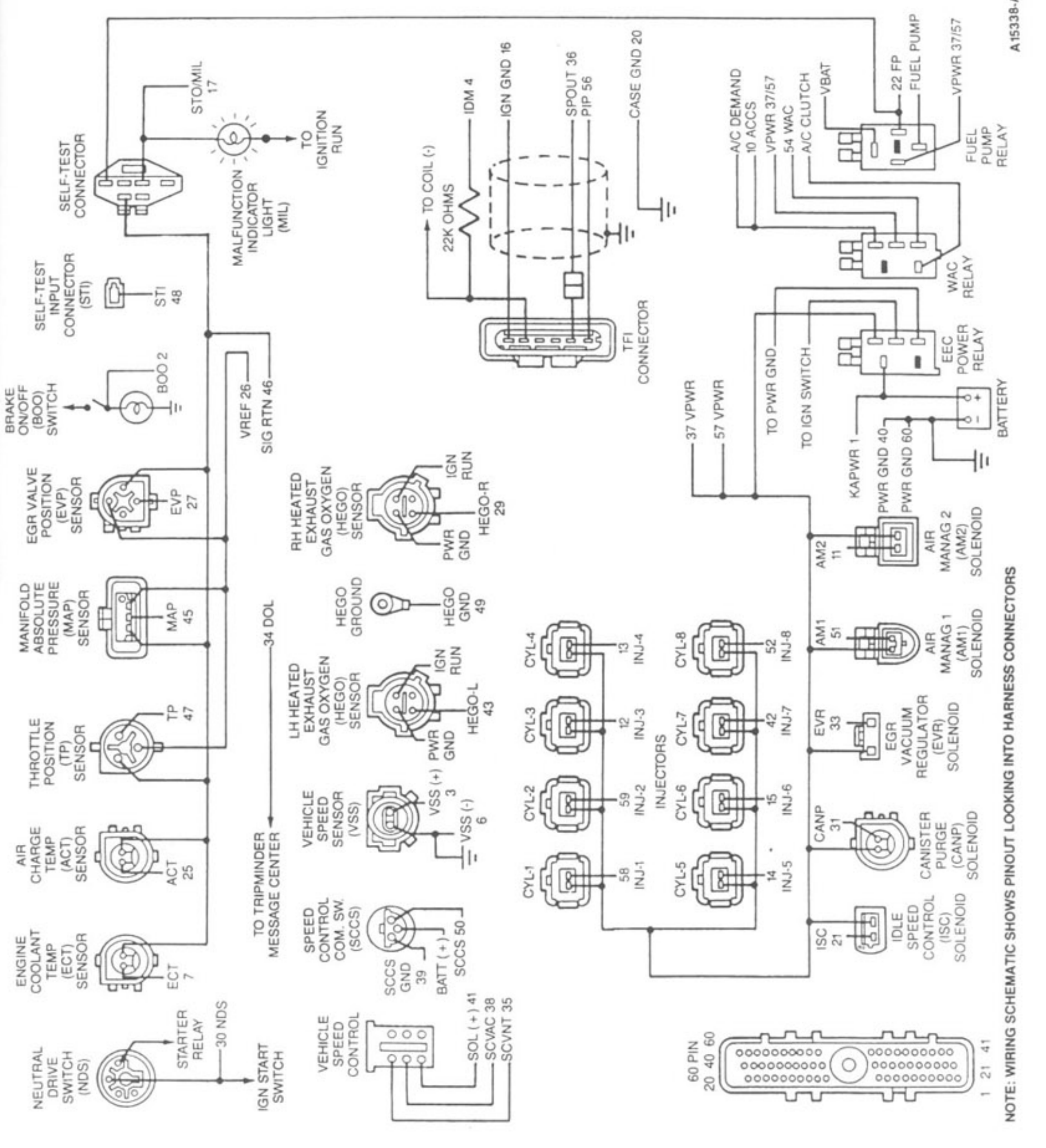
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



1992 Mark VII

5.0L MAP-SFI
(VIN Code E)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

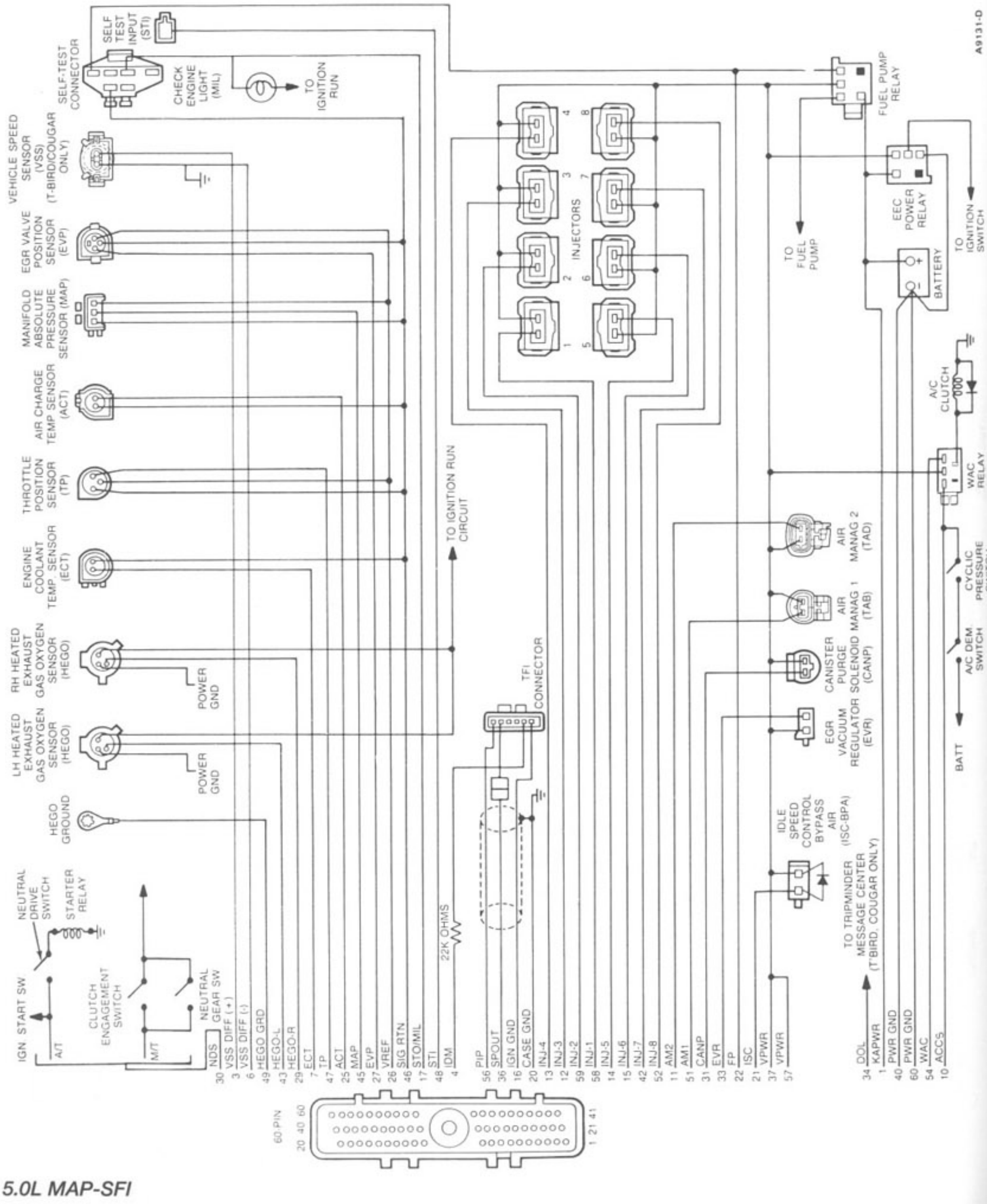


12

5.0L MAP-SFI
(VIN Code E)

1988
T-Bird, Cougar

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

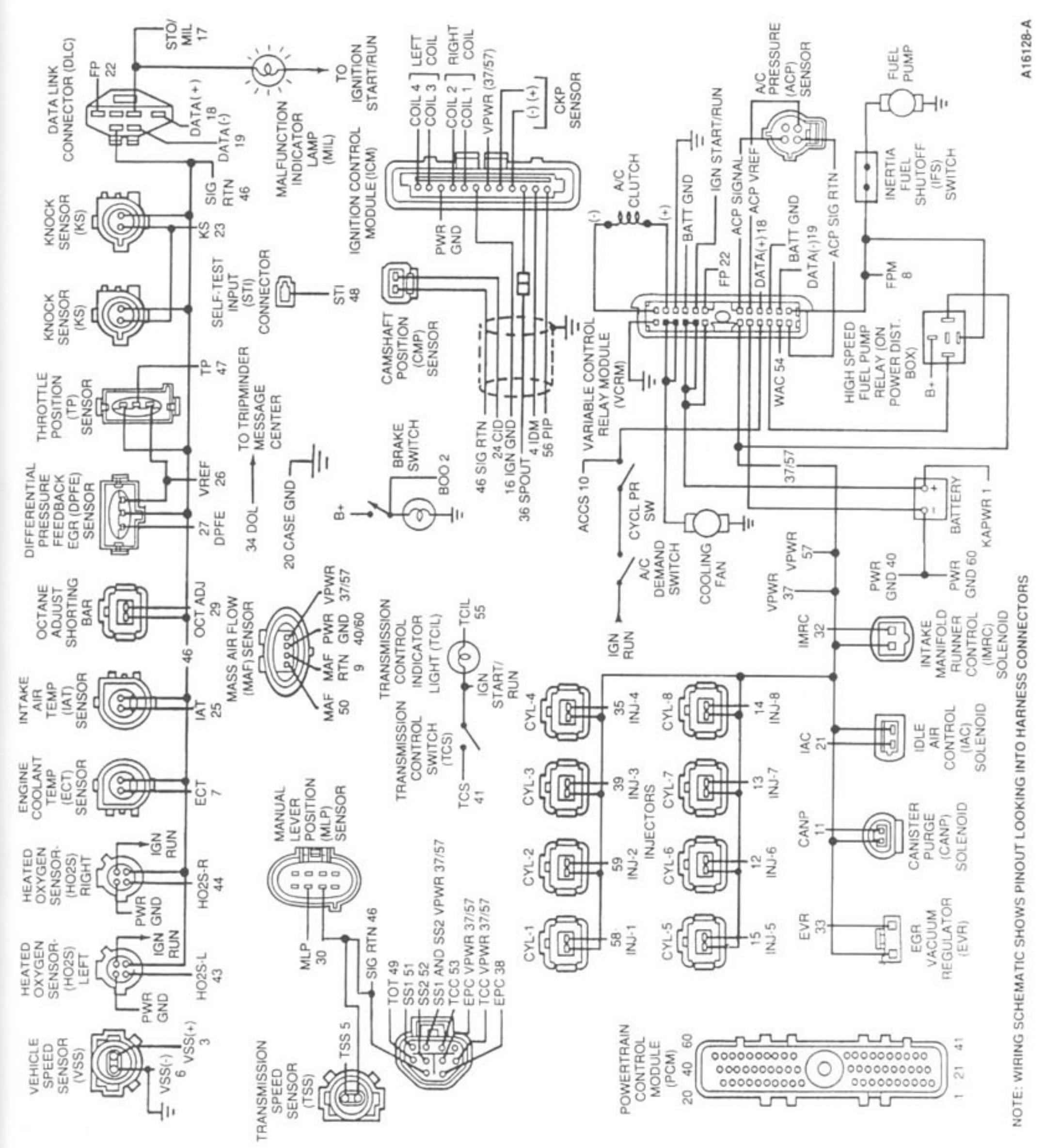


1993 Mark VIII

4.6L 4V MAF-SFI
(VIN Code V, 4R70W)

VIN: 1 2 3 4 5 6 7 8 ... 17

Engine code



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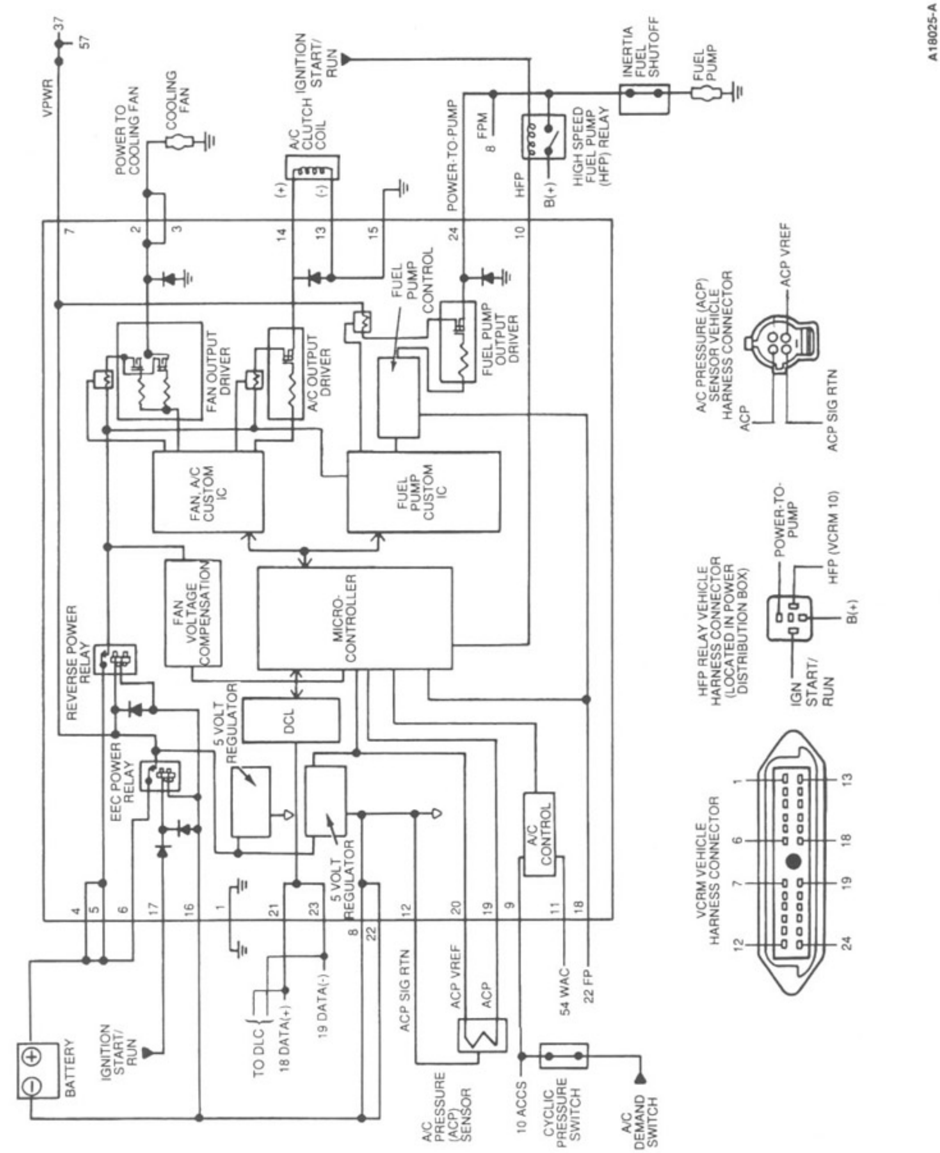
4.6L 4V
MAF-SFI
VIN Code V, 4R70W)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

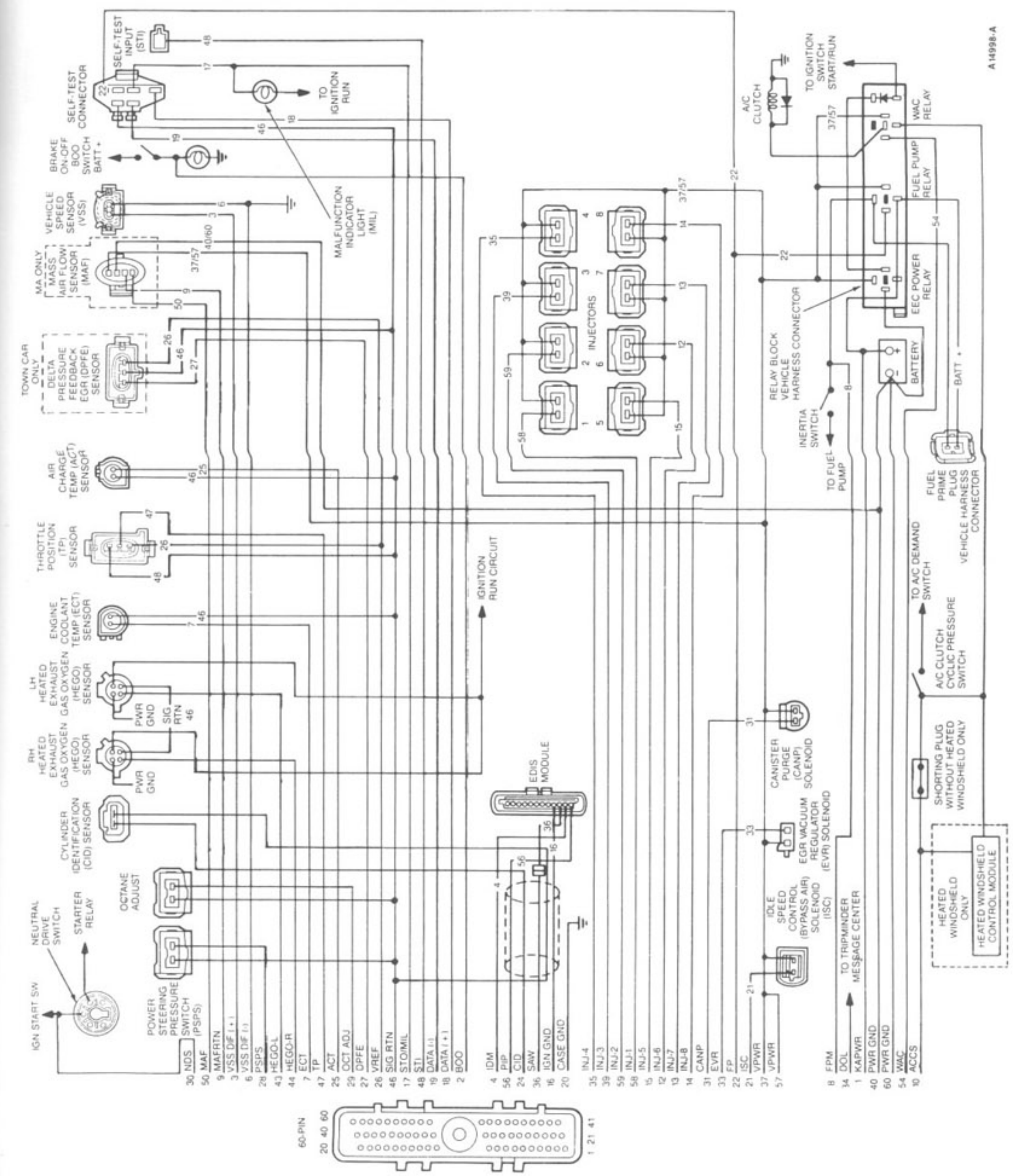
1993
Mark VIII Variable CRModule



1991
Crown Victoria, Grand Marquis, Town Car

4.6L
MAF-SFI
(VIN Code W, AXODE)

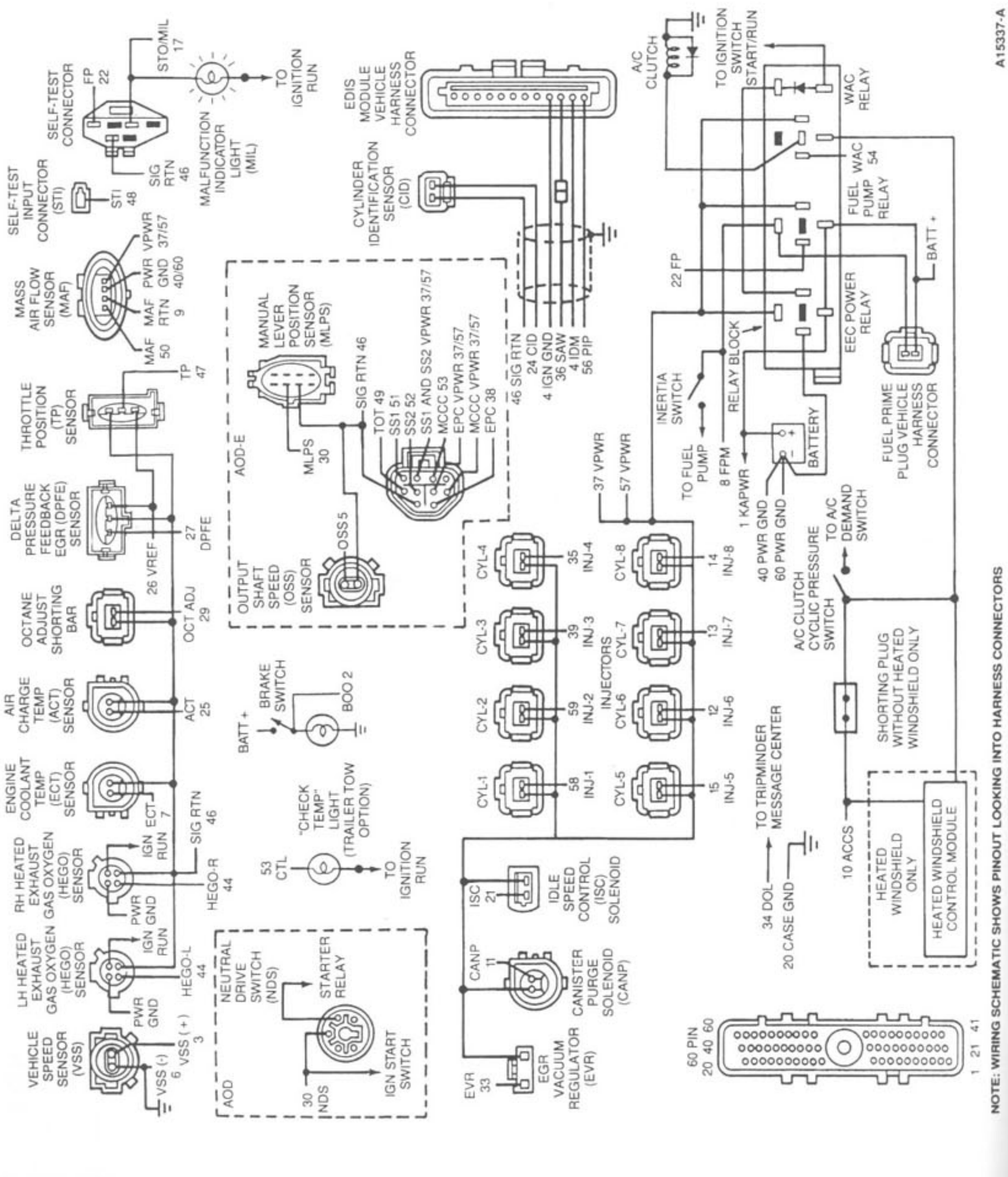
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



4.6L MAF-SFI
(VIN Code W, AXODE)

1992–1993
Crown Victoria, Grand Marquis, Town Car

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



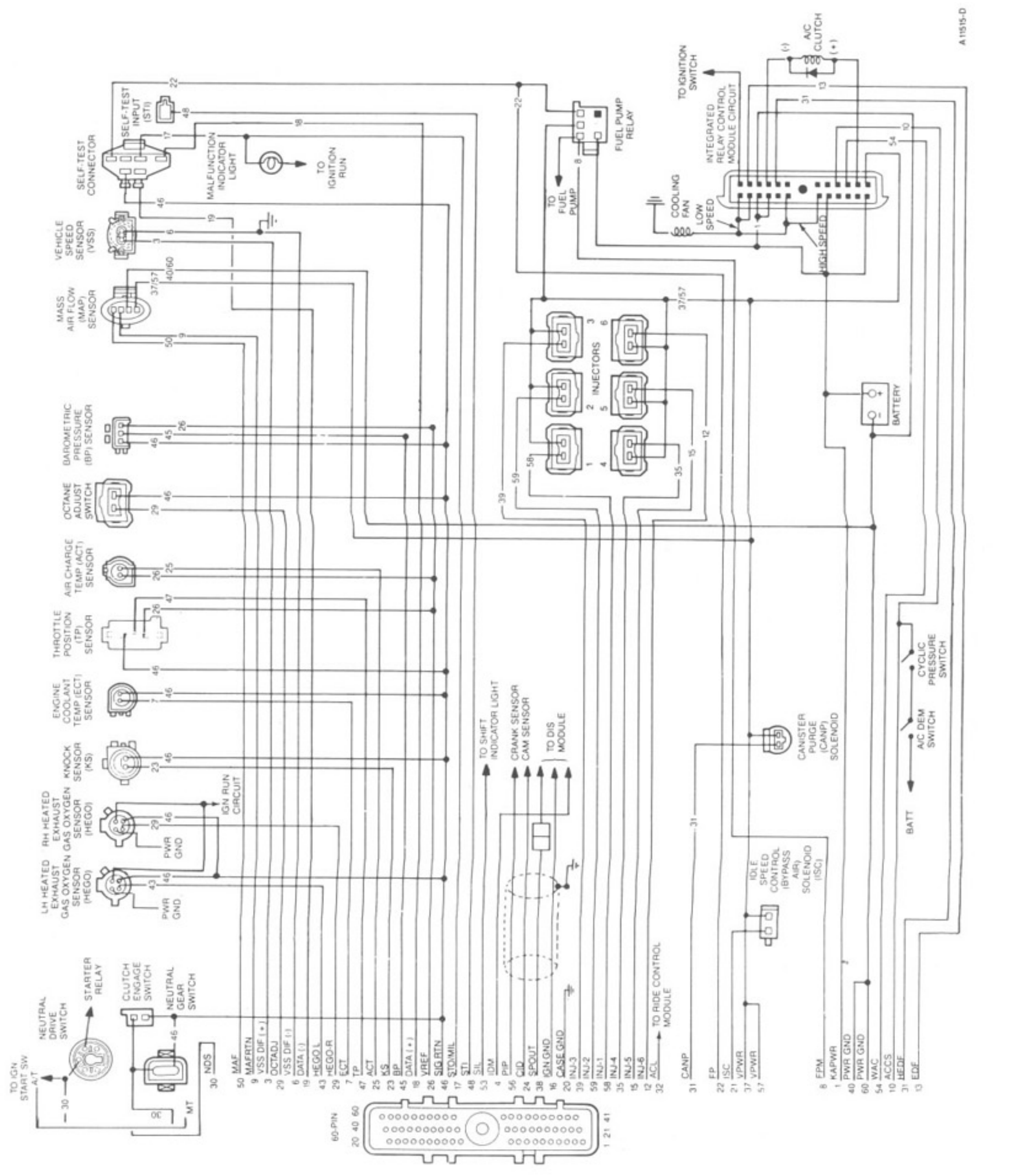
NOTE: WIRING SCHEMATIC SHOWS PINOUT LOOKING INTO HARNESS CONNECTORS

1989–1991 T-Bird SC

3.8L MAF-SFI SC (VIN Code R, C early)

VIN: 1 2 3 4 5 6 7 8 ... 17

Engine code

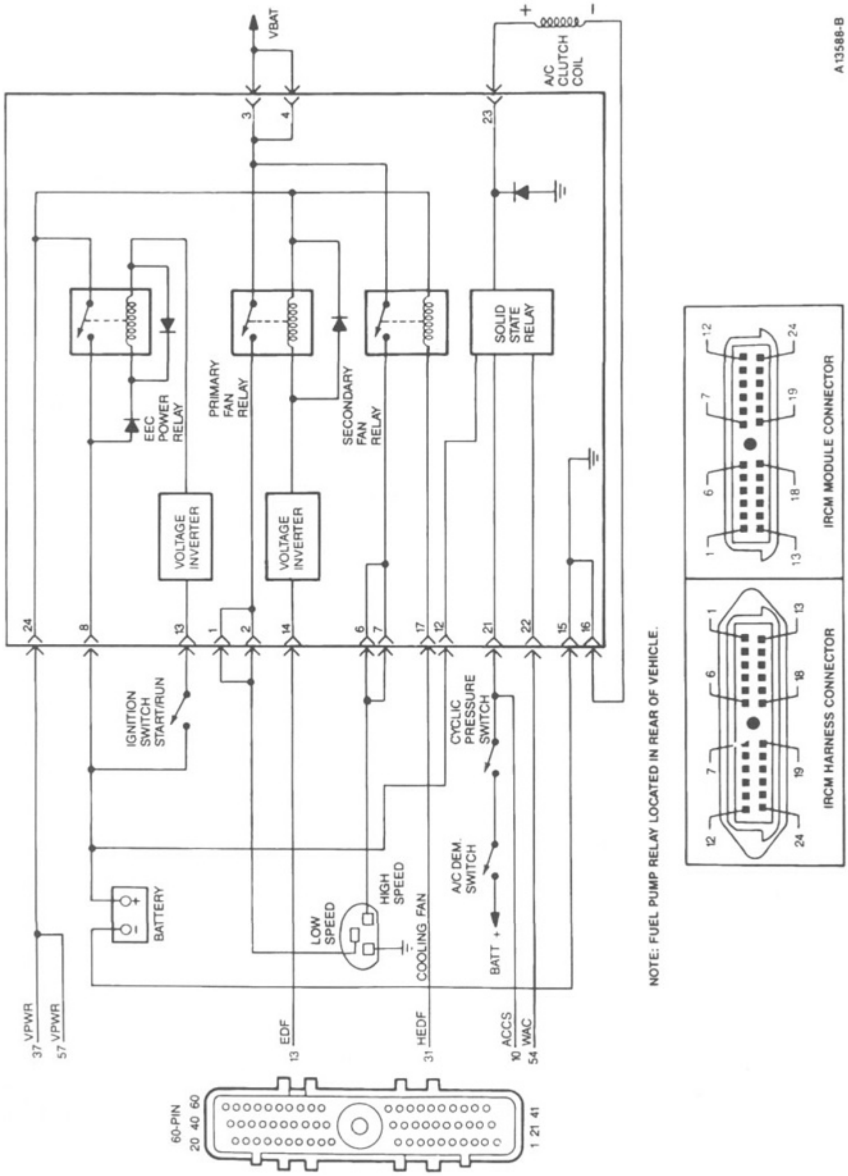


12

3.8L
MAF-SFI SC
(VIN Code R, C early)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

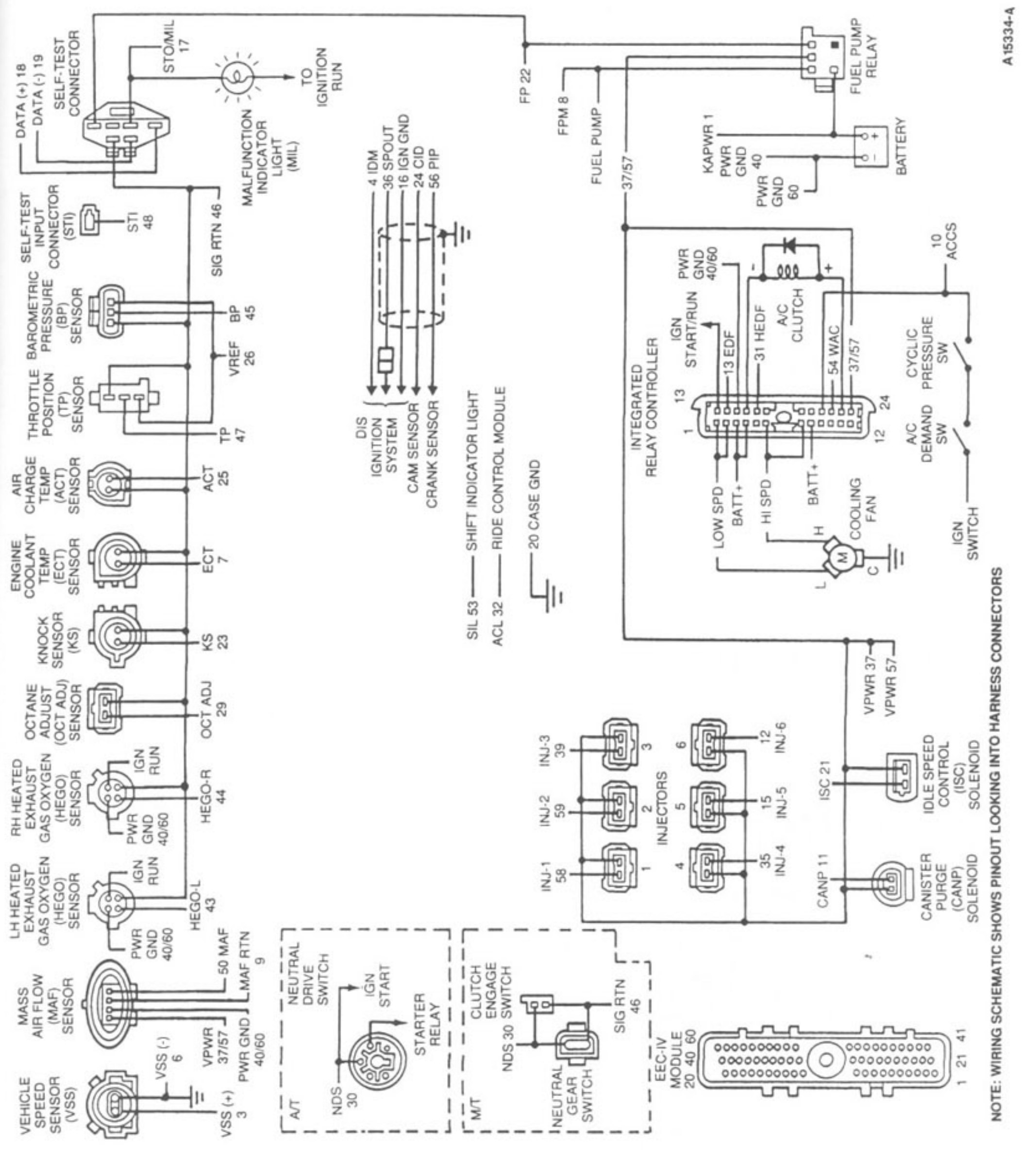
1990–1991
T-Bird SC
Integrated Relay Control Module



1992–1993 T-Bird SC

3.8L MAF-SFI SC
(VIN Code R, C early)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



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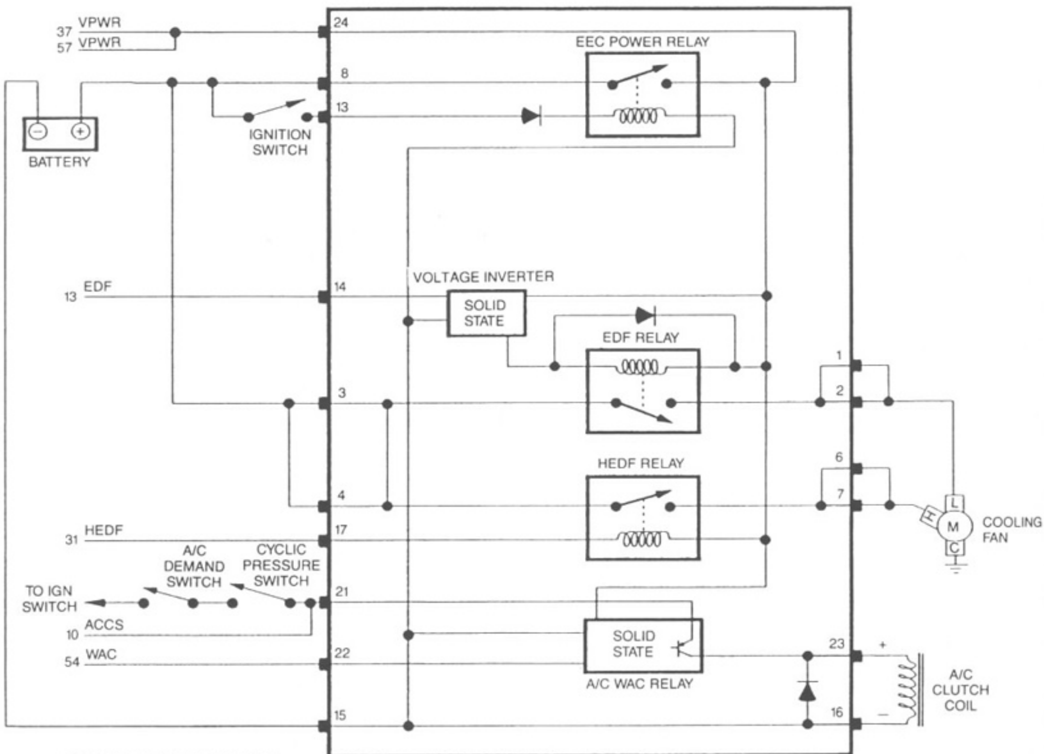
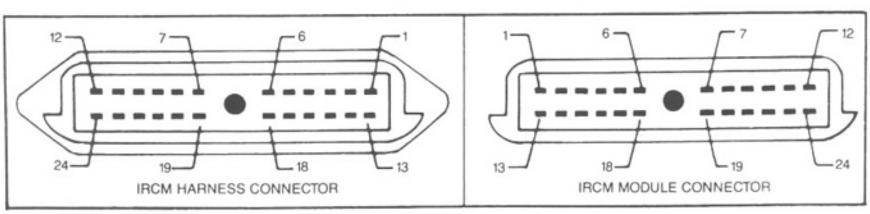
3.8L MAF-SC
(VIN Code R, C early)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

1992 T-Bird SC Integrated Relay Control Module



NOTE: FUEL PUMP RELAY IS A "STAND-ALONE" RELAY

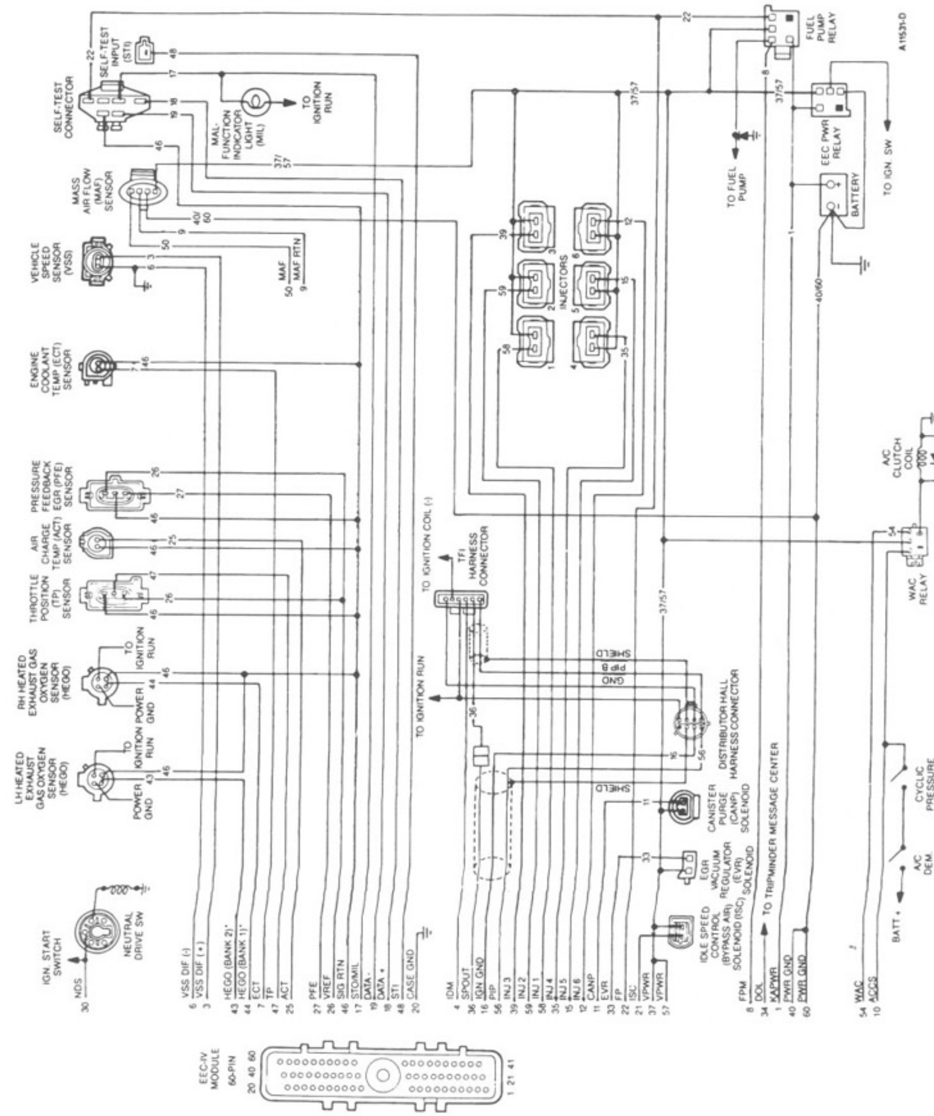


A15336-A

1988–1991 T-Bird, Cougar

3.8L MAF-SFI (VIN Code 4, RWD)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



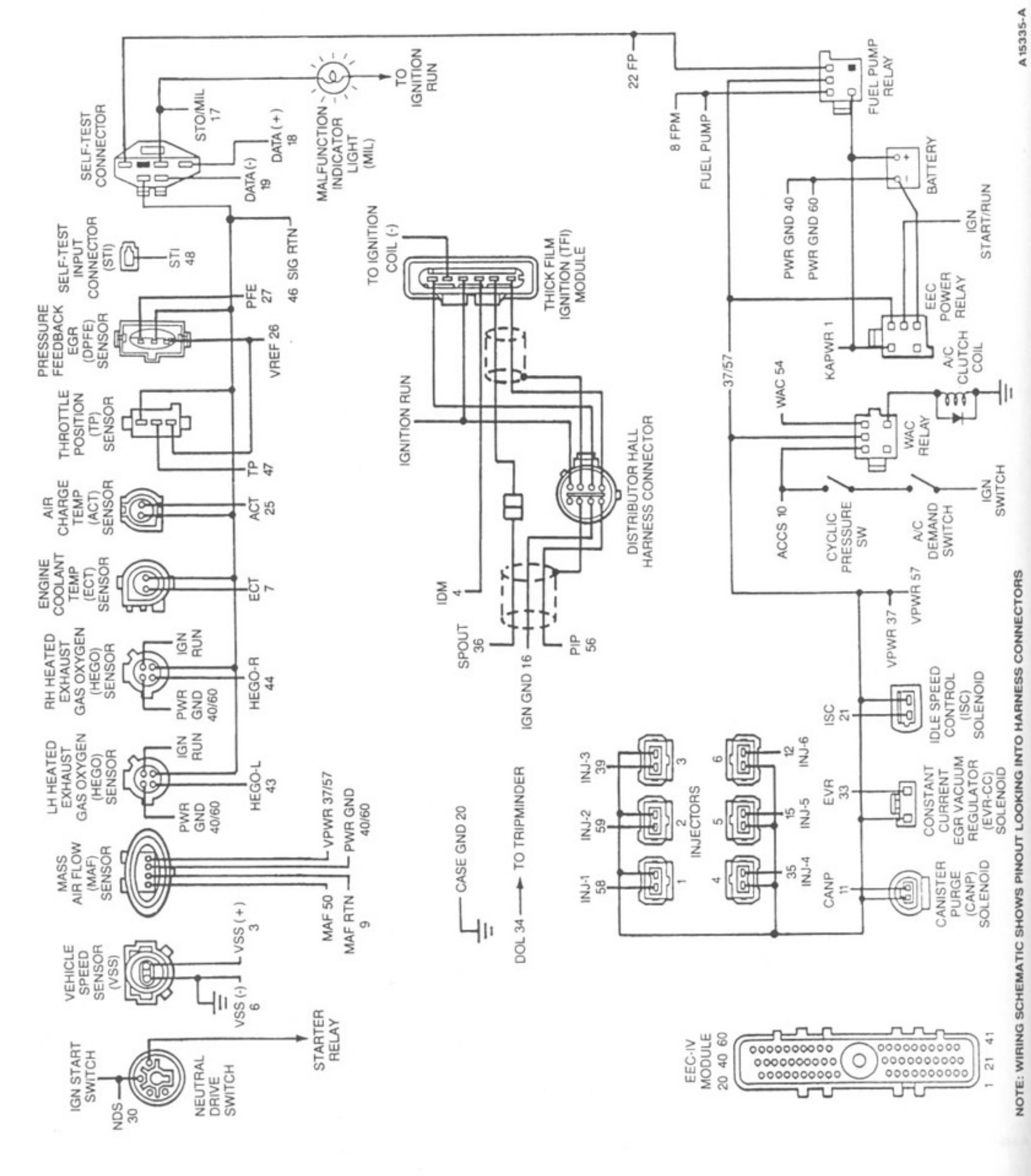
3.8L MAF-SFI SC

(VIN Code 4, RWD)

1992–1993
T-Bird, Cougar

VIN: 1 2 3 4 5 6 7 8 ... 17

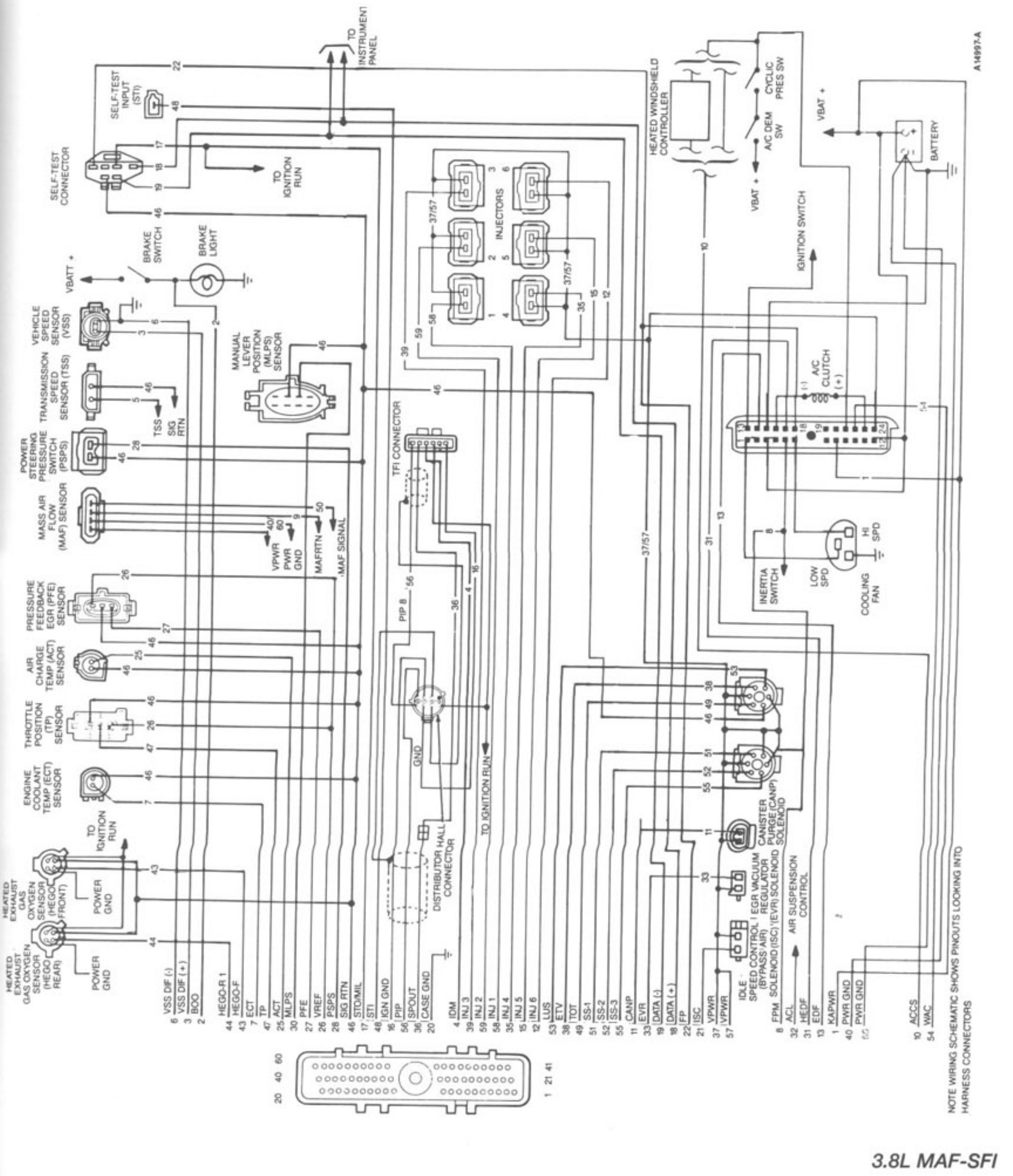
Engine code



1988–1991 Continental

3.8L MAF-SFI
(VIN Code 4, FWD, AXODE)

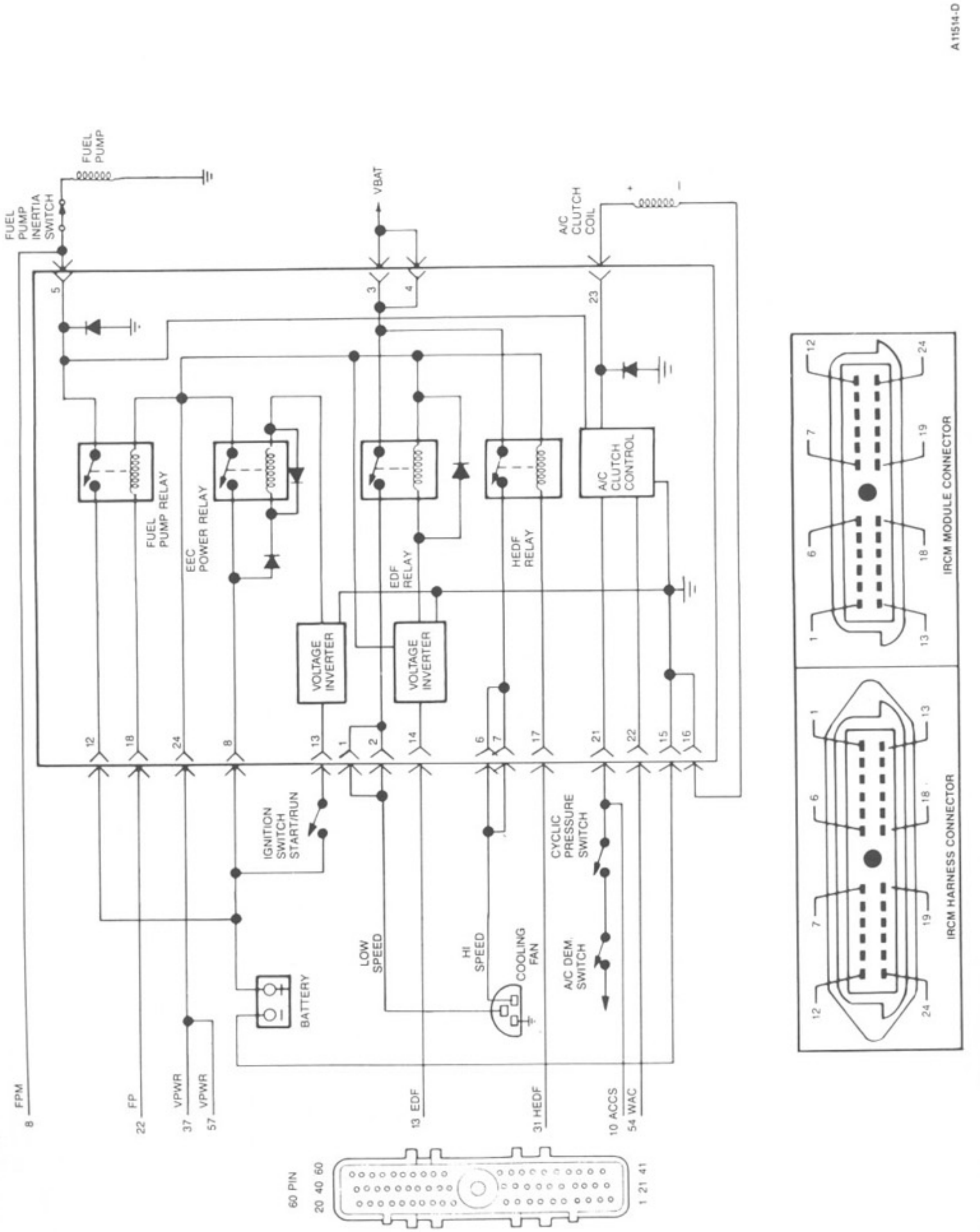
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



3.8L
MAF-SFI
(VIN Code 4, FWD, AXODE)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

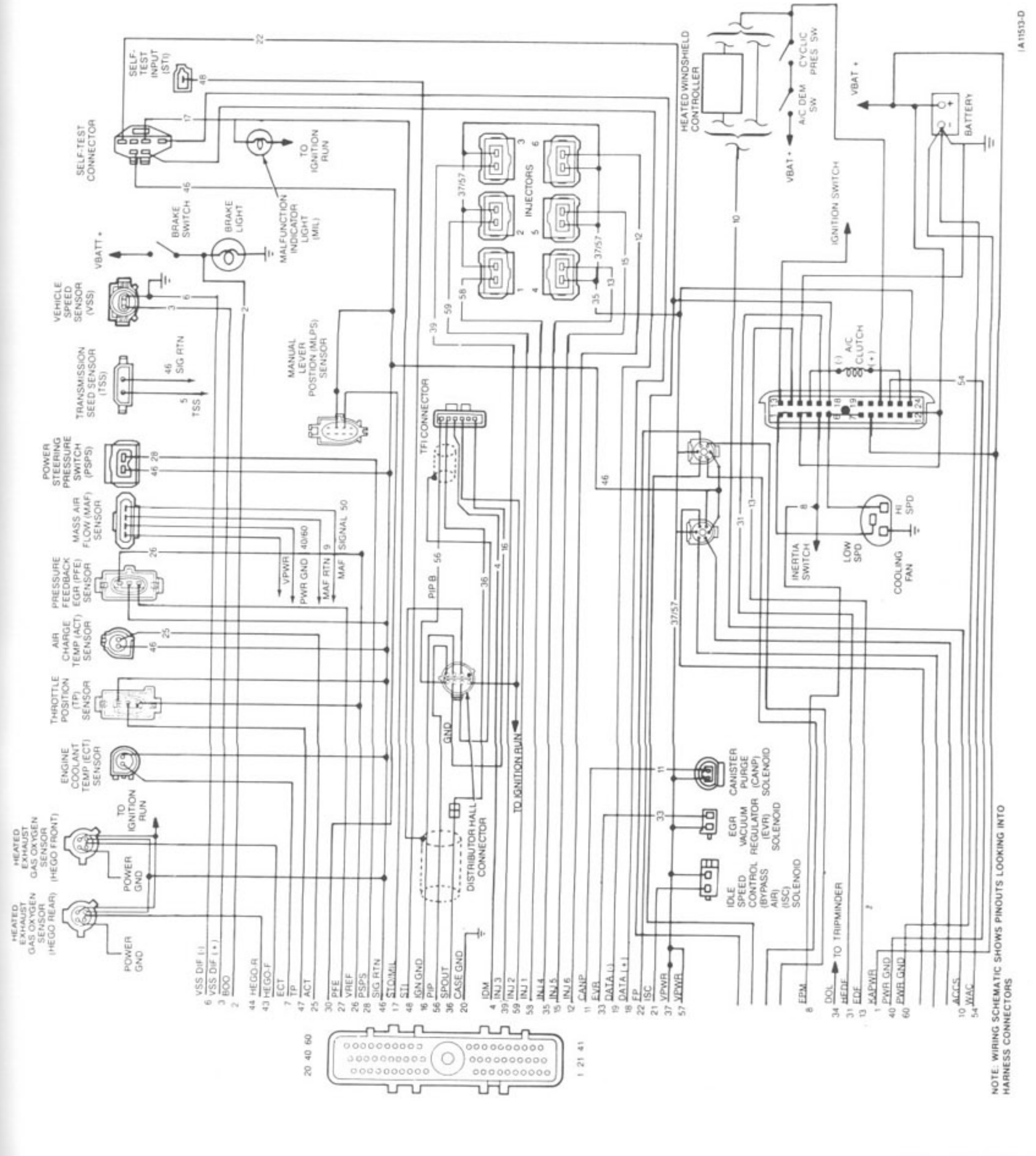
1988–1991
Continental
Integrated Relay Control Module



1988-1991
Taurus, Sable

3.8L
MAF-SFI
(VIN Code 4, FWD, AXODE)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

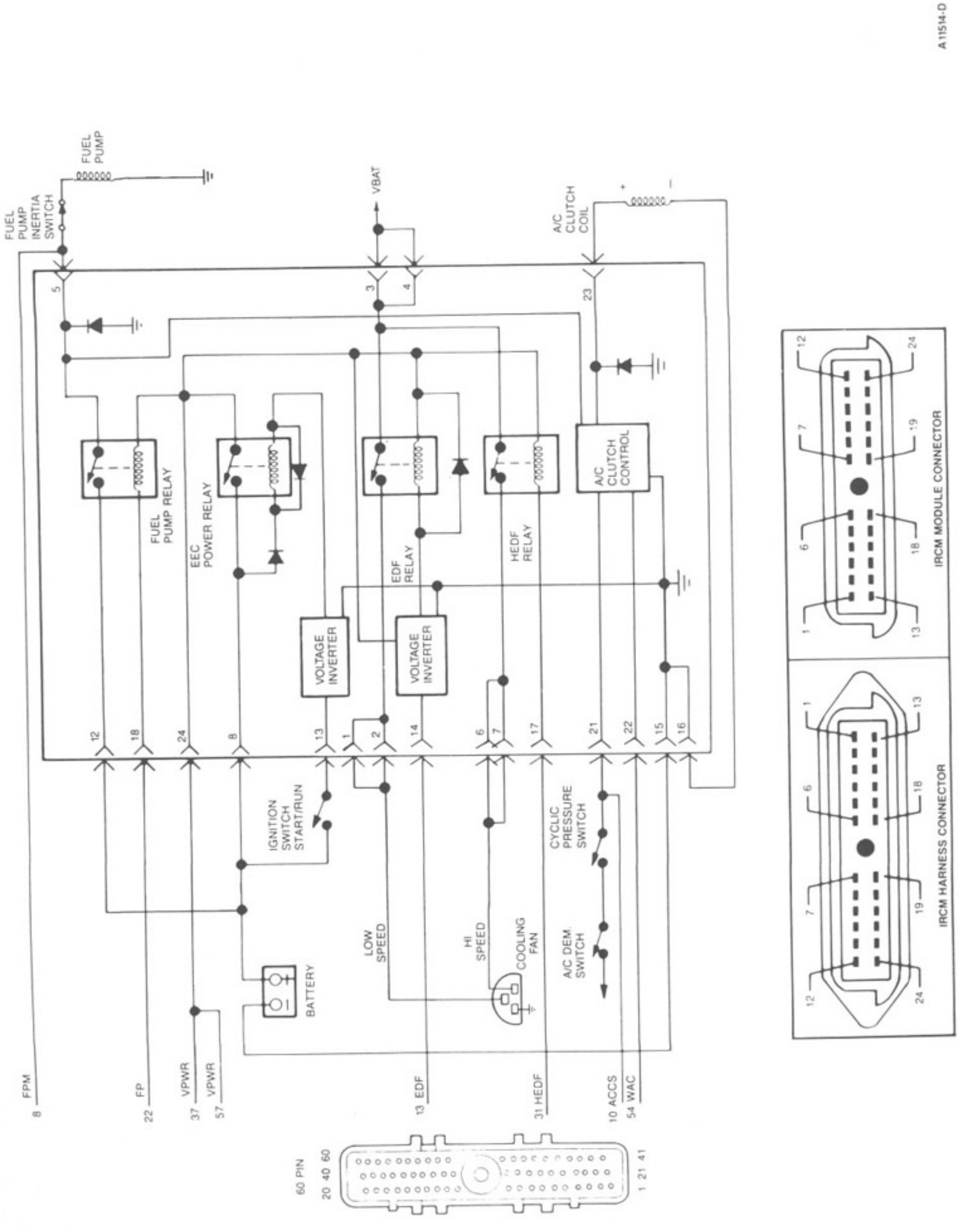


12

3.8L MAF-SFI
(VIN Code 4, FWD, AXODE)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

1988–1991
Taurus, Sable
Integrated Relay Control Module

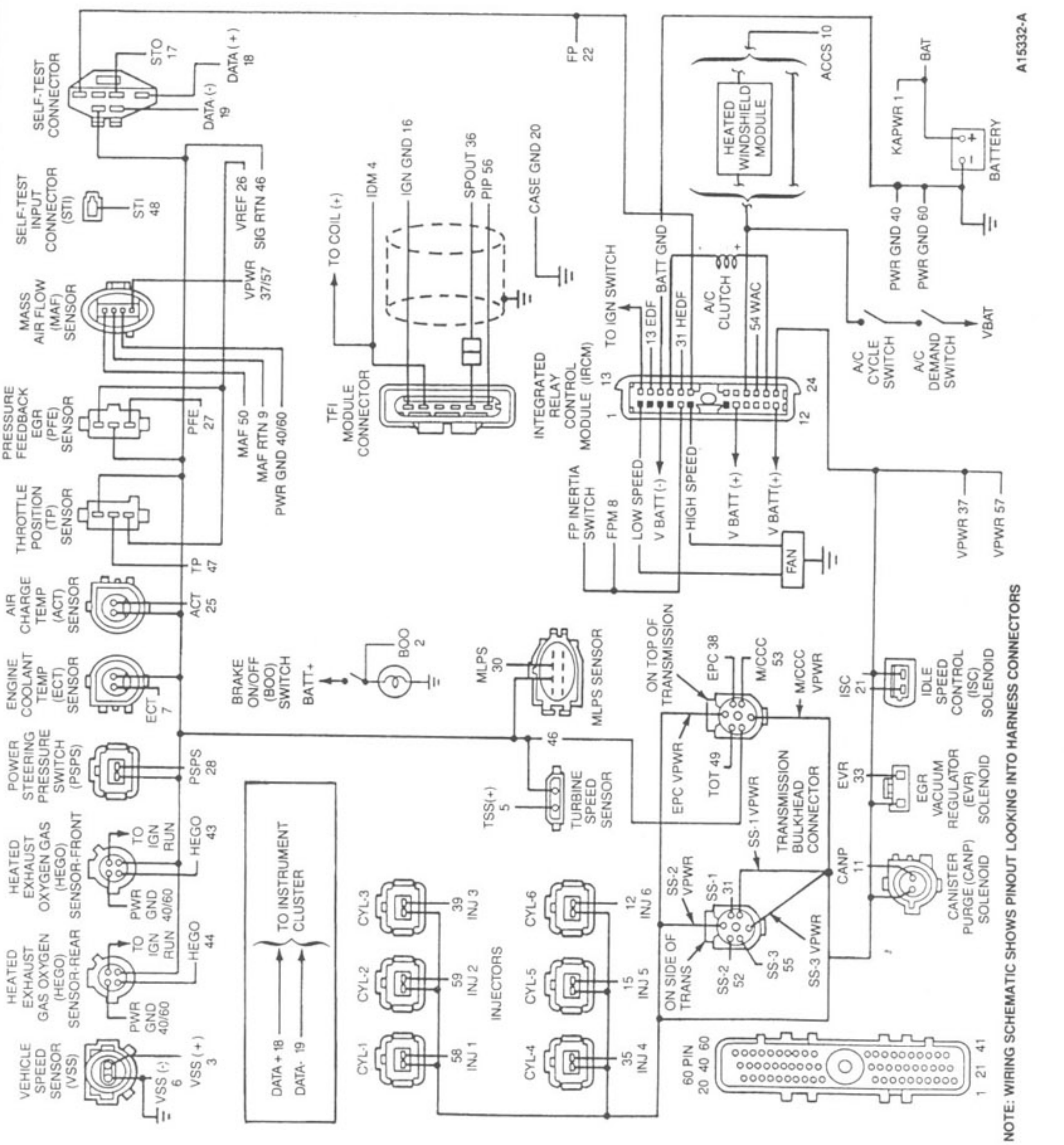


1992–1993 Continental

3.8L MAF-SFI

(VIN Code 4, FWD, AXODE)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



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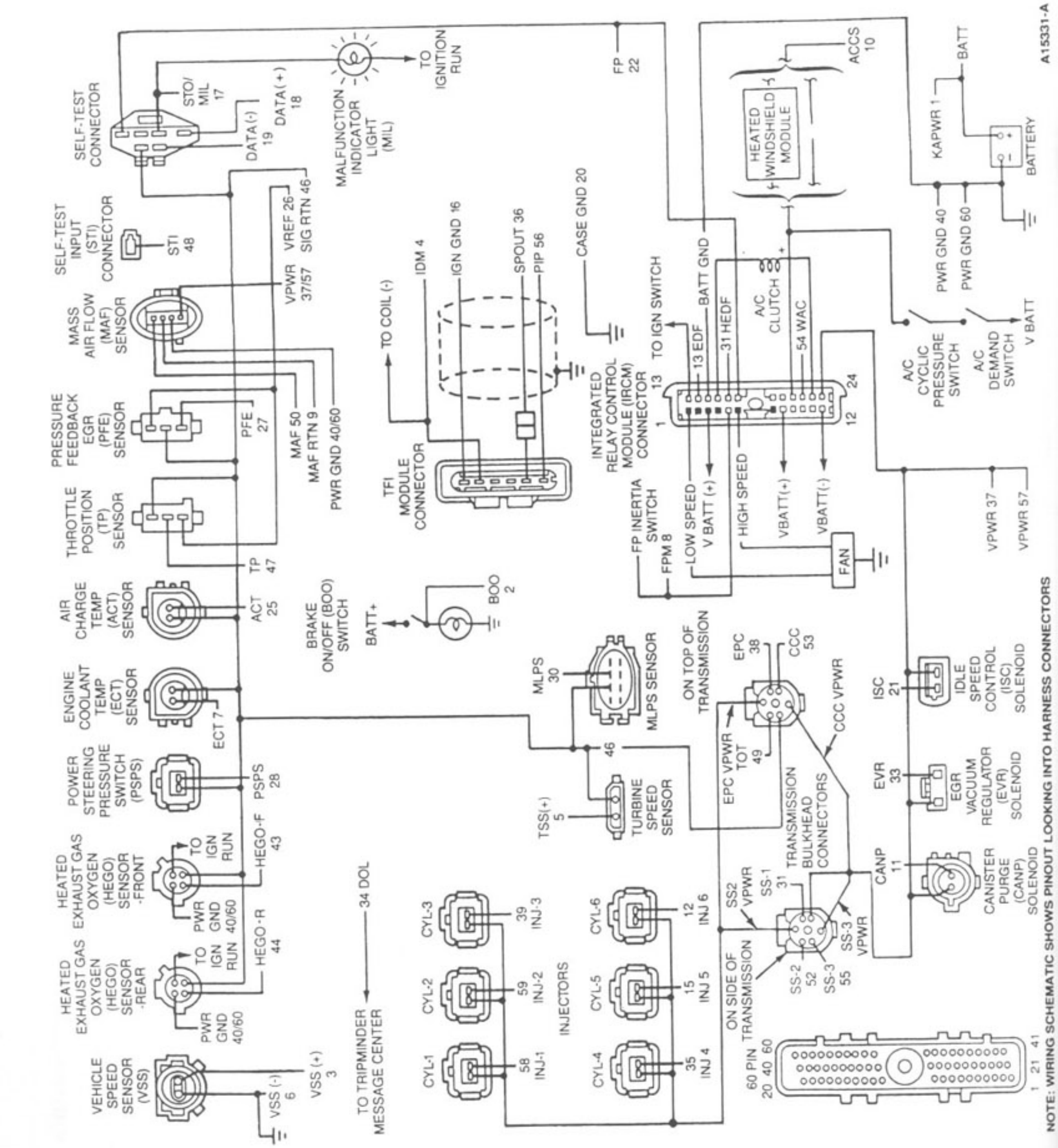
3.8L MAF-SFI

(VIN Code 4, FWD, AXODE)

1992–1993 Taurus, Sable

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

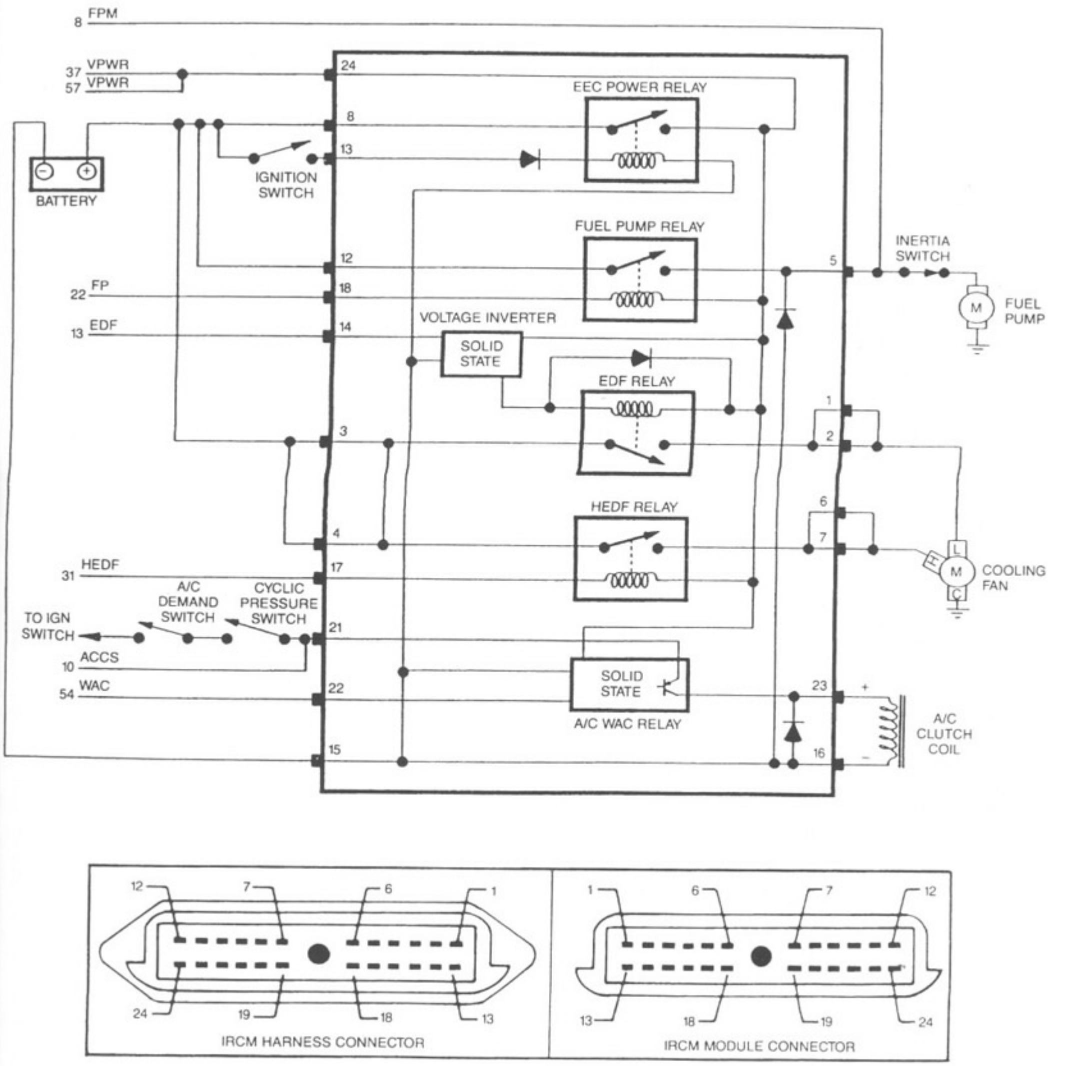


NOTE: WIRING SCHEMATIC SHOWS PINOUT LOOKING INTO HARNESS CONNECTORS

1992 Taurus, Sable, Continental Integrated Relay Control Module

3.8L MAF-SFI
(VIN Code 4, FWD, AXODE)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



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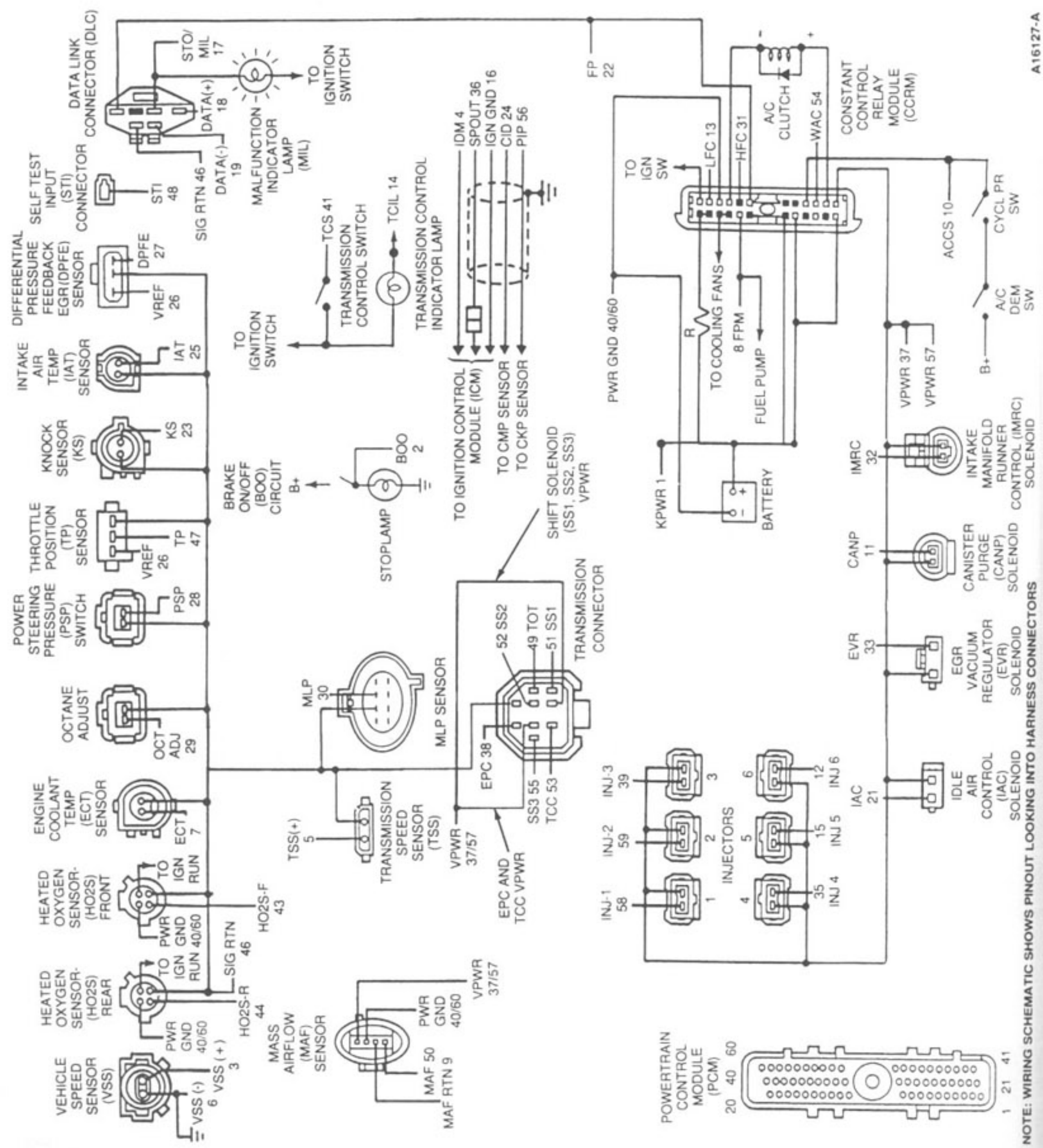
12

3.2L MAF-SFI SHO
(VIN Code P, AX4S)

1993 Taurus SHO

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



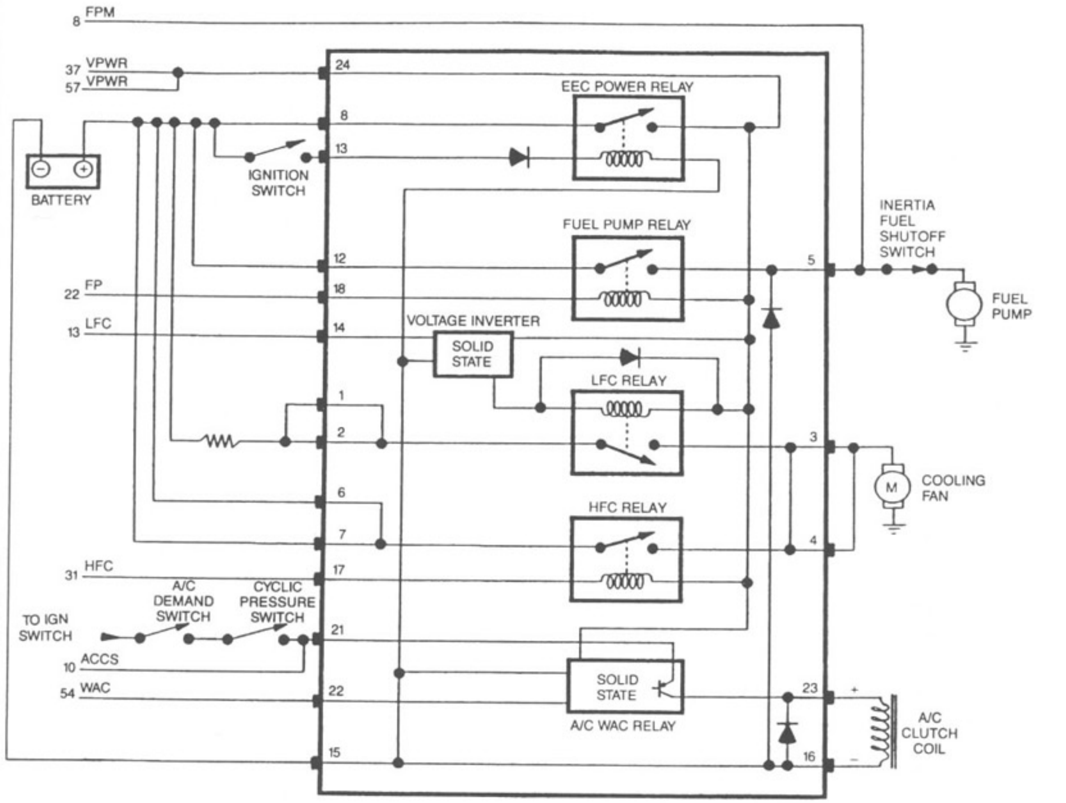
1993 Taurus CCRM

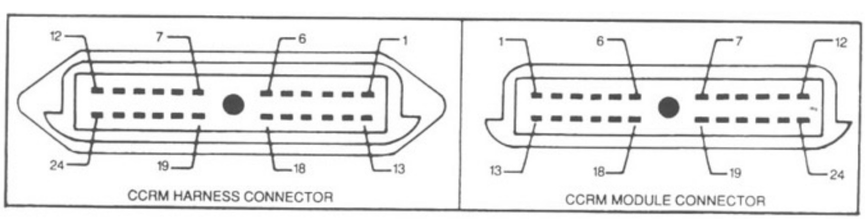
3.2L MAF-SFI SHO

(VIN Code P, AX4S)

VIN: 1 2 3 4 5 6 7 8 ... 17

Engine code





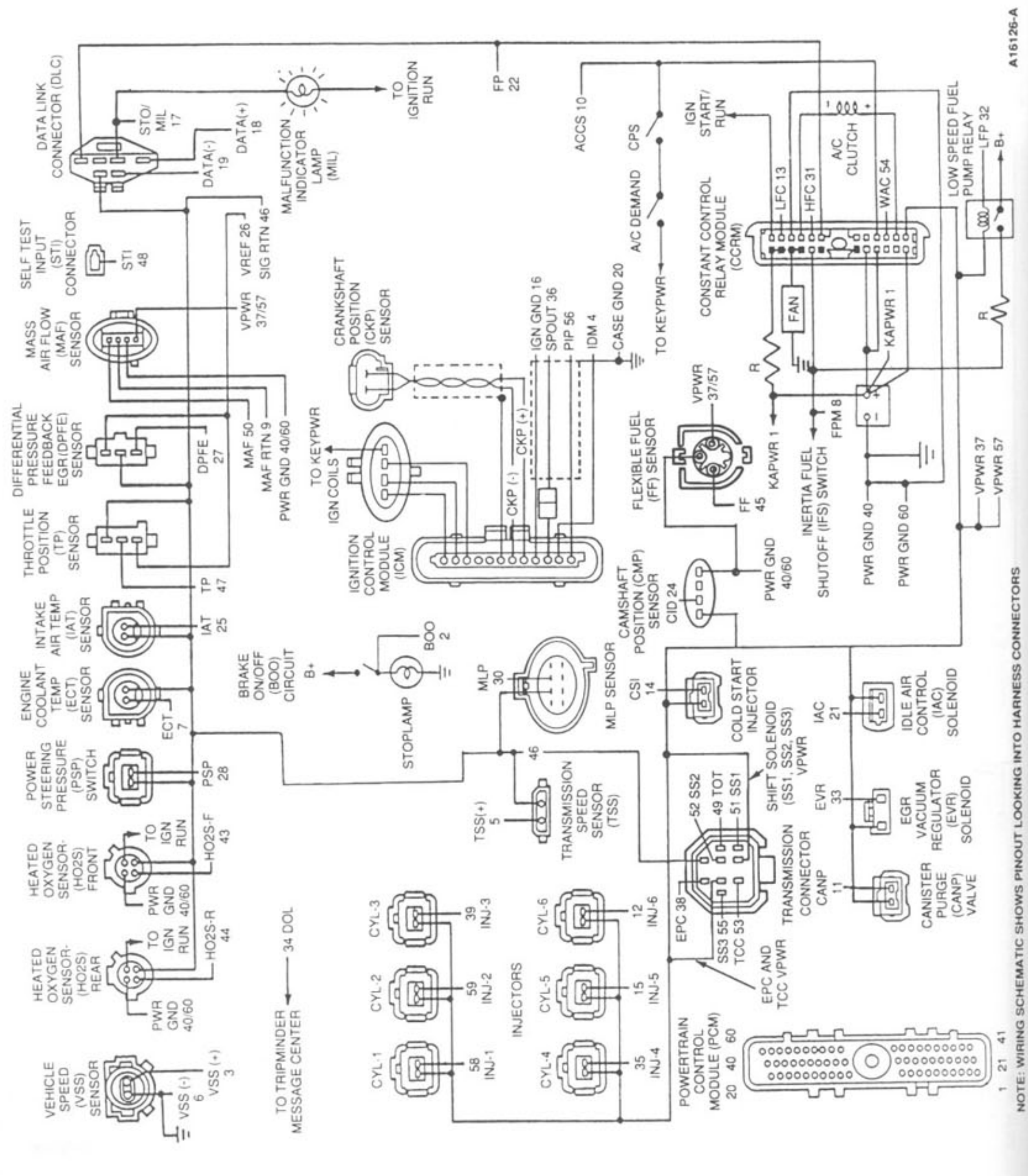
A15328-B

12

3.0L FF (Flexible Fuel)
(VIN Code 1, AXODE)

1993 Taurus Flexible Fuel

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



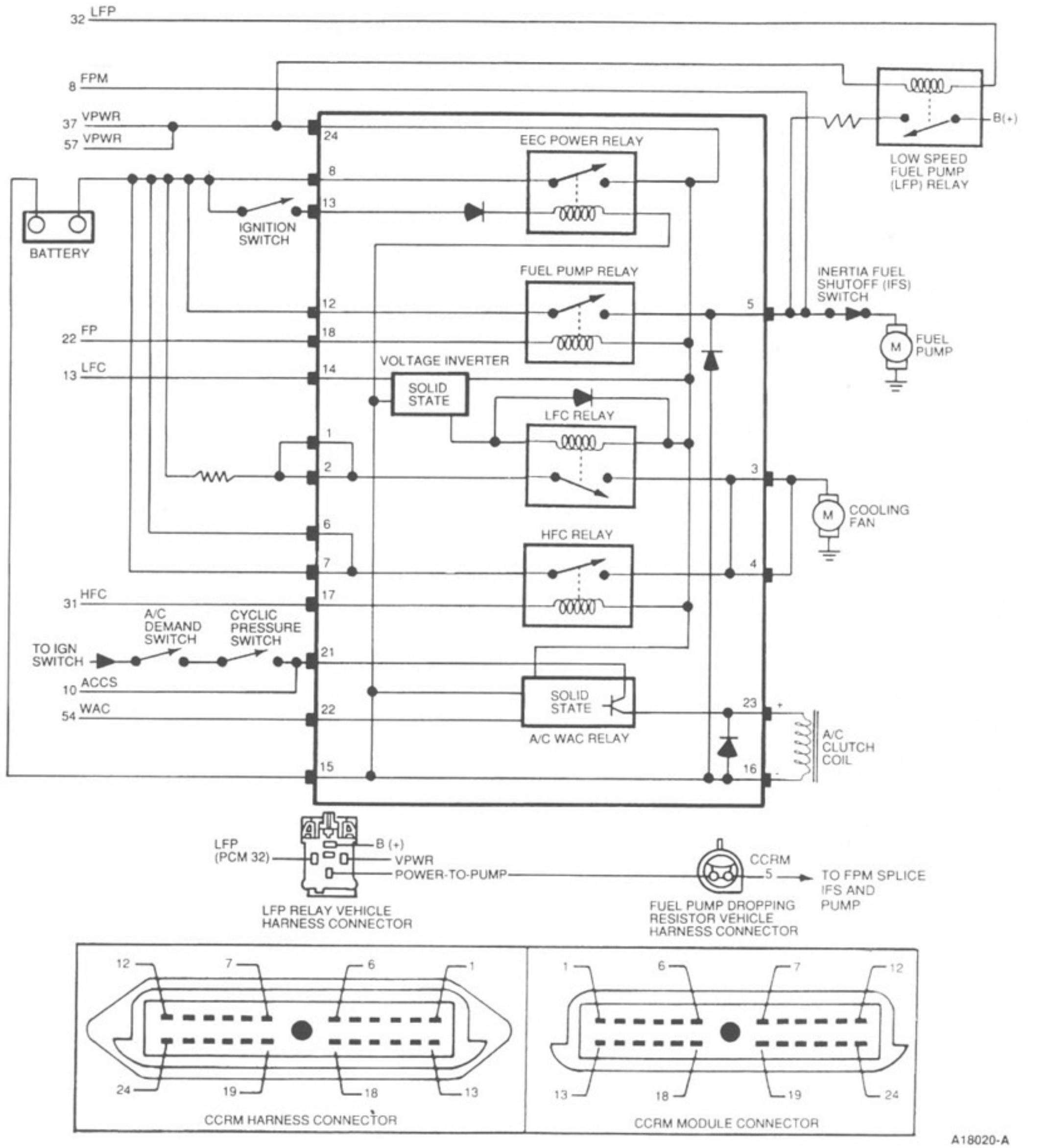
1993 Taurus Flexible Fuel CCRM

3.0L FF (Flexible Fuel)

(VIN Code 1, AXODE)

VIN: 1 2 3 4 5 6 7 8 ... 17

Engine code



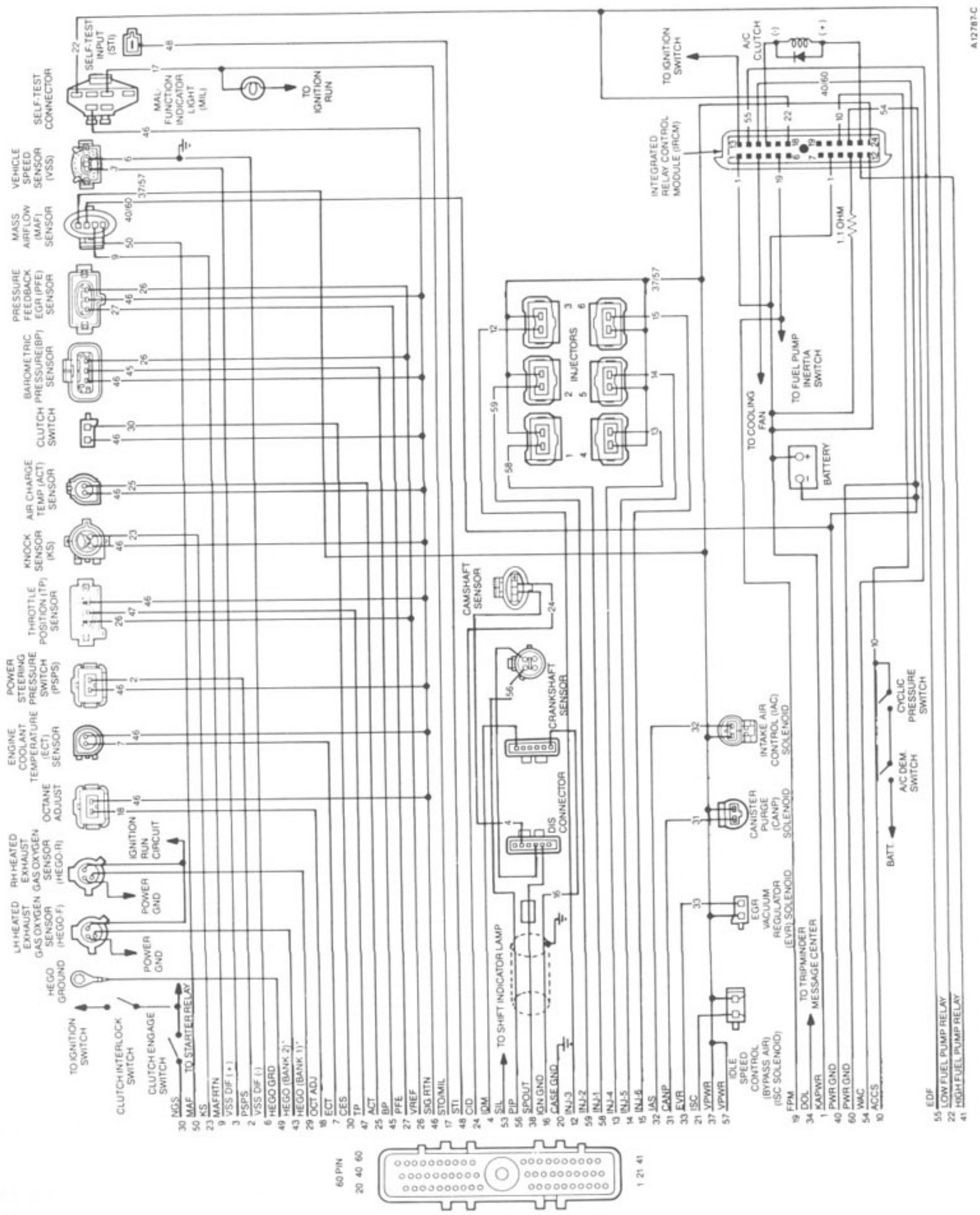
A18020-A

12

3.0L
MAF-SFI SHO
(VIN Code Y)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

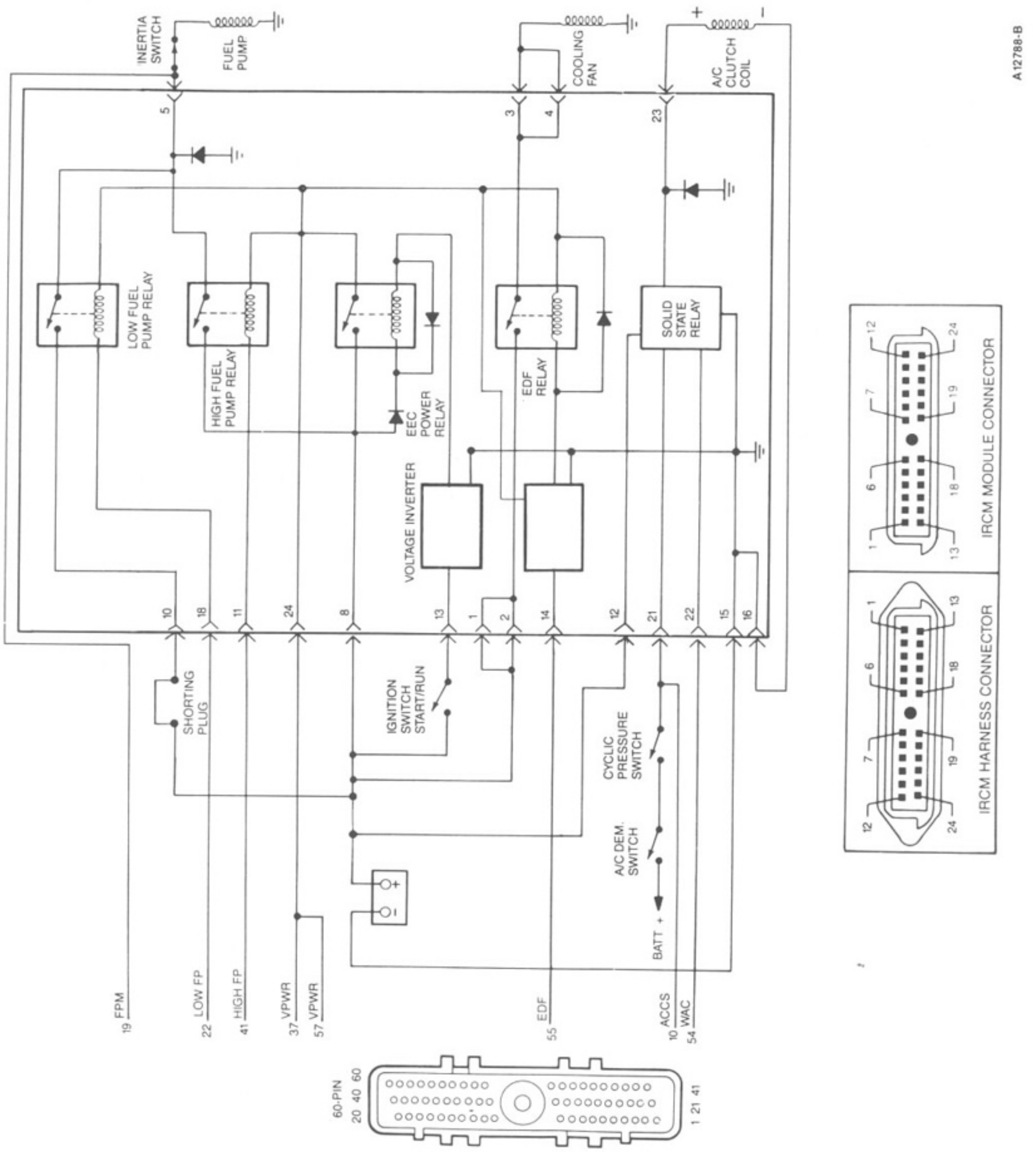
1989–1991
Taurus
SHO



1989–1991
Taurus
SHO, Integrated Relay Control Module

3.0L
MAF-SFI SHO
(VIN Code Y)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

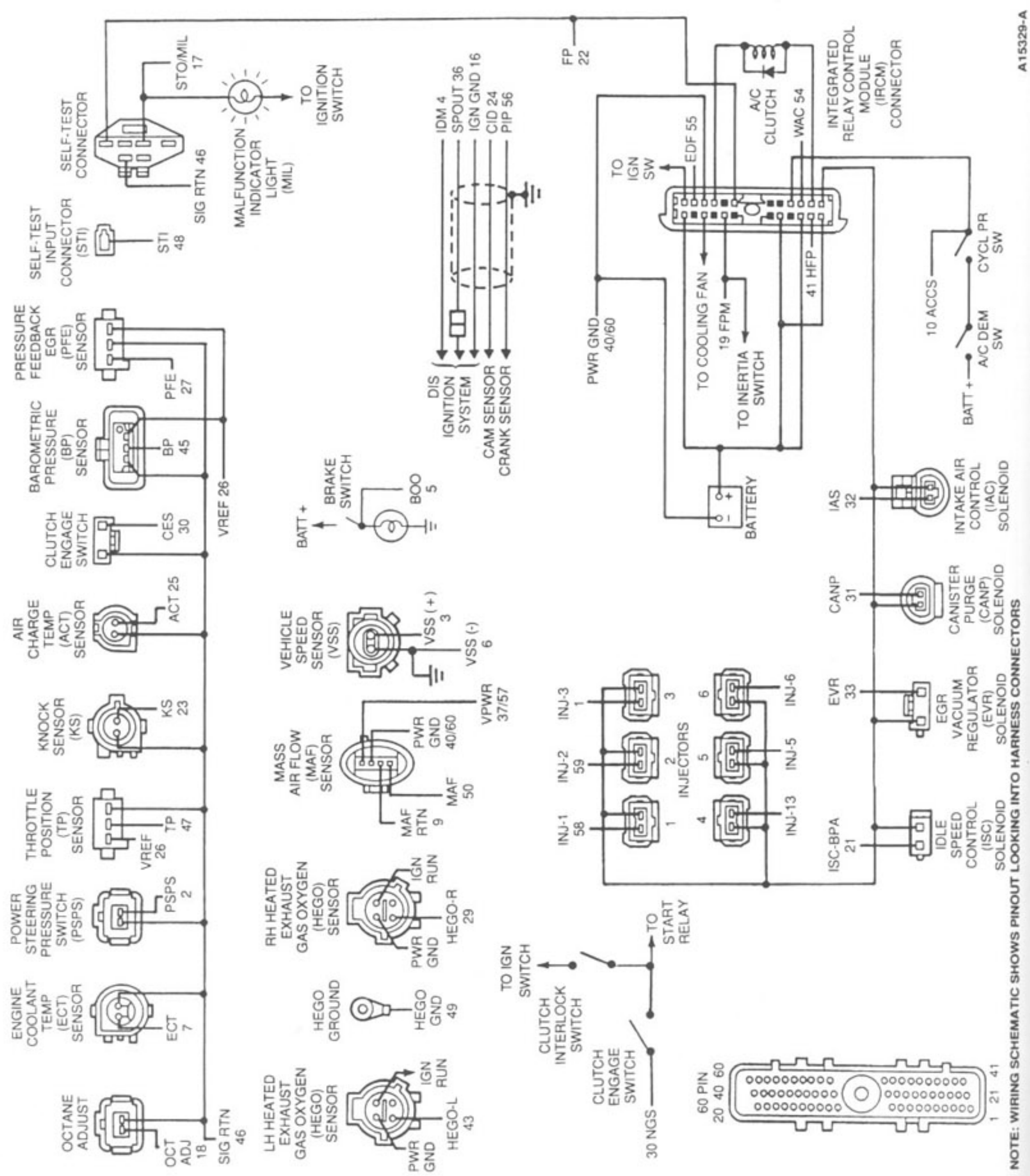


12

3.0L MAF-SFI SHO
(VIN Code Y)

1992–1993
Taurus
SHO

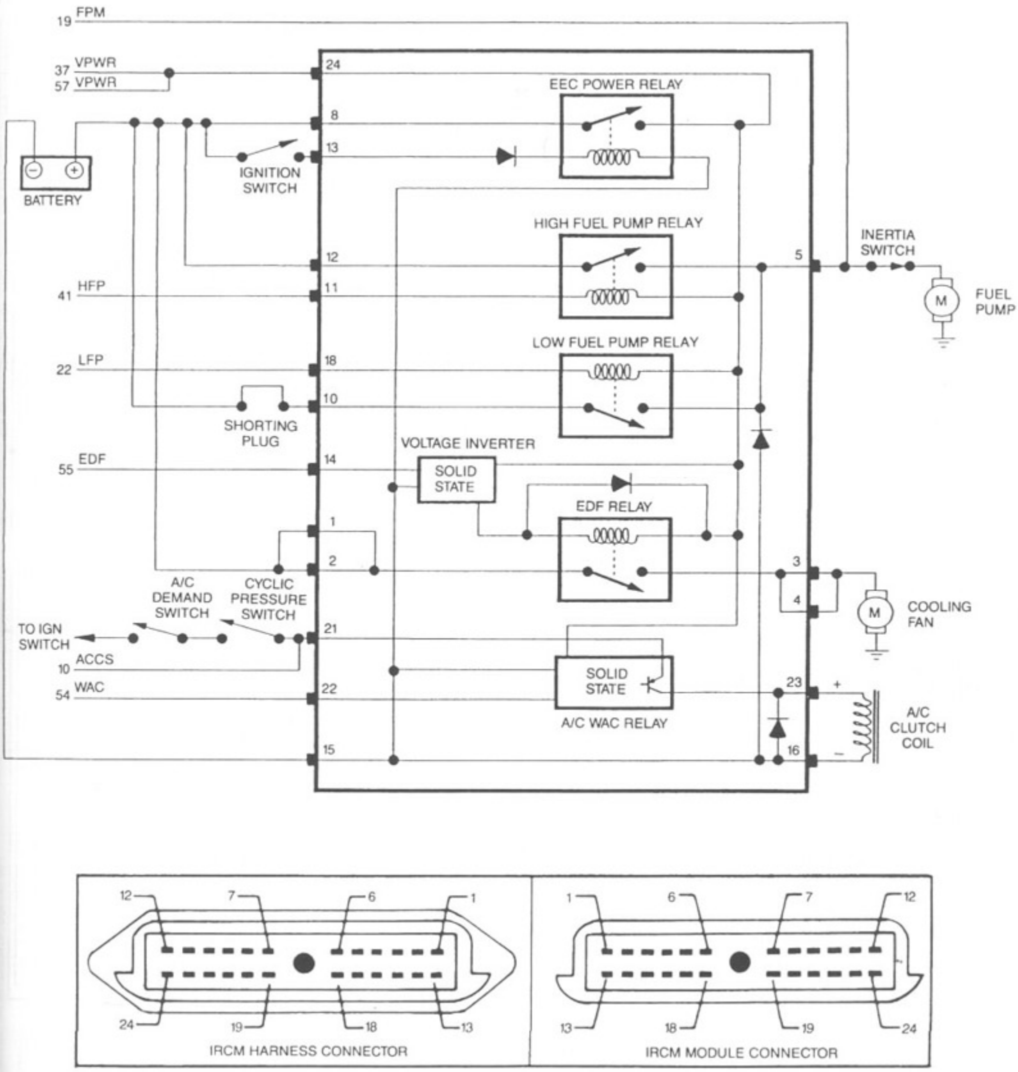
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



1992–1993 Taurus SHO, Integrated Relay Control Module

3.0L MAF-SFI SHO
(VIN Code Y)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



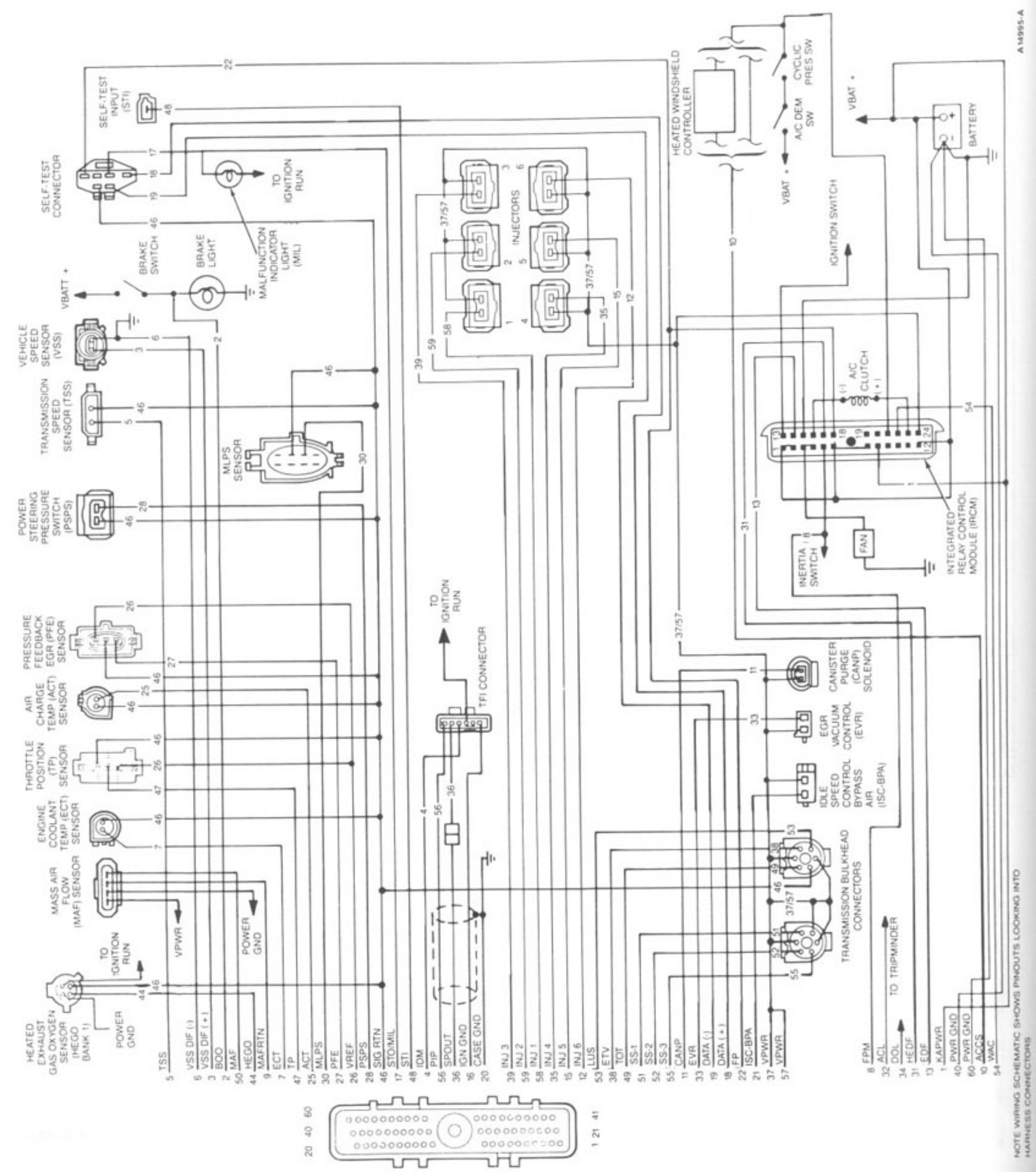
A15330-A

3.0L MAF-SFI
(VIN Code U, AXODE)

1991
Taurus, Sable

VIN: 1 2 3 4 5 6 7 8 ... 17

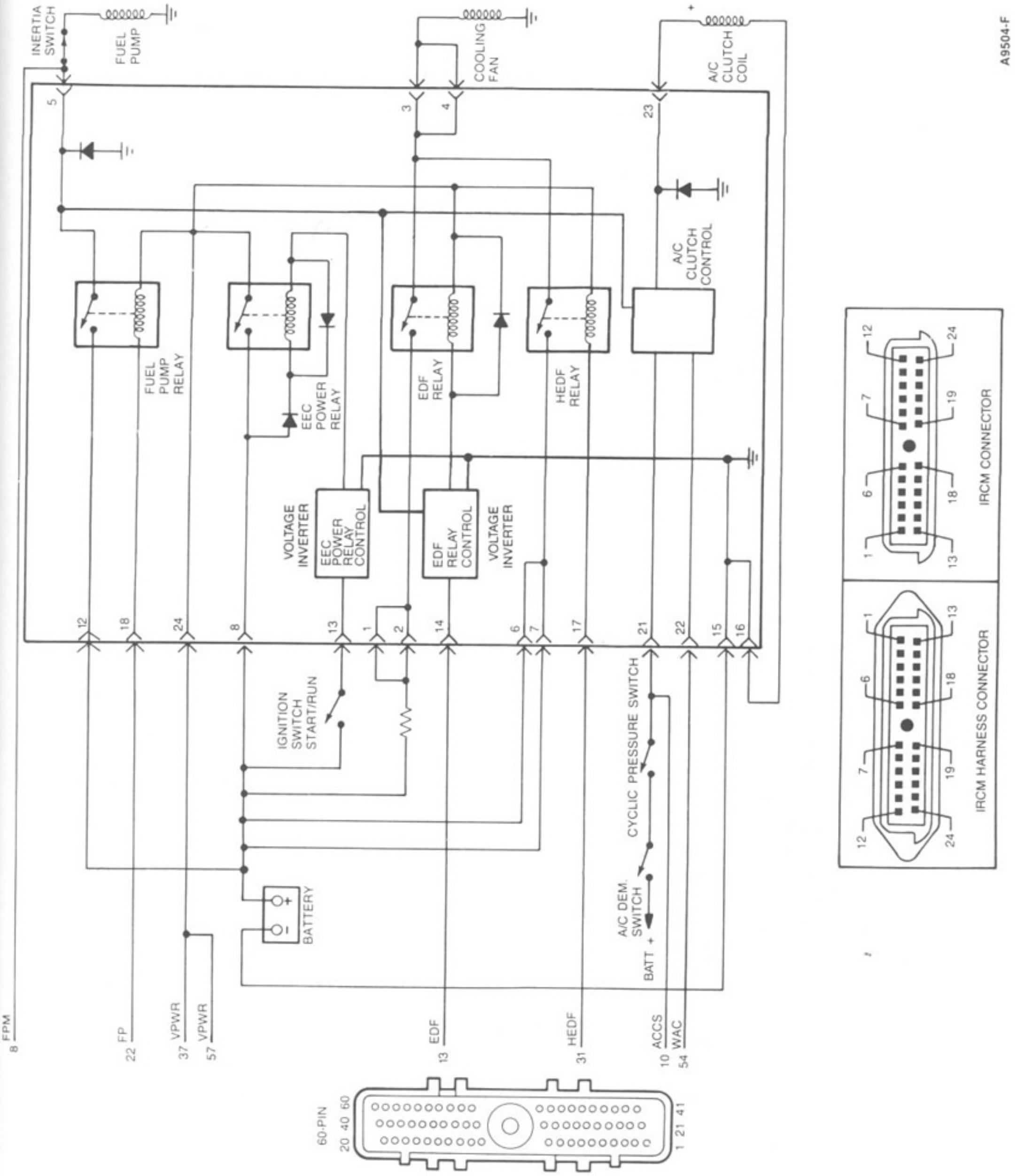
Engine code



1991 Taurus, Sable Integrated Relay Control Module

3.0L MAF-SFI
(VIN Code U, AXODE)

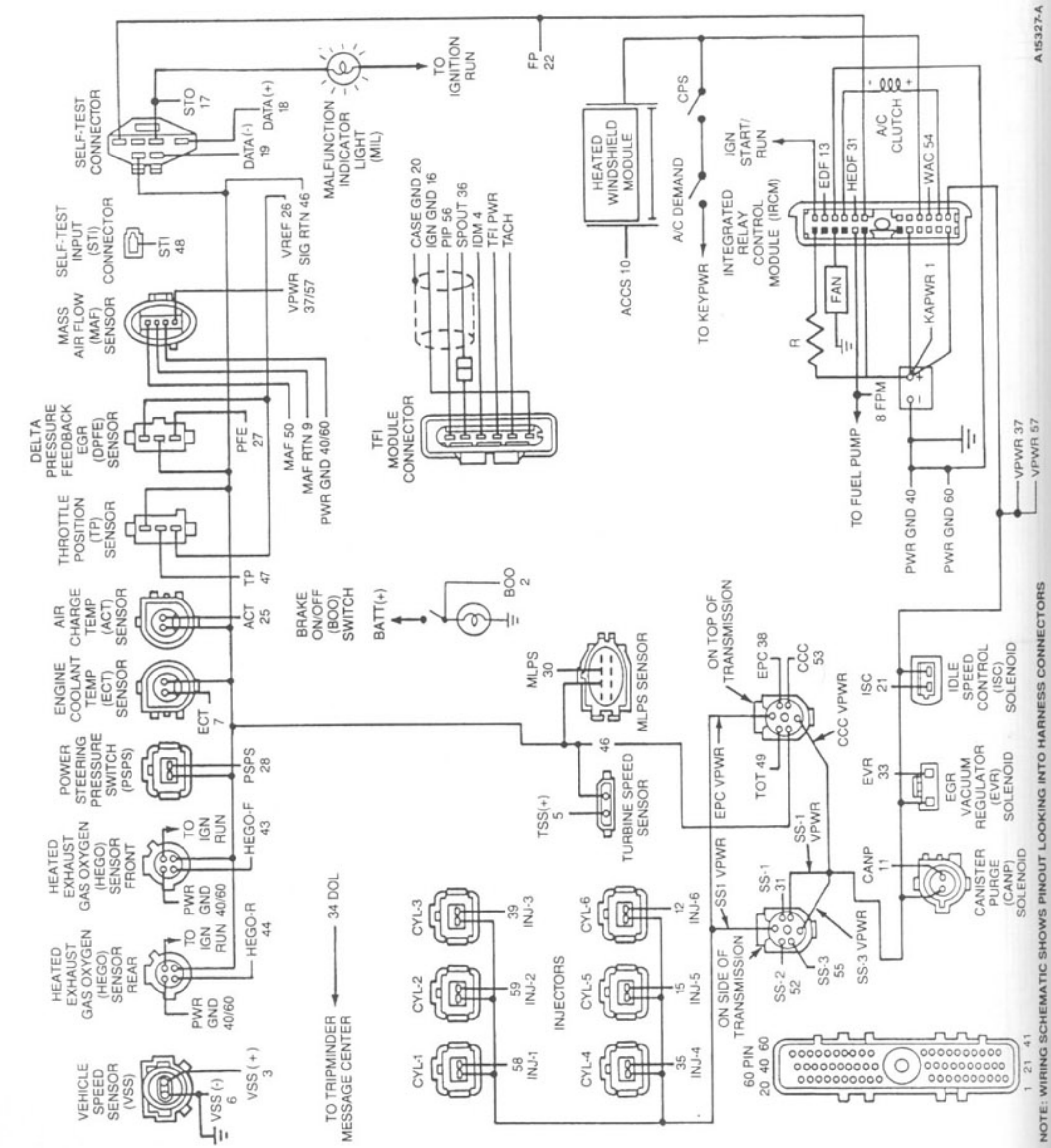
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



3.0L MAF-SFI
(VIN Code U, AXODE)

1992–1993
Taurus, Sable

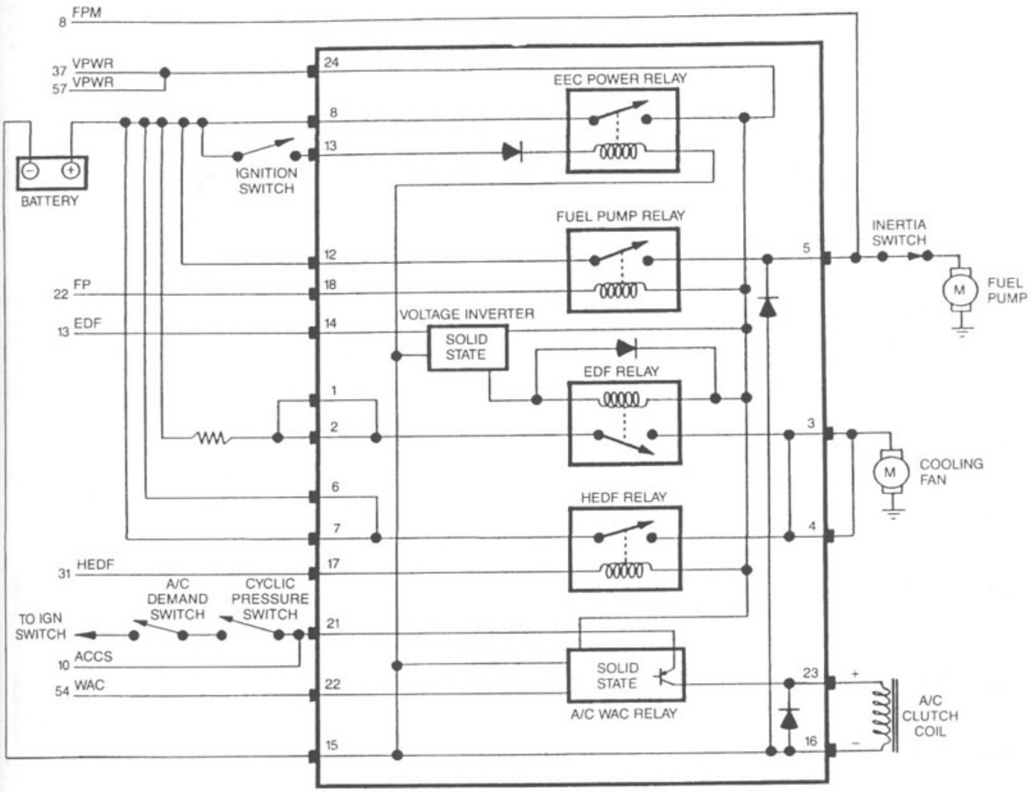
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

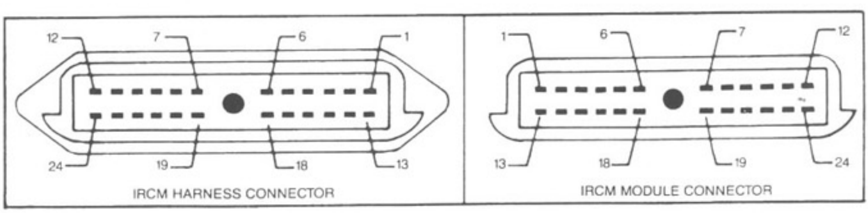


1992
Taurus, Sable
Integrated Relay Control Module

3.0L
MAF-SFI
(VIN Code U, AXODE)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



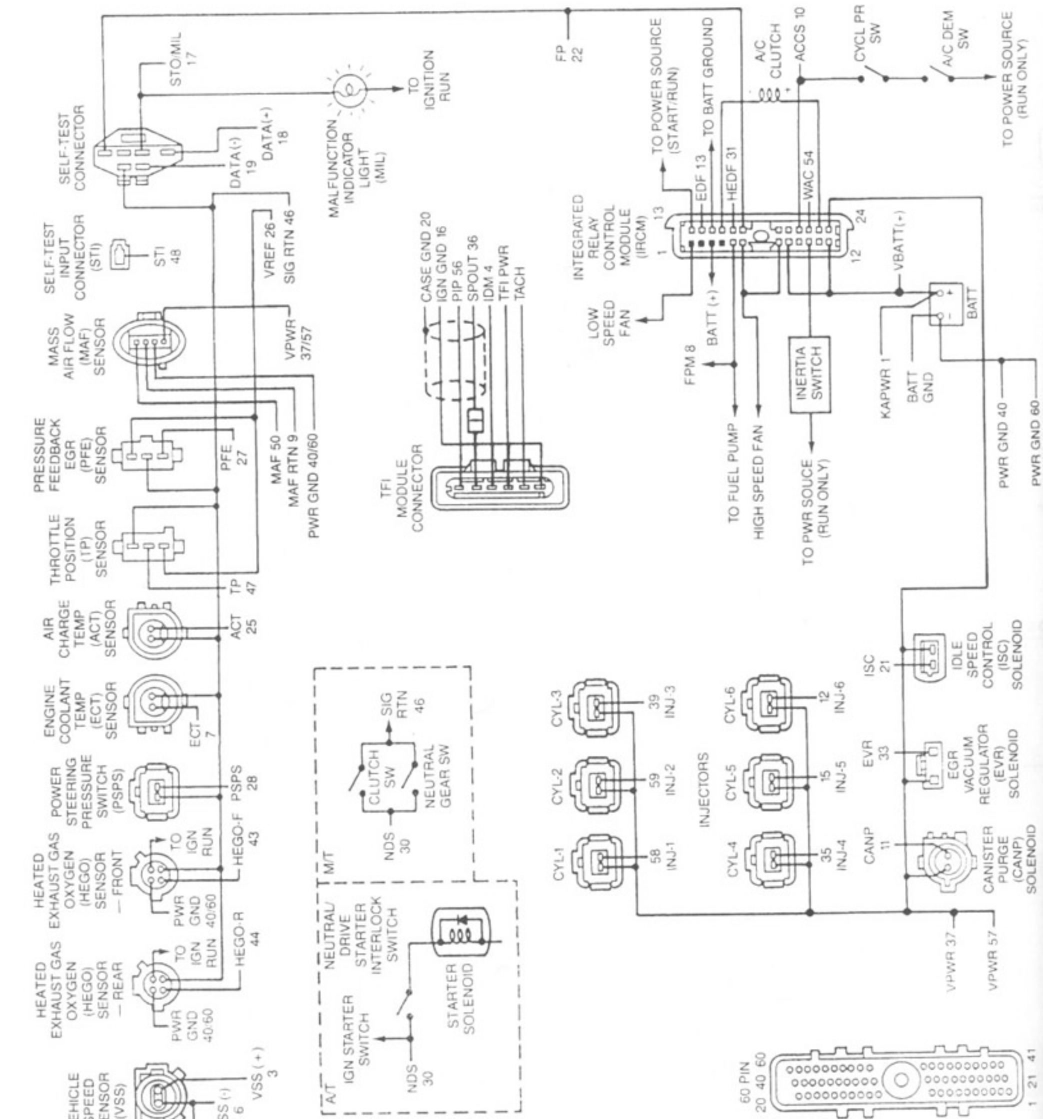


A15328-A

3.0L MAF-SFI
(VIN Code U, AXODE)

1992–1992
Tempo, Topaz V-6

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

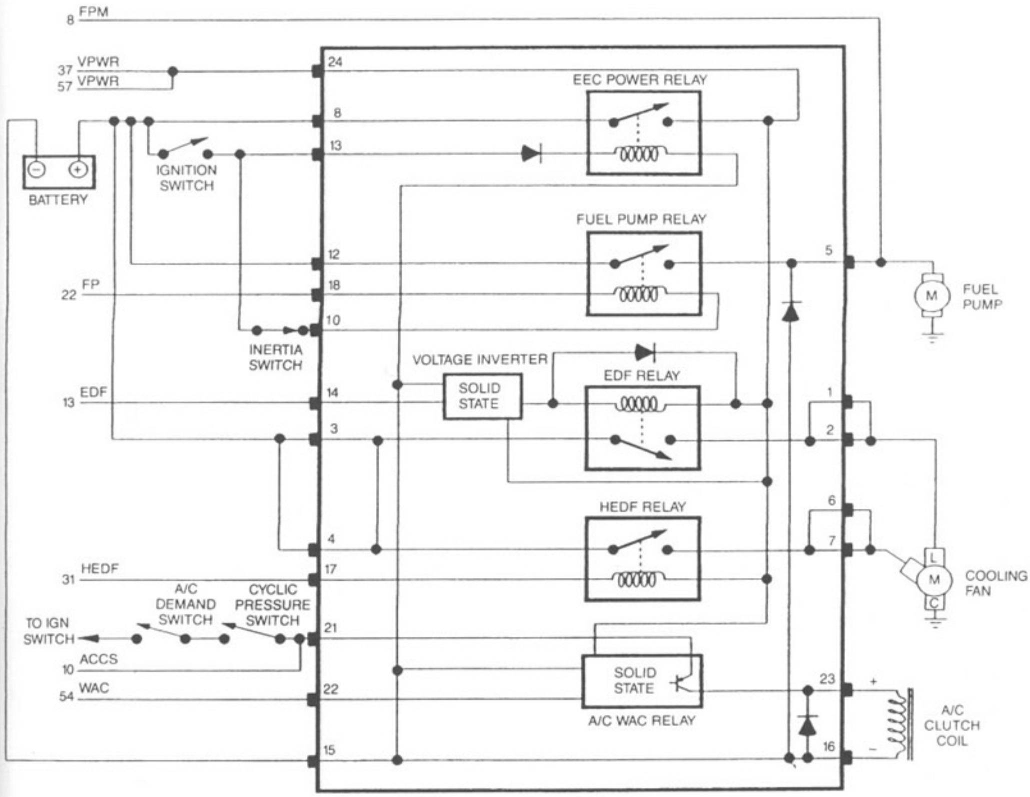


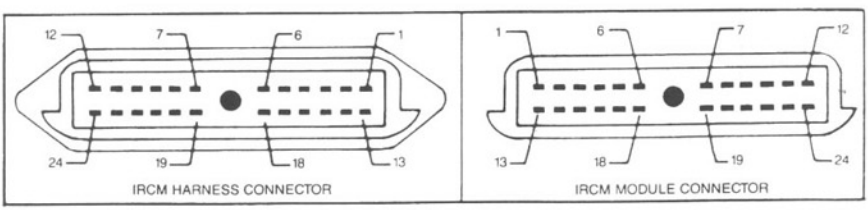
NOTE: WIRING SCHEMATIC SHOWS PINOUT LOOKING INTO HARNESS CONNECTORS

1992–1993 Tempo, Topaz V-6 Integrated Relay Control Module

3.0L MAF-SFI
(VIN Code U, AXODE)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



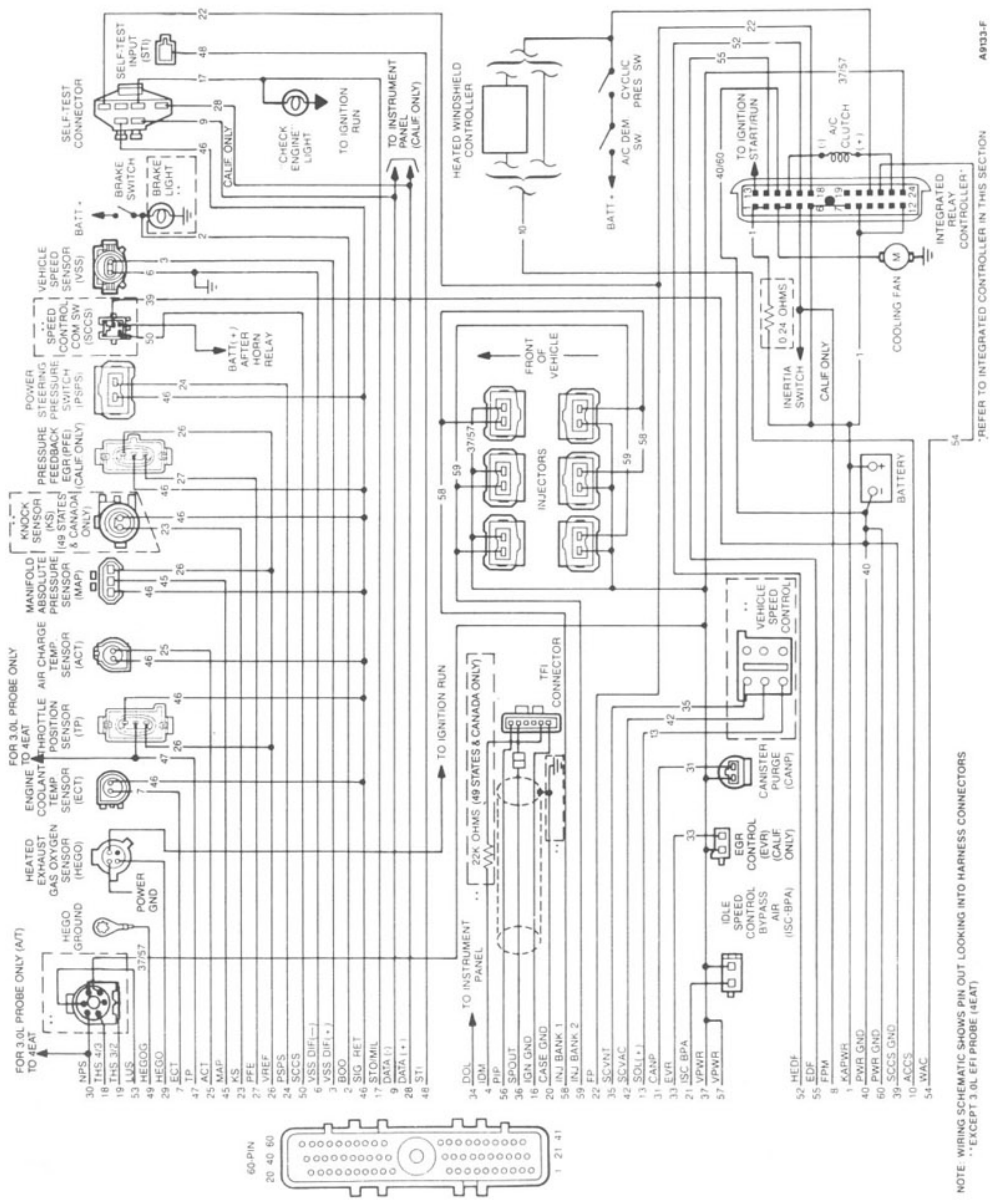


A 15326-A

3.0L
MAP
(VIN Code U)*

1988–1990
Taurus, Sable

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



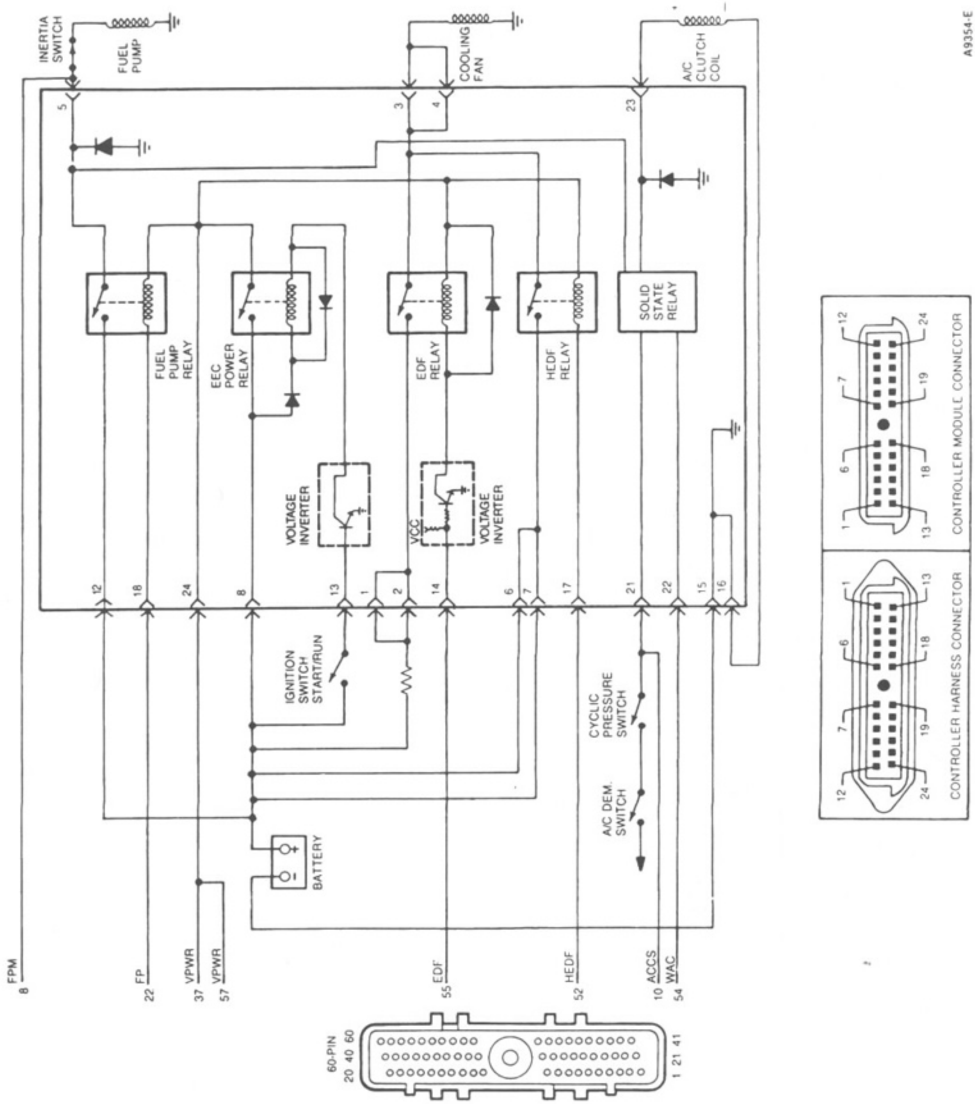
NOTE: WIRING SCHEMATIC SHOWS PIN OUT LOOKING INTO HARNESS CONNECTORS
**EXCEPT 3.0L EFI PROBE (4EAT)

**See MECS for 4-cyl. Probe*

1988–1990
Taurus, Sable
Integrated Relay Control Module

3.0L
MAP
(VIN Code U)*

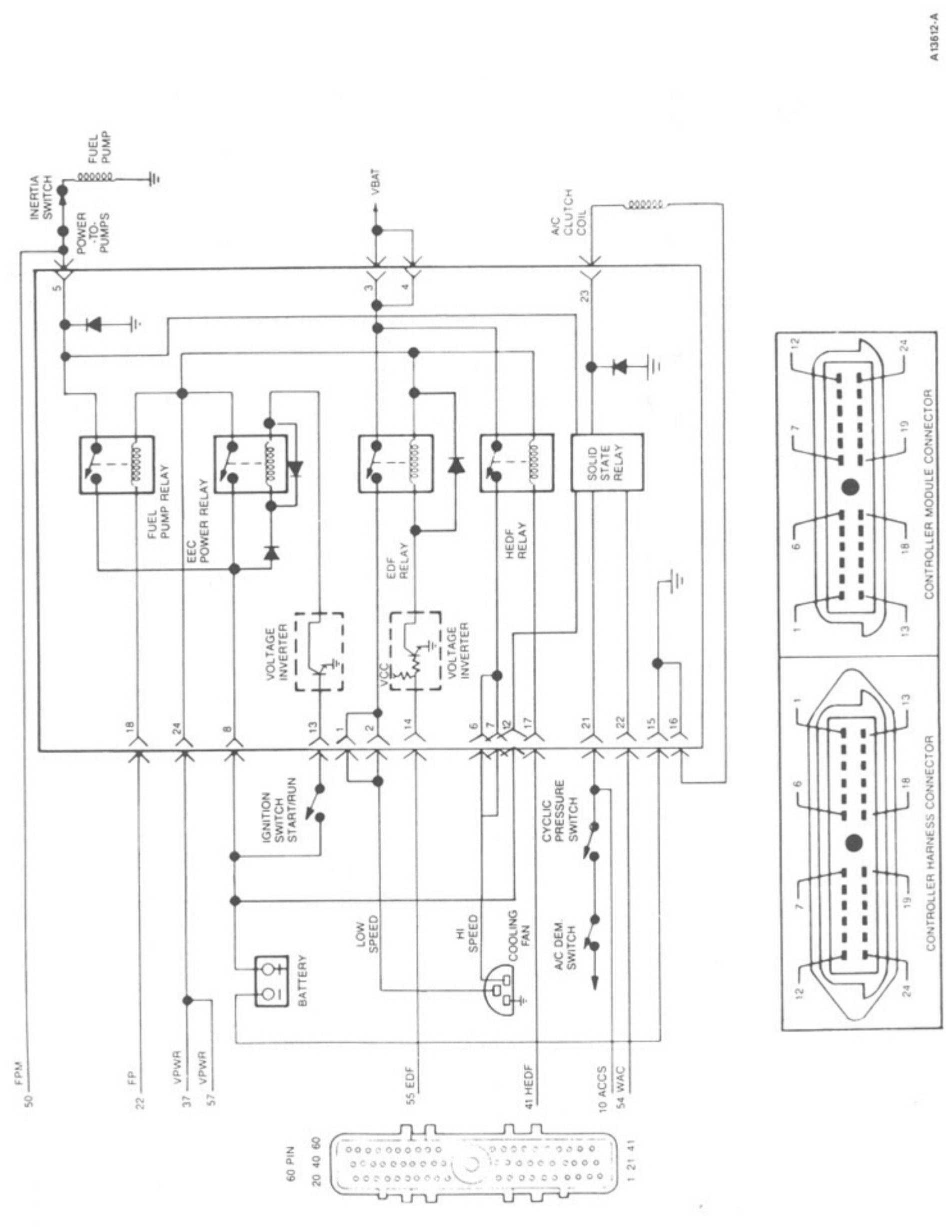
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



3.0L
MAP
(VIN Code U)*

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

1988–1990
Taurus, Sable
Integrated Relay Control Module

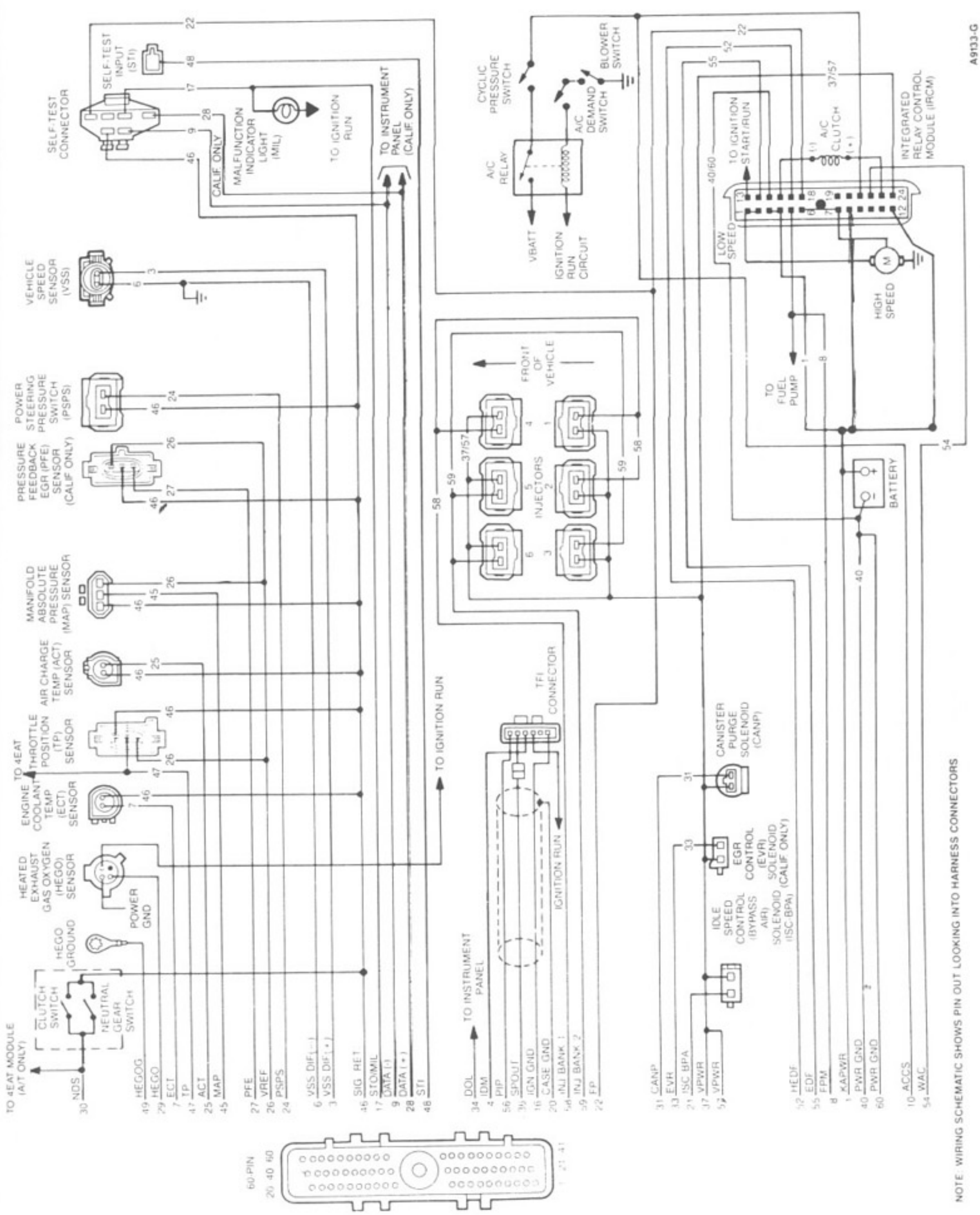


*See MECS for 4-cyl. Probe

1990–1991 Probe V-6

3.0L MAP
(VIN Code U)*

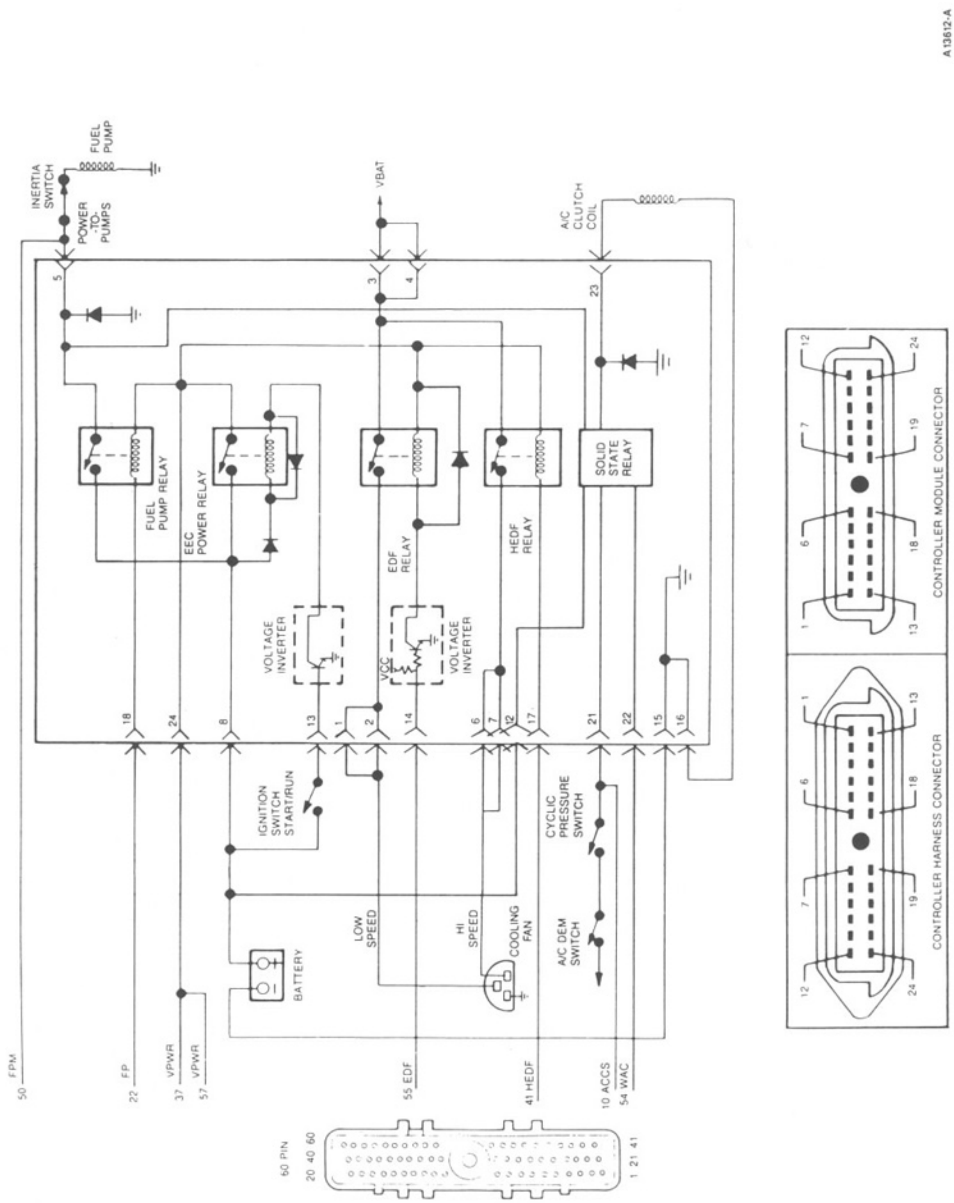
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



3.0L
MAP
(VIN Code U)*

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

1990
Probe V-6
Integrated Relay Control Module

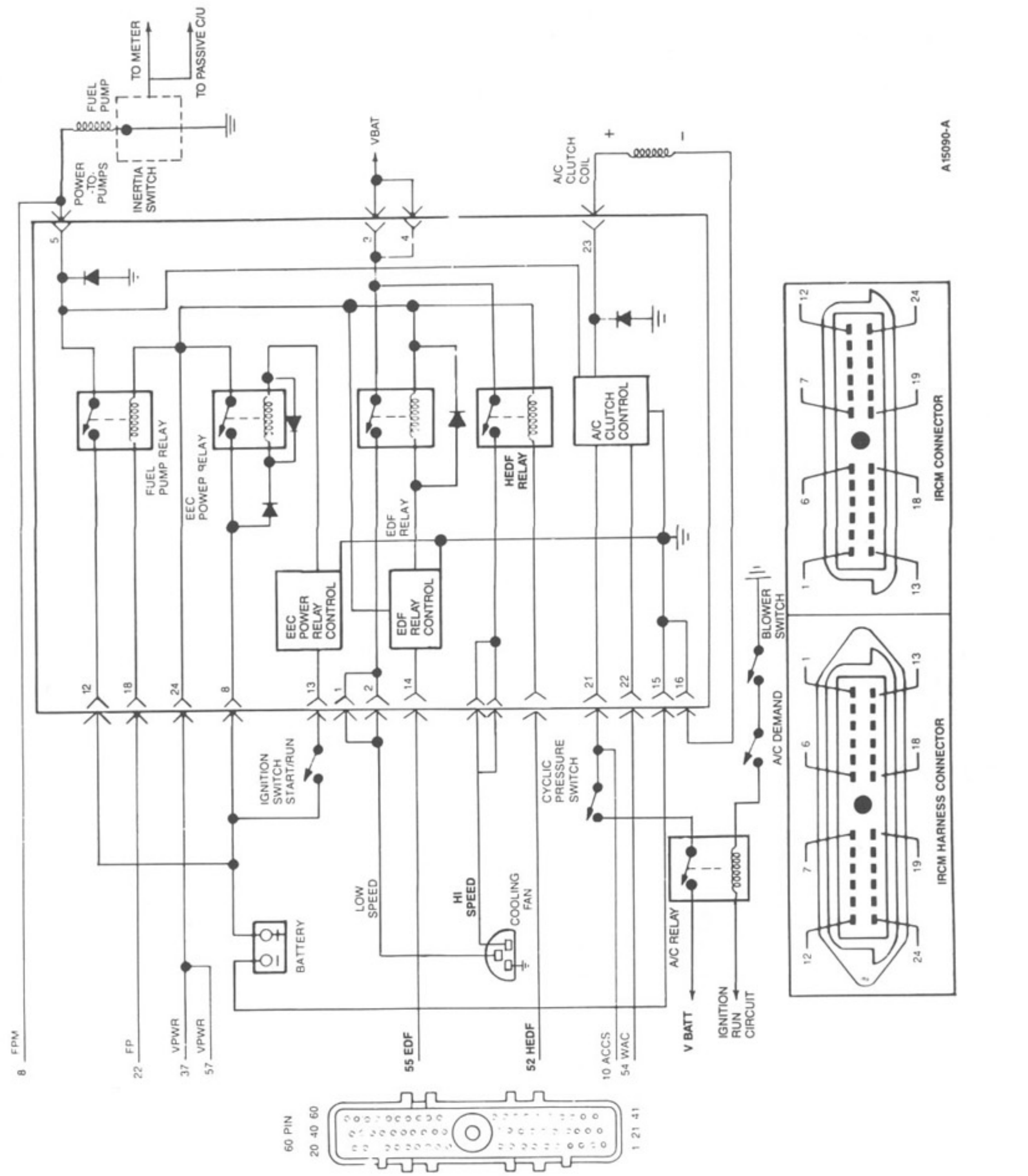


*See MECS for 4-cyl. Probe

1991 Probe V-6 Integrated Relay Control Module

3.0L MAP (VIN Code U)*

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



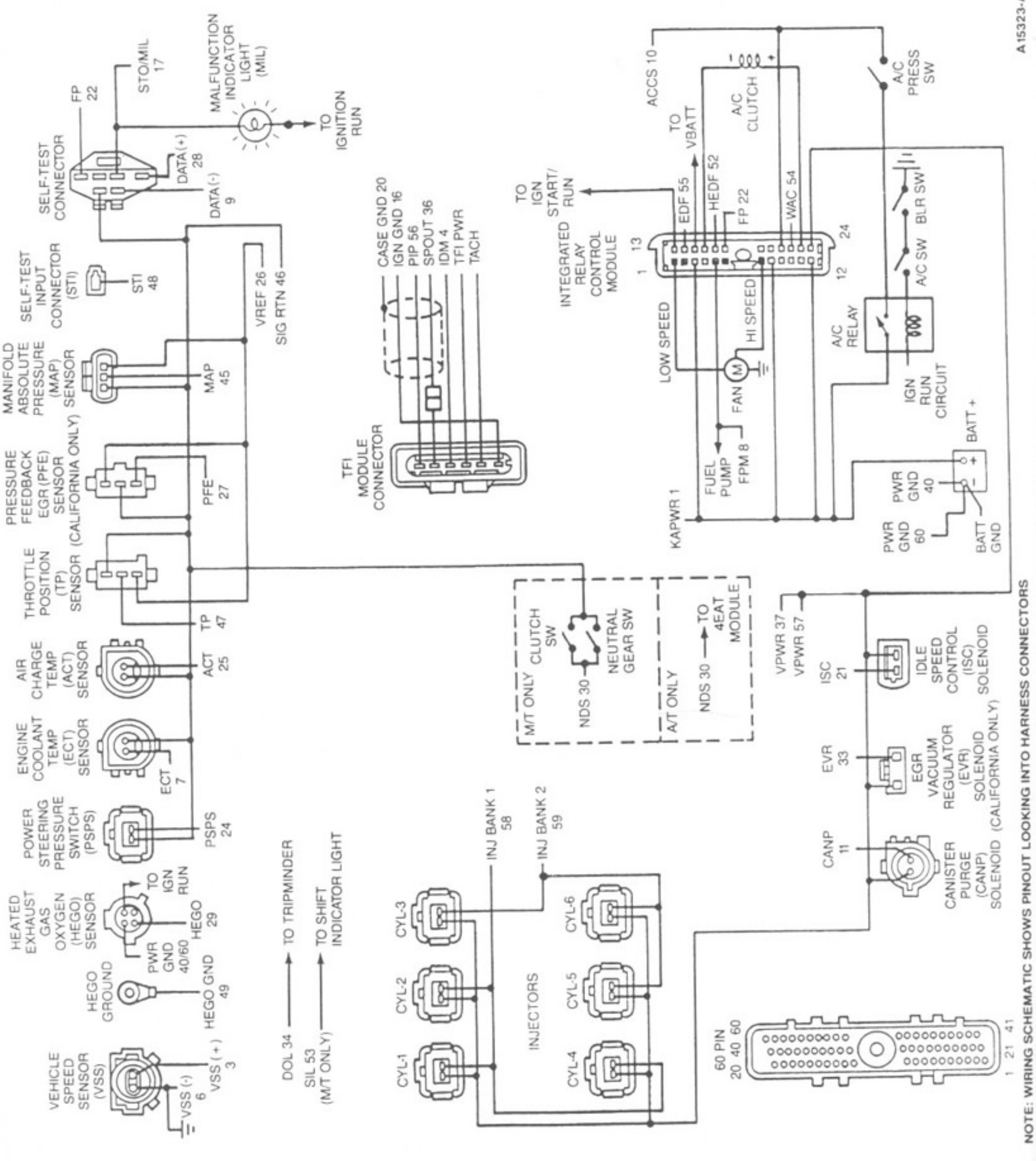
*See MECS for 4-cyl. Probe

3.0L
MAP
(VIN Code U)*

VIN: 1 2 3 4 5 6 7 8 ... 17

Engine code

1992
Probe V-6

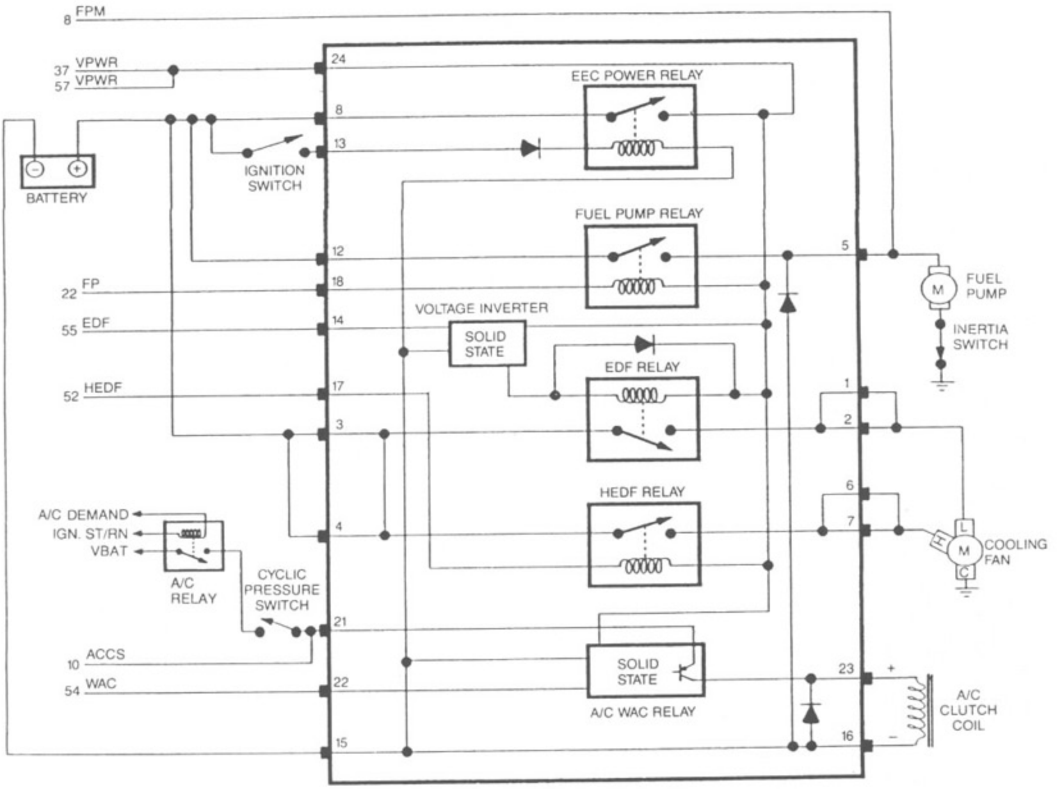


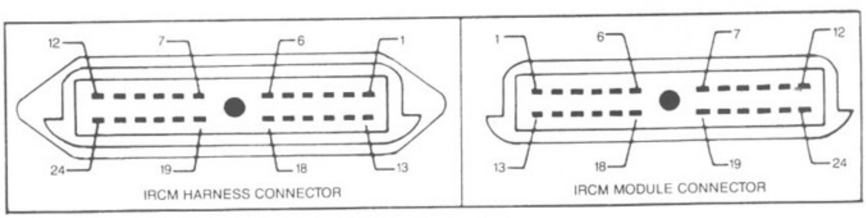
*See MECS for 4-cyl. Probe

1992 Probe V-6 Integrated Relay Control Module

3.0L MAP
(VIN Code U)*

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code





A15324-A

12

NOTE: WIRING SCHEMATIC SHOWS PINOUT LOOKING INTO HARNESS CONNECTORS

A15323-A

2.3L MAF-SFI HSC

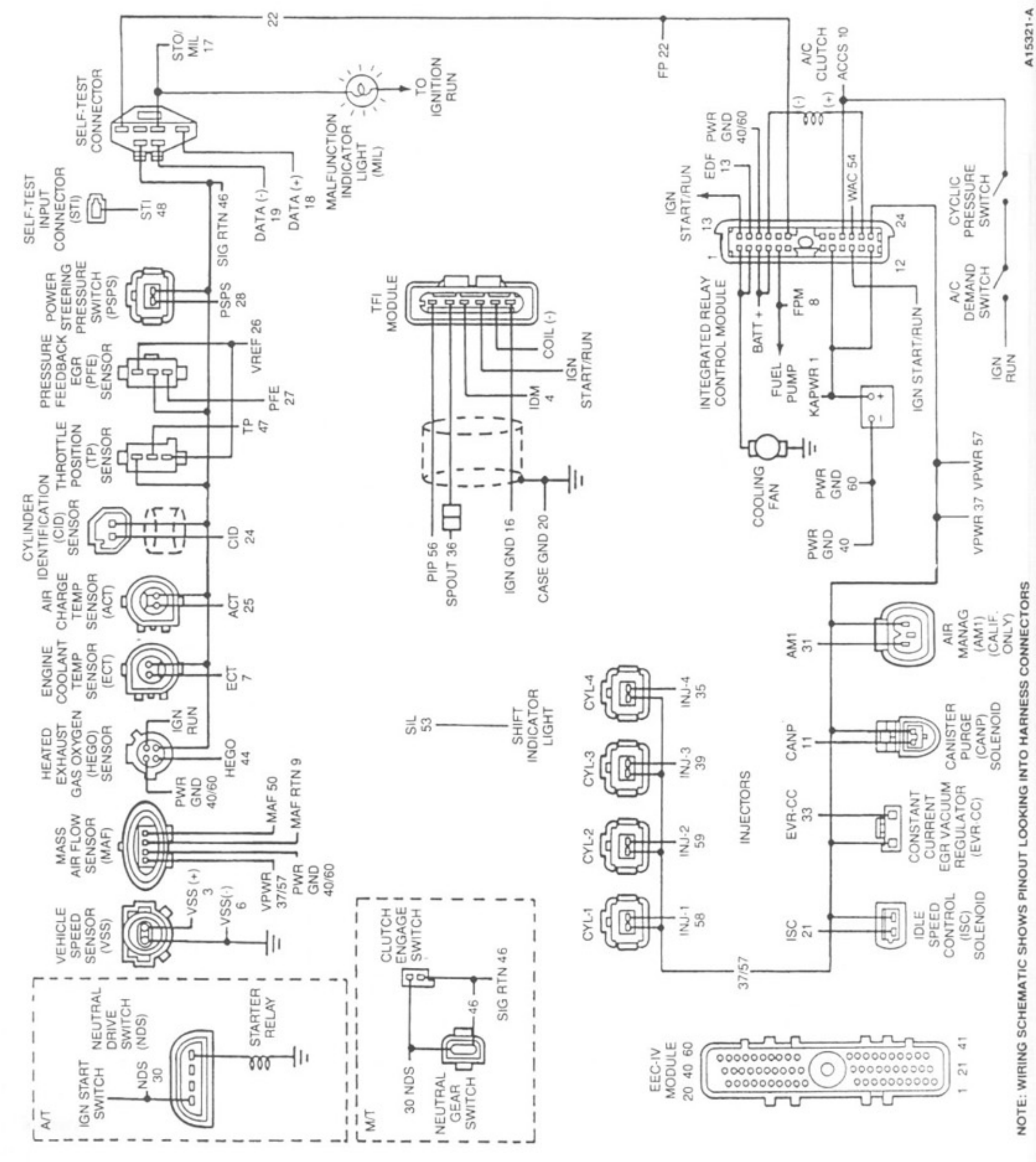
(VIN Code A)

1992

Tempo, Topaz

VIN: 1 2 3 4 5 6 7 8 ... 17

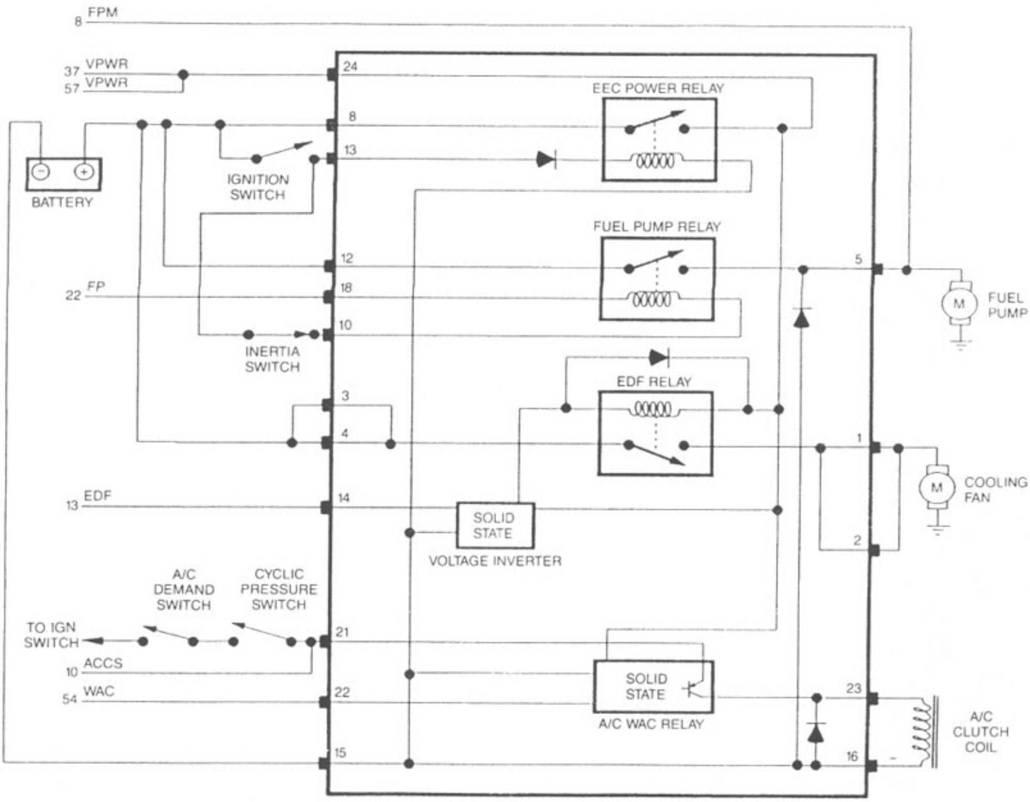
Engine code

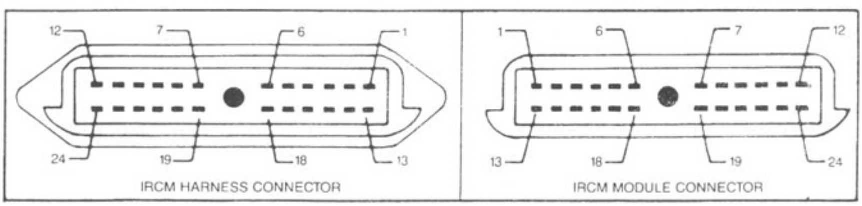


1992 Tempo, Topaz Integrated Relay Control Module

2.3L MAF-SFI HSC
(VIN Code A)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code





A15322-A

12

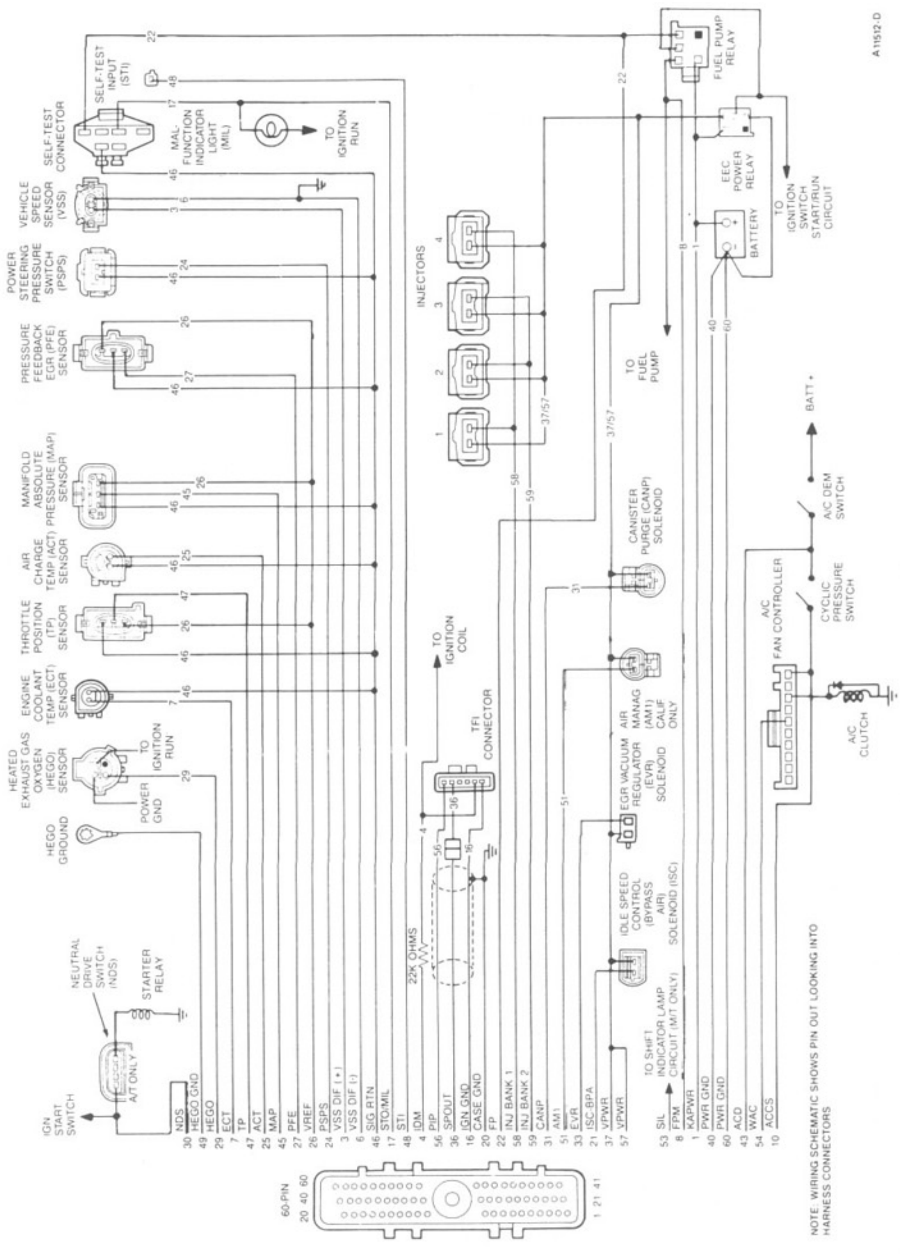
2.3L MAP HSC

(VIN Code A)

1988–1991 Tempo, Topaz

VIN: 1 2 3 4 5 6 7 8 ... 17

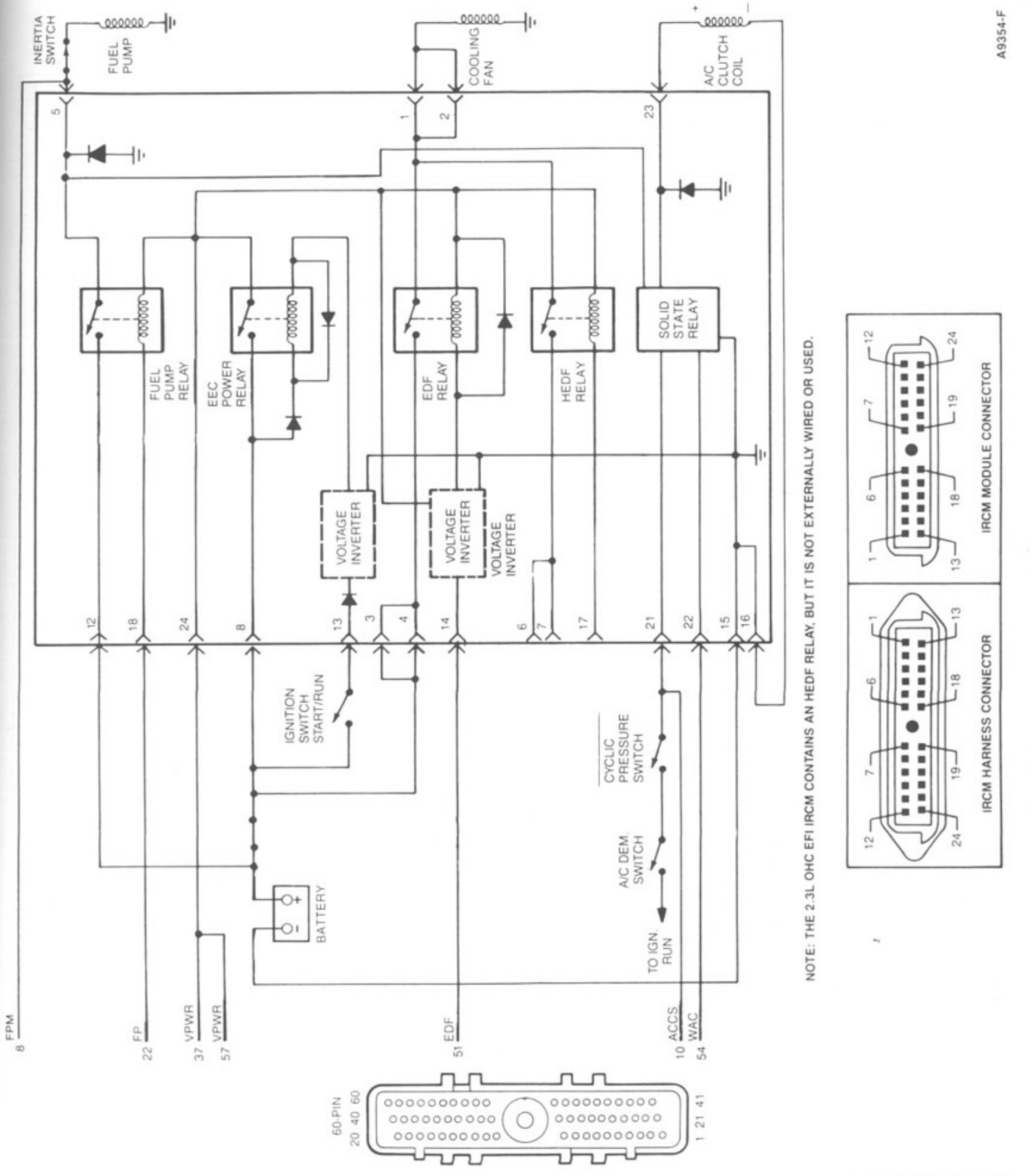
Engine code



1988–1991
Tempo, Topaz
Integrated Relay Control Module

2.3L
MAP HSC
(VIN Code A)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

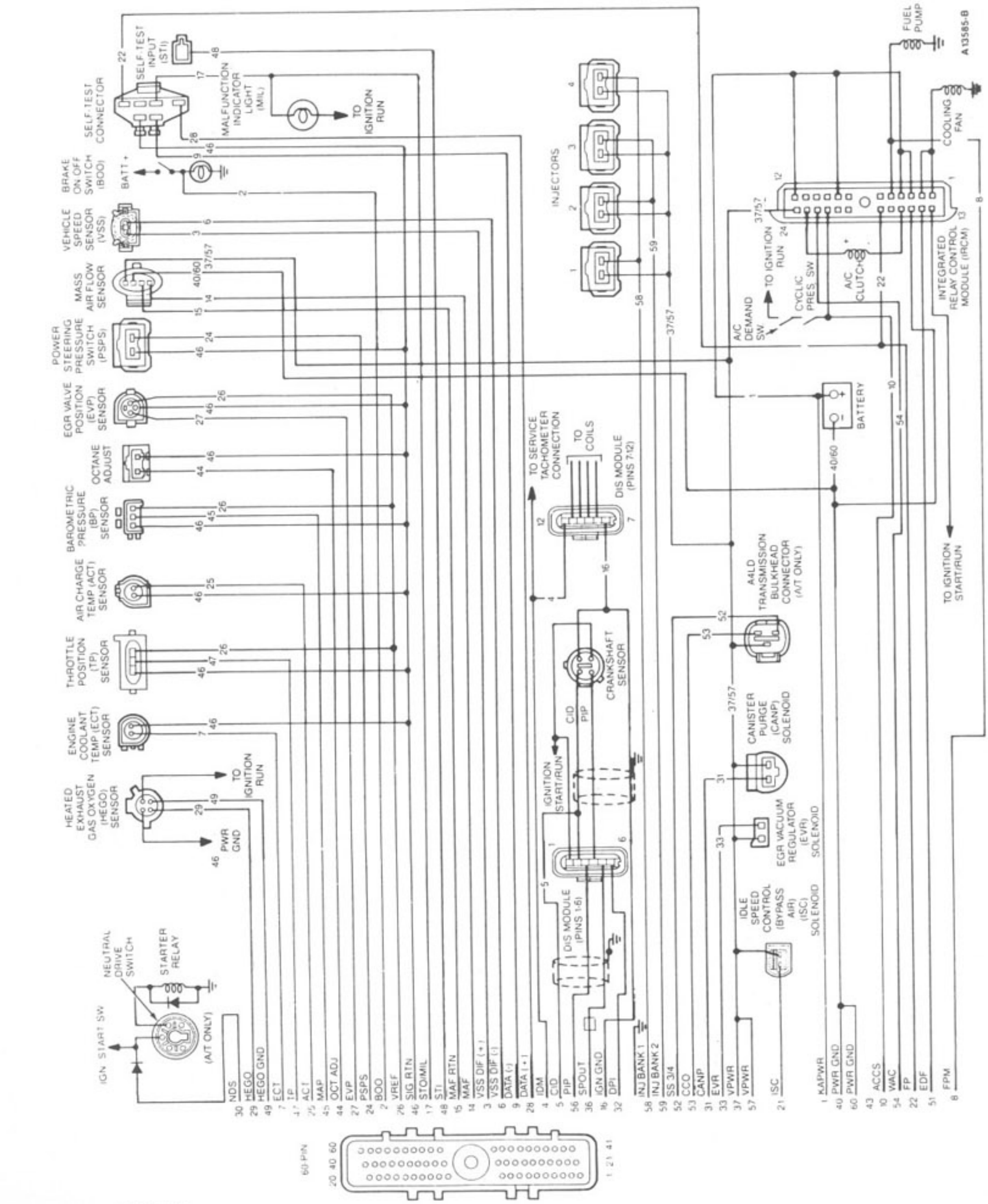


12

2.3L
MAF-SFI OHC
(VIN Code S)

1990–1991
Mustang

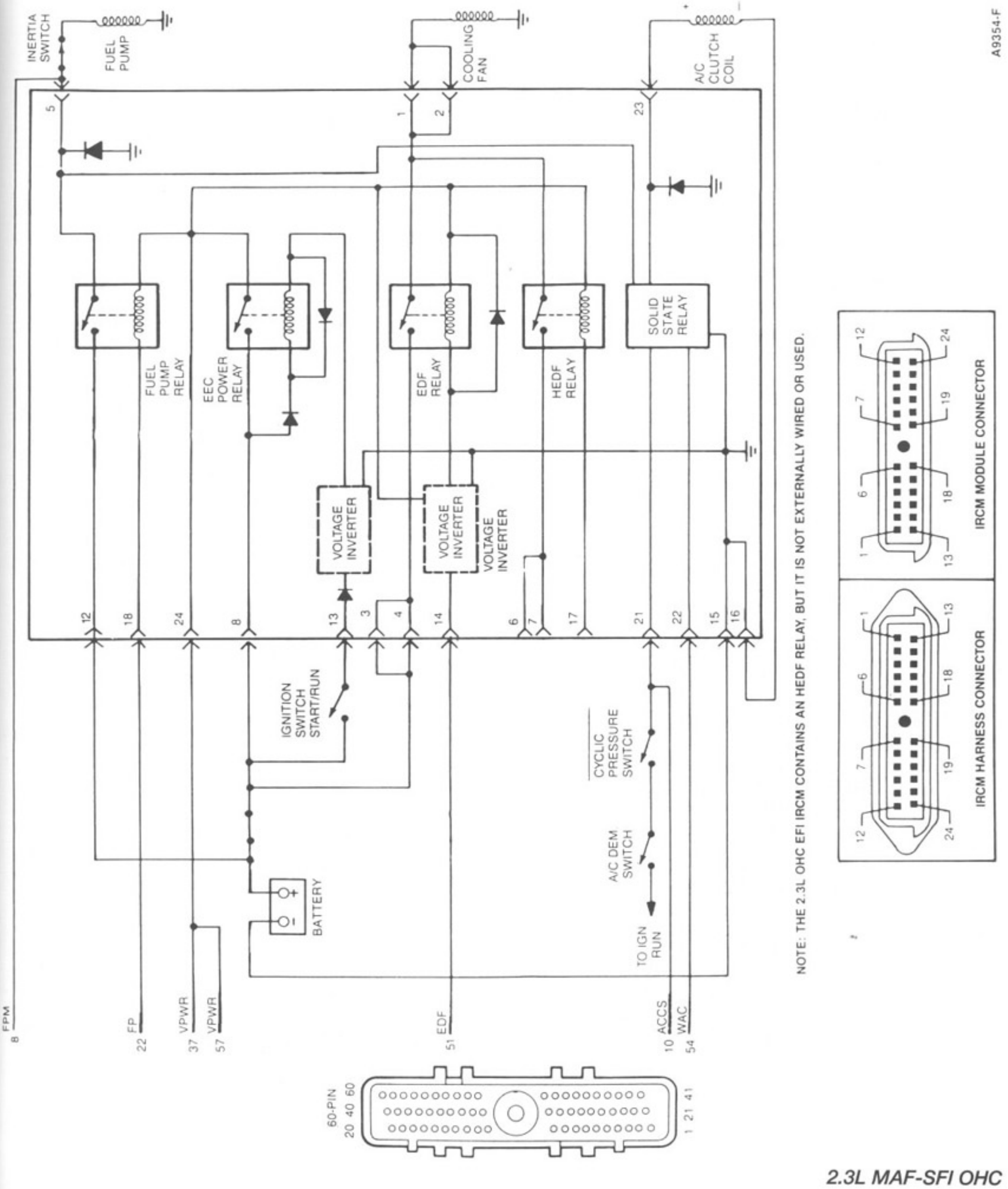
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



1990–1991 Mustang Integrated Relay Control Module

2.3L MAF-SFI OHC
(VIN Code S)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

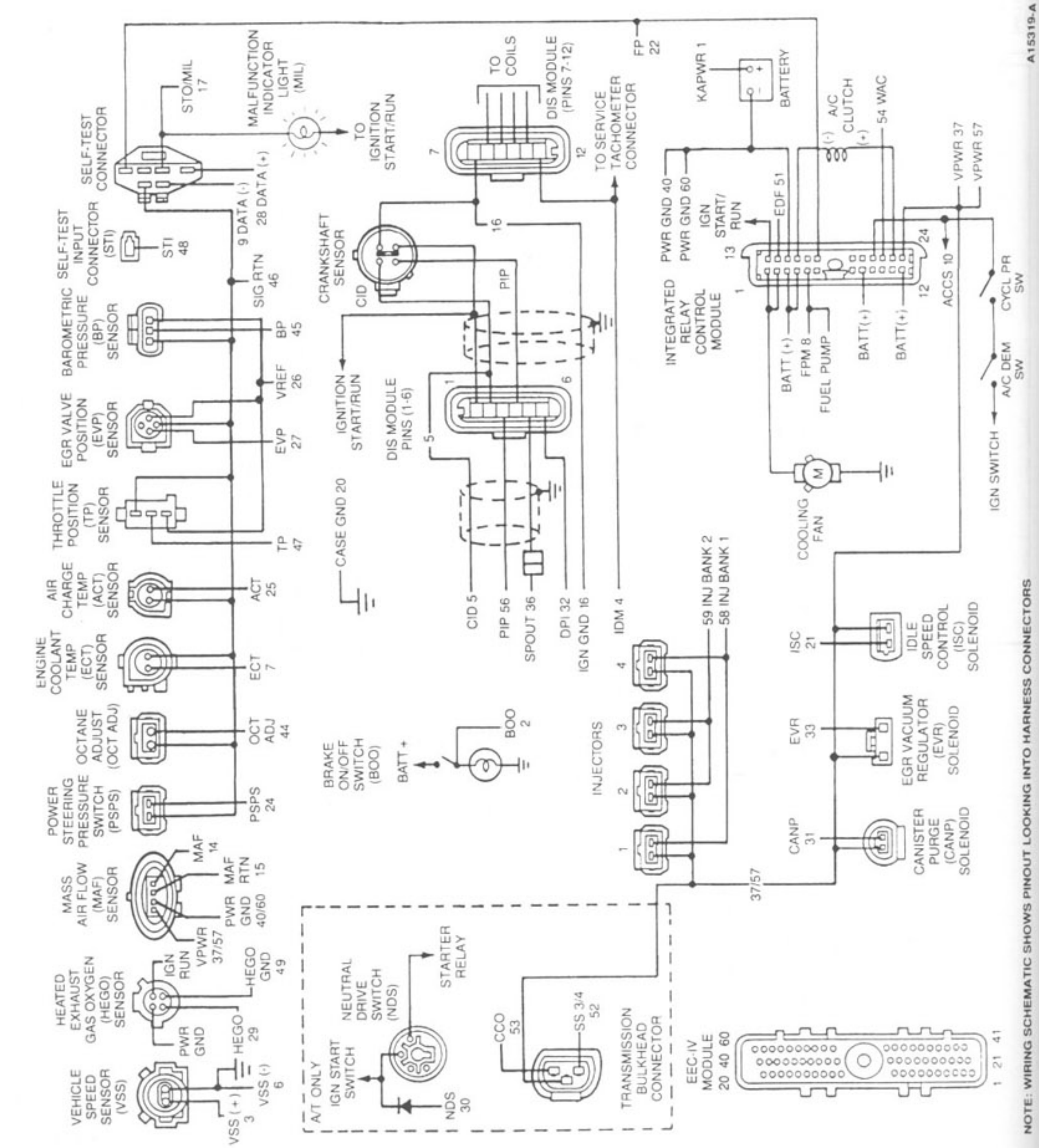


12

2.3L MAF-SFI OHC
(VIN Code S)

1992–1993 Mustang

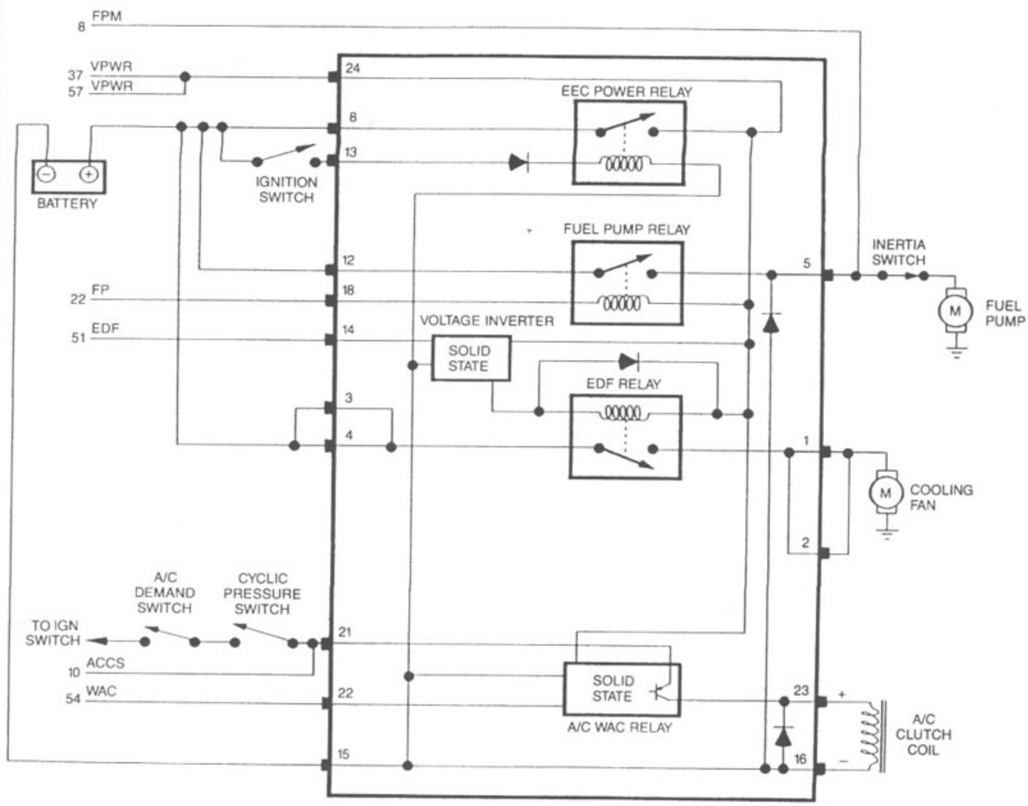
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

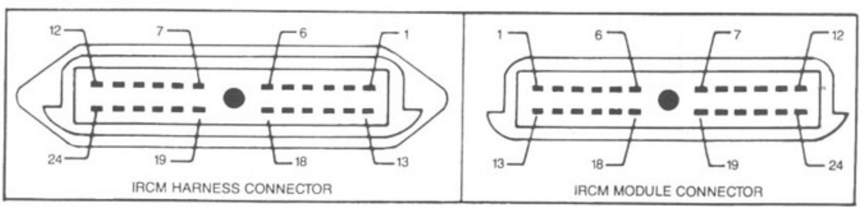


1992–1993 Mustang Integrated Relay Control Module

2.3L MAF-SFI OHC
(VIN Code S)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code





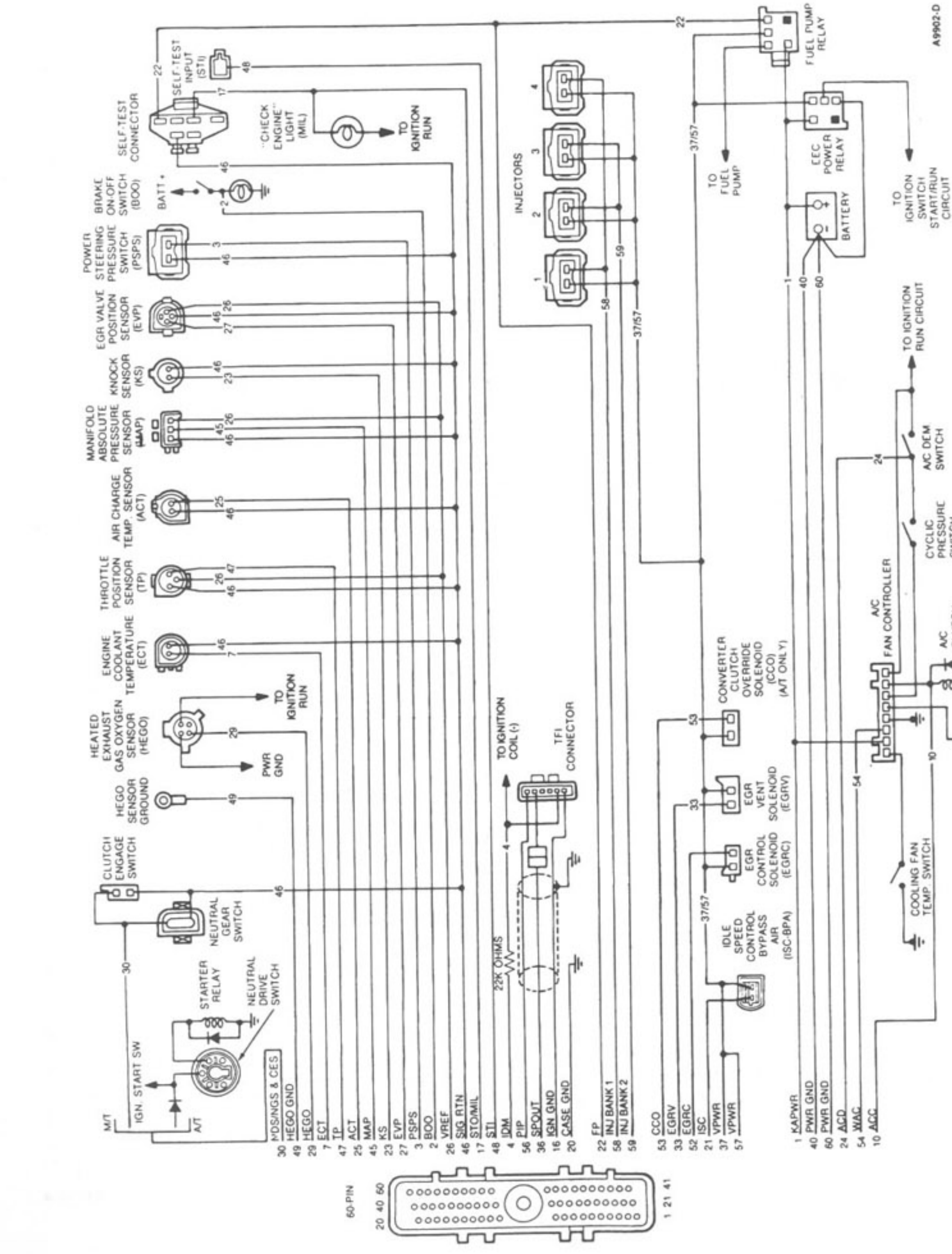
A15320-A

2.3L MAP OHC
(VIN Code S)

1988–1990 Mustang

VIN: 1 2 3 4 5 6 7 8 ... 17

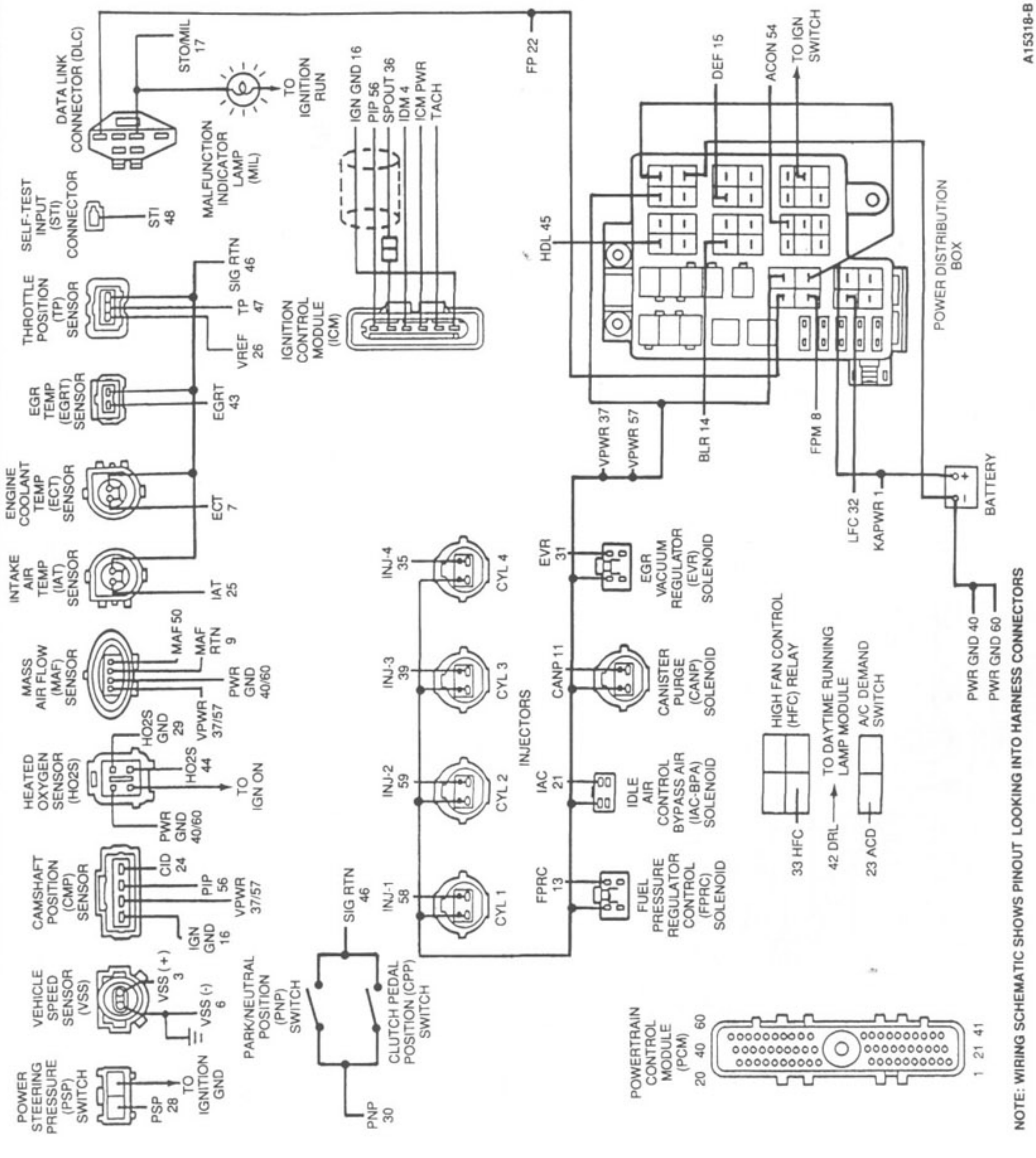
Engine code



1993 Probe Manual Transaxle

2.0L MAF-SFI
(VIN Code A, MTX)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

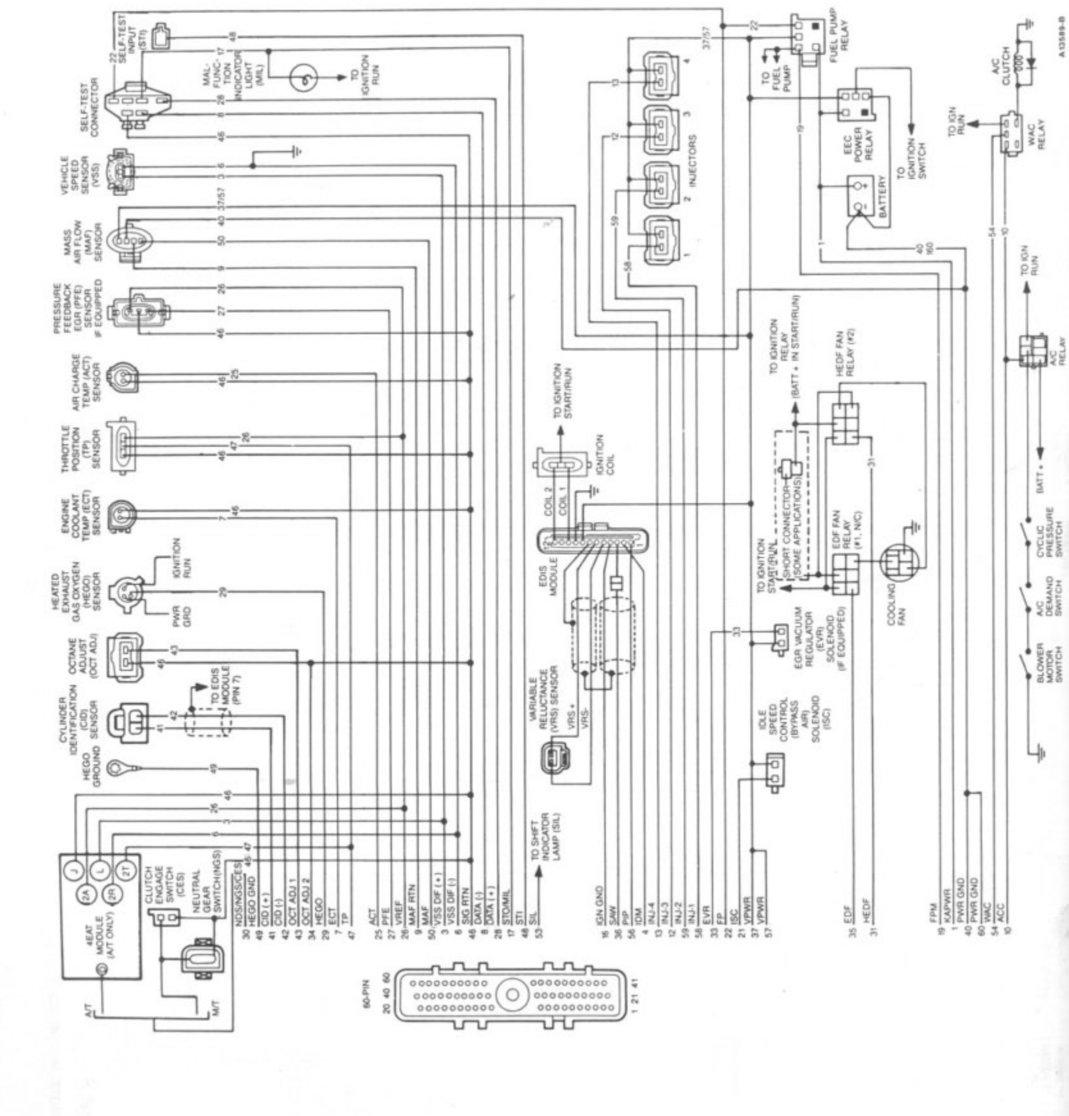


12

1.9L MAF-SFI
(VIN Code J)

1990–1991
Escort, Tracer

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



2.0L MAF-SFI

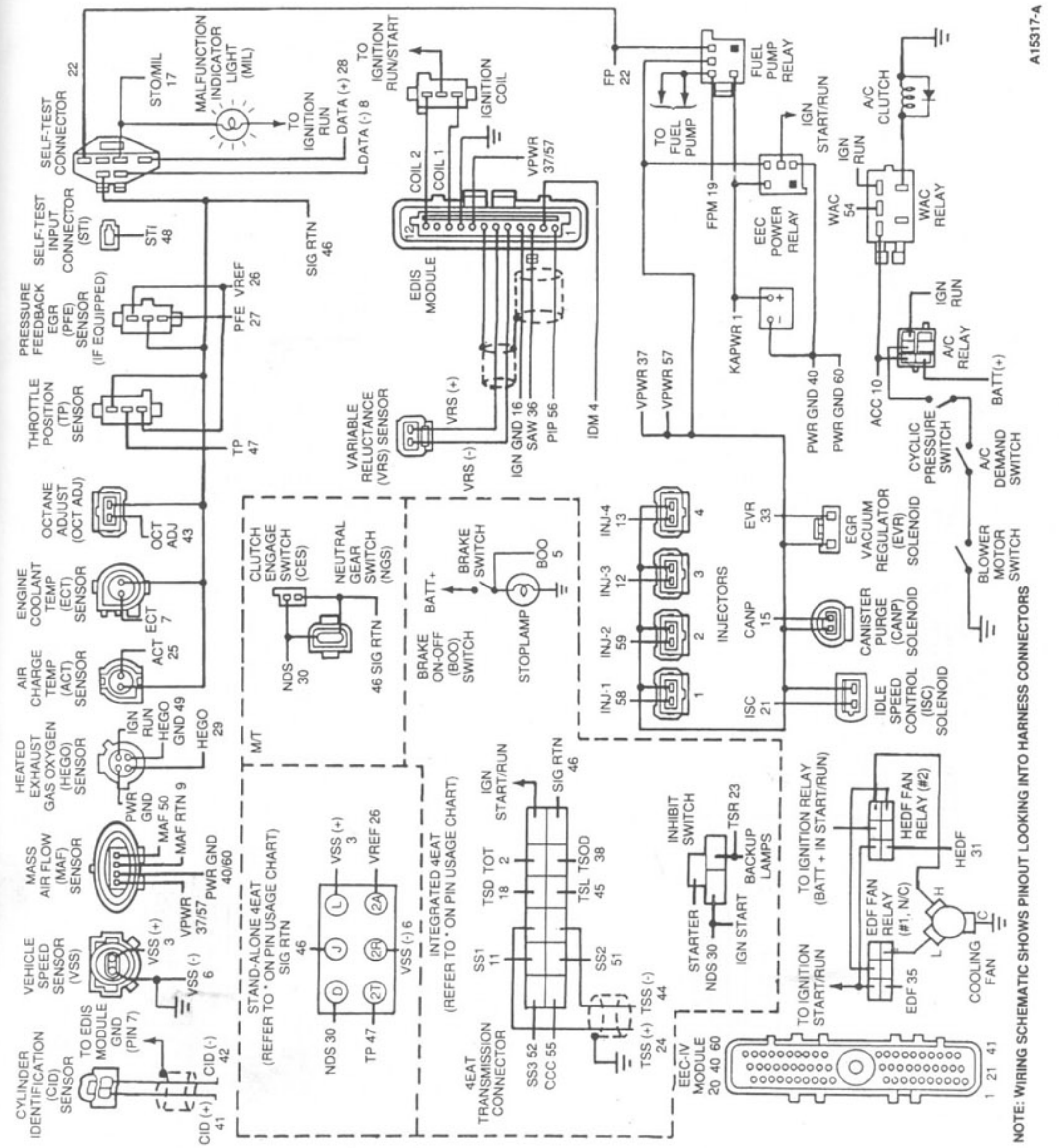
J2W1

1992–1993 Escort, Tracer

1.9L MAF-SFI

(VIN Code J)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

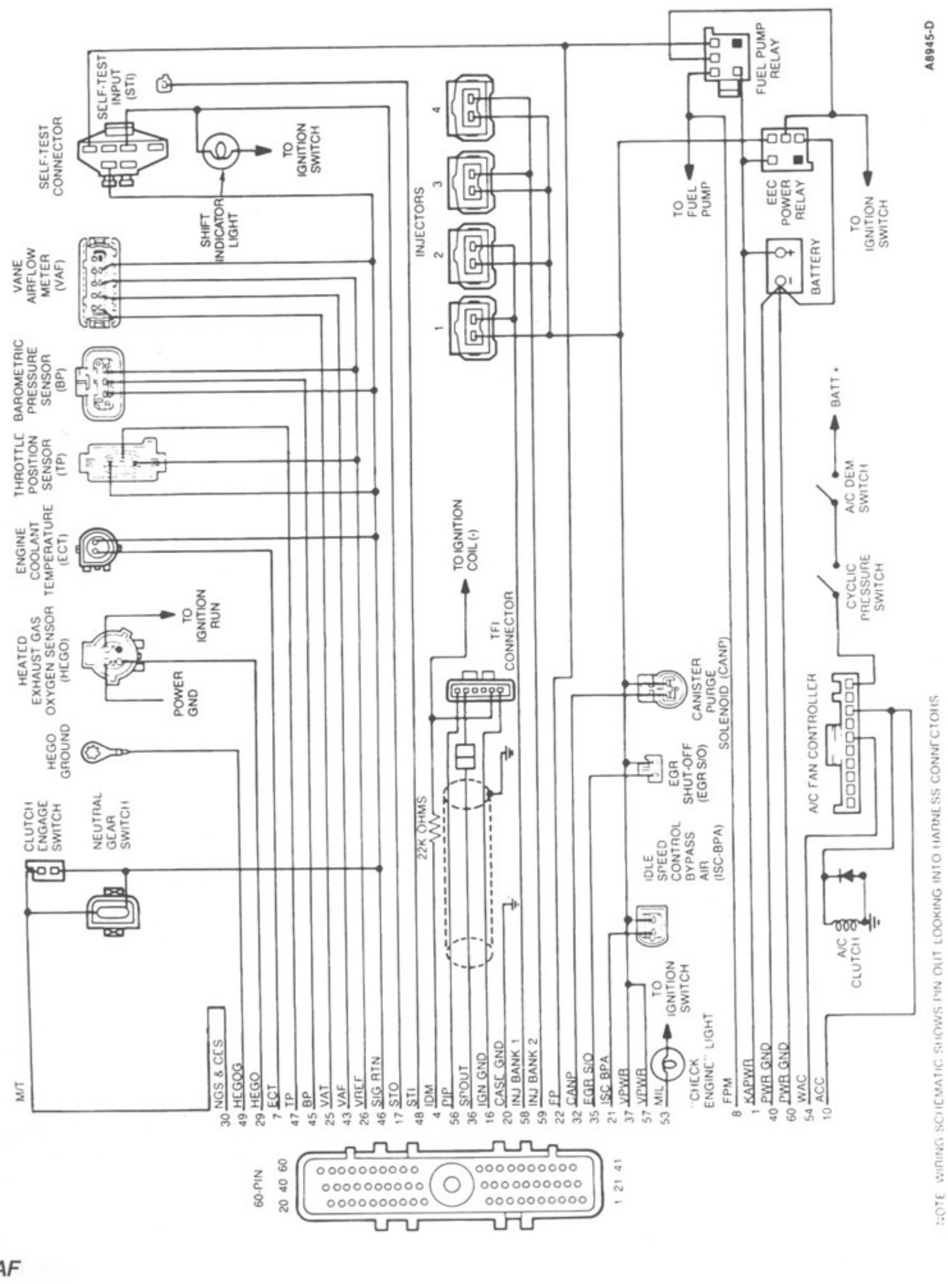


12

1.9L VAF (VIN Code X)

1988–1989 Escort

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

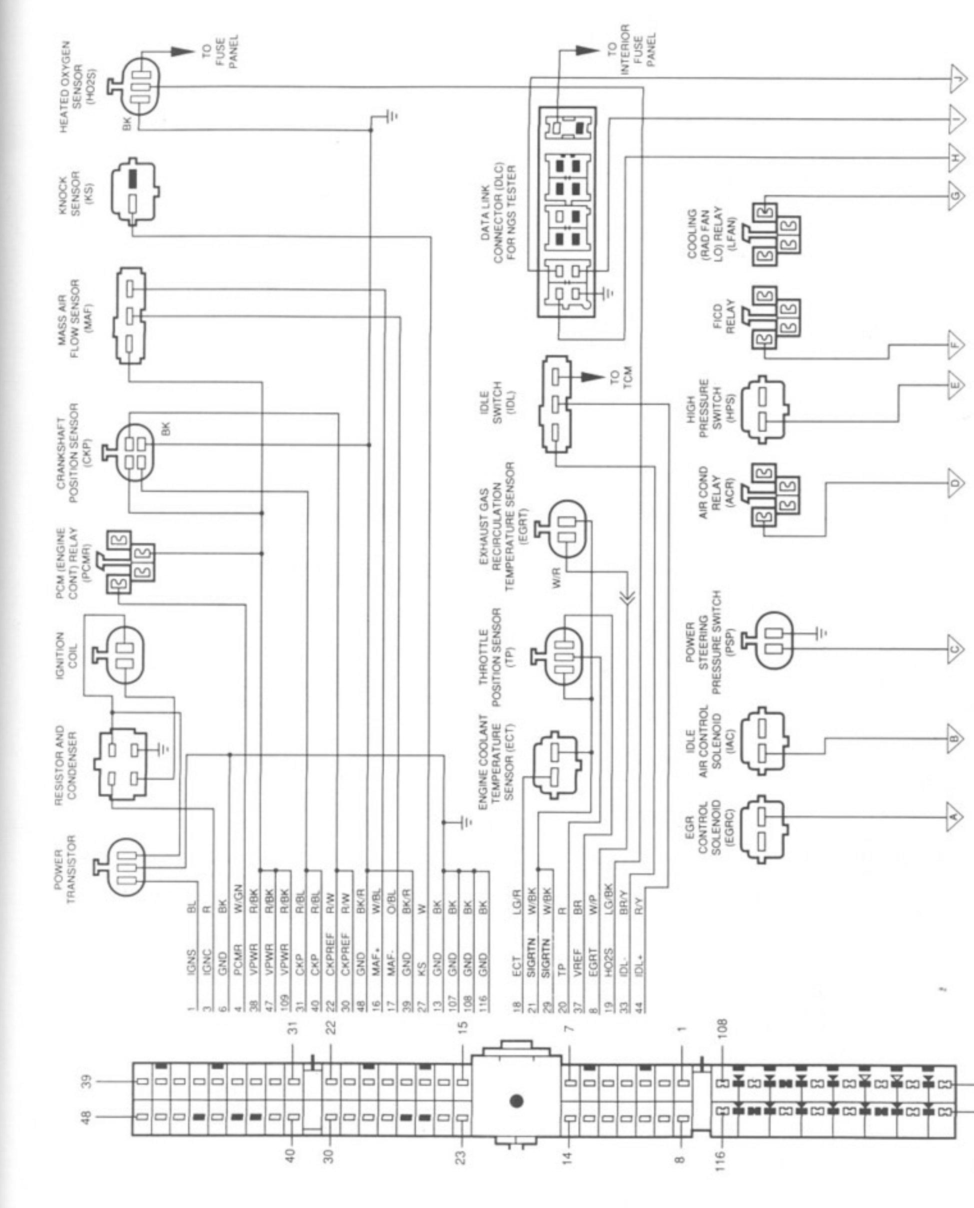


1993 Mercury Villager (Nissan Electronic Concentrated Control System)

NECCS 3.0L MAF-SFI

VIN: 1 2 3 4 5 6 7 8 ... 17

Engine code

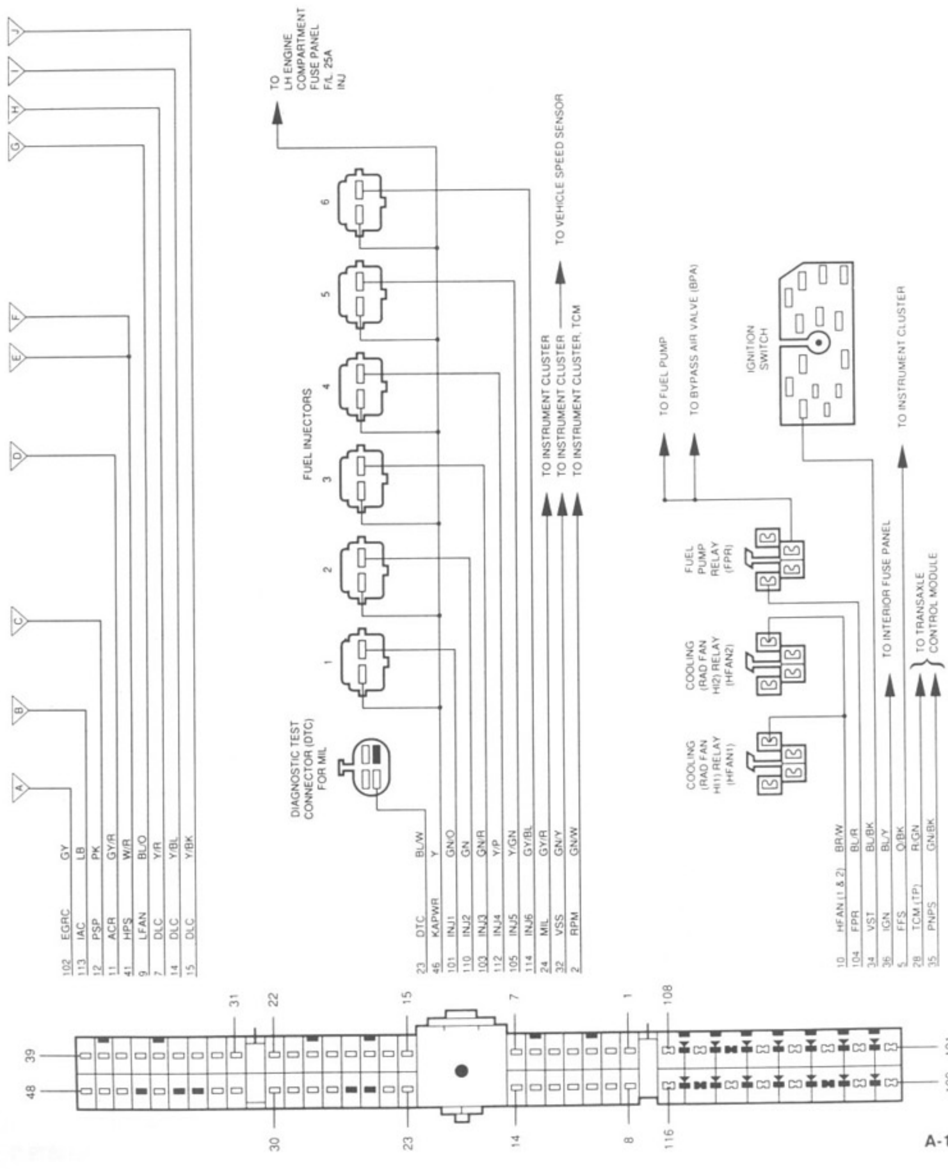


A-16879-D

NECS 3.0L MAF-SFI

1993 Mercury Villager (Nissan Electronic Concentrated Control System)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

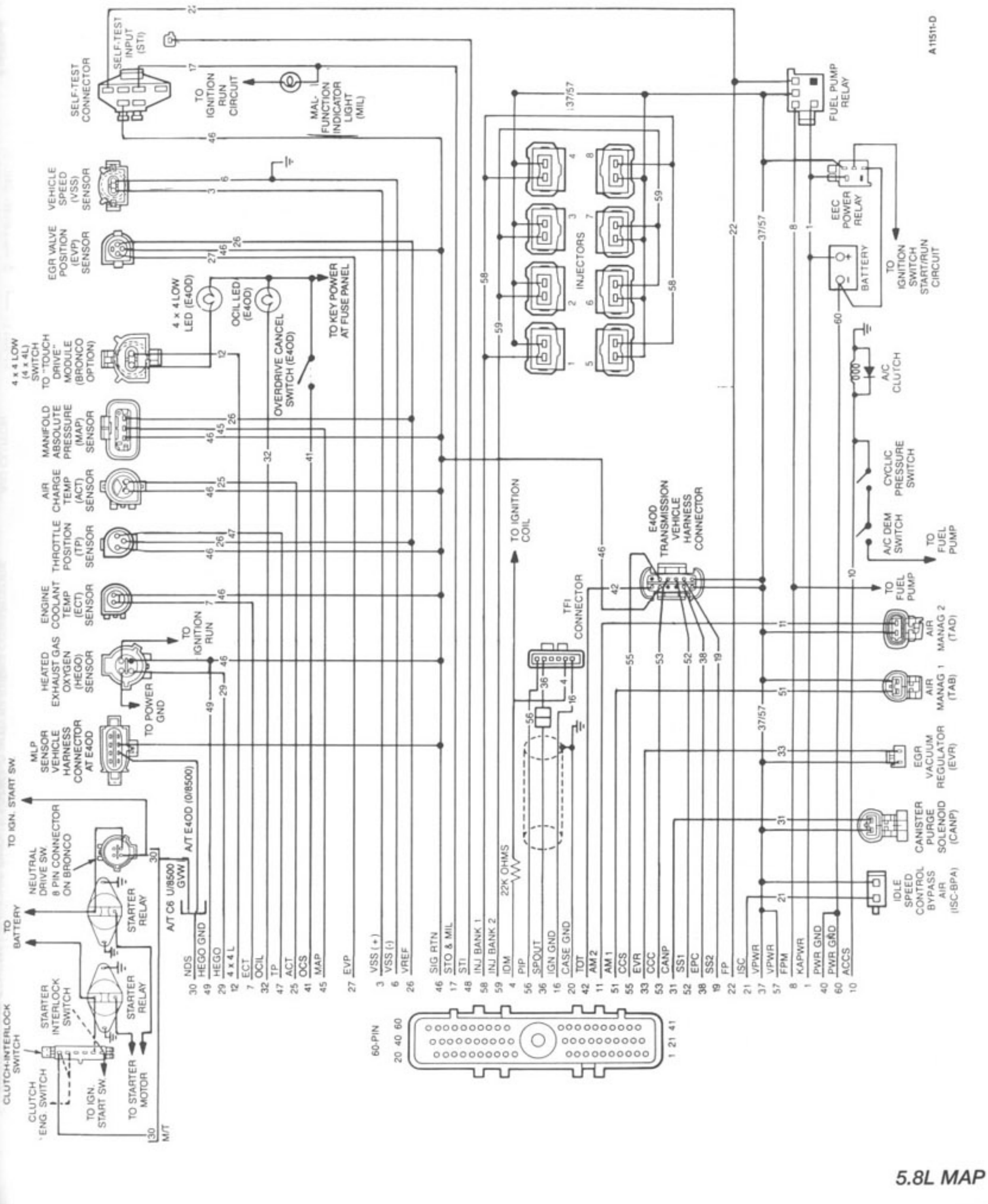


A-16970-D

1988–1991 E/F Series, Bronco

5.8L MAP
(VIN Code H)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



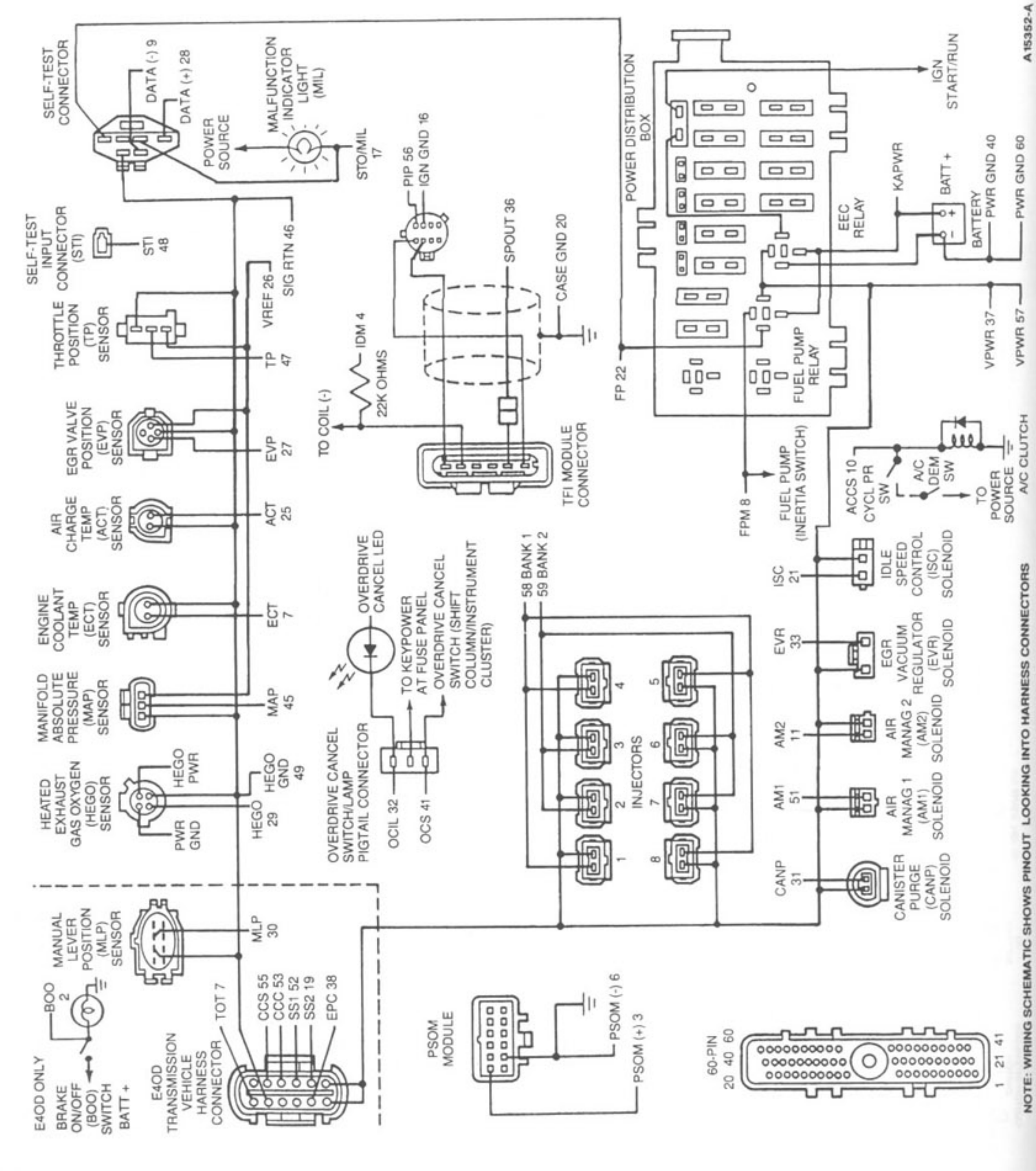
12

5.8L MAP (VIN Code H)

1992–1993 E Series, Bronco

VIN: 1 2 3 4 5 6 7 8 ... 17

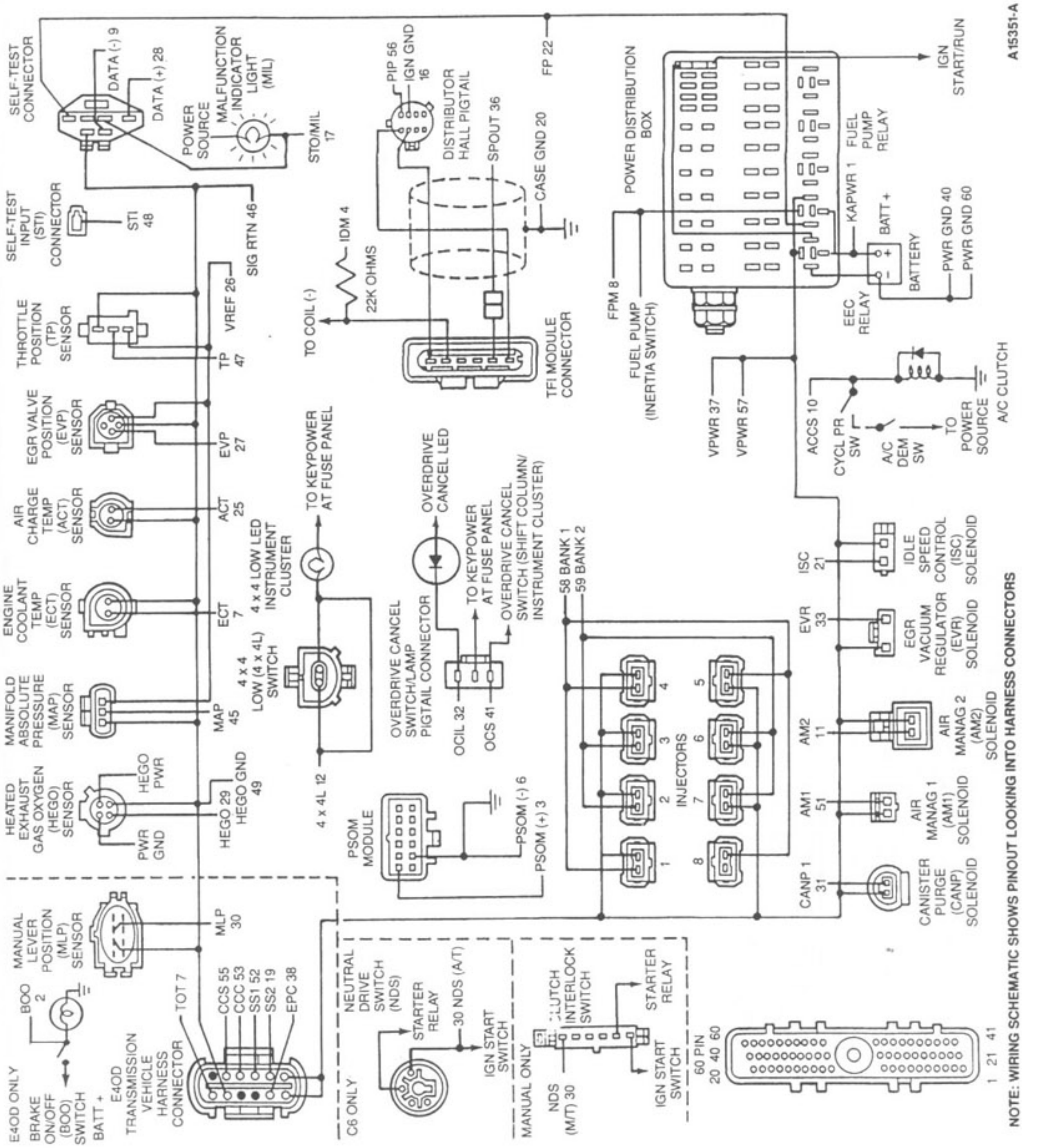
Engine code



1992–1993
F Series, Bronco

5.8L MAP
(VIN Code H)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

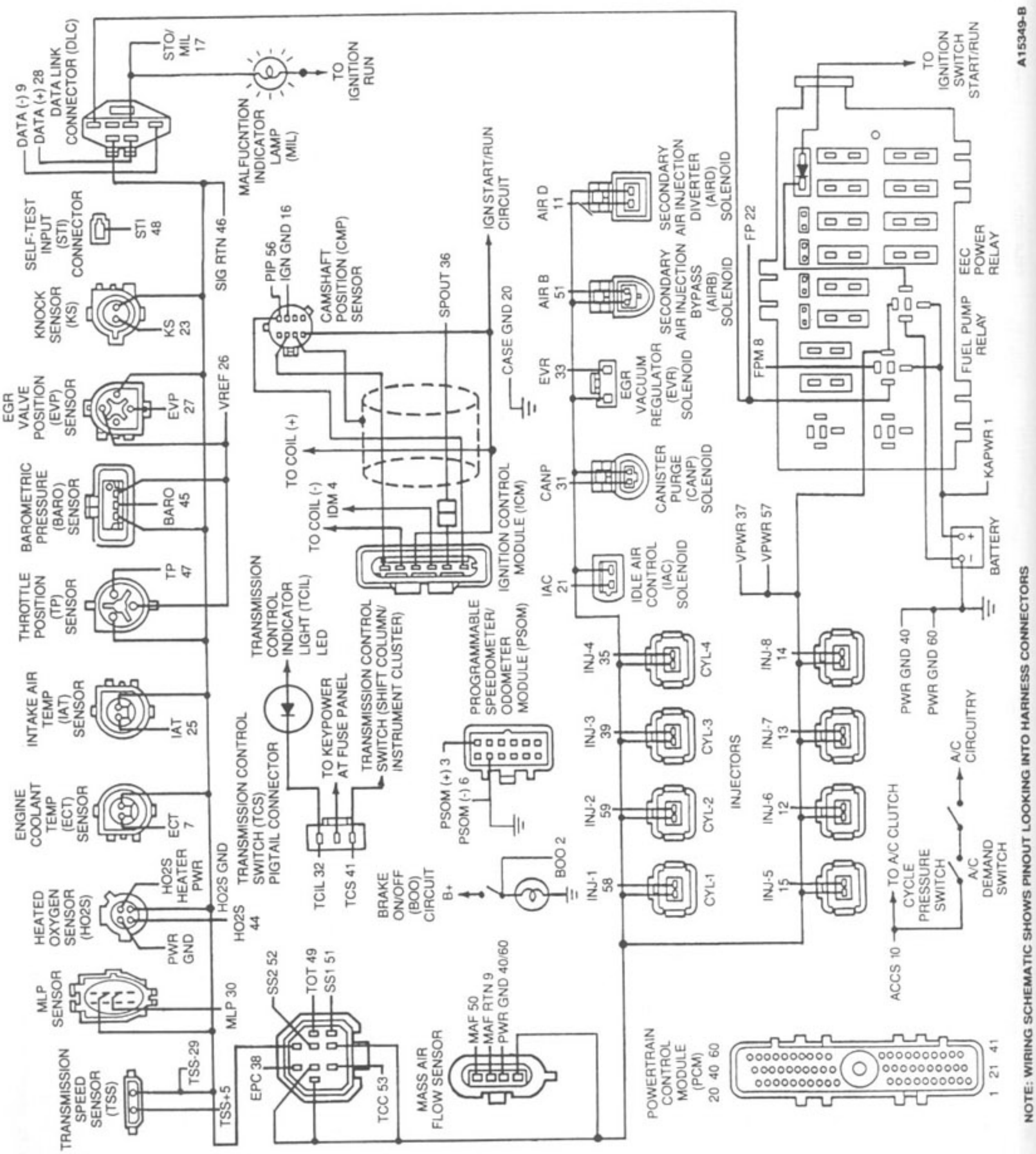


12

5.0L MAF-SFI
(VIN Code N, AXODE)

1993
E Series

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



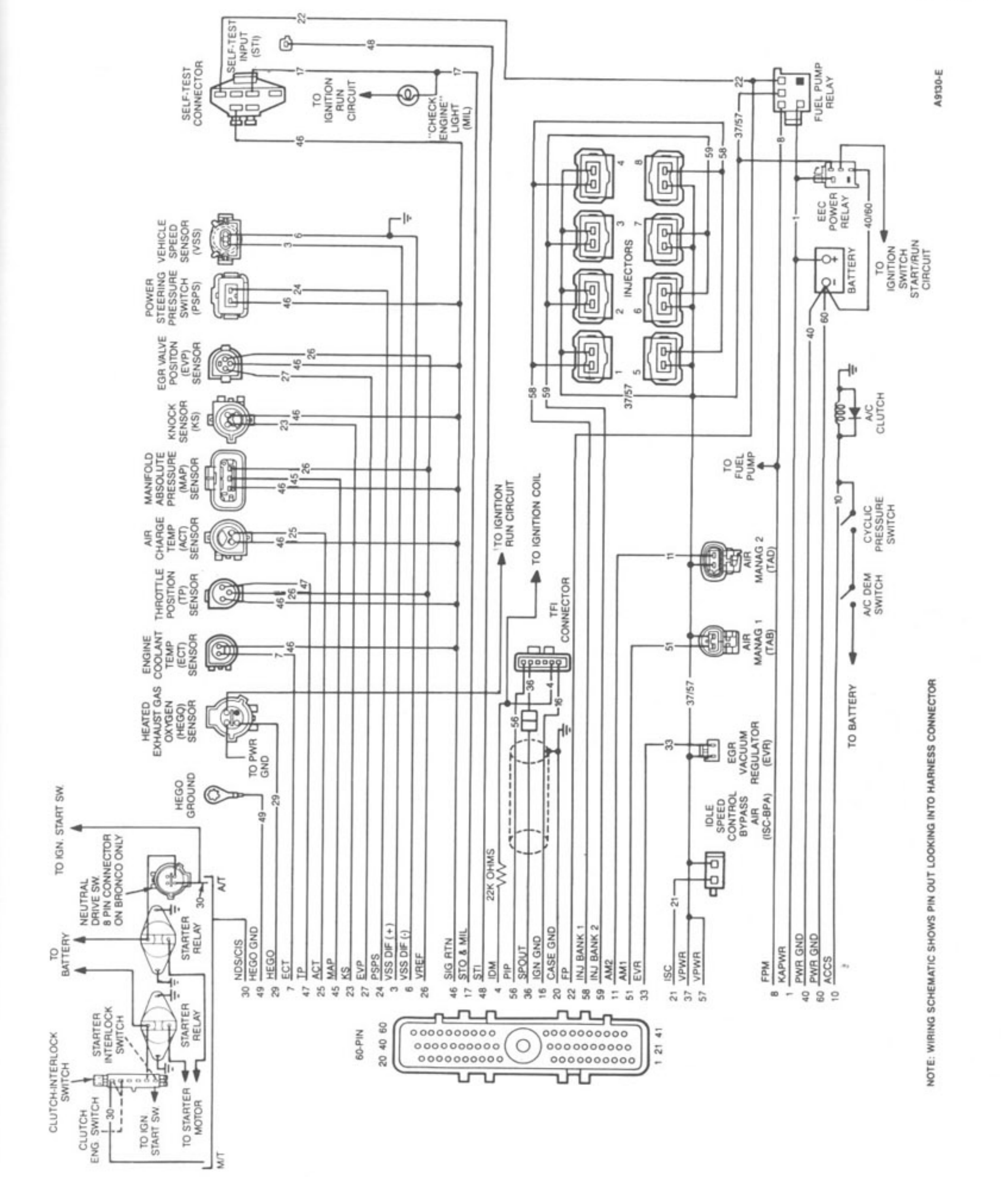
1988–1990
E/F Series, Bronco

5.0L MAP
(VIN Code N)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

A15349-B

NOTE: WIRING SCHEMATIC SHOWS PINOUT LOOKING INTO HARNESS CONNECTORS



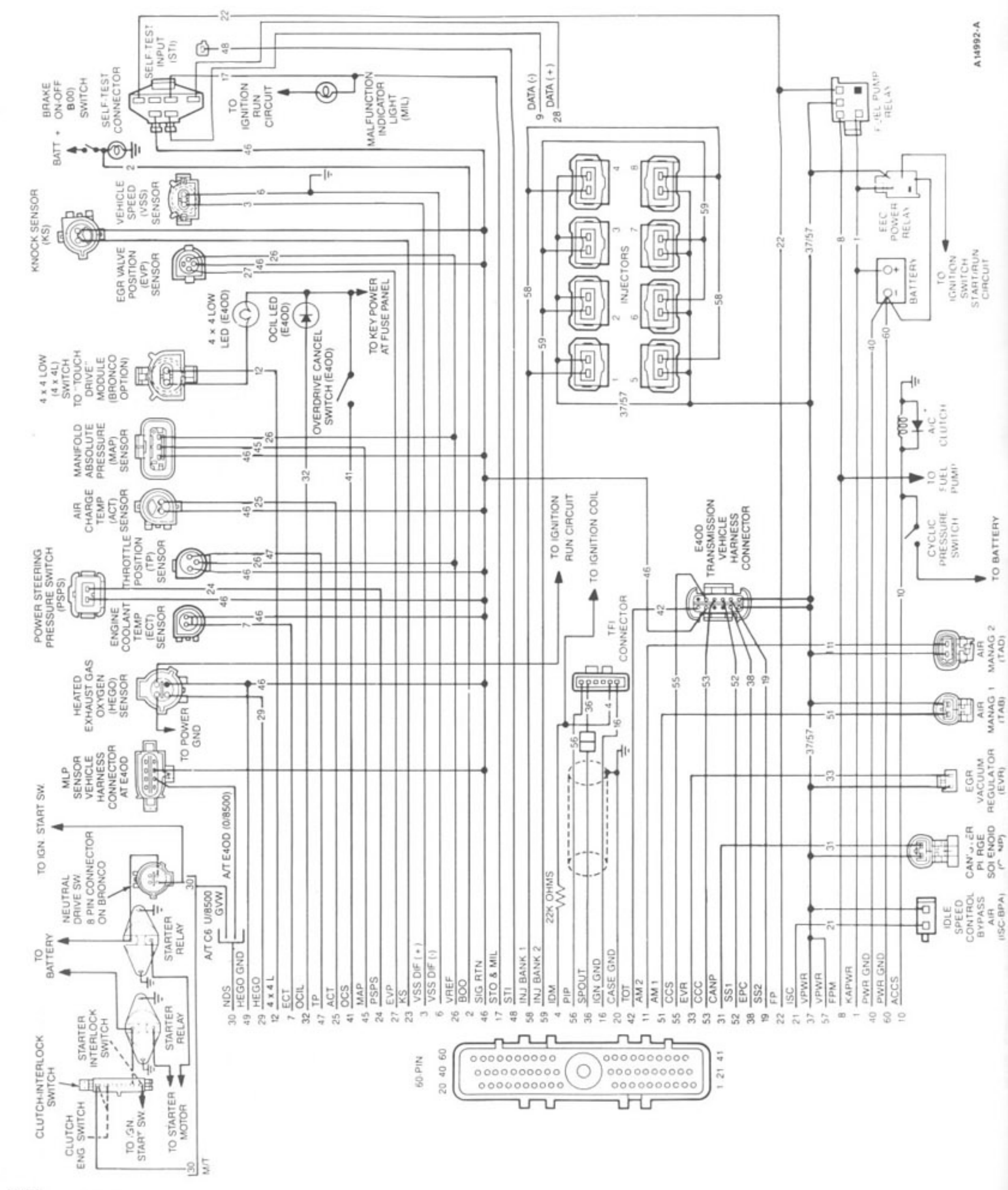
12

5.0L MAP
(VIN Code N)

1991
E/F Series, Bronco

VIN: 1 2 3 4 5 6 7 8 ... 17

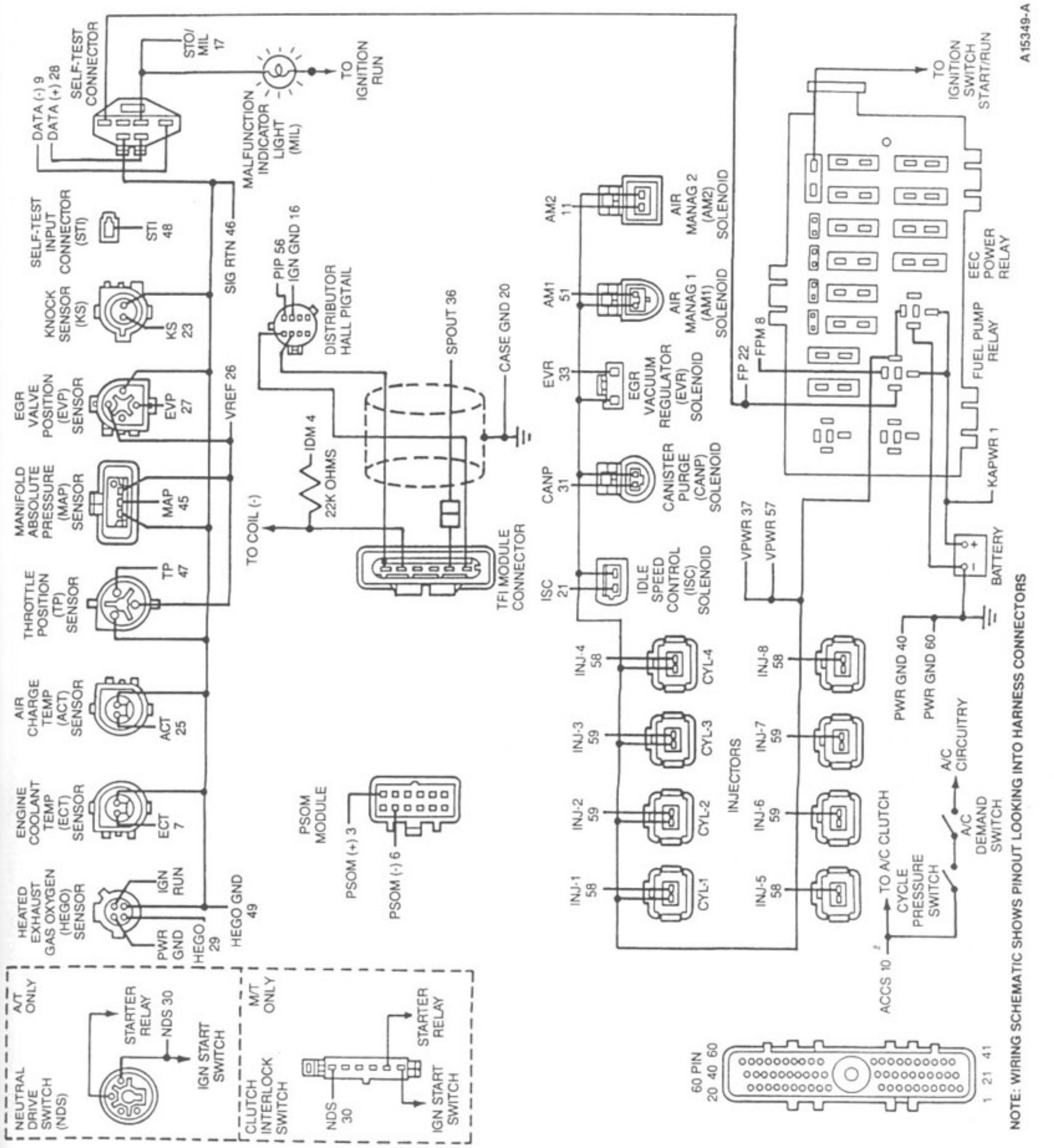
Engine code



1992 E Series

5.0L MAP
(VIN Code N)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

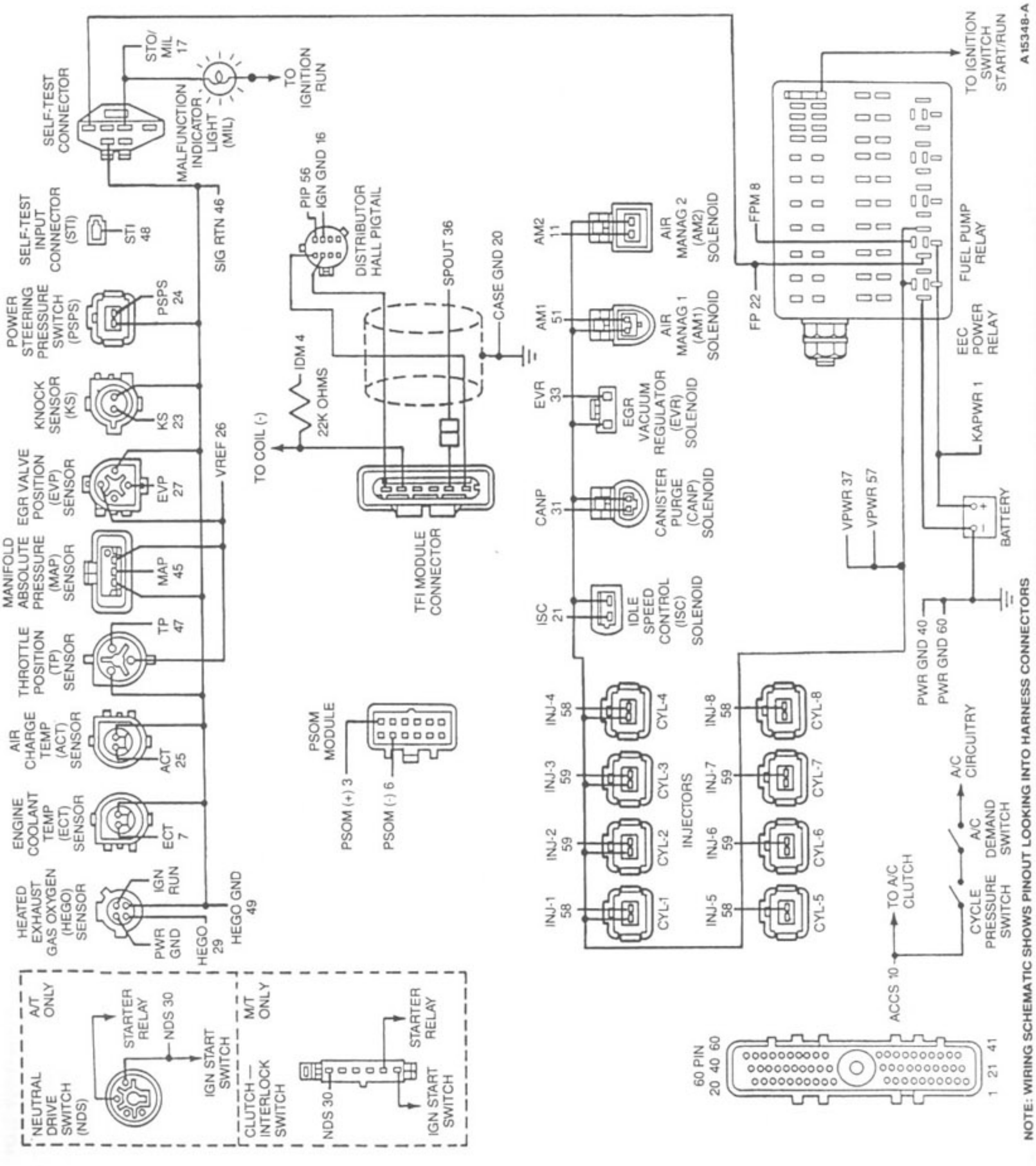


12

5.0L MAP
(VIN Code N)

1992–1993
F Series, Bronco

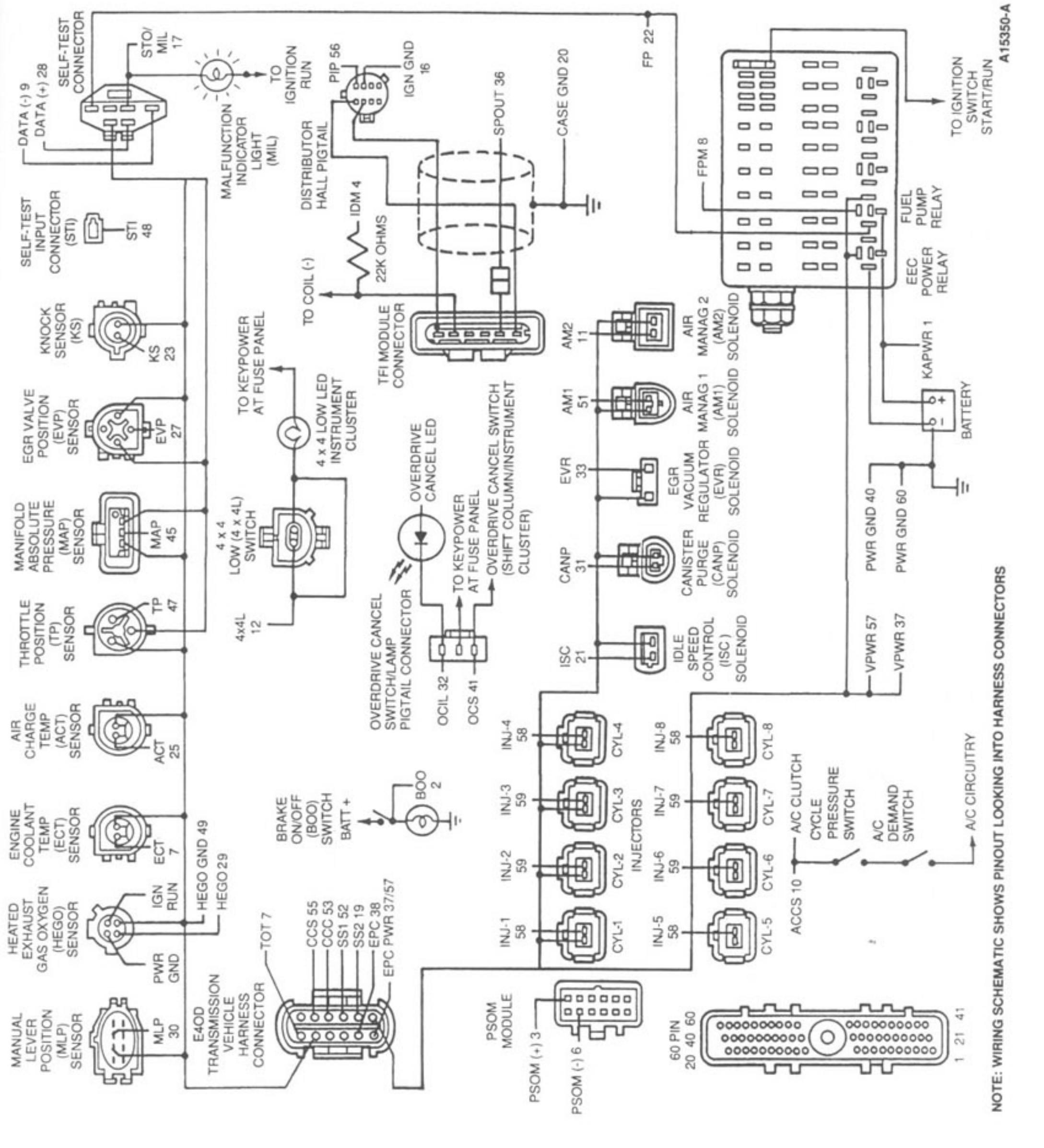
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



1992 F Series, Bronco (E4OD)

5.0L MAP
(VIN Code N)

VIN: 1 2 3 4 5 6 7 8 … 17
Engine code



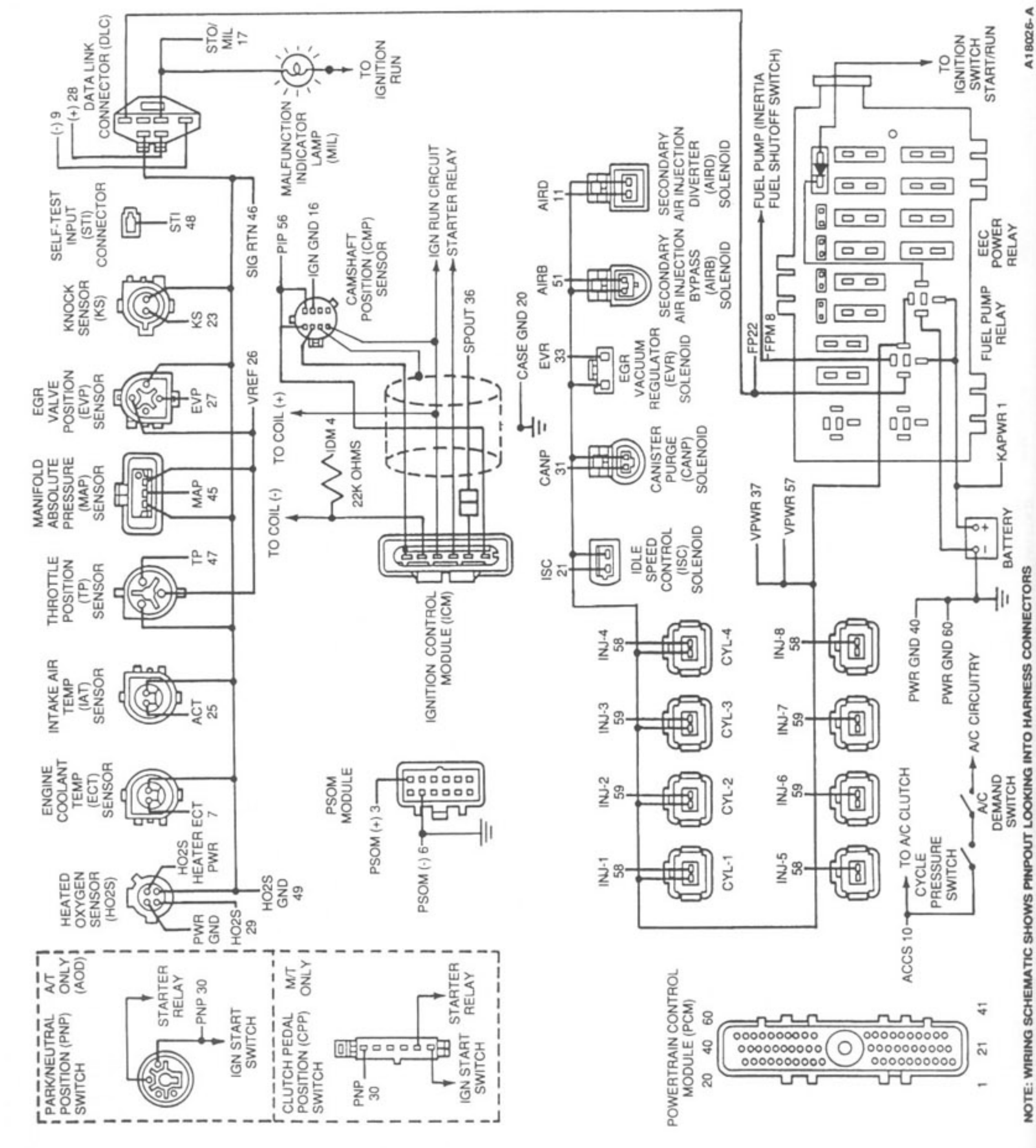
12

5.0L MAP (VIN Code N)

1993 E Series

VIN: 1 2 3 4 5 6 7 8 ... 17

Engine code

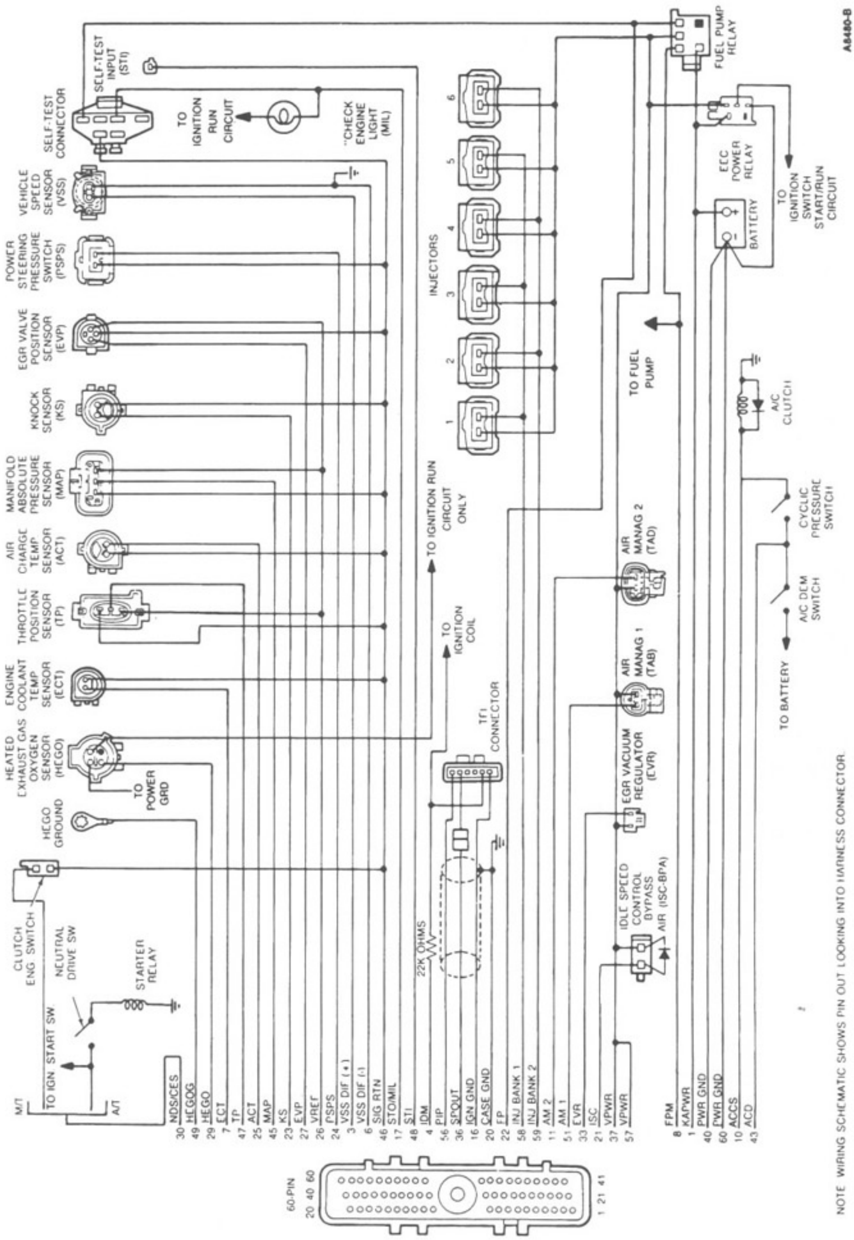


NOTE: WIRING SCHEMATIC SHOWS PINPOUT LOOKING INTO HARNESS CONNECTORS

1988–1989 E/F Series, Bronco

4.9L MAP
(VIN Code Y)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

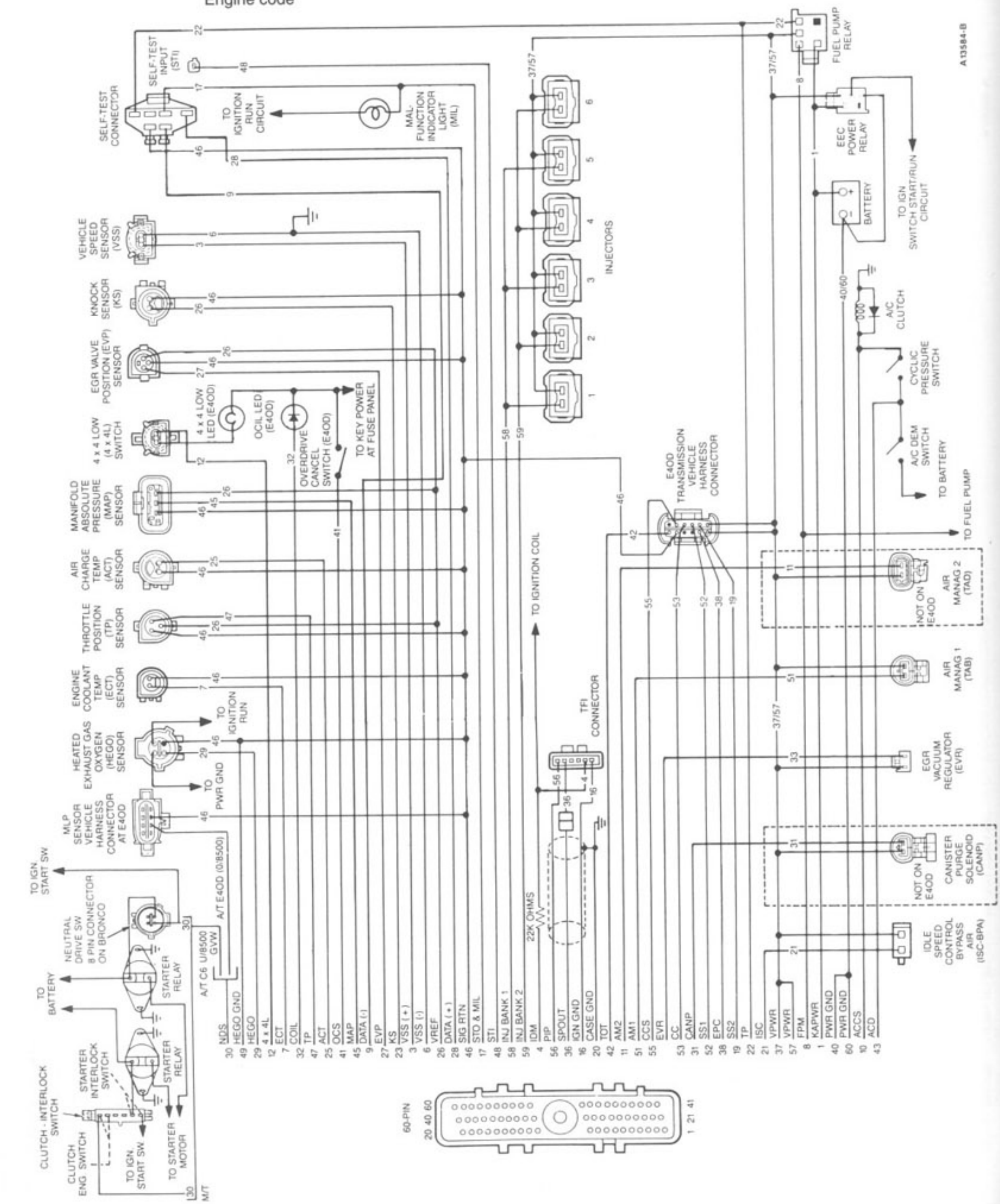


12

4.9L
MAP
(VIN Code Y)

1990–1991
E/F Series, Bronco

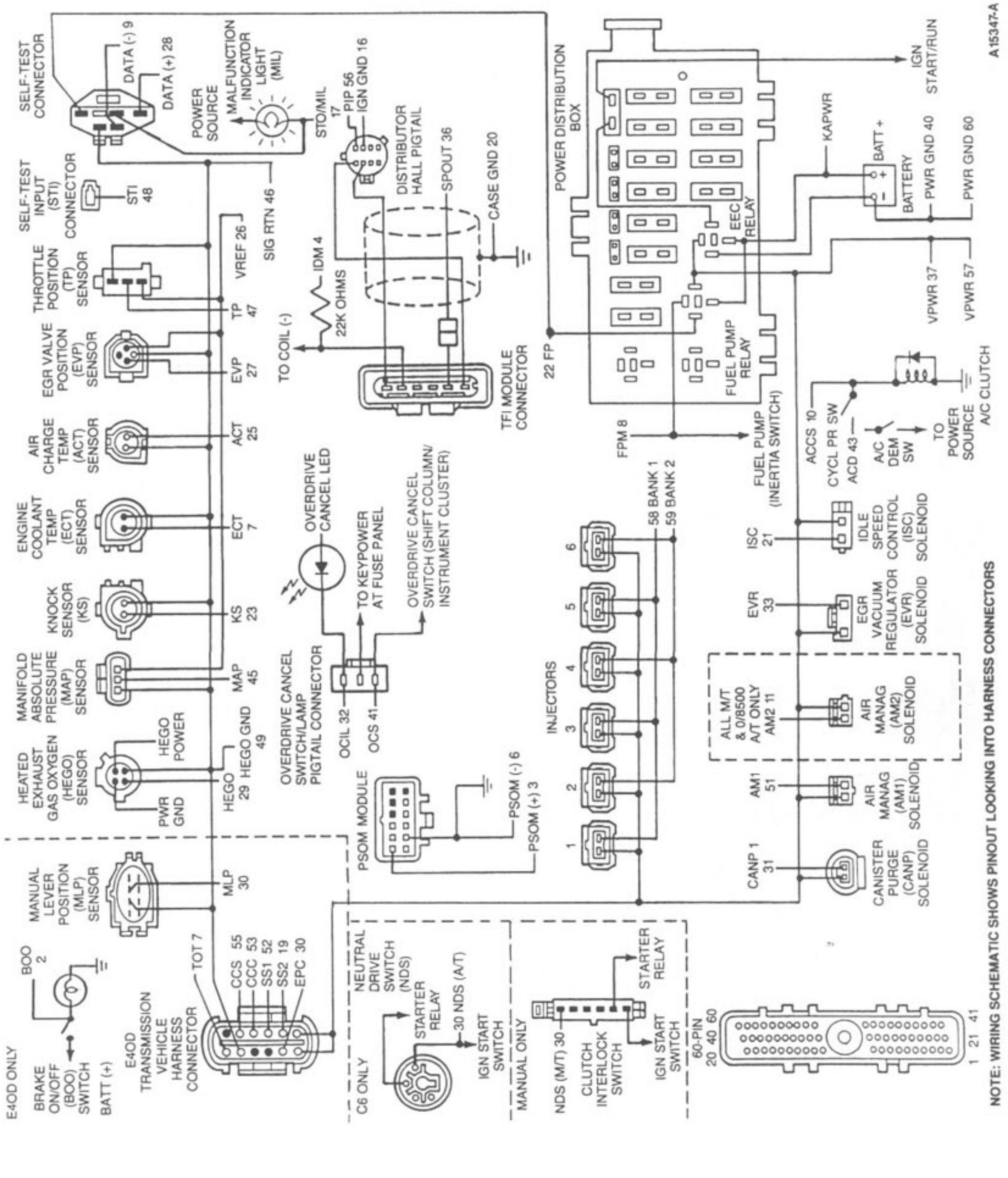
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



1992–1993 E Series

4.9L MAP (VIN Code Y)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



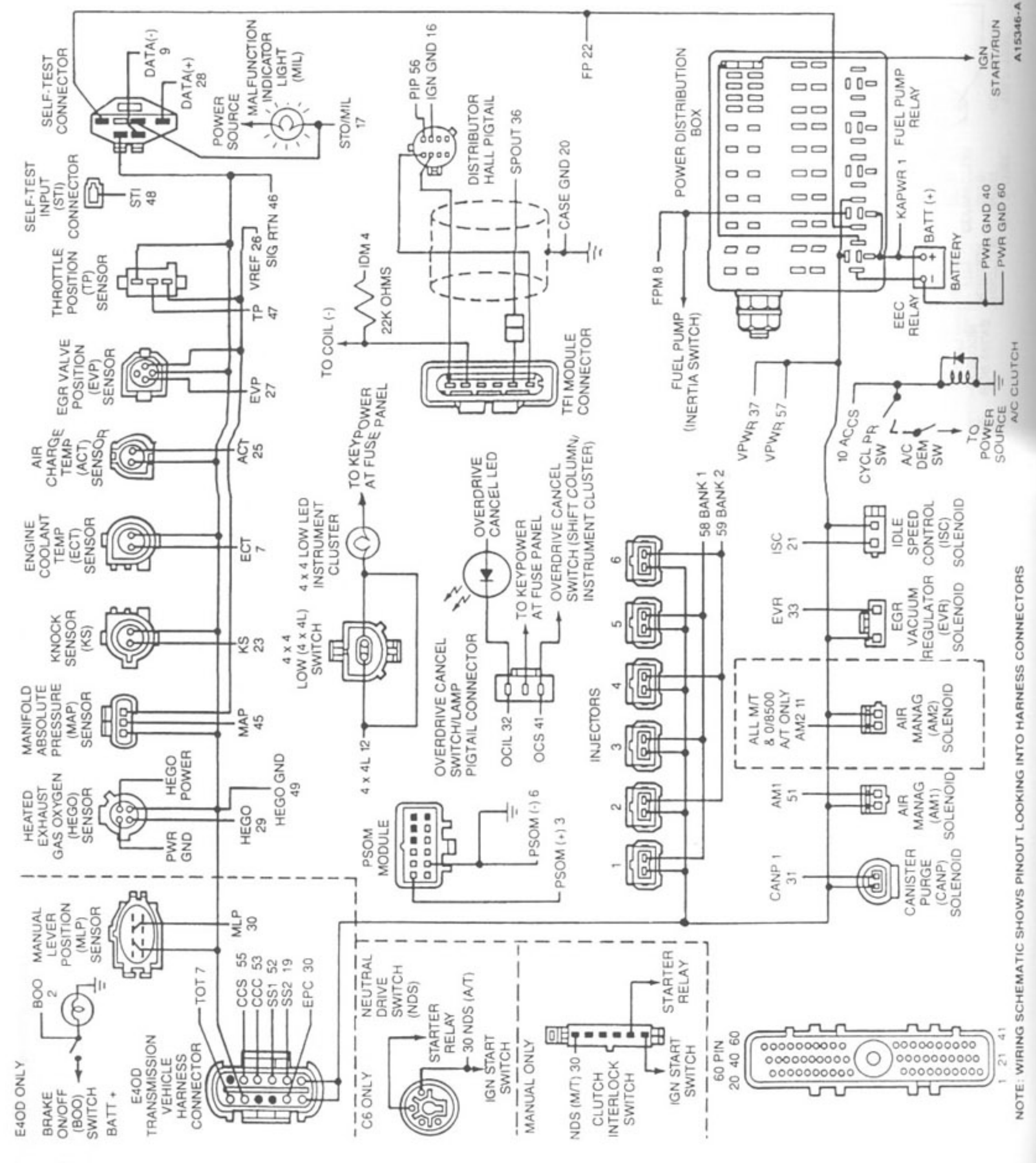
1

4.9L MAP (VIN Code Y)

1992–1993 F Series, Bronco

VIN: 1 2 3 4 5 6 7 8 ... 17

Engine code



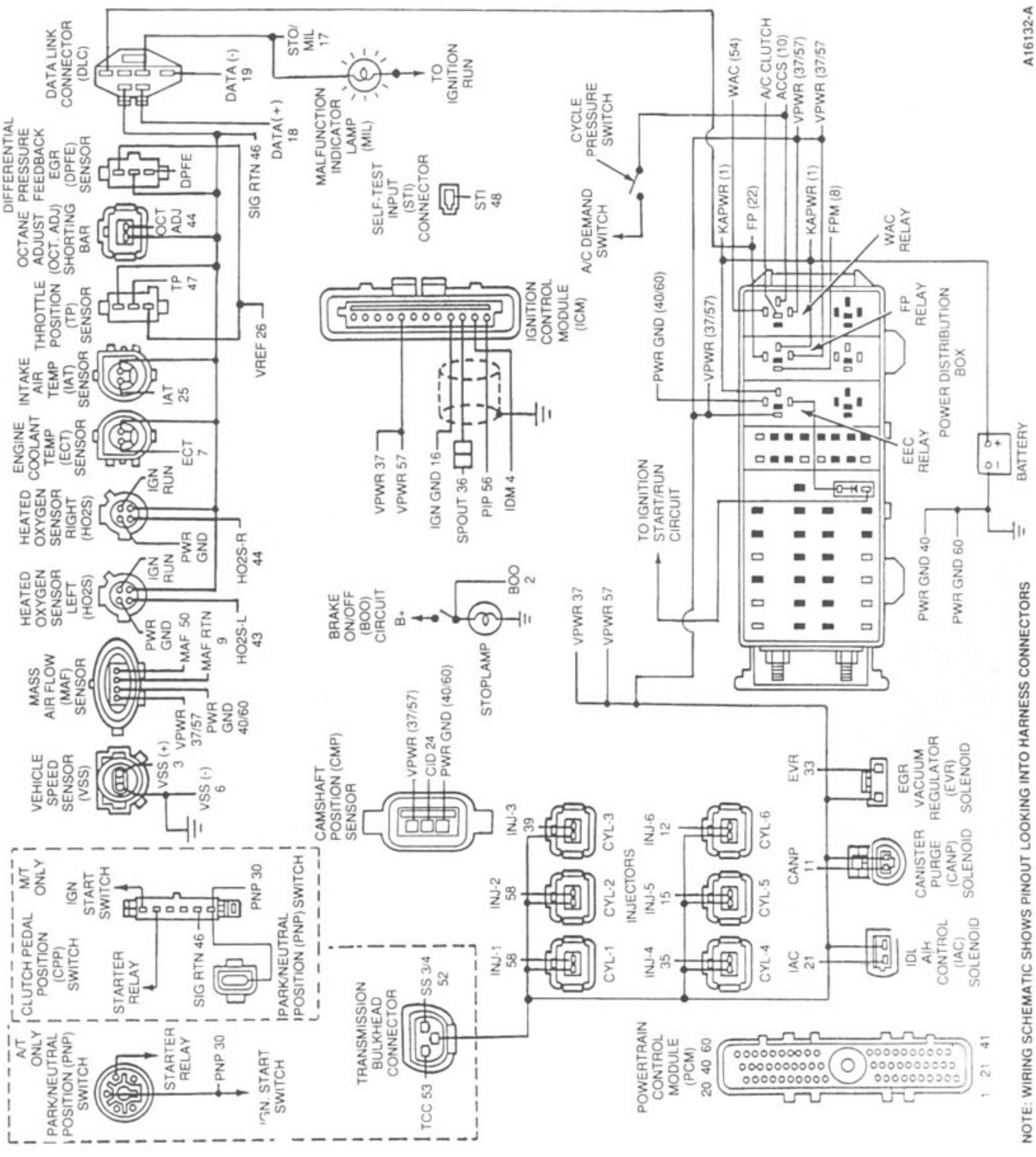
1993 Explorer CA

4.0L MAF-SFI

(VIN Code X)

VIN: 1 2 3 4 5 6 7 8 ... 17

Engine code



12

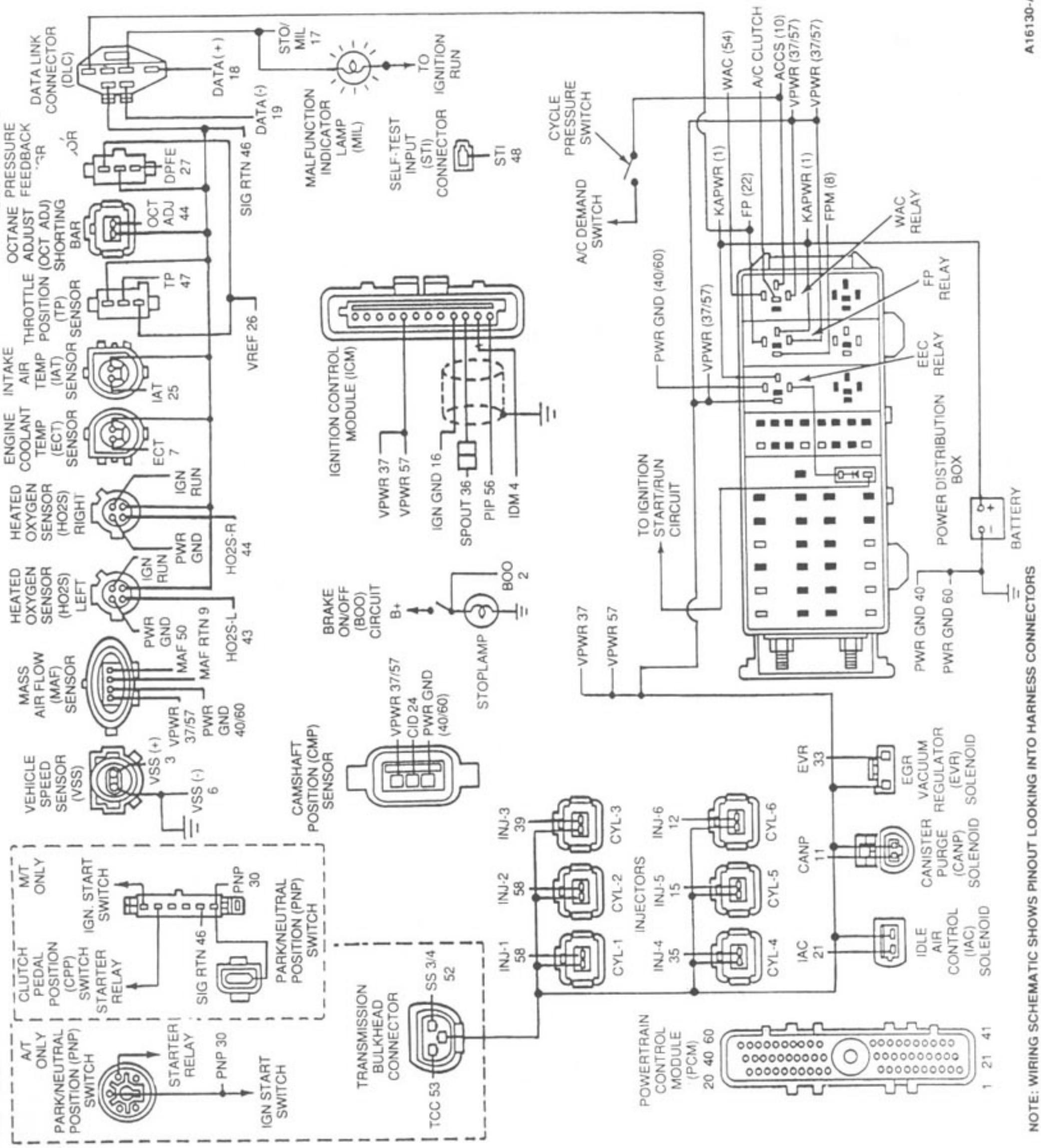
4.0L MAF-SFI

(VIN Code X)

1993 Ranger CA

VIN: 1 2 3 4 5 6 7 8 ... 17

Engine code

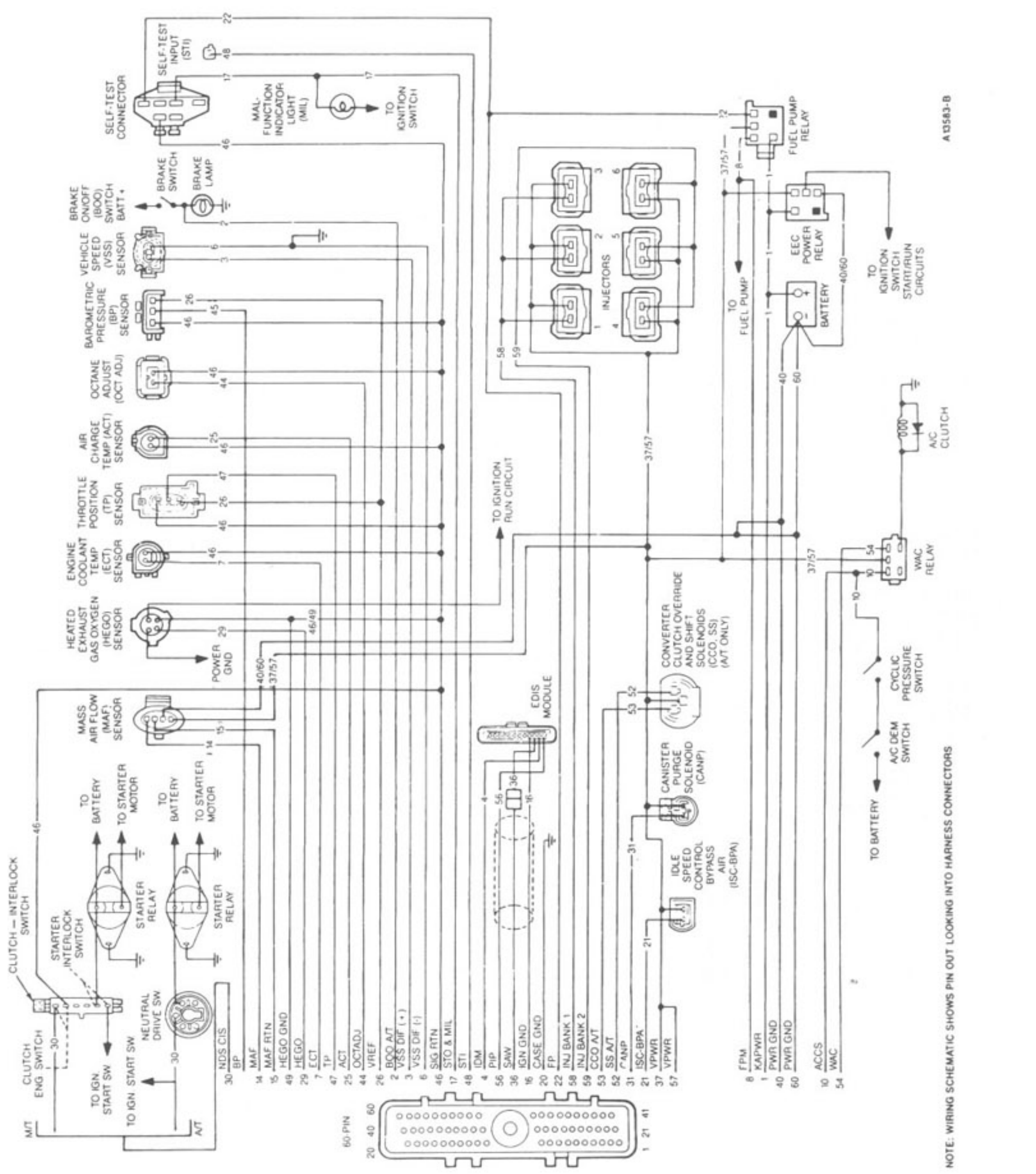


NOTE: WIRING SCHEMATIC SHOWS PINOUT LOOKING INTO HARNESS CONNECTORS

1990–1991
Ranger, Explorer, 1991 Aerostar, 1990 Bronco II

4.0L
MAF
(VIN Code X)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

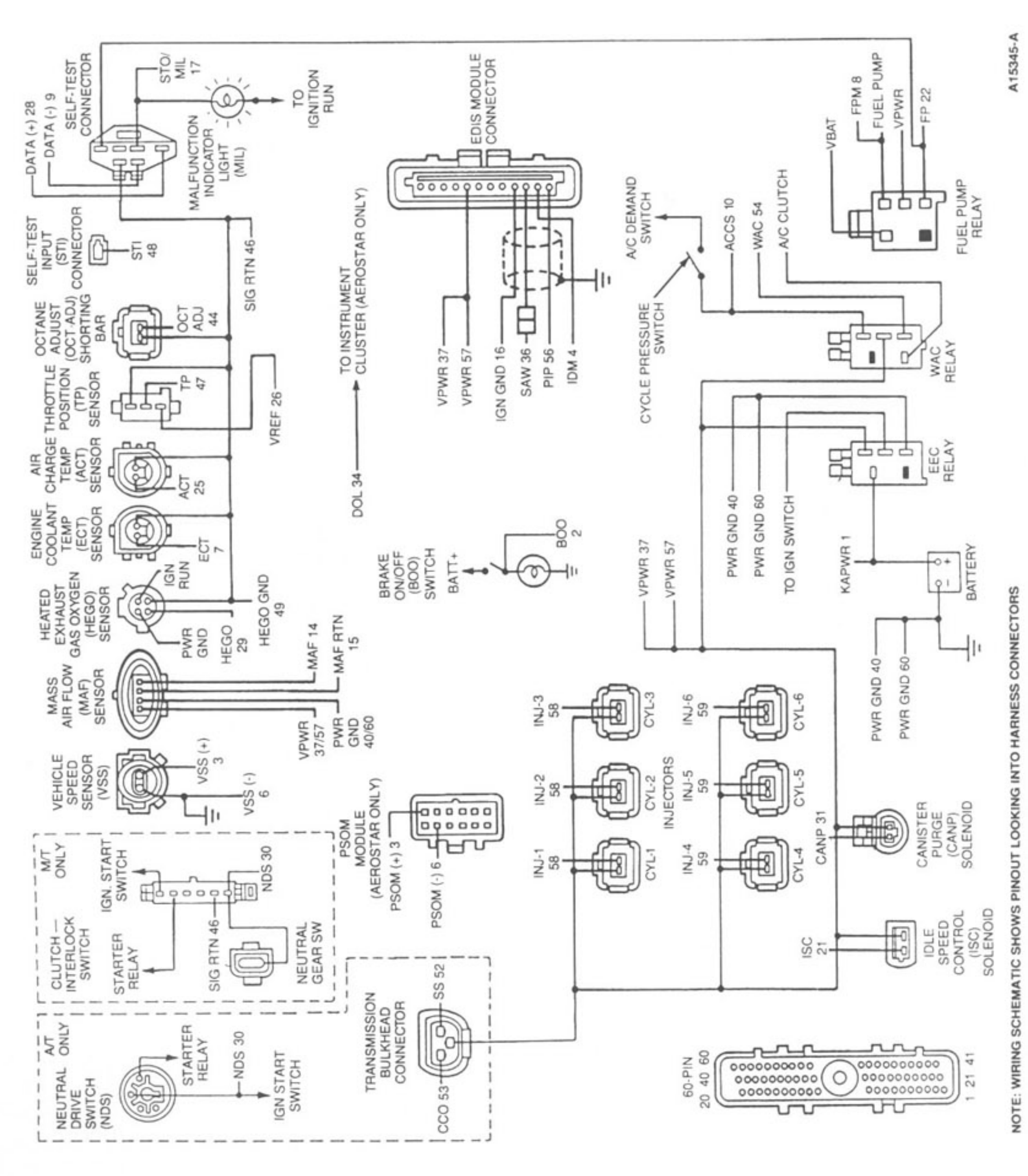


12

4.0L
MAF
(VIN Code X)

1992
Ranger, Explorer, 1992–1993 Aerostar

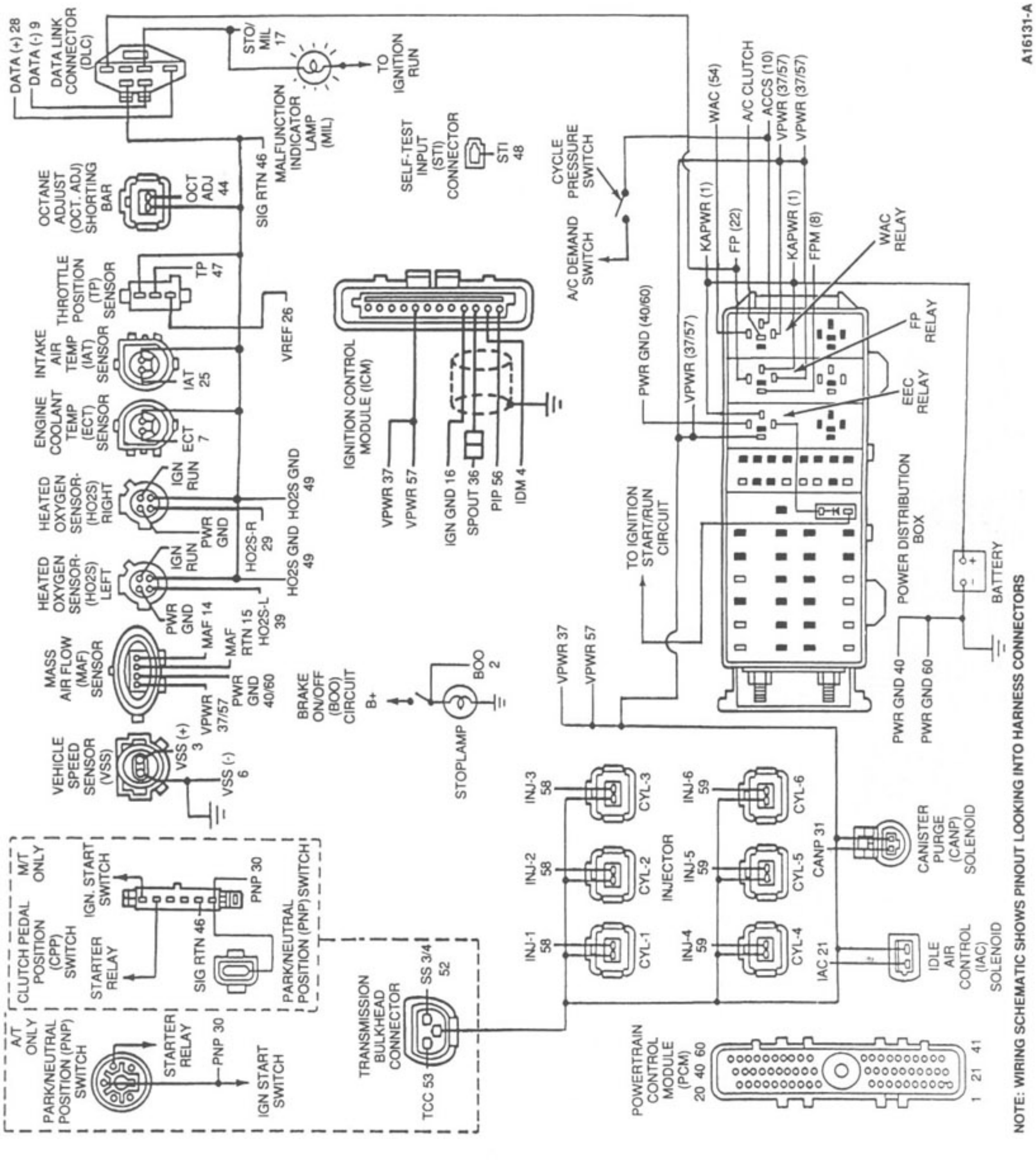
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



1993 Explorer (49-state)

4.0L MAF
(VIN Code X)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

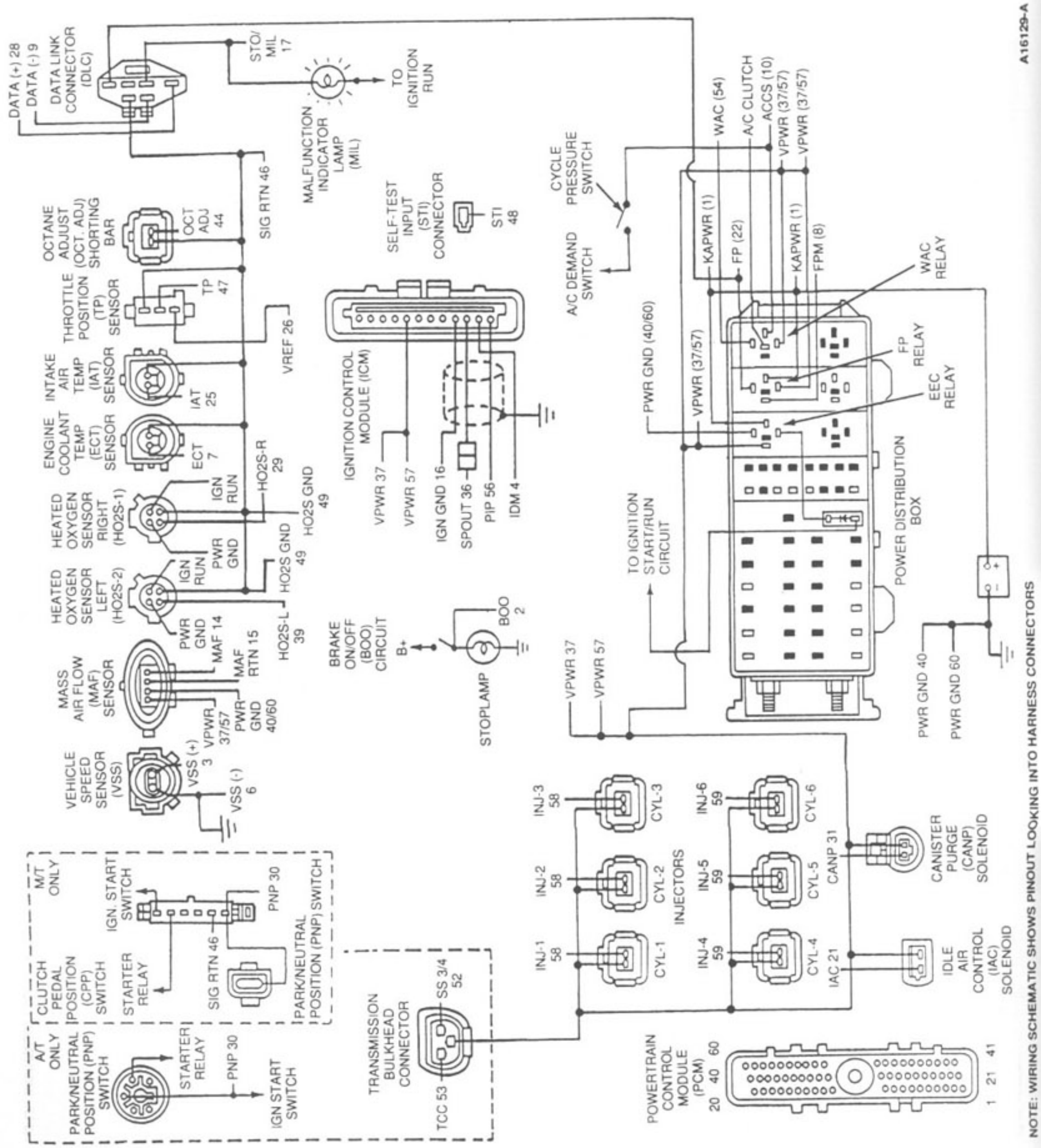


12

4.0L
MAF
(VIN Code X)

1993
Ranger (49-state)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

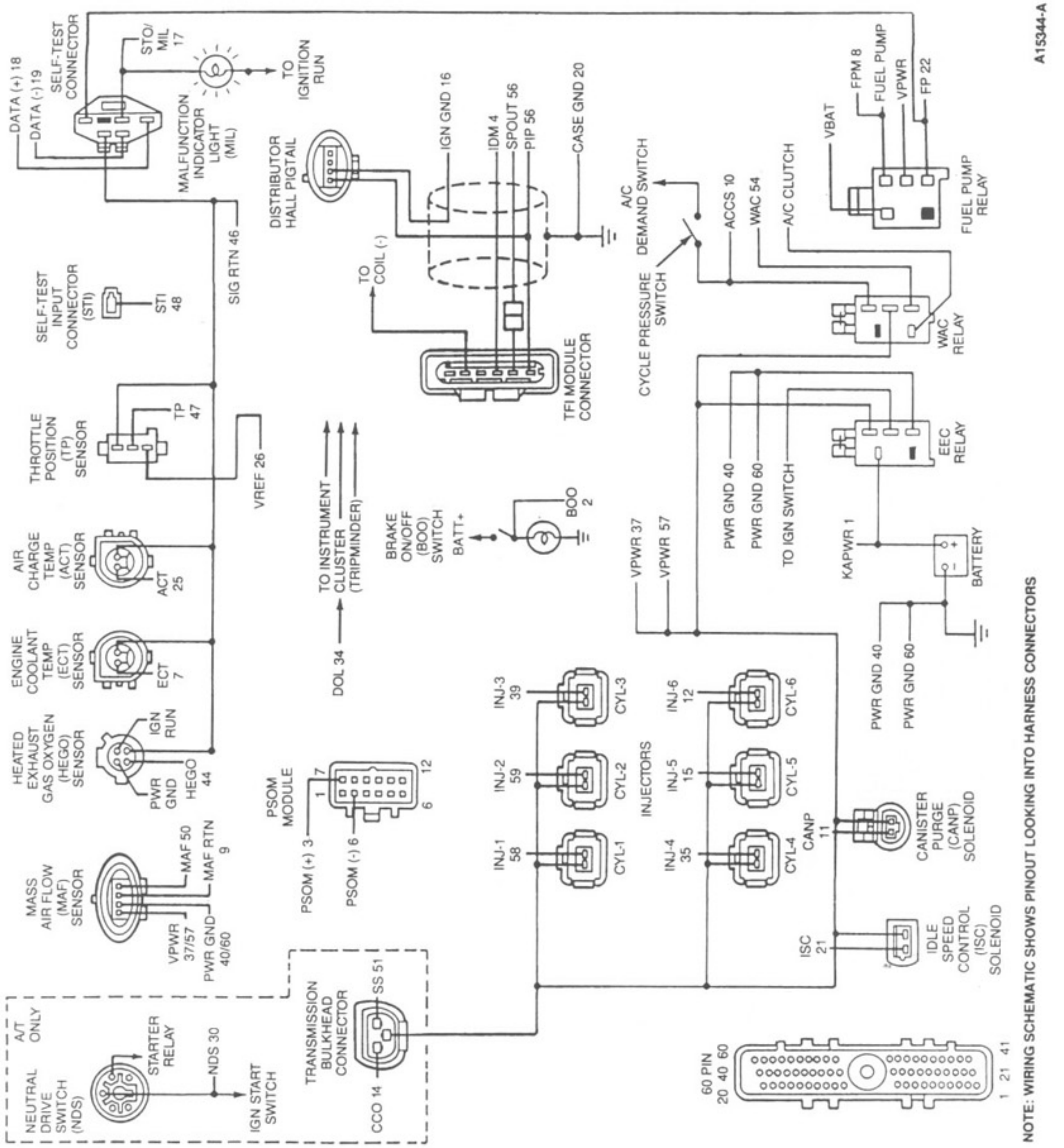


1992–1993 Aerostar

3.0L MAF-SFI (VIN Code U)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

NOTE: WIRING SCHEMATIC SHOWS PINOUT LOOKING INTO HARNESS CONNECTORS



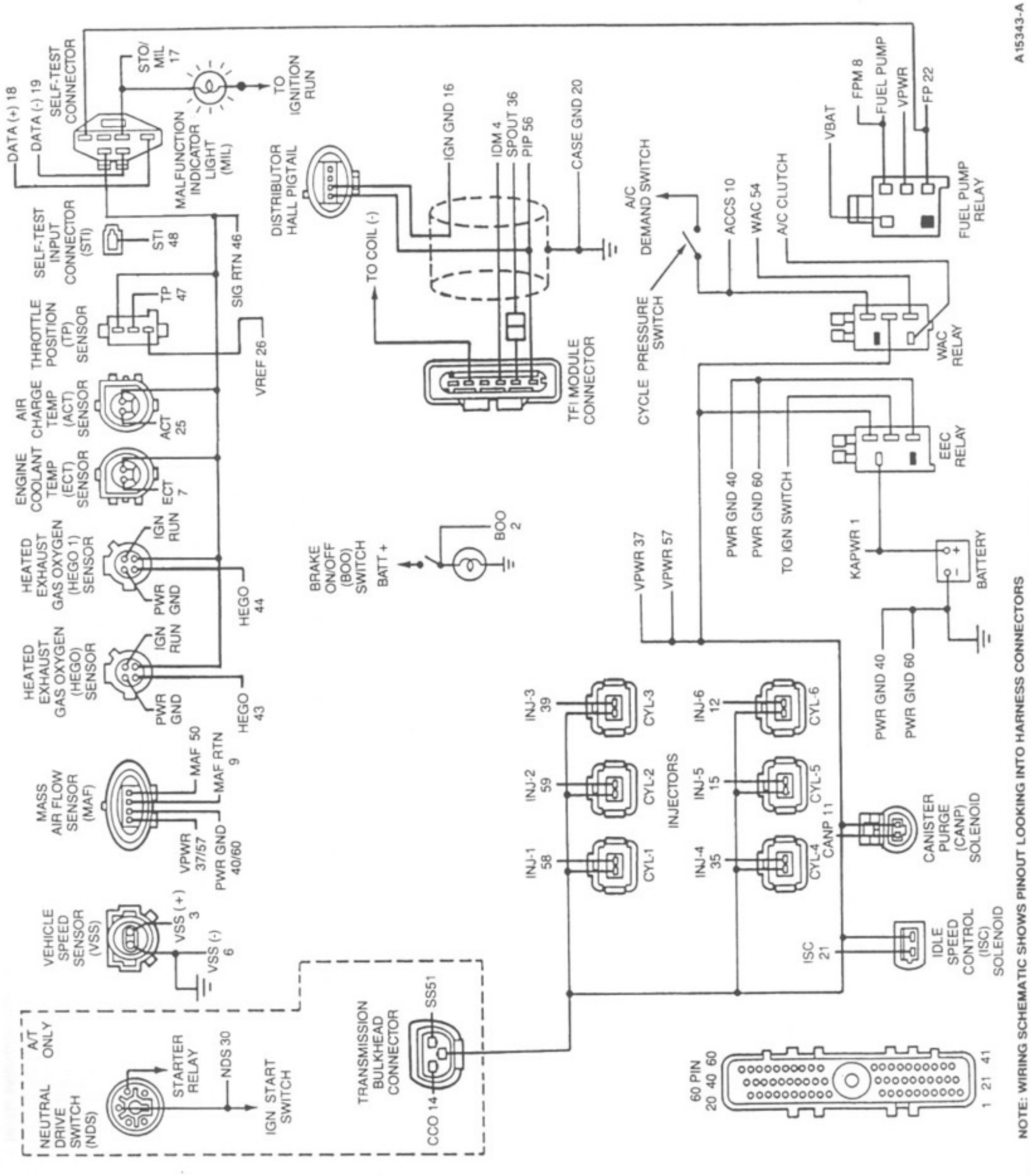
NOTE: WIRING SCHEMATIC SHOWS PINOUT LOOKING INTO HARNESS CONNECTORS

12

3.0L MAF-SFI
(VIN Code U)

1992–1993
Ranger

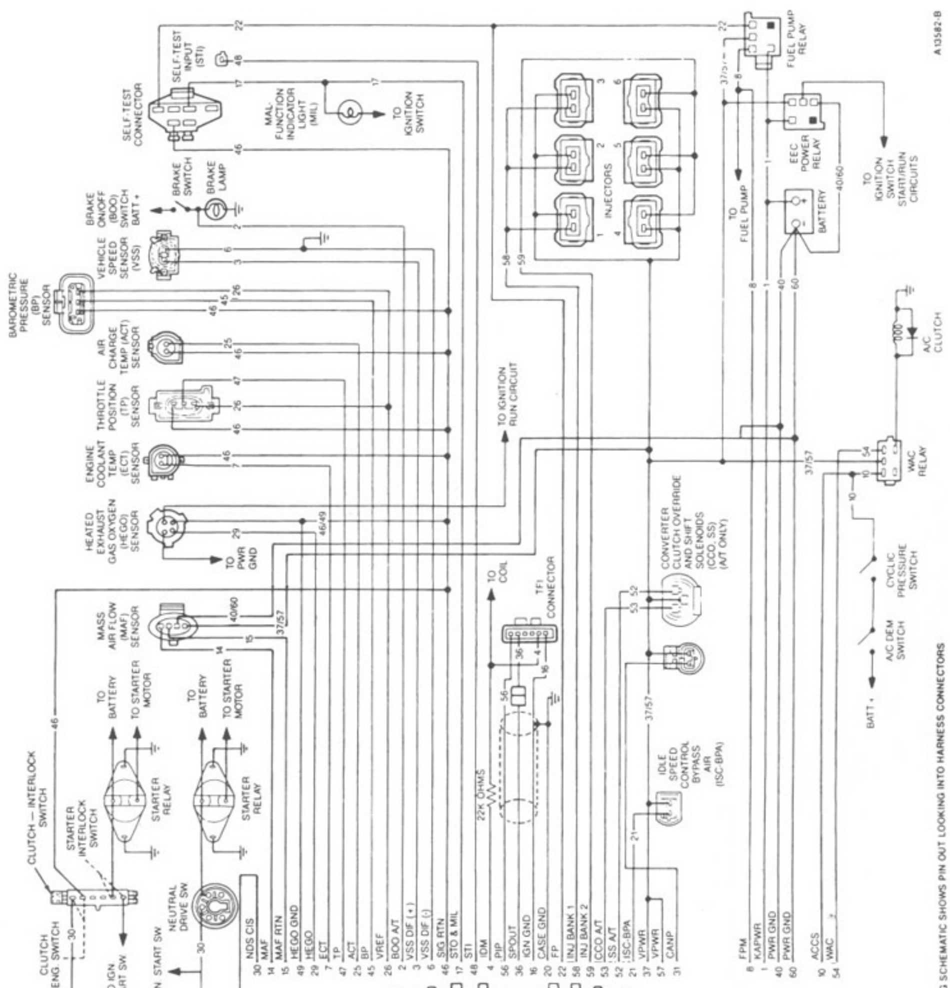
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



1991 Ranger

3.0L MAF
(VIN Code U)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

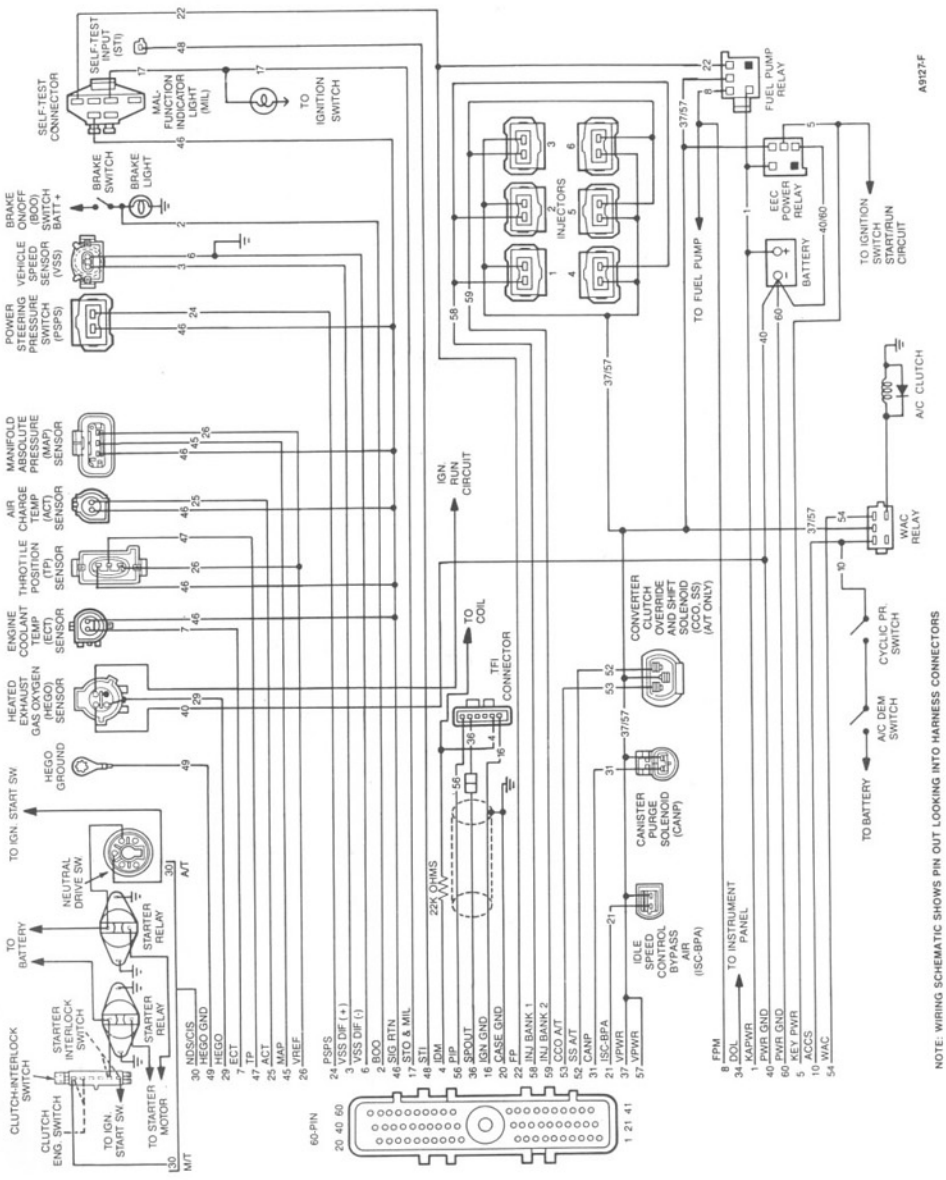


12

3.0L MAP
(VIN Code U)

1988–1991 Aerostar

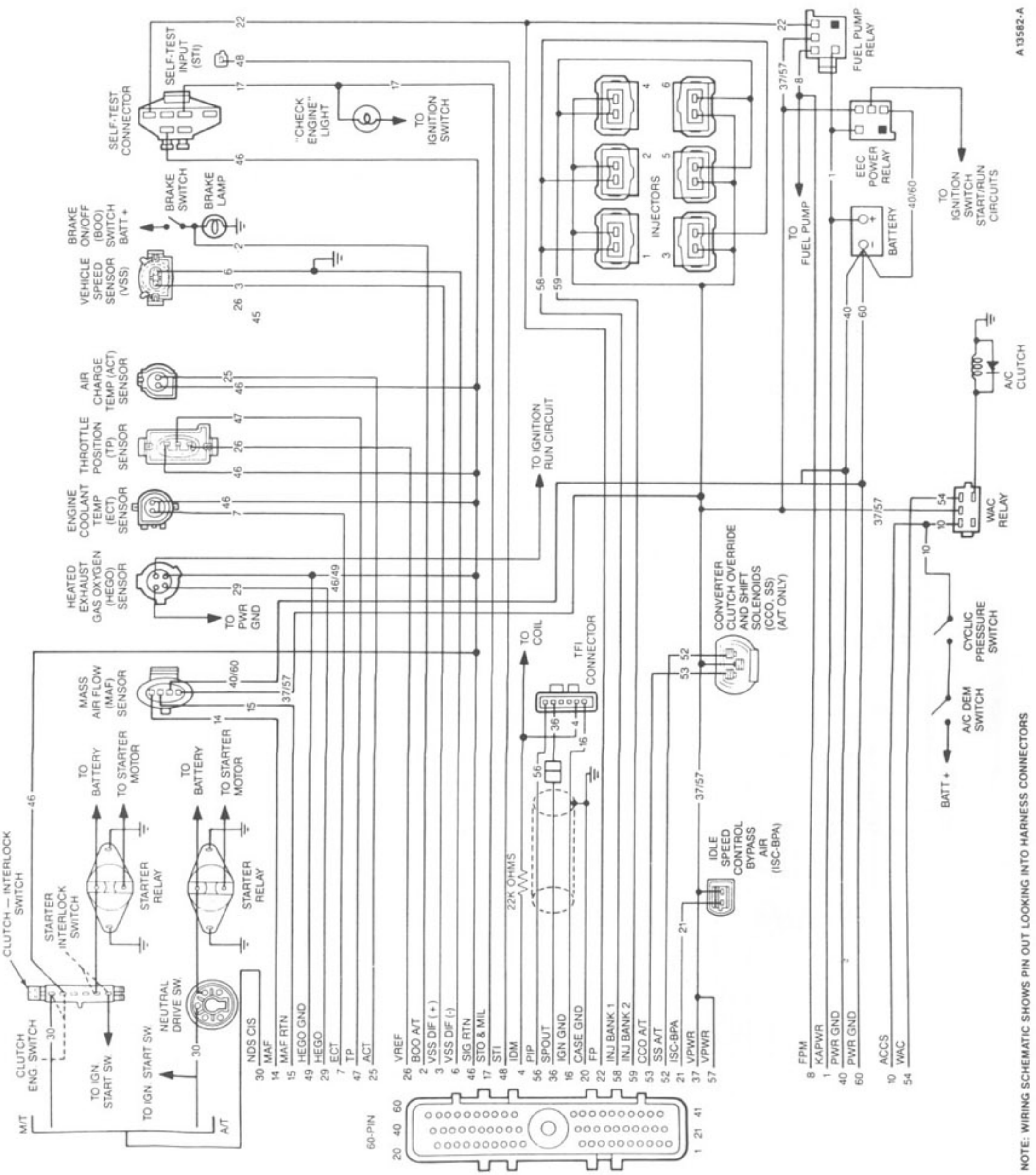
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



1990 Ranger, Bronco (CA)

2.9L MAF
(VIN Code T)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

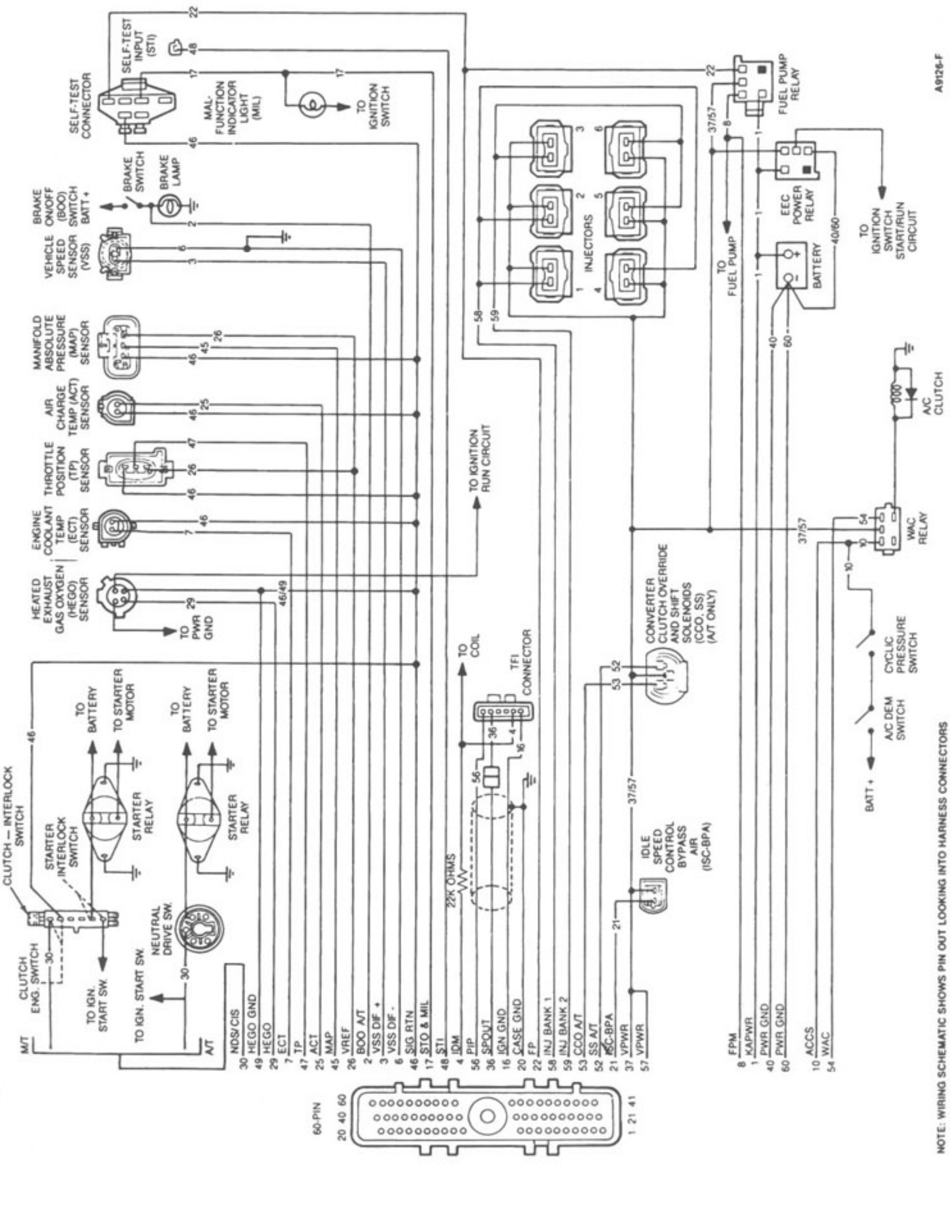


2.9L MAP (VIN Code T)

1988–1991 Ranger, 90 Bronco

VIN: 1 2 3 4 5 6 7 8 ... 17

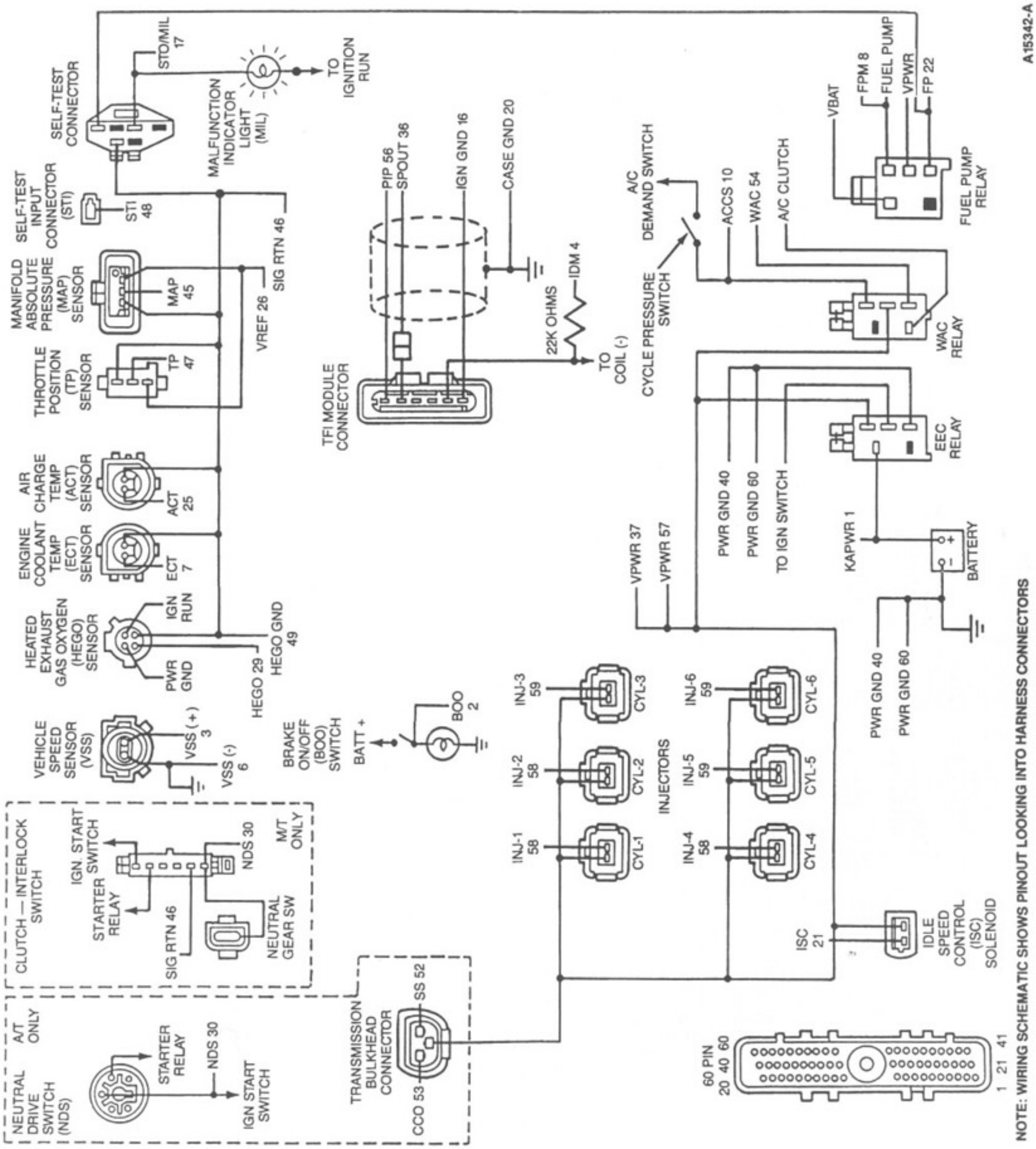
Engine code



1992 Ranger

2.9L MAP (VIN Code T)

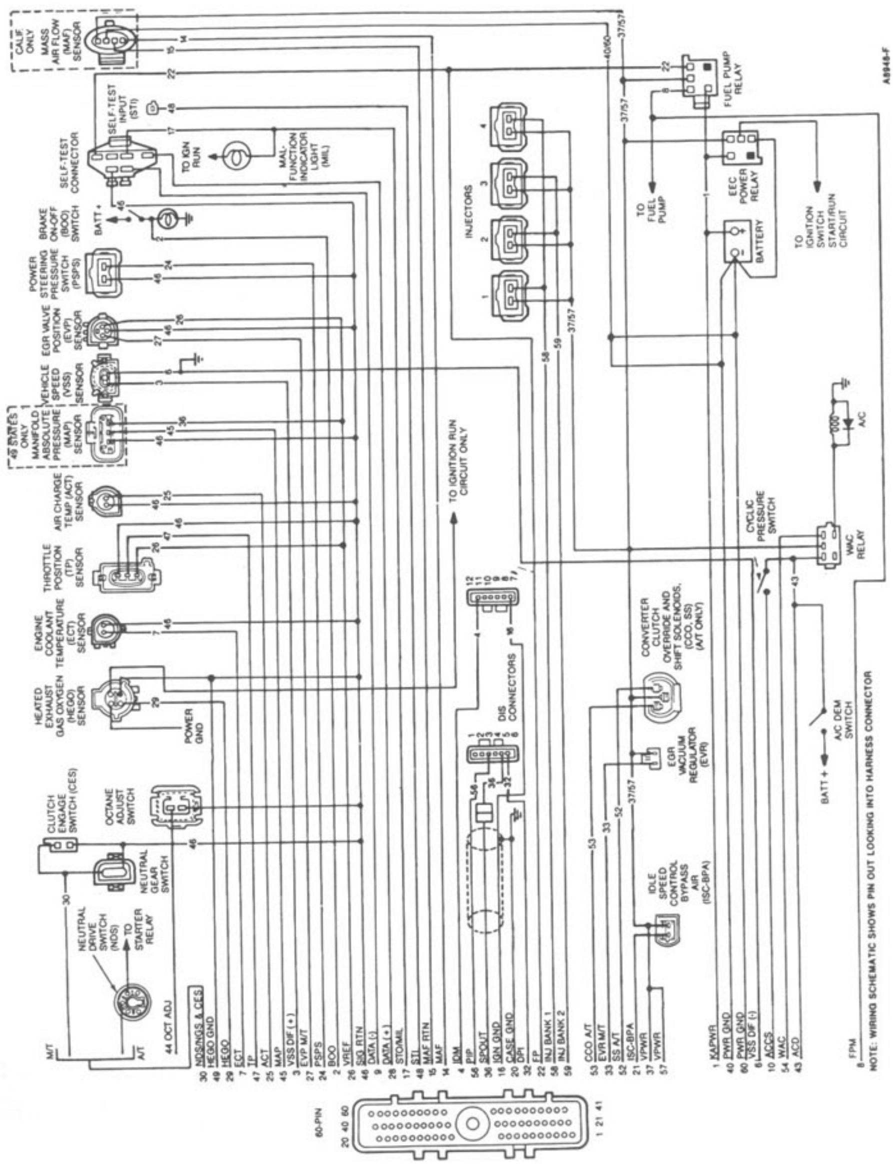
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



2.3L OHC MAF
(VIN Code A)

1988–1991 Ranger

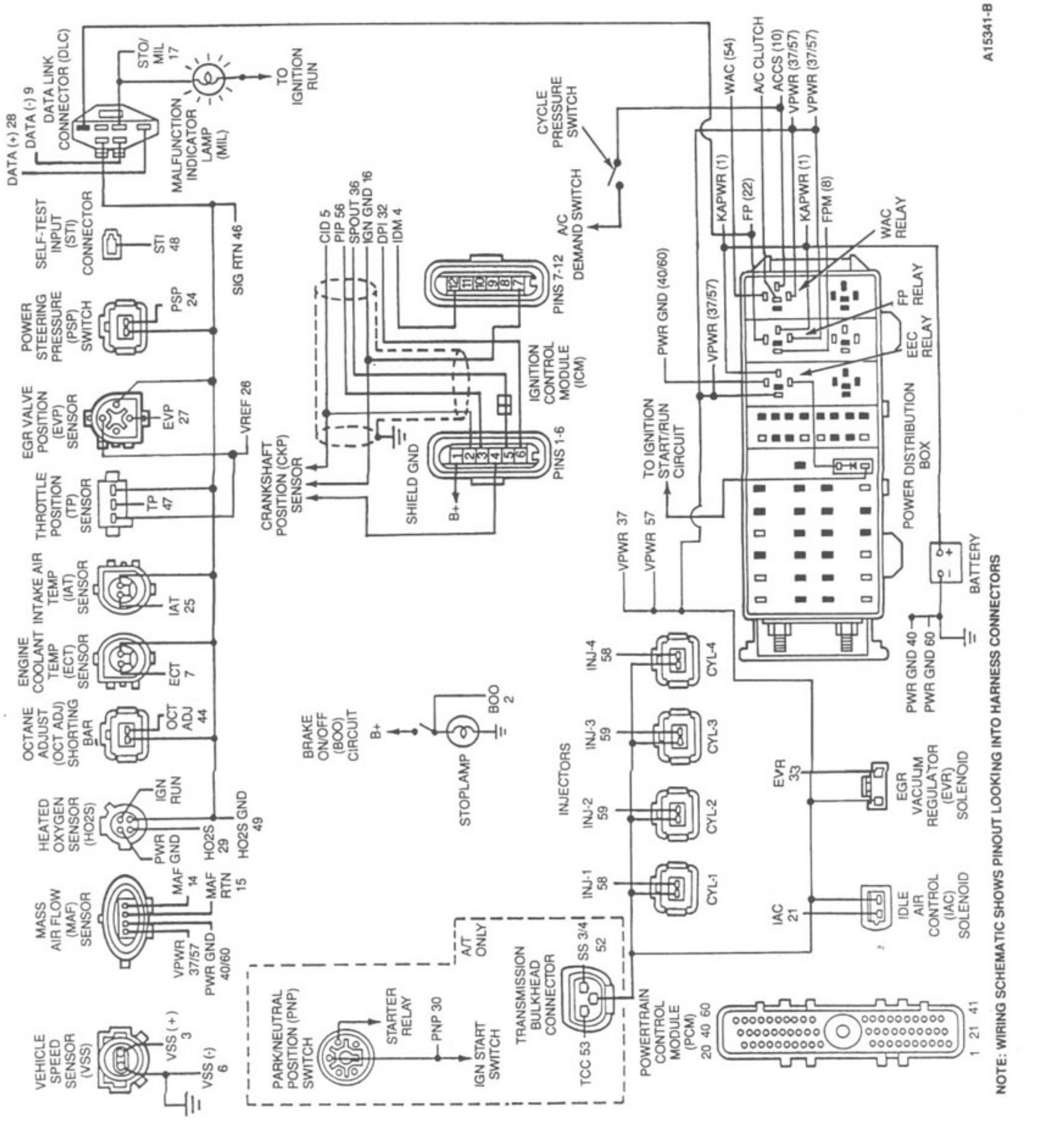
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



1992–1993 Ranger

2.3L OHC MAP (VIN Code A)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

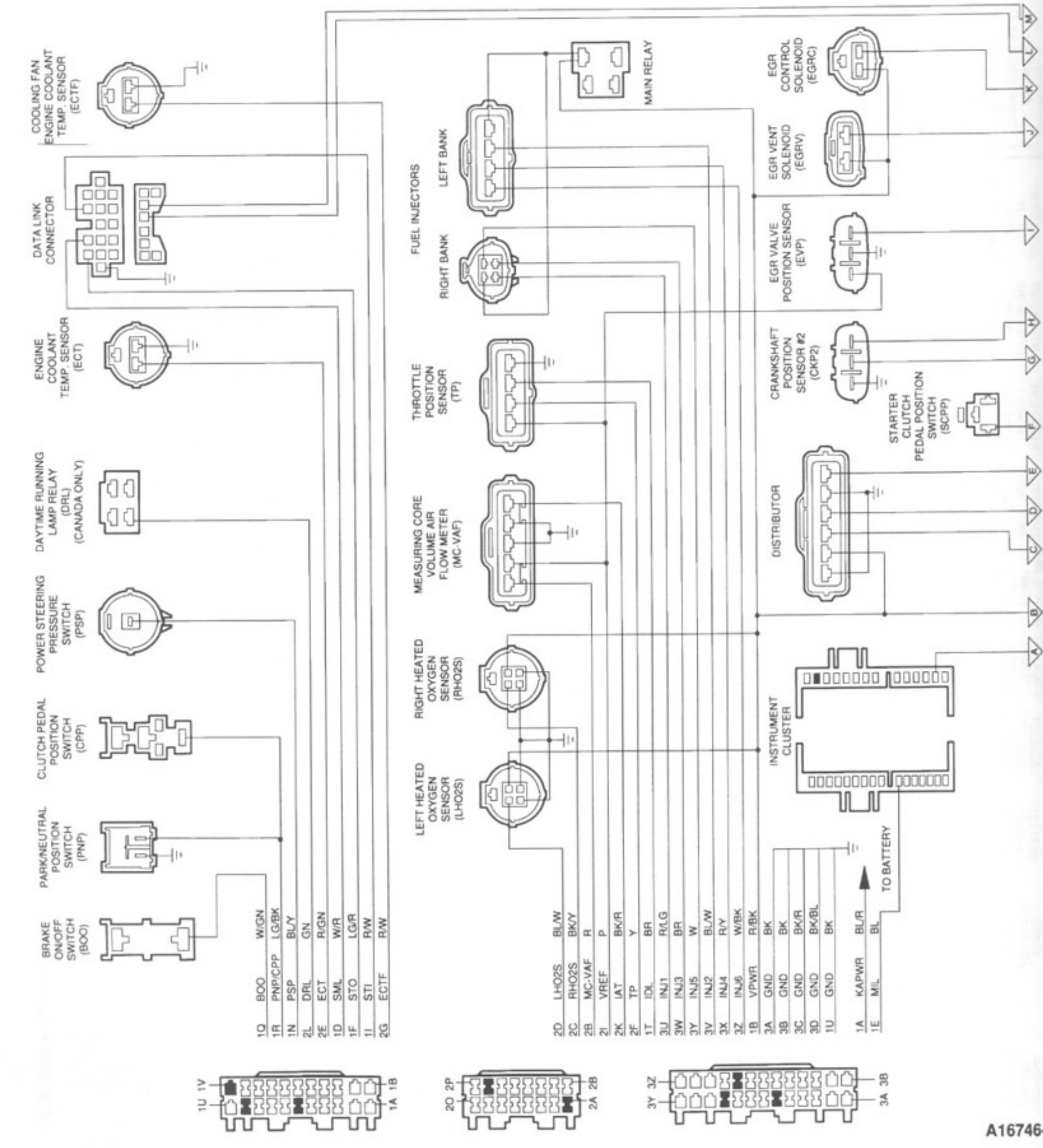


12

2.5L V-6 MC VAF-SFI
(VIN Code B)

1993 Probe MTX inputs

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

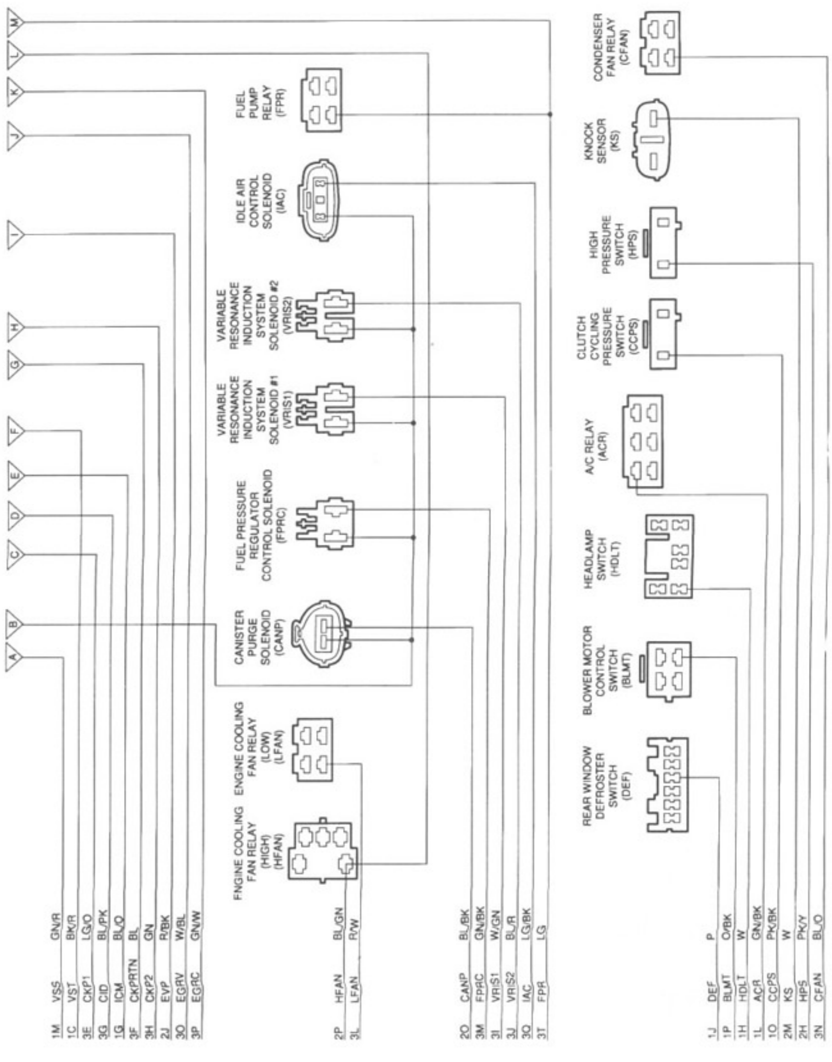


A16746-B

1993 Probe MTX outputs

2.5L V-6 MC VAF-SFI
(VIN Code B)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



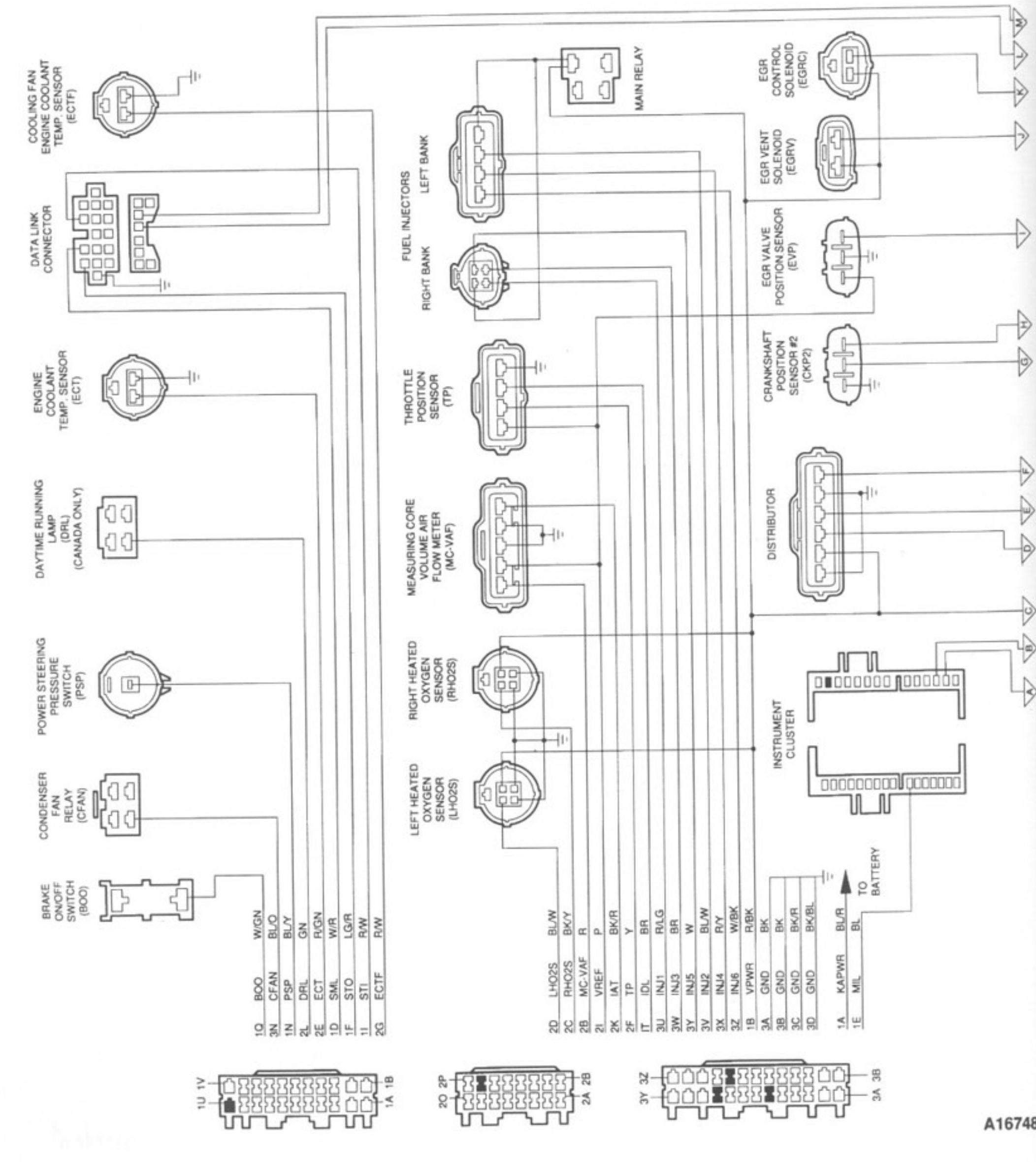
A16747-B

12

2.5L V-6 MC VAF-SFI
(VIN Code B)

1993 Probe 4EAT inputs

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



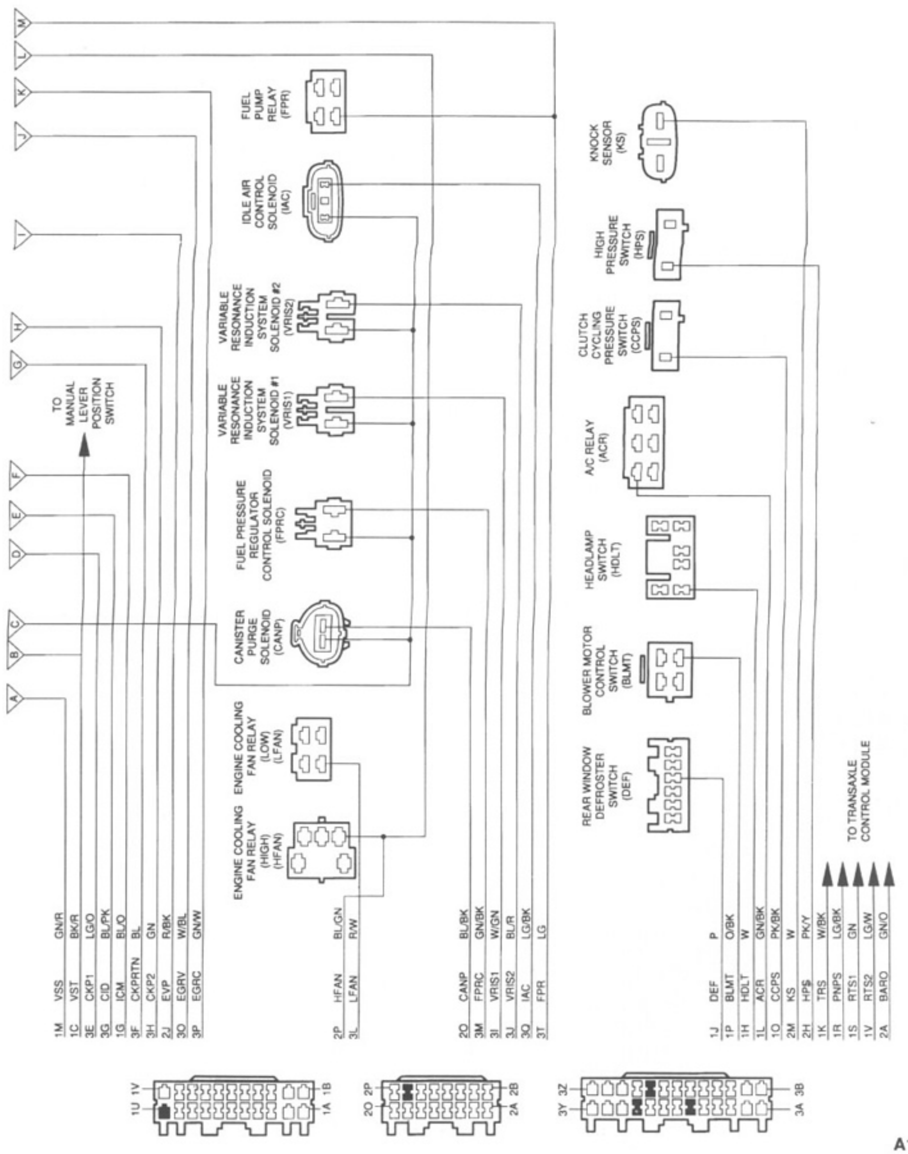
A16748-B

1993 Probe 4EAT outputs

2.5L V-6 MC VAF-SFI

(VIN Code B)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



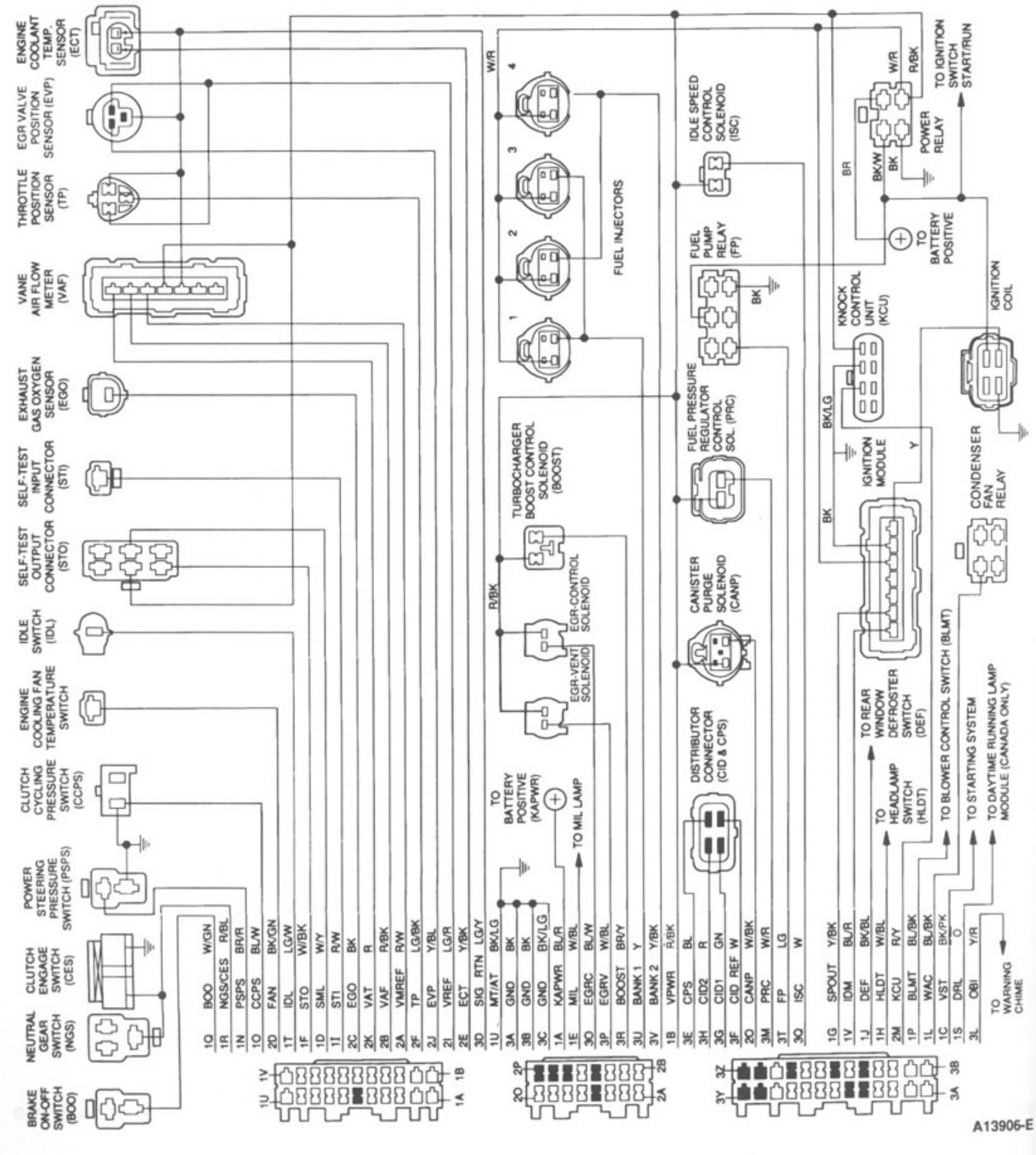
A16749-B

12

2.2L Turbo VAF
(VIN Code L)

1989–1992 Probe MTX

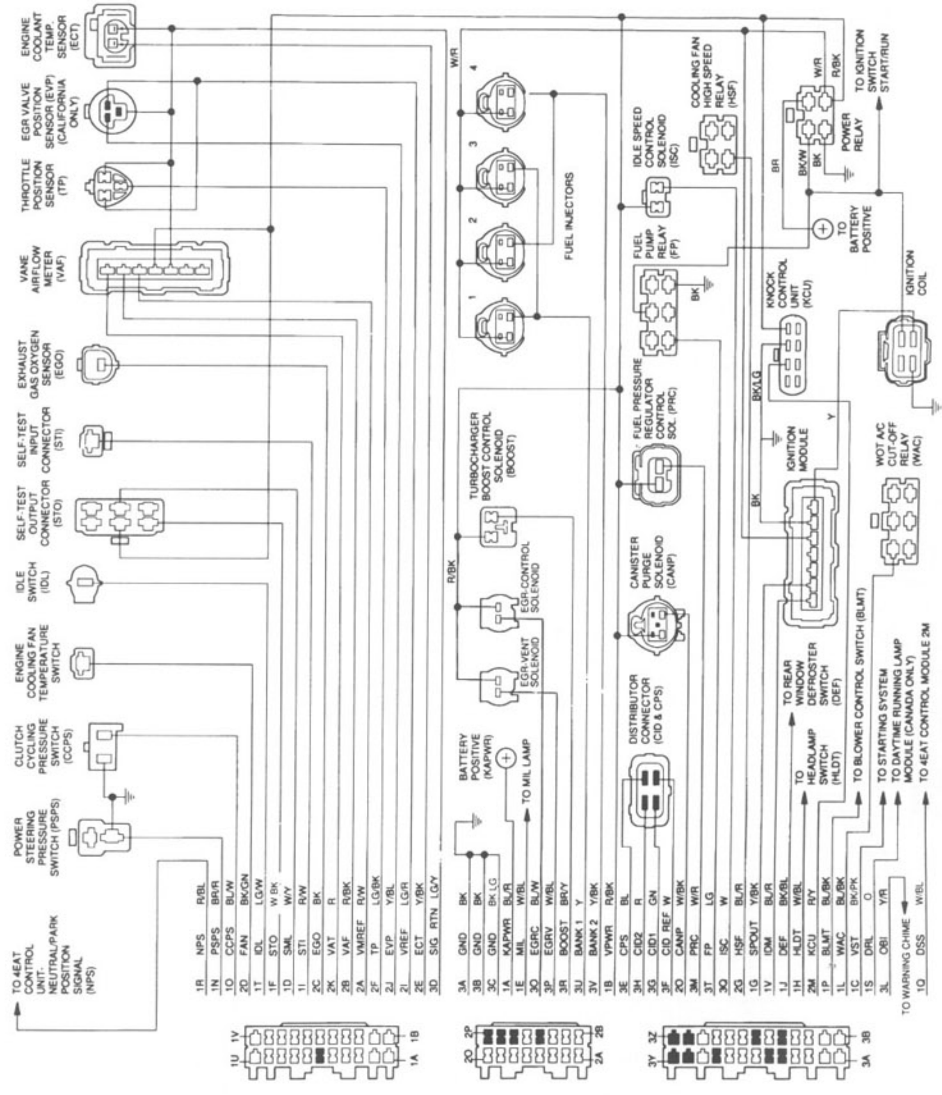
VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



1991–1992
Probe
4EAT

2.2L
Turbo VAF
(VIN Code L)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

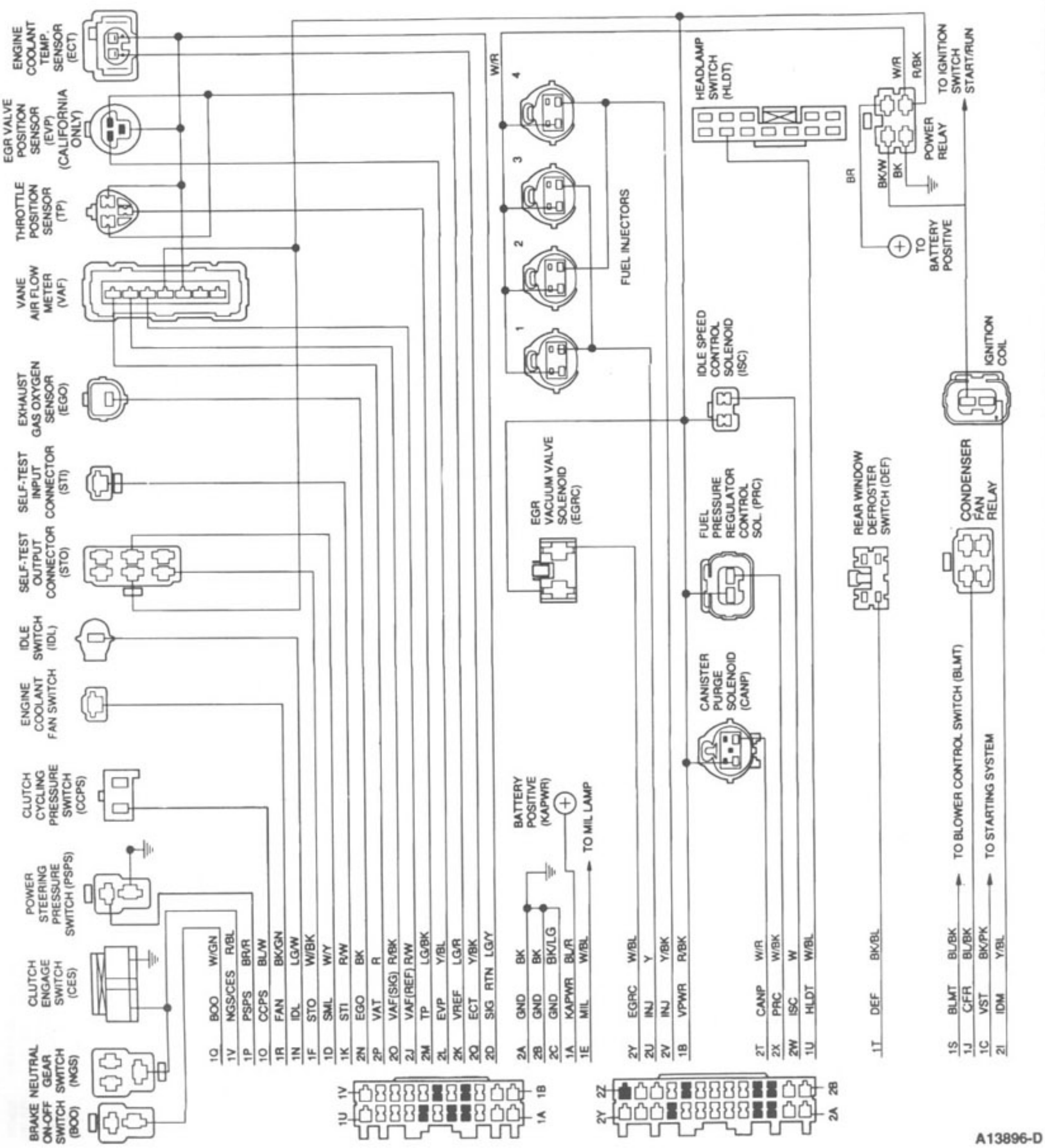


A13910-D

2.2L Non-turbo VAF
(VIN Code C)

1989–1992
Probe
MTX

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

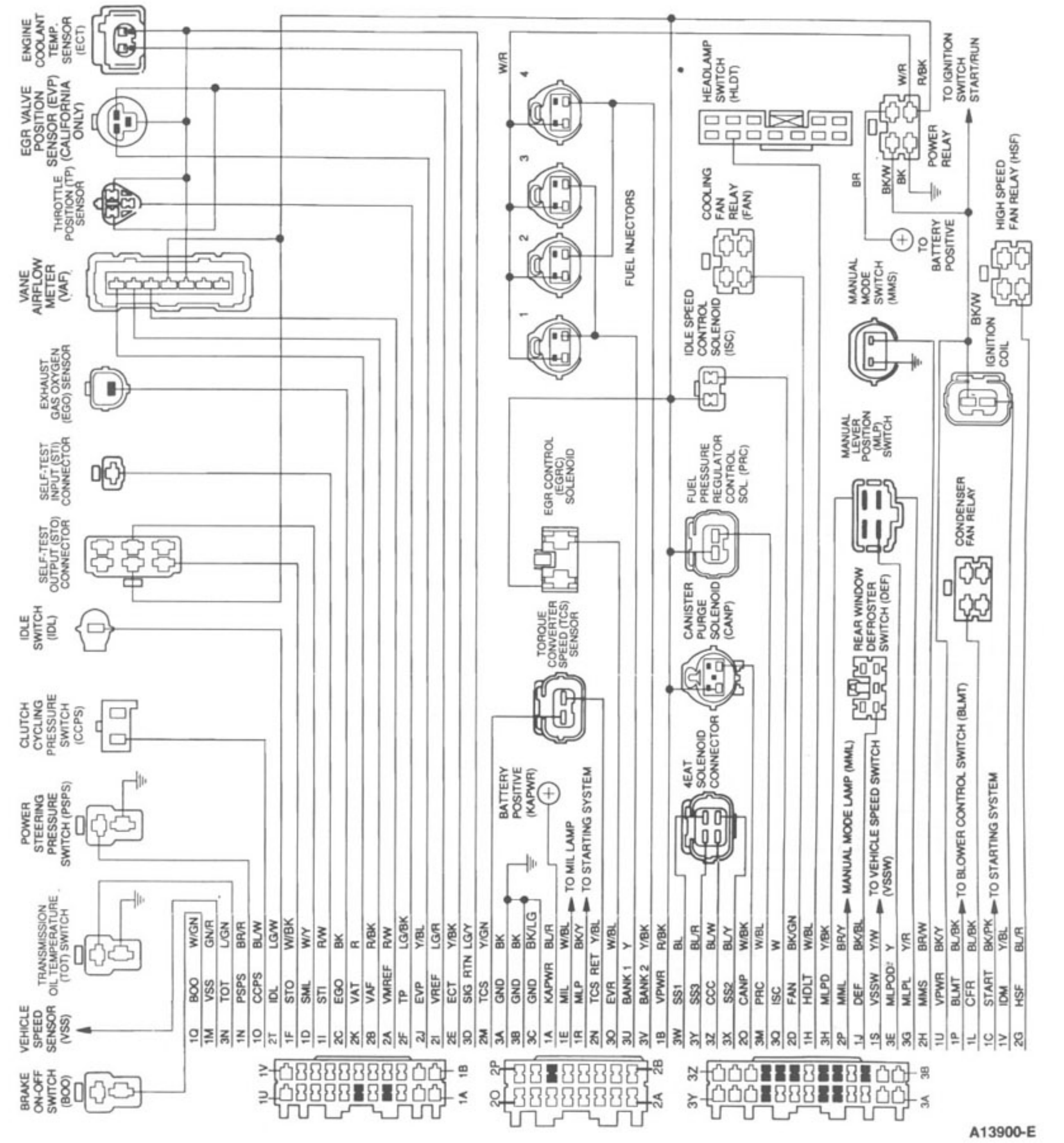


A13896-D

1991–1992 Probe 4EAT

2.2L Non-turbo VAF (VIN Code C)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



A13900-E

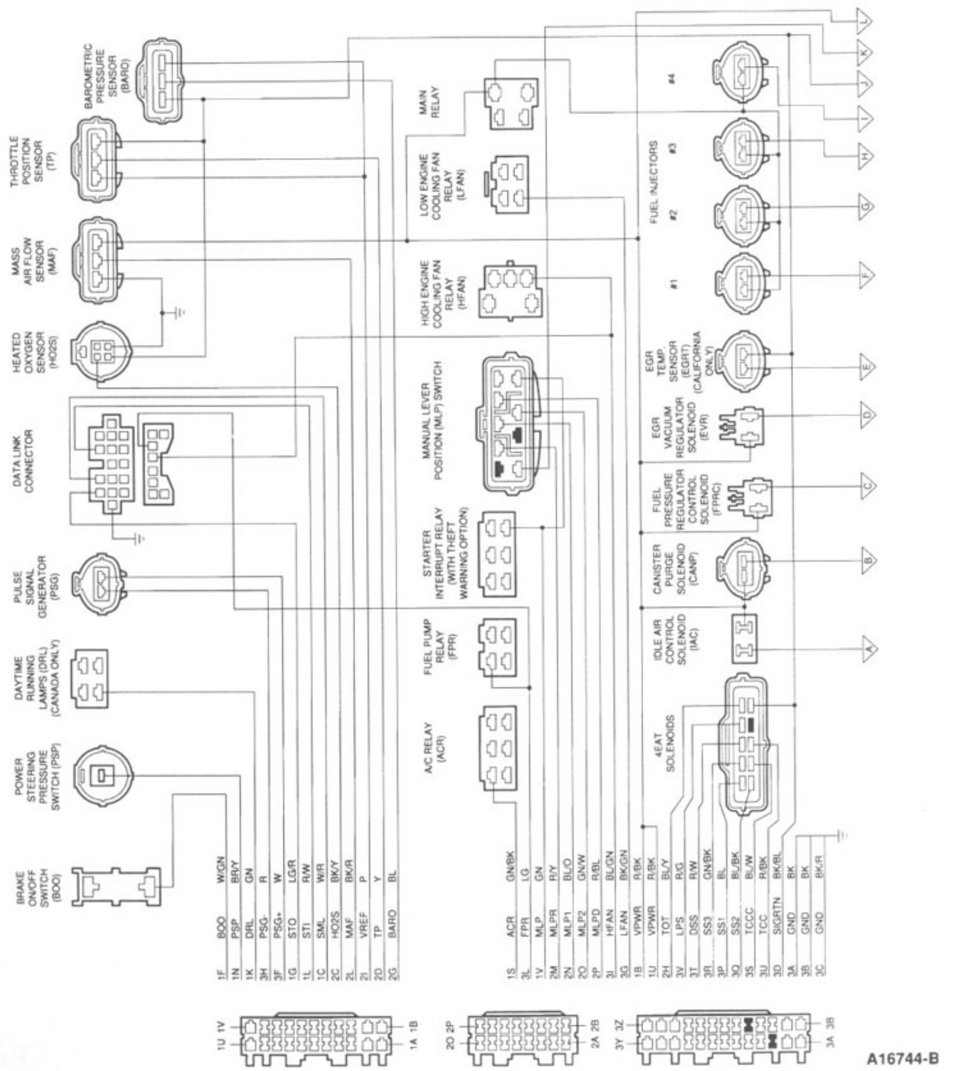
12

2.0L
MAF
(VIN Code A, 4EAT)

1993
Probe
4EAT inputs

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

NOTE: The transaxle control module is integrated with the powertrain control module on 2.0L 4EAT vehicles.

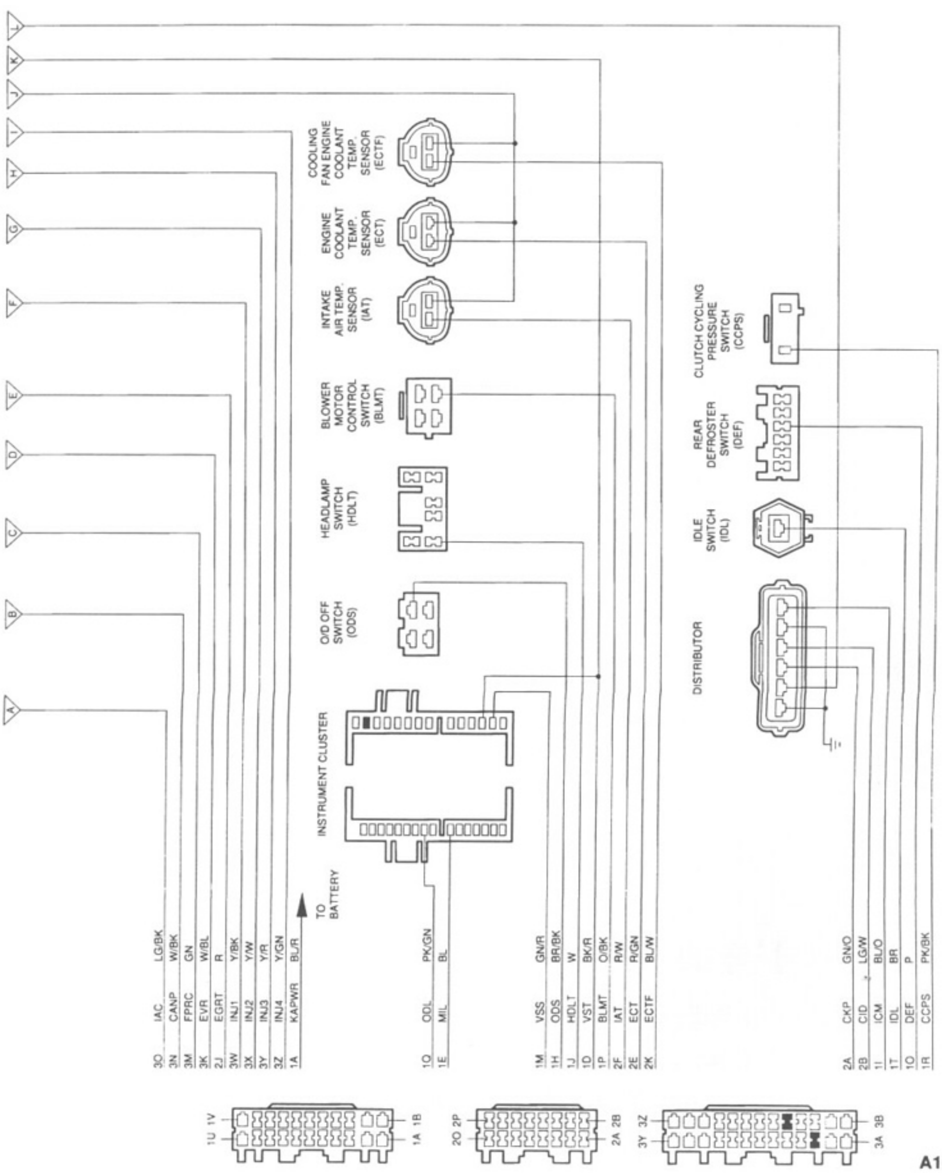


A16744-B

1993 Probe 4EAT outputs

2.0L MAF
(VIN Code A, 4EAT)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



A16745 -B

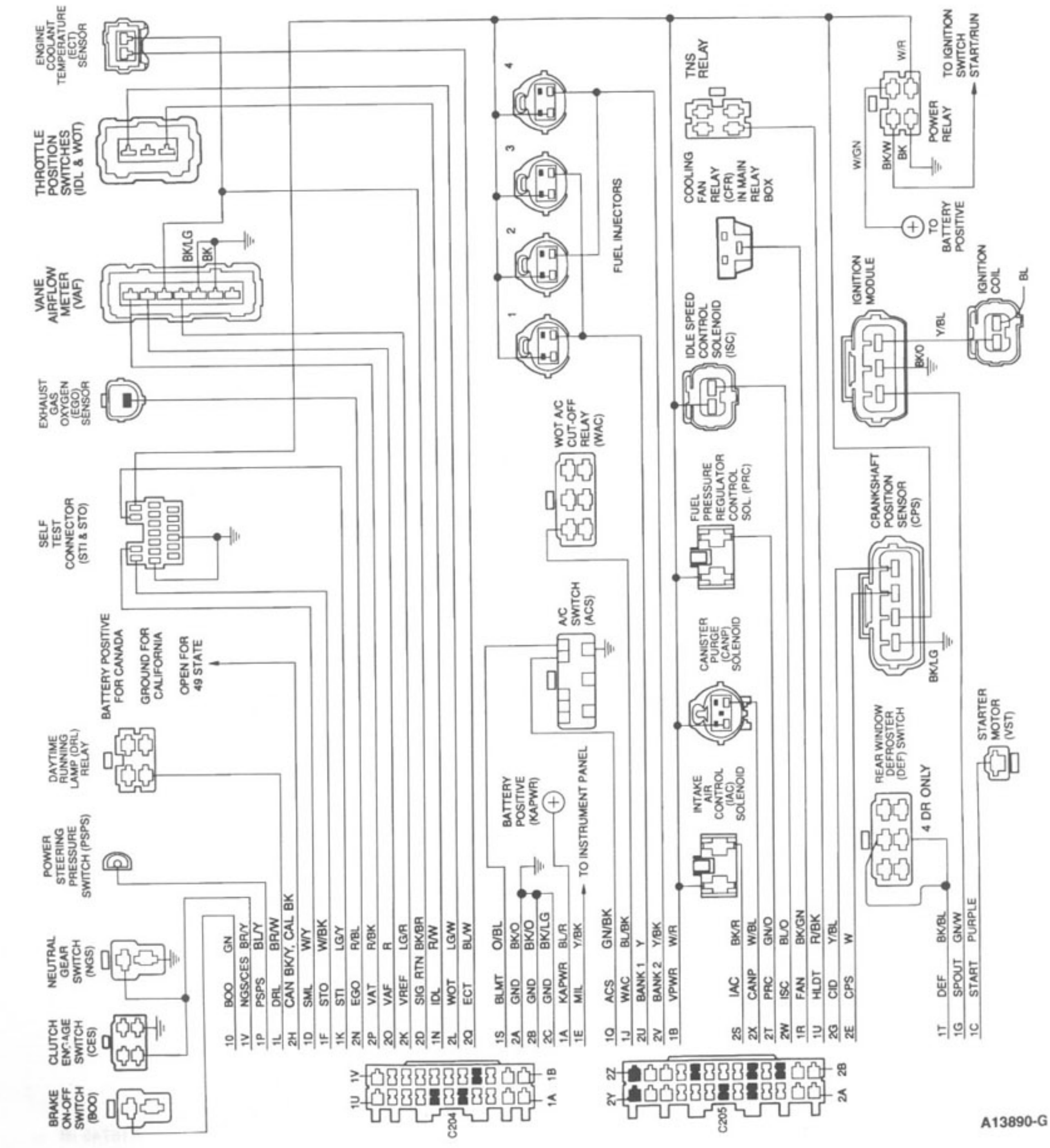
12

1.8 VAF
(VIN Code 8)

1991–1993 Escort, Tracer MTX

VIN: 1 2 3 4 5 6 7 8 ... 17

Engine code

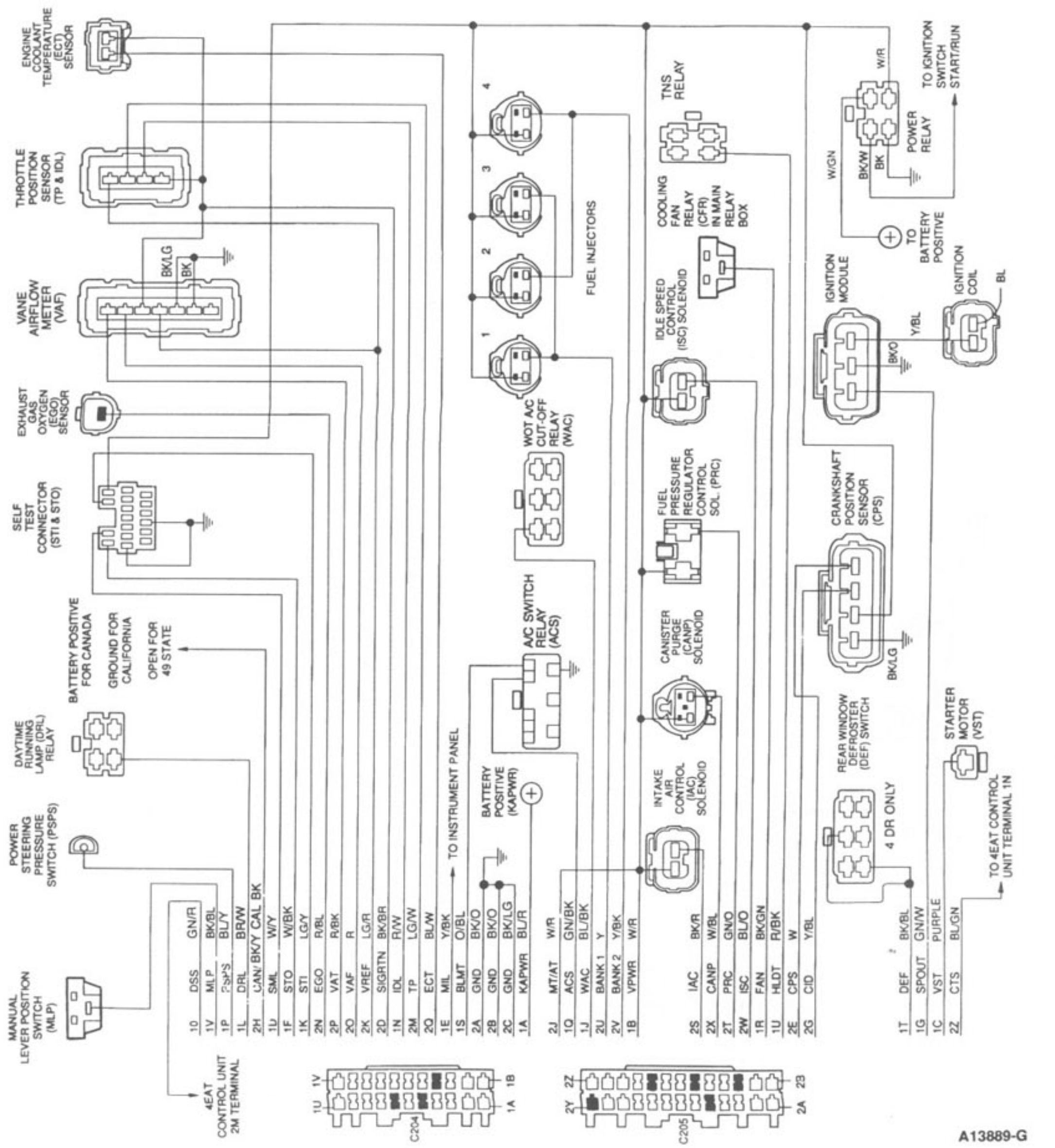


A13890-G

1991–1993 Escort, Tracer 4EAT

1.8 VAF
(VIN Code 8)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



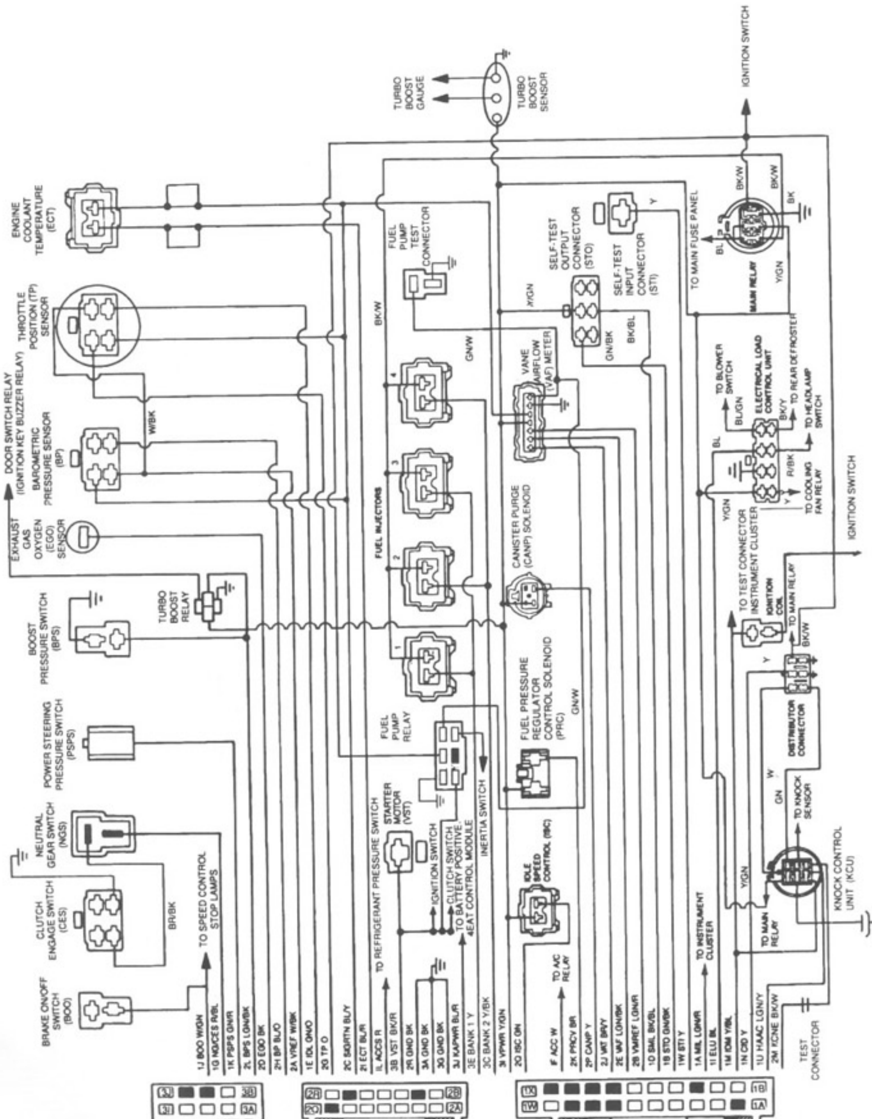
A13889-G

12

1.6L Turbo VAF
(VIN Code 6)

1991–1993
Capri

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

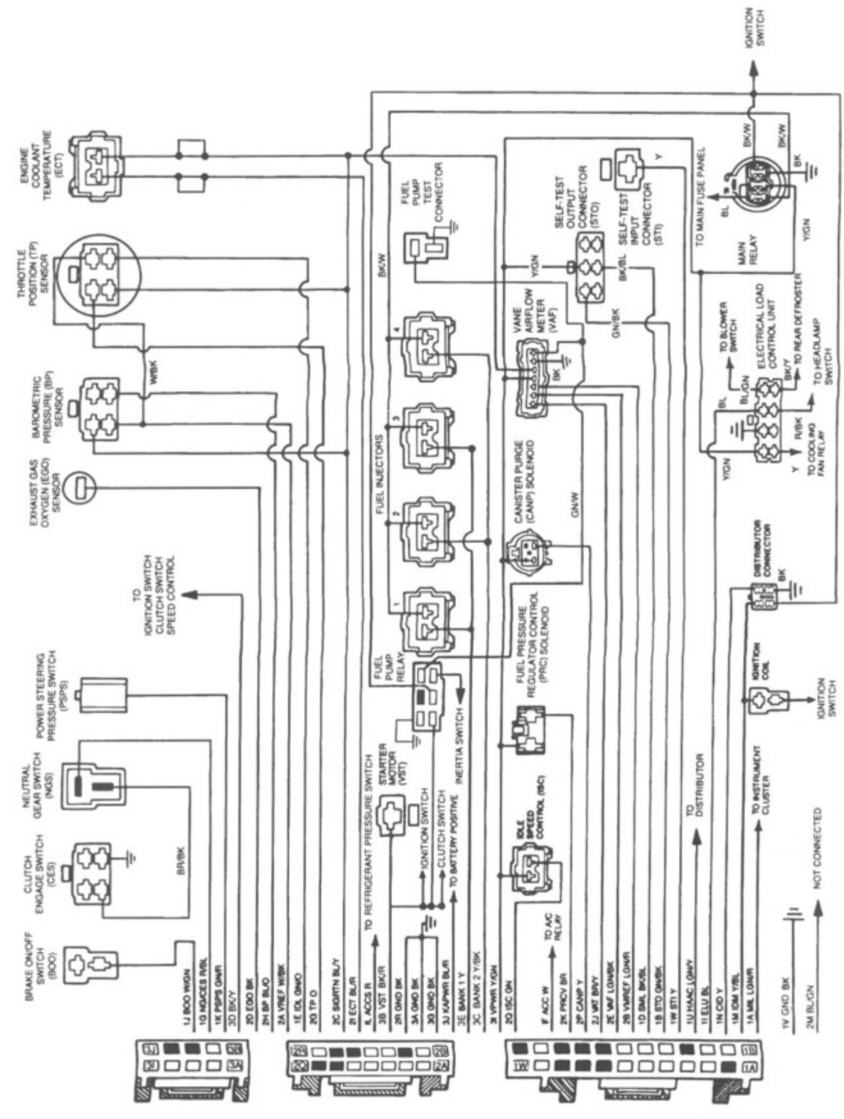


A14757-E

1991–1993
Capri
MTX

1.6L
Non-turbo VAF
(VIN Code Z)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

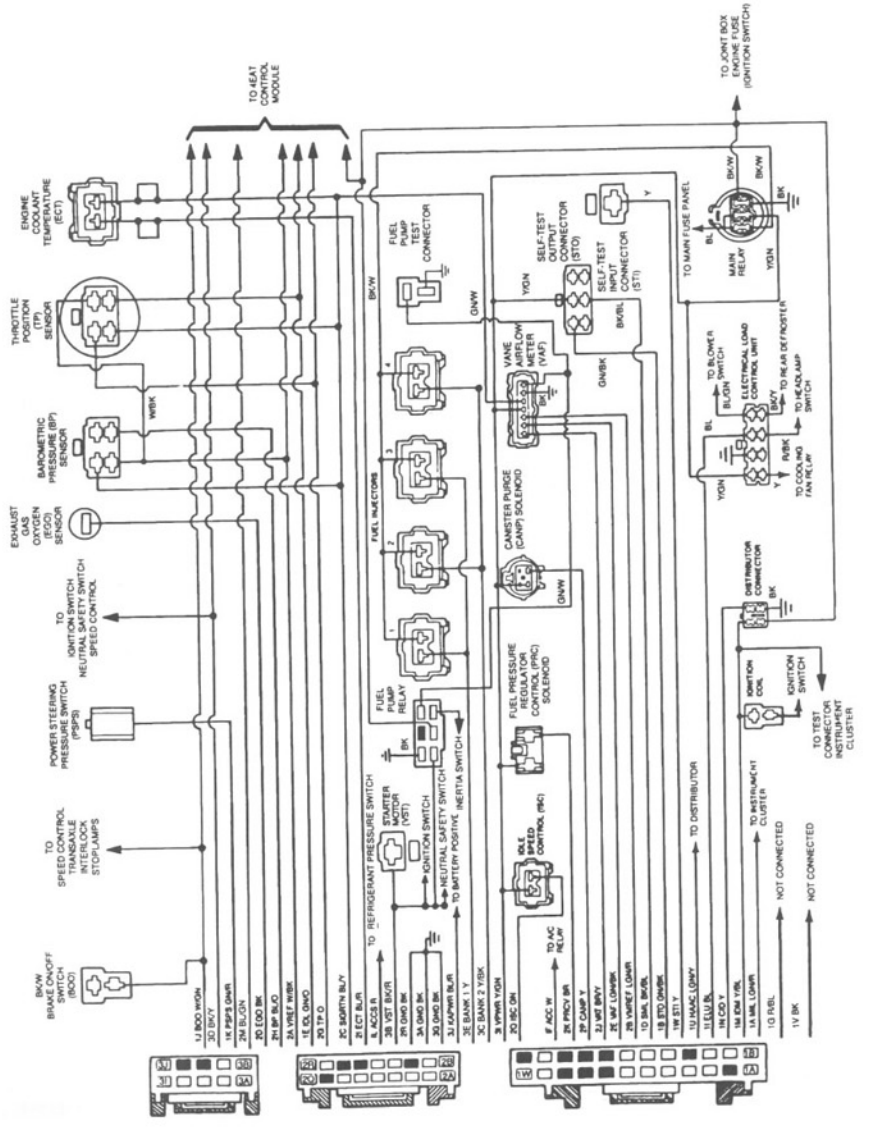


A15150-D

1.6L Non-turbo VAF
(VIN Code Z)

1991–1993
Capri
4EAT

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code

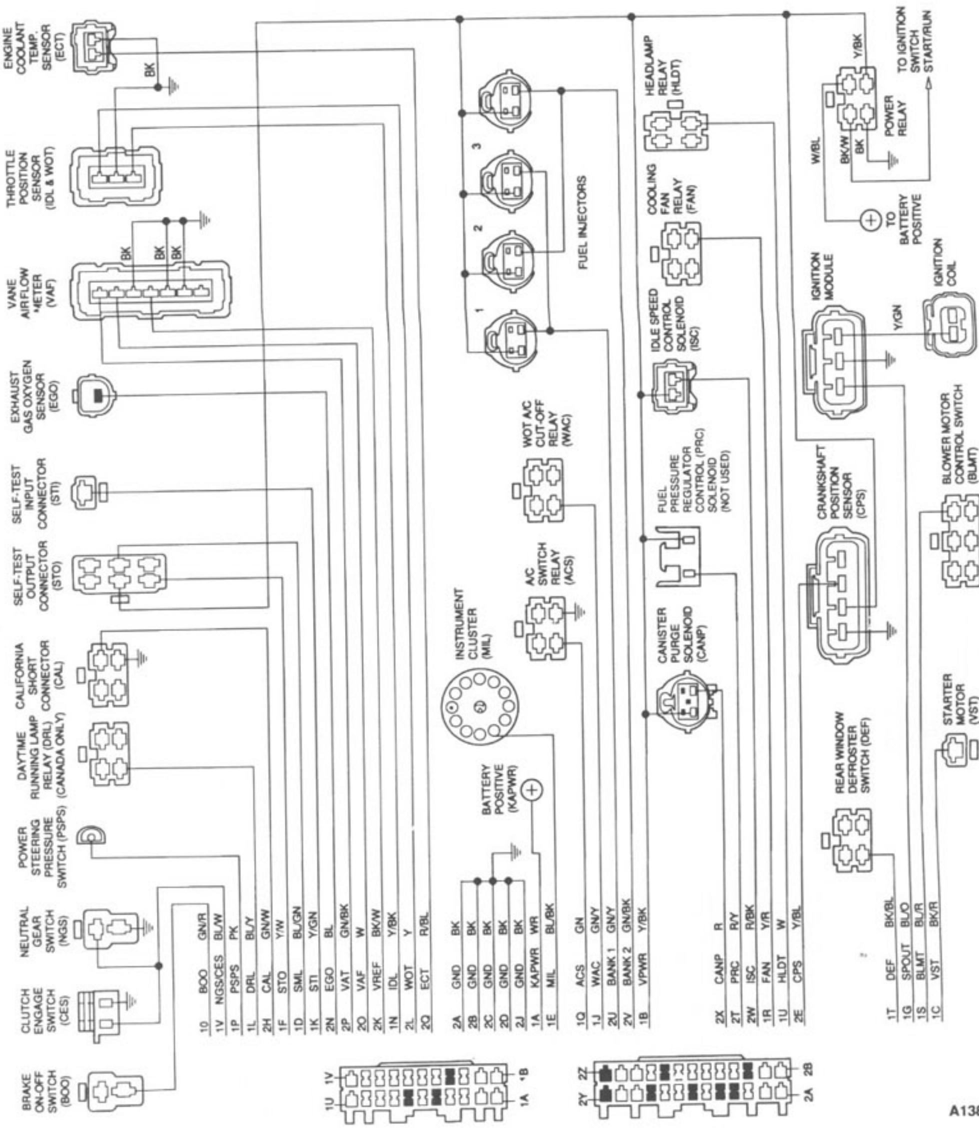


A15149-D

1991–1993 Festiva MTX

1.3L VAF (VIN Code H)

VIN: 1 2 3 4 5 6 7 8 ... 17
Engine code



A13882-C

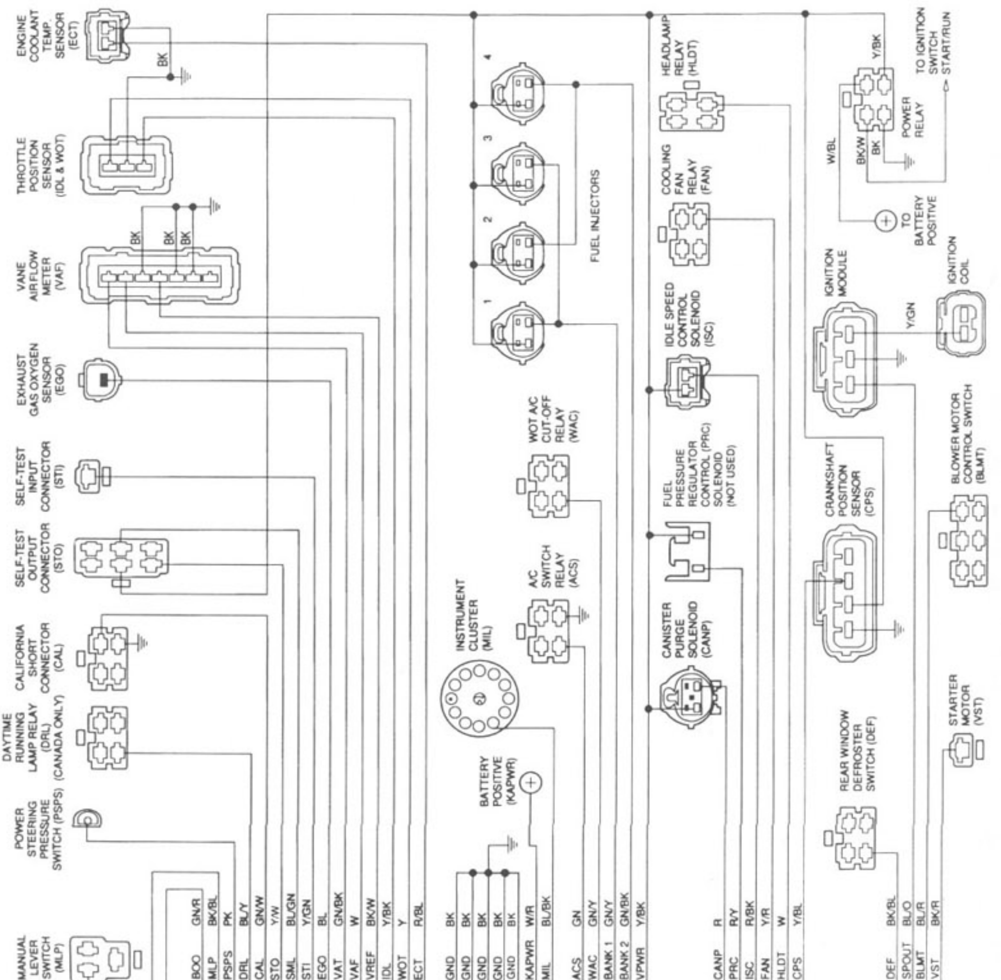
12

1.3L VAF (VIN Code H)

1991–1993 Festiva ATX

VIN: 1 2 3 4 5 6 7 8 ... 17

Engine code



1. Suppliers

Ford Products

Ford Motorsport Performance Equipment is available from selected Ford and Lincoln-Mercury dealers and selected automotive specialty performance outlets.

SVO catalog information, general inquiries and technical questions on products should be addressed to:

Ford Motorsport Performance Equipment
44050 N. Groesbeck Highway
Clinton Township, MI 48036-1108

or phone 313/337-1356

For official Ford Motor Company Shop Manuals and wiring diagrams, call "Helm Publications" at 1-800-782-4356.

Aftermarket Suppliers

The following list of suppliers will give you a starting point for investigation of possible modifications to your system. Again, I list these without making any particular judgments about their merits.

Autotronics Controls Corp.
1490 Henry Brennan Dr.
El Paso TX 79936
915/857-5200

BBK Performance
1611 Railroad
Corona CA 91720
909/735-8892

Best Products/Pro-Flow
1250 A. Rankin St.
Troy, MI 48083
313/585-6890

Charlie's Mustangs
766-A N 9th
San Jose CA 95112
408/275-6511
5.0 Performance Center

Crane Cams, Inc.
530 Fentress Blvd.
Daytona Beach FL 32114
904/258-6174

Fairway
1350 Yorba Linda Blvd.
Placentia CA 92670
714/528-4670
ADS superchip

Flo-master
22 Oak Ln.
Stonington, CT 06378
203/536-1700
ECU not street legal, convert small block carb

Granatelli Performance
21417 Ingomar #5
Canoga Park CA 91304
818/727-7122
Superchargers

HKS USA
20310 Gramercy Pl.
Torrance CA 90501
310/328-8100
High performance for MEC engines

Hypertech, Inc.
1910 Thomas Rd.
Memphis TN 38134
901/382-8888
Power modules

Kaufman Products, Inc.
12420 Benedict Ave.
Downey CA 90242
310/803-5531
Hi-flow intake system

Kenne Bell
10743 Bell Court
Rancho Cucamonga, CA 91730
909/941-6646

Nitrous Oxide Systems, Inc.
5930 Lakeshore Drive
Cypress CA 90630
714/821-0580

Paxton Superchargers
1260 Calle Suarte
Camarillo CA 93012
805/987-5555
Street-legal superchargers

Saleen
3080 29th St.
Long Beach CA 90806
310/595-5964
Throttle bod, other eng mods

Spearco Performance,
14664 Titus
Panorama City, CA 91402
818/901-7851
Twin turbo 5.0L, intercoolers

Specialty Equipment Market Association (SEMA)
1575 South Valley Vista Dr.
Diamond Bar, CA 91765
909/396-0289

Steeda Autosports
2241 Hammondville Rd.
Pompano FL 33069
305/960-0774
Engine mods

Texas Turbo
9703 Plainfield
Houston TX 77036
713/988-0541
5.0 piggyback proc, removable chips, 4 stages

Turbo Tech
6229 S. Adams
Tacoma WA 98409
206/475-8319
Turbo, 5.0L

Vortech Engineering
5351 Bonsai Ave.
Moorpark CA 93021
805/529-9330
Centrifugal superchargers, street legal

1. CARB Exemption Order List

Table CARB Exemption Order Components

Manufacturer/Model Kit	Application	Model Year	General Exemption Order #
Autotronics Controls Corp. *MSD ignition components*	All	All	D-40
ACF Industries *Engine Knock Eliminator*	All single TFI coil		D-137
BBK Performance *Equal-Length Shorty Header*	5.0L Mustang, Capri, Mark VII		D-245
Crane Cams, Inc. *Interceptor ECU* *Digital Timing Control* *Modular Trigger Ignition* *Ignition Coil*	5.0L Mustang All EEC-IV TFI ignition	1990–On 1988–On	D-225
Edelbrock Corp. *Tubular Exhaust System*	5.0L passenger cars	1986–On	D-215
HKS USA, Inc. *Twin-Power CD Ignition* *Intercooler*	All 2.2L Probe	1988–On 1988–On	D-186
Hedman Mfg. Co. *Tubular Exhaust Manifold*	5.0L Mustang	1986–On	D-167
J. Bittle American *Shorty Headers*	5.0L Mustang 5.0L, 5.8L Trucks 5.0L T-Bird 5.0L Lincoln LSC 4.0L Trucks 5.7L F-150 Trucks	1985–91 1985–On 1990–On 1986–On 1990–On 1988–On	D-216
Kenne Bell *Twin Screw Whipplecharger TS 1000*			D-271
M.A.C. Products *Stubbie Header*	5.0L Mustang, Truck 5.0L T-Bird/Cougar	1986–On 1990–On	D-241
Nitrous Oxide Systems *NO2 Injection Kit*	5.0L	1986–On	D-266
Paxton Superchargers *Supercharger SN-89, V-1*	5.0L, 5.8L	1986–On	D-195
Professional Flow Tech *Pro-M Mass Air Flow Sensor*	5.0L Mustang 3.8L T-Bird	1988–On 1990–On	D-242
Spearco Performance Products *Intercooler*	2.3L Turbo	1988–On	D-140
Vortech Engineering *Supercharger* *Boost Timing Master*	5.0L Passenger cars	1986–On	D-213

Warning—

- Automotive service and repair is serious business. You must be alert, use common sense, and exercise good judgement to prevent personal injury.
- Before beginning any work on your vehicle, thoroughly read all the Cautions and Warnings listed near the front of this book.
- Always read the complete procedure before you begin the work. Pay special attention to any Cautions and Warnings that accompany that procedure, or other information on a specific topic.

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- Always read the complete procedure before you begin the work. Pay special attention to any Cautions and Warnings that accompany that procedure, or other information on a specific topic.

V

W

Art courtesy of Ford Motor Company

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Chapter 12

All except Fig. 1-1, and Fig. 1-2

Art courtesy of Centerline

Chapter 9

Fig. 4-2

Art courtesy of Chevron

Chapter 11

Fig. 2-16, Fig. 2-18

Art courtesy of Probst

Chapter 1

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Glossary

NOTE —
This glossary list terms used by Ford up through 1992. For new terms instituted in 1993 (as per SAE J1930) see inside front cover.

4EAT: 4-Speed Electronic Automatic Transaxle.

4X4L: 4X4 Low input switch.

A4LD: Automatic 4-Speed Lock-up-converter Drive.

ABSOLUTE PRESSURE: Pressure measured from the point of total vacuum. For example, absolute atmospheric pressure at sea level is 14.5 psi (1 bar).

A/C: Air Conditioning.

ACC: A/C Clutch Compressor signal input to the EEC-IV control module relating status of the A/C clutch.

ACCS: A/C Cycling Switch.

A/C P: A/C Pressure Cut-out switch.

ACL: Automatic Adjustable Shock Controller.

A/CL BIMET: Air Cleaner Bimetal sensor.

ACD: Air Conditioner Demand switch.

ACs: Air Conditioner switch or its signal circuit.

ACT: Air Charge Temperature sensor or its signal circuit.

ACV: Air Control Valve (Thermactor).

ADAPTIVE CONTROL: The ability of the control module to adapt closed-loop control to changing operating conditions such as engine wear, fuel quality, or altitude to improve control of the air-fuel ratio, ignition timing, or idle rpm. Sometimes referred to as self-learning.

AHFSS: Air Condition/Heater Function Select Switch input to the EEC-IV control module relating status of the A/C heater function select switch.

AIR BPV: (Thermactor) Air Bypass Valve.

AIR-FUEL RATIO: The amount of air compared to the amount of fuel in the air-fuel mixture, almost always expressed in terms of mass. See also Stoichiometric Ratio.

AM1: Thermactor Air Management 1 (TAB).

AM2: Thermactor Air Management 2 (TAD).

AMBIENT TEMPERATURE: The temperature of the surrounding air.

AMPERE (AMPS): A measure of current flow. See also Milliampere (mA).

ATMOSPHERIC PRESSURE: Normal pressure in the surrounding atmosphere, generated by the weight of the air above us pressing down. At sea level, in average weather conditions, atmospheric pressure is approximately 100 kPa (about 14.5 psi) above vacuum or zero absolute pressure. See also Barometric Pressure.

ANTI-BFV: Anti-Backfire Valve.

AOD: Automatic Overdrive Transmission.

A/T or **ATX**: Automatic Transmission/Transaxle

ATDC: After Top Dead Center.

AVOM: Analog Volt-Ohm Meter.

AXOD: Automatic Transaxle Overdrive.

AXOD-E: Automatic Transaxle Overdrive, Electronically Controlled.

BAROMETRIC PRESSURE: Another term for atmospheric pressure. Expressed in inches of Mercury (in.Hg.): how high atmospheric pressure (relative to zero absolute pressure) forces Mercury up a glass tube. 14.5 psi = 29.92 in.Hg. See also Atmospheric Pressure.

BASE IDLE: Idle RPM when the throttle lever rest on the throttle stop and Idle Speed Control is fully retracted and disconnected.

BATT: Battery

BATT (+): Battery positive post or its circuit.

BATT (–): Battery negative post or its circuit.

BOB: Breakout Box. An EEC-IV test device that connects in series with the control module and the EEC-IV harness to permits measurements of control module inputs and outputs.

BOO: Brake On-Off input to the EEC-IV control module indicating braking.

BOOST: Condition of over-pressure (above atmospheric) in the intake manifold; caused by intake air being forced in by a turbocharger or supercharger.

BP: Barometric Pressure sensor or its signal circuit.

BPA: By-Pass Air Solenoid or Valve. Used to control idle speed and deceleration.

BREAKOUT BOX: See BOB.

BTDC: Before Top Dead Center.

BVT: Back Pressure Variable Transducer.

BYPASS: A channel that permits passage (usually of air) around a closed valve such as the throttle.

CANP: Canister Purge solenoid or its control circuit.

CSE GND: Case Ground (EEC-IV control module case).

CATALYST: Material that starts or speeds up a chemical reaction without being consumed itself. The metal coatings inside a catalytic converter.

CATALYTIC CONVERTER: Device mounted in the exhaust system that converts harmful exhaust emissions into harmless gases. Works by catalytic action which promotes additional chemical reaction after combustion.

CBD: Closed Bowl Distributor.

CCC: Converter Clutch Control solenoid or its control circuit.

CCD: Computer Controlled Dwell.

CCO: Converter Clutch Override output from the EEC-IV control module to the transmission.

CCS: Coast Clutch Solenoid or its control circuit.

CES: Clutch Engage Switch.

CFI: Central Fuel Injection. A computer controlled fuel metering system which sprays atomized fuel into a throttle body mounted atop the intake manifold.

CHECK ENGINE LIGHT: A dash panel light used either to aid in the identification and diagnosis of EEC system problems or to indicate that maintenance is required on non-EEC equipped vehicles. See MIL.

CID: Cylinder Identification sensor or its signal circuit.

CLC: Converter Lock-up Clutch.

CLOSED-LOOP CONTROL: A feedback system that maintains a prescribed limit in another system by monitoring the output of that system.

CLUTCH: Clutch engagement switch or its control circuit.

CO: Carbon Monoxide. One of the harmful gases produced by combustion. CO in the exhaust is measured during a tune-up as an indication of combustion efficiency.

COC: Conventional Oxidation Catalyst.

COLD-START: Starting the engine when it is cold; when the engine has not run for several hours.

COMBUSTION: Controlled, rapid burning of the air-fuel mixture in the engine's cylinders.

COMBUSTION CHAMBER: Space left between the cylinder head and the top of the piston at TDC; where combustion of the air-fuel mixture takes place.

COMPRESSION RATIO: The ratio of maximum engine cylinder volume (when the piston is at the bottom of its stroke) to minimum engine cylinder volume (with the piston at TDC). Thus, the theoretical amount that the air-fuel mixture is compressed in the cylinder.

COMPUTED TIMING: The total spark advance in degrees before top dead center. Calculated by the EEC-IV control module based on input from a number of sensors.

CONTINUITY: Little or no resistance in an electrical circuit to the flow of current. A solid electrical connection between two points in a circuit. The opposite of an open circuit.

CONTINUOUS SELF-TEST: A continuous test of the EEC-IV system conducted whenever the vehicle is in operation.

CONTROL MODULE: A transistorized device that processes electrical inputs and produces output signals to control various engine functions.

CPS: Crankshaft Position Sensor or its signal circuit.

CTS: Coolant Temperature Switch.

CURB IDLE: Computer controlled Idle RPM.

CURRENT: Amount or intensity of flow of electricity. Measured in Amperes.

CWM: Cold Weather Modulator.

DCL: Data Communications Link.

DENSITY: The ratio of the mass of something to the volume it occupies. Air has less density when it is warm, and less density at higher altitude.

DFS: Decel Fuel Shut-off.

DIS: Distributorless Ignition System (low data rate).

DMIVA: Distributor Mounted Ignition with Vacuum Advance.

DOL: Data Output Link. Fuel calculation data from the EEC-IV control module to the electronic tripminder.

DPDIS: Dual Plug Distributorless Ignition System.

DPFE: Delta Pressure Feedback EGR sensor or its signal circuit.

DPH: Dual Plug Head.

DPI: Dual Plug Inhibit.

DRIVEABILITY: Condition describing a car in which it starts easily and idles, accelerates, and shifts smoothly and with adequate power for varying temperatures.

DUTY CYCLE: In components which cycle on and off, measurement of the amount of time a component is on. The measurement is expressed in percent, with 100/% the maximum. See also Dwell.

DV: Delay Valve.

DVOM: Digital Volt-Ohm Multimeter that displays voltage or resistance measurements in digital form on a liquid crystal display (LCD).

DV TW: Delay Valve Two-Way.

DWELL: The amount of time that primary voltage is applied to the ignition coil to energize it. Also, a measurement of the duration of time a component is on relative to the time it is off. Dwell measurements are expressed in degrees, for example degrees of crankshaft rotation. See also Duty Cycle.

EATC: Electronic Automatic Temperature Control.

E40D: Electronic 4-Speed Overdrive transmission.

ECA: Electronic Control Assembly.

ECT: Engine Coolant Temperature sensor or its signal circuit.

EDF: Electro-Drive Fan relay or its control circuit.

EDIS: *Electronic Distributorless Ignition System* (high data rate).

EEC: Electronic Engine Control. A computer controlled system of engine control.

EEGR: Electronic EGR Valve (Sonic).

EFI: Electronic Fuel Injection. A computer controlled fuel system that distributes atomized fuel through an injector located in each intake port of the engine. The fuel injectors are fired using bank-to-bank circuitry.

EGO: Exhaust Gas Oxygen sensor or its signal circuit.

EGOG: EGO Ground.

EGR: Exhaust Gas Recirculation. The process of feeding a small amount of exhaust gas back into the intake manifold to reduce combustion temperatures as a method of controlling emissions.

EGRC: EGR Control vacuum solenoid valve or its control circuit.

EGR S/O: EGR Shut Off.

EGRV: EGR Vent vacuum solenoid valve or its control circuit.

EHC: Exhaust Heat Control vacuum solenoid valve or its control circuit.

EMISSIONS: By-products of combustion released in the exhaust. Refers mostly to carbon monoxide (CO), hydrocarbons (HC), and nitrous oxides (NO_x).

EMW: Emission Maintenance Warning Module. the EEC-IV system conducted with the engine running and the vehicle at rest.

ENGINE POWER: Measure of the ability of the engine to *move the car. See also Horsepower.*

ENGINE RUNNING SELF-TEST: A test of the EEC-IV system conducted with power applied and the engine at rest.

EPC: Electronic Pressure Control solenoid or its control circuit.

ER: Engine Running Self-Test (same as KOER).

ERS: Engine RPM Sensor or its signal circuit.

EVP: EGR Valve Position sensor or its signal circuit.

EVR: EGR Vacuum Regulator solenoid or its control circuit.

FALSE AIR: Air that leaks into the intake system without being measured by the fuel injection system.

FCS: Fuel Control Solenoid or its control circuit.

FI: Fuel Injector or its control circuit.

FIPL: Fuel Injection Pump Lever sensor or its signal circuit.

FLOODING: An excess of fuel in the cylinder, from an over-rich mixture, that prevents combustion.

FMEM: *Failure Mode Effects Management.*

FP: Fuel Pump relay or its control circuit.

FPM: Fuel Pump Monitor. A circuit in the EEC system used to monitor the electric fuel pump operation on some EEC-IV equipped vehicles.

FTO: Filtered Tach Output. An output from the DIS TFI-IV module which provides a filtered ignition signal to the control module to control dwell.

FUEL INJECTION: Fuel delivery system that generally uses an air-flow sensing device as an input signal for precise metering of the fuel for a given air flow, injecting that fuel into the air stream at the intake ports of the engine. Replaces a carburetor or carburetors.

FUEL METERING: Control of the amount of fuel that is mixed with engine intake air to form a combustible mixture.

FUEL RAIL: Pipe on EFI systems delivering fuel at system pressure to the injectors. Storage volume of the fuel rail influences stability of fuel pressure in the system.

FUEL RICH/LEAN: A qualitative evaluation of air/fuel ratio based on an air-fuel value known as stoichiometry or 14.7. In the EEC-IV system rich/lean is determined by a voltage signal from the oxygen sensor. An excess of oxygen (lean) is a voltage of less than.4 volts. A rich condition is indicated by a voltage of greater than.6 volts.

FWD: Front Wheel Drive.

GND or **GRND**: The return path for current in a circuit. Because the negative terminal of the battery is connected to the car chassis, the metal parts of the car usually serve as this path.

GOOSE: A brief opening and closing of the throttle (Dynamic Response Test).

HALL EFFECT: A process where current is passed through a small slice of semi- conductor material at the same time as a magnetic field to produce a small voltage in the semi-conductor.

HBV: Heater Blower Voltage input to the EEC-IV control module reflecting heater blower voltage demand.

HEDF: High speed Electro-Drive Fan relay or its control circuit.

HEGO: Heated EGO sensor or its signal circuit.

HEGOG: Heated EGO Ground.

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HERTZ: Measure of frequency: cycles per second. Abbreviated as Hz.

HIC: Hot Idle Compensator.

HLOS: Hardware Limited Strategy. Certain types of malfunction will place the into HLOS mode. Output commands are replaced with fixed values.

HO: High Output.

HORSEPOWER: The rate of doing work. A common measure of engine output also expressed in metric kilowatts (Kw).

HOT START: Starting the engine when it is at or near normal operating temperature.

HSC: High Swirl Combustion.

HSF: High Speed Cooling Fan or itscontrol circuit.

HSIA: High Speed Inlet Air.

IAC: Inlet Air Control solenoid or its circuit.

IAS: Inlet Air Solenoid valve or its control circuit.

IBP: Integral Back Pressure.

IDEAL AIR-FUEL RATIO: (See Stoichiometric Ratio)

IDL: Idle switch or its control circuit.

IDLE LIMITER: A device to control minimum and maximum idle fuel richness. The idle limiter is intended to prevent unauthorized persons from making overly rich idle adjustments.

IDM: Ignition Diagnostics Monitor. A continuous monitor of the ignition input to the EEC-IV control module used to detect intermittent ignition faults.

IGN: Ignition circuit or system.

IGNITION: The point at which the spark causes combustion to begin.

IGNITION ADVANCE/RETARD: Changing the moment of combustion in relation to the point of piston travel. Ignition advance begins combustion earlier; ignition retard begins combustion later.

IMS: Inferred Mileage Sensor. A circuit using an E-cell which deflates its state with the application of a current. As the vehicle ages (in terms ofKey-On time) the EEC-IV control module compensates for aging of the vehicle by changing calibration parameters.

In.Hg: (See Barometric Pressure)

INJ: Injector (Fuel).

INJ GND: Injector Ground (Fuel).

IRCM: Integrated Relay Control Module.

ISC: Idle Speed Control. Currently there are two types of computer controlled idle speed control: D.C. motor ISC and air bypass ISC-BPA.

ITS: Idle Tracking Switch.

KAM: Keep Alive Memory. A series of vehicle battery powered memory locations in the microprocessor which allows the microprocessor to store input failures identi ed during normal operation for use in later diagnostic routines and adapts some calibration parameters to compensate for changes in the vehicle system.

KAPWR: Keep Alive Power.

KC: Knock Control circuit.

KCU: Knock Control Unit or its control circuit.

KILOPASCALS (kPa): 1,000 pascals, a unit of pressure. 100 kPa ≈ Atmospheric Pressure at sea level.

KNOCK: Sudden increase in cylinder pressure caused by pre-ignition of some of the air-fuel mixture as the ame front moves from the spark-plug ignition point. Pressure waves in the combustion chamber crash into the piston or cylinder walls. This results in the sounds known as knock or ping. Strongly in uenced by fuel-octane rating, ignition timing, and compression ratio.May be caused by hot carbon deposits on the piston or cylinder head.

KNOCK SENSOR: A vibration sensor attached to the cylinder block that generates voltage when knock occurs. The voltage signals a control unit that adjusts timing (and limits boost on turbocharged cars) to stop the knock.

KOEO: Key On Engine Off.

KOER: Key On Engine Running (same as Engine Running (ER)).

kPa: (See Kilopascals)

KS: Knock Sensor or its signal circuit

LED: Light Emitting Diode. A semiconductor that emits light when current is applied to it. Often used as an indicator in place of a light bulb.

LFP: Low Fuel Pump relay.

LOAD: The amount of work the engine must do. When the car accelerates quickly from a standstill, the engine is under a heavy load.

LUS: Lock-Up Solenoid.

MAF: Mass Air Flow Sensor or its signal circuit.

MAP: Manifold Absolute Pressure sensor or its signal circuit. Manifold pressure measured on the absolute pressure scale, an indication of engine load. At sea level, with the engine off, MAP ≈ 100 kPa (14.5 psi).

Map: A pictorial representation of a series of data points stored in the control module memory. The control module refers to these maps to control different functions, including fuel injection and ignition timing.

MASS: The quantity of matter contained in an object. Also a measure of that object's resistance to acceleration. With normal earth gravity, it is equivalent to weight. In fuel injection, measured air volume must be corrected for temperature and density to determine its approximate mass.

MCU: Microprocessor Control Unit.

MECS: Mazda Engine Control System.

MFI: Multi-port Fuel Injection.

MIL: Malfunction Indicator Light or its control circuit. A light in the dash panel that indicates a malfunction in the EEC system. May read either CHECK ENGINE or SERVICE ENGINE SOON .

MILLIAMPERE (mA): One-one-thousandth of one ampere.

MLP: Manual Lever Position sensor or its signal circuit.

MLUS: Modulated Lock Up Solenoid or its control circuit.

MONITOR BOX: An EEC-IV test device which connects in series with the EEC-IV control module and its harness, and permits measurements of control module inputs and outputs.

M/T or **MTX**: Manual Transmission/Transaxle

MULTI-PORT INJECTION: An injection system where fuel is injected into the intake manifold at each manifold port near the intake valve.

NDS: Neutral Drive Switch and its signal circuit.

NECCS: Nissan Electronic Concentrated engine Control System.

NGS: Neutral Gear Switch or its signal circuit.

NPS: Neutral Pressure Switch or its signal circuit.

NTC: Negative Temperature Coef cient. Resistance decreases as temperature increases. See also Temperature Sensor.

OASIS: On-line Automotive Service Information System.

OBI: Overboost Indicator.

OCC: Output Circuit Check.

OCIL: Overdrive Cancel Indicator Light.

OCT: Octane Switch.

OCT ADJ: Octane Adjust device which modi es spark advance.

OHC: Overhead Cam.

OHM: Unit of measure of resistance to ow of electrical current. The more ohms of resistance the less current ow.

OPEN CIRCUIT: A circuit which does not provide a complete path for the ow of current.

OPEN-LOOP CONTROL: Control of an engine system based on xed, pre-set values.

OSC: Output State Check.

OVERLAY CARD: A plastic card used with the Monitor box to identify EEC-IV signals for each engine. The card also programs the monitor for auto mode measurements.

NO_x: Oxides of Nitrogen. One of the harmful gases produced by combustion. NO_x formation is affected by combustion chamber temperatures.

PART-LOAD: Throttle opening between idle and fully-open.

PCV: Positive Crankcase Ventilation. A system which controls the flow of crankcase vapors into the engine intake manifold where they are burned in combustion rather than being discharged into the atmosphere.

PFE: Pressure Feedback EGR sensor or its signal circuit.

PGC: Power and Ground Connection.

PINTLE: The tip of the injector that opens to deliver fuel. Shape of the pintle determines the spray pattern of the atomized fuel.

PIP: Profile Ignition Pickup. A Hall-effect vane switch that furnishes crankshaft position data to the EEC-IV control module.

PORT INJECTION: A fuel-injection system where the fuel is injected into the intake manifold by individual injectors at each cylinder intake port, upstream of the intake valve.

PRC: Fuel Pressure Regulator Control.

PRESSURE REGULATOR: A spring-loaded relief valve that returns excess fuel to the fuel tank to maintain system pressure.

PROCESSOR: EEC-IV System electronic control unit (control module).

PSI: Abbreviation for Pounds-per-Square-Inch. PSI can be a measure of air or fluid pressure.

PSPS: Power Steering Pressure Switch. An EEC-IV control module input to regulate idle speed based on power steering load demand.

PULSE AIR SYSTEM: Part of the emission control system that utilizes a reed-type check valve which allows air to be drawn into the exhaust system as a result of exhaust pulses.

PULSE PERIOD: The available time, dependent on the speed of crankshaft rotation, for opening of pulsed solenoid injectors.

PULSE TIME: The amount of time that solenoid injectors are open to inject fuel. Also known as Pulse Width, especially when displayed on an oscilloscope as a voltage pattern.

PULSE WIDTH: (See Pulse Time)

PVS: Ported Vacuum Switch.

PWR GND: Power Ground.

QUICK TEST: A functional diagnostic test of the EEC system consisting of vehicle preparation and hookup, Key On Engine Off, Engine Running and Continuous self-tests.

RECORDER: An optional EEC-IV test device which works jointly with the Monitor box. It allows up to 8 EEC-IV signals to be electronically recorded over a 50-second period.

RELATIVE PRESSURE: In pulsed injection, the difference in pressure between fuel pressure in the injector, and pressure in the intake manifold.

RELAY: A switching device operated by a low current circuit which controls the opening and closing of another circuit of higher current capacity.

RELIEF VALVE: A pressure limiting valve located in the exhaust chamber of the thermactor air pump. It functions to relieve part of the exhaust air flow if the pressure exceeds a calibrated value.

RICH MIXTURE: A lack of air. Less air is drawn into the engine than is required for the stoichiometric ratio. There is still fuel left after all of the oxygen has burned. The air-fuel mixture is less than 14.7:1.

RPM: Revolutions-Per-Minute. The speed of crankshaft rotation.

RWD: Rear Wheel Drive.

SAW: Spark Angle Word. Timing information sent from EEC-IV to the EDIS module. This information is used by the EDIS module to calculate final ignition timing.

SBS: Supercharger Bypass Solenoid or its control circuit.

SC: Super Charged (Super Coupe).

SFI: Sequential Electronic Fuel Injection (also known as SEFI). Port fuel injection triggered off ignition timing that fires each injector separately.

SELF-TEST: One of three subsets of the EEC Quick Test; Key On Engine Off, Engine Running, and Continuous.

SDV: Spark Delay Valve.

SHED: Sealed Housing Evaporative Determination System.

SHO: Super High Output.

SHORT CIRCUIT: An undesirable connection between a circuit and any other point.

SIG RTN: Signal Return circuit for all sensor signals except HEGO.

SIL: Shift Indicator Light. A system that provides a visual indication to the driver of a vehicle when to shift to the next higher gear to obtain optimum fuel economy.

SML: Switch Monitor Lamp.

SOLENOID: An electromagnet that moves a plunger or metal strip when current is applied.

SPOUT: Spark Output Signal from the EEC- IV control module.

SS1: Shift Solenoid 1 or its control circuit.

SS2: Shift Solenoid 2 or its control circuit.

SS 3/4-4/3: Shift Solenoid 3/4-4/3. Output from the EEC-IV control module to the transmission that selects 3rd and 4th gears.

STAR: Self-Test Automatic Readout. A testing device in which the EEC and MCU systems output service codes in a digital format.

STG: Switch To Ground.

STI: Self Test Input circuit in the EEC and MCU systems used to initiate self test.

STO: Self Test Output circuit in the EEC and MCU systems that transmits service codes (pulses) to either a VOM or star tester.

STOICHIOMETRIC RATIO: An air-fuel ratio of 14.7:1. All of the air and all of the fuel is burned in the cylinder. The stoichiometric ratio is the best compromise between a rich air-fuel ratio for best power, and a lean air-fuel ratio for best economy. Also called the Ideal Air-Fuel Ratio.

STP: Switch To Power.

SVO: Special Vehicle Operations.

SYSTEM PRESSURE: Fuel pressure in the fuel lines and at the pressure regulator, created by the fuel pump.

TAB/TAD: Thermactor Air Bypass/ Thermactor Air Diverter vacuum solenoid valves or their control circuits.

TCP: Temperature Compensated (Acceleration) Pump.

TEMPERATURE SENSOR: A solid-state resistor, called a thermistor. Used to sense coolant (engine) temperature and air temperature. Sometimes referred to as an NTC sensor for its Negative Temperature Coefficient.

TFI: Thick Film Ignition. Distributor mounted module comprised of a custom integrated circuit, Darlington output device and associated thick film integrated components.

TGS: Top Gear Switch. A lock out mechanism that prevents the SIL from lighting when the vehicle is in top gear

THERMACTOR: A system for injection of air into the exhaust system to aid in the control of hydrocarbon and carbon monoxide in the exhaust.

THERMACTOR 11: See Pulse Air System.

THROTTLE VALVE: The movable plate in the intake tract controlled by the accelerator pedal. It controls the amount of air drawn into the engine.

THS: Transmission Hydraulic Switch.

THS 3/2: Transmission Hydraulic Switch - 3rd/2nd gear.

THS 4/3: Transmission Hydraulic Switch - 4th/3rd gear.

TIMING: Relationship between spark plug firing and piston position usually expressed in crank shaft degrees before (BTDC) or after (ATDC) top dead center of the

TIV: Thermactor Idle Vacuum Valve.

TK: Throttle Kicker vacuum solenoid valve or its control circuit.

TOT: Transmission Oil Temperature Sensor or its signal circuit.

TP: Throttle Position sensor or its signal circuit.

TPOUT: Throttle Position Output.

TSB: Technical Service Bulletin.

TSP: Throttle Solenoid Positioner.

TSS: Transmission Speed Sensor.

TTS: Transmission Temperature Switch.

TVS: Temperature Vacuum Switch.

TVV: Thermal Vent Valve.

TWC: Three Way Catalyst.

VACUUM: Anything less than atmospheric pressure.

VAF: Vane Air Flow sensor or its signal circuit.

VAPOR LOCK: A situation where fuel in the fuel system becomes so hot that it vaporizes, slowing or stopping fuel flow.

VAT: Vane Air Temperature sensor or its signal circuit.

VBAT: Vehicle Battery voltage.

VCK-V: Vacuum Check Valve.

VCV: Vacuum Control Valve.

VDV: Vacuum Delay Valve.

VM: Vane Meter.

VOLT: Unit of measure of electrical force. Voltage causes current (electrons) to flow in a circuit.

VOM: Volt-Ohm Meter used to measure voltage and resistance. Readings are indicated by sweep hand on a printed scale rather than a digital display.

VOTM: Vacuum Operated Throttle Modulator.

VPWR: Vehicle Power supply voltage regulated to 10 to 14 volts.

VR/S: Vacuum Regulator/Solenoid.

VRDV: Vacuum Retard Delay Valve.

VREF: Reference voltage supplied by the EEC-IV control module to some sensors and regulated to 5 volts.

VRESER: Vacuum Reservoir.

VREST: Vacuum Restrictor.

VR or **VRS**: Variable Reluctance Sensor. A non-contact transducer that converts mechanical motion into electrical control signals.

VRV: Vacuum Regulator Valve.

VSC: Vehicle Speed Control sensor or its signal circuit.

VSS: Vehicle Speed Sensor or its signal circuit.

VVA: Venturi Vacuum Amplifier.

VVC: Variable Voltage Choke relay or its control circuit.

VVV: Vacuum Vent Valve.

WAC: Wide-open throttle A/C Cutoff.

WOT: Wide-Open Throttle.

ZERO ABSOLUTE PRESSURE: A total vacuum. Zero on the absolute pressure scale.

About the Author

Charles O. Probst received his BSE (ME—Automotive) from the University of Michigan. His career specialty is technical communication, primarily in automotive subjects. He works as an instructional-system designer, writer and filmmaker, and has been responsible for numerous video and film productions, manuals, job guides, and other systems for improving human performance. He is also a writer/producer of many technician training videos, including "Dyno Diagnostics," and "Diagnostics by Scope and Scan Tool."

Probst was the Senior Author for Motor's Auto Engines & Electrical Systems, and also served as Technical Editor for a 60-volume set of self-instructional auto technology courses developed by the Commercial Trades Institute. He has been published in Automotive Engineering, Automobile Quarterly, Car Life, Consumer Digest, and Road Test.

He is active in the SAE as Chairman of the Technician Training Task Force, which is responsible for SAE Recommended Practices for technician-training systems.

In a second career, Probst served 27 years (with 8 on active duty) in the Air Force Reserve, concluding as a Colonel.

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