Chapter 5

Control Module—Computing Engine Operation

Contents

TABLES

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 trans–axles/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

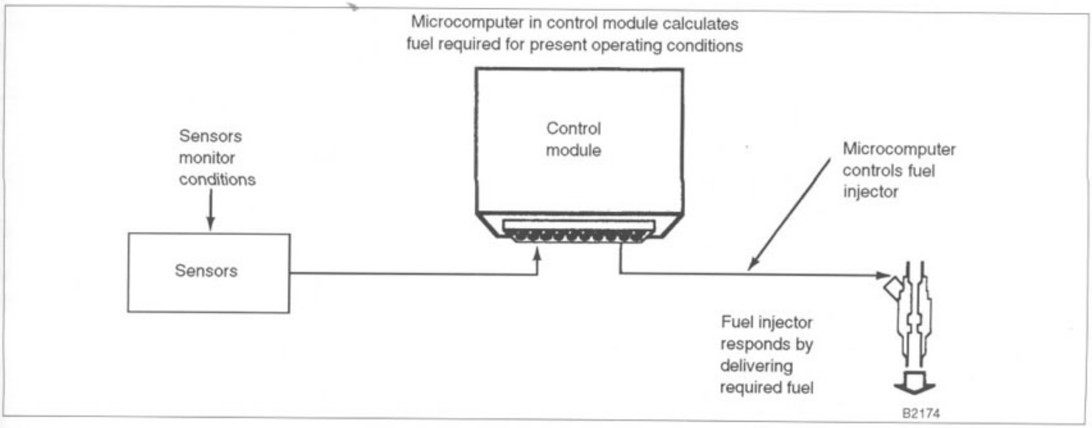


Fig. 1-1. Sensors monitor engine conditions, signal control module. Microcomputer calculates necessary operations and signals actuators. Fuel injector is actuator we think of first.

- *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.

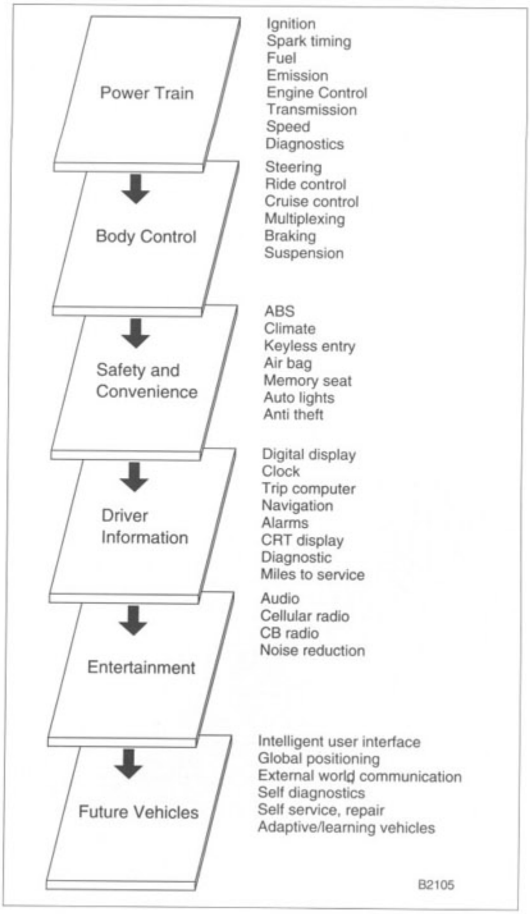


Fig. 1-2. EEC-IV engine control module is only beginning of applications to automotive systems.

What a Control Module Does

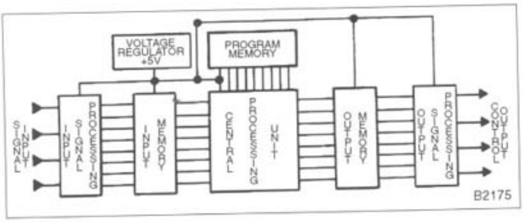


Fig. 1-3. Within control module, seven different functions are performed, from processing input signals to processing output signals.

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.

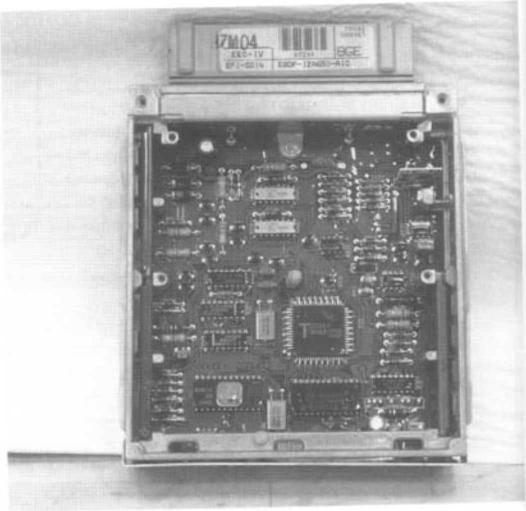


Fig. 1-5. Don't do this: Opening the EEC control module to make modifications (such as the installation of performance chips) can at the very least violate EPA regulations, and at the worst cause your engine to run poorly or ruin the control module.

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.

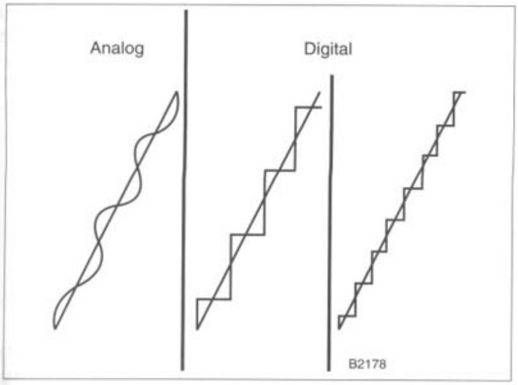


Fig. 2-2. Analog accuracy is limited by many variables. Digital is limited by number of steps.

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.

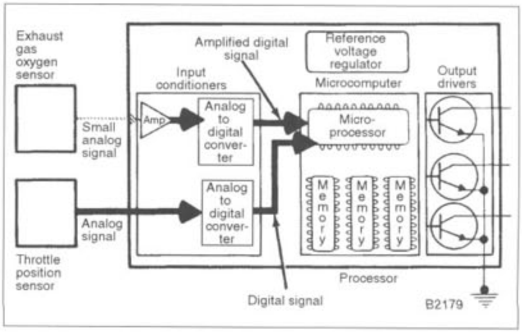


Fig. 2-3. Input conditioning. Input signals, from oxygen sensor, must be amplified and then converted Analog to Digital. Signals from ECT and ACT need A/D conversion. Also signals from TP.

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.

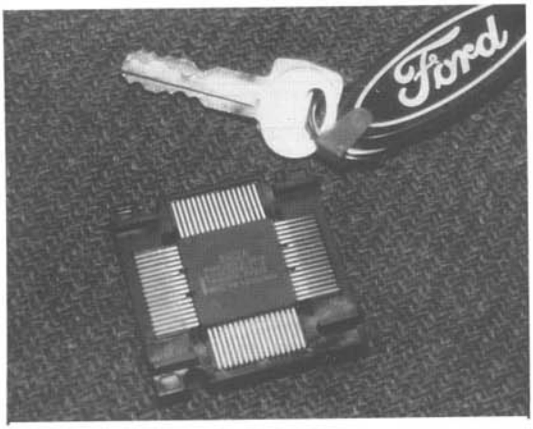


Fig. 3-1. Intel 8061 chip, a 16-bit microprocessor. Memory chip 8361 is similar. Each chip is an LSI—Large Scale Integrated circuit.

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.

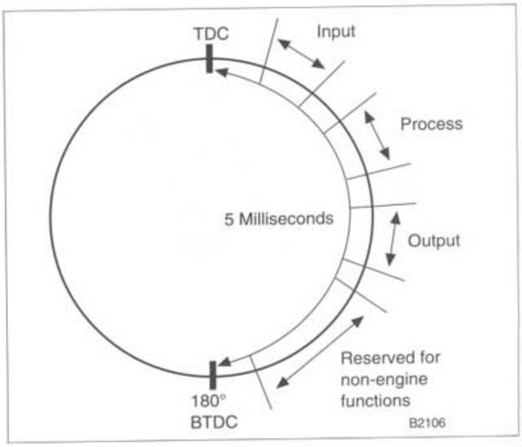


Fig. 3-2. For an SFI V-6 engine running 6,000 rpm, microprocessor must sense, process, and output individual-cylinder injection times and spark timing every 3.3 milliseconds.

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

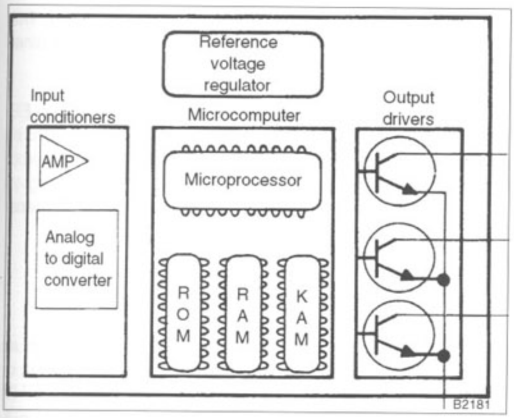


Fig. 3-. Three kinds of memory: 1) ROM—permanent engine data, 2) RAM—temporary storage, 3) KAM—stored semi-permanently, even with key off, lost when battery is disconnected.

3.1 Read Only Memory (ROM)

Strategy

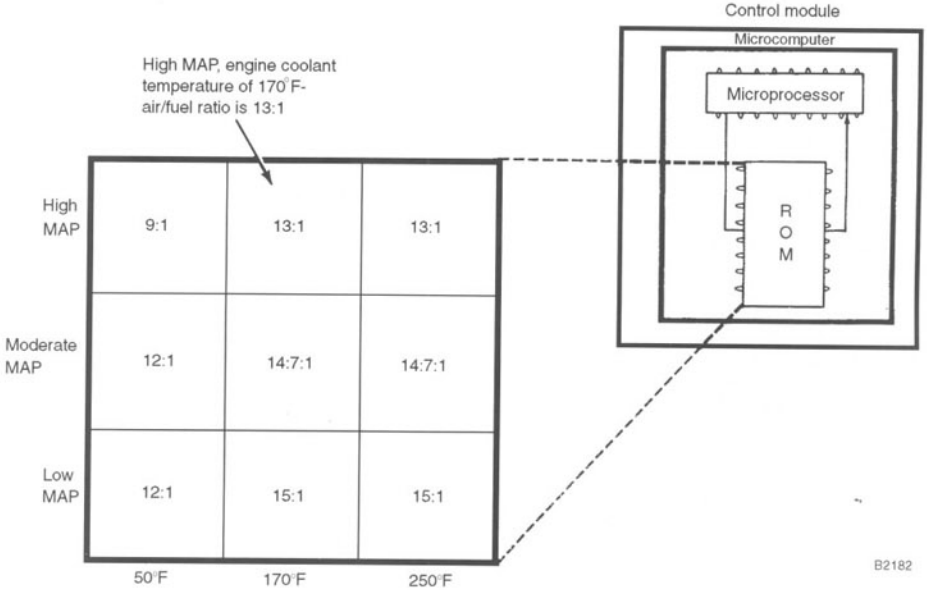
Strategy, a long-term memory in ROM, holds plans created by engine designers for the timing and control of EEC systems. For example, normal fuel control strategy is to maintain stoichiometric air-fuel ratios, while cold cranking fuel-control strategy is to enrich the mixture. More on Strategies in Chapter 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



High MAP	9:1	13:1	13:1
Moderate MAP	12:1	14:7:1	14:7:1
Low MAP	12:1	15:1	15:1
	50°F	170°F	250°F

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.

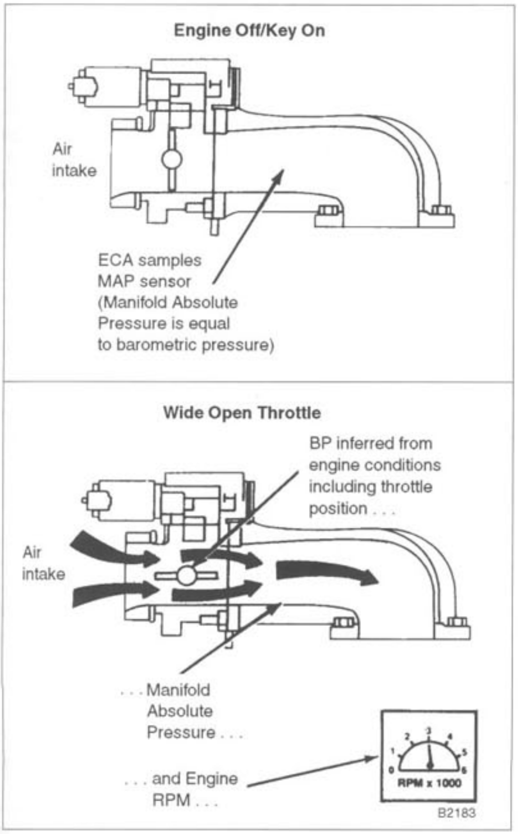


Fig. 3-5. In some engines, control module collects BP in RAM under two conditions: Key ON, engine OFF; WOT (Wide Open Throttle).

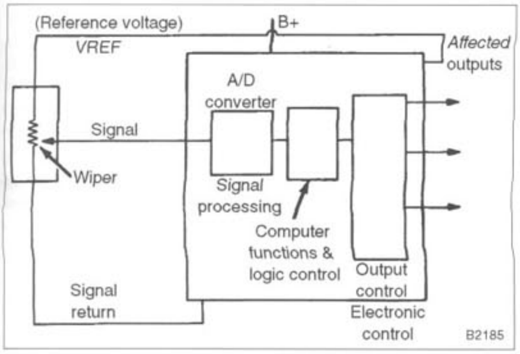


Fig. 3-6. For accuracy, some sensors require a steady fixed voltage input generated in the control module as Voltage Reference (VREF). EEC-IV VREF is 5v.

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

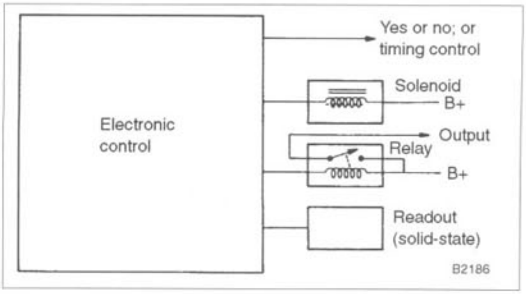


Fig. 4-1. Control module outputs are usually digital: yes/on = voltage, or no/off = no voltage. Output can operate a solenoid, a relay, or a solid-state readout.

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

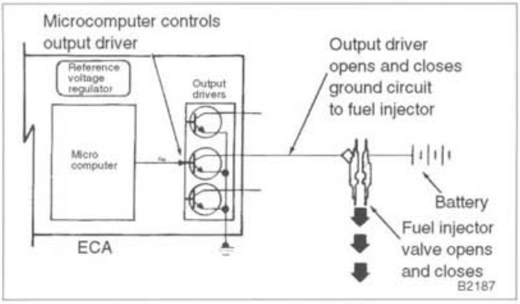


Fig. 4-2. Each output driver opens and closes ground circuit to its fuel injector. Each injector is supplied Vehicle Power (VPWR) from battery.

(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.

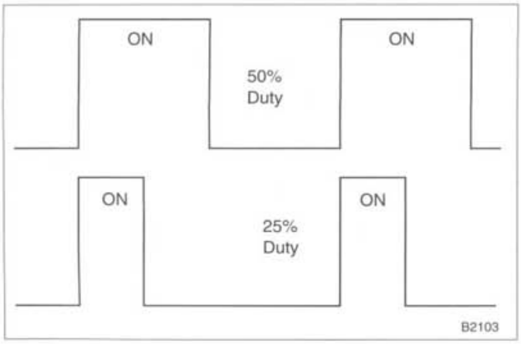


Fig. 4-3. If pulses are on 50% of time, circuit is passing 50% of current that it would with a closed circuit, 100%. A digital voltmeter will average input voltage. 50% duty cycle would read 6 v. from a 12 v. input source. 25%, 3V

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.

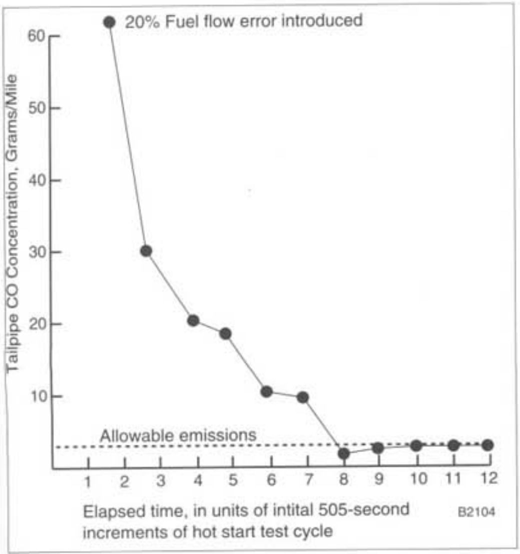


Fig. 5-1. In Ford test, control module Adaptive Strategy corrects an engine purposely set 20% rich, from over 60 g/mi. CO tailpipe emissions (about 17 times normal) to allowable, 3.4 g/mi. or less.

> 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.

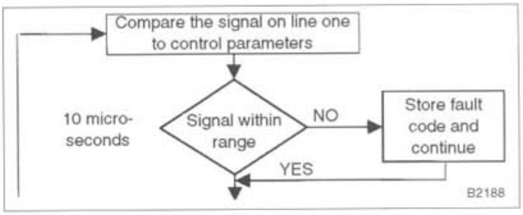


Fig. 6-1. Diagnostic-Test samples one signal at a time. Even at the blinding speed of microprocessor, this can take up to 10 microseconds (10 millionths of a second).

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.

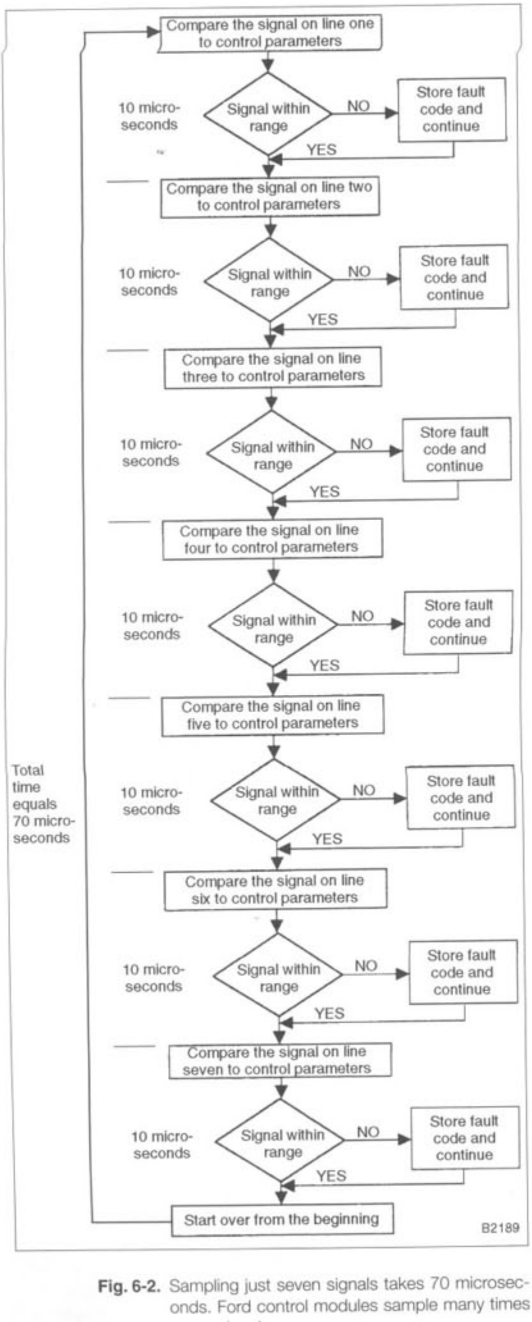


Fig. 6-2. Sampling just seven signals takes 70 microseconds. Ford control modules sample many times seven signals.

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

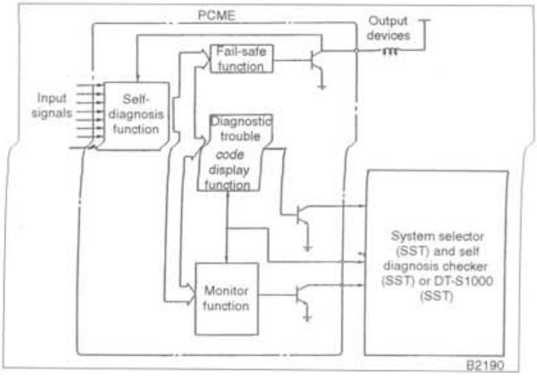


Fig. 7-1. MECS-II Diagnostic Test Mode (DTM) includes fail-safe function, similar to EEC Failure Mode Effects Management, with Code Display, and Code readout by scan tool.