Electronics in the

The XR6 is a factory-produced, high-performance version of the EF Falcon. Its 4-litre engine produces 164kW under the control of the newly-introduced EEC-V engine management system.

The latest EF Falcon has a new engine management module with 88Kb of on-board memory. In addition, the system now features sequential fuel injector operation & triple-coil ignition.

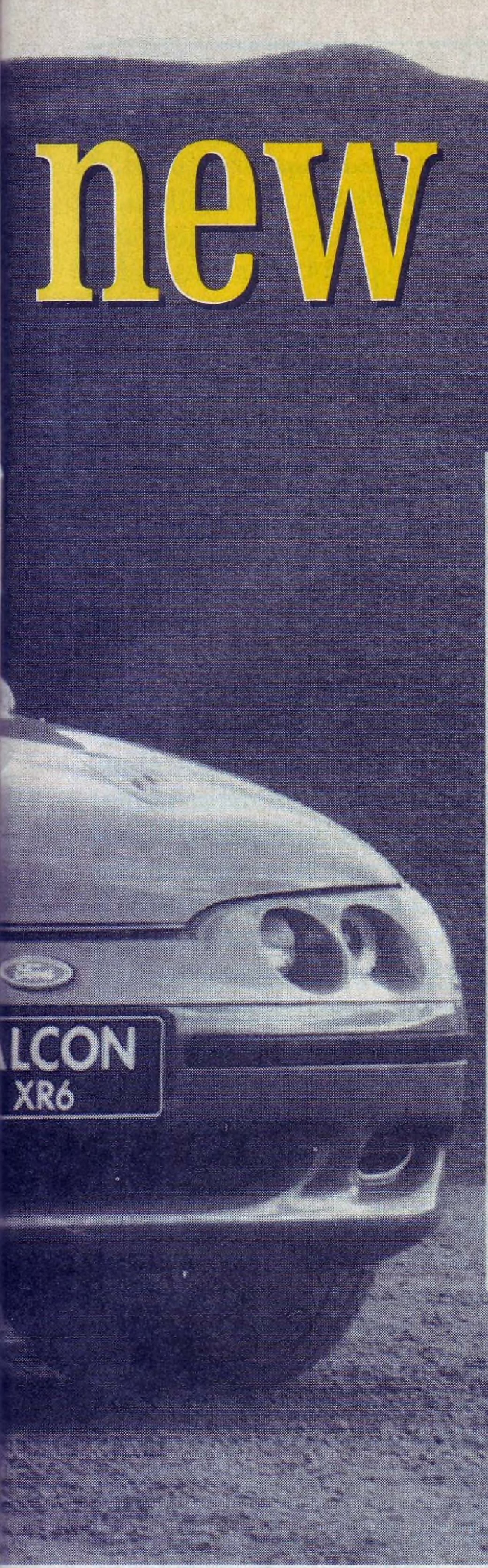
Pt.1: the engine management system

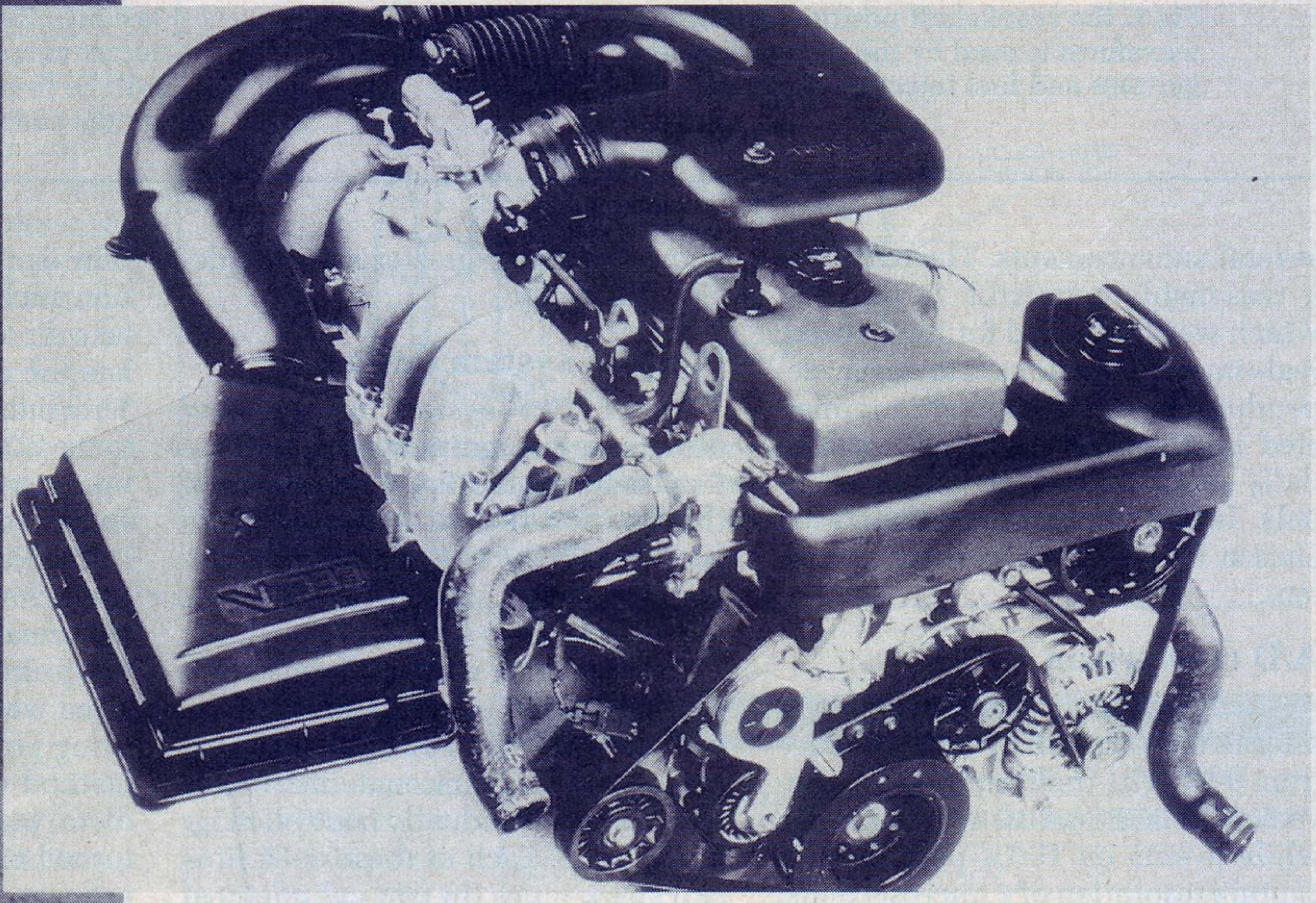
The EEC-V Ford engine management system (pronounced 'Eck-5') replaces the EEC-IV system introduced on the Falcon in 1985. Initially used for controlling ignition and fuel delivery only, the system was subsequently upgraded in 1992 to also control automatic transmission and air-conditioner compressor operation. However, with these additional demands, the system was at its limits in terms of both input/output (I/O) and microprocessor throughput.

The new EEC-V system now allows the incorporation of knock detection and control, as well as a multi-coil distributorless ignition system. In addition, the system's greater processor

By JULIAN EDGAR

new EF Falcon





Above: the EF Falcon 6-cylinder engine uses a new engine management system & a triple-coil ignition system to eliminate the distributor.

speed has translated directly to improvements in vehicle performance, drivability, fuel economy and emissions.

Microcontroller I/O

The microprocessor in an engine management system must be able to sense physical parameters in the form of electrical signals. Two different types of sensors are used: analog and digital.

Analog sensors provide a varying output voltage and measure factors such as throttle position, engine coolant temperature and intake air temperature. Digital sensors, on the other hand, provide either an "on" (logic 1) or "off" (logic 0) signal, or can deliver a variable frequency digital pulse train. The square-wave output from a speed sensor is a good example of this latter type.

Analog sensors are read via analog to digital (A/D) convertors, while on/off binary signals can be read by a low speed digital input port. The microcontroller software reads the input port periodically to determine the state of the switch but this approach is appropriate only for inputs which change state at a frequency of less than 2Hz. For signals which change more rapidly than this, a high speed digital input is used. This allows an event to be captured closer to the time at which the transition took place.

Output ports must also be suited to their specific applications. A low speed digital output (LSDO) is appropriate for the control of an air-conditioning compressor clutch, for example. On the other hand, a high speed digital output (HSDO) is necessary for a function that requires accurate timing control (such as fuel injector operation).

For an output which repeats at a fixed time interval, it would be possible to use an HSDO and continually schedule the output events to generate an appropriate signal. However the software requirement makes this undesirable. Instead, circuitry which is activated once and then "forgotten" until a change in periodicity is required is used. These outputs use pulse width modulation (PWM) and are referred to as "Duty Cycle Outputs".

The 8065 microprocessor

The 8065 microprocessor is based on the previous system's 8061 but with

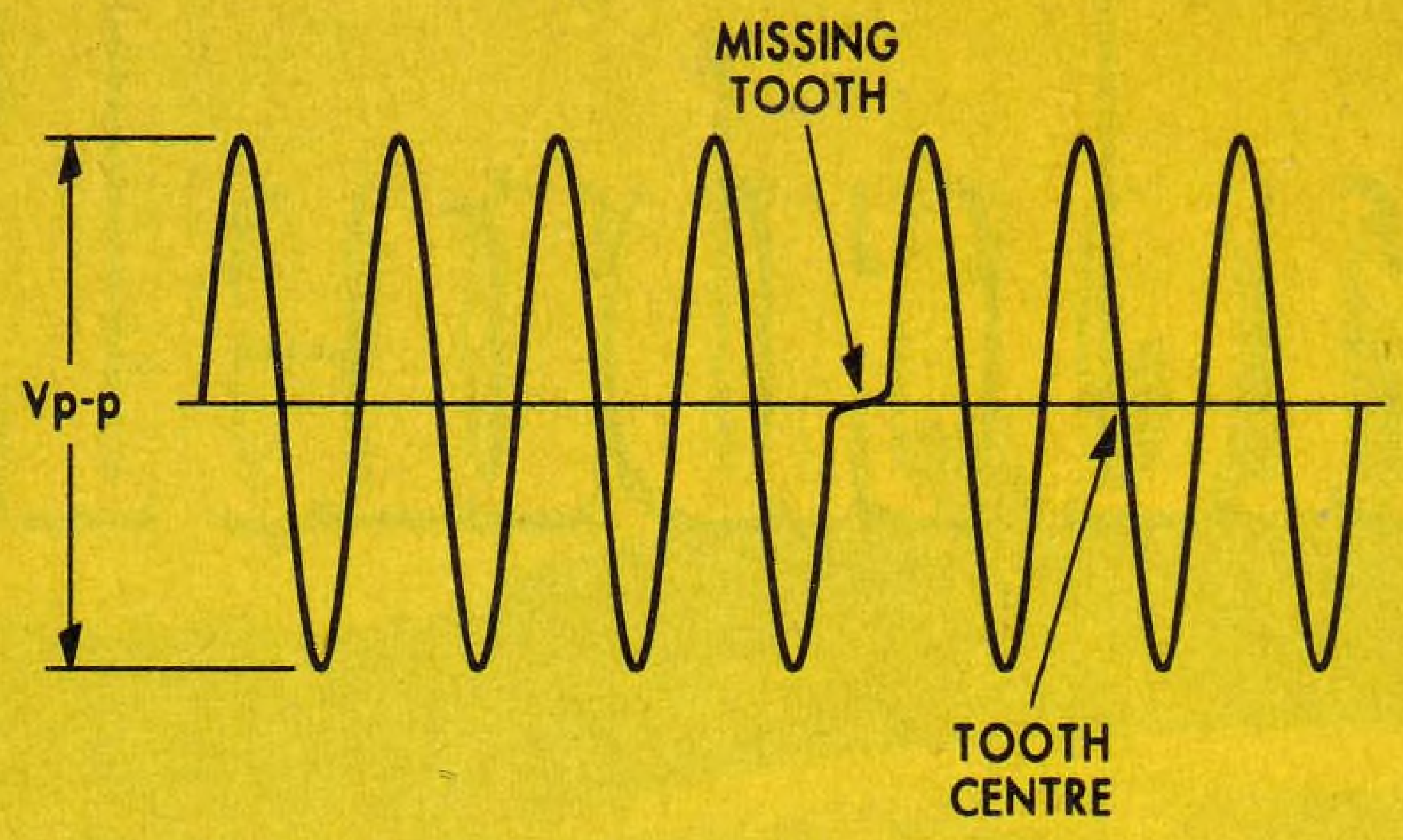


Fig.1: the crankshaft position sensor output waveform is used by the ECU to time the ignition and fuel injection systems.

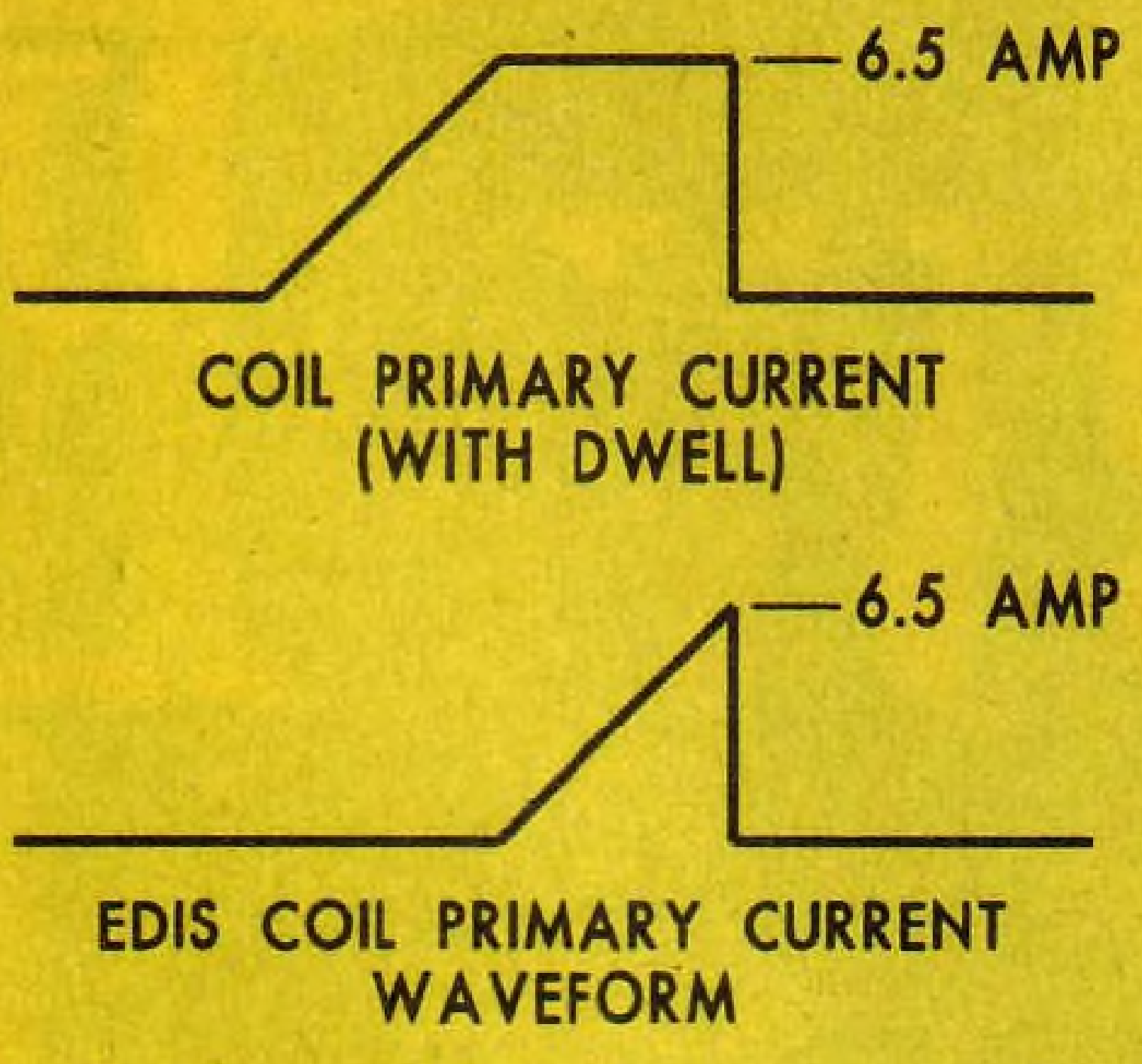


Fig.2: the coil primary current ramp is controlled so that it reaches its target value at the point where it will be fired. This reduces the load on the car's electrical system.

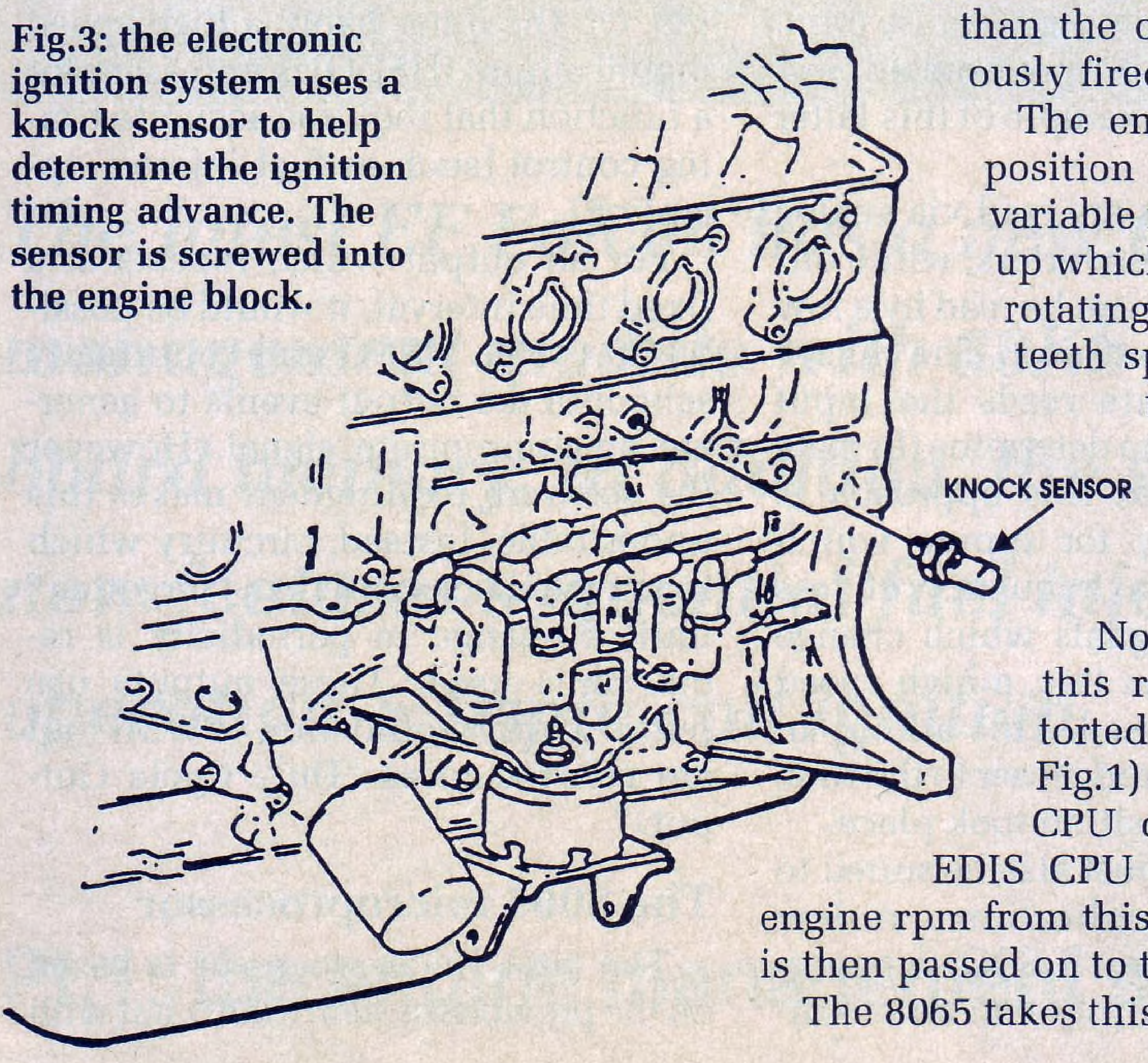
several enhancements. The 8061 was a reasonably powerful 16-bit chip which was optimised for high-speed, real-time applications. However, depending on which I/O mode it is operated in, the 8065 can offer substantially more input and output channels. Table 1 shows the configuration chosen for the EF Falcon EEC-V system.

A/D conversion

The 20 channels of A/D conversion offer 10 bits of accuracy over the range from 0-5V. The time required for conversion is less than 30 microseconds, while events on HSDI ports have a capture resolution of 2 microseconds.

HSDO's are also accurate to within 2 microseconds. In addition, the 32Kb PROM of the previous system has been replaced with an 88Kb memory, which allows for much greater software design flexibility.

Fig.3: the electronic ignition system uses a knock sensor to help determine the ignition timing advance. The sensor is screwed into the engine block.



Ignition system design

The EEC-V system uses a new distributorless ignition system on the 6-cylinder engine. Previously, most of the ignition-related activities were controlled by the EEC-IV's 8061 microprocessor, whereas the new system uses its own CPU.

The ignition system, termed the Electronic Distributorless Ignition System (or "EDIS" in Ford parlance), replaces the conventional distributor with three individually controlled ignition coils. Each of these coils fires two spark plugs (in two cylinders) at once, with one cylinder fired on its compression stroke and the other on its exhaust stroke. The spark plug fired on the compression stroke uses far more of the available energy than the other simultaneously fired plug.

The engine crankshaft position is sensed by a variable reluctance pickup which is excited by a rotating sprocket with teeth spaced at 10° intervals. A missing tooth is positioned at 60° before top dead centre for No.1 cylinder and this results in a distorted waveform (see Fig.1) which the EDIS CPU can sense. The EDIS CPU also calculates engine rpm from this sensor and this is then passed on to the 8065 CPU.

The 8065 takes this speed information and, along with other information such as throttle position and intake air temperature, uses it to calculate the desired spark advance angle. This information is then passed back to the EDIS CPU which carries out the necessary calculations to provide a spark at the desired angle of advance.

The EDIS system also energises the coil primary in a way different to conventional ignition systems. Generally, the primary side of the coil is energised well in advance of the required firing point. By contrast, EDIS uses a method of dwell control which predicts when a given coil should be turned on so that it reaches its target primary current at the point where it will be fired – see Fig.2. This not only reduces the load on the car's electrical system but also reduces the need for current-limiting circuitry in the ignition system.

Knock detection

Spark timing has a major influence when it comes to obtaining the best fuel economy and performance. At the same time, engine knock (detonation) must be avoided to prevent engine damage.

Detonation can occur due to variables in engine build, the fuel octane rating, the air/fuel ratio and internal carbon build-up. In fact, the need for a safety margin between engine-damaging detonation and optimal outcomes has seen the ignition timing retarded by as much as 6° in some cars, with a consequent reduction in performance.

To overcome this problem, EDIS uses a knock detector to sense engine detonation. The sensor is attached to the engine block and is used to measure vibration within a specific frequency range. This frequency range was chosen by analysing the frequency of engine block vibration both with and without perceptible knock and then selecting the range in which there was the most noticeable change. Specifically, a band about 600Hz wide and centred on 7.5kHz is used.

Detonation occurs only during the firing stroke, hence the background noise of the valve train, crankshaft rotation and so on can be measured separately and used as a reference value. During firing, the knock sensor signal is constantly compared to this reference signal. If the threshold is exceeded, knock is deemed to have occurred and the EEC-V processor retards the timing for the next cylinder by 1°. If knock continues to occur, the spark advance is then retarded by either an additional one or two degrees for each cylinder, depending on speed and load conditions.

When knocking is no longer detected, the spark timing for each cylinder is advanced in 0.25° increments until knock is again detected. As a result, the spark advance hovers just below the level at which audible detonation occurs.

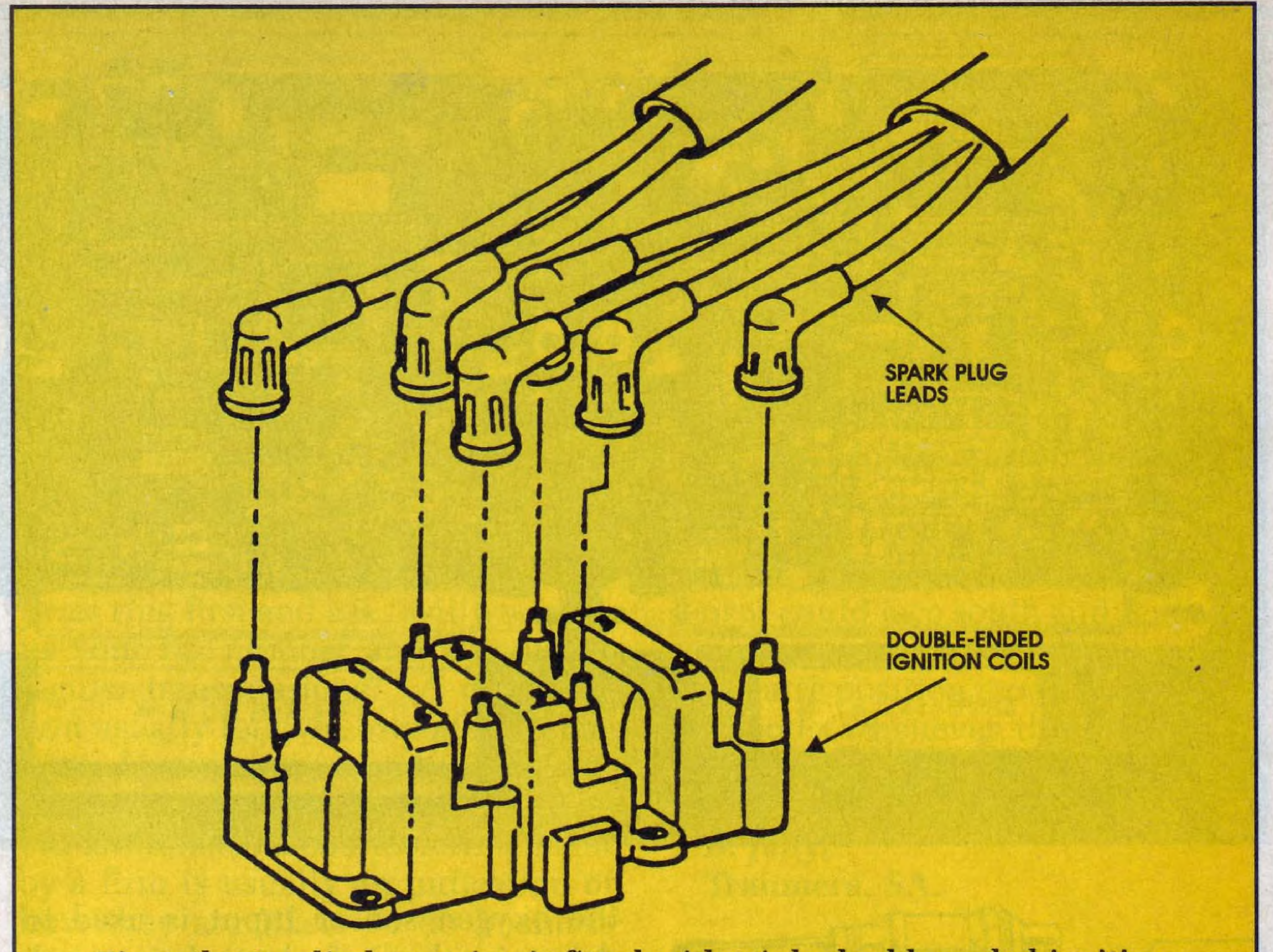


Fig.5: the 6-cylinder engine is fitted with triple double-ended ignition coils, with each coil used to fire two spark plugs simultaneously. In this system, one cylinder is fired on its compression stroke & the other on its exhaust stroke.

Fuel injection

Two different systems of fuel injection are used in the EF Falcon range, one for the V8 engine and the other for the 6-cylinder engine. The V8 uses sequential injection with airflow measured by a hotwire mass airflow meter. The 6-cylinder engine, on the other hand, uses a combination of manifold absolute pressure (MAP) sensing, intake air temperature sensing and an rpm signal to calculate the airflow mass.

In the case of the 6-cylinder engine, the fuel injection system uses a heated exhaust gas oxygen sensor to provide constant feedback of the air/fuel ratio to the ECU. This oxygen sensor is also used to provide information to an adaptive learning mechanism.

This works as follows. The sensor output values during closed loop operation are compared with those predicted by the ECU as needed under the current operating conditions. If there is a difference between the amount of fuel the ECU predicted would be required and the amount being used to provide the appropriate mixtures, then the correction values are stored and applied when the engine is later being driven in open-loop mode. This occurs under full throttle, during cold conditions and when the engine is in lean cruise mode.

Table 1: I/O Channels For EEC-V ECM

Type of I/O	Number of Channels	
	EEC-V (8065)	EEC-IV (8061)
A/D conversion	20	13
Low-speed digital input	13	0
High-speed digital input	8	8
Low-speed digital output	24	8
High-speed digital output	16	10
Duty cycle output	9	0

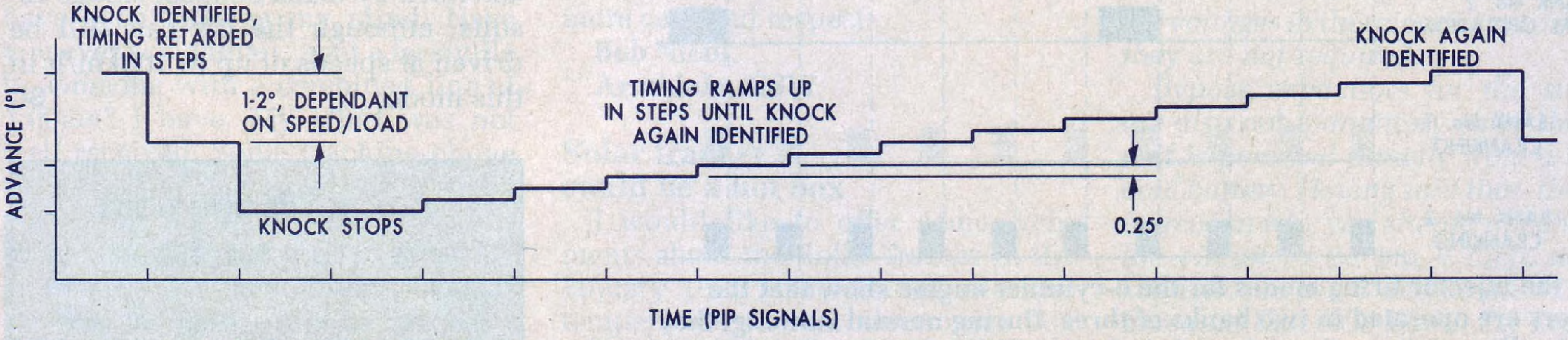
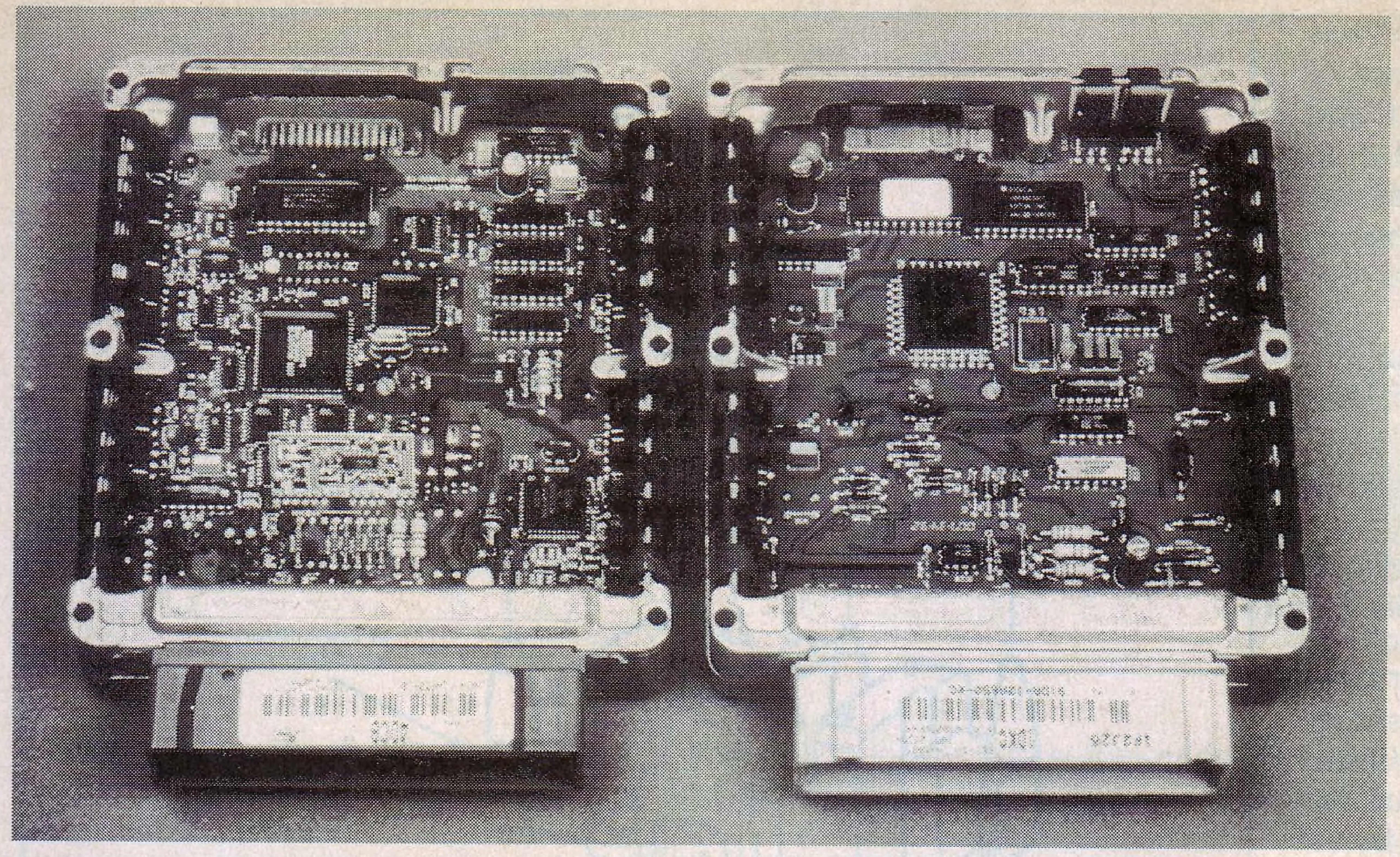


Fig.4: when knock (or detonation) is detected by the knock sensor, the ignition timing is initially retarded in steps of either 1 or 2 degrees (depending on the engine speed & load) & then re-advanced in 0.25 degree increments.



This photo shows the new EEC-V electronic control unit (ECU) on the left, while the older EEC-IV ECU is on the right. The EEC-V uses an 8065 microprocessor capable of over a million operations per second & has 88Kb of memory.

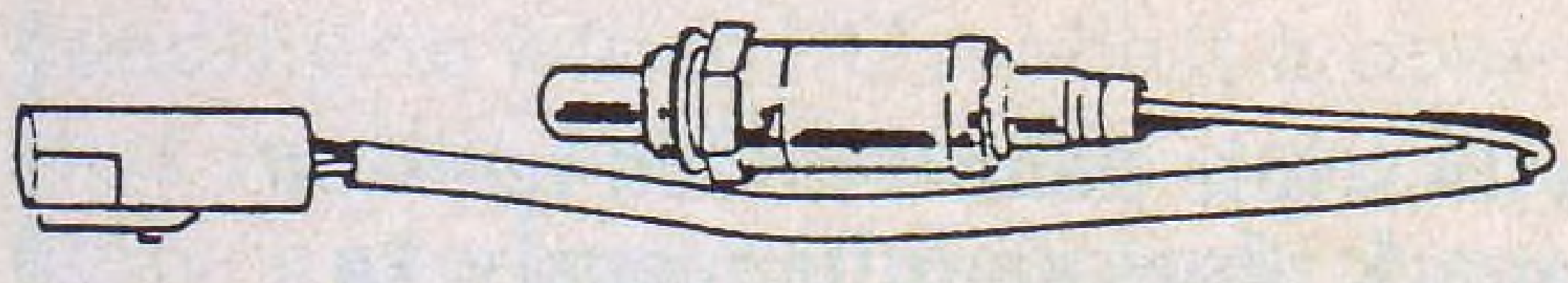


Fig.6: a heated exhaust gas oxygen sensor is used to provide vital feedback on the air/fuel mixtures.

The fuel injectors are fired in two banks, with cylinders 1, 3 and 5 operating as one bank and cylinders 2, 4 and 6 as the other. The banks are fired in response to the ignition signal pulses derived from the EDIS, with the injectors in each bank opening on every third pulse (ie, once per rev). During cranking, the firing frequency is increased to give better starting.

Operating modes

A number of different modes of operation are employed by the ECU:

(1). Closed Loop Mode. This is where the oxygen sensor input is used to determine the air/fuel ratio being used. This will normally occur after the first few minutes of engine operation, when the sensor has reached its operating temperature.

(2). Open Loop Mode. The input from the oxygen sensor is disregarded in this mode. This occurs for two reasons: (a) either the sensor has not reached its operating temperature; or (b) it is necessary to run the engine at air/fuel ratios other than stoichiometric (that is, other than at a 14.64:1 air/fuel ratio).

(3). Crank Mode. This occurs during engine starting. In this mode, the ignition advance is set at 10° BTDC, the idle speed control bypass valve is fully open, and the evaporated fuel canister purge is closed. The injector pulse width (and thus fuel flow) is dependent on engine coolant temperature.

(4). Run Mode. Once the car has started (and if it doesn't there is an Underspeed Mode to cater for this), the ECU switches to Run Mode. In this condition, the throttle position has a large controlling influence on fuel injection behaviour.

(5). Cruise Mode. When the throttle position sensor output is within a certain range, the ECU selects this mode. The ignition timing is now calculated as a function of RPM, load and the coolant and intake air temperatures. The fuel flow is derived from the calculated airflow and then made richer or leaner to suit the coolant temperature.

(6). Wide Open Throttle Mode. This mode is selected when the throttle position sensor exceeds a prescribed value. It selects a richer mixture than in other running modes to increase engine power. Note that the ignition timing remains the same, as it is already at optimal levels.

(7). Limp Home Mode. If an electronic malfunction occurs, the system reverts to the following settings: the ignition timing is fixed at 0° BTDC; the canister purge is locked out; the injector pulse width is fixed at 3ms; the injectors are fired on the rising edge of each ignition signal; and the idle speed control valve duty cycle is set to 75%.

A very rich mixture which is characterised by black exhaust smoke results, although the car can still be driven at speeds of up to 100km/h in this mode. **SC**

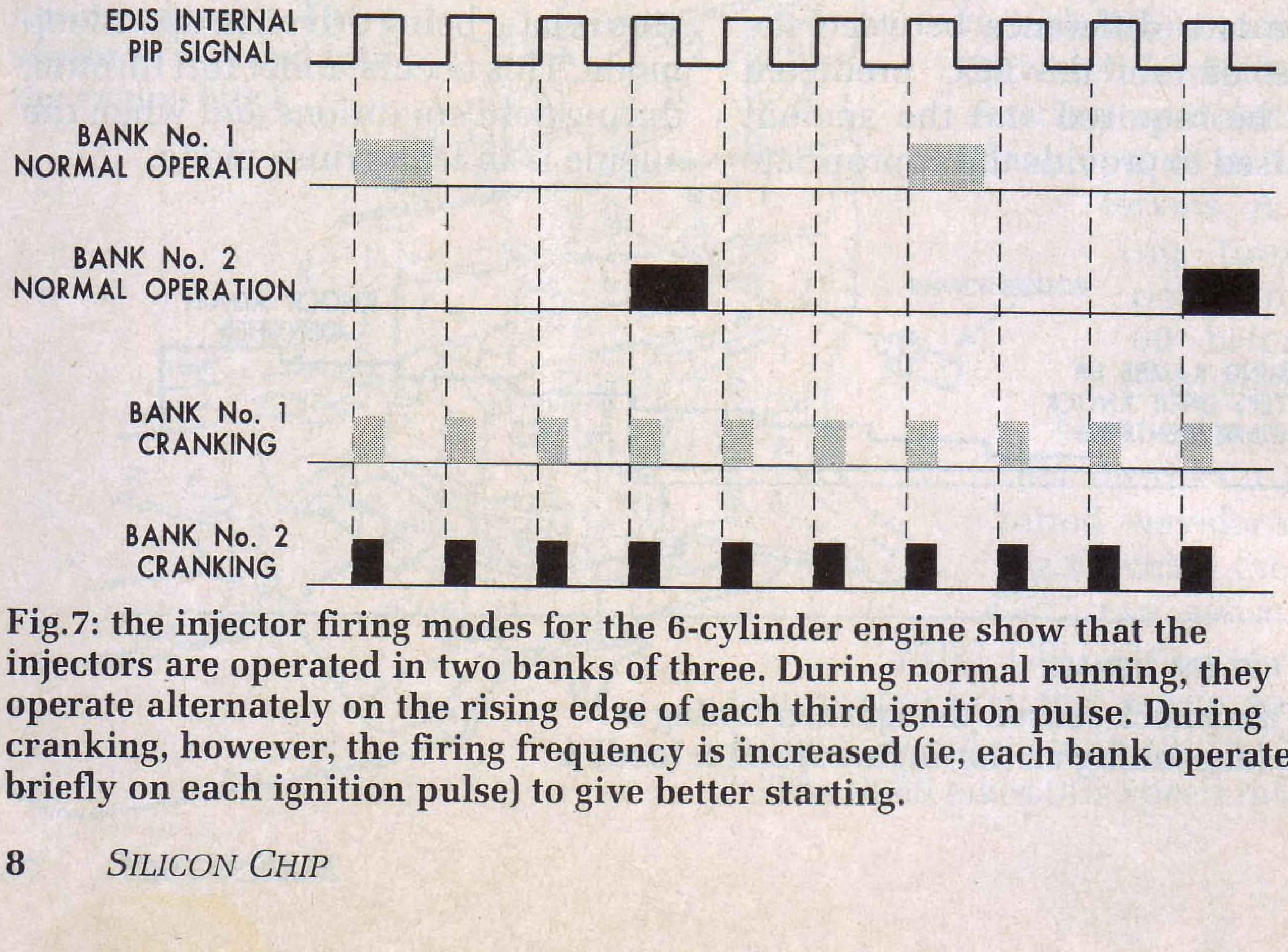


Fig.7: the injector firing modes for the 6-cylinder engine show that the injectors are operated in two banks of three. During normal running, they operate alternately on the rising edge of each third ignition pulse. During cranking, however, the firing frequency is increased (ie, each bank operates briefly on each ignition pulse) to give better starting.

Acknowledgement

Thanks to Ford Australia and the Society of Automotive Engineers for permission to use material from the "SAE Australasia" journal of October/November 1994.