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Engine control module (ECM)

Electrical signals from engine and vehicle sensors are received and processed by the electronic circuits in the ECM.

Functions

Input signals are received from some or all of the following:

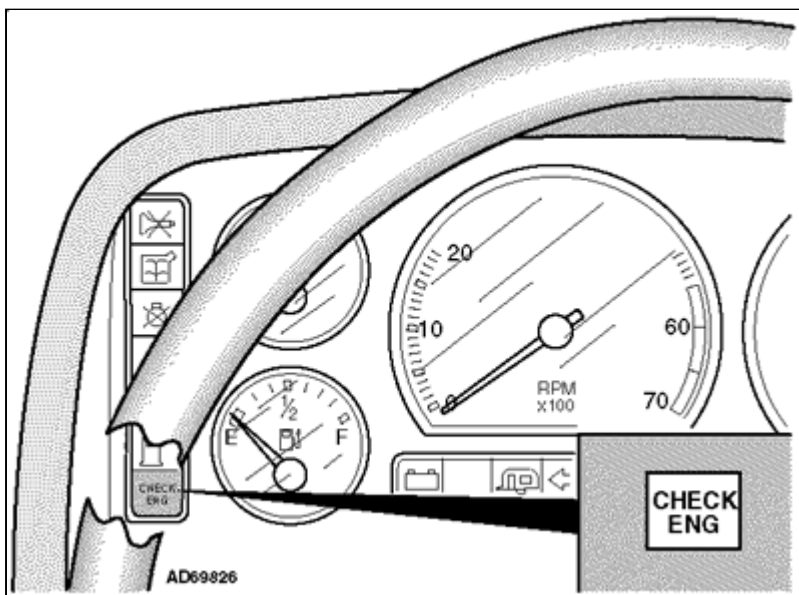
- Accelerator position (APP) sensor.
- Fuel lever position sensor.
- Injector needle lift sensor.
- Fuel temperature sensor.
- Engine coolant temperature (ECT) sensor.
- Intake air temperature (IAT) sensor.
- Throttle position (TP) sensor.
- Load sensor - mass air flow (MAF) sensor or manifold absolute pressure (MAP) sensor.

- Vehicle speed (VSS) sensor.
- Crankshaft position (CKP) sensor.
- Engine speed (RPM) sensor.
- Barometric pressure (BARO) sensor.
- Immobilizer control module.

Outputs from the ECM control some or all of the following:

- Injectors (electrical type only) - by controlling the length of time each injector remains open.
- Fuel pump relay.
- Fuel injection timing solenoid.
- Fuel quantity adjuster.
- Fuel pressure control solenoid.
- Idle speed control system.
- Exhaust gas recirculation system.
- Turbocharger (TC) wastegate regulating valve.
- Intake manifold air control solenoid.
- Glow plug relay.
- Glow plug warning lamp.
- Self-diagnosis of faults, indicated by a malfunction indicator lamp (MIL) or check engine warning light on the instrument panel **Fig. 1**.
- Emergency 'limp-home' programme, which substitutes an average value for certain sensors enabling the vehicle to be driven to a workshop for correction.

Fig. 1



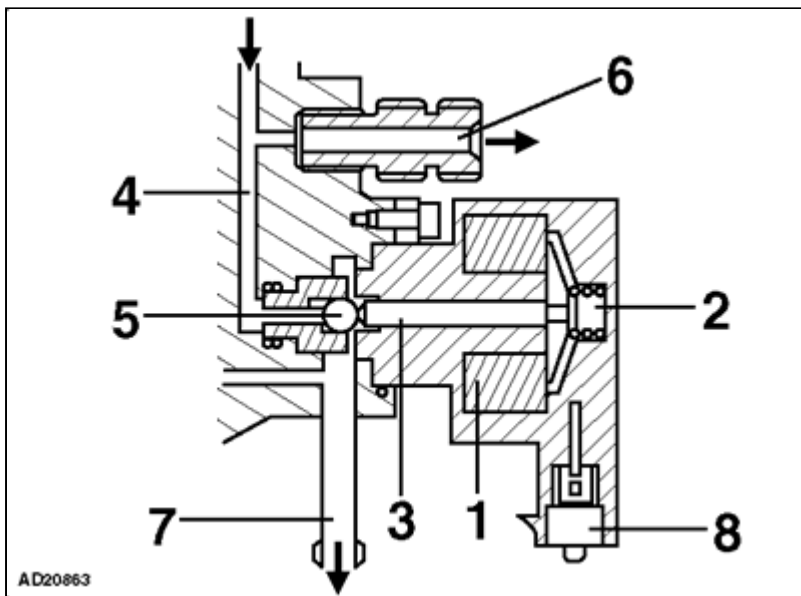
Fuel supply system

Fuel pressure regulator - Common rail

Maintains an even supply pressure to the injectors.

Located in the high-pressure pump or the fuel rail.

Fig. 2



1. Solenoid
2. Spring
3. Magnetic core
4. Pressurised fuel inlet
5. Ball valve
6. Fuel outlet to common rail
7. Fuel return
8. Electrical connector

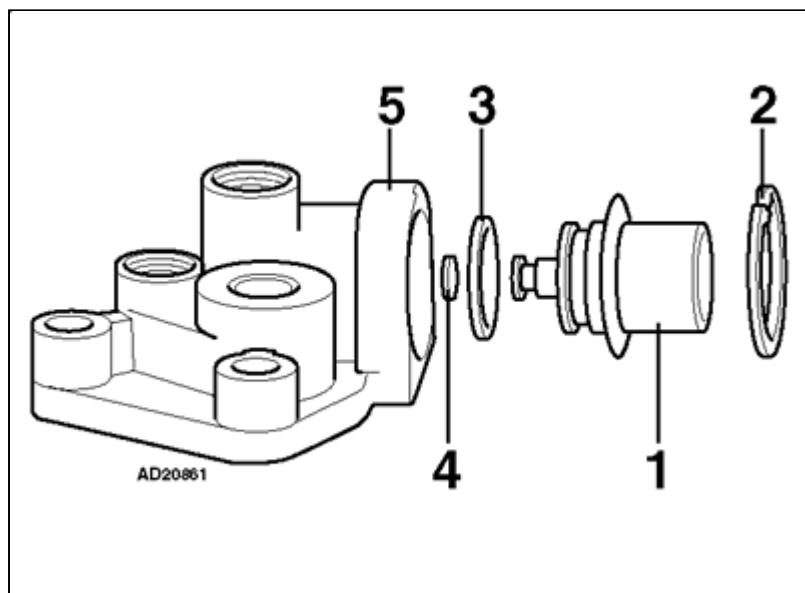
Operation

- A ball-type valve separates the high-pressure fuel supply from the fuel return circuit. The valve remains closed under pressure from the high-pressure supply pump. When the solenoid is energised the magnetic core pushes the ball valve off its seat and allows the excess fuel to flow back to the tank.
- The regulator is continually switched on and off (cycled) by the engine control module (ECM) and the delivery pressure is dependent on the duty cycle.

Fuel pressure regulator - unit injector

Located in the fuel supply housing on the cylinder head.

Fig. 3



1. Pre-set regulator
2. Circlip
3. 'O' ring
4. 'O' ring
5. Regulator housing

Operation

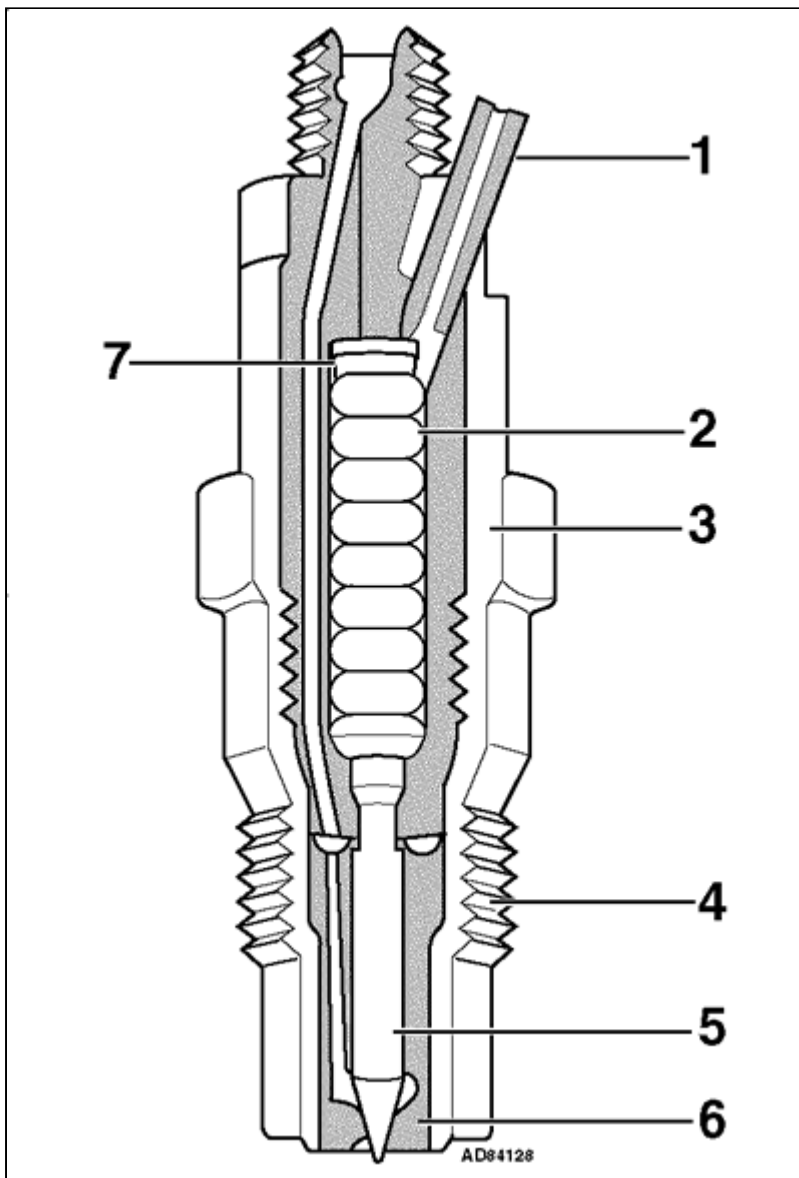
- The pressure regulator consists of a spring-loaded regulator that acts on a valve in the regulator housing.
- When the fuel supply pressure exceeds the preset regulator pressure the valve opens and allows the excess fuel to flow back to the tank.

Injectors - mechanical type

Operation

- Fuel is delivered to the high-pressure connection at the commencement of injection. The pressure acts against the injector spring pressure and lifts the needle from its seat. Atomized fuel is sprayed from the nozzle into the engine swirl or combustion chamber.

Fig. 4



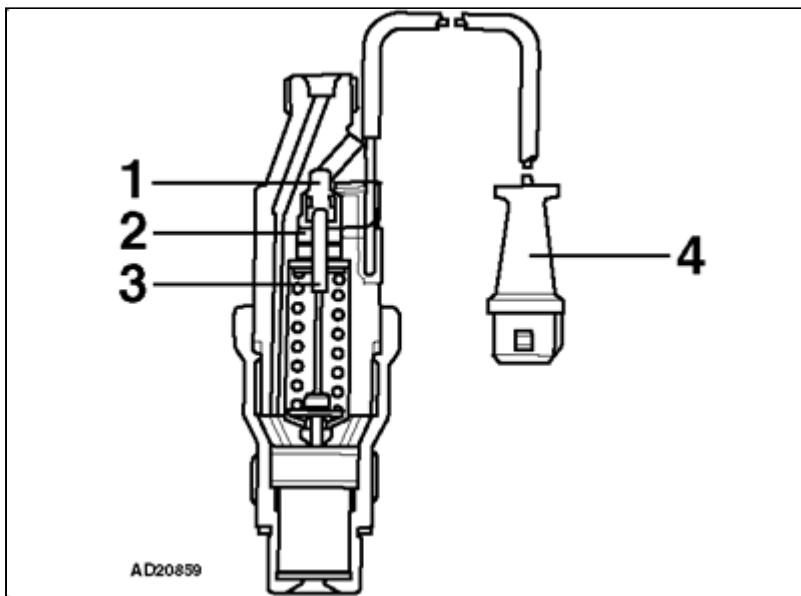
1. Fuel return connection
2. Compression spring
3. Body
4. Cap nut/nozzle holder
5. Nozzle needle
6. Pintle
7. Shim

Injectors - mechanical type, with needle lift sensor

Operation

- This injector operates in the same way as in Fig. 4, but has an integral inductive sensor. At the commencement of injection the magnetic setting pin moves upwards and induces an alternating current into the sensor windings. This information, together with signals from the crankshaft position (CKP) sensor, is used by the engine control module (ECM) to measure the injection timing.

Fig. 5



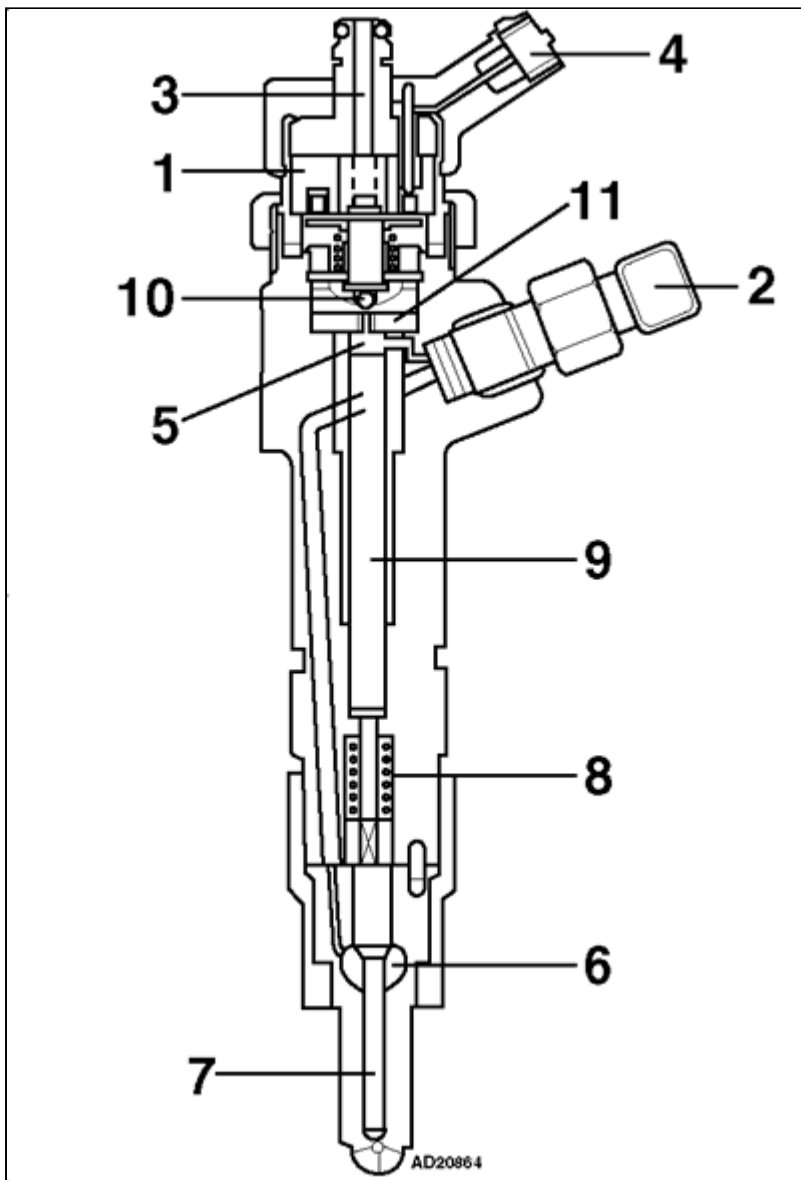
1. Setting pin
2. Sensor winding
3. Pressure pin
4. Electrical connector

Injectors - electrical type

Operation

- Electronically controlled injectors are supplied with a constant supply of fuel at high pressure. A solenoid operated ball-type valve separates the control chamber from the return circuit and ensures that the needle is held on its seat by the injector spring.
- At the commencement of injection the solenoid is energised and the ball valve opens allowing the pressure in the control chamber to fall. The pressure in the pressure chamber acts against the injector spring and lifts the needle from its seat. Atomized fuel is sprayed from the nozzle into the engine combustion chamber.
- To reduce the high current required to operate the injector, the engine control module (ECM) rapidly switches the solenoid during the opening duration.

Fig. 6



1. Solenoid
2. Fuel inlet
3. Fuel return
4. Electrical connector
5. Control chamber
6. Pressure chamber
7. Injector needle
8. Injector spring
9. Control piston
10. Ball valve
11. 1Return nozzle

Unit injector

Operation

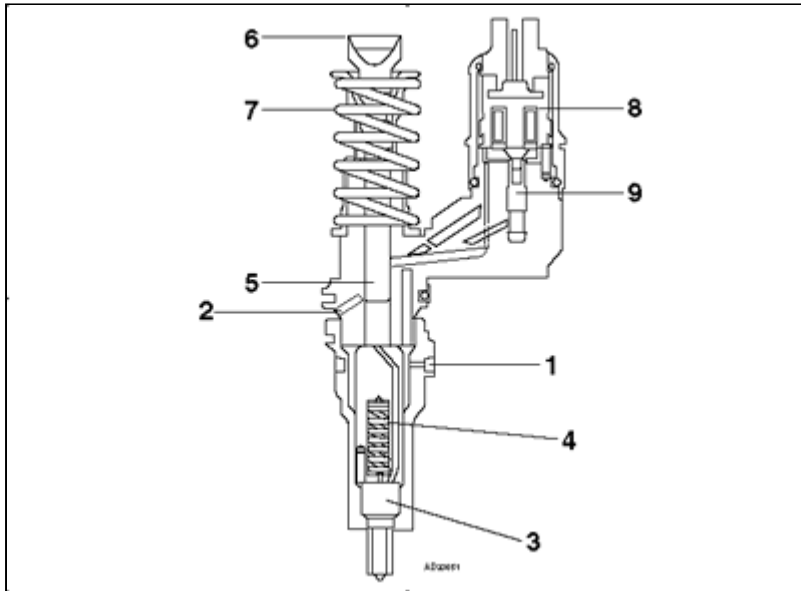
Fuel is supplied at a regulated pressure to the injector by an electrical fuel lift pump.

The solenoid is energised by the engine control module (ECM) and the spill port is closed. As the engine rotates, the engine camshaft pressurises the fuel in the unit injector. The pressure acts against the injector spring pressure and lifts the needle from its seat. Atomized fuel is sprayed from the nozzle into the engine combustion chamber. When the correct

quantity of fuel has been injected the solenoid is de-energised, the spill port opens and allows excess fuel to return to the fuel tank.

The unit injectors use low resistance solenoids. To reduce the current being switched by the ECM, the voltage is rapidly switched during the injection period.

Fig. 7



1. Fuel inlet
2. Fuel return
3. Injector
4. Injector spring
5. Pump plunger
6. Pushrod
7. Pushrod return spring
8. Solenoid
9. Solenoid valve

Load sensing

Mass air flow (MAF) sensor - hot-wire type

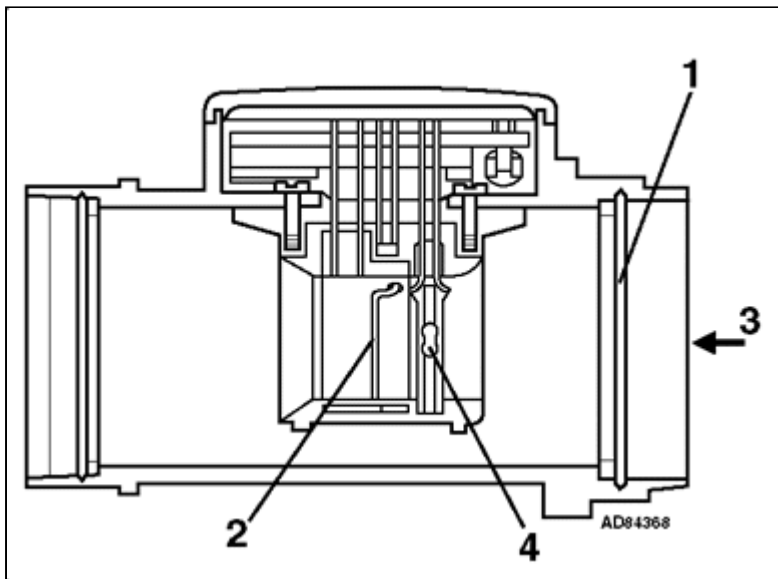
The MAF sensor has no moving parts and provides very little restriction to the air flow. It is fitted between the air filter and intake manifold.

Operation

- The MAF sensor consists of a venturi with a resistance wire exposed to the incoming air.
- An air temperature sensor or compensating wire is also exposed to the air flow.
- The engine control module (ECM) senses changes in temperature caused by variations in air mass passing through the sensor body and increases or decreases the current flowing through the measuring wire.
- An internal electronic circuit maintains the approximate temperature of the measuring wire at a constant 120°C above the intake air temperature.
- As the mass of air passing the wire increases, so the current required to maintain the temperature also increases.

- This increase in current is sensed by the ECM.

Fig. 8



1. Protective mesh
2. Resistance wire
3. Intake air
4. Compensating wire

Mass air flow (MAF) sensor - hot-film type

Similar to the hot-wire type, but with the measuring element incorporated in a ceramic plate.

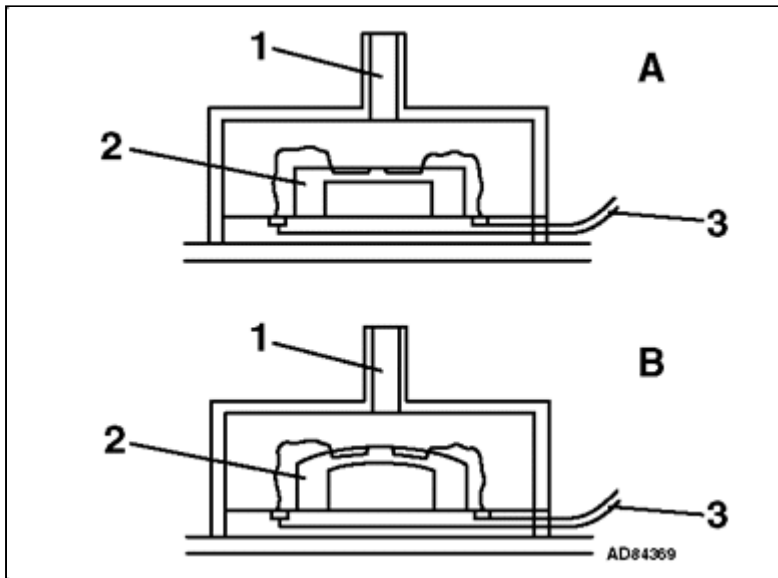
Manifold absolute pressure (MAP) sensor

- Fitted to the intake manifold or located in the engine bay and connected by vacuum hose.

Operation

- The sensor consists of a diaphragm and piezo-electric circuit which varies the resistance in proportion to the pressure in the manifold.
- The sensor has a 5 volt supply and sends a signal voltage to the ECM which is proportional to the manifold pressure.
- The ECM uses the voltage signals from the MAP sensor to monitor turbocharger (TC) boost pressure and adjust fuel injection quantity and timing.

Fig. 9



- A. Full load
- B. Idling

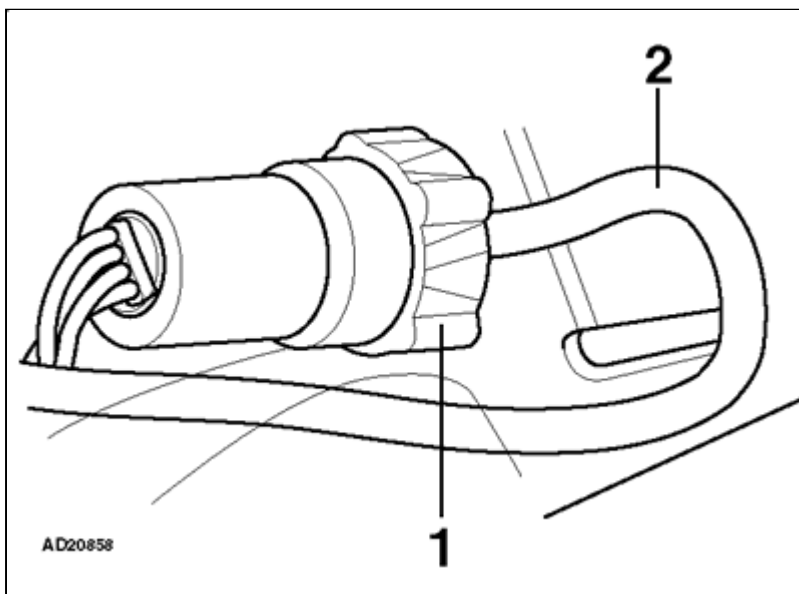
- 1. Vacuum connector
- 2. Piezo-electric crystal
- 3. Electrical connections

Idle speed control

Idle speed control (ISC) actuator

The ISC actuator is used in conjunction with mechanical fuel injection pumps and allows the idle speed to be controlled to suit all operating conditions.

Fig. 10



- 1. Idle speed control (ISC) actuator

2. Operating cable

Operation

- The device consists of a reversible electric motor-driven geartrain, acting on an operating cable attached to the idle lever of the injection pump. The ECM monitors the engine speed and if necessary the motor is energised to either extend or shorten the cable.
- The actuator also incorporates a switch to confirm its fully retracted position.

Sensors

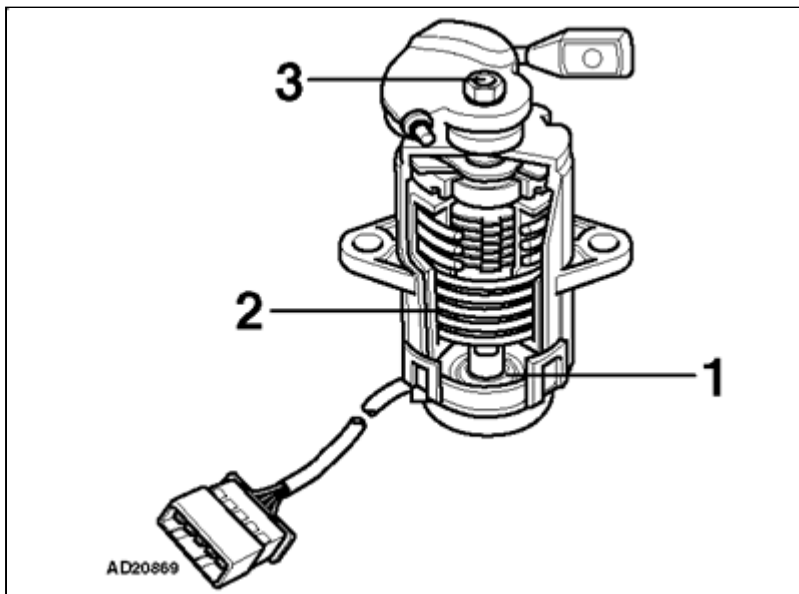
Accelerator position (APP) sensor

The APP sensor can comprise of a potentiometer, idle and/or full load switch, or an electronic circuit.

The APP sensor can be mounted on the accelerator pedal bracket and operated directly, or operated by a cable and located in the engine bay.

Signals from the APP sensor are used by the ECM to determine the exact accelerator position.

Fig. 11



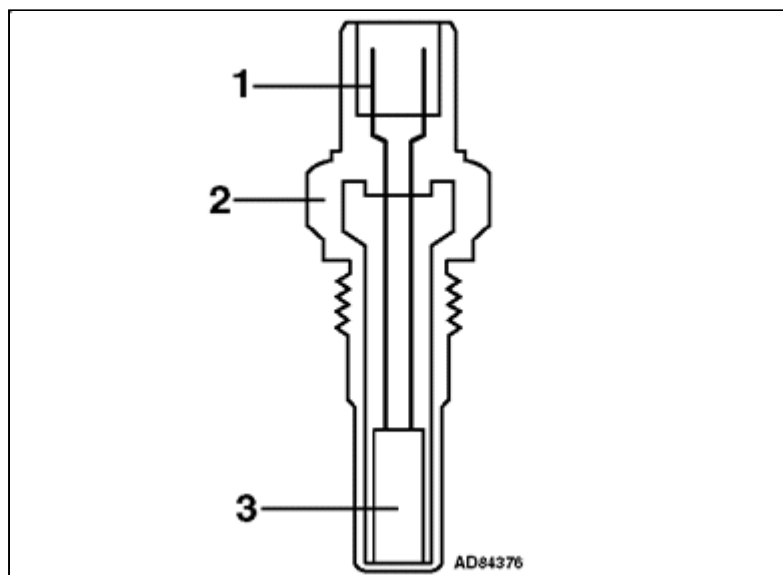
1. Potentiometer and idle/full load switch
2. Spring
3. Shaft

Engine coolant/intake air temperature sensor

The engine coolant (ECT) sensor probe is immersed in coolant and changes its resistance in proportion to engine coolant temperature changes.

The intake air temperature (IAT) sensor probe is either incorporated in the mass air flow (MAF) sensor or is mounted in the air stream of the intake system. Its resistance changes in proportion to intake air temperature changes.

Fig. 12



1. Electrical connections
2. Housing
3. NTC resistor

Operation

- In most cases the sensor incorporates a negative temperature coefficient (NTC) resistor, which decreases in resistance as the temperature rises.

Engine speed and position sensors

Engine speed (RPM), crankshaft position (CKP) and camshaft position (CMP) sensors are of two basic types, inductive or Hall effect. CMP sensors may be mounted on the camshaft housing or cylinder head, CKP sensors may be mounted on the crankcase or bell housing.

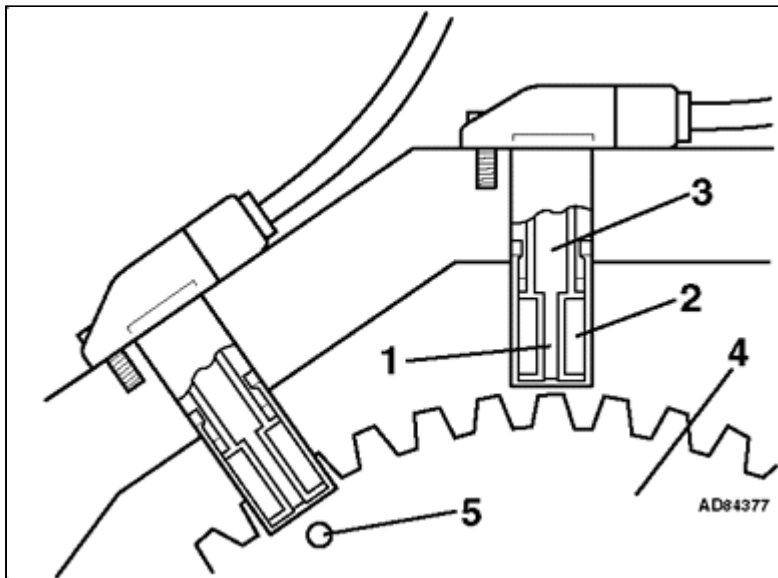
Inductive type

These sensors contain a permanent magnet partly enclosed in a soft iron core and partly in a field winding.

The tip of the sensor is positioned close to the flywheel ring gear, a separate toothed trigger wheel, or a toothed wheel attached to the crankshaft pulley.

In certain applications the sensor(s) are incorporated in the fuel injection pump.

Fig. 13



1. Soft iron core
2. Field winding
3. Permanent magnet
4. Flywheel ring gear
5. TDC pin

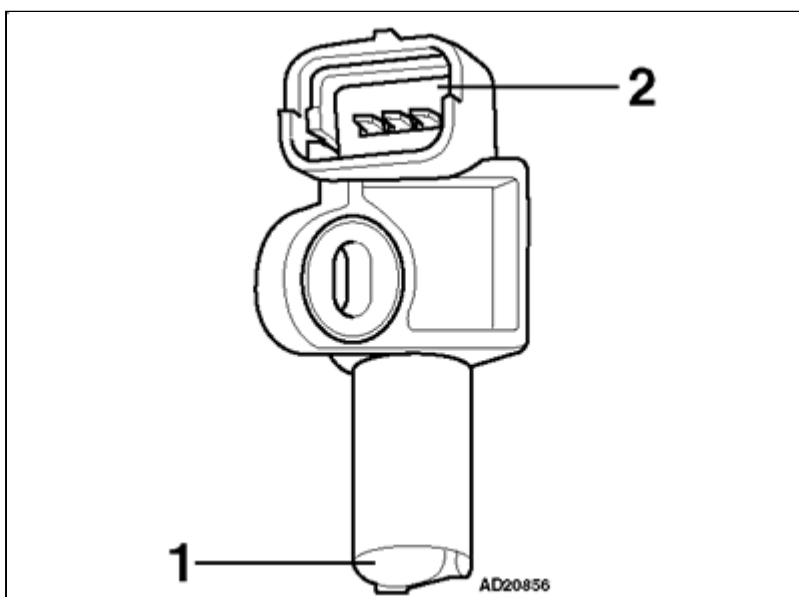
Operation

- As the teeth or pins of the trigger wheel pass the sensor the magnetic field changes, inducing a voltage signal which is sent to the engine control module (ECM).

Hall-effect type

The Hall effect sensor consists of a semi-conductor material, through which a current flows, enclosed by a magnetic field at right angles to the current flow.

Fig. 14

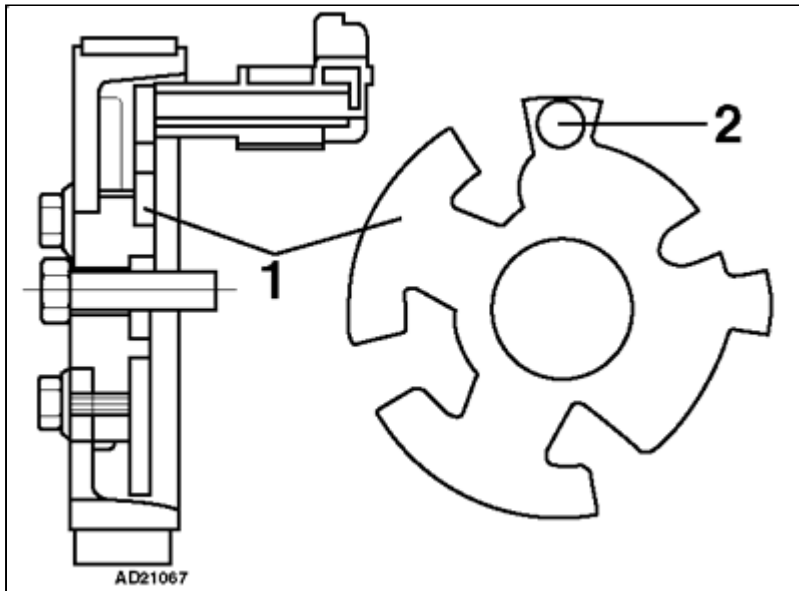


1. Sensor
2. Electrical connector

Operation

- The trigger wheel **Fig. 15 [1]** rotates allowing a magnetic field to pass between the sensor's magnet poles when aligned **Fig. 15 [2]**.
- This magnetic field is used to control the flow of current through a semiconductor which then operates an integral control circuit.
- The sensor is supplied with a control current from the ECM which is switched to earth as the sensor operates generating a square wave signal.

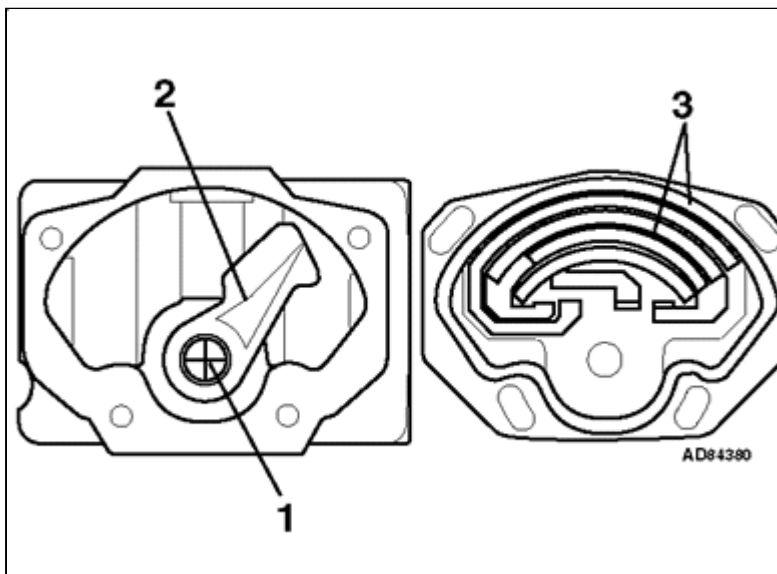
Fig. 15



Throttle position (TP) sensor

The throttle position sensor is a variable resistance (potentiometer) connected to the throttle valve shaft.

Fig. 16



1. Throttle butterfly shaft
2. Wiper arm
3. Resistance tracks

Operation

- It is supplied with a reference voltage and the output signal voltage is used by the ECM to interpret the exact throttle position.
-

Valves

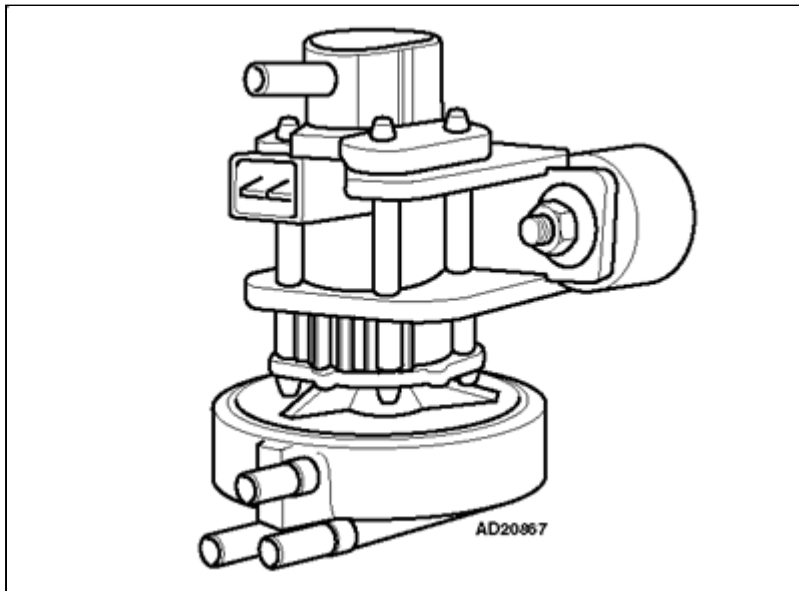
Exhaust gas recirculation (EGR) valve

To reduce the oxides of nitrogen emitted by the exhaust, a proportion of the exhaust gas can be returned to the inlet manifold when operating conditions allow.

Operation

- The exhaust gas recirculation valve is operated by a vacuum-controlled solenoid-operated modulator valve. The duty cycle is varied according to the operating conditions to control the flow of exhaust gas into the inlet manifold.

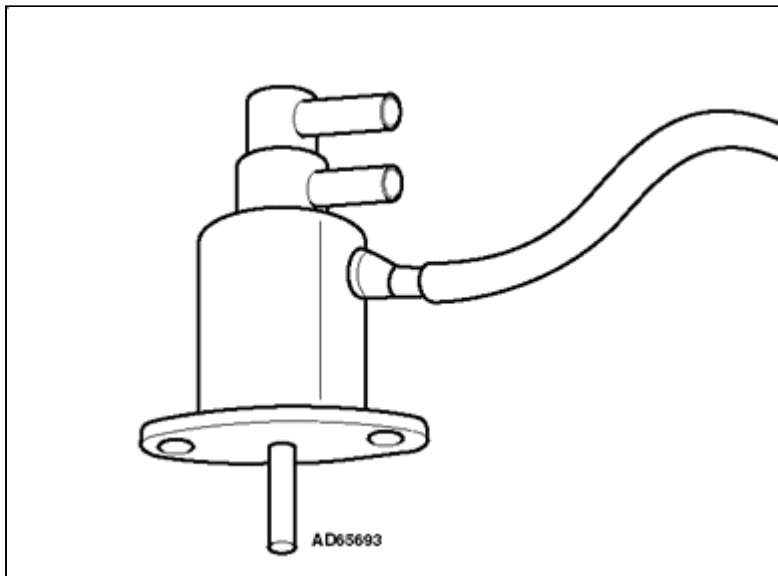
Fig. 17



Turbocharger (TC) wastegate regulating valve

The turbocharger boost pressure can be controlled by the engine control module (ECM) with a solenoid-operated modulator valve. Signals from the manifold absolute pressure (MAP) sensor are monitored and the maximum boost pressure controlled.

Fig. 18



Operation

- The turbocharger wastegate actuator is operated by a vacuum-controlled solenoid-operated modulator valve (turbocharger wastegate regulating valve). The duty cycle is varied according to the operating conditions to control the maximum boost pressure.

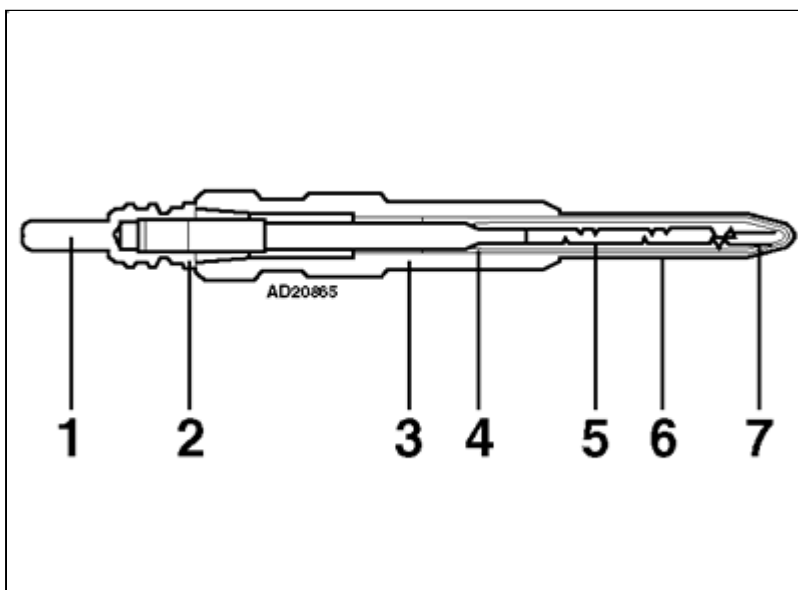
Cold starting equipment

Glow plugs

To enable the engine to be started in low temperatures glow plugs are used to raise the temperature in the combustion chambers (pre-heating). The glow plugs can also be used during cold running to reduce harmful exhaust emissions, blue smoke and knocking (post-heating).

Although the pre-heating and post-heating can be controlled by a dedicated glow plug control unit, it is more common on modern systems to be controlled by the engine control module (ECM).

Fig. 19



1. Terminal
2. Insulator
3. Casing
4. Element seal
5. Heater and control coils
6. Glow tube
7. Powder

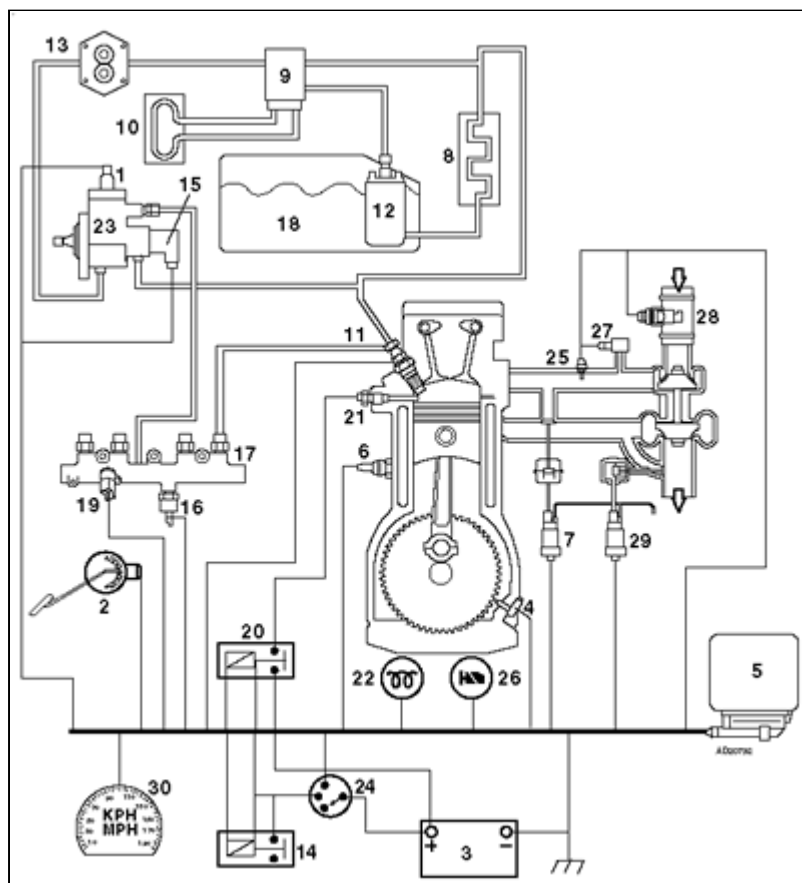
Operation

- The glow plug comprises heater and control coils embedded in magnesium-oxide powder. When voltage is applied to the terminal current flows through the heating elements and the temperature rapidly rises. Current also flows through the control coils and this produces heat but at a slower rate. The resistance rises as the temperature increases at the tip to approximately 1200°C.
- The glow plugs can remain energised after starting (post-heating), when cold until the engine coolant temperature reaches a predetermined point, or for a maximum time in the region of 180 seconds.

Bosch Common rail

Fuel injection system components

Fig. 1



1. 3rd piston cut-off solenoid
2. Accelerator position (APP) sensor
3. Battery
4. Crankshaft position (CKP) sensor
5. Engine control module (ECM)
6. Engine coolant temperature (ECT) sensor

7. Exhaust gas recirculation (EGR) solenoid
8. Fuel cooler
9. Fuel filter
10. Fuel heater
11. Fuel injector
12. Fuel lift pump (electrical)
13. Fuel lift pump (mechanical)
14. Fuel lift pump relay
15. Fuel pressure control solenoid
16. Fuel pressure sensor
17. Fuel rail
18. Fuel shut-off solenoid
19. Fuel tank
20. Fuel temperature sensor
21. Glow plug relay
22. Glow plug
23. Glow plug warning lamp
24. High-pressure fuel pump
25. Ignition switch
26. Intake air temperature (IAT) sensor
27. Malfunction indicator lamp (MIL)
28. Manifold absolute pressure (MAP) sensor
29. Mass air flow (MAF) sensor
30. Turbocharger (TC) wastegate regulating valve
31. Vehicle speed sensor (VSS)

System operation

The Bosch Common rail system uses the latest diesel injection technology.

The fuel injection quantity and timing together with control of exhaust emissions are electronically controlled.

Signals from the accelerator pedal position (APP) sensor [2] together with information from other engine and vehicle sensors are transmitted to the engine control module (ECM) [5].

An electrical fuel pump [12] or an engine driven mechanical pump [13] or both supply fuel at low pressure to the high-pressure pump.

The high-pressure fuel supply is provided by an engine-driven mechanical high-pressure pump [24]. The pump comprises three pumping elements driven by an eccentric shaft.

The pressure is controlled by a fuel pressure control solenoid [15] mounted on the rear of the pump.

On some applications a 3rd piston cut-off solenoid [1] is used to enable the pump to operate only two pumping elements, resulting in less engine power being absorbed at low engine loads.

High-pressure fuel from the high-pressure fuel pump is delivered to the fuel rail [17] where it is distributed to the injectors [11]. Operating conditions in the fuel rail are monitored by the fuel temperature sensor [20] and fuel pressure sensor [16].

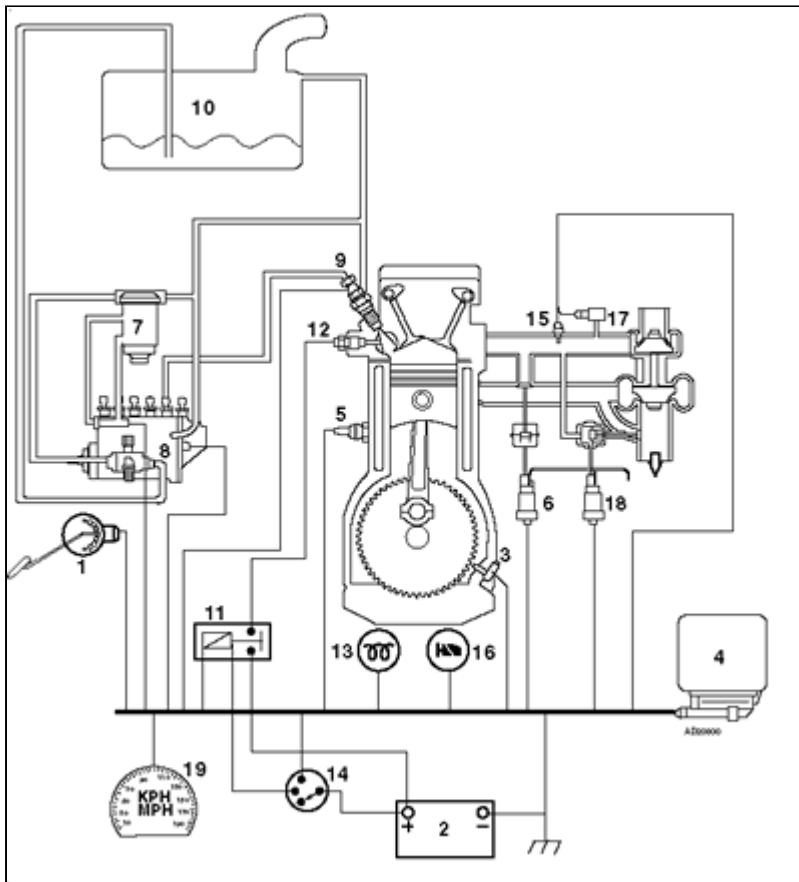
The fuel injectors are electrically operated by the ECM [5] and use low-resistance solenoids. To reduce the current being switched by the ECM, the voltage is rapidly switched during the injection period.

The fuel is injected in two stages (or three where exhaust emission standards are higher), firstly the PILOT injection to precondition the combustion chamber, followed very shortly afterwards by the MAIN injection. Some applications where higher exhaust emission standards are required use a third period of injection called POST injection, where fuel is injected into the exhaust stroke and reburnt via the exhaust gas recirculation (EGR) system.

Bosch in-line with EDC

Fuel injection system components

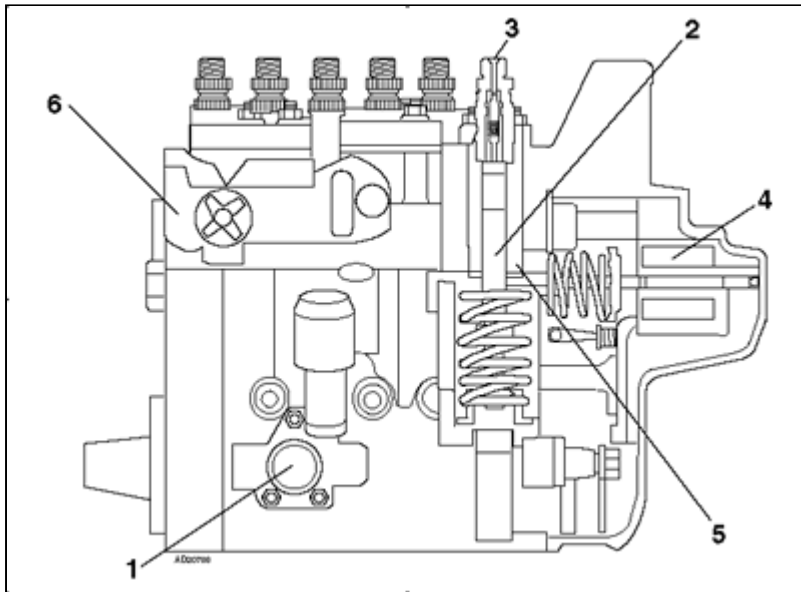
Fig. 1



1. Accelerator position (APP) sensor
2. Battery
3. Crankshaft position (CKP) sensor
4. Engine control module (ECM)
5. Engine coolant temperature (ECT) sensor
6. Exhaust gas recirculation (EGR) solenoid
7. Fuel filter
8. Fuel injection pump
9. Fuel injector
10. Fuel tank
11. Glow plug relay
12. Glow plug
13. Glow plug warning lamp
14. Ignition switch
15. Intake air temperature (IAT) sensor
16. Malfunction indicator lamp (MIL)
17. Manifold absolute pressure (MAP) sensor
18. Turbocharger (TC) wastegate regulating valve
19. Vehicle speed sensor (VSS)

Injection pump operation

Fig. 2



1. Low-pressure plunger-type pump
2. High-pressure pump plunger
3. Delivery valve holder
4. Fuel quantity adjuster
5. Control rod
6. Fuel shut-off solenoid

The Bosch in-line fuel injection pump has been used by many vehicle manufacturers in cars and commercial vehicles for many years.

The pump is driven at engine camshaft speed via gears or chain.

Fuel is supplied to the injection pump by an integral low-pressure plunger-type pump **[1]**.

Excess fuel is allowed to drain from the injection pump via the overflow restriction in the pump return connection.

Fuel is pressurised by the high-pressure pump plunger **[2]** and delivered to the injectors at high pressure via the delivery valve holder **[3]**.

Unlike the earlier version, the Electronic Diesel Control (EDC) in-line pump uses computer technology to control fuel injection quantity.

The fuel injection quantity is controlled by an electrical actuator (fuel quantity adjuster) **[4]** acting on the control rod **[5]**, and its position is monitored by an integral quantity adjuster position sensor. A crankshaft position (CKP) sensor is used to monitor engine speed which allows closed-loop control.

The fuel injection timing is controlled by a mechanical unit integral to the fuel injection pump drive gear or sprocket.

Signals from the accelerator pedal position (APP) sensor together with information from other engine and vehicle sensors are used by the engine control module (ECM) to calculate the fuel injection quantity.

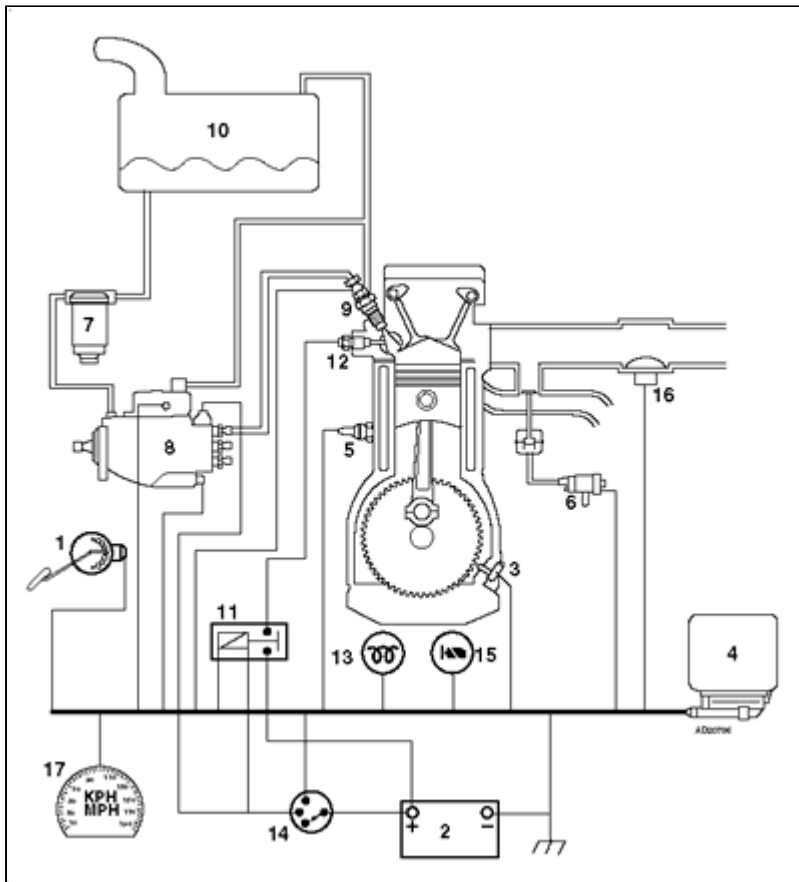
When the ignition is in the OFF position (or if the vehicle immobilizer is not deactivated), the fuel quantity adjuster will return to the position of zero fuel quantity and the engine will stop.

To ensure that the engine can be stopped in the event of a fault in the control system or actuator, a fuel shut-off solenoid **[6]** is retained.

Bosch VE with EDC

Fuel injection system components

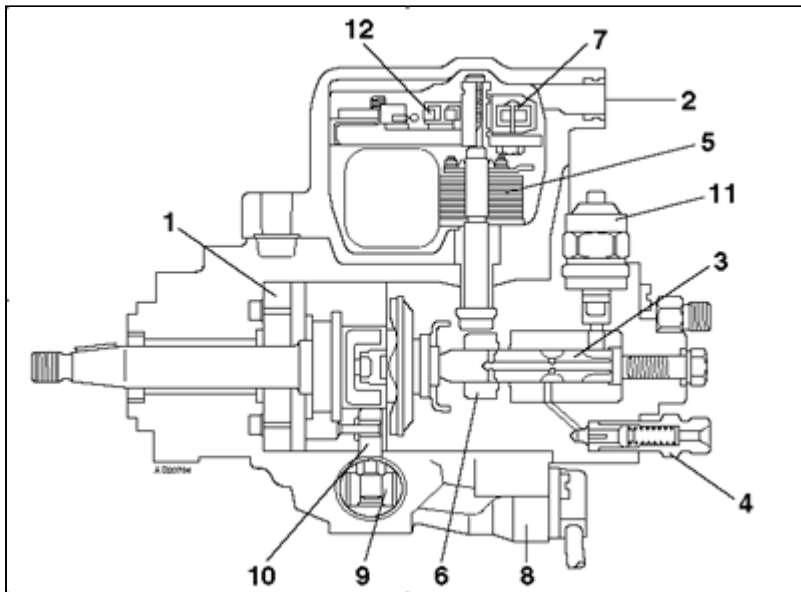
Fig. 1



1. Accelerator position (APP) sensor
2. Battery
3. Crankshaft position (CKP) sensor
4. Engine control module (ECM)
5. Engine coolant temperature (ECT) sensor
6. Exhaust gas recirculation (EGR) solenoid
7. Fuel filter
8. Fuel injection pump
9. Fuel injector (with needle lift sensor)
10. Fuel tank
11. Glow plug relay
12. Glow plug
13. Glow plug warning lamp
14. Ignition switch
15. Malfunction indicator lamp (MIL)
16. Mass air flow (MAF) sensor
17. Vehicle speed sensor (VSS)

Injection pump operation

Fig. 2



1. Vane-type low-pressure pump
2. Return connection
3. Distributor plunger
4. Distributor head
5. Fuel quantity adjuster
6. Control collar
7. Fuel quantity adjuster position sensor
8. Fuel injection timing solenoid
9. Timing actuator
10. Roller ring
11. Fuel shut-off solenoid
12. Fuel temperature sensor

The Bosch VE rotary fuel injection pump has been used by many vehicle manufacturers in cars and light commercial vehicles for many years.

The pump is driven at engine camshaft speed either via gears, chain or toothed belt.

Fuel is drawn into the injection pump by a vane-type low-pressure pump **[1]** and the pump internal pressure is regulated by a pressure control valve.

Excess fuel is allowed to drain from the injection pump via the overflow restriction in the return connection **[2]**.

Fuel is pressurised by the distributor plunger **[3]** and delivered to the injectors at high pressure via the distributor head **[4]**.

Unlike the earlier version, the Electronic Diesel Control (EDC) VE pump uses computer technology to control fuel injection quantity and timing.

The fuel injection quantity is controlled by an electrical actuator (fuel quantity adjuster) **[5]** acting on the control collar **[6]**, and its position is monitored by the quantity adjuster position sensor **[7]** which allows closed-loop control.

The fuel injection timing is controlled by the fuel injection timing solenoid **[8]**, which regulates the control pressure acting on the timing actuator **[9]**. The timing actuator varies the position of the roller ring **[10]**. A crankshaft position (CKP) sensor and an injector needle lift sensor are used to monitor the actual injection timing which allows closed-loop control.

Signals from the accelerator pedal position (APP) sensor together with information from other engine and vehicle sensors are used by the engine control module (ECM) to calculate the fuel quantity and injection timing.

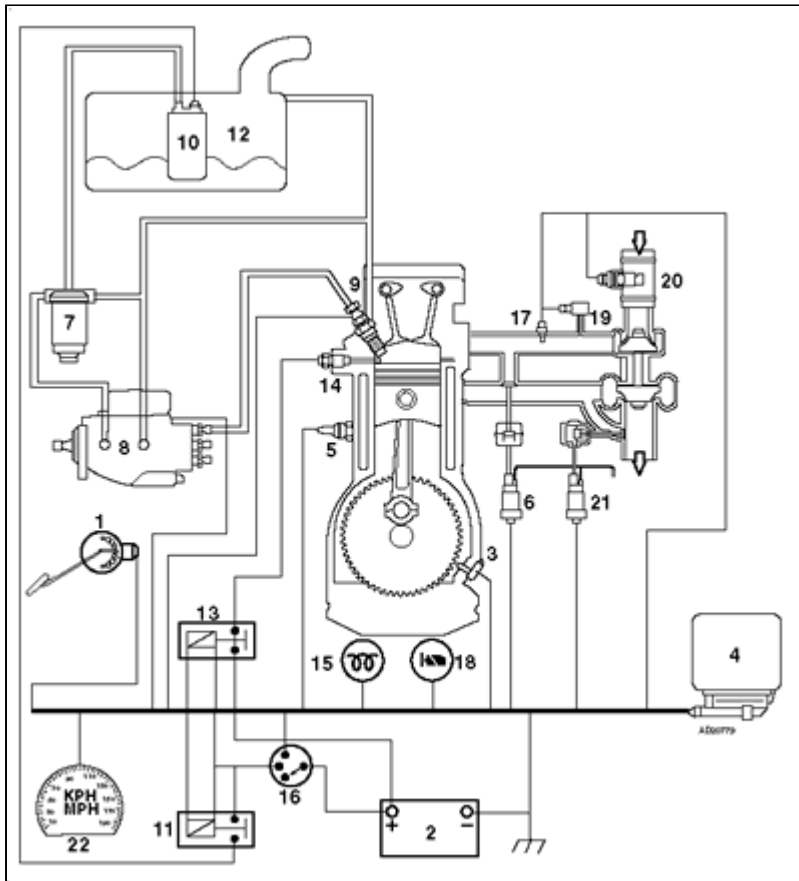
When the ignition is in the OFF position (or if the vehicle immobilizer is not deactivated), the fuel quantity adjuster will return to the position of zero fuel quantity and the engine will stop.

To ensure that the engine can be stopped in the event of a fault in the control system or actuator, a fuel shut-off solenoid [11] is retained.

Bosch VP & VR

Fuel injection system components

Fig. 1

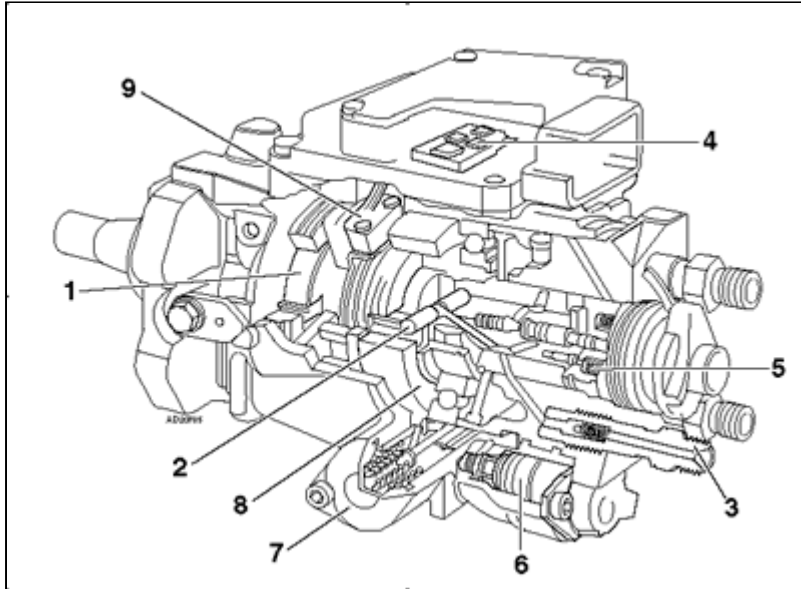


1. Accelerator position (APP) sensor
2. Battery
3. Crankshaft position (CKP) sensor
4. Engine control module (ECM)
5. Engine coolant temperature (ECT) sensor
6. Exhaust gas recirculation (EGR) solenoid
7. Fuel filter
8. Fuel injection pump
9. Fuel injector (with needle lift sensor)
10. Fuel lift pump
11. Fuel lift pump relay
12. Fuel tank
13. Glow plug relay
14. Glow plug
15. Glow plug warning lamp
16. Ignition switch
17. Intake air temperature (IAT) sensor
18. Malfunction indicator lamp (MIL)
19. Manifold absolute pressure (MAP) sensor

- 20. Mass air flow (MAF) sensor
- 21. Turbocharger (TC) wastegate regulating valve
- 22. Vehicle speed sensor (VSS)

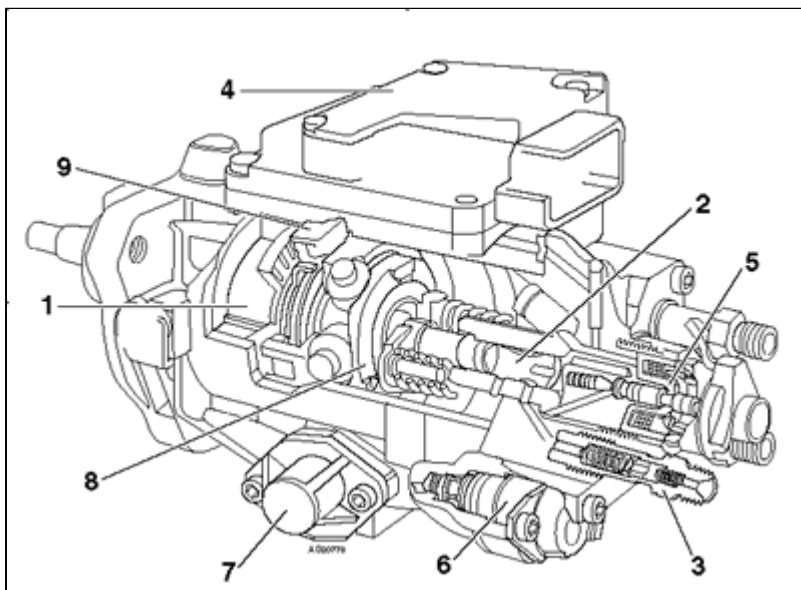
Injection pump operation

Fig. 2



- 1. Vane-type low-pressure pump
- 2. High-pressure plungers
- 3. Distributor head
- 4. Fuel injection pump control module
- 5. Fuel quantity adjuster
- 6. Fuel injection timing solenoid
- 7. Timing actuator
- 8. Cam ring
- 9. Injection pump position sensor

Fig. 2



1. Vane-type low-pressure pump
2. Distributor plunger
3. Distributor head
4. Fuel injection pump control module
5. Fuel quantity adjuster
6. Fuel injection timing solenoid
7. Timing actuator
8. Cam ring
9. Injection pump position sensor

This Bosch rotary fuel injection pump is available with either radial (VR-type pump) **Fig. 2** or axial (VP-type pump) **Fig. 3** high-pressure pumping elements.

Both pumps uses computer technology to control fuel injection quantity and timing.

The pump is driven at engine camshaft speed either via gears, chain or toothed belt. NOTE: Damage may occur to the injection pump if it is operated without an adequate fuel supply. Refer to the manufacturers instructions when changing fuel filters or opening the fuel lines.

Fuel is drawn into the injection pump by a vane-type low-pressure pump **Fig. 2 [1]** & **Fig. 3 [1]** and the pump internal pressure is regulated by a pressure control valve.

Excess fuel is allowed to drain from the injection pump via the overflow restriction in the return connection.

In the radial-type (VR) pump **Fig. 2**, fuel is pressurised by the two high pressure plungers **Fig. 2 [2]** and delivered to the injectors at high pressure via the distributor head **Fig. 2 [3]**.

In the axial-type (VP) pump **Fig. 3**, fuel is pressurised by the distributor plunger **Fig. 3 [2]** and delivered to the injectors at high-pressure via the distributor head **Fig. 3 [3]**.

Signals from the accelerator pedal position (APP) sensor together with information from other engine and vehicle sensors are transmitted to the engine control module (ECM). Signals from sensors mounted in the injection pump are transmitted to the fuel injection pump control module **Fig. 2 [4]** & **Fig. 3 [4]** mounted on the injection pump. The two control modules communicate by a CAN data bus system enabling the calculation of the fuel quantity and injection timing.

The fuel injection quantity is controlled by a solenoid (fuel quantity adjuster) **Fig. 2 [5]** & **Fig. 3 [5]**. The fuel quantity adjuster is energised during the pressure stroke until the calculated quantity of fuel has been injected. The fuel quantity adjuster is then de-energised allowing excess fuel to be diverted to the return circuit.

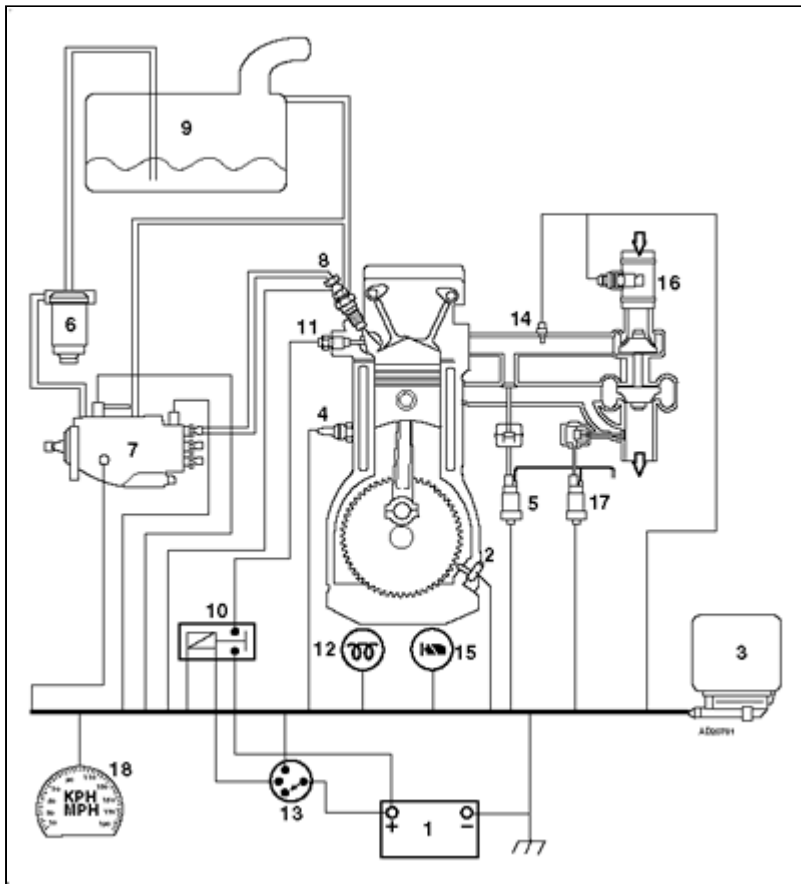
The fuel injection timing is controlled by the fuel injection timing solenoid **Fig. 2 [6]** & **Fig. 3 [6]**, which regulates the control pressure acting on the timing actuator **Fig. 2 [7]** & **Fig. 3 [7]**. The timing actuator varies the position of the cam ring **Fig. 2 [8]** & **Fig. 3 [8]**. An injection pump position sensor **Fig. 2 [9]** & **Fig. 3 [9]** mounted in the injection pump together with a crankshaft position (CKP) sensor and an injector needle lift sensor are used to monitor the actual injection timing which allows closed-loop control.

When the ignition is in the OFF position (or if the vehicle immobilizer is not deactivated), the fuel quantity adjuster will remain de-energised (zero fuel quantity) and the engine will stop

Lucas DPC-N & DPI-N

Fuel injection system components

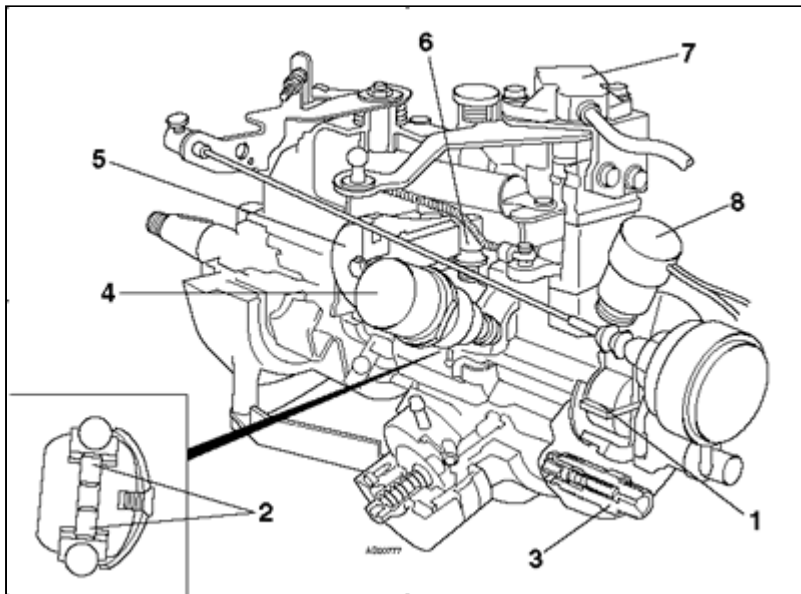
Fig. 1



1. Battery
2. Crankshaft position (CKP) sensor
3. Engine control module (ECM)
4. Engine coolant temperature (ECT) sensor
5. Exhaust gas recirculation (EGR) solenoid
6. Fuel filter
7. Fuel injection pump
8. Fuel injector (with needle lift sensor)
9. Fuel tank
10. Glow plug relay
11. Glow plug
12. Glow plug warning lamp
13. Ignition switch
14. Intake air temperature (IAT) sensor
15. Malfunction indicator lamp (MIL)
16. Mass air flow (MAF) sensor
17. Turbocharger (TC) wastegate regulating valve
18. Vehicle speed sensor (VSS)

Injection pump operation

Fig. 2



1. Vane-type low-pressure pump
2. High-pressure plungers
3. Distributor head
4. Fuel injection timing solenoid
5. Timing actuator
6. Cam ring
7. Fuel lever position sensor
8. Fuel shut-off solenoid

The Lucas DPC rotary fuel injection pump has been used by many vehicle manufacturers in cars and light commercial vehicles for many years.

The pump is driven at engine camshaft speed either via gears, chain or toothed belt.

Fuel is drawn into the injection pump by a vane-type low-pressure pump [1] and the pump internal pressure is regulated by a pressure control valve.

Excess fuel is allowed to drain from the injection pump via the overflow restriction in the return connection.

Fuel is pressurised by the two high-pressure plungers [2] and delivered to the injectors at high pressure via the distributor head [3].

The fuel injection quantity is controlled by a mechanical governor.

Unlike the earlier DPC injection pump, the DPC-N and DPI-N (N = Numeric) pumps use computer technology to control fuel injection timing.

The fuel injection timing is controlled by the fuel injection timing solenoid [4], which regulates the control pressure acting on the timing actuator [5]. The timing actuator varies the position of the cam ring [6]. A crankshaft position (CKP) sensor and an injector needle lift sensor are used to monitor the actual injection timing which allows closed-loop control.

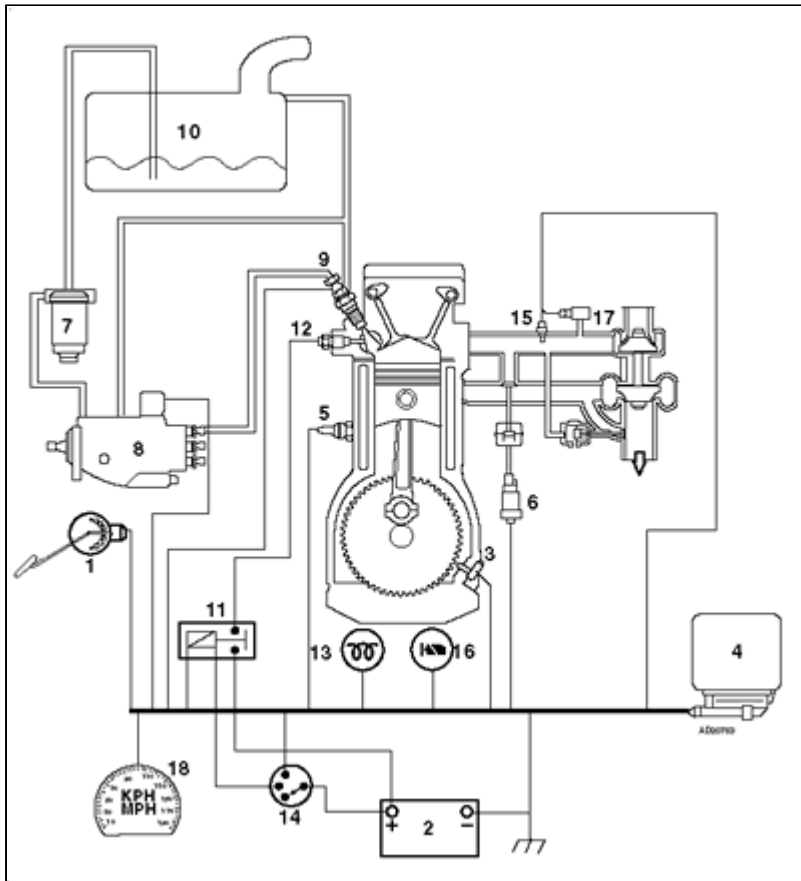
Signals from the fuel lever position sensor [7], together with information from other engine and vehicle sensors are used by the engine control module (ECM) to calculate the fuel injection timing.

When the ignition is switched OFF (or if the vehicle immobilizer is not deactivated), the fuel shut-off solenoid [8] will return to the closed position and the engine will stop.

Lucas EPIC

Fuel injection system components

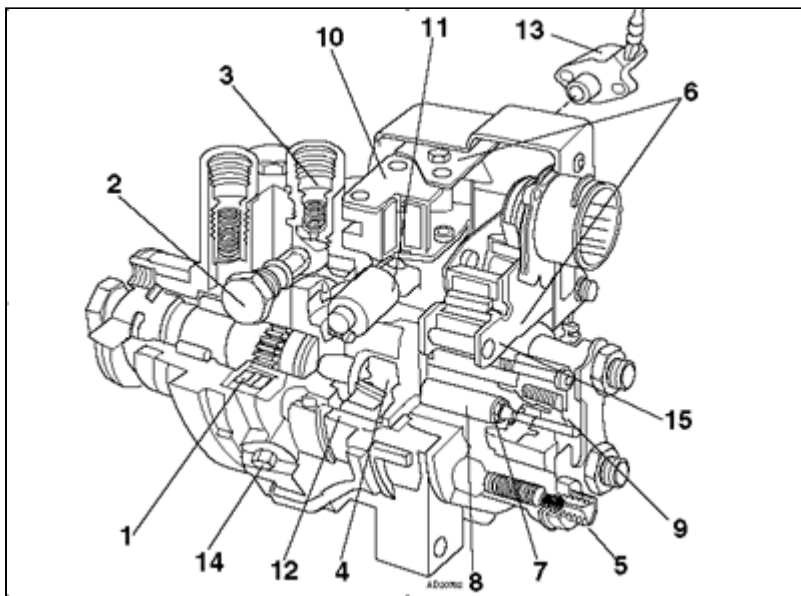
Fig. 1



1. Accelerator position (APP) sensor
2. Battery
3. Crankshaft position (CKP) sensor
4. Engine control module (ECM)
5. Engine coolant temperature (ECT) sensor
6. Exhaust gas recirculation (EGR) solenoid
7. Fuel filter
8. Fuel injection pump
9. Fuel injector (with needle lift sensor)
10. Fuel tank
11. Glow plug relay
12. Glow plug
13. Glow plug warning lamp
14. Ignition switch
15. Intake air temperature (IAT) sensor
16. Malfunction indicator lamp (MIL)
17. Manifold absolute pressure (MAP) sensor
18. Vehicle speed sensor (VSS)

Injection pump operation

Fig. 2



1. Vane-type low-pressure pump
2. Pressure control valve
3. Fuel return connection
4. Distributor plungers
5. Distributor head
6. Fuel quantity adjusters
7. Rotor cavity
8. Rotor
9. Injection pump rotor position sensor
10. Injection timing solenoid
11. Timing actuator
12. Cam ring
13. Injection pump cam ring position sensor
14. Injection pump position sensor
15. Fuel shut-off solenoid

The Lucas EPIC is a fully electronically controlled rotary fuel injection pump. It is used by many vehicle manufacturers in cars and light commercial vehicles.

The pump is driven at engine camshaft speed either via gears, chain or toothed belt.

Fuel is drawn into the injection pump by a vane-type low-pressure pump **[1]** and the pump internal pressure is regulated by a pressure control valve **[2]**.

Excess fuel is allowed to drain from the injection pump via the fuel return connection **[3]**.

Fuel is pressurised by the distributor plungers **[4]** and delivered to the injectors at high pressure via the distributor head **[5]**.

The fuel injection quantity is controlled by two solenoids (fuel quantity adjusters) **[6]**. The solenoids act on valves controlling the flow of fuel into (feed valve) and out of (drain valve) the cavity at the end of the rotor **[7]**. When the feed valve is opened the rotor **[8]** is forced against spring pressure and moves towards the front of the pump (minimum fuel position). When the drain valve is opened the spring forces the rotor towards the rear of the pump (maximum fuel position). The solenoids are continually switched to control fuel injection quantity.

Closed-loop control of the rotor position is maintained with the use of a rotor position sensor mounted at the rear of the pump **[9]**.

The fuel injection timing is controlled by the fuel injection timing solenoid **[10]**. The solenoid acts on a valve controlling the

flow of fuel to the timing actuator [11]. The timing actuator varies the position of the cam ring [12].

Closed-loop control of the cam ring position is maintained with the use of an injection pump cam ring position sensor mounted on the side of the pump [13].

A crankshaft position (CKP) sensor, and either an injector needle lift sensor or an injection pump position sensor [14] are used to monitor the actual injection timing.

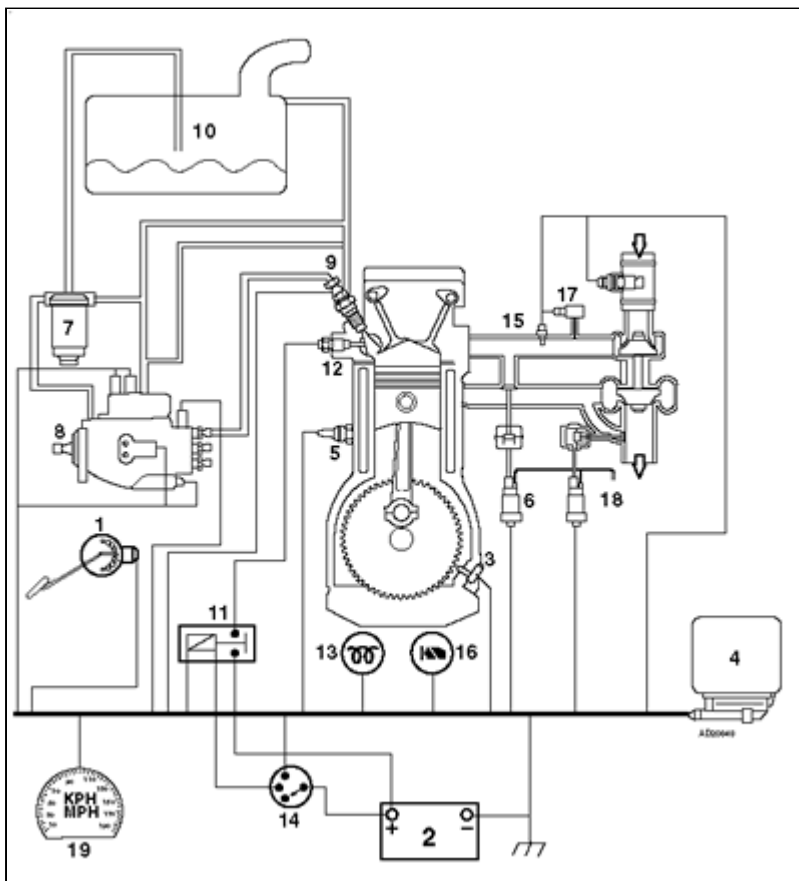
Signals from the accelerator pedal position (APP) sensor together with information from other engine and vehicle sensors are used by the engine control module (ECM) to calculate the fuel quantity and injection timing.

When the ignition is in the OFF position (or if the vehicle immobilizer is not deactivated), the fuel shut-off solenoid [15] will be de-energised and the engine will stop.

Toyota ECD - Denso

Fuel injection system components

Fig. 1

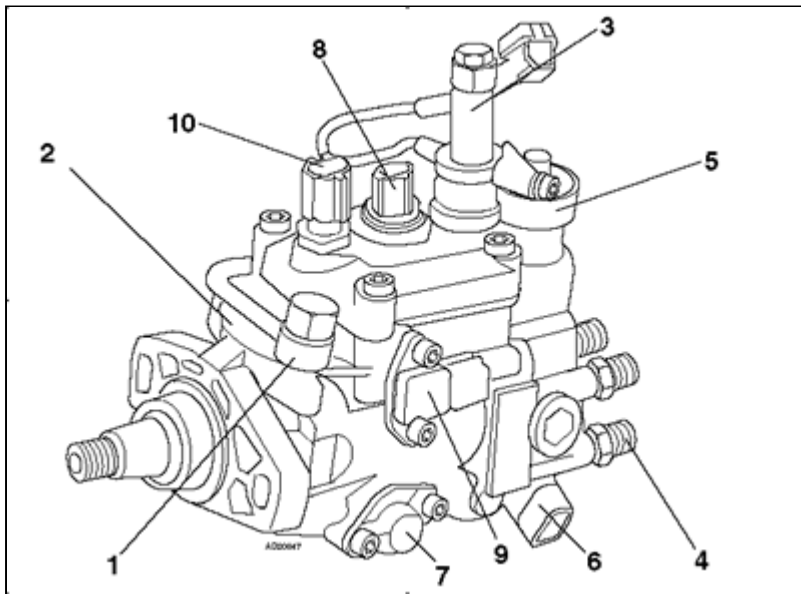


1. Accelerator position (APP) sensor
2. Battery
3. Crankshaft position (CKP) sensor
4. Engine control module (ECM)
5. Engine coolant temperature (ECT) sensor
6. Exhaust gas recirculation (EGR) solenoid
7. Fuel filter
8. Fuel injection pump
9. Fuel injector
10. Fuel tank

11. Glow plug relay
12. Glow plug
13. Glow plug warning lamp
14. Ignition switch
15. Intake air temperature (IAT) sensor
16. Malfunction indicator lamp (MIL)
17. Manifold absolute pressure (MAP) sensor
18. Turbocharger (TC) wastegate regulating valve
19. Vehicle speed sensor (VSS)

Injection pump operation

Fig. 2



1. Inlet connection
2. Pressure control valve
3. Return overflow valve
4. Distributor head
5. Fuel quantity adjuster
6. Fuel injection timing solenoid
7. Timing actuator
8. Injection pump position sensor
9. Module coding plug
10. Fuel temperature sensor

The Denso rotary fuel injection pump is of the axial type and has been used by many Asian vehicle manufacturers in cars and light commercial vehicles for many years.

The pump is driven at engine camshaft speed either via gears, chain or toothed belt.

Fuel is drawn into the injection pump by a vane-type low-pressure pump at the inlet connection **[1]**, and the pump internal pressure is regulated by a pressure control valve **[2]**.

Excess fuel is allowed to drain from the injection pump via the return overflow valve in the return connection **[3]**.

Fuel is pressurised by the distributor plunger and delivered to the injectors at high pressure via the distributor head **[4]**.

Unlike the earlier version, the electronic control diesel (ECD) pump uses computer technology to control fuel injection quantity and timing.

The fuel injection quantity is controlled by an electrical solenoid (fuel quantity adjuster) [5] which is continually switched by the engine control module (ECM).

The fuel injection timing is controlled by the fuel injection timing solenoid [6], which regulates the control pressure acting on the timing actuator [7]. The timing actuator varies the position of the roller ring. An injection pump position sensor [8], (which also gives pump speed information), together with a crankshaft position (CKP) sensor are used to monitor the actual injection timing which allows closed-loop control.

A module coding plug [9] is used to correct manufacturing variations between injection pumps.

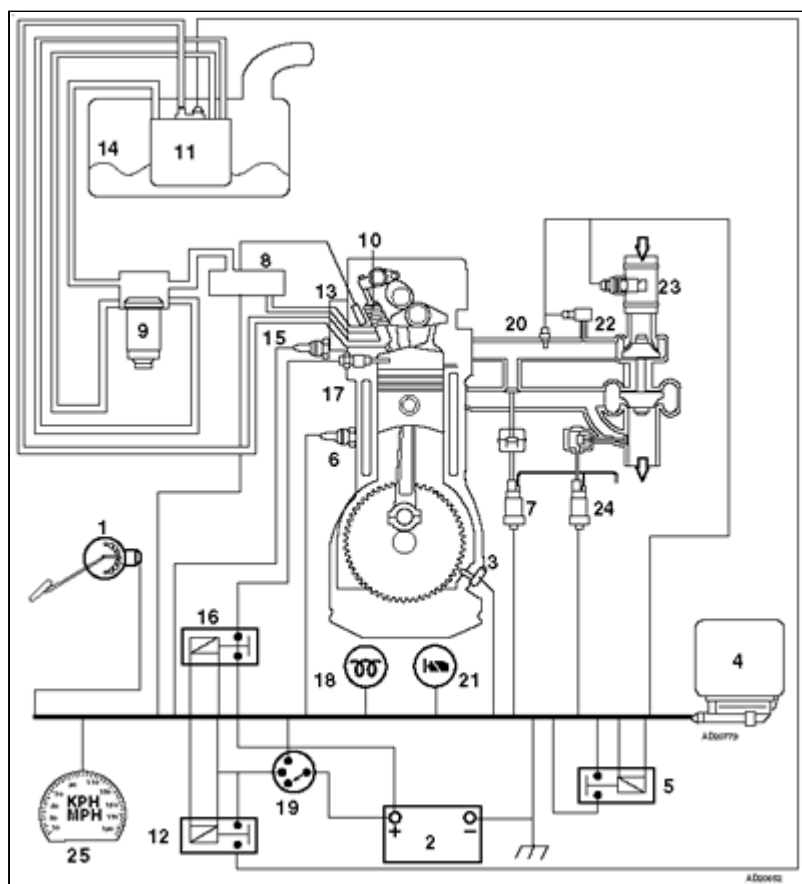
Signals from the accelerator pedal position (APP) sensor together with information from other engine and vehicle sensors are used by the ECM to calculate the fuel quantity and injection timing.

When the ignition is in the OFF position (or if the vehicle immobilizer is not deactivated), the fuel quantity adjuster will return to the position of zero fuel quantity and the engine will stop.

Lucas Unit injector

Fuel injection system components

Fig. 1

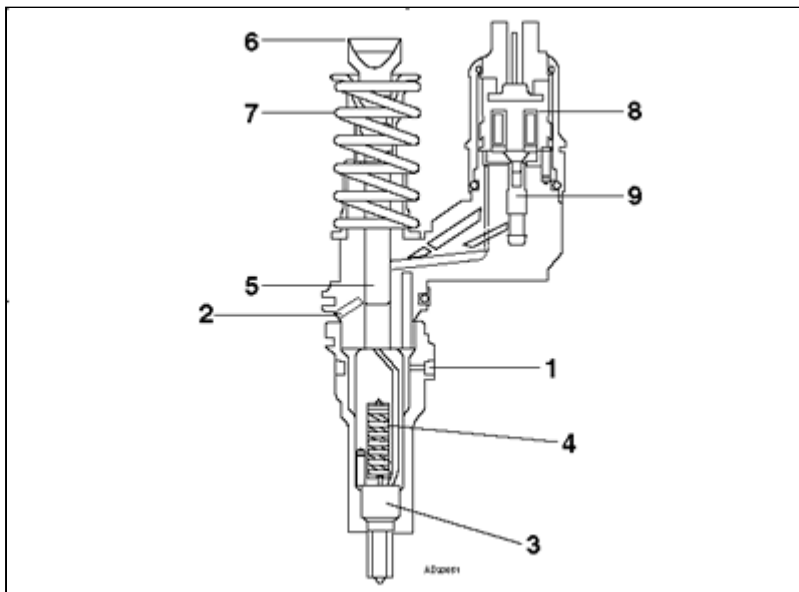


1. Accelerator position (APP) sensor
2. Battery
3. Crankshaft position (CKP) sensor
4. Engine control module (ECM)
5. Engine control relay
6. Engine coolant temperature (ECT) sensor

7. Exhaust gas recirculation (EGR) solenoid
8. Fuel cooler
9. Fuel filter
10. Unit injector
11. Fuel lift pump
12. Fuel lift pump relay
13. Fuel pressure regulator
14. Fuel tank
15. Fuel temperature sensor
16. Glow plug relay
17. Glow plug
18. Glow plug warning lamp
19. Ignition switch
20. Intake air temperature (IAT) sensor
21. Malfunction indicator lamp (MIL)
22. Manifold absolute pressure (MAP) sensor
23. Mass air flow (MAF) sensor
24. Turbocharger (TC) wastegate regulating valve
25. Vehicle speed sensor (VSS)

System operation

Fig. 2



1. Fuel inlet
2. Fuel return
3. Injector
4. Injector spring
5. Pump plunger
6. Pushrod
7. Pushrod return spring
8. Solenoid
9. Solenoid valve

The unit injector system has been used on diesel engines for many years. The injectors are mechanically operated and until recently the system has been used mainly for large commercial vehicles, marine applications and stationary engines.

The latest systems, now being used for smaller engines, use computer technology to control the injectors **Fig. 2** .

Signals from the accelerator pedal position (APP) sensor **Fig. 1 [1]** together with information from other engine and vehicle sensors are transmitted to the engine control module (ECM) **Fig. 1 [4]**.

A two-stage electrical fuel lift pump **Fig. 1 [11]** supplies fuel via a fuel filter **Fig. 1 [9]** to the fuel pressure regulator **Fig. 1 [13]**. Fuel at a regulated pressure (approximately 4 bar) is supplied to the unit injector and the excess is allowed to return to the fuel tank after its temperature is lowered by the fuel cooler **Fig. 1 [8]**.

As the engine rotates, the engine camshaft pressurises the fuel in the unit injector to approximately 1500 bar.

The unit injectors **Fig. 2** are electrically operated by the engine ECM **Fig. 1 [4]** and use low resistance solenoids. To reduce the current being switched by the ECM, the voltage is rapidly switched during the injection period.

The pump plunger is depressed by the camshaft, and at a point determined by the ECM the solenoid valve is energised closing the spill port. Pressure rises until the injector needle is forced from its seat and injection takes place.

After the injection period the solenoid valve is de-energised and the rotation of the camshaft releases the pump plunger allowing cool fuel to replenish the injector in readiness for the next cycle.

Safety precautions

Airbags (Supplementary Restraint System - SRS)

Electrical

Mechanical

Airbags (Supplementary Restraint System - SRS)

Many of the models covered by this manual are fitted with airbags as standard equipment. When working on a vehicle fitted with such a system, extreme caution must be taken to avoid accidental firing of the airbag, which could result in personal injury.

Unauthorised repairs to the system could render it inoperative, or cause it to inflate accidentally.

NOTE: All related wiring may be encased in a yellow outer covering.

When the engine is started the AIRBAG warning lamp should go out after approximately 5-10 seconds. If not this indicates a fault in the system. Refer to the Autodata manual Airbags & seat belt pretensioners.

- NEVER attempt to test the system using a multi-meter.
- NEVER tamper with or disconnect the airbag wiring harness.
- NEVER make extra connections to any part of the system wiring harness or terminals.
- ALWAYS ensure that the airbag wiring harness has not been trapped or damaged in any way when working on adjacent components or systems.

Electrical

- ALWAYS ensure that the battery is properly connected before attempting to start the engine.
- DO NOT attempt to start the engine using a source in excess of 12 volts, such as a fast charger (16 volts) or by connecting two batteries in series (24 volts). ALWAYS disconnect the battery before charging it.
- DO NOT disconnect the battery while the engine is running.
- DO NOT connect the battery with reverse polarity.
- DO NOT connect or disconnect the engine control module (ECM), or any other component of the diesel injection system while the ignition is switched ON.
- DO NOT disconnect ECM multi-plug within 30 seconds of switching ignition OFF.

- DO NOT connect or disconnect multi-meters, voltmeters, ammeters or ohmmeters with the ignition switched ON.
- DO NOT reverse the polarity of the fuel pump.
- ALWAYS ensure that all electrical connections are in good condition and making good contact, PARTICULARLY the ECM connector.
- ALWAYS disconnect the ECM, fuel pump relay/fuse before carrying out a compression test.
- DO NOT flash a wire or circuit to ground to check that continuity exists.
- ALWAYS ensure that any replacement electrical parts are correct for the application in question. Many units share common external features, but differ internally.

Mechanical

CAUTION: Do not connect pressure testing equipment to the fuel rail or other high pressure fuel system components of a common rail diesel injection system.

- DO NOT attempt to slacken any high pressure fuel pipe connections with the ignition on or the engine running.
- AVOID the risk of fire - NEVER work on the diesel injection system when SMOKING or close to a NAKED FLAME.
- ALWAYS keep a fire extinguisher close at hand when working on the diesel injection system.
- ALWAYS ensure that any replacement fuel system parts are correct for the application in question. Many units share common external features, but differ internally.

module (ECM) to calculate the fuel quantity and injection timing.

When the ignition is in the OFF position (or if the vehicle immobilizer is not deactivated), the fuel shut-off solenoid [15] will be de-energised and the engine will stop.

Tools & equipment

Using multi-meters

General recommendations

The majority of electrical tests described in this manual require the use of a digital multi-meter.

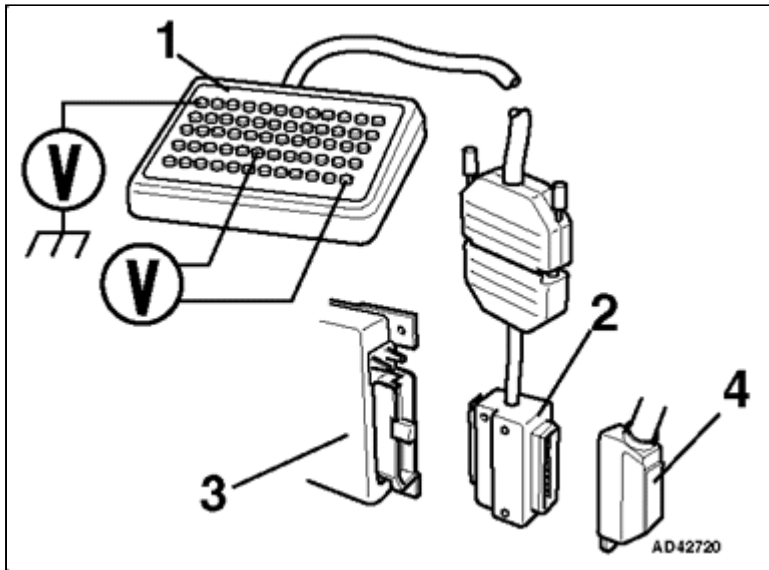
Many suitable instruments are available, with a wide range of prices and specifications, as described below.

Certain other tools, such as a breakout box or a digital oscilloscope (see separate section), will be necessary, or desirable to make best use of this manual.

Breakout box

- Whenever possible a breakout box should be used for testing pinout signals.
- A breakout box [1] is a means of connecting test equipment to the ECM pins, without the need to probe into the back of the harness multi-plug. It is connected by an adaptor lead [2], between the ECM [3] and the car's wiring harness [4].
- The pin connections are laid out in rows in numerical order and have large connecting sockets, enabling test leads to be securely plugged into a circuit, and avoiding the possibility of connecting to the incorrect pin, due to miscounting.
- The possibility of damaging components or wiring, due to shorting live pins to ground or to other components, is also much reduced.
- The limiting factor is the range of adaptor leads. Several equipment manufacturers produce breakout boxes, but none are able to supply a complete range of leads to cover all the models included in this manual.

Fig 1 - Breakout Box



ECM harness multi-plug testing

- If a breakout box and suitable adaptor leads are not available, testing must be carried out at the wire side of the ECM harness multi-plug **Fig. 2**.
- To access the terminals the protective cover must be removed from the plug. Many different types of plug are used for engine management wiring harnesses and two examples are shown in **Fig. 3** and **Fig. 4**.
- Use the appropriate ECM harness multi-plug - wire side diagram and identify the pin(s) to be tested.
- Use only very fine test probes to access the connections and measure the signal between the pin and earth **Fig. 2 [1]**, or between two ECM pins **Fig. 2 [2]**, where a second pin number is given in brackets after the first number.

Fig 2 - ECM harness multi-plug testing

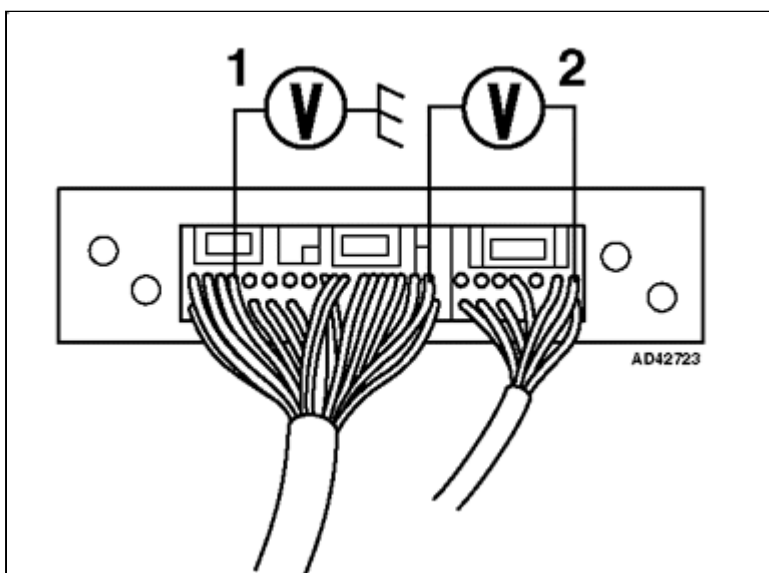


Fig 3 - ECM harness multi-plug testing

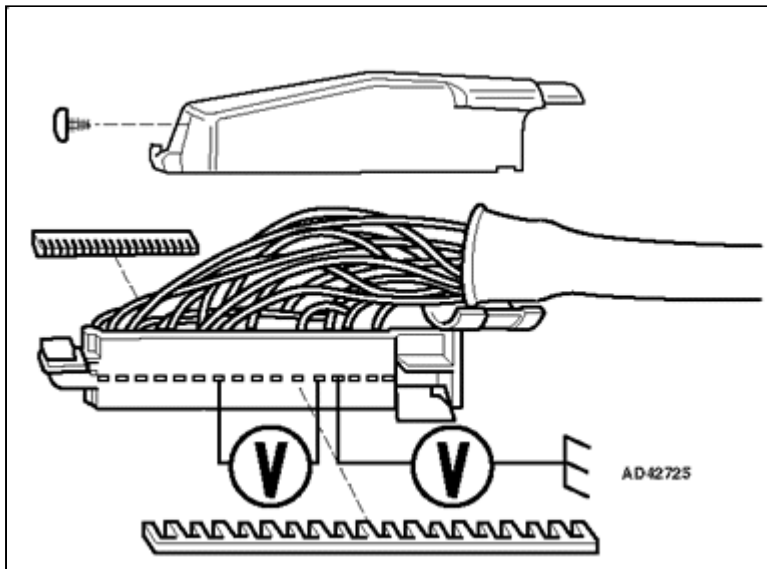
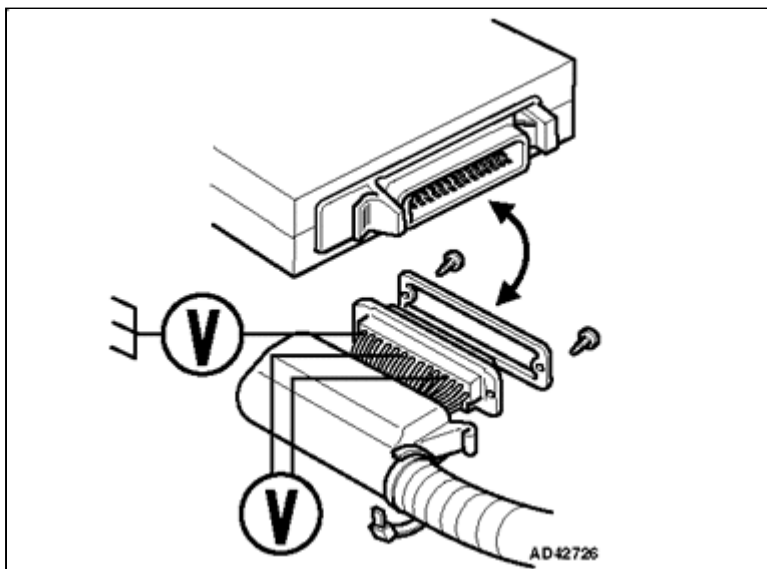


Fig 4 - ECM harness multi-plug testing



Multi-meters

- A high impedance ($10\text{ K } \Omega/\text{volt}$ minimum) multi-meter that includes a 0-20 V voltage scale and a low (0-200 Ω) and high (0-20 $\text{K} \Omega$) range ohm scale is recommended for measuring the voltage and resistance of the system components.
- Analogue **Fig. 5** and digital **Fig. 6** electrical multi-test meters are available in a wide range of prices and specifications. In view of the fact that the instrument will be used in the harsh environment of the workshop, the extra expense of a shock-proof digital type will be a good investment.
- In addition to the usual volts, ohms and milliamp scales, features such as the facility to read frequency (Hz) and duty cycle (%), will also be useful.

Fig 5 - Analogue

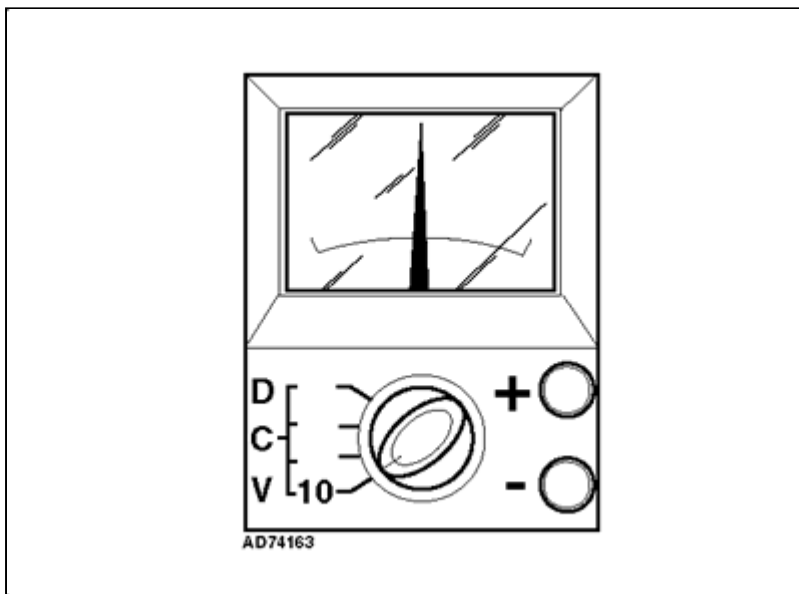
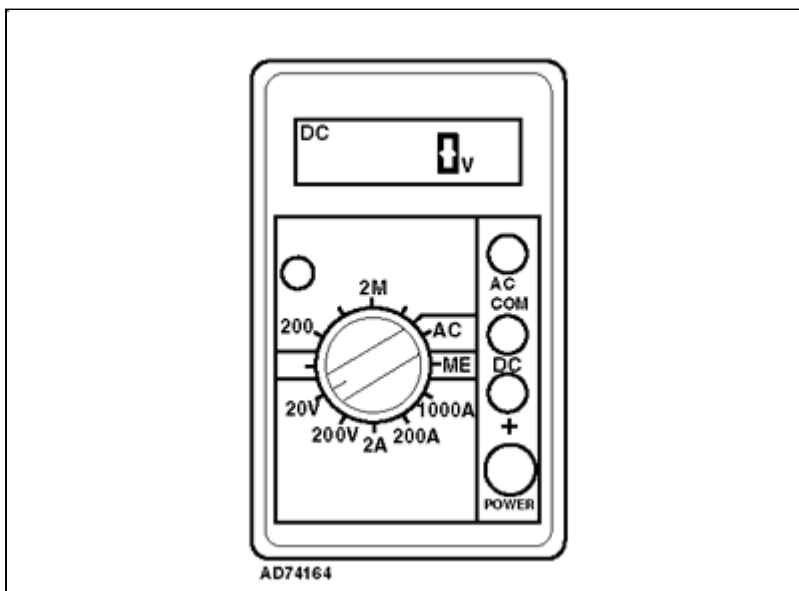


Fig 6 - Digital



Using multi-meters

Voltage checking

- Connect negative test lead to a good earth, or direct to the negative battery terminal.
- Observe conditions for test, e.g. ignition OFF, ignition ON etc.
- If the meter does not automatically select the appropriate voltage range, ensure correct meter scale selected, e.g. 0-12 volts.
- Connect positive test lead to ECM pin being tested.

Continuity checking

- Ensure that battery supply voltage is not present at test terminals.
- Select appropriate resistance scale.
- Connect meter leads together and check zero reading (analogue meters only).

NOTE: If unable to zero meter, this usually indicates that the internal battery requires replacement.

- Connect ohmmeter leads to each end of component or wire to be tested.
- Read off resistance.

NOTE: If meter indicates zero **Fig. 7** this indicates continuity between the two test points. If the meter indicates infinity **Fig. 8**, this indicates an open circuit (broken wire, burnt out component etc.) between the two test points.

Fig 7 - Continuity indicated

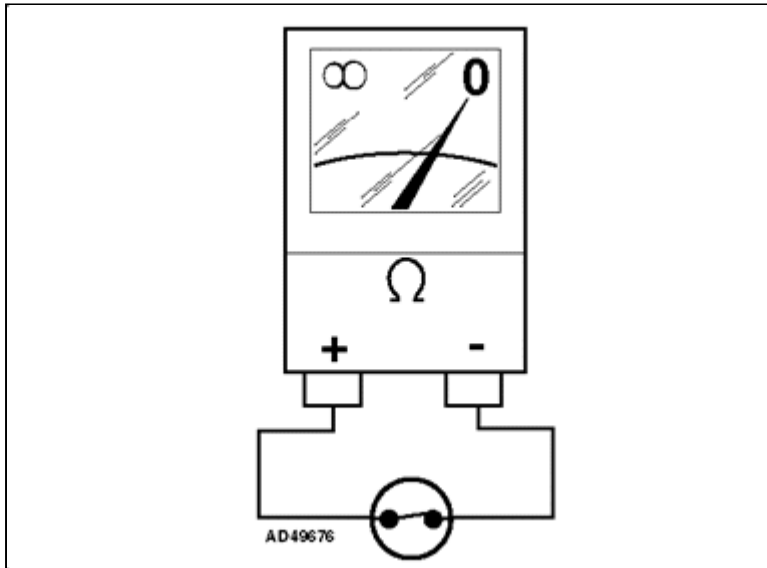
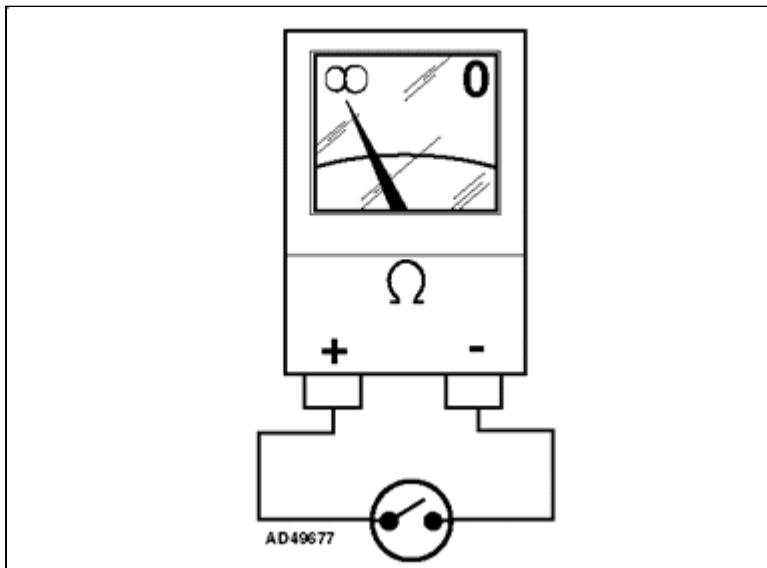


Fig 8 - Open circuit indicated



Diode checking

- To check a diode connect the meter negative lead to the positive side of the diode and the positive lead to the negative side of the diode. The meter should indicate continuity **Fig. 9**.
- When the meter connections are reversed the meter should indicate an open circuit **Fig. 10**.
- If continuity is indicated in each direction, the diode is faulty.

Fig 9 - Continuity indicated

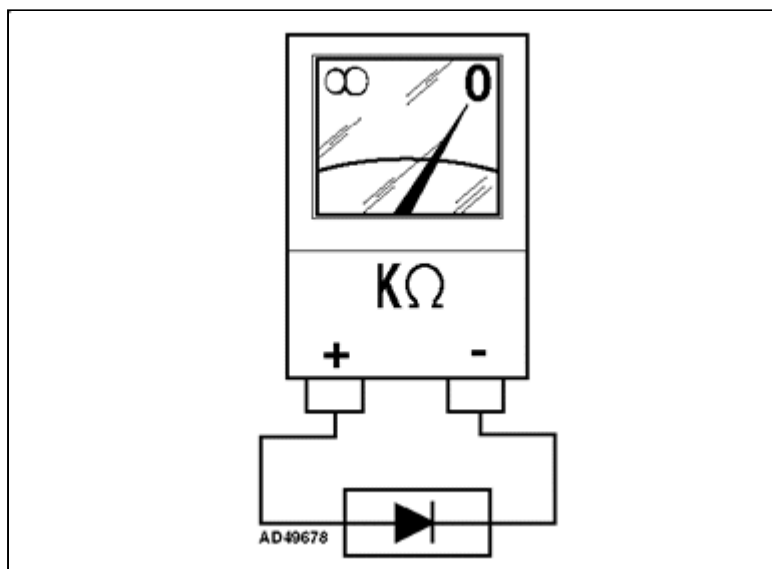
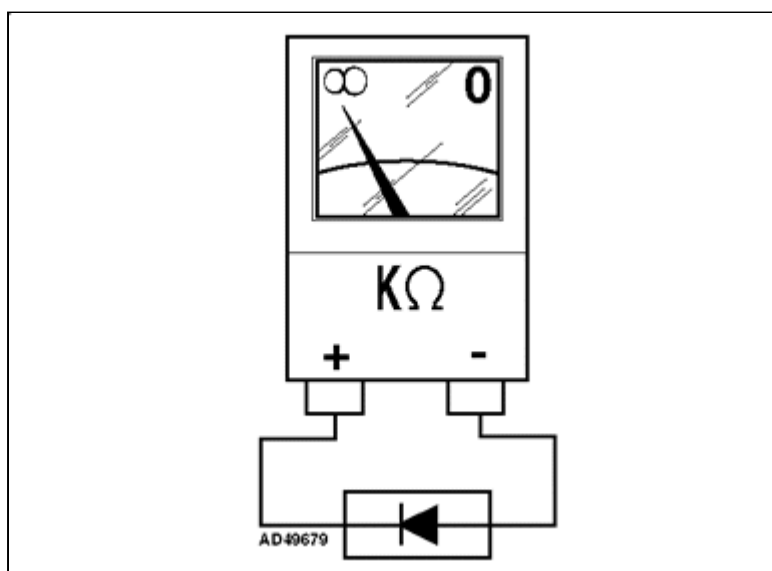


Fig 10 - Open circuit indicated

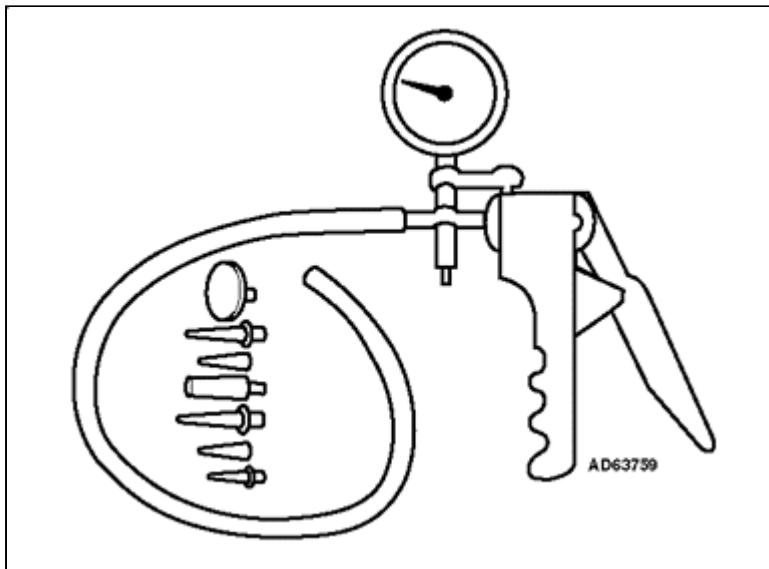


Vacuum pump

A hand operated vacuum pump, with gauge, will be necessary for testing certain components, such as manifold absolute pressure (MAP) sensors.

Several types are available and are usually supplied with a connecting hose and a selection of adaptors **Fig. 11**.

Fig 11 - Vacuum Pump



Memory savers

With the increasing number of electronic devices incorporating a memory, whenever the battery is disconnected inconvenience is caused by the loss of such information as radio security codes and station settings, clock settings and ECM memories.

This situation can be avoided by the use of an alternative power source such as the memory savers marketed by several of the leading test equipment manufacturers.

Oscilloscope testing

[Why use an oscilloscope?](#)

[Oscilloscope scales](#)

[Wave forms](#)

[Interpreting wave forms](#)

[Component testing](#)

Why use an oscilloscope?

- Digital multi-meters are entirely satisfactory for checking circuits in a static condition and for instances where any change in reading is a gradual one, but for dynamic checking (with the engine running) and the diagnosis of intermittent faults, the oscilloscope is a very powerful workshop tool.
- Unlike older analogue oscilloscopes dedicated to HT ignition testing, a modern digital oscilloscope has a variable voltage scale, enabling low voltages (typically 0-5 V or 0-12 V) to be displayed and also an adjustable time scale, enabling any wave form to be displayed in the ideal manner.
- Most oscilloscopes designed for automotive use can be hand-held and are therefore ideal for use in the workshop. They can also be used inside the car, while the vehicle is driven, to capture dynamic data.
- Usually it is possible to store wave forms and associated data in an internal memory and then print it out or download it onto a PC, enabling the scope patterns to be studied in detail.
- The oscilloscope display can show the amplitude, frequency, pulse width, shape and pattern of the signal received, by effectively drawing a graph of voltage (vertically) and time (horizontally).
- It is easy to connect (normally just two leads) and the speed of sampling can be far in excess of even the best of digital multi-meters.
- This fast response time enables diagnosis of intermittent problems and also enables the effect of disturbing parts of the system to be observed. When necessary, the response time can be slow

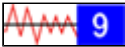
enough to display signals such as the accelerator position (APP) sensor.

- Once the cause of a problem has been diagnosed and rectified, the repair can be verified by retesting with the oscilloscope.
- Currently available oscilloscopes are easy to connect and use, enabling a trace to be displayed on the screen without any specialist knowledge or experience. The interpretation of this trace can be greatly assisted by reference to the typical wave forms illustrated in this topic.

Oscilloscope scales

- To enable testing of the circuit's operating voltage and frequency, each oscilloscope wave form reference in the Pin Data tables has been assigned a voltage and time scale.
- When testing the circuit, set the oscilloscope to given voltage and time scale.
- Ensure that the oscilloscope is set to either DC (direct current) or AC (alternating current) as appropriate, and that the trigger level is within the voltage range quoted.

NOTE: Some circuits may require very fine adjustment of the oscilloscope to enable the pattern to be viewed.

- Refer to the wave form number  and overlay the voltage and time scale given.
- For the example:

Typical value

2 V 50 ms per division

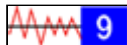
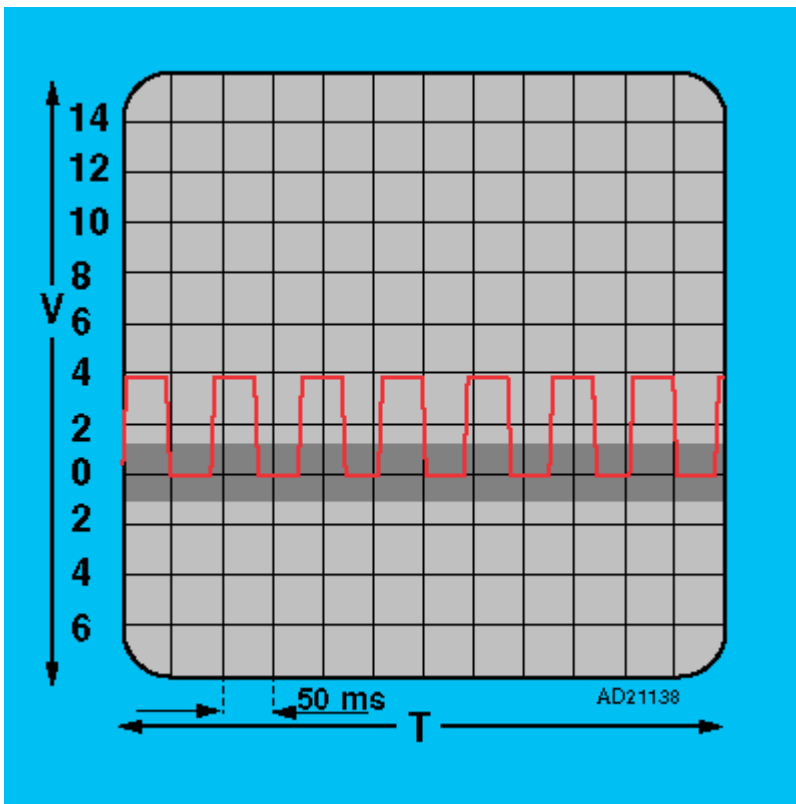


Fig. 1 - Voltage and time scale



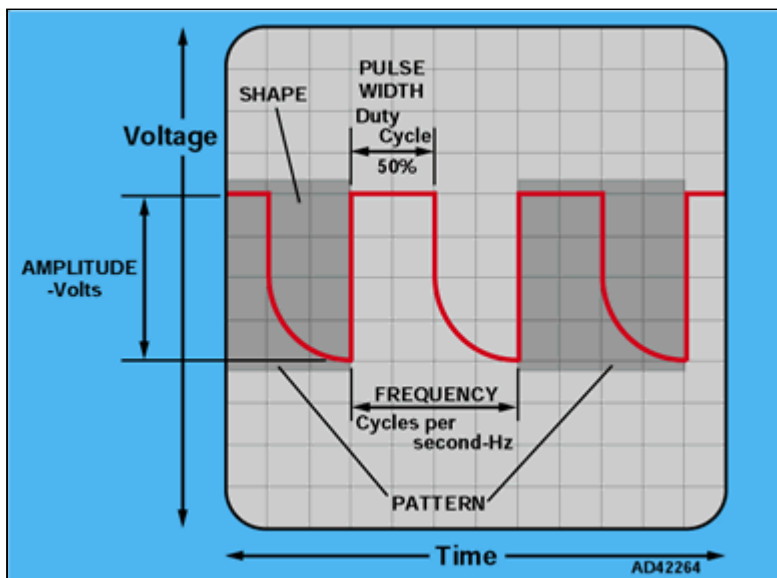
- In this example the circuit is operating at approximately 4 volts, switching at approximately 50 ms intervals.
- Voltage scales used for the patterns in this publication range from 5 mV (mv = millivolt, 1/1000 V) to 20 V per division.

- Time scale units used for the patterns in this publication are s = seconds, ms = milliseconds (one thousandth of a second) or μ s = microsecond (one millionth of a second).

Wave forms

- Each oscilloscope wave form has one or more of the following parameters:
 - Amplitude - voltage (V)
 - The signal voltage at a certain moment in time
 - Frequency - cycles per second (Hz)
 - The time between points of the signal
 - Pulse width - duty cycle (%)
 - The period during which the signal is ON - expressed as a percentage (%) of the total
 - Shape - spike, curve, saw-tooth etc.
 - The overall 'picture' of the signal

Fig. 2 - Wave form parameters



- Pattern - repeated shapes
 - The pattern of repetition of the overall shape of the signal
- The oscilloscope will show all these parameters in one display and by comparing the scope traces from the vehicle under test with those illustrated, a judgement can be made about the condition of each circuit and its components.
- The scope trace for a faulty circuit or component will usually appear very different to that for a satisfactory one, thus simplifying fault identification.
- The five parameters listed above can be categorised as follows:

Direct current (DC) voltage signals - amplitude only

- Analogue signal voltages from components such as:

Fig. 3 - Engine coolant temperature (ECT) sensor

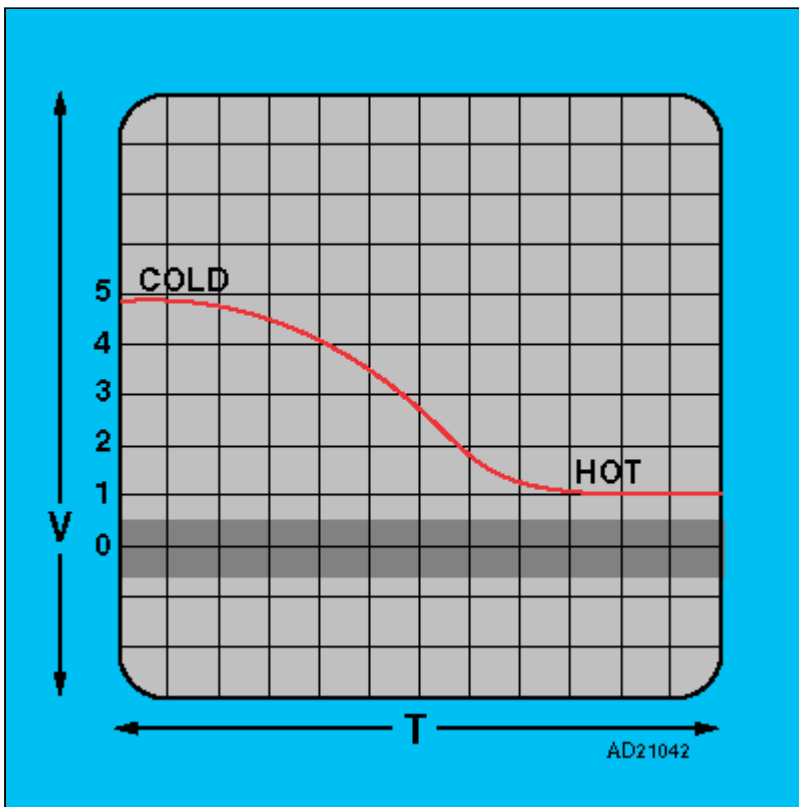


Fig. 4 - Intake air temperature (IAT) sensor

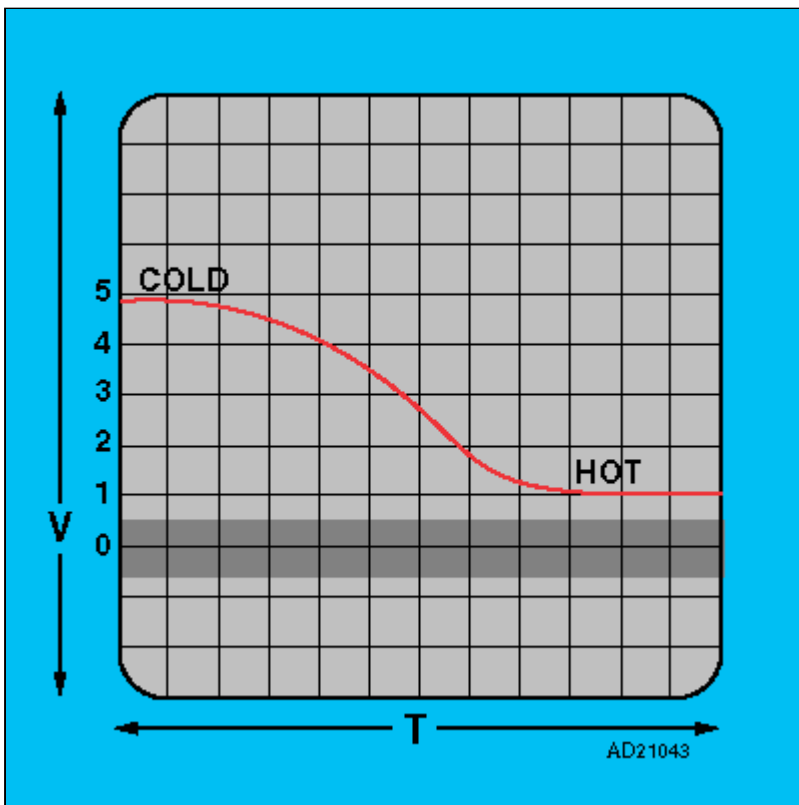


Fig. 5 - Accelerator position (APP) sensor

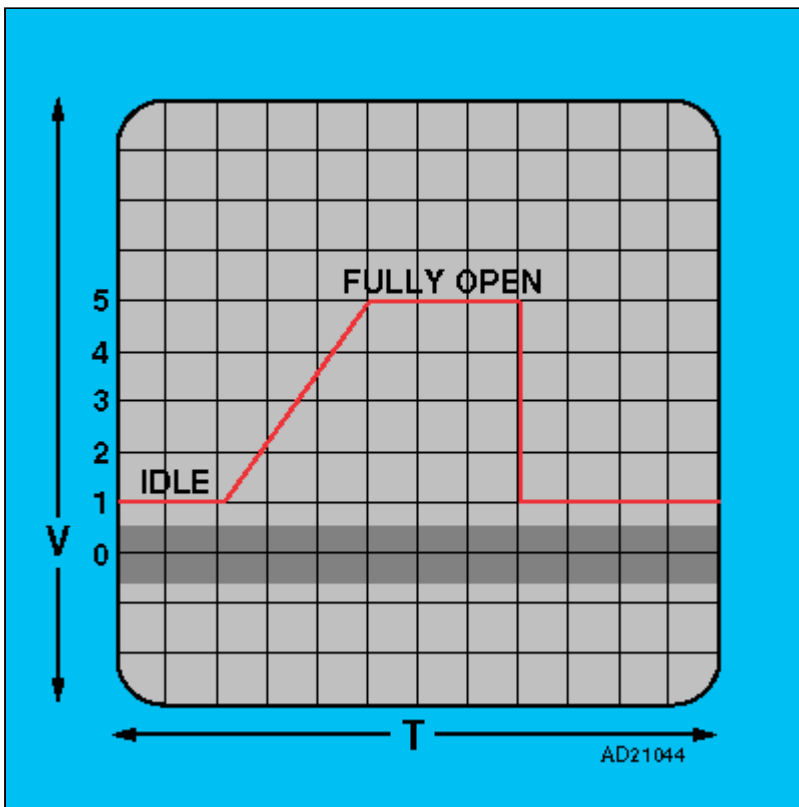
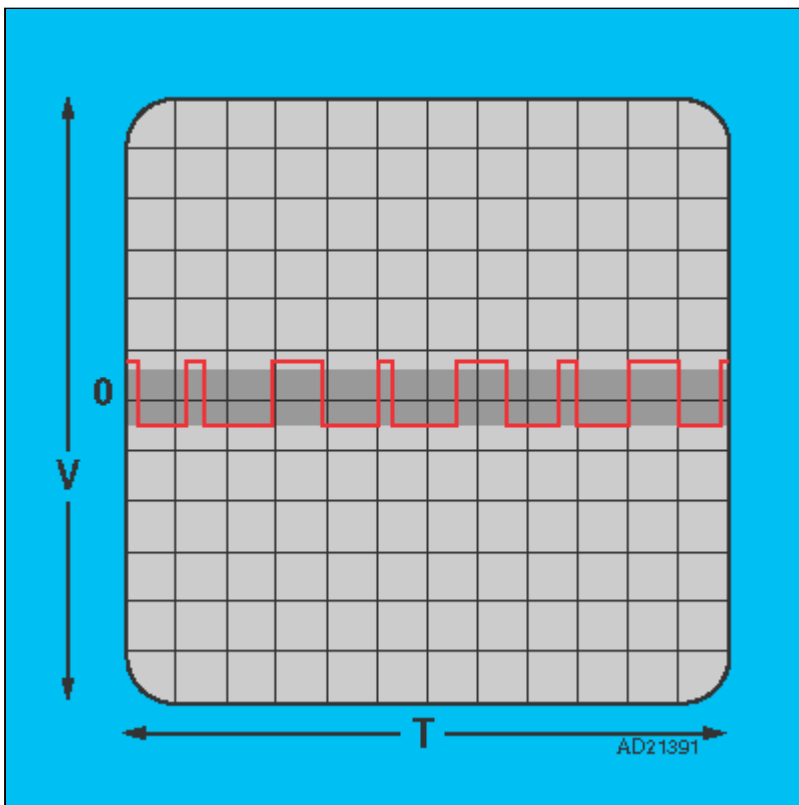


Fig. 6 - Mass air flow (MAF) sensor



Alternating current (AC) voltage signals - amplitude, frequency and shape

- AC voltage signals are generated by components such as:

Fig. 7 - Injector needle lift sensor

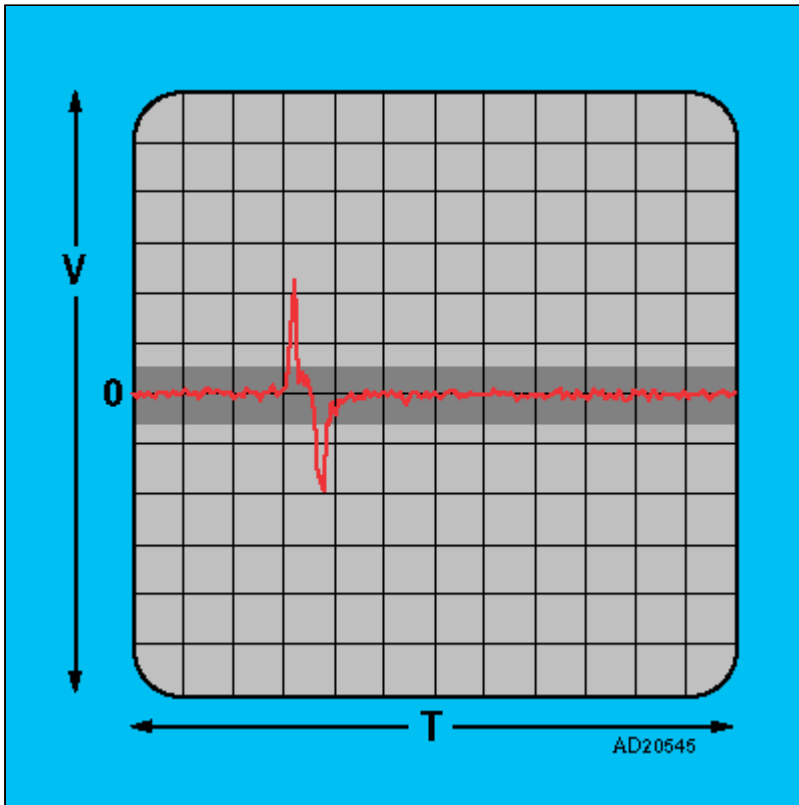
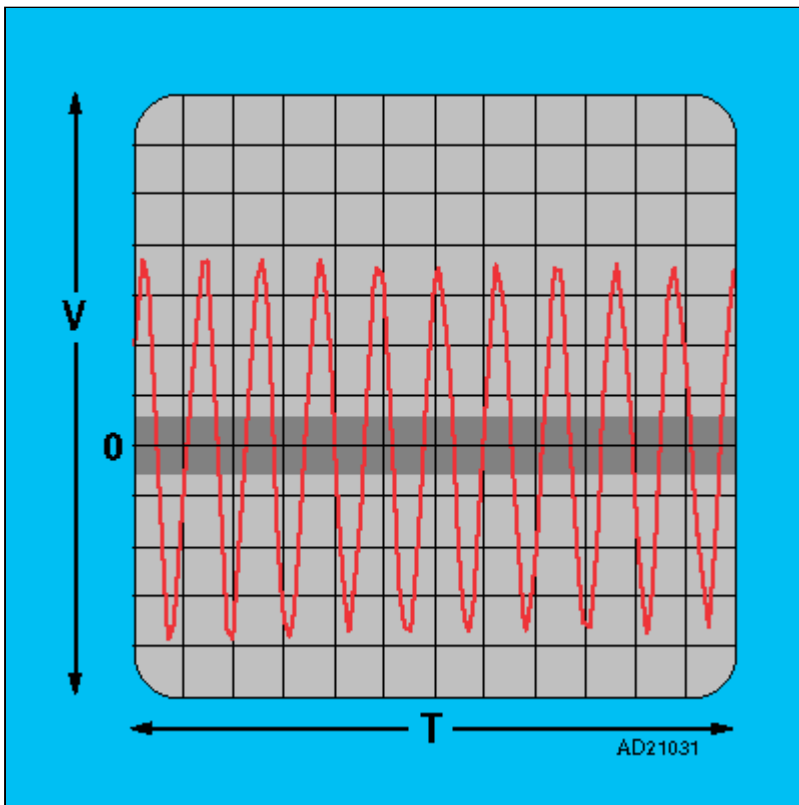


Fig. 8 - Engine speed (RPM) sensor - inductive type



Frequency modulated signals - amplitude, frequency, shape and pulse width

- Frequency modulated signals are generated by components such as:

Fig. 9 - Crankshaft position (CKP) sensor - inductive type

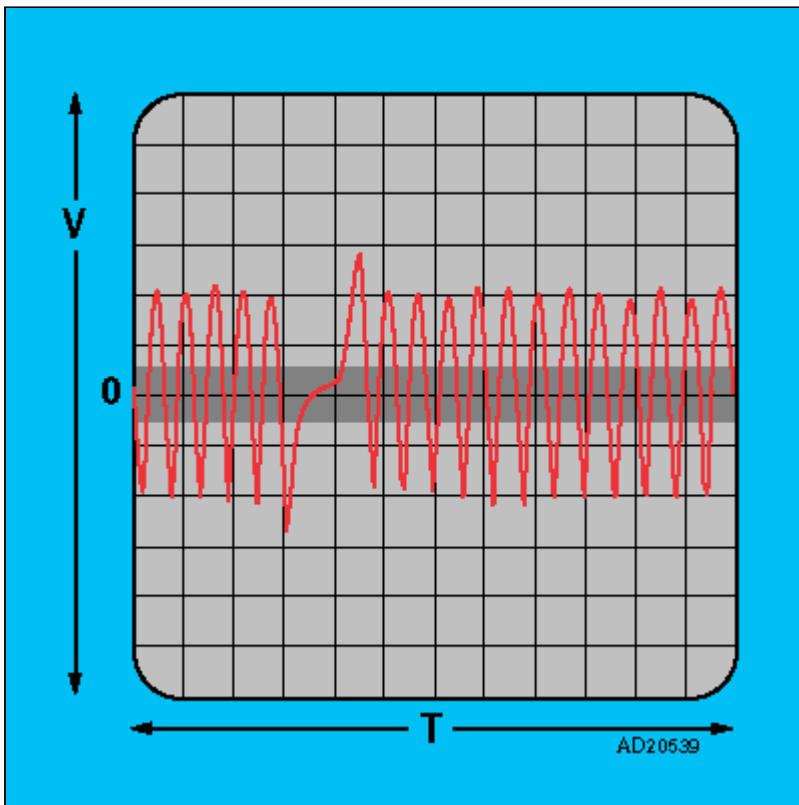


Fig. 10 - Camshaft position (CMP) sensor - inductive type

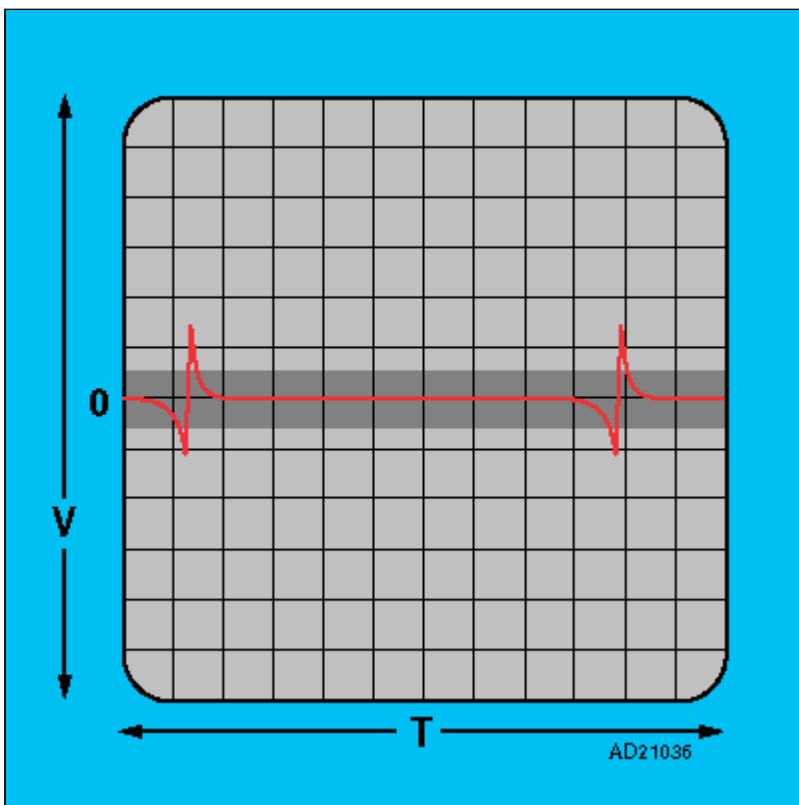


Fig. 11 - Vehicle speed (VSS) sensor - inductive type

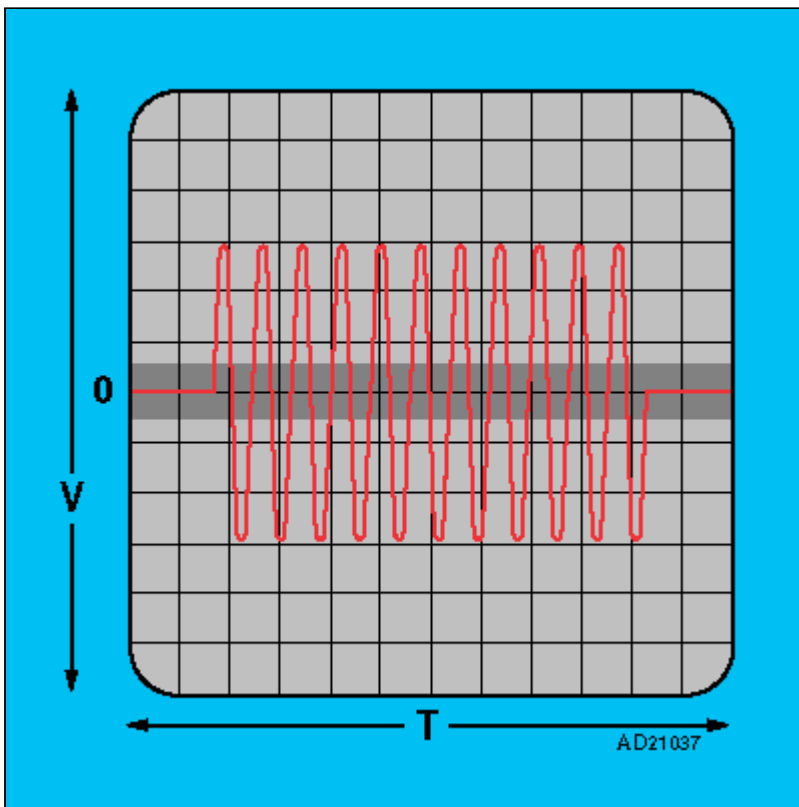
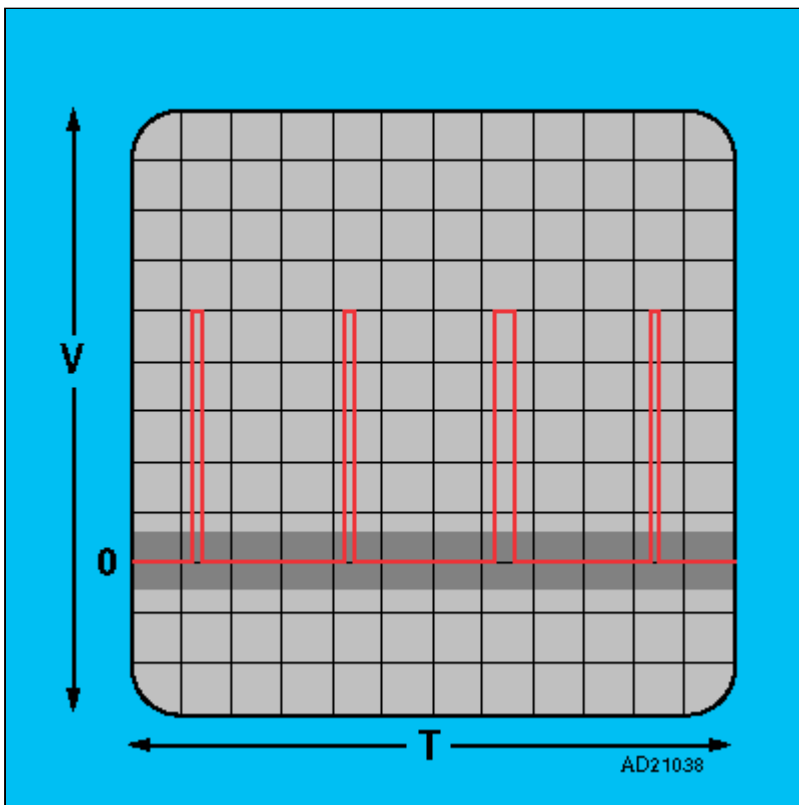


Fig. 12 - Hall-effect speed and position sensors



Pulse width modulated signals - amplitude, frequency, shape, pulse width

- Pulse width modulated signals from components such as:

Fig. 13 - Injectors

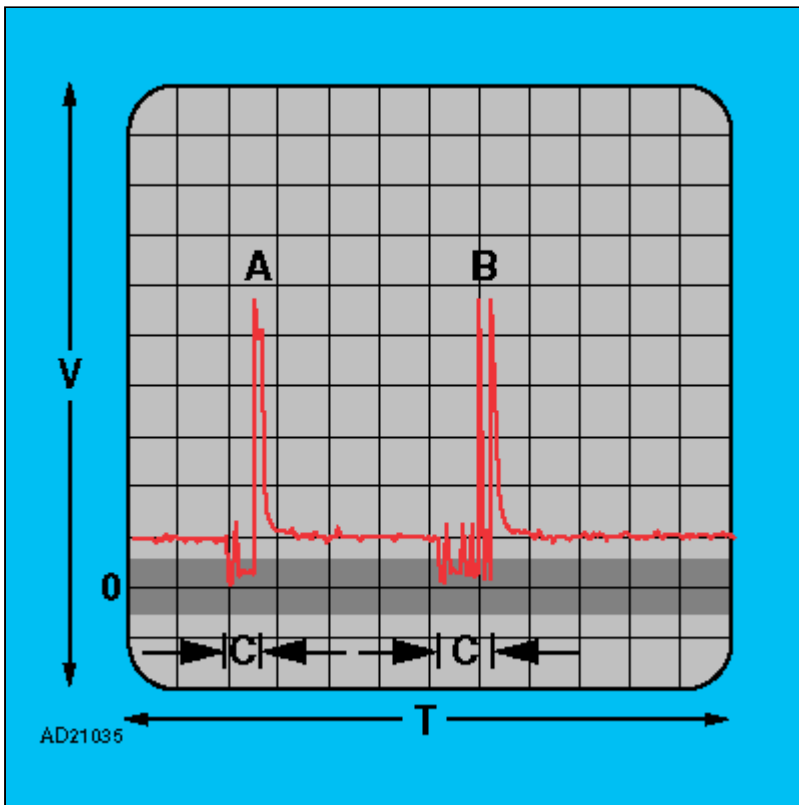


Fig. 14 - Fuel injection timing solenoid

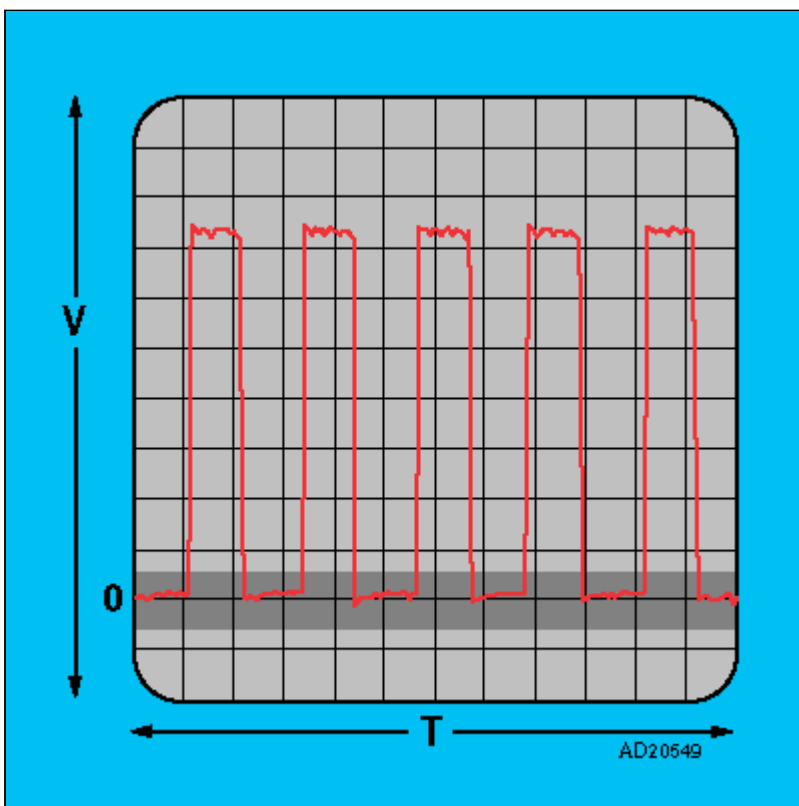


Fig. 15 - Fuel quantity adjuster

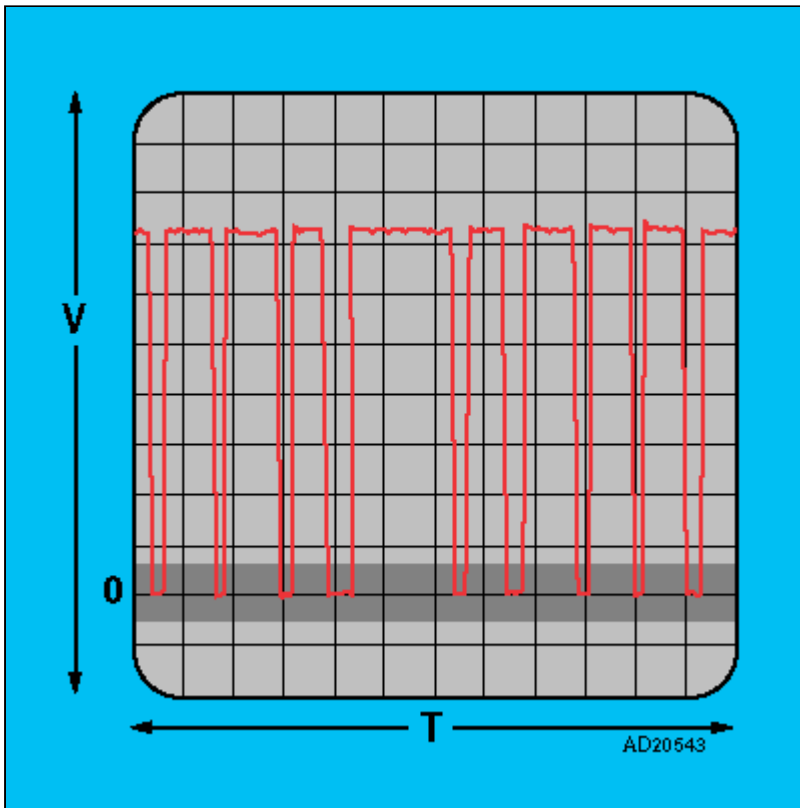
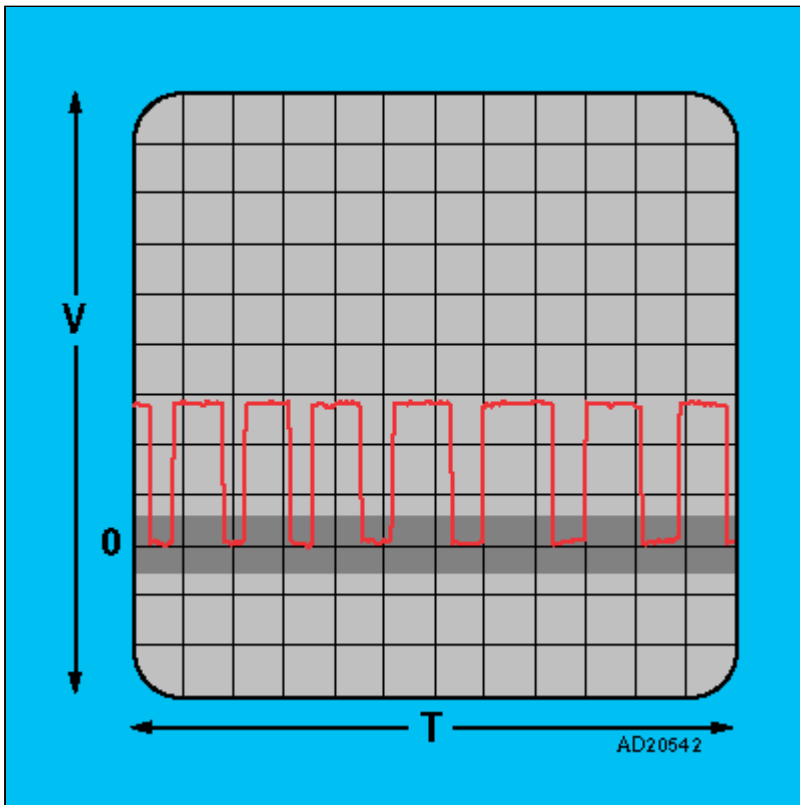


Fig. 16 - Exhaust gas recirculation (EGR) valves



Interpreting wave forms

Typical wave forms

- Oscilloscope wave form patterns can vary greatly and are dependent on many factors. Therefore prior to making a diagnosis or changing components the following points should be considered when the wave form obtained does not appear to be correct when compared with the 'typical' wave form in the pin data table being used.

Voltage

- Typical wave forms indicate the approximate position of the wave form in relationship to the 'zero grid', but this may vary **Fig. 17 [1]**, dependent on the system being tested and may be positioned anywhere within the approximate 'zero range' **Fig. 17 [2]** & **Fig. 18 [1]**.
- The amplitude or overall height of the pattern (the voltage) **Fig. 17 [3]** & **Fig. 18 [2]**, will depend on the circuit's operating voltage.
- For direct current (DC) circuits this will depend on the voltage being switched, for example, the fuel injection timing solenoid voltage will be constant and will not vary with engine speed.
- For alternating current (AC) circuits this will depend on the speed of the signal generator, for example, an inductive crankshaft position (CKP) sensor's output voltage will increase with engine speed.
- Therefore if the oscilloscope pattern is too high (or the upper part is missing) increase the voltage scale to obtain the view required. If the pattern is too low decrease the voltage scale.
- Some circuits operating solenoid components, for example the fuel injection timing solenoid, may display voltage spikes **Fig. 17 [4]**, when the circuit is switched off. This voltage is generated by the component and can normally be ignored.
- Some circuits that have a square wave type of typical wave form may display the voltage decaying at the end of the switching period **Fig. 17 [5]**. This is a characteristic of some systems and can normally be ignored, as it does not by itself indicate a fault.

Frequency

- The overall width of the pattern (the frequency), will depend on the circuit's operating speed.
- The typical wave forms illustrated show the wave form viewed with the oscilloscope's time scale set to enable detailed observation.
- In direct current (DC) circuits the time scale will be dependent on the speed at which the circuit is switched **Fig. 17 [6]**, for example, the frequency of a fuel quantity adjuster will vary with engine load.
- In alternating current (AC) circuits the time scale will depend on the speed of the signal generator **Fig. 18 [3]**, for example, an inductive crankshaft position (CKP) sensor's frequency will increase with engine speed.
- If the oscilloscope pattern is too compressed, decrease the time scale to obtain the view required. If the pattern is too expanded, increase the time scale.
- If the pattern is reversed **Fig. 18 [4]**, this indicates that the system being tested has its component connected in the opposite polarity to the typical wave form shown and can normally be ignored as it does not by itself indicate a fault.

[Fig. 17 - Digital wave form](#)

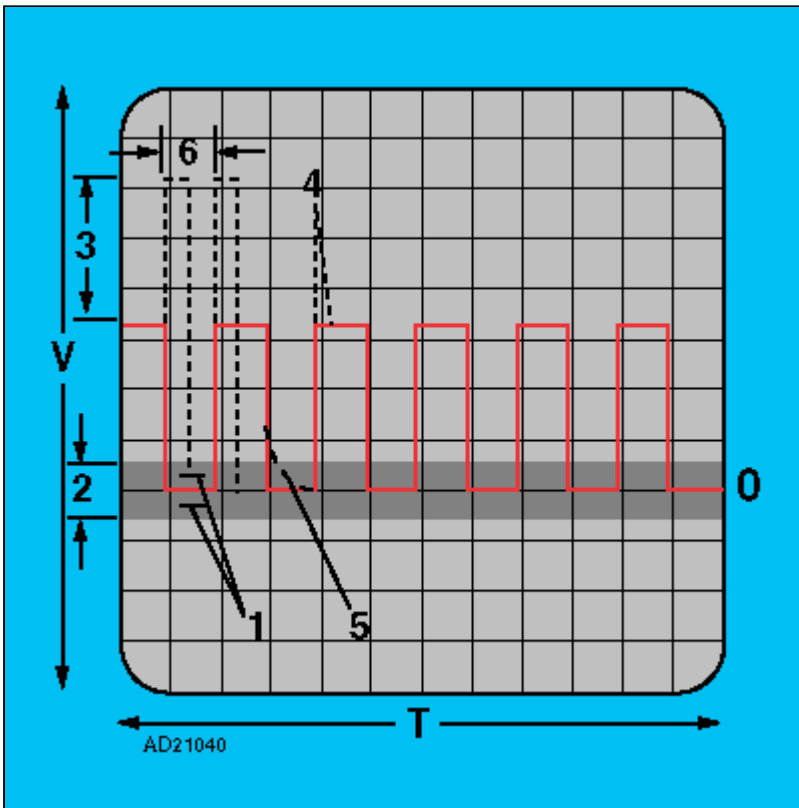
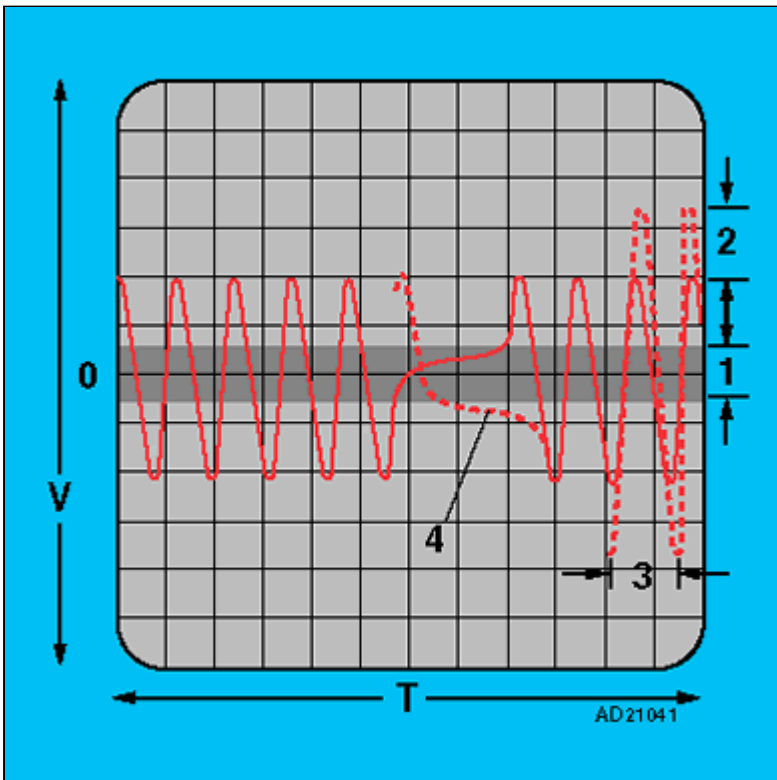


Fig. 18 - Analogue wave form



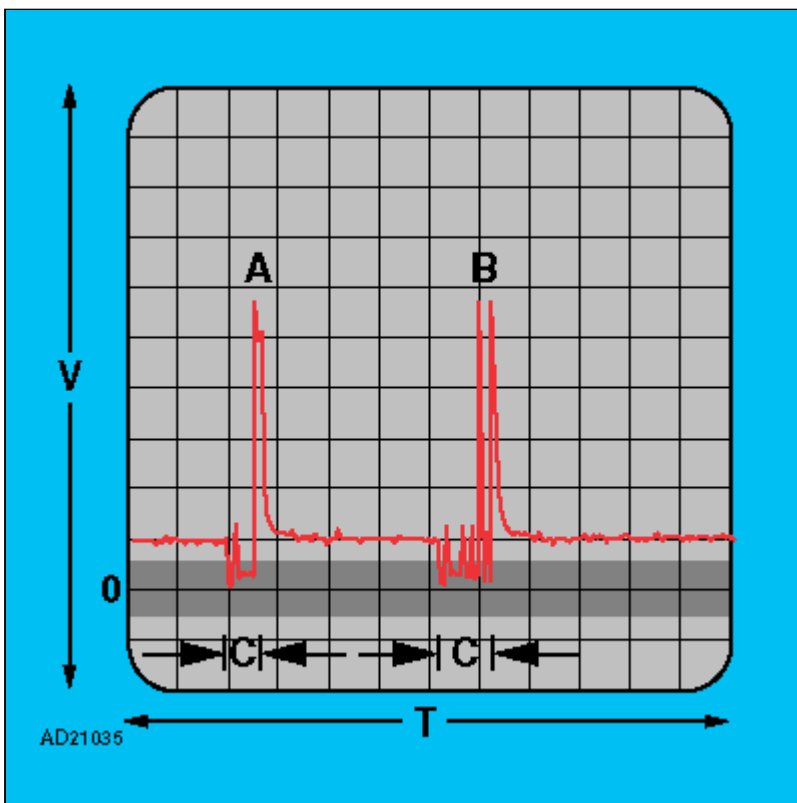
Component testing

- Wave forms for a variety of components can be displayed. A few of the more common examples are

described below.

- Most modern oscilloscopes have just two test leads, used with a variety of interchangeable test probes. The red lead is the positive and is normally connected to the ECM pin. The black lead is the negative and is normally connected to a good earth.
- If the leads are inadvertently connected with the wrong polarity, usually the only consequence is that the wave form will be displayed upside down.
- All common rail and electronically controlled unit injector systems operate by varying the opening time of the injectors to match the quantity of fuel supplied with the engine operating conditions.
- The duration of the electrical impulses from the control unit is measured in milliseconds (ms) and typically ranges from 1 to 2 at idle speed. The oscilloscope on most engine testers can be used to display the injector pulse, enabling the duration to be measured.
- A typical oscilloscope trace is shown in **Fig. 19**.
- Most modern Diesel engines inject fuel in stages called pilot, main and post injection.
- The first injection (pilot) **Fig. 19 [A]**, occurs as the piston is rising on its compression stroke and is used to pre-condition the combustion chamber.
- The second injection (main) **Fig. 19 [B]**, occurs at or near top dead centre (TDC) and provides most of the combustion.
- The third injection (post), used where exhaust emission standards dictate, occurs in the exhaust stroke and is used in conjunction with the exhaust gas recirculation (EGR) system to reduce exhaust emissions.
- The injectors operate at very high fuel pressures and have to react rapidly necessitating the use of high current solenoids. To reduce the current switched by the ECM, the injector solenoid is rapidly modulated during its open period **Fig. 19 [C]**.
- As the injector is energised the voltage at the signal pin falls to, or near zero, and as it is de-energised the returning armature of the solenoid generates a pulse (spike) of high voltage.
- It is therefore possible to check that the control unit is operating correctly by observing the changes in injector opening times during various engine operating conditions.
- Injector opening during cranking may be higher than at idle speed, and will increase as the engine load rises.

Fig. 19 - Injectors



Injector pulse

- Using a thin probe, connect the oscilloscope test probe to the ECM injector terminal and the second test probe to earth.
- Start engine and observe the wave form at idle speed.
- Depress the accelerator pedal rapidly to increase engine speed to around 3000 rpm.
- The measured pulse duration should increase during acceleration and then stabilise at a reading equal to or slightly below the idle speed value.
- Release the accelerator pedal rapidly and the trace should become a straight line with no pulse indicating that injection has been cut-off.

Technical Data

Injection Duration

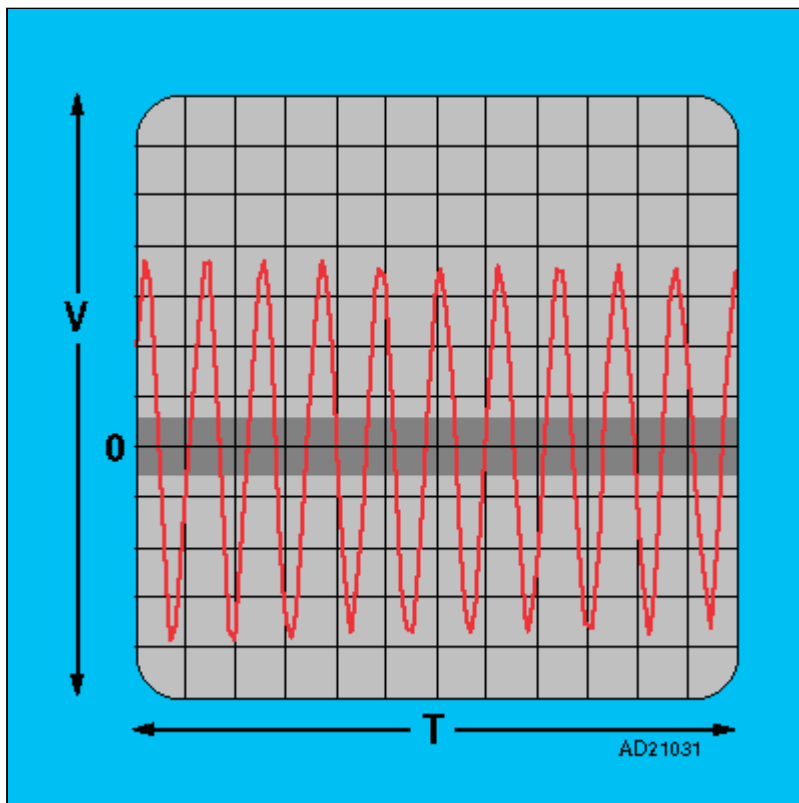
Pilot 1-2 ms

Main 1-2 ms

Inductive sensors

- The general procedure is as follows:
- Select sensor pin from pin data list with wave form reference.
- Connect oscilloscope probe to ECM pin and second probe to earth.
- Start engine and observe test conditions.
- Compare scope trace with wave form reference.
- Raise the engine speed and watch for the voltage (amplitude) display to increase.

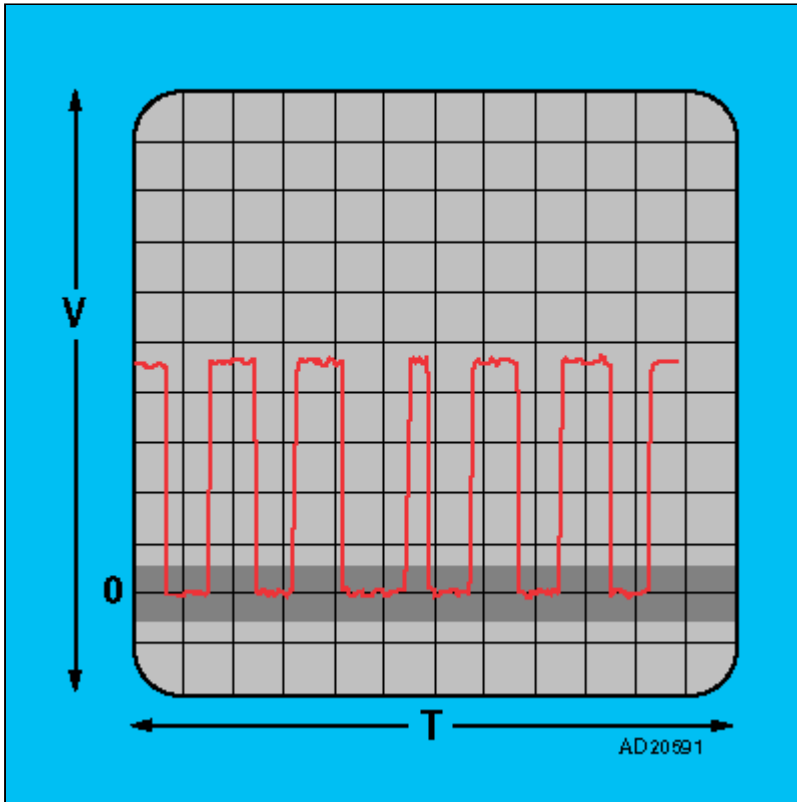
Fig. 20 - Inductive sensor wave form



Fuel injection timing solenoid/fuel quantity adjuster

- Fuel injection timing solenoids and fuel quantity adjusters come in many different types, each with a different wave form.
- In each case the duty cycle (or ON time) of the solenoid should increase when additional engine load is applied.
- If the wave form shows a straight line around the zero mark, or the line is constant at the 5 V or 12 V level, this indicates a fault in the control circuit or ECM signal output.

Fig. 21 - Fuel injection timing solenoid/fuel quantity adjuster wave form



Injector needle lift sensor

- Connect oscilloscope test probes between injector needle lift sensor ECM pin and earth.
- Compare scope trace with wave form reference **Fig. 22**.
- If the trace shows no wave form but instead is a straight line, this usually indicates a wiring fault or a defective sensor.

NOTE: This sensor only produces a small amount of voltage which may be difficult to detect if the oscilloscope is incorrectly adjusted.

Fig. 22 - Injector needle lift sensor wave form

