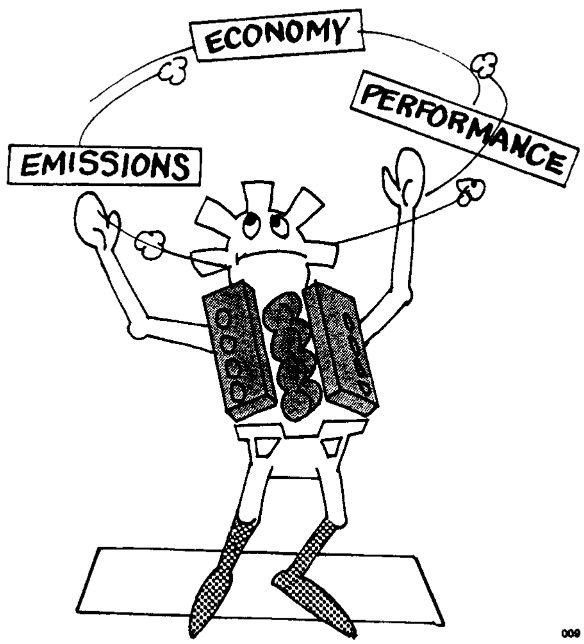
INTRODUCTION

Overview

Modern engine management systems allow powertrain designers to maintain the critical balance between performance, fuel economy, and emissions. As government regulations concerning emissions and fuel economy become more demanding, the need for advanced fuel delivery technologies and operational strategies that can meet these exacting standards becomes greater.

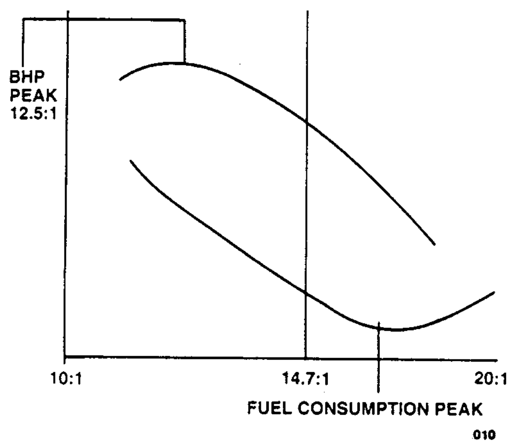


Balancing Operating Priorities

To assist technicians servicing today's engine control systems, the Society of Automotive Engineers (SAE) has developed standards that apply to all vehicle manufacturers. Topics covered include diagnostic trouble codes (Standard J2012) diagnostic connector form and location (J1962) and even automotive terms and acronyms (J1930). These terms and standards, used throughout this book, can help build a bridge between your knowledge of basic vehicle operating systems and specific Land Rover applications.

THEORY

It has long been known that the key to efficient combustion is maintaining the proper relationship between air and fuel. The point at which fuel burns most efficiently is known as the stoichiometric ratio. With gasoline engines, the stoichiometric ratio is approximately 14.7 (air) to 1 (fuel). Keeping this relationship constant is a challenge, as the engine must operate under continually changing conditions and loads.



Stoichiometric Ratio

Once the stoichiometric ratio has been achieved, igniting the air/fuel mixture at the appropriate time presents the next big challenge. Although it seems to occur instantaneously, combustion takes time.

And while combustion time remains relatively constant, the environment in which it occurs (an automotive cylinder with a moving piston) changes dramatically depending on engine speed. The appropriate spark timing at idle will not be the most effective point of ignition at 4,000 rpm. The key is not to compromise, but to provide the best point of ignition for every operating condition.

A modern engine needs a system to manage the complex collection of inputs and outputs and correctly interpret the ways they relate to each other. This course is about the sophisticated systems that have been developed to control the supply of air and fuel, and to control the exact moment at which this mixture is ignited.

Incorrect application of any of these three inputs (air/fuel/ignition) can lead to unsatisfactory performance, poor fuel economy, and/or excessive exhaust emissions.

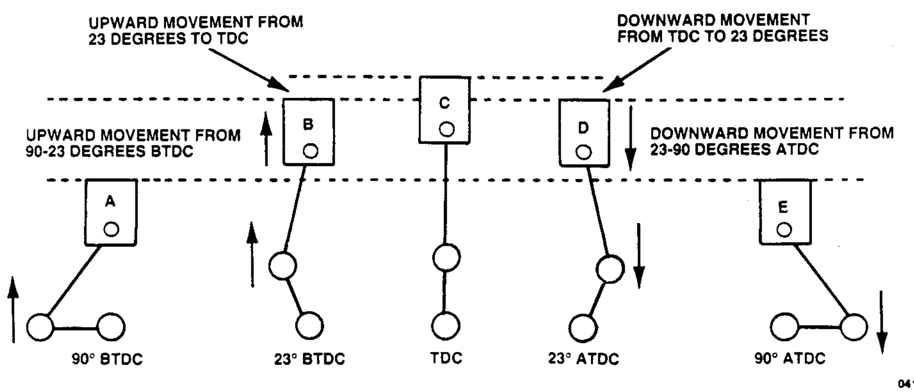
IGNITION SYSTEMS

Introduction

Providing the proper air/fuel mixture is an important factor in promoting efficient engine operation. However, once the air/fuel mixture is introduced into the cylinder, it must be burned efficiently. The combustion process on a gasoline engine can't begin until a spark is introduced. Accurate timing of the spark in relation to piston position and can provide the difference between peak performance and inefficient operation.

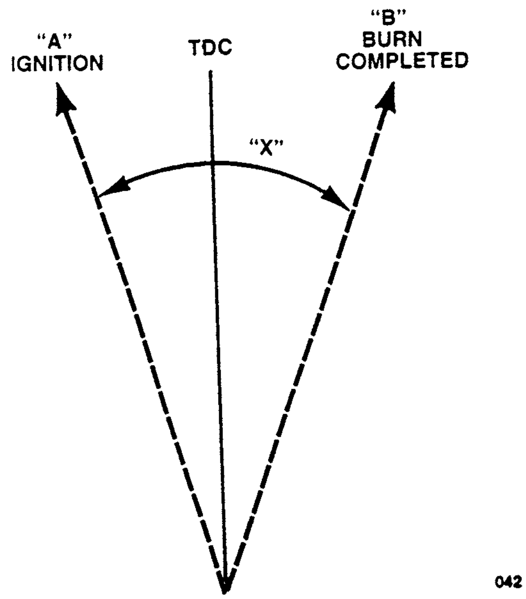
When a spark is introduced to the air/fuel mixture in the cylinder, a flame front is generated. With proper ignition timing, the flame front exerts force on the piston just as it begins its downward movement. To allow time for the force to reach the piston, ignition occurs before the piston reaches Top Dead Center (TDC). However, if ignition occurs too soon, the force of combustion contacts the piston on its way up. This produces engine knock. If ignition takes place too late, engine performance lags.

The natural rotation of the crankshaft keeps the piston at or near TDC for approximately 46° of its rotation (23° Before TDC to 23° After TDC). The crankshaft rotates at a constant speed, but the piston moves very little at this point. Once past 23° ATDC, the piston begins to move very rapidly. For best results, the burn should be completed as close to 23° ATDC as possible.



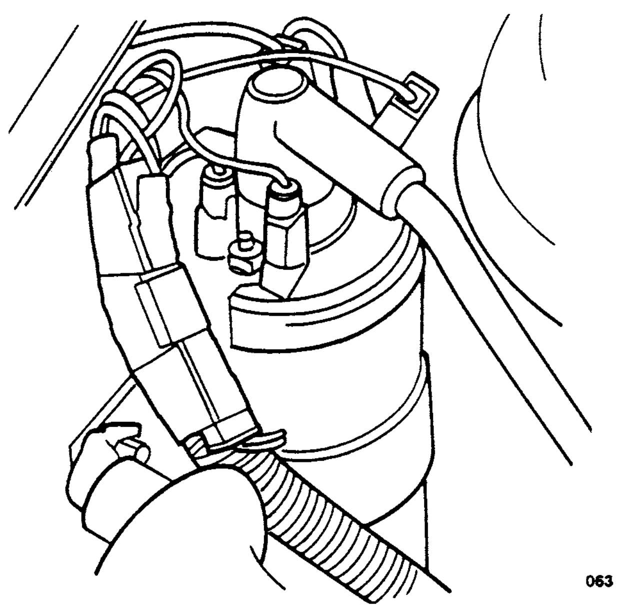
Piston Position at Top of Stroke

As engine speed increases, spark must be further ahead of TDC to allow adequate time for the air/fuel mixture to burn completely. Because of this, increasingly sophisticated methods of advancing and retarding ignition have been implemented.



Spark Timing Window

The high voltage required for ignition is generated in the vehicle's ignition coil. It contains two sets of windings, primary and secondary, that allow battery voltage to be stepped up to approximately 30,000 volts.



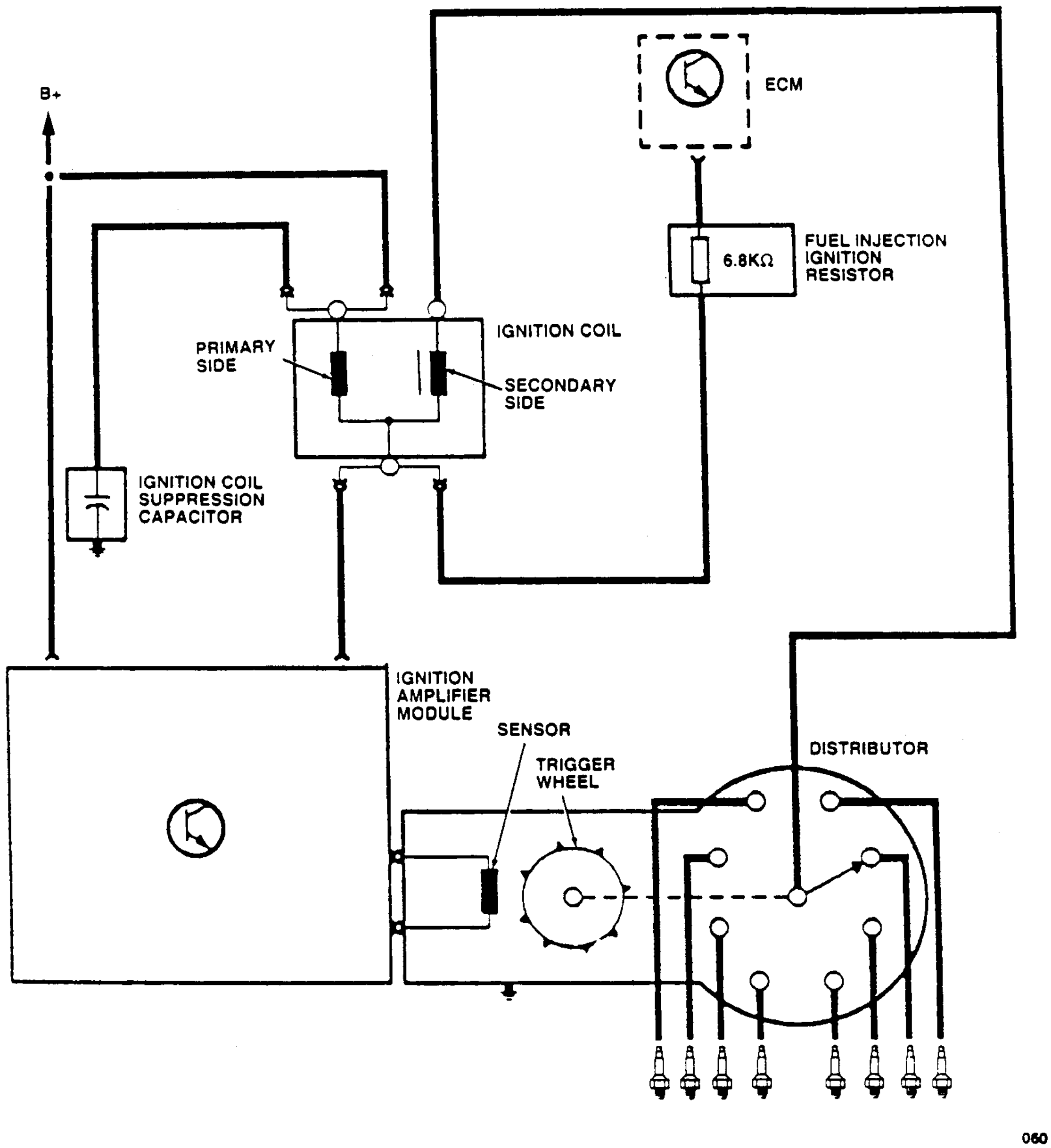
Ignition Coil

ELECTRONIC IGNITION SYSTEMS

Early electronic ignition systems used a single coil with a distributor to fire the cylinders in the correct sequence. The spark was triggered by a pickup within the distributor. The main timing control was a mechanical advance geared to the crankshaft rotational speed, additional advance at part throttle was provided by a vacuum servo mounted on the distributor body.

A sensor (pickup) mounted in the distributor generates pulses as a trigger wheel mounted to the distributor shaft passes it. Later models have the ignition control module mounted to the ignition coil bracket.

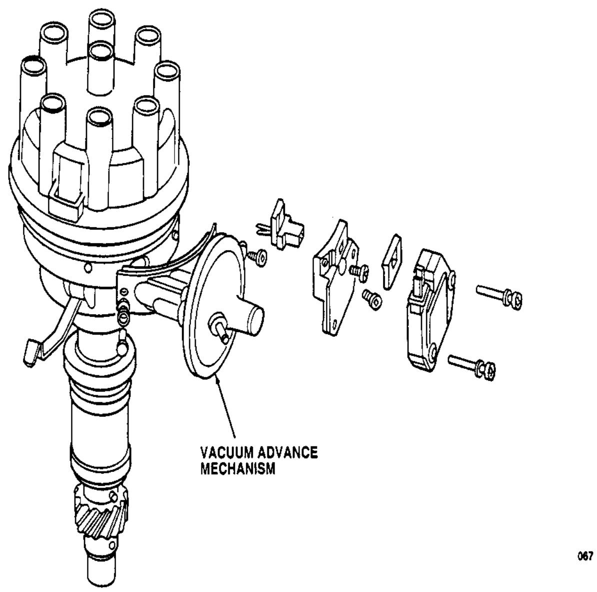
Land Rover vehicles discontinued use of this system in 1996.



Solid State Ignition System

Two methods are used to advance ignition timing. A centrifugal mechanism mounted internally in the distributor advances timing as rotational speed of the engine (and distributor shaft) increases.

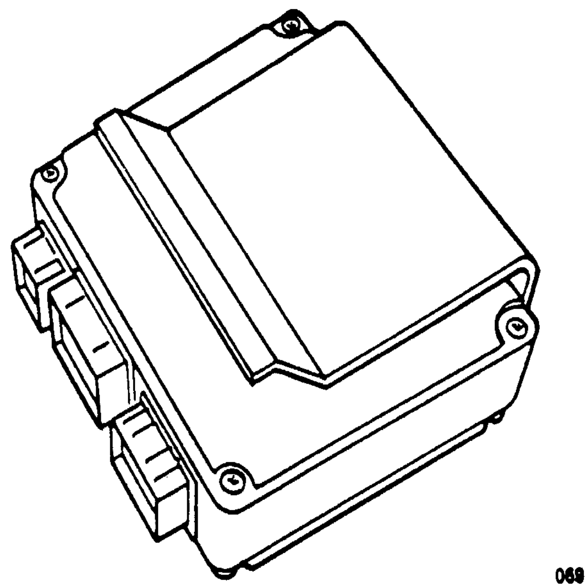
A vacuum advance mechanism is mounted externally on the distributor body. This helps provide advance over and above that provided by the centrifugal mechanism when operating at part throttle.



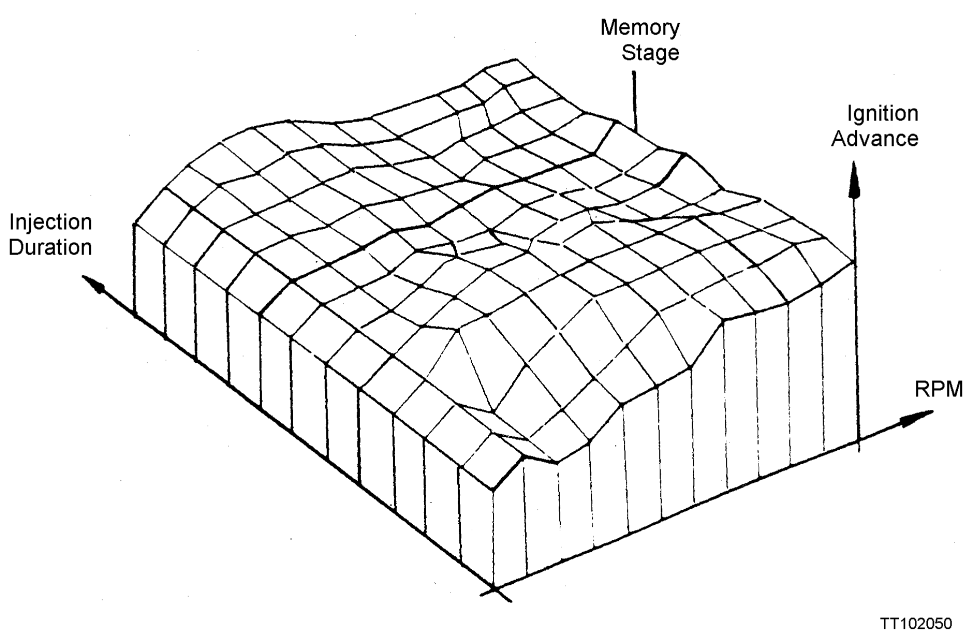
Distributor

DIRECT IGNITION SYSTEM

To more accurately control engine operation and emissions, most modern systems use a Direct Ignition System (DIS). The ignition system is controlled by the Engine Control Module (ECM) which receives inputs from a variety of sensors. This information is then processed to provide the optimum spark advance for every operating condition.



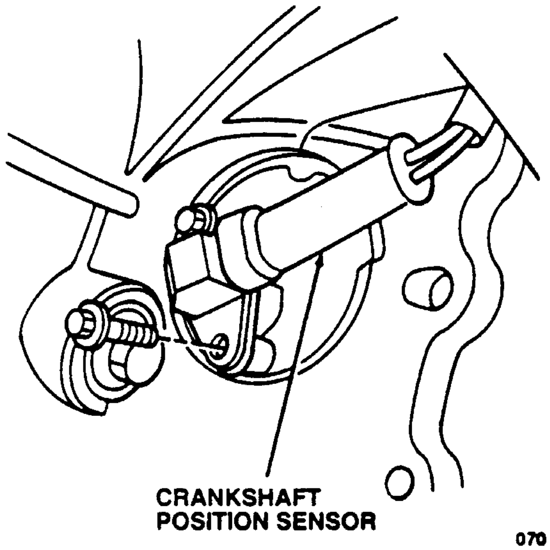
Engine Control Module



Typical ECM Ignition Control Map

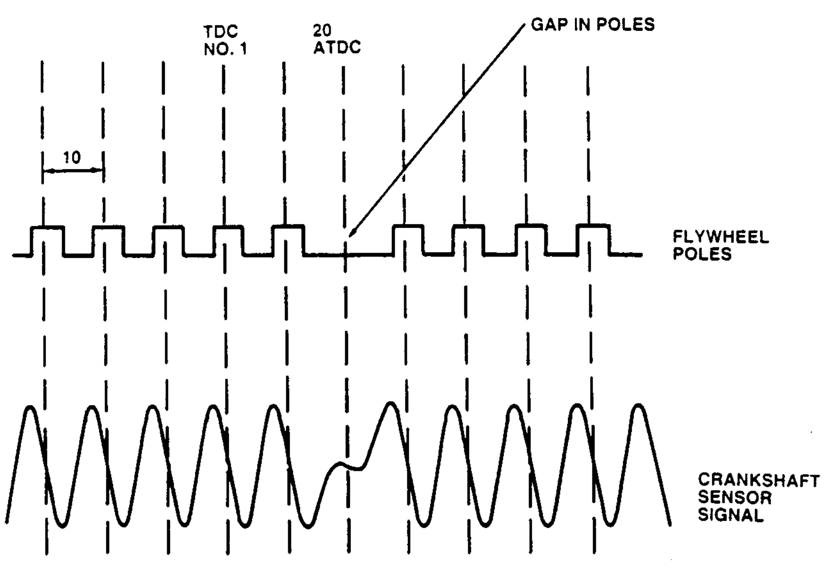
INPUTS

Crankshaft Position Sensor (CPS)
Basic engine timing is controlled by the ECM using input from the crankshaft position sensor. It is mounted on the flywheel housing, opposite the starter motor.



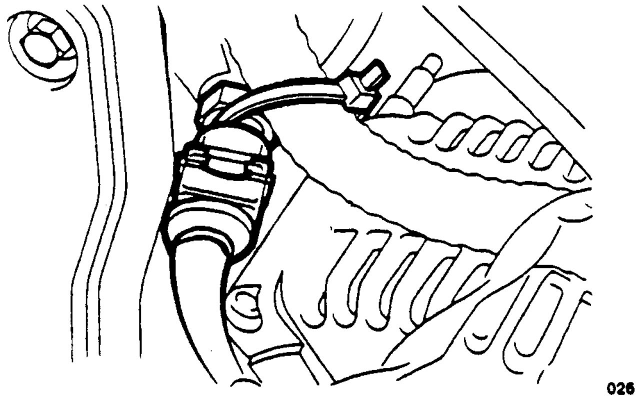
Crankshaft Position Sensor

The sensor reacts to reluctor teeth placed on the flywheel at precise intervals, with some means of identifying the TDC position of the #1 piston. In the example pattern shown, the teeth are spaced at 10º intervals, and one missing reluctor tooth identifies the T.D.C. position of the #1 piston. The electrical signal produced by the crankshaft position sensor as the teeth pass it provides a constant update of engine speed and crankshaft position to the ECM.



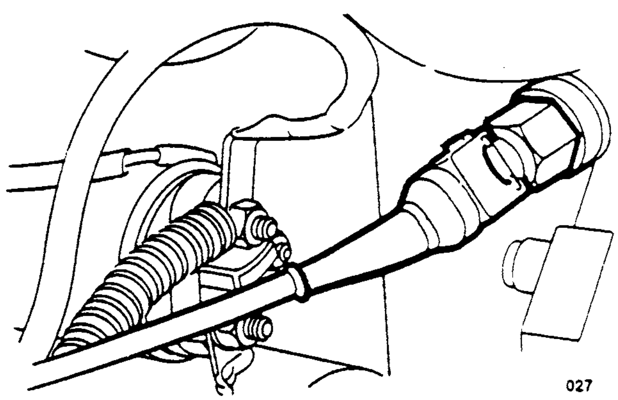
Typical Crankshaft Position Sensor Signal

Engine Coolant Temperature Sensor
Variations in engine operating temperature require variations in ignition timing to maintain the optimum balance between driveability and emissions. The ECM advances ignition timing when the engine is cold and retards it as the engine warms up. The coolant temperature sensor provides the ECM with data on which to base these timing decisions.



Coolant Temperature Sensor

Knock Sensors
A pair of knock sensors monitors engine noise and vibration for the ECM. Engine knock is often caused by detonation or pre-ignition which can damage pistons and valves. The ECM is able to identify the characteristics of engine knock and retard ignition timing when knock is present. The ability to sense engine knock allows the ECM to operate the engine close to its limits of ignition advance. This is the most efficient ignition timing for maximum performance and fuel economy.



Knock Sensor

The sensors are mounted in the cylinder block located between cylinders 3 and 5 and between cylinders 4 and 6. Positioning a sensor in each bank of cylinders allows the ECM to precisely identify which of the eight cylinders is knocking.

OUTPUTS

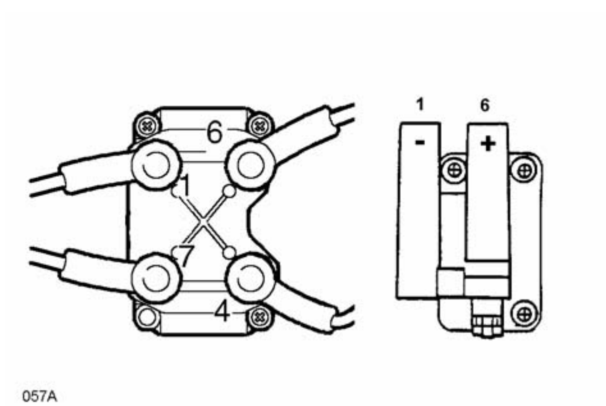
Coils

Spark distribution is achieved by a pack of coils mounted at the rear of the engine compartment. Coil operation is controlled by the ECM. A single coil is used to fire two plugs simultaneously - one on the compression stroke and the other on the exhaust stroke. The circuit for each coil is completed by switching within the ECM.

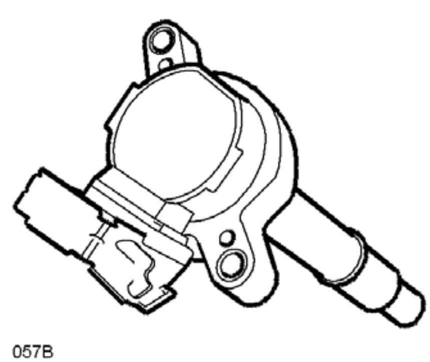
The spark on the exhaust stroke is said to be wasted hence, the term “wasted” or “lost” spark ignition system. Actually, little in the way of voltage is wasted on the spark in the cylinder on the exhaust stroke. The cylinder containing the air/fuel mixture (compression stroke) conducts the electrical charge far more efficiently than the cylinder containing exhaust gasses. Most of the voltage takes this path of least resistance to ground.

Performance is also improved. By using more than one coil (as opposed to the traditional single coil system) each coil is allowed more time to charge between firings.

Other DI systems may use a separate coil for each cylinder, mounted directly on the plug (COP) or connected via a short high voltage lead. Each coil is controlled directly by the ECM.



Multiple Ignition Coil Packs- Bosch (left), GEMS (right)



Coil On Plug

FUEL INJECTION SYSTEMS

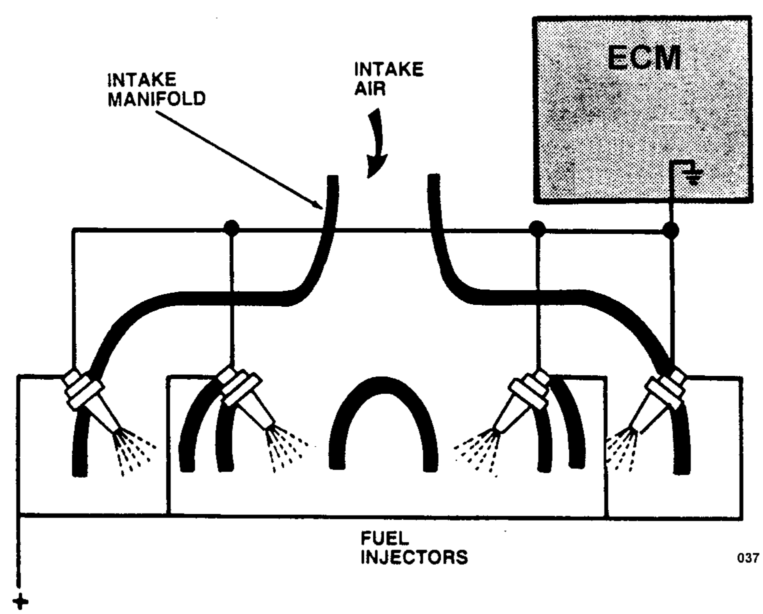
Recent years have seen the process of automotive fuel delivery evolve from carburetors to fuel injection. Current Land Rover vehicles use one of two types of electronically controlled fuel injection systems: Multiport Fuel Injection (MFI) or Sequential Multiport Fuel Injection (SMPI).

MULTIPORT FUEL INJECTION (MFI)

Multiport fuel injection systems utilize an injector for each engine cylinder. These injectors are mounted above the cylinder's intake valve in the intake manifold. The injectors for each bank of cylinders open twice during the four-stroke engine cycle - once each during the intake and exhaust strokes.

Since the injectors spray fuel into the manifold on the back face of each intake valve, there is no need for injection to be precisely timed to valve operation or combustion stroke.

Fuel is injected twice per stroke because two small portions of fuel are more easily atomized than a single large quantity. The atomized fuel is then drawn into the cylinder intake for combustion. MFI allows for precise fuel control for each bank of cylinders.



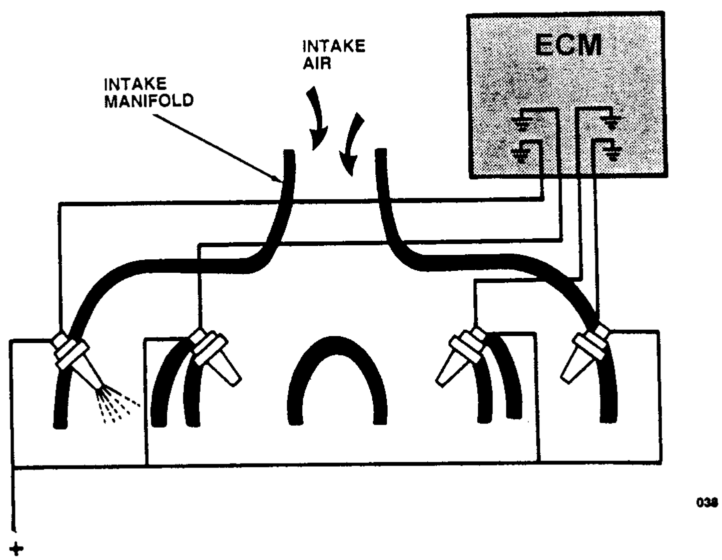
Multiport Fuel Injection

SEQUENTIAL MULTIPORT FUEL INJECTION (SFI)

Sequential multiport injection goes a step further in fuel delivery precision. By providing separate ECM ground controls for each injector, SFI provides control of individual injectors. This differs from MFI systems which control operation of the injector banks.

The SFI system allows the supply of fuel to be matched to the specific needs of each individual cylinder. It also requires that injector operation be precisely timed to valve operation. The ECM in an SFI system uses additional inputs, over and above those found in an MFI system, to control injector operation.

Because an equal amount of fuel is injected into each cylinder, engines equipped with port fuel injection systems must ensure that equal amounts of air enter each cylinder. This is achieved by providing equal length intake tracts connected to a common chamber or plenum.



Sequential Multiport Fuel Injection

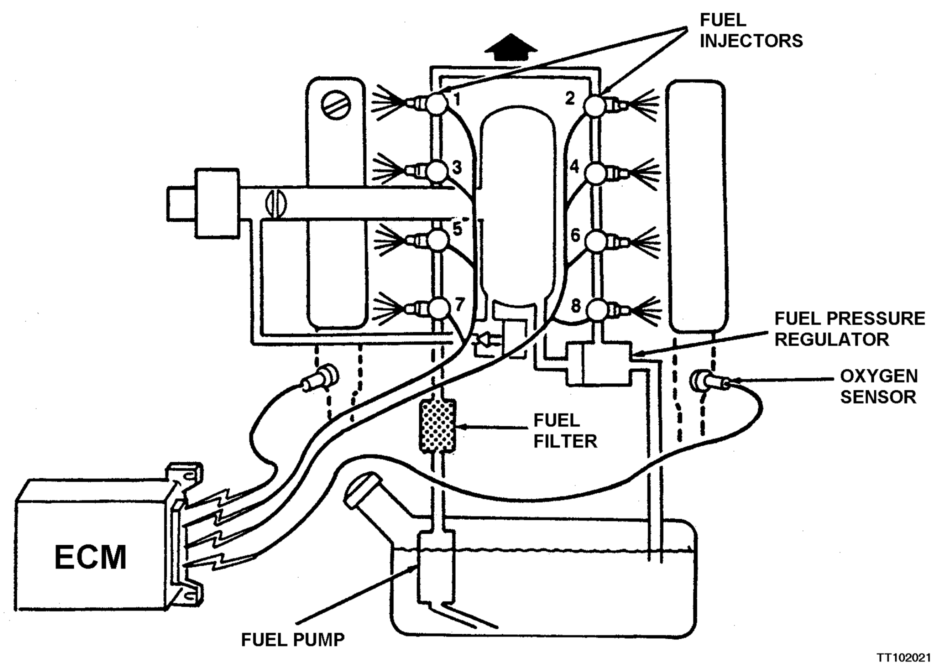
FUEL SYSTEM COMPONENTS

The following components are included in a basic fuel injection system:

- Engine Control Module (ECM)
- Oxygen Sensor (HO2S)
- Fuel Pump
- Fuel Filter
- Fuel Pressure Regulator
- Fuel Injectors

Additional components are used to monitor and control the “air” portion of the air/fuel mixture. These are listed below:

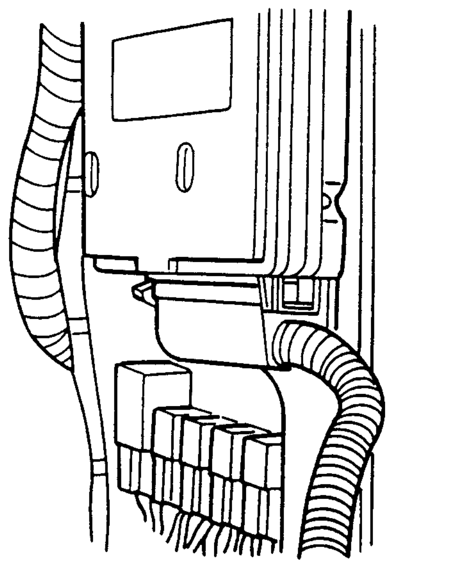
- Mass Air Flow Sensor (MAFS)
- Throttle Butterfly
- Throttle Position Sensor (TPS)
- Idle Air Control (IAC)



Basic Fuel Injection System

Engine Control Module (ECM)
The Engine Control Module (ECM) is the heart of the vehicle's fuel delivery system. It monitors information from several inputs to determine the fuel delivery strategy required to produce efficient operation. As the sophistication of the fuel injection system increases, the amount of information processed by the ECM also increases. Additional strategies to cover fueling requirements for situations such as cold starting, hot starting, and wide-open throttle acceleration may also be added to the ECM software.

Newer generations of engine management systems include additional ECM memory to allow such features as adaptive sensor mapping strategies, cylinder knock control, active ignition timing, and extended fault diagnostics.



Engine Control Module (ECM)

FUEL SYSTEM OUTPUTS

Fuel Pump

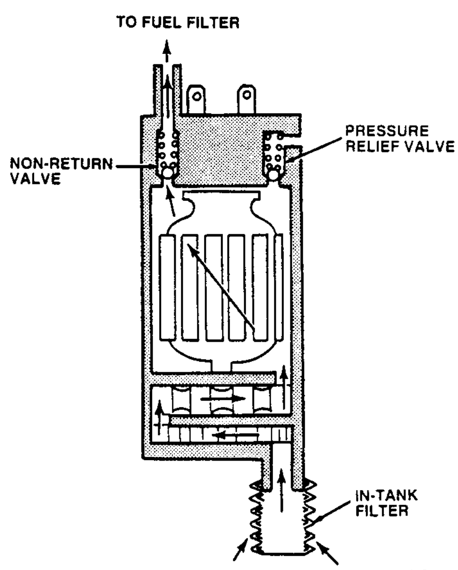
Fuel is supplied to the engine via a tank-mounted electric pump. In the case of a system that uses an external fuel filter, an additional filter may also be used on the pump inlet to protect the fuel pump itself.

The pump is usually mounted inside the fuel tank. The advantage of mounting the pump in the fuel tank is that the pump armature and bearings are cooled by the surrounding fuel. The tank also helps isolate any noise produced by pump operation. The pump is capable of delivering more fuel volume and pressure than required by the engine. A non-return valve in the pump prevents fuel from the injector supply pipe from draining back into the tank when the pump is not running.

There are two general types of fuel supply strategies in use- the Fuel Return type, and the Non-Return type.

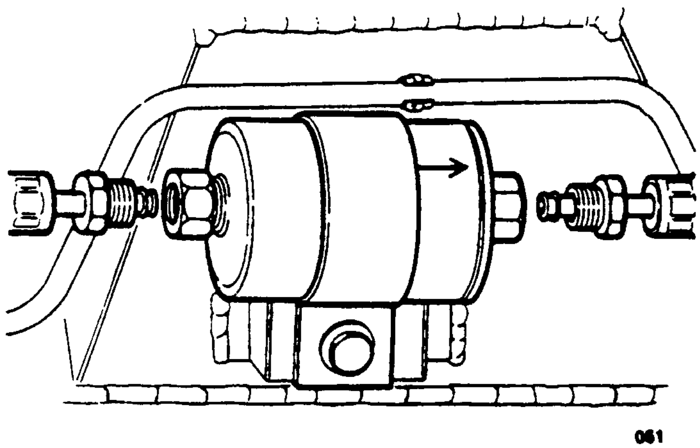
In the return type, most of the fuel circulates through the fuel rail and is returned to the fuel tank. This constant supply of relatively cool fuel through the system helps prevent vapor lock. This type of system uses a pressure regulator mounted on or near the fuel rail. The regulator senses engine manifold pressure and adjusts the quantity of fuel returned to the fuel tank. On the fuel pump itself, there is a pressure relief valve to prevent over-pressure in the event of a system blockage.

In the Non-Return type, the fuel rail has no means to return fuel to the tank. In this type of system the pressure at the fuel rail is typically higher than in the return type system, and regulation is integral with the pump. Excess fuel can be returned to the tank, but it is done via the relief valve inside the pump.



Fuel Pump

Fuel Filter
Because of the close internal tolerances of the injectors, thorough filtration of fuel is required. The filter element is able to trap particles down to 20 microns in size.



Fuel Filter

Most modern engine management systems use a filter that is mounted on the fuel pump, and inside the fuel tank. Some systems however (typically the Return type), use an externally mounted filter.

The fuel filter is a simple component that is commonly overlooked as a source of fuel system concerns. Check for proper system pressure at the fuel rail before disassembling the fuel rail or injectors in search of an obstruction.

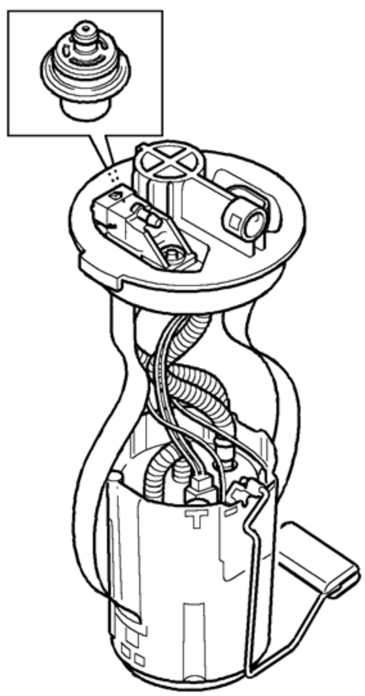
Fuel Pressure Regulator

A constant pressure to the fuel injectors must be maintained during all engine operating conditions to ensure correct fuel metering and emission levels. As previously mentioned, return type systems use an external regulator, while non-return type systems use a regulator mounted inside the fuel tank, on the fuel pump.

Non-return type Systems

This type of fuel pressure regulator is located in the fuel pump assembly, and maintains a constant fuel pressure relative to atmospheric pressure. The supply pressure at each injector must be sufficient to provide adequate fuel flow during high demand such as acceleration under load, and wide open throttle. There must also be sufficient pressure to keep the injectors seated during periods of high intake vaccum, such as during deceleration.

Since fuel pressure is regulated well before the fuel rail assembly, proper engine fuelling with this type of supply system is slightly more sensitive to restrictions in the supply pipes than in a return type system. Typically, a fuel pressure test port is provided on the fuel rail to verify adequate pressure at the injectors.



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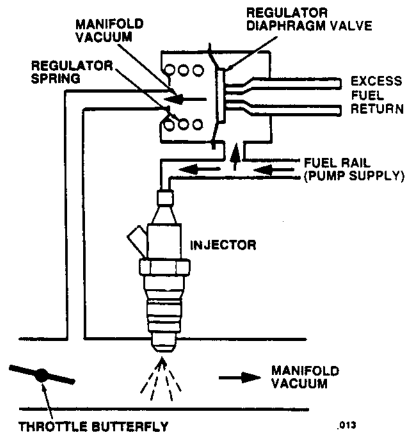
Typical Non-Return Type System Pressure Regulator

Return type systems

A constant fuel pressure relative to, and above intake manifold pressure, is controlled by a regulator valve mounted at the end of the fuel injector rail. The fuel pressure regulator contains two chambers separated by a spring-loaded diaphragm. One chamber contains fuel from the supply line. The other chamber is linked to the engine side of the throttle butterfly to sense manifold vacuum (negative pressure).

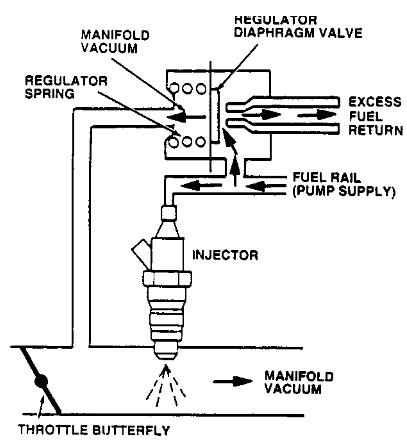
When fuel pressure and manifold vacuum are low (full throttle), spring pressure holds the diaphragm valve against the fuel return pipe. This assures a higher level of fuel pressure to satisfy the fuel needs of the injectors. Fuel pressure must exceed a calibrated amount before the spring is compressed and fuel is allowed to enter the return line.



Regulator Closed

When manifold vacuum is high (idle and coast-down), the combination of fuel pressure and vacuum is able to overcome the pressure of the regulator spring. The fuel return line opens at much lower fuel pressures when vacuum assist is present. This reduces the tendency of manifold vacuum to draw excess fuel from the injector nozzle and ensures that the amount of fuel actually delivered matches the level desired by the ECM.

The fuel pressure regulator is pre-set during manufacture. No service adjustments are provided.

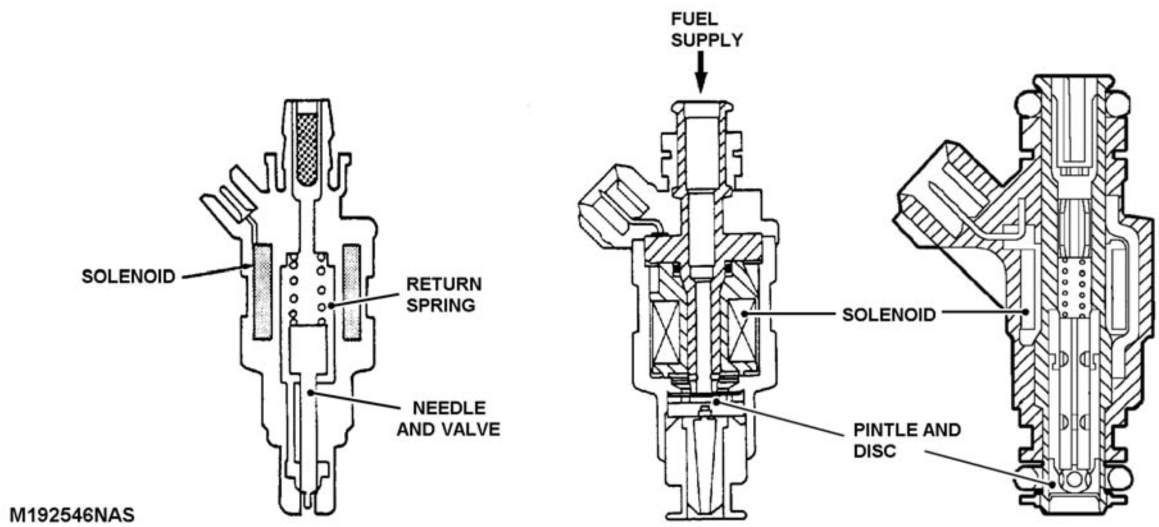


Regulator Open

Fuel Injectors

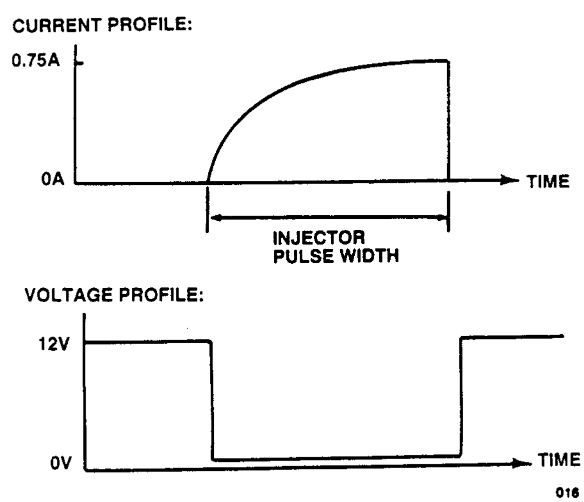
The electronically operated fuel injector provides a simple and effective way of metering the fuel provided for combustion.

Each injector contains a precisely machined needle valve or a pintle and sealing valve held in position by a spring. When the injector solenoid is energized, the needle or pintle is lifted, allowing fuel to pass. When the solenoid is de-energized, the needle or pintle snaps shut under spring pressure, cutting off fuel flow.



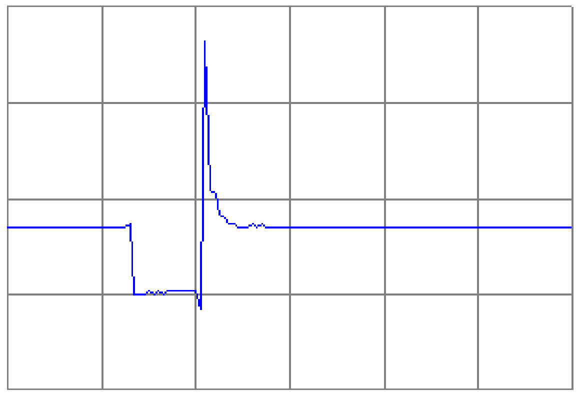
Fuel Injector Types

The length of time the injector is energized and delivering fuel is referred to as injector "pulse width." This varies between 1.5 to 10 milliseconds, depending on operating conditions. The longer the injector is energized, the greater the volume of fuel delivered. The ECM uses the duration of its ON signal to the injector (where it provides a ground for the circuit) to control fuel delivery to the cylinder.



Injector Pulse Width

When looking at injector operation using an oscilloscope, an additional ‘spike’ will be observed along with the 'on-time', or pulse width. This spike is the result of voltage build-up, current flow and limiting, and collapse in the injector solenoid winding.



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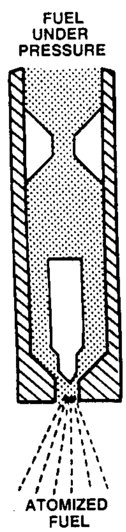
To further enhance the combustion process, the tip of the injector's needle valve is precision ground to a shape that produces a fine atomized fuel spray. This enables the fuel to vaporize faster and more completely than fuel introduced by a carburetor. The result is more complete and efficient combustion.



Atomized Fuel

As long as the supply of fuel to the injector is sufficient, the volume of fuel delivered can be precisely controlled by the length of time the injector needle valve is open. The valve remains open as long as a path to ground is provided by the ECM.

Idle Air Control (IAC)

To ensure a smooth and constant idle speed, a port allows a measured amount of air to bypass the throttle plate and enter the plenum chamber. Generally the system allows this bypass when the following conditions are present:

- Low or No road speed
- Throttle closed
- Engine above cranking speed rpm

The amount of air flowing through an orifice is controlled by the ECM. This orifice and its control mechanism is called an Idle Air Control Valve (IACV). The IACV can be a tapered valve mounted in the by-pass port, or a slotted disc or drum rotating into the bypass air flow. In either case, the precise movement of this variable restriction is controlled by the ECM, usually using an electric motor.

NOTE: Electronic throttle control systems do not use an IACV as they are able to control the throttle plate directly.

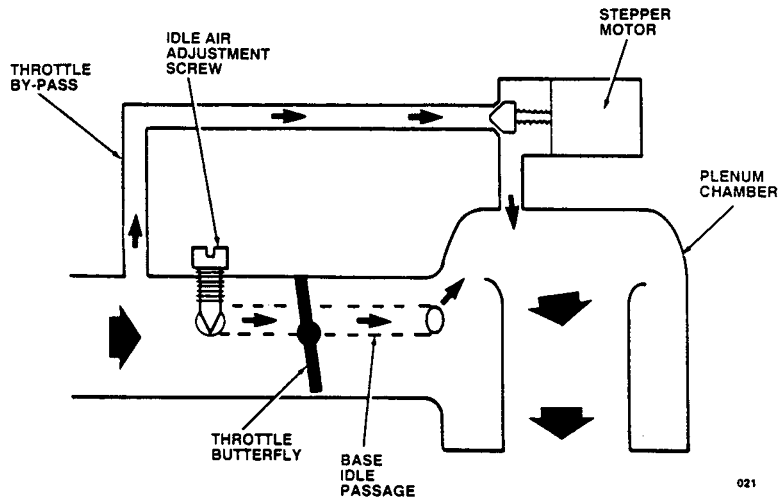
The ECM makes idle air control adjustments based on sensor inputs (ambient temperature, engine load produced by accessories such as air conditioning or defrosters) to keep idle speed sufficient for the situation.

If a tapered valve type of IACV is used, the motor uses multiple windings that are powered in sequence to allow small ‘steps’ of motor movement. Thus, this type of motor is called a ‘stepper’ motor.

If a disc or drum type of IACV is used, the position of the disc or drum is controlled by a motor with two opposing windings. The power to the windings is alternated between the two by varying the amount of time each recieves current. In this way, the disc or drum can be precisely positioned.

Failure of the stepper motor can result in either a high or low idle speed, engine stall or no-start.

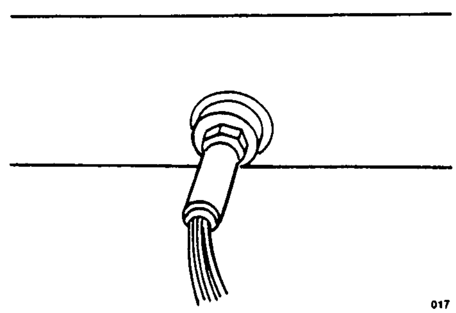
"Base" idle is controlled through a separate bypass port located in the housing for the throttle butterfly. The volume of air allowed to bypass the throttle butterfly is controlled by an adjustment screw. The size of this orifice does not vary during engine operation.



Stepper type Idle Air Control

FUEL SYSTEM INPUTS

Heated Oxygen Sensor (HO2S)
The oxygen (Lambda) sensor mounted in the exhaust downpipe serves as the key input in an electronic fuel injection system. The sensor is used by the ECM to determine the amount of oxygen present in the exhaust gas. The ECM uses this information to increase or decrease injector open time to bring the air/fuel ratio as close to Stoichiometric as possible.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Heated Oxygen Sensor

Oxygen sensors operate efficiently only when warm. Sensors include heaters to help them reach operating temperatures quickly. This allows the sensors to provide accurate information to the ECM soon after start-up and allows the system to enter closed loop operation (based on sensor inputs) sooner. Closed loop operation helps provide an efficient fuel mixture and controls emissions when the engine is cold. Closed loop also guards against catalytic converter overheating from the introduction of too much fuel.

"Closed loop" simply means that the ECM is controlling fuel to the engine based on the oxygen sensor "feedback", rather than using a programmed mixture based solely on engine temperature, speed, and load. Closed loop operation helps provide an efficient fuel mixture and controls emissions when the engine is cold. Closed loop also guards against catalytic converter overheating from the introduction of too much fuel.

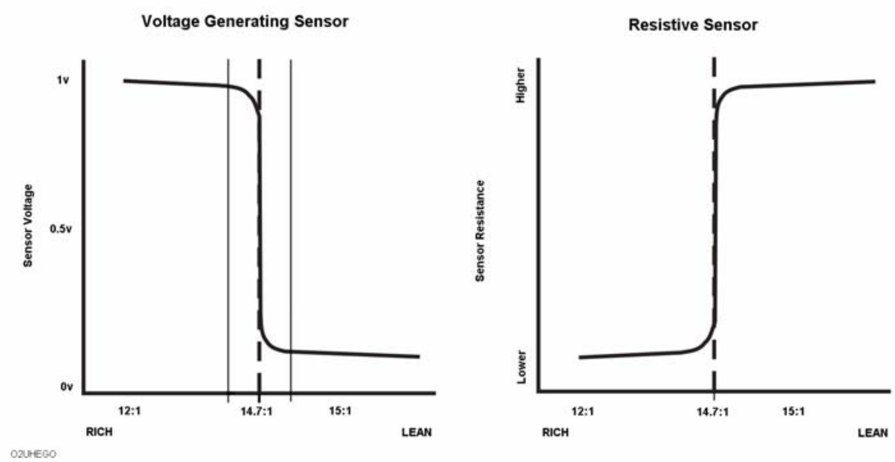
There are three general types of Oxygen Sensors:

- Those that change resistance in the presence of oxygen in the exhaust
- Those that generate a voltage based on the absence of oxygen in the exhaust
- "Wide Band" sensors that change a current flow signal in a reference circuit, based on the air/fuel content of the exhaust gas. These are also sometimes referred to as "Air/Fuel ratio", or A/F sensors

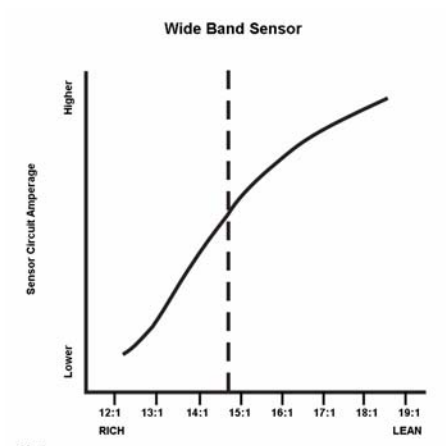
The first two types of oxygen sensors are referred to as "Heated Exhaust Gas Oxygen-Sensor" (HEGO) and their signals are continually "switching" between rich and lean as the exhaust gas content changes. The engine management system is programmed to understand that a stoichiometric air/fuel ratio is roughly mid-way between the low and high signal values from the sensor, and constantly corrects the fuel mixture to maintain an average mid-point reading.

It is best to measure HEGO operation through the ECM with a diagnostic tester, although it is possible to measure them directly at the sensor or wire harness connections.

"Wide Band" sensors are referred to as "Universal Heated Exhaust Gas Oxygen-Sensor" (UHEGO) and are able to provide the system with a much more accurate air/fuel ratio reading. Their signals change in direct proportion to the changes in air/fuel ratio, and consequently change more slowly. The signals from these sensors cannot be easilly measured at the sensor, and must be measured through the ECM via a diagnostic tester such as T4/WDS.



Typical HEGO sensor operating ranges



Typical "Wide Band" or UHEGO sensor operating range

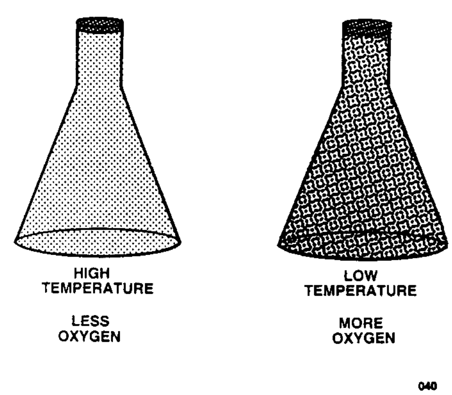
On systems with more than one sensor, the ECM monitors each sensor separately. Fuel trim adjustments are made independently to each cylinder bank, or individual cylinder, depending on the fuel system. Sensors located downstream of the catalyst are used to verify proper catalytic converter operation.

In their operating environment, oxygen sensors are quite durable. However, they are easily damaged if dropped, exposed to excessive heat, or contaminated. Care should be taken when handling oxygen sensors. Avoid overtightenig or jarring the sensor. Contamination of the sensor body can lead to premature failure. The sensor threads must be sealed with the material provided to ensure there are no oxygen leaks. Do not use silicone sealants for this purpose as they will contaminate the sensor.

Mass Air Flow Sensor (MAFS)

The Mass Air Flow Sensor (MAFS) is an electronic device mounted between the air filter and the plenum chamber. It serves as a key ECM input, performing two functions: indicating the volume and temperature of air being drawn into the engine. These two factors allow the ECM to adjust the fuel supply accordingly.

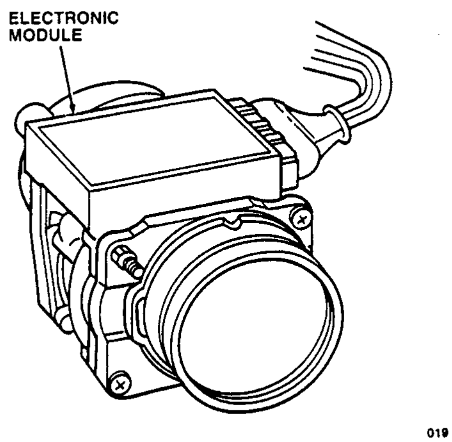
Air density varies with temperature and altitude. Cold air is denser and contains more of the oxygen required for combustion. At higher temperatures and altitudes, more air must enter the engine to deliver the same amount of oxygen.



Air Density

The “Hot Wire” type of MAF sensor contains two wires with current passing through them. Both are connected to the module mounted on the MAF unit. One wire, which is unheated, reacts to intake air temperature. The second wire is heated to a known fixed temperature value above the unheated wire. As air flow increases, the current required to maintain this difference in temperature increases. The electronic module monitors this wire's current requirements to determine the amount of air entering the intake manifold. It then provides a signal to the ECM that corresponds to the air flow. While air temperature is also a factor that affects the current requirements of the wire, a separate sensor for air temperature is commonly used.

Another type of MAF sensor contains two elements made of a film material, that behave similar to the wires in the hot-wire type.



Mass Air Flow Sensor

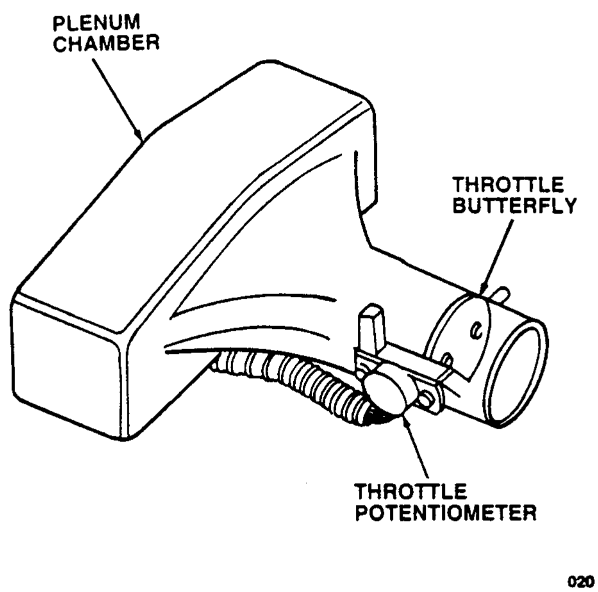
Throttle Butterfly

The throttle butterfly is located between the plenum chamber and the MAF sensor. The throttle butterfly controls the volume of air entering the plenum chamber and is either linked directly to the accelerator pedal or is controlled by the ECM via a motor. As the accelerator pedal is depressed, the throttle butterfly opens. This allows a greater volume of air to enter the plenum chamber.

Throttle Position Sensor (TPS)

A potentiometer mounted at the throttle butterfly converts throttle position into an electrical signal used by the ECM (along with data from the air flow meter) to determine the volume of air entering the intake manifold.

The ECM also monitors the throttle position sensor for the rate of throttle application. During periods of hard acceleration, the ECM will enhance the fuel mixture to prevent a lag in engine response.



Throttle Position Sensor

Electronic throttles ("drive by wire" systems) use 2 potentiometers. One potentiometer is mounted on the throttle pedal, and monitors driver demand. The second potentiometer is mounted at the throttle butterfly to monitor the actual butterfly position.

Electronic throttle systems provide the ECM with accurate and consistent feedback of the throttle position and allow the system to adapt to variations caused by throttle stop wear and component differences. These ECM adaptions must be reset if throttle components are replaced of disturbed.

CLOSED LOOP OPERATION

During closed loop, or feedback operation, the ECM controls fuel system operation based on information provided by the various vehicle inputs. Because these inputs represent actual operating conditions, the system is most able to meet performance and efficiency targets when operating in closed loop.

The primary input during closed loop operation is the oxygen sensor since it indicates the result of the combustion process, regardless of the engine speed and load.

The primary output during closed loop operation is the fuel injector timing and duration.

All other sensors generally serve to help the ECM 'trim' or anticipate the operation of the engine to meet a particular oxygen sensor value or known tailpipe emission condition.

OPEN LOOP OPERATION

At times (start-up, full throttle) engine operating requirements may fall outside the bounds of that suggested by the ECM inputs. Some sensors do not operate at peak efficiently until warm. At these times, the ECM substitutes a pre-programmed set of reference inputs that are most likely to produce desired engine operation. This is referred to as open loop operation.

The system may also default to open loop operation when component failure provides an input signal outside the range of known parameters recognized by the ECM. The ECM will substitute a signal value that allows the vehicle to continue to operate. The Malfunction Indicator Lamp (CHECK ENGINE) on the instrument panel is illuminated at this time to indicate the failure of an emissions-related component.

EMISSION CONTROLS

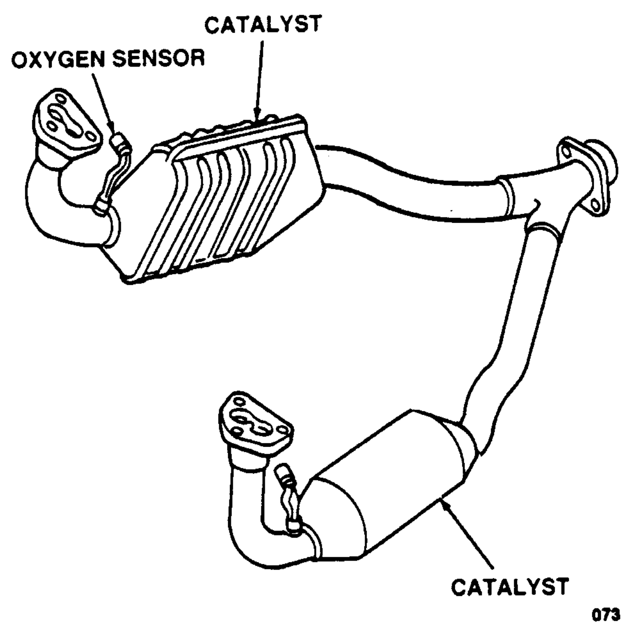
Introduction

Emissions control systems on Land Rover vehicles work closely with fuel system controls to reduce airborne pollutants. Improper operation of these systems can lead to increased emissions and poor engine performance. The catalytic converter is used to clean up tailpipe emissions. Crankcase ventilation and evaporative purge address a different concern - the evaporative emissions produced by the vehicle.

CATALYTIC CONVERTER

Even when operating at peak efficiency, engines produce undesirable emissions as a result of the combustion process. A three-way catalytic converter, located in the vehicle's exhaust system, is able to reduce the three greatest sources of concern - Hydrocarbons (HC) Carbon Monoxide (CO) and a variety of Nitrous Oxides (NOx) - from tailpipe emissions.

To operate properly, a catalytic converter must reach very high temperatures (approximately 760° C or 1400° F). That is why it is mounted directly downstream from the exhaust manifold



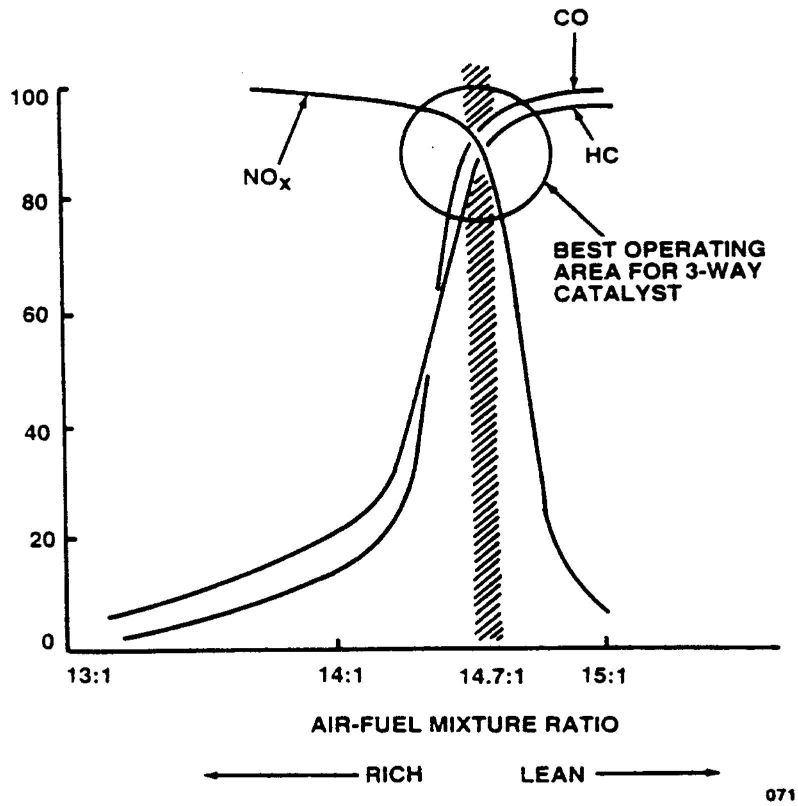
Catalytic Converter

Exhaust gasses pass through and heat the converter core which contains a mixture of platinum and rhodium. The combination of materials in the core and extreme temperature promotes chemical reactions that reduce the HC, CO and NOx to harmless Carbon Dioxide (CO_2) Nitrogen (N_2) and water (H_2O). (Three way catalyst.)

Precise control of the air/fuel ratio is critical for effective catalyst operation. The chart below shows that once the mixture moves away from stoichiometric, catalyst efficiency suffers.

The two greatest enemies of catalyst life are leaded fuels and overheating. The use of leaded fuels will cause deposits to form in the converter core and reduce its ability to produce the desired chemical reactions.

Excessive core temperatures are produced during misfire situations when raw gas in the exhaust ignites in the catalyst core. This can cause the core to fuse into a solid mass that exhaust gasses cannot pass through. Because of this, the desired chemical reactions cannot take place. Poor engine performance due to high backpressure is often a result of this situation.



Catalyst Operating Efficiency

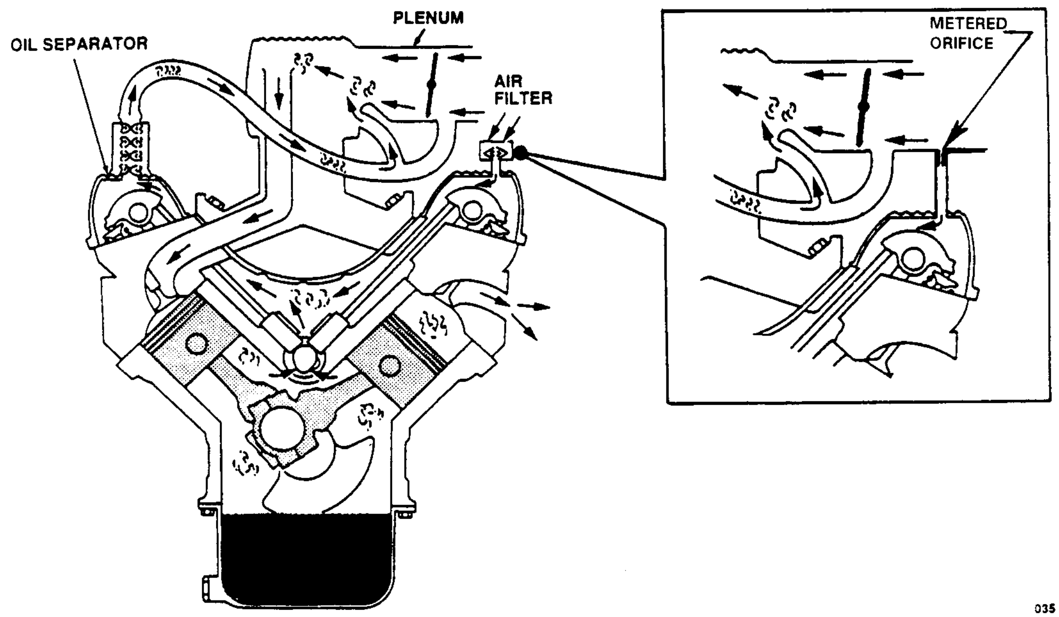
CRANKCASE VENTILATION

During engine operation, noxious gasses are produced in the engine's crankcase. The crankcase ventilation system allows these gasses to be burned along with the air/fuel mixture. As an additional source of air to the engine's plenum chamber, the crankcase ventilation system could be considered an integral part the vehicle's air intake system.

Manifold vacuum (negative pressure) draws oil laden vapor in the crankcase through an oil separator on the valve cover. The separator prevents engine oil from being drawn into the plenum.

The remaining gasses flow through a line where they are mixed with fresh air and directed to the plenum. Here the gasses become part of the air/fuel mixture and are burned during normal engine combustion.

The air intake on the valve cover of the opposing cylinder head prevents excessive crankcase vacuum or pressure from developing during engine operation. It is fitted with a filter to prevent contaminants from entering the crankcase. On some models, the filter has been replaced by a hose supplying air that has already passed through the engine's air filter.



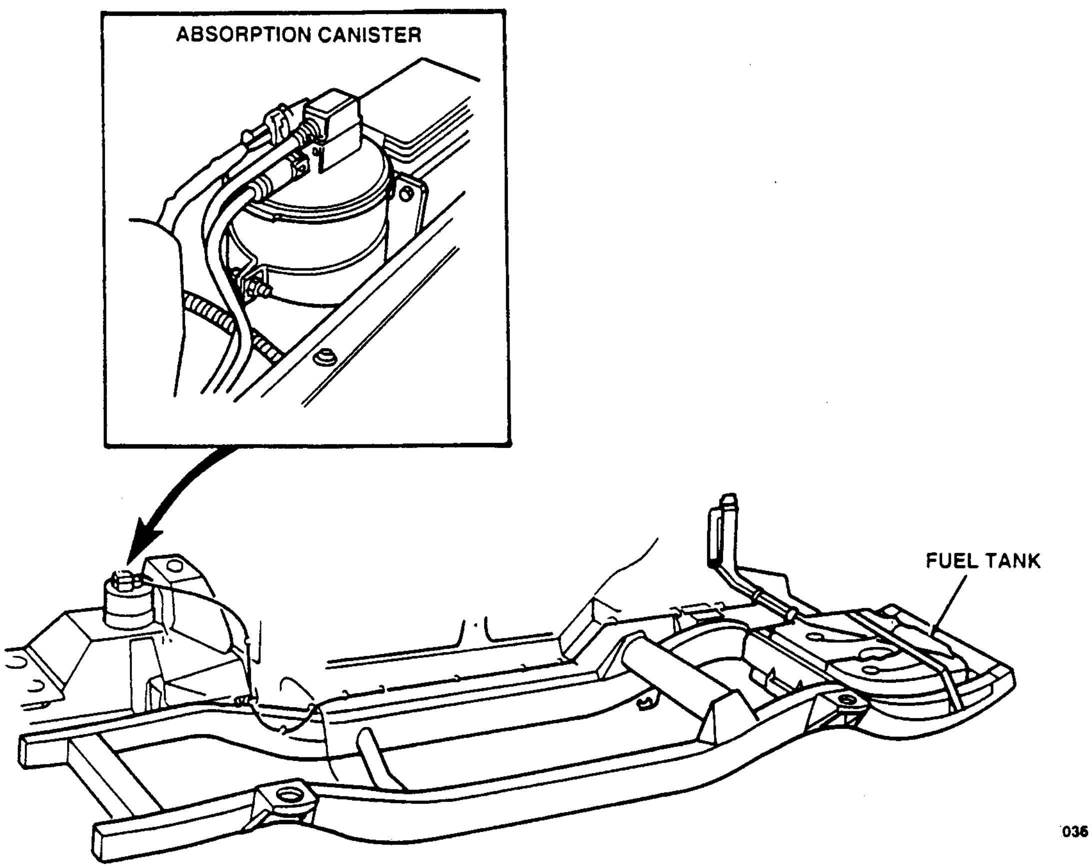
Crankcase Ventilation

Evaporative Emission Control System (EVAP)

EVAPORATIVE PURGE

As gasoline from the fuel tank is pumped to the engine, air must enter the system to prevent a vacuum from developing. However, harmful hydrocarbon vapors form in the fuel tank as gasoline evaporates. Venting the fuel tank directly to the atmosphere would allow these vapors to escape.

To prevent this from occurring, fuel system vapors are routed to a charcoal canister which absorbs and stores fuel vapor from the tank when the engine is not running. Once the engine is started, the vapor is purged from the canister by fresh air drawn through an orifice at the base of the canister and the vacuum introduced at the top.



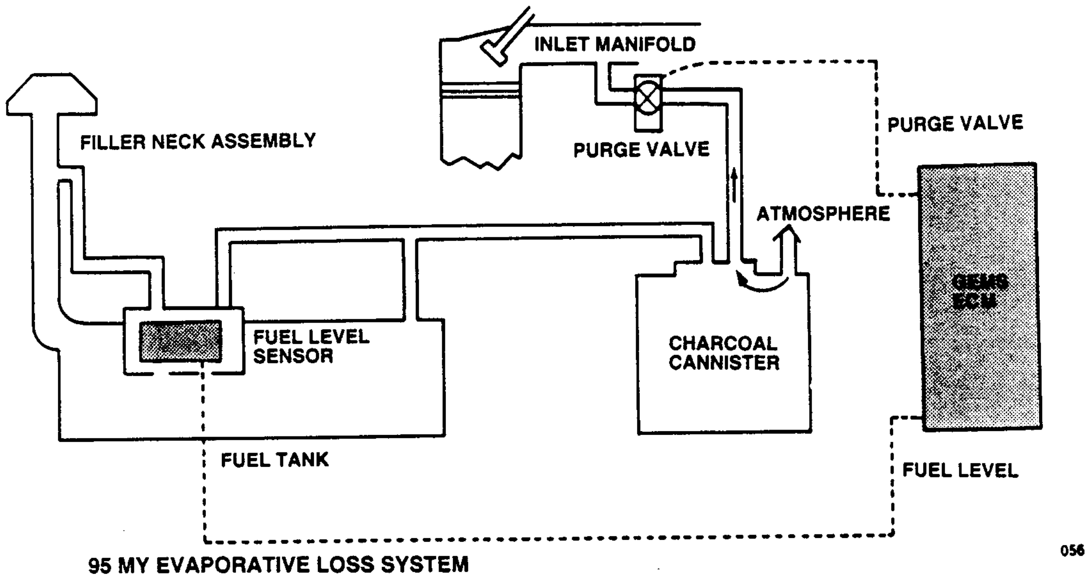
Evaporative Purge System Components

On 1989 and later vehicles, purge operation is controlled by the ECM through a solenoid valve. When the valve is opened, the vapor is drawn into the plenum to be added to the air/fuel mixture. Control of evaporative purge operation is an important ECM function for effective emission control.

When operating, purge flow into the plenum is not accounted for in the ECM's air/fuel calculations. Because of this, purge operation is saved for those times when the additional vapor is least likely to affect emissions. Typically, this is when the engine is warm and operating well above idle speed.

The ECM controls the flow rate by opening, closing, or pulsing the solenoid valve. The ECM monitors purge flow by looking for signs from the oxygen sensors that the fuel mixture has been enriched when the solenoid valve is opened. When this no longer occurs, the ECM interprets this to mean that no more vapor is present. Purge operation is discontinued at this time.

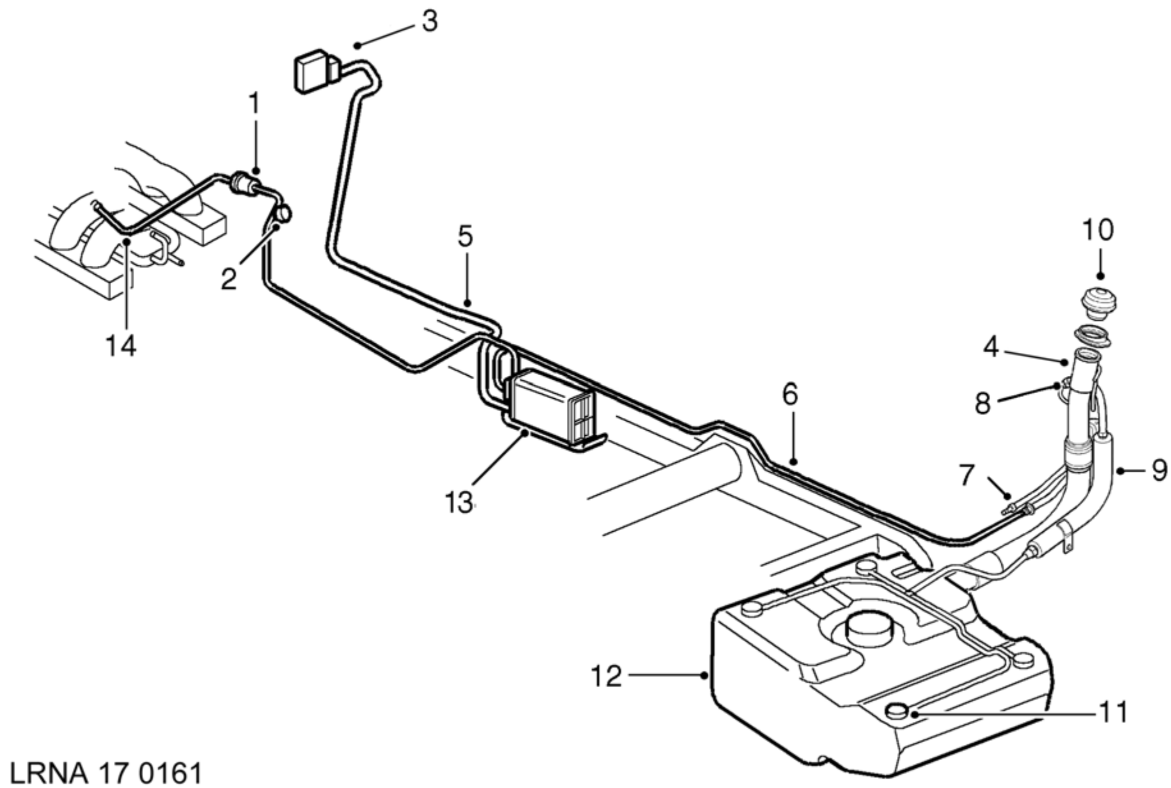
It is important that purge occur only as long as vapor is present. This reduces the time period in which unmetered air is introduced into the plenum. A purge solenoid stuck in the open position will increase vehicle emissions and affect driveability, especially at idle.



Purge Operation

EVAP With Leak Detection

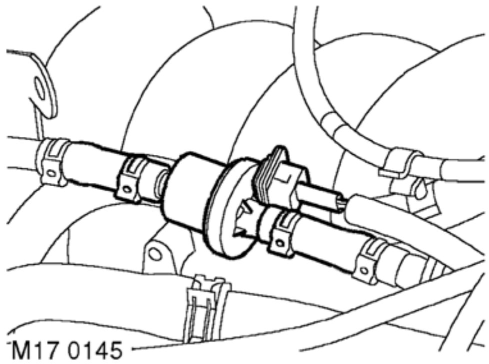
OBDII Legislation requires that the ECM must indicate the occurrence of a fault to the driver, if a leak in the fuel system allows hydrocarbons to escape to atmosphere. It will do this whenever it detects leakage greater than a predetermined rate. This rate was initially based upon the amount permitted to escape through a 1 mm (0. 04”) diameter hole, and for later models, a 0.5mm (0.02”) diameter hole.



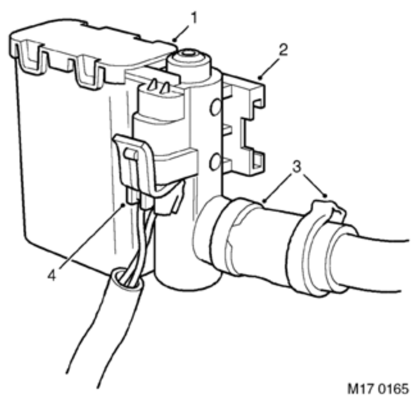
1	Purge valve	8	Anti-trickle valve
2	Service port	9	Liquid vapor separator
3	Canister Vent Solenoid (CVS) unit	10	Fuel filler cap
4	Filler neck	11	Roll over valves (ROV's)
5	Charcoal canister breather tube	12	Fuel tank assembly
6	Vent pipe to charcoal canister	13	Charcoal canister
7	Pipe connection to OBD sensor in fuel pump	14	Purge line connection to engine manifold

The ECM uses the purge system and a fuel tank pressure sensor to check the integrity of the fuel system. The ECM purges the charcoal canister of vapor and then closes the charcoal canister vent valve. This action produces a vacuum within the fuel tank. At a predetermined vacuum, the purge valve is closed. This action seals the fuel system. The ECM then monitors the rate at which the pressure within the fuel tank climbs to atmospheric pressure. The rate at which the pressure equalises is assessed against a ‘model’ (i.e. a pre-programmed map) of fuel evaporation. If a leak exists, then the pressure will equalize rapidly.

The ECM completes the purge test only while the vehicle is stationary and the engine is at idle. The test compensates for the natural evaporation of gasoline, which occurs when it is exposed to a slight vacuum. If any condition is detected that would produce an excessive level of natural evaporation levels (e.g. excessive air temperatures or a large degree of movement of fuel within the fuel tank), the diagnostic is cancelled.

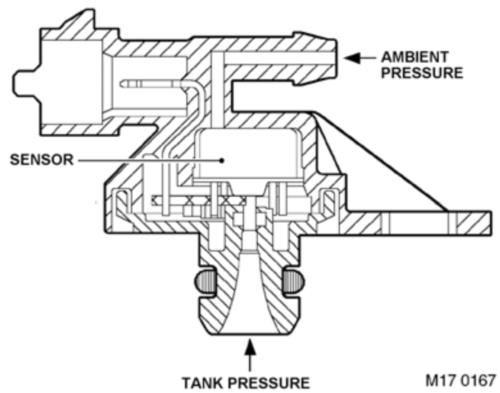


Canister Vent Solenoid Assy.



Purge Control Valve

If the ECM detects a leak in the fuel system (i.e. it has an air leak greater than 1 mm (0. 04”) in it), it will record a fault code. A loose fuel filler cap can cause the ECM to incorrectly diagnose an excessive air leak, so always ensure that the fuel filler cap is tight if the ECM has logged a present fault with the EVAP system. If the ECM records a fault code, the engine speed, engine coolant temperature and battery voltage is also recorded when the fault is first recognized. If the ECM detects a fault within the EVAP system on two consecutive ‘journeys’, then it will illuminate the MIL lamp.



Fuel Tank Pressure Sensor

Secondary Air Injection (SAI)

The secondary air injection system is used to limit the emission of carbon monoxide (CO) and hydrocarbons (HCs) that are prevalent in the exhaust during cold starting of a spark ignition engine. The concentration of hydrocarbons experienced during cold starting at low temperatures are particularly high until the engine and catalytic converter reach normal operating temperature. The lower the cold start temperature, the greater the prevalence of hydrocarbons emitted from the engine.

There are several reasons for the increase of HC emissions at low cold start temperatures, including the tendency for fuel to be deposited on the cylinder walls, which is then displaced during the piston cycle and expunged during the exhaust stroke. As the engine warms up through operation, the cylinder walls no longer retain a film of fuel and most of the hydrocarbons will be burned off during the combustion process.

The secondary air injection (SAI) system uses the following components:

- Secondary air injection pump
- SAI vacuum solenoid valve
- SAI control valves (2 valves, 1 for each bank of cylinders)
- SAI pump relay
- Vacuum reservoir
- Vacuum harness and pipes

The SAI pump is used to provide a supply of air into the exhaust ports in the cylinder head, onto the back of the exhaust valves, during the cold start period. The hot unburned fuel particles leaving the combustion chamber mix with the air injected into the exhaust ports and immediately combust. This subsequent combustion of the unburned and partially burned CO and HC particles help to reduce the emission of these pollutants from the exhaust system. The additional heat generated in the exhaust manifold also provides rapid heating of the exhaust system catalytic converters. The additional oxygen which is delivered to the catalytic converters also generate an exothermic reaction which causes the catalytic converters to ’light off’ quickly.

The catalytic converters only start to provide effective treatment of emission pollutants when they reach an operating temperature of approximately 250° C (482° F) and need to be between temperatures of 400° C (752° F) and 800° C (1472º F) for optimum efficiency. Consequently, the heat produced by the secondary air injection “afterburning”, reduces the time delay before the catalysts reach an efficient operating temperature.

The engine control module (ECM) checks the engine coolant temperature when the engine is started, and if it is below 55° C (131° F), the SAI pump is started. Secondary air injection will remain operational for a period controlled by the ECM and is dependent on the starting temperature of the engine. This varies from approximately 95 seconds for a start temperature of 8° C (46° F) to 30 seconds for a start temperature of 55° C (131° F). The SAI pump operation can be cut short due to excessive engine speed or load.

Air from the SAI pump is supplied to the SAI control valves via pipe work and an intermediate T-piece which splits the air flow evenly to each bank.

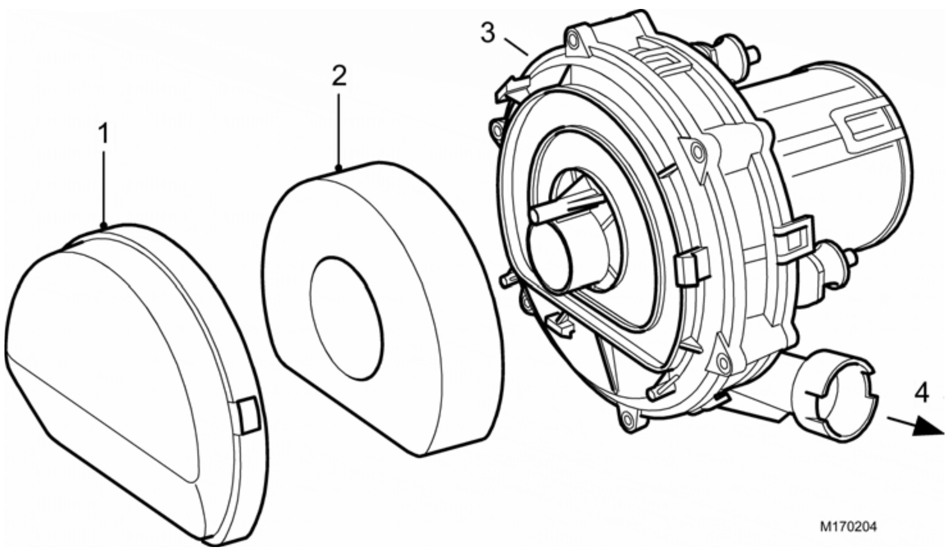
At the same time the secondary air pump is started, the ECM operates a SAI vacuum solenoid valve, which opens to allow vacuum from the reservoir to be applied to the vacuum operated SAI control valves on each side of the engine.

When the vacuum is applied to the SAI control valves, they open simultaneously to allow the air from the SAI pump through to the exhaust ports. Secondary air is injected into the inner most exhaust ports on each bank.

When the ECM breaks the ground circuit to de-energize the SAI vacuum solenoid valve, the vacuum supply to the SAI control valves is cut off and the valves close to prevent further air being injected into the exhaust manifold. At the same time as the SAI vacuum solenoid valve is closed, the ECM opens the ground circuit to the SAI pump relay, to stop the SAI pump.

A vacuum reservoir is included in the vacuum line between the intake manifold and the SAI vacuum solenoid valve. This prevents changes in vacuum pressure from the intake manifold being passed on to cause fluctuations of the secondary air injection solenoid valve. The vacuum reservoir contains a one way valve and ensures a constant vacuum is available for the SAI vacuum solenoid valve operation. This is particularly important when the vehicle is at high altitude.

Secondary air injection (SAI) pump



1	SAI pump cover	3	SAI pump
2	Foam filter	4	Pressurized air to exhaust manifolds

The SAI pump is attached to a bracket at the rear RH side of the engine compartment and is fixed to the bracket by three studs and nuts. The pump is electrically powered from a 12V battery supply via a dedicated relay and supplies approximately 35kg/hr of air when the vehicle is at idle in Neutral/Park on a start from 20C (68F).

Air is drawn into the pump through vents in its front cover and is then passed through a foam filter to remove particulates before air injection. The air is delivered to the exhaust manifold on each side of the engine through a combination of plastic and metal pipes.

The air delivery pipe is a flexible plastic type, and is connected to the air pump outlet via a plastic quick-fit connector.

The other end of the flexible plastic pipe connects to the fixed metal pipe work via a short rubber hose. The part of the flexible plastic pipe which is most vulnerable to engine generated heat is protected by a heat reflective sleeve. The metal delivery pipe has a fabricated T-piece included where the pressurized air is split for delivery to each exhaust manifold via the SAI control valves.

The pipes from the T-piece to each of the SAI control valves are approximately the same length, so that the pressure and mass of the air delivered to each bank will be equal. The ends of the pipes are connected to the inlet port of each SAI control valve through short rubber hose connections.

The T-piece is mounted at the rear of the engine (by the ignition coils) and features a welded mounting bracket which is fixed to the engine by two studs and nuts.

The foam filter in the air intake of the SAI pump provides noise reduction and protects the pump from damage due to particulate contamination. In addition, the pump is mounted on rubber mountings to help prevent noise which is generated by pump operation from being transmitted through the vehicle body into the passenger compartment.

The SAI pump has an integral thermal cut-out switch, to stop pump operation when the pump overheats. The pump automatically enters a 'soak period' between operations, to allow the pump motor a cooling off period.

If the secondary air injection pump malfunctions, the following fault codes may be stored in the ECM diagnostic memory, which can be retrieved using 'Testbook':

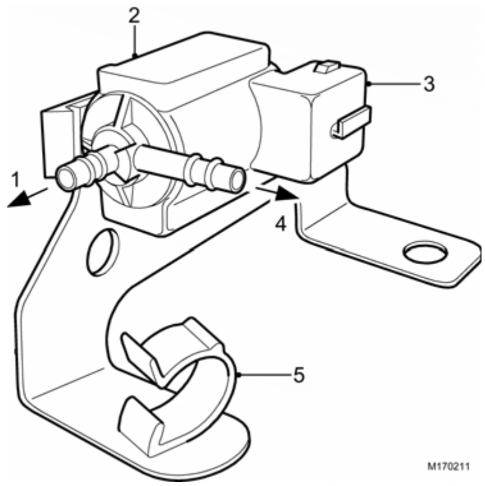
P-code	Description
P0418	Secondary air injection pump power stage fault (e.g. - SAI pump relay fault / SAI pump or relay not connected / open circuit / harness damage).

Secondary air injection (SAI) pump relay

The secondary air injection pump relay is located in the engine compartment fuse box. The engine control module (ECM) is used to control the operation of the SAI pump via the SAI pump relay. Power to the coil of the relay is supplied from the vehicle battery via the main relay and the ground connection to the coil is via the ECM.

Power to the SAI pump relay contacts is via fusible link FL2 which is located in the engine compartment fuse box.

Secondary air injection (SAI) vacuum solenoid valve



1	Vacuum port to intake manifold (via vacuum reservoir)	4	Vacuum port to vacuum operated SAI control valves
2	SAI vacuum solenoid valve	5	Purge valve clip
3	Electrical connector		

The SAI vacuum solenoid valve is located at the rear LH side of the engine and is electrically operated under the control of the ECM. The SAI vacuum solenoid valve is mounted on a bracket together with the EVAP system purge valve.

Vacuum to the SAI vacuum solenoid valve is provided from the intake manifold depression via a vacuum reservoir. A small bore vacuum hose with rubber elbow connections at each end provides the vacuum route between the vacuum reservoir and SAI vacuum solenoid valve. A further small bore vacuum hose with a larger size elbow connector is used to connect the SAI vacuum solenoid valve to the SAI control valves on each side of the engine via an intermediate connection. The SAI vacuum solenoid valve port to the SAI control valves is located at a right angle to the port to the vacuum reservoir.

The intermediate connection in the vacuum supply line is used to split the vacuum equally between the two SAI control valves. The vacuum hose intermediate connection is located midpoint in front of the inlet manifold. All vacuum hose lines are protected by flexible plastic sleeves.

Electrical connection to the SAI vacuum solenoid valve is via a 2–pin connector. A 12V electrical power supply to the SAI vacuum solenoid valve is provided via the Main relay and Fuse 2 in the engine compartment fuse box. The ground connection is via the ECM which controls the SAI vacuum solenoid valve operation.

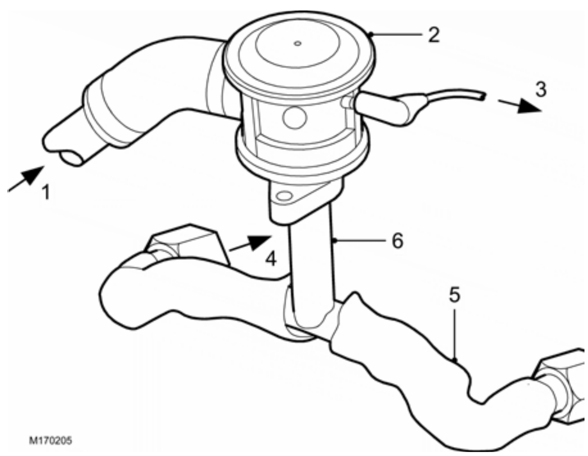
NOTE: The harness connector to the SAI solenoid valve is grey, and must not be confused with the harness connector to the EVAP system purge valve which is black.

The ECM switches on the SAI vacuum solenoid valve at the same time as initiating SAI pump operation. When the SAI vacuum solenoid valve is open, a steady vacuum supply is allowed through to open the two vacuum operated SAI control valves. When the ECM breaks the earth path to the SAI vacuum solenoid valve, the valve closes and immediately shuts off the vacuum supply to the two SAI control valves at the same time as the SAI pump operation is terminated.

If the SAI vacuum solenoid valve malfunctions, the following fault codes may be stored in the ECM diagnostic memory, which can be retrieved using ’Testbook’:

P-code	Description
P0413	SAI vacuum solenoid valve not connected, open circuit
P0414	SAI vacuum solenoid valve short circuit to ground
P0412	SAI vacuum solenoid valve power stage fault - harness damage, short circuit to battery supply voltage

SAI control valves



1 Pressurized air from SAI pump

2 Vacuum operated SAI control valve

3 Vacuum hose from SAI vacuum solenoid valve

4 Pressurized air to exhaust manifold

5 Protective heat sleeve

6 Air delivery pipe to exhaust manifold

The SAI control valves are located on brackets at each side of the engine.

The air injection supply pipes connect to a large bore port on the side of each SAI control valve via a short rubber connection hose. A small bore vacuum port is located on each SAI control valve at the opposite side to the air injection supply port. The vacuum supply to each vacuum operated SAI control valve is through small bore nylon hoses from the SAI vacuum solenoid valve. An intermediate connector is included in the vacuum supply line to split the vacuum applied to each vacuum operated valve, so that both valves open and close simultaneously.

When a vacuum is applied to the SAI control valves, the valve opens to allow the pressurized air from the SAI pump through to the exhaust manifolds. The injection air is output from each SAI control valve through a port in the bottom of each unit. A metal pipe connects between the output port of each SAI control valve and each exhaust manifold via an intermediate T-piece. The T-piece splits the pressurized air delivered to ports at the outer side of the two center exhaust ports on each cylinder head. The pipes between the T-piece and the exhaust manifold are enclosed in thermal sleeves to protect the surrounding components from the very high heat of the exhaust gas, particularly at high engine speeds and loads.

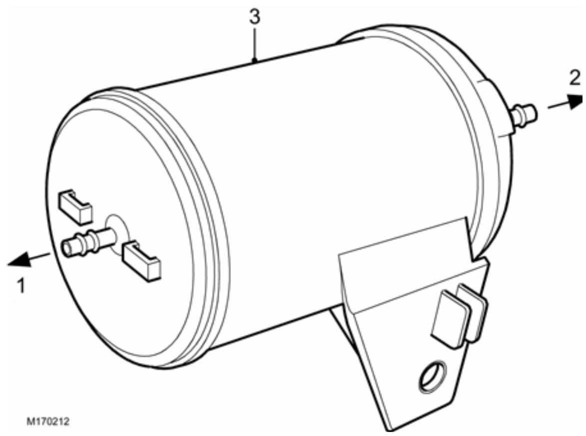
When the SAI vacuum solenoid valve is de-energized, the vacuum supply line opens to atmosphere, this causes the vacuum operated valves to close automatically and completely to prevent further air injection.

If the vacuum operated SAI control valves malfunction, the following fault codes may be stored in the ECM diagnostic memory, which can be retrieved using ’Testbook’:

P-code	Description
P1412	SAI system fault (LH side) - air delivery not reaching catalysts
P1414	SAI system fault (LH side) - air delivery not reaching catalysts
P1413	SAI system fault (LH side) - air delivery not reaching catalysts
P1415	SAI system fault (RH side) - air delivery not reaching catalysts
P1417	SAI system fault (RH side) - air delivery not reaching catalysts
P1416	SAI system fault (RH side) - air delivery not reaching catalysts

The above system faults could be attributable to anything which might prevent air delivery to the exhaust manifolds (e.g. disconnected or blocked SAI delivery pipe, disconnected or blocked vacuum pipe etc.)

Vacuum reservoir



1 Vacuum port to SAI vacuum solenoid valve
2 Vacuum port to intake manifold (one-way valve end)
3 Vacuum reservoir

A vacuum reservoir is included in the vacuum supply line between the intake manifold and the SAI vacuum solenoid valve. The vacuum reservoir contains a one-way valve, to stop vacuum from leaking back towards the intake manifold side. The reservoir holds a constant vacuum so that the SAI control valves open instantaneously as soon as the SAI solenoid valve is energized.

The vacuum reservoir is a plastic canister construction located on a bracket at the LH side of the engine compartment.

It is important to ensure the reservoir is installed in the correct orientation, and the correct vacuum hoses are attached to their corresponding ports. The one-way valve end of the vacuum reservoir (cap end, to inlet manifold) is installed towards the rear of the vehicle.

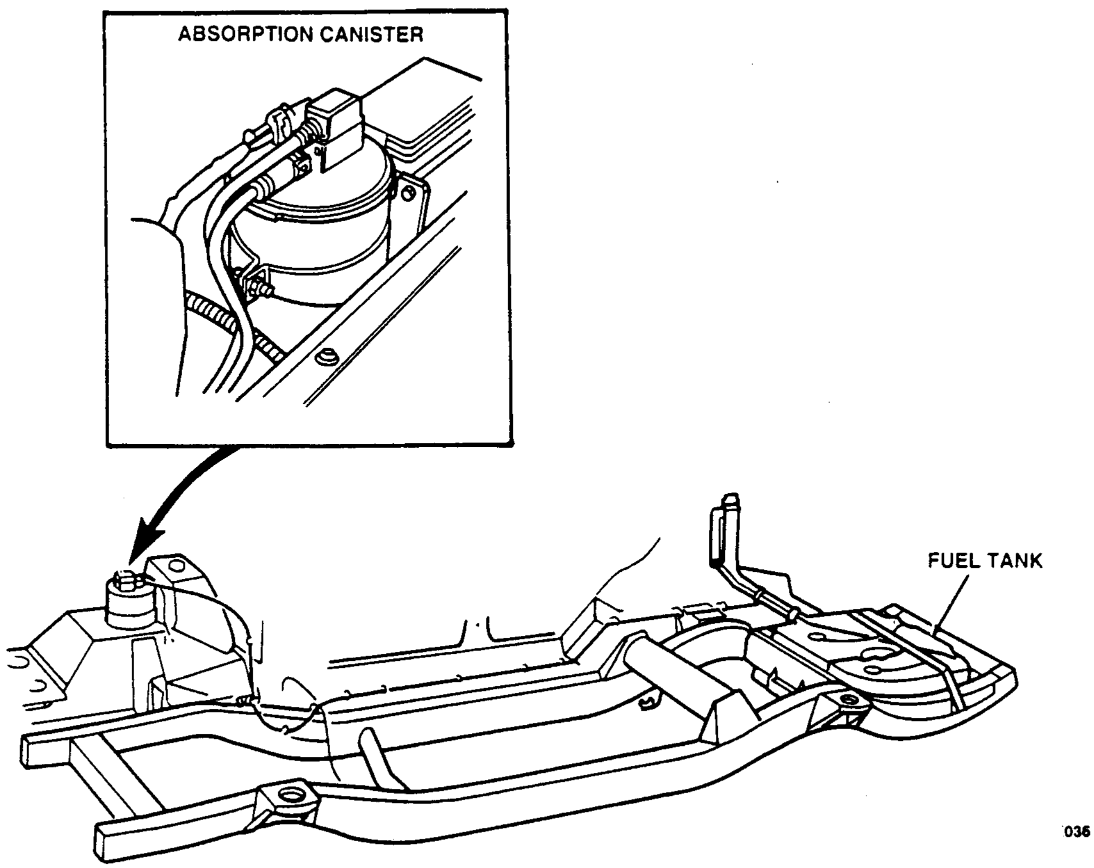
A small bore nylon hose is used to connect the one-way valve end of the vacuum reservoir to a port on the RH side of the inlet manifold. A further hose connects between the other port on the vacuum reservoir and a port on the front of the SAI vacuum solenoid valve.

EVAPORATIVE EMISSION CONTROL SYSTEM (EVAP)

EVAPORATIVE PURGE

As gasoline from the fuel tank is pumped to the engine, air must enter the system to prevent a vacuum from developing. However, harmful hydrocarbon vapors form in the fuel tank as gasoline evaporates.   Venting the fuel tank directly to the atmosphere would allow these vapors to escape.

To prevent this from occurring, fuel system vapors are routed to a charcoal canister which absorbs and stores fuel vapor from the tank when the engine is not running. Once the engine is started, the vapor is purged from the canister by fresh air drawn through an orifice at the base of the canister and the vacuum introduced at the top.



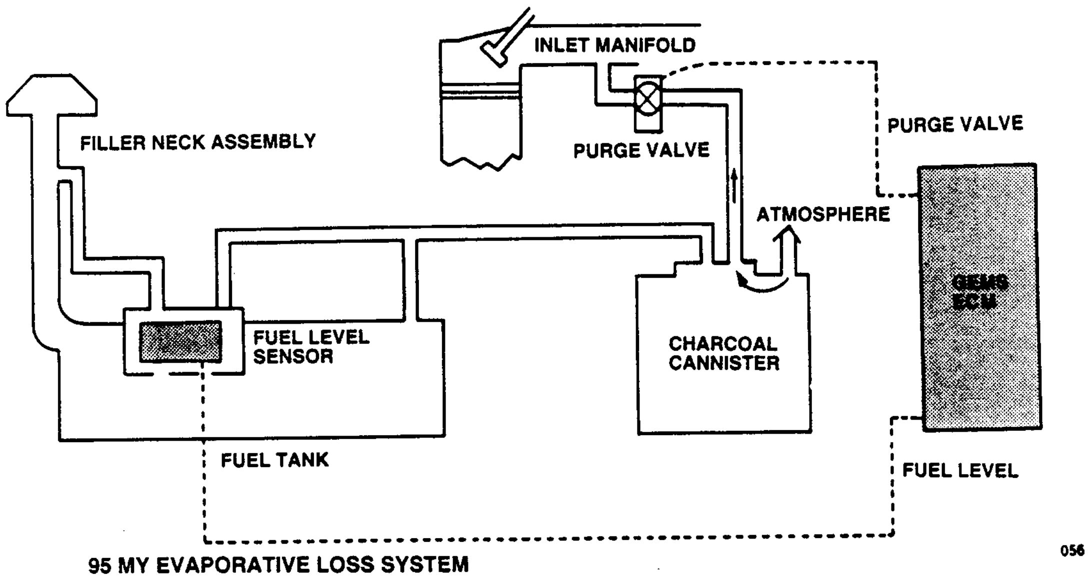
Evaporative Purge System Components

On 1989 and later vehicles, purge operation is controlled by the ECM through a solenoid valve. When the valve is opened, the vapor is drawn into the plenum to be added to the air/fuel mixture. Control of evaporative purge operation is an important ECM function for effective emission control.

When operating, purge flow into the plenum is not accounted for in the ECM's air/fuel calculations. Because of this, purge operation is saved for those times when the additional vapor is least likely to affect emissions. Typically, this is when the engine is warm and operating well above idle speed.

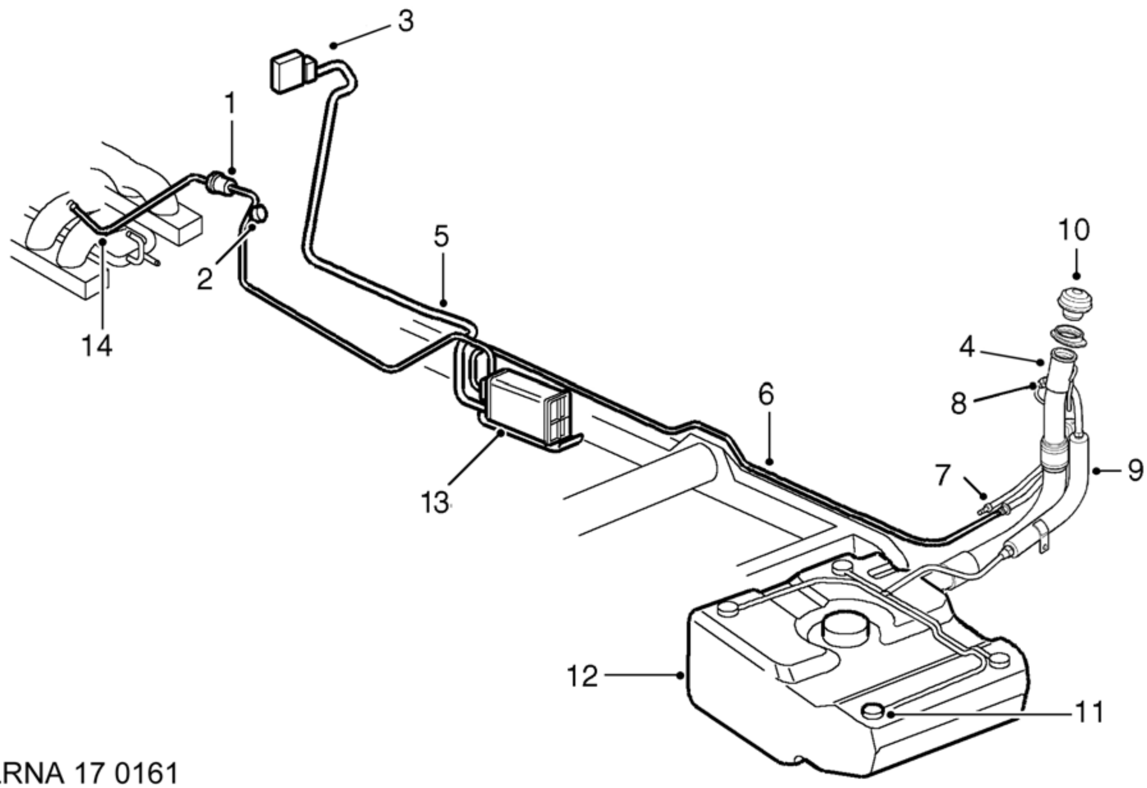
The ECM controls the flow rate by opening, closing, or pulsing the solenoid valve. The ECM monitors purge flow by looking for signs from the oxygen sensors that the fuel mixture has been enriched when the solenoid valve is opened. When this no longer occurs, the ECM interprets this to mean that no more vapor is present. Purge operation is discontinued at this time.

It is important that purge occur only as long as vapor is present. This reduces the time period in which unmetered air is introduced into the plenum. A purge solenoid stuck in the open position will increase vehicle emissions and affect driveability, especially at idle.



Purge Operation

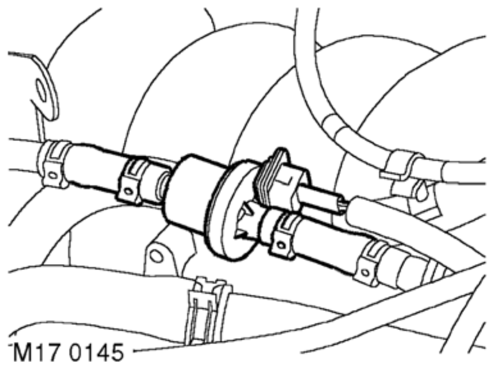
EVAP With Leak Detection
OBDII Legislation requires that the ECM must indicate the occurrence of a fault to the driver, if a leak in the fuel system allows hydrocarbons to escape to atmosphere. It will do this whenever it detects leakage greater than a predetermined rate. This rate was initially based upon the amount permitted to escape through a 1 mm (0. 04”) diameter hole, and for later models, a 0.5mm (0.02”) diameter hole.



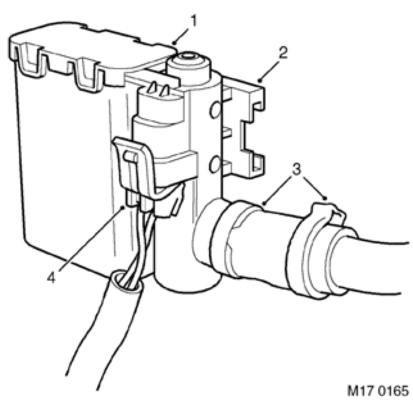
1	Purge valve	8	Anti-trickle valve
2	Service port	9	Liquid vapor separator
3	Canister Vent Solenoid (CVS) unit	10	Fuel filler cap
4	Filler neck	11	Roll over valves (ROV's)
5	Charcoal canister breather tube	12	Fuel tank assembly
6	Vent pipe to charcoal canister	13	Charcoal canister
7	Pipe connection to OBD sensor in fuel pump	14	Purge line connection to engine manifold

The ECM uses the purge system and a fuel tank pressure sensor to check the integrity of the fuel system. The ECM purges the charcoal canister of vapor and then closes the charcoal canister vent valve. This action produces a vacuum within the fuel tank. At a predetermined vacuum, the purge valve is closed. This action seals the fuel system. The ECM then monitors the rate at which the pressure within the fuel tank climbs to atmospheric pressure. The rate at which the pressure equalises is assessed against a ‘model’ (i.e. a pre-programmed map) of fuel evaporation. If a leak exists, then the pressure will equalize rapidly.

The ECM completes the purge test only while the vehicle is stationary and the engine is at idle. The test compensates for the natural evaporation of gasoline, which occurs when it is exposed to a slight vacuum. If any condition is detected that would produce an excessive level of natural evaporation levels (e.g. excessive air temperatures or a large degree of movement of fuel within the fuel tank), the diagnostic is cancelled.

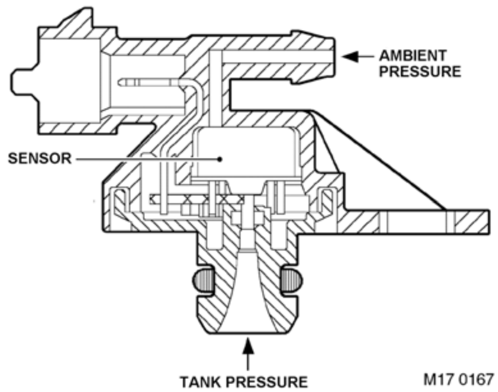


Canister Vent Solenoid Assy.



Purge Control Valve

If the ECM detects a leak in the fuel system (i.e. it has an air leak greater than 1 mm (0. 04") in it), it will record a fault code. A loose fuel filler cap can cause the ECM to incorrectly diagnose an excessive air leak, so always ensure that the fuel filler cap is tight if the ECM has logged a present fault with the EVAP system. If the ECM records a fault code, the engine speed, engine coolant temperature and battery voltage is also recorded when the fault is first recognized. If the ECM detects a fault within the EVAP system on two consecutive 'journeys', then it will illuminate the MIL lamp.



Fuel Tank Pressure Sensor

ON-BOARD DIAGNOSTICS

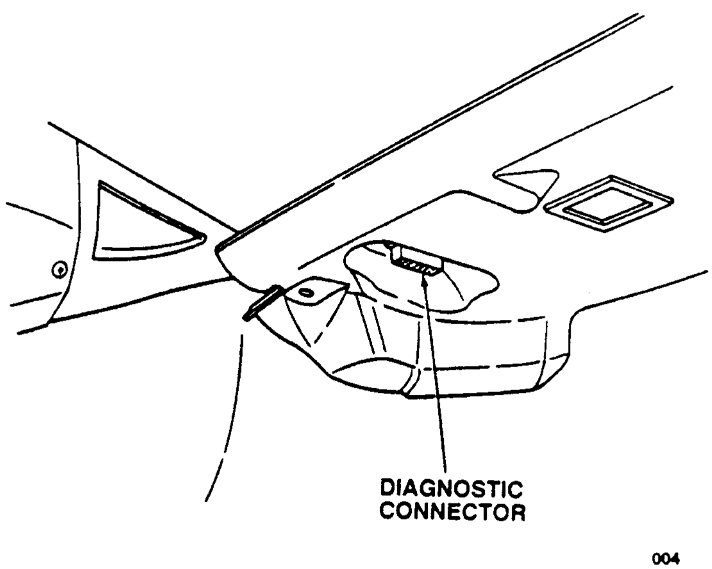
The development and adoption of legislation calling for more stringent automotive emission requirements, initiated by the California Air Resources Board (CARB), is now part of the Federal Clean Air Act. This legislation is an extension and enhancement of previous requirements (OBD) and is known as On-Board Diagnostics II (OBD II). Federal law requires that by the 1996 model year, vehicles sold in the United States meet common standards for emission control and diagnostic capability. GEMS allows Land Rover products to meet these operating standards.

Monitoring Emissions Performance

The original OBD required that vehicles monitor operation of key components such as oxygen sensors, fuel delivery system, and the module controlling the system's powertrain. Failure of components in these systems is indicated by MIL illumination and generation of a Diagnostic Trouble Code (DTC).

OBD II takes this monitoring a step further by not only checking the operation of emission components, but their performance. While the difference between monitoring operation and performance may sound small, the changes to ECM operating strategies required to accomplish this are enormous.

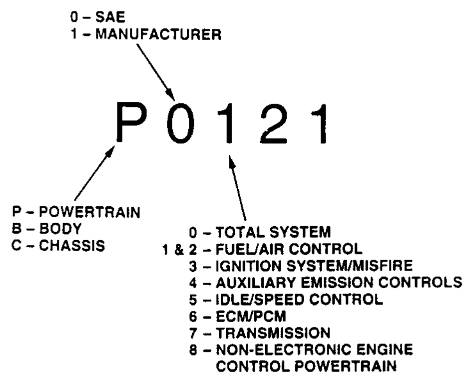
OBD II regulations require the vehicle's MIL to be illuminated and a DTC generated when system operating conditions are such that vehicle emissions will exceed 15% of the original emissions specification. DTCs are retrieved using the TestBook or any diagnostic scan tool. All vehicles meeting OBD II standards use a standardized 16-pin connector for engine management system diagnostics. The Diagnostic connector on the Range Rover is located in the front passenger's footwell, near the center console.



16-Pin Connector

Diagnostic Trouble Codes (DTC)

OBD II requires that diagnostic trouble codes for common components are provided by all manufacturers. These codes must follow the format developed in the Society of Automotive Engineer's (SAE) standard J2012. This five-digit code consists of four numbers preceded by a single letter.

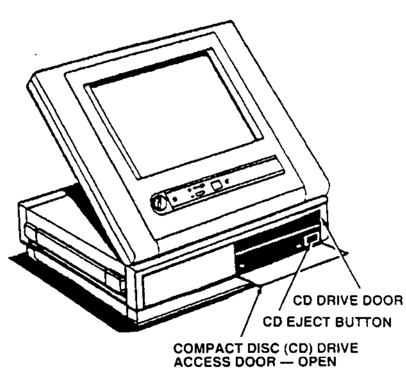


Five-Digit DTC

The initial letter designates the vehicle system to which the code refers. All powertrain codes begin with the letter P. The first number indicates who was responsible for the DTC definition. The number “0” indicates an SAE defined code required under OBD II while “1” indicates that this code definition is manufacturer-specific (in this case, Land Rover). The “1” codes allow manufacturers to develop diagnostic capabilities over and above those required by OBD II.

The third digit (second number) of the powertrain DTC ranges from 0 through 8 and indicates the specific system subgroup. The fourth and fifth places indicate the specific concern the DTC addresses.

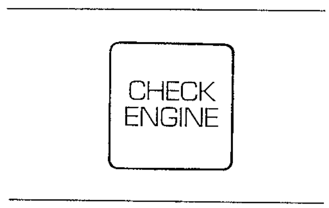
The number of diagnostic codes that can be produced by the ECM has increased substantially with the introduction of OBD II. A complete list of P-codes is included at the end of this chapter. The good news is that these codes are far more specific than those previously available. This helps technician's pinpoint the cause of a customer concern more quickly than in the past. All DTCs can be retrieved with a hand held scan tool or T4/WDS.



TestBook

Diagnostic System Manager

OBD II requires that more components be monitored for a wider range of “failures” that previously may have gone unnoticed. Because of this, you can expect the MIL to illuminate more often than in the past.



Malfunction Indicator Lamp (MIL)

The ECM does, however, contain a special diagnostic strategy or Diagnostic System Manager (DSM) to help prevent unnecessary MIL illumination. The DSM delays vehicle self-tests, known as OBD II monitors, until the appropriate operating conditions for the test (engine temperature, rpm, engine load conditions) are present. This provides the best indicator of fuel system and emissions control operation under real driving conditions.

The designers of OBD II also recognize that unique operating conditions can produce emissions that, for a brief period, exceed allowable levels even though engine systems are operating properly. To prevent these infrequent glitches from triggering the MIL, in most cases the DSM requires that the system exceed allowable levels on two consecutive test sequences (known as trips) before the MIL is illuminated.

The DSM software also runs the tests in a specific order. This minimizes the production of misleading DTCs. If a component or system should fail, there is no sense in performing additional tests on systems or components which rely on the failed component. They'll fail too! The GEMS diagnostic strategy doesn't bother to run tests dependent on failed components/ systems until they are operating properly.

OBDII Monitoring

The OBD II system test strategy performs self-diagnostics on related systems (known as Monitors) as required by federal regulations. These OBD II Monitors are listed below. They will be covered in greater detail later in the lesson.

- Misfire Monitor
- Comprehensive Component Monitor
- Fuel System Monitor
- Catalyst Efficiency Monitor

Warm-up Cycle
A term used in discussing OBD II diagnostic strategy is warm-up cycle. The ECM uses the number of warm-up cycles as a counting device. After a specified number of warm-up cycles (typically 40) DTCs that are no longer relevant to the engine operating condition are automatically erased from the ECM’s memory.

This is important from a technician's standpoint because DTCs and information from a concern that illuminated a customer's MIL at one time may no longer be in the ECM's memory. If the source of the concern is no longer present (bad gasoline) and the customer has waited a long time before coming in - you won't find information to work with. On the other hand, old and irrelevant information isn't likely to be present to mislead you when searching for current concerns.

The definition of a warm-up cycle is very specific. It includes engine operation, after an engine OFF period, where engine coolant temperature rises at least 22° C (40° F) and reaches at least 71° C (160° F). It then must cool down below 71° C (160° F).

OBD II Trip
Another important concept is that of the OBD II Trip. This is defined as engine operation after an engine OFF period, where OBD II components are tested and the following monitors are completed:

- Misfire
- Comprehensive Component
- Fuel System

The completion of an OBD II Trip is required for most of the new diagnostic strategies that can produce MIL illumination.

OBDII Monitors
The ECM performs a battery of tests on specific vehicle systems to determine if they are operating within the parameters set by OBD II. The Diagnostic System Manager software ensures that the tests are performed at specific times and in the correct sequence in order to produce valid results. Testing the vehicle while cold, or in unusual operating conditions (such as during evaporative purge) could produce false readings that would illuminate the vehicle's MIL unnecessarily .

Comprehensive Component Monitor
ECM inputs and outputs are checked frequently during engine operation. As in the original OBD application, these components and their circuits are checked for operation. Tests for shorts and opens are performed. Some tests require system or component actuation so a change of state can be observed. DTCs and MIL illumination occur when a fault is recorded.

OBD II requires even more careful review of these input and output components by not only determining if they are operating, but also by performing rationality checks. By comparing the readings from other sensors, the GEMS can determine if a sensor reading is appropriate for the current operating conditions. An example of this is a throttle position sensor signal indicating the throttle is half open when other inputs and outputs (rpm, IACV) suggest the engine is at idle.

A specific DTC is stored as soon as a fault is detected. The system must fail the test on two consecutive drive cycles before the MIL is illuminated.

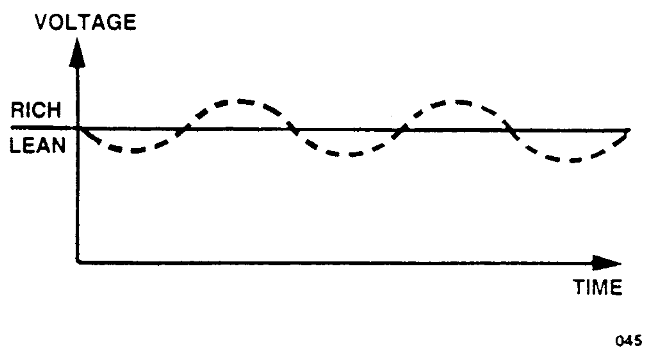
The GEMS will continue testing failed or out of range components, even after the MIL is illuminated. Should the system pass the test on three consecutive trips, the MIL will turn off. The DTC will remain stored however, for 40 more warm-up cycles.

Fuel System Monitor
The ECM continually adjusts fuel trim when in closed loop operation. If a system malfunction occurs, requiring an amount of fuel trim compensation that exceeds standards set in the GEMS program, a DTC will be stored. The ECM monitors the fuel system continuously once it is operating in closed loop.

Should fuel trim requirements fall outside of the acceptable parameters on a second consecutive trip, the MIL will be illuminated. If the system concern does not repeat itself for three consecutive trips, the MIL will turn off. The DTC will remain stored for 40 more warm-up cycles.

NOTE: It is important to understand that two consecutive trips is not the same as two warm-up cycles. Two consecutive trips could occur two weeks apart, with dozens of warm-up cycles in between.

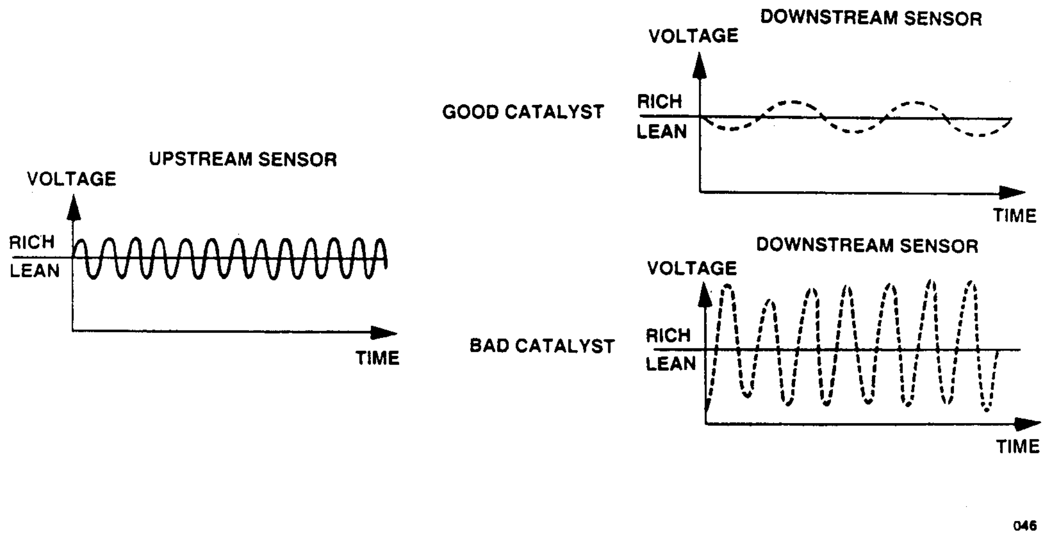
Catalyst Efficiency Monitor
The Three-Way Catalyst (TWC) or catalytic converter, is a central device in the vehicle's emissions control system. Over time, deterioration of a catalyst's operating efficiency can lead to an increase in hydrocarbon emissions. OBD II requires that the ECM monitor operation of the vehicle's TWCs to ensure that they are operating within specification. This is accomplished by monitoring signals produced by oxygen sensors mounted ahead of (upstream) and below (downstream) of each TWC.



Catalyst Signal

A properly functioning three-way catalyst stores oxygen during lean engine operation and gives up that stored oxygen during rich engine operation to consume unburned hydrocarbons. Catalyst efficiency is estimated by monitoring the oxygen storage capacity of the catalyst during closed-loop operation.

The GEMS monitors the switching frequency of the downstream HO2S during the test. Because the sensor switches in the presence of oxygen, it should have a significantly lower switching frequency than the sensor mounted ahead of the catalyst.



Rear Catalyst Monitor

A frequency approaching that of the upstream sensor would indicate that the TWC is not storing oxygen during lean operation. This lack of stored oxygen renders the TWC incapable of burning off excess hydrocarbons produced during the rich cycle. The result is excessive hydrocarbon emissions.

Catalyst efficiency is tested once each drive cycle. The first time the system fails a self-test, the ECM will store a DTC. The system must fail the test on two consecutive drive cycles before the MIL is illuminated.

The Diagnostic System Manager will continue testing for catalyst efficiency once each drive cycle, even after the MIL is illuminated. Should the system pass the test on three consecutive drive trips, the MIL will turn off. The DTC will remain stored, however, for 40 more warm-up cycles.

Misfire Monitor

Cylinder misfire poses a serious threat to the vehicle's emissions system. Misfires produce concerns ranging from open ignition circuits to fouled spark plugs. As a cylinder misfires, the raw hydrocarbons (HC) that should have been consumed during ignition are forced out of the exhaust manifold. Obviously, this adversely affects vehicle emissions. Worse however, is what happens after these raw HCs leave the engine and enter the three-way catalyst (TWC).

As these raw hydrocarbons move into the catalyst, the internal temperature of the converter increases. Continued operation can cause the catalytic honeycomb to melt into a solid mass, destroying the catalyst's ability to function. Eventually, the TWC may cause so much restriction that the excessive backpressure prevents the engine from running. Obviously, detecting and preventing engine operation under misfire conditions is a high priority of an emissions control system.

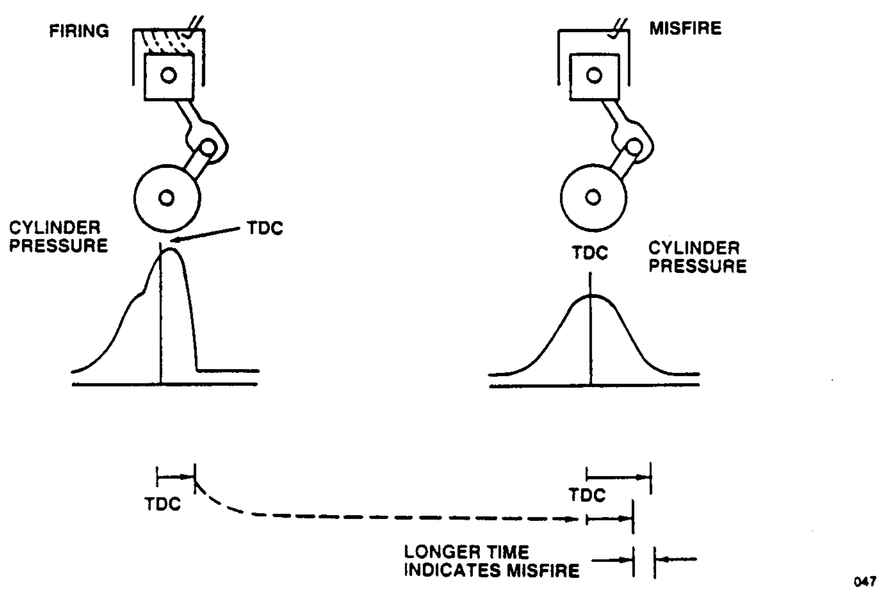
The ECM detects engine misfire by measuring the contribution each cylinder makes to engine performance. This is calculated from measurements of crankshaft acceleration for each cylinder provided by the crankshaft position sensor.

The acceleration for each cylinder is determined from the crankshaft rotation velocity. The GEMS performs a series of calculations to determine the acceleration rates of the individual cylinders. When a cylinder's acceleration falls outside of a predetermined range, the GEMS takes a closer look at the signal.

For example, operating conditions such as rough roads or high rpm/light load operation can provide misfire-like changes in crankshaft acceleration. Internal programming in the GEMS is designed to filter out these look-alike signals and focus on real misfire. The GEMS separates misfire into two classifications, and has a different response for each.

Type A Misfire:
This is a serious misfire situation where raw fuel entering the TWC can cause excessive catalyst temperatures. This could quickly cause permanent damage to the TWC. In this situation, the MIL lamp illuminates immediately and flashes to attract the driver's attention. Continued operation at this point will damage the TWC.

Type B Misfire:
A second type of response occurs when the GEMS detects a low-level misfire. At lower levels, misfire will not significantly raise TWC temperature but will produce excessive vehicle emissions. In this situation, the GEMS records a DTC. The GEMS will illuminate the MIL if this failure is repeated during a second consecutive drive cycle where operating conditions (engine warm-up, rpm and load) are approximately the same. Should the misfire not reappear under these conditions on three consecutive trips, the MIL will turn off.



Crankshaft Acceleration Signal

Freeze Frame
OBD II provides a special diagnostic screen known as freeze frame, to help technicians determine the exact conditions that caused a MIL to be illuminated. Freeze frame traps the following data the moment a monitor fails:

- DTC
- Fuel System Status (Open/Closed Loop)
- Engine Load*
- Coolant Temperature
- Short Term Fuel Trim (Bank 1)**
- Long Term Fuel Trim (Bank 1)**
- Short Term Fuel Trim (Bank 2)***
- Long Term Fuel Trim (Bank 2)***
- RPM
- Vehicle Speed
- Intake Air Temperature
- Throttle Position

Accessing this data can help you determine the nature of the concern and the steps required to solve the problem.

* Engine load is represented by a "Calculated load value" which refers to an indication of the current airflow divided by peak airflow, where peak airflow is corrected for altitude, if available. This definition provides a unitless number that is not engine specific, and provides the service technician with an indication of the percent engine capacity that is being used (with wide open throttle as 100%).

$$CLV = \frac{\text{Current Airflow}}{\text{•Peak airflow (@ sea level)}} \text{ X } \frac{\text{Atm Pressure (@ sea level)}}{\text{•Barometric pressure}}$$

** Also known as Bank “A”, Odd bank, or left bank

*** Also known as Bank “B”, Even bank, or right bank

Service Drive Cycles
While each of the OBD II monitors is often completed during the course of normal driving, there is a way to be sure they run in a single driving session. This is called the Service Drive Cycle, and is of value to technicians diagnosing OBD II concerns.

Plan a test route that will allow you to accomplish the tasks listed. Obey posted speeds and all traffic laws.

1. Allow vehicle to cold soak until coolant temperature is less than 60° C (140° F).
2. Start engine.
3. Idle for approximately 8 minutes. Diagnostics for misfire, sensors and actuators will run and produce an outcome. An additional test requiring the engine to run for a total of 15 minutes is present. Idling is the most efficient way to achieve this.
4. Shift to Drive. Accelerate up an incline at wide open throttle to maintain a high engine load for approximately 10 seconds. This allows Neutral/Drive switch and Road Speed diagnostics to take place.
5. Drive on and off the throttle so that a total of 40 gear changes take place. (Shifts from Park to Drive or Drive to Neutral don't count toward this total).
6. Accelerate to 35-45 mph and maintain this speed at a steady load for approximately three minutes. This allows fuel trim adaptations and catalyst monitoring to take place.
7. Slow to idle and place the transmission in Park.
8. Bring the engine to 1500-2000 rpm for approximately one minute.
9. Idle for two minutes, then turn ignition to OFF.