EUROPEAN ON-BOARD DIAGNOSTICS

Workbook

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Preface

This document has been issued to support the Technical Academy training programme.

Every effort has been taken to ensure the information contained in this document is accurate and correct. However, technical changes may have occurred following the date of publication. This document will not necessarily have been updated as a matter of course. Therefore, details of any subsequent change may not be included in this copy.

The primary function of this document is to support the Technical Academy training programme. It should not be used in place of the workshop manual. All applicable technical specifications, adjustments procedures and repair information can be found in the relevant document published by Rover Group Technical Communication.

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Introduction

Introduction

An on-board diagnostics system is an integral part of the engine control module ECM, it is used to monitor the integrity and effectiveness of the emission system components.

In order to comply with the latest European legislation relating to vehicle emissions for passenger cars and light-duty trucks, vehicles with petrol engines must be equipped with an on-board diagnostics system from 2000MY. On-board diagnostics for diesel engines is not a statutory requirement until 2003 and so engine management systems and OBD for vehicles with diesel engines will not be covered in depth in this document, although some mention will be made of the type of emissions pertinent to diesel engines.

The fundamental requirement for an OBD system is that in the event that an emissions related component malfunctions, the fault is stored in the ECM's memory. A malfunction indicator light (MIL) is included in the vehicle's instrument pack which is used to indicate a warning to the driver that a failure has occurred. The fault code stored in memory can be retrieved using diagnostic equipment such as "Testbook" to determine the nature and status of the fault condition.

The objectives of an on-board diagnostics system is to provide a means for the following:

- Fault detection of components relevant to exhaust emissions (performed as part of the engine management system)
- Fault storage (in ECM internal memory, including failure conditions)
- Fault display (MIL lamp and/or LCD display)
- Fault retrieval (using a diagnostic tool such as "Testbook")

The OBD system is not designed to directly limit passenger vehicle emissions itself, but rather to check the integrity and operation of other systems and components on the vehicle. A component or system failure could adversely affect fuel efficiency and /or emissions produced; the OBD ensures that these critical items continue to operate to the required standard throughout the lifetime of the vehicle.

The compulsory introduction of E-OBD is likely to have a big impact in the service aftermarket. There is a general fear that a scenario could occur whereby garages become swamped with vehicles returned by customers because the MIL warning light keeps coming on. In reality, this should not occur if the systems perform as design intended. Essentially, On-board Diagnostic systems assist the diagnosis, repair and maintenance of vehicles to provide benefits to both the vehicle owner and the environment. It will also help the garage mechanic to determine the cause of a particular fault much more quickly and accurately and so result in less time for a faulty vehicle to be off the road for repairs.

OBD History

The development of OBDs can be appreciated by consideration of the associated legislation and the recommendations of the controlling bodies which has brought about its introduction.

California Air Resources Board (CARB)

Limitations on the quantities of pollutants that are deemed acceptable are becoming ever more stringent and differs in accordance with the relevant market legislation in force. The limitations prescribed by the California Environmental Protection Agency (CAL EPA) and its policy implementing arm, the California Air Resources Board (CARB) have air-quality programs that have led the way with regards to emissions legislation for quite some time. These measures are usually adopted at a later date by other emission control authorities around the world, and an analysis of the measures imposed by CARB are a good indication of what to expect in other markets.

To achieve clean air, CARB develops increasingly stringent emission standards for motor vehicles, transportation control measures, improvements to consumer products and specifications for cleaner fuels.

OBD-I

The origins of OBDII actually date back to 1982 in California, when CARB began developing regulations requiring all vehicles sold in the State from 1988 to have an on-board diagnostic system (OBDI). OBDI was relatively simple and only monitored the oxygen sensor, EGR system, fuel delivery system and engine control module.

The essential functionality for OBD-I systems was that the engine management system monitors all electrical components that affect exhaust emissions and provide an optical warning signal in the event of a relevant malfunction. The corresponding fault could be read via a flashing code without the aid of a testing device.

OBDI did not provide guidelines or legislation to provide standardisation between different vehicle manufacturer’s or vehicle models. Consequently, different adapters were needed to work on different vehicles and some systems could only be accessed using dealer specific scan tools.

Another limitation of OBDI was that it couldn’t detect certain kinds of problems such as a non-functioning or missing catalytic converter, ignition misfires, or evaporative emission problems. In addition, the MIL lamp would only illuminate after a failure had occurred, it had no way of monitoring progressive deterioration of emissions-related components.

OBD-II

CARB proposed a new set of standards for an enhanced OBD system in 1989 which were incorporated into the federal Clean Air Act of 1990. In 1994, the US Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) issued this strict new set of guidelines and a phase-in program concerning the application of on-board diagnostics systems began; this was to be mandatory for certain passenger vehicles. These guidelines known as OBD-II were designed to detect emissions systems related malfunctions and facilitate their repair before vehicle performance could deteriorate.

The MIL warning light on OBDII systems is set to illuminate any time a vehicle's hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO_x) or evaporative emissions exceed 1.5 times the Federal Test Procedure (FTP) standards for that model year of vehicle. This includes:

- Any time random misfires cause an overall rise in HC emissions
- Any time the operating efficiency of the catalytic converter drops below a certain threshold
- Any time the system detects air leakage in the sealed fuel system
- Any time a key sensor or other emission control related device fails
- For diesel systems – any time a fault in the EGR system causes NO_x emissions to rise

Therefore the MIL light may illuminate even though the vehicle seems to be running normally and there are no apparent driveability problems. Because a vehicle may appear to be running well even though the emission levels have increased due to a system or component fault, the MIL warning lamp provides a means for alerting the driver of the vehicle that they are causing pollution and they need to get their emissions problems fixed.

Because motorists may ignore the warning lamp even when it is indicating a fault, regulators want to incorporate OBDII into existing and enhanced vehicle emissions inspection programs. If the MIL lamp is found to be on when a vehicle is tested, it will not pass the tests even if the exhaust pipe emissions are within acceptable limits.

Another important development of OBDII over OBDI was the introduction of defined standards for trouble codes and diagnostic equipment. The Air Resources Board required that all manufacturer's must conform to standards for the following:

- 16–pin serial data link connector with specific pins assigned specific functions
- electronic protocols
- diagnostic trouble codes (DTCs)
- terminology

In 1996, the phase-in period for vehicles in California was to be completed and the scope of the OBDII regulations were expanded to apply to all passenger cars in the US market.

In addition to more advanced software, OBDII systems typically include the following features over and above that used on OBDI systems:

- Twice the number of oxygen sensors than non-OBDII vehicles, with the sensors usually being heated (HO_2S). The additional HO_2 sensors are positioned downstream of the catalytic converters to determine catalyst efficiency.
- More powerful electronic control modules (ECMs)
- Electrically Erasable Programmable Read Only Memory (EEPROM) which allows the ECM to be reprogrammed with the latest software changes using external computers connected via the diagnostic connector.
- Modified evaporative emission control systems with a diagnostic switch for purge testing or an advanced EVAP system with vent solenoid, fuel tank pressure sensor and diagnostic test routine
- EGR systems with linear EGR valve which is electronically operated and has a pintle position sensor
- Sequential fuel injection rather than multiport or throttle body injection
- Manifold Absolute Pressure (MAP) sensor and Mass Air Flow (MAF) sensors for monitoring engine load and airflow

Standardization is an important part of the OBD regulations and it facilitates for access to emission-related fault codes, emission-related powertrain test information (i.e., parameter values), emission related diagnostic procedures, and stored freeze frame data based on industry specifications.

Standardization of the message content (including test modes and test messages) as well as standardization of the downloading protocol for fault codes, parameter values and their units, and freeze frame data are specified in SAE recommended practices “OBD II Scan Tool” (J1978) which was issued in June 1994, and “E/E Diagnostic Test Modes” (J1979) which was issued in July 1996. Fault codes, parameter values, and freeze frame data have to be capable of being downloaded to a generic scan tool which meets these SAE specifications.

The OBDII standards have now been adopted by the European community and developed for the European automotive sector for compulsory implementation in 2000MY.

E-OBD

The European Parliament has issued its own directive aimed at reducing pollution from motor vehicles which is commonly known as 'EURO-3', and is a development of the earlier EU-1 and EU-2 regulations.

In addition to lower emission limits, the directive also covers the monitoring of emission-related components and functions during operation, based on the US OBD-II model.

If an emissions related fault is diagnosed by the engine management system, which results in a significant increase in the vehicle emissions, a Malfunction Indicator Lamp (MIL) must be illuminated to inform the driver that the vehicle needs to be checked for emission-related faults.

For petrol-engined passenger cars up to a total weight of 2500 kg the following maximum pollutant limits have been set by the EURO-3 legislation:

- **Carbon Monoxide (CO)** – 3.2 g/km
- **Hydrocarbons (HC)** – 0.4 g/km
- **Nitrous Oxides (NO_x)** – 0.6 g/km

E-OBD stipulates the monitoring of the functions of the following systems:

- Catalytic converter
- Catalytic-converter heater (where applicable)
- Misfire detection
- Fuel system
- HO_2 sensors
- Secondary-air system (if applicable)
- Fuel filler cap captive or monitored (where applicable)

The engine management system (ECM) monitors the above systems by checking the data from different sensors fitted to the vehicle and the associated data records stored in internal memory (memory mapping) to monitor environmental conditions and engine operation.

Default values for some components are stored in system memory, which the ECM uses if it cannot determine the environmental or engine operating conditions due to a faulty signal. If a faulty sensor is detected, the MIL warning lamp is illuminated when the fault has been confirmed over the relevant number of drive cycles.

Legislation

The relevant market authorities such as the European Parliament are responsible for introducing legislation designed to reduce emissions from motor-vehicles. The aim of this legislation is in order to protect the environment in accordance with internationally set targets and agreements.

OBDII Legislation

OBD-II legislation requires all vehicle manufacturer's to provide detailed information on all emission related diagnostic trouble codes (P-codes) caused by faults in the engine management system and any other systems likely to have an effect on vehicle emissions. The emission effect threshold is an increase of 1.5 times that of the base vehicle standard.

The operational reliability of the exhaust treatment system must be guaranteed for 5 years and/or 100,000 miles. The data relevant to exhaust emissions are read out via a standardised interface using a diagnostic tool such as "Testbook".

If a violation of the OBD system is identified, the vehicle manufacturer is legally bound to eliminate the fault throughout the entire vehicle series. The severe implications of this can be appreciated by observation of the case of the lawsuit by the US justice department against Toyota Motor Co. who are facing the prospects of recalling 2.2 million vehicles manufactured between 1996 and 1998, because the company's in-car emissions monitoring equipment does not comply with federal requirements. The suit also wants the company to be fined between $25,000 and $27,500 per vehicle and may demand other actions to solve the problem with a number of models. In addition, the California Air Resources Board is looking to recall up to 380,000 Toyota vehicles across the state, which failed to comply with the stricter Californian standards. The OBD system used on the vehicles fails to warn the driver when it is emitting high levels of hydrocarbons. Toyota is disputing the claim, saying the emission rules were changed after the cars in question were sold.

E-OBD Legislation

The European Commission and its Council for the environment is responsible for the drafting and implementation of legislation concerned with protection of the environment. This includes the setting of limits for the level of permissable emissions from road transport across all Member States in the European Union.

In order to set realistic and achievable goals for pollutant limitation, the Commission works in co-operation with a number of bodies such as ACEA.

In many cases, the European Commission has had the advantage of being able to learn from the introduction of emission control measures imposed through legislation set by CARB in California. As from 2000MY, this will include the mandatory introduction of OBD systems on new vehicles sold within the European Union.

The first item of legislation to set specific limits for the emission of certain pollutants from motor vehicles in the European Union was Directive 70/220/EEC. This Directive has been regularly updated since its introduction, up to the present date, whereby Directive 98/69/EC is used to amend Directive 70/220/EC to include the OBD requirements.

Evolution of European Community Directives on Vehicle Emissions

The following information highlights some of the Directives issued through European Union legislation and demonstrates the progressive tightening of emissions standards, a trend which can be expected to continue for the foreseeable future. This includes a commitment to the introduction of on-board diagnostics systems.

The first programme of action of the European Community with regards to emissions from motor vehicles was established 22nd November 1973. This directive called for scientific advances in technology to be adopted to tackle the problem as and when it became available. This was amended and updated over time by further resolutions.

The fifth programme of action was approved by the Council in its Resolution of 1st February 1993. This called for additional efforts to be made for a considerable reduction in the then present levels of emissions of pollutants from motor vehicles and also set targets in terms of emission reductions for various pollutants.

Council Directive **70/220/EEC** (20th March 1970) laid down the limit values for carbon monoxide and unburnt hydrocarbon emissions from vehicle engines and these limits were further reduced by Council Directive **74/290/EEC** (28th May 1974). This was supplemented with Commission Directive **77/102/EEC** (30th November 1976) which imposed limit values for permissible emissions of nitrogen oxides. Limit values for all three types of pollution were successively reduced by Commission Directive **78/665/EEC** (14th July 1978) and Council Directives **83/351/EEC** (16th June 1983) and **88/76/EEC** (3rd December 1987).

Council Directive **88/436/EEC** (16th June 1988) introduced limit values for particulate emissions from diesel engines.

Council Directive **88/458/EEC** (18th July 1989) introduced more stringent European standards for emissions of gaseous pollutants from motor vehicles below 1400 cm^3. This standard was extended to all passenger cars independently of their engine capacity on the basis of an improved European test procedure comprising an extra-urban driving cycle.

Council Directive **91/441/EEC** (26th June 1991) introduced requirements relating to evaporative emissions and to the durability of emission-related vehicle components, as well as more stringent particulate pollutant standards for motor vehicles equipped with diesel engines.

Passenger cars designed to carry more than six occupants and having a maximum mass of more than 2500 kg, light commercial vehicles and off-road vehicles were previously covered by Directive 70/220/EEC which benefited from less stringent standards. These were superseded by Council Directive **93/59/EEC** (28th June 1993) and Directive **96/69/EC** (8th October 1996) of the European Parliament and of the Council which impose standards as stringent as the respective standards for passenger cars, taking into account the specific conditions of these vehicles.

Directive **94/12/EC** (23rd March 1994) of the European Parliament and Council introduced more stringent limit values for all pollutants and a new method for checking on the conformity of production.

In the course of it efforts to improve air quality, the European Parliament and Council issued the 'Directive **98/69/EC** (13th October 1998) on Measures to Counter the Pollution of Air by Emissions from Motor Vehicles'. The directive published on 28/12/98 has an immediate impact on car manufacturers. The stipulations laid down in the directive must be satisfied within specific time limits for all new vehicles with petrol and diesel engines up to a total weight of 2.5 tons which are sold in the member states of the EU. The most stringent values laid down by Directive 98/69/EC, shall apply from 2000 and 2005 according to the type of vehicle:

- **2000 –** petrol-engined passenger cars
- **2005 –** light diesel-engined commercial vehicles
- **2003 –** other types of vehicle with an OBD system, enabling emission levels to be checked and any malfunction in a vehicle's anti-pollution equipment to be detected

The Directives apply to tailpipe emissions, evaporative emissions, emissions of crankcase gases and the durability of anti-pollution devices for all motor vehicles equipped with spark-ignition engines and to the tailpipe emissions and durability of anti-pollution devices of certain category vehicles fitted with compression-ignition engines.

Details of Directive 94/12/EC

Article 4 of Directive 94/12/EC required the Commission to propose standards to be enforced after the year 2000, according to a new multi-faceted approach, based on a comprehensive assessment of costs and efficiency of all measures aimed at reducing road transport pollution. These proposals included the following areas of consideration:

- Tightening of car emission standards
- Improvement in fuel quality
- Strengthening of motor-vehicle inspection and maintenance program

The proposal is based on the establishment of air quality criteria and associated emission reduction objectives, and an evaluation of the cost-effectiveness of each package of measures. The proposal also takes into account the potential contribution of other measures such as traffic management, enhancement of urban public transport, new propulsion technologies and the use of alternative fuels. Given the urgency of community action on the limitation of pollutant emissions by motor vehicles, the proposals are based on present or anticipated best available anti-pollution technologies which are liable to speed up the replacement of polluting motor vehicles.

The proposals stipulated the provisions for OBD should be introduced with a view to permitting an immediate detection of failure of anti-pollution vehicle equipment and thus allowing a significant upgrading of the maintenance of initial emissions performance on in-service vehicles through periodic or kerbside control. It was recognised that OBD for diesel engined vehicles was at a less developed stage and could not be fitted to all diesel vehicles until 2005.

Other measures specific to OBD include the following:

- “On-board measurement (OBM) systems or other systems to detect any faults by measuring individual pollutants emitted will be permissible provided that the OBD system integrity is maintained”;
- “In order for Member States to ensure that vehicle owners meet their obligation to repair faults once they have been indicated, the distance travelled since the fault is indicated shall be recorded”;
- “On-board diagnostics systems must offer unrestricted and standardised access”;
- “Manufacturers must provide the information required for the diagnosis, servicing or repair of the vehicle”;
- “Access and information are required to ensure that vehicles may be inspected, serviced and repaired without hindrance throughout the European Union. Competition in the market for vehicle parts and repairs must not be distorted to the disadvantage of part manufacturers, independent vehicle-part wholesalers, independent repair garages and consumers”;
- “Manufacturers of spare or retrofit parts are obliged to make parts they manufacture compatible with the on-board diagnostic system with a view to fault-free operation, assuring the user against malfunctions”.

Land Rover vehicles compliant with OBDII systems legislation in force in the United States and particularly in California, include additional emissions system controls such as Advanced EVAPs systems to detect for leaks in the fuel evaporative system and secondary air injection during cold starting. Such measures are likely to be introduced within the European Union in future legislation and will lead to the introduction of more sophisticated OBD systems. Proposals for these and other measures have been stipulated in Directive 94/12/EC as follows:

- “A 'Type IV' test will make it possible to determine the evaporative emissions from vehicles with positive-ignition engines and will be improved to represent real evaporative emissions as well as the status of measuring techniques”;
- “To adapt the behaviour of exhaust-emission control system of vehicles with positive-ignition engines to the actual requirements of practice, a new test should be introduced to measure emissions at low temperatures”;
- “The characteristics of the reference fuels used for emission testing should reflect the evolution of the market fuel specifications to be available following legislation on the quality of petrol and diesel fuels”;
- “A new method for checking conformity of production on in-service vehicles has been identified as a cost-effective accompanying measure which is included in the emissions directive with the objective of implementation in the year 2001”;
- “The circulation of obsolete vehicles which causes many times more pollution than vehicles now being produced is an important source of road transport pollution. Measures to promote the faster replacement of existing vehicles with vehicles having a lower environmental impact should be investigated”;
- “The Member States should be allowed to expedite the placing of vehicles on the market which satisfy the requirements adopted at Community level by means of tax incentives. Such incentives have to comply with the provisions of the Treaty and satisfy certain conditions intended to avoid distortions of the internal market. The Directive does not affect the Member States' rights to include emissions of pollutants and other substances in the basis for calculating road traffic taxes on motor vehicles”;
- “With a view to the harmonious development of the internal market and the protection of consumer interests, a binding long-term approach to the introduction of stricter emission control limits is required. A two-stage approach is to be established with mandatory limits applied from the years 2000 and 2005 which can be used for the purpose of granting tax incentives to encourage the early introduction of vehicles containing the most advanced anti-pollution equipment”;
- “The Commission will closely monitor technological developments in emission control and where appropriate will propose the adaption of this directive. The Commission is carrying out research projects to deal with outstanding questions, the findings of which will be incorporated in a proposal for future legislation after the year 2005”;
- “Member States may take measures to encourage the retrofitting of older vehicles with emission control devices and components”;
- “Member States may take measures to encourage faster progress towards replacing existing vehicles with low-emission vehicles”;

Directive 98/69/EC

Directive 98/69/EC deals with motor vehicle emissions and reduces the permitted level of nitrogen oxides and total hydrocarbons by 40%. The directive also lays down new mandatory limit values for carbon monoxide and particulate emissions from passenger cars and light commercial vehicles fitted with petrol or diesel engines. New vehicles should meet the directive limit values with effect from 1st January 2000 in order to be granted EC or national type-approval.

The Directive's new limit values entail large investments from the EU car industry in research and development of new technologies. The requirements also introduce new mandatory legislation for petrol vehicles to be equipped with an On-Board Diagnostic System from 2000 MY and diesel vehicles to be equipped with OBD systems from 2003MY.

Significant extracts from Directive 98/69/EC of the European Parliament and of the Council of 13th October 1998 relating to measures to be taken against air pollution by emissions from motor vehicles and amending Council Directive 70/220/EEC are reproduced below:

"Not later than 31st December 1999, the Commission shall submit a proposal to the European Parliament and the Council concerning more stringent measures to take effect from 1st January 2005 which include":

- limit values for emissions from cold start in low temperature ambient air (-7° C);
- Community provisions for improved roadworthiness testing;
- changes to the requirements concerning vehicle durability;
- fuel quality standards;
-
- threshold limit values for OBD for 2005/6 MY vehicles

Future developments which are likely to have an impact on after sales service in direct relation to OBD, include the following proposals:

- "By 30th June 2002 the Commission shall submit a report to the European Parliament and Council on the development of OBD, giving its opinion on the need for an extension of the OBD procedure and the requirements for the operation of an on-board measurement system (OBM). On the basis of the report, the Commission will submit a proposal for measures to be implemented no later than 1st January 2005, to include the technical specifications in order to provide for the type approval of OBM systems, ensuring at least equivalent levels of monitoring to the OBD system and which shall be compatible with these systems".
- "The Commission shall submit a report to the European Parliament and Council on the extension of OBD to cover other electronic vehicle control systems relating to active and passive safety in a manner which is compatible with emission control systems".
- "By 1st January 2001, the Commission shall take appropriate measures to ensure that replacement or retro-fitted components can be brought to the market. Such measures shall include suitable approval procedures for replacement parts to be defined as soon as possible for those emission control components that are critical to the correct functioning of OBD systems".
- "By 30th June 2000 the Commission shall take appropriate measures to ensure that the development of replacement or retro-fit components which are critical to the functioning of the OBD system is not restricted by the unavailability of pertinent information, unless that information is covered by intellectual property rights or constitutes specific know-how of the manufacturers or Original Equipment Manufacturers (OEM) suppliers: in this case the necessary technical information shall not be improperly witheld".
- "The Commission shall submit by 30th June 2000, appropriate proposals to ensure that spare and retrofit parts are compatible with the specifications of the on-board diagnostic system, so that repair, replacement and fault-free operation are possible".

When drawing up these proposals, the Commission will have to take account of several factors:

- the contribution to air quality made by the existing directives;
- examination of technical feasibility
- cost effectiveness ratio;
- availability of advanced technologies
- compatability with other aims

Directive 98/69?EC also provides, where appropriate, for the drafting of standards concerning the component approval of vehicles using alternative power plants or fuels.

Member States may introduce tax or financial incentives for the re-equipment of in-use vehicles to meet the values laid down in Directive 98/69/EC or previous amendments to Directive 70/220/ EEC, and for laying up vehicles which do not comply.

Tax incentives for early emissions compliance

The Directives lay down differing limit values for emissions by petrol and diesel cars:

- of carbon monoxide;
- of unburnt hydrocarbons;
- of nitrogen oxides;
- and, specifically for diesel engines, limit values for particulate pollutants.

Tax incentives can be granted by Member states to encourage the advance compliance with new limit values. These incentives are permitted on the following conditions:

- they are valid for all new vehicles offered for sale within a Member State if they, in advance, meet the requirements of the existing Directives;
- they shall be discontinued on the date when the limit values are applied;
- are worth less than the cost of the devices used on any type of motor vehicle in order to guarantee that the values laid down are not exceeded, and that of their fitting to such vehicles.

EC approval

The procedure for the component-approval of vehicles includes:

- the application for EC approval with regard to tailpipe emissions, evaporative emissions and the durability of anti-pollution devices is submitted by the vehicle manufacturer or by the authorized representative;
- it must contain the information required pursuant to the Directives;
- there are six types of type-approval test, depending on the category to which the vehicles belong. They concern:
- average tailpipe emissions after a cold start
- carbon monoxide emissions under idling conditions;
- crankcase gas emissions;
- evaporative emissions;
- durability of anti-pollution devices;
- carbon monoxide and hydrocarbon emissions after a cold start.
- if the vehicle type meets the test requirements, an EC approval certificate is issued by the competent body of the Member State which is responsible for the type-approval.

Up to 28th September 1999, the full European test cycle provided for by Directive 91/441/EEC will be used as the testing procedure in order to establish compliance with the limit values. After that date the test procedure introduced by Directive 89/69/EC shall apply.

Directive definitions

The EC Directives include explanations of the scope of the legislation and the terms used. A list of generally used abbreviations and acronyms are included later in this document, but the following lists definitions as prescribed by the EC legislation:

- "The directive applies to tailpipe emissions at normal and low ambient temperature, evaporative emissions, emissions of crankcase gases, the durability of anti-pollution devices and on-board diagnostic (OBD) systems of motor vehicles equipped with positive-ignition engines; and tailpipe emissions, the durability of anti-pollution devices and on-board diagnostic (OBD) systems of vehicles equipped with compression ignition engines".
- **OBD –** "an on-board diagnostic system for emission control which has the capability of identifying the likely area of malfunction by means of fault codes stored in computer memory".
- **In-service test –** "the test and evaluation of conformity conducted in accordance with the specifications laid down in the appropriate directive".
- **Defeat device –** "any element of design which senses temperature, vehicle speed, engine RPM, transmission gear, manifold vacuum or any other parameter for the purpose of activating, modulating, delaying or deactivating the operation of any part of the emission control system, that reduces the effectiveness of the emission control under conditions which may reasonably be expected to be encountered in normal vehicle operation and use".
- **Vehicle type –** "category of power-driven vehicles which do not differ in such essential engine and OBD system characteristics as defined in the directive".
- **Vehicle family –** "manufacturer's grouping of vehicles which through their design are expected to have similar exhaust emission and OBD system characteristics. Each engine of the family must have complied with the requirements of the directive".
- **Emission control system –** "the electronic engine management controller and any emission-related component in the exhaust or evaporative system which supplies an input to or receives an output from this controller".
- **Malfunction Indicator (MI) –** "a visible or audible indicator that clearly informs the driver of the vehicle in the event of a malfunction of any emission-related component connected to the OBD system, or the OBD system itself".
- **Malfunction –** "the failure of an emission-related component or system that would result in emissions exceeding the specified limits".
- **Secondary air –** "air introduced into the exhaust system by means of a pump or aspirator valve or other means that is intended to aid in the oxidation of HC and CO contained in the exhaust gas stream".
- **Engine misfire –** "lack of combustion in the cylinder of a positive-ignition engine due to absence of spark, poor fuel metering, poor compression or any other cause. In terms of OBD monitoring it is that percentage of misfires out of a total number of firing events (as declared by the manufacturer) that would result in emissions exceeding the specified limits, or that percentage that could lead to an exhaust catalyst, or catalysts, overheating causing irreversible damage".
- **Driving cycle –** "consists of engine start-up, driving mode where a malfunction would be detected if present and engine shut-off".
- **Warm-up cycle –** "sufficient vehicle operation such that the coolant temperature has risen by at least 22° K from engine starting and reaches a minimum temperature of 343° K (70° C)".
- **Fuel trim –** "feedback adjustments to the base fuel schedule. Short-term fuel trim refers to dynamic or instantaneous adjustments. Long-term fuel trim refers to much more gradual adjustments to the fuel calibration schedule than short-term trim adjustments. These long-term adjustments compensate for vehicle differences and gradual changes that occur over time".
- **Calculated load value –** "indication of the current airflow divided by peak airflow, where peak airflow is corrected for altitude, if available. This definition provides a dimensionless number that is not engine specific and provides the service technician with an indication of the proportion of engine capacity that is being used (with wide open throttle as 100%)".

- **Permanent emission default mode –** "case where the engine management controller permanently switches to a setting that does not require an input from a failed component or system where such a failed component or system would result in an increase in emissions from the vehicle to a level above the specified limits".
- **Power take-off unit –** "an engine-driven output provision for the purposes of powering auxiliary, vehicle mounted equipment".
- **Access –** "availability of all emission-related OBD data including all fault codes required for the inspection, diagnosis, servicing or repair of emissions-related parts of the vehicle, via the serial interface for the standard diagnostic connection".
- **Unrestricted –** "means access is not dependent on an access code obtainable only from the manufacturer or a similar device, or access allowing evaluation of the data produced without the need for any unique decoding information, unless that information is itself standardised".
- **Standardised –** "means that all data stream information, including all fault codes used, shall be produced only in accordance with industry standards which, by virtue of the fact that their format and their permitted options are clearly defined, provide for a maximum level of harmonisation in the motor vehicle industry, and whose use is expressly permitted in the directive".

Type Tests

To date, the European legislation relating to vehicle emissions has introduced specifications for six specific emissions tests:

- **Type I Test –** verifying the average tailpipe emissions after a cold start
- **Type II Test –** carbon monoxide emission test at idling speed
- **Type III Test –** verifying emissions of crankcase gases
- **Type IV Test –** determination of evaporative emissions from vehicles with positive-ignition engines
- **Type V Test –** ageing test for verifying the durability of anti-pollution devices
- **Type VI Test –** verifying the average low ambient temperature carbon monoxide and hydrocarbon tailpipe emissions after a cold start

Compression-ignition engined vehicles are subjected to Type I and Type V tests only.

E-OBD Requirements and Tests

The 98/69/EC directive defines the OBD requirements and tests as follows:

- “All vehicles must be equipped with an OBD system so designed, constructed and installed in a vehicle as to enable it to identify types of deterioration or malfunction over the entire life of the vehicle. In achieving this objective, the approval authority must accept that vehicles which have travelled distances in excess of the Type V durability distance may show some deterioration in OBD system performance such that the specified emission limits may be exceeded before the OBD system signals a failure to the driver of the vehicle”.
- “Access to the OBD system required for the inspection, diagnosis, servicing or repair of the vehicle must be unrestricted and standardised. All emission-related fault codes must be consistent with ISO DIS 15031–6 (SAE J2012, dated July 1996)”.
- “No later than three months after the manufacturer has provided any authorised dealer or repair shop within the Community with repair information, the manufacturer shall make that information (including all subsequent amendments and supplements) available upon reasonable and non-discriminatory payment and shall notify the approval authority accordingly. In the event of failure to comply with these provisions the approval authority shall take appropriate measures to ensure that repair information is available, in accordance with the procedures laid down for type-approval and in-service surveys”.
- “The OBD must be so designed, constructed and installed in a vehicle as to enable it to comply with the requirements of the directive during conditions of normal use”.
- “A manufacturer may disable the OBD system if its ability to monitor is affected by low fuel levels. Disablement must not occur when the fuel tank level is above 20% of the nominal capacity of the fuel tank”.
- “A manufacturer may disable the OBD system at ambient engine starting temperatures below -7° C (266° K) or at elevations over 2500 metres above sea level provided the manufacturer submits data and/or an engineering evaluation which adequately demonstrate that monitoring would be unreliable when such conditions exist. A manufacturer may also request disablement of the OBD system at other ambient engine starting temperatures if he demonstrates to the authority with data and/or an engineering evaluation that misdiagnosis would occur under such conditions”.
- “For vehicles designed to accommodate the installation of power take-off units, disablement of affected monitoring systems is permitted provided disablement occurs only when the power take-off unit is active”.
- “Manufacturers may adopt higher misfire percentage malfunction criteria than those declared to the authority, under specific engine speed and load conditions where it can be demonstrated to the authority that the detection of lower levels of misfire would be unreliable”.
- “Manufacturers who can demonstrate to the authority that the detection of higher levels of misfire percentages is still not feasible may disable the misfire monitoring system when such conditions exist”.

E-OBD requirements for vehicles with positive-ignition engines

In satisfying the requirements of Directive 98/69/EC, the OBD system must, at a minimum, monitor for:

- reduction in the efficiency of the catalytic converter with respect to the emissions of HC only;
- the presence of engine misfire in the engine operating region bounded by the following lines:
- a maximum speed of 4500 rev/min or 1000 rev/min greater than the highest speed occurring during a Type I test cycle, whichever is the lower;
- the positive torque line (i.e. engine load with the transmission in neutral);
- a line joining the following engine operating points: the positive torque line at 3000 rev/min and a point on the maximum speed line (defined above) with the engine's manifold vacuum at 13,33 kPa lower than that at the positive torque line;
- oxygen sensor deterioration;
- other emission control system components or systems, or emission-related powertrain components or systems which are connected to a computer, the failure of which may result in tailpipe emissions exceeding the limits specified in the directive;
- any other emission-related powertrain component connected to a computer must be monitored for circuit continuity;
- the electronic evaporative emission purge control must, at a minimum, be monitored for circuit continuity.

For both positive-ignition and compression ignition vehicles, the sequence of diagnostic checks must be initiated at each engine start and completed at least once provided that the correct test conditions are met. The test conditions must be selected in such a way that they all occur under normal driving as represented in the Type I test.

E-OBD requirements for vehicles with compression-ignition engines

Directive 98/69/EC also establishes the test requirements for vehicles with compression engines. Although OBD requirements for diesel engines do not have to be implemented until 2003 MY they are included in the directive and are listed here for completeness. The OBD system must monitor:

- a reduction in the efficiency of the catalytic converter (where fitted);
- the functionality and integrity of the particulate trap (where fitted);
- the fuel-injection system electronic fuel quantity and timing actuators are monitored for circuit continuity and total functional failure;
- other emission control system components or systems, or emission-related powertrain components or systems, which are connected to a computer, the failure of which may result in tailpipe emissions exceeding the limits specified in the directive. Examples of such systems or components are those for monitoring and control of air mass-flow, air volumetric flow (and temperature), boost pressure and inlet manifold pressure (and relevant sensors to enable these functions to be carried out);
- any other emission-related powertrain component connected to a computer must be monitored for circuit continuity;
- manufacturers may demonstrate to the approval authority that certain components or systems need not be monitored if, in the event of their total failure or removal, emissions to not exceed the limits specified in the directive.

E-OBD requirements for MIL activation

With regards activation of the MIL lamp, Directive 98/69/EC specifies the operational requirements as follows:

- “The OBD system must incorporate a malfunction indicator readily perceivable to the vehicle operator. The MI must not be used for any other purpose except to indicate emergency start-up or limp-home routines to the driver. The MI must be visible in all reasonable lighting conditions. When activated, it must display a symbol in conformity with ISO 2575 (International Standard of symbols for controls, indicators and tell-tales for road vehicles). A vehicle must not be equipped with more than one general purpose MI for emission-related problems. Separate specific purpose telltales (e.g. brake system, fasten seat belt, oil pressure etc.) are permitted. The use of red for an MI is prohibited”.
- “For strategies requiring more than two preconditioning cycles for MI activation, the manufacturer must provide data and/or an engineering evaluation which adequately demonstrates that the monitoring system is equally effective and timely in detecting component deterioration. Strategies requiring on average more than 10 driving cycles for MI activation are not accepted. The MI must also activate whenever the engine control enters a permanent emission default mode of operation if the specified emission limits are exceeded. The MI must operate in a distinct warning mode e.g. a flashing light, under any period during which the engine misfire occurs at a level likely to cause catalyst damage, as specified by the manufacturer. The MI must also activate when the vehicle's ignition is in the 'key-on' position before engine starting or cranking and de-activate after engine starting if no malfunction has previously been detected”.

With regards extinguishing a malfunction indication, the directive specifies the following requirements:

- “For misfire malfunctions at levels likely to cause catalyst damage (as specified by the manufacturer), the MI may be switched to the normal mode of activation if the misfire is not present any more, or if the engine is operated after changes to speed and load conditions where the level of misfire will not cause catalyst damage”.
- “For all other malfunctions, the MI may be de-activated after three subsequent sequential driving cycles during which the monitoring system responsible for activating the MI ceases to detect the malfunction and if no other malfunction has been identified that would independently activate the MI”.

OBD requirements for fault code storage

Directive 98/69/EC specifies the following requirements for OBD fault code storage:

- “The OBD system must record code(s) indicating the status of the emission-control system. Separate status codes must be used to identify correctly functioning emission control systems and those emission control systems which need further vehicle operation to be fully evaluated. Fault codes that cause MI activation due to deterioration or malfunction or permanent emission default modes of operation must be stored and that fault code must identify the type of malfunction”.
- “The distance travelled by the vehicle since the MI was activated must be available at any instant through the serial port on the standard link connector. This requirement is only applicable to vehicles with an electronic speed input to the engine management provided the ISO standards are completed within a lead time compatible with the application of the technology. It applies to all vehicles entering into service from 1st January 2005”.
- “In the case of vehicles with positive-ignition engines, misfiring cylinders need not be uniquely identified if a distinct single or multiple cylinder misfire code is stored”.

The specifications for erasing a fault code are listed below:

- “The OBD system may erase a fault code and the distance travelled and freeze-frame information if the same fault is not re-registered in at least 40 engine warm-up cycles”.

Functional aspects of on-board diagnostic (OBD) systems

In order to assure that OBD systems fitted to a manufacturer's vehicles are compliant with directive 98/69/EC, the OBD systems have to be tested according to test procedures specified within the directive. The procedure describes a method for checking the function of the on-board diagnostic (OBD) system installed on the vehicle by failure simulation of relevant systems in the engine management or emission control system. It also sets procedures for determining the durability of OBD systems.

The manufacturer must make available the defective components and/or electrical devices which are used to simulate failures. When measured over the Type I test cycle, such defective components or devices must not cause the vehicle emissions to exceed the specified limits by more than 20%.

When the vehicle is tested with the defective component or device fitted, the OBD system is approved if the MI is activated.

The testing of OBD systems consists of the following phases:

- simulation of malfunction of a component of the engine management or emission control system;
- preconditioning of the vehicle with a simulated malfunction over preconditioning specified in the directive;
- driving the vehicle with a simulated malfunction over the Type I test cycle and measuring the emissions of the vehicle;
- determining whether the OBD system reacts to the simulated malfunction and indicates the malfunction in an appropriate manner to the vehicle driver.

Emissions

Vehicles powered by internal combustion engines produce by-products in the form of emissions, some of which are harmful to the environment. The main by-products which are produced are water (H_2O) and Carbon Dioxide (CO_2). In addition, relatively low concentrations of the following potentially harmful substances are produced:

- **Carbon Monoxide (CO)** – a colourless, odourless gas which is formed when hydrocarbon fuels are burnt in the combustion process and is a result of incomplete combustion.

  Spark-ignition engines are particularly responsible for carbon monoxide emissions; an air/fuel mixture which is rich in fuel produces an excessive concentration of CO. It is important that vehicles with petrol engines are correctly tuned and maintained to provide the optimum air/fuel mixture and so ensure that carbon monoxide emissions are minimised.

  In comparison, diesel engines are lean running, so tend to produce less CO emissions than equivalent petrol engines. However, if there is not enough excess air in the combustion chamber, increased emissions of carbon monoxide will result, as well as higher concentrations of soot and hydrocarbons (HC).

  According to a 1997 study “Improving air quality in Europe” conducted by the Club de Bruxelles, in 1996 road transport produced 65% of carbon monoxide emissions. Carbon monoxide has a significant impact on human health, in particular on the body's ability to absorb oxygen.

  WARNING: Carbon monoxide is dangerous to inhale and is potentially lethal. Concentrations are particularly high when an engine is running in a workshop or other confined space.

- **Hydrocarbons (HC)** – present in exhaust gases and like carbon monoxide, are a result of unburned fuel during combustion. HC concentrations increase as the air/fuel mixture becomes rich and also increase if a misfire occurs. Hydrocarbons are particularly prevalent when an engine is cold and are evident by the presence of white or blue smoke from the exhaust. Hydrocarbons are also produced in the crankcase in the form of vaporized lubrication oil and through evaporation of fuel from the fuel tank and fuel system.

  Diesel fuels contain a large number of hydrocarbons which have boiling points between about 180°C and 360°C and the required ignition temperature for diesel fuel is approximately 220°C. It is difficult to ensure a high enough ignition temperature for cold engines and at low speeds which have a corresponding low final compression pressure. Consequently the presence of hydrocarbons is predominant at cold starting.

- **Carbon Dioxide (CO_2)** – is a by-product of complete combustion and contributes to the 'greenhouse effect', the principal cause of global warming. Carbon Dioxide is produced even under perfect combustion conditions. According to Society of Motor Maufacturers and Traders (SMMT) figures, the global warming attributable to vehicular CO_2 emissions is 12% in the UK.

  However, according to a 1997 study “Improving air quality in Europe” conducted by the Club de Bruxelles, in 1996 road traffic produced some 80% of total carbon dioxide (CO_2).

- **Oxides of Nitrogen (NO_x)** – includes Nitric Oxide (NO) and Nitrogen Dioxide (NO_2) and is produced in exhaust gases as a by-product of the combustion process. Lean mixtures produce more oxides of nitrogen than rich mixtures as the combustion temperature is increased.

  According to the 1997 study, road transport is responsible for over half of all NO_2 emissions. NO_2 causes respiratory illnesses and damage to lung tissue and contributes to acid rain and smog. It also corrodes stone buildings, statues and monuments.

- **Sulphur Dioxide (SO_2)** – along with sulphuric acid (H_2SO_4) and Oxides of Nitrogen, contribute to the formation of 'acid rain'. It is one of the main atmospheric acidifiers and is the main culprit in the gradual errosion of buildings and other monuments of cultural heritage exposed to ambient air.

- **Soot particles (diesel vehicles)** – tiny particles of carbon are produced which can carry fuel and oil. The start of injection influences the emission of soot particles; if the start of injection is delayed such that there is incomplete combustion, increased levels of soot particles will result. The use of high injection pressures, particularly at low engine speeds can greatly reduce soot emissions and optimum injection direction such as that provided by EUI nozzles (used on Discovery II) help to limit black smoke production.

  Growing concern has been attracted by the emissions of particulate matter, since it is composed of tiny particles which can linger in the lungs with serious health effects, including cancer.

In addition to the above, the transport sector produces a substantial share (about 30%) of emissions of non-methane volatile organic compounds (VOC) in Europe. Other air pollutants of concern come from substances in petrol such as lead and benzine which are also considered to be carcinogenic.

The European Commission proposes to limit benzene values from 1st January 2010 and carbon monoxide levels from 1st January 2005. The two pollutants have been exempt from controls so far, but have been linked to an increased risk of leukaemia and heart disease.

Motor vehicle emissions also create concentrations of ozone at ground level which when exposed to heat form the type of pollution known as “summer smog”. Ozone causes breathing problems, reduced lung function, asthma, eye irritation, nasal congestion and reduced resistance to colds and other infections. Ozone can be especially dangerous for the young and the elderly, and can also damage plants and trees and cause deterioration of rubber and fabrics.

The approximate proportions of exhaust gas constituents for modern petrol vehicles is listed below:

- Water (H_2O) – 14%
- Carbon Dioxide (CO_2) – 13%
- Nitrogen (N) – 72.9%
- $CO + NO_x + HC = 0.1\%$

Reduction of CO_2 Emissions

One of the conclusions reached by the European Union Council for the Environment on the 25th June 1996 was an agreement for a Community strategy to reduce CO_2 emissions from passenger cars and the improvement of fuel economy to reduce the average CO_2 emissions of newly registered passenger cars to 120 g of CO_2 per kilometre by 2005 or 2010 at the latest.

A voluntary agreement between the European Commission and the European Automobile Manufacturer's Association (ACEA) under the 'Auto-Oil Programme' in 1999, included the commitment to achieve an emission target of 140 g of CO_2 per kilometre for the average of the new car sales by ACEA members in the EU by 2008 and 120 g/km by 2012. Japanese and Korean associations of automotive manufacturers (JAMA and KAMA) are negotiating with the Commission to conclude environmental agreements equivalent to that agreed to by ACEA.

Although these voluntary measures require additional investments in technology by the manufacturers (e.g. improved combustion engines, new means of propulsion etc.), these costs are justified on the grounds of protection of human health and the environment.

In order to achieve its objectives with regards the limitation of CO_2 emissions, the Commission is proposing monitoring of CO_2 emissions from new passenger cars registered in a given calendar year as well as information on the manufacturer, fuel type, mass, engine power and engine capacity.

In addition, the Council has reached a political agreement that will make it mandatory for the consumer to be supplied with information concerning fuel consumption and the CO_2 emissions of new cars. The customer can then use the comparable information from different manufacturers and vehicles before making a purchase decision. The aim of this is to influence consumer choice in favour of more fuel efficient and environmentally friendly cars. The following sources of information would have to be made available to customers:

- Points of sale would have to display information on fuel consumption and CO_2 emissions on or near each new passenger car model (fuel economy label);
- a poster would provide this same information for all cars on sale at the garage or showroom;
- all promotional literature (advertising) referring to a particular model would have to include information on fuel consumption and CO_2 emissions;
- Member States would have to ensure that a fuel economy guide is produced, in consultation with manufacturers, at least on an annual basis and that it is available to consumers free of charge, including from the dealers. It would provide information on the fuel consumption of all new passenger car models on sale in that Member State, grouped by makes in alphabetical order. The guide would have to include a prominent listing of the 10 most fuel-efficient new car models ranked in order of increasing specific CO_2 emissions for each fuel type. It would also include an explanation of the effects of carbon dioxide on the climate. Furthermore, it would offer motorists advice on how to economize on fuel when driving. Dealers would be under an obligation to make consumers aware of the guide's existence. The Community will produce a guide at Community level, available on the Internet.

Service

From an emissions perspective, it is extremely important that vehicles are properly maintained. It is estimated that approximately 50% of vehicle pollution is attributable to the 10% of vehicles that are badly maintained or worn out.

Emission limitation through engine design and control

Car manufacturers are investing substantial sums in Research and Development in order to produce 'cleaner' more environmentally friendly engines. The emissions produced by SI engines are to a large extent dependent on engine design, power output and working load. By precisely controlling ignition timing and optimising the air:fuel ratio in the combustion chambers under all prevailing conditions, the emission levels encountered can be minimised before supplementary emission control systems need to be employed. The engine control module (ECM) is primarily responsible for ensuring the optimum engine operating conditions. This is achieved by constant monitoring of all variable factors using periphery sensors and utilising an internal memory map to determine the optimum ignition and fuelling characteristics to be delivered at any instance in time.

By supplementing these design and control measures through the utilisation of additional emission control equipment, pollutant levels can be maintained below the legislated maximum levels.

The introduction of the compulsory fitting of catalytic converters has resulted in a dramatic improvement in emissions produced by cars. The Society of Motor Manufacturers and Traders (SMMT) estimate that less than 10% toxic gases are produced by cars fitted with catalytic converters in comparison with pre-1993 cars.

Some areas of design related improvements to CO_2 emissions are sometimes offset by improvements in other areas of vehicle performance, such as safety, noise and emissions legislation and by customer demand for additional features as standard, such as air conditioning and power assisted steering.

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Emissions improvement through fuel quality

Continuing reductions in new car emissions reaching 95% have already been achieved by the motor industry. In order to achieve significant further reductions, enhanced fuel quality will be necessary and/or the commercial acceptance of alternative power sources (e.g. electric vehicles, hydrogen fuel cells etc.).

Cleaner fuel is an essential factor in improving ambient air quality, by reducing the level of particulates produced, and improving the performance of catalytic converters. Some engine developments aimed at improving air quality cannot be introduced unless there are significant improvements in the quality of fuel.

European Commission Directive **98/70/EC** tackles the issue of quality of petrol and diesel fuel and sets a time limit (2005) for the introduction of higher quality diesel and petrol including a banning of leaded petrol throughout Member States. The Directive is an outcome of the “Auto/Oil Programme” which was a joint programme initiated in 1992 between the European Commission, ACEA and EUROPIA (European oil industry). The objective of the programme is to reduce vehicle emissions and attain air quality targets through cost-effective measures which include vehicle technology, fuel quality, improved durability and other non-technical means.

Whilst both engine development and fuel quality make an important contribution to air quality, only the latter has the potential of providing an across the board effect to the entire car parc. In collaboration with government, the UK Motor Industry has undertaken an extensive programme of research into the emission of particulates from petrol and diesel engines.

Fuel Quality impact on OBD

With regards OBD, poor fuel quality could cause MIL light operation, a situation which has been known to occur in the United States where OBD has been used for some time. When the vehicle with the active MIL light has been diagnosed, a P0300 diagnostic trouble code has been registered which would normally be associated with a lean misfire condition due to a vacuum leak, low fuel pressure, dirty injectors or an ignition problem such as fouled spark plugs, plug leads or weak ignition coils. The OBDII diagnostics treats a 2% misfire rate on an individual cylinder as normal, but water in the fuel or variations in the fuel additives in reformulated fuel can increase the misfire rate to the point where it triggers the fault code and consequent MIL operation.

LEVs, ULEVs and ZEVs

The lowering of permitted emission levels from vehicles is being made progressively more stringent and the trend is set to continue for the foreseeable future until zero or near zero emission levels can be attained. In California, Low Emission Vehicles (LEVs) are already compulsory, whereby a percentage of all vehicles sold by a manufacturer must be low emission types. Land Rover has complied with this requirement by supplying Discovery II and Range Rover vehicles with supplementary emissions systems which provides compliance to the low emission requirements.

From 1991 through 1995, the state of California offered an income tax credit to individuals and businesses for the partial costs of purchasing or converting standard fuel vehicles to low emission vehicles.

Pursuant to State law, the CARB in 1990 adopted LEV and clean fuels regulations. The regulations establish an annual, increasingly stringent, average emission standard that auto manufacturers must meet for their fleet of light-duty vehicles which are available for sale in California. These regulations do not specify the type of fuel to be used by the vehicles and do not require automotive manufacturers to produce alternative-fuelled vehicles. The manufacturers may produce any combination of vehicles (LEVS, alternative-fuel vehicles etc.) as long as the average of the emissions out of the tailpipe do not exceed the mandated average emission standard for the light-duty fleet as a whole.

In addition, CARB has separate regulations dealing with the mandatory production of Ultra Low Emission Vehicles (ULEVs) and Zero-Emission Vehicles (ZEVs) such as electric powered vehicles. Originally, 2% of large auto manufacturer’s fleets for sale in California were required to be ZEV type in 1998, with the proportion increasing to 5% in 2001 and 10% in 2003. This legislation was later amended, to scrap the initial targets, but the 10% requirement by 2003 is still currently in place.

Engine Management Systems

The engine management systems used on Land Rover and Rover vehicles employ closed-loop control techniques to ensure the exhaust emissions operate around the stoichiometric ideal to meet the environmental legislation requirements. Should the closed-loop conditions stray from the ideal (e.g. because of component failure such as worn catalyst or HO_2 sensor), the driver of the vehicle must be alerted to the failure so that rectification can take place. A failure of an emissions system is notified to the driver by the illumination of a malfunction indicator lamp (MIL) in the instrument pack. The activation of the MIL warning lamp for emission system failure is an essential part of E-OBD compliance for vehicles with petrol engines from 2000 MY.

The engine management systems used on Land Rover and / or Rover petrol engined vehicles which are compliant with the ECD3 requirements include the following:

- Bosch M5.2.1 EMS – V8 engines
- MEMS3 – 'K' Series engines
- Siemens EMS 2000 (when available)

The basic control loop comprises the engine (controlled system), the heated oxygen sensors (measuring elements), the engine management ECM (control) and the injectors and ignition (actuators). Other factors also influence the calculations of the ECM, such as air flow, air intake temperature and throttle position. Additionally, special driving conditions are compensated for, such as starting, acceleration, deceleration, overrun and full load.

Malfunction Indicator Lamp (MIL)

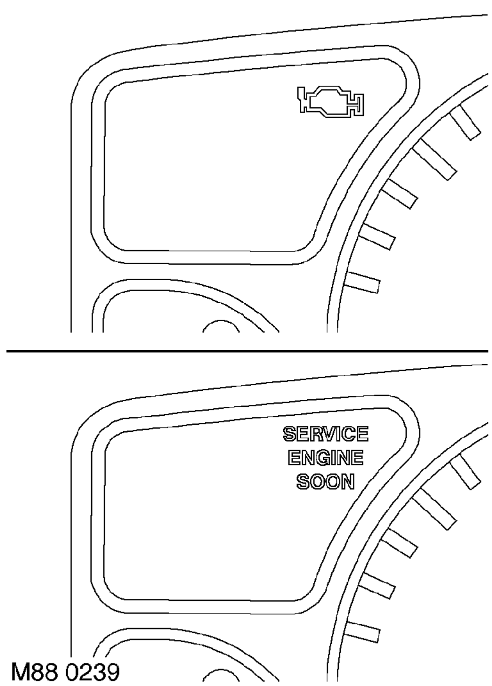


Figure 1

The MIL/Service Engine Soon warning lamp within the instrument pack utilises an amber LED and a clear legend. If an emission related fault is detected by the engine management system, the ECM will illuminate the LED providing the driver with a visible warning.

The warning lamp will illuminate whenever the vehicle is driven until the fault is repaired, and the ECM fault code memory is cleared using “TestBook”.

When the ignition is switched on, the ECM carries out a self-test function of the lamp. The lamp will illuminate for approximately 3 seconds then extinguish if no faults exist. If a fault is present, the lamp will be extinguished for 1 second before illuminating again to indicate a fault exists. If the MIL lamp doesn't illuminate when the ignition is first switched on, the warning lamp bulb in the instrument pack needs to be replaced; refer to the relevant Workshop Manual.

There are two configurations of the legend for the warning lamp:

- NAS and Canada = SERVICE ENGINE SOON text.
- All other markets = MIL SAE J1930 (engine) symbol.

The MIL will illuminate to indicate a EURO-3 type failure under the following conditions:

- A fault resulting in cylinder cutout (Misfire Detection). In order to protect the catalytic converter from damage, the MIL lamp will flash immediately to alert the driver to the problem, and remain flashing for as long as the fault is present.
- An emission related component failure. The MIL lamp will be illuminated if the fault persists for more than two drive cycles.
- The engine control module (ECM) detects a “self-test” fault.

When the OBD system detects a fault for the first time, the corresponding trouble code is stored in the memory of the ECM. The MIL lamp is not activated unless the fault involves misfire, in which case the MIL lamp is activated immediately and remains flashing as long as the misfire fault is current. On OBDII, this type of fault is termed a 'Type A' fault and is considered the most serious. When a Type A code is set, the OBDII system also stores a history code, failure record and freeze frame data to help diagnosis of the problem.

If the emission related fault occurs again on the second drive cycle, the fault is stored in memory, and if the fault is present on the third drive cycle the MIL lamp is activated (i.e. when the same emission related fault has been confirmed, the MIL lamp is activated). On OBDII, this type of fault is termed a 'Type B' fault and is considered to be a less critical emissions problem. The same fault must occur at least once on two consecutive trips before the MIL lamp comes on. If the fault doesn't recur on the second drive cycle, the MIL lamp stays off. If a Type B fault is registered on the second drive cycle, as well as MIL lamp illumination, a history code, failure record and freeze frame data are stored in ECM memory the same as for Type A faults.

If the second drive cycle is not completed so that a specific component is not checked, the third drive cycle is treated as if it were the second drive cycle.

If the emission-related fault is sporadic, the MIL lamp will only light up if the fault is registered in two complete successive driving cycles. The MIL light stays off if the fault fails to re-occur in the third successive driving cycle.

On OBDII systems, once a Type A or Type B code has been set, the MIL will come on and remain on until the component that failed passes a self-test on three consecutive trips. If the fault involves something like a P0300 random misfire or a fuel balance problem, the light won't go out until the system passes a self-test under similar operating conditions (within 375 rpm and 10% of load) that originally caused it to fail.

The MIL lamp won't go out until the emissions problem has been repaired. Clearing the ECM's diagnostic trouble codes with a scan tool or disconnecting the power supply won't prevent the lamp coming back on if the problem hasn't been fixed. It may take several drive cycles to reset the fault code, but eventually the MIL lamp will come back on if the problem hasn't been fixed.

A single fault entry is automatically cleared from the ECM memory if the same fault fails to re-occur in 40 successive driving cycles in which the same operating conditions are satisfied. In order for a single fault entry to be automatically cleared without the same operating conditions being satisfied as when the fault first occurred, 80 successive driving cycles must be clear for the fault to be cancelled.

Diagnostic tools

Diagnostic tools such as 'Testbook' are used to interrogate the ECM memory to determine the nature of the fault. Diagnostic trouble codes are read from memory which relate the emissions problem being experienced.

In order to hook up a diagnostic scan tool for fault code checking, vehicles equipped with OBD have a 16–pin J1962 diagnostic connector, which is usually located under the front facia, either driver side or passenger side.

The scan tool contains software that analyzes the signals received from the vehicle and displays text or diagrammed readout of any malfunctions found and suggests possible solutions to the problem. The OBD fault codes are most often accessed in response to MIL lamp illumination or driveability problems experienced with the vehicle. The data provided on the scan tool can often pinpoint the specific component that has malfunctioned, saving substantial diagnosis time and effecting quick and accurate repairs.

Data received by the scan tool includes a "freeze frame" of all sensor readings experienced at the time the fault is recorded, which helps diagnosis in the case of intermittent failures.

Fuel metering

For a satisfactory combustion process, precise fuel injection quantity, timing and dispersion must be ensured. If the air:fuel mixture in the combustion chamber is not thoroughly atomized and dispersed during the combustion stroke, some of the fuel may remain unburnt which will lead to high HC emissions.

The fuel injection system provides accurately metered quantities of fuel to the combustion chambers to ensure the most efficient air to fuel ratio under all operating conditions. A further improvement to combustion is made by measuring the oxygen content of the exhaust gases to enable the quantity of fuel injected to be varied in accordance with the prevailing engine operation and ambient conditions; any unsatisfactory composition of the exhaust gas is then corrected by adjustments made to the fuelling by the ECM.

Air : fuel ratio

The theoretical ideal air:fuel ratio to ensure complete combustion and minimise emissions in a spark-ignition engine is 14.7:1 and is referred to as the stoichiometric ratio.

The excess air factor is denoted by the Lambda symbol λ, and is used to indicate how far the air:fuel mixture ratio deviates from the theoretical optimum during any particular operating condition.

- When $\lambda = 1$, the air to fuel ratio corresponds to the theoretical optimum of 14.7:1 and is the desired condition for minimising emissions.
- When $\lambda > 1$, (i.e. $\lambda = 1.05$ to $\lambda = 1.3$) there is excess air available (lean mixture) and lower fuel consumption can be attained at the cost of reduced performance. For mixtures above $\lambda = 1.3$, the mixture ceases to be ignitable.
- When $\lambda < 1$, (i.e. $\lambda = 0.85$ to $\lambda = 0.95$) there is an air deficiency (rich mixture) and maximum output is available, but fuel economy is impaired.

The engine management system used with V8 engines operates in a narrower control range about the stoichiometric ideal between $\lambda = 0.97$ to 1.03 using closed-loop control techniques. When the engine is warmed up and operating under normal conditions, it is essential to maintain λ close to the ideal ($\lambda = 1$) to ensure the effective treatment of exhaust gases by the three-way catalytic converters installed in the downpipes from each exhaust manifold.

Changes in the oxygen content has subsequent effects on the levels of exhaust emissions experienced. The levels of hydrocarbons and carbon monoxide produced around the stoichiometric ideal control range are minimised, but peak emission of oxides of nitrogen are experienced around the same range.

Ignition timing

The ignition timing can be changed to minimise exhaust emissions and fuel consumption in response to changes due to the excess air factor. As the excess air factor increases, the optimum ignition angle is advanced to compensate for delays in flame propagation.

The reliability of the ignition system is critical for efficient catalytic converter operation, since misfiring will lead to irreparable damage of the catalytic converter due to the overheating that occurs when unburned combustion gases are burnt inside it.

CAUTION: If the engine is misfiring, it should be shut down immediately and the cause rectified. Failure to do so will result in irreparable damage to the catalytic converter.

Exhaust Emission Control System Components

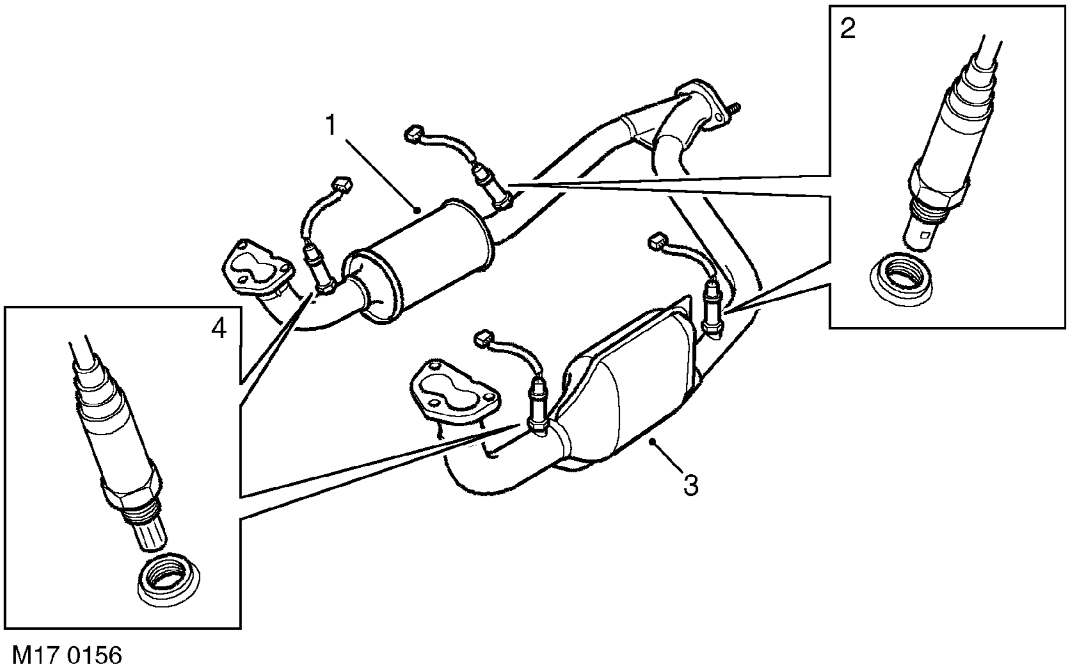


Figure 2

Components for a typical V8 application shown

1.RH catalytic converter
2.Heated oxygen sensors – post-catalytic converter (2 off)
3.LH catalytic converter
4.Heated oxygen sensors – pre-catalytic converter (2 off)

The exhaust emission control components are described below:

Catalytic converter

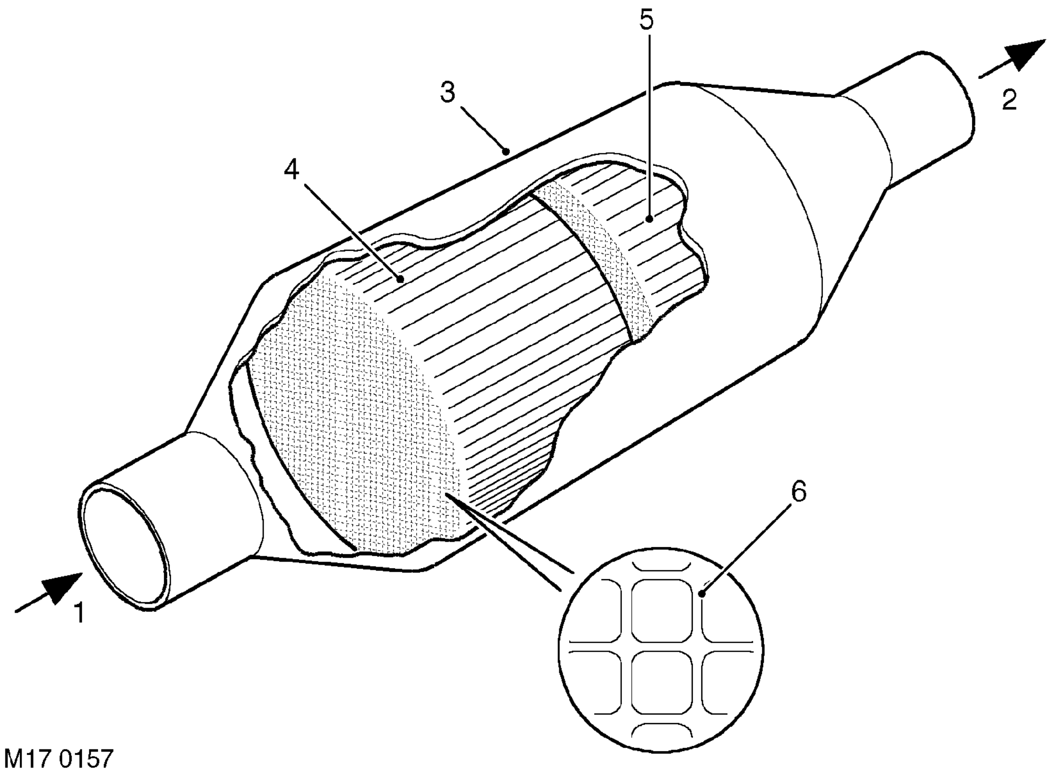


Figure 3

1.Exhaust gas from manifold ($CO + HC + NO_x$)
2.Cleaned exhaust gas to tail pipe ($CO_2 + H_2O + N_2$)
3.Catalytic converter outer case
4.1st ceramic brick
5.2nd ceramic brick
6.Honeycomb structure

The main components of an exhaust emission system are the catalytic converters which are an integral part of the front exhaust pipe assembly. The catalytic converters are included in the system to reduce the emission to atmosphere of carbon monoxide (CO), oxides of nitrogen (NO_x) and hydrocarbons (HC). The active constituents of the catalytic converters are platinum (Pt), palladium (PD) and rhodium (Rh). **Catalytic converters for NAS low emission vehicles (LEVs) from 2000MY have active constituents of palladium and rhodium only.** The correct functioning of the converters is dependent upon close control of the oxygen concentration in the exhaust gas entering the catalyst.

A catalytic converter is located in each of the front pipes from the exhaust manifolds for V-type engines; a single catalytic converter is located in the front pipe for a single in-line straight cylinder engine.

The catalytic converter's housings are fabricated from stainless steel and are fully welded at all joints. Each catalytic converter contains two elements comprising of an extruded ceramic substrate which is formed into a honeycomb of small cells (those used on Discovery II have a density of 62 cells / cm^2). The ceramic element is coated with a special surface treatment called 'washcoat' which increases the surface area of the catalyst element by approximately 7000 times. A coating is applied to the washcoat which contains the precious elements Platinum, Palladium and Rhodium in the following relative concentrations: **1 Pt : 21.6 PD : 1 Rh**

Catalytic converters used on low emission vehicles (LEVs) from 2000MY in NAS markets have active constituents of palladium and rhodium only in the ratio 14PD: 1Rh.

The metallic coating of platinum and palladium oxidize the carbon monoxide and hydrocarbons and convert them into water (H_2O) and carbon dioxide (CO_2). The coating of rhodium removes the oxygen from nitrogen oxide (NO_x) and converts it into nitrogen (N_2).

CAUTION: Catalytic converters contain ceramic material, which is very fragile. Avoid heavy impacts on the converter casing.

WARNING: To prevent personal injury from a hot exhaust system, do not attempt to disconnect any components until the exhaust system has cooled down.

CAUTION: Serious damage to the catalytic converter may occur if a lower octane number fuel is used , and definately will occur if leaded fuel is used. The fuel tank filler neck is designed to accommodate only unleaded fuel pump nozzles.

CAUTION: Ensure the exhaust system is free from leaks. Exhaust gas leaks upstream of the catalytic converter could cause internal damage to the catalytic converter.

The function and efficiency of the catalytic converter is assessed by measuring the oxygen content of the exhaust gases before and after the catalytic converter. The relevant oxygen content is calculated from the signals of the pre-catalytic converter HO_2 sensor and the post-catalytic converter HO_2 sensor. A properly functioning catalytic converter consumes the oxygen contained in the exhaust gases that are introduced in order to convert the pollutants or stores it. The gases flowing into the catalytic converter are converted from CO, HC and NO_x into CO_2, H_2O and N_2.

In order to determine whether the catalytic converter is functioning correctly, the signal from the post-catalytic converter HO_2 sensor is observed over a period in which the pre-catalytic converter HO_2 sensor is operating (i.e. the pre-catalytic converter HO_2 sensor is oscillating). During this measurement period, the post-catalytic converter HO_2 sensor must remain relatively constant as the catalytic converter keeps the oxygen content of the emerging gases constant.

In the normal control range, the fluctuating air:fuel ratio in the exhaust gas before the catalyst results in an oscillating pre-catalytic converter HO_2 sensor signal. Exhaust-gas conversion / oxygen storage in the functioning catalytic converter results in a relatively constant signal in the post-catalytic converter HO_2 sensor. Depending on how the vehicle is being operated at the time of measurement and which catalytic-converter type or which coating is used, the signal is to be found in the "lean" or "rich" voltage range.

New petrol-engined cars fitted with catalytic converters produce less than 10% of the toxic gases of pre-1993 cars.

The catalytic converter is monitored once per trip.

Heated oxygen (HO_2) sensor

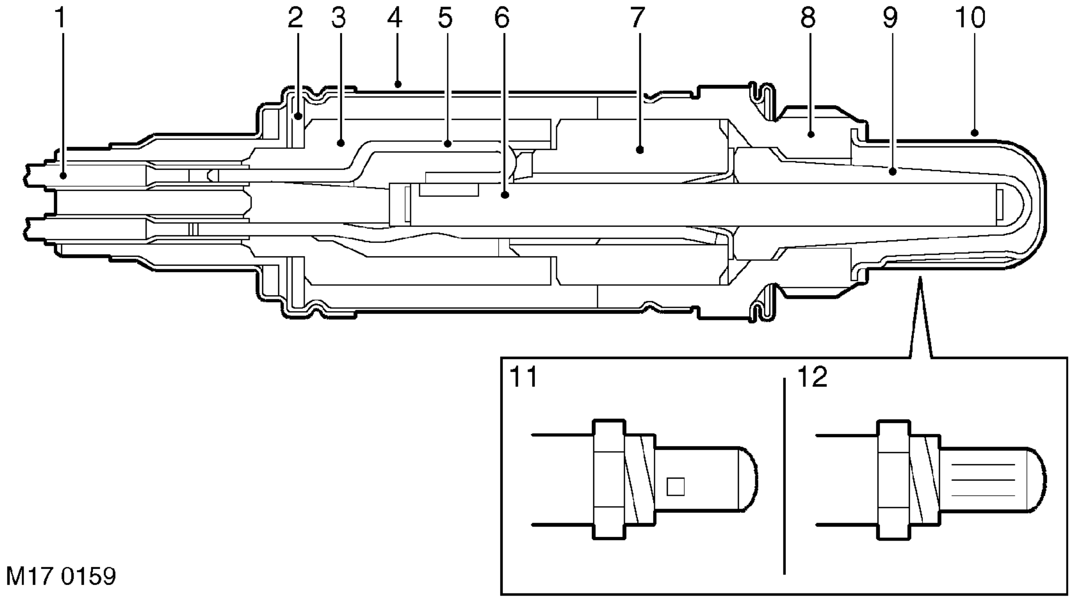


Figure 4

1.Connection cable
2.Disc spring
3.Ceramic support tube
4.Protective sleeve
5.Clamp connection for heating element
6.Heating element
7.Contact element
8.Sensor housing
9.Active sensor ceramic
10.Protective tube
11.Post-catalytic converter sensor
12.Pre-catalytic converter sensor

The heated oxygen sensor is an integral part of the exhaust emission control system and is used in conjunction with the catalytic converters and the engine management control unit to ensure that the air:fuel mixture ratio stays around the stoichiometric point of $\lambda = 1$, where the catalytic converters are most effective. Combinations of four or two heated lambda sensors are used in the exhaust system dependent on market legislation and engine type. For vehicles with OBD, V-type engines use four HO_2 sensors, and K-series straight cylinder engines use two HO_2 sensors.

On V-type engines, two pre-catalytic converter heated oxygen sensors are mounted in the front pipes for monitoring the oxygen content of the exhaust gas and two additional post-catalytic converter heated oxygen sensors are mounted in the exhaust tail pipe. On straight cylinder engines there is one pre-catalytic converter and one post catalytic converter HO_2 sensor.

The pre-catalytic and post-catalytic converter sensors are not interchangeable, and although it is possible to mount them in transposed positions, their harness connections are of different gender and colour. **It is important not to confuse the sensor signal pins; the signal pins are gold plated, whilst the heater supply pins are tinned, mixing them up will cause contamination and adversely affect system performance.**

Each of the heated oxygen sensors have a four pin connector with the following wiring details:

- Sensor signal ground (connects to engine management ECM)
- Sensor signal (connects to engine management ECM)
- Heater drive (connects to engine management ECM)
- Heater supply (connects to voltage supply source via a fuse)

The oxygen sensors consist of a ceramic body (Galvanic cell) which is a practically pure oxygen-ion conductor made from a mixed oxide of zirconium and yttrium. The ceramic is then coated with gas-permeable platinum, which when heated to a sufficiently high temperature ($\geq$ 350° C) generates a voltage which is proportional to the oxygen content in the exhaust gas stream.

The heated oxygen sensor is protected by an outer tube with a restricted flow opening to prevent the sensor's ceramics from being cooled by low temperature exhaust gases at start up. The post-catalytic sensors have improved signal quality, but a slower response rate.

The heated oxygen sensors should be treated with extreme care so as not to damage the sensor housing or tip. The ceramic material within the sensors can be easily cracked if dropped, banged or over-torqued; the sensors should be torqued to the recommended values indicated in the repair procedures. Damage can also be caused by excessive heat. Apply anti-seize compound to the sensor's threads when refitting.

The heated oxygen sensors are screwed into threaded mountings welded in the exhaust pipes at suitable locations before and after the catalytic converters. They are used to detect the level of residual oxygen in the exhaust gas to provide an instantaneous indication of whether combustion is complete. By positioning sensors in the stream of exhaust gases from each separate bank of the exhaust manifold (V-types), the engine management system is better able to control the fuelling requirements on each bank independently of the other, so allowing much closer control of the air:fuel ratio and optimising catalytic converter efficiency.

For example, if the HO_2 sensors signal “Exhaust too rich” = $\lambda < 1$, the ECM reduces the injection time in order to reduce the fuel delivery rate.

As part of the E-OBD requirements, all the HO_2 sensors must be monitored separately with regard to electrical function, sensor heating, control frequency and control function. In order for the HO_2 sensor to be monitored by the ECM, the system must be operating in the control range (i.e. the system is not using fixed “default” values such as during emergency operation programs or operating temperature not yet reached).

If the OBD system registers a HO_2 sensor fault, misfire detection, catalytic converter monitoring and fuel mixture control are interrupted until the fault is rectified. Typical conditions for HO_2 sensor monitoring are listed in the following table:

Systems	Requirements / status
HO_2 sensor control	In control operation
Engine coolant temperature	Operating temperature
Roadspeed of vehicle	3 to 50 mph (5 to 80 km/h, due to flow)
Secondary air injection (if applicable)	Not active
Catalytic-converter temperature	Operating temperature (> 350° C)
Accelerator-pedal position	As constant as possible
Engine speed	As constant as possible
Average λ value	As constant as possible (steady load)

The catalytic-converter temperature is a value determined by the ECM as a function of load, air mass and time (exhaust-gas temperature model)

The HO_2 sensors are monitored for electrical integrity during normal driving operation. The ECM checks for open circuit or short circuit faults to ground or battery supply voltage to identify faults in cables or connectors, and a plausibility check to ensure the signal received is valid and logical. Diagnostic trouble codes identifying the relevant fault to the associated P-code are listed later in this document.

If the HO_2 sensor signal voltage falls below the minimum threshold value, the ECM interprets this as a short circuit to ground and the associated fault code is stored in memory. If the HO_2 sensor signal voltage exceeds the maximum threshold value, the ECM interprets this as a short circuit to battery voltage and the associated fault code is stored in memory.

If the monitored HO_2 sensor signal voltage remains unchanged or does not remain in a previously determined voltage band after the HO_2 sensor has been heated and the engine temperature has exceeded a specified threshold value, the ECM interprets this as an open circuit and stores the related fault code in memory.

For each of the faults, the MIL lamp is illuminated if the faults are confirmed after the next drive cycle.

The HO_2 sensor must be heated so that it can measure the oxygen content in the exhaust gas. If the heating does not function properly, the sensor signal fails to reach the specified threshold values of the voltage band “Operation-readiness detection”. This results in:

- delayed introduction of HO_2 sensor control after starting, thus affecting the emission values;
- increased emissions values during operation with HO_2 sensor control.

The functions of the pre-catalytic and post-catalytic convertor HO_2 sensor heating is monitored cyclically as long as the heating is activated by the ECM.

Depending on the measured values, the HO_2 sensor heating circuits are also checked for open circuit, short circuit to ground or short circuit to battery voltage. The relevant fault codes (P-codes) associated with the different fault conditions are listed later in this document.

In the case of the Bosch M5.2.1 engine management system, both the current and the voltage are measured in order to determine the resistance of the HO_2 sensor heater. The current of the HO_2 sensor heater is determined by means of the voltage drop at a series-connected resistor in the sensor heating circuit. Other engine management systems may utilise different methods for fault detection in the HO_2 sensor heater circuits.

In addition to HO_2 sensor heater circuit integrity, the heating effect of the sensors is also checked. A Bosch LSH25 HO_2 sensor is used with the M5.2.1 engine management system which operates according to the “voltage source” principle with a voltage range between 0.05 V and 0.9V.

Exhaust Emission System Diagnostics

The engine management ECM contains an on-board diagnostics (OBD) system which performs a number of diagnostic routines for detecting problems associated with the closed loop emission control system. The diagnostic unit monitors ECM commands and system responses and also checks the individual sensor signals for plausibility, these include:

- Lambda ratio outside of operating band
- Lambda heater diagnostic
- Lambda period diagnostic
- Post-catalytic converter lambda adaptation diagnostic
- Catalyst monitoring diagnostic

Lambda ratio outside operating band

The system checks to ensure that the system is operating in a defined range around the stoichiometric point. If the system determines that the upper or lower limits for the air:fuel ratio are being exceeded, the error is stored as a fault code in the ECM diagnostic memory and the MIL light is illuminated.

Lambda heater diagnostic

The system determines the heater current and supply voltage so that the heater's resistance can be calculated. After the engine has been started, the system waits for the heated oxygen sensors to warm up, then calculates the resistance from the voltage and current measurements. If the value is found to be outside of the upper or lower threshold values, then the fault is processed and the MIL light is illuminated.

Lambda period diagnostic

The pre-catalytic converter sensors are monitored. As the sensors age, the rich to lean and the lean to rich switching delays increase, leading to increased emissions if the lambda control becomes inaccurate. If the switching period exceeds a defined limit, the sensor fault is stored in the ECM diagnostic memory and the MIL light is illuminated.

Post-catalytic converter lambda adaptation diagnostic

The ageing effects of the pre-catalytic converter sensors are compensated for by an adaptive value derived from the post-catalytic converter sensors. This is a long term adaption which only changes slowly. For a rich compensation the additive value is added to the rich delay time. For a lean compensation, the adaptive value is added to the lean delay time. The adaptive time is monitored against a defined limit, and if the limit is exceeded, the fault is stored in the ECM's diagnostic memory and the MIL light is illuminated on the instrument pack.

Catalyst monitoring diagnostic

The catalysts (V8) are monitored both individually and simultaneously for emission pollutant conversion efficiency. The conversion efficiency of a catalyst is monitored by measuring the oxygen storage, since there is a direct relationship between these two factors. The closed loop lambda control fuelling oscillations produce pulses of oxygen upstream of the catalyst, as the catalyst efficiency deteriorates, its ability to store oxygen is decreased.

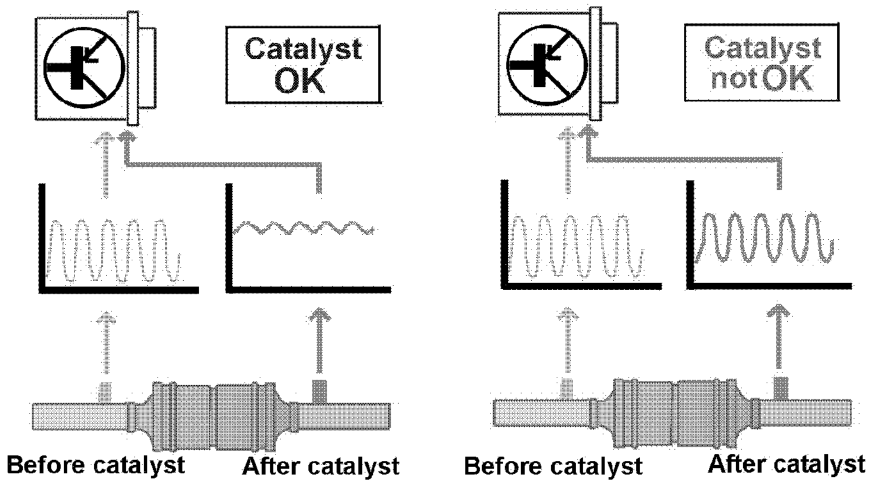


Figure 5

The amplitudes of the signals from the pre-catalytic and post-catalytic converter heated oxygen sensors are compared. As the oxygen storage decreases, the post-catalytic converter sensor begins to follow the oscillations of the pre-catalytic converter heated oxygen sensors. Under steady state conditions the amplitude ratio is monitored in different speed / load sites. There are three monitoring areas, and if the amplitude ratio exceeds a threshold in all three areas, the catalyst conversion limit is exceeded; the catalyst fault is stored in the diagnostic memory and the MIL light is illuminated on the instrument pack. There is a reduced threshold value for both catalysts monitored as a pair. In either case, a defective catalyst requires replacement of the downpipe assembly.

In the case of a catalytic converter failure the following failure symptoms may be apparent:

- MIL light on after 2 driving cycles (i.e. lights up on the third drive cycle if still present).
- High exhaust back pressure if catalyst partly melted.
- Excessive emissions
- Strong smell of H_2S (rotten eggs).

Oxygen sensor voltages can be monitored using 'Testbook', the approximate output voltage from the heated oxygen sensors (example is Discovery II) with a warm engine at idle and with closed loop fuelling active are shown in the table below:

Measurement	Normal catalyst	Defective catalyst
Pre-catalytic heated oxygen sensors	~ 100 to 900 mV switching @ ~ 0.5 Hz	~ 100 to 900 mV switching @ ~ 0.5 Hz
Post-catalytic heated oxygen sensors	~ 200 to 650 mV, static or slowly changing	~ 200 to 850 mV, changing up to same frequency as pre-catalytic heated oxygen sensors
Amplitude ratio (LH HO_2 sensors & RH HO_2 sensors)	<0.3 seconds	>0.6 seconds (needs to be approximately 0.75 seconds for single catalyst fault)
Number of speed/load monitoring areas exceeded (LH & RH)	0	>1 (needs to be 3 for fault storage)

Mass air flow sensor and air temperature sensor

The engine management ECM uses the mass air flow sensor to measure the mass of air entering the intake and interprets the data to determine the precise fuel quantity which needs to be injected to maintain the stoichiometric air:fuel ratio for the exhaust catalysts. If the mass air flow sensor fails, lambda control and idle speed control will be affected and the emission levels will not be maintained at the optimum level. If the device should fail and the ECM detects a fault, it invokes a software backup strategy.

The air temperature sensor is used by the engine management ECM to monitor the temperature of the inlet air. If the device fails, catalyst monitoring will be affected. For certain vehicles such as Discovery II, the air temperature sensor is integral to the mass air flow sensor.

As emissions are affected, the OBD system may activate the MIL lamp and the relevant fault code and freeze-frame conditions will be stored in ECM memory.

Throttle position sensor

If the engine management ECM detects a throttle position sensor failure, it may indicate a blocked or restricted air intake filter. Failure symptoms may include:

- Poor engine running and throttle response
- Emission control failure
- No closed loop idle speed control
- Altitude adaption is incorrect

If a signal failure should occur, a default value is derived using data from the engine load and speed.

Atmospheric pressure will vary with altitude and have a resulting influence on the calculations performed by the ECM in determining the optimum engine operating conditions to minimise emissions. The following are approximate atmospheric pressures for the corresponding altitudes:

- 0.96 bar at sea level
- 0.70 bar at 2,750 m (9,000 ft.)

As emissions are affected, the OBD system may activate the MIL lamp and the relevant fault code and freeze-frame conditions will be stored in ECM memory.

Faulty sensors

The ECM identifies a faulty signal or a faulty sensor by way of three test steps:

1. Signal or component short-circuited to ground
2. Signal or component short-circuited to battery voltage
3. No signal or component missing (open circuit)

A specific trouble code is set for each type of test , this helps the technician to determine the cause of the fault during the diagnostic analysis.

Misfire Monitoring

Misfire monitoring is vital to avoid damage to the catalytic converters. The Engine Control Module (ECM) must therefore monitor the firing of each individual cylinder to detect misfire and be capable of recognizing the type of misfire likely to cause catalyst damage or the failure of an emission test. During misfire monitoring, the signal from the Crankshaft Position Sensor (CKP) is used to determine engine speed and position as a reference for engine timing.

Spark timing

Spark timing is automatically optimised by the EMS, the timing is advanced when engine speed is increased or when the air:fuel ratio (AFR) is weakened. Spark timing advance is decreased when engine load is increased or when the HO_2 sensors detect that the exhaust emission of HC and NO_x is too high.

Cold starting

From year 2000, ECD3 legislation requires passenger car catalytic converters to work within a few seconds of cold engine start up. Catalysts must be capable of working effectively in a wide range of ambient temperature conditions from sub-zero to 50°C. Secondary air injection can assist cold starting, and is currently used on Land Rover vehicles sold in California. OBD is used to check the operation of the SAI system when fitted. Description and operation of secondary air systems are included later in this document as means of an introduction to the topic.

Diagnostic Trouble Codes (DTCs)

The Diagnostic Trouble Codes or “P-codes”, are distinguished between 'Mandatory' and 'Voluntary' codes. The Society of Automotive Engineers (SAE) defines mandatory (core) codes. The SAE codes can be identified by a '0' before the 3-digit numeric part of the code (e.g. P-**0**234). Voluntary codes are manufacturer specific codes (e.g. Land Rover) and are identified by a '**1**' before the three digit code (e.g. P-**1**234).

The mandatory P-codes are consistent for all vehicle types worldwide, irrespective of manufacturer or market i.e. the occurrence of a particular mandatory P-code will indicate the same type of component error as defined by the SAE description irrespective of vehicle type or manufacturer.

A comprehensive list of P-codes is included in tabular form later in this document.

Service Drive Cycles

To ensure that a fault causing a diagnostic trouble code (DTC) has been successfully resolved, drive cycles have to be carried out. Testbook indicates the relevant drive cycles to be carried out following the incidence of a specific P-code.

A driving cycle consists of engine start-up, vehicle operation (exceeding starting speed), overrunning and engine stopping. On OBDII, a drive cycle is simply defined as starting the engine and driving the vehicle long enough to raise the coolant temperature by at least 40° F (if the start-up temperature is less than 160° F).

A complete driving cycle should perform diagnostics on all systems.

The following are the TestBook drive cycles used on Discovery II with V8 engines and Bosch 5.2.1 engine management system:

⇒ Drive cycle A:

1. Switch on the ignition for 30 seconds.
2. Ensure engine coolant temperature is less than 60°C (140°F).
3. Start the engine and allow to idle for 2 minutes.
4. Connect TestBook and check for fault codes.

⇒ Drive cycle B:

1. Switch ignition on for 30 seconds.
2. Ensure engine coolant temperature is less than 60°C (140°F).
3. Start the engine and allow to idle for 2 minutes.
4. Perform 2 light accelerations (0 to 35 mph (0 to 60 km/h) with light pedal pressure).
5. Perform 2 medium accelerations (0 to 45 mph (0 to 70 km/h) with moderate pedal pressure).
6. Perform 2 hard accelerations (0 to 55 mph (0 to 90 km/h) with heavy pedal pressure).
7. Allow engine to idle for 2 minutes.
8. Connect TestBook and with the engine still running, check for fault codes.

⇒ Drive cycle C:

1. Switch ignition on for 30 seconds.
2. Ensure engine coolant temperature is less than 60°C (140°F).
3. Start the engine and allow to idle for 2 minutes.
4. Perform 2 light accelerations (0 to 35 mph (0 to 60 km/h) with light pedal pressure).
5. Perform 2 medium accelerations (0 to 45 mph (0 to 70 km/h) with moderate pedal pressure).
6. Perform 2 hard accelerations (0 to 55 mph (0 to 90 km/h) with heavy pedal pressure).
7. Cruise at 60 mph (100 km/h) for 8 minutes.
8. Cruise at 50 mph (80 km/h) for 3 minutes.
9. Allow engine to idle for 3 minutes.
10. Connect TestBook and with the engine still running, check for fault codes.

NOTE: The following areas have an associated readiness test which must be flagged as complete, before a problem resolution can be verified:

- catalytic converter fault;
- Evaporative loss system fault;
- HO_2 sensor fault;
- HO_2 sensor heater fault.

When carrying out a drive cycle C to determine a fault in any of the above areas, select the readiness test icon to verify that the test has been flagged as complete.

⇒ Drive cycle D:

1. Switch ignition on for 30 seconds.
2. Ensure engine coolant temperature is less than 35°C (95°F).
3. Start the engine and allow to idle for 2 minutes.
4. Perform 2 light accelerations (0 to 35 mph (0 to 60 km/h) with light pedal pressure).
5. Perform 2 medium accelerations (0 to 45 mph (0 to 70 km/h) with moderate pedal pressure).
6. Perform 2 hard accelerations (0 to 55 mph (0 to 90 km/h) with heavy pedal pressure).
7. Cruise at 60 mph (100 km/h) for 5 minutes.
8. Cruise at 50 mph (80 km/h) for 5 minutes.
9. Cruise at 35 mph (60 km/h) for 5 minutes.
10. Allow engine to idle for 2 minutes.
11. Connect TestBook and check for fault codes.

⇒ Drive cycle E:

1. Ensure fuel tank is at least a quarter full.
2. Carry out Drive Cycle A.
3. Switch off ignition.
4. Leave vehicle undisturbed for 20 minutes.
5. Switch on ignition.
6. Connect TestBook and check for fault codes.

Driving cycles for other vehicles and engine management systems may differ slightly depending on the type of emissions related equipment fitted to the vehicle (e.g. secondary air injection system). Refer to the engine management system for a particular engine in the relevant vehicle workshop manual.

Driving conditions can be performed on a roller dynamometer or test track.

Homologation Procedure

The emissions testing procedure for vehicles produced after the introduction of EURO-3 includes a modified driving cycle for measuring the pollutants in the emissions of passenger cars and light-duty trucks. As part of the homologation procedure, the manufacturer must provide proof that the vehicle successfully completes the driving cycle stipulated in accordance with this EU directive, twice in succession without any malfunctions.

The driving cycle consists of the previous EDC (urban) as Part 1 and the new Part 2 (out of town).

System Monitoring

Within the framework of OBD, certain components/systems must be monitored once per driving cycle while other control systems (e.g. misfire detection) must be monitored continuously throughout the drive cycle.

Permanently monitored systems are monitored according to temperature immediately after start-up and may in the event of malfunctions (e.g. HO_2 sensor) result in the MIL illuminating straight away. The following are permanently monitored throughout the drive cycle:

- Misfire detection
- Fuel system (duration of injection)
- All electric circuits for emission-related components

Systems which are monitored once per driving cycle will only result in a fault being registered after the corresponding operating conditions have been completed. It may not be possible for the system to perform a complete check if the engine is only operating for a brief period before shutting down again. The following components are monitored once per driving cycle:

- HO_2 Sensor function
- Catalytic converter function

Diagnostic Trouble Codes (DTCs) / P-Codes

The following table lists the fault descriptions associated with particular P-codes, the list is not intended to be exhaustive, as additional P-codes may be added at any time dependent on emissions systems employed, introduction of new components particular to a manufacturer or ECM specific codes.

P-Codes beginning with the designation P-0xxx are Society of Automotive Engineers (SAE) defined codes and are generic to all vehicles and manufacturers worldwide. The DTCs were originally developed for OBDII systems and are referred to as SAE J2012 standards.

P-Codes beginning with the designation P-1xxx are manufacturer specific codes which may be associated with a particular ECM, component or system.

The following table lists all SAE designated codes and examples of Land Rover / Rover specific codes:

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P0100	Mass or Volume Air Flow Circuit Malfunction	
P0101	Mass or Volume Air Flow Circuit Range / Performance Problem	Load monitoring, the ratio of throttle position to air flow
P0102	Mass or Volume Air Flow Circuit Low Input	
P0103	Mass or Volume Air Flow Circuit High Input	MAF signal greater than maximum threshold
P0104	Mass or Volume Air Flow Circuit Intermittent	
P0105	Manifold Absolute Pressure / Barometric Pressure Circuit Malfunction	
P0106	Manifold Absolute Pressure / Barometric Pressure Circuit Range / Performance Problem	
P0107	Manifold Absolute Pressure / Barometric Pressure Circuit Low Input	
P0108	Manifold Absolute Pressure / Barometric Pressure Circuit High Input	
P0109	Manifold Absolute Pressure / Barometric Pressure Circuit Intermittent	
P0110	Intake Air Temperature Circuit Malfunction	
P0111	Intake Air Temperature Circuit Range / Performance Problem	
P0112	Intake Air Temperature Circuit Low Input	Air temperature signal greater than maximum threshold, after time for exhaust to warm up
P0113	Intake Air Temperature Circuit High Input	Air temperature less than minimum
P0114	Intake Air Temperature Circuit Intermittent	
P0115	Engine Coolant Temperature Circuit Malfunction	
P0116	Engine Coolant Temperature Circuit Range / Performance Problem	Signal differs too much from temperature model
P0117	Engine Coolant Temperature Circuit Low Input	Open circuit or short circuit to battery supply
P0118	Engine Coolant Temperature Circuit High Input	Short circuit to earth
P0119	Engine Coolant Temperature Circuit Intermittent	
P0120	Throttle / Pedal Position Sensor / Switch A Circuit Malfunction	TPS signal exceeds minimum threshold
P0121	Throttle / Pedal Position Sensor / Switch A Circuit Range / Performance Problem	
P0122	Throttle / Pedal Position Sensor / Switch A Circuit Low Input	TPS signal exceeds maximum threshold
P0123	Throttle / Pedal Position Sensor / Switch A Circuit High Input	

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P0124	Throttle / Pedal Position Sensor / Switch A Circuit Intermittent	
P0125	Insufficient Coolant Temperature for Closed Loop Fuel Control	
P0126	Insufficient Coolant Temperature for Stable Operation	
P0130	O_2 Sensor Circuit Malfunction (Bank 1 Sensor 1)	Front HO_2 Sensor LH bank stoichiometric ratio outside operating band
P0131	O_2 Sensor Circuit Low Voltage (Bank 1 Sensor 1)	Front HO_2 Sensor LH bank short circuit to earth
P0132	O_2 Sensor Circuit High Voltage (Bank 1 Sensor 1)	Front HO_2 Sensor LH bank short circuit to battery supply
P0133	O_2 Sensor Circuit Slow Response (Bank 1 Sensor 1)	Front HO_2 Sensor aged - period time too long / too short LH bank
P0134	O_2 Sensor Circuit - No Activity Detected (Bank 1 Sensor 1)	Front HO_2 Sensor LH bank open circuit
P0135	O_2 Sensor Heater Circuit Malfunction (Bank 1 Sensor 1)	Upstream HO_2 Sensor heater LH bank - short / open circuit
P0136	O_2 Sensor Circuit Malfunction (Bank 1 Sensor 2)	Rear HO_2 Sensor LH bank stoichiometric ratio outside operating band
P0137	O_2 Sensor Circuit Low Voltage (Bank 1 Sensor 2)	Rear HO_2 Sensor LH bank short circuit to battery supply
P0138	O_2 Sensor Circuit High Voltage (Bank 1 Sensor 2)	Rear HO_2 Sensor LH bank short circuit to earth
P0139	O_2 Sensor Circuit Slow Response (Bank 1 Sensor 2)	
P0140	O_2 Sensor Circuit - No Activity Detected (Bank 1 Sensor 2)	Rear HO_2 Sensor LH bank open circuit
P0141	O_2 Sensor Heater Circuit Malfunction (Bank 1 Sensor 2)	Downstream HO_2 Sensor heater LH bank - short/open circuit
P0142	O_2 Sensor Circuit Malfunction (Bank 1 Sensor 3)	
P0143	O_2 Sensor Circuit Low Voltage (Bank 1 Sensor 3)	
P0144	O_2 Sensor Circuit High Voltage (Bank 1 Sensor3)	
P0145	O_2 Sensor Circuit Slow Response (Bank 1 Sensor 3)	
P0146	O_2 Sensor Circuit No Activity Detected (Bank 1 Sensor 3)	
P0147	O_2 Sensor Heater Circuit Malfunction (Bank 1 Sensor 3)	
P0150	O_2 Sensor Circuit Malfunction (Bank 2 Sensor 1)	Front HO_2 Sensor RH bank Stoichiometric ration outside operating band
P0151	O_2 Sensor Circuit Low Voltage (Bank 2 Sensor 1)	Front HO_2 Sensor RH bank short circuit to earth
P0152	O_2 Sensor Circuit High Voltage (Bank 2 Sensor 1)	Front HO_2 Sensor RH bank short circuit to battery supply
P0153	O_2 Sensor Circuit Slow Response (Bank 2 Sensor 1)	Front HO_2 sensor aged - period time too long / too short RH bank
P0154	O_2 Sensor Circuit - No Activity Detected (Bank 2 Sensor 1)	Front HO_2 Sensor RH bank open circuit
P0155	O_2 Sensor Heater Circuit Malfunction (Bank 2 Sensor 1)	Upstream HO_2 Sensor heater RH bank - short/open circuit
P0156	O_2 Sensor Circuit Malfunction (Bank 2 Sensor 2)	Rear HO_2 sensor RH bank stoichiometric ratio outside operating band
P0157	O_2 Sensor Circuit Low Voltage (Bank 2 Sensor 2)	Rear HO_2 Sensor RH bank short circuit to battery supply
P0158	O_2 Sensor Circuit High Voltage (Bank 2 Sensor 2)	Rear HO_2 Sensor short circuit to earth
P0159	O_2 Sensor Circuit Slow Response (Bank 2 Sensor 2)	
P0160	O_2 Sensor Circuit - No Activity Detected (Bank 2 Sensor 2)	Rear HO_2 Sensor RH bank open circuit
P0161	O_2 Sensor Heater Circuit Malfunction (Bank 2 Sensor 2)	Downstream HO_2 Sensor heater RH bank - short/open circuit
P0162	O_2 Sensor Circuit Malfunction (Bank 2 Sensor 3)	
P0163	O_2 Sensor Circuit Low Voltage (Bank 2 Sensor 3)	
P0164	O_2 Sensor Circuit High Voltage (Bank 2 Sensor 3)	
P0165	O_2 Sensor Circuit Slow Response (Bank 2 Sensor 3)	

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P0166	O_2 Sensor Circuit No Activity Detected (Bank 2 Sensor 3)	
P0167	O_2 Sensor Heater Circuit Malfunction (Bank 2 Sensor 3)	
P0170	Fuel Trim Malfunction (Bank 1)	High leak rate
P0171	System too Lean (Bank 1)	Multiplication injector adaptive fuelling lean limit exceeded LH bank
P0172	System too Rich (Bank 1)	Multiplication injector adaptive fuelling rich limit exceeded RH bank
P0173	Fuel Trim Malfunction (Bank 2)	
P0174	System too Lean (Bank 2)	Multiplication injector adaptive fuelling lean limit exceeded RH bank
P0175	System too Rich (Bank 2)	Multiplication injector adaptive fuelling rich limit exceeded RH bank
P0176	Fuel Composition Sensor Circuit Malfunction	
P0177	Fuel Composition Sensor Circuit Range / Performance	
P0178	Fuel Composition Sensor Circuit Low Input	
P0179	Fuel Composition Sensor Circuit High Input	
P0180	Fuel Temperature Sensor A Circuit Malfunction	
P0181	Fuel Temperature Sensor A Circuit Range / Performance	
P0182	Fuel Temperature Sensor A Circuit Low Input	
P0183	Fuel Temperature Sensor A Circuit High Input	
P0184	Fuel Temperature Sensor A Circuit Intermittent	
P0185	Fuel Temperature Sensor B Circuit Malfunction	
P0186	Fuel Temperature Sensor B Circuit Range / Performance	
P0187	Fuel Temperature Sensor B Circuit Low Input	
P0188	Fuel temeprature Sensor B Circuit High Input	
P0189	Fuel Temperature Sensor B Circuit Intermittent	
P0190	Fuel Rail Pressure Sensor Circuit Malfunction	
P0191	Fuel Rail Pressure Sensor Circuit Range / Performance	
P0192	Fuel Rail Pressure Sensor Circuit Low Input	
P0193	Fuel Rail Pressure Sensor Circuit High Input	
P0194	Fuel Rail Pressure Sensor Circuit Intermittent	
P0195	Engine Oil Temperature Sensor Malfunction	
P0196	Engine Oil Temperature Sensor Range / Performance	
P0197	Engine Oil Temperature Sensor Low	
P0198	Engine Oil Temperature Sensor High	
P0199	Engine Oil Temperature Sensor Intermittent	
P0200	Injector Circuit Malfunction	
P0201	Injector Circuit Malfunction - Cylinder1	Fuel injector cylinder 1 open circuit
P0202	Injector Circuit Malfunction - Cylinder 2	Fuel injector cylinder 2 open circuit
P0203	Injector Circuit Malfunction - Cylinder 3	Fuel injector cylinder 3 open circuit
P0204	Injector Circuit Malfunction Cylinder 4	Fuel injector cylinder 4 open circuit
P0205	Injector Circuit Malfunction - Cylinder 5	Fuel injector cylinder 5 open circuit
P0206	Injector Circuit Malfunction - Cylinder 6	Fuel injector cylinder 6 open circuit
P0207	Injector Circuit Malfunction - Cylinder 7	Fuel injector cylinder 7 open circuit
P0208	Injector Circuit Malfunction - Cylinder 8	Fuel injector cylinder 8 open circuit
P0209	Injector Circuit Malfunction - Cylinder 9	
P0210	Injector Circuit Malfunction - Cylinder 10	
P0211	Injector Circuit Malfunction - Circuit 11	

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P0212	Injector Circuit Malfunction - Cylinder 12	
P0213	Cold Start Injector 1 Malfunction	
P0214	Cold Start Injector 2 Malfunction	
P0215	Engine Shutoff Solenoid Malfunction	
P0216	Injection Timing Control Circuit Malfunction	
P0217	Engine Overtwmp Condition	
P0218	Transmission Over Temperature Condition	
P0219	Engine Overspeed Condition	
P0220	Throttle / Pedal Position Sensor / Switch B Circuit Malfunction	
P0221	Throttle / Pedal Position Sensor / Switch B Circuit Range / Performance Problem	
P0222	Throttle / Pedal Position Sensor / Switch B Circuit Low Input	
P0223	Throttle / Pedal Position Sensor / Switch B Circuit High Input	
P0224	Throttle / Pedal Position / Switch B Circuit Intermittent	
P0225	Throttle / Pedal Position Sensor / Switch C Circuit Malfunction	
P0226	Throttle / Pedal Position Sensor / Switch C Circuit Range / Performance Problem	
P0227	Throttle / Pedal Position Sensor / Switch C Low Input	
P0228	Throttle / Pedal Position Sensor / Switch C High Input	
P0229	Throttle / Pedal Position Sensor / Switch C Circuit Intermittent	
P0230	Fuel Pump Primary Circuit Malfunction	
P0231	Fuel Pump Secondary Circuit Low	
P0232	Fuel Pump Secondary Circuit High	
P0233	Fuel Pump Secondary Circuit Intermittent	
P0234	Engine Overboost Condition	
P0235	Turbocharger Boost Sensor A Circuit malfunction	
P0236	Turbocharger Boost Sensor A Circuit / Range Performance	
P0237	Turbocharger Boost Sensor A Circuit Low	
P0238	Turbocharger Boost Sensor A Circuit High	
P0239	Turbocharger Boost Sensor B Malfunction	
P0240	Turbocharger Boost Sensor B Circuit Range / Performance	
P0241	Turbocharger Boost Sensor B Circuit Low	
P0242	Turbocharger Boost Sensor B Circuit High	
P0243	Turbocharger Wastegate Solenoid A Malfunction	
P0244	Turbocharger Wastegate Solenoid A Range / Performance	
P0245	Turbocharger Wastegate Solenoid A Low	
P0246	Turbocharger Wastegate Solenoid A High	
P0247	Turbocharger Wastegate Solenoid B Malfunction	
P0248	Turbocharger Wastegate Solenoid B Range / Performance	
P0249	Turbocharger Wastegate Solenoid B Low	
P0250	Turbocharger Wastegate Solenoid B High	
P0251	Injection Pump Fuel Metering Control "A" Malfunction (Cam / Rotor / Injector)	
P0252	Injection Pump Fuel Metering Control "A" Range / Performance (Cam / Rotor / Injector)	

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P0253	Injection Pump Fuel Metering Control "A" Low (Cam / Rotor / Injector)	
P0254	Injection Pump Fuel Metering Control "A" High (Cam / Rotor / Injector)	
P0255	Injection Pump Fuel Metering Control "A" Intermittent (Cam / Rotor / Injector)	
P0256	Injection Pump Fuel Metering Control "B" Malfunction (Cam / Rotor / Injector)	
P0257	Injection Pump Fuel Metering Control "B" Range / Performance (Cam / Rotor / Injector)	
P0258	Injection Pump Fuel Metering Control "B" Low (Cam / Rotor / Injector)	
P0259	Injection Pump Fuel Metering Control "B" High (Cam / Rotor / Injector)	
P0260	Injection Pump Fuel Metering Control "B" Intermittent (Cam / Rotor / Injector)	
P0261	Cylinder 1 Injector Circuit Low	Fuel injector cylinder 1 short circuit to earth
P0262	Cylinder 1 Injector Circuit High	Fuel injector cylinder 1 short circuit to battery supply
P0263	Cylinder 1 Contribution / Balance Fault	
P0264	Cylinder 2 Injector Circuit Low	Fuel injector cylinder 2 short circuit to earth
P0265	Cylinder 2 Injector Circuit High	Fuel injector cylinder 2 short circuit to battery supply
P0266	Cylinder 2 Contribution / Balance Fault	
P0267	Cylinder 3 Injector Circuit Low	Fuel injector cylinder 3 short circuit to earth
P0268	Cylinder 3 Injector Circuit High	Fuel injector cylinder 3 short circuit to battery supply
P0269	Cylinder 3 Contribution / Balance Fault	
P0270	Cylinder 4 Injector Circuit Low	Fuel injector cylinder 4 short circuit to earth
P0271	Cylinder 4 Injector Circuit High	Fuel injector cylinder 4 short circuit to battery supply
P0272	Cylinder 4 Contribution / Balance Fault	
P0273	Cylinder 5 Injector Circuit Low	Fuel injector cylinder 5 short circuit to earth
P0274	Cylinder 5 Injector Circuit High	Fuel injector cylinder 5 short circuit to battery supply
P0275	Cylinder 5 Contribution / Balance Fault	
P0276	Cylinder 6 Injector Circuit Low	Fuel injector cylinder 6 short circuit to earth
P0277	Cylinder 6 Injector Circuit High	Fuel injector cylinder 6 short circuit to battery supply
P0278	Cylinder 6 Contribution / Balance Fault	
P0279	Cylinder 7 Injector Circuit Low	Fuel injector cylinder 7 short circuit to earth
P0280	Cylinder 7 Injector Circuit High	Fuel injector cylinder 7 short circuit to battery supply
P0281	Cylinder 7 Contribution / Balance Fault	
P0282	Cylinder 8 Injector Circuit Low	Fuel injector cylinder 8 short circuit to earth
P0283	Cylinder 8 Injector Circuit High	Fuel injector cylinder 8 short circuit to battery supply
P0284	Cylinder 8 Contribution / Balance Fault	
P0285	Cylinder 9 Injector Circuit Low	
P0286	Cylinder 9 Injector Circuit High	
P0287	Cylinder 9 Contribution / Balance fault	
P0288	Cylinder 10 Injector Circuit Low	
P0289	Cylinder 10 Injector Circuit High	
P0290	Cylinder 10 Contribution / Balance Fault	
P0291	Cylinder 11 Injector Circuit Low	
P0292	Cylinder 11 Injector Circuit High	
P0293	Cylinder 11 Contribution / Balance Fault	
P0294	Cylinder 12 Injector Circuit Low	
P0295	Cylinder 12 Injector Circuit High	
P0296	Cylinder 12 Contribution / Balance Fault	
P0300	Random / Multiple Cylinder Misfire Detected	Excess emissions / catalyst damaging level of misfire detected on more than one cylinder

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P0301	Cylinder 1 Misfire Detected	Fuel injector cylinder 1 excess emissions / catalyst damaging level of misfire
P0302	Cylinder 2 Misfire Detected	Fuel injector cylinder 2 excess emissions / catalyst damaging level of misfire
P0303	Cylinder 3 Misfire Detected	Fuel injector cylinder 3 excess emissions / catalyst damaging level of misfire
P0304	Cylinder 4 Misfire Detected	Fuel injector cylinder 4 excess emissions / catalyst damaging level of misfire
P0305	Cylinder 5 Misfire Detected	Fuel injector cylinder 5 excess emissions / catalyst damaging level of misfire
P0306	Cylinder 6 Misfire Detected	Fuel injector cylinder 6 excess emissions / catalyst damaging level of misfire
P0307	Cylinder 7 Misfire Detected	Fuel injector cylinder 7 excess emissions / catalyst damaging level of misfire
P0308	Cylinder 8 Misfire Detected	Fuel injector cylinder 8 excess emissions / catalyst damaging level of misfire
P0309	Cylinder 9 Misfire Detected	
P0310	Cylinder 10 Misfire Detected	
P0311	Cylinder 11 Misfire Detected	
P0312	Cylinder 12 Misfire Detected	
P0320	Ignition / Distributor Engine Speed Input Circuit Malfunction	
P0321	Ignition / Distributor Engine Speed Input Circuit Range / Performance	
P0322	Ignition / Distributor Engine Speed Input Circuit No Signal	
P0323	Ignition / Distributor Engine Speed Input Circuit Intermittent	
P0325	Knock Sensor 1 Circuit Malfunction (Bank 1 or Single Sensor)	
P0326	Knock Sensor 1 Range / Perforance (Bank 1 or Single Sensor)	
P0327	Knock Sensor 1 Circuit Low Input (Bank 1 or Single Sensor)	Knock Sensor LH bank - signal smaller than threshold determined from ECM model above 2200 rev/min.
P0328	Knock Sensor 1 Circuit High Input (Bank 1 or Single Sensor)	Knock Sensor LH bank - signal greater than threshold determined from ECM model above 2200 rev/min.
P0329	Knock Sensor 1 Circuit Intermittent (Bank 1 or Single Sensor)	
P0330	Knock Sensor 2 Circuit Malfunction (Bank 2)	
P0331	Knock Sensor 2 Circuit Range / Performance (Bank 2)	
P0332	Knock Sensor 2 Circuit Low Input (Bank 2)	Knock Sensor RH bank - signal smaller than threshold determined from ECM model above 2200 rev/min.
P0333	Knock Sensor 2 Circuit High Input (Bank 2)	Knock Sensor RH bank - signal greater than threshold determined from ECM model above 2200 rev/min.
P0334	Knock Sensor 2 Circuit Intermittent (Bank 2)	
P0335	Crankshaft Position Sensor A Circuit Malfunction	CKP Sensor reference mark outside search window with engine speed above 500 rev/min for 2 rev/min
P0336	Crankshaft Position Sensor A Circuit Range / Performance	CKP Sensor - incorrect number of teeth detected ± 1 tooth between reference marks
P0337	Crankshaft Position Sensor A Circuit Low Input	
P0338	Crankshaft Position Sensor A Circuit High Input	
P0339	Crankshaft Position Sensor A Circuit Intermittent	
P0340	Camshaft Position Sensor Circuit Malfunction	Open/short circuit to vehicle supply or earth
P0341	Camshaft Position Sensor Circuit Range / Performance	
P0342	Camshaft Position Sensor Circuit Low Input	
P0343	Camshaft Position Sensor Circuit High Input	
P0344	Camshaft Position Sensor Circuit Intermittent	
P0350	Ignition Coil Primary / Secondary Circuit Malfunction	

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P0351	Ignition Coil A Primary / Secondary Circuit Malfunction	
P0352	Ignition Coil B Primary / Secondary Circuit Malfunction	
P0353	Ignition Coil C Primary / Secondary Circuit Malfunction	
P0354	Ignition Coil D Primary / Secondary Circuit Malfunction	
P0355	Ignition Coil E Primary / Secondary Circuit Malfunction	
P0356	Ignition Coil F Primary / Secondary Circuit Malfunction	
P0357	Ignition Coil G Primary / Secondary Circuit Malfunction	
P0358	Ignition Coil H Primary / Secondary Circuit Malfunction	
P0359	Ignition Coil I Primary / Secondary Circuit Malfunction	
P0360	Ignition Coil J Primary / Secondary Circuit Malfunction	
P0361	Ignition Coil K Primary / Secondary Circuit Malfunction	
P0362	Ignition Coil L Primary / Secondary Circuit Malfunction	
P0370	Timing Reference High Resolution Signal A Malfunction	
P0371	Timing Reference High Resolution Signal A Too Many Pulses	
P0372	Timing Reference High Resolution Signal A Too Few Pulses	
P0373	Timing Reference High Resolution Signal A Intermittent / Erratic Pulses	
P0374	Timing Reference High Resolution Signal A No Pulses	
P0375	Timing Reference High Resolution Signal B Malfunction	
P0376	Timing Reference High Resolution Signal B Too Many Pulses	
P0377	Timing Reference High Resolution Signal B Too Few Pulses	
P0378	Timing Reference High Resolution Signal B Intermittent / Erratic Pulses	
P0379	Timing Reference High Resolution Signal B No Pulses	
P0380	Glow Plug / Heater Circuit "A" Malfunction	
P0381	Glow Plug / Heater Indicator Circuit Malfunction	
P0382	Exhaust Gas Recirculation Flow Malfunction	
P0385	Crankshaft Position sensor B Circuit Malfunction	
P0386	Crankshaft Position Sensor B Circuit Range / Performance	
P0387	Crankshaft Position Sensor B Circuit Low Input	
P0388	Crankshaft Position sensor B Circuit High Input	
P0389	Crankshaft Position Sensor B Circuit Intermittent	
P0400	Exhaust Gas Recirculation Flow Malfunction	
P0401	Exhaust Gas Recirculation Flow Insufficient Detected	
P0402	Exhaust Gas Recirculation Flow Excessive Detected	
P0403	Exhaust Gas Recirculation Circuit Malfunction	
P0404	Exhaust Gas Recirculation Circuit Range / Performance	
P0405	Exhaust Gas Recirculation Sensor A Circuit Low	

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P0406	Exhaust Gas Recirculation Sensor A Circuit High	
P0407	Exhaust Gas Recirculation Sensor B Circuit Low	
P0408	Exhaust Gas Recirculation Sensor B Circuit High	
P0410	Secondary Air Injection System Malfunction	
P0411	Secondary Air Injection System Incorrect Flow Detected	
P0412	Secondary Air Injection System Switching Valve A Circuit Malfunction	
P0413	Secondary Air Injection System Switching Valve A Circuit Open	
P0414	Secondary Air Injection System Switching Valve A Circuit Shorted	
P0415	Secondary Air Injection System Switching Valve B Circuit Malfunction	
P0416	Secondary Air Injection System Switching Valve B Circuit Open	
P0417	Secondary Air Injection System Switching Valve B Circuit Shorted	
P0418	Secondary Air Injection System Relay "A" Circuit Malfunction	
P0419	Secondary Air Injection System Relay "B" Circuit Malfunction	
P0420	Catalyst System Efficiency Below Threshold (Bank 1)	Catalyst efficiency deteriorated - bank A
P0421	Warm Up Catalyst Efficiency Below Threshold (Bank 1)	Catalyst efficiency deteriorated - bank B
P0422	Main Catalyst Efficiency Below Threshold (Bank 1)	
P0423	Heated Catalyst Efficiency Below Threshold (Bank 1)	
P0424	Heated Catalyst Temperature Below Threshold (Bank 1)	
P0430	Catalyst System Efficieny Below Threshold (Bank 2)	
P0431	Warm Up Catalyst Efficiency Below Threshold (Bank 2)	
P0432	Main Catalyst Efficiency Below Threshold (Bank 2)	
P0433	Heated Catalyst Efficiency Below Threshold (Bank 2)	
P0434	Heated Catalyst Temperature Below Threshold (Bank 2)	
P0440	Evaporative Emission Control System Malfunction	Purge valve not sealing
P0441	Evaporative Emission Control System Incorrect Purge Flow	
P0442	**Evaporative Emission Control System Leak Detected (small leak)**	Small leak within system
P0443	Evaporative Emission System Purge Control Valve Circut Malfunction	Purge valve short circuit to battery voltage
P0444	Evaporative Emission Control System Purge Control Valve Circuit Open	Purge valve open circuit
P0445	Evaporative Emission Control System Purge Control Valve Circuit Shorted	Purge valve short circuit to ground
P0446	Evaporative Emission Control System Vent Control Circuit Malfunction	Purge canister vent valve functionality fault
P0447	Evaporative Emission Control System Vent Control Circuit Open	Purge canister vent valve power stage fault
P0448	Evaporative Emission Control System Vent Control Circuit Shorted	Purge canister vent valve power stage fault
P0449	Evaporative Emission Control System Vent Valve / Solenoid Circuit Malfunction	Purge canister vent valve power stage fault
P0450	Evaporative Emission Control System Pressure Sensor Malfunction	

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P0451	Evaporative Emission Control System Pressure Sensor Range / Performance	Fuel tank pressure signal stuck high within range
P0452	Evaporative Emission Control System Pressure Sensor Low Input	Fuel tank pressure signal short circuit to battery voltage (Out of range High)
P0453	Evaporative Emission Control System Pressure Sensor High Input	DST signal short circuit to ground or open circuit (out of range Low)
P0454	Evaporative	
P0455	Evaporative Emission Control System Leak Detected (gross leak)	
P0460	Fuel Level Sensor Circuit Malfunction	
P0461	Fuel Level Sensor Circuit Range / Performance	
P0462	Fuel Level Sensor Circuit Low Input	
P0463	Fuel Level Sensor Circuit High Input	
P0464	Fuel Level Sensor Circuit Intermittent	
P0465	Purge Flow Sensor Circuit Malfunction	
P0466	Purge Flow Sensor Circuit Range / Performance	
P0467	Purge Flow Sensor Circuit Low Input	
P0468	Purge Flow Sensor Circuit High Input	
P0469	Purge Flow Sensor Circuit Intermittent	
P0470	Exhaust Pressure Sensor Malfunction	
P0471	Exhaust Pressure Sensor Malfunction	
P0472	Exhaust Pressure Sensor Range / Performance	
P0473	Exhaust Pressure Sensor High	
P0474	Exhaust Pressure Sensor Intermittent	
P0475	Exhaust Pressure Control Valve Malfunction	
P0476	Exhaust Pressure Control Valve Range / Performance	
P0477	Exhaust Pressure Control Valve Low	
P0478	Exhaust Pressure Control Valve High	
P0479	Exhaust Pressure Control Valve Intermittent	
P0480	Cooling Fan 1 Control Circuit Malfunction	
P0481	Cooling Fan 2 Control Circuit Malfunction	
P0482	Cooling Fan 3 Control Circuit Malfunction	
P0483	Cooling Fan Rationality Check Malfunction	
P0484	Cooling Fan Circuit Over Current	
P0485	Cooling Fan Power / Ground Circuit Malfunction	
P0500	Vehicle Speed Sensor Malfunction	Vehicle speed signal open / short circuit
P0501	Vehicle Speed Sensor Range / Performance	Vehicle speed signal implausible
P0502	Vehicle Speed Sensor Circuit Low Input	
P0503	Vehicle Speed Sensor Intermittent / Erratic / High	
P0505	Idle Control System Malfunction	
P0506	Idle Control System RPM Lower Than Expected	
P0507	Idle Control System RPM Higher Than Expected	
P0510	Closed Throttle Position Switch Malfunction	
P0520	Engine Oil Pressure Sensor / Switch Circuit Malfunction	
P0521	Engine Oil Pressure Sensor / Switch Circuit Range / Performance	
P0522	Engine Oil Pressure Sensor / Switch Circuit Low Voltage	
P0523	Engine Oil Pressure Sensor / Switch Circuit High Voltage	
P0530	A/C Refrigerant Pressure Sensor Circuit Malfunction	
P0531	A/C Refrigerant Pressure Sensor Circuit Range / Performance	

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P0532	A/C Refrigerant Pressure Sensor Circuit Low Input	
P0533	A/C Refrigerant Pressure Sensor Circuit High Input	
P0534	Air Conditioner Refrigerant Charge Loss	
P0550	Power Steering Pressure Sensor Circuit Malfunction	
P0551	Power Steering Pressure Sensor Circuit Range / Performance	
P0552	Power Steering Pressure Sensor Circuit Low Input	
P0553	Power Steering Pressure Sensor Circuit High Input	
P0554	Power steering Pressure sensor Circuit Intermittent	
P0560	System Voltage Malfunction	Power supply system voltage error
P0561	System Voltage Unstable	
P0562	System Voltage Low	Power supply system voltage low
P0563	System Voltage High	Power supply system voltage high
P0565	Cruise Control On Signal Malfunction	
P0566	Cruise Control Off Signal Malfunction	
P0567	Cruise Control Resume Signal Malfunction	
P0568	Cruise Control set Signal Malfunction	
P0569	Cruise Control Coast Signal Malfunction	
P0570	Cruise Control Accel Signal Malfunction	
P0571	Cruise Control / Brake Switch A Circuit Malfunction	
P0572	Cruise Control / Brake Switch A Circuit Low	
P0573	Cruise Control / Brake Switch A Circuit High	
P0574	Cruise Control Related malfunction	
P0575	Cruise Control Related Malfunction	
P0576	Cruise Control Related Malfunction	
P0577	Cruise Control Related Malfunction	
P0578	Cruise Control Related Malfunction	
P0579	Cruise Control Related Malfunction	
P0580	Cruise Control Related Malfunction	
P0600	Serial Communication Link Malfunction	Controller Area Network (CAN) timed out
P0601	Internal Control Module Memory Check Sum Error	CPU ROM fault
P0602	Control Module Programming Error	
P0603	Internal Control Module Keep Alive Memory (KAM) Error	External RAM fault or fault memory errors implausible
P0604	Internal Control Module Random Access Memory (RAM) Error	Internal RAM fault
P0605	Internal control Module Read Only Memory (ROM) Error	
P0606	PCM Processor Fault	Knock ASIC test pulse or zero test error encountered (ECU self test)
P0608	Control Module VSS Output "A" Malfunction	
P0609	Control Module VSS Output "B" Malfunction	
P0620	Generator Control Circuit Malfunction	
P0621	Generator Lamp "L" Control Circuit Malfunction	
P0622	Generator Field "F" Control Circuit Malfunction	
P0650	Malfunction Indicator Lamp (MIL) Control Circuit Malfunction	
P0654	Engine RPM Output Circuit Malfunction	Engine speed signal open circuit, short to ground or short to battery voltage

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P0655	Engine Hot Lamp Output Control Circuit Malfunction	
P0656	Fuel Level Output Circuit Malfunction	
P0700	Transmission Control system Malfunction	
P0701	Transmission Control System Range / Performance	
P0702	Transmission Control system Electrical	
P0703	Torque Converter / Brake Switch B Circuit Malfunction	
P0704	Clutch Switch Input Circuit Malfunction	
P0705	Transmission Range Sensor Circuit Malfunction (PRNDL Input)	
P0706	Transmission Range Sensor Circuit Range / Performance	
P0707	Transmission Range Sensor Circuit Low Input	
P0708	Transmission Range Sensor Circuit High Input	
P0709	Transmission Range Sensor Circuit Intermittent	
P0710	Transmission Fluid Temperature Sensor Circuit Malfunction	
P0711	Transmission Fluid Temperature Sensor Circuit Range / Performance	
P0712	Transmission Fluid Temperature Sensor Circuit Low Input	
P0713	Transmission Fluid Temperature Sensor Circuit High Input	
P0714	Transmission Fluid Temperature Sensor Circuit Intermittent	
P0715	Input / Turbine Speed Sensor Circuit Malfunction	
P0716	Input / Turbine Speed Sensor Circuit Range / Performance	
P0717	Input / Turbine speed Sensor Circuit No Signal	
P0718	Input / Turbine Speed Sensor Circuit Intermittent	
P0719	Torque Converter / Brake Switch B Circuit Low	
P0720	Output Speed Sensor Circuit Malfunction	
P0721	Output Speed Sensor Circuit Range / Performance	
P0722	Output Speed Sensor No Signal	
P0723	Output Speed Sensor Intermittent	
P0724	Torque Converter / Brake Switch B Circuit High	
P0725	Engine Speed Input Circuit Malfunction	
P0726	Output Speed sensor Range / Performance	
P0727	Engine Speed Input Circuit No Signal	
P0728	Engine Speed Input Circuit Intermittent	
P0730	Incorrect Gear Ratio	
P0731	Gear 1 Incorrect Ratio	
P0732	Gear 2 Incorrect Ratio	
P0733	Gear 3 Incorrect Ratio	
P0734	Gear 4 Incorrect Ratio	
P0735	Gear 5 Incorrect Ratio	
P0736	Reverse Gear Incorrect Ratio	
P0740	Torque Converter Clutch Circuit Malfunction	
P0741	Torque Converter Clutch Circuit Performance or Stuck Off	
P0742	Torque Converter Clutch Circuit Stuck On	
P0743	Torque Converter Clutch Circuit Electrical	
P0744	Torque Converter Clutch Circuit Intermittent	
P0745	Pressure Control Solenoid Malfunction	

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P0746	Pressure Control Solenoid Performance or Stuck Off	
P0747	Pressure Control Solenoid Stuck On	
P0748	Pressure Control Solenoid Electrical	
P0749	Pressure Control Solenoid Intermittent	
P0750	Shift Solenoid A Malfunction	
P0751	Shift Solenoid A Performance or Stuck Off	
P0752	Shift Solenoid A Stuck On	
P0753	Shift Solenoid A Electrical	
P0754	Shift Solenoid A Intermittent	
P0755	Shift Solenoid B Malfunction	
P0756	Shift Solenoid B Performance or Stuck Off	
P0757	Shift Solenoid B Stuck On	
P0758	Shift Solenoid B Electrical	
P0759	Shift Solenoid B Intermittent	
P0760	Shift Solenoid C Malfunction	
P0761	Shift Solenoid C Performance or Stuck Off	
P0762	Shift Solenoid C Stuck On	
P0763	Shift Solenoid C Electrical	
P0764	Shift Solenoid C Intermittent	
P0765	Shift Solenoid D Malfunction	
P0766	Shift Solenoid D Performance or Stuck Off	
P0767	Shift Solenoid D Stuck On	
P0768	Shift Solenoid D Electrical	
P0769	Shift Solenoid D Intermittent	
P0770	Shift Solenoid E Malfunction	
P0771	Shift Solenoid E Performance or Stuck Off	
P0772	Shift Solenoid E Stuck On	
P0773	Shift Solenoid E Electrical	
P0774	Shift Solenoid E Intermittent	
P0780	Shift Malfunction	
P0781	1-2 Shift Malfunction	
P0782	2-3 Shift Malfunction	
P0783	3-4 Shift Malfunction	
P0784	4-5 Shift Malfunction	
P0785	Shift / Timing Solenoid Malfunction	
P0786	Shift / Timing Solenoid Range / Performance	
P0787	Shift / Timing Solenoid Low	
P0788	Shift / Timing Solenoid High	
P0789	Shift / Timing Solenoid Intermittent	
P0790	Normal / Performance Switch Circuit Malfunction	
P0801	Reverse Inhibit Control Circuit Malfunction	
P0803	1-4 Upshift (Skip Shift) Solenoid Control Circuit Malfunction	
P0804	1-4 Upshift (Skip Shift) Lamp Control Circuit Malfunction	
P1000	PCM has been reset, no diagnostic results available	Permanent power supply interrupted
P1117	Engine Coolant Temperature Radiator Outlet Sensor Low Input	
P1118	Engine Coolant Temperature Radiator Outlet Sensor High Input	
P1129	**O_2 Sensors Swapped Bank to Bank (Sensor 1)**	Front HO_2 Sensors transposed

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P1170	Downstream Fuel Trim Malfunction (Bank 1)	Front HO_2 Sensor aged - ATV adaption too lean / too rich LH bank
P1171	System too Lean Bank A	Additive injector adaptive fuelling, lean limit exceeded LH bank
P1172	System too Rich Bank A and Bank B	Additive injector adaptive fuelling, rich limit exceeded LH bank
P1173	Downstream Fuel Trim Malfunction (Bank 2)	Front HO_2 Sensor aged - ATV adaption too lean / too rich RH bank
P1174	System too Lean Bank B	Additive injector adaptive fuelling, lean limit exceeded RH bank
P1175	System too Rich Bank B	Additive injector adaptive fuelling, rich limit exceeded RH bank
P1776		Electronic Automatic Transmission (EAT) Torque interface error
P1188	Fuelling Trim Adaption Bank A	
P1189	Fuelling Trim Adaption Bank B	
P1230	Fuel Pump Relay Malfunction	Fuel pump relay open circuit
P1231	Fuel Pump Relay Circuit Low	Fuel pump relay short circuit to battery supply
P1232	Fuel Pump Relay Circuit High	Fuel pump relay short circuit to earth
P1300	Misfire Detected Sufficient to Cause Catalyst Damage	Catalyst damaging level of misfire on more than onecylinder
P1301	No description	Catalyst damaging level of misfire detected on cylinder No.1
P1302	No description	Catalyst damaging level of misfire detected on cylinder No. 2
P1303	No description	Catalyst damaging level of misfire detected on cylinder No. 3
P1304	No description	Catalyst damaging level of misfire detected on cylinder No.4
P1305	No description	Catalyst damaging level of misfire detected on cylinder No.5
P1306	No description	Catalyst damaging level of misfire detected on cylinder No.6
P1307	No description	Catalyst damaging level of misfire detected on cylinder No.7
P1308	No description	Catalyst damaging level of misfire detected on cylinder No. 8
P1319		Misfire Detected at Low Fuel Level
P1412	Secondary Air Injection System Malfunction (Bank 1)	
P1413	Secondary Air Injection System Air Control Valve Always Open (Bank 1)	
P1414	Secondary Air Injection System Low Air Flow (Bank 1)	
P1415	Secondary Air Injection System Malfunction (Bank 2)	
P1416	Secondary Air Injection System Air Control Valve Always Open (Bank 2)	
P1417	Secondary Air Injection System Low Air Flow (Bank 2)	
P1450	Evaporative Emission Control System Leakage Pump Circuit Plausibility	
P1451	Evaporative Emission Control System Leakage Pump Circuit High	
P1452	Evaporative Emission Control System Leakage Pump Circuit Low Current	
P1453	Evaporative Emission Control System Leakage Pump Circuit High Current	
P1509	IACV Opening Coil Malfunction	Open circuit or short circuit to battery supply or earth - opening windings
P1510	IACV - Opening Coil Circuit Malfunction	
P1513	IACV - opening Coil Circuit Low	
P1514	IACV Opening Coil Circuit High	
P1535	Air Conditioning Compressor Request Malfunction	ATC requested when not in standby mode

P-Code	SAE J2012 Description	Land Rover / Rover Description (Example - depends on ECM)
P1536	Air Conditioning Compressor Request Range / Performance	ATC compressor clutch relay open circuit
P1537	Air Conditioning Compressor Request Low Input	**ATC compressor clutch relay short to earth**
P1538	Air Conditioning Compressor Request High Input	ATC compressor clutch relay short to battery supply
P1550	IACV - Closing Coil Malfunction	Open circuit or short circuit to battery supply or earth - closing windings
P1551	IACV - Closing Coil Circuit Malfunction	
P1552	IACV - Closing Coil Circuit Low	
P1553	IACV - Closing Coil Circuit High	
P1590	ABS Rough Road Signal Circuit Malfunction	Hardware is OK but the SLABS ECU is sending an error signal
P1591	ABS Rough Road Signal Circuit Low	Signal from SLABS ECU shorted to ground or open circuit
P1592	ABS Rough Road Signal Circuit High	Signal from SLABS ECU shorted to battery voltage
P1663	Throttle Angle / Torque Signal Circuit Malfunction	SLABS HDC link open circuit
P1664	Throttle Angle / Torque Signal Circuit Low	SLABS HDC link short to ground
P1665	Throttle Angle / Torque Signal Circuit High	SLABS HDC link short circuit to battery voltage
P1666	Engine Anti-Theft Signal Circuit Malfunction	BCU serial link frame / bit timing error
P1667	Engine Anti-Theft Signal Circuit Low	Serial link short to earth
P1668	Engine Anti-Theft Signal Circuit High	Serial link open circuit
P1669	Engine Control Module Cooling Fan Circuit Malfunction	
P1670	Engine Control Module Cooling Fan Circuit Low	
P1671	Engine Control Module Cooling Fan Circuit High	
P1672	Engine Anti-Theft Signal Wrong Code Received	Secure ECM, received incorrect code
P1673	Engine Anti-Theft Signal New Engine Control Module Not Configured	New ECM fitted
P1674	**Engine Anti-Theft Signal**	No code ECM, valid code received
P1675	Condensor Fan Circuit Malfunction	
P1700	Transfer Box Indicated Range - Performance	Low range signal implausible
P1701	Transfer Box has signalled a fault condition to the Engine Control Module	
P1702	Transfer Box - Signal Line Communication Frame Error	
P1703	Transfer box link - signal line permanently at 12V or open circuit	
P1708	Transfer box link - signal line permanently at ground	
P1776	Transmission Control System Torque Interface Malfunction	

List of Abbreviations and Acronyms

The following list contains explanations of abbreviations and acronyms likely to be encountered when dealing with emissions and On-Board Diagnotics systems:

Abbreviation	Description
ABS	Anti-lock Brake System
ACEA	European Automobile Manufacturer's Association
ASC	Automatic Stability Control
C	Centigrade (temperautre reading in °C)
CAL EPA	California Environmental Protection Agency
CARB	California Air Resources Board
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DDE	Digital Diesel Electronics
DLC	Data Link Connector (standardised 16-pin diagnostic connector)
Drive Cycle	A specific sequence of start-up, warm-up and driving tasks that tests all OBD functions
DTC	Diagnostic Trouble Code (standardised trouble codes)
EC	European Community
ECM	Engine Control Module - the main in-car computer controlling emissions and engine operation
EDC	European Drive Cycle
EEPROM	Electrically Erasable Programmable Read Only Memory
EFI	Electronic Fuel Injection
EGR	Exhaust Gas Recirculation
E-OBD	European On-Board Diagnostics
EPA	Environmental Protection Agency
ESC	Electronic Spark Control
EST	Electronic Spark Timing
EU	European Union (relates to European exhaust-emissions legislation)
EUI	Electronic Unit Injector
EVAP	Evaporative Emissions
FTP	Federal Test Procedure
Fuel Trim	Engine computer function that keeps the air / fuel mixture as close to the ideal stoichiometric ratio as possible (when λ = 1, air:fuel = 14.7 :1)
g	Gramme
H_2O	Water
HC	Hydrocarbons
HO_2S	Heated Oxygen Sensor
H_2SO_4	Sulphuric Acid
ISO 9141	International Standards Organization OBDII communications mode. One of three hardware layers defined by OBDII
J1850PWM	Pulse Width Modulated - SAE-establihed OBDII communication standard. One of three hardware layers defined by OBDII
J1850VPW	Variable Pulse Width Modulated - SAE-established OBDII communication standard. One of three hardware layers defined by OBDII
J1962	SAE-established standard for the connector plug layout used for all OBDII scan tools
J1978	SAE-established standard for OBDII scan tools
J1979	SAE-established standard for diagnostic test modes
J2012	SAE-established standard accepted by EPA as the standard report language for emission tests
JAMA	Japanese Association of Automotive Manufacturers
KAMA	Korean Association of Automotive Manufacturers

Abbreviation	Description
K	Kelvin (temperature reading in °K)
kg	Kilogramme
km	**Kilometre**
kPa	KiloPascal (pressure measurement)
LCD	Liquid Crystal Display
LEV	Low Emission Vehicle
MAF	Mass Air Flow
MAP	Manifold Absolute Pressure
MAT	Manifold Air Temperature
MI	Malfunction Indicator
MIL	Malfunction Indicator Light - also known as "Check Engine Light" and "Service Engine Soon Light"
MY	Model Year
NEDC	New European Driving Cycle
N_2	Nitrogen
NO_x	Oxides of Nitrogen
NO_2	Nitrogen Dioxide
O_2S	Oxygen Sensor
OBD	On-Board Diagnostics
OBDII	Updated On-Board Diagnostics standard effective in cars sold in the US after 1-1-96
OBM	On-Board Measurement
OEM	Original Equipment Manufacturer
Parameters	Readings on scan tools representing functions measured by OBDII and proprietry readings
PCM	Powertrain Control Module, the on-board computer that controls engine and drive train
PCV	Positive Crankcase Ventilation
PM	Particulate Matter
Proprietry Readings	Parameters shown by on-board computers which are not required by OBDII, but included by manufacturer to assist in trouble-shooting specific vehicles.
PTC	Pending Trouble Code
RPM or rev/min.	Revolutions Per Minute
SAE	Society of Automotive Engineers, professional organization that set the standards that EPA adopted for OBD and OBDII
Scan Tool	Computer based read-out equipment to display OBDII parameters
SES	Service Engine Soon warning lamp - see MIL
SFI	Sequential Fuel Injection
SI	Spark Ignition
SMMT	Society of Motor Manufacturers and Traders
SO_2	Sulphur Dioxide
Stoichiometric Ratio	Theoretical perfect combustion ratio of 1 part fuel to 14.7 parts air
TBI	Throttle Body Injection
Testbook	Diagnostic tool used by Rover / Land Rover
TPS	Throttle Position Sensor
UK	United Kingdom
ULEV	Ultra Low Emission Vehicle
US	United States
VAC	Vacuum
VOC	Volatile Organic Compound
VSS	Vehicle Speed Sensor
WOT	Wide Open Throttle
ZEV	Zero Emission Vehicle

Secondary Air Injection

Secondary air injection is not yet mandatory in the European market, but is scheduled for introduction from 2002MY. Land Rover vehicles currently sold in the California market are already equipped with a Secondary Air Injection (SAI) system and include OBD monitoring. A description and operation of the SAI systems and components used on Discovery II vehicles with V8 engine for the California market have been included here as a means of introduction to the topic and technology.

Secondary air injection system component layout

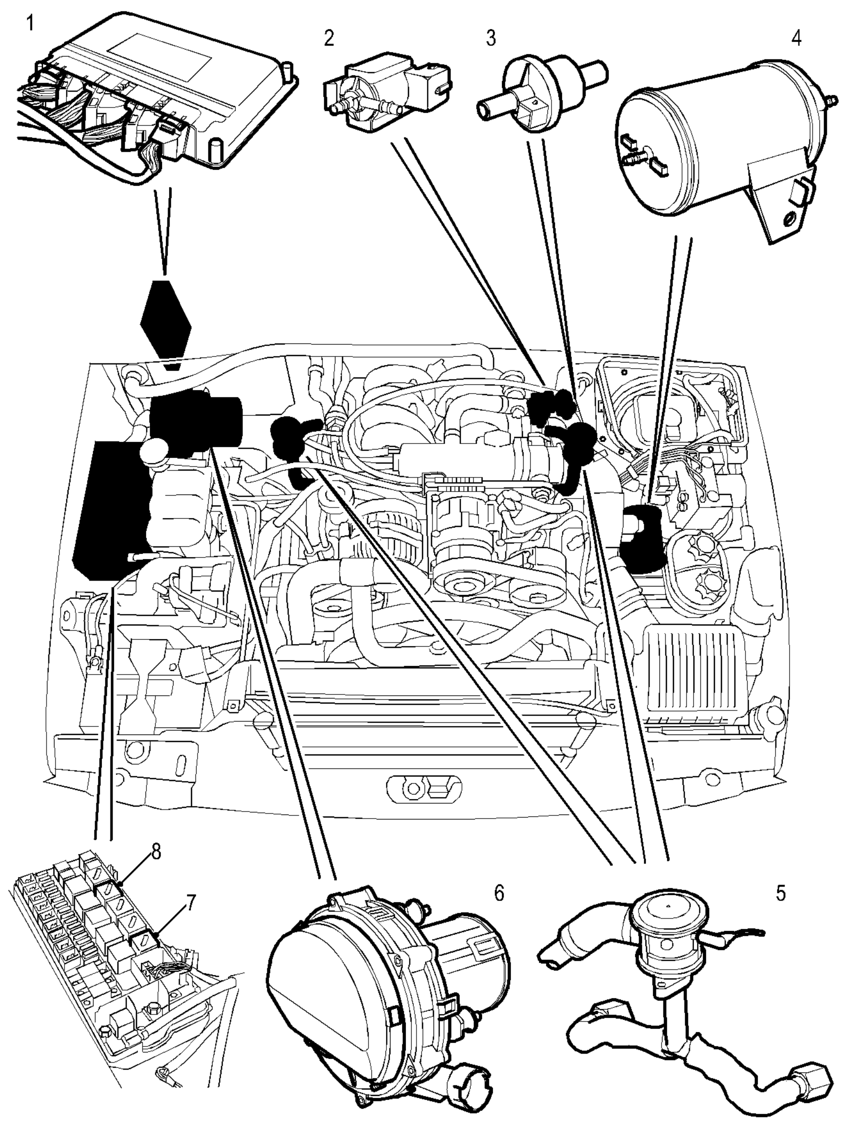


Figure 6

1.Engine Control Module (ECM)
2.SAI vacuum solenoid valve
3.Purge valve
4.Vacuum reservoir
5.SAI control valve (2 off)
6.SAI pump
7.SAI pump relay
8.Main relay

Secondary air injection system control diagram

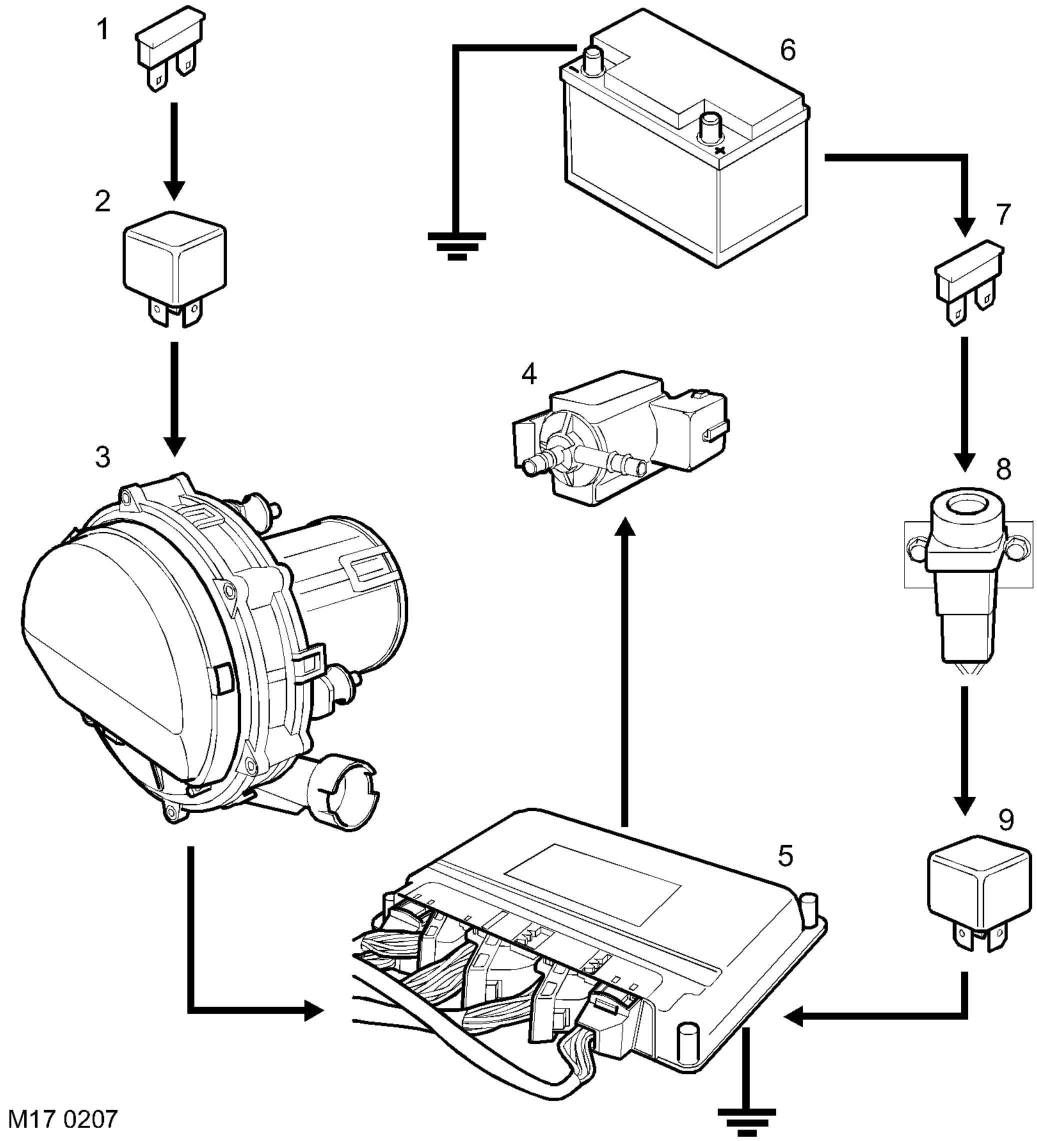


Figure 7

1.Fuselink (engine compartment fusebox)
2.SAI pump relay
3.SAI pump
4.SAI vacuum solenoid valve (grey harness connector)
5.Engine Control Module (ECM)
6.Battery
7.Fuse (engine compartment fusebox)
8.Inertia switch
9.Main relay

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 burnt off during the combustion process.

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 unburnt fuel particles leaving the combustion chamber mix with the air injected into the exhaust ports and immediately combust. This subsequent combustion of the unburnt and partially burnt 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 (1472°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 55º 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 pipework 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-energise 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 system components

The secondary air injection (SAI) system components are described below:

Secondary air injection (SAI) pump

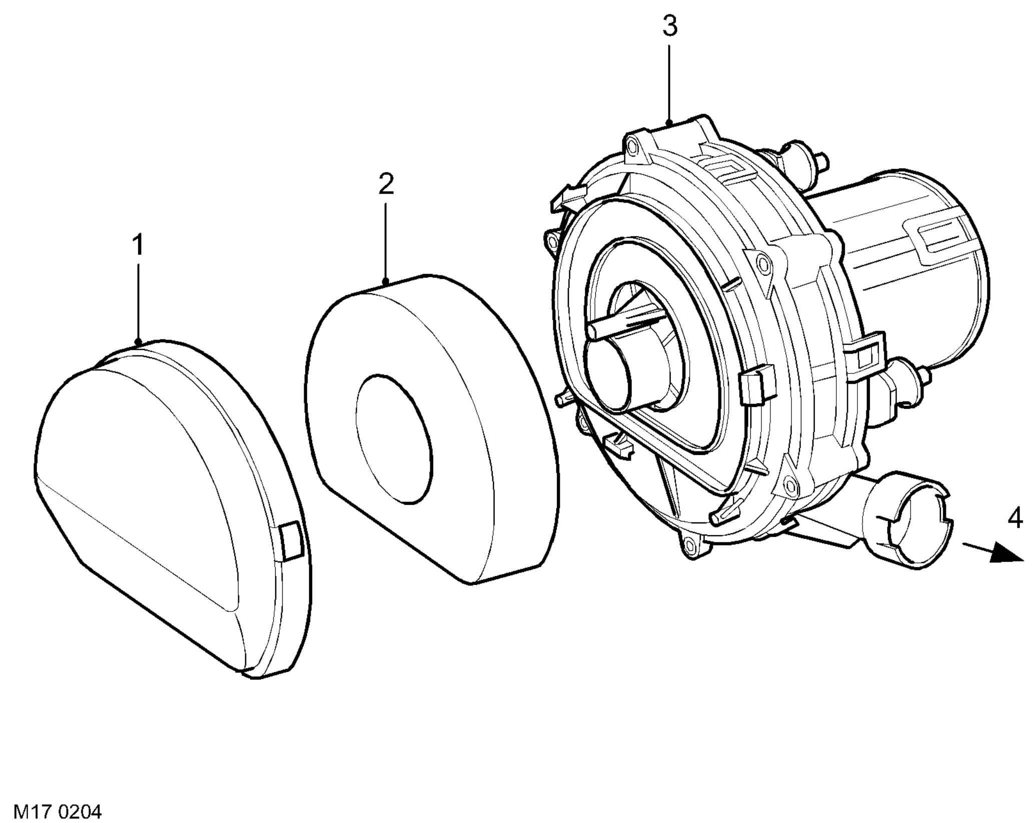


Figure 8

1.SAI pump cover
2.Foam filter
3.SAI pump
4.Pressurised 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 35 kg/hr of air when the vehicle is at idle in Neutral/Park on a start from 20°C (68°F).

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 pipework via a short rubber hose. The metal delivery pipe has a fabricated T-piece included where the pressurised 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 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 fitted 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	SAE J2012 Description	Land Rover Description
P0418	Secondary Air Injection System Relay "A" Circuit Malfunction	Secondary air injection pump powerstage 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 fusebox. 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 a fusible link located in the engine compartment fusebox.

Secondary air injection (SAI) vacuum solenoid valve

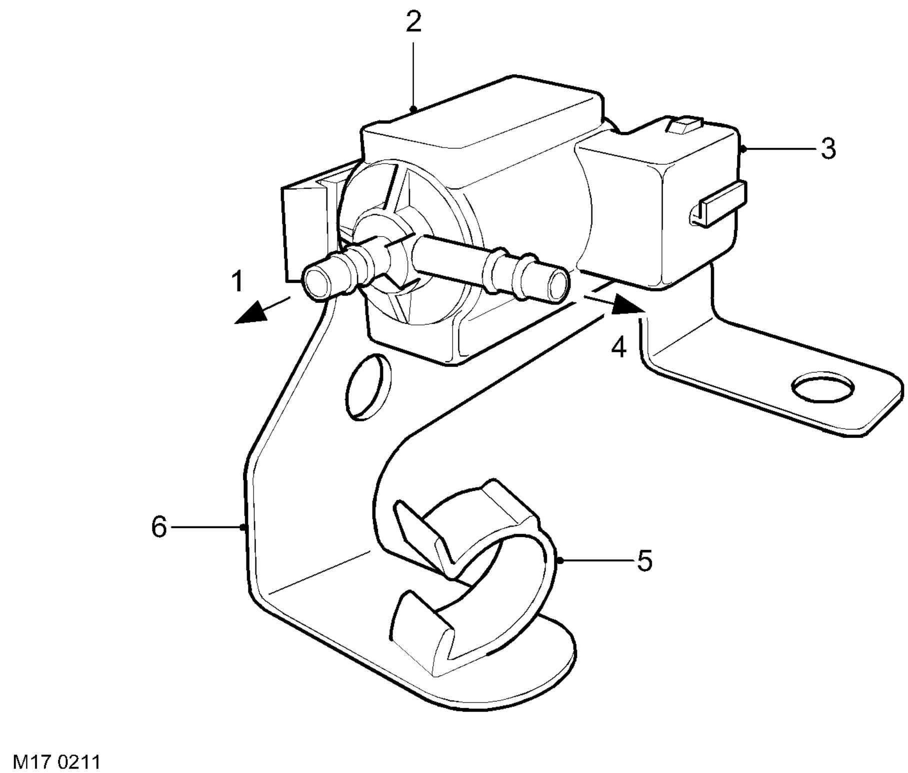


Figure 9

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

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 sleeving.

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 a fuse in the engine compartment fusebox. The ground connection is via the ECM which controls the SAI vacuum solenoid valve operation.

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	SAE J2012 Description	Land Rover Description
P0413	Secondary Air Injection System Switching Valve A Circuit Open	SAI vacuum solenoid valve not connected, open circuit
P0414	Secondary Air Injection System Switching Valve A Circuit Shorted	SAI vacuum solenoid valve short circuit to ground
P0412	Secondary Air Injection System Switching Valve A Circuit Malfunction	SAI vacuum solenoid valve powerstage fault - harness damage, short circuit to battery supply voltage

SAI control valves

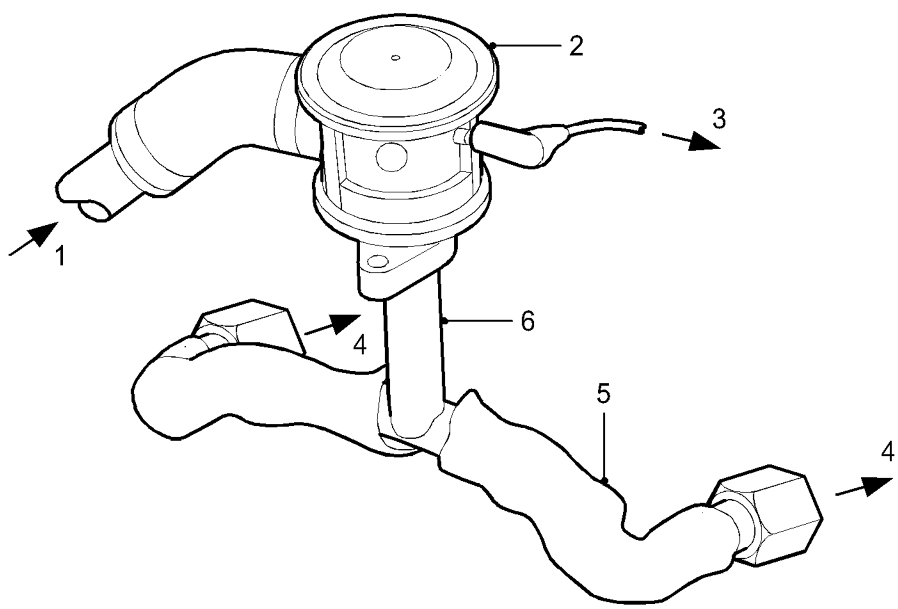


Figure 10

1.Pressurised air from SAI pump
2.Vacuum operated SAI control valve
3.Vacuum hose from SAI vacuum solenoid valve
4.Pressurised air to exhaust manifold
5.Protective heat sleeving
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 pressurised 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 pressurised air delivered to ports at the outer side of the two centre exhaust ports on each cylinder head. The pipes between the T-piece and the exhaust manifold are enclosed in thermal sleeving 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-energised, 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	Land Rover 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

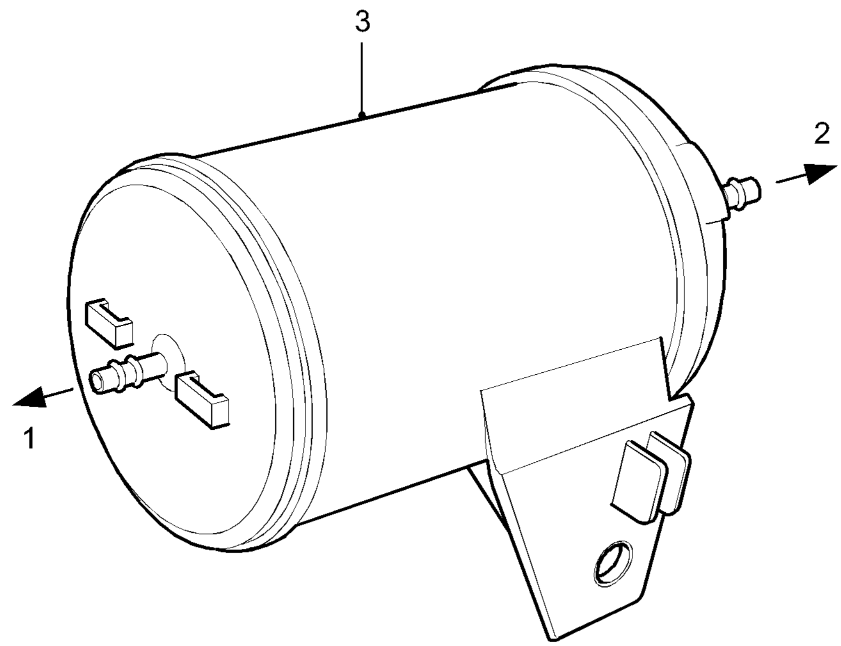


Figure 11

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 depression 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 energised.

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 fitted 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 fitted 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.

Secondary air injection system operation

When the engine is started, the engine control module checks the engine coolant temperature and if it is below 55° C, the ECM grounds the electrical connection to the coil of the secondary air injection (SAI) pump relay.

A 12V battery supply is fed to the inertia switch via a fuse in the engine compartment fusebox. When the inertia switch contacts are closed, the feed passes through the switch and is connected to the coil of the Main relay. An earth connection from the Main relay coil is connected to the ECM. When the ECM completes the earth path, the coil energises and closes the contacts of the Main relay.

The Main and Secondary Air Injection (SAI) pump relays are located in the engine compartment fusebox. When the contacts of the Main relay are closed, a 12V battery supply is fed to the coil of the SAI pump relay. An earth connection from the coil of the SAI pump relay is connected to the ECM. When the ECM completes the earth path, the coil energises and closes the contacts of the SAI pump relay to supply 12V to the SAI pump via a fusible link in the engine compartment fusebox. The SAI pump starts to operate, and will continue to do so until the ECM switches off the earth connection to the coil of the SAI pump relay.

The SAI pump remains operational for a period determined by the ECM and depends on the starting temperature of the engine, or for a maximum operation period determined by the ECM if the target engine coolant temperature has not been reached in the usual time.

When the contacts of the main relay are closed, a 12V battery supply is fed to the SAI solenoid valve via a fuse in the engine compartment fusebox.

The ECM grounds the electrical connection to the SAI vacuum solenoid valve at the same time as it switches on the SAI pump motor. When the SAI vacuum solenoid valve is energised, a vacuum is provided to the operation control ports on both of the vacuum operated SAI control valves at the exhaust manifolds. The control vacuum is sourced from the intake manifold depression and routed to the SAI control valves via a vacuum reservoir and the SAI vacuum solenoid valve.

The vacuum reservoir is included in the vacuum supply circuit to prevent vacuum fluctuations caused by changes in the intake manifold depression affecting the operation of the SAI control valves.

When a vacuum is applied to the control ports of the SAI control valves, the valves open to allow pressurised air from the SAI pump to pass through to the exhaust ports in the cylinder heads for combustion.

When the ECM has determined that the SAI pump has operated for the desired duration, it switches off the earth paths to the SAI pump relay and the SAI vacuum solenoid valve. With the SAI vacuum solenoid valve de-energised, the valve closes, cutting off the vacuum supply to the SAI control valves. The SAI control valves close immediately and completely to prevent any further pressurised air from the SAI pump entering the exhaust manifolds.

The engine coolant temperature sensor incurs a time lag in respect of detecting a change in temperature and the SAI pump automatically enters a 'soak period' between operations to prevent the SAI pump overheating. The ECM also compares the switch off and start up temperatures, to determine whether it is necessary to operate the SAI pump. This prevents the pump running repeatedly and overheating on repeat starts.

Other factors which may prevent or stop SAI pump operation include the prevailing engine speed / load conditions.

Evaporative Emissions Systems

Although OBD monitoring of EVAP systems is not yet mandatory within the European Union, it is likely that stricter control of evaporative emissions will be introduced in future legislation. By way of introduction to the topic, description and operation of systems currently fitted to Land Rover Discovery II vehicles for sale in California are included here.

Evaporative emission system component layout

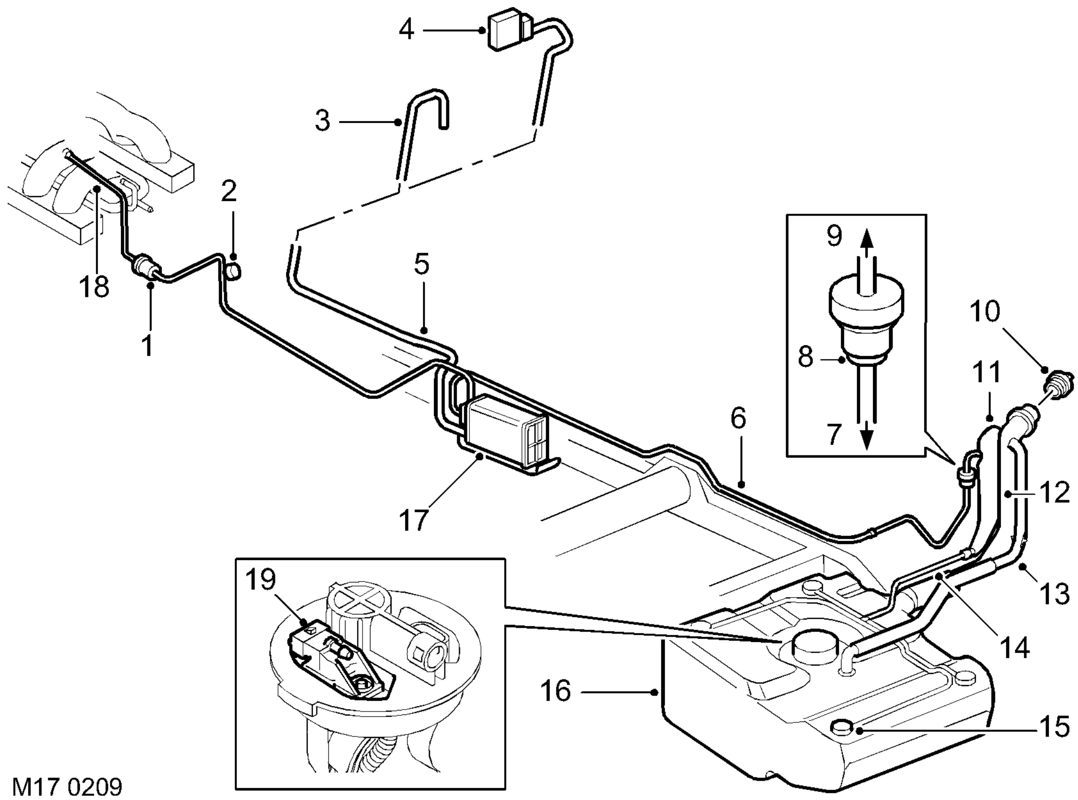


Figure 12

1.Purge valve
2.Service port
3.Snorkel tube (vehicles without OBD for EVAPs)
4.CVS unit (vehicles with OBD vacuum type leak detection only)
5.EVAP canister breather tube
6.Vent pipe – fuel tank to EVAP canister
7.Relief valve regulated flow
8.Relief valve (where applicable)
9.Relief valve free flow
10.Fuel filler cap
11.Liquid vapour separator
12.Fuel filler hose
13.Tank breather hose
14.Vent hose
15.Roll over valves (ROV's) – (4 off)
16.Fuel tank and breather assembly
17.EVAP canister
18.Purge line connection to engine manifold
19.Tank EVAP system pressure sensor (vehicles with OBD vacuum type leak detection only)

Evaporative emission system (with OBD positive pressure leak detection) component layout

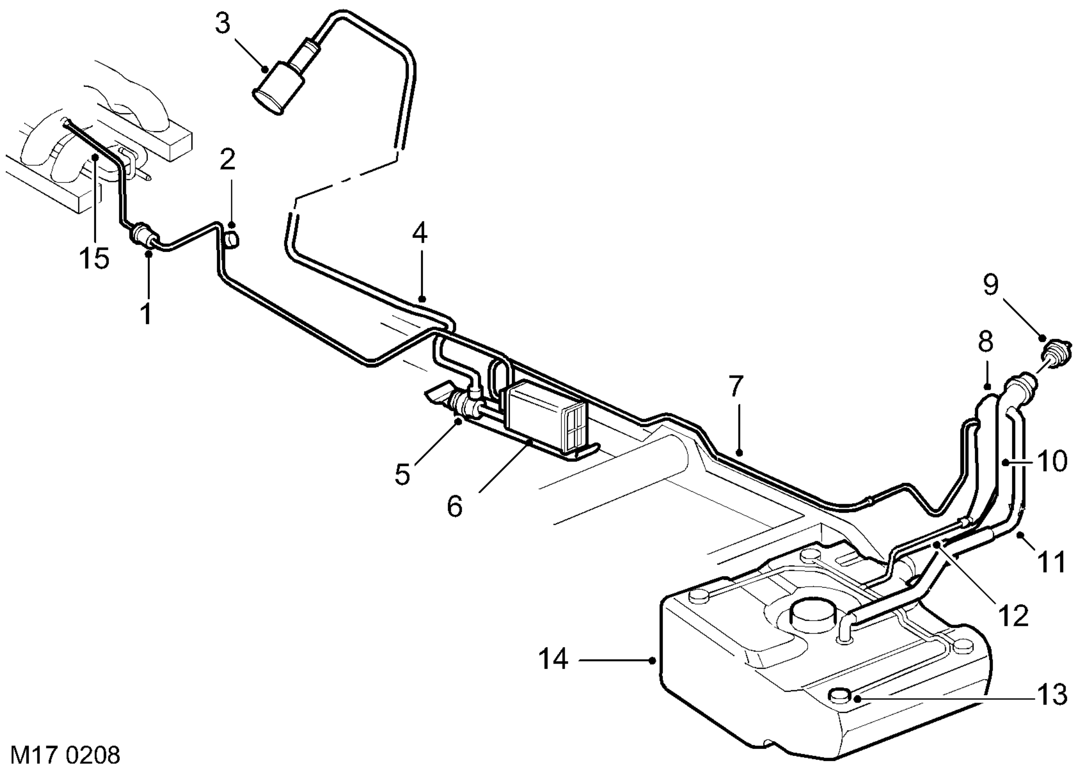


Figure 13

1.Purge valve
2.Service port
3.Air filter canister
4.EVAP canister breather tube
5.Leak detection pump
6.EVAP canister
7.Vent pipe – fuel tank to EVAP canister
8.Liquid vapour separator (metal)
9.Fuel filler cap
10.Fuel filler
11.Fuel tank breather assembly
12.Vent hose
13.Roll over valves (inside fuel tank)
14.Fuel tank
15.Purge line connection to engine manifold

Evaporative emission control system

The evaporation emission control (EVAP) system is used to reduce the level of hydrocarbons emitted into the atmosphere from the fuel system. The system comprises an EVAP canister which stores the hydrocarbons from the fuel tank, pressure valves, vent lines and a purge control solenoid valve.

Fuel vapour is stored in the canister until it is ready to be purged to the inlet manifold under the control of the Engine Control Module (ECM).

Four ROV's are fitted to the fuel tank. Nylon vent lines from the ROV's connect to the liquid vapour separator allow vapour to pass to the EVAP canister via the LVS. To prevent the canister from being overloaded (particularly in hot ambient conditions) and to prevent wastage of fuel, the vapour is allowed to condense within the LVS and flow back through the ROVs into the tank.

Pressure / vacuum relief valves are incorporated into the fuel filler cap which operate in the event of an evaporation system failure (e.g. blockage in the evaporation system line to atmosphere). The cap relieves fuel tank pressure to atmosphere at approximately 1.8 to 2.0 psi (12 to 14 kPa) and opens in the opposite direction at approximately – 0.7 psi (- 5kPa) vacuum. All plastic bodied fuel fillers are fitted with a tank overpressure relief valve.

A vent line flow restrictor (anti-trickle valve) is sometimes fitted to the filler pipe in the line between the tank and the canister. The purpose of the anti-trickle valve is to preserve the vapour space in the tank by blocking the vent line during the fuel filling process. The valve is operated by the action of inserting the filler gun, so that when the fuel in the tank reaches the level of the filling breather, flow cut off occurs due to fuel filling the filler pipe.

The breather ports from the EVAP canister are located high up in the engine bay (CVS unit on OBD vehicles with vacuum type, fuel evaporation leak detection capability; via an air filter on OBD vehicles with positive pressure type, fuel evaporation leak detection capability; snorkel tubes on non-OBD vehicles), to prevent water ingress during vehicle wading.

Fuel leak detection system (vacuum type)

The advanced evaporative loss control system equipped with a vacuum type, fuel evaporation leak detection capability is similar to the standard evaporative loss system, but also includes additional components to enable the engine control module (ECM) to perform a fuel evaporation leak detection test as part of the OBD strategy. The system includes an EVAPs canister and purge valve, and in addition, a canister vent solenoid (CVS) valve and a fuel tank pressure sensor.

The function of the CVS valve is to block the atmospheric vent side of the EVAP canister under the control of the ECM so that an evaporation system leak check can be performed. The test is carried out when the vehicle is stationary and the engine is running at idle speed. The system test uses the natural rate of fuel evaporation and engine manifold depression. Failure of the leak check will result in illumination of the Malfunction Indicator Lamp (MIL).

The fuel evaporation leak detection is part of the On-Board Diagnostics (OBD) strategy and it is able to determine vapour leaks from holes or breaks greater than 1 mm (0.04 in.) in diameter. Any fuel evaporation system leaks which occur between the output of the purge valve and the connection to the inlet manifold cannot be determined using this test, but these will be detected through the fuelling adaption diagnostics.

Fuel leak detection system (positive pressure type)

The evaporative loss control system equipped with a positive pressure type, fuel evaporation leak detection capability is similar to the vacuum type, but it is capable of detecting smaller leaks by placing the evaporation system under the influence of positive air pressure. The system includes an EVAPs canister and purge valve, and in addition, a leak detection pump comprising a motor and solenoid valve.

The solenoid valve contained in the leak detection pump assembly performs a similar function to the CVS valve utilised on the vacuum type pressure test. The solenoid valve is used to block the atmospheric vent side of the EVAP canister under the control of the ECM so that an EVAP system leak check can be performed. At the same time, pressurised air from the pump is allowed past the valve into the EVAP system to set up a positive pressure. The test is carried out at the end of a drive cycle when the vehicle is stationary and the ignition is switched off. The test is delayed for a brief period (approximately 10 seconds) after the engine is switched off to allow any slosh in the fuel tank to stabilise. Component validity checks and pressure signal reference checking takes a further 10 seconds before the pressurised air is introduced into the EVAP system.

During reference checking, the purge valve is closed and the leak detection pump solenoid valve is not energised, while the leak detection pump is operated. The pressurised air is bypassed through a restrictor which corresponds to a 0.5 mm (0.02 in) leak while the current consumption of the leak detection pump motor is monitored.

The system test uses the leak detection pump to force air into the EVAP system when the purge valve and solenoid valves are both closed (solenoid valve energised), to put the evaporation lines, components and fuel tank under the influence of positive air pressure. Air is drawn into the pump through an air filter which is located in the engine compartment.

The fuel leak detection pump current consumption is monitored by the ECM while the EVAP system is under pressure, and compared to the current noted during the reference check. A drop in the current drawn by the leak detection pump motor, indicates that air is being lost through holes or leaks in the system which are greater than the reference value of 0.5 mm (0.02 in). An increase in the current drawn by the leak detection pump motor, indicates that the EVAP system is well sealed and that there are no leaks present which are greater than 0.5 mm (0.02 in).

The presence of leakage points indicates the likelihood of hydrocarbon emissions to atmosphere from the evaporation system outside of test conditions and the necessity for rectification work to be conducted to seal the system. Failure of the leak check will result in illumination of the Malfunction Indicator Lamp (MIL).

The fuel evaporation leak detection is part of the On-Board Diagnostics (OBD) strategy and it is able to determine vapour leaks from holes or breaks down to 0.5 mm (0.02 in.) diameter. Any fuel evaporation leaks which occur between the output of the purge valve and the connection to the inlet manifold cannot be determined using this test, but these will be detected through the fuelling adaption diagnostics.

Evaporative emission control components

The evaporative emission control components and the fuel evaporation leak detection test components are described below:

Fuel vapour separator

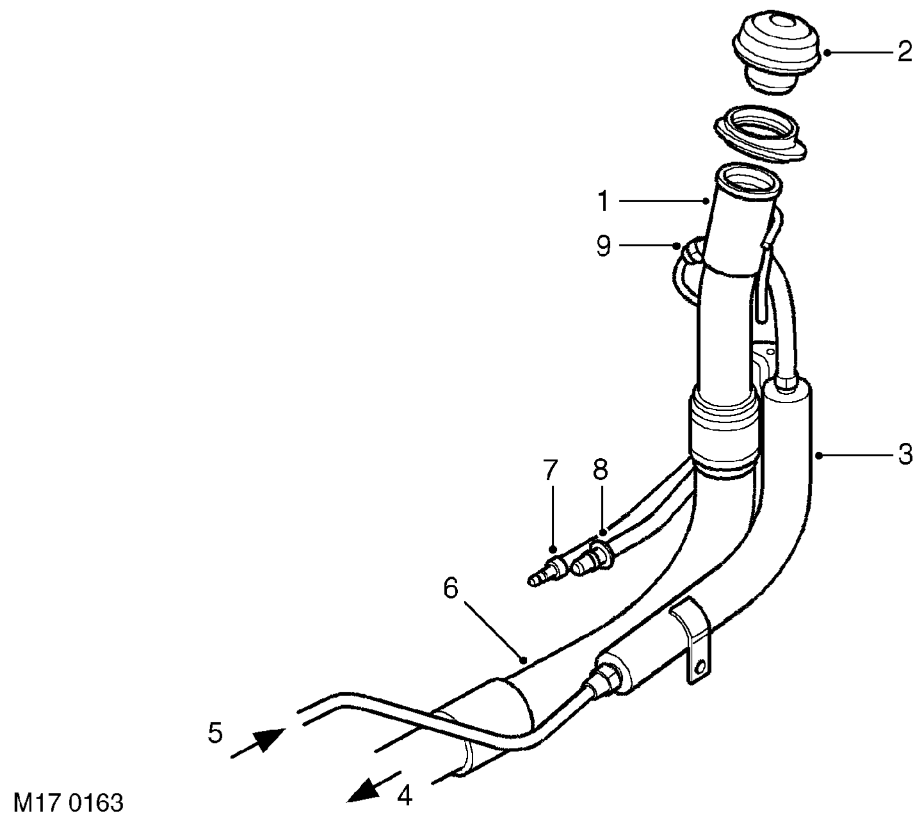


Figure 14

1.Filler neck
2.Filler cap
3.Liquid vapour separator (LVS)
4.To fuel tank
5.Vapour from fuel tank to liquid vapour separator (LVS)
6.Rubber hose
7.Pipe connection to OBD sensor in fuel pump (OBD vehicles with vacuum type leak detection system only)
8.Vent pipe to EVAP canister
9.Anti-trickle valve (where applicable)

The fuel vapour separator is located under the rear wheel arch next to the filler neck and protected by the wheel arch lining. The connections to the separator unit are quick release devices at the end of the flexible hoses which connect the fuel tank to the inlet side of the separator and the outlet of the separator to the evaporation vent line.

EVAP (charcoal) canister

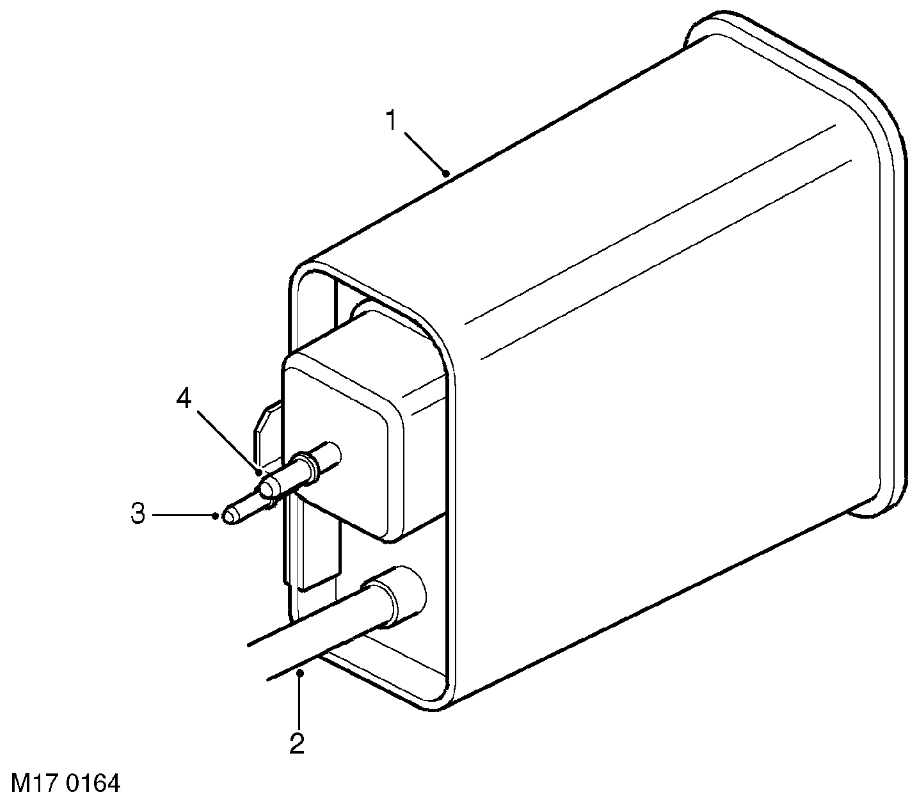


Figure 15

1.EVAP canister
2.Port to breather tube
3.Port – vent line from fuel tank
4.Port – purge line

The EVAP canister is usually mounted on a bracket fitted beneath the vehicle. The EVAP canister has inscriptions next to each port for identification of the 'purge', 'tank' and 'air' connections.

The purge line from the EVAP canister is connected to the back of the inlet manifold plenum, after the throttle body via a purge valve.

The vent line from the fuel tank to the EVAP canister connects to the vent port on the canister.

The plastic pipe to the atmosphere vent line connects to the port on the EVAP canister. The atmosphere end of the plastic pipe terminates in a quick fit connector to the pipe leading to the CVS unit on OBD vehicles with vacuum type, EVAP system leak detection and two snorkel tubes situated behind the engine at the bulkhead on non-OBD vehicles. The bore of the plastic breather pipe is larger on OBD vehicles than on non-OBD vehicles.

For OBD vehicles with positive pressure, EVAP system leak detection capability, the atmosphere vent line from the EVAP canister connects to a port on the fuel leak detection pump via a short, large bore hose which is secured to the component ports by crimped metal clips at each end. A large bore plastic hose from the top of the leak detection pump connects to an air filter canister. Under normal operating conditions (when the fuel leak detection solenoid valve is not energised), the EVAP canister is able to take in clean air via the air filter, through the pipework and past the open solenoid valve to allow normal purge operation to take place and release any build up of EVAP system pressure to atmosphere.

Purge valve

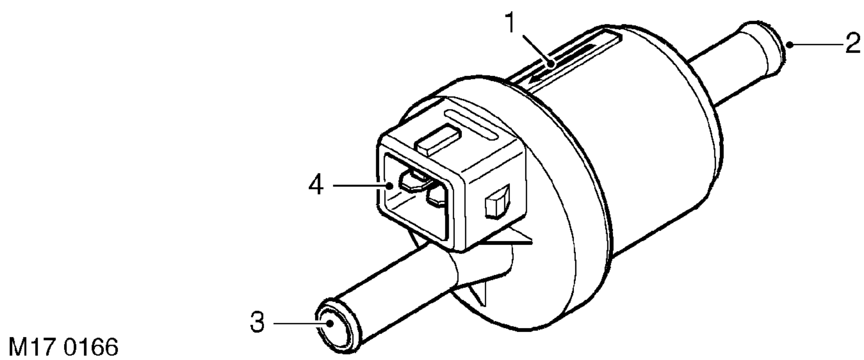


Figure 16

1.Direction of flow indicator
2.Inlet port – from EVAP canister
3.Outlet port – to inlet manifold
4.Integral electrical connector

A service port is connected in line between the EVAP canister and the inlet side of the purge valve and is rated at 1 psi maximum regulated pressure. The service port must be mounted horizontally and is located close to the bulkhead at the rear of the engine bay. The service point is used by dealers for pressure testing using specialist nitrogen test equipment for localising the source of small leaks.

The purge valve has a plastic housing, and a directional arrow is moulded onto the side of the casing to indicate the direction of flow. The head of the arrow points to the outlet side of the valve which connects to the plenum chamber.

Purge valve operation is controlled by the engine control module (ECM). The purge valve has a two-pin electrical connector which links to the ECM via the engine harness. Pin-1 of the connector is the power supply source from fuse 2 in the engine compartment fusebox, and pin-2 of the connector is the switched earth from the ECM (pulse width modulated (PWM) signal) which is used to control the purge valve operation time.

When the purge valve is earthed by the ECM, the valve opens to allow hydrocarbons stored in the EVAP canister to be purged to the engine inlet manifold for combustion.

If the purge valve breaks or becomes stuck in the open or closed position, the EVAP system will cease to function and there are no default measures available. The ECM will store the fault in memory and illuminate the MIL warning lamp if the correct monitoring conditions have been achieved (i.e. valve status unchanged for 45 seconds after engine has been running for 15 minutes). If the purge valve is stuck in the open position, a rich air:fuel mixture is likely to result at the intake manifold, this could cause the engine to misfire and the fuelling adaptions will change.

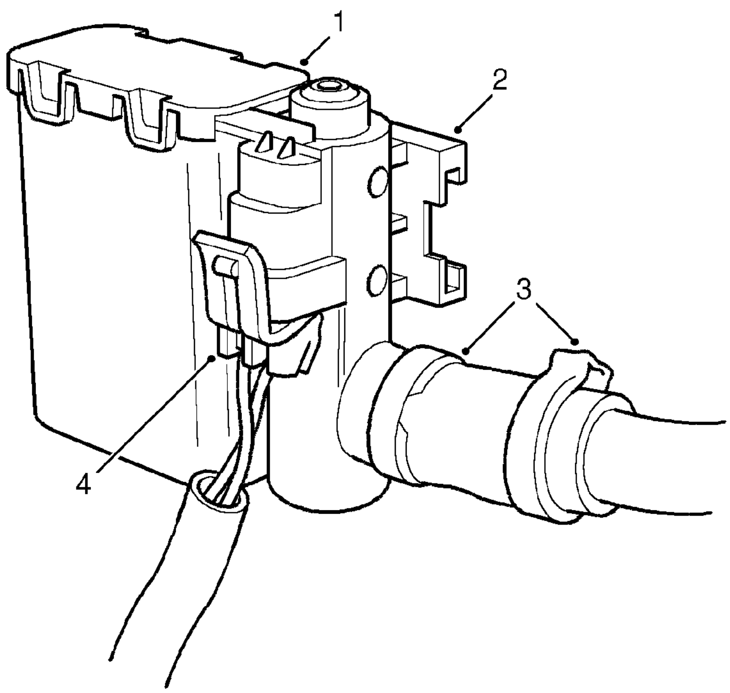
The following failure modes are possible:

- Sticking valve
- Valve blocked
- Connector or harness wiring fault (open or short circuit)
- Valve stuck open

If the purge valve malfunctions, the following fault codes may be stored in the ECM diagnostic memory, which can be retrieved using 'Testbook':

P-code	Fault Description
P0440	Purge valve not sealing
P0444	Purge valve open circuit
P0445	Purge valve short circuit to ground
P0443	Purge valve short circuit to battery voltage

Canister Vent Solenoid (CVS) unit – (OBD vehicles with vacuum type, fuel evaporation leak detection system only)



M17 0165

Figure 17

1.CVS unit
2.Mounting bracket
3.Spring clips to pipe from EVAP canister
4.Harness connector

The canister vent solenoid (CVS) valve is normally open, allowing any build up of air pressure within the evaporation system to escape, whilst retaining the environmentally harmful hydrocarbons in the EVAP canister. When the ECM is required to run a fuel system test, the CVS valve is closed to seal the system. The ECM is then able to measure the pressure in the fuel evaporative system using the fuel tank pressure sensor.

The ECM performs electrical integrity checks on the CVS valve to determine wiring or power supply faults. The ECM can also detect a valve blockage if the signal from the fuel tank pressure sensor indicates a depressurising fuel tank while the CVS valve should be open to atmosphere.

The following failure modes are possible:

- Connector or harness wiring fault (open or short circuit)
- Valve stuck open or shut
- Valve blocked

If the CVS valve malfunctions, the following fault codes may be stored in the ECM diagnostic memory, which can be retrieved using 'Testbook':

P-code	Fault Description
P0446	CVS valve / pipe blocked
P0447	CVS valve open circuit
P0448	CVS valve short circuit to ground
P0449	CVS valve short circuit to battery voltage

Fuel Tank Pressure Sensor (OBD vehicles with vacuum type leak detection system only)

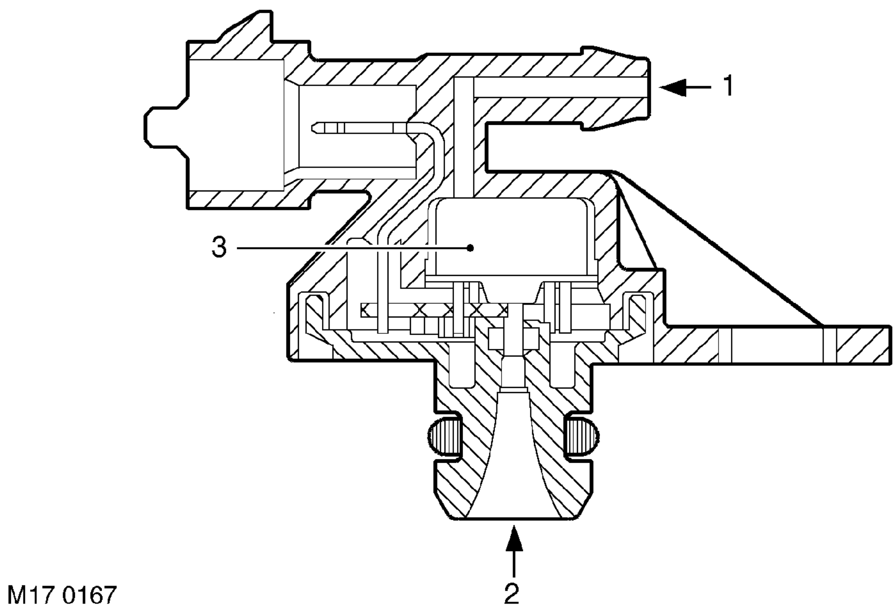


Figure 18

1.Ambient pressure
2.Tank pressure
3.Sensor cell

The fuel tank pressure sensor is located in the top flange of the fuel tank sender / fuel pump module and is a non-serviceable item (i.e. if the sensor becomes defective, the complete fuel tank sender unit must be replaced).

The pressure sensor is a piezo-resistive sensor element with associated circuitry for signal amplification and temperature compensation. The active surface is exposed to ambient pressure by an opening in the cap and by the reference port. It is protected from humidity by a silicon gel. The tank pressure is fed up to a pressure port at the back side of the diaphragm.

For systems utilising the vacuum method for determining evaporation leaks, the sensor is used to monitor for a drop in vacuum pressure. The evaporation system is sealed by the CVS valve and purge valve after a vacuum has been previously set up from the intake manifold while the purge valve is open and the CVS valve is closed. If any holes or leaks are present at the evaporation system joints, the vacuum pressure will gradually drop and this change in pressure will be detected by the fuel tank pressure sensor. This system is capable of determining leaks down to 1 mm (0.04 in.) in diameter.

The fuel tank pressure sensor is part of the OBD system, a component failure will not be noticed by the driver, but if the ECM detects a fault, it will be stored in the diagnostic memory and the MIL light will be illuminated on the instrument pack. Possible failures are listed below:

- Damaged or blocked sensor
- Harness / connector faulty
- Sensor earthing problem
- Open circuit
- Short circuit to battery voltage
- Short circuit to ground
- ECM fault

Possible failure symptoms of the fuel tank pressure sensor are listed below:

- Fuel tank pressure sensor poor performance
- Fuel tank pressure sensor low range fault
- Fuel tank pressure sensor high range fault

If the fuel tank pressure sensor should malfunction, the following fault codes may be stored in the ECM diagnostic memory, which can be retrieved using 'Testbook':

P-code	Fault Description
P0451	Fuel tank pressure signal stuck high within range
P0452	Fuel tank pressure signal short circuit to battery voltage (out of range - High)
P0453	Fuel tank pressure signal short circuit to ground or open circuit (out of range - Low)

Leak Detection Pump (OBD vehicles with positive pressure EVAP system leakage test only)

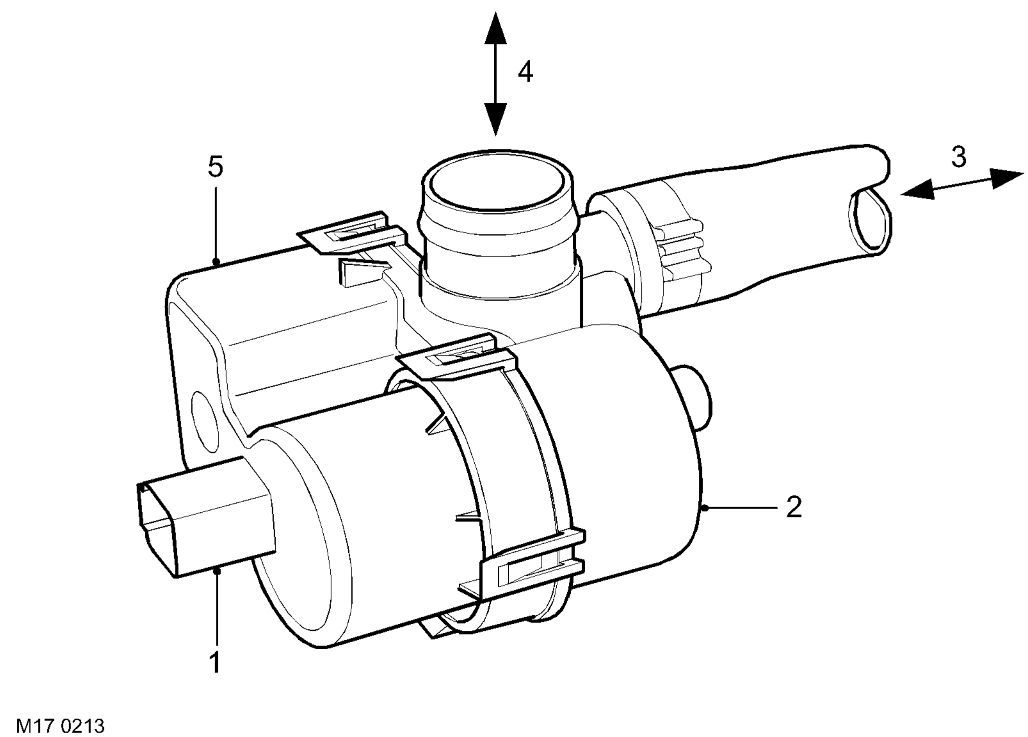


Figure 19

1.Harness connector
2.Leak detection pump motor
3.Atmosphere connection to/from EVAP canister
4.Atmosphere connection to/from air filter
5.Leak detection pump solenoid valve

The leak detection pump incorporates a 3–pin electrical connector. Pin-1 is the earth switched supply to the ECM for control of the pump solenoid valve. Pin-2 is the earth switched supply to the ECM for the operation of the pump motor. Pin-3 is the power supply to the pump motor and solenoid valve and is switched on at system start up via the main relay and fuse 2 in the engine compartment fusebox.

Under normal circumstances (i.e. when the leak detection pump is not operating and the solenoid is not energised), the EVAP canister vent port is connected to atmosphere via the open solenoid valve.

The pump is operated at the end of a drive cycle when the vehicle is stationary and the ignition is switched off.

The leak detection pump module contains an integral air by-pass circuit with restrictor (reference-leak orifice) which is used for providing a reference value for the leak detection test. The restrictor corresponds to an air leak equivalent to 0.5 mm (0.02 in) diameter. With the solenoid valve open and the purge valve closed, the pump forces pressurised air through the orifice while the current drawn by the leak detection pump motor is monitored to obtain the reference value. The orifice must be kept free from contamination, otherwise the reference restriction may appear less than for a 0.5 mm leak and consequently adversely affect the diagnostic results.

During the leakage test, the solenoid valve is energised, closing the atmosphere vent line between the EVAP canister and atmosphere and opening a path to the pressurised air supplied from the leak detection pump motor. Air is pumped into the EVAP system, while the current drawn by the pump motor is monitored. The current drawn during the leakage test is compared against the value obtained during the reference check, to determine if an EVAP system leak is present.

The fuel leak detection pump is powered from a 12V supply and operates at a working pressure of 3 kPa.

Air filter – (OBD vehicles with positive pressure leak detection system only)

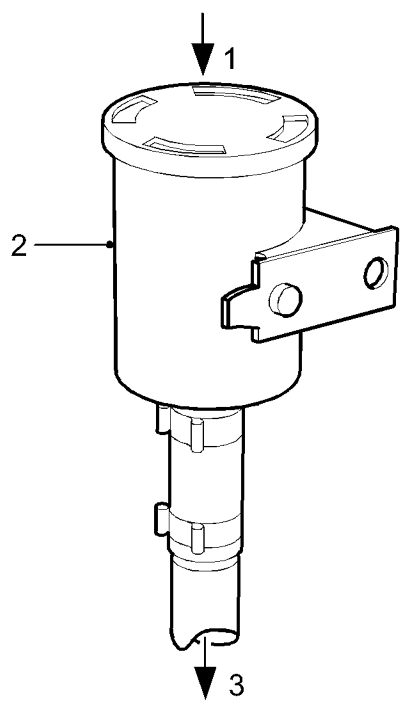


Figure 20

1.Air vents through canister lid
2.Air filter canister
3.To fuel leak detection pump (EVAP canister atmosphere vent)

The air filter is used to prevent particulate contaminants down to 40 µm from entering the fuel leak detection pump. A press-fit lid on top of the canister contains slots to allow the passage of air into and out of the EVAP system.

The bottom end of the paper element is sealed to the canister and is non-serviceable (i.e fit for life). If necessary, the canister and paper filter must be replaced as a single, complete assembly.

Evaporative emission control operation

Fuel vapour is stored in the activated charcoal (EVAP) canister for retention when the vehicle is not operating. When the vehicle is operating, fuel vapour is drawn from the canister into the engine via a purge control valve. The vapour is then delivered to the intake plenum chamber to be supplied to the engine cylinders where it is burned in the combustion process.

During fuel filling the fuel vapour displaced from the fuel tank is allowed to escape to atmosphere, valves within the fuel filler prevent any vapour escaping through to the EVAP canister as this can adversely affect the fuel cut-off height. Only fuel vapour generated whilst driving is prevented from escaping to atmosphere by absorption into the charcoal canister. The fuel filler shuts off to leave the tank approximately 10% empty to ensure the ROVs are always above the fuel level and so vapour can escape to the EVAP canister and the tank can breathe. The back pressures normally generated during fuel filling are too low to open the pressure relief valve, but vapour pressures accumulated during driving are higher and can open the pressure relief valve. Should the vehicle be overturned, the ROVs shut off to prevent any fuel spillage.

Fuel vapour generated from within the fuel tank as the fuel heats up is stored in the tank until the pressure exceeds the operating pressure of the two-way valve. When the two-way valve opens, the fuel vapour passes along the vent line from the fuel tank (via the fuel tank vapour separator) to the evaporation inlet port of the EVAP canister. The fuel tank vents between 5.17 and 6.9 kPa.

Fuel vapour evaporating from the fuel tank is routed to the EVAP canister through the fuel vapour separator and vent line. Liquid fuel must not be allowed to contaminate the charcoal in the EVAP canister. To prevent this, the fuel vapour separator fitted to the fuel neck allows fuel to drain back into the tank. As the fuel vapour cools, it condenses and is allowed to flow back into the fuel tank from the vent line by way of the two-way valve.

The EVAP canister contains charcoal which absorbs and stores fuel vapour from the fuel tank while the engine is not running. When the canister is not being purged, the fuel vapour remains in the canister and clean air exits the canister via the air inlet port.

The engine management ECM controls the electrical output signal to the purge valve. The system will not work properly if there is leakage or clogging within the system or if the purge valve cannot be controlled.

When the engine is running, the ECM decides when conditions are correct for vapour to be purged from the EVAP canister and opens the canister purge valve. This connects a manifold vacuum line to the canister and fuel vapour containing the hydrocarbons is drawn from the canister’s charcoal element to be burned in the engine. Clean air is drawn into the canister through the atmosphere vent port to fill the displaced volume of vapour.

The purge valve remains closed below preset coolant and engine speed values to protect the engine tune and catalytic converter performance. If the EVAP canister was purged during cold running or at idling speed, the additional enrichment in the fuel mixture would delay the catalytic converter light off time and cause erratic idle. When the purge valve is opened, fuel vapour from the EVAP canister is drawn into the plenum chamber downside of the throttle housing, to be delivered to the combustion chambers for burning.

The purge valve is opened and closed in accordance with a pulse width modulated (PWM) signal supplied from the engine management ECM. The system will not work properly if the purge valve cannot be controlled. Possible failure modes associated with the purge valve are listed below:

- Valve drive open circuit.
- Short circuit to vehicle supply or ground.
- Purge valve or pipework blocked or restricted.
- Purge valve stuck open.
- Pipework joints leaking or disconnected.

Possible symptoms associated with a purge valve or associated pipework failure is listed below:

- Engine may stall on return to idle if purge valve is stuck open.
- Poor idling quality if the purge valve is stuck open
- Fuelling adaptions forced excessively lean if the EVAP canister is clear and the purge valve is stuck open.
- Fuelling adaptions forced excessively rich if the EVAP canister is saturated and the purge valve is stuck open.
- Saturation of the EVAP canister if the purge valve is stuck closed.

To maintain driveability and effective emission control, EVAP canister purging must be closely controlled by the engine management ECM, as a 1% concentration of fuel vapour from the EVAP canister in the air intake may shift the air:fuel ratio by as much as 20%. The ECM must purge the fuel vapour from the EVAP canister at regular intervals as its storage capacity is limited and an excessive build up of evaporated fuel pressure in the system could increase the likelihood of vapour leaks. Canister purging is cycled with the fuelling adaptation as both cannot be active at the same time. The ECM alters the PWM signal to the purge valve to control the rate of purging of the canister to maintain the correct stoichiometric air:fuel mixture for the engine.

Fuel leak detection system (vacuum type)

The advanced evaporative loss control system used on OBD vehicles is similar to the standard system, but also includes a CVS valve and fuel tank pressure sensor and is capable of detecting holes in the fuel evaporative system down to 1 mm (0.04 in.). The test is carried out in three parts. First the purge valve and the canister vent solenoid valve closes off the storage system and the vent pressure increases due to the fuel vapour pressure level in the tank. If the pressure level is greater than the acceptable limit, the test will abort because a false leak test response will result. In part two of the test, the purge valve is opened and the fuel tank pressure will decrease due to the depression from the intake manifold, evident at the purge port of the EVAP canister during purge operation. In part three of the test, the leak measurement test is performed. The pressure response of the tests determines the level of leak, and if this is greater than the acceptable limit on two consecutive tests, the ECM stores the fault in diagnostic memory and the MIL light on the instrument pack is illuminated. The test is only carried out at engine idle with the vehicle stationary, and a delay of 15 minutes after engine start is imposed before diagnosis is allowed to commence.

The EVAP system leak detection is performed as follows:

1. The ECM checks that the signal from the fuel tank pressure sensor is within the expected range. If the signal is not within range, the leakage test will be cancelled.
2. Next the purge valve is held closed and the canister vent solenoid (CVS) valve is opened to atmosphere. If the ECM detects a rise in pressure with the valves in this condition, it indicates there is a blockage in the fuel evaporation line between the CVS valve and the EVAP canister, or that the CVS valve is stuck in the closed position and thus preventing normalisation of pressure in the fuel evaporation system. In this instance, the leakage test will be cancelled.
3. The CVS valve and the purge valve are both held in the closed position while the ECM checks the fuel tank pressure sensor. If the fuel tank pressure sensor detects a decline in pressure, it indicates that the purge valve is not closing properly and vapour is leaking past the valve seat face under the influence of the intake manifold depression. In this instance, the leakage test will be cancelled.
4. If the preliminary checks are satisfactory, a compensation measurement is determined next. Variations in fuel level occur within the fuel tank, which will influence the pressure signal detected by the fuel tank pressure sensor. The pressure detected will also be influenced by the rate of change in the fuel tank pressure, caused by the rate of fuel evaporation which itself is dependent on the ambient temperature conditions. Because of these variations, it is necessary for the ECM to evaluate the conditions prevailing at a particular instance when testing, to ensure that the corresponding compensation factor is included in its calculations.

   The CVS valve and purge valves are both closed while the ECM checks the signal from the fuel tank pressure sensor. The rise in fuel pressure detected over a defined period is used to determine the rate of fuel evaporation and the consequent compensation factor necessary.
5. With the CVS valve still closed, the purge valve is opened. The inlet manifold depression present while the purge valve is open, decreases EVAP system pressure and sets up a small vacuum in the fuel tank. The fuel tank pressure sensor is monitored by the ECM and if the vacuum gradient does not increase as expected, a large system leak is assumed by the ECM (e.g. missing or leaking fuel filler cap) and the diagnostic test is terminated.

   If the EVAP canister is heavily loaded with hydrocarbons, purging may cause the air:fuel mixture to become excessively rich, resulting in the upstream oxygen sensors requesting a leaner mix from the ECM to bring the mixture back to the stoichiometric ideal. This may cause instability in the engine idle speed and consequently the diagnostic test will have to be abandoned. The ECM checks the status of the upstream oxygen sensors during the remainder of the diagnostic, to ensure the air:fuel mixture does not adversely affect the engine idle speed.
6. When the fuel tank pressure sensor detects that the required vacuum has been reached (-800 Pa), the purge valve is closed and the EVAP system is sealed. The ECM then checks the change in the fuel tank pressure sensor signal (diminishing vacuum) over a period of time, and if it is greater than expected (after taking into consideration the compensation factor due to fuel evaporation within the tank, determined earlier in the diagnostic), a leak in the EVAP system is assumed. If the condition remains, the MIL warning light will be turned on after two drive cycles.

   The decrease in vacuum pressure over the defined period must be large enough to correspond to a hole equivalent to 1 mm (0.04 in.) diameter or greater, to be considered significant enough to warrant the activation of an emissions system failure warning.

The diagnostic test is repeated at regular intervals during the drive cycle, when the engine is at idle condition. The diagnostic test will not be able to be performed under the following conditions:

- During EVAP canister purging
- During fuelling adaption
- If excess slosh in the fuel tank is detected (excess fuel vapour will be generated, invalidating the result)

Following the test, the system returns to normal purge operation after the canister vent solenoid opens. Possible reasons for an EVAP system leak test failure are listed below:

- Fuel filler not tightened or cap missing.
- Sensor or actuator open circuit.
- Short circuit to vehicle supply or ground.
- Either purge or CVS valve stuck open.
- Either purge or CVS valve stuck shut or blocked pipe.
- Piping broken or not connected.
- Loose or leaking connection.

If the piping is broken forward of the purge valve or is not connected, the engine may run rough and fuelling adaptions will drift. The fault will not be detected by the leak detection diagnostic, but it will be determined by the engine management ECM through the fuelling adaption diagnostics.

The evaluation of leakage is dependent on the differential pressure between the fuel tank and ambient atmospheric pressure, the diagnostic is disabled above altitudes of 9500 ft. (2800 m) to avoid false detection of fuel leaks due to the change in atmospheric pressure at altitude.

Fuel leak detection system (positive pressure leak detection type)

The EVAP system with positive pressure leak detection capability used on some OBD vehicles is similar to the standard system, but also includes a fuel evaporation leak detection pump with integral solenoid valve. It is capable of detecting holes in the EVAP system down to 0.5 mm (0.02 in.). The test is carried out at the end of a drive cycle, when the vehicle is stationary and the ignition switch has been turned off. The ECM maintains an earth supply to the Main relay to hold it on, so that power can be supplied to the leak detection pump.

First a reference measurement is established by passing the pressurised air through a by-pass circuit containing a fixed sized restriction. The restriction assimilates a 0.5 mm (0.02 in) hole and the current drawn by the pump motor during this procedure is recorded for comparison against the value to be obtained in the system test. The purge valve is held closed, and the reversing valve in the leak detection pump module is not energised while the leak detection pump is switched on. The pressurised air from the leak detection pump is forced through an orifice while the current drawn by the pump motor is monitored.

Next the EVAP system diagnostic is performed; the vacuum solenoid valve is energised so that it closes off the EVAP system's vent line to atmosphere, and opens a path for the pressurised air from the leak detection pump to be applied to the closed EVAP system.

The current drawn by the leak detection pump is monitored and checked against that obtained during the reference measurement. If the current is less than the reference value, this infers there is a hole in the EVAP system greater than 0.5 mm (0.02 in) which is allowing the positive air pressure to leak out. If the current drawn by the pump motor is greater than the value obtained during the reference check, the system is sealed and free from leaks. If an EVAP system leak is detected, the ECM stores the fault in diagnostic memory and the MIL light on the instrument pack is illuminated.

Following the test, the solenoid valve is opened to normalise the EVAP system pressure and the system returns to normal purge operation at the start of the next drive cycle. Possible reasons for an EVAP system leak test failure are listed below:

- Fuel filler not tightened or cap missing.
- Sensor or actuator open circuit.
- Short circuit to vehicle supply or ground.
- Either purge or solenoid valve stuck open.
- Either purge or solenoid valve stuck shut.
- Blocked pipe or air filter.
- Piping broken or not connected.
- Loose or leaking connection.

If the piping is broken forward of the purge valve or is not connected, the engine may run rough and fuelling adaptions will drift. The fault will not be detected by the leak detection test, but will be determined by the engine management ECM through the fuelling adaption diagnostics.