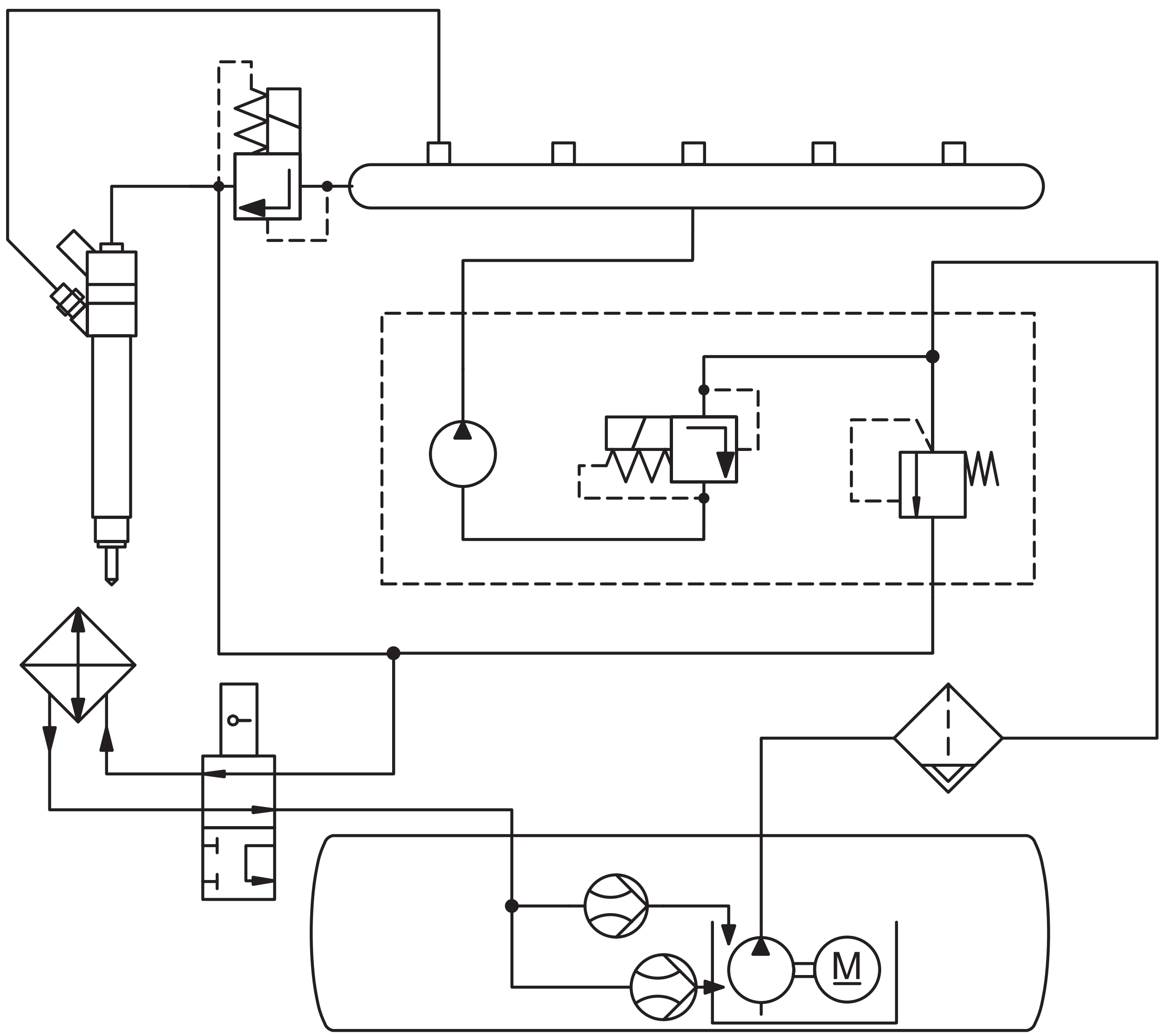
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ACRONYMS AND ABBREVIATIONS

The following is a list of acronyms used throughout this course:

ADR	Constant RPM Option (Arbeitsdrehzahlregler)
CAN	Controller Area Network
CARB	Californian Air Resources Board
DLC	Data Link Connector
DTC	Diagnostic Trouble Code
EEPROM	Electrical Erasable Programmable Read Only Memory
EGR	Exhaust Gas Recirculation
EPA	Environmental Protection Agency
H2O	Water
K-Line	Serial Communications Line for Diagnostics
LCD	Liquid Crystal Display
MAPPS	Magnetic Passive Position Sensor
MgO	Magnesium Oxide
MIL	Malfunction Indicator Lamp
MOSFET	Metal-Oxide-Semiconductor Field Effect Transistor
NTC	Negative Temperature Coefficient (Thermistor)
O2	Oxygen
OBDII	On Board Diagnostics Second Generation
PTC	Positive Temperature Coefficient
RAM	Random Access Memory
SCI	Serial Communications Interface (K-Line may also be used)
SmCo	Samarium Cobalt
SRS	Supplemental Restraint System
TERMINAL 15	Ignition Powered Circuit
TERMINAL 30	Battery Powered Circuit
TERMINAL 31	Ground Circuit
TERMINAL 58	Circuit That is Powered When Parking Lights are ON
TERMINAL D+	Circuit That is Powered When The Engine is Running
WIF	Water-in-Fuel Sensor
ZRO2	Zirconium Dioxide

COMPONENT CROSS-REFERENCE CHART

Description	Dodge	Freightliner
Accelerator Pedal Position Sensor	APPS	B147
Airbag Control Module	ACM	AB
Automatic Temperature Control	ATC	HZR
Antilock Brakes	CAB	ABS
Boost Pressure Sensor	BPS	B141
Boost Air Temperature Sensor	BTS	G14
Crank Position Sensor	CKP	B73
Cam Position Sensor	CMP	B108
Diagnostic Scan Tool	DRB III	DAS
EGR Actuator	EGR	Y85
Engine Control Module	ECM	CR3
Engine Coolant Temperature Sensor	ECT	B16
Engine Oil Sensor	EOS	B110
Fuel Pressure Solenoid	FPS	Y92
Fuel Quantity Valve	FQV	Y93
Fuel Rail Pressure Sensor	FRPS	B113
Fuel Temperature Sensor	FTS	B30
Intake Air Pressure Sensor	IAP	B142
Keyless Entry Module & Immobilizer	SKREEM	WSP
Kickdown Switch	KS	B97
Mass Air Flow Sensor	MAF	B101
Oxygen Sensor	O2	R25
Shift Lever Module	SLA	EWM
Transmission Control Module	TCM	EGS
Water-in-Fuel Sensor	WIF	B129

COURSE OBJECTIVES

This course is intended to provide the experienced diesel technician with the knowledge and skills necessary to service the common rail fuel system found on the Sprinter's OM647 engine. The course will provide a system overview, component description and location, and system and component diagnosis.

After completing this course, you should be able to:

- Identify and locate all fuel system components
- Describe the fuel flow of the Sprinter common-rail system
- Identify the operation of fuel system components
- Identify the inputs, control and outputs of the fuel system
- Diagnose fuel system failures with the diagnostic scan tool
- Perform tests using special tools as specified in the service information

MODULE 1 COMPONENT LOCATION

ENGINE DESCRIPTION

The Sprinter 2.7 liter OM647 diesel engine utilizes the following major systems:

- Common-rail direct injection
- Four-valve per cylinder technology
- Symmetrical combustion chambers with the injectors positioned in the center
- Water-cooled exhaust gas recirculation
- Electronically-Controlled Variable Geometry Turbocharging
- Intercooling

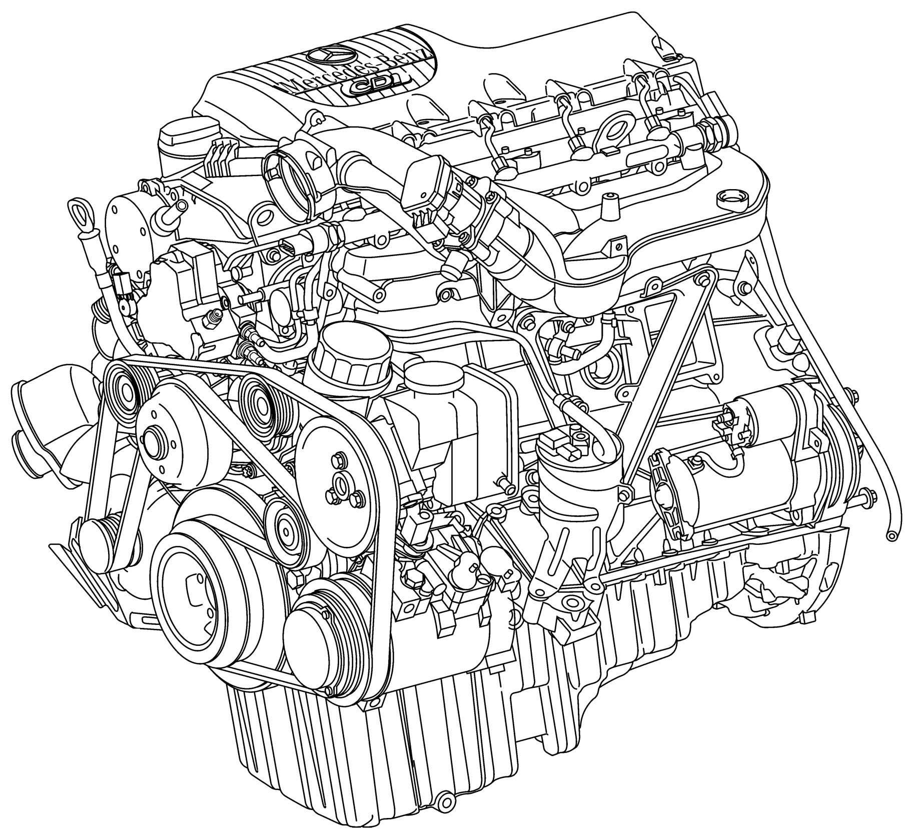


Figure 1 Sprinter 2.7 liter OM647 Diesel Engine

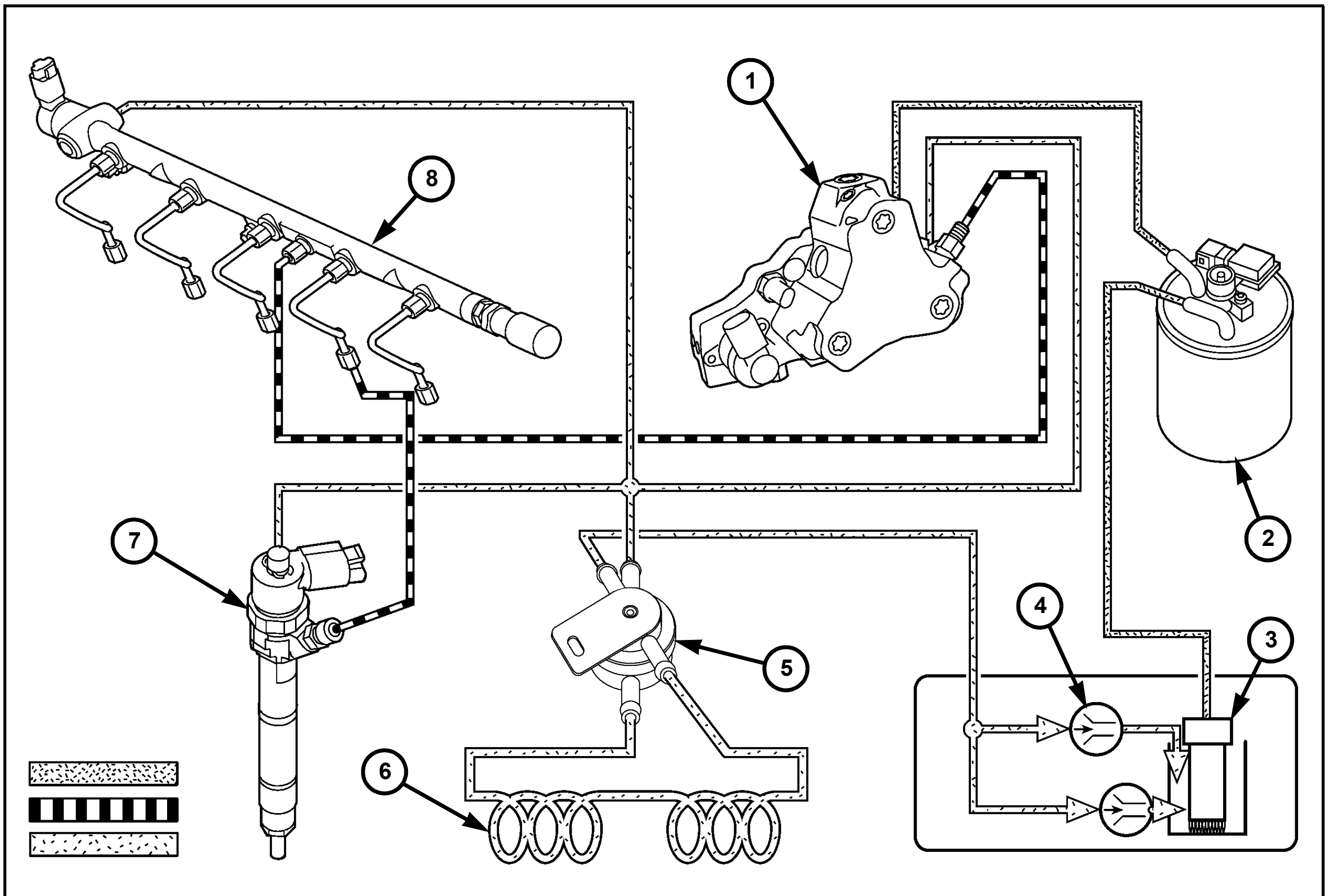
Common rail direct injection stores fuel in a fuel rail under high pressure. Injection is cylinder-selective and delivered as required. Advantages include:

- Reduction in fuel consumption
- Compliance with international emission regulations (EPA and CARB)
- High torque at low engine speeds
- Reduction in noise emissions

FUEL SYSTEM COMPONENTS

The Sprinter 2.7L Diesel Engine has the following fuel system components:

- Fuel tank
- Dual-coil fuel cooler
- Fuel lines
- Fuel filter
- Electric fuel pump
- Regulated high pressure pump
- Fuel rail
- Fuel injectors



1	High Pressure Pump	5	Preheating Valve
2	Fuel Filter	6	Fuel Cooler
3	Electric Fuel Pump	7	Fuel Injector
4	Suction Jet Pump	8	Fuel Rail

Figure 2 Fuel System Components

ACTIVITY 1: COMPONENT LOCATION WALKAROUND

The purpose of this activity is to familiarize the technician with the location of the fuel system components.

TASK 1: UNDER THE HOOD COMPONENTS (GROUP 1)

Using service information, locate the following components in the engine compartment. Mark the position of the components on figures 3 through 6 using the numbers from this list as callout numbers.

1. Fuel filter
2. Fuel filter drain valve
3. Water in fuel sensor
4. High pressure pump
5. High pressure pump flange
6. Fuel quantity valve
7. Fuel temperature sensor
8. Fuel common rail
9. Fuel pressure solenoid
10. Crankshaft position sensor
11. Oil sensor
12. EGR actuator
13. Intake manifold
14. Coolant temperature sensor
15. Boost pressure actuator
16. Turbo silencer
17. Crankcase ventilation heater
18. Fuel injectors
19. Fuel return line, including leak port lines from injectors
20. Three-stage oil separator
21. Camshaft position sensor
22. Mass air flow sensor
23. O2 sensor and sensor harness connector
24. Intake air pressure sensor
25. Glow plug module
26. Boost pressure sensor
27. Boost temperature sensor

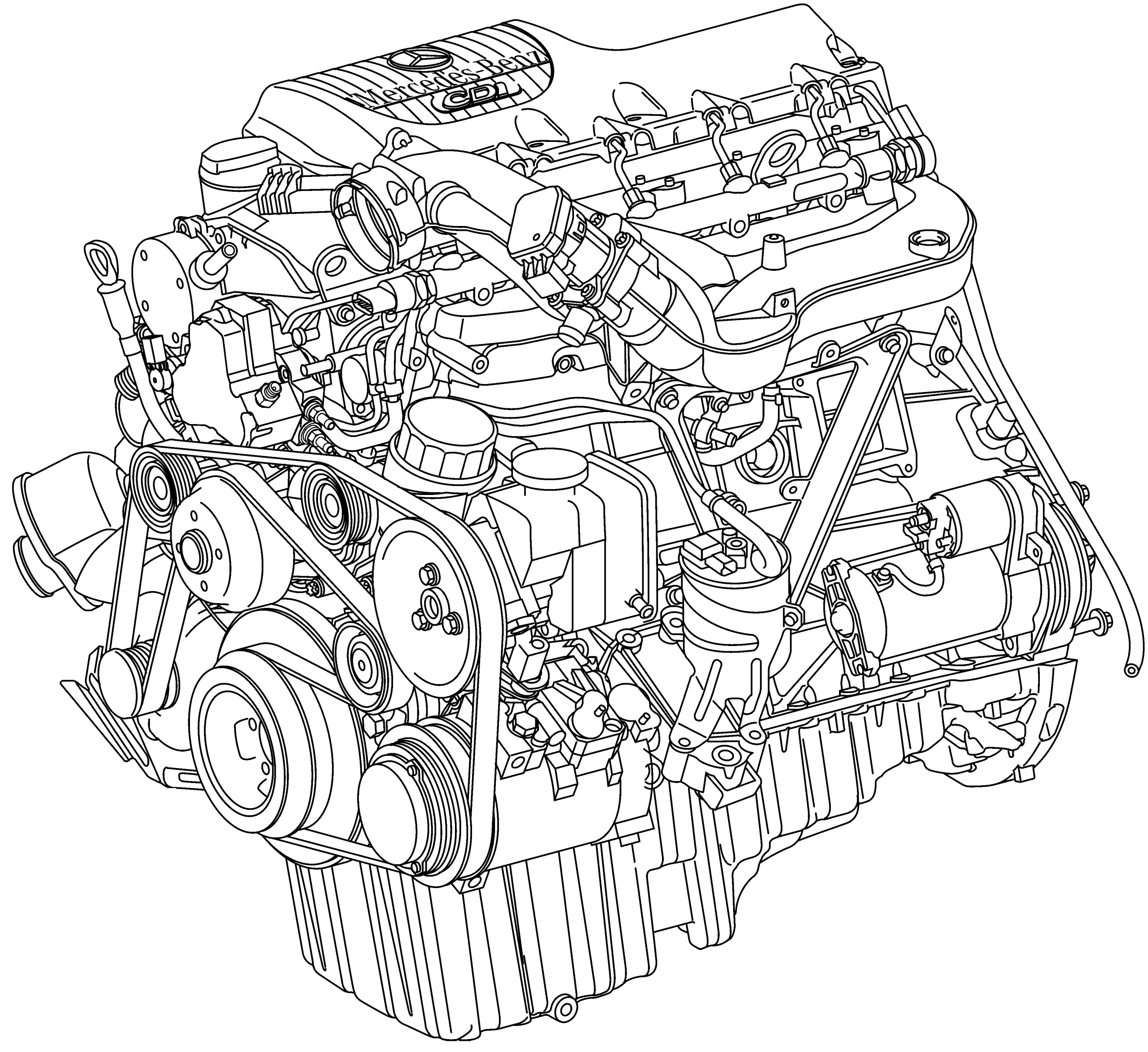


Figure 3 Left Front View of Engine

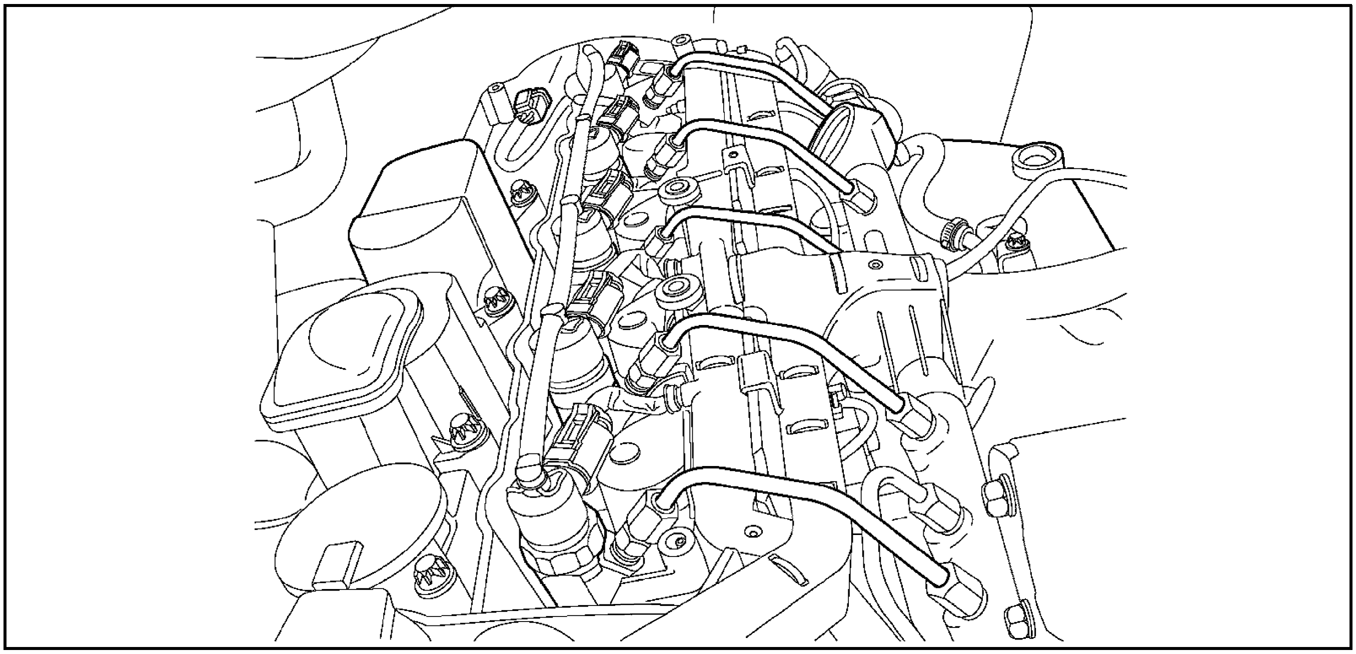


Figure 4 Top View of Engine

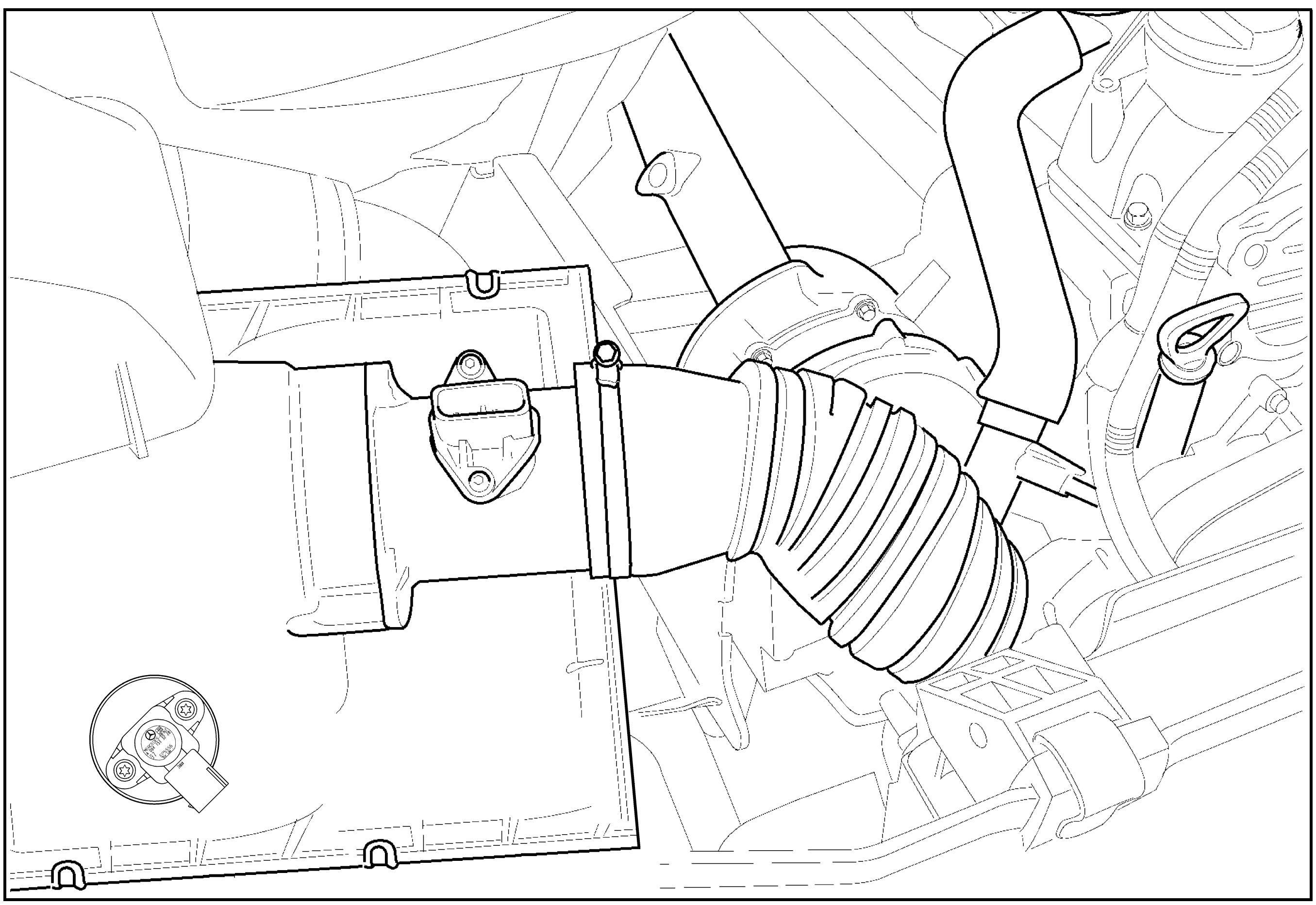


Figure 5 Right Hand Side of Engine Compartment

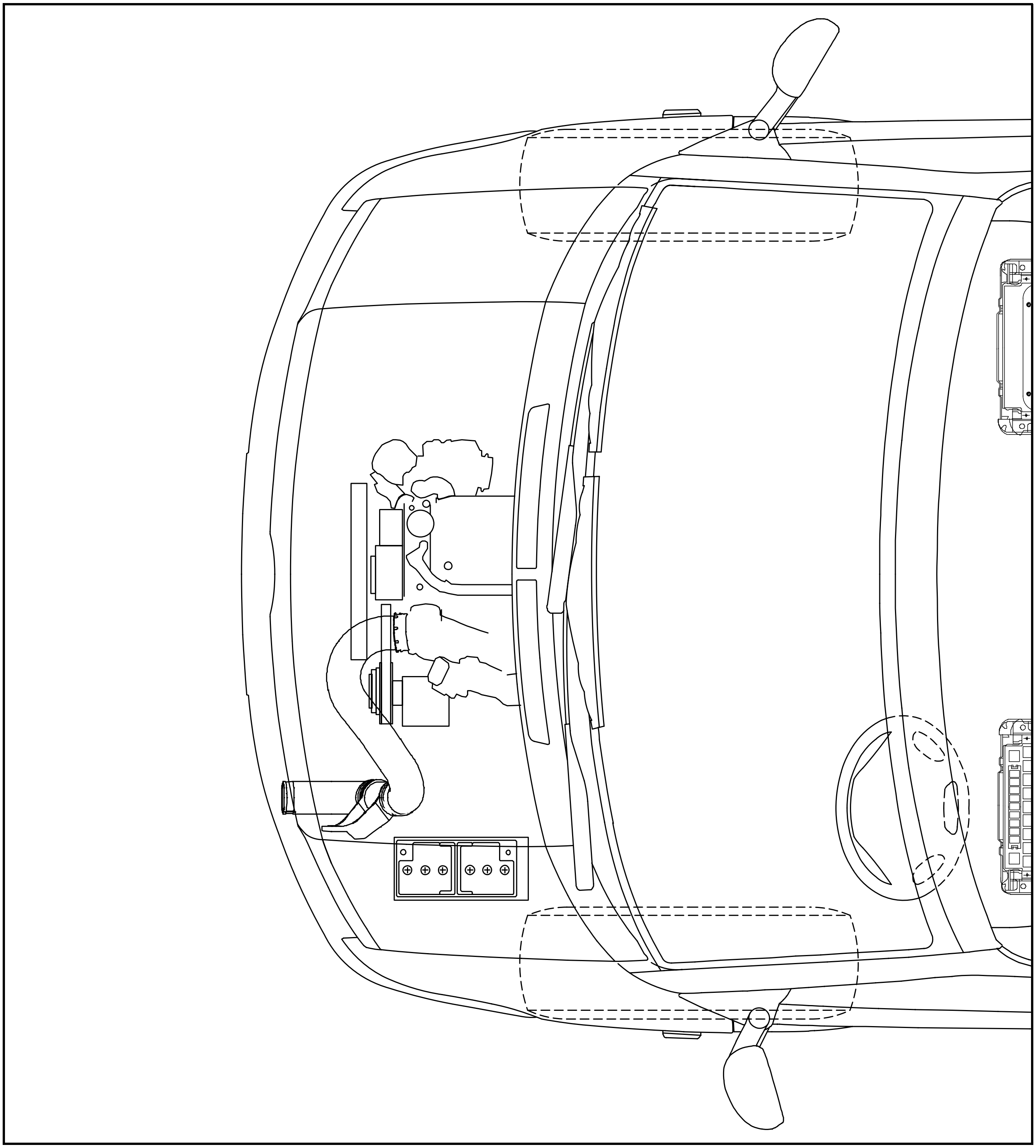


Figure 6 Engine Compartment Top View

TASK 2: COMPONENTS UNDER VEHICLE (GROUP 2)

Locate the following components under the vehicle using the service information. Mark the position of the components on the drawings below using the numbers from this list.

1. Fuel tank
2. Fuel pump module
3. Roll-over valves
4. Pressure control valve
5. Fuel supply line
6. Fuel return line
7. Heater booster line
8. Fuel cooler
9. Preheating valve

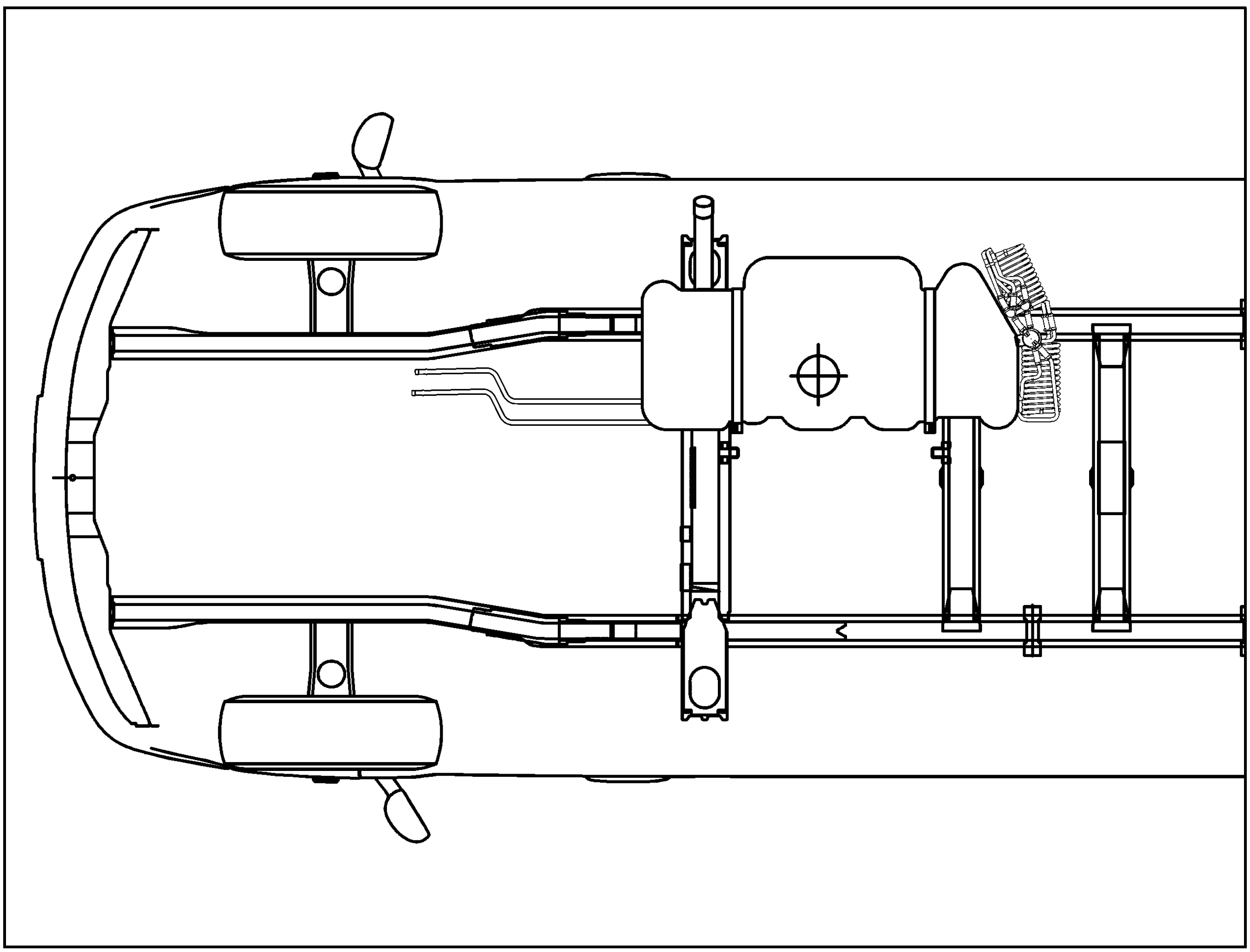


Figure 7 Components Under the Vehicle

MODULE 2 FUEL SYSTEM MECHANICAL COMPONENTS

SAFETY

Safety is important when working on high-pressure fuel systems. The fuel is under high-pressure and can penetrate the skin. When working on the fuel system, always follow all cautions, warnings and safety instructions listed in the service literature and on the engine compartment labels.

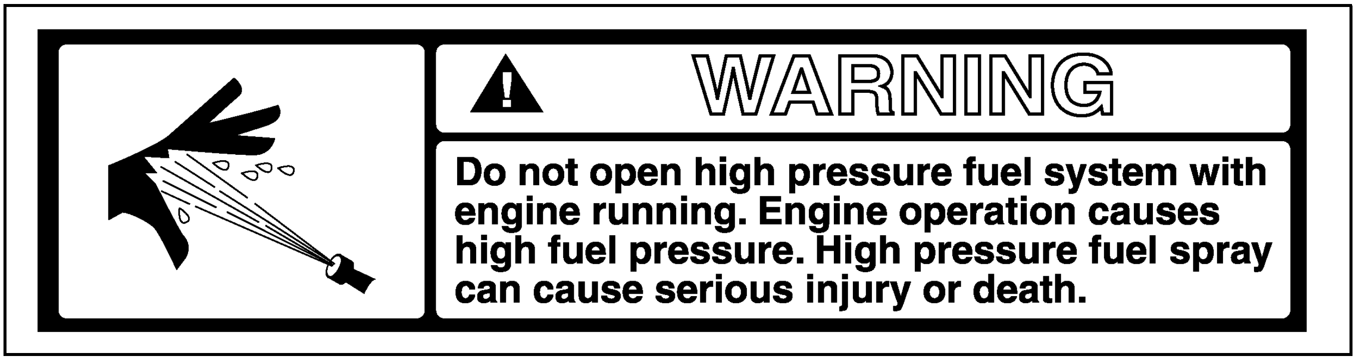


Figure 8 Safety Warning Label

GENERAL DESCRIPTION

This section will cover the mechanical components of the common-rail fuel system. The common-rail fuel system for the Sprinter is comprised of the low-pressure, high-pressure and return fuel circuits. The low-pressure circuit incorporates:

- Electric fuel pump
- Fuel filter
- High pressure pump flange
- Low-pressure fuel lines

The high-pressure circuit incorporates the following components:

- High pressure pump
- Fuel rail
- Injectors (although a mechanical part of the high pressure system, they are considered an ECM output and covered in that section)

The fuel return circuit incorporates the following components:

- Fuel return lines
- Preheating valve
- Fuel cooler
- Fuel tank and fuel pump module

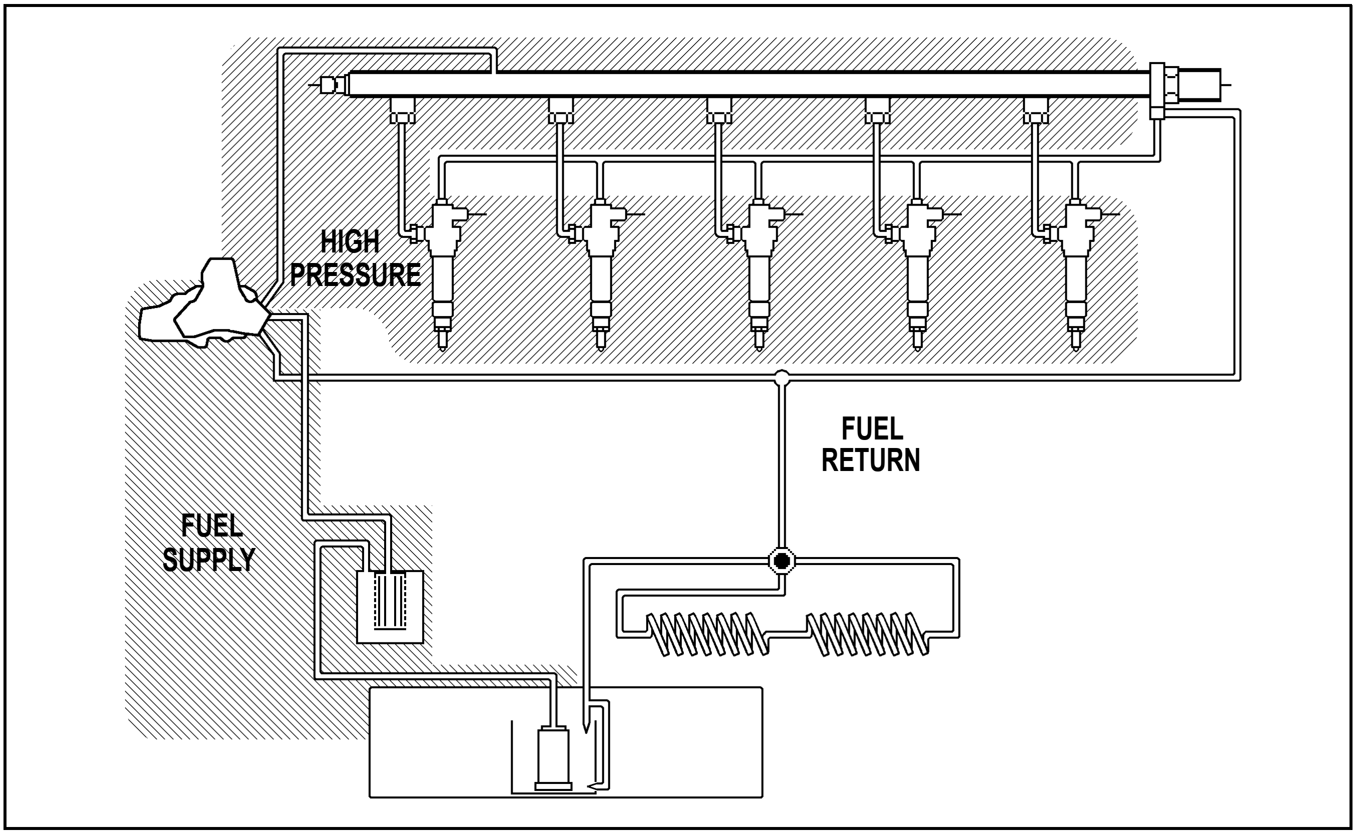


Figure 9 Common Rail Fuel Circuits

FUEL FLOW

Fuel Supply

The electric fuel pump delivers fuel from the fuel tank, through the fuel filter to the inlet side of the high pressure pump flange.

High Pressure Circuit

Fuel flows from the outlet side of the high pressure pump to the fuel rail to the injectors

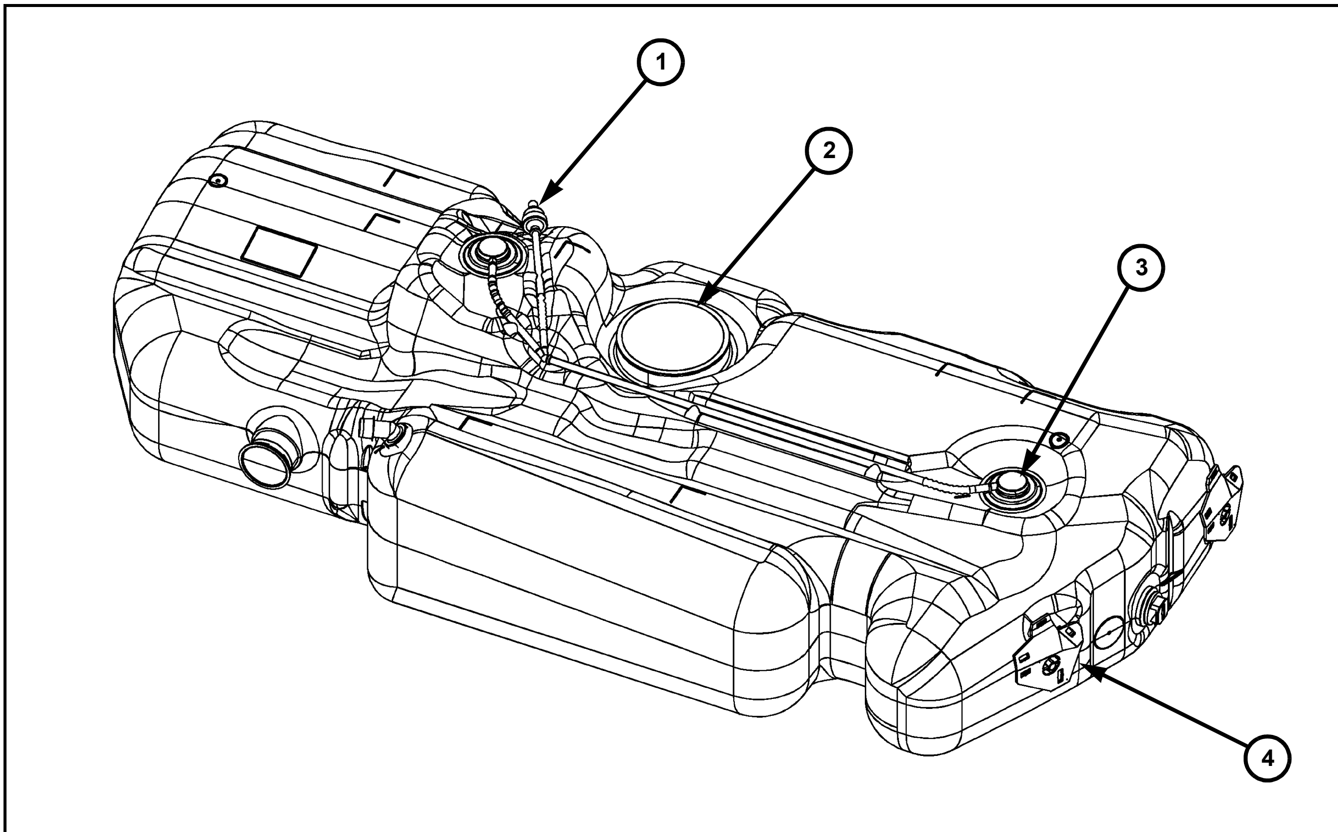
Fuel Return

Return fuel from the injectors (control fuel), the fuel pressure solenoid and high pressure pump flange flows into the fuel return system and is returned to the fuel filter or the fuel tank (depending on the temperature of the returned fuel).

LOW-PRESSURE/RETURN FUEL CIRCUIT COMPONENTS

FUEL TANK

A polyethylene fuel tank with a capacity of 25 gallons is mounted under the left/center side of the vehicle. The tank contains a serviceable fuel pump module (Figure 16) equipped with 2 fuel lines: a fuel supply line and a fuel return line. A section of the fuel return line is coiled at the rear section of the tank, and functions as a fuel cooler. An additional fuel supply line is installed on vehicles equipped with the optional heater booster/auxiliary heater. A redesigned fuel cooler mounting bracket makes the fuel tank different from those found on earlier models.



1	Pressure Control Valve	3	Vent Valve/Rollover Valve
2	Fuel Pump Module	4	Fuel Cooler Mounting Bracket

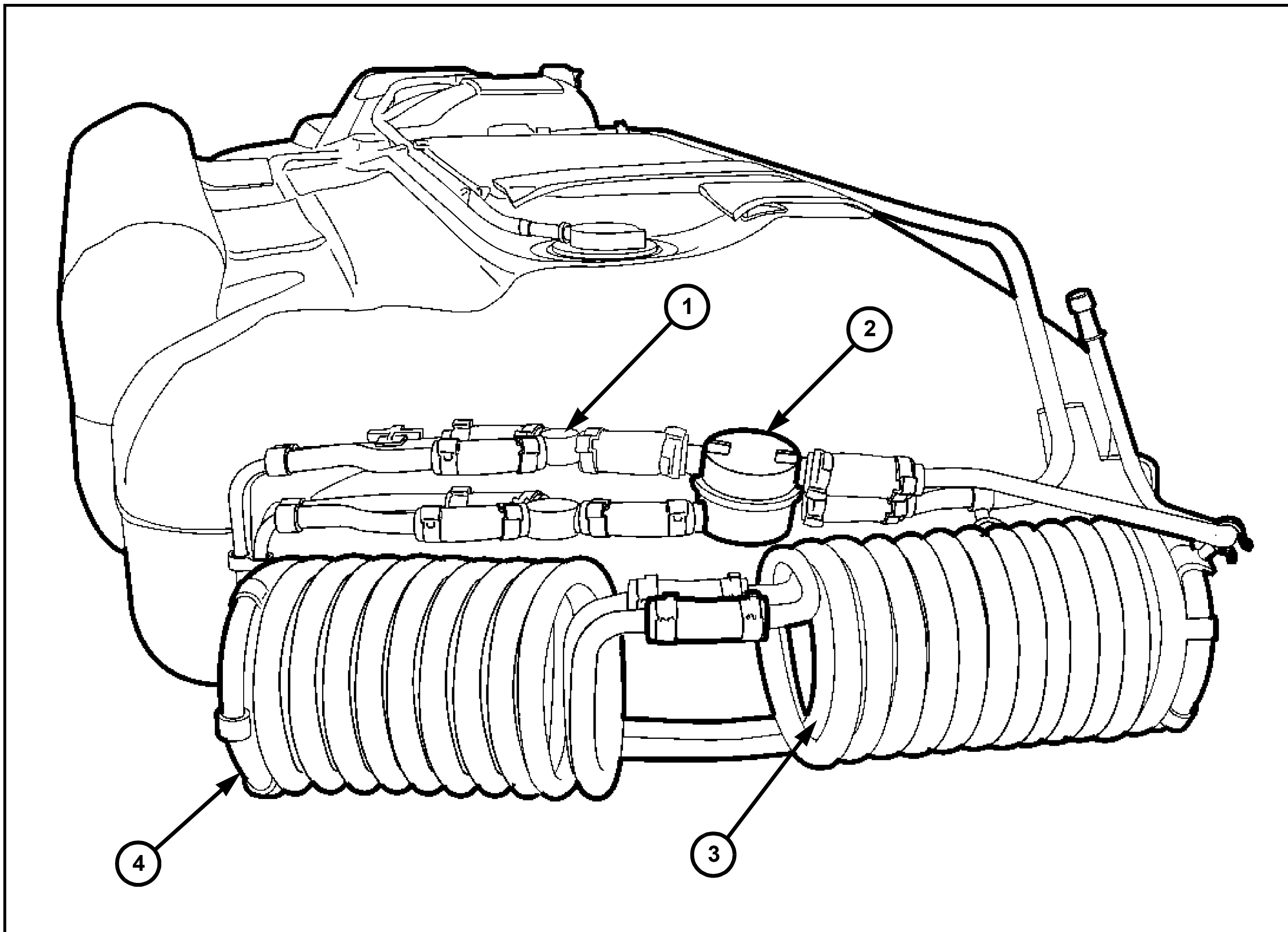
Figure 10 Fuel Tank

PRESSURE COMPENSATION/VENTILATION

A roll-over valve installed in each of the two vent valves helps to prevent fuel leakage when the tank is tilted or turned. Pressure/vacuum compensation is carried out by a separate pressure control valve in the common vent line.

FUEL COOLER

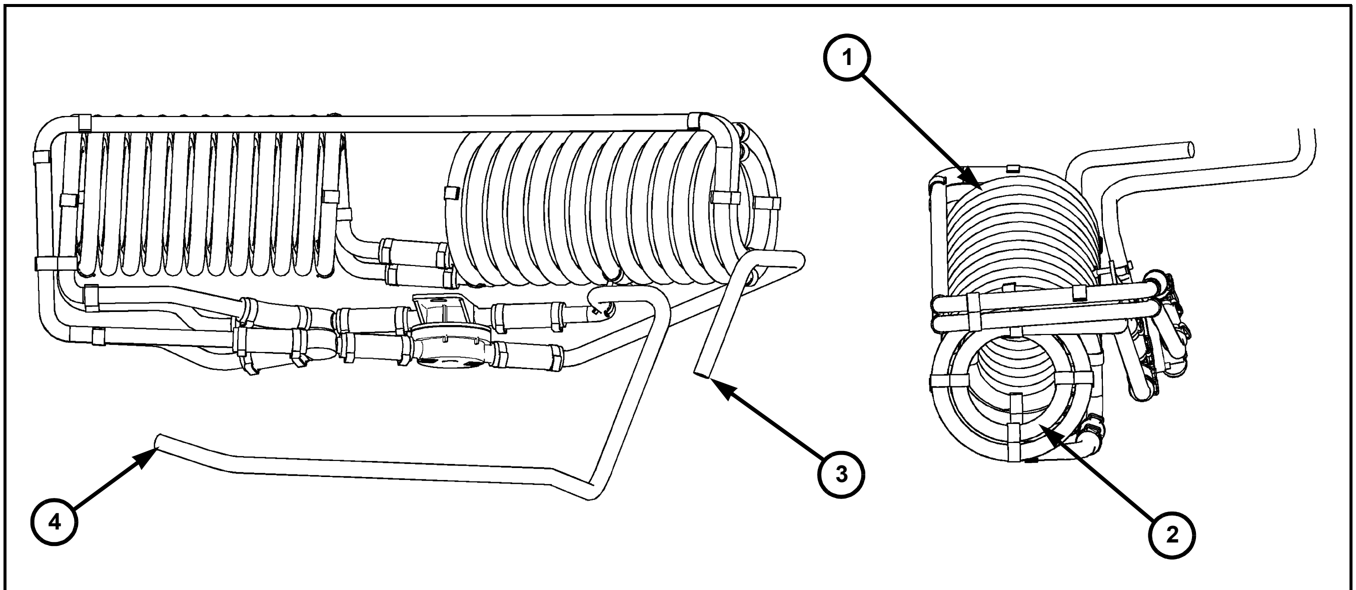
The fuel tank is designed to withstand fuel temperatures of about 80°C (176°F). Depending on the operating conditions, the fuel in the return line can reach temperatures of up to 130-140°C (266-284°F). To avoid damage to plastic parts in the fuel tank, an aluminum fuel cooler coil is installed behind the tank to help drop the fuel return temperature. Hot fuel also reduces the amount of BTUs per volume of fuel, which affects engine performance.



1	Coil Y-Fitting	3	Inner Coil
2	Preheating Valve	4	Outer Coil

Figure 11 Fuel Cooler

The fuel cooler consists of a twin coil to reduce the counterpressure in the fuel return line. The twin coils have an uncoiled combined length of 16 meters (52 ft.). The coils are made of aluminum tubing, 10 mm (0.394 in.) in diameter, with a protective polyamide coating.



1	Outer Coil	3	Fuel Return Line (From Engine)
2	Inner Coil	4	Line to Fuel Tank

Figure 12 Fuel Cooler

Depending on the operating conditions, the return fuel temperature can reach up to 140°C (284°F) inside the engine compartment. The fuel releases some of its heat as it flows through the return line, and is approximately at 120°C (248°F) when entering the cooling coils. The fuel leaving the cooler is approximately at 110°C (230°F). This hot fuel does not flow directly into the fuel tank. Instead, it flows into the fuel pump module reservoir, which is surrounded by much cooler fuel.

PREHEATING VALVE

A fuel preheating valve is installed next to the fuel cooler. The preheating valve is a bimetal controlled valve that directs the flow of return fuel through either the fuel tank or the fuel cooler.

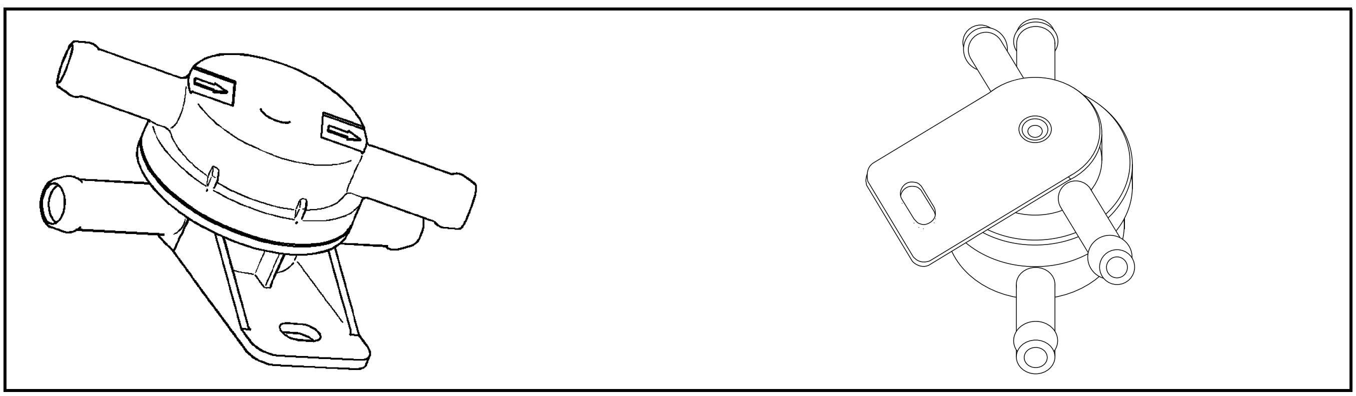
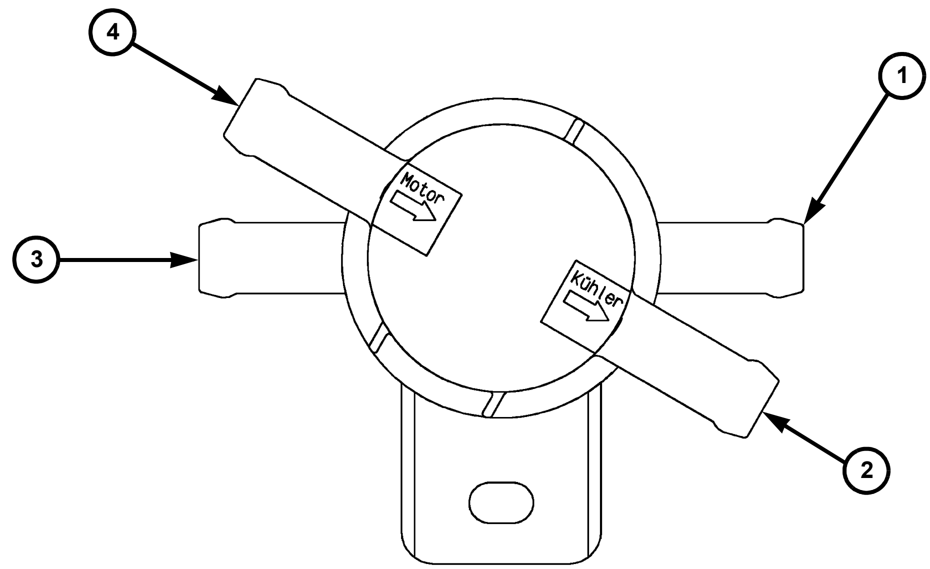


Figure 13 Preheating Valve

The preheating valve consists of a plastic housing with four fuel line fittings. The housing is split in the middle, with a bimetal disk sandwiched in between. Two of the fittings are located on the upper half of the valve and the other two on the lower half. To allow enough clearance for hose clamps, the upper and lower fittings are offset by 30°. The fittings on the upper half are marked with arrows to indicate the direction of fuel flow. The bottom half contains two fittings and a flange. Fuel returning from the engine flows through the fitting identified as “Motor”. Depending on fuel temperature, the fuel will flow either to the fuel cooler through the fitting identified as “Kühler” or to the fuel tank through the lower left fitting.



1	Return Fuel Line From Cooler	3	Fuel Line To Fuel Tank
2	Fuel Line To Cooler	4	Return Fuel From Engine

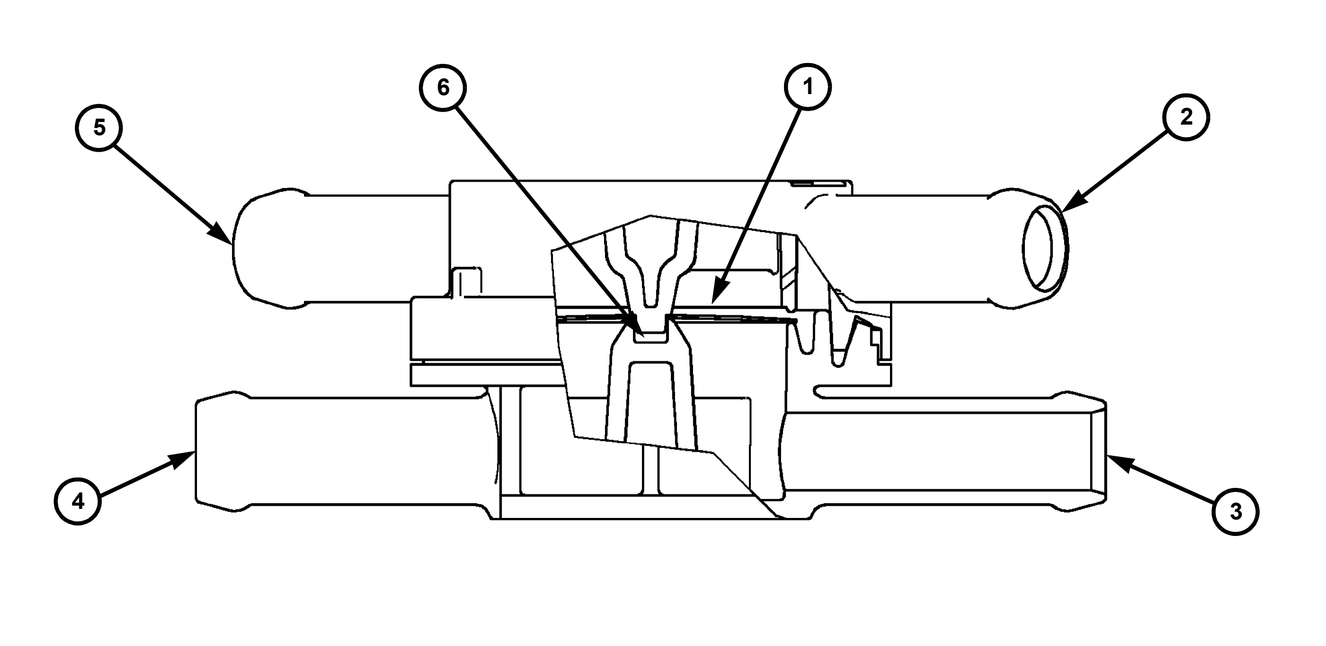
Figure 14 Preheating Valve

Preheating (A)

If the fuel temperature is less than about 65°C (149 °F), the bimetal plate (2) shuts off the return passage to the fuel cooler (b) and opens the passage in the direction of the fuel tank. The return fuel (a) flows into the fuel tank (c).

No preheating (B)

If the fuel temperature is greater than about 75°C (167°F), the bimetal plate (2) shuts off the passage to the fuel tank (c). The return fuel (a) now flows into the fuel cooler (b).



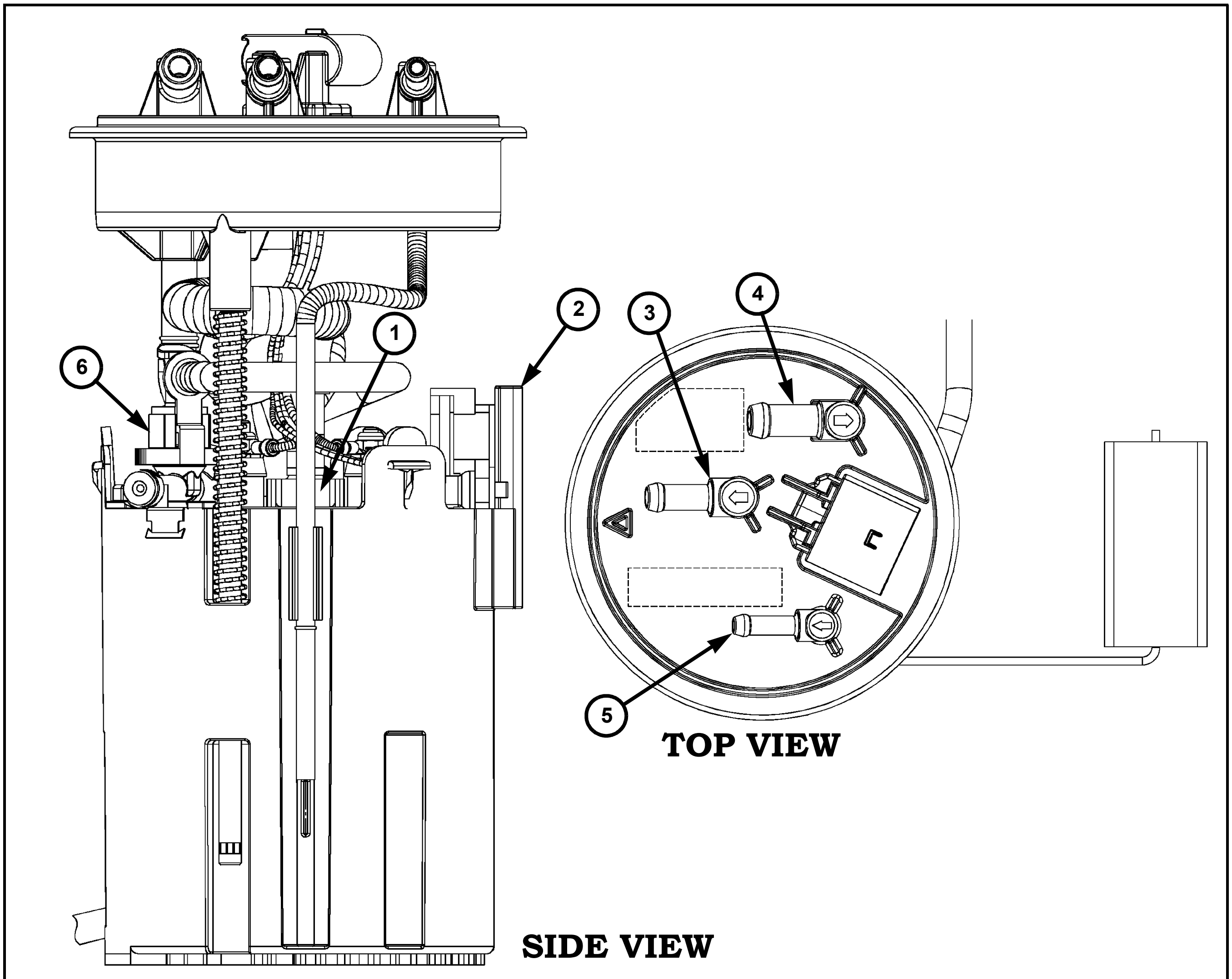
1	Bimetal Plate	4	Connection to Fuel Tank
2	Connection to Fuel Cooler	5	Fuel Return From Engine
3	Fuel Return From Cooler	6	Bypass

Figure 15 Preheating Valve Cutaway

FUEL PUMP MODULE

The fuel level sensor module is installed in the top of the fuel tank. It contains the following components:

- Electric fuel pump
- MAPPS fuel gauge sending unit
- Fuel supply/return pick-up tubes
- Suction jet pumps/throttle bypass
- Fuel pump module reservoir/baffle



1	Electric Fuel Pump	4	Fuel Return
2	MAPPS Fuel Gauge Sending Unit	5	Heater Booster Pick-Up (Option)
3	Fuel Outlet (Inlet to Fuel System)	6	Upper Suction Jet Pump

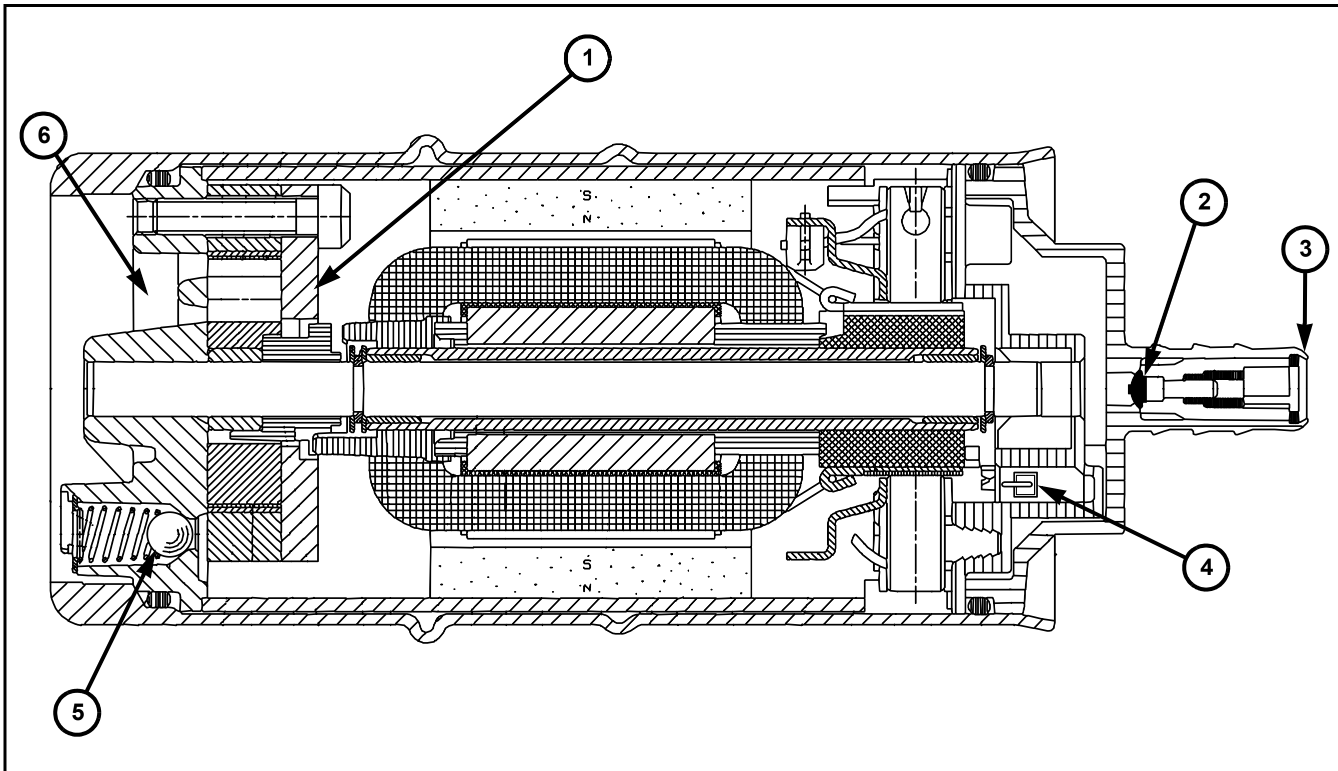
Figure 16 Fuel Tank Module

Electric Fuel Pump

The electric fuel pump delivers fuel from the fuel tank, through the filter to the high pressure pump. Excess fuel flows back to the tank through the fuel return circuit. When activated, the fuel pump runs continuously independent of engine speed.

A safety circuit prevents the delivery of fuel when the ignition is on and the engine not running. When the ignition is switched on, the electric lift pump runs for 20-30 seconds. If the engine starts, the pump will remain activated.

The electric fuel pump operates at a pressure between 4-4.5 bar (58-65 psi).

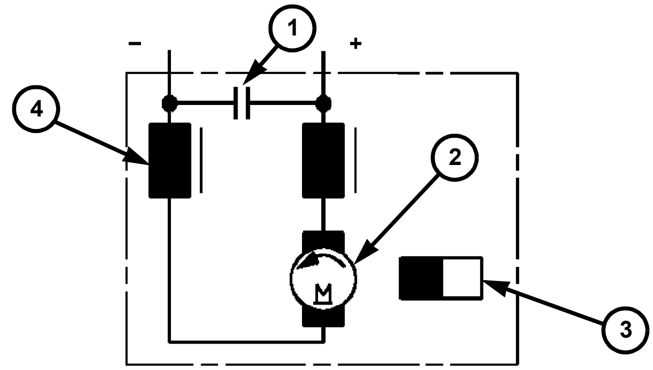


1	Roller Cell Pump	4	Suppression Capacitor
2	Check Valve	5	Presssure Relief Valve
3	Fuel Outlet Port	6	Fuel Inlet Port

Figure 17 Fuel Pump Cutaway

The fuel pump is comprised of a positive-displacement pump and an electric motor within an aluminum housing. An end cover is crimp-sealed on the upper part of the pump housing. The fuel pump end cover contains the electrical connections and the fuel outlet port. A check valve in the fuel outlet port prevents the fuel in the supply line from draining back to the pump, maintaining system pressure. A 1uF/50V capacitor is integrated in the end cover for interference suppression. The end cover also includes the carbon brushes for the drive motor commutator.

The electric motor consists of an armature with a permanent magnet. When the pump is running, the fuel cools the electric motor and pumping element.

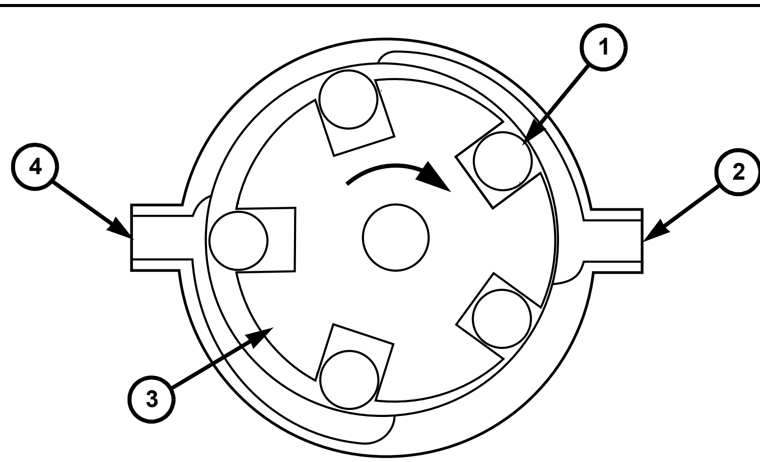


1	Suppression Capacitor	3	Permanent Magnet
2	Commutator With Brushes	4	Stator Winding (2)

Figure 18 Fuel Pump Circuit Diagram

The pumping element is a roller-cell type (positive displacement pump). The pump consists of an eccentric chamber with a slotted rotor. A movable roller is located in each slot. Rotor rotation and fuel pressure causes the rollers to move outward against the bearing surface of the stator and against the driving flanks of the slots. The rollers act as rotating seals, forming a chamber between the rollers of adjacent slots and the roller path.

As the positive-displacement pump element rotates it draws in fuel through the inlet port. When the inlet port closes, the chamber volume is continuously reduced. Fuel then flows through the outlet port when it opens.



1	Roller	3	Rotor
2	Outlet Port	4	Inlet Port

Figure 19 Roller Cell Pump

Pressure limitation is achieved by an integrated spring-loaded relief valve, which opens if there is a restriction in the fuel supply line. If the fuel pressure exceeds the tension of the spring, the check ball will unseat, opening a passage to the inlet side of the pump. The fuel is bypassed to the inlet side of the pump as long as the check ball remains unseated.

Fuel Pump Flow Rate—The nominal value is 165 l/h (43.6 gal/h).

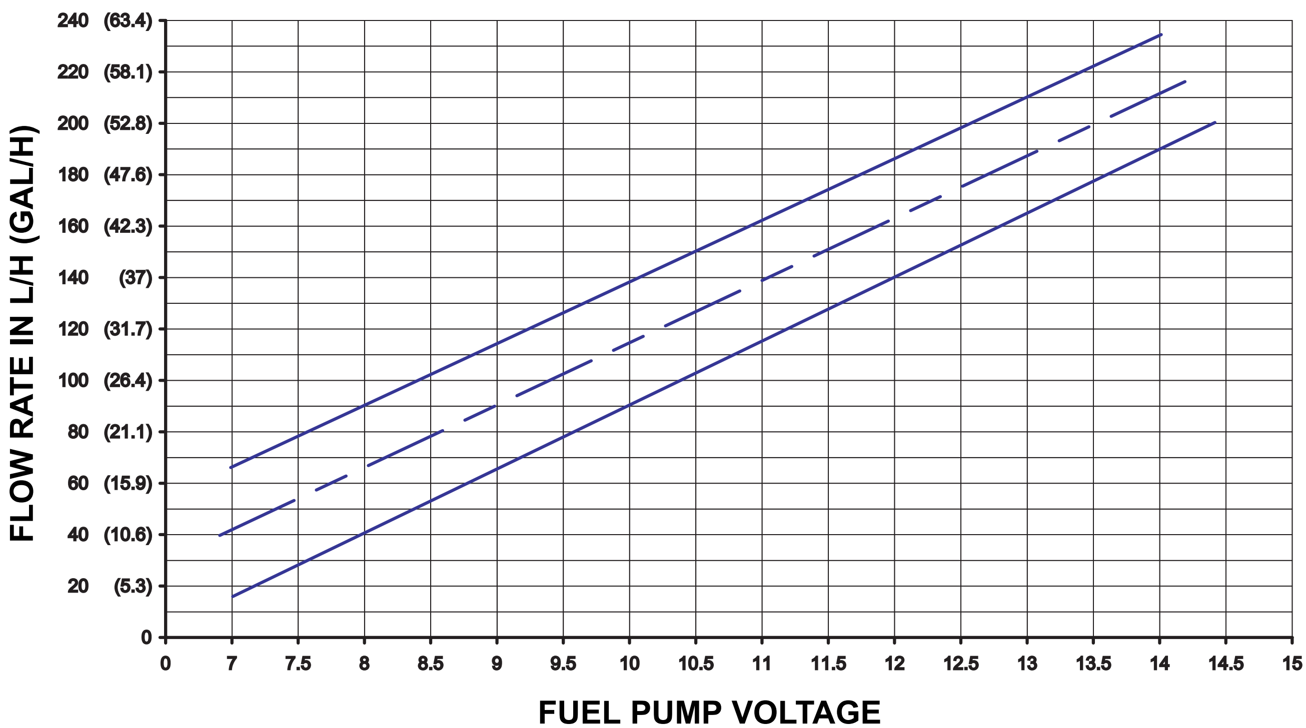


Figure 20 Fuel Pump Performance Chart

Fuel Pump Current Draw—The nominal value is 8A with a system voltage of 12.6 V.

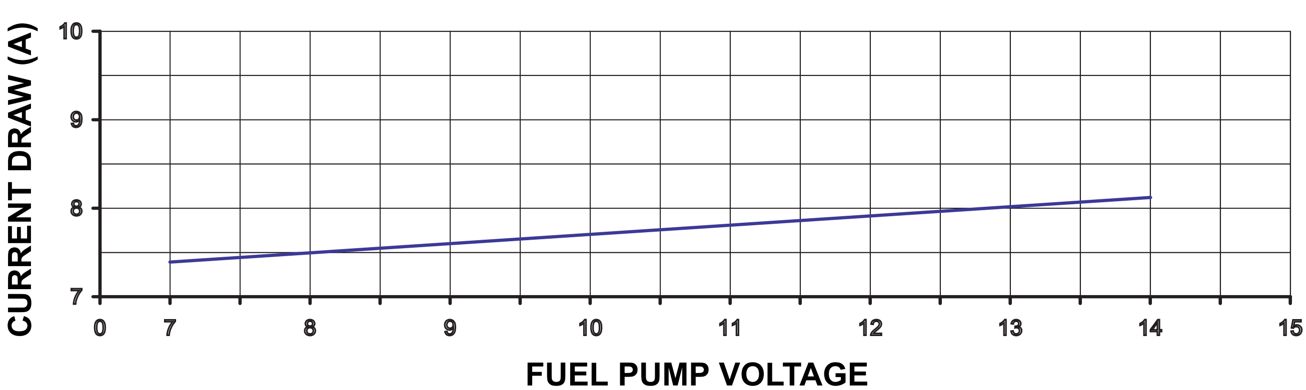
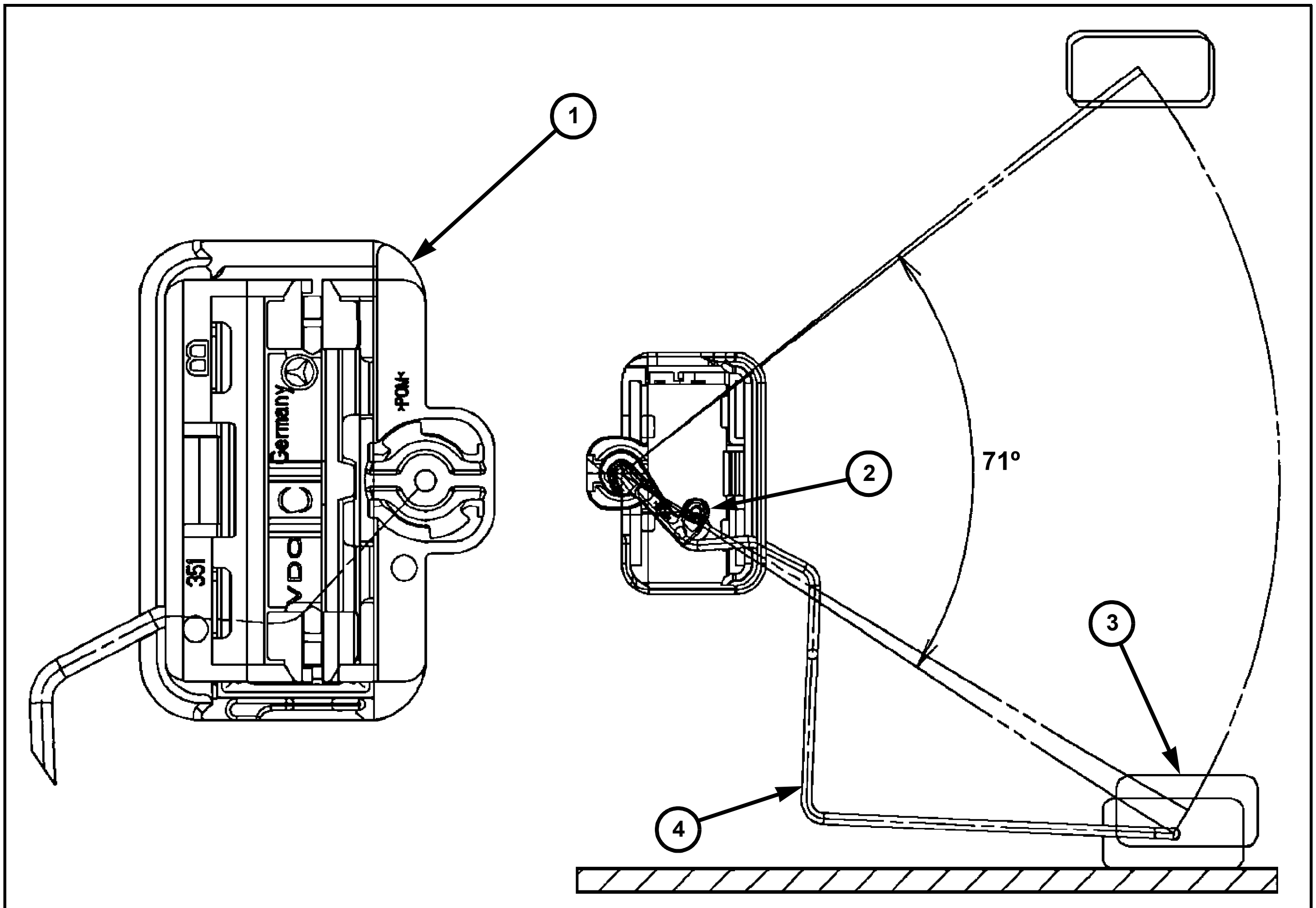


Figure 21 Fuel Pump Current Draw Chart

MAPPS Fuel Gauge Sending Unit

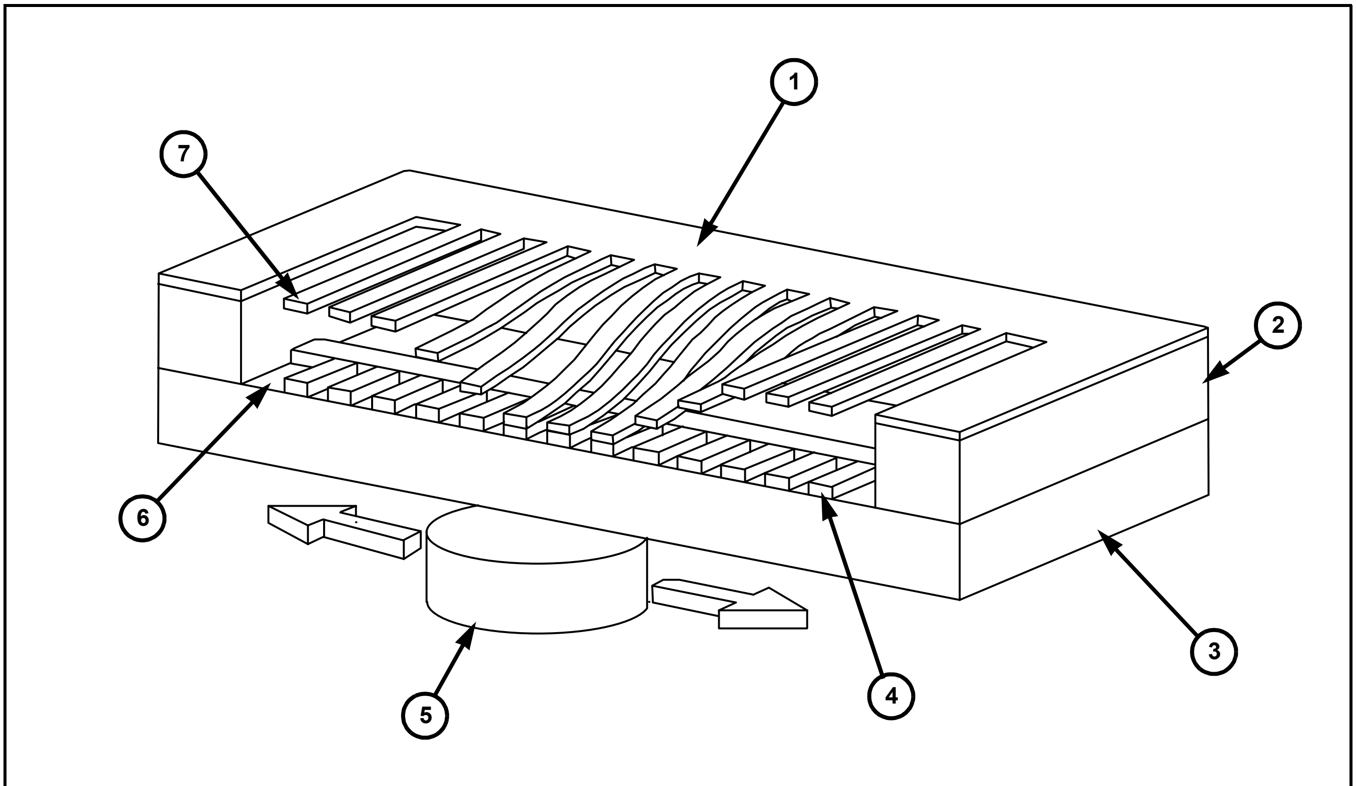
The Magnetic Passive Position Sensor (MAPPS) fuel gauge sending unit is mounted to the fuel pump module. The sending unit consists of a molded nitrile rubber ebonite float, a stainless steel support rod and a MAPPS element encased in a plastic housing. The low-wear encapsulated MAPPS element consists of a ceramic substrate with 52 film resistors in a radial layout, wired in series with individual contacts. Separated by a spacer, a soft magnetic foil (contact spring) with a corresponding number of fingers is mounted a small distance above the contacts.



1	MAPPS Fuel Gauge Housing	3	Float
2	Magnet	4	Support Rod

Figure 22 MAPPS Fuel Gauge Sending Unit

The fuel sending unit float support rod has a travel range of 71 degrees. A samarium cobalt (SmCo) magnet located below the ceramic substrate is attached to the end of the float support rod. As the rod moves, the magnet attracts the closest finger, which closes an electrical contact. The electrical output signal changes proportionally depending on the position of the magnet. Due to the magnetic coupling, the measuring element can be hermetically sealed to prevent the contamination of the microcontacts.



1	Contact Spring	5	Magnet
2	Spacer	6	Resistor Film
3	Ceramic Substrate	7	Contact Spring Finger
4	Resistor Film Contacts		

Figure 23 MAPPS Element

Fuel level measurement using MAPPS provides the following advantages:

- Longer sensor life due to wear-resistant measurement system
- Protection against contamination from any fuel types
- Lower contact current
- Redundant contacts
- Best EMC because of passive system

MAPPS Diagnostics

The resistance of the MAPPS fuel level sending unit varies between 51-527 Ω depending on the fuel level in the tank. The actual resistance of the MAPPS fuel level sending unit can be verified with the diagnostic scan tool. The following table and chart compares the sending unit resistance with the fuel gauge needle position on the instrument cluster.

Fuel Gauge Needle Position	MAPPS Specified Resistance
E	527 Ω
1/4	370 Ω
1/2	234 Ω
3/4	130 Ω
F	51 Ω

Table 1 MAPPS Fuel Gauge Resistance Values

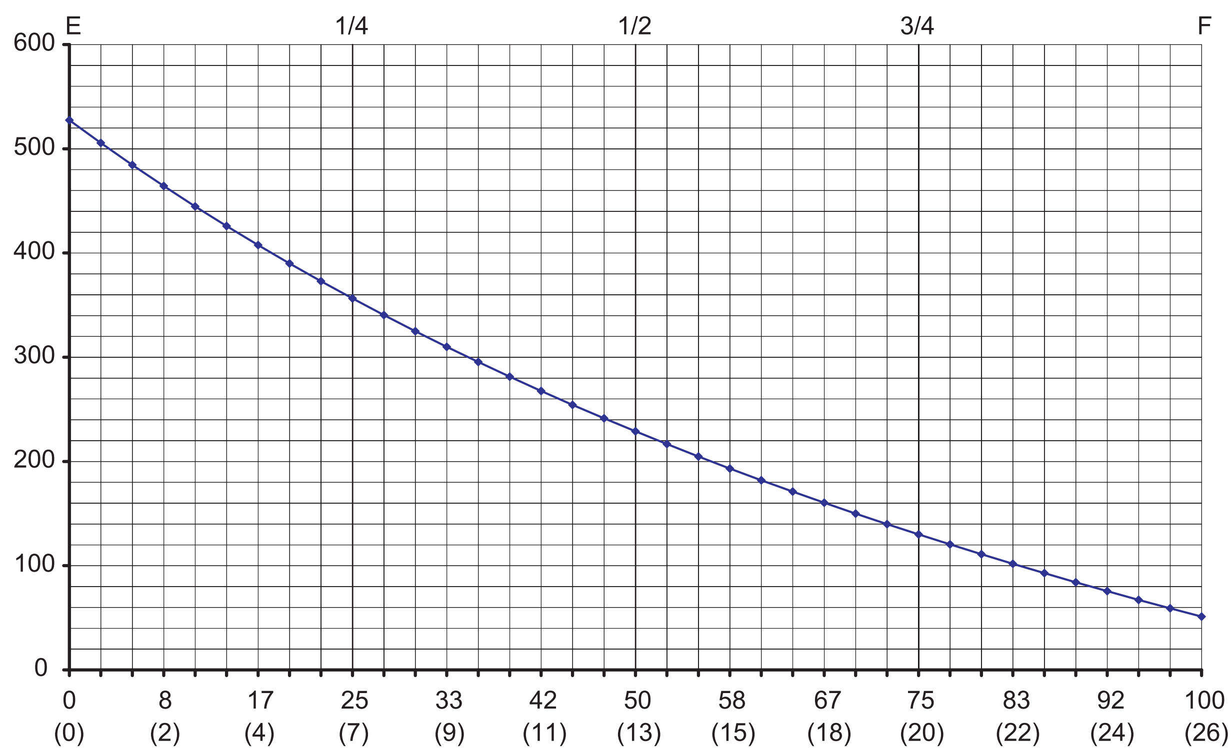
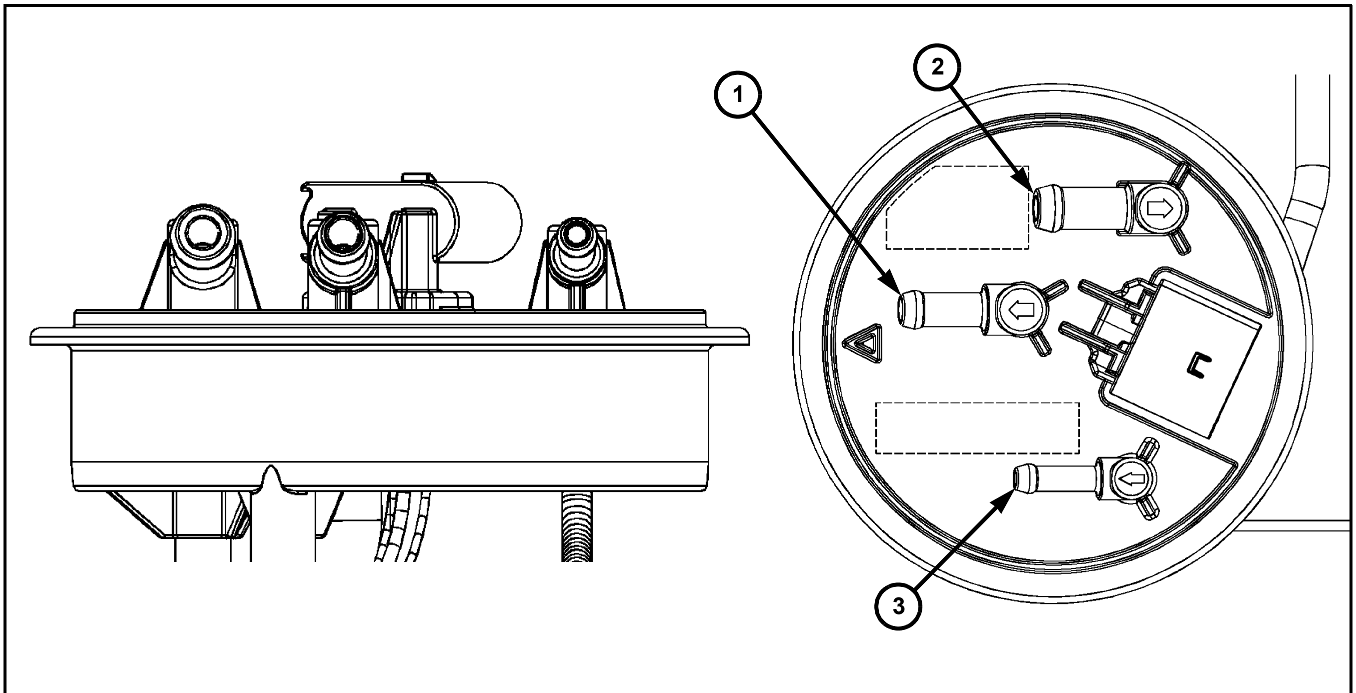


Figure 24 MAPPS Fuel Gauge Resistance Chart

Fuel Supply/Return Pick-Up Tubes

The fuel inlet and outlet ports are located on top of the fuel pump module. Arrows on the ports indicate the direction of fuel flow. On vehicles featuring the optional diesel-powered auxiliary heater, the fuel pump module is equipped with an additional supply port.

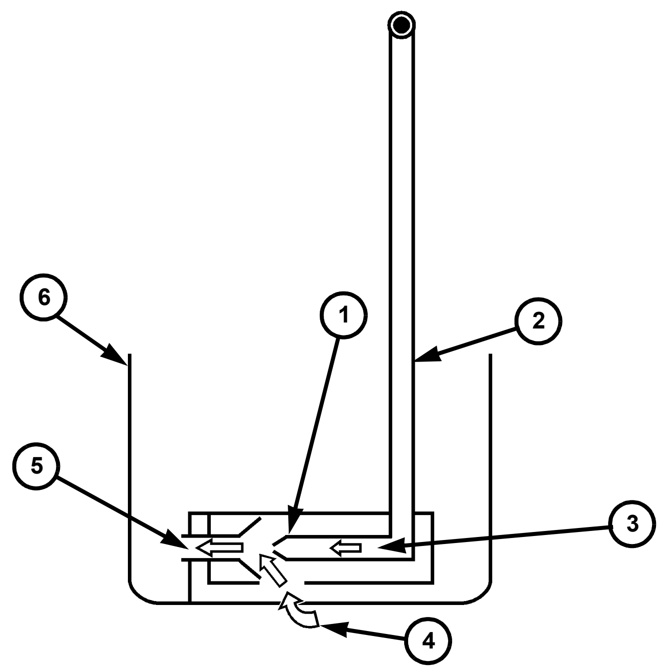


1	Fuel Outlet (Inlet to Fuel System)	3	Heater Booster Pickup (Option)
2	Fuel Return		

Figure 25 Fuel Pump Module Pick-Up Tubes

Suction Jet Pump

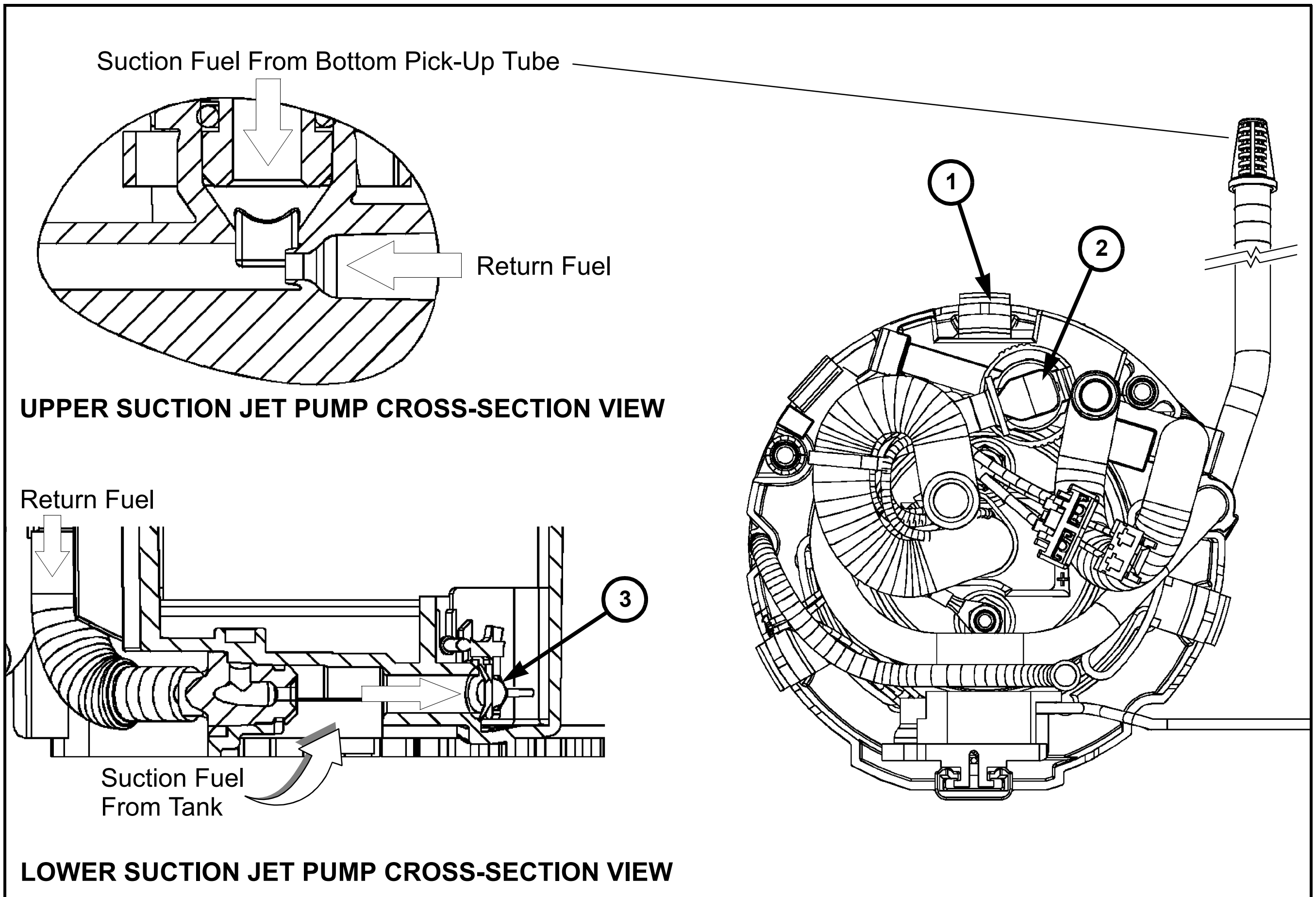
The suction jet pump (Figure 26) helps fill the fuel tank module reservoir with fuel up to a certain level. When cornering with a low fuel level in the fuel tank the reservoir prevents the system from drawing in air. The nozzle (1) in the suction jet pump accelerates the returning fuel (3). The fuel jet produces a differential pressure, which draws fuel from the tank into the reservoir (6).



1	Suction Jet Pump Nozzle	4	Fuel From Tank
2	Return Pick-Up Tube	5	Mixed Fuel
3	Return Fuel	6	Tank Module Reservoir

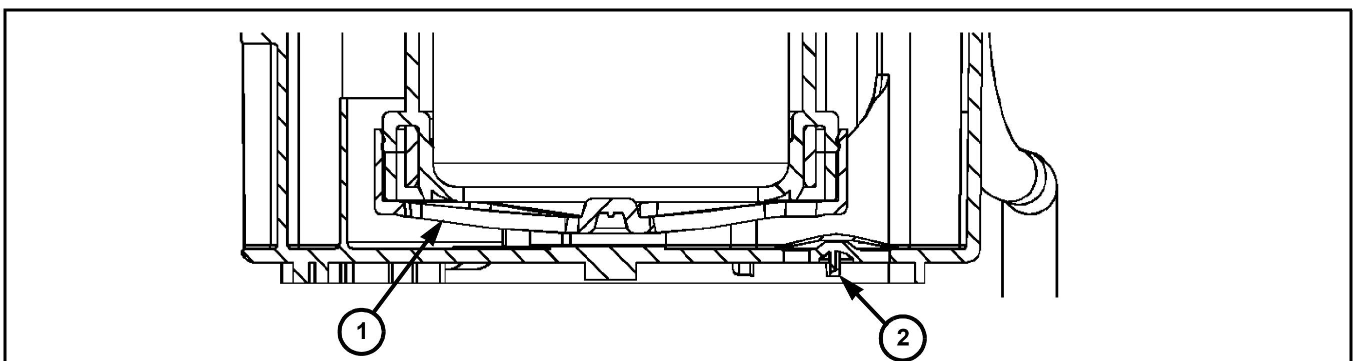
Figure 26 Suction Jet Pump

The fuel pump module features two jet pumps. The lower jet pump draws in warm fuel directly at the bottom of the reservoir cup, while the upper jet pump draws in cool fuel from the fuel tank through the bottom pickup tube. The cool fuel is drawn in and is mixed with the fuel already in the reservoir cup in a 50-50 mix ratio.



1	Lower Suction Jet Pump	3	Hinged Check Valve
2	Upper Suction Jet Pump		

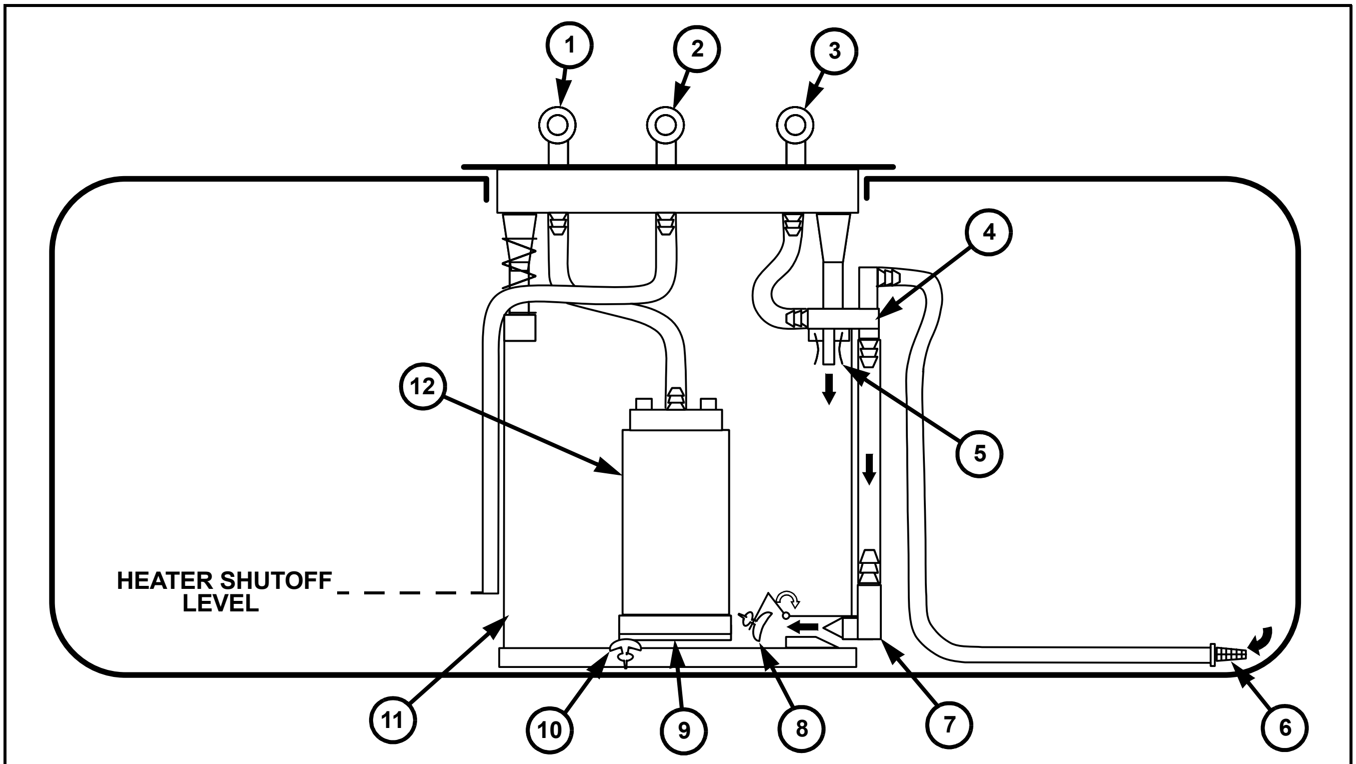
Figure 27 Upper and Lower Suction Jet Pumps



1	Fuel Pump Inlet Screen	3	Reservoir Filling Check Valve

Figure 28 Fuel Pump Module Lower-End View

The throttle bypass allows some of the return fuel to flow directly into the reservoir cup. The lower jet pump passage check valve prevents the fuel in the reservoir cup from draining back into the tank. The check valve is pushed open by the stream of fuel from the jet pump and closes when the flow stops. The bottom check valve in the reservoir cup opens if a completely emptied fuel tank is refilled. Fuel flows through the bottom check valve into the reservoir cup enabling the fuel pump to draw in fuel.



1	Fuel Supply Line	7	Lower Jet Pump
2	Optional Heater Supply Line	8	Jet Pump Passage Check Valve
3	Fuel Return Line	9	Fuel Pump Inlet Port with Screen
4	Upper Jet Pump	10	Bottom Check Valve
5	Throttle Bypass	11	Fuel Reservoir Cup
6	Bottom Pickup Tube	12	Electric Fuel Pump

Figure 29 Fuel Pump Module Layout

Electrical Connector

The electrical connector is located on top of the fuel pump module. The four-pin connector provides the electrical path to supply the fuel pump and the fuel level sending unit with power. A two-pin connector containing the wires to the fuel level sending unit plugs to the back of the four-pin connector. Pins 1 and 4 supply power to the fuel pump, while pins 2 and 3 provide the electrical path to the MAPPS fuel level sending unit.

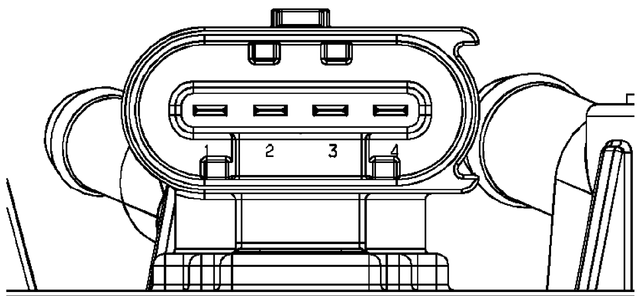


Figure 30 Fuel Pump Module Connector

FUEL LINES

The fuel lines connect the components of the common rail fuel system together to form a closed fuel system.

LOW PRESSURE FUEL LINES

The fuel feed and return lines installed in the chassis are made of aluminum and have an outside diameter of 10 mm (0.393 in.).

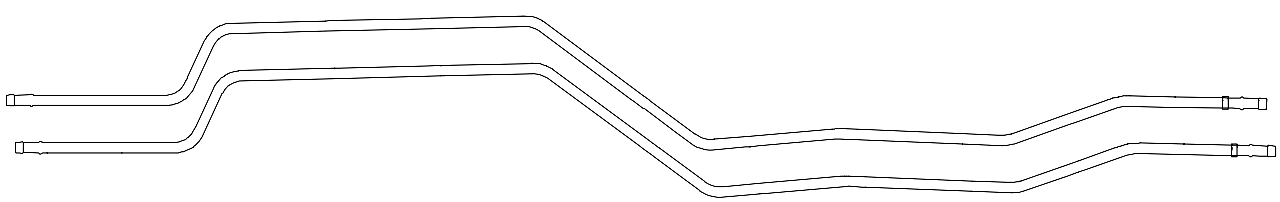
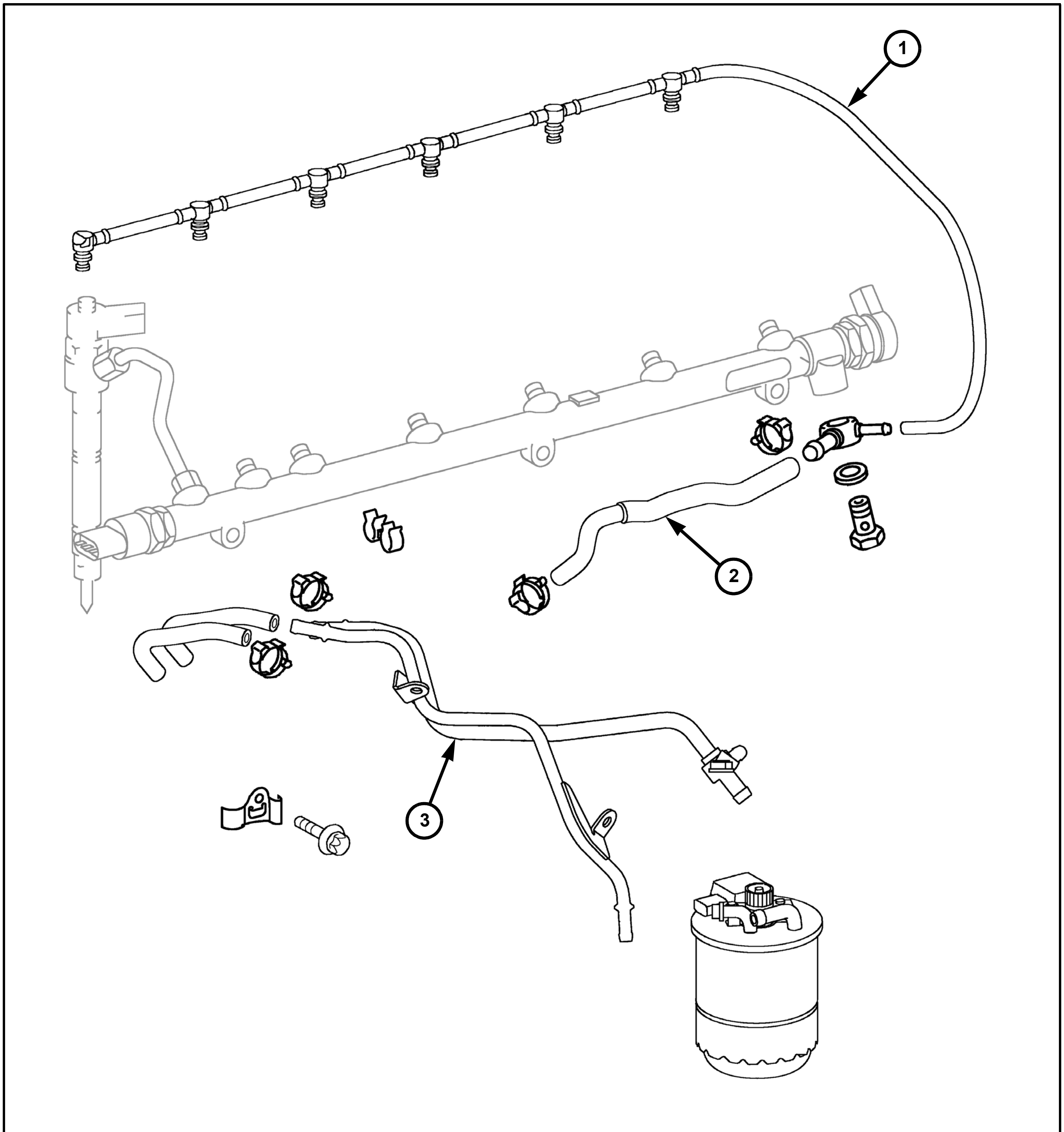


Figure 31 Fuel Feed and Return Lines

The underhood low pressure fuel lines (Figure 32) are made of the following materials:

- HNBR (Hydrogenated Nitrile Butadiene Rubber) hose—Used to attach the fuel lines to the high-pressure pump, fuel filter and fuel return banjo fitting. Standard crimp-type clamps are used.
- Braided rubber hose—Used in the fuel return line from the injectors.
- Stainless steel fuel line—Used in the high pressure pump supply and return circuits.



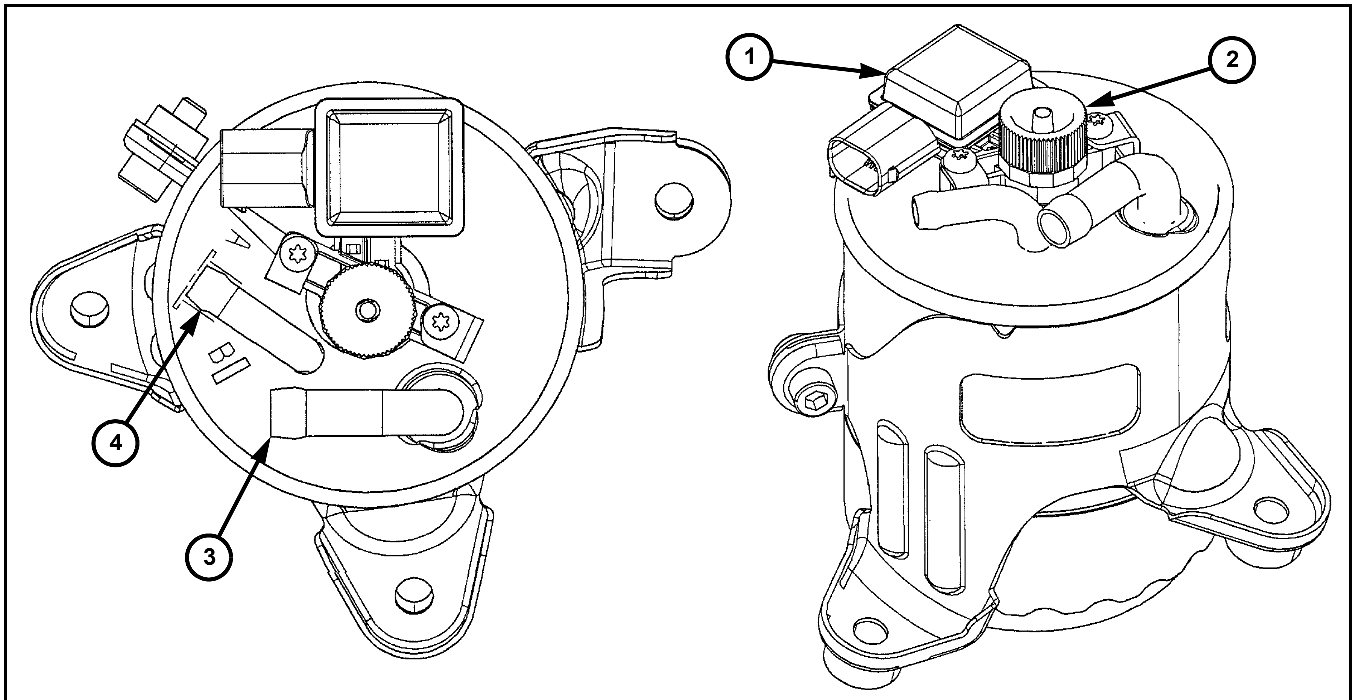
1	Braided Rubber Hose	3	Stainless Steel Tubing
2	HNBR Rubber Hose		

Figure 32 Low Pressure Fuel Lines

FUEL FILTER

The fuel filter is mounted on top of the left engine mount bracket. The filter has the task of cleaning the fuel before it is fed through the fuel supply pump to the high-pressure system and ultimately to the injector nozzles. The fuel filter has been designed for better re-start after the fuel tank has been completely emptied. The filter incorporates the following components:

- 5 micron fuel filter element
- Water separator
- Water drain valve
- WIF sensor



1	Water In Fuel (WIF) Sensor	3	Fuel Inlet (From Tank)
2	Water Drain Valve	4	Fuel Outlet (To Pump)

Figure 33 Fuel Filter

Fuel flows from the outside surface to the inside (Figure 34). The fuel filter has a pressure differential of 200-300 mbar (2.9-4.4 psi) when new. When dirty, the pressure differential rises to 800 mbar (11.6 psi). Fuel filtering is critical in common-rail systems. Small amounts of impurities may damage the precision mechanical components over time. Water entering the injection system can also lead to damage. Consult the service information for the fuel filter element service interval.

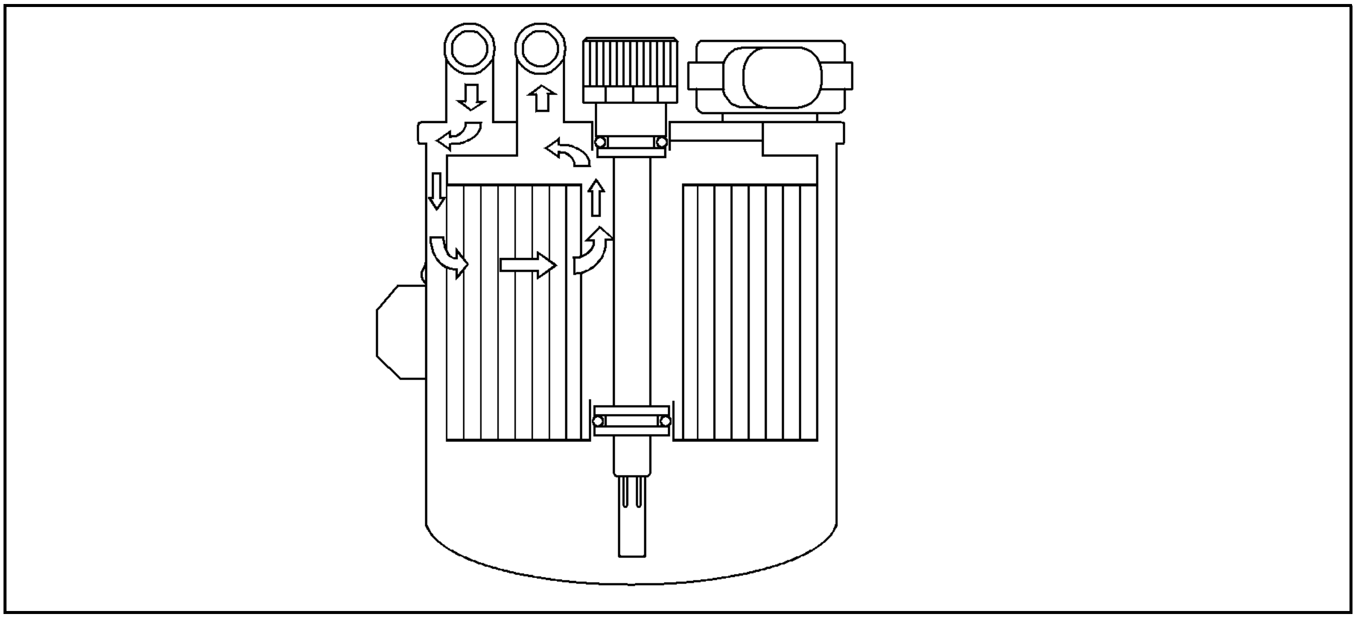


Figure 34 Fuel Filter Flow

Water Drain Valve

A water reservoir is located at the bottom of the filter to collect any water contained in the fuel. A drain valve is mounted on the top of the filter housing. The filter should be drained if the WIF light is illuminated. Water is drained by opening the drain valve and activating the electric fuel pump to generate fuel flow. When draining the filter, attach a hose to the drain valve to avoid spilling fuel.

Bleeding the system

The fuel system is bled automatically during engine start. Do not interrupt start operation.

ACTIVITY 2.1 FUEL PUMP AND FILTER TEST

The purpose of this activity is to test the performance of the electric fuel pump and the fuel filter.

ELECTRIC FUEL PUMP PRESSURE TEST

1. Using service information, connect a fuel pressure gauge to the low-pressure fuel system between the fuel tank supply line and the fuel filter. Ensure the fuel level is higher than 1/8 of a tank.
2. Switch the ignition ON to activate the electric fuel pump. Inspect the fuel lines for leaks.
3. Determine how long does the fuel pump run after switching the ignition ON.
   Approximately 30 seconds
4. Read the pressure on the fuel gauge with the electric fuel pump running.
5. What is the fuel pressure reading?
   Approximately 58 psi
6. What is the specified value? (check the service manual)
   4-4.5 bar (58-65 psi).
7. Is the measured value within specifications? YES __*X*__ NO ______
8. What could be the probable cause if the readings were lower than the specified value?
   Electric fuel pump, restriction in fuel supply line
9. What could be the probable cause if the readings were higher than the specified value?
   Restriction in fuel return line, fuel filter or high pressure pump
10. Switch the ignition OFF to turn off the fuel pump and observe the pressure reading.
11. Is there a visible pressure drop? YES __*X*___ NO ______
12. Is this normal? YES ___*X*___ NO _______
13. Where is the pressure being lost?
    At the fuel return line
14. Switch the ignition OFF. Connect the diagnostic scan tool to the vehicle and find the fuel rail pressure value.
15. Compare the scan tool and gauge readings. Do they match? YES ____ NO __*X*_
16. Explain why
    The ECM's 10-bit ADC divides the fuel rail pressure into 1024 slices. Each slice =32 psi. The resolution is not enough for checking low pressure with accuracy

17. What is the allowable pressure drop across the fuel filter?
 800 mbar (11.6 psi).

TO CALCULATE THE PRESSURE DROP ACROSS THE FUEL FILTER, CHECK THE FUEL PRESSURE BEFORE AND AFTER THE FUEL FILTER.

ACTIVITY 2.2 ELECTRIC FUEL PUMP DELIVERY TEST

The purpose of this activity is to test the performance of the electric fuel pump.

1. Ensure the fuel level is higher than 1/8 of a tank.
2. Using service information, disconnect the high pressure pump fuel supply line (ensure the ignition is switched OFF). Attach an extension hose to the supply line and place it in a measuring container. Seal off the end of the fuel hose with clamping pliers.
3. Switch the ignition ON and wait 5 seconds.
4. Remove the clamping pliers and allow fuel to collect for 15 seconds.
5. Is the fuel pump running? YES ______ NO ______
6. Measure the fuel in the container.
7. What is the total amount of fuel collected?

   Approximately 40 - 50 fl.oz (1.2 - 1.5 l)
8. What is the specified value? (check the service manual)

   At least 0.5 liters (17 fl.oz) in a maximum of 15 seconds.
9. Is the measured value within specifications? YES __*X*__ NO ______
10. What could be the probable cause if the amount of fuel collected is lower than the specified value?

    Faulty electric fuel pump, restriction in fuel line, leakage
11. What could be the probable cause if the amount of fuel collected is higher than the specified value?

    Normal. The fuel pump output is higher than the specified value
12. What part of the six step diagnosis process would you connect the low pressure fuel gauge?

    To isolate a concern with the fuel pump

ACTIVITY 2.3 ELECTRIC FUEL PUMP CURRENT DRAW TEST

The purpose of this activity is to test the performance of the electric fuel pump.

1. Ensure the fuel level is higher than 1/8 of a tank.
2. Using service information, locate and disconnect the fuel pump relay fuse.
3. Record the fuel pump relay fuse information on the following table:

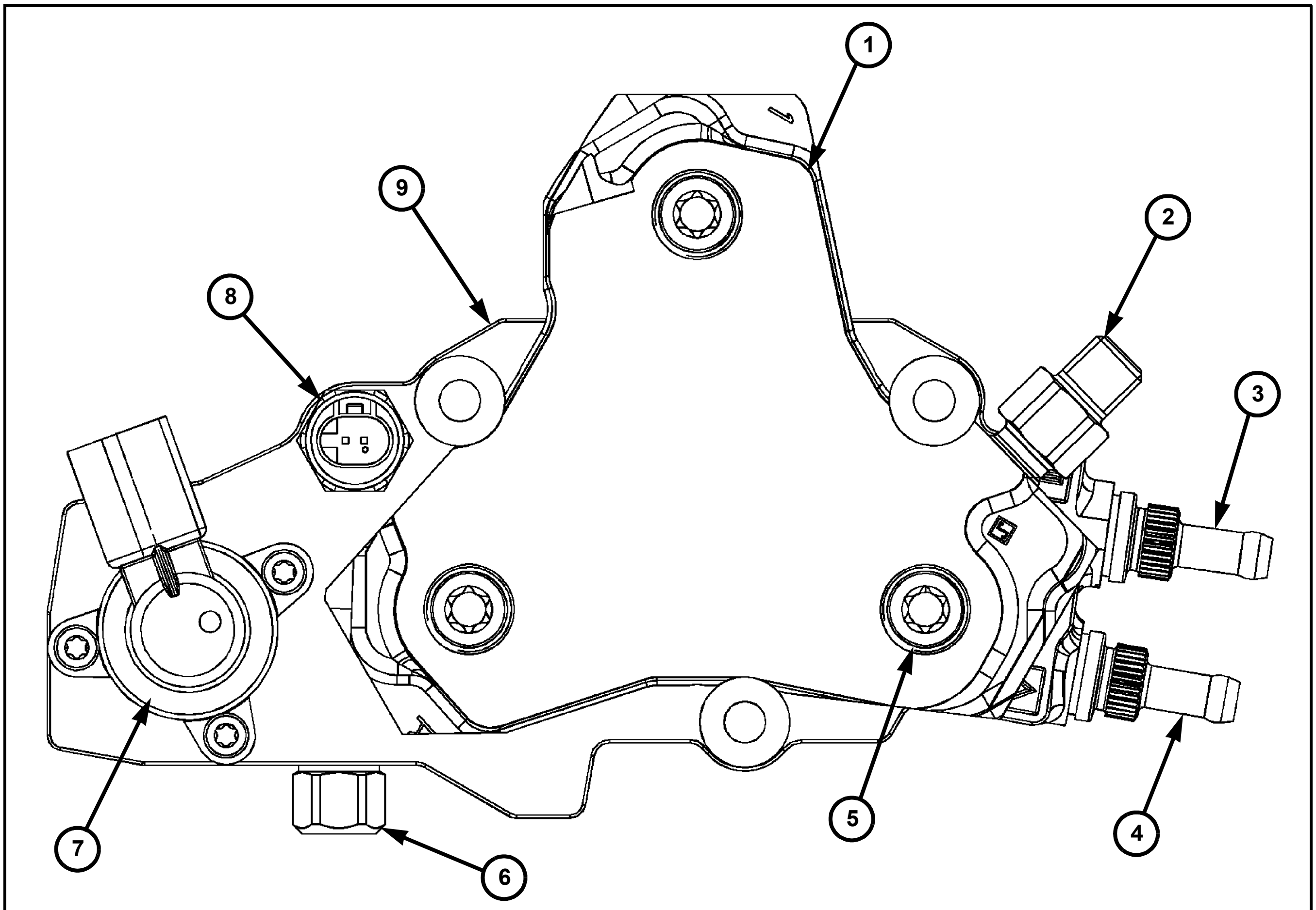
Fuse Block Number	Fuse Number	Fuse Rating (A)
1	*19*	*15A*

4. Connect an ammeter to the fuse contact slot.
5. Switch the ignition ON.
6. Measure the current draw of the fuel pump.
7. What is the measured current draw?
   Approximately 5.8 A
8. What is the specified value? (check the service manual)
   Between 4-9 A
9. Is the measured value within specifications? YES __*X*__ NO ______
10. What could be the probable cause if the readings were lower than the specified value?
    High electrical resistance in the circuit
11. What could be the probable cause if the readings were higher than the specified value?
    Internal fuel pump problem (windings shorted, armature dragging, etc.)
12. What part of the six step diagnosis process would you connect the low pressure fuel gauge?
    To isolate a concern with the fuel pump
13. Remove the ammeter, fuel gauge and reassemble the van.
14. Start the van and check for fuel leaks. Correct any leakage you find.

HIGH-PRESSURE FUEL CIRCUIT COMPONENTS

HIGH PRESSURE PUMP

The high pressure pump is mounted to the front of the cylinder head. The pump is driven at about 1.3 times the speed of the camshaft and requires no timing. Fuel that enters the high-pressure pump is pressurized between 200-1600 bar (2900 - 23,205 psi). The pressurized fuel is then supplied to the fuel rail.



1	High Pressure Pump Housing	6	Fuel Pressure Relief Valve
2	High Pressure Port	7	Fuel Quantity Valve
3	Fuel Inlet Port (From Filter)	8	Fuel Temperature Sensor
4	Fuel Return Port	9	Pump Flange
5	Pump Element Check Ball Plug (3)		

Figure 35 High Pressure Pump

The high pressure pump is a radial piston pump with three pistons arranged at an angle of 120°. The flange located behind the pump contains fuel passages and control elements, which regulate the flow of fuel to the pump.

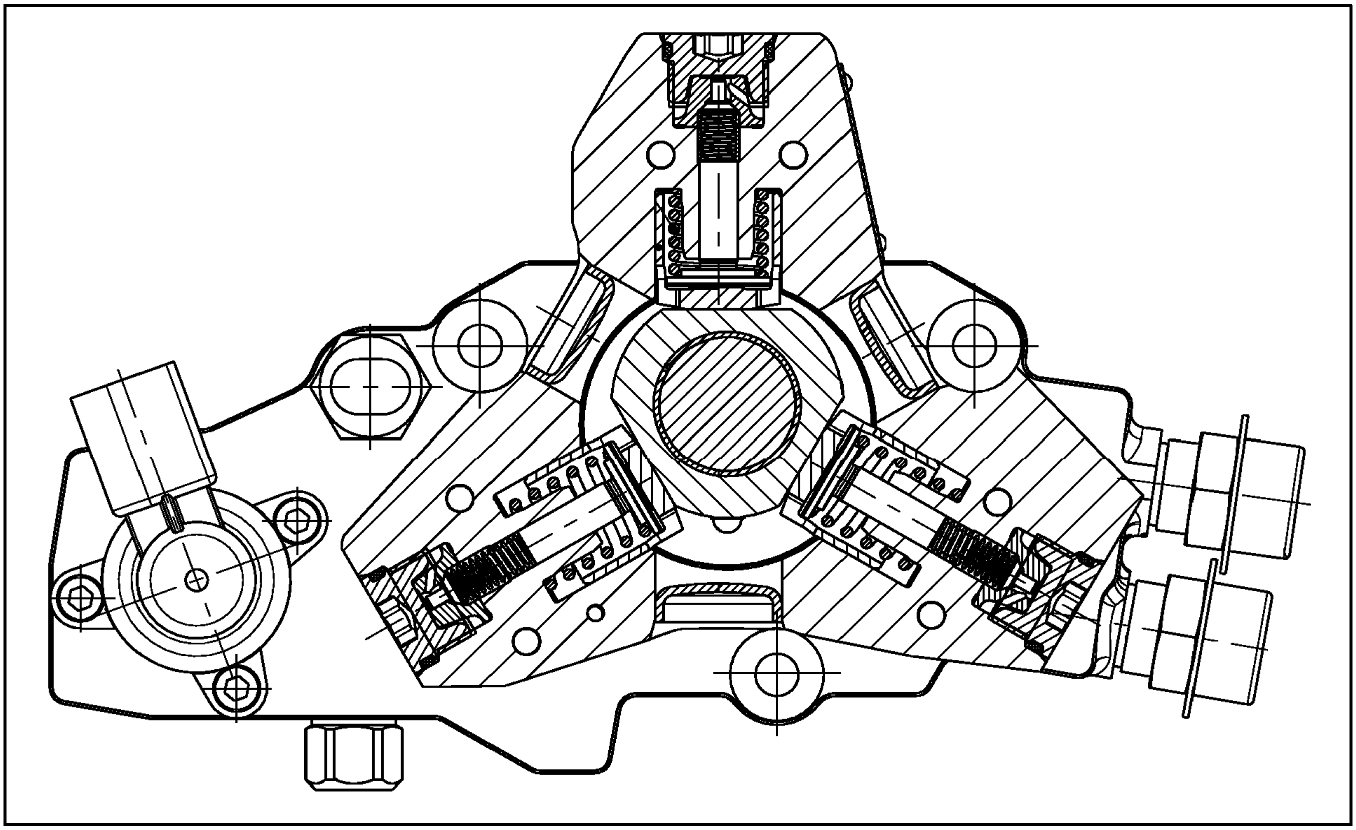


Figure 36 High Pressure Pump Cutaway View

Specific moving parts inside the high pressure pump feature a carbon based (C2) coating to assist with the lubrication process during operation. The high pressure pump is non-serviceable and must be replaced as an assembly.

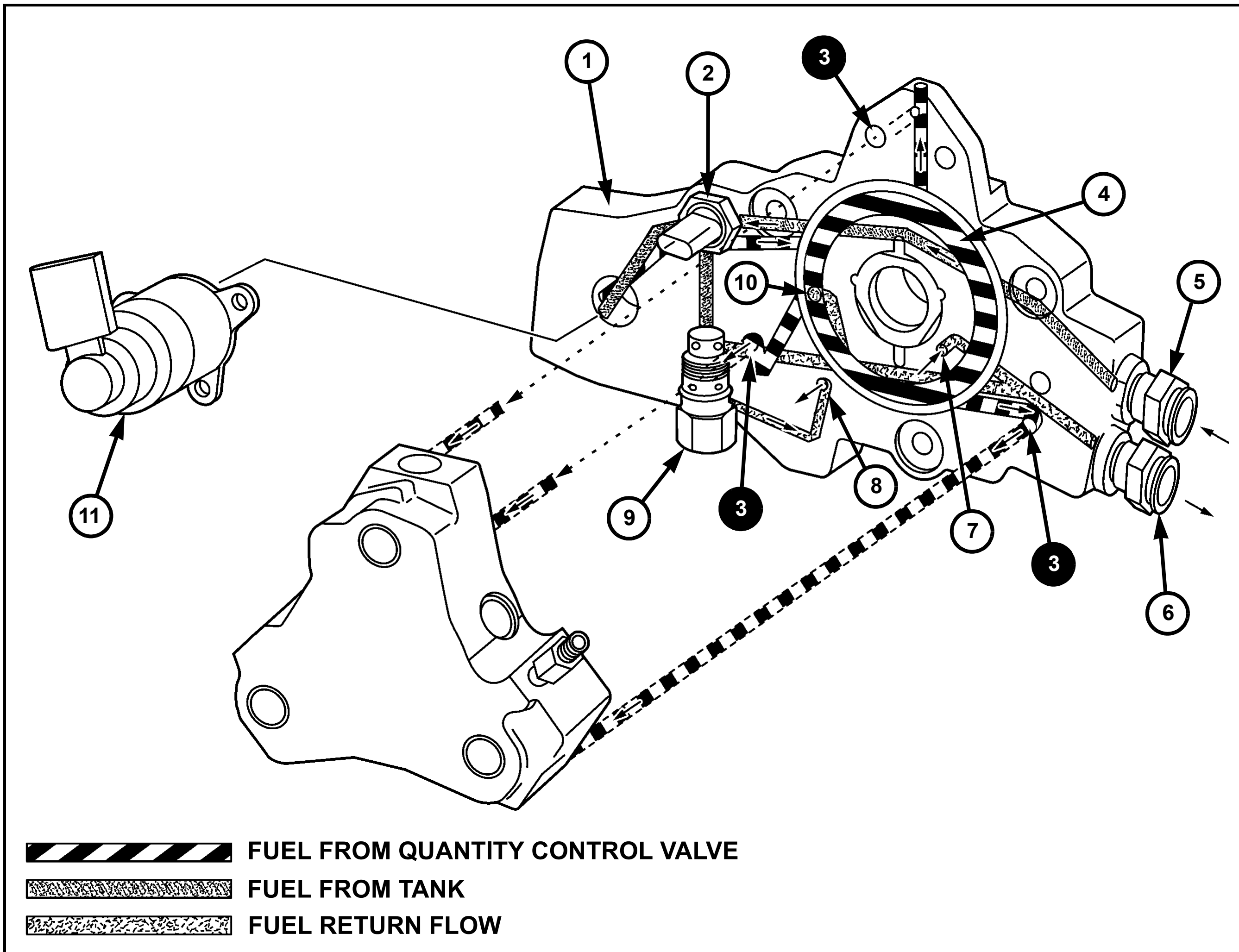
Operation

Low Pressure Side

Refer to Figure 37. The fuel supplied by the electric fuel pump flows through the fuel feed (5) at the high pressure pump flange (1) and is passed from there to the fuel quantity valve (11) and to the fuel pressure relief valve (9).

The fuel quantity control valve (11) controls the volume of fuel which flows along the annular passage (4) through the feed ports (3) to the three pump elements of the high pressure pump. To lubricate the plunger-and-barrel assemblies when the quantity control valve is closed (overrun mode), fuel is led directly into the annular port (4) via the zero delivery restrictor (10).
The fuel pressure relief valve (9) limits the fuel pressure which exists at the fuel quantity control valve (11) to approximately 5 bar (72.5 psi) maximum. If this pressure is exceeded, the pressure relief valve opens and again passes the excess fuel into the return flow (6) to the fuel tank.

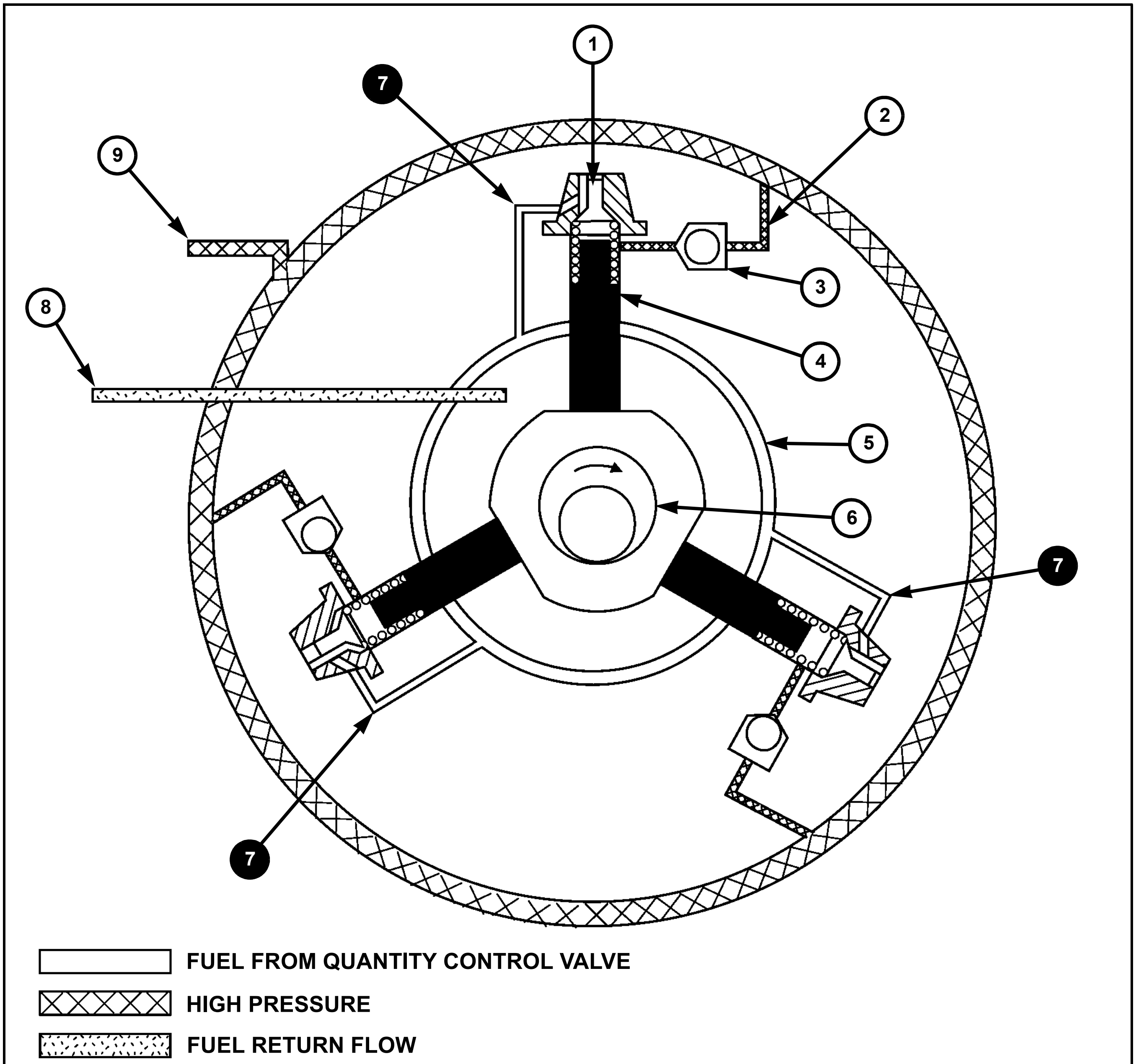
In addition, the fuel pressure relief valve (9) directs a part of the fuel as a lubrication quantity to the eccentric shaft (lubrication port 8).
Any air entrained by the fuel is passed through the fuel pressure relief valve to the return flow of the high pressure pump (bleed port 7).



1	High Pressure Pump Flange	7	Bleed Port
2	Fuel Temperature Sensor	8	Eccentric Shaft Lubrication Port
3	Fuel Feed to Pump Elements	9	Fuel Pressure Relief Valve
4	Fuel Annular Port	10	Zero Delivery Restrictor
5	Fuel Inlet Port (From Fuel Filter)	11	Fuel Quantity Valve
6	Fuel Return Port (To Fuel Tank)		

Figure 37 Low Pressure Side, Pump Flange

Refer to Figure 38 to follow the fuel flow into the high pressure pump. Fuel from the quantity control valve flows along the annular passage (5) through the feed ports (7) to the three pump elements of the high pressure pump.

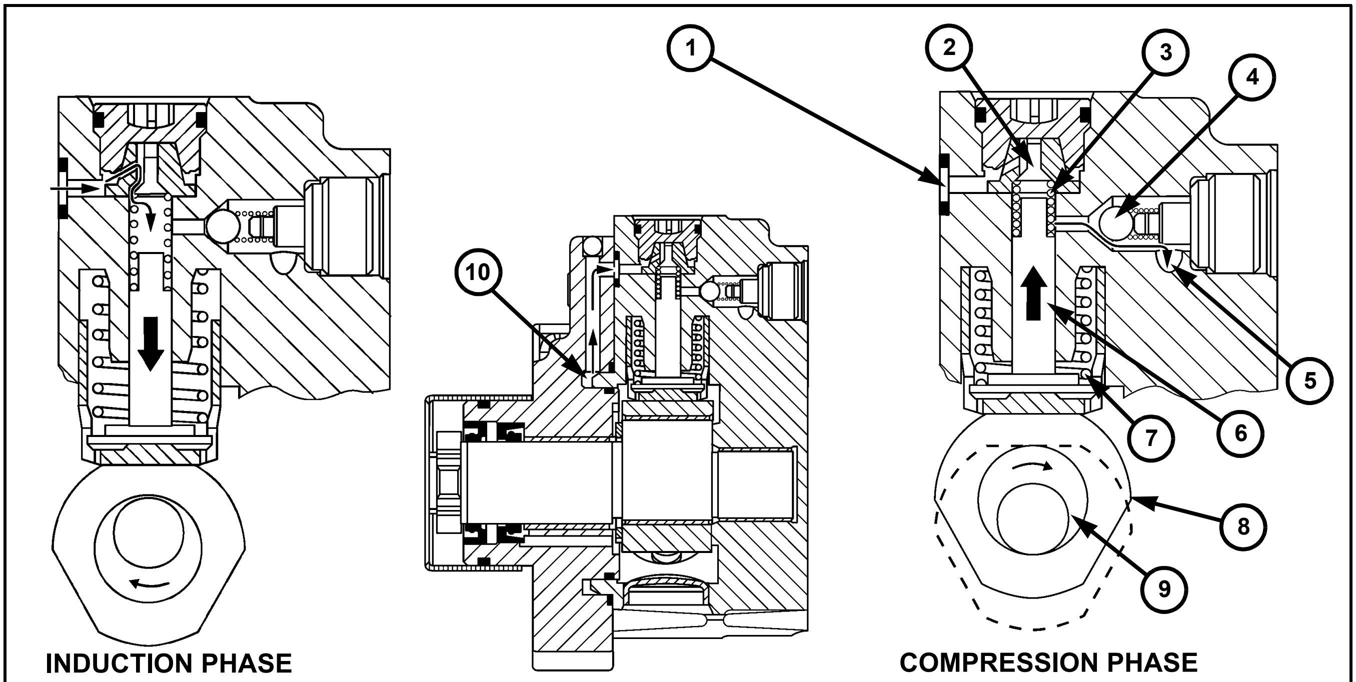


1	Valve	6	Eccentric Shaft
2	High Pressure Passage	7	Feed to High Pressure Elements
3	Check Ball	8	Return Port
4	Piston	9	High Pressure Line to Fuel Rail
5	Annular Passage		

Figure 38 Low Pressure Side, Pump Elements

High pressure side

Refer to Figure 39. The cam (8) of the eccentric shaft (9) moves the pistons (6) up and down against the piston spring (7).



1	Fuel Feed to Pump Elements	6	Piston
2	Valve	7	Piston Spring
3	Valve Spring	8	Cam
4	Check Ball	9	Eccentric Shaft
5	High Pressure Passage	10	Annular Passage

Figure 39 Fuel Pump, High Pressure Side

Filling the piston (Induction Phase)

The piston (6) is moved down as a result of the piston spring (7). The fuel supplied by the electric fuel delivery pump flows along the annular passage (10), the fuel feed (1) and, by overcoming the force of the valve spring (3) through the valve (2) into the cylinder. The check ball (4) prevents the fuel being able to flow back from the high pressure passage (5).

Producing high pressure (Compression Phase)

The piston (6) is moved up by the ascending eccentric shaft (9) and the fuel is pressurized. The valve (2) shuts off the delivery volume to the fuel feed (1). Once the fuel pressure in the cylinder rises beyond the pressure which exists in the high pressure circuit (5), the check ball (4) opens and the fuel is pumped into the high pressure circuit (5).

ACTIVITY 2.4 HIGH PRESSURE PUMP PERFORMANCE TEST

The purpose of this activity is to test the performance of the high pressure pump using the diagnostic scan tool.

1. Connect the diagnostic scan tool to the vehicle.
2. Find the high pressure pump actuation test.
3. What is the target fuel pressure for this test?
   20304 psi
4. Run the actuation test with the engine at idle.
5. What is the pressure built-up by the high pressure pump
   Approximately 20516 psi
6. Is the pressure value within specifications? YES __*X*__ NO ______

FUEL RAIL

The rail is located above the intake manifold. The fuel pressure solenoid, fuel pressure sensor, high pressure lines and return lines are attached to the rail. The rail acts as a high pressure fuel storage device (accumulator) for the injectors.

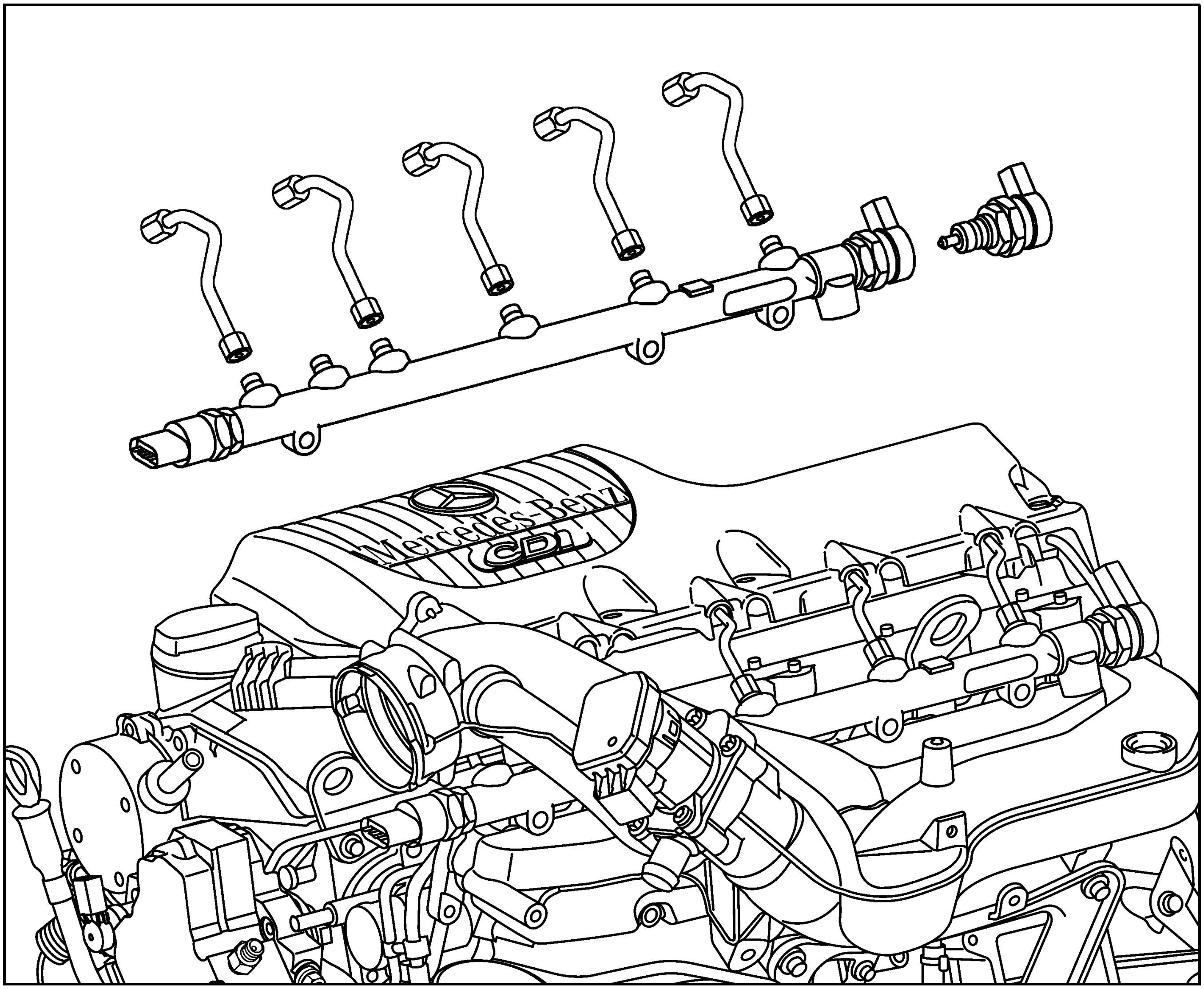
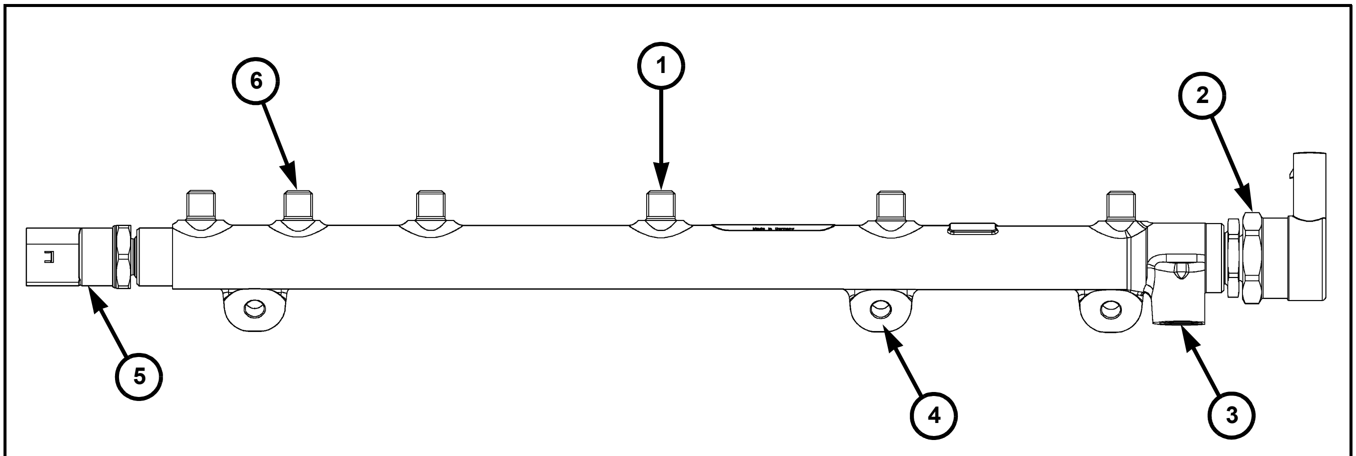


Figure 40 Fuel Rail

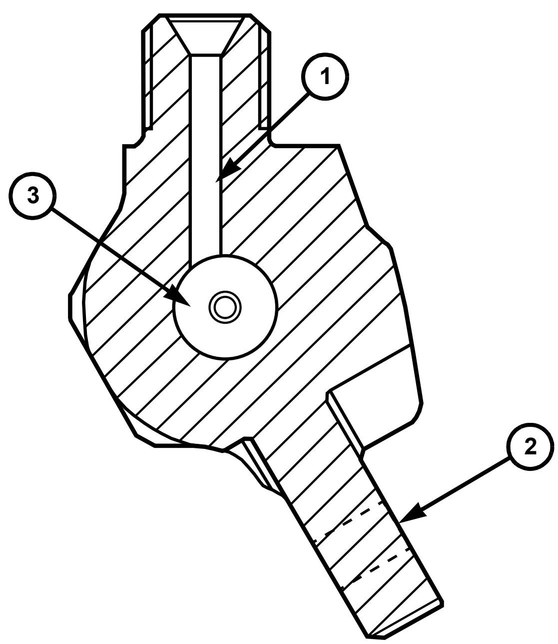
The stored volume also acts as a damper for pressure fluctuations resulting from the pulsating of the high pressure pump and the brief, large extraction of fuel by the injectors during injection. The constant pressure in the rail enables the ECM to accurately control the injected quantity.



1	Fuel Outlet Port to Injector (5)	4	Rail Mounting Hole (3)
2	Fuel Rail Pressure Solenoid	5	Fuel Rail Pressure Sensor
3	Fuel Return Port	6	Fuel Inlet Port From Pump

Figure 41 Fuel Rail Components

The drop forged steel fuel rail has a yellow chromate finish for surface protection. Due to the high fuel pressures it contains, the fuel gallery inside the rail has a small diameter relative to its outside diameter. The fuel rail has an ID of 10 mm (0.394 in.) and an OD of approximately 27 mm (1.063 in).



1	Fuel Outlet Port to Injector	3	Fuel Gallery
2	Rail Mounting Hole		

Figure 42 Fuel Rail Cross Section View

INJECTOR FUEL LINES

High grade steel lines carry the high-pressure fuel from the fuel rail to the injectors. The short-length fuel lines have thick walls to withstand the maximum system pressures and high frequency pressure waves. The outside diameter of the lines is 6 mm (0.236 in.) and the inside diameter is 2.4 mm (0.094 in.).

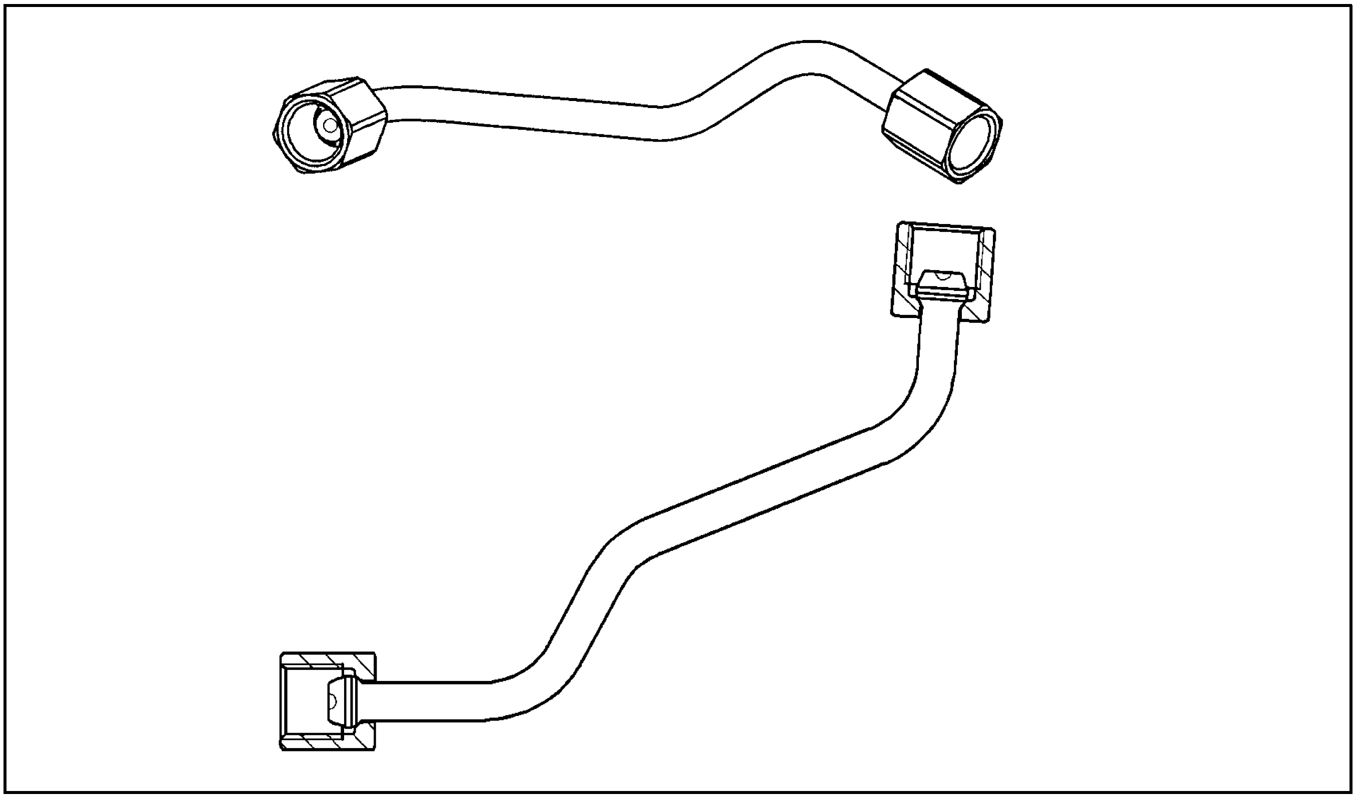


Figure 43 Injector Fuel Lines

FUEL INJECTORS

Five electronically-controlled fuel injectors are positioned on top of the cylinder head, under the engine cover (Figure 44). The injectors must be able to generate a fine fuel atomization at injection pressures up to 1,600 bar (23,205 psi) and small injection rates (approx 1.5 mm3/stroke).

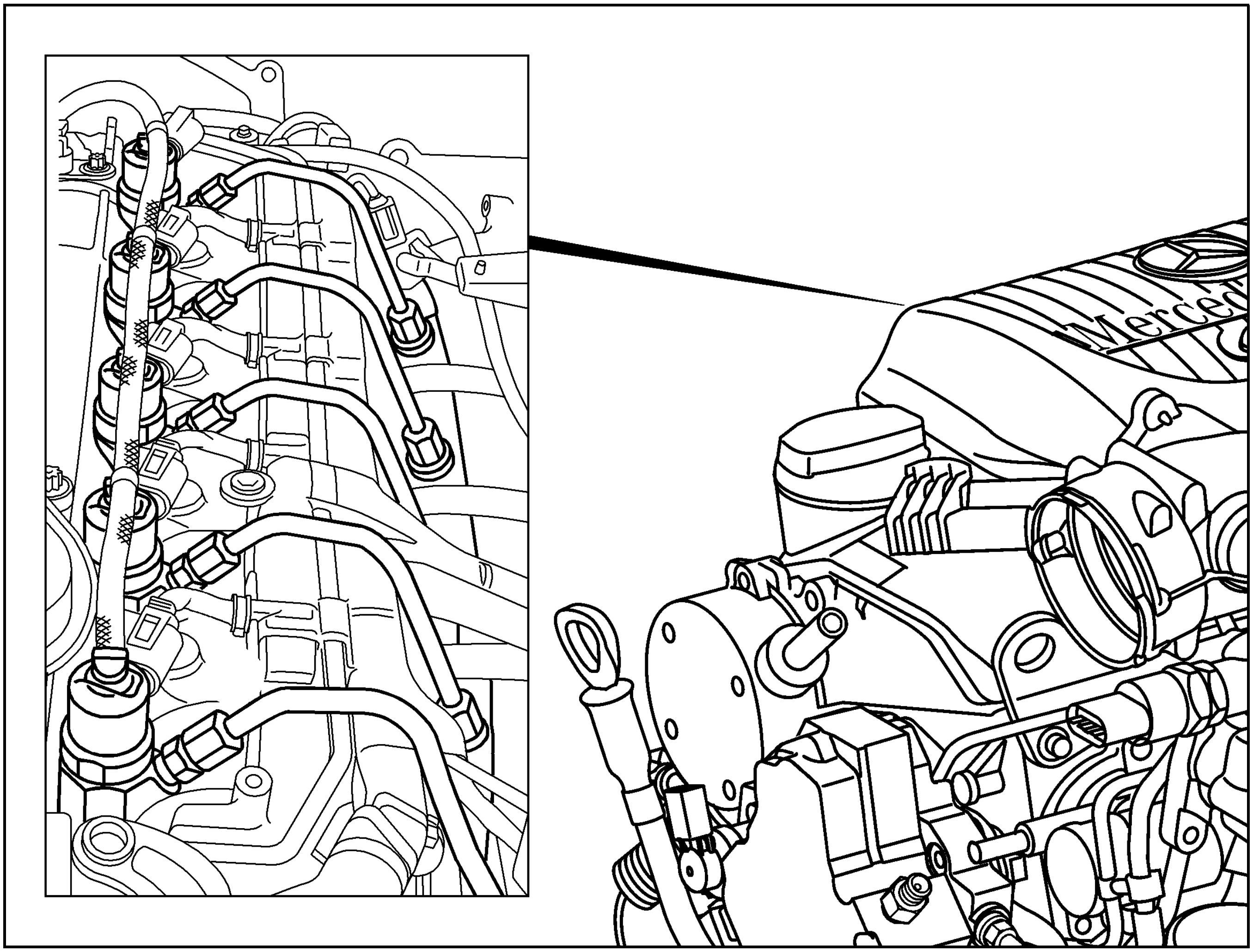
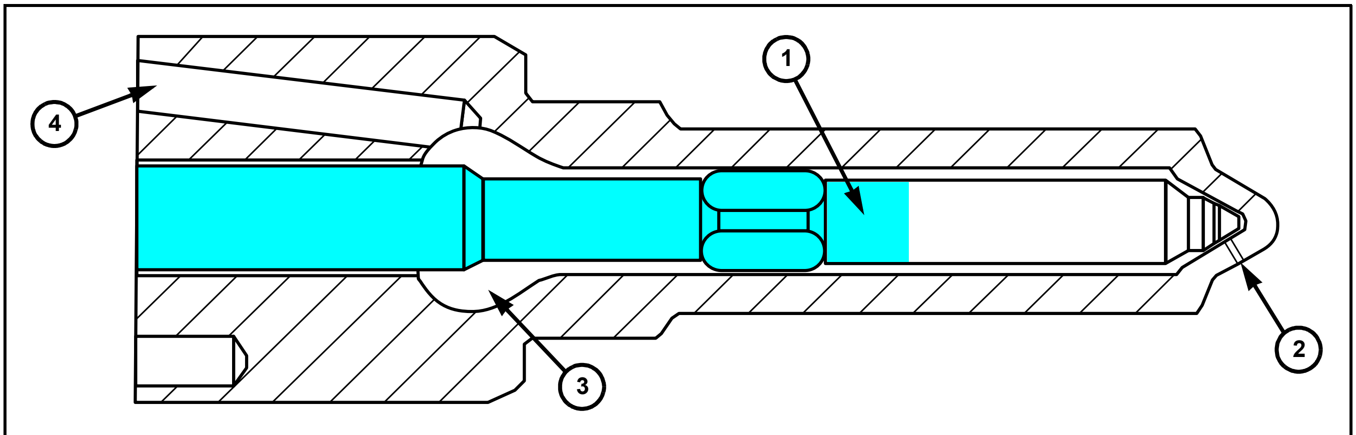


Figure 44 Fuel Injectors

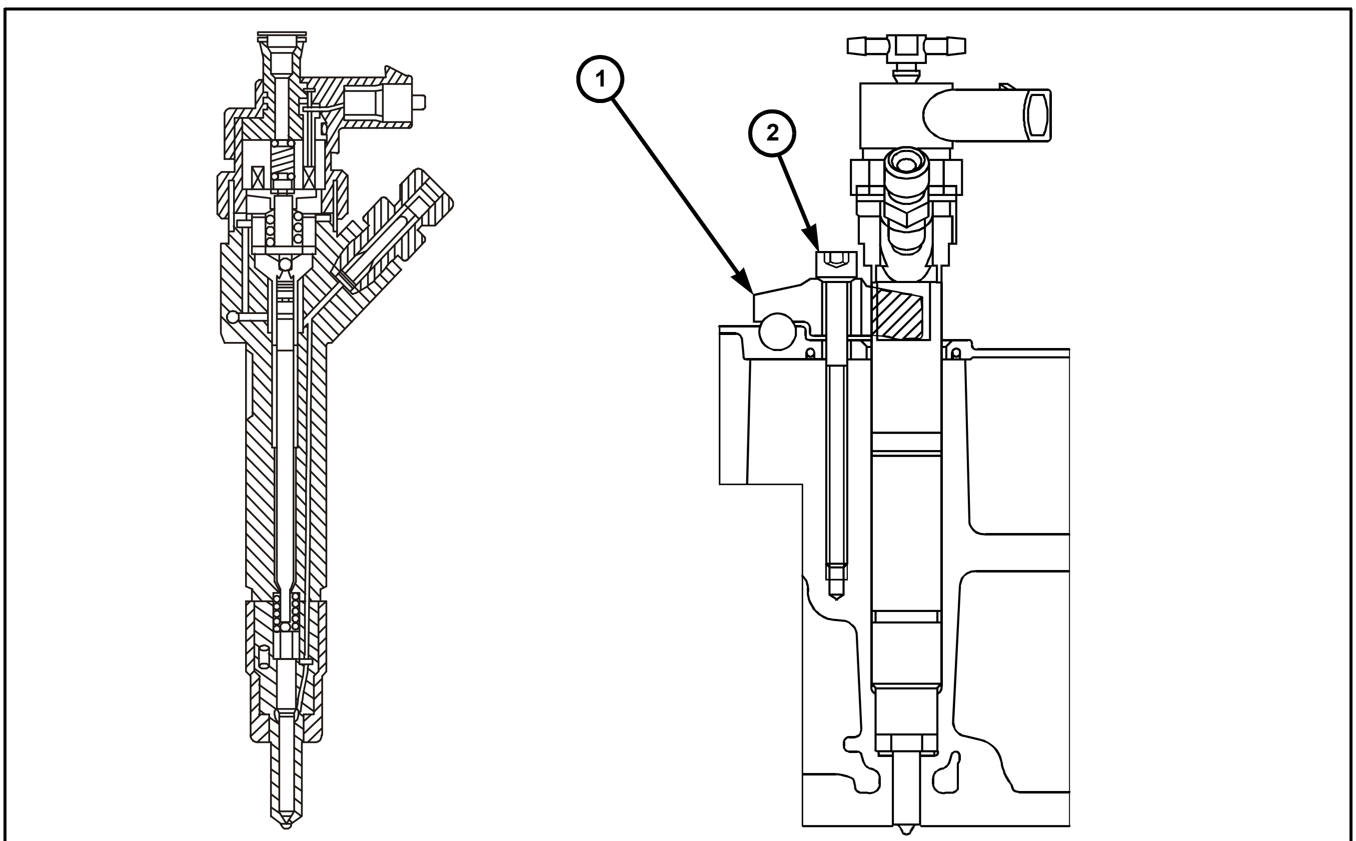
The fuel injectors feature seat-hole type nozzles with seven spray holes. The spray holes have a diameter of approximately 0.135 mm (0.005 in.) and are formed by electrical discharge machining (EDM). EDM is a non-conventional machining technique in which the material is removed by the erosive action of electrical discharges (sparks) provided by a generator. The nozzle needle and injector plunger have a carbon based (C2) coating to reduce wear.



1	Coated Nozzle Needle	3	Pressure Chamber
2	Injector Spray Hole (7)	4	Fuel Inlet Passage

Figure 45 Injector Nozzle

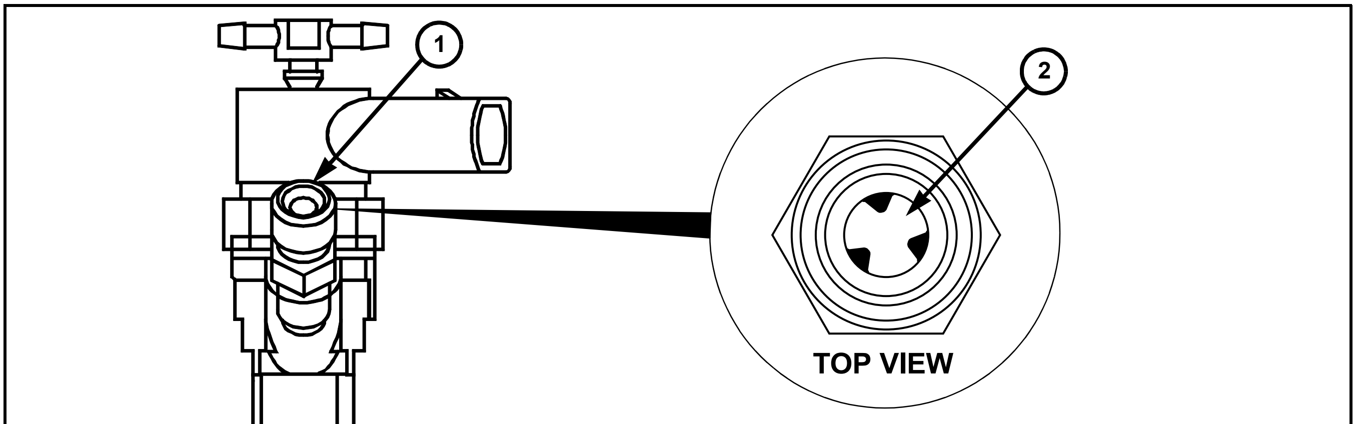
Each injector is held in its recess by a tensioning claw and a retaining stretch bolt (Figure 46). A seal ring is located on the injector tip to seal off the injector to the combustion chamber. When removing the injectors, the seals and torque to yield bolts must always be replaced.



1	Tensioning Claw	2	Retaining Stretch Bolt

Figure 46 Fuel Injector Position

An edge filter is mounted in the injector high pressure connector to filter impurities and dirt upstream of the injector nozzle (Figure 47). Edge filters are effective to filter particles in the fuel or particles created by machining of components and/or from the high pressure fuel flow. The edge filter has a flat front face with three V-shaped openings leading to V-shaped channels.



1	High Pressure Connector	2	Edge Filter

Figure 47 High Pressure Connector With Edge Filter

The injector operation can be subdivided into four operating states with the engine running and the high-pressure pump generating pressure:

Injector Closed (At-Rest State)

Refer to Figure 48. The fuel coming from the rail is present at the fuel inlet (2) in the valve control chamber (8) and in the chamber volume (4). The rail pressure builds up in both areas (8) and (4).
The surface difference of the valve control chamber (8) compared to the chamber volume (4) and the additionally acting force of the nozzle spring (6), prevent the nozzle needle (5) from opening. This condition exists when the start phase begins or if the vehicle is in the deceleration mode (engine running and high pressure pump delivering).

Injector Opens (Start of Injection)

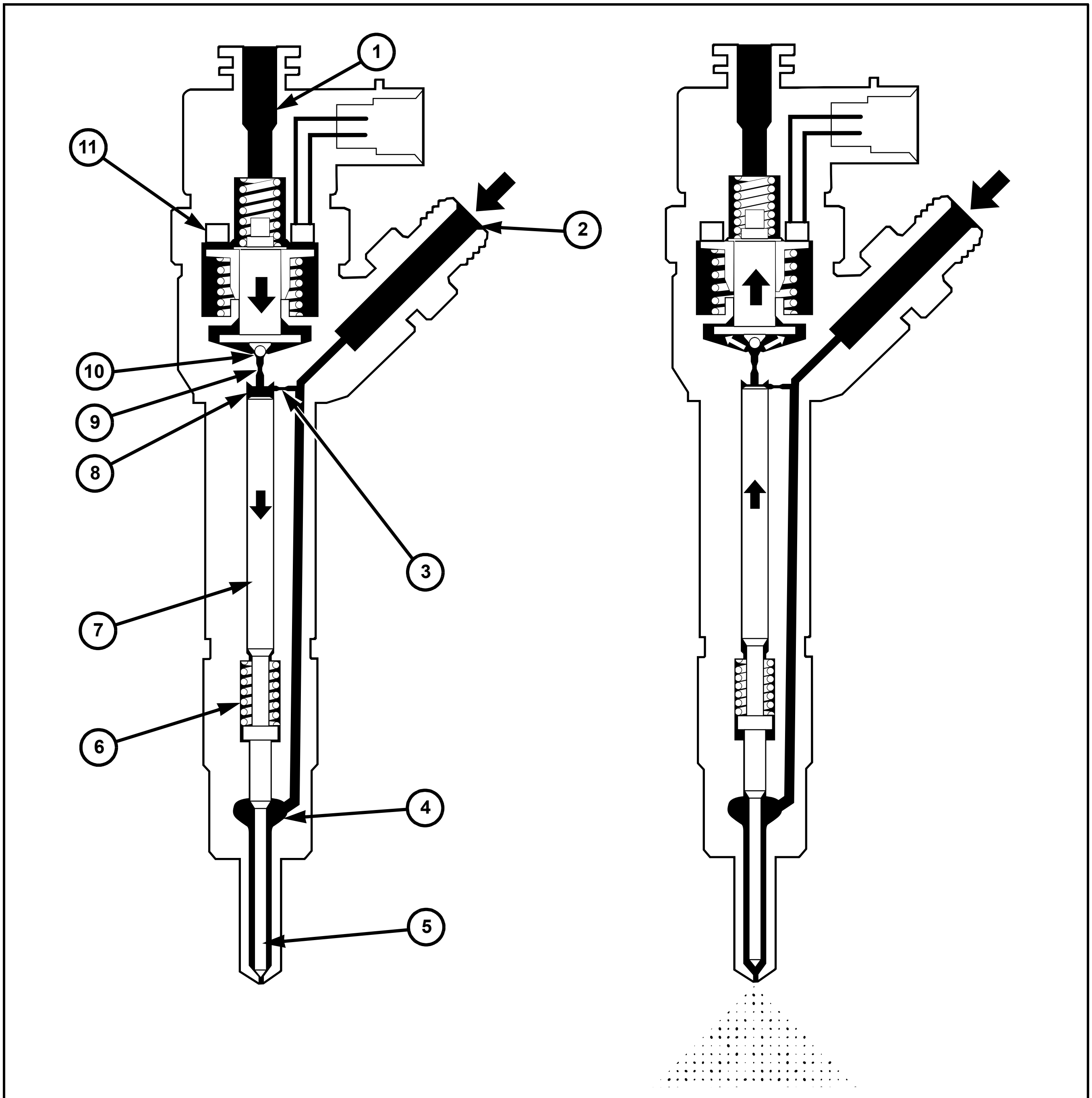
When the solenoid valve (11) is energized, the check ball (10) is attracted and overcomes the force of the valve spring. The check ball now opens the valve control chamber (8) and the controlled quantity of fuel is able to flow along the fuel return (1) back to the fuel tank. As a result of the pressure drop in the valve control chamber (8) the nozzle needle (5) is raised by virtue of the difference in pressure. The rate of opening of the nozzle needle depends on the cross-section of the bleed orifice (9) above the valve control chamber (8) and the feed orifice (3) positioned between high pressure feed (2) and valve control chamber.

Injector Opened Fully

The control plunger (7) reaches its upper stop where it remains supported by a cushion of fuel, which is generated by the flow of fuel between the bleed and feed orifices. The injector nozzle has now opened fully, and the fuel is injected into the combustion chamber at a pressure almost equal to that in the fuel rail.

Injector Closes (End of injection)

After the solenoid valve current is switched off, the valve spring pushes the check ball (10) back onto the valve seat. The bleed orifice is closed as a consequence of this and the pressure in the valve control chamber (8) rises to the level of the system pressure. The closing force which is active in the valve control chamber (8), is greater than that in the chamber volume (4), as a result of which the nozzle needle (5) closes.

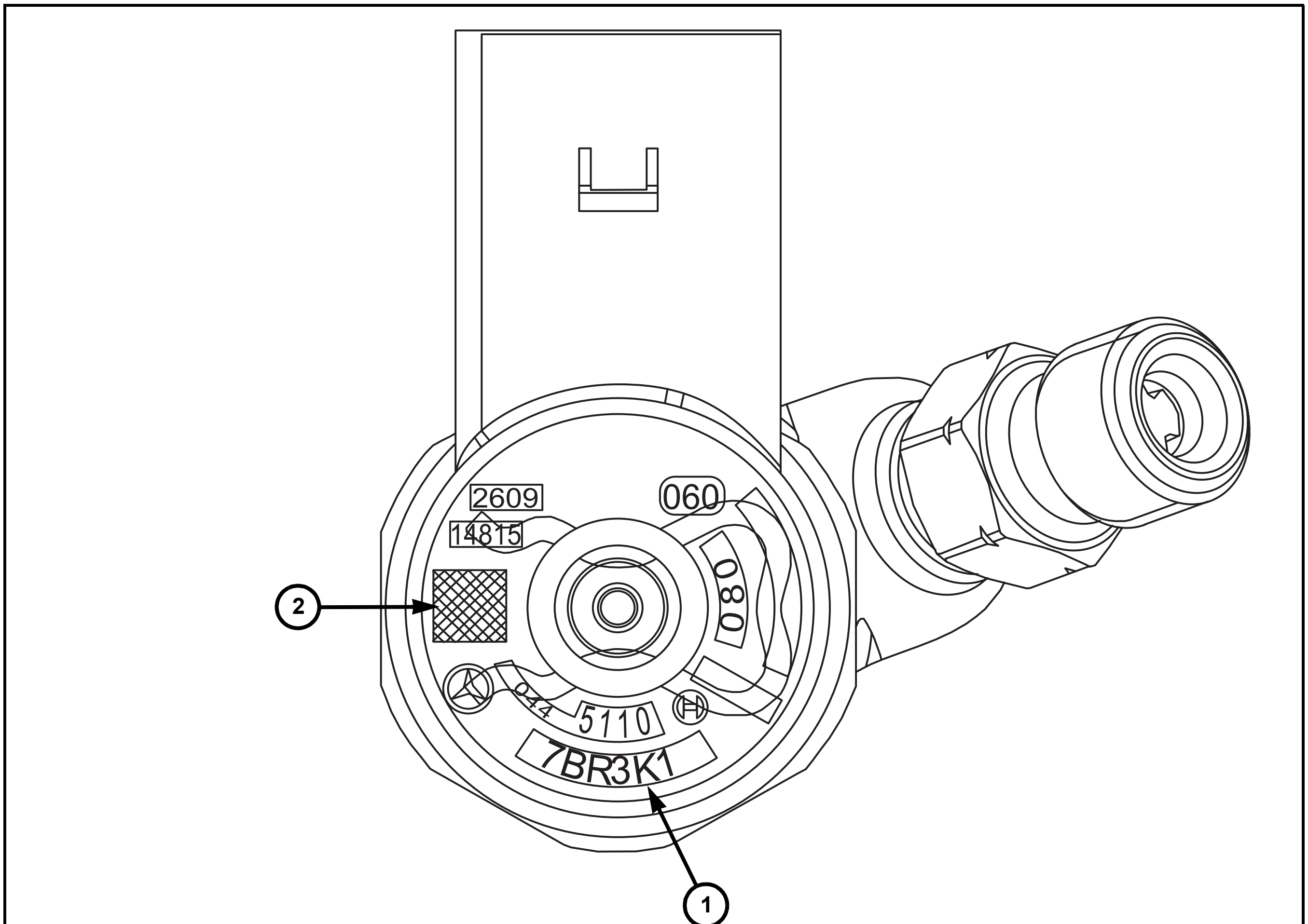


1	Fuel Return	7	Control Plunger
2	Fuel Inlet	8	Valve Control Chamber
3	Feed Orifice	9	Bleed Orifice
4	Chamber Volume	10	Check Ball
5	Nozzle Needle	11	Solenoid Valve
6	Nozzle Spring		

Figure 48 Fuel Injector Cutaway

Fuel Injector Classification

The ECM compensates for both injector variations due to production tolerances as well as due to injector wear over the life of the injector. The injectors are identified with a six-digit alphanumeric code etched on the injector top. To allow the ECM to compensate for tolerances, the code is programmed into the ECM memory using the diagnostic scan tool. At the end of the coding procedure, the diagnostic tool performs a proof check to ensure the code has been entered correctly.



1	Six-Digit Alphanumeric Code	2	Data Matrix Bar Code (Plant Use)

Figure 49 Injector Top View

SERVICE NOTE: WHEN REMOVING THE INJECTORS, THE SEAL RINGS AND TORQUE TO YIELD BOLTS MUST ALWAYS BE REPLACED. COAT THE INJECTOR BODY WITH THE APPROVED LUBRICANT BEFORE INSTALLING ON THE ENGINE.

ACTIVITY 2.5 INJECTOR CODING

The purpose of this activity is to perform the injector coding procedure using the diagnostic scan tool.

1. Connect the diagnostic scan tool to the vehicle.
2. Find the injector classification screen and read the injector codes.
3. Record the injector codes from the scan tool on the table below

Injector #	Injector Code
1	
2	
3	
4	
5	

4. In the engine compartment, locate the injector codes and record the codes on the table below.

Injector #	Injector Code
1	
2	
3	
4	
5	

5. Compare the codes from the injectors with the scan tool data.
6. Do the codes match? YES _____ NO _____
7. Enter the correct injector codes with the diagnostic scan tool if the codes do not match
8. When is it required to perform the coding of the injectors?
   When replacing injectors or the engine control module

MODULE 3 ECM INPUTS

The ECM output decisions are based on input values. As the input values change, the ECM will change the fuel curve for optimum performance.

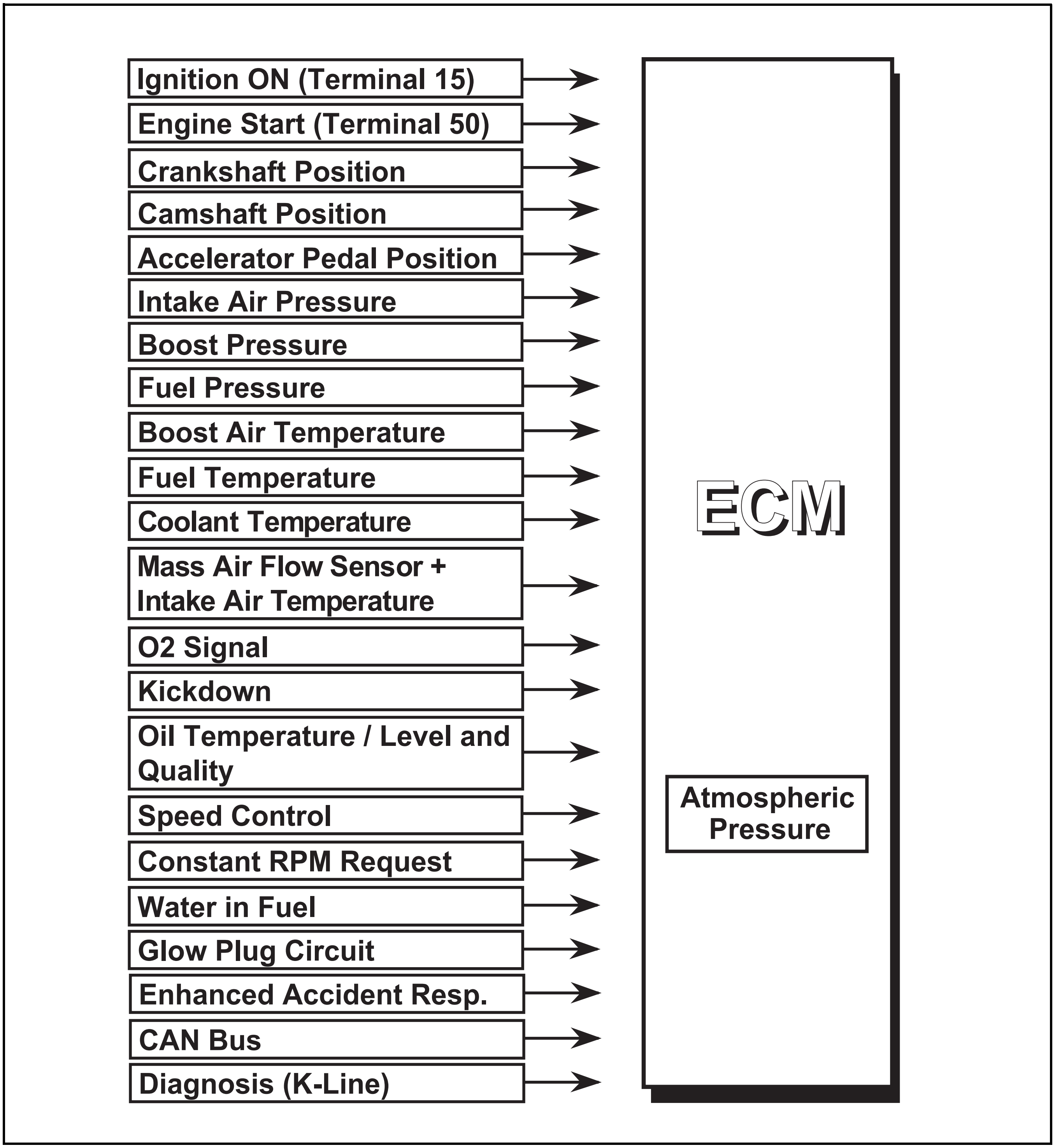


Figure 50 Block Diagram ECM Inputs

POWER SUPPLY INPUTS

The ECM receives a start input, a timer-controlled battery power input and three timer-controlled ignition power inputs. Timer-controlled power enables the ECM to perform key OFF diagnostics, store DTCs and reduce the vehicle's overall current draw.

START INPUT

Battery voltage is supplied to the ECM through the ignition switch when the ignition is in the START position. The module activates the starter motor relay based on this start sense input, as well as the information supplied by the SKREEM.

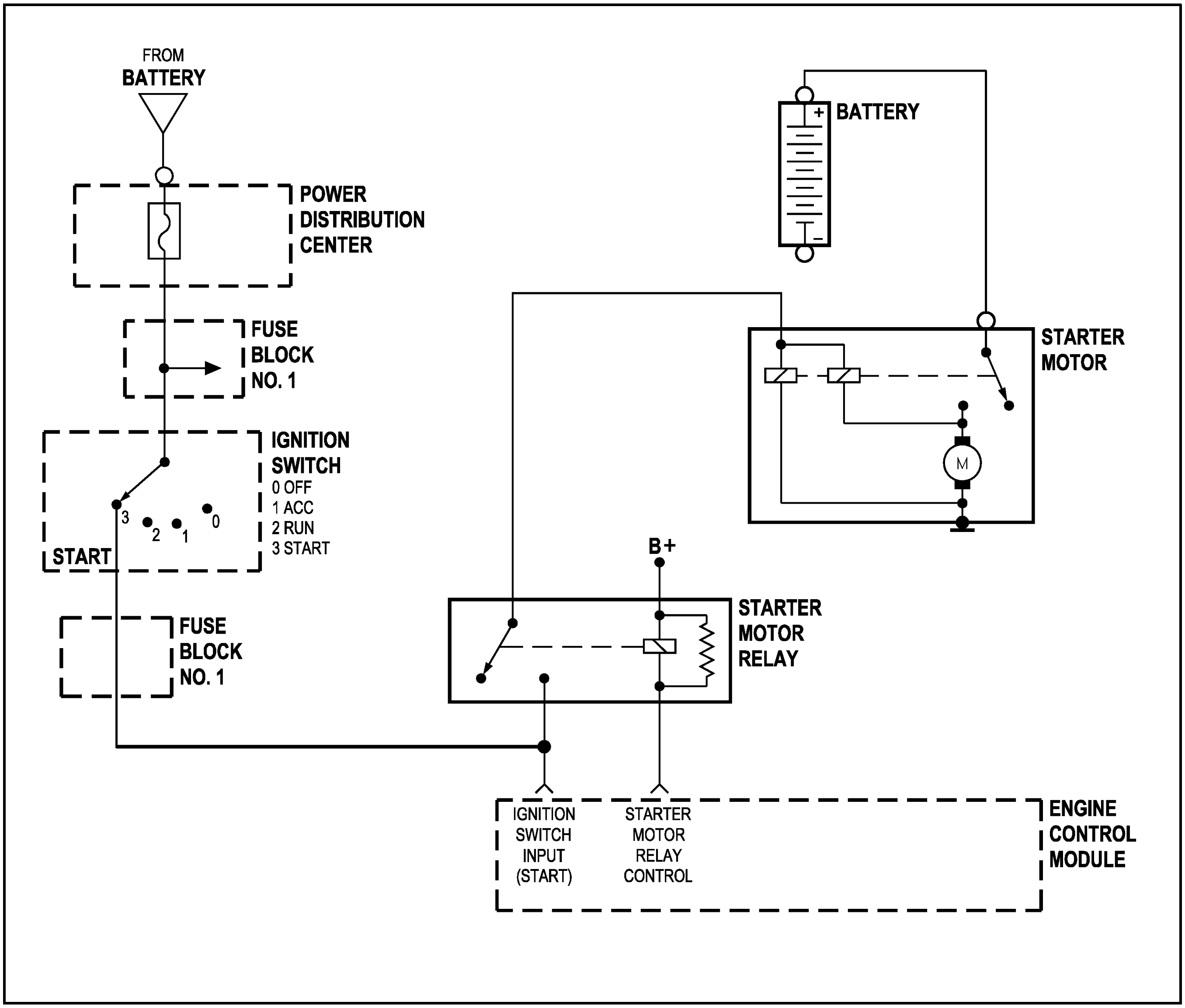


Figure 51 Start Input Diagram

KEY-ON INPUT

Battery voltage is supplied to the timer module within fuse block No.1 through the ignition switch when the ignition is in the START or RUN position. The timer module uses this ignition sense circuit to "wake up" the ECM. The timer module activates the engine control (M) relay and power flows to the ECM through three timer-controlled ignition power circuits.

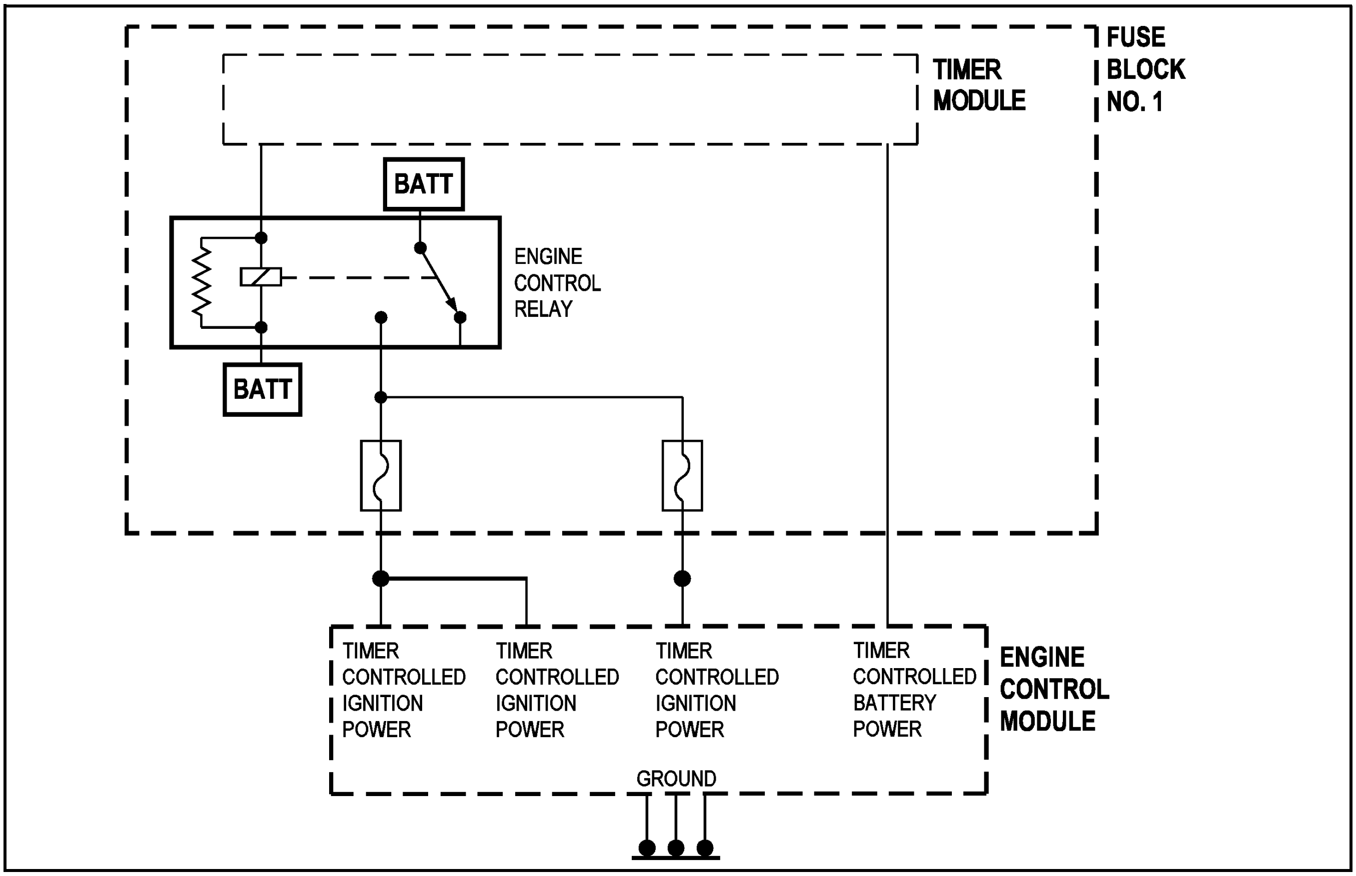


Figure 52 ECM Key-On and Key-Off Power Inputs

KEY-OFF POWER INPUT

The timer module maintains ignition power during the ECM shutdown sequence to allow for key-off diagnostics, storage of DTCs in memory and the self-cleaning function of the EGR valve. Approximately six seconds after the ignition key is turned to the OFF position, power is removed from the three timer-controlled ignition power circuits. Power is then supplied to the ECM through the timer-controlled battery power circuit to “keep alive” the ECM.

It is important that the ECM have good power and ground circuits to ensure proper operation of the engine. When diagnosing an electronic control malfunction on the common rail diesel engine, it is important that the integrity of all fuses, relays, connectors, and grounds are checked and proper connections are made.

POSITION SENSORS

CRANKSHAFT POSITION SENSOR (CKP)

The crankshaft position sensor (CKP) is located opposite the teeth on the flywheel and uses a non contact method to record the position of the crankshaft. When the crankshaft is rotating, an alternating current signal is produced. The leading edges of each tooth on the flywheel generate a positive current signal in the CKP, while the trailing edges generate a negative current signal. The period or frequency of the signal is the time required by the crankshaft to turn through the gap between two flywheel teeth.

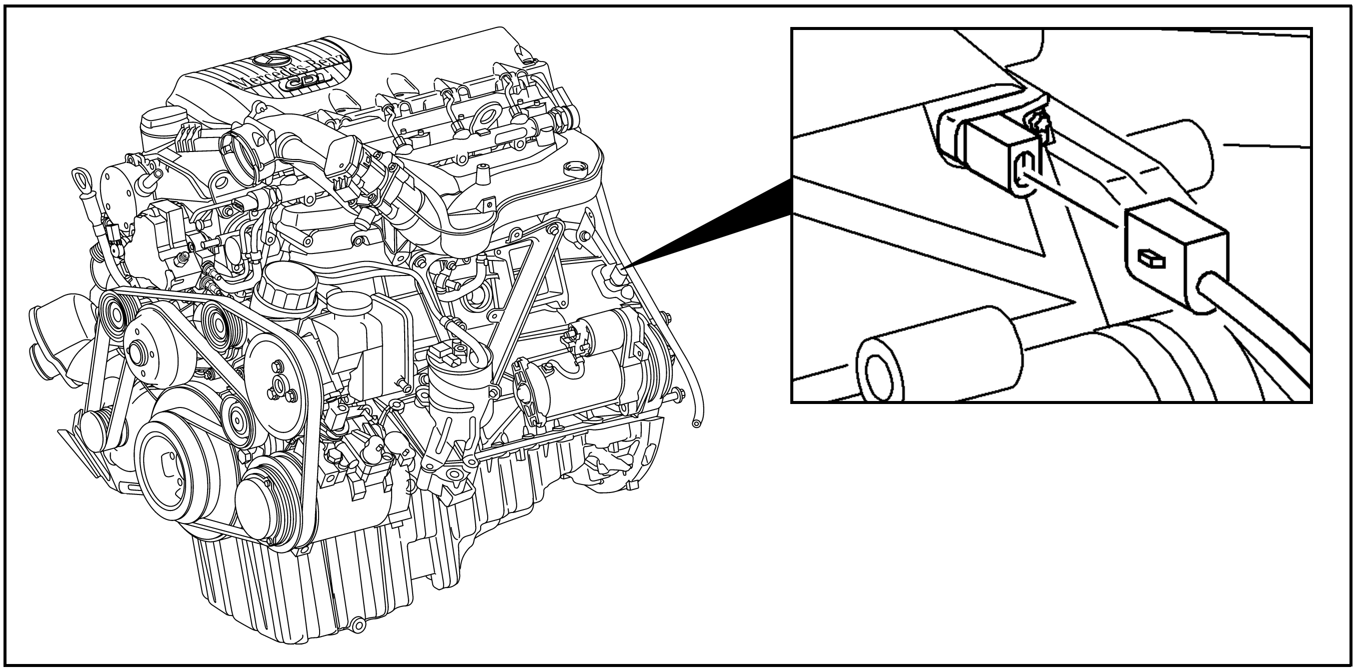


Figure 53 Crankshaft Position Sensor (CKP)

OPERATION

The clearance between the CKP and the flywheel are fixed by the installation position. The flywheel toothed ring has 58 teeth, which are evenly spaced every 6°. Two teeth on the flywheel are missing (the 59th and 60th). The resulting gap is used by the ECM to detect TDC of cylinder number one. The angle between the gap and TDC of cylinder number one is 108°, or 18 teeth. The crankshaft position is calculated so that the start and end of injection can occur at the right moment. The engine speed signal is also processed by the ECM from the crankshaft position sensor. This signal is then broadcast to other control modules over the CAN bus.

The loss of crank signal will cause the ECM to stop triggering the injectors. The engine shuts down and will not restart.

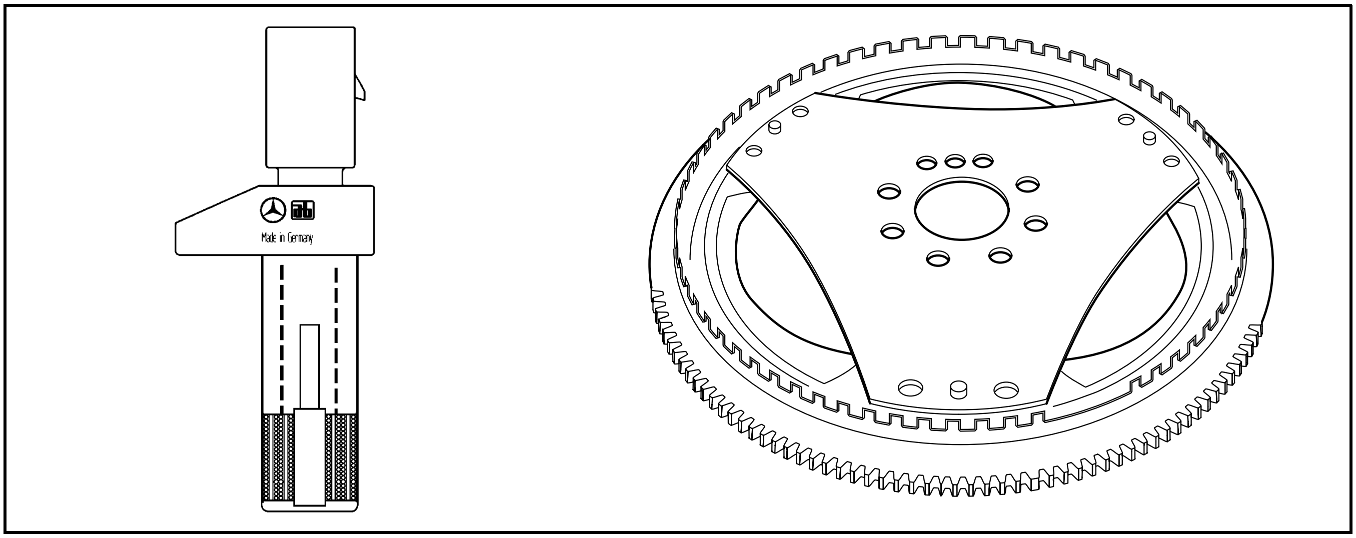


Figure 54 CKP Sensor and Flywheel Toothed Ring

When the crankshaft rotates, an alternating voltage is generated (Figure 55) in the CKP by the flywheel teeth. The front edge of a tooth generates a positive voltage pulse and the rear edge a negative voltage pulse. The distance from the positive to the negative voltage peak corresponds to the length of a tooth.
The gap produced by 2 missing teeth results in no voltage being generated in the CKP. This is used to detect the position of cylinder number one.

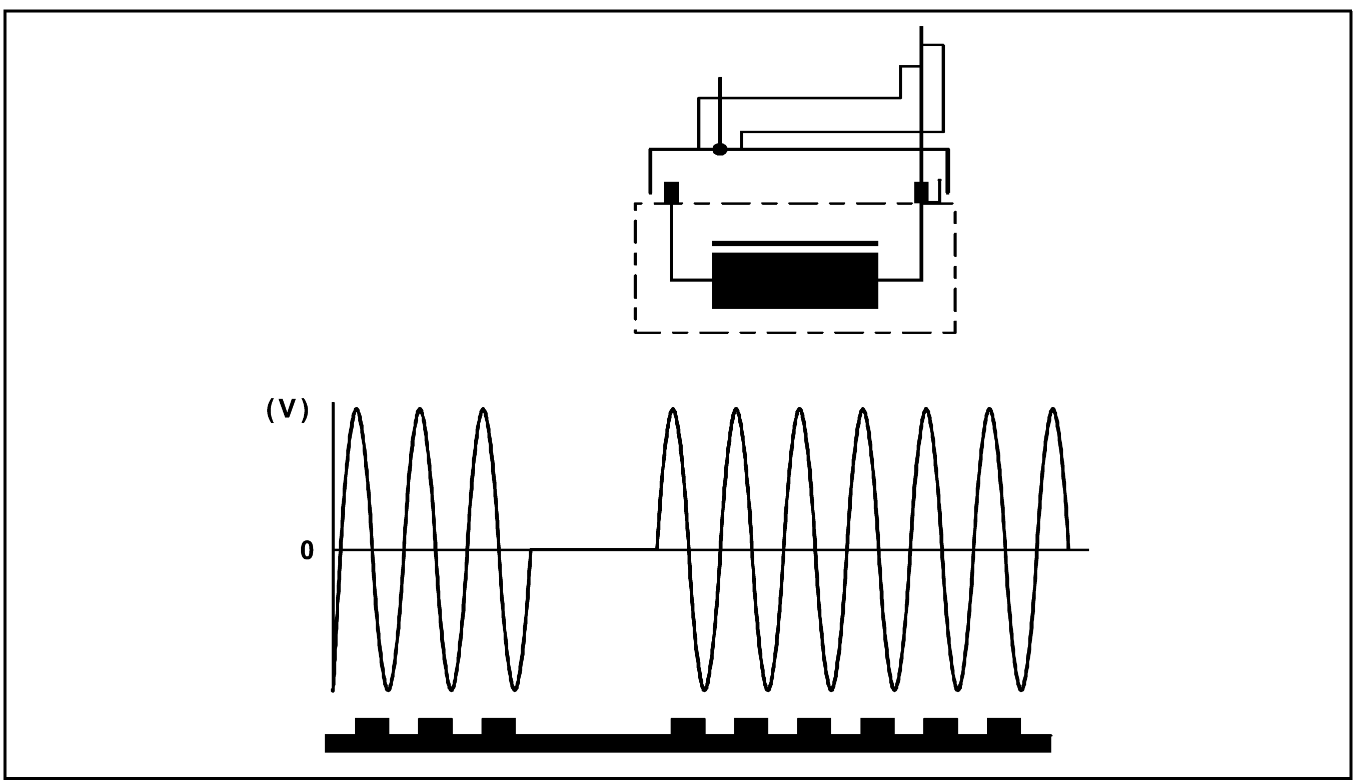


Figure 55 Crankshaft Position Sensor Signal

Failure Modes

The ECM monitors the operation of the CKP and stores fault codes related to the following conditions:

- Crankshaft sensor plausibility 1
- Crankshaft sensor plausibility 2
- Crankshaft sensor over speed detection
- Synchronization between crankshaft and camshaft - flow limiter activated
- Synchronization between crankshaft and camshaft - no crankshaft signal
- Synchronization between crankshaft and camshaft - plausibility
- Synchronization between crankshaft and camshaft - main injection correction is faulty

CAMSHAFT POSITION SENSOR (CMP)

The camshaft position sensor (CMP) is located on top of the exhaust camshaft, at the rear of the engine near injector number 5. The CMP utilizes a non contact method on one segment of the camshaft to record the camshaft position. When the ECM receives the signal from the CMP, it can then detect TDC of cylinder number one. The signal from the CMP is only required during engine starting for synchronizing injection timing.

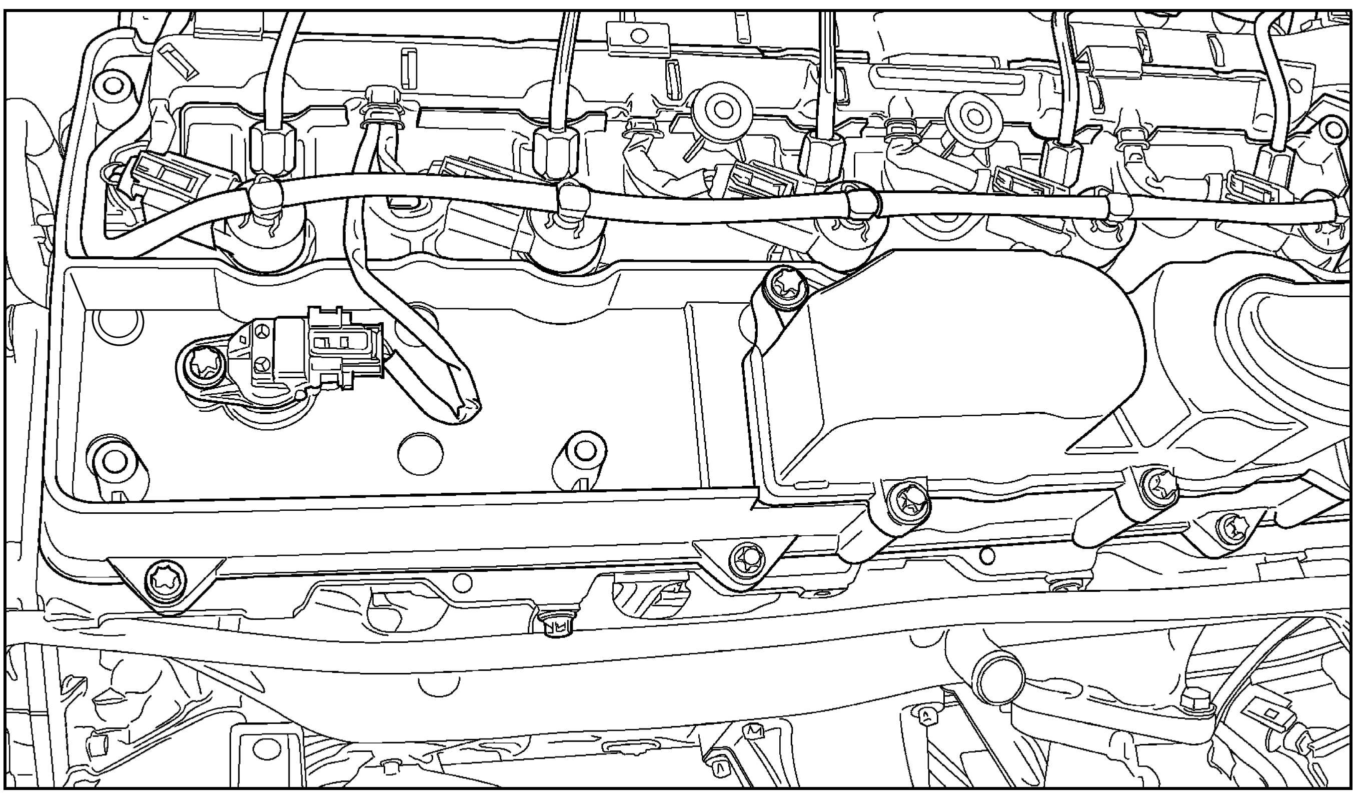


Figure 56 Camshaft Position Sensor (CMP)

OPERATION

The CMP consists of a Hall-effect integrated circuit, flexible printed circuit board, capacitors and a magnet (Figure 57).

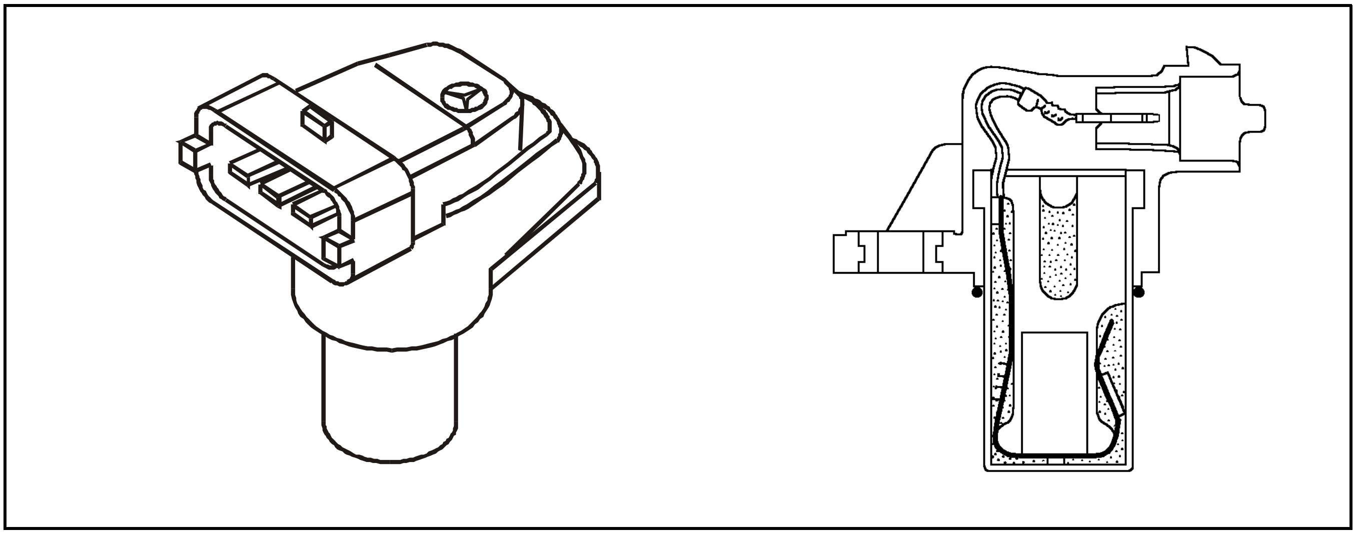


Figure 57 Camshaft Position Sensor (CMP)

The CMP is a 12 volt Hall-effect type sensor, with a return signal that switches from 0 to 5 volts depending on the position of the segment machined into the exhaust camshaft.

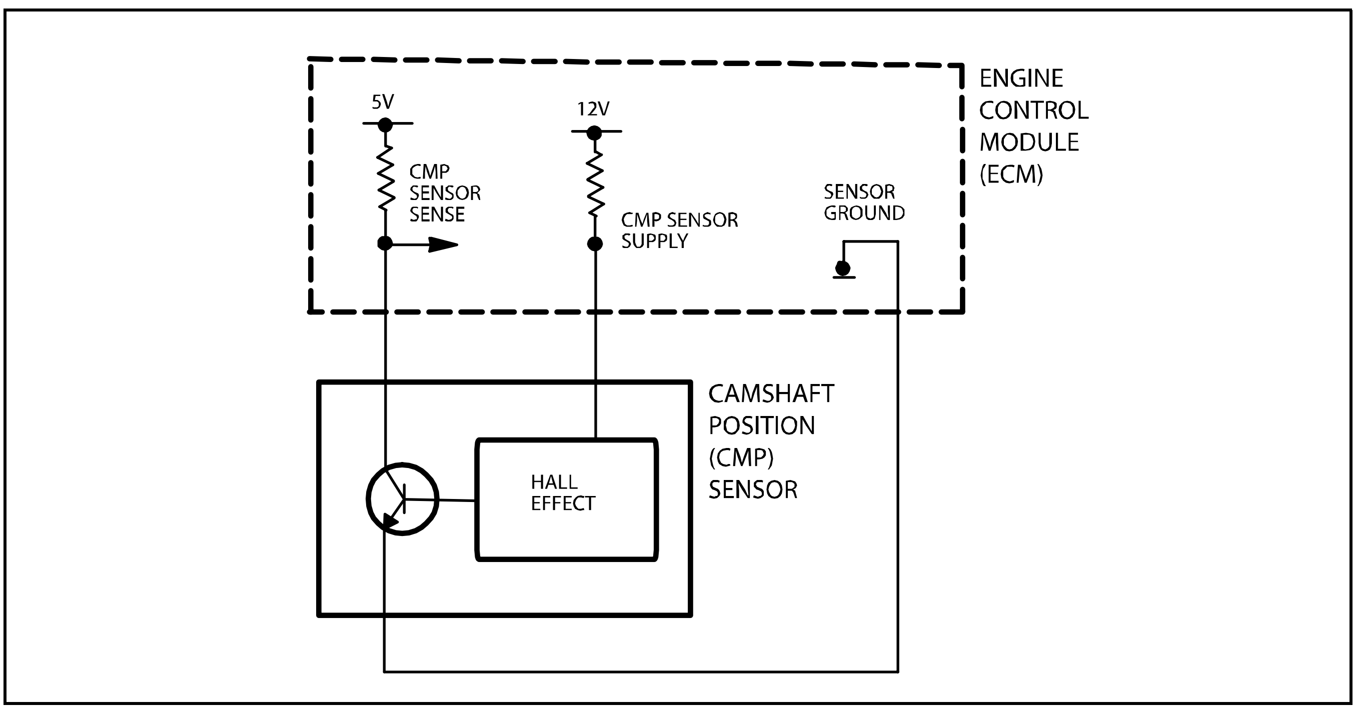


Figure 58 CMP Schematic

The signal wire of the CMP is normally switched high (approximately 5 volts). When the segment machined into the exhaust camshaft is positioned opposite the CMP, the camshaft signal switches to low (approximately 0V). A low signal is used for detecting ignition TDC of cylinder 1 by the ECM. If no signal is supplied by the CMP, the vehicle will not start because cylinder order can not be detected (Figure 59).

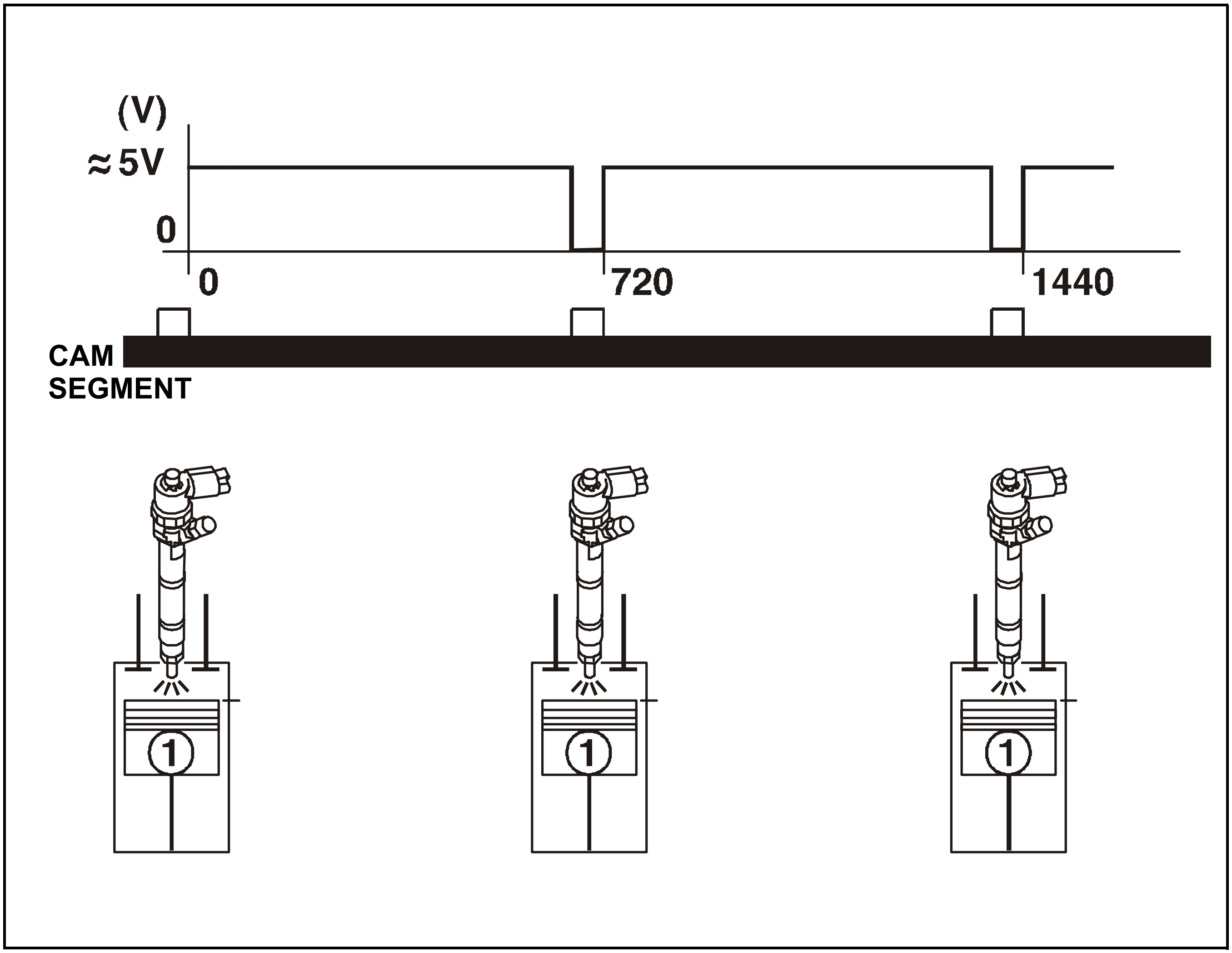


Figure 59 CMP Signal

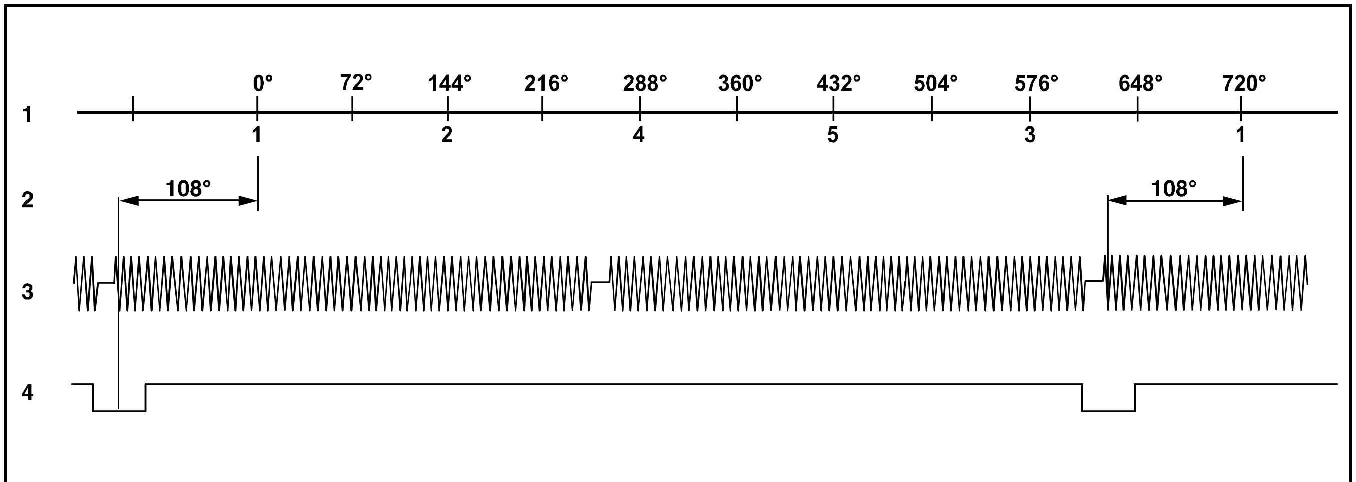
Failure Modes

The ECM monitors the operation of the CMP and stores fault codes related to the following conditions:

- Synchronization between crankshaft and camshaft - no camshaft signal
- Synchronization between crankshaft and camshaft - flow limiter activated
- Synchronization between crankshaft and camshaft - camshaft frequency signal too high

INJECTION TIMING SYNCHRONIZATION

The injection timing is synchronized by means of the signals supplied by the CKP and the CMP. The ECM analyzes both signals to detect the TDC position of cylinder number one. When the ECM detects the voltage gap resulting from the two missing teeth on the flywheel, it must also detect the low signal from the segment on the exhaust camshaft. The simultaneous voltage gaps are an indication to the ECM that the engine is 108° BTDC of cylinder number one.



1	Crankshaft Angle / Firing Order	3	CKP Signal
2	Offset Angle Cylinder No. 1	4	CMP Signal

Figure 60 Injection Timing Synchronization

ACTIVITY 3.1 CAM AND CRANK SENSORS

The purpose of this activity is to familiarize the students with the engine's behavior resulting from various Cam and Crank sensor failures.

1. With the engine running, disconnect the Crank sensor and observe the result.
   Engine stalls
2. Are there any DTCs present?
   - ☐ YES ____
   - ☑ NO
3. What is the status of the MIL lamp?
   - ☐ ON
   - ☑ OFF
4. With the sensor still disconnected attempt to start the engine. Does the engine start?
   - ☐ YES
   - ☑ NO
5. Are there any DTCs present?
   - ☑ YES *1 fault - crankshaft signal missing (2045-001)*
   - ☐ NO
6. What is the status of the MIL lamp?
   - ☑ ON
   - ☐ OFF
7. Reconnect the Crank sensor and clear DTCs.
8. With the engine running, disconnect the Cam sensor and observe the result.
   The engine continues to run
9. Are there any DTCs present?
   - ☑ YES *1 fault - camshaft position sensor open (2043-001)*
   - ☐ NO
10. What is the status of the MIL lamp?
    - ☐ ON
    - ☑ OFF

11. With the sensor still disconnected attempt to start the engine. Does it start?
    - ☐ YES
    - ☑ NO
12. Are there any DTCs present?
    - ☑ YES *2043-001, 2043-002 ONLY WHEN CRANKING*
    - ☐ NO
13. What is the status of the MIL lamp?
    - ☐ ON
    - ☑ OFF
14. Explain the results of steps 1 through 13.

    Engine sync

15. Connect a dual trace lab scope to the Cam and Crank sensor signal wires (back-probe the sensors) and observe the relation of the two patterns with the engine running.

    Cam signal low at flywheel missing teeth

16. With the engine running and the scope connected as in step 15, short the Cam sensor signal wire to ground and observe the results. Will the engine start under these circumstances?
    - ☐ YES
    - ☑ NO
17. Connect a dual trace lab scope to the Crank sensor signal and ground the sensor wires individually. Observe the patterns.

18. Perform the following tests (with the engine running) and explain the results:
- ☐ Short the crank sensor signal wire to ground.

  ____

  ____

- ☐ Short the crank sensor ground wire to ground.

  ____

  ____

- ☐ Short the crank sensor signal and sensor ground wire together.

  ____

  ____

ACCELERATOR PEDAL POSITION SENSOR (APP)

The accelerator pedal position (APP) sensor is located within the accelerator pedal assembly. The driver supplies the torque requirements for the engine by operating the accelerator pedal in accordance with the desired speed or acceleration. The pedal sensor converts the mechanical operation of the pedal into an electrical signal and sends the information to the ECM. The ECM adjusts the quantity of the fuel that is injected into the engine.

The APP is serviced as an assembly with the pedal assembly.

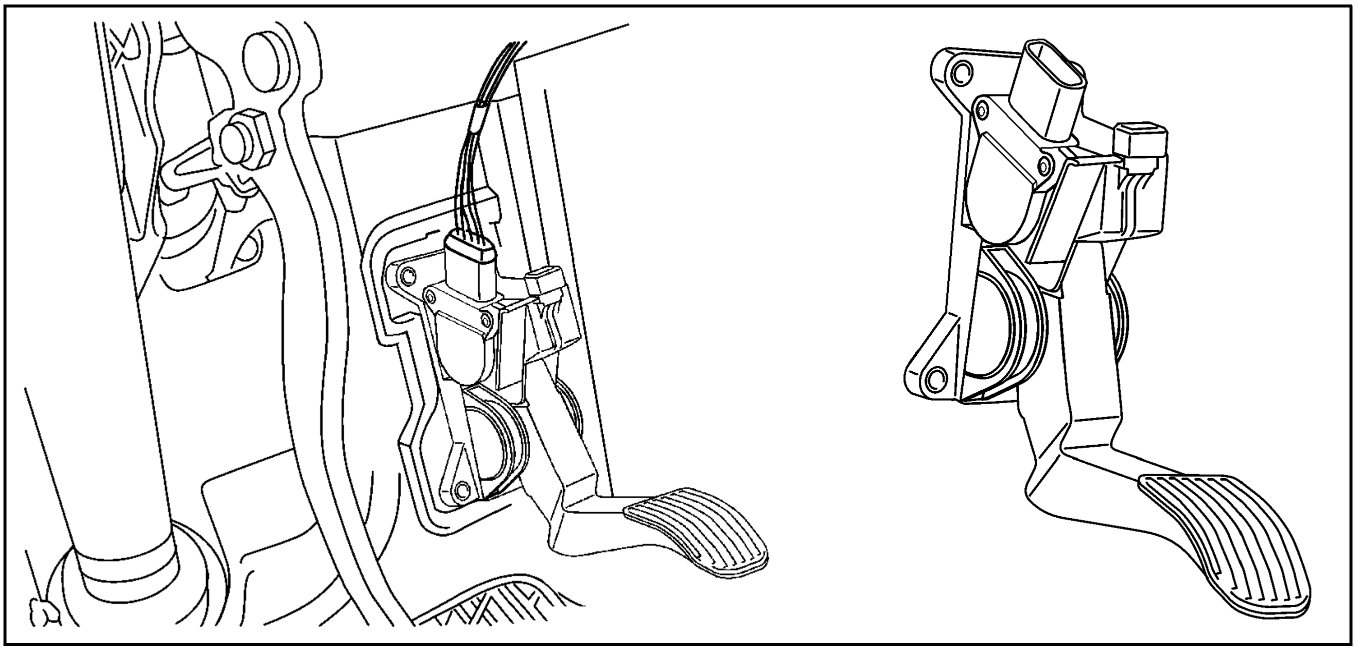


Figure 61 Accelerator Pedal Position Sensor

Operation

The APP sensor is comprised of two Hall-Effect sensors (sensors 1 and 2) that provide the ECM with redundant analog voltage signals (Figure 62). As the position of the accelerator pedal changes, the voltage signal of the sensor changes. The ECM sends a 5 volt reference signal to the APP sensor and the APP sensor returns two variable voltage signals. The voltage signal increases in direct proportion to the depressing of the pedal. The voltage signal from sensor 2 is always half the value of sensor 1 (Figure 63). The signal of sensor 1 ranges from 0.2 to 4.7 volts, while the sensor 2 signal ranges from 0.1 to 2.4 volts.

Certain diagnostic scan tools are able to read the APP voltage value. Others may only display the APP sensor value in percentage (0-100%).

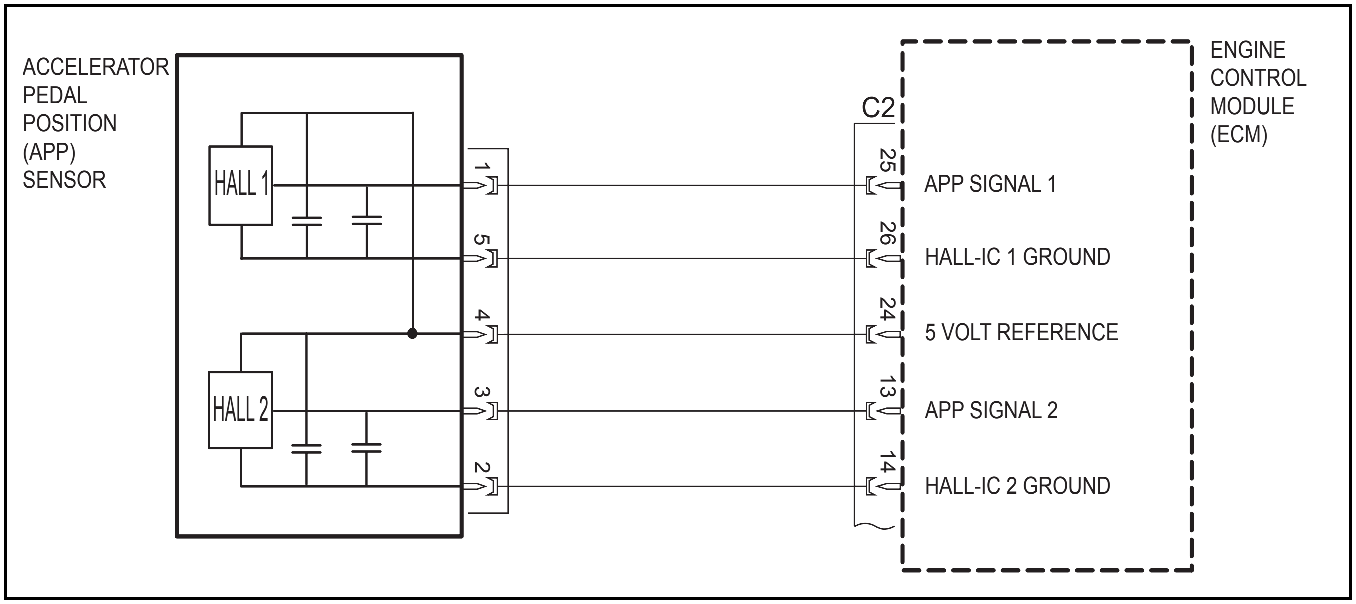


Figure 62 APP Sensor Schematic

Failure Modes

The ECM monitors the operation of the APP sensor and stores fault codes related to the following conditions:

- Sensor 1 signal voltage too low
- Sensor 1 signal voltage too high
- Sensor 1 supply voltage too high or too low
- Sensor 1 plausibility 1
- Sensor 1 plausibility 2
- Sensor 1 plausibility 3
- Sensor 2 signal voltage too low
- Sensor 2 signal voltage too high
- Sensor 2 supply voltage too high or too low
- Sensor 2 circuit implausibility, sensor 1 and 2

Substitute Values

An APP sensor value of 0% will be displayed under the following circumstances, regardless of the pedal position:

- Short circuit to ground of the signal wire
- Open circuit in the signal wire
- Short circuit to ground of the 5V supply
- Open circuit of the 5V supply

If there is an open circuit of the ground wire, the actual value displayed is 100%

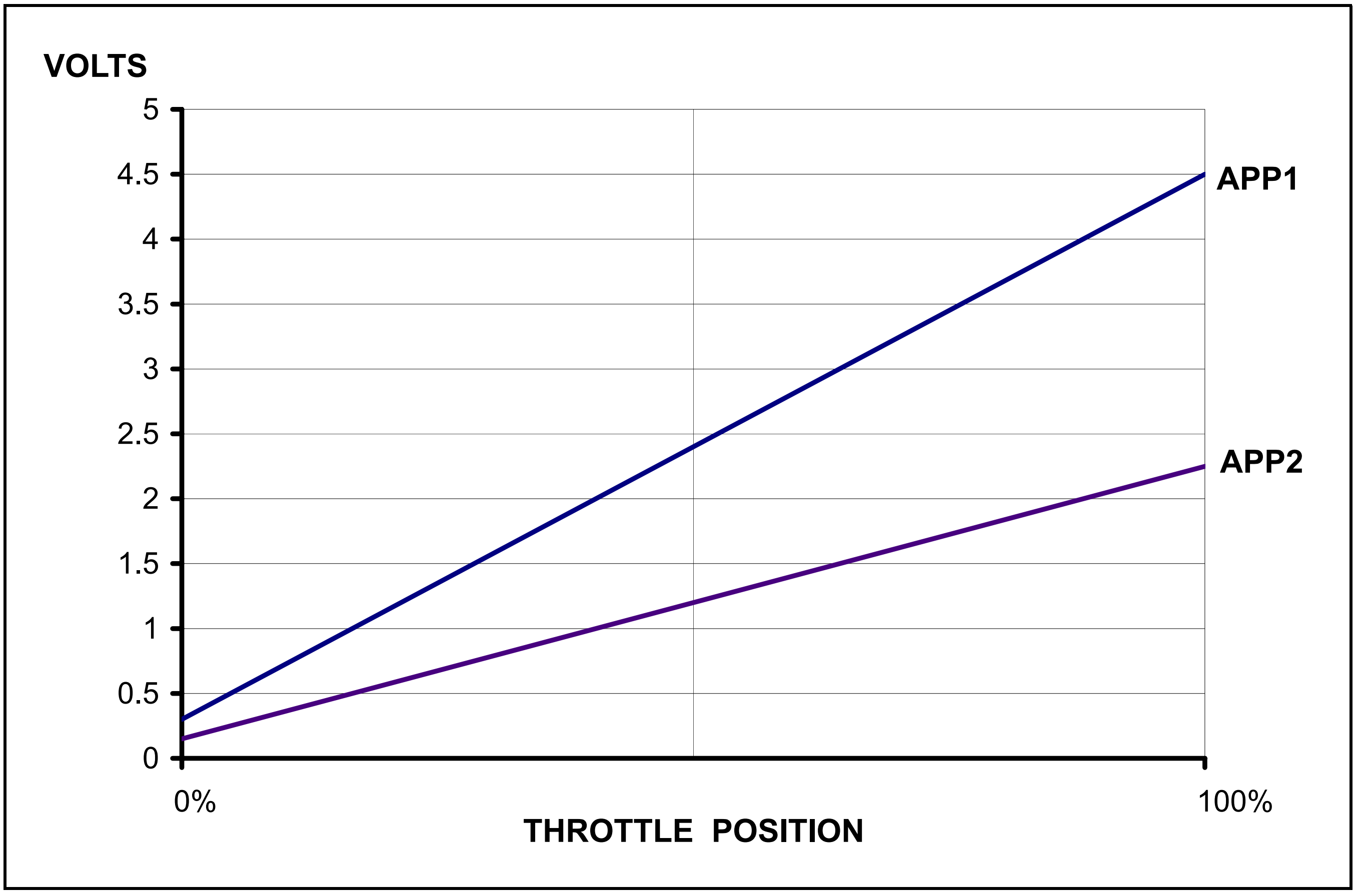


Figure 63 APP Sensor Signal (Approximate Values)

ACTIVITY 3.2 ACCELERATOR PEDAL ACTIVITY

The purpose of this activity is to gain an understanding of the accelerator pedal position sensor and kickdown switch.

ACCELERATOR PEDAL POSITION SENSOR

1. Connect the diagnostic scan tool to the vehicle and access the engine sensors.
2. What information is available for display regarding the accelerator pedal position sensor?

   Pedal position APP1 and APP2 (DRB III displays volts for APPS1 and APPS2

3. With the key on engine off slowly press the accelerator pedal to W.O.T. What do you notice about the percentages shown for sensors 1 and 2 on the scan tool versus pedal feel and physical position?

   The scan tool display will show you reach 100% before the pedal is to the metal.

   Also, the percentages should nearly match each other.

4. Compared to pedal travel when do both pedal sensor values reach 100%?

   Before the pedal reaches the floor.

5. How many circuits are there on the APP sensor and what are their functions? List below.

   PIN 1 APPS Signal #1 18 bl/dg

   PIN 2 APPS2 Ground 18 br/gy

   PIN 3 APPS Signal #2 18 gy/dg

   PIN 4 APPS 5V supply 18 bl/rd

   PIN 5 APPS1 Ground 18 br/bl

6. Using the proper service information locate the two signal wires on the APP sensor and backprobe.
7. With the key on engine off what is the voltage range throughout the accelerator pedal travel?

   SENSOR 1: Idle *0.35V* WOT *4.14V*

   SENSOR 2: Idle *0.18V* WOT *2.07V*

8. Using the diagnostic scan tool, read out the accelerator pedal sensor voltage values (optional). Do the values agree with the voltages measured? YES ____ NO ____
9. Read out the pedal position value (duty cycle of pedal value). Explain the purpose of this value.

   The APPS supplies dual voltage signals to the ECM, which filters these signals to calculate pedal position. This filtered and processed value is the duty cycle value

10. Is there a procedure to adjust the APP sensor?

    No. It is serviced as an assembly

KICKDOWN SWITCH

1. Connect the diagnostic scan tool to the vehicle and access the transmission control module.
2. What information is available for display regarding the kick down switch? Record below.

   *WOT _Kickdown=Operated_*

   Idle Kickdown=Not Operated_ (values found in the transmission control module)
3. What is this input used for?

   ATC compressor cutout/ Transmission downshift control
4. Is there a procedure to adjust the kickdown switch?

   NO

PRESSURE SENSORS

AIR INTAKE PRESSURE SENSOR

The air intake pressure sensor is mounted to the air filter housing.

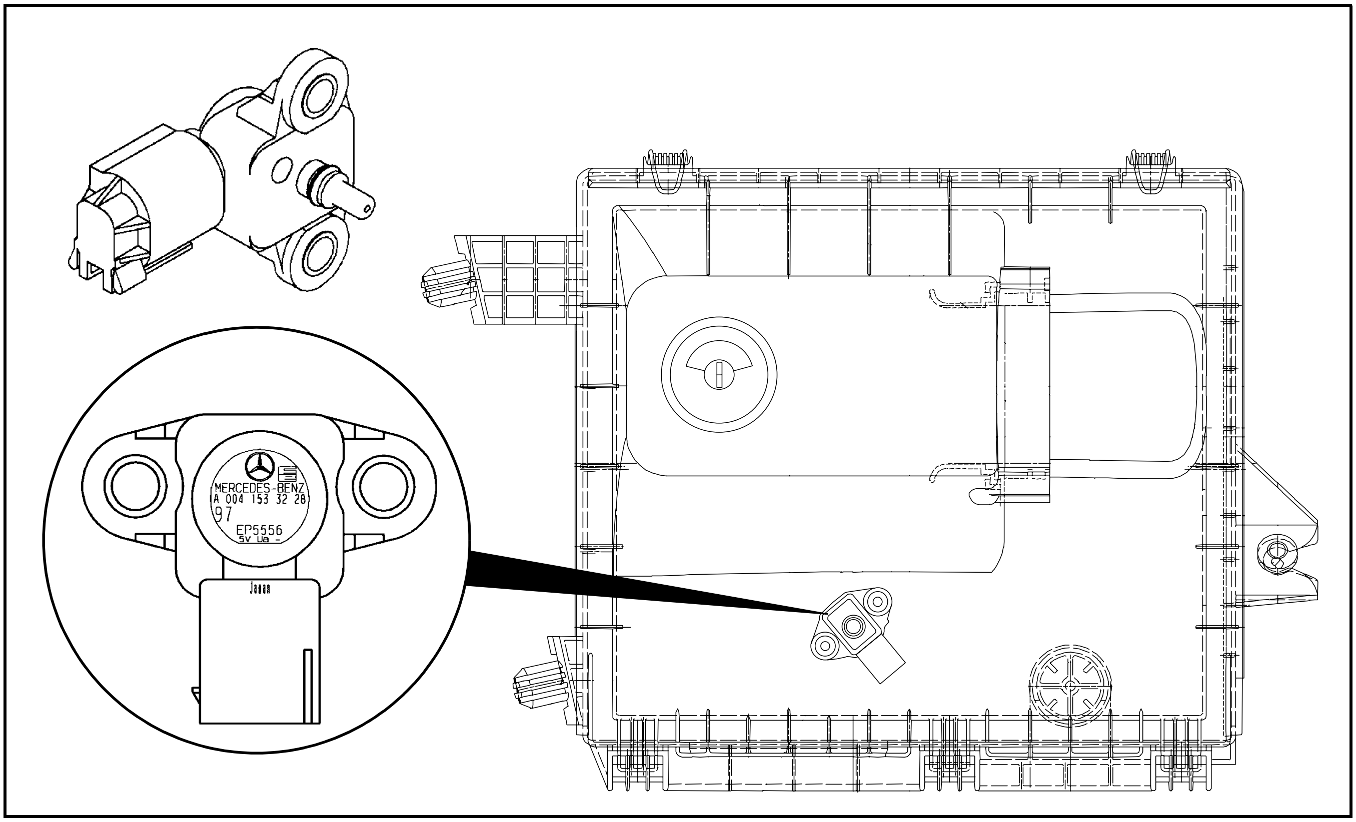


Figure 64 Air Intake Pressure Sensor Location

The ability to monitor intake pressure allows better control of variable geometry turbocharger to suit driving environment and preserve turbocharger durability. The sensor is used by the ECM to adjust for changes in altitude and for air intake obstructions due to clogging of the air filter.

OPERATION

The air intake pressure sensor consists of piezoresistive elements attached to a measuring diaphragm. The resistance value changes when stress is applied to the diaphragm. The resistors form a measuring bridge, so that when the diaphragm moves the bridge balance is changed. The bridge voltage is a measure for the boost presssure.

The sensor receives a 5-volt reference from the ECM. Sensor ground is also provided by the ECM. The bridge voltage varies from 0.5 to 4.5 volts depending on air intake pressure.

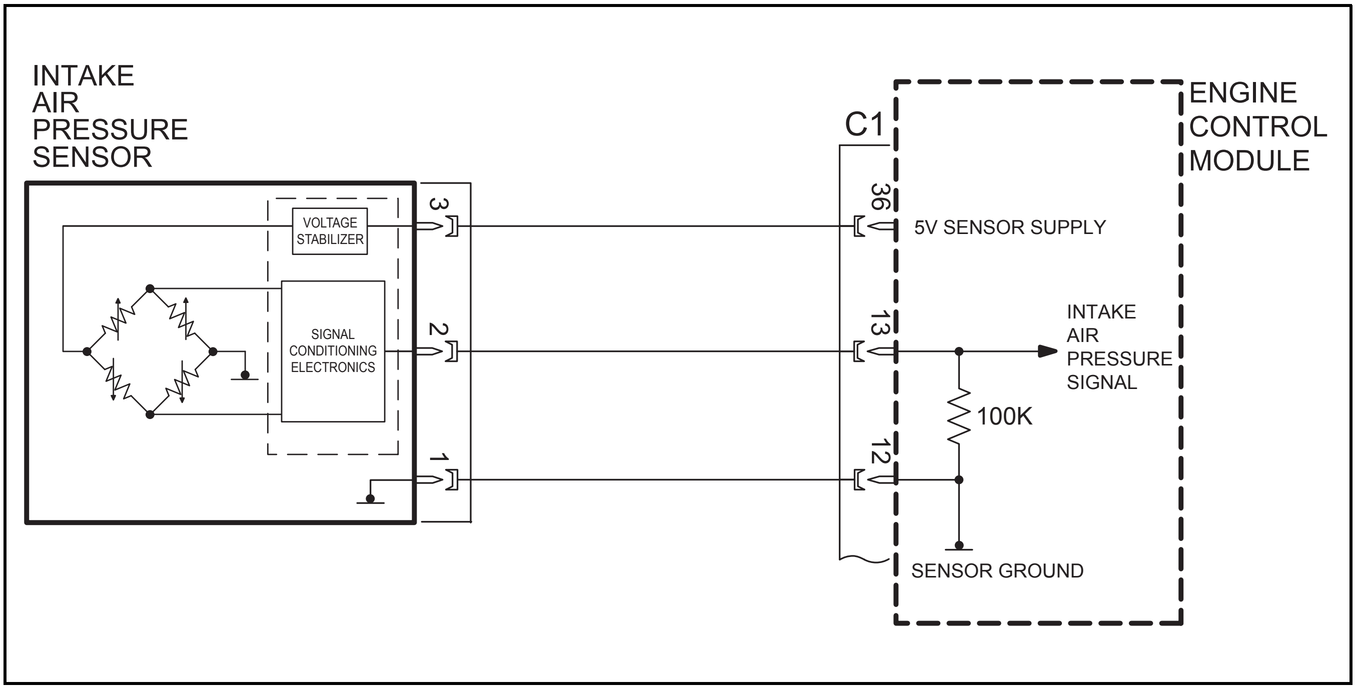


Figure 65 Air Intake Pressure Sensor Schematic

As air intake pressure increases, the signal voltage also increases. If the engine is not running, the value sent to the ECM is equal to the atmospheric pressure. The air intake pressure operating range is from 0.1 to 1.2 bar (1.45 to 17.4 psi).

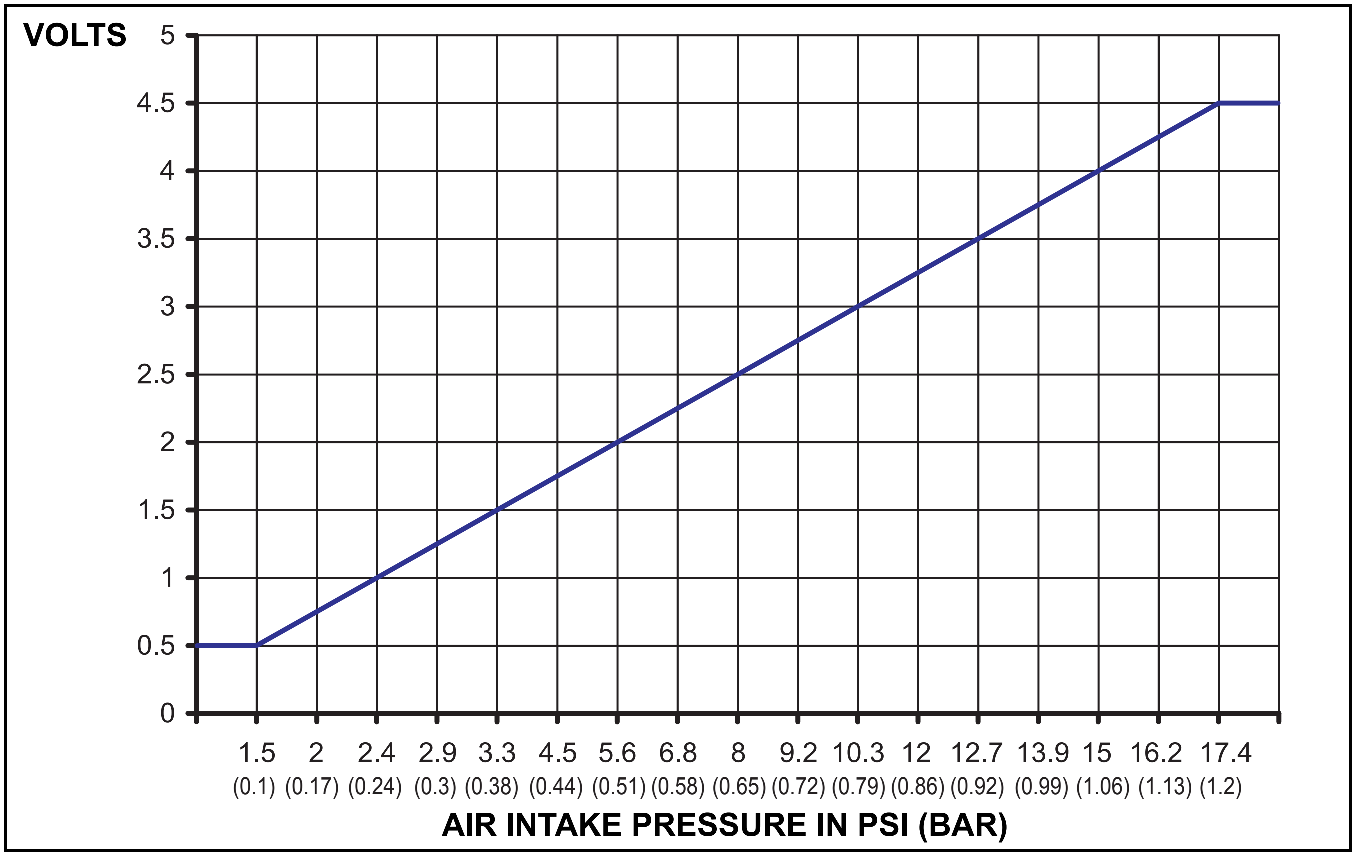


Figure 66 Air Intake Pressure Sensor Signal (Approximate Values)

Failure Modes

If the air intake pressure sensor fails, the ECM records a DTC into memory and continues to operate the engine in limp-in mode. When the engine is operating in this mode, a loss of power will be present, as if the turbocharger was not operating.

The ECM monitors the operation of the air intake pressure sensor and stores fault codes related to the following conditions:

- Signal voltage too low
- Signal voltage too high
- Supply voltage too high or too low

Substitute Values

- If the sensor ground wire has an open circuit, the actual value displayed is 38.29 psi
- If the signal wire has a short circuit to ground or open circuit, the substitute value is 11.2 psi
- If the 5-volt power supply has a short circuit to ground or open circuit, the substitute value is 11.2 psi

BOOST PRESSURE SENSOR

The boost pressure sensor is mounted to the charge air pipe (Figure 67). The sensor allows the ECM to monitor intake air downstream of the turbocharger.

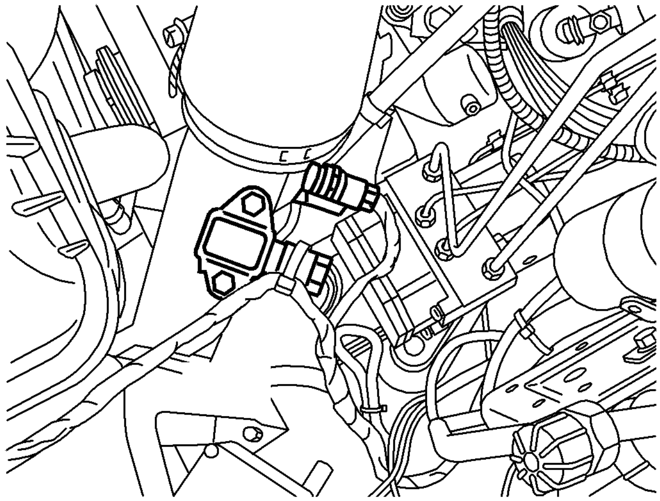


Figure 67 Boost Pressure Sensor Location

The boost pressure sensor is a three-wire sensor with a sensing pressure port on the bottom. The pressure port is inserted into the charge air pipe through an access hole. An O-ring provides the sealing once the sensor is mounted to the charge air pipe (Figure 68). The ECM uses boost pressure combined with intake air temperature to determine the volume of air entering the engine.

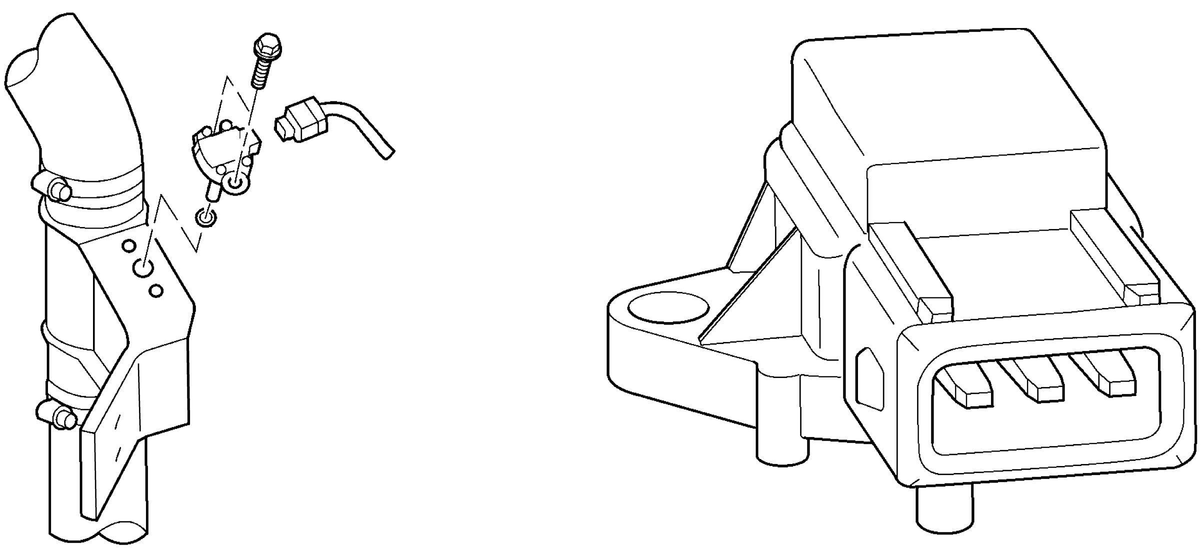


Figure 68 Boost Pressure Sensor

OPERATION

The boost pressure sensor consists of piezoresistive elements attached to a measuring diaphragm. The resistance value changes when stress is applied to the diaphragm. The resistors form a measuring bridge, so that when the diaphragm moves the bridge balance is changed. The bridge voltage is a measure for the boost presssure.

The sensor receives a 5-volt reference from the ECM. Sensor ground is also provided by the ECM. The bridge voltage varies from 0.5 to 4.5 volts depending on boost pressure.

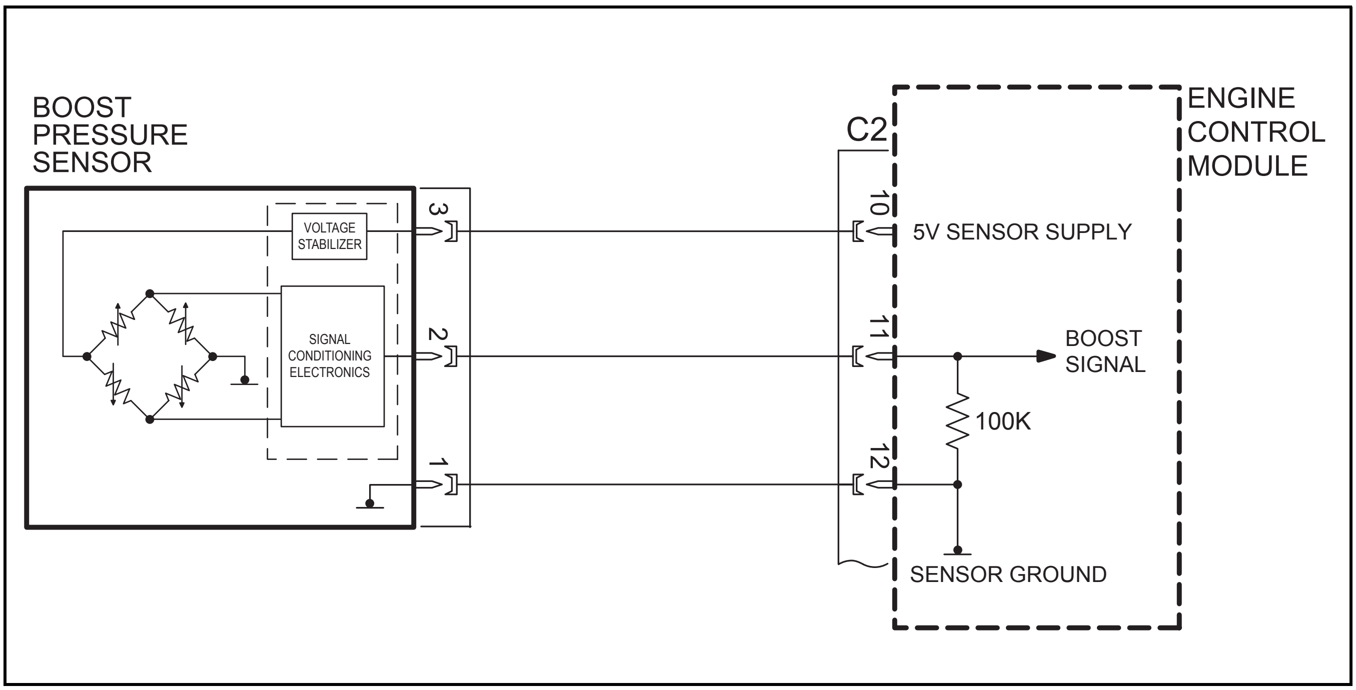


Figure 69 Boost Pressure Sensor Schematic

As boost pressure increases, the boost signal voltage also increases. If the engine is not running, the value sent to the ECM is equal to the atmospheric pressure. The boost pressure operating range is from 0 to 3 bar (0 to 43.5 psi).

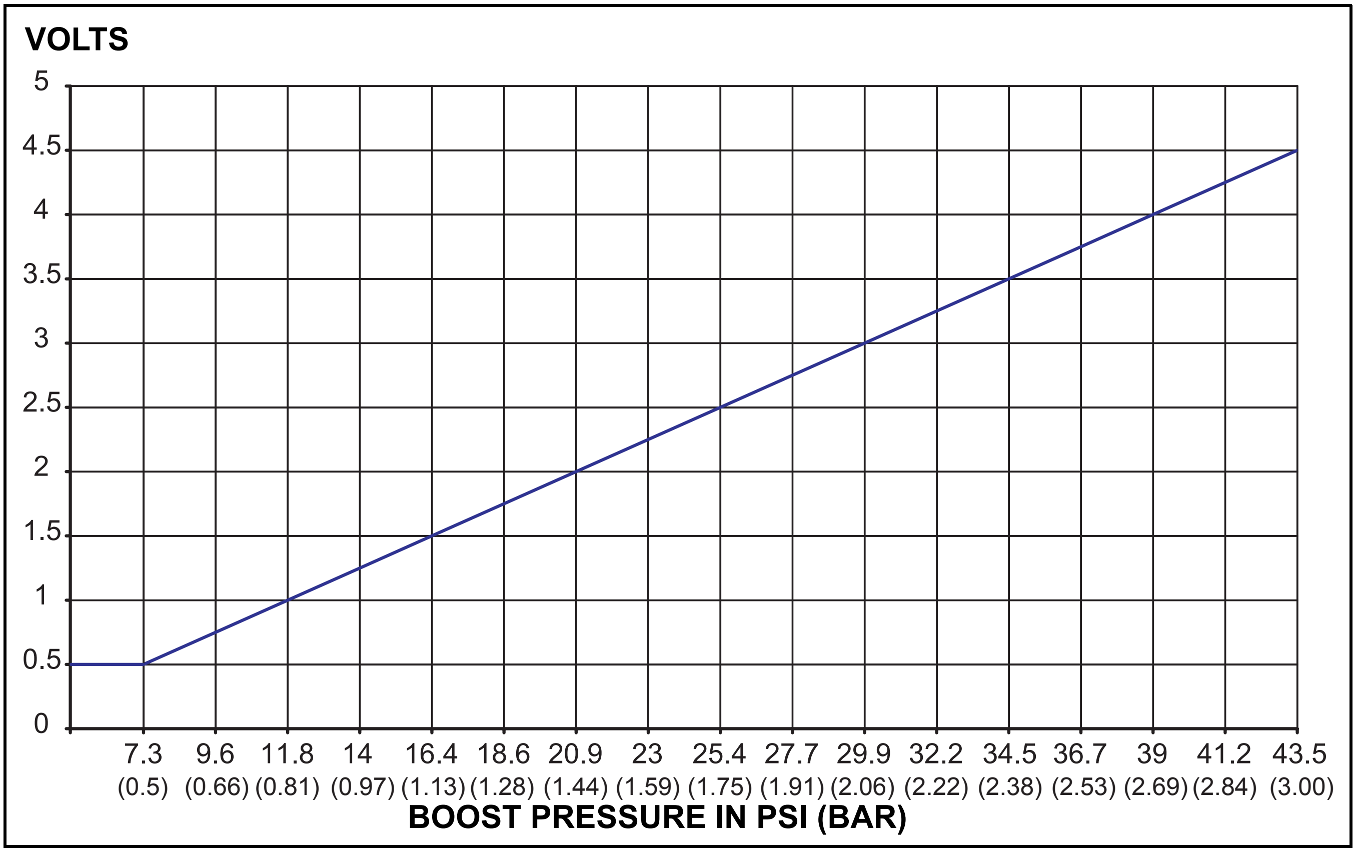


Figure 70 Boost Pressure Sensor Signal (Approximate Values)

Failure Modes

If the boost pressure sensor fails, the ECM records a DTC into memory and continues to operate the engine in limp-in mode. When the engine is operating in this mode, a loss of power will be present, as if the turbocharger was not operating.

The ECM monitors the operation of the boost pressure sensor and stores fault codes related to the following conditions:

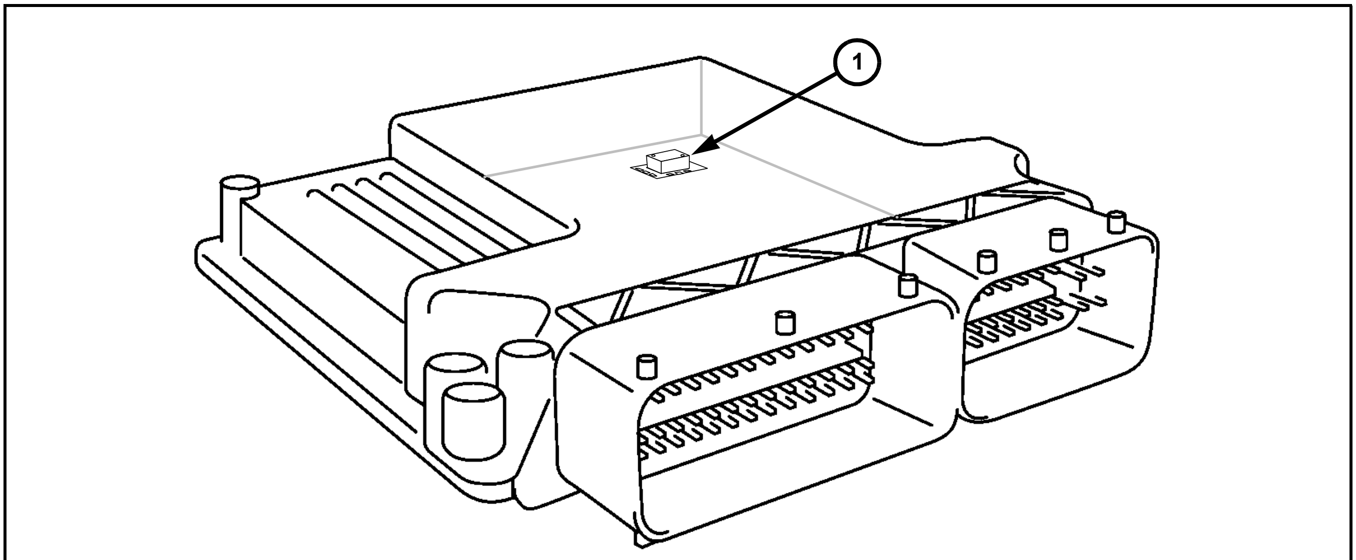
- Signal voltage too low
- Signal voltage too high
- Supply voltage too high or too low

Substitute Values

- If the sensor ground wire has an open circuit, the actual value displayed is 38.29 psi
- If the signal wire has a short circuit to ground or open circuit, the substitute value is 2.90 psi
- If the 5-volt power supply has a short circuit to ground or open circuit, the substitute value is 2.90 psi

BAROMETRIC SENSOR

The barometric sensor is located in the ECM. The pressure range of the sensor is from 950 to 1100 mbar (13.78 to 15.95 psi). This pressure value can be verified with the diagnostic scan tool.



1	Barometric Sensor

Figure 71 Internal View of ECM, Barometric Sensor Location

Failure Modes

The ECM monitors the operation of the barometric sensor and stores fault codes under any of the following conditions:

- Signal voltage too high
- Signal voltage too low

FUEL RAIL PRESSURE SENSOR

The fuel rail pressure sensor is mounted on the front of the fuel rail. The sensor provides an output voltage to the engine control module that corresponds to the applied pressure.

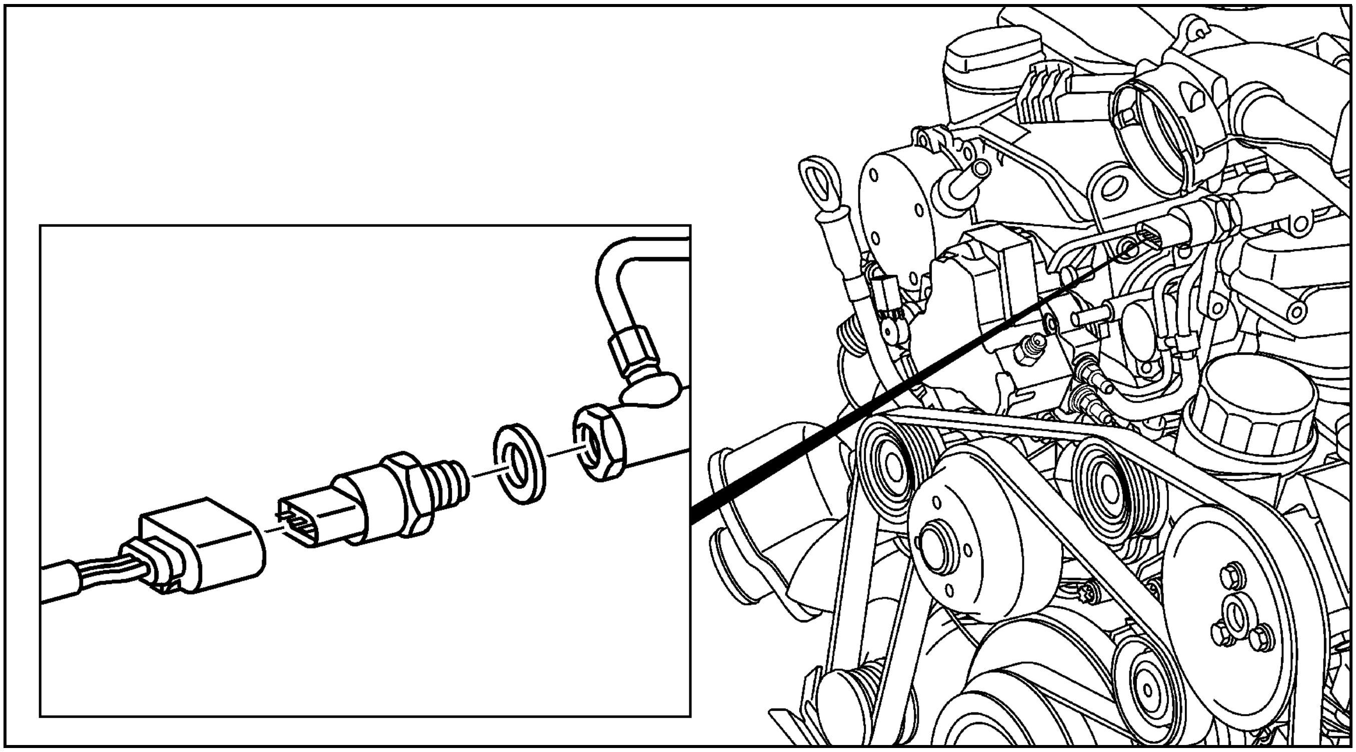
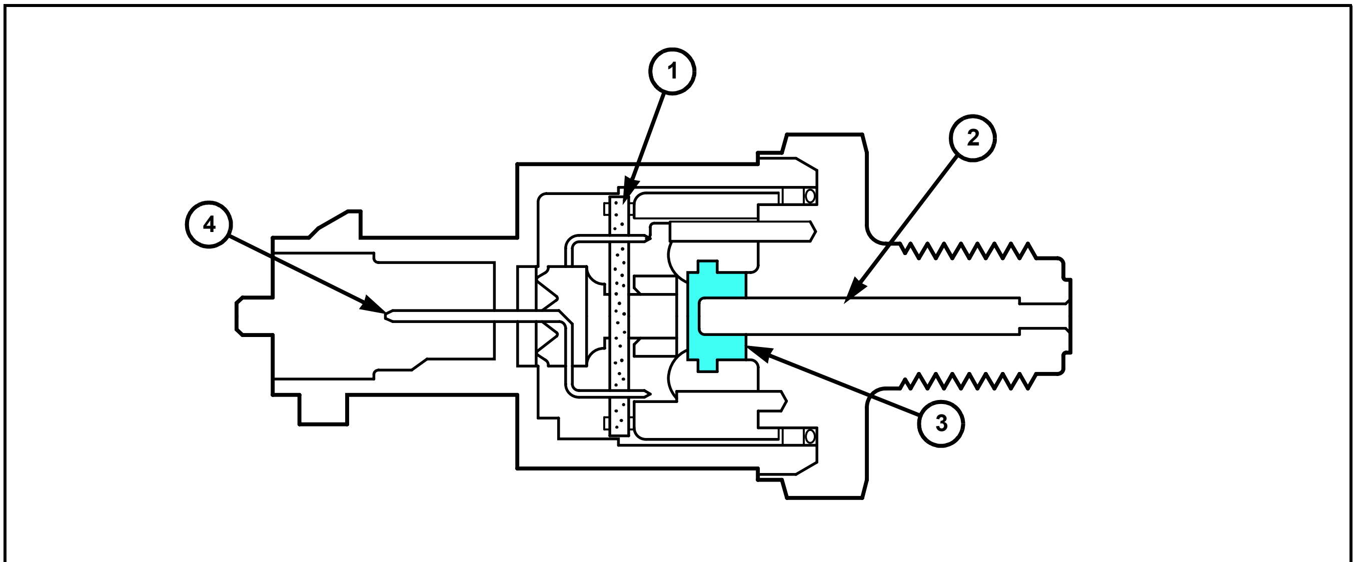


Figure 72 Fuel Rail Pressure Sensor

OPERATION

The fuel rail pressure sensor consists of a high-grade spring steel diaphragm with an attached strain gage. The deflection of the diaphragm changes the resistance of the strain gage. The sensor measures the current fuel rail pressure and sends a voltage signal to the ECM. The ECM then actuates the fuel rail pressure solenoid and fuel quantity valve until the desired rail pressure is achieved. If the rail pressure sensor fails, the engine will run in limp-in mode. The pressure actual value ranges from 200 to 1600 bar (2,900 to 23,205 psi).



1	Signal Conditioning Electronics	3	Metal Diaphragm & Sensor Circuit
2	Fuel Pressure Port	4	Electrical Connector

Figure 73 Fuel Rail Pressure Sensor Construction

The ECM uses the fuel rail pressure input to control the output of the fuel pressure solenoid. The ECM sends a 5 volt supply to the fuel rail pressure sensor. Depending on the fuel rail pressure, the sensor output signal varies from 0.5 to 4.5 volts (Figure 75).

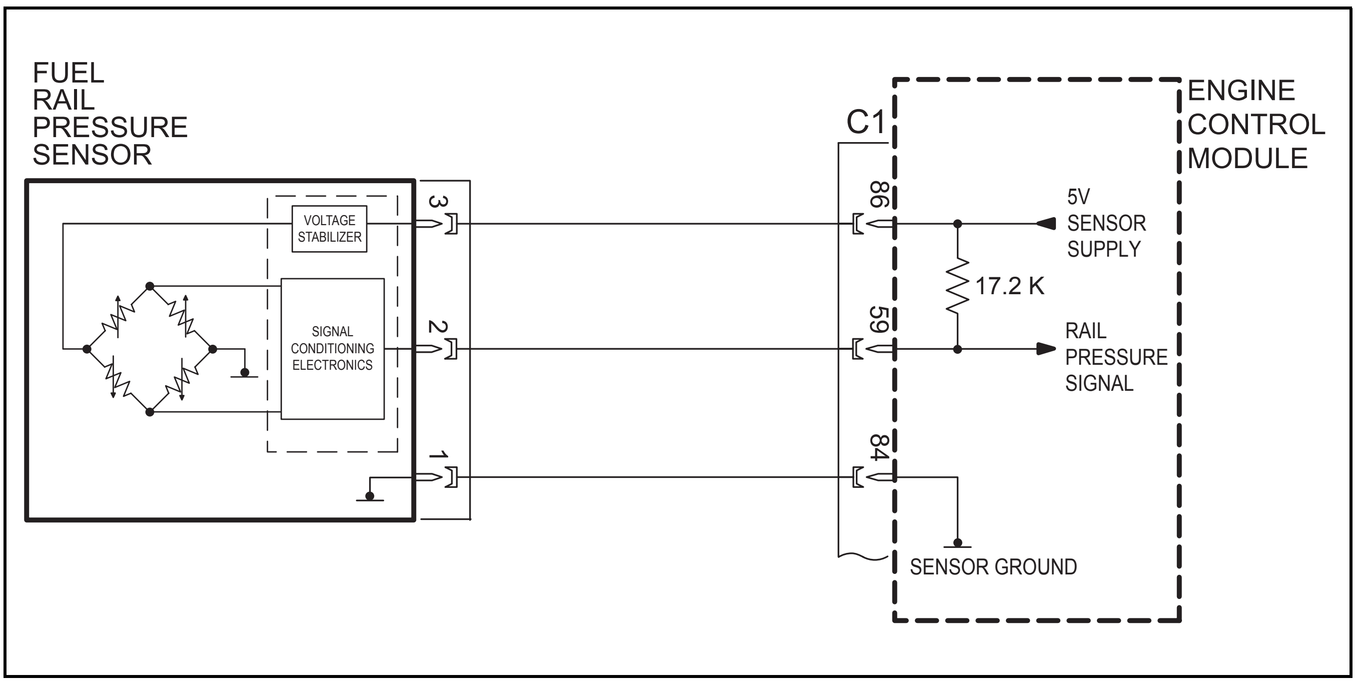


Figure 74 Fuel Rail Pressure Sensor Schematic

Failure Modes

The ECM stores fault codes under any of the following conditions:

- Voltage too high
- Voltage too low
- Voltage too high or too low
- Plausibility between fuel rail pressure sensor and fuel pressure solenoid
- Maximum pressure has been exceeded
- Rail pressure too low
- No pressure build up. Fuel pressure solenoid open
- Fuel pressure solenoid stuck in closed position
- Fuel pressure leakage detected
- Control deviation engine speed too high

Substitute Values

No substitute values are displayed on the diagnostic scan tool for the rail sensor.

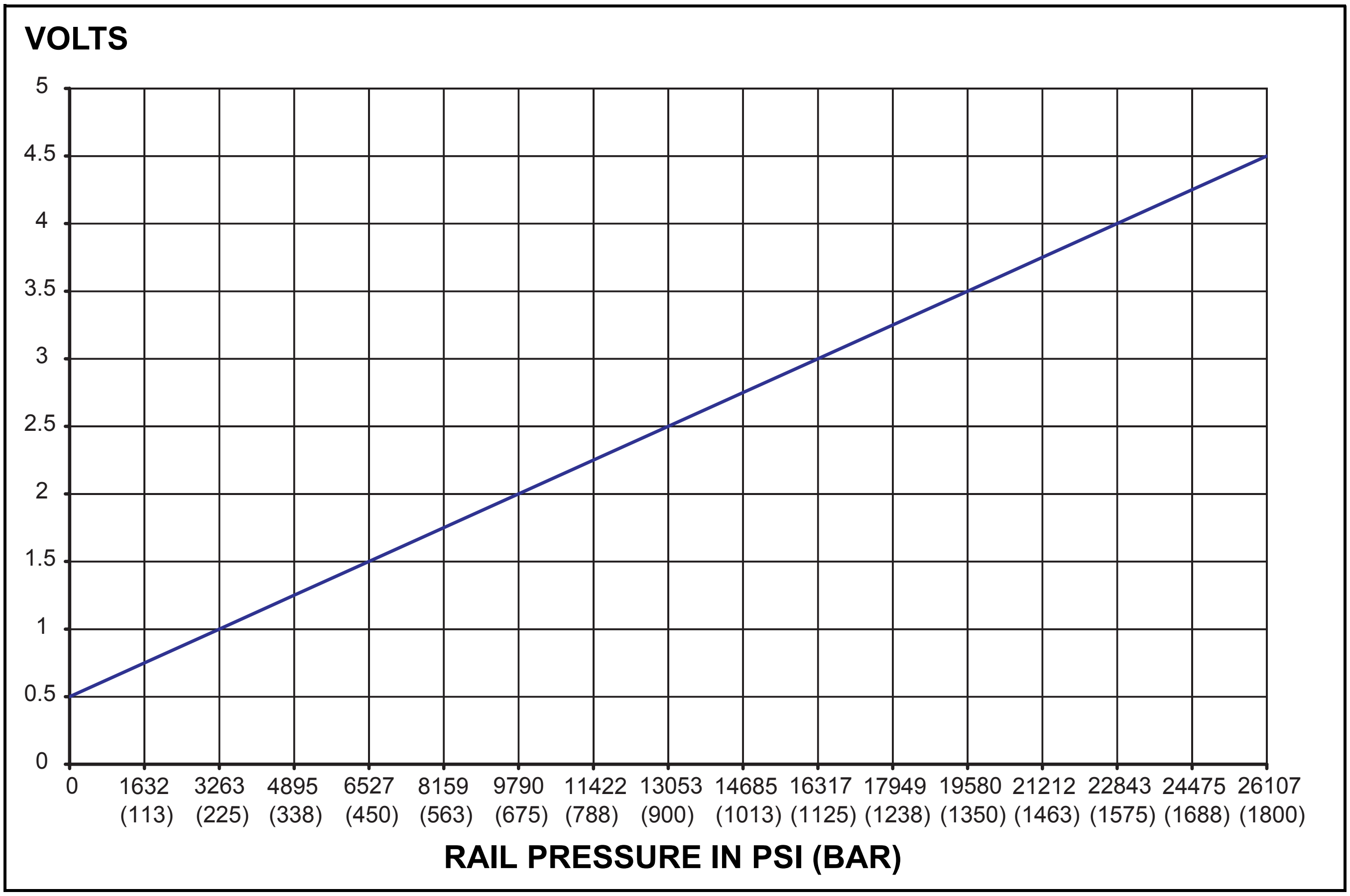


Figure 75 Fuel Rail Pressure Sensor Signal (Approximate Values)

ACTIVITY 3.3 FUEL RAIL PRESSURE TEST

The purpose of this activity is to test the operation of the fuel rail pressure sensor.

TASK 1 RAIL PRESSURE VALUE TEST

1. Connect the diagnostic scan tool to the vehicle and find the rail pressure value.
2. Switch the ignition ON to activate the electric fuel pump.
3. Is the fuel pump running? YES __*X*__ NO ______
4. Monitor the fuel pressure sensor value until it stabilizes.
5. What is the pressure reading?
   Approximately 62 psi
6. What is the specified value? (check the service manual)
   Between 0-15 bar (0-218 psi)
7. Is the measured value within specifications? YES __*X*___ NO ______
8. What could be a probable cause if the readings were outside of the specified value?
   Faulty fuel rail pressure sensor

TASK 2 SENSOR SIGNAL VOLTAGE TEST

9. Back probe the fuel rail pressure sensor to read the signal voltage. Start the engine and allow it to run at idle.
10. What is the signal voltage displayed?
    Approximately 1.24 volts, which corresponds to 4876 psi
11. Using the pressure/voltage chart determine the pressure that corresponds to the signal voltage.
12. What is the fuel pressure value that corresponds to the voltage reading?
    ____
13. Read the rail pressure value with the diagnostic scan tool and compare with the value from the pressure chart.
14. Is the voltage reading within specifications? YES __*X*__ NO _____
15. Remove the voltmeter from the engine and switch the ignition OFF.

TEMPERATURE SENSORS

INTAKE AIR TEMPERATURE SENSOR (IAT)

The inlet air temperature (IAT) sensor is mounted to the charge air pipe. The IAT is a two-pin sensor, which consists of an NTC resistor in a plastic housing. The IAT is locked in place by two retaining clips and sealed with an O-Ring (Figure 76).

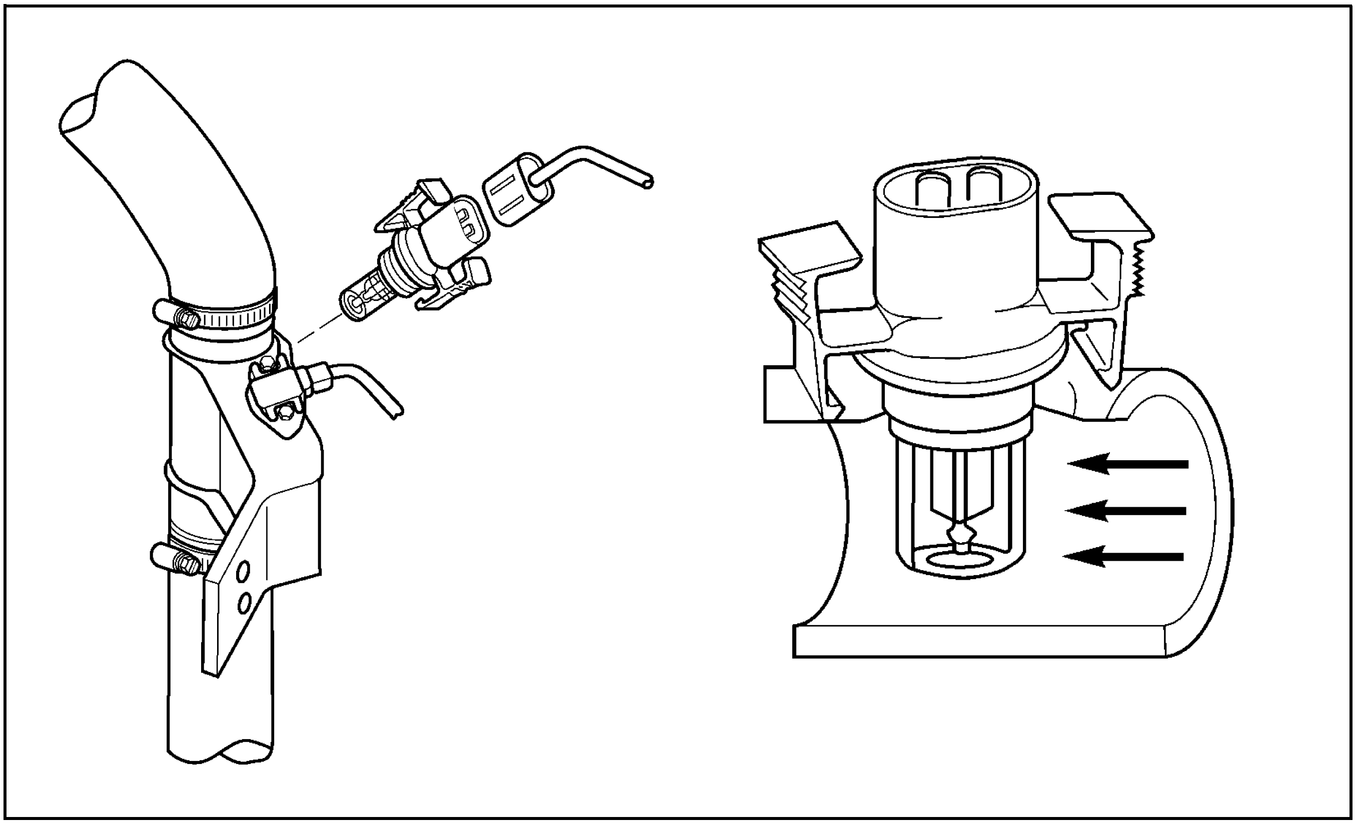


Figure 76 Inlet Air Temperature Sensor

Operation

The NTC resistor located within the IAT changes its resistance in line with the charge air temperature. The ECM sends 5 volts to the NTC resistor and grounds it through the sensor return line. The ECM interprets the voltage as air temperature.

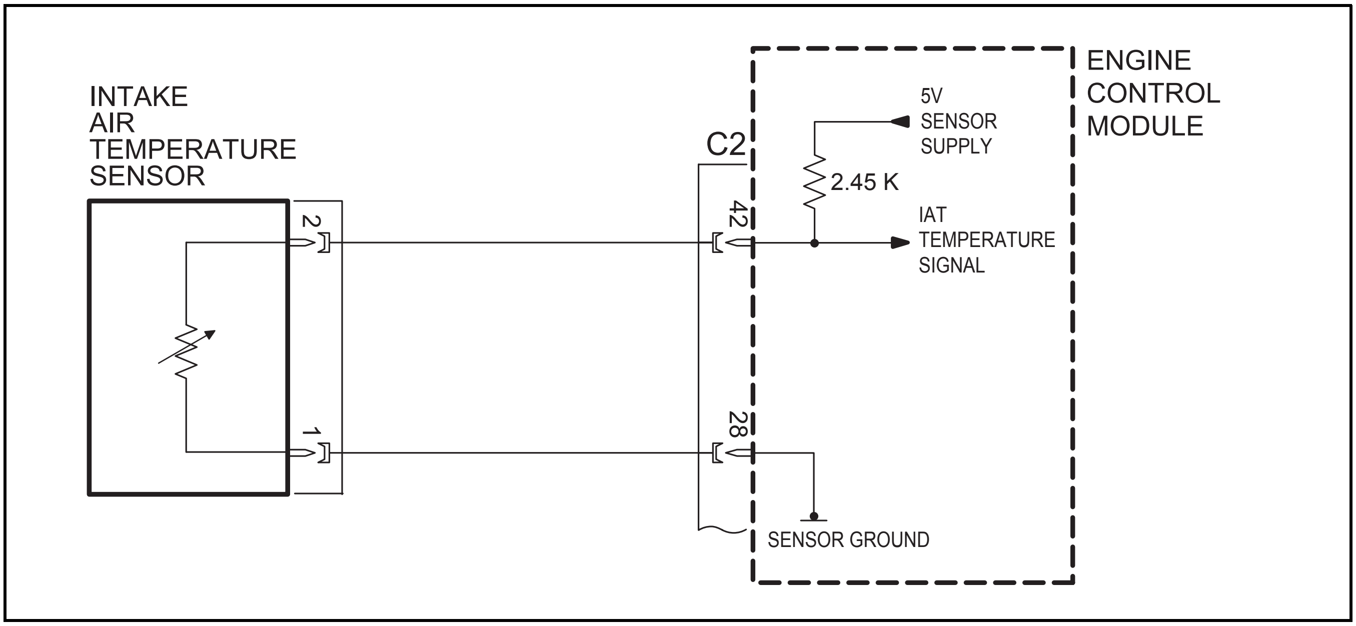


Figure 77 IAT Sensor Schematic

The IAT temperature value ranges from -40°C to 150°C (-40°F to 302°F). If the engine is cold, the IAT actual value equals the ambient temperature.

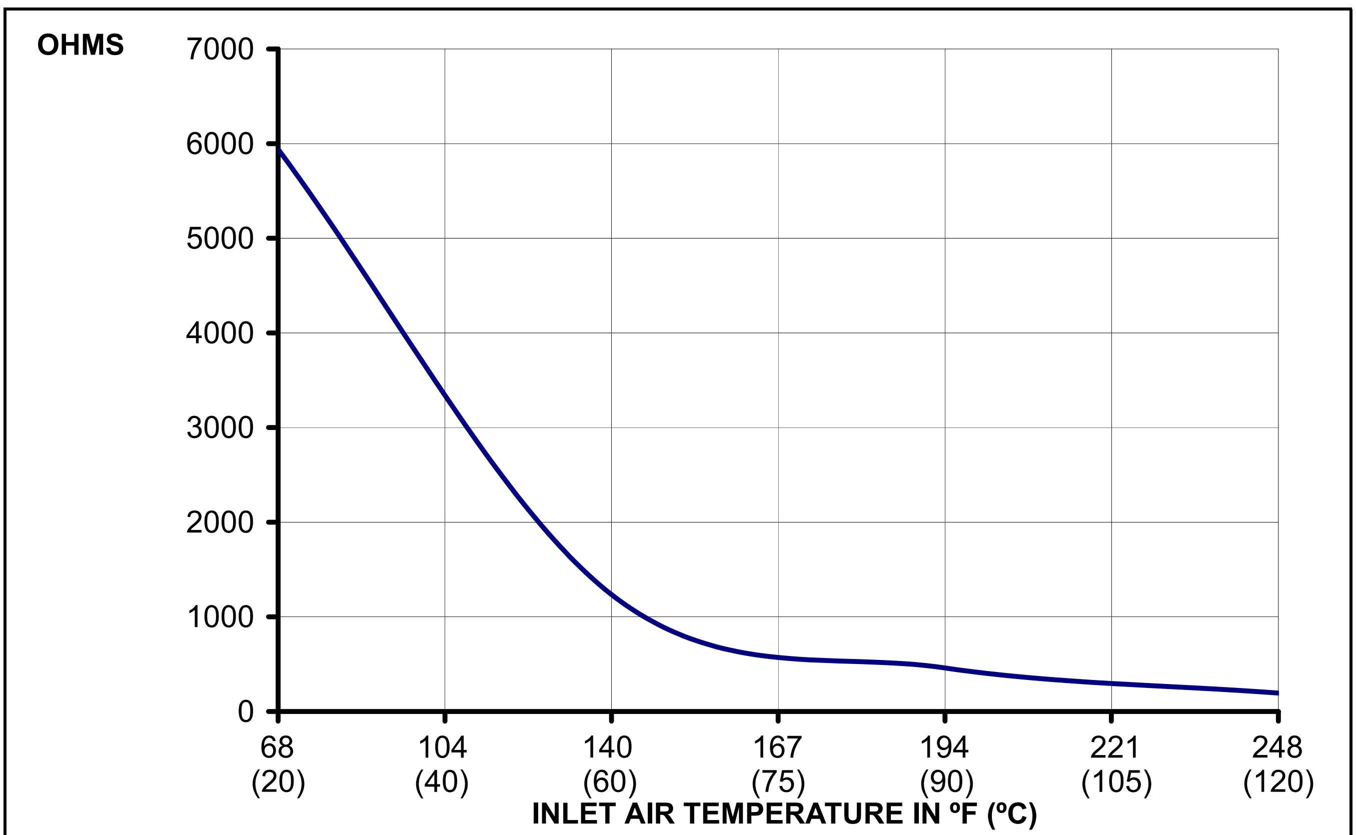


Figure 78 IAT Sensor Resistance Chart (Approximate Values)

Failure Modes

The ECM monitors the operation of the inlet air temperature sensor and stores fault codes under any of the following conditions:

- Signal voltage too high
- Signal voltage too low

Substitute Values

- If the signal wire is shorted to ground, the actual value displayed is 150°C (302°F)
- If the signal wire is shorted to positive, the actual value displayed is -40°
- If the signal wire has an open circuit, the actual value displayed is -40°

COOLANT TEMPERATURE SENSOR

The engine coolant temperature sensor (ECT) is a two-pin sensor located in the thermostat housing. The sensor consists of a plastic housing, which contains an NTC resistor. The ECT is locked in place by a locking spring and sealed with an O-Ring.

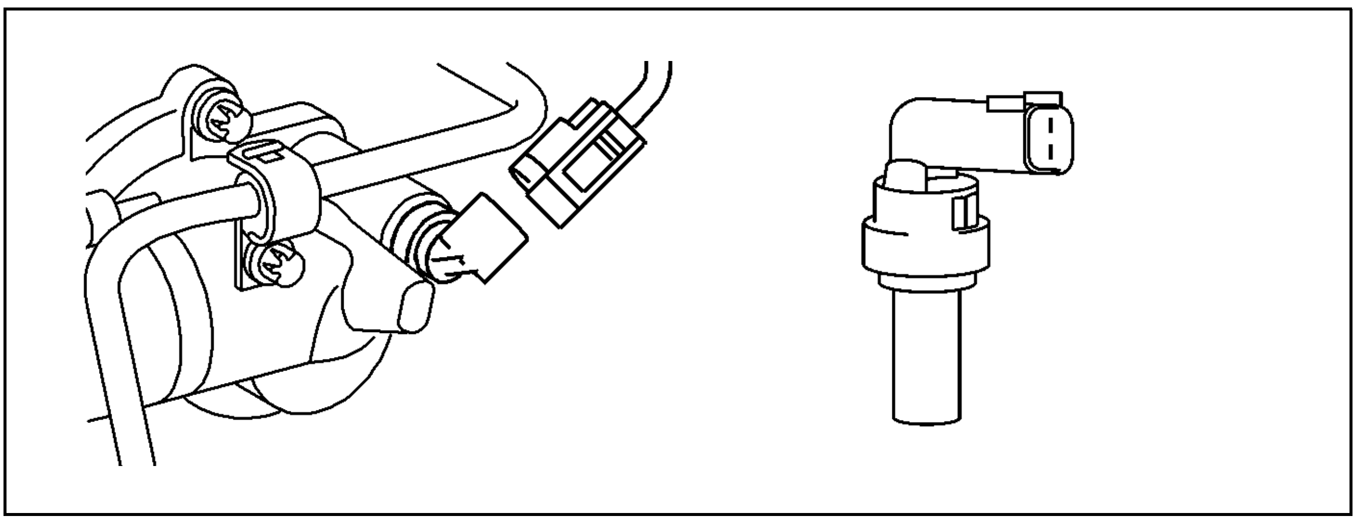


Figure 79 Coolant Temperature Sensor

Operation

The ECM sends 5 volts to the NTC resistor and grounds it through the sensor return line. The ECM determines the coolant temperature based on the voltage drop within the sensor circuit and changes the fuel supply accordingly.

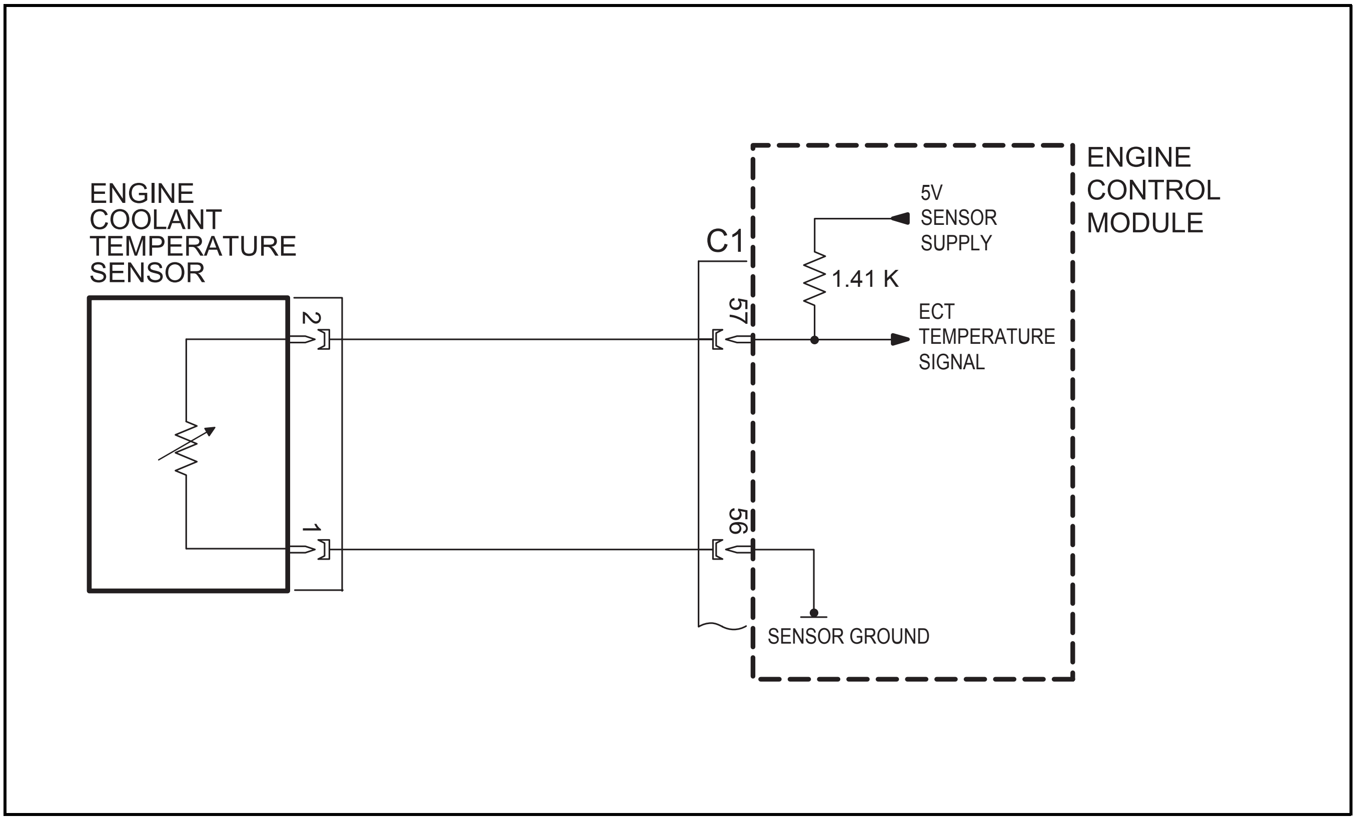


Figure 80 ECT Sensor Schematic

The ECT temperature value ranges from -40°C to 140°C (-40°F to 284°F). If the engine is cold, the ECT actual value is equal to the ambient temperature.

Failure Modes

The ECM monitors the operation of the coolant temperature sensor and stores fault codes under any of the following conditions:

- Signal voltage too high
- Signal voltage too low
- Operating temperature not reached

Substitute Values

- If the signal wire is shorted to ground the actual value displayed is 140°C (284°F)
- If the signal wire is shorted to positive, the actual value displayed is -40°
- If a wire has an open circuit, the actual value displayed is -40°

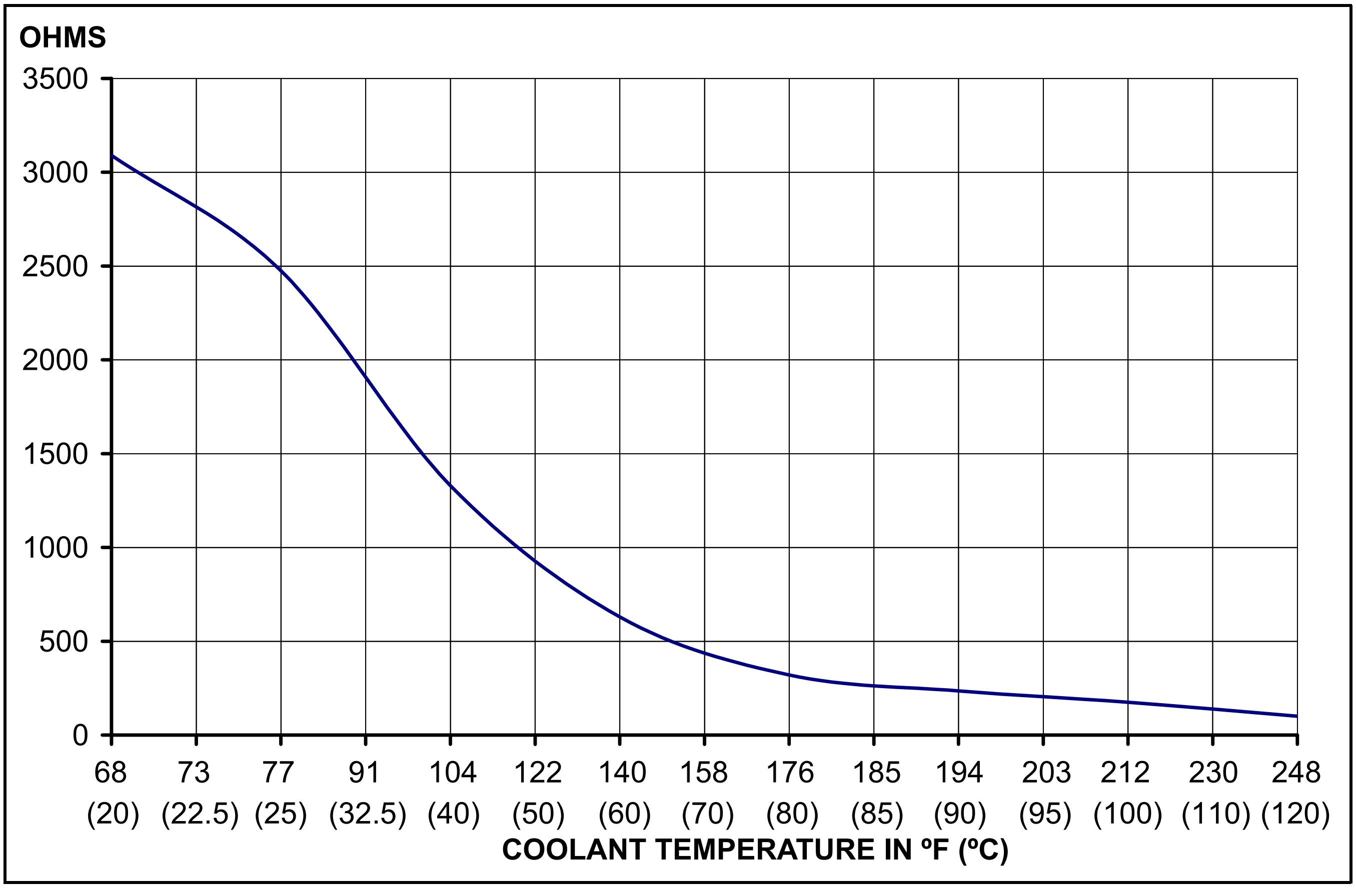


Figure 81 ECT Sensor Resistance Chart (Approximate Values)

FUEL TEMPERATURE SENSOR

The temperature sensor is located at the front of the engine, on the high-pressure pump flange. The sensor detects the fuel temperature and supplies information to the engine control module (ECM). If the fuel is too warm, the rail pressure in the system is lowered. The controlled quantity of the pressure regulating valve is reduced and the fuel temperature lowered. The NTC resistor integrated in the fuel temperature sensor alters its electrical resistance in line with the fuel temperature. The electrical resistance becomes less as the temperature rises.

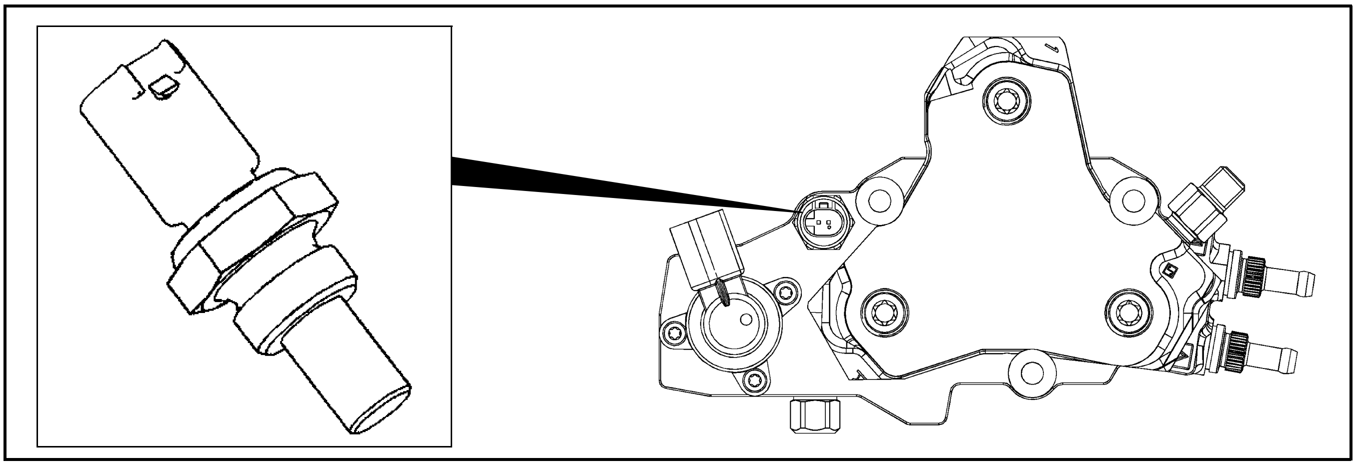


Figure 82 Fuel Temperature Sensor

The sensor ranges from - 40°C (-40°F) to 120°C (248°F). If the engine is cold, the actual value sent will read ambient temperature. The value rises after the engine has been started.

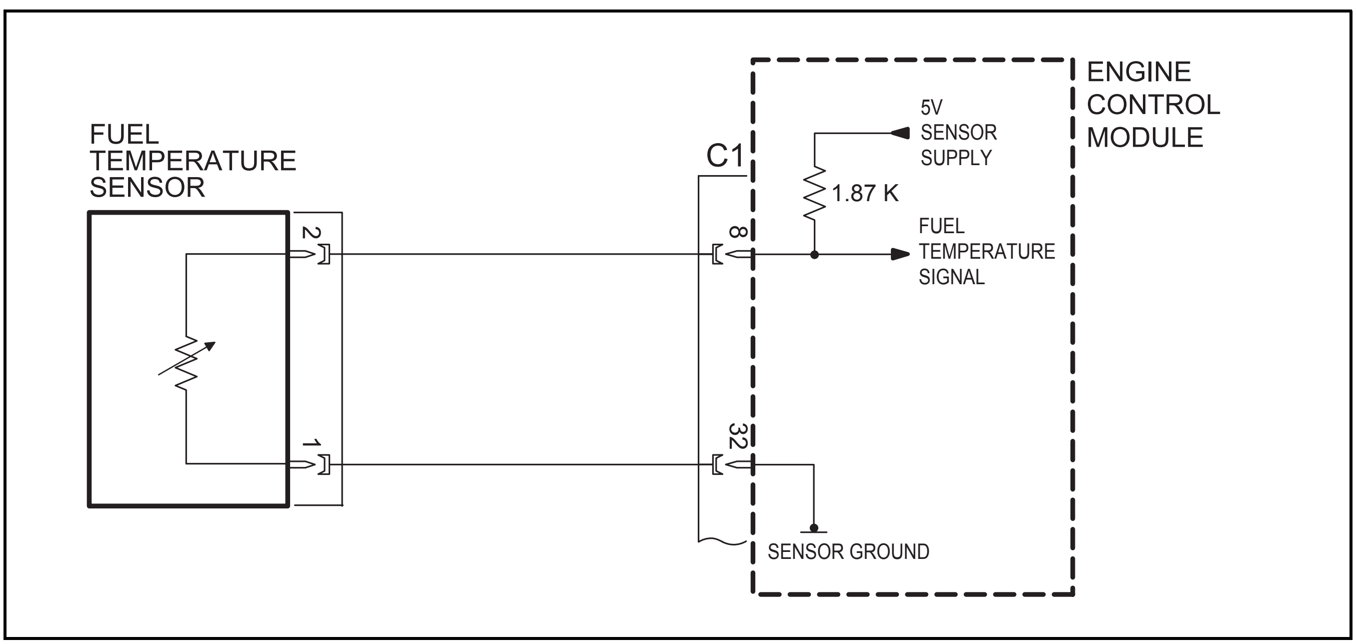


Figure 83 Fuel Temperature Sensor Schematic

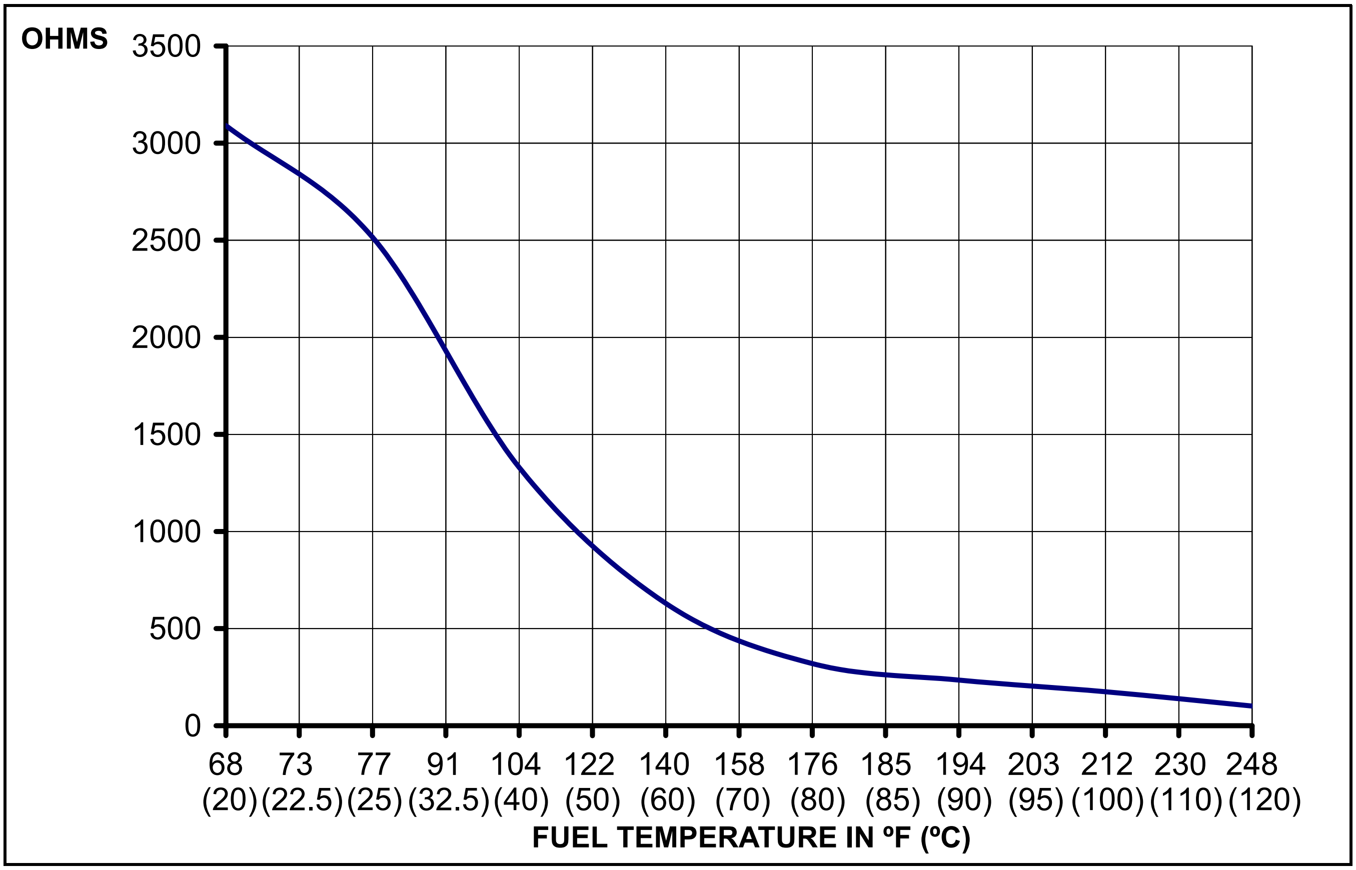


Figure 84 Fuel Temperature Sensor Resistance Chart (Approximate Values)

Failure Modes

The ECM monitors the operation of the fuel temperature sensor and stores fault codes under any of the following conditions:

- Signal voltage too high
- Signal voltage too low

Substitute Values

- If the signal wire is shorted to ground, or if the sensor wires short circuit to each other, the actual value displayed is 120°C (248°F)
- If the signal wire is shorted to positive, the actual value displayed is -40°. The intake temperature value displayed is also -40°
- If a wire has an open circuit, the actual value displayed is -40°

ENGINE OIL SENSOR

The engine oil sensor is a three-wire sensor located on the left side of the oil pan, near the oil drain plug (Figure 85). The oil sensor detects oil temperature, oil level and oil quality. The sensor operates on the capacitance principle and an integrated electronic circuit analyzes the three signals.

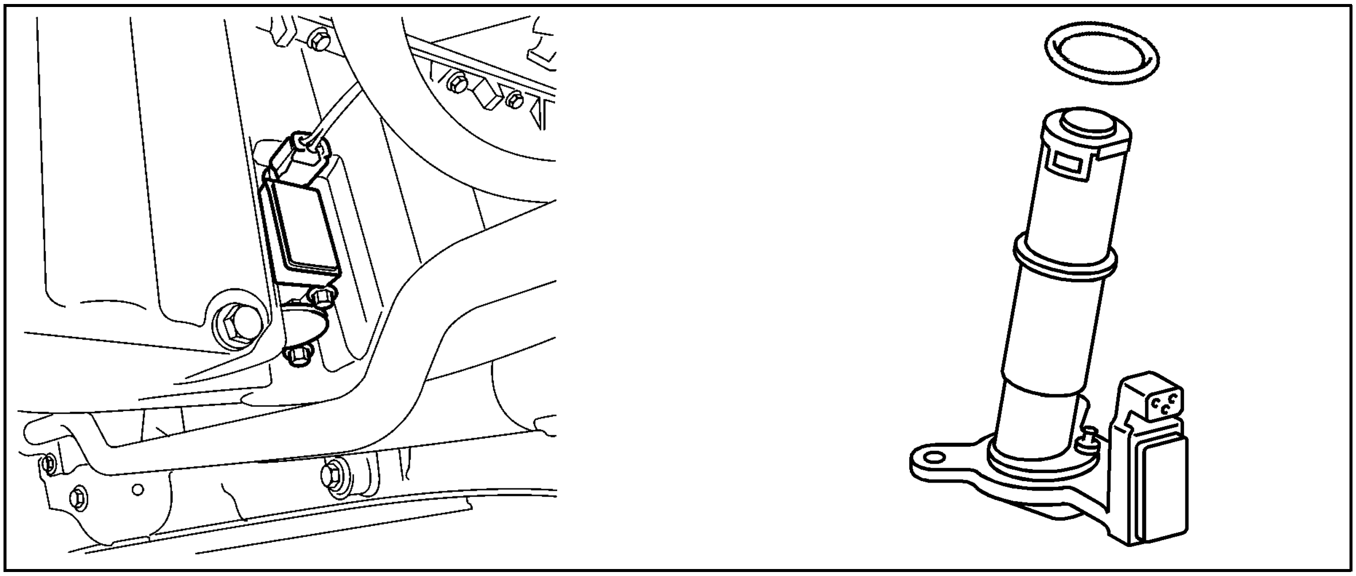


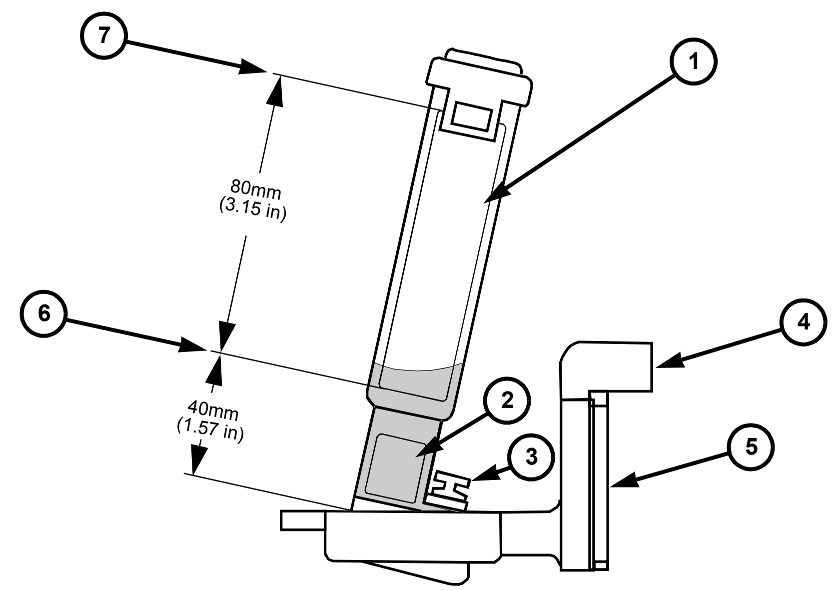
Figure 85 Engine Oil Sensor

Operation

The engine oil sensor consists of a platinum temperature element (Pt 1000), two cylindrical measuring capacitors and integrated electronics (Figure 86). The platinum element measures the oil temperature. One of the capacitors measures the oil quality, and is totally immersed in oil. The second capacitor measures the oil level and is positioned between the expected minimum and maximum oil levels. The measured values are transmitted as pulse-width-modulated (PWM) signals to the ECM.

The oil level sensor has a measuring range of 80 mm (3.15 in.). The minimum measuring limit for the oil level is approximately 40 mm (1.57 in.) The maximum measuring limit is approximately 120 mm (4.72 in.). The accuracy of the oil level measurement is approximately ±3 mm (0.118 in.).

The oil quality is used to determine oil change intervals. The engine oil condition measurement is based on the dielectric properties of the oil (dielectrics: does not conduct electricity). As engine oil breaks down and additives are depleted, the dielectric properties gradually increase. The oil quality sensor determines the dielectric constant number of the oil in a scale from 1 to 6. An oil quality number between 1 and 4 is good. A number between 5 and 6 indicates poor oil quality.



1	Oil Level Sensor	5	Electronic Circuit
2	Oil Quality Sensor	6	Start of Measuring Range
3	Oil Temperature Sensor	7	End of Measuring Range
4	Electrical Connector		

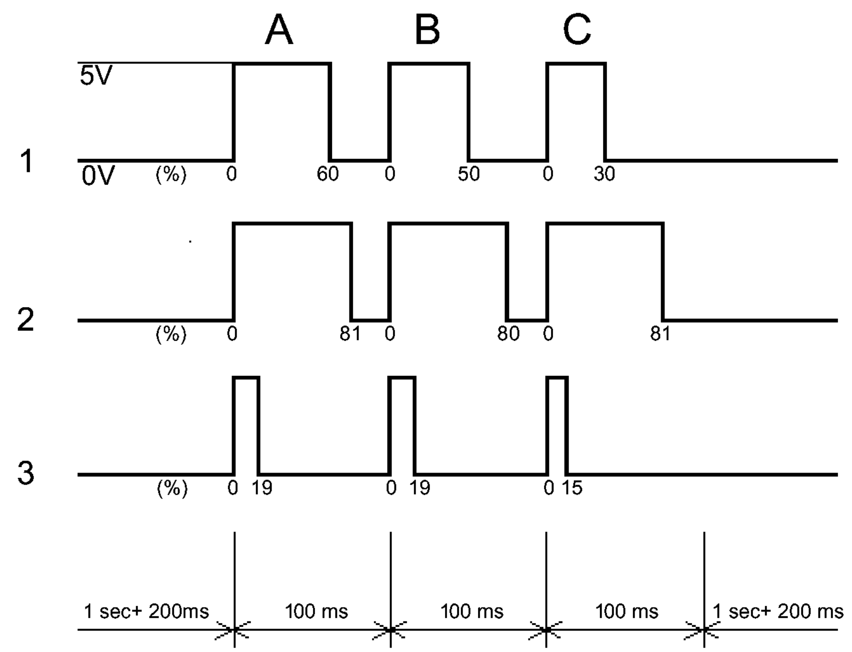
Figure 86 Engine Oil Sensor

The engine oil sensor constantly supplies data to the ECM in the form of information blocks (Figure 87). Each information block consists of three successive square wave signals of 100 ms each, followed by a synchronization pause of 1 second + 200 ms. A measured variable is assigned to each square-wave signal (A, B, C). The values are determined by the ON/OFF ratio, which ranges from 19 to 81%.

Refer to the examples shown in Figure 87. The first information block (1) contains square wave signals which fall between the 20-80% window. The values for oil temperature (60%), oil level (50%) and oil quality (30%) are in order.

The second information block (2) contains square wave signals with ON/OFF ratios above 80%. The oil temperature signal (81%) indicates a temperature higher than 160°C (320°F), the oil level signal (80%) indicates an oil level higher than 80 mm (3.15 in.), and the oil quality (81%) indicates good oil quality.

The third information block (3) contains square wave signals with ON/OFF ratios below 20%. The oil temperature signal (19%) indicates a temperature lower than -40°C, the oil level signal (19%) indicates an oil level lower than 0 mm, and the oil quality (15%) indicates poor oil quality.



A	Oil Temperature Signal	1	On/Off Ratio Between 20-80%
B	Oil Level Signal	2	On/Off Ratio > 80%
C	Oil Quality Signal	3	On/Off Ratio < 20%
T	Time Period		

Figure 87 Engine Oil Sensor Information Block

If the engine is cold, the oil temperature actual value is equal to the ambient temperature actual value. The actual value rises after the engine has been started.

Failure Modes

The ECM monitors the operation of the oil sensor and stores fault codes under any of the following conditions:

- Synchronization pause error
- Wire open or shorted to ground
- Supply voltage too high or too low
- Timing error
- Oil level plausibility
- Oil quality plausibility
- Water contamination

Substitute Values

The engine coolant temperature is used as a substitute value under the following circumstances:

- Signal wire is shorted to ground
- 5-volt supply wire is shorted to ground
- Open circuit in any wire

An oil quality value of 2 is displayed under the following circumstances:

- Signal wire is shorted to ground
- 5-volt supply wire is shorted to ground
- Open circuit in any wire

An oil level value of 40 mm (1.57 in.) is displayed under the following circumstances:

- Signal wire is shorted to ground
- 5-volt supply wire is shorted to ground
- Open circuit in any wire

MASS AIR FLOW SENSOR (MAF)

The Mass Air Flow (MAF) Sensor is located in the air intake duct between the air filter and the turbocharger (Figure 88). The MAF sensor uses semiconductor technology throughout, and is used to calculate the air mass flowing past it per time unit.
The ECM uses the mass air flow (MAF) sensor value for EGR control, particularly at high engine load. The MAF sensor also supplies an air temperature input to the ECM.

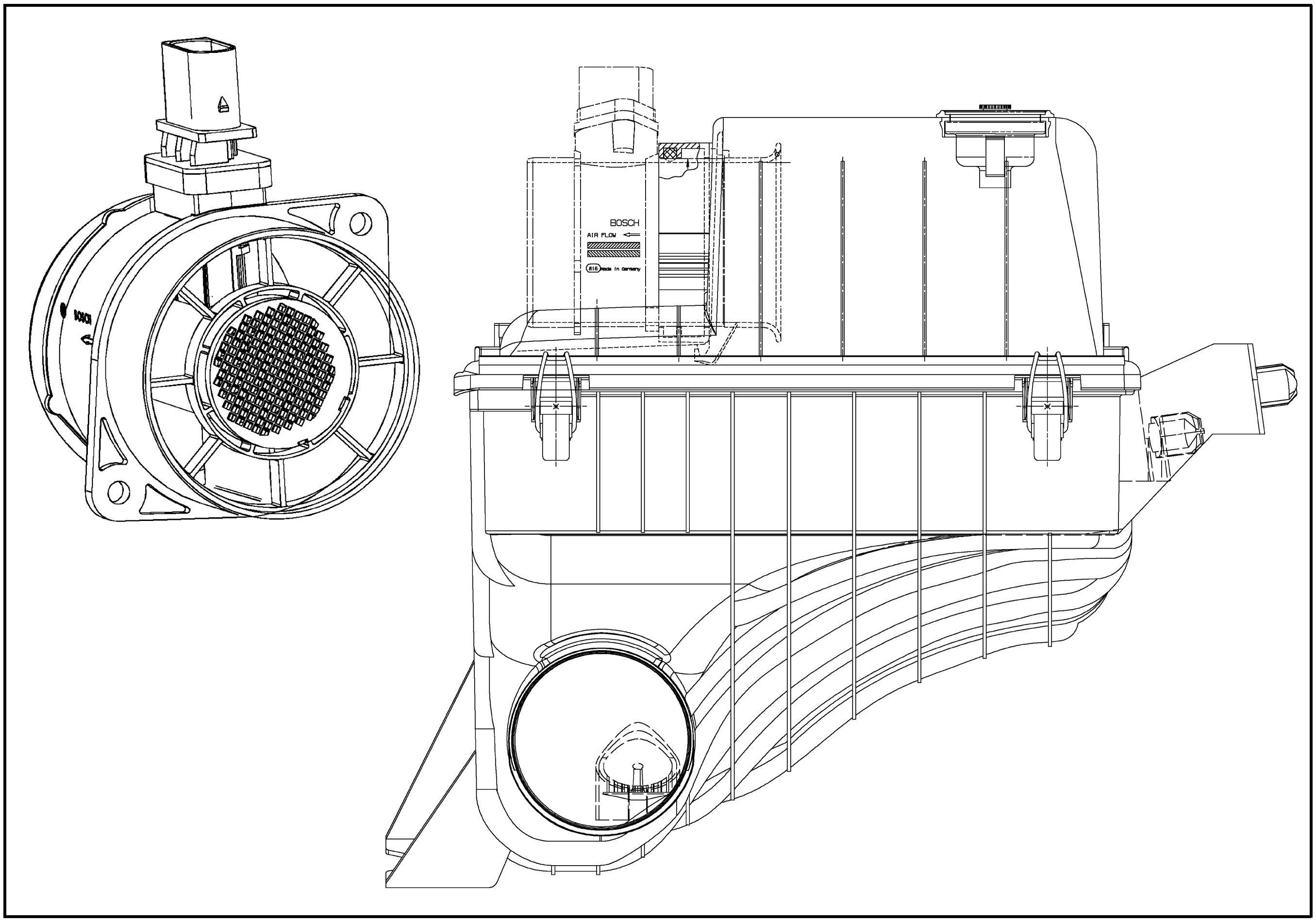
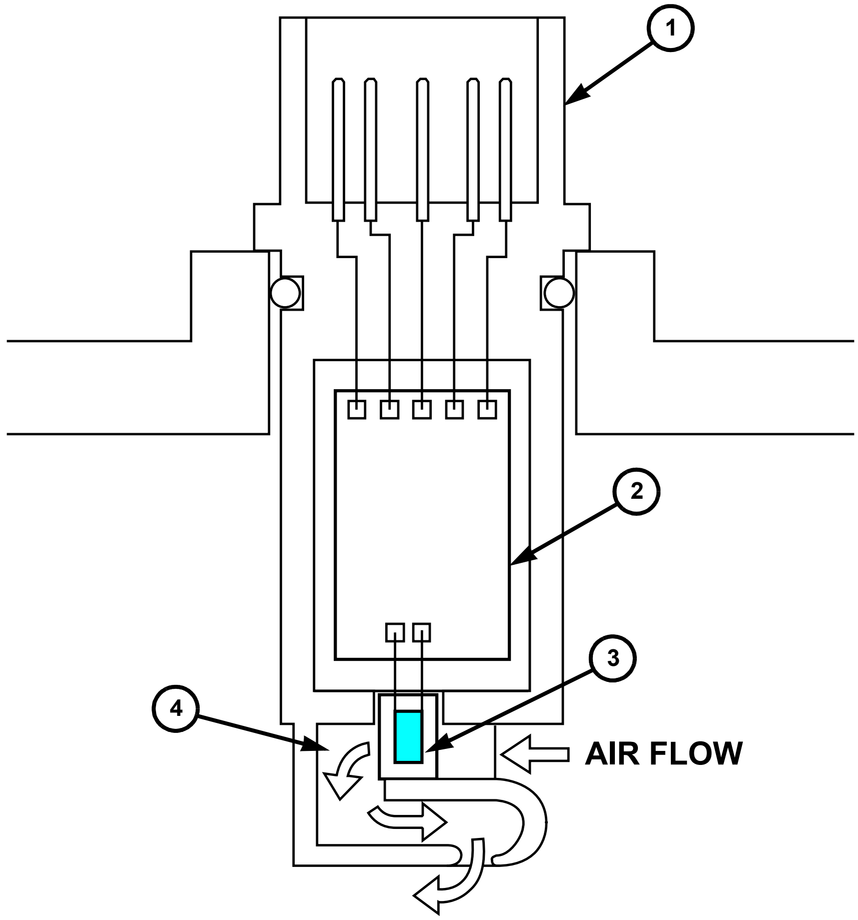


Figure 88 MAF Location

CONSTRUCTION

The MAF sensor contains an internal measuring tube with deflector screen. The shape of the measuring tube removes whirl effects from the incoming air. The deflector screen protects the sensor element against dirt and contamination. The screen separates water from the intake air and prevents clogging by dust particles.

The sensor uses a micromachined sensing element, which is etched from a silicon chip which is only a few thousandths of a millimeter thick. An integrated temperature sensor measures the incoming air temperature. A hybrid electronic circuit within the MAF sensor evaluates and conditions the sensor signals.

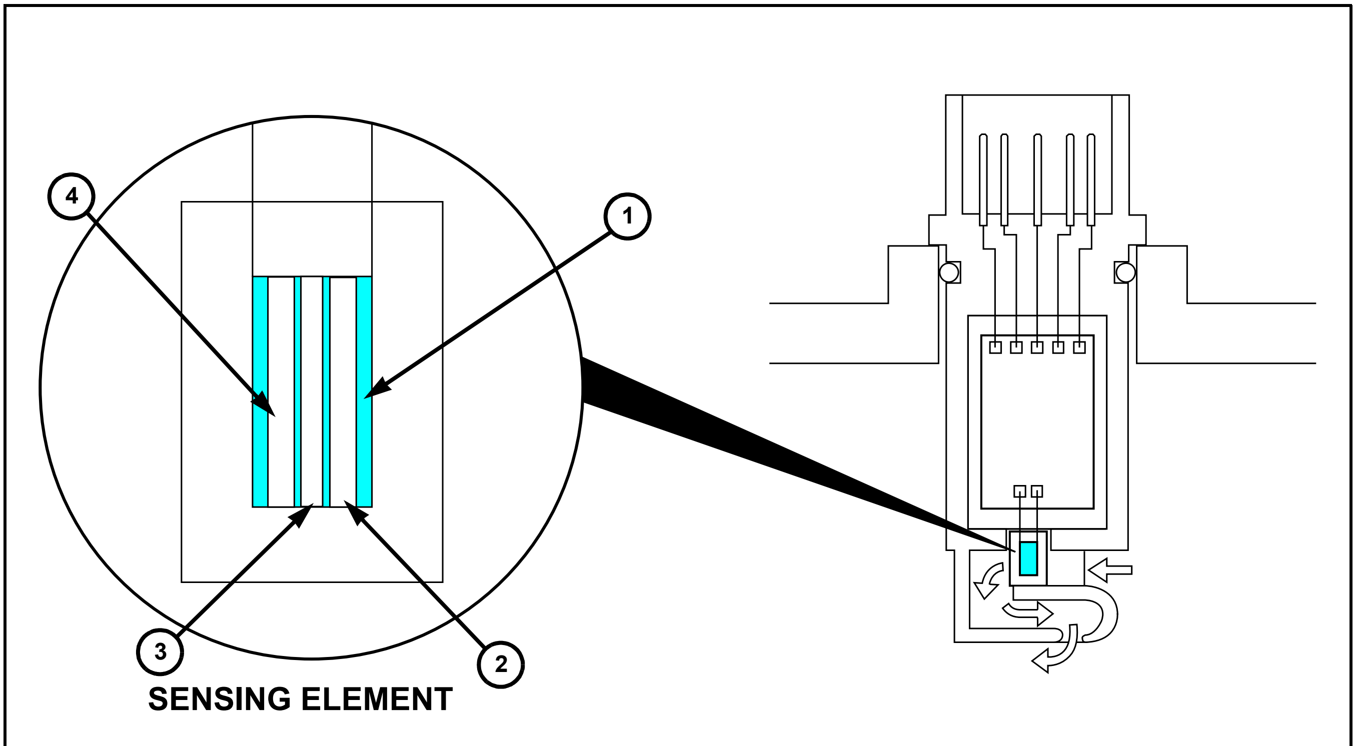


1	Electrical Connector	3	Sensing Element
2	Hybrid Circuit	4	Measuring Tube

Figure 89 Mass Air Flow Sensor

OPERATION

A micromechanical sensor diaphragm on the sensor element is heated by a central heating resistor and held at a constant temperature of 160°C (320°F) above the intake air temperature. The temperature on the diaphragm is measured by two resistors. Without air flow, the temperature is the same on both resistors. When air flows over the sensor element, a temperature differential is created between both resistors. The temperature differential is a measure of the air mass flow.



1	Sensor Diaphragm	3	Central Heating Resistor
2	Upstream Measuring Resistor	4	Downstream Measuring Resistor

Figure 90 MAF Sensing Element

The ECM provides a 12-volt signal and ground to the electronic evaluation circuit within the MAF sensor. The difference between both resistor values is converted by the electronic evaluation circuit within the MAF sensor into an air mass value. The measured air mass value is sent to the ECM as a digital signal with a 50% duty cycle and a variable frequency, which depends on air mass flow. The signal from the integrated intake air temperature sensor is also evaluated and converted into a PWM signal.

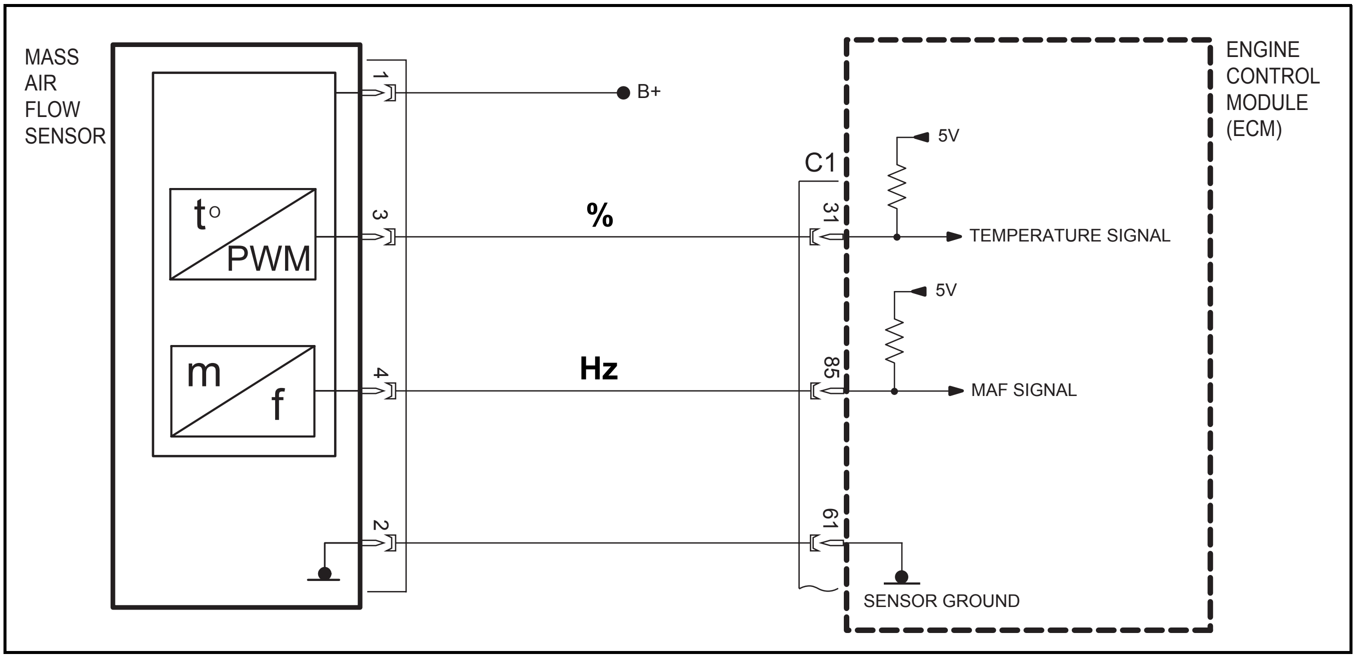


Figure 91 MAF Sensor Schematic

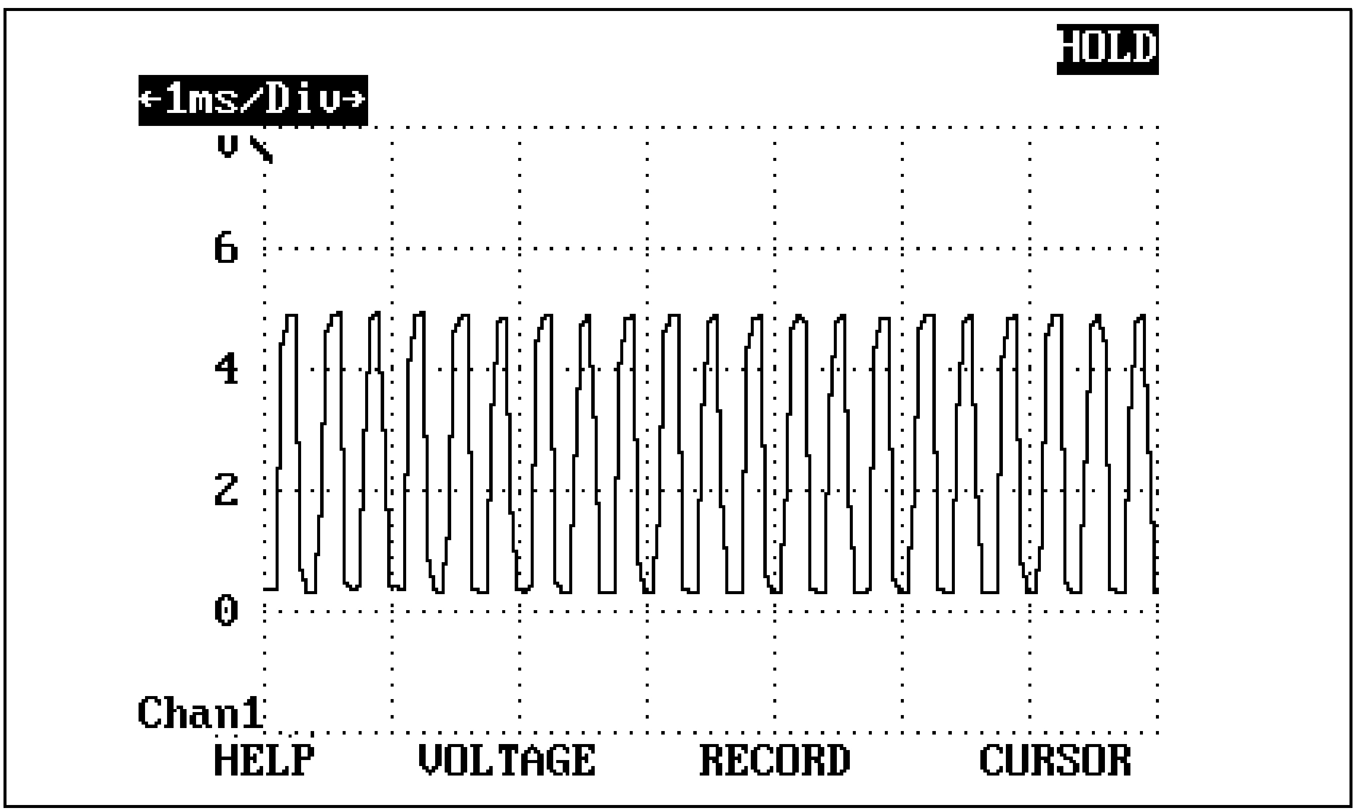


Figure 92 MAF Sensor Signal

Failure Modes

The ECM monitors the operation of the MAF sensor and stores fault codes under any of the following conditions:

- Signal voltage too low
- Signal voltage too high
- Supply voltage too high or too low
- Plausibility

SWITCH INPUTS

KICK-DOWN SWITCH

The kickdown switch is located on the accelerator pedal assembly and consists of a spring loaded electric switching contact. The switch influences the shift program of the electronic transmission control.

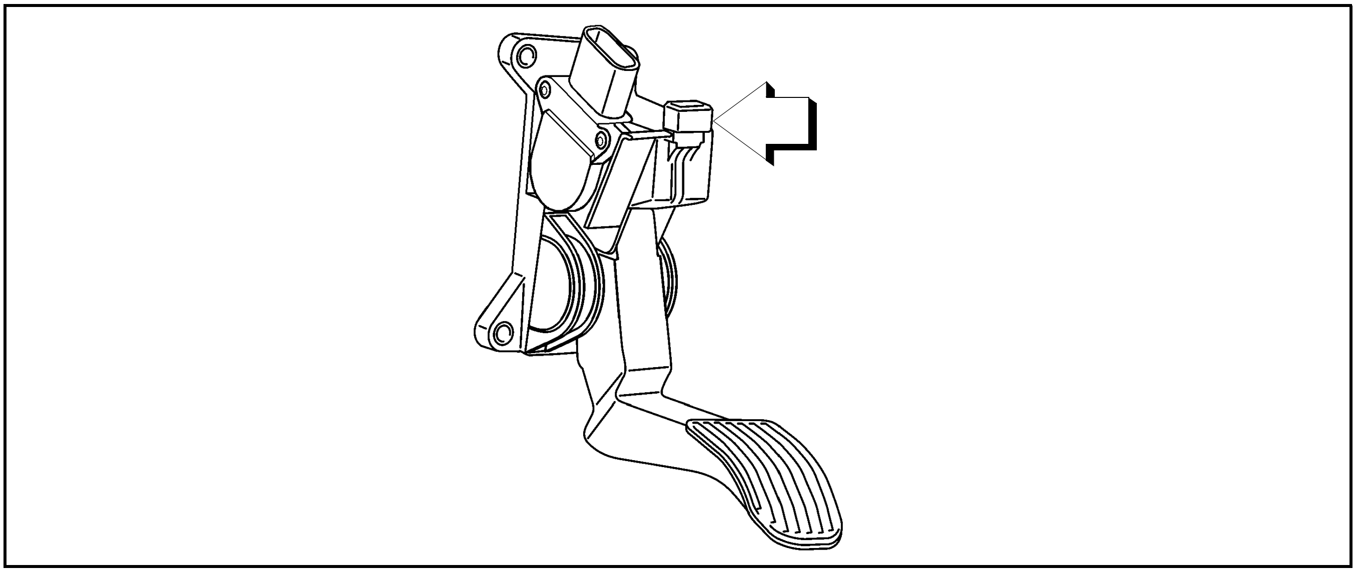


Figure 93 Kick-Down Switch

When the kickdown switch is actuated via the accelerator pedal, a CAN bus signal is sent from the ECM to the transmission control module (TCM). The TCM processes the information and controls the downshifting of the automatic transmission.

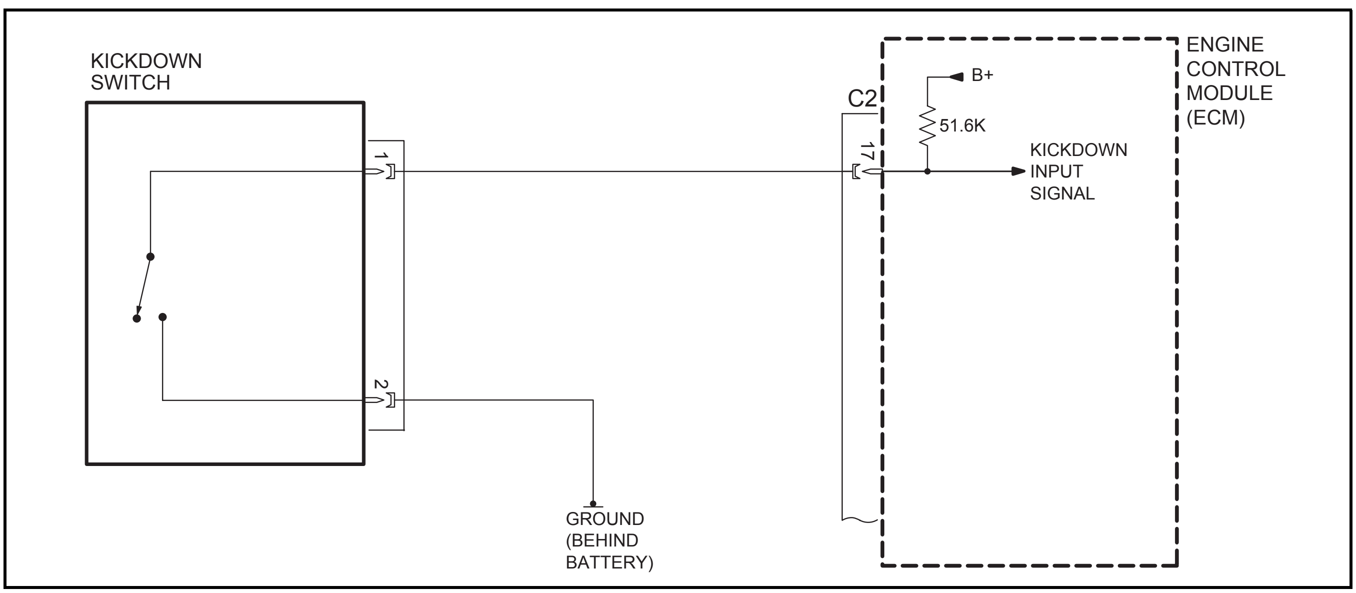


Figure 94 Kick-Down Switch Schematic

CONSTANT RPM SWITCH

The optional constant rpm switch is located on the center stack. The constant rpm feature increases the engine idle speed to a set speed level of 2000 rpm and maintains this level regardless of engine load.

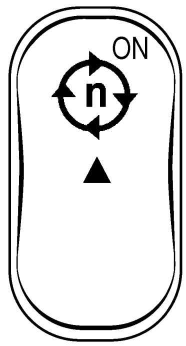


Figure 95 Constant RPM Switch

Upon pressing the switch, the constant rpm feature will be activated if the following conditions are met:

- Vehicle stationary
- Parking brake engaged
- Shift lever in park position

The ADR indicator lamp in the instrument cluster will light up when the constant rpm switch is pressed. The ADR acronym comes from the German term “Arbeitsdrehzahlre-gler”, which stands for variable engine speed governor.

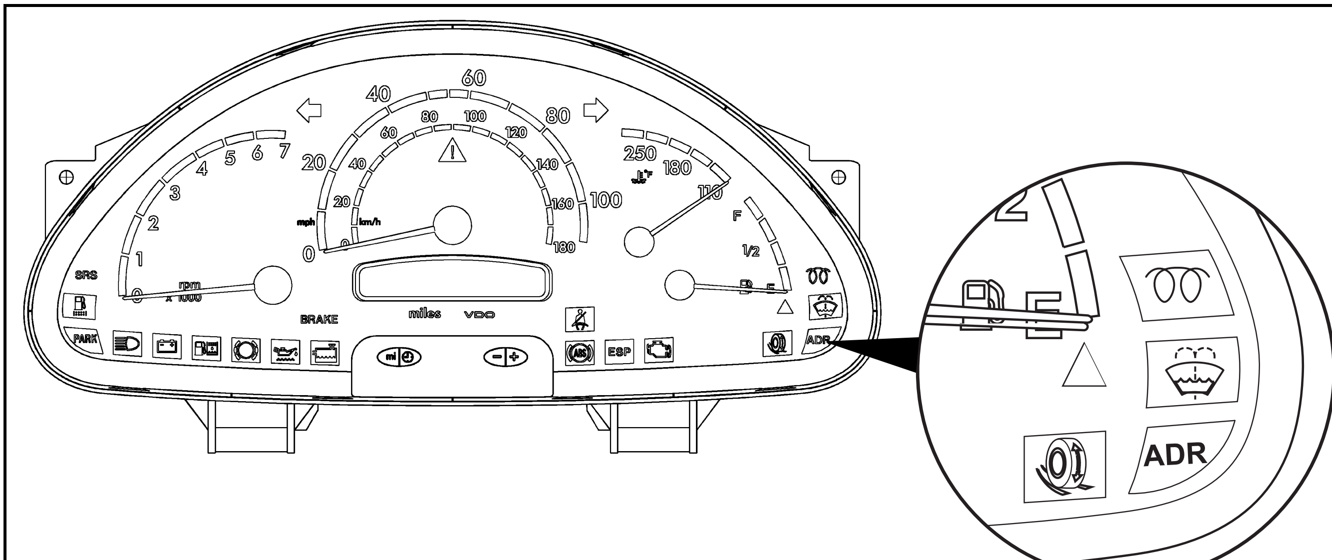


Figure 96 ADR Indicator Lamp

The constant rpm speed will switch off automatically when the parking brake is released, the vehicle is in motion or the ECM detects a malfunction. The constant rpm speed will also switch off automatically if the brake pedal is depressed. In this case, the constant rpm speed will resume its normal operation once the brake pedal is released.

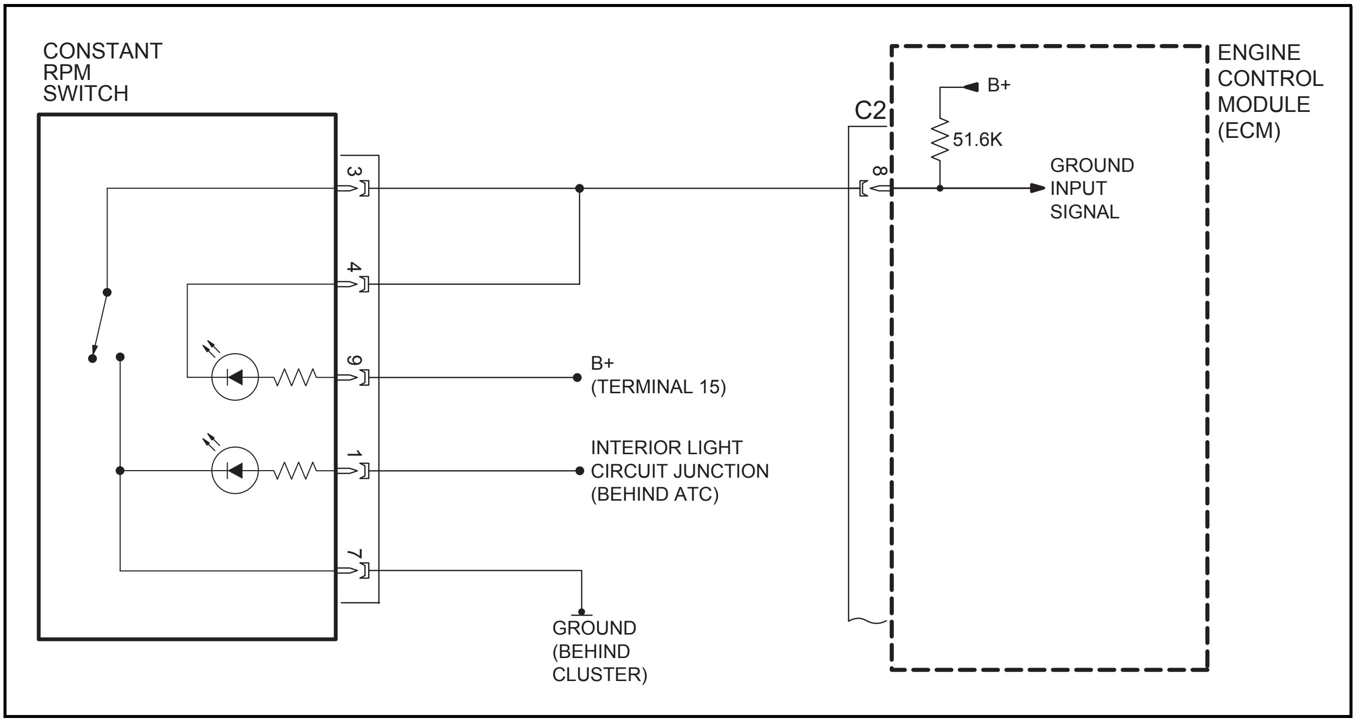


Figure 97 Constant RPM Schematic

When the constant rpm switch is pressed to the ON position, the electrical contact closes, pulling the input signal circuit to ground. If the conditions for activating the constant rpm feature are met, the ECM gradually increases the engine speed until it reaches 2000 rpm. A message is also sent to the instrument cluster via the CAN bus to activate the ADR lamp. Pressing the switch to the OFF position causes the ground to be lost and the engine speed to revert back to a base idle. The ECM also sends a message to the instrument cluster to turn off the ADR lamp.

SPEED CONTROL SWITCH

The speed control switch is located behind the steering wheel. At vehicle speeds above 25 MPH, the switch activates the speed control function integrated in the ECM. The ECM is supplied with the following inputs for speed control operation:

- Vehicle speed signal from the ESP module
- Park/Neutral signal from the TCM
- Stop lamp switch

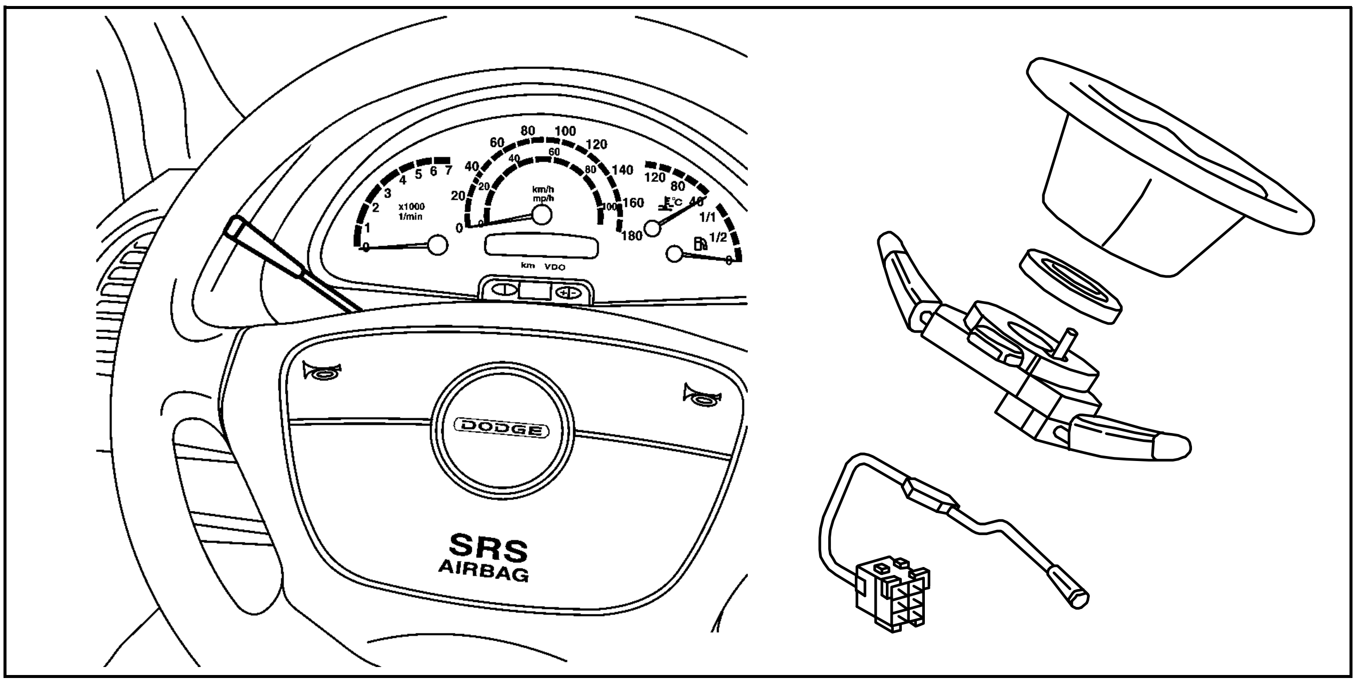
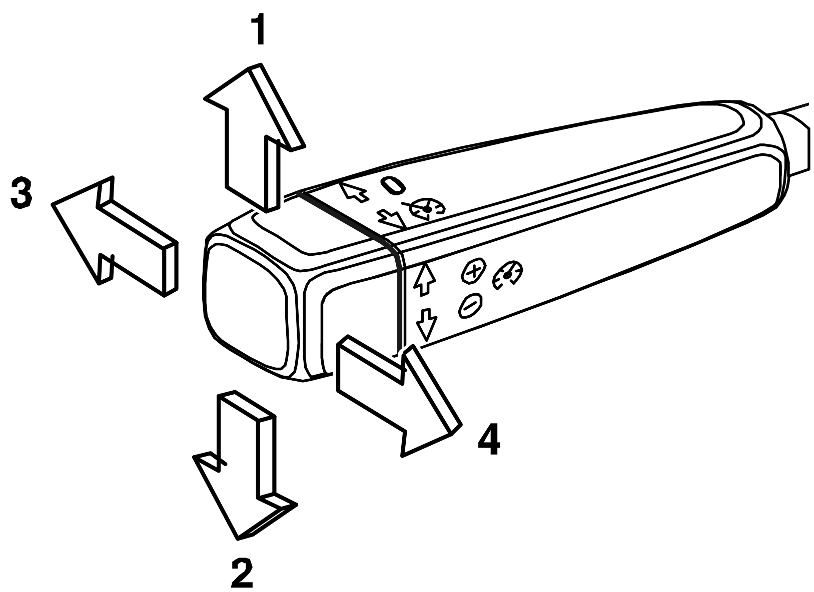


Figure 98 Speed Control Switch Location

The speed control lever can be moved in four different directions (up/down and forward/back) to select the desired setting. The lever knob is labeled to identify the speed control functions (Figure 99).



1	Set/Accelerate Speed	3	Off
2	Set/Decelerate Speed	4	Resume Set Speed

Figure 99 Speed Control Switch

Operation

The speed control lever is comprised of five sets of contacts. Two switch contacts operate simultaneously when the cruise control lever is actuated. One contact provides the actual input while a safety contact provides a verification input to the ECM. The safety contact must close at the same time for the selected input to be accepted by the ECM and recognized as an intentional action on the part of the driver (Figure 100).

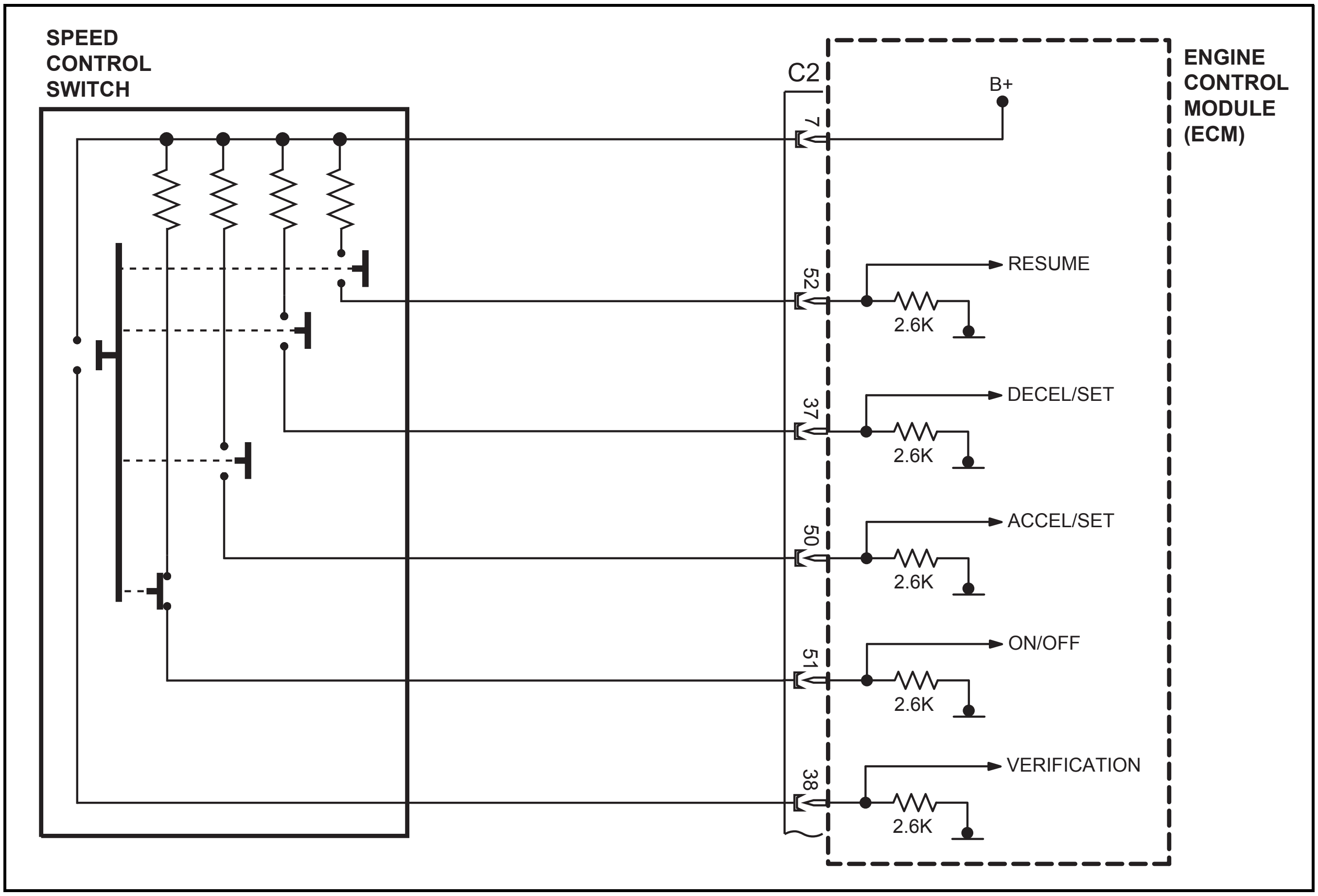


Figure 100 Speed Control Switch Schematic

Failure Modes

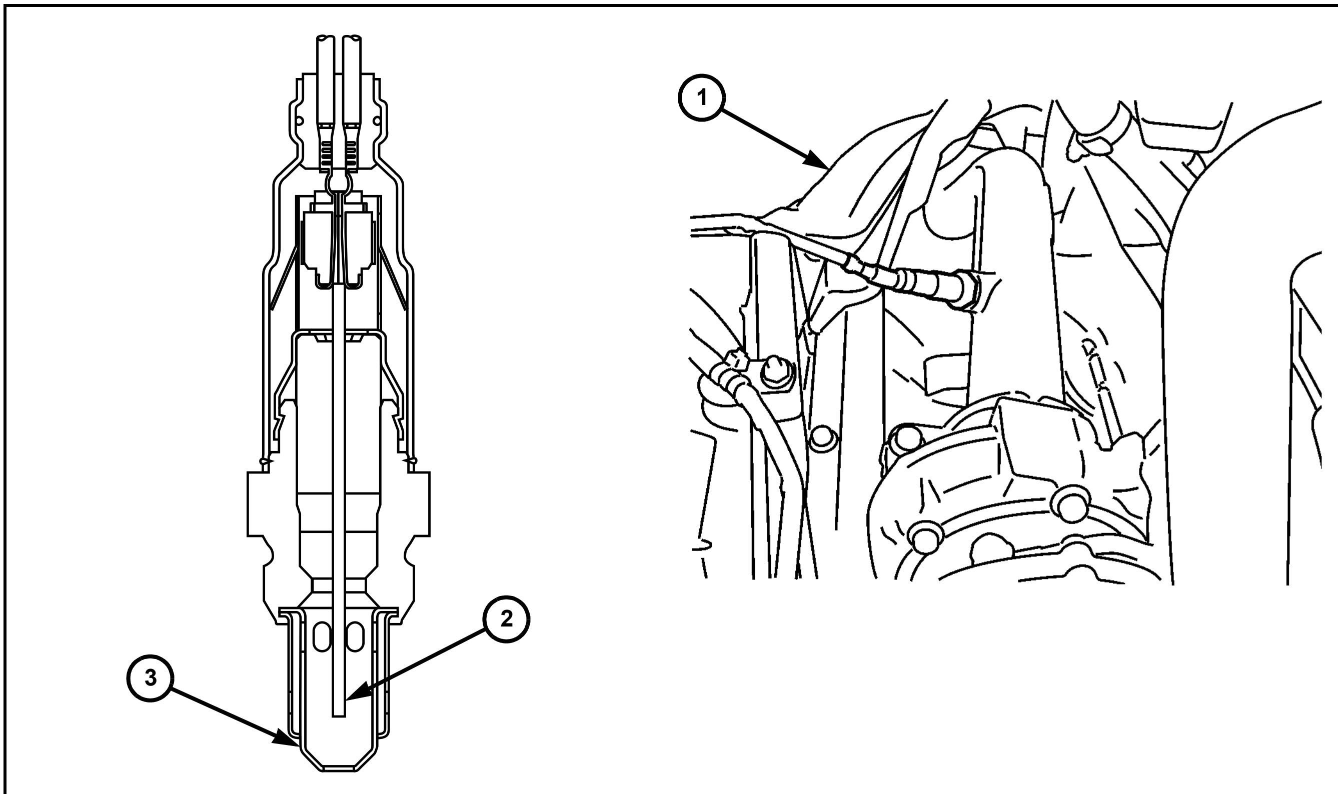
The ECM monitors the operation of the speed control switch and stores fault codes under any of the following conditions:

- Negative acceleration deviation
- Positive acceleration deviation
- Control contact alone
- No verification contact
- Speed control signals through CAN are implausible
- Operating unit has contact short (two contacts synchronous)

OTHER INPUTS

OXYGEN (O2) SENSOR

A heated wide-band oxygen sensor measures the oxygen content in the exhaust gas to control EGR. The sensor is mounted in the exhaust pipe at a 30 degree angle to prevent the collection of liquids between the sensor housing and sensor element during the cold start phase. The sensor is located close to the turbocharger for a quicker response.



1	O2 Sensor Location	3	Protective Tube
2	Planar Sensor Element (Pump Cell & Sensor Cell)		

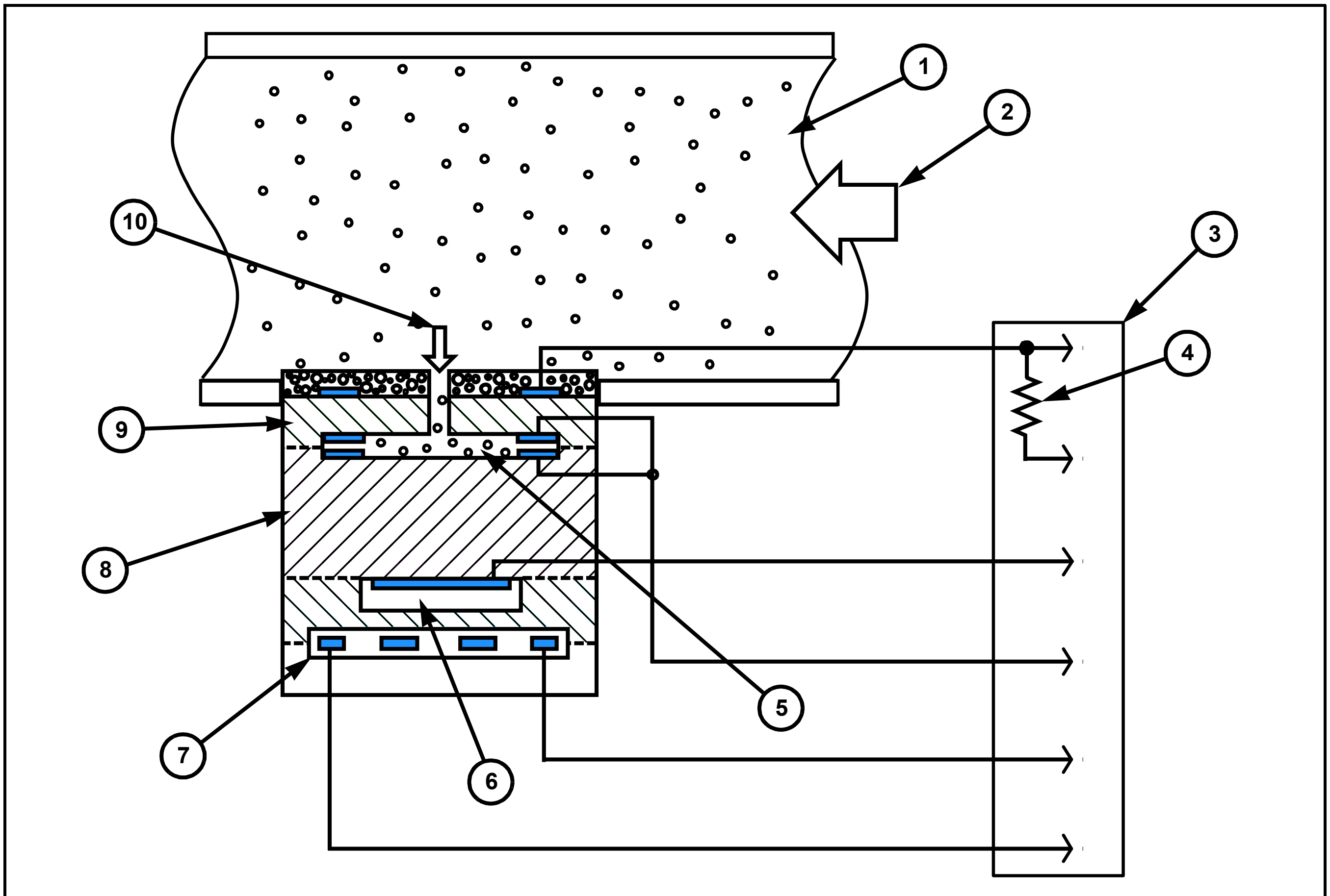
Figure 101 Oxygen (O2) Sensor

The O2 sensor is a planar zirconium-dioxide (ZrO_2) dual cell limiting current probe with an integrated heater. The term wide-band refers to the ability of the sensor to generate a clear signal within a wide air-fuel ratio measuring range (from 0.7 to ∞). As a dual cell sensor, it incorporates a second chamber (oxygen pump cell), which requires a separate voltage supply. The O2 sensor has 5 wires (Heater power and ground, reference voltage, and 2 wires for pump cell current) and connects to a six-wire harness leading to the ECM.

Construction

Refer to Figure 102. The sensor element combines a sensor cell (8) and an oxygen pump cell (9). Both cells are made of zirconium-dioxide (ZrO_2) and are coated with porous platinum electrodes. The sensor cell operates just like a typical O_2 sensor. The oxygen pump cell transports oxygen ions when voltage is applied to it.

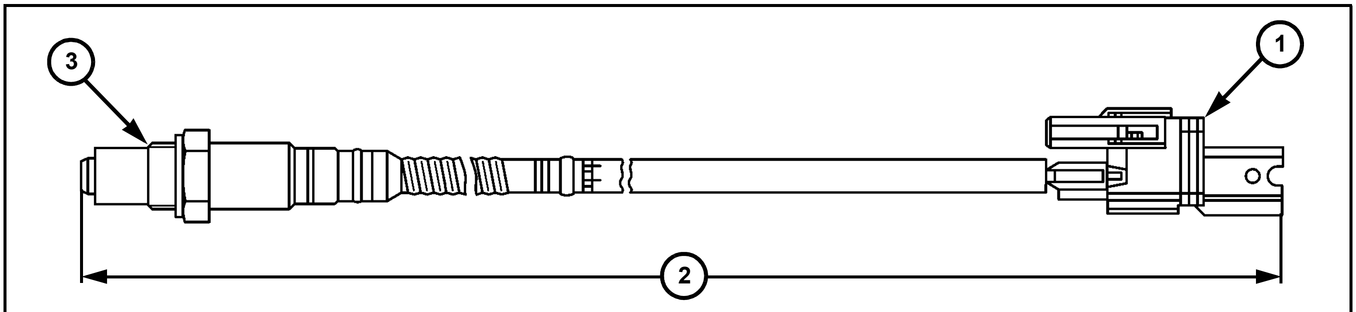
A gas sample chamber (5) is sandwiched between the oxygen pump cell and the sensor cell. A pump cell electrode and a sensor cell electrode are located in the sample chamber. A sample passage (10) connects the sample chamber to the surrounding exhaust gas. A sensor cell electrode is located in the reference air channel (6), which connects to the outside air.



1	Exhaust Pipe	6	Reference Air Channel
2	Exhaust Gas Flow	7	Heater Element
3	O2 Sensor Connector	8	Sensor Cell
4	Trimming Resistor	9	Oxygen Pump Cell
5	Gas Sample Chamber	10	Sample Passage

Figure 102 Oxygen Sensor Construction

A trimming resistor is built into the O2 sensor connector. The resistance value is dependent on the overall length and the type of sensor.



1	Connector With Trimming Resistor	3	O2 Sensor
2	Overall Sensor Length		

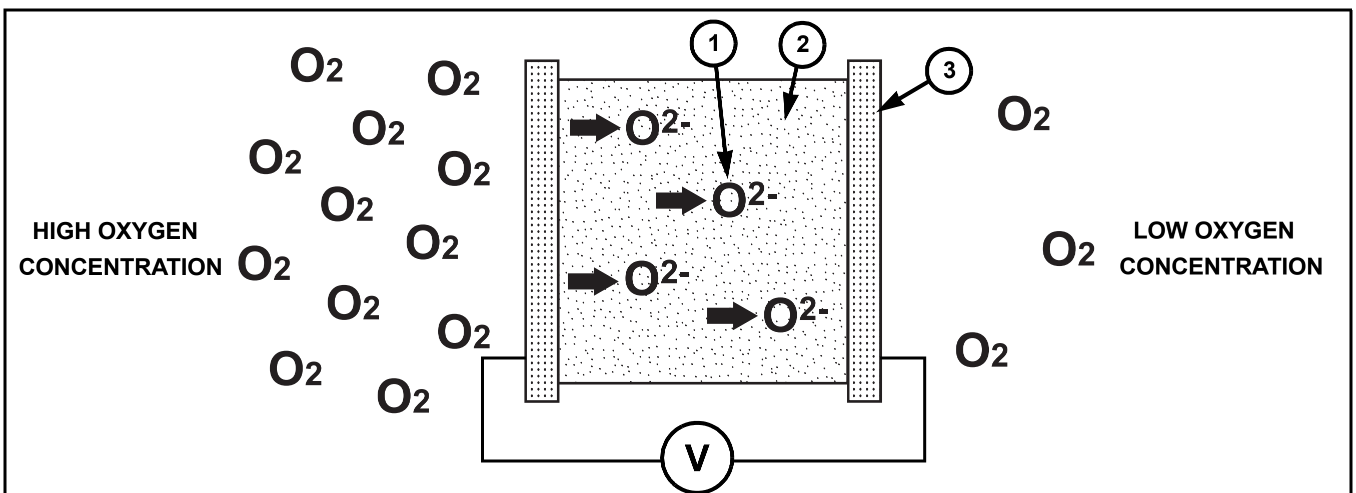
Figure 103 O2 Sensor and Cable

When replacing the O2 sensor, the trimming resistor is already installed in the new sensor and must not be changed (resistor is dependent on sensor).

O2 Sensor Fundamentals

At high temperatures, certain ceramic materials, such as zirconium-dioxide (ZrO2) become oxygen ion conductors.

In a typical O2 sensor, the ZrO2 is used as a solid electrolyte, which conducts oxygen ions. The solid electrolyte is sandwiched between two platinum electrodes. The sensor generates a small voltage when oxygen ions moves from the high concentration side to the low concentration side.

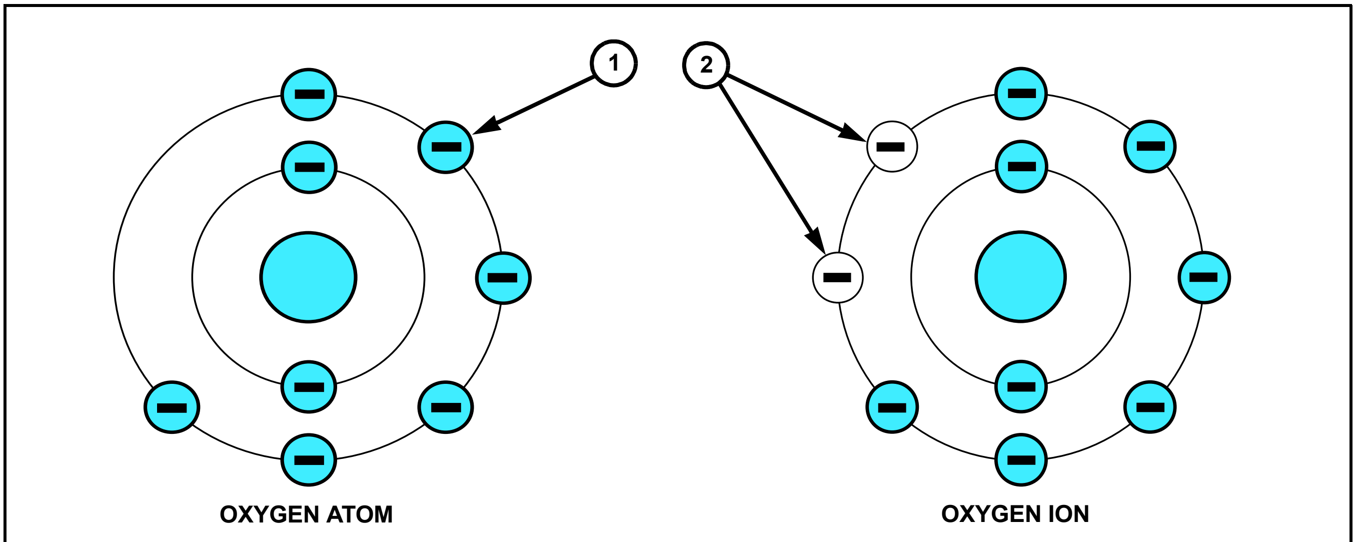


1	Oxygen Ion	3	Platinum Electrode (2)
2	Solid Electrolyte (ZrO2)		

Figure 104 Typical O2 Sensor Construction

The same holds true if the process is reversed. If a voltage is applied to the platinum electrodes, oxygen can be pumped from one side of the solid electrolyte to the other (from cathode to anode), becoming an oxygen pump. The amount of current flow is directly proportional to the amount of oxygen pumped by the sensor. When the oxygen level on the supply side reaches zero, the current stops.

Oxygen atoms have six valence electrons in its outer shell and would like to gain two more (octet rule). Once they pick two free electrons they become oxygen ions, which have a negative charge.



1	Valence Electrons	2	Gained Electrons

Figure 105 Oxygen Atom and Oxygen Ion

Oxygen atoms pick up two electrons from the negative electrode (cathode) to become oxygen ions. These ions are then transported through the solid electrolyte (ZrO_2) to the positive electrode (anode). The ions transfer the negative charge (two electrons) to the anode and combine with other oxygen atoms to form O_2.

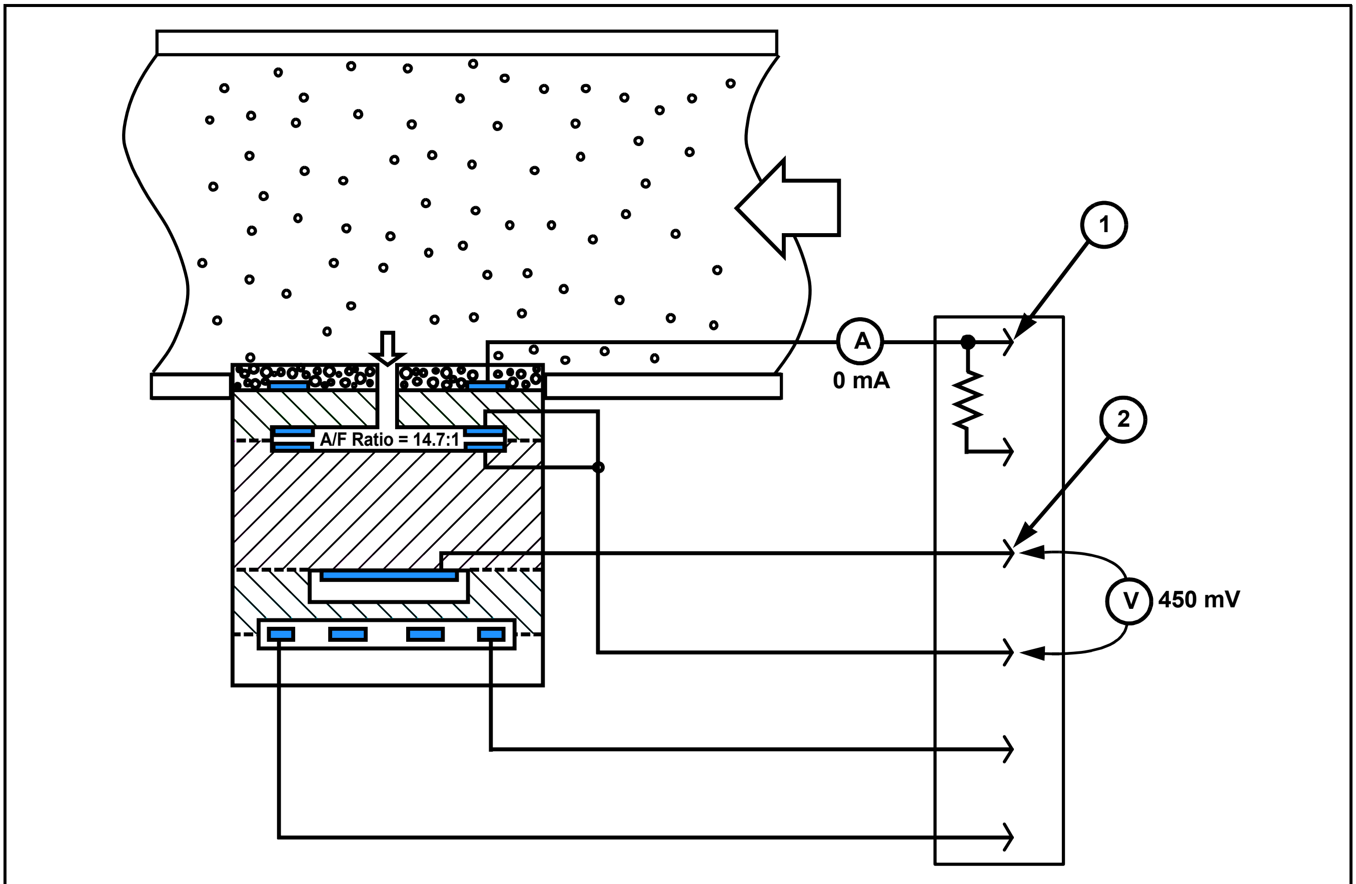
Stoichiometry

Stoichiometry is the ideal air-fuel ratio for perfect combustion. In theory, this ratio is 14.7:1 (14.7 pounds of dry air for 1 pound of fuel). A value of 1 is used as a reference point to denote stoichiometry. When stoichiometry equals 1, the ideal air-fuel ratio is achieved. A value higher than 1 means that more air is present than is needed for perfect combustion (lean mixture). A value lower than 1 indicates the amount of air is insufficient to produce a perfect combustion (rich mixture).

Gasoline engines run on air-fuel mixtures that are very close to stoichiometric (stoichiometry = 1). Diesel engines however, always run with excess air (stoichiometry > 1). If the excess air is low (stoichiometry < 1), the diesel engine will produce higher amounts of CO, HC and soot.

Wide-Band O2 Sensor Operation

The ECM activates the integral heater element to raise the temperature of the sensor to 700°C (1292° F) for the ZrO2 to become conductive. Once the sensor is heated, the exhaust-gas components diffuse through the gas sample chamber. Upon reaching the electrodes on the oxygen pump and concentration cells they achieve a state of thermodynamic balance.

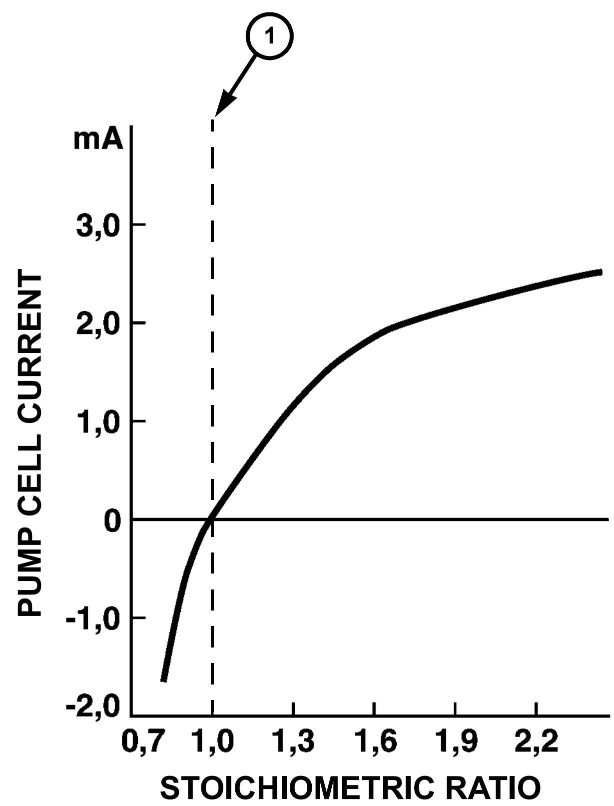


1	Oxygen Pump Cell Circuit	2	Sensor Cell Circuit

Figure 106 Wide-Band O2 Sensor Construction

The sensor cell measures the difference between the oxygen concentration in the gas sample chamber and the oxygen concentration in the outside air from the reference air channel. A small voltage is generated across the sensor, which is proportional to the air-fuel ratio in the sample chamber. At stoichiometry, the corresponding open-circuit voltage at the sensor cell is 450 mV. If the stoichiometric ratio in the sample chamber is higher than 1 (excess air) a lower voltage is produced. If the stoichiometric ratio is lower than 1 (insufficient air) a higher voltage is produced.

The ECM uses this voltage signal to determine how and when to run the oxygen pump cell. The goal of the ECM is to modulate the pumping current through the pump cell to always maintain a stoichiometric air-fuel ratio of 1 (14.7 to 1) in the gas sample chamber. When stoichiometry is reached, there is no current flowing to the oxygen pump cell.

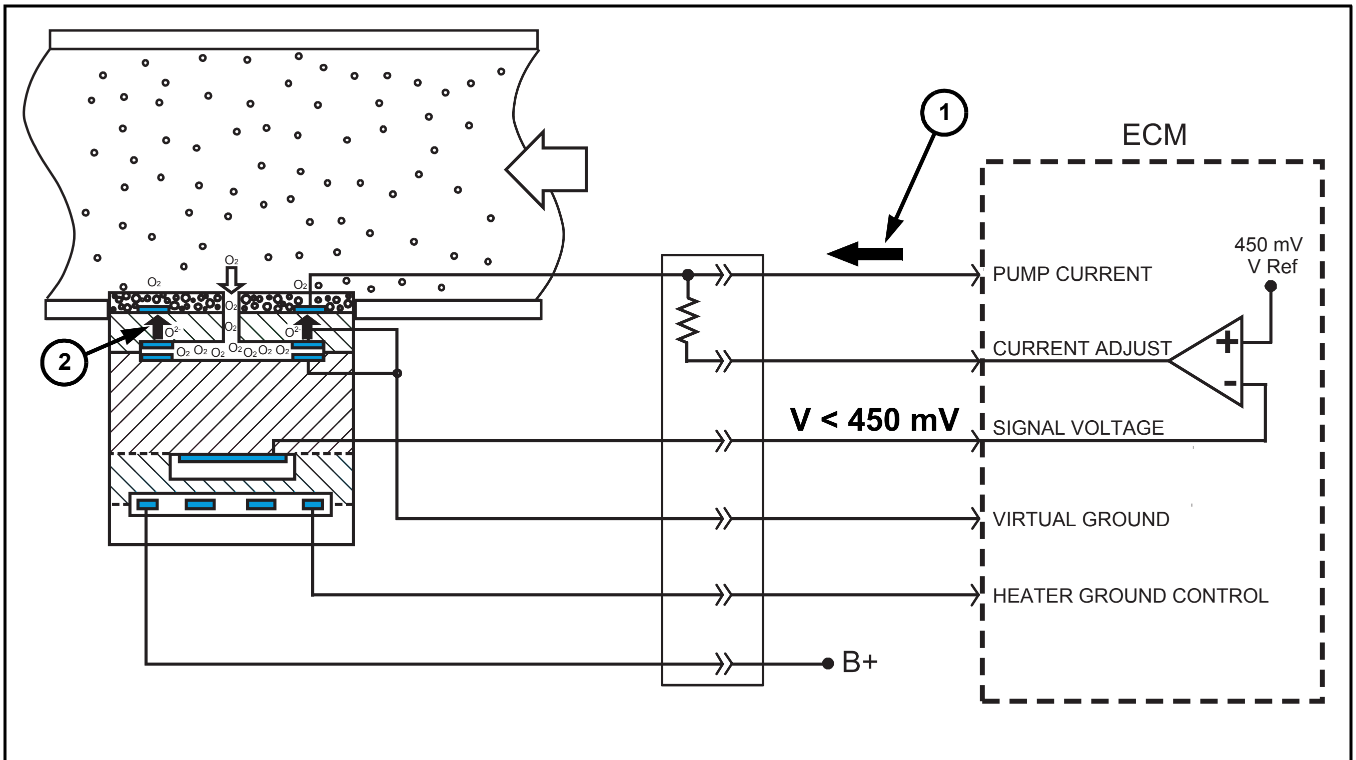


1	Stoichiometric Point (14.7:1)

Figure 107 Oxygen Pump Cell Current Curve

High Excess-Air Mode

When the exhaust gas is too lean, the oxygen concentration in the gas sample chamber is high. The sensor cell measures the difference between oxygen concentrations in the gas sample chamber and the reference air channel. A voltage lower than 450 mV is generated across the sensor cell, which is proportional to the air-fuel ratio in the sample chamber. The ECM compares the sensor cell voltage to a reference voltage (V Ref), which corresponds to the stoichiometric point voltage. Since sensor cell voltage is lower than V Ref, The ECM determines a lean condition exists. An amplifier applies an appropriate voltage to the pump cell to transfer oxygen from the gas sample chamber.



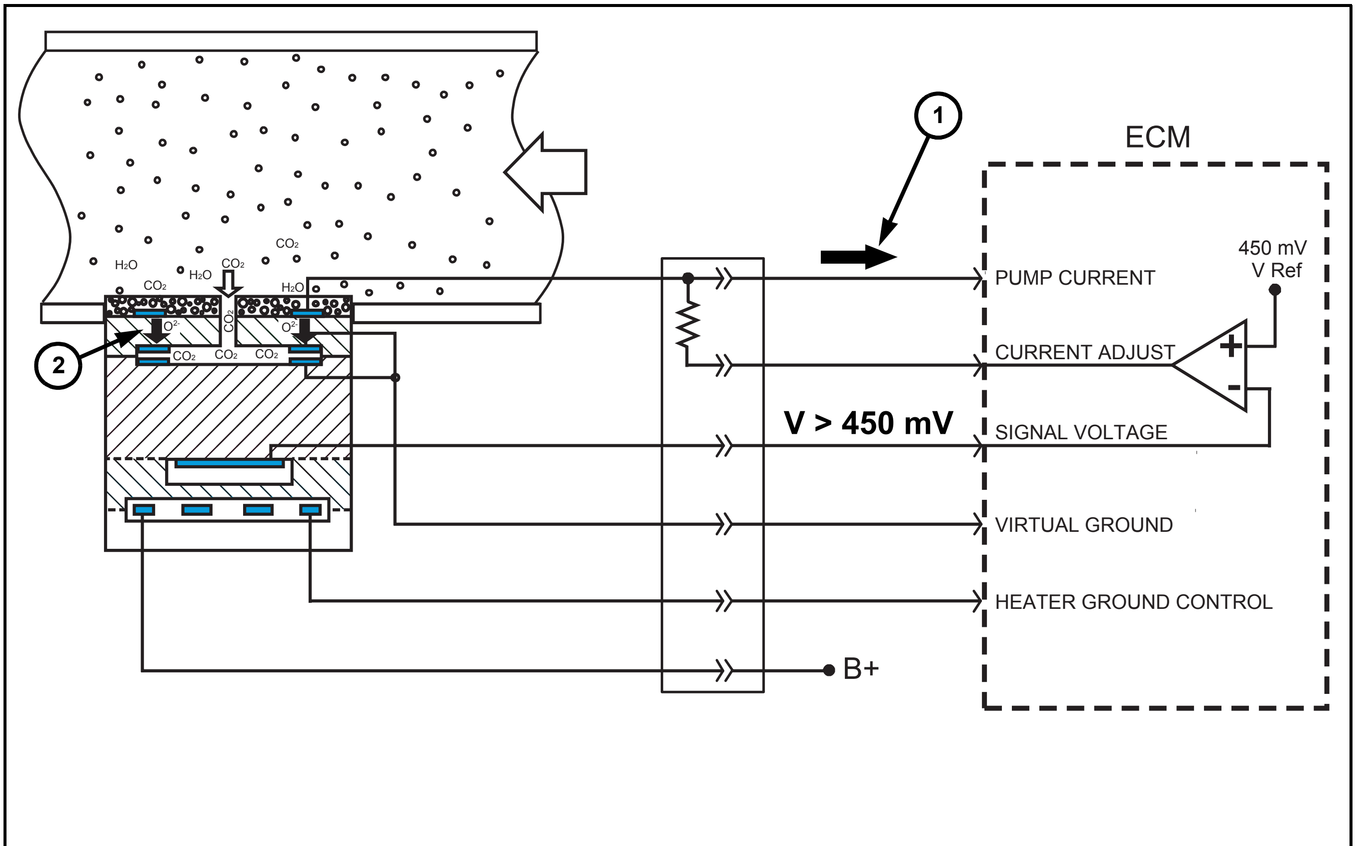
1	Flow of Pump Current	2	Flow of Oxygen Ions

Figure 108 O2 Sensor, High Excess Air

The oxygen atoms in the pump cell pick up two electrons from the negative electrode (cathode) to become oxygen ions. The ions are transported through the solid electrolyte (ZrO2) to the positive electrode (anode). Each ion transfers its negative charge (two electrons) to the anode and combines with other oxygen atoms to form O2. The amount of current flow is directly proportional to the amount of oxygen pumped by the pump cell. While the sensor cell voltage only provides a rough indication of the air-fuel ratio, the ECM can determine with precision the stoichiometric ratio based entirely on the amount of current flowing through the oxygen pump cell.

Low Excess-Air Mode

With low excess air, the oxygen concentration in the gas sample chamber is low. The sensor cell measures the difference between oxygen concentrations in the gas sample chamber and the reference air channel. A voltage higher than 450 mV is generated across the sensor cell, which is proportional to the air-fuel ratio in the sample chamber. The ECM compares the sensor cell voltage to V Ref. Since sensor cell voltage is lower than V Ref, The ECM determines a low excess-air condition exists. The polarity of the pump cell is reversed and so is the direction of the current flow.



1	Flow of Pump Current	2	Flow of Oxygen Ions

Figure 109 O2 Sensor, Low Excess-Air

Decomposition of water (H2O) and carbon-dioxide (CO2) molecules occurs in the exhaust pipe, next to the pump cell. Oxygen atoms separate from the molecules and pick up two electrons from the cathode to become oxygen ions. The ions are transported through the solid electrolyte to the anode in the gas sample chamber (the direction of flow has been reversed). The ECM determines the stoichiometric ratio based on the amount of current flowing through the oxygen pump cell.

ACTIVITY 3.4 OXYGEN SENSOR

The purpose of this activity is to gain an understanding of the operation of the O2 sensor.

1. With the engine running at operating temperature (O2 sensor in closed-loop condition), back probe the O2 sensor harness connector with a voltmeter to read the sensor signal wire voltage. Use the vehicle chassis or engine for a reference ground.
2. Identify the sensor signal wire and record on the table below.

Connector Pin Number	Sensor Harness Wire Color	Engine Harness Wire Color
6	*Black*	*Gray*

3. What is the voltage reading at the sensor signal wire?
   Approximately 2.98 V
4. Read the sensor signal voltage again, using the O2 sensor ground wire as reference.
5. Identify the sensor ground wire and record on the table below.

Connector Pin Number	Sensor Harness Wire Color	Engine Harness Wire Color
2	*Yellow*	*Gray/White*

6. What is the voltage reading at the sensor signal wire?
   Approximately 0.456 V
7. Compare both voltage readings. Are the readings different? YES __*X*__ NO _____
8. Explain why
   The O2 sensor ground is about 2.5 volts higher than chassis ground
9. Create a rich and lean engine condition, while reading the sensor signal voltage.
10. Is there any change in voltage? YES _____ NO __*X*__
11. Explain why
    This value is kept constant at 0.45 V by correcting the pump current
12. Back probe the pump current wire with the voltmeter. Use the O2 sensor ground wire as reference.
13. Identify the pump current wire and record on the table below.

Connector Pin Number	Sensor Harness Wire Color	Engine Harness Wire Color
1	*Violet*	*Green/Black*

14. What is the voltage reading at the pump current wire at idle speed?
 Approximately 0.660 V (when in closed loop - engine warm)
15. Create a rich engine condition, while reading the pump current voltage. Record the voltage reading below.
 The voltage should drop a couple tenths of a volt
16. Is there a change in voltage? YES __*X*___ NO ______
17. Explain why.
 Don't need to pump as much O2 out of the sample chamber. Current & volts drop
18. Create a lean engine condition, while reading the pump current voltage. Record the voltage reading below.
19. Is there a change in voltage? YES __*X*___ NO _____
20. Explain why
 Need to pump more O2 out of the sample chamber. Current & volts increase

WATER IN FUEL SENSOR (WIF)

The WIF sensor is located on top of the fuel filter. The WIF is a three-wire sensor within a plastic housing. The plastic housing combines the WIF sensor with the drain valve and drain pickup tube. The housing is inserted into the fuel filter access hole and secured with two screws. An O-Ring seals the sensor housing in the filter.

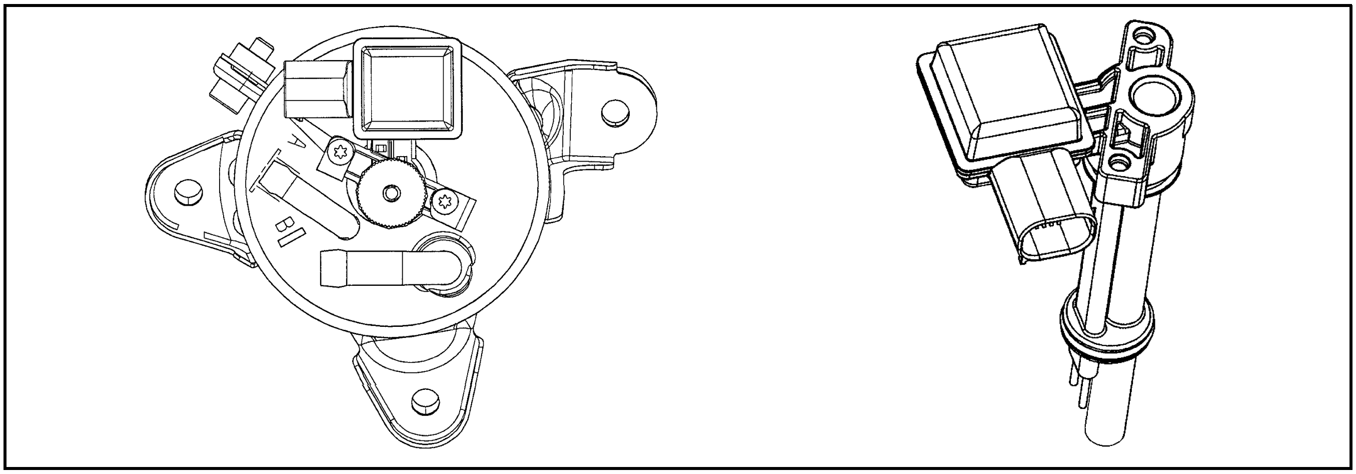


Figure 110 Water in Fuel Sensor

Operation

Diesel fuel does not provide any electrical contact between the sensor probes. Battery voltage is present in the WIF sensing circuit when the ignition is ON. When water is present in the system, the conducting properties of the water allow the sensor probes to close the electrical circuit. The digital integrated circuit senses the ground and pulls the WIF sensing circuit down to 0 volts after a time delay of approximately 9 seconds.

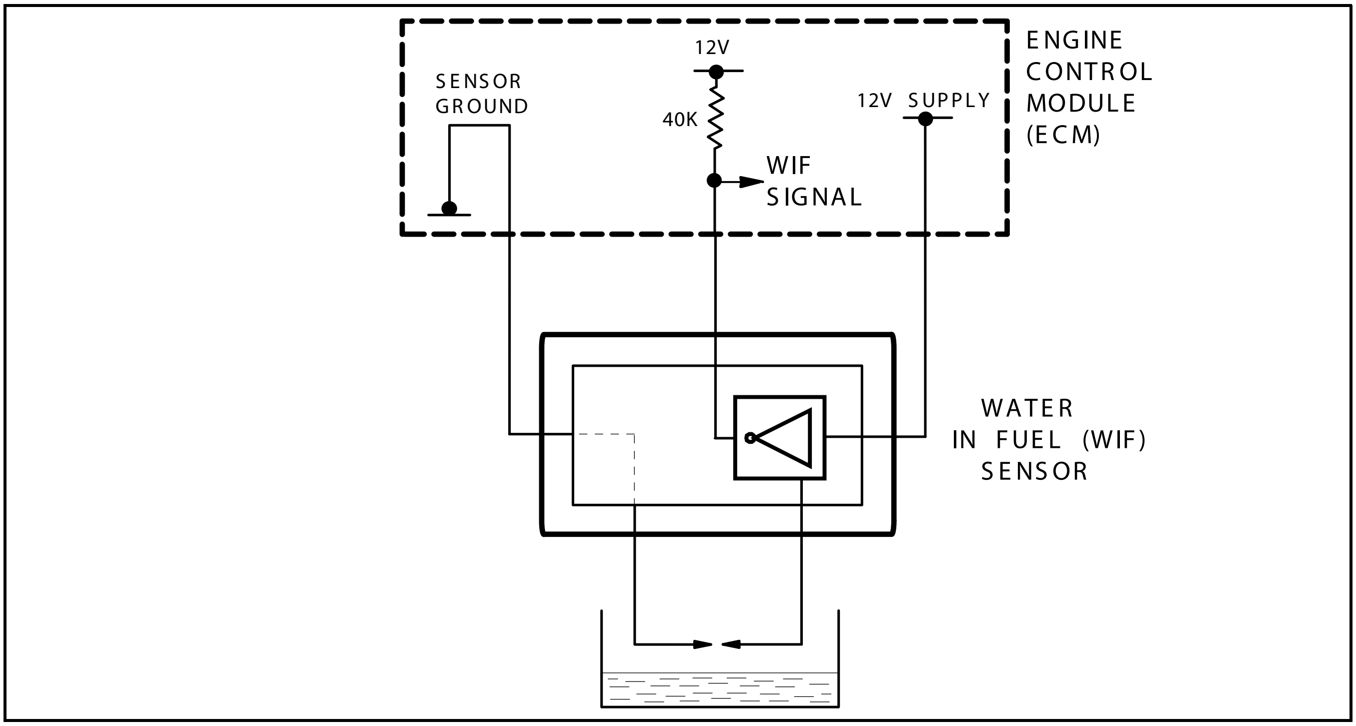


Figure 111 WIF Sensor Schematic

When the ECM senses 0 volts in the WIF signal circuit, it signals the instrument cluster via the CAN bus to illuminate the WATER IN FUEL indicator lamp.

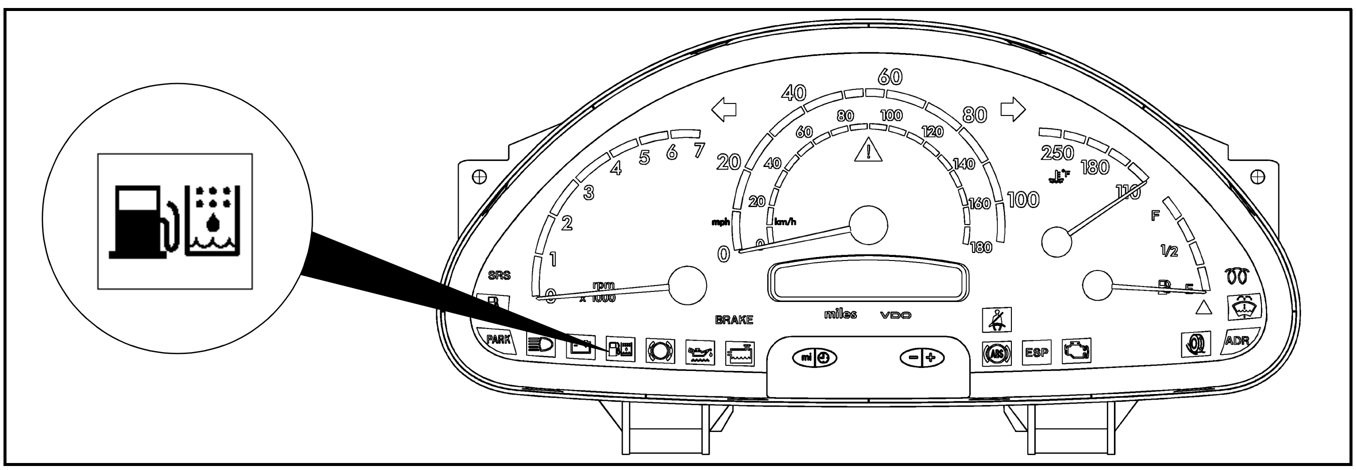


Figure 112 WIF Indicator Lamp

Failure Modes

The ECM monitors the WIF sensor signal and stores a single fault code, which could indicate any of the following conditions:

- Water in fuel filter, or sensor malfunction, or short to ground, or short to positive, or open circuit in any of the wires

GLOW PLUG MODULE

The glow plug module is located in the engine compartment under the battery tray. The module integrates diagnostics and an electronic system that processes the input signals from the ECM for glow plug activation.

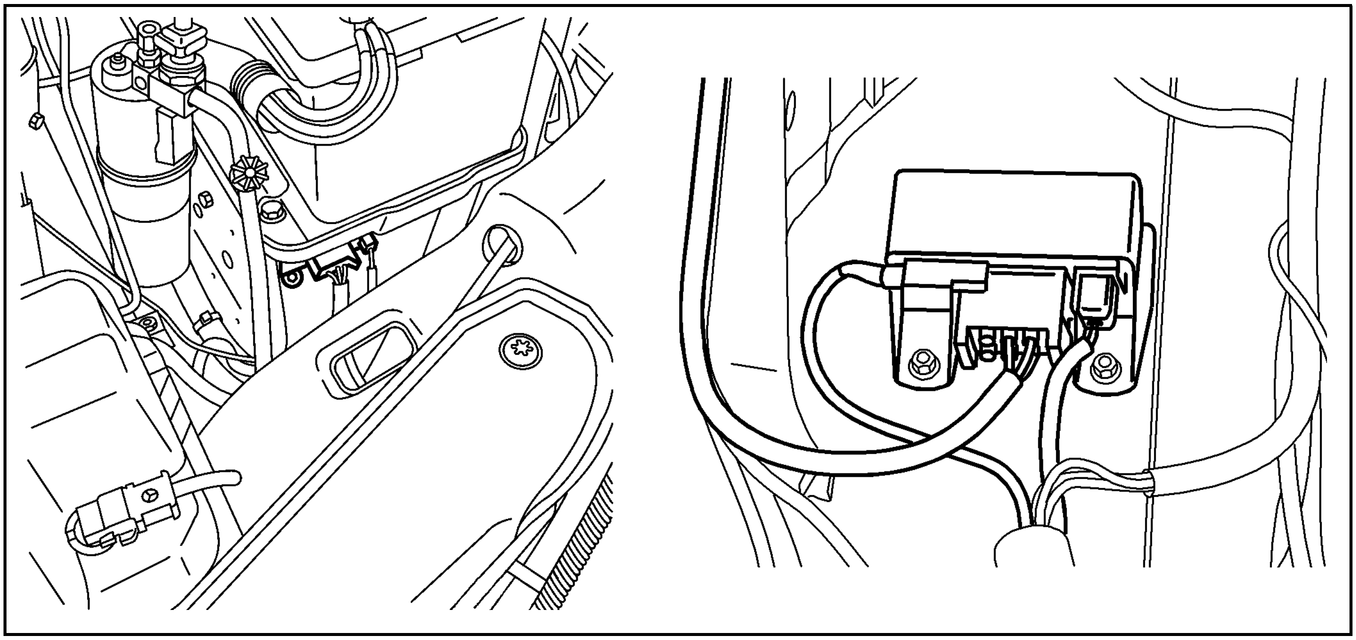
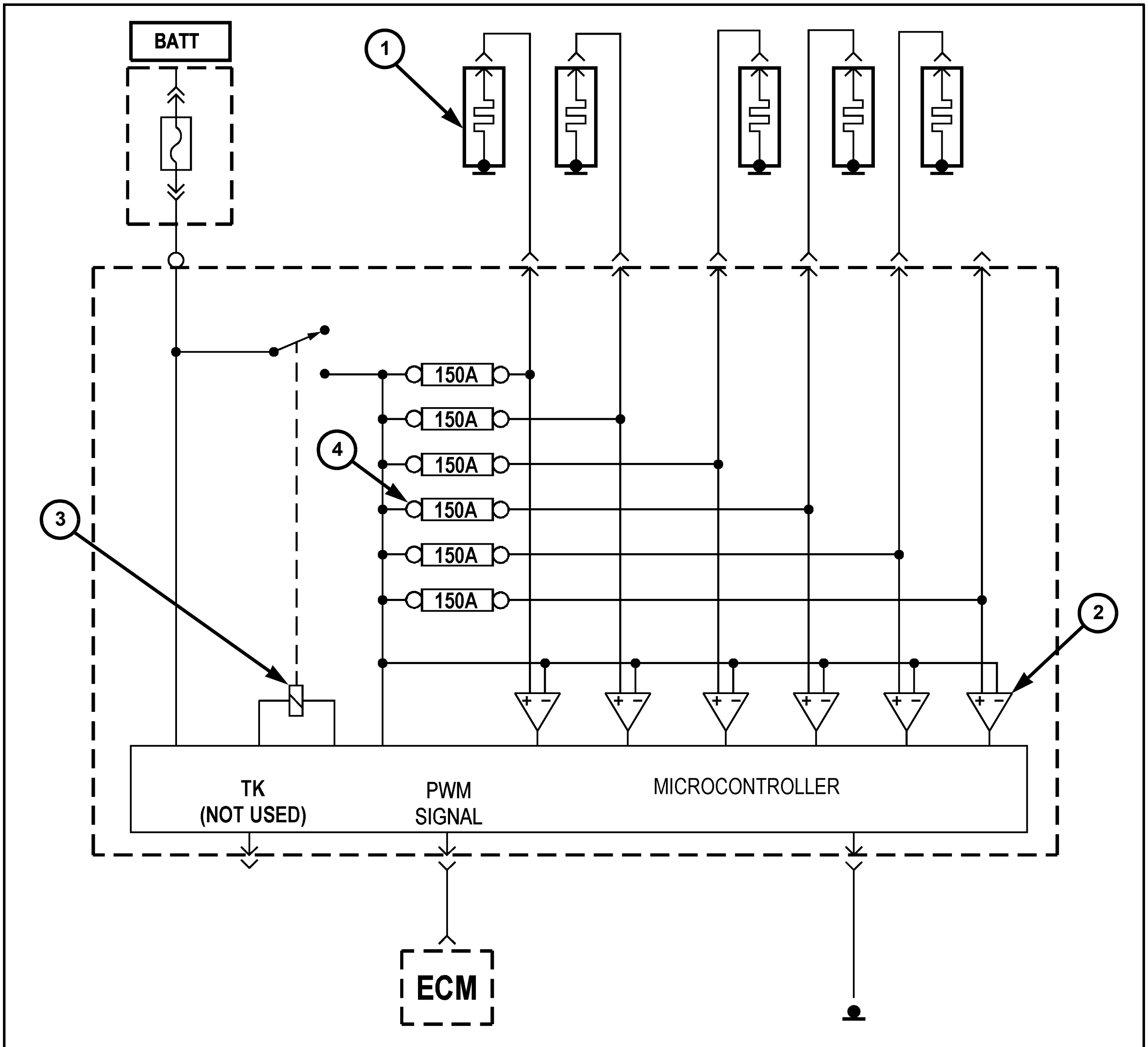


Figure 113 Glow Plug Module

The glow plug module is equipped with a single-wire serial communication interface for bi-directional data communication with the ECM. The glow plug module monitors the operation of the glow plugs and continuously informs the ECM by sending a PWM signal through the single-wire interface about the operating state (glow plugs ON/OFF), and the presence of any system faults.

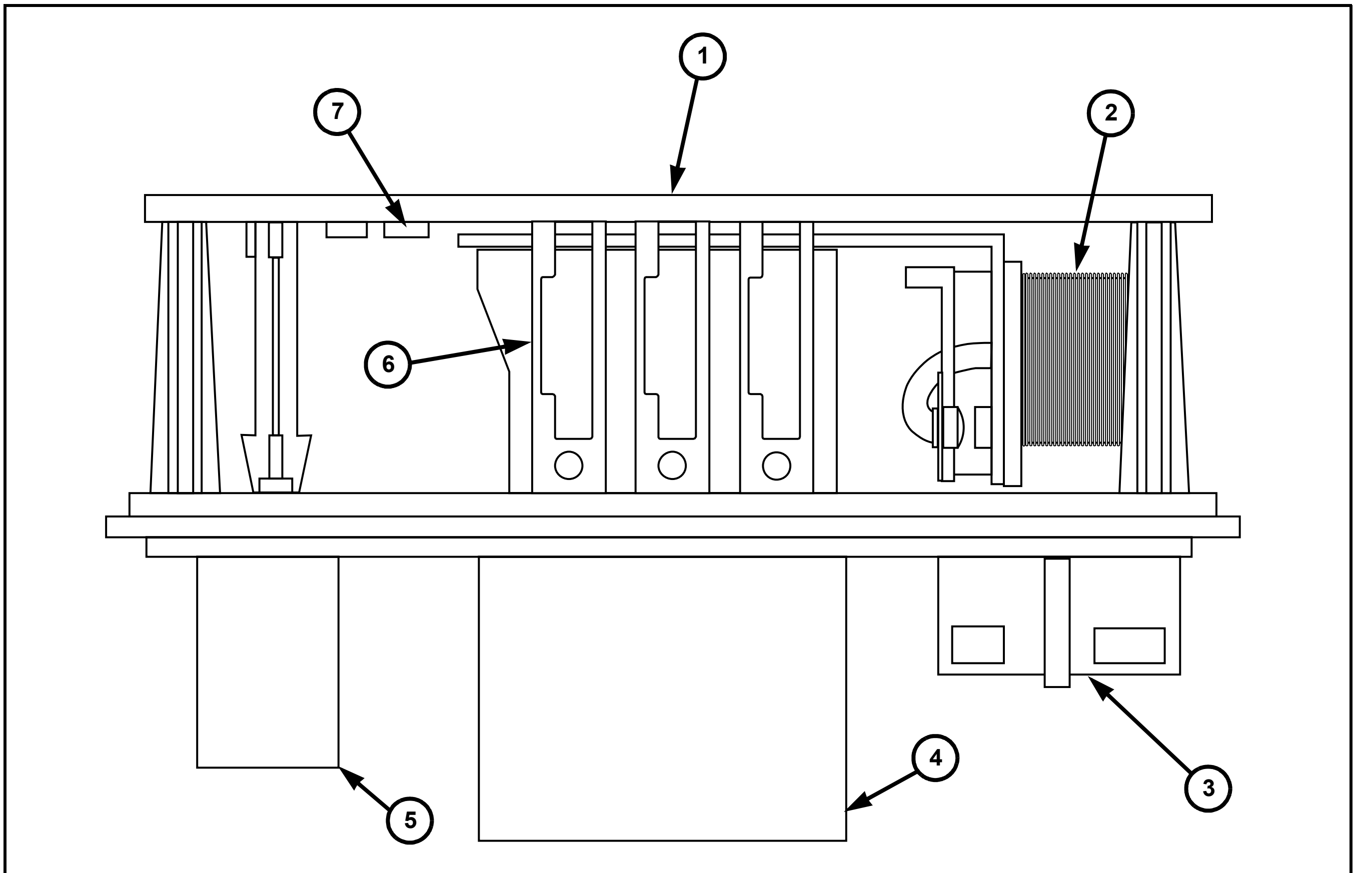
Detected faults in the glow plug system are stored in the diagnostic memory (RAM) of the glow plug module. The contents of the diagnostic memory are sent sequentially to the ECM through the single-wire communication interface.



1	Glow Plug	3	Relay
2	Voltage Comparator	4	Fusible Link

Figure 114 Glow Plug Module Schematic

The glow plug module monitors the PTC properties of the glow plugs for diagnostics. Each glow plug circuit contains a fusible link rated at 150 A. When activated, current flows through the fusible links to the glow plugs and a small voltage drop is produced across the fusible links. A voltage comparator circuit within the glow plug module detects the voltage drop across each fusible link and triggers a signal if a threshold voltage is exceeded. Since the comparator circuit measures voltage drop, the monitoring is only possible while the glow plugs are energized.



1	Printed Circuit Board	5	Datalink to ECM Connector
2	Relay	6	Fusible Link
3	B+ Terminal	7	Voltage Comparator Circuit
4	Glow Plug Connector		

Figure 115 Glow Plug Module

Fault Recognition

The following faults are recognized by the glow plug module and transmitted to the ECM:

- Open circuit/short circuit to battery positive—The comparator circuit detects open circuit voltage instead of the desired voltage drop. The glow plug module stores a DTC (open circuit) in its memory.
- Short circuit to ground (same DTC as above)—The increase in current flow will cause the 150A fusible link within the glow plug module to blow out, leading to an open circuit. The comparator circuit detects no voltage and the glow plug module stores same DTC as above (open circuit), plus a general overcurrent fault. Once a fuse is blown, the glow plug module has to be replaced.
- Internal relay fault

The ECM stores a fault code when it receives an open glow plug circuit message from the glow plug module. The ECM will also activate the preglow indicator lamp in the instrument cluster for about one minute once the engine is running. If the message received by the ECM is related to a short circuit, or a communication fault, it will store a fault code and immediately activate the preglow indicator lamp. The lamp will remain activated until the fault is no longer current or the ignition is switched off.

SERVICE NOTE: TO AVOID INTERNAL DAMAGE, ALWAYS ENSURE THE GLOW PLUGS ARE NOT SHORTED BEFORE REPLACING A GLOW PLUG MODULE.

ACM ENHANCED ACCIDENT RESPONSE INPUT

The airbag control module (ACM) enhanced accident response input is received by the ECM in the event of an accident where the airbags have deployed. A hardwire signal from the ACM is sent to the ECM and central timer module (CTM) simultaneously (Figure 116).

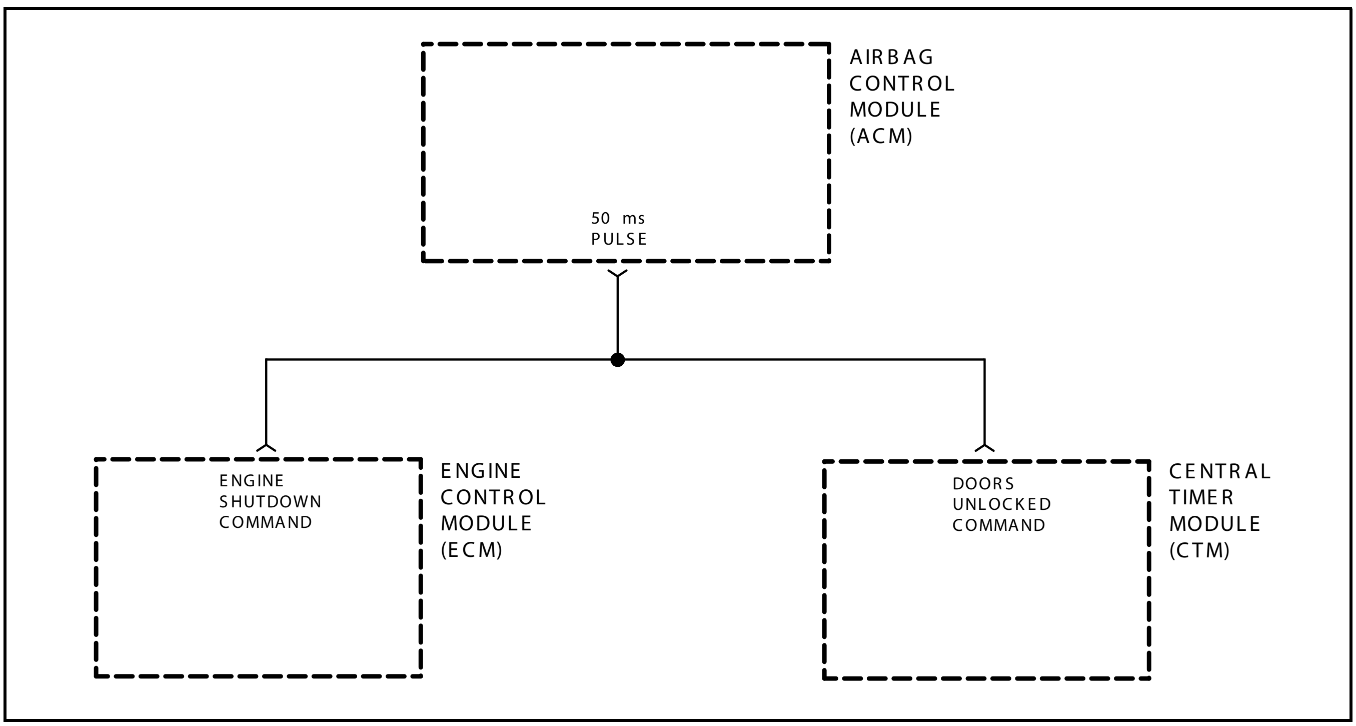


Figure 116 ACM Enhanced Accident Response Input

The enhanced accident response input signal consists of a 12 volt, 50 millisecond pulse generated by the ACM during airbag deployment. Upon receipt of this input, the ECM shuts the engine down. The engine can be restarted again if necessary.

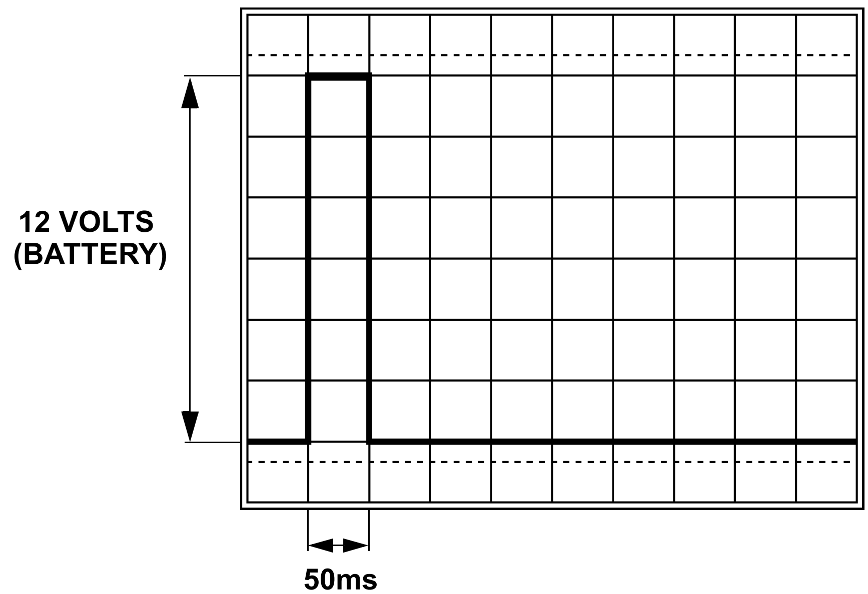


Figure 117 Enhanced Accident Response ACM Input Signal

INDIRECT INPUTS

CAN BUS INPUTS

In addition to the hardwired inputs, the ECM receives data from other control modules through the CAN bus.

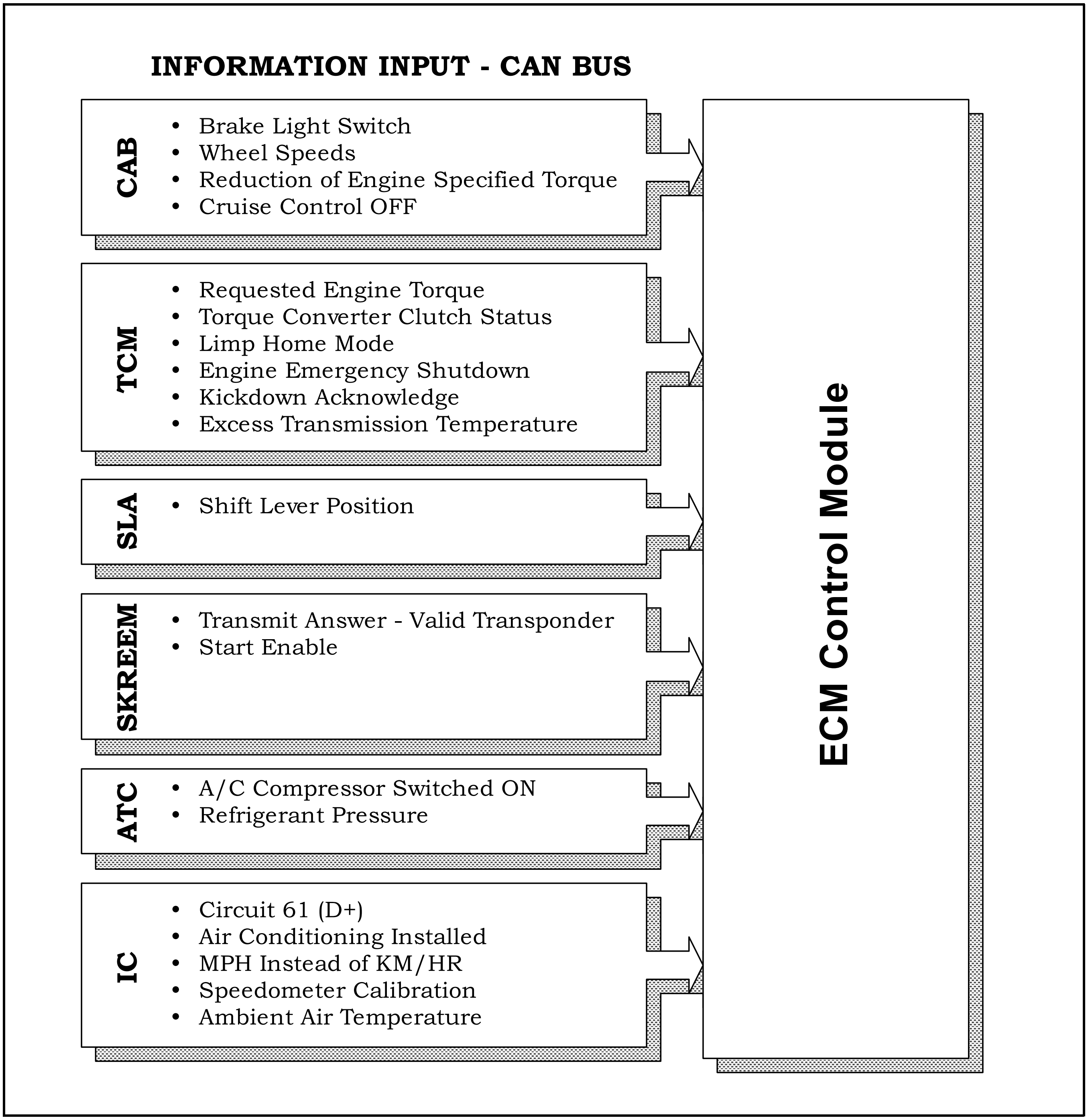


Figure 118 CAN Inputs

ACTIVITY 3.5 ENGINE SENSORS

The purpose of this activity is to familiarize the students with the engine's behavior resulting from various sensor failures. Task 2 of the activity familiarizes the students with the operation of the cruise control switch.

TASK 1

1. Disconnect the following sensors and observe the details as indicated. Use the diagnostic scan tool to read the sensor substitute values.

Fuel Temp Sensor:

Does the engine run? ☑ YES ☐ NO

Is the MIL lamp ON ? ☑ YES ☐ NO *(after 2nd start on 50 state van)*

Engine maximum RPM: *4200 RPM*

DTCs: *P0180-001 Fuel temp sensor voltage too high (clear code to turn out MIL)*

Sensor value displayed: *-40.1°F*

Coolant Temp Sensor:

Does the engine run? ☑ YES ☐ NO

Is the MIL lamp ON ? ☑ YES ☐ NO *(after 2nd start on 50 state van)*

Engine maximum RPM: *4200 RPM*

DTCs: *P0115-001 ECT Voltage too high (clear the code to turn out the MIL)*

Sensor value displayed: *-40.1°F*

Connect a DMM to the coolant temperature sensor and measure its resistance.

Sensor resistance value: ______________________________

Compare the resistance reading to the values of the ECT resistance chart in the student book. Does the sensor value agree with the chart ? ☐ YES ☐ NO

Fuel Rail Pressure Sensor:

Does the engine run? ☑ YES ☐ NO

Is the MIL lamp ON ? ☑ YES ☐ NO *(after 2nd start on 50 state van)*

Engine maximum RPM: *2800 RPM*

DTCs: *P0190-001 Fuel Pressure Sensor Voltage too high*

Sensor value displayed: *KOEO=5801. Goes up with throttle (could be spec value)*

Oil Temp Sensor:

Does the engine run? ☑ YES ❑ NO

Is the MIL lamp ON ? ❑ YES ☑ NO *(oil level indicator - 10 seconds)*

Engine maximum RPM: *4200 RPM*

DTCs: *P2061-001, P2014-004, 2040-004, 2041-004*

Sensor value displayed: *Uses coolant temp, Oil Quality 2, Oil Level 1.57 in.*

Intake Air Temp Sensor:

Does the engine run? ☑ YES ❑ NO

Is the MIL lamp ON ? ☑ YES ❑ NO *(after 2nd start on 50 state van)*

Engine maximum RPM: *4200*

DTCs: *P0110-001 IAT voltage too high (clear fault to turn out MIL)*

Sensor value displayed: *-40.1°F*

Boost Sensor:

Does the engine run? ☑ YES ❑ NO *(engine runs rough)*

Is the MIL lamp ON ? ☑ YES ❑ NO *(after 2nd start on 50 state van)*

Engine maximum RPM: *4200 RPM with stumble*

DTCs: *P0105-002 boost pressure voltage too low (clear stored fault to turn out MIL)*

Sensor value displayed: *Uses ATM pressure value (fixed)*

MAF Sensor:

Does the engine run? ☑ YES ❑ NO *(engine runs rough)*

Is the MIL lamp ON ? ☑ YES ❑ NO *(after 2nd start on 50 state van)*

Engine maximum RPM: *4200 RPM with stumble*

DTCs: *P2067-002, 2067-004, 2068-004 (2 faults on 1st, add. fault on 2nd start)*

Sensor value displayed: *Low 500s (518-543 mg/stroke) very little movement*

Intake Pressure Sensor:

Does the engine run? ☑ YES ☐ NO

Is the MIL lamp ON ? ☑ YES ☐ NO *(after 2nd start on 50 state van)*

Engine maximum RPM: *4200 RPM*

DTCs: *P2025-002 Intake pressure voltage too low*

Sensor value displayed: *11.4 and 0.000 volts on DRBIII - 11.269 on DAS*

TASK 2 CRUISE CONTROL SWITCH

1. Connect the diagnostic scan tool to the vehicle and access the engine.
2. Actuate/Press the cruise control stalk. Record your findings below.

   Position: *UP* ACC: *YES* Safety Contact: *ON*

   Position: *DN* DEC: *YES* Safety Contact: *ON*

   Position: *BK* RES: *YES* Safety Contact: *ON*

   Position: *FWD* OFF: *YES* Safety Contact: *ON*
3. How does the ECM determine a fault, or an unintentional actuation?

   By receiving a combination of switch inputs rather than single input.

MODULE 4 ECM CONTROL

ENGINE CONTROL MODULE (ECM) HARDWARE

The engine control module (ECM) is located on the left hand side, under the instrument panel (Figure 119).

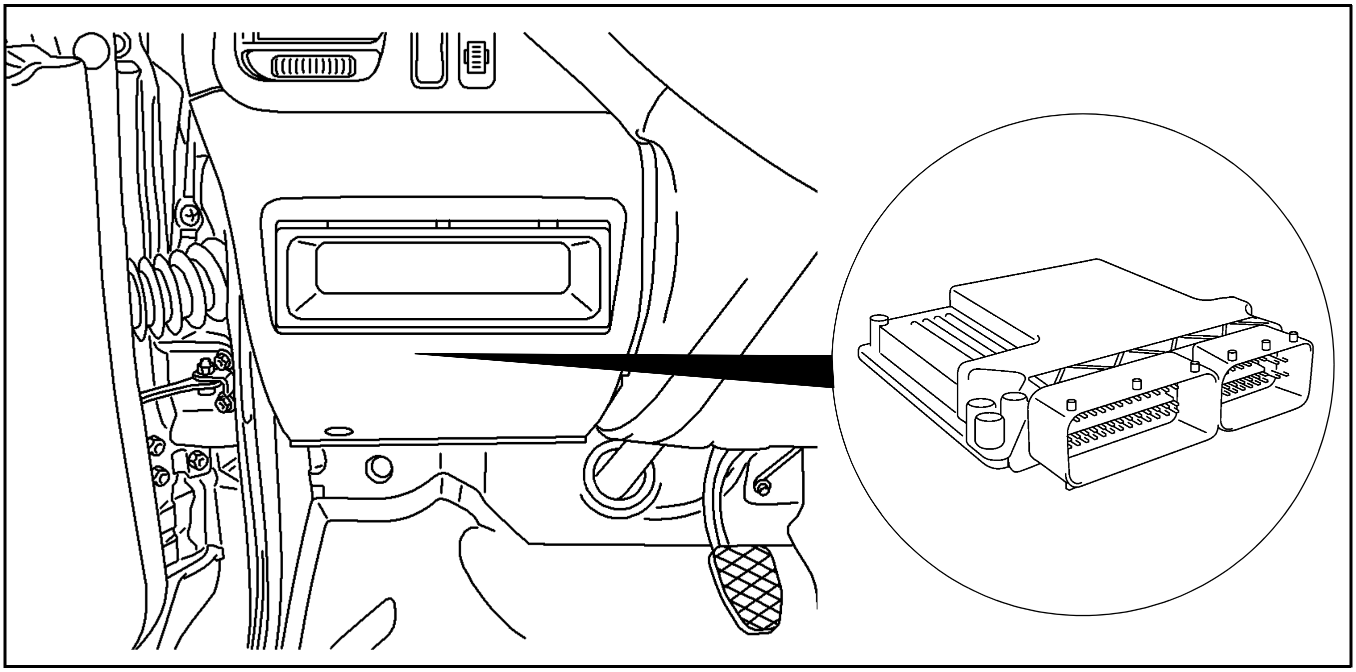
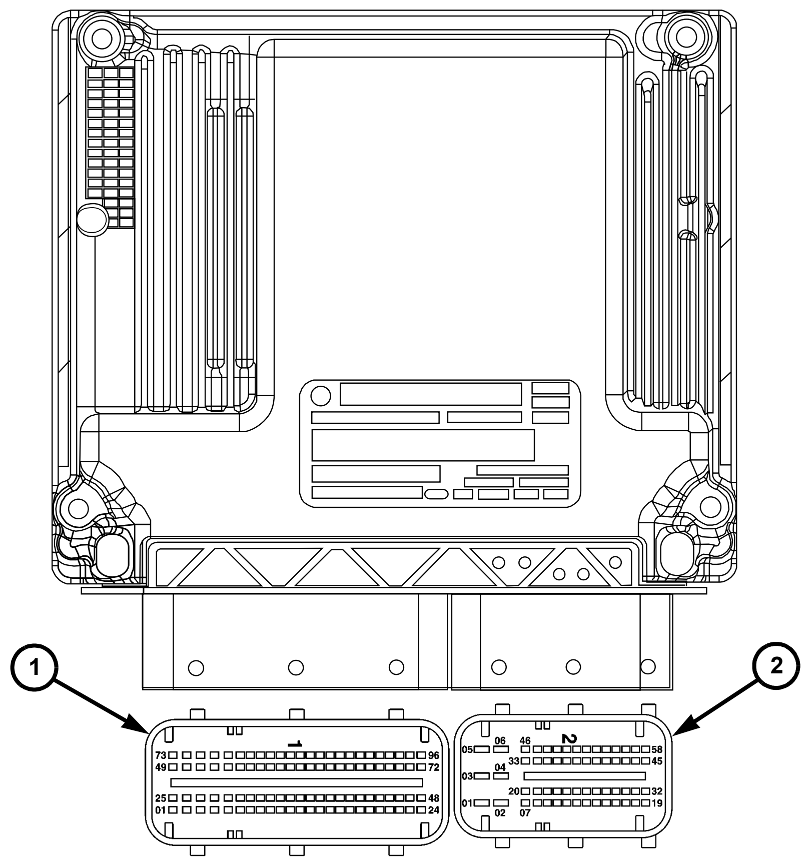


Figure 119 ECM Control Module Location

The ECM is made by Bosch and has a metal housing with finned surfaces for heat dissipation. The inputs, outputs, power supply and grounds are connected to the ECM through two plug-in connectors with a total of 154 pins. Six of the pins have a heavier gauge for carrying the higher current load from the main power supply and ground circuits.



1	96-Pin Engine Connector	2	58-Pin Vehicle Connector

Figure 120 ECM Connectors

The electrical circuits at the ECM are split into two separate wiring harnesses (vehicle and engine wiring harness). The 58-pin connector (marked F) is used for the vehicle wiring harness. The 96-pin connector marked M is for the engine wiring harness.

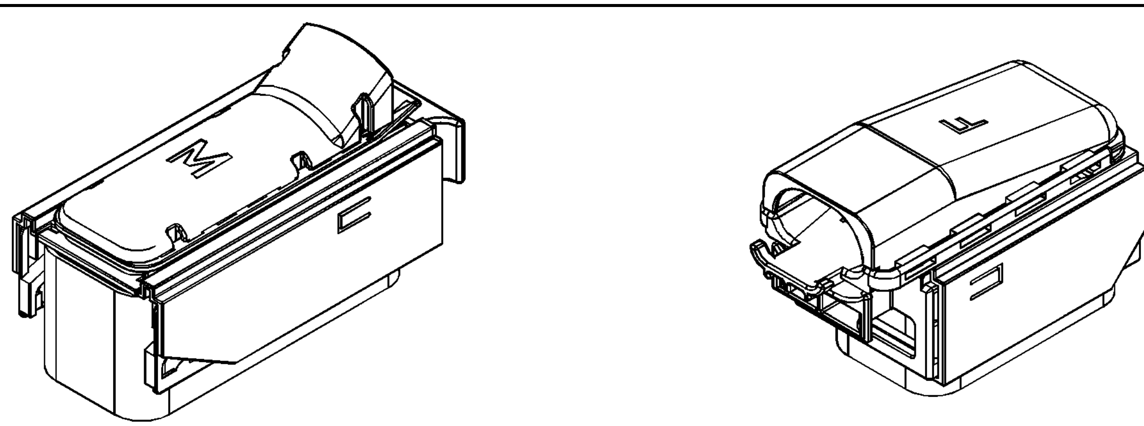
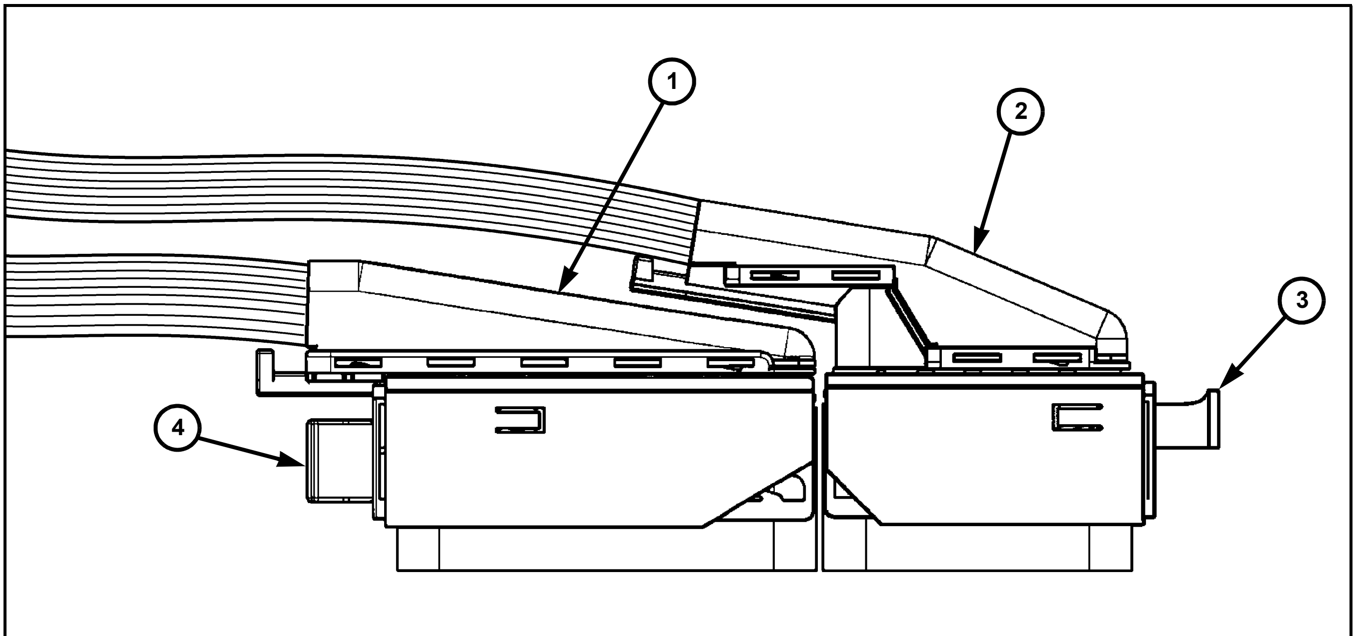


Figure 121 ECM Harness Connectors

Both plug-in connectors are secured in place by means of slide locks. The slide locks are located on opposite ends. The 58-pin connector is mounted on top of the 96-pin connector. For this reason, it must be removed first and installed last during disassembly and assembly procedures. To remove the plug-in connectors, pull the slide locks sideways to the end of their travel and lift the plug-in connectors.



1	Engine Plug-In Connector	3	Vehicle Connector Slide Lock
2	Vehicle Plug-In Connector	4	Engine Connector Slide Lock

Figure 122 ECM Connector Mounting Position

The ECM has guide pegs to ensure the correct mounting position of the plug-in connectors. When re-installing the plug-in connectors, align the connector tracks with the guide pegs. Push the connector down while pressing the slide lock in to the end of its travel.

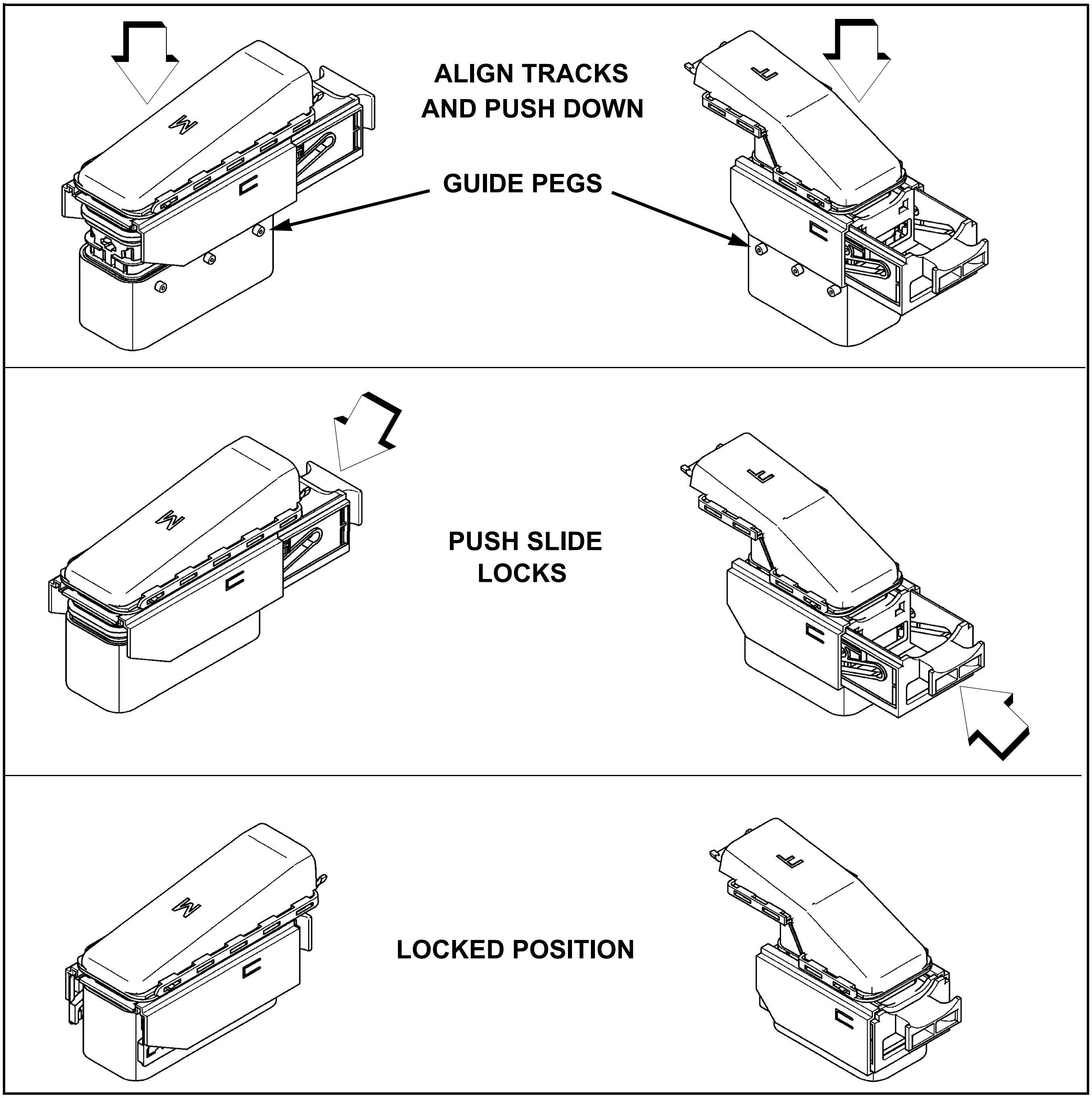
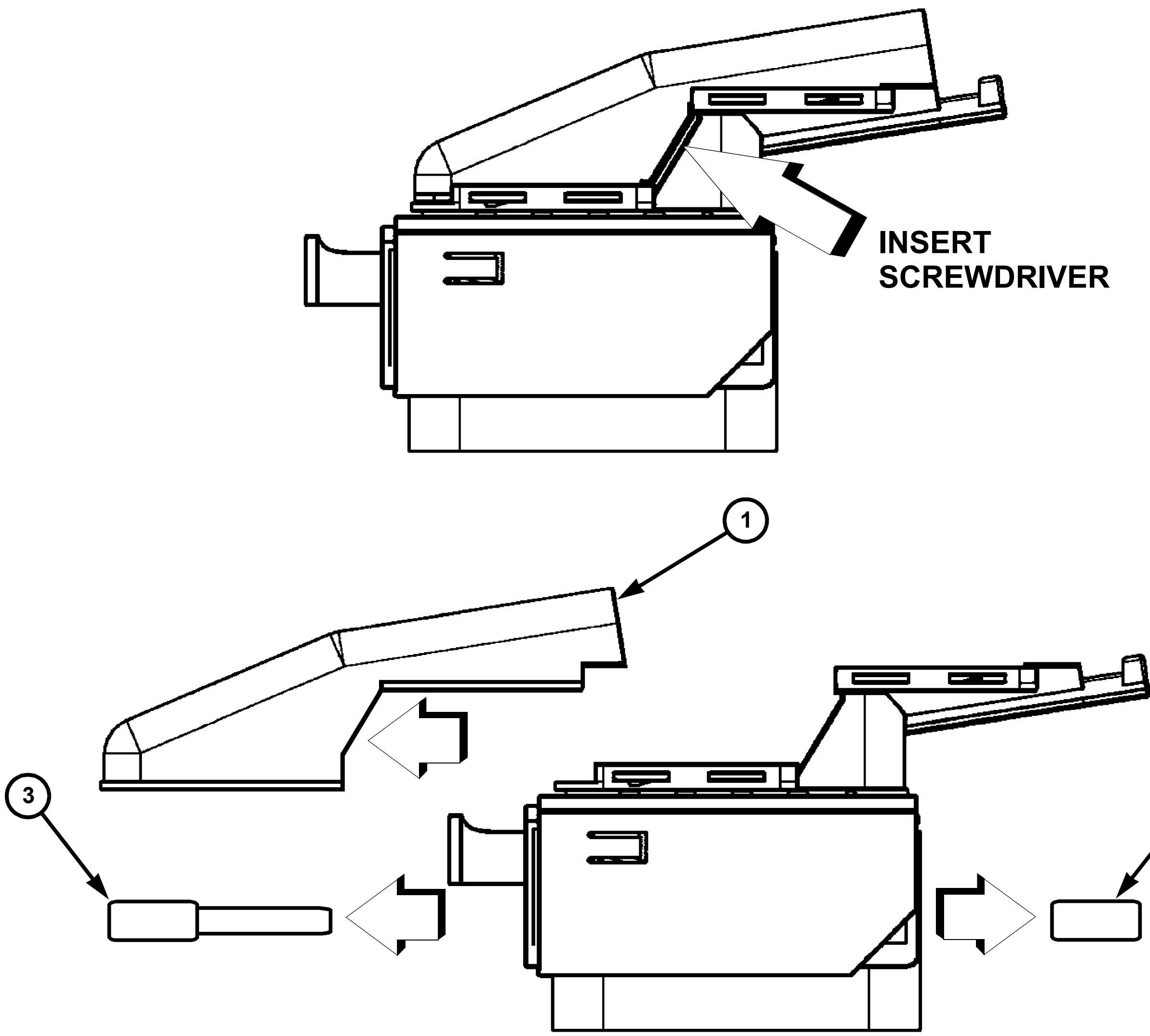


Figure 123 ECM Connector Installation

When retrofitting optional features to the vehicle, the 58-pin vehicle harness plug-in connector must be disassembled for inserting additional wires. Extreme care must be observed to avoid damage to the electrical pins or the connector housing.

Refer to Figure 124 for disassembly of the vehicle plug-in connector. Insert a wide blade screwdriver in the wedged area between the connector housing and protective cap (arrow). Alternating between both sides of the connector, gently twist on the screwdriver handle to separate the protective cap from the connector housing. Slide the protective cap away from the housing.
Remove the electrical terminal holders only if you require more clearance when inserting additional wires. The electrical terminal holders are held in place with two locking pins. Carefully remove both locking pins with a small screwdriver and pull them out.

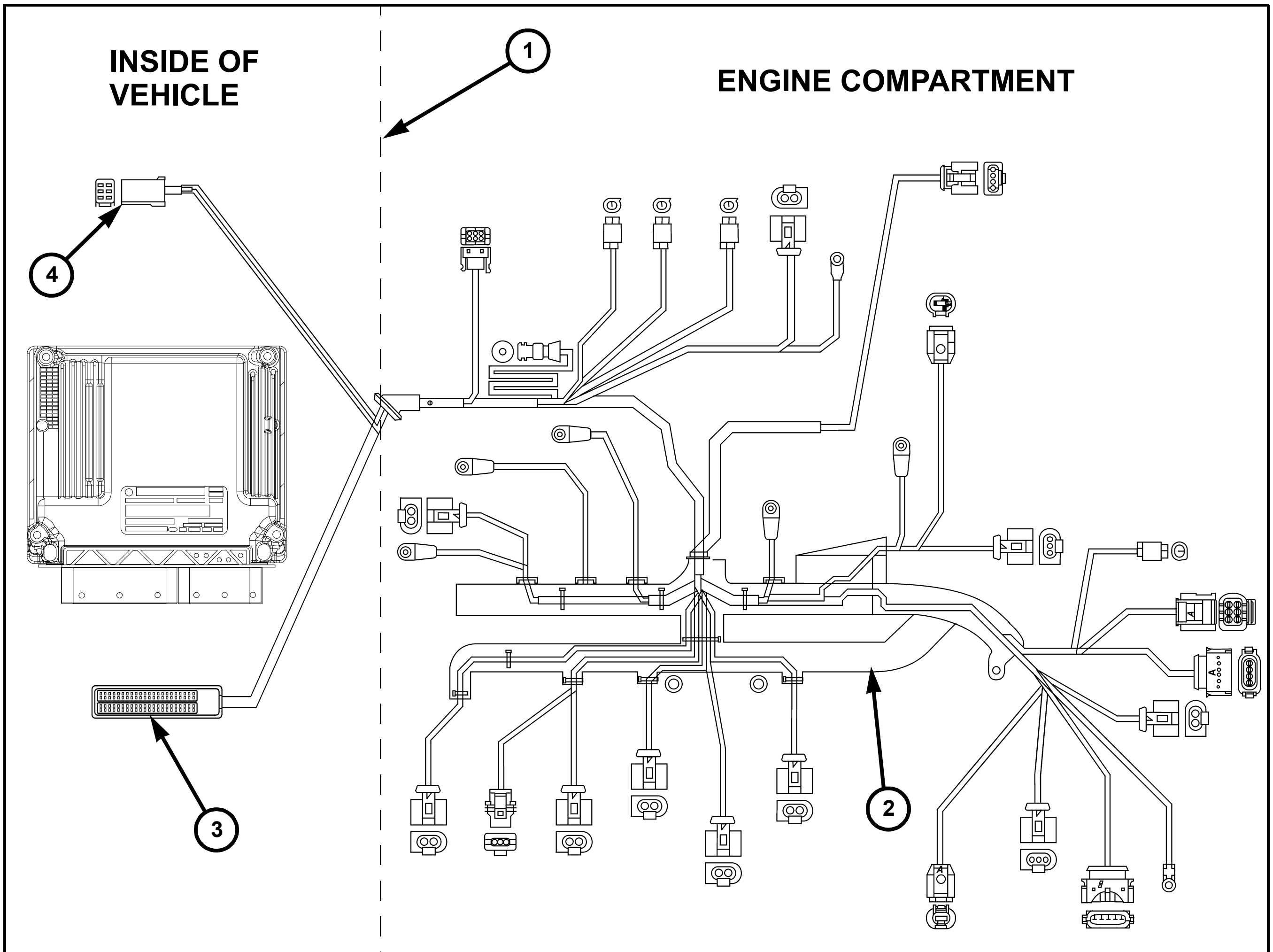


1	Protective Cap	3	Front Locking Pin
2	Rear Locking Pin		

Figure 124 Vehicle Harness Connector Disassembly

ENGINE WIRING HARNESS

The OM647 engine wiring harness contains the input and output circuits of engine system components that are mounted to the engine. Specific circuits carrying PWM signals (actuators), high voltage signals (injectors), and inductive signals (CKP sensor) use twisted wires to provide protection against electromagnetic interference (EMI). A braided loom and plastic harness channel protect the wires against chafing. The electrical circuits are routed through the bulkhead to the vehicle's interior through two separate connectors. The 96-pin connector plugs into the ECM. A six-pin connector, which contains accessories circuits, such as alternator, starter motor and air conditioning compressor plugs into the vehicle main harness.



1	Engine Bulkhead	3	Engine Harness ECM Connector
2	Plastic Harness Channel	4	Engine Accessories Connector

Figure 125 Engine Harness

ENGINE CONTROL MODULE INTERNAL CIRCUITRY

The ECM provides the following reference voltage levels to input and output components:

- Three regulated 5-volt power supplies
- Two 12-volt power supplies
- Four PWM power supplies
- High voltage power supply for injectors

A Motorola 32-bit microprocessor uses control algorithms to process the input signals and calculates the injected fuel based on stored maps. The microprocessor triggers the driver stages for switching the output components.

The ECM contains the following data storage elements:

- **Flash EPROM—**stores engine-specific curves, engine-management maps, and variant coding (engine and equipment options).
- **EEPROM—**stores SKREEM data, calibration and manufacturing data, adaptation values, operational faults and variant coding.
- **RAM—**stores variable data such as calculations data and input values.

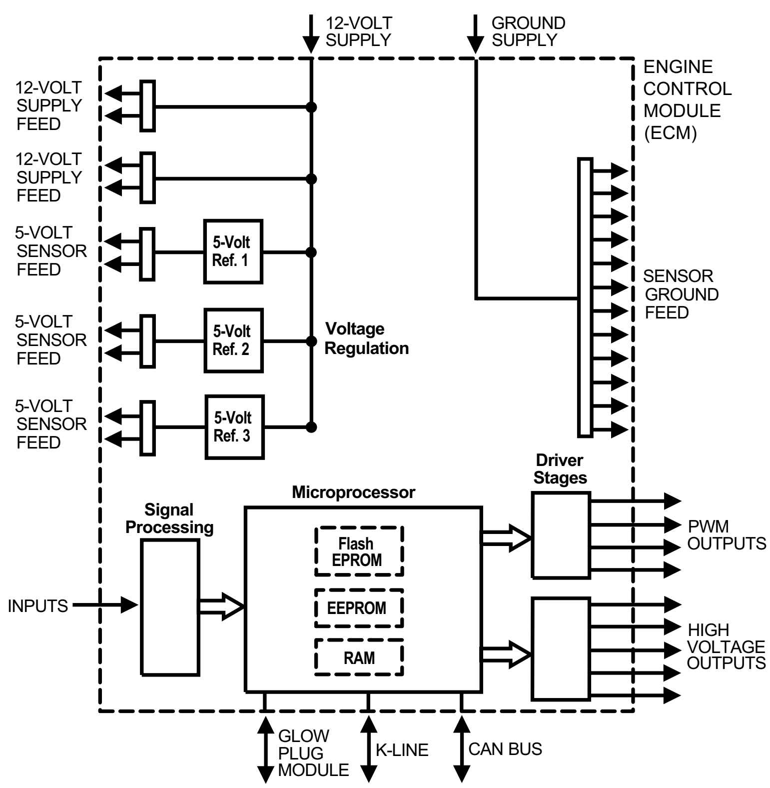


Figure 126 ECM Internal Block Diagram

ECM CONTROL STRATEGIES

The ECM uses control algorithms to process the input signals and make decisions. Algorithms are routines or step-by-step instructions programmed in the ECM software, which are used to complete a task or deal with a particular situation. The different control algorithms used by the ECM will be discussed in this section.

IGNITION ON FUNCTION

The ECM activates the engine control (M) relay and electric fuel pump relay. The ECM also supplies a preglowing signal to the glow plug module and initiates data interchange with the SKREEM module for drive authorization.

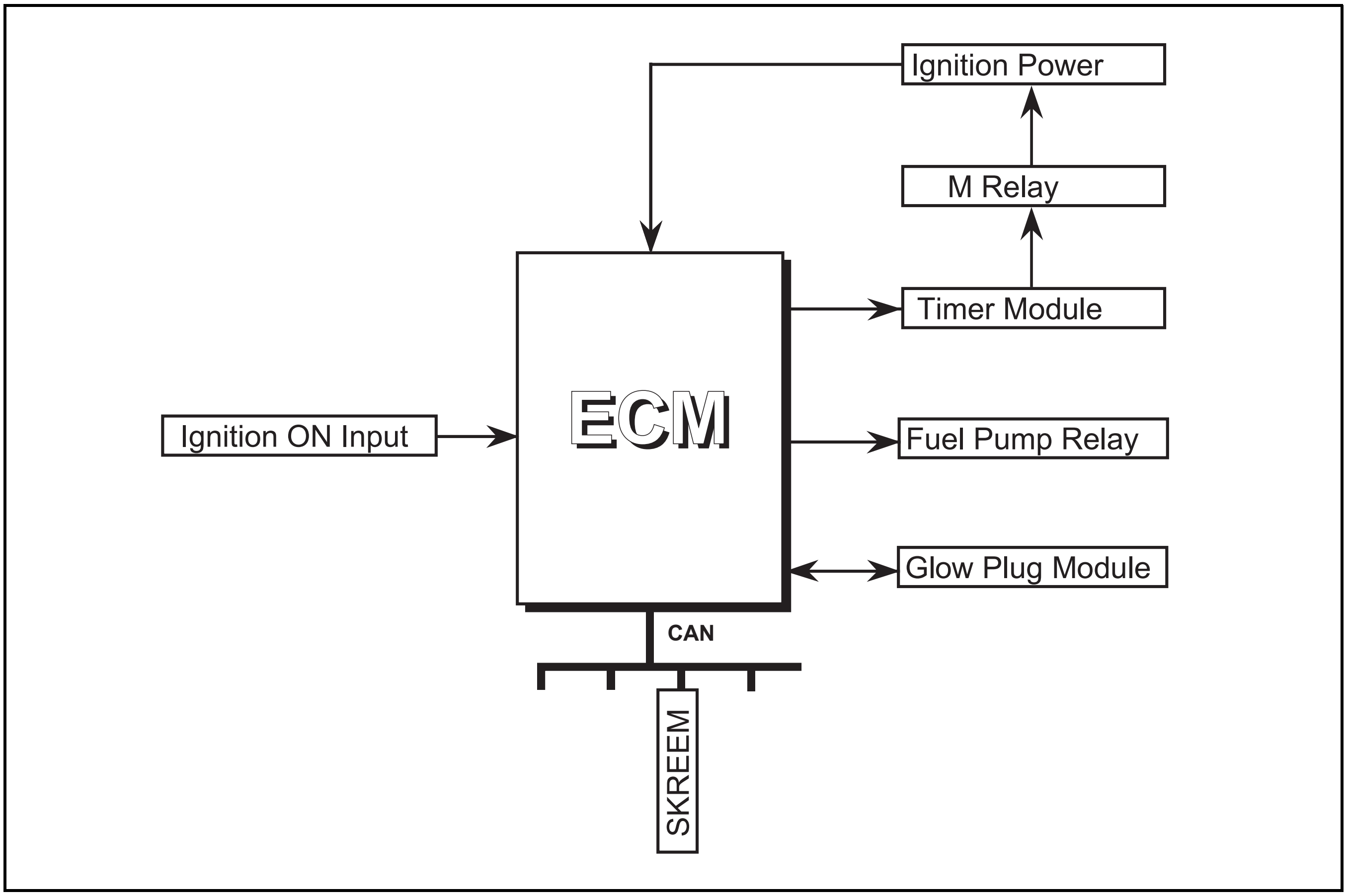


Figure 127 Ignition On Function

START QUANTITY CONTROL

The ECM controls the amount of fuel injected during starting regardless of the accelerator pedal position. The start quantity function is enabled after the ECM has completed synchronization of the injection timing based on cam and crank position. The ECM uses the coolant temperature value to determine the required fuel quantity for starting. Once the ECM detects the fuel rail pressure, it adjusts the pressure through the fuel solenoid.

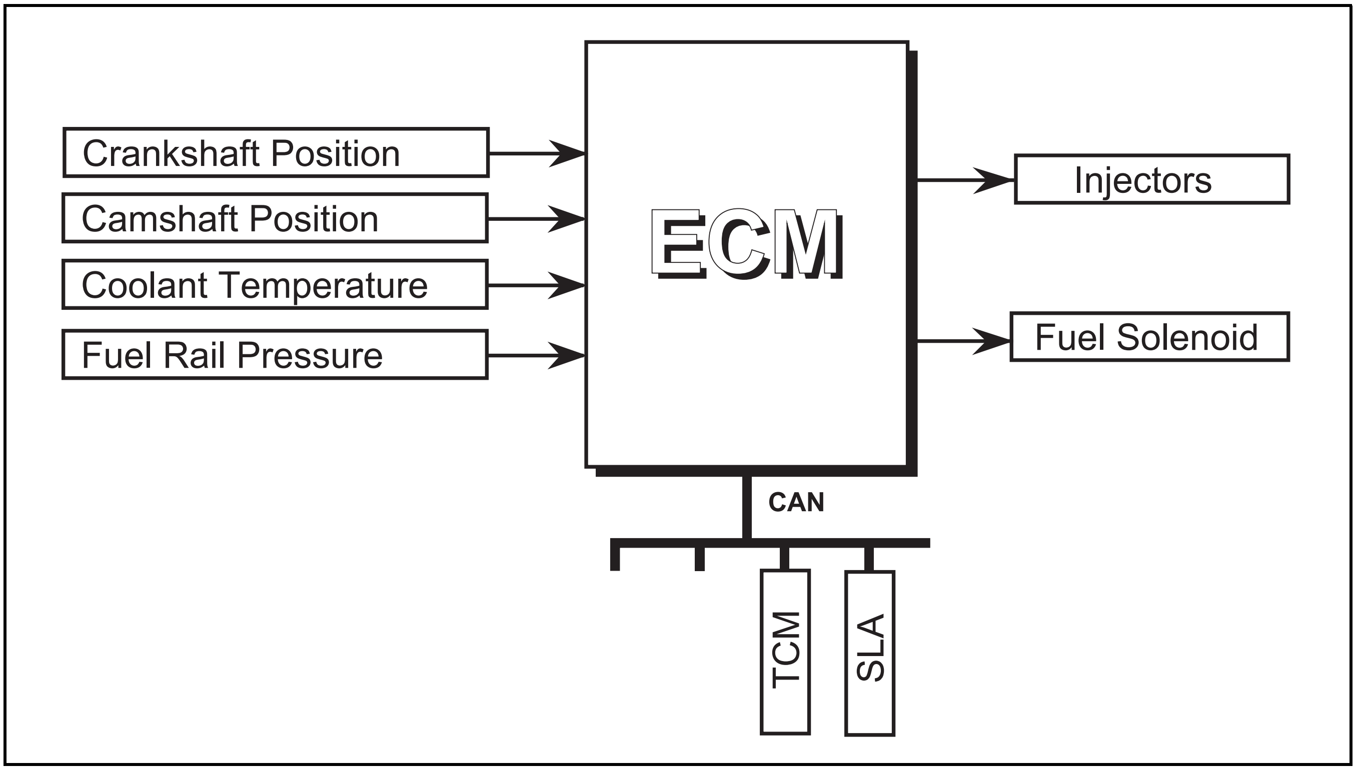


Figure 128 Start Quantity Control

The start quantity function controls the amount of fuel injected up to an engine speed of 500 rpm, independently of the accelerator pedal position. The start quantity function is shut off after all of the following conditions have been met:

- Engine has started
- Engine speed is higher than 500 rpm
- Coolant temperature is at least 80°C (176°F)

The engine speed can be controlled from the accelerator pedal only after engine speed has exceeded 500 rpm (dependent on coolant temperature). The higher the coolant temperature, the lower the start quantity released by the ECM to the fuel injectors.

IDLE SPEED CONTROL

The idle speed control maintains a constant idle speed of 680 rpm independent of engine load, for example, selector lever in gear or A/C compressor engaged. The ECM calculates the engine speed via the crankshaft position sensor (CKP) and compares the actual value with the specified value. The ECM then regulates the rail pressure via the fuel quantity valve and the injection time via the fuel injectors. The rail pressure and injection time produce the injected fuel quantity.

The following signals are required for the idle speed control:

- Crankshaft position sensor
- Coolant temperature sensor
- Pedal value sensor
- Rail pressure sensor

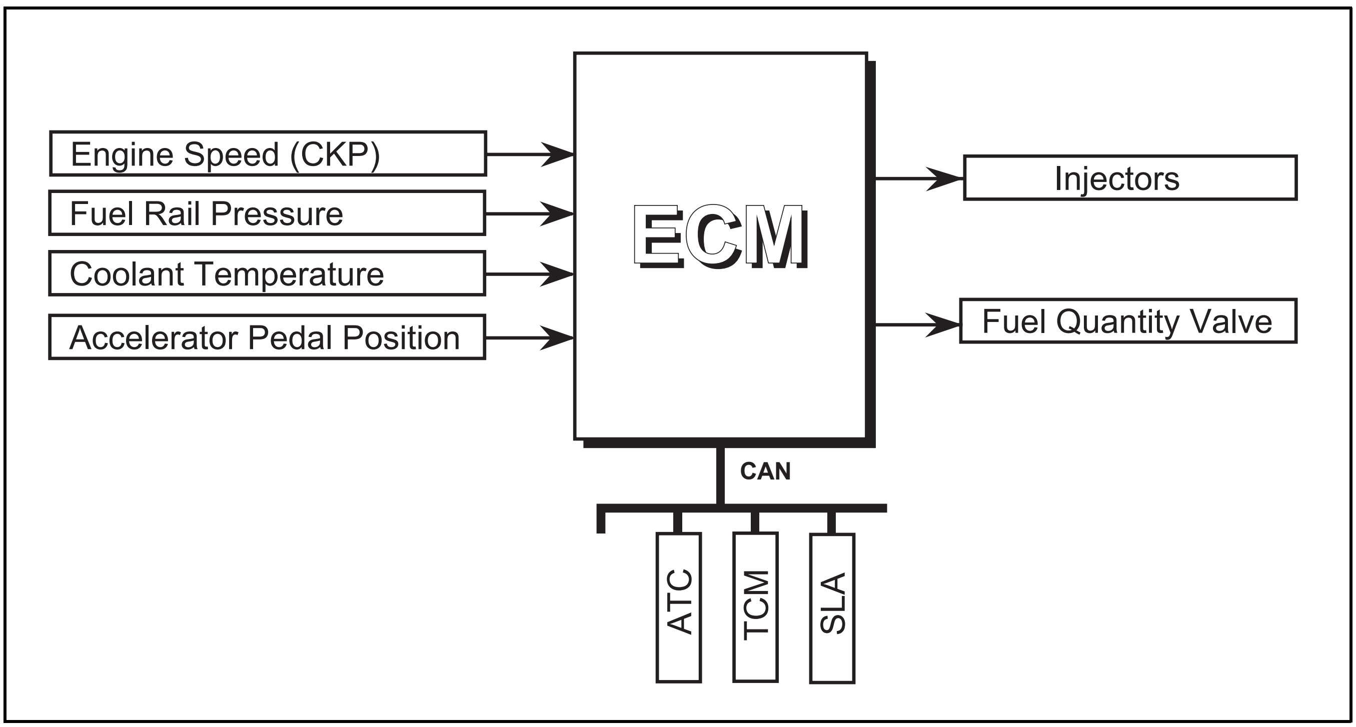


Figure 129 Idle Speed Control

The idle speed is dependent on the ambient temperature and the atmospheric pressure.

Example:

- idle speed at 20°C (68°F) and 1000 mbar (29.5 inHg) = 680 rpm
- idle speed at -30°C (-22°F) and 700 mbar (20.7 inHg) = 1100 rpm

FUEL QUANTITY CONTROL

The ECM controls the fuel quantity separately for each cylinder under all operating conditions. Based on actual input values, the ECM adapts the fuel quantity injected by either one of the following strategies:

- Adjust the fuel rail pressure via the fuel solenoid and the quantity control valve
- Adjust the actuation time of the fuel injector solenoid valves

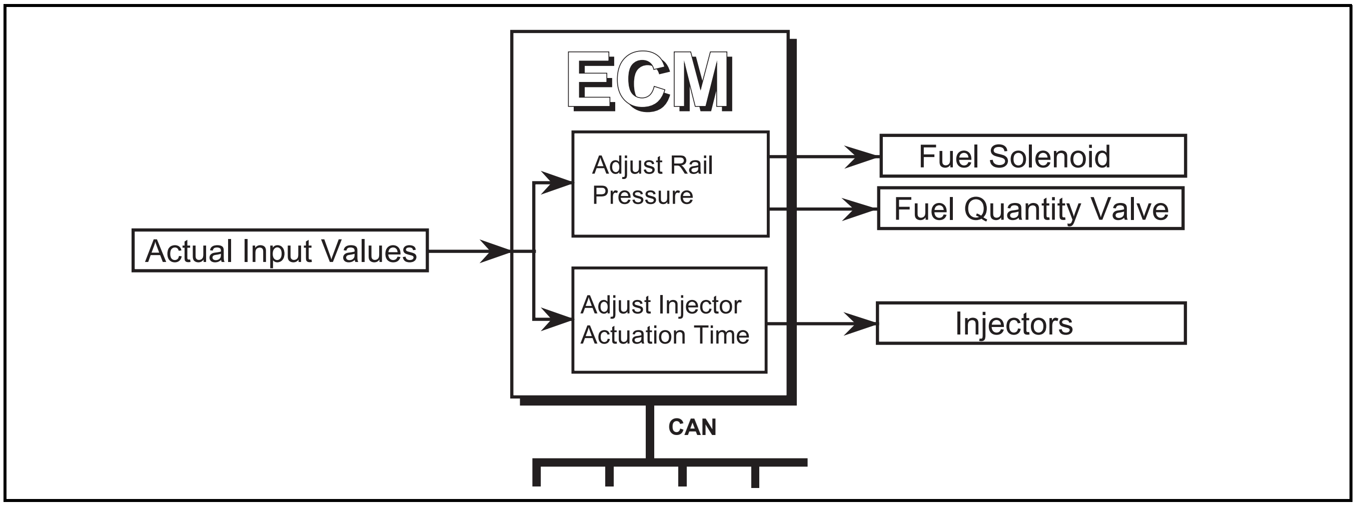


Figure 130 Fuel Quantity Control

INJECTION PRESSURE CONTROL

The ECM controls the storage of fuel required for injection. The fuel rail pressure sensor measures the actual fuel pressure in the rail and transmits an appropriate voltage signal to the ECM. Based on current fuel pressure and other input values, the ECM modulates the fuel quantity valve or the fuel solenoid, which depends on a characteristic map, until the specified pressure is adjusted in the fuel rail. These two components are controlled differently depending on the operating conditions.

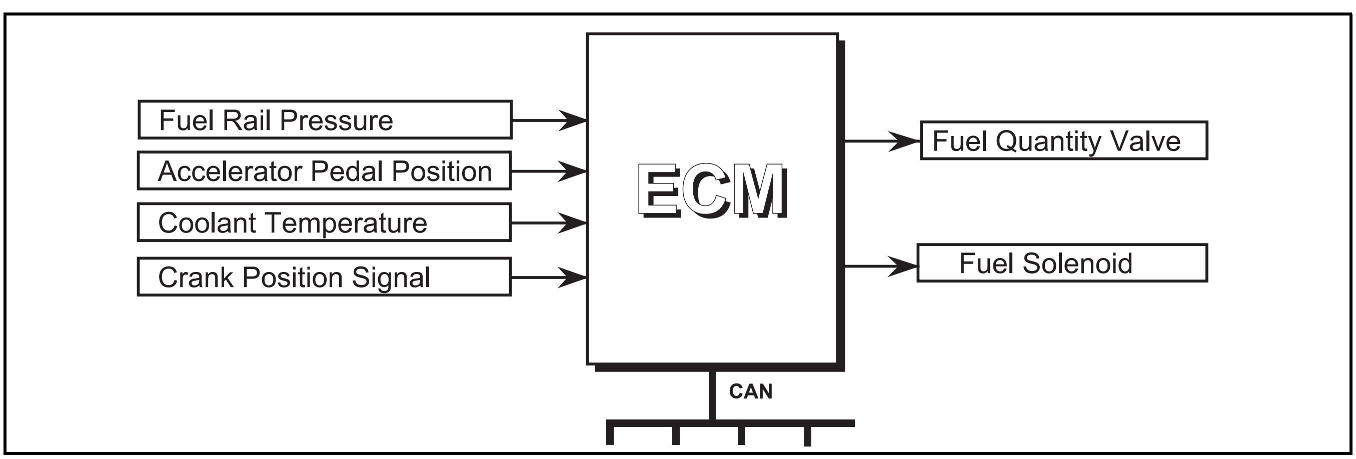


Figure 131 Injection Pressure Control

SMOOTH ENGINE RUNNING CONTROL

The smooth engine running function corrects the irregularities in engine speed by varying the amount of fuel injected at each cylinder. The ECM monitors the engine speed signal received from the crankshaft position sensor (CKP) and detects any drop in speed.

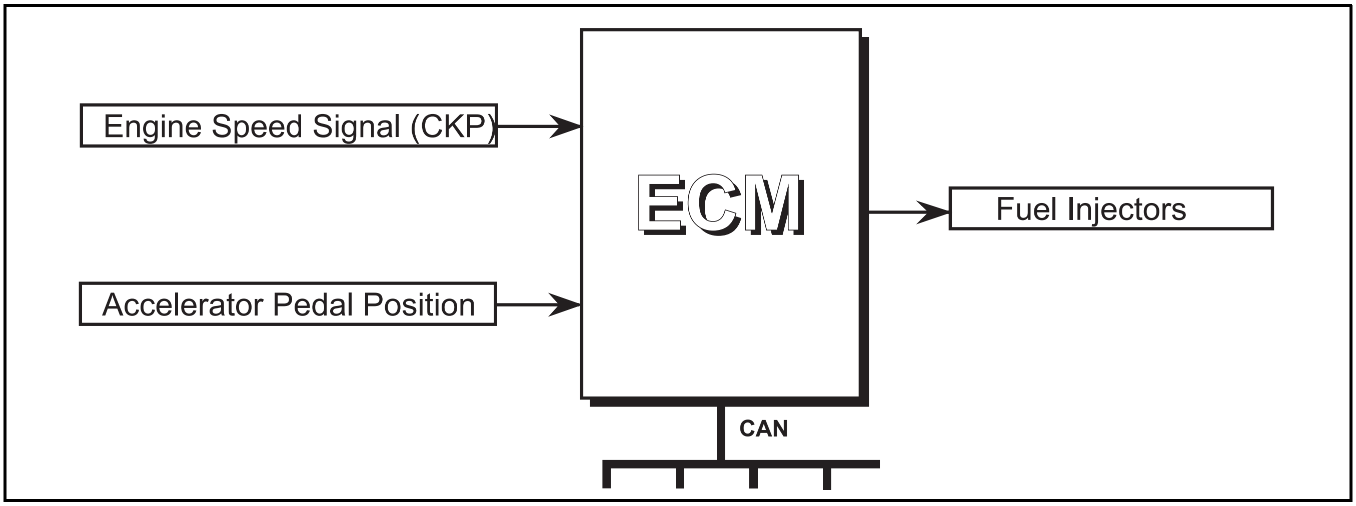


Figure 132 Smooth Engine Running Control

The ECM adjusts the amount of fuel injected within a 10 mm^3 per stroke window (0.010 cc/stroke) at the specific cylinders.

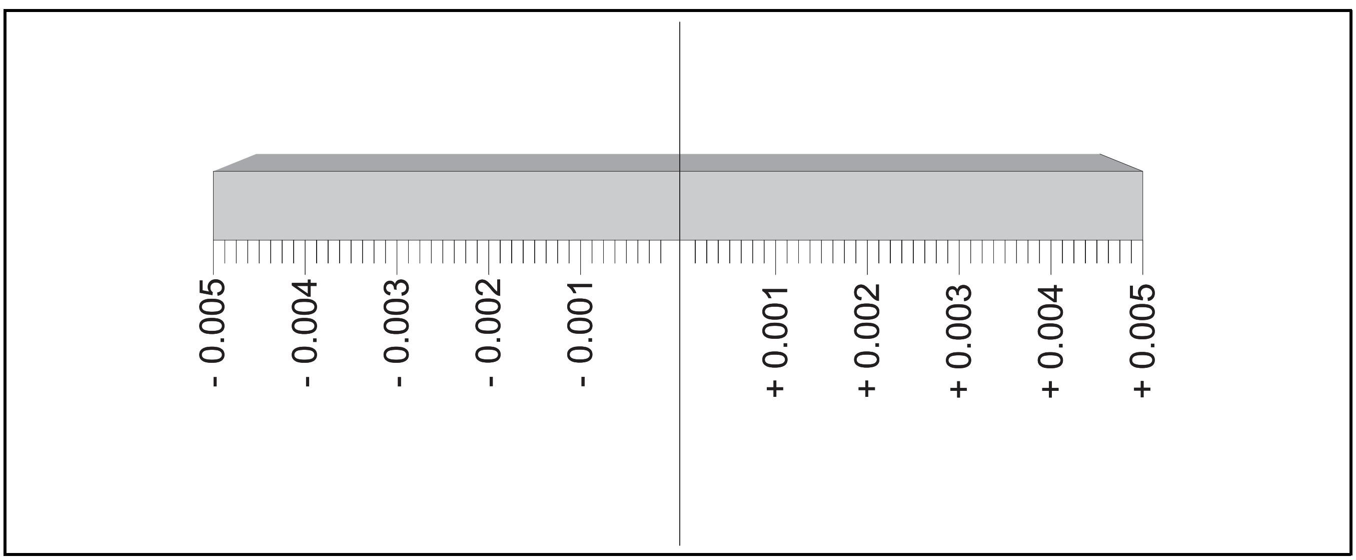


Figure 133 Injection Quantity Correction

The smooth running function is active up to an engine speed of approximately 3200 rpm on the 50-state engine (2800 rpm on the non-CARB engine). The engine speed drop and corrected amount of fuel injected at each cylinder can be verified with the diagnostic scan tool.

ANTI-JERK CONTROL

The ECM detects irregularities in engine speed (resulting, for example, from load changes or gearshifts) from the signals supplied by the crankshaft position sensor and reduces them by adjusting the quantity injected into each of the cylinders.

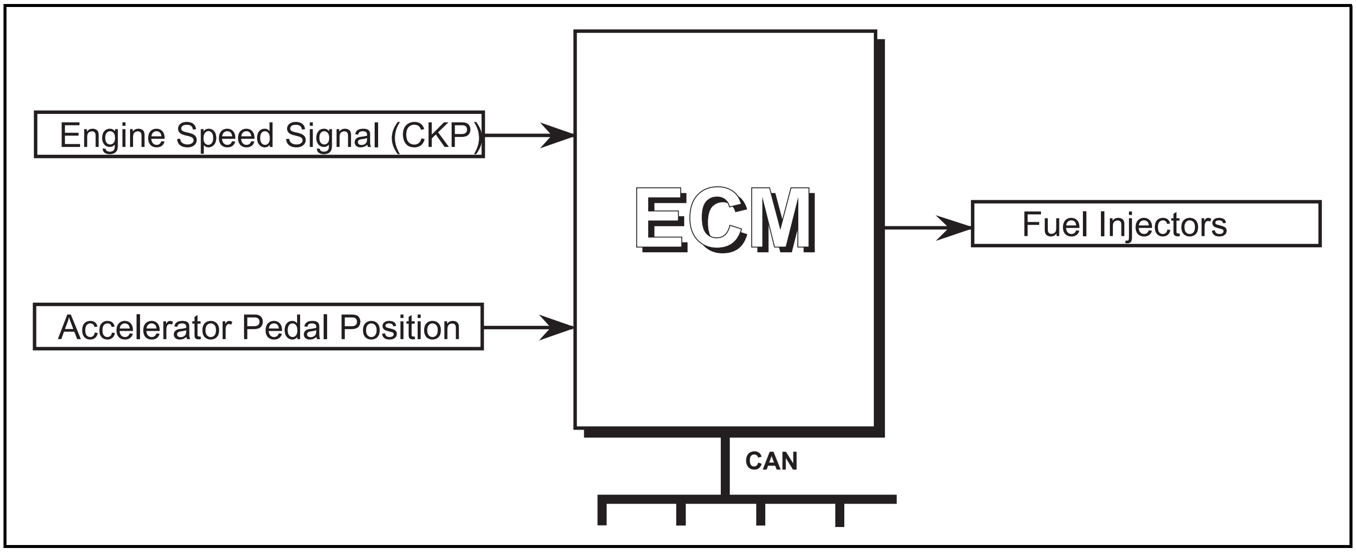


Figure 134 Anti-Jerk Control

FULL LOAD LIMITING

The ECM limits the injection quantity at full load to minimize smoke. If the engine is operating at full load, the ECM limits the amount of fuel injected and modulates the fuel quantity valve to limit the rail pressure. If there are faults in the boost pressure control system, the full load injected quantity is also reduced.

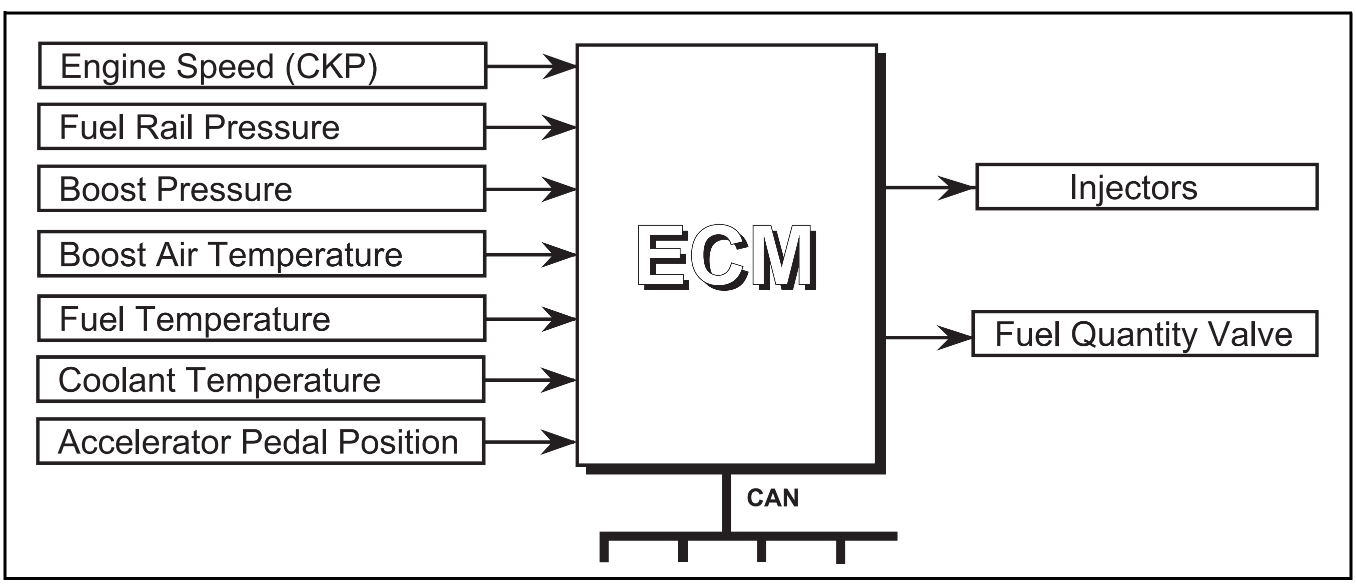


Figure 135 Full Load Limiting Control

MAXIMUM ENGINE SPEED CONTROL

Based on the signal from the crankshaft position sensor (CKP), the ECM limits the maximum engine speed by reducing the injected quantity. The engine speed is normally limited to a no load speed of 4200 rpm. In emergency running mode, the engine speed is limited to 3200 rpm by the ECM. A fuel rail pressure sensor failure limits the engine speed to 2800 rpm.

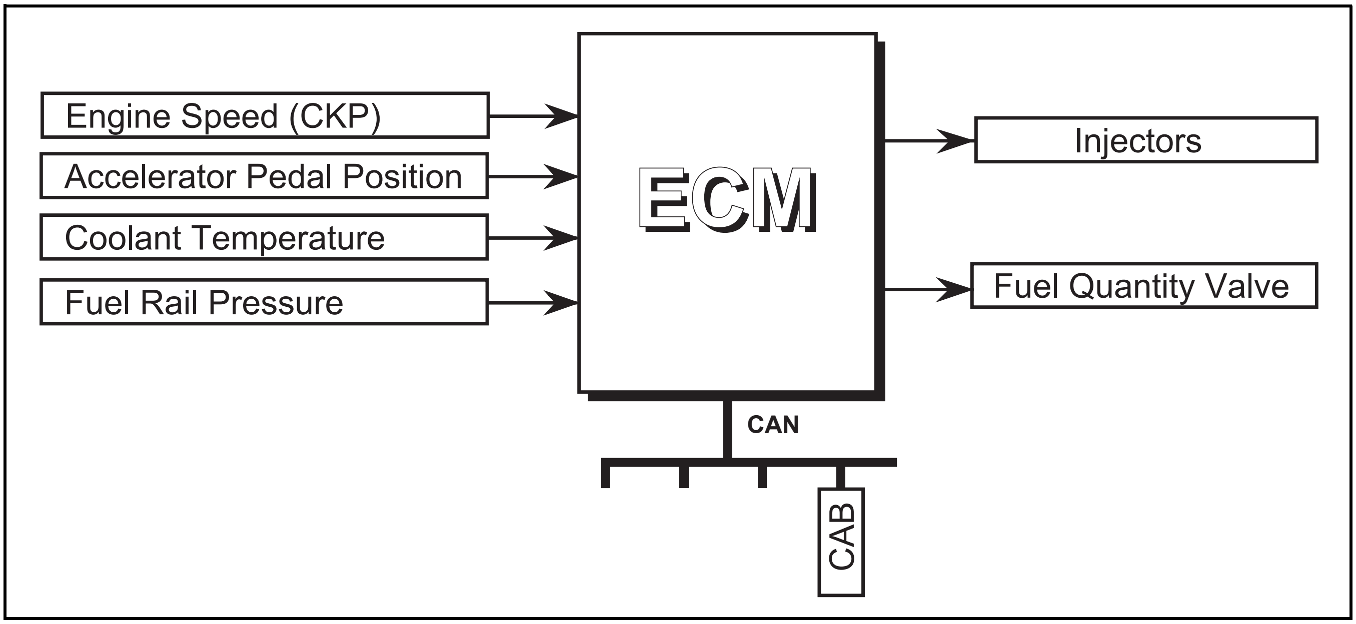


Figure 136 Maximum Engine Speed Control

MAXIMUM VEHICLE SPEED

The maximum vehicle speed is programmable from 22 - 82 mph

ENGINE DECELERATION CONTROL

The ECM deactivates the injectors in deceleration mode (zero delivery) based on signals from the accelerator pedal position sensor and crankshaft position sensor. If the accelerator pedal is not depressed and the engine speed is below 1600 rpm, the ECM deactivates the fuel injectors during engine deceleration. The ECM also reduces the rail pressure via the fuel solenoid.

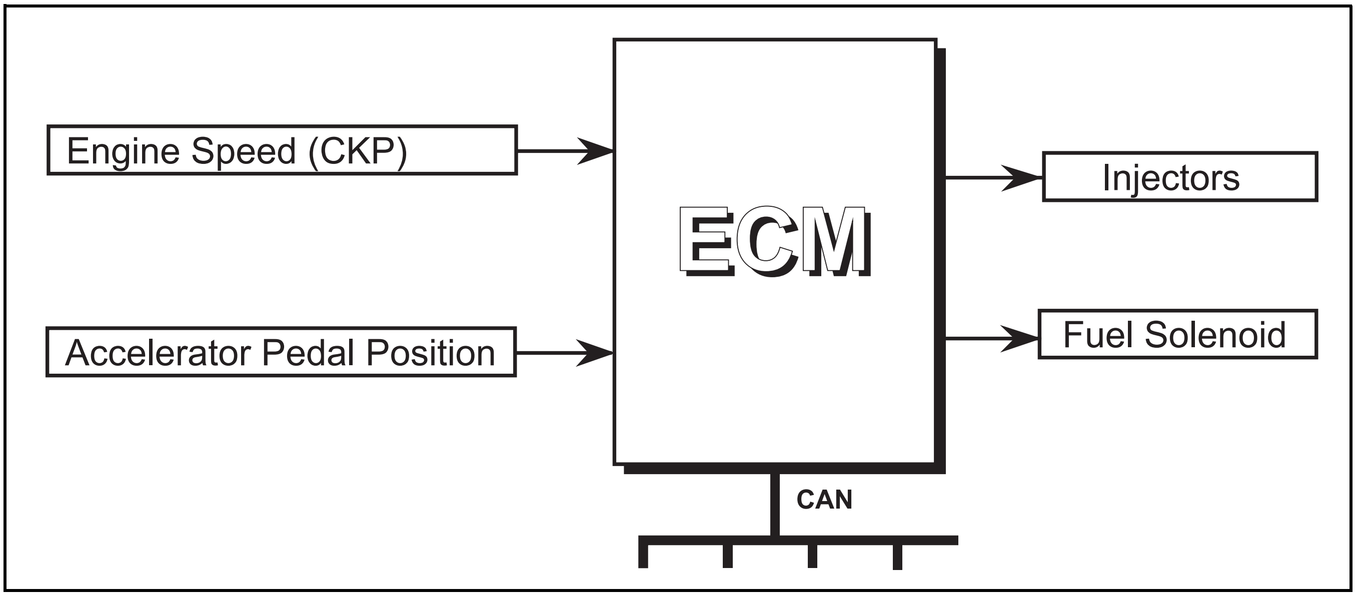


Figure 137 Engine Deceleration Control

ZERO QUANTITY CALIBRATION

The zero quantity calibration function measures the time delay between fuel injector activation and actual start of injection, caused by friction when opening and closing the injectors. The ECM compensates for the delay by increasing the duration of injection.
The time delay is measured during engine deceleration mode. The ECM sets a constant rail pressure via the fuel quantity valve. The ECM then increases the injector pulse width until a speed increase is detected by the crankshaft position sensor.

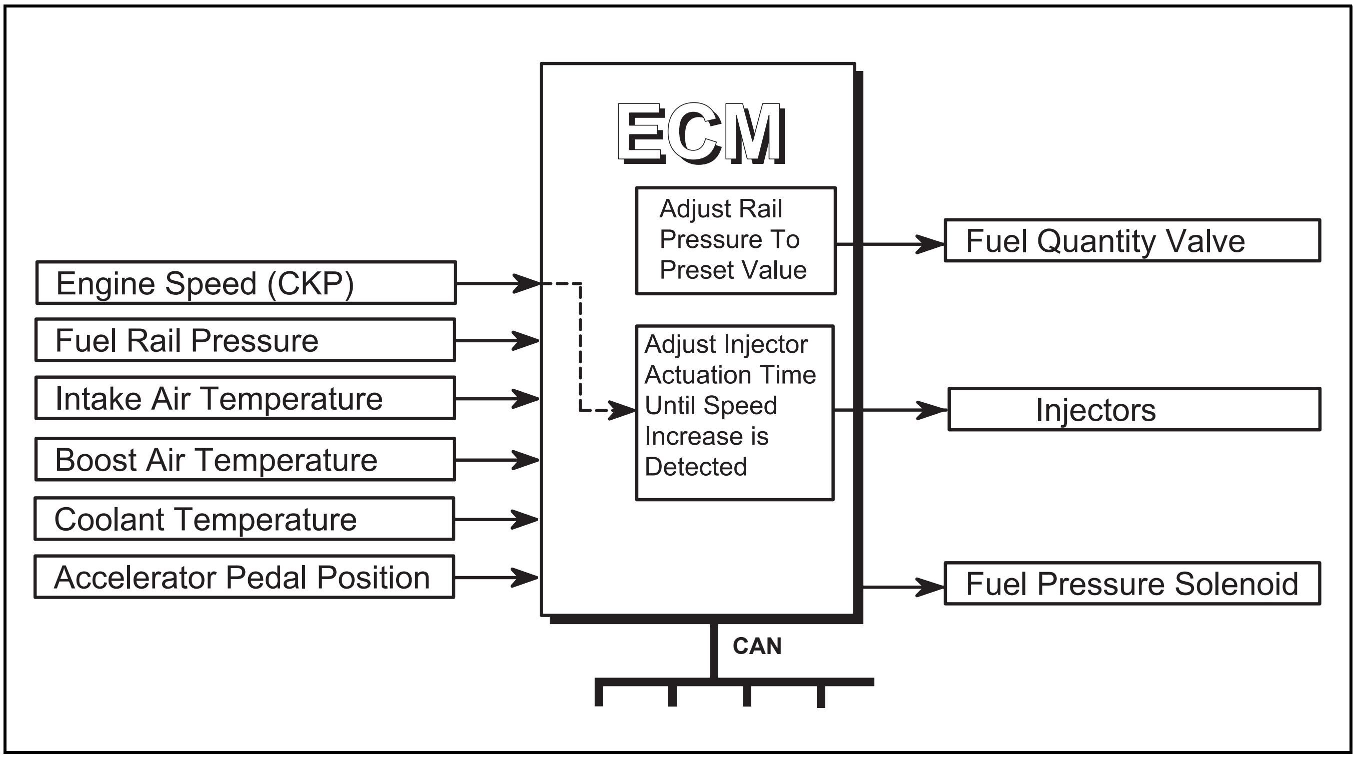


Figure 138 Zero Quantity Calibration

The determined injector pulse width serves as a learned value for the ECM. The learned value (quantity zero) is used as a new output value.

FUEL TANK PROTECTION

The ECM ensures the fuel supplied to the high pressure pump is delivered in adequate quantity and with adequate pressure. The fuel quantity valve meters the amount of fuel to the high pressure pump plungers so the return flow quantity through the fuel pressure solenoid is as small as possible in order to achieve good efficiency and to reduce the fuel temperature in the return flow.

The ECM lowers the fuel rail pressure to protect the fuel tank from overheating. The fuel temperature sensor in the high pressure pump flange measures the temperature of the fuel being supplied from the fuel tank. If the fuel is too warm the rail pressure is reduced further by the fuel quantity valve.

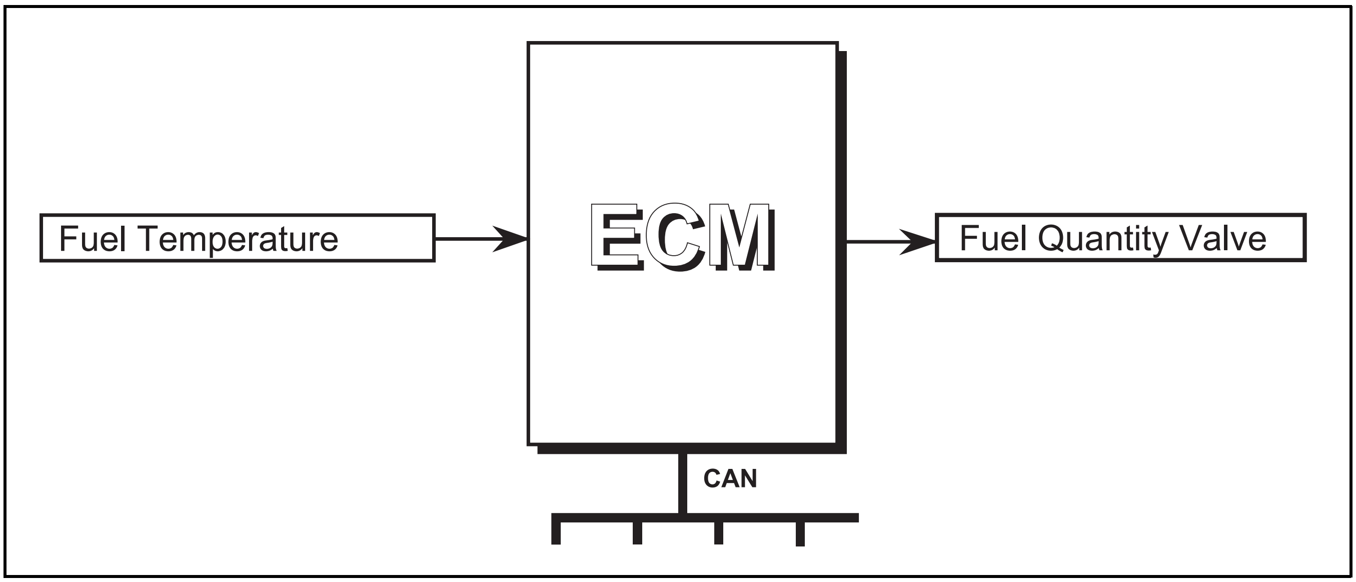


Figure 139 Fuel Tank Protection Function

A/C COMPRESSOR SHUTOFF

The A/C compressor shutoff function switches off the refrigerant compressor to improve the availability of power output when starting-off or accelerating. The ATC module receives a signal from the ECM to switch the refrigerant compressor off or on, depending on load and engine speed.

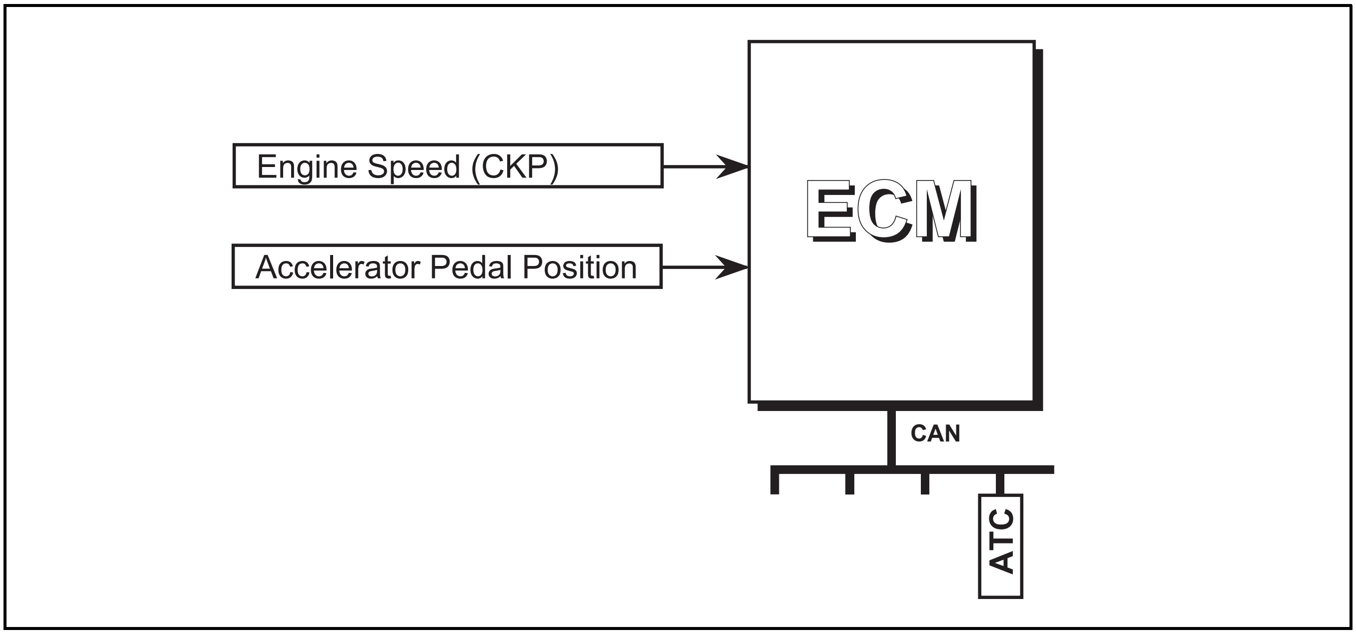


Figure 140 A/C Compressor Shutoff

The refrigerant compressor is switched off if the engine load is higher than 90 % and the engine speed is below 2000 rpm. The compressor is switched back on if the engine load is lower than 90 % or if the engine speed is above 2000 rpm.

EXTERNAL QUANTITY FUNCTION

CAN bus messages may be sent to the ECM by the TCM or ESP modules to request a reduction in engine power. The external quantity function will reduce the injected fuel when the request message is received by the ECM. A hardwired signal may also be transmitted by the ACM requesting engine shutdown in the event of an airbag deployment.

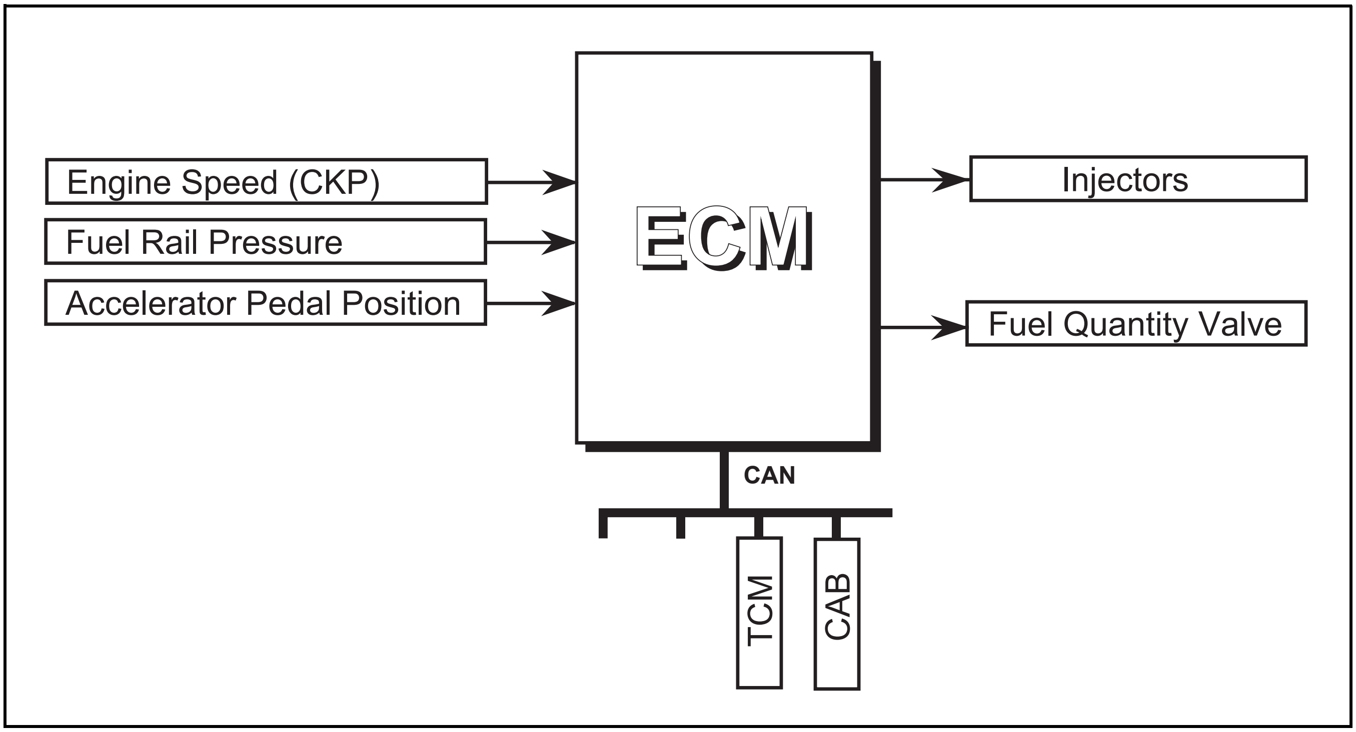


Figure 141 External Quantity Function

ENGINE STOP CONTROL

When the ignition switch is turned to the off position, the ECM detects a voltage drop at circuit 15 (connector 2, pin 19) and shuts off the fuel injectors.
Voltage is still supplied for approximately 6 seconds by the engine control (M) relay in fuse block No.1. During the ECM power-down process, the function of the fuel quantity valve or of the fuel solenoid is alternately checked (one check for each driving cycle). For this purpose the fuel quantity valve is closed briefly or the fuel solenoid is opened briefly. The pressure in the rail must drop in both cases. If this is not the case, a corresponding DTC is stored in the ECM fault memory.

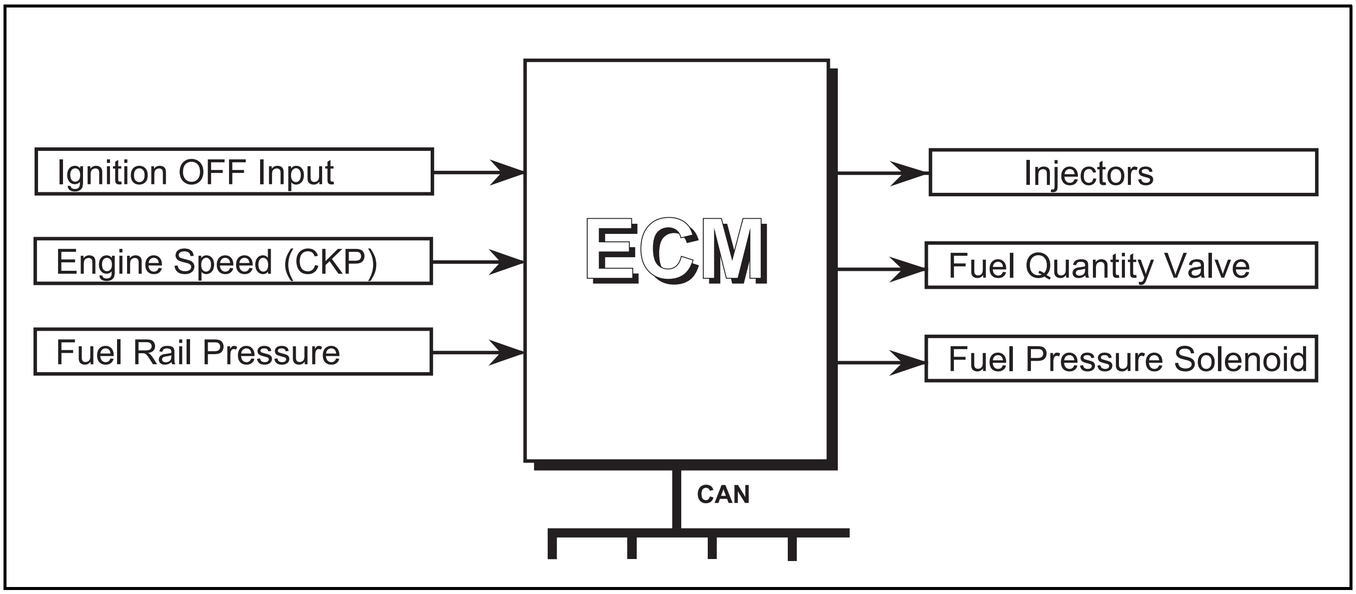


Figure 142 Engine Stop Control

CLOSED LOOP CONTROL

The ECM uses the pressure, temperature and injected fuel quantity values, as well as inputs from the O2 and MAF sensors to perform the following functions for closed loop control and monitoring of emission-related components:

- **Injector quantity drift compensation in the partial load range—**The oxygen content in the exhaust (air-fuel ratio) is calculated from the air mass and injection quantity values and is then compared to the oxygen content measured by the O2 sensor. If the calculated oxygen content differs from the measured oxygen content, there is no correction of the injection quantity but the EGR rate and the boost pressure are adjusted to the actual injection quantity
- **Injector quantity drift compensation at full load—**The ECM limits the maximum injection quantity for engine protection. The ECM compares the actual injection quantity value to a calculated injection quantity based on the O2 sensor and MAF signals. If the comparison shows that the actual injection quantity is too high, it is limited to the maximum permissible injection quantity
- **Air-fuel ratio controlled smoke limiter (full load control)—**The ECM limits the injection quantity based on the measured air mass flow and the calculated EGR rate. As a consequence, the generation of smoke due to an excessive injection quantity is avoided under all operating conditions. At the same time, the O2 sensor signal is used to ensure that the air-fuel ratio does not exceed the permissible value and, if necessary, the injection quantity is adjusted accordingly

MAF Sensor Drift Compensation

The MAF drift compensation function detects and corrects any possible drifting of the MAF sensor by comparing the MAF measured air mass with the projected air mass calculated by the ECM based on various influencing conditions. The MAF sensor drift compensation provides the air mass measurement with the precision needed for the functions mentioned above. The high-precision MAF measurement allows the calculation of the actual injection quantity from the measured air mass and O2 sensor signals in order to correct the injection quantity signal. Due to its high precision, the MAF signal can also be used as an input value for the smoke limiter function.

ON-BOARD DIAGNOSTICS (OBD)

On-Board Diagnosis (OBD) involves:

- Monitoring emission-relevant components and systems during driving
- Detecting and storing malfunctions
- Displaying malfunctions by activating the MIL lamp
- Transferring detected faults to a scan tool in the workshop via a standardized interface

The following systems are monitored electronically:

- Exhaust gas recirculation (EGR)
- Smooth running control (cylinders 1 to 5)
- Fuel system
- ECM and TCM control units
- Glow plug system
- Intake air path

Readiness Code

The readiness code makes it possible to recognize that test procedures (function chains) relating to fault recognition have been completed. The readiness code does not include all the electronic systems. The code is set when the following tests are completed:

- Exhaust gas recirculation (after 15 seconds)
- Fuel system (after 35 seconds)
- Smooth running control (after 70 seconds)

Warm-Up Cycle

Systems that are not constantly monitored are checked only when a warm-up cycle is executed. One warm-up cycle consists of:

- Engine start
- Temperature increase higher than 4.5 °C (40.1 °F)
- Final temperature higher than 60 °C (140 °F)
- Engine switched off

Driving Cycle

One driving cycle consists of:

- Engine start
- 35 seconds at idle
- Engine switched off

Fault Detection

The following faults and error states are detected:

Signals above or below the limit value (open circuits, short circuits, faulty sensor)

- Plausibility of signals
- Function chains with faults
- Fault messages over the CAN data bus (ECM and TCM control modules)

Fault Storage

Faults detected are stored in the fault memory as a fault together with freeze frame data. If the fault is not confirmed in the subsequent driving cycle, it is erased. Emission-relevant faults are always entered, they have a high priority.
An emission-relevant fault is erased from the fault memory after 40 fault-free driving cycles.

Fault Freeze Frame Data/Operating Conditions

Certain engine parameters are stored in memory when a fault is detected. Although the data stored depends on the particular fault, the following parameters are usually stored by the ECM:

- Fault code
- Vehicle speed
- Engine speed
- Coolant temperature
- Charge air temperature
- Boost pressure
- Engine load

Consequential Faults

If a faulty signal is detected and the corresponding fault code is stored, all the tests in which the signal is required as a comparative parameter are aborted. This ensures that no consequential faults are stored.

Malfunction Indicator Lamp (MIL)

If an emission-relevant fault occurs in two consecutive driving cycles, or if limp-home mode is activated for a second time, the MIL lamp in the instrument cluster lights up. In the event of a fault which could damage the catalytic converter, the MIL lamp flashes.
The MIL lamp is switched off automatically after 3 or 4 consecutive fault-free driving cycles.

Reading out the Fault Memory

The ECM is linked via the K-LINE with the data link connector. Stored faults can be retrieved and erased using the factory diagnostic scan tool or a standard readout unit (generic scan tool) with ignition "ON" or with the engine running via the data link connector.

The fault memory is not erased if the vehicle battery is disconnected.

ECM Power-Down

After faults are erased it may be necessary to wait until the processor has completed its power-down sequence after the ignition is switched off. The processor power-down sequence lasts approximately six seconds.
The readiness code should be set manually after every workshop visit.

ECM REPLACEMENT

Access to the FDOK mainframe (available through the Star Center) is required in some cases when replacing the new engine control module (ECM). In most cases, technicians will still be able to replace the ECM by performing the usual automatic replacement procedure. However, access to the FDOK mainframe is required if the ECM has to be replaced because there has been a part number change (new version ECM), or if the ECM is damaged and the diagnostic tool cannot download the parameters, or if a special option is being added or modified (air conditioning, cruise control, different axle ratio). The Star Center will access FDOK in order to enter the changes performed (screen update) and create a new software calibration number (SCN). A new code is then entered to the ECM using the diagnostic scan tool.

SOFTWARE CALIBRATION NUMBER (SCN)

The Software Calibration Number (SCN) is part of a new coding method for engine and automatic transmission control modules (production breakpoint with the OM647 engine as of September 2003)

With 2004 vehicles, American legislation requires for all flashable emission-relevant control modules, the Software Calibration Number (SCN) as an unequivocal identification of the control module version installed on the vehicle. The goal is to be able to easily detect variations from the approved SCN.

The SCN is a 16-digit number. It identifies both the control module software as well as the coding conforming to the vehicle. The SCN consists of the following data frames:

- Position 1-10 Part number of electronic control module
- Position 11-12 Plant identification code
- Position 13-16 Serial code

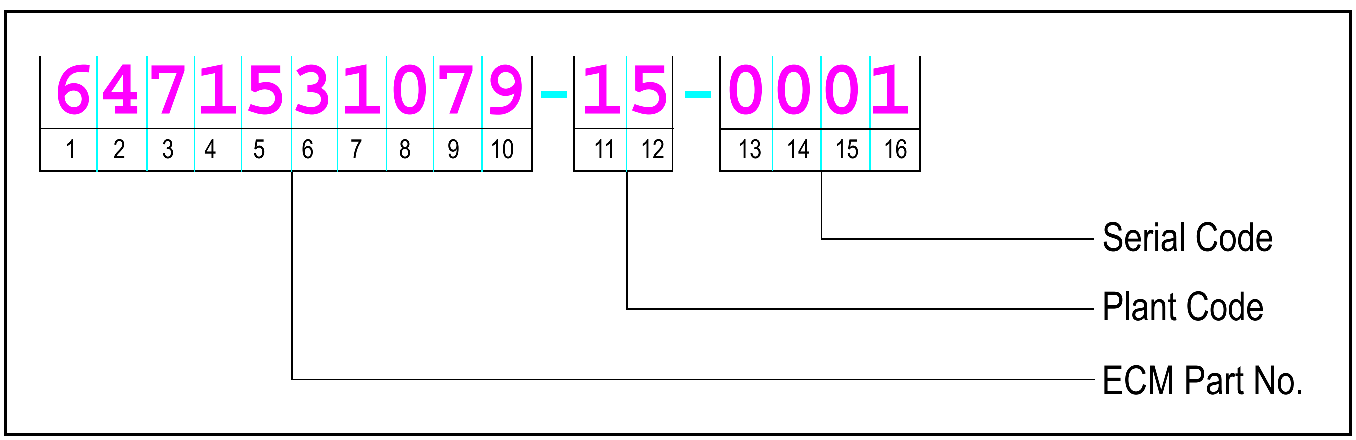


Figure 143 Software Calibration Number (SCN)

The SCN codes and coding strings are available through the FDOK mainframe system and can be written into the control module with the diagnostic scan tool. The SCN coding procedure is performed in the following steps:

1. The vehicle identification number (VIN) and the part number of the control module to be coded are read out with the diagnostic scan tool.
2. The vehicle information is provided to the Star Center. The Star Center will enter the VIN and the CONTROL MODULE OBJECT NUMBER in the FDOK mainframe. In the event that the vehicle is retrofitted or converted, the new retrofit codes must be entered additionally.
3. The FDOK mainframe provides the following data in the response screen:
   - SCN determined
   - Coding string determined
   - Check digit determined (for safeguarding input and coding procedure)
4. The FDOK data is entered using the diagnostic scan tool.
5. After the entry is made, the diagnostic scan tool verifies on the basis of the check digit whether the entry is correct. If errors are found in the entry, an appropriate error message is displayed.
   The diagnostic scan tool also verifies whether the coding is to be performed on the same vehicle and control module that was present when determining the VIN and part number. If the VIN or the part number of the control module to be coded differs, an appropriate error message is displayed and the coding operation cannot be performed.
   The SCN and the coding string are written into the control module only if all the checks have been completed without errors. The coding procedure will then be completed in full and successfully. After this, the learning process of the drive authorization system can be performed.

MODULE 5 ECM OUTPUTS

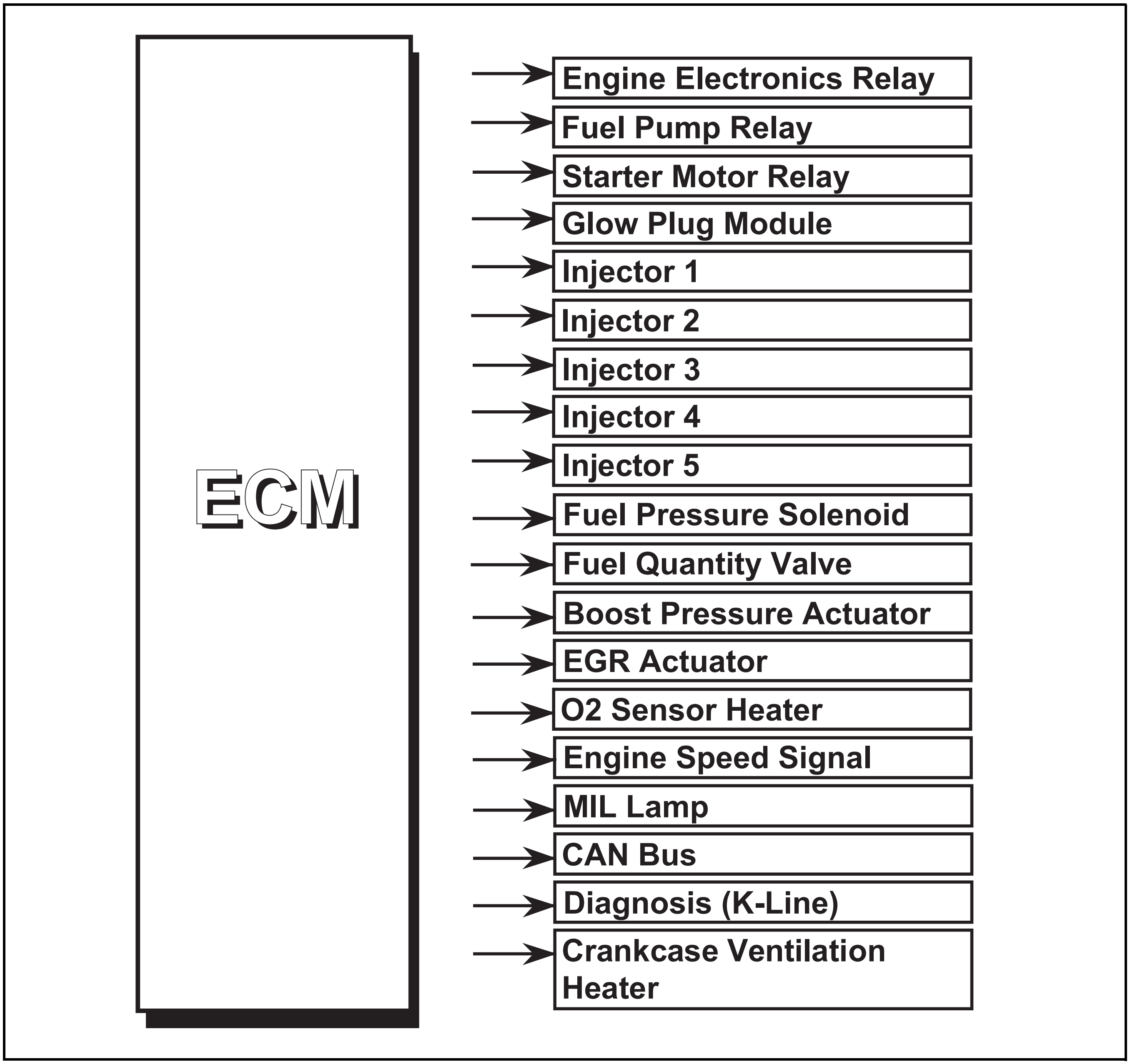
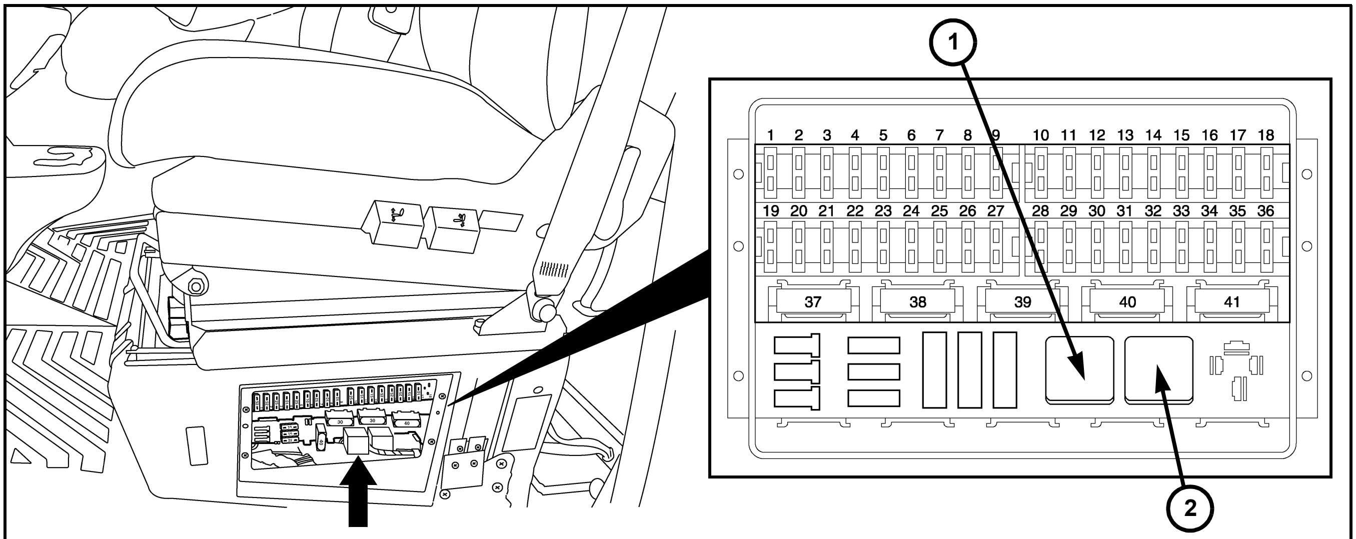


Figure 144 ECM Outputs

RELAYS

The ECM has control of the engine control (M) relay, fuel pump relay and starter relay. The engine control (M) relay is located in fuse block No.1. The fuel pump relay and starter relay are located in fuse block No.2.



1	Fuel Pump Relay	2	Starter Relay

Figure 145 Fuel Pump Relay

Engine Control (M) Relay

When the ignition is switched to the ON position, the ECM grounds the timer module within fuse block No.1, which activates the engine control (M) relay. The ignition circuits to the ECM are switched on.
When the ignition is switched off, the timer module continues to supply power to the M relay coil for six seconds (ECM power-down).

Electric fuel pump relay

The ECM grounds the fuel pump relay and the fuel pump is switched on. If the engine is not started, the ECM switches off the fuel pump relay after approximately 30 seconds.

Starter relay

The ECM grounds the starter relay to activate the starter motor when the following conditions have been met:

- Ignition key in start position
- Selector lever in position P or N
- Engine speed = 0 rpm
- CAN message from SKREEM authorizing the starting event

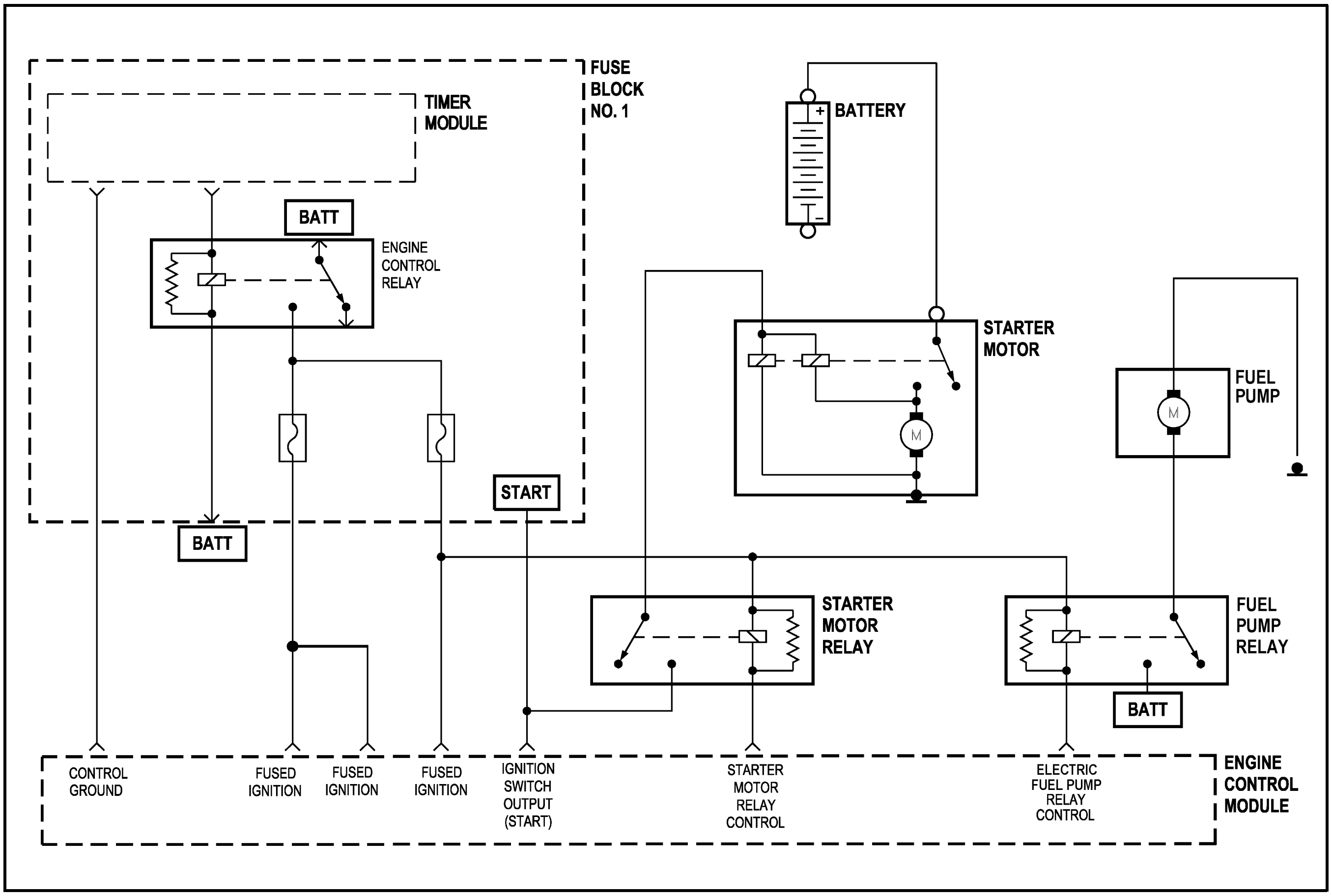


Figure 146 Schematic of ECM Controlled Relays

GLOW PLUG MODULE

The glow plug module activates the glow plugs to preheat the combustion chambers. Two relays within the module provide power to the glow plugs. With the ignition ON, a control signal is transmitted by the ECM to the glow plug module. If no data transfer takes place with the ECM, preglowing is switched off after two seconds.

The operation of the glow plugs is divided into three phases (Figure 147):

- Preglow phase
- Glow phase
- Afterglow phase

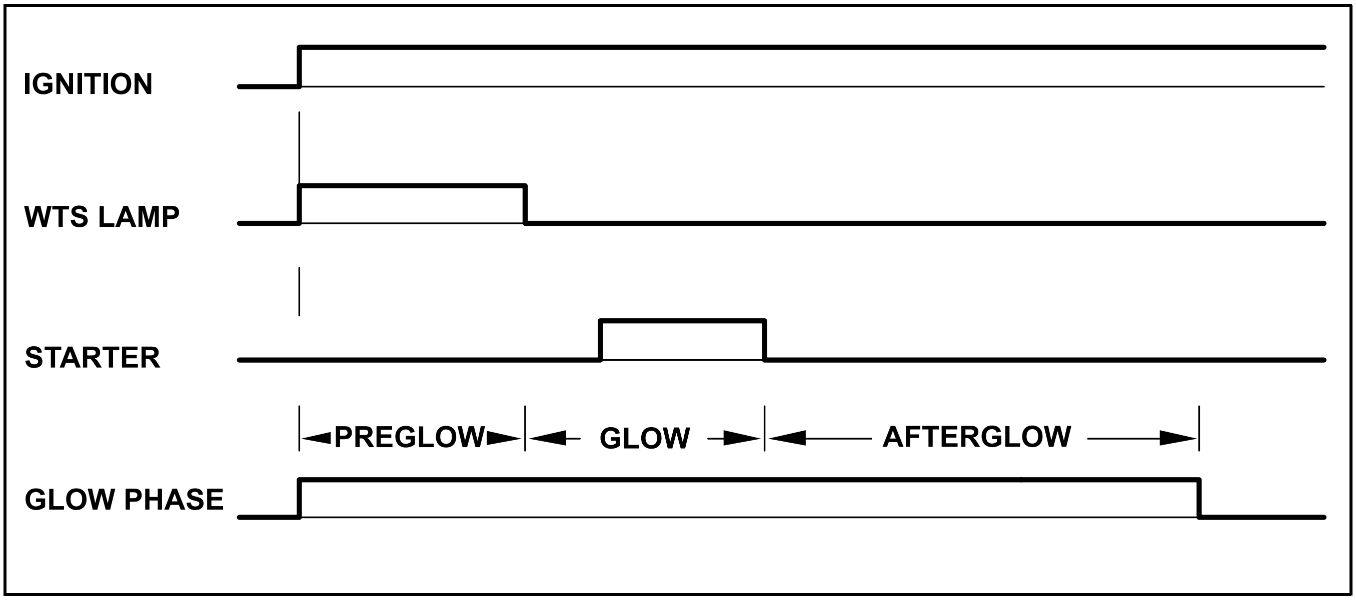


Figure 147 Glow Phases

Preglow Phase

The combustion chambers are preheated in order to achieve the ignition temperature required for burning of the air/fuel mixture. With the ignition on, the glow plug module and the preglow indicator lamp in the instrument cluster are activated by the ECM depending on coolant temperature. The glow plug module supplies the current required to activate the glow plugs.

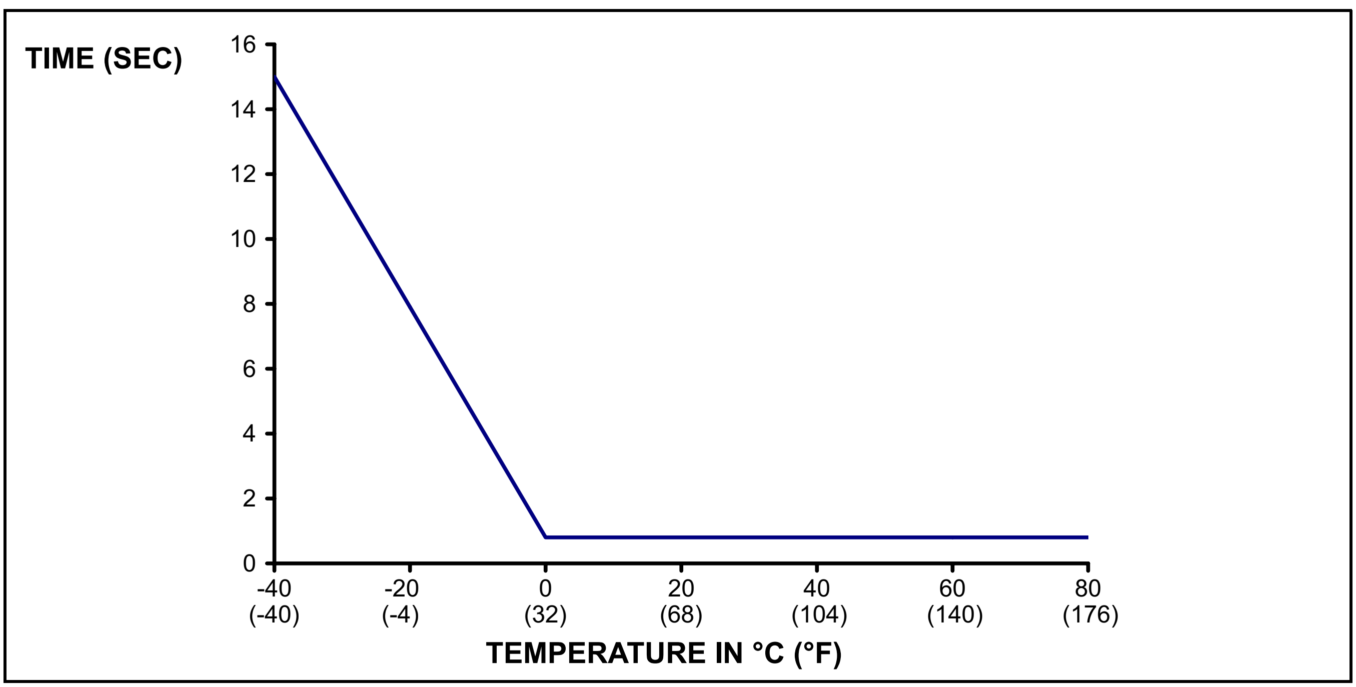


Figure 148 Preglow Phase

Glow Phase

The glow phase starts once the glow indicator lamp goes out and the ignition switch is turned to the engine start position. An engine start signal is supplied to the glow plug module by the ECM, and the glow plugs continue to be supplied with current.

Afterglow Phase

The ECM determines the afterglow period after engine start depending on coolant temperature. Afterglow is activated for 30 seconds in the event that no signal is received from the coolant temperature sensor.

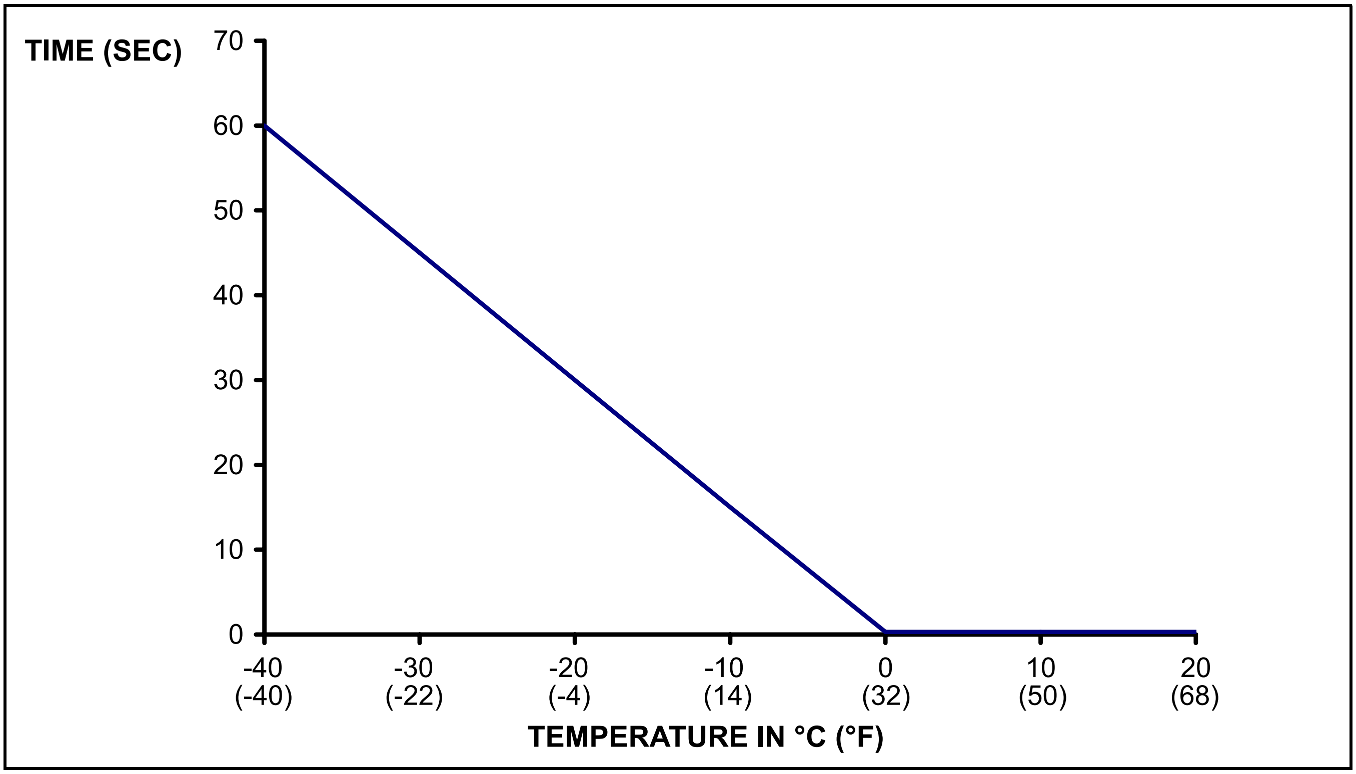


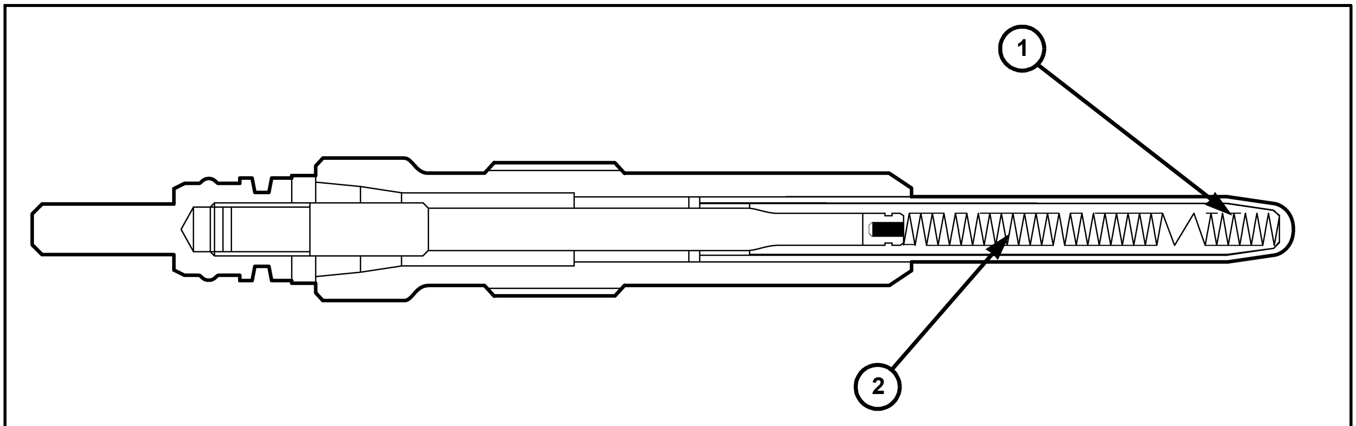
Figure 149 Afterglow Phase

Afterglow provides the following benefits:

- Improves engine warm-up
- Prevents exhaust smoke after a cold start
- Stabilizes the cold start speed

Glow Plugs

The glow plugs are located in the combustion chamber. The glow plug consists of a housing with a threaded fitting and an interference-fit glow tube. The glow tube contains the heating element. The heating elements is comprised of the heating winding and control winding, which are connected in series (Figure 150). The windings are surrounded by compressed magnesium oxide (MgO) powder. MgO powder is widely used as a filling for electrical heating elements for applications in contact with air or liquids. The MgO powder forms a layer between the windings and the outer sheath.



1	Heating Winding	2	Control Winding

Figure 150 Glow Plug Heating Element

Operation

The resistance of the heating winding is virtually unaffected by temperature. The control winding however, has positive temperature coefficient (PTC) properties. When the preglow system is activated, a current between 8-25A flows through each glow plug. The amount of current depends on the actual temperature of the glow plug. The heating winding (1) heats up the glow plug. The control winding (2) increases its resistance as the temperature rises, and limits the current. The glow plugs are protected this way from overloads.

The glow plugs reach the temperature needed for ignition of 850°C (1562°F) in 4 seconds. The glow plug temperature is also limited to a non-critical level to allow activation for up to 3 minutes following engine start.

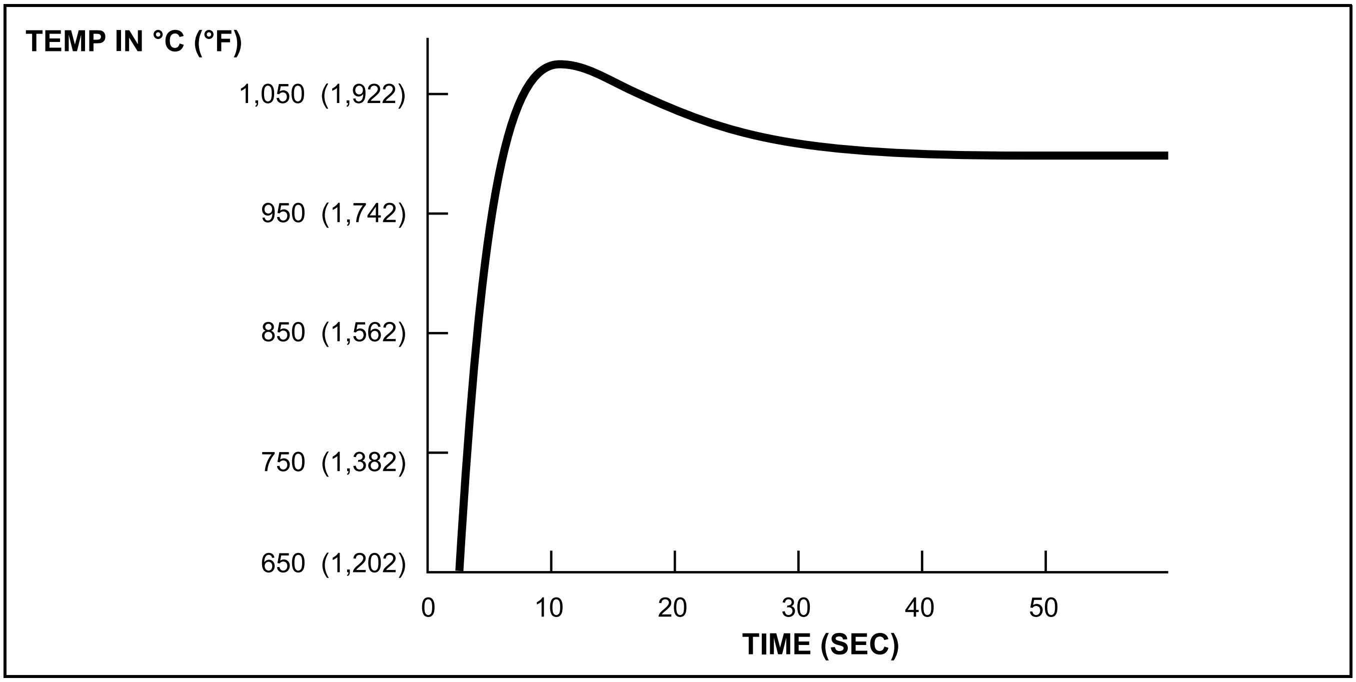


Figure 151 Glow Plug Temperature vs. Time

ACTIVITY 5.1 GLOW PLUG SYSTEM CHECK

The purpose of this activity is to familiarize the students with the glow plug system components and diagnostics.

1. Locate the C2 connector at the glow plug control module, check resistance through each glow plug to ground.

	Resistance	Wire Size/Color
Glow Plug #1:	*1 ohm*	*14 bk/dg*
Glow Plug #2:	*1 ohm*	*14 bk/yl*
Glow Plug #3:	*1 ohm*	*14 bk/rd*
Glow Plug #4:	*1 ohm*	*14 bk/vt*
Glow Plug #5:	*1 ohm*	*14 bk/bl*

2. What would incorrect resistance values indicate?
   Shorted/Open glow plug. Additional resistance in the circuit.

3. Are their any special tools associated with the Sprinter glow plugs?
   Glow plug connector pliers. Miller 9286

4. Disconnect #1 glow plug. Check for DTCs and list below.
   Glow plug faulty cylinder #1

5. List any other DTCs related to the glow plug system.
   Glow plug module faulty:1482-001/002/003/008; 2132-001/002/008
   Glow plug faults: 2133-001; 2134-001; 2135-001; 2136-001; 2137-001
   Preglow lamp: 1480-1; Preglow fault: 2537-1/2/8 ; Module: 2538-2/4/8

6. How does the glow plug control module communicate with the ECM and diagnostic scan tool? List wire color, connector, and pin number.
   18 bk/rd, C1, pin 2

FUEL OUTPUTS

INJECTORS

The ECM controls the injection process separately for each cylinder and each crankshaft revolution. The injectors incorporate fast-switching solenoid valves required for high-speed activation.

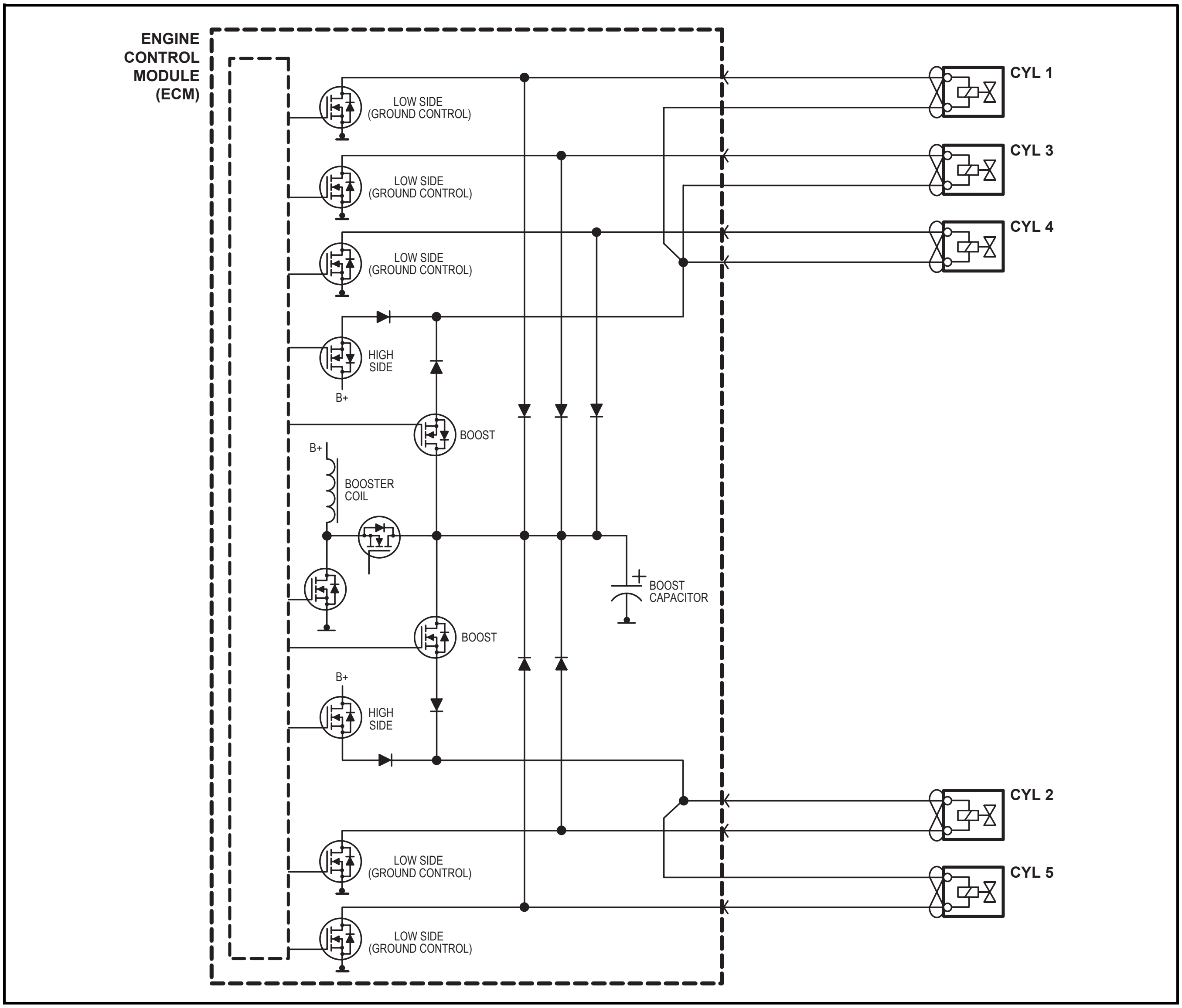


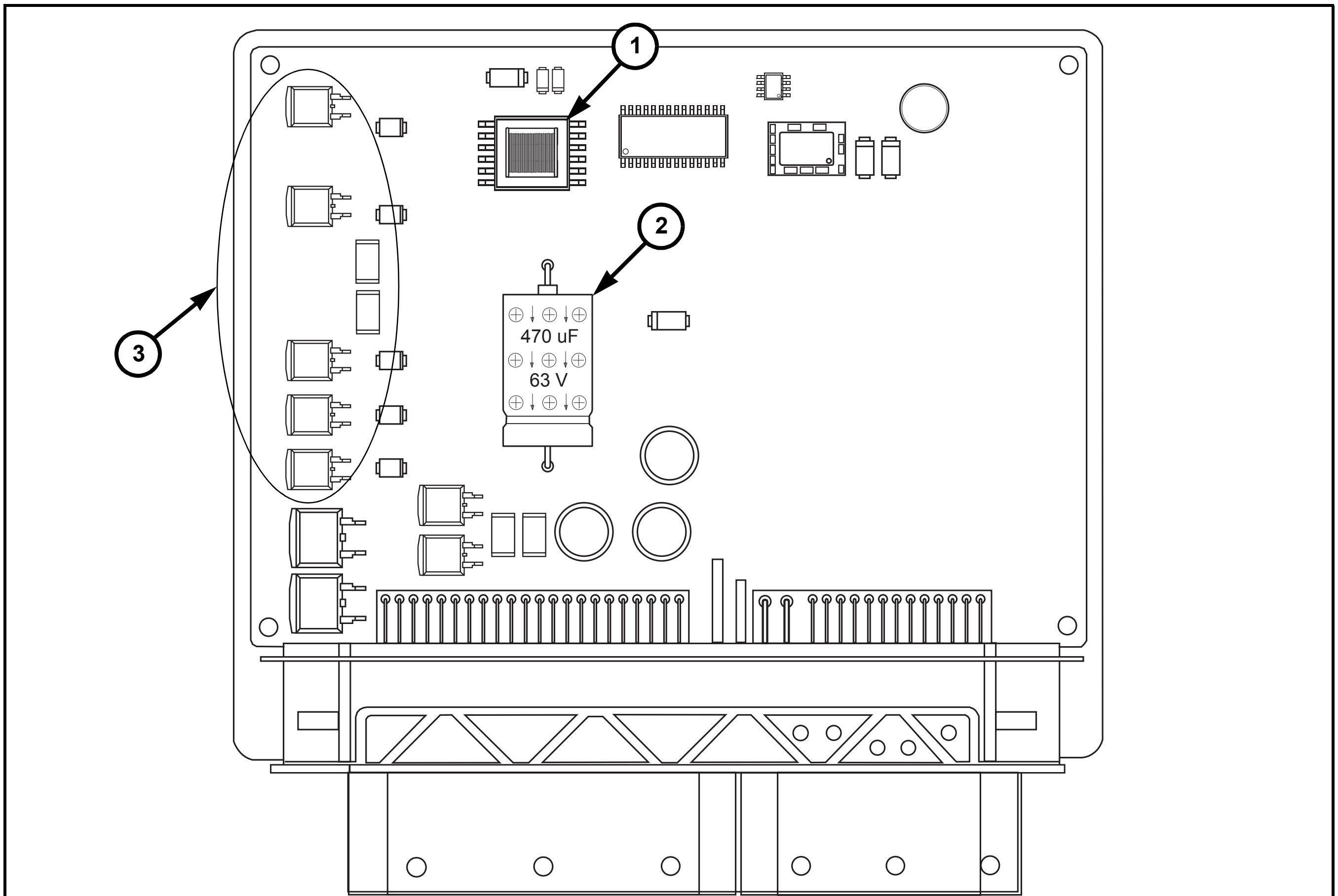
Figure 152 Injector Circuit Schematic

The fuel injectors are arranged in two banks (Figure 152). Bank 1 is composed of injectors 2 and 5, sharing a common high side. Bank 2 is composed of injectors 1, 3 and 4 sharing another high side. The ECM controls the power and ground side of each injector solenoid via metal-oxide-semiconductor field effect transistors (MOSFETS). The low side (ground) is used to control the activation of each injector individually.

High Voltage Drive Circuit

In order to inject small pilot quantities of approximately 0.0015 cm^3/stroke under high pressure conditions, the injector solenoid valves must switch quickly and reliably within 200 microseconds. To achieve this, the injector coil must be triggered with steep current flanks. This requires high voltages being made available in the ECM.

With pilot injection, main injection and post injection, the number of injector activations have increased significantly. At idle speed for example, the ECM activates the injectors 85 times every second. Enough energy needs to be quickly stored by the ECM to properly activate the injectors within these time constraints. The ECM contains a special aluminum electrolytic capacitor (boost capacitor) and a ferrite core inductor (booster coil) to ensure the fast switching of the fuel injector solenoid valves. The capacitor has a rated capacitance of 470 µF and a nominal voltage of 63V. Once charged, the capacitor supplies the necessary current to energize the solenoids. Current peaks of up to 30 A at high frequencies (kilohertz range) are produced during the unloading and charging phases of the capacitor.

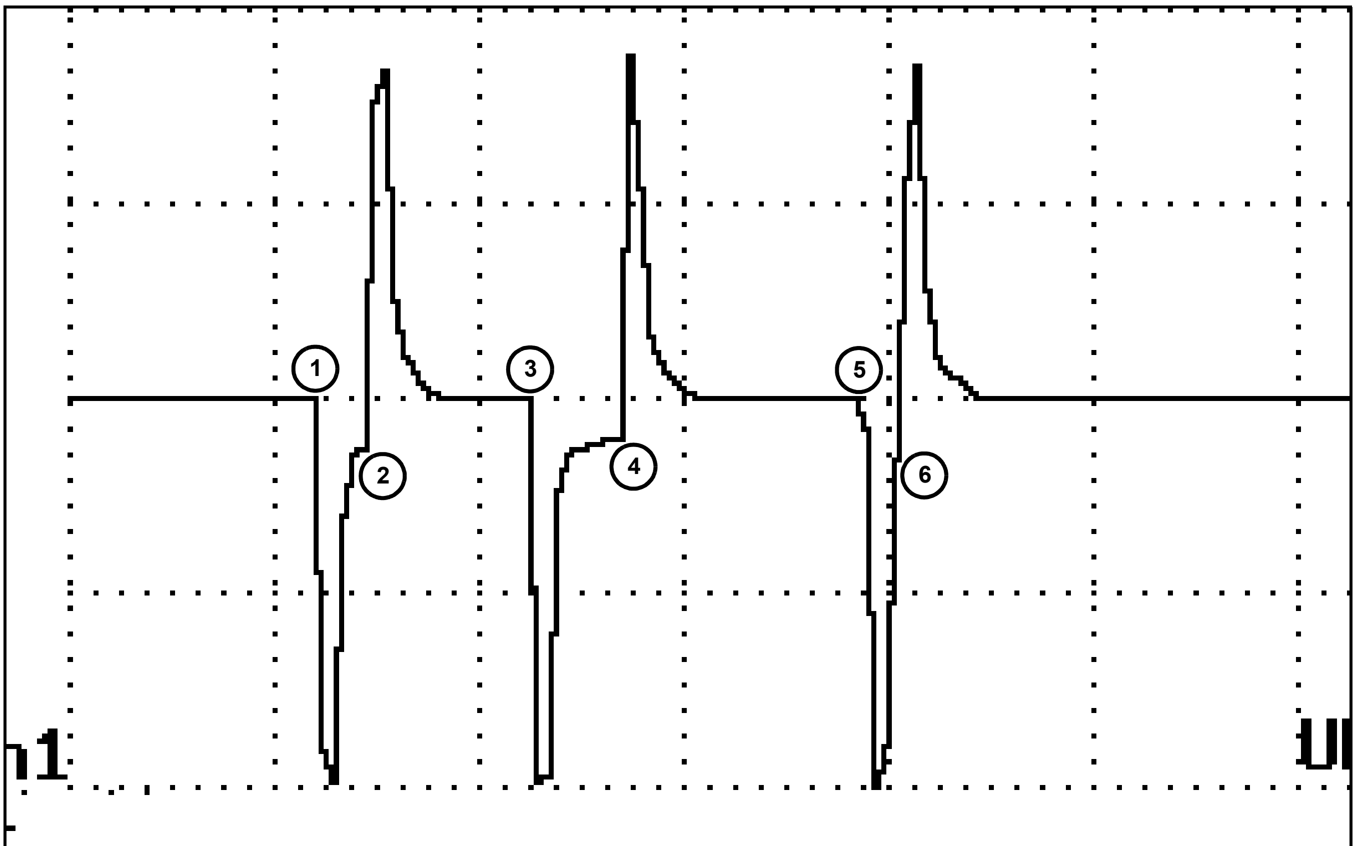


1	Booster Coil	3	Injector Ground Control MOSFETs
2	Boost Capacitor		

Figure 153 ECM Printed Circuit Board Layout

By delivering the energy from the capacitor to the injector solenoid, the control current required to open the injector is reached within a few microseconds. Afterwards the voltage drops approximately to the electrical system level and the current flow is maintained by the vehicle's battery.

The high voltages induced in the injector coil and booster coil are used to charge the capacitor. The capacitor is recharged with approximately 80 volts during the periods in which the injector solenoid is switched off (for most of the duration of the working, exhaust and compression strokes).



1	Injector Solenoid is Energized For Pilot Injection
2	Injector Solenoid is De-Energized (Inductive Kick Charges Boost Capacitor)
3	Injector Solenoid is Energized For Main Injection
4	Injector Solenoid is De-Energized (Inductive Kick Charges Boost Capacitor)
5	Injector Solenoid is Energized For Post-Injection
6	Injector Solenoid is De-Energized (Inductive Kick Charges Boost Capacitor)

Figure 154 Voltage Waveform, Injector Activation

Injector Output Stage Components

The injector output stage contains 11 power transistors (MOSFETs). All the power transistors are identical and can each handle loads of up to 55 A. According to their use, the transistors can be classified as follows:

- **Common-Circuit MOSFETs—**Applies to power transistors controlling a circuit shared by all injectors, such as the booster coil control and booster coil unload MOSFETs (2 transistors total).
- **Bank-Specific MOSFETs—**Applies to power transistors unique to a bank of injectors, such as the high side and boost MOSFETs (4 transistors total).
- **Injector-Specific MOSFETs—**Applies to power transistors that are unique to an injector, such as the low side MOSFETs (5 transistors total).

The output stage power transistors are controlled in a specific sequence to achieve all injection phases (preinjection, main injection and post-injection).

Activation Sequence	**0**	**1**	**2**	**3**	**4**
High Side Mosfet	OFF	OFF	ON	OFF	ON
Low Side Mosfet	OFF	ON	ON	ON	OFF
Boost Mosfet	OFF	ON	OFF	OFF	OFF
Booster Coil Control Mosfet	OFF	OFF	ON	OFF	OFF
Booster Coil Unload Mosfet	OFF	OFF	OFF	ON	OFF
STAGES					
Cylinder Overlap (Injector At Rest)	X				
Boost Capacitor Unload (Current Rise)		X			
Break-Away Current			X	X	
Injector De-Energized (Capacitor Recharge)					X
Holding Current			X	X	
Capacitor Reloading			X		X

Table 1 MOSFET Activation Sequence

MOSFET Activation Stages

The following stages are achieved with the power transistors:

- Cylinder Overlap (Injector At Rest)
- Boost Capacitor Unload (Current Rise)
- Break-Away Current
- Injector De-Energized (Capacitor Recharge)
- Holding Current
- Capacitor Reloading

Three power transistors are directly involved in the activation of each injector. Each injector has a low side MOSFET for ground control and shares a high side MOSFET for battery power. A boost MOSFET (one for each bank) allows the energy stored in the boost capacitor to flow through the injector solenoid, if there is a complete circuit to ground (injector grounded).

Two additional power transistors are involved indirectly, and are used to assist with the charging of the boost capacitor. The booster coil control MOSFET controls the buildup and collapse of the booster coil's magnetic field. The booster coil unload MOSFET allows the capacitor to be charged with the induced high-voltage produced by the collapse of the booster coil's magnetic field.

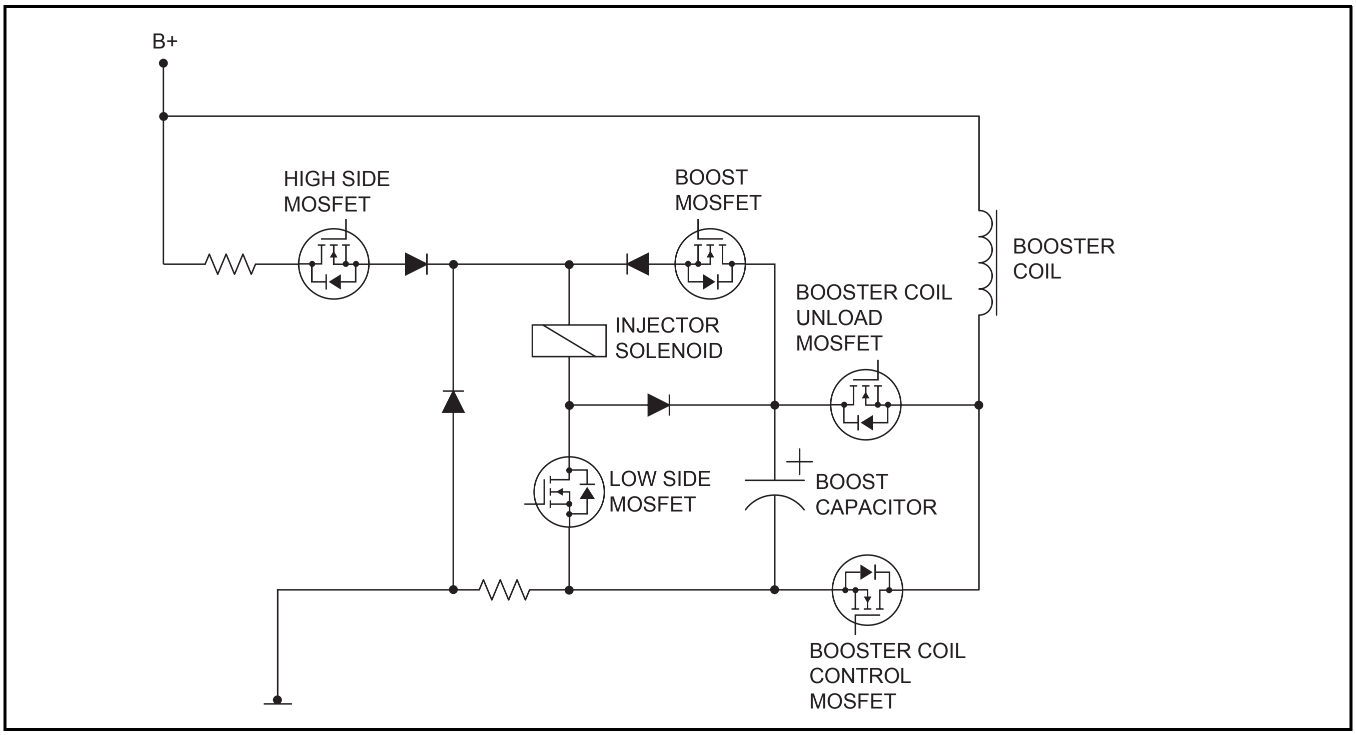


Figure 155 Injector Output Stage

Power transistors can be thought of as ON-OFF switches. The MOSFETS in the following schematics are shown as switches for the purpose of clarification.

Cylinder Overlap Stage (Injector At Rest)

In the cylinder overlap stage all transistors are switched off. No current flows in the circuit.

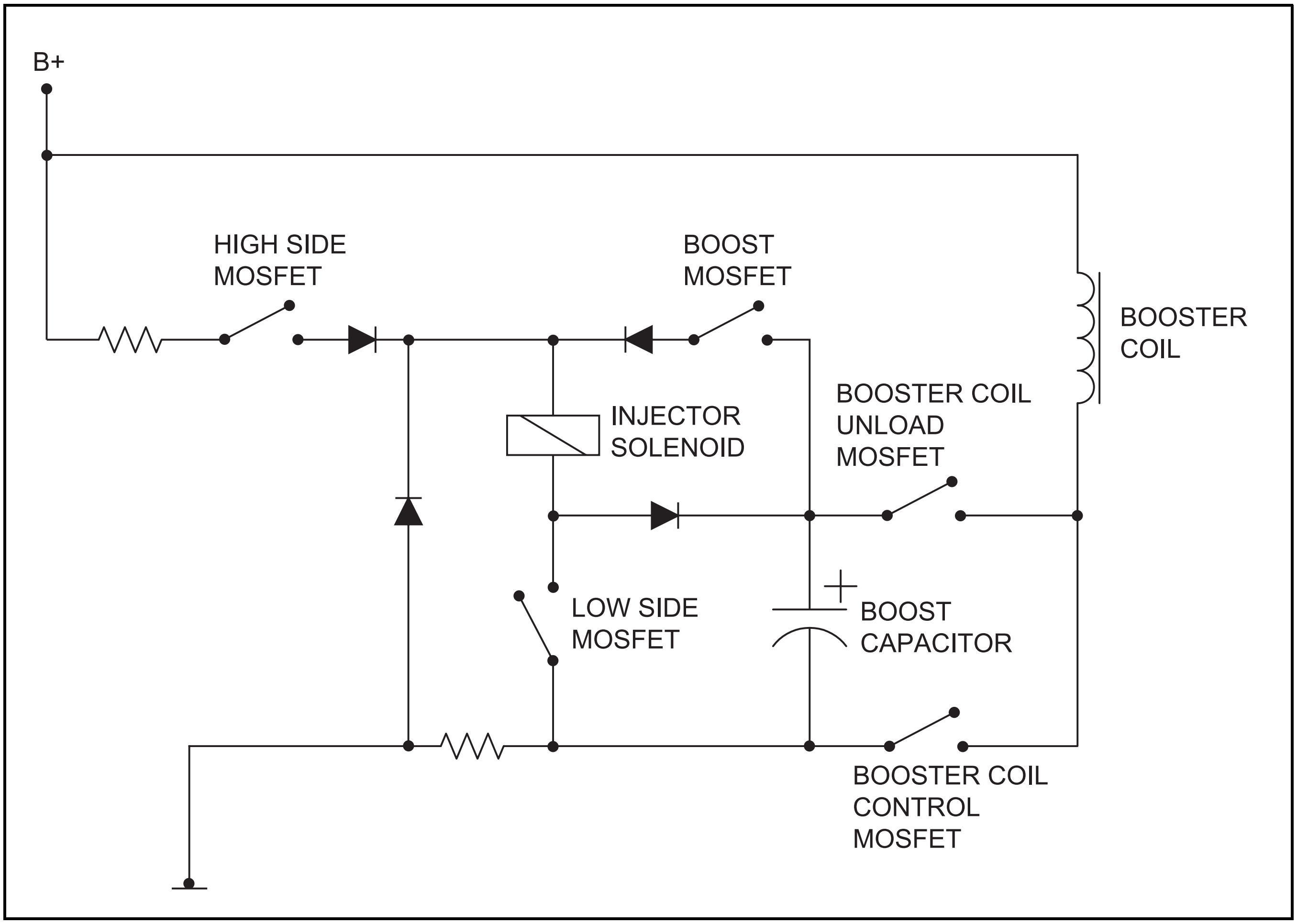


Figure 156 Cylinder Overlap Stage

Boost Capacitor Unload Stage (Current Rise)

Used in: Pilot Injection Phase, Main Injection Phase and Post-Injection Phase

In the boost capacitor unload stage, the low-side and boost MOSFETs are switched on. The energy stored in the boost capacitor is released and flows through the injector solenoid. The low-side MOSFET completes the solenoid path to ground. The capacitor unloads producing a steep rise in current. The injector solenoid is activated with approximately 80 volts.

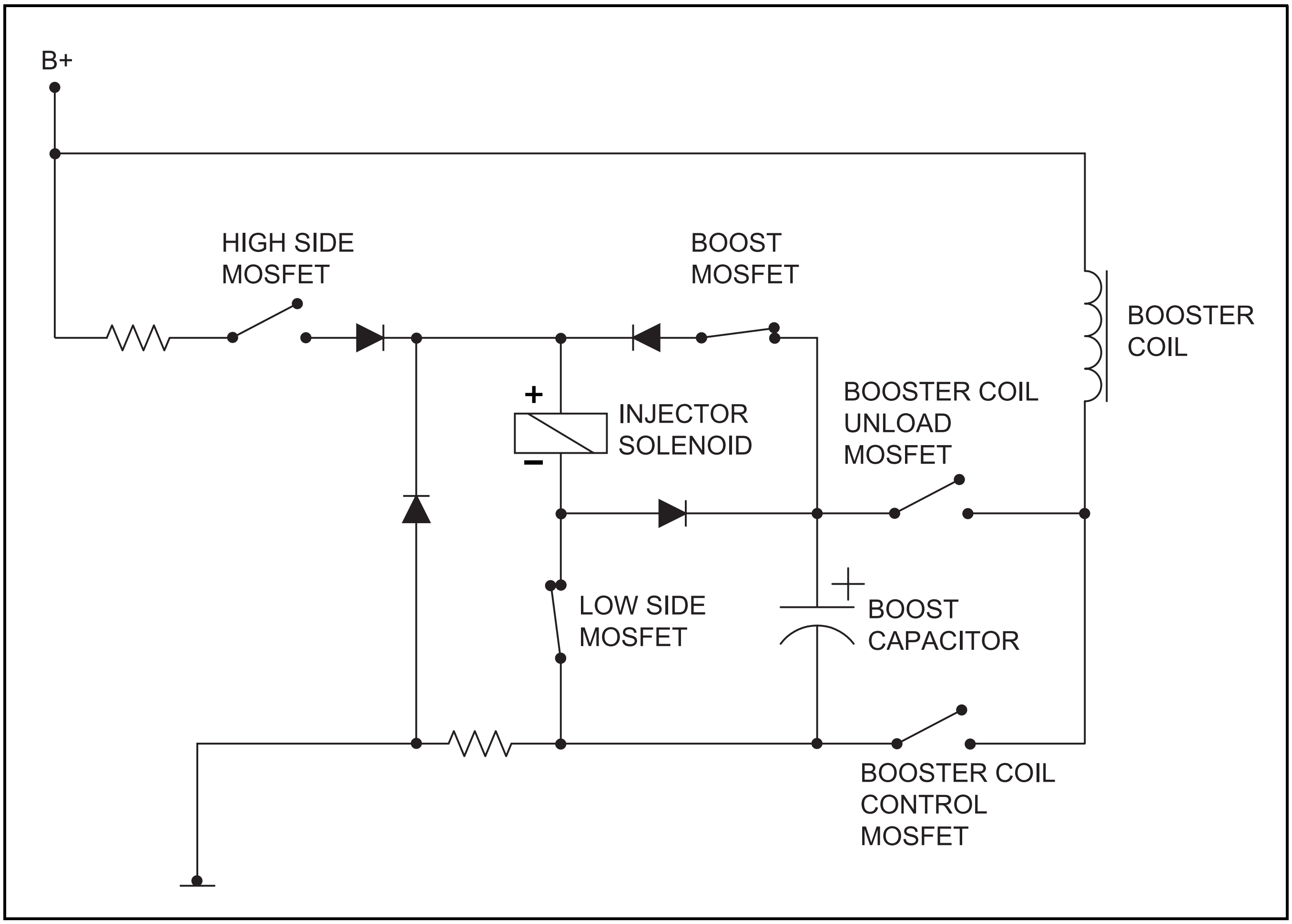


Figure 157 Boost Capacitor Unload Stage

Break-Away Current Stage

Used in: Pilot Injection Phase, Main Injection Phase and Post-Injection Phase

In the break-away current stage, the boost MOSFET is switched off and the high-side MOSFET is switched on. The low-side MOSFET is still on. Current from the vehicle's electrical system (B+) flows into the solenoid. During this phase, a two-step action circuit holds the current to a value of approximately 20 A by switching the high-side MOSFET on and off as required. The switching action maintains the current level, which guarantees a safe opening of the injector.

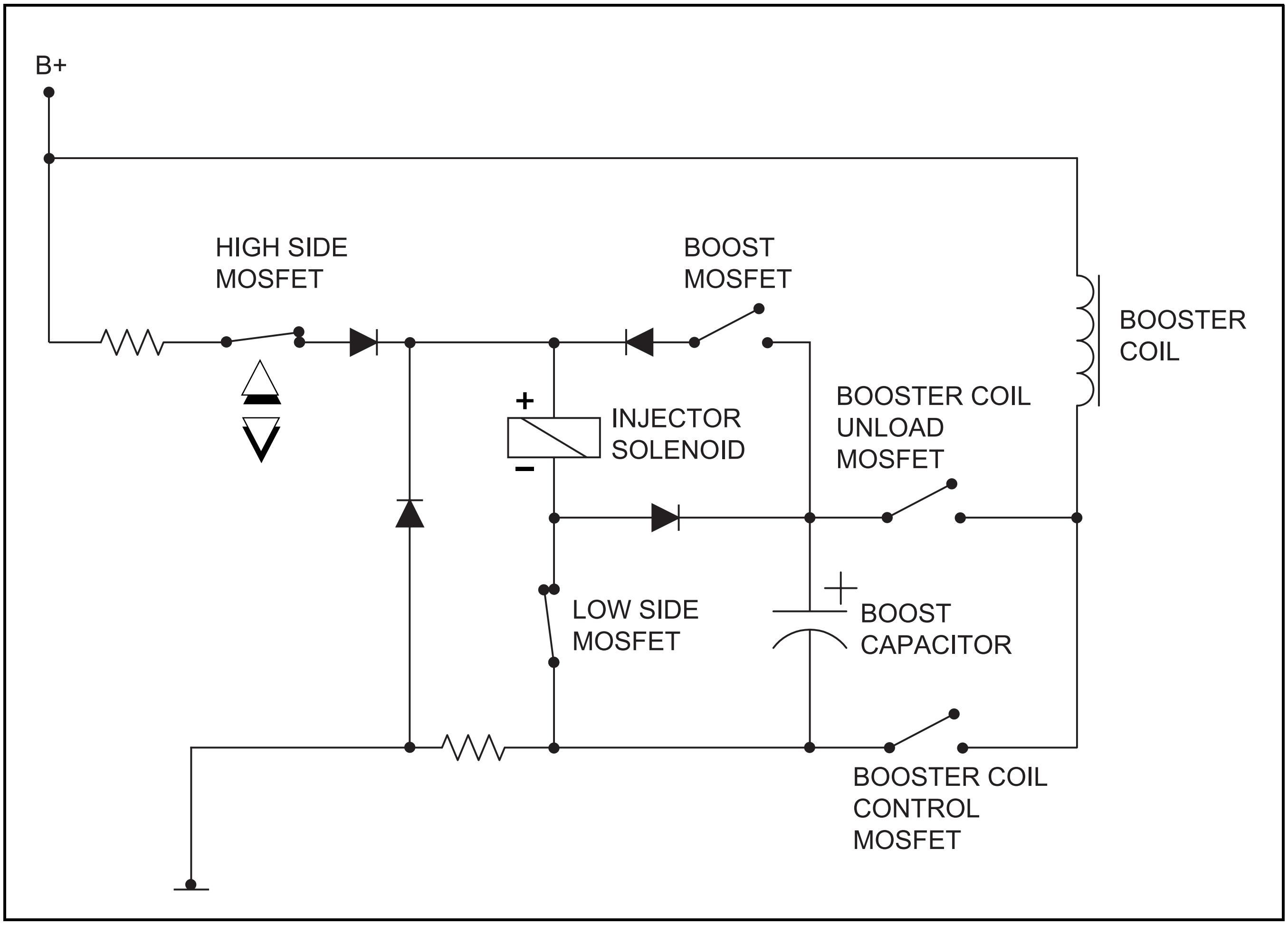


Figure 158 Break-Away Current Stage

Injector De-Energized Stage (Capacitor Recharge)

Used in: Pilot Injection Phase, Main Injection Phase and Post-Injection Phase

In the injector de-energized stage, the high-side MOSFET remains on and the low-side MOSFET is switched off. The low-side MOSFET removes the ground, interrupting the flow of current to the injector solenoid. A high-voltage inductive kick with reversed polarity is produced in the solenoid. Current flows back through the diode and charges the boost capacitor.

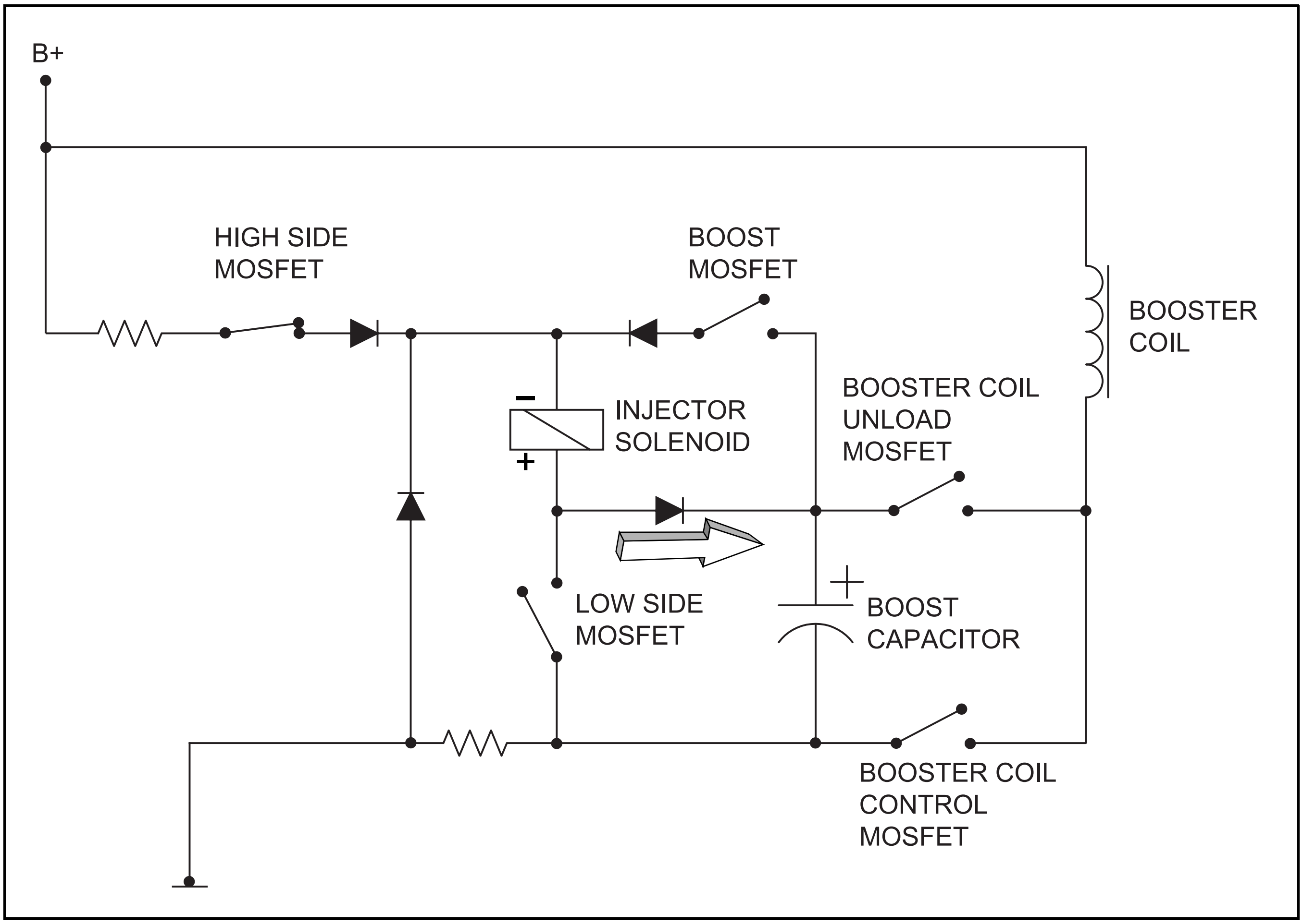


Figure 159 Injector De-Energized State

Holding Current Stage

Used in: Main Injection Phase

In the holding current stage, the high-side MOSFET stays on and the low-side MOSFET is switched on. The current level is lowered to approximately 12 A by switching the high-side MOSFET off and on. The current is kept between two levels, which is sufficient to hold the solenoid open without wasting electric power, due to the smaller magnetic air gap. The current level is reduced to lower system energy requirements and to speed the flux decay when the ECM is turned off.

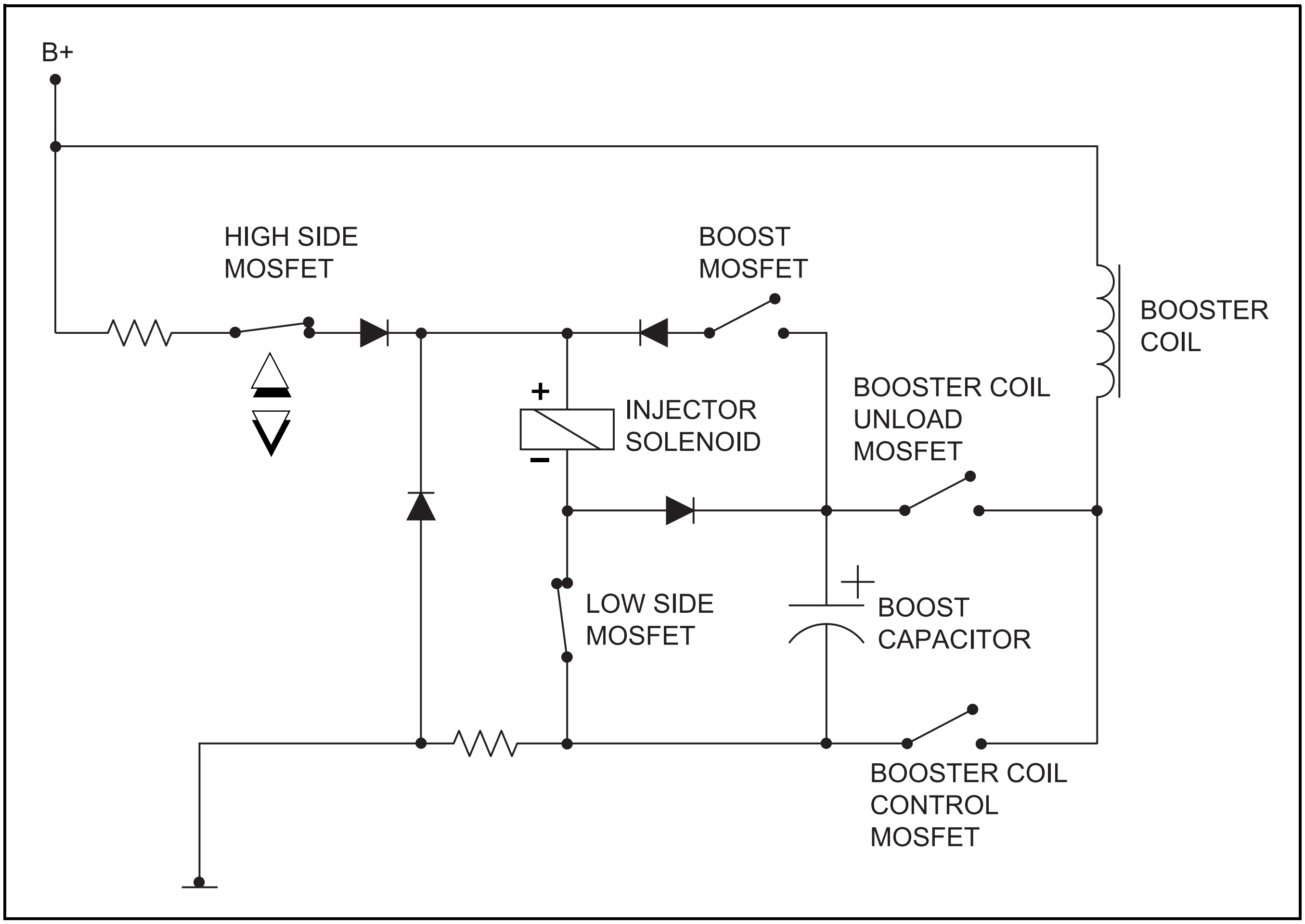


Figure 160 Holding Current Stage

Capacitor Reloading Stage

In the capacitor reloading stage, the booster coil control MOSFET is switched on to build the booster coil's magnetic field. When the booster coil control MOSFET is switched off, the magnetic field collapses and a high voltage is induced. The booster coil unload MOSFET is switched on, allowing the boost capacitor to store the energy.

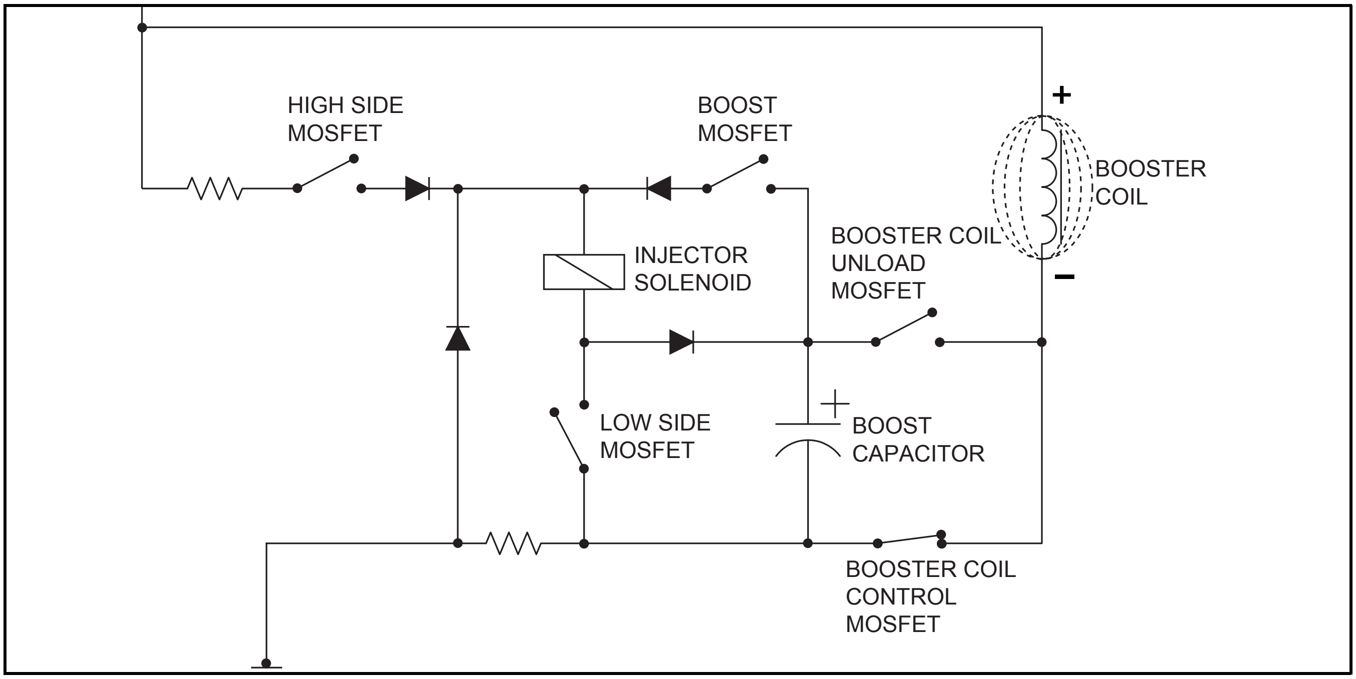


Figure 161 Capacitor Reloading Stage, Build-up of Booster Coil's Magnetic Field

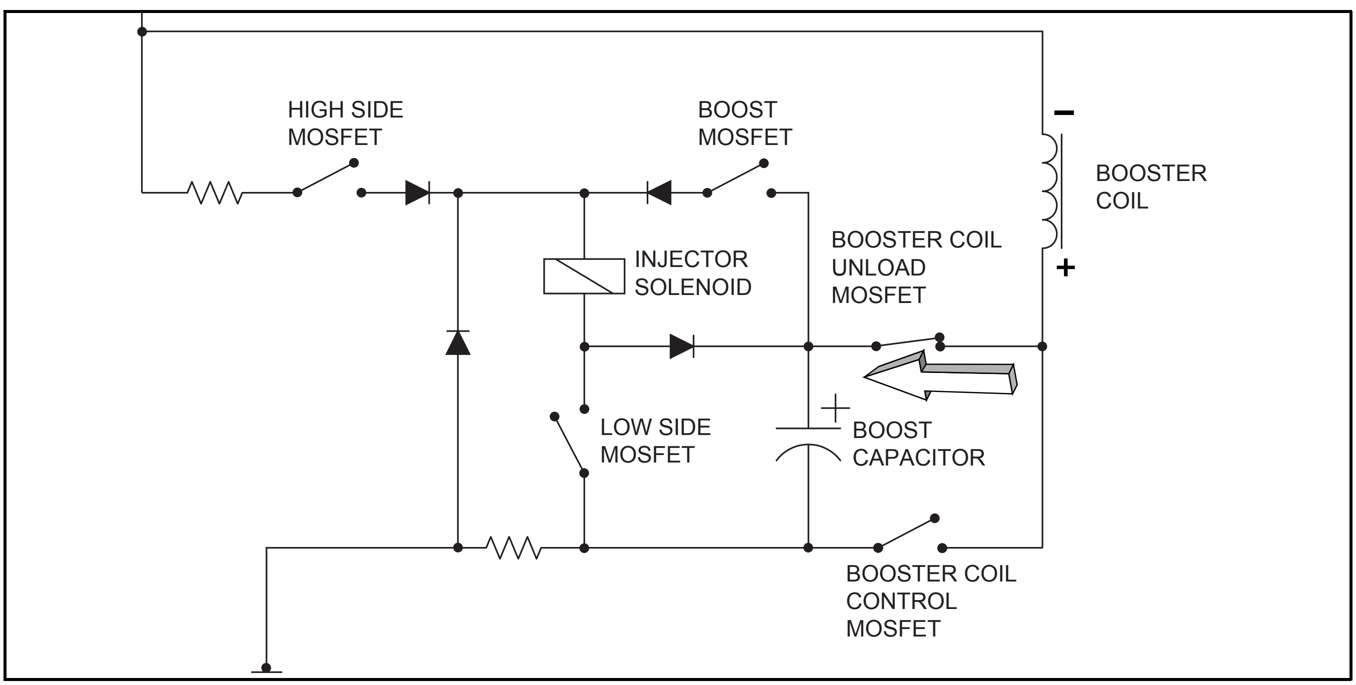
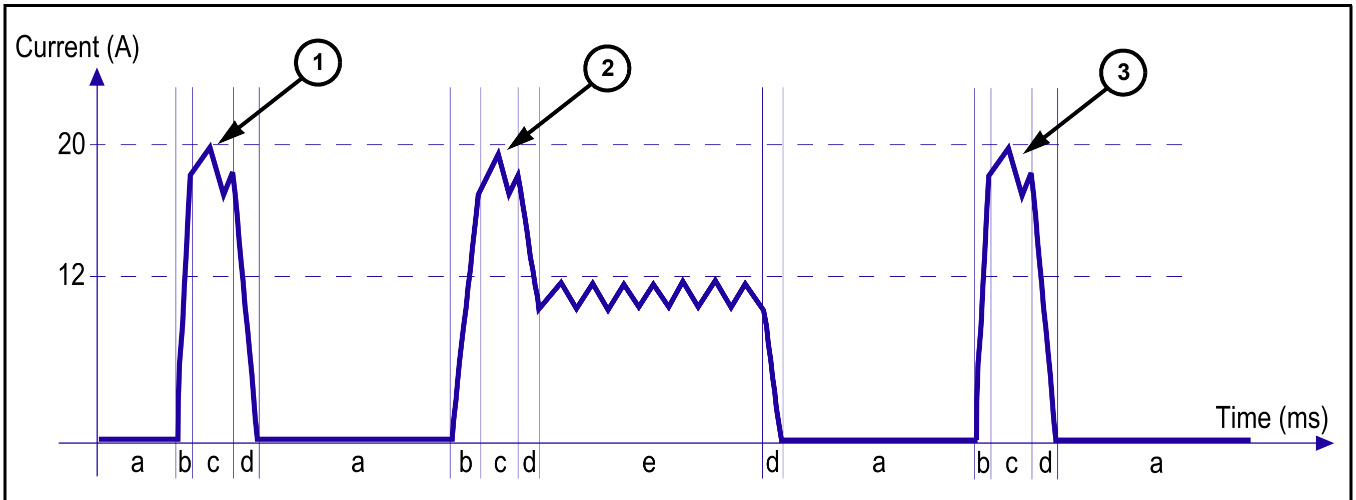


Figure 162 Capacitor Reloading Stage, Magnetic Field Collapse & Capacitor Charge

The injector current waveform shows the order in which the injection stages occur.



1	Pilot Injection	b	Injector On (Capacitor Unload)
2	Main Injection	c	Injector Break-Away Current
3	Post-Injection	d	Injector Off (Capacitor Charges)
a	Cylinder Overlap	e	Injector Holding Current

Figure 163 Current Waveform, Injector Activation

Pilot Injection

With pilot injection, a small amount of diesel fuel is injected into the cylinder to reduce combustion noise and emission of pollutants. Pilot injection is used throughout the entire operating range, up to an engine speed of approximately 3500 rpm. The ECM controls the amount of pilot injected fuel by adjusting the start of pilot injection and the pilot injection duration.

The start of pilot injection is calculated based on the following values:

- Last start of actuation of main injection
- Coolant temperature
- Engine speed
- Onboard electrical system voltage
- Injection time

The ECM calculates the duration of pilot injection based on the following inputs:

- Engine speed
- Atmospheric pressure
- Coolant temperature
- Intake air temperature
- Rail pressure

The coolant temperature, intake air temperature and atmospheric pressure are required to correct the amount of pilot injection. The calculated pilot injection amount is deducted from the main injection amount to determine whether a sufficient amount of fuel is available for the following main injection. High fuel rail pressure is produced so that a a minimum amount of fuel can be injected. If the main injection amount of fuel is too low, the pilot injection is shut off.

The pilot injection is shut off if any of the following conditions are met:

- The pilot injection time is exceeded
- The engine speed is too high
- The calculated pilot injection fuel amount is too low
- The calculated main injection fuel amount is too low
- The fuel pressure in the rail is inadequate
- The engine is switched off

Main Injection

The engine's torque and power are produced from the main injection phase. To control the main injected quantity, the ECM adjusts the start of main injection and main injection duration.
The start of main injection depends on engine speed and fuel amount required. The ECM also corrects the start of main injection based on the following values:

- Coolant temperature
- Boost air temperature
- Atmospheric pressure
- Pilot injection (YES/NO)

The ECM calculates the duration of main injection fuel based on the following inputs:

- Engine speed
- Atmospheric pressure
- Coolant temperature
- Intake air temperature
- Rail pressure
- Boost pressure

The main injection duration also depends on whether a pilot injection has taken place and for how long.

As stated before, pilot injection is shut off if the amount of main injection calculated by the ECM turns out to be less than the minimum amount specified, which is dependent on rail pressure. If the amount is still below the minimum specified, neither main injection nor pilot injection takes place (coasting).

The main injection is switched off if any of the following conditions are met:

- Engine speed too high (higher than 4200 rpm)
- Calculated main injection quantity is below the minimum specified
- Inadequate fuel pressure exists in the rail
- Engine switched off
- External quantity control (ESP)
- Coasting mode

Post Injection

With post injection, a small amount of fuel is injected while combustion is still in progress. The soot particles are burned and soot emissions can be reduced between 20 to 70%.

Failure Modes

The ECM monitors the operation of the injectors and stores fault codes related to the following conditions:

- Excess current on injector control or return wires
- Open or short circuits

ACTIVITY 5.2 CYLINDER TESTING

The purpose of this activity is to use the diagnostic scan tool and compression gauge to check cylinder condition and injector operation.

TASK 1 INJECTOR SHUTOFF (KILL) TEST

The injector shutoff is a quick way to isolate the operation of the injectors.

1. Connect the diagnostic scan tool to the vehicle and access the ECM.
2. Start the engine and let it run at idle.
3. Perform the injector shutoff (kill) test on each cylinder. Notice any changes in engine idling characteristics.
4. Is there a noticeable change in all cylinders? YES __*X*__ NO _____
5. Although this test in itself is not conclusive, is there a cylinder you should pay closer attention to? YES ______ NO ___*X*___

TASK 2 ELECTRICAL COMPRESSION TEST

The electrical compression test is performed with the engine at cranking speed. The test determines the power output from each of the engine's cylinders by measuring the engine rpm drop. During this test, all cylinders should have the same amount of speed drop, within a 7 rpm range of each other.

1. Connect the diagnostic scan tool to the vehicle and access the ECM.
2. Start the engine and let it run at idle.
3. Perform the engine compression test.
4. Record the compression readings on the table below.

Cylinder	RPM Reading
1	*231*
2	*231*
4	*230*
5	*232*
3	*231*

5. Is the engine rpm drop in all cylinders within specifications? YES __*X*__ NO _____
6. Although this test in itself is not conclusive, is there a cylinder you should pay closer attention to? YES ______ NO ___*X*___

TASK 3 MECHANICAL COMPRESSION TEST

The mechanical compression test verifies the mechanical condition of the engine.

1. Disable the engine to avoid starting.
2. Remove the glow plugs.
3. Use the compression gauge to measure the compression of all cylinders.
4. Record the compression readings on the table below.

Cylinder	Compression Reading
1	
2	
3	
4	
5	

5. Are the compression readings within specifications? YES _____ NO _____

TASK 4 SMOOTH RUNNING CONTROL TEST

The smooth running control test displays variations in engine speed between cylinders with the engine running.

1. Connect the diagnostic scan tool to the vehicle and access the ECM.
2. Start the engine and let it run at idle.
3. Perform the smooth running control test.
4. Record the engine speed value of each cylinder on the table below. Notice that the table is arranged by engine firing order.

Cylinder	**Engine Speed**
1	
2	
4	
5	
3	
1	

Speed Variation Between Cylinders

		↓↑
Between 1-2		
Between 2-4		
Between 4-5		
Between 5-3		
Between 3-1		

5. Is there a noticeable engine drop between any of the cylinders? YES ____ NO ___
6. Although this test in itself is not conclusive, which cylinder do you need to pay closer attention to?

____

TASK 5 INJECTOR CORRECTION QUANTITY TEST

The injector correction quantity test displays the amount of fuel being added or removed at each injector by the smooth engine running control function of the ECM.

1. Connect the diagnostic scan tool to the vehicle and access the ECM.
2. Start the engine and let it run at idle.
3. Perform the injector correction quantity test (snap throttle once test has begun).
4. Record the injection quantities on the table below. Include whether the value is positive or negative.

Cylinder	(+/-)	With Good Injector	(+/-)	With Bad Injector
1	-	*00000*	+	*00511*
2	+	*00045*	-	*00162*
3	-	*00003*	+	*00153*
4	-	*00041*	-	*00257*
5	+	*00015*	-	*00241*

5. Install a bad injector and repeat the test. Fill out the last column of the table.
6. Are the correction quantities within specifications? YES ______ NO ______
7. Which injector(s) appear to be out of specifications?

____

TASK 6 INJECTOR LEAKAGE TEST

The injector leakage procedure tests the internal leak-tightness of each injector.

1. Using the service manual, find the procedure for removing the injector return lines and installing the test vials.
2. Connect the diagnostic tool to the vehicle and access the ECM.
3. Perform the injector leakage test.
4. Are all injectors within specifications? YES __*X*___ NO ______

FUEL PRESSURE SOLENOID

The fuel rail pressure solenoid is attached to the rear of the fuel rail (Figure 164). The fuel solenoid has a hex nut design with a threaded fitting for mounting the valve to the fuel rail. A sealing metal disk is used instead of O-rings. The seal is not serviceable and its sealing properties will be lost upon removal of the fuel pressure solenoid. Therefore, the fuel solenoid must always be replaced when removed from the rail.

When installing the fuel pressure solenoid, an angle torque procedure is required for proper seating. The installation procedure is as follows: Tighten the nut to 60 Nm (44.2 ft.lbs.). Loosen the nut 90 degrees. Retighten the nut to 80 Nm (59 ft.lbs.). Important: a torque wrench must be used for this procedure. For this reason, the fuel rail must be removed to service the control valve. The fuel rail can be removed without removing the intake manifold.

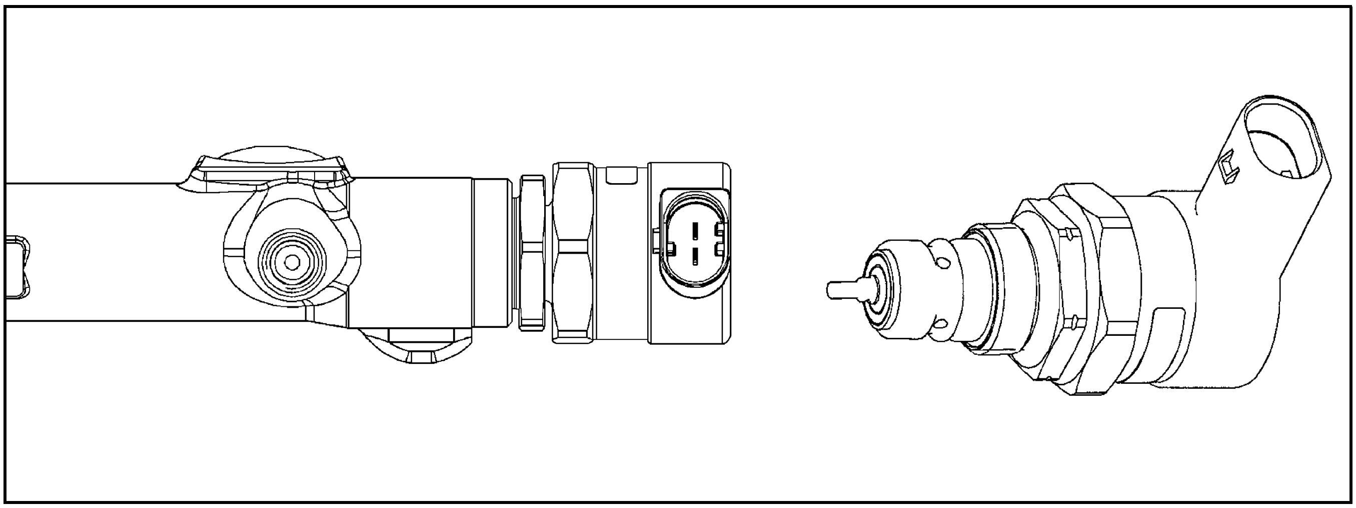


Figure 164 Fuel Pressure Solenoid

Two wires connect the fuel pressure solenoid to the Engine Control Module (ECM). The ECM supplies battery power to one end of the solenoid and sends a pulse width modulated (PWM) ground through the other end. The PWM signal has a fixed frequency of 1 kHz and a duty cycle between 5-95% depending on engine operating conditions (Figure 168). The 1 kHz frequency is high enough to avoid undesired armature oscillations, which could produce pressure fluctuations in the rail.

The solenoid has a current draw of approximately 400-600 mA with the engine at idle speed. After engine start up, the current draw remains in the lower end of the specified value for 30 seconds. After 30 seconds the current draw increases to the higher end of the specified value.

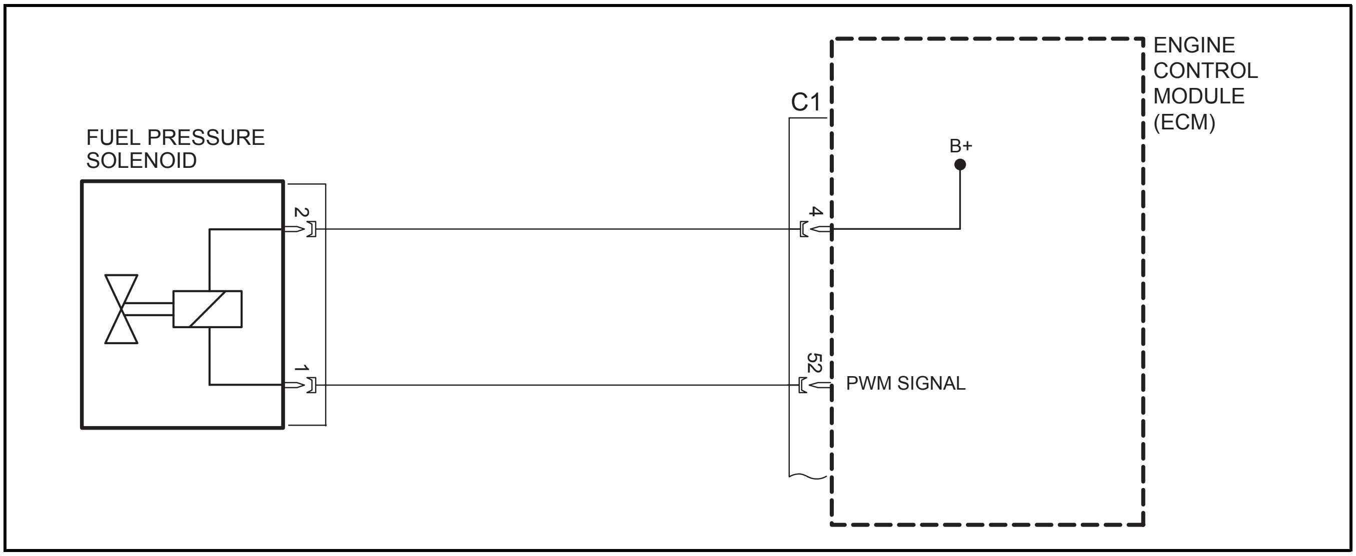
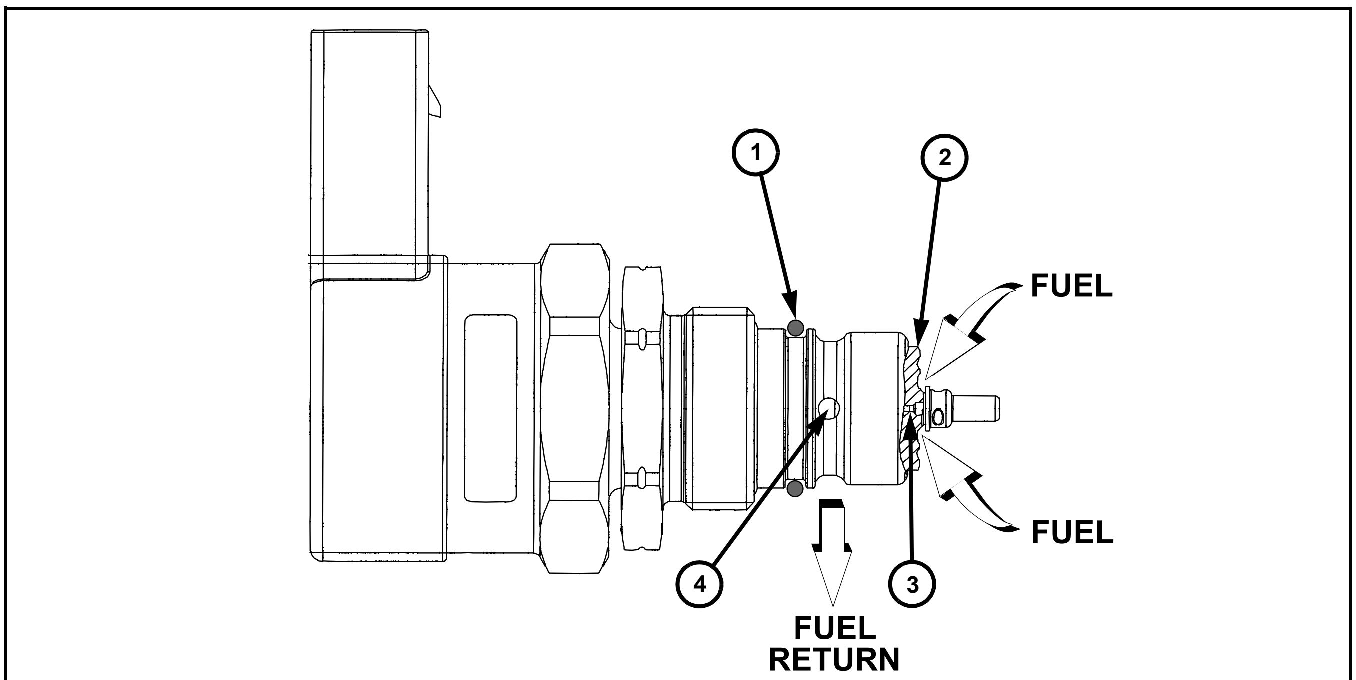


Figure 165 Fuel Rail Pressure Solenoid Schematic

Together with the quantity valve, the fuel pressure solenoid controls the fuel rail pressure and keeps it constant. The fuel pressure sensor measures the current rail pressure and supplies an appropriate voltage signal to the engine control module (ECM). Via a control circuit, the fuel pressure solenoid or fuel quantity control valve is activated accordingly by the ECM until the required rail pressure is reached.

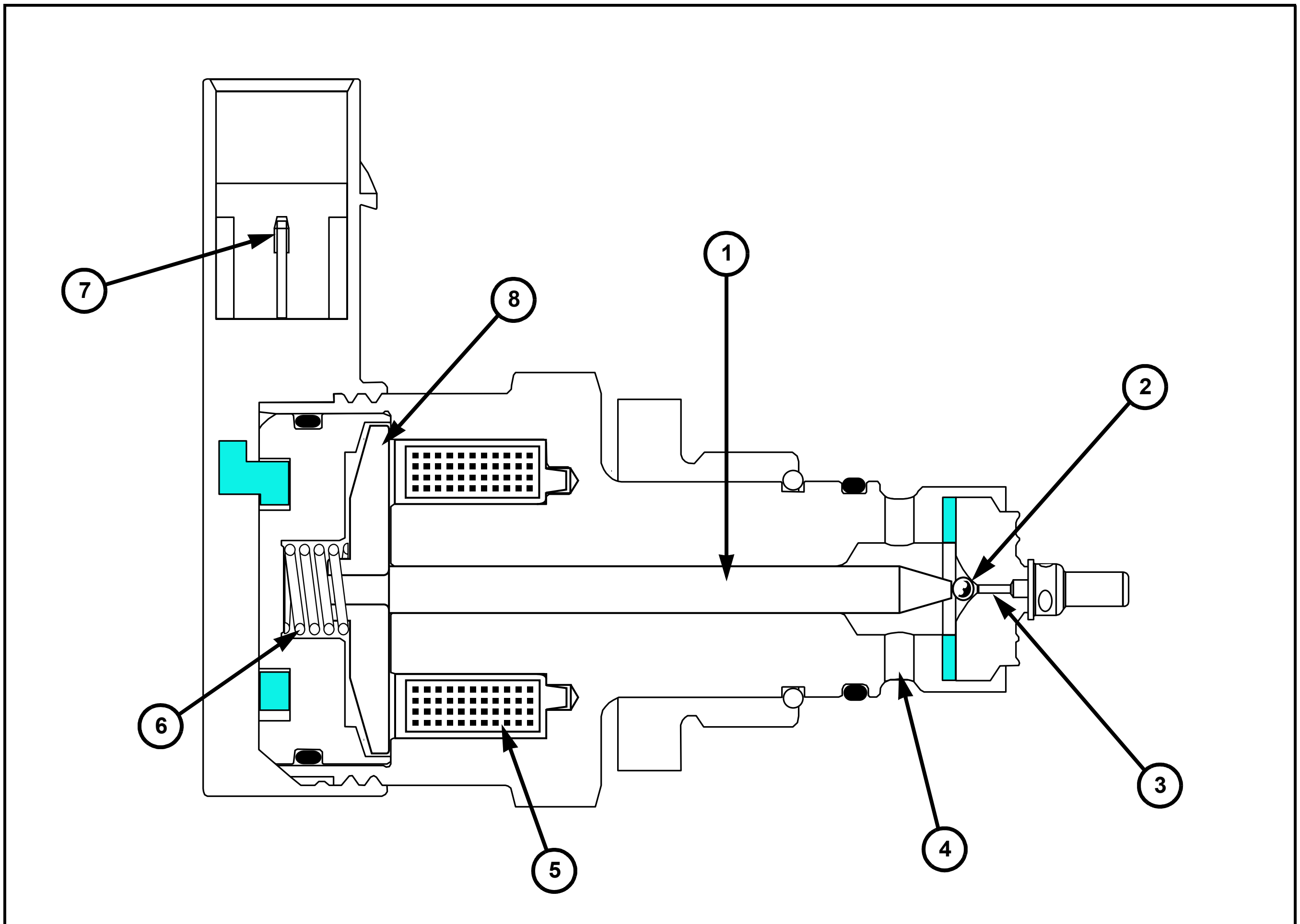


1	O-Ring	3	Fuel Passage
2	Metal Sealing Disc	4	Fuel Return Hole

Figure 166 Fuel Pressure Solenoid

Operation

When deactivated, the fuel pressure solenoid is closed, due to the spring force pressing the ball into the seat (Figure 167). The spring pressure maintains a minimum pressure of about 60 bar (870 PSI).



1	Armature Plunger	5	Magnetic Coil
2	Ball and Seat	6	Spring
3	Fuel Inlet Passage	7	Electrical Terminal
4	Fuel Return Passage	8	Armature

Figure 167 Fuel Pressure Solenoid Cutaway View

When operating, the ECM regulates the PWM signal (Figure 168) and the fuel pressure solenoid opens to a greater or lesser degree. At idle the control value is approximately 18% for the first 30 seconds after engine start up. The control value rises to approximately 24% after 30 seconds. The pressure of the fluid counteracts the force of the magnet coil and the spring force. A minimum fuel pressure of 200 bar (2900 PSI) must be achieved in order to start the engine.

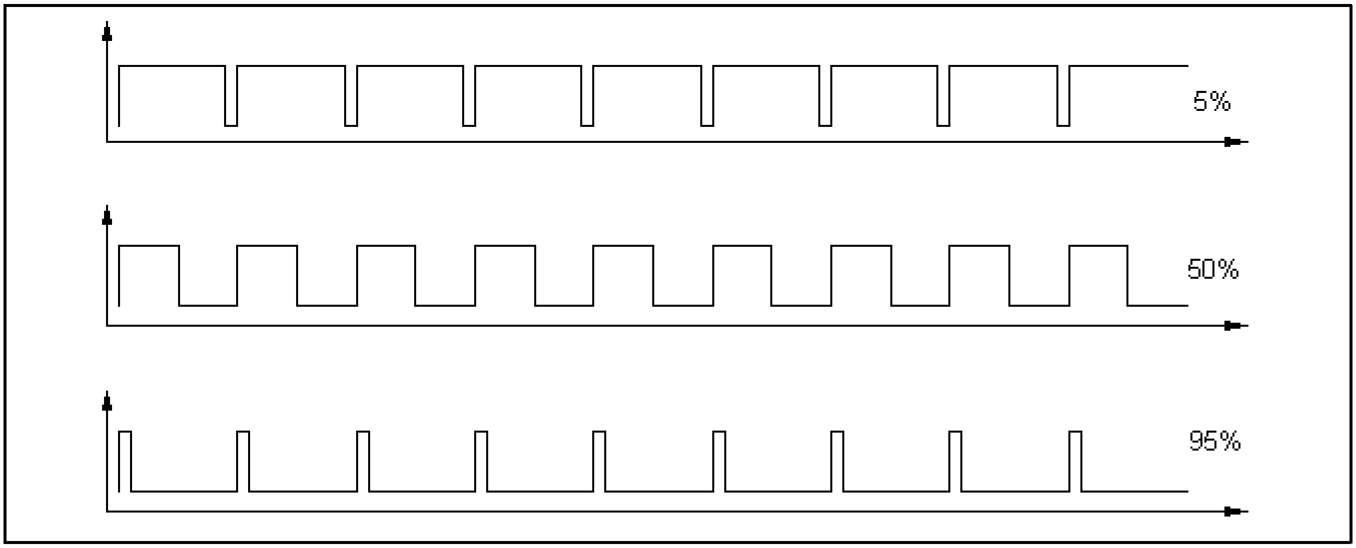


Figure 168 Fuel Pressure Solenoid PWM Signal

Failure Modes

The ECM monitors the operation of the fuel pressure solenoid and stores fault codes related to the following conditions:

- Wire shorted to positive or shorted to ground
- Open circuit
- Plausibility

FUEL QUANTITY VALVE

The high pressure pump flange has an integrated fuel quantity valve for metering the fuel into the high pressure pump elements (Figure 169). The ECM sends a PWM signal (pulse width modulating signal) to the fuel quantity valve to regulate the amount of fuel to the high pressure pump plunger-and-barrel assemblies. The fuel quantity valve also interrupts the fuel supply to the high pressure pump plunger-and-barrel assemblies when the engine is switched off and during engine deceleration mode.

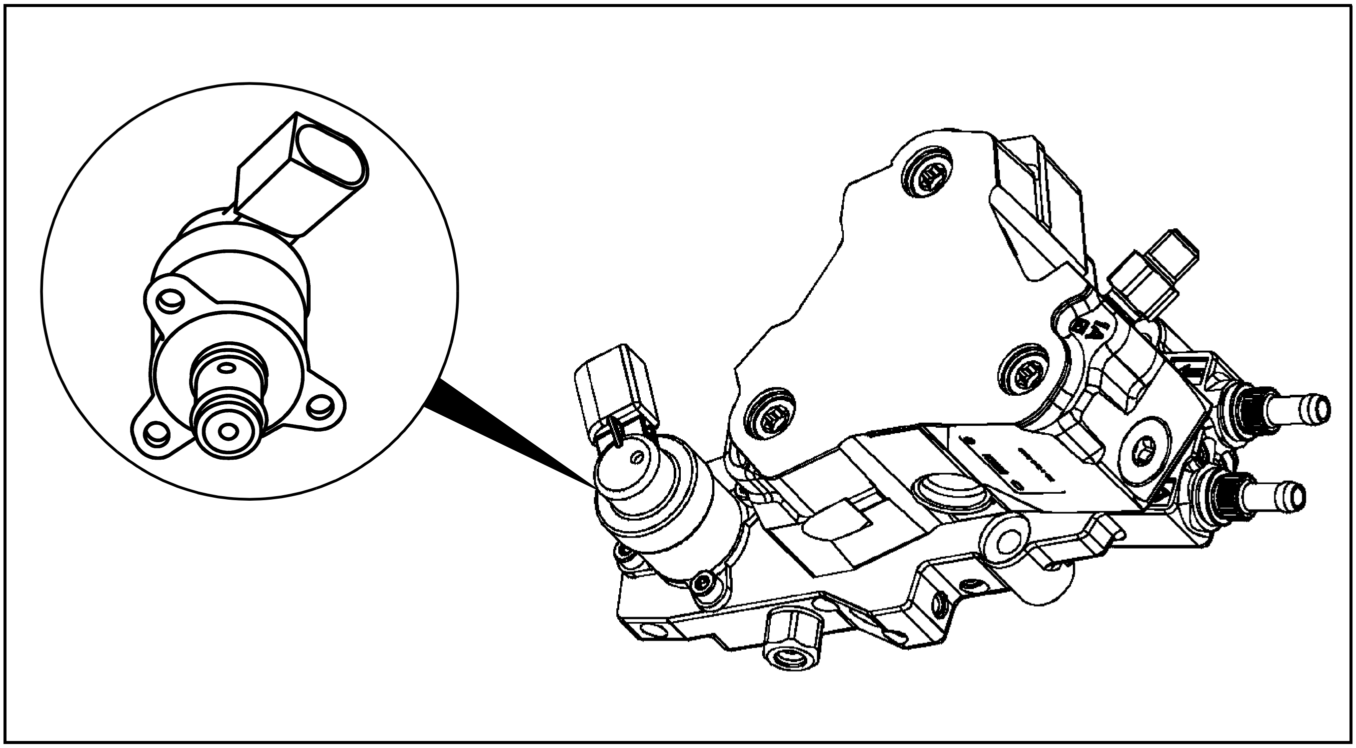


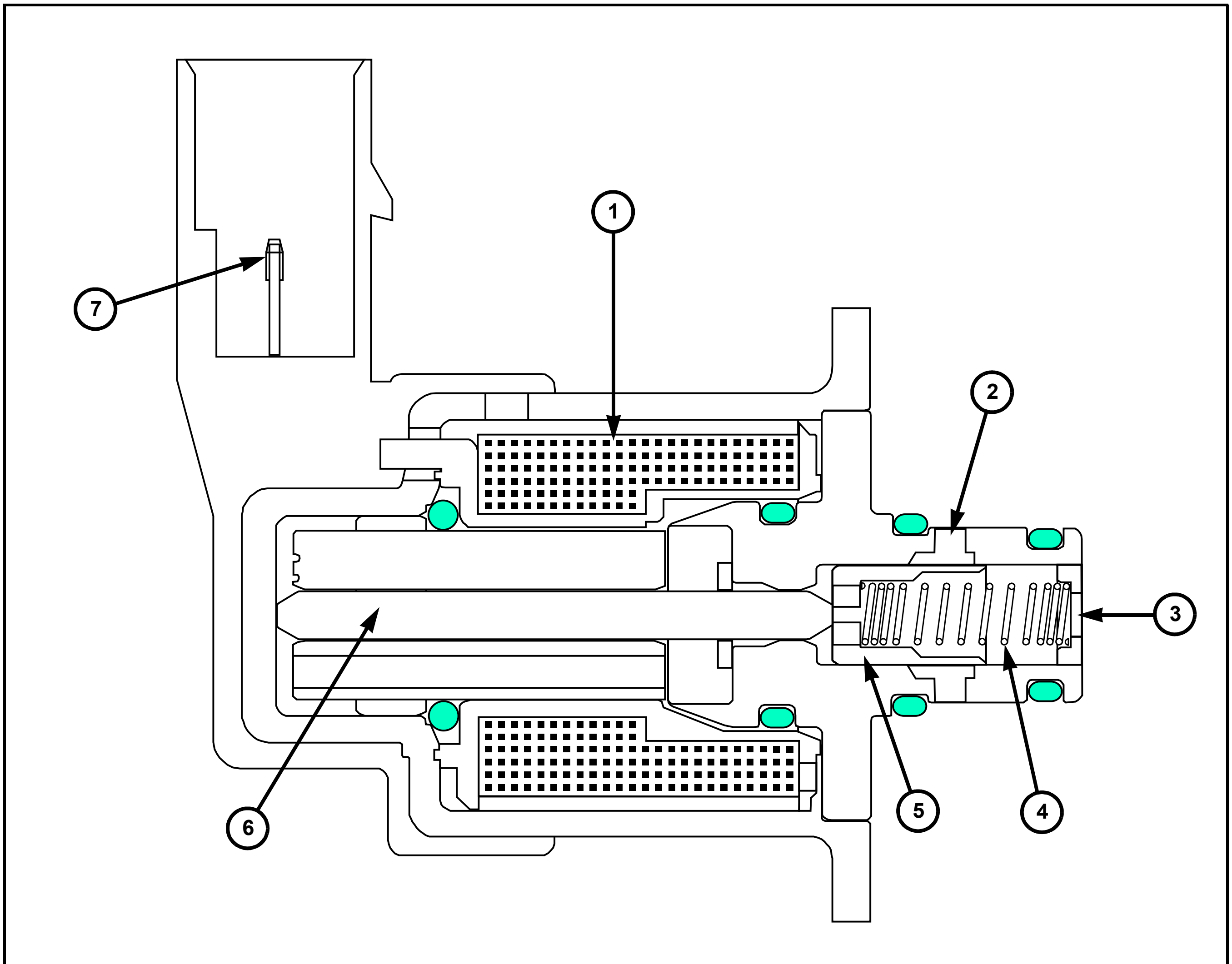
Figure 169 Fuel Quantity Valve

The fuel quantity valve is a serviceable unit and can be replaced separately. Three screws are used to mount the valve to the high-pressure pump flange. Two O-rings are used to seal the fuel quantity valve to the pump flange.

Operation

When deactivated, the fuel quantity valve is fully open, due to the spring force pressing the plunger against its seat (Figure 170). The fuel inlet passage is open, allowing fuel to flow through the fuel outlet (maximum delivery).

When operating, the ECM energizes the magnetic coil. The magnetic field attracts the armature, which presses the plunger against the force of the spring. The effective area of the fuel inlet opening is reduced and less fuel flows through the outlet passage. The stronger the magnetic field, the further the plunger reduces the fuel opening.



1	Magnetic Coil	5	Plunger
2	Fuel Inlet Passage	6	Armature
3	Fuel Outlet Passage	7	Electrical Terminal
4	Spring		

Figure 170 Fuel Quantity Valve Cutaway View

The position of the plunger determines the amount of fuel flowing through the fuel outlet passage to the high pressure pumping elements. When the coil is fully energized, the plunger moves to the fully closed position (zero delivery) and no fuel flows through the fuel outlet passage.

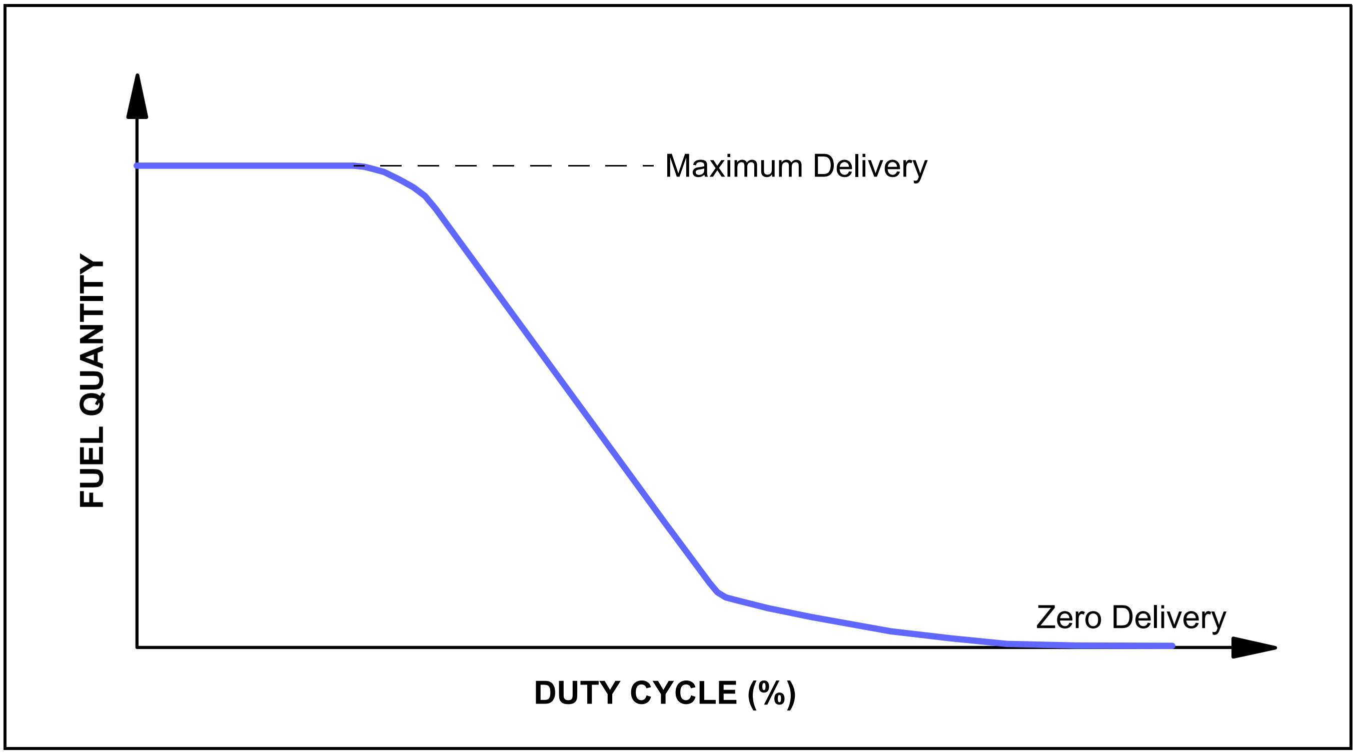


Figure 171 Fuel Quantity Valve Characteristic Curve

Two wires connect the fuel quantity valve to the engine control module (ECM). The ECM supplies battery power to one end of the valve and sends a pulse width modulated (PWM) ground through the other end (Figure 172). The PWM signal has a fixed frequency of 185 Hz.

The ECM regulates the fuel quantity valve 30 seconds after the engine has started. At idle the control value is approximately 35% for the first 30 seconds after engine start up. The control value rises to approximately 40% after 30 seconds.

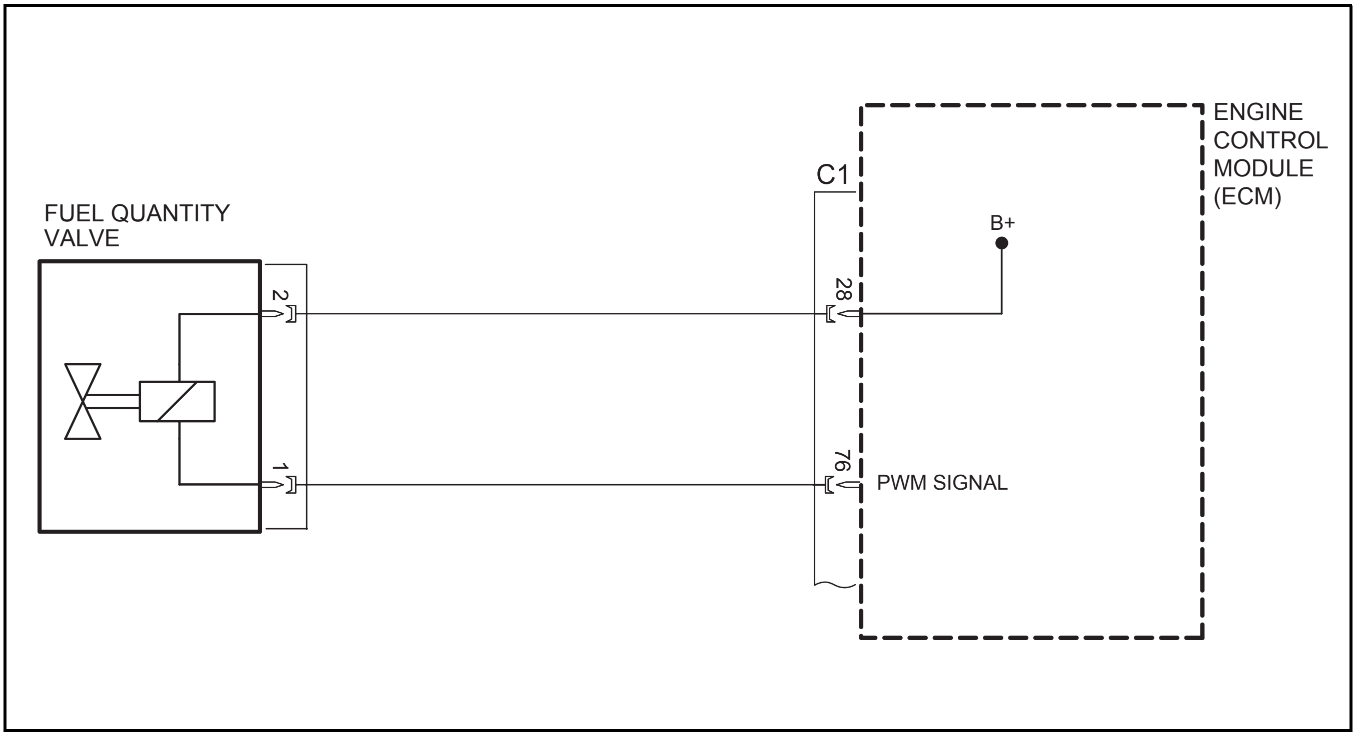
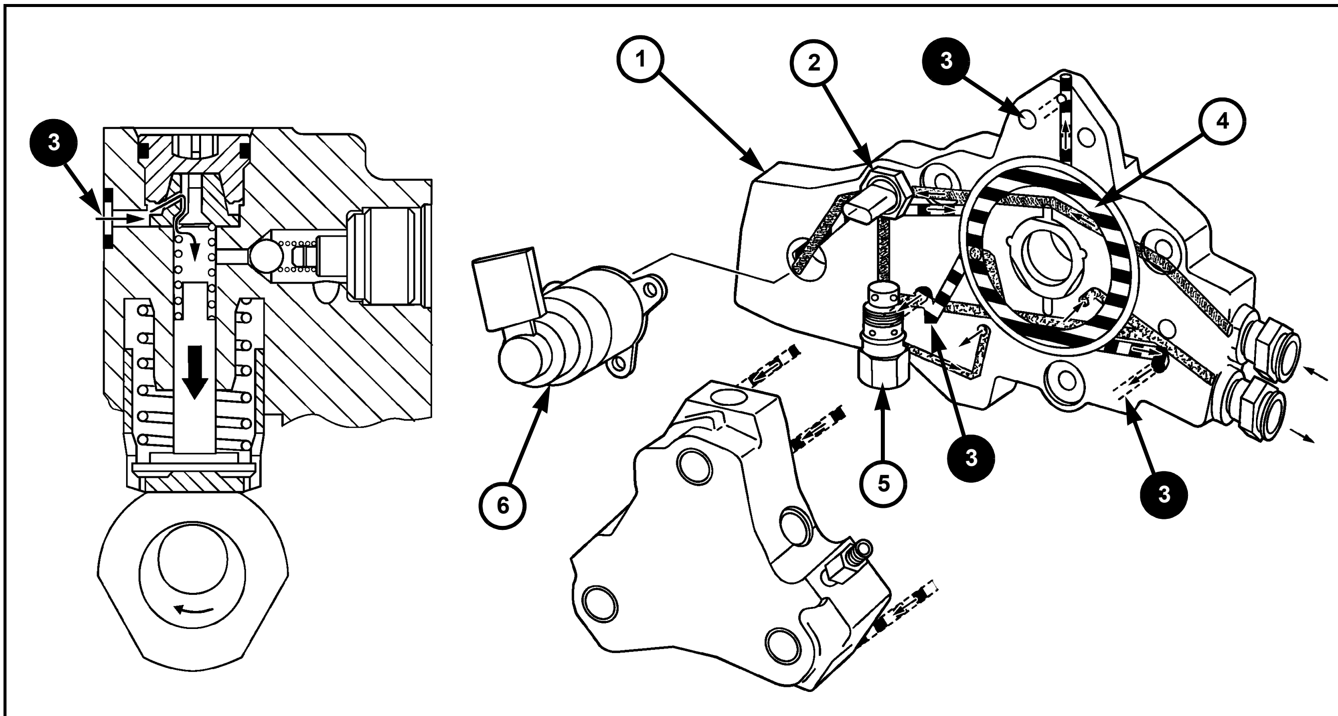


Figure 172 Fuel Quantity Valve Schematic

The coil has a current draw of approximately 1.3-1.5 A with the engine at idle speed. After engine start up, the current draw remains in the lower end of the specified value for 30 seconds. After 30 seconds the current draw increases to the higher end of the specified value.

If the quantity valve fails, the engine will run with reduced power (limp-in mode).

Refer to Figure 173 for the function in part load range. The fuel delivered by the electric fuel pump flows into the high pressure pump flange (1) and is passed from there through the fuel temperature sensor (2) to the fuel quantity valve (6) and to the fuel pressure relief valve (5).



1	High Pressure Pump Flange	4	Annular Passage
2	Fuel Temperature Sensor	5	Pressure Relief Valve
3	Fuel Feed to Pump Elements	6	Fuel Quantity Valve

Figure 173 Fuel Quantity Valve Circuit

The fuel quantity valve (6) controls the quantity of fuel in line with the signal supplied by the engine control module (ECM). A controlled quantity of fuel is supplied to the three pump elements through the annular passage (4) and the feed passages (3). This alters the charge in the cylinder and also the fuel quantity. Fuel quantity control is performed under the following operating conditions:

- Approximately 30 seconds after the engine has started
- Fuel temperature > 20° C (68° F)
- Engine not in deceleration mode

A fuel tank heat protection function is provided by the fuel quantity valve, which meters the exact amount of fuel to prevent excess heated fuel from returning to the tank, along with the greater cooling surface of the fuel cooler, and the two jet pumps to draw cooler fuel into the system.

With the OM 612 LA, a high-pressure pump element shut-off function was used to limit the amount of hot fuel returned to the fuel tank if the fuel level in the tank was low. This function is no longer necessary with the OM 647 LA due to the inlet metering valve (fuel quantity valve) in the high-pressure pump.

Failure Modes

The ECM monitors the operation of the fuel quantity valve and stores fault codes related to the following conditions:

- Wire shorted to positive or shorted to ground
- Open circuit

ACTIVITY 5.3 FUEL SOLENOID & FUEL QUANTITY VALVE TEST

The purpose of this activity is to familiarize the students with the operation and testing of the fuel pressure solenoid and the fuel quantity valve (also known as the fuel management valve).

TASK 1 FUEL PRESSURE SOLENOID TEST

1. Start the engine and let it run at idle for at least 15 seconds before testing the fuel pressure solenoid. Ensure all consumers are switched off.
2. With the engine idling, use the diagnostic scan tool to perform the fuel solenoid actuation test.
3. Did the fuel solenoid pass the actuation test? YES _____ NO _____
4. Switch off the ignition and wait a few seconds. Start the engine and within 30 seconds read out the actual value of the fuel pressure solenoid. Record the value on the table below.

Engine RPM	Actual Value
680	*18%*

5. Read out the actual value of the fuel pressure solenoid after 30 seconds and record it on the table below.

Engine RPM	Actual Value
680	*25%*

6. Explain why does the fuel pressure solenoid value change after 30 seconds.
   The quantity valve starts regulating after 30 sec. and the solenoid compensates.
   ____
7. At idle speed, the fuel pressure solenoid value should be less than 30%, before and after the 30 second value shift. Is the fuel solenoid actual value within specifications? YES __*X*__ NO _____
8. Switch the engine off.
9. Using an adapter cable, connect a digital multimeter to the fuel solenoid. Set the multimeter to read resistance.
10. Read the resistance of the solenoid and record on the space below.
    4.3 ohms
11. Is the resistance value between 4-5Ω? YES __*X*__ NO _____
12. SET THE MULTIMETER TO READ VOLTAGE.

13. Start the engine and let it run at idle speed. Read the voltage within 30 seconds after engine startup. Record the voltage reading on the space below.
    1.83 volts

14. Record the voltage reading after the engine has run for at least 30 seconds.
    2.5 volts

15. At idle speed, the fuel pressure solenoid voltage should increase slightly after 30 seconds and the value should remain between 2.4-3.0 volts after 30 seconds. Is the voltage value within specifications? YES __X___ NO _____
16. Switch the engine off.

TASK 2 FUEL QUANTITY VALVE (ENGINE MANAGEMENT VALVE) TEST

1. Start the engine and let it run at idle. Briefly snap the throttle.
2. Within 30 seconds, read out the actual value of the engine management valve and record on the table below.

Engine RPM	Actual Value
680	*36.3%*

3. Is the fuel quantity valve value higher than 30%? YES __X__ NO ____
4. Read out the fuel quantity value after 30 seconds and record on the table below.

Engine RPM	Actual Value
680	*40%*

5. Is the fuel quantity valve value higher than 30%? YES __X__ NO _____
6. Switch the engine off.
7. Using an adapter cable, connect a digital multimeter to the fuel quantity valve. Set the multimeter to read resistance.
8. Read the resistance of the quantity valve solenoid and record on the space below.
   2.9 ohms

9. Is the resistance value between 2.9-3.3Ω? YES __X__ NO _____
10. SET THE MULTIMETER TO READ VOLTAGE.
11. Start the engine and let it run at idle speed. Record the voltage reading on the space below.
    <30 sec = 3.65 volts; >30 sec = 4.26 volts

12. Is the voltage value between 3.5-4.5V ? YES __X___ NO _____
13. Switch the engine off.

INTAKE/EXHAUST OUTPUTS

BOOST PRESSURE ACTUATOR

The boost pressure actuator is mounted at the bottom of the turbocharger. It controls the position of the guide vane ring in the turbocharger, adjusting the boost pressure according to the signal from the ECM.

The boost pressure actuator is essentially a “smart actuator”. Smart actuators have integrated electronics that allow them to measure and process data in order to perform tasks.

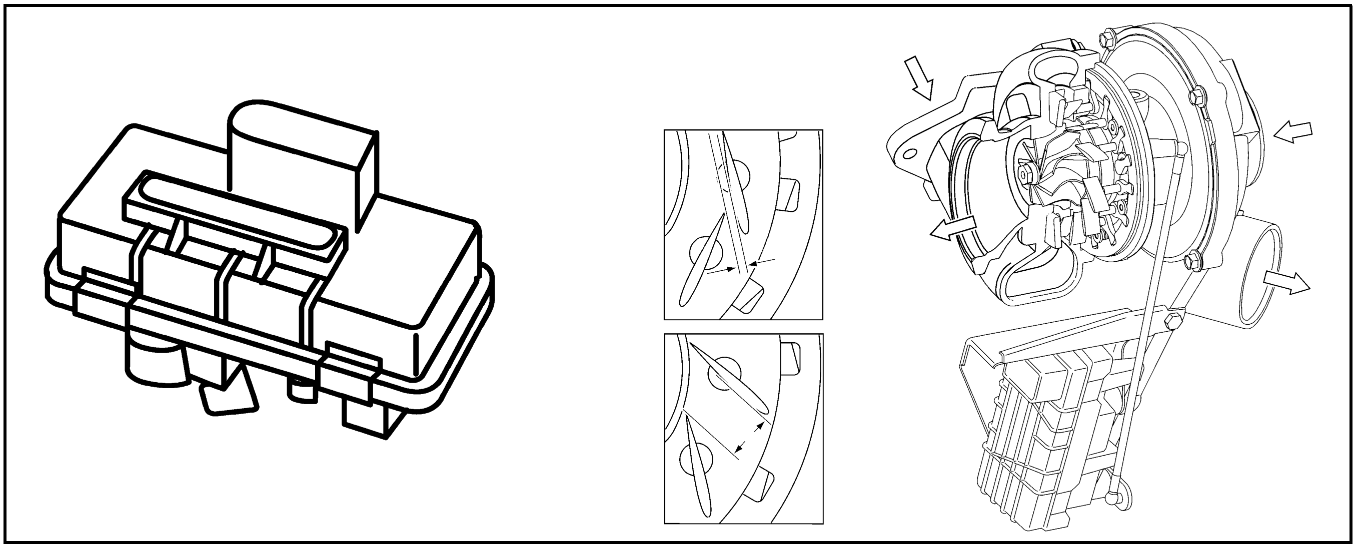


Figure 174 Boost Pressure Actuator

Operation

The boost pressure actuator consists of an electronic circuit board integrated in the actuator housing and an actuator motor which operates the adjusting shaft via a worm gear drive mechanism.

When deactivated, the boost pressure actuator defaults to the low boost position (the turbocharger vanes are in the open position). When operating, the actuator regulates the position of the vanes based on the PWM control signal from the ECM.

With the ignition on, the PWM control value is approximately 10%. With the engine at idle, the PWM value is approximately 95%. The PWM control value decreases as the accelerator pedal is depressed.

An integrated Hall-effect sensor detects the movement of the control lever and provides position feedback to the electronic circuit board. Based on this input, the electronic circuit board verifies the actual position of the vanes.

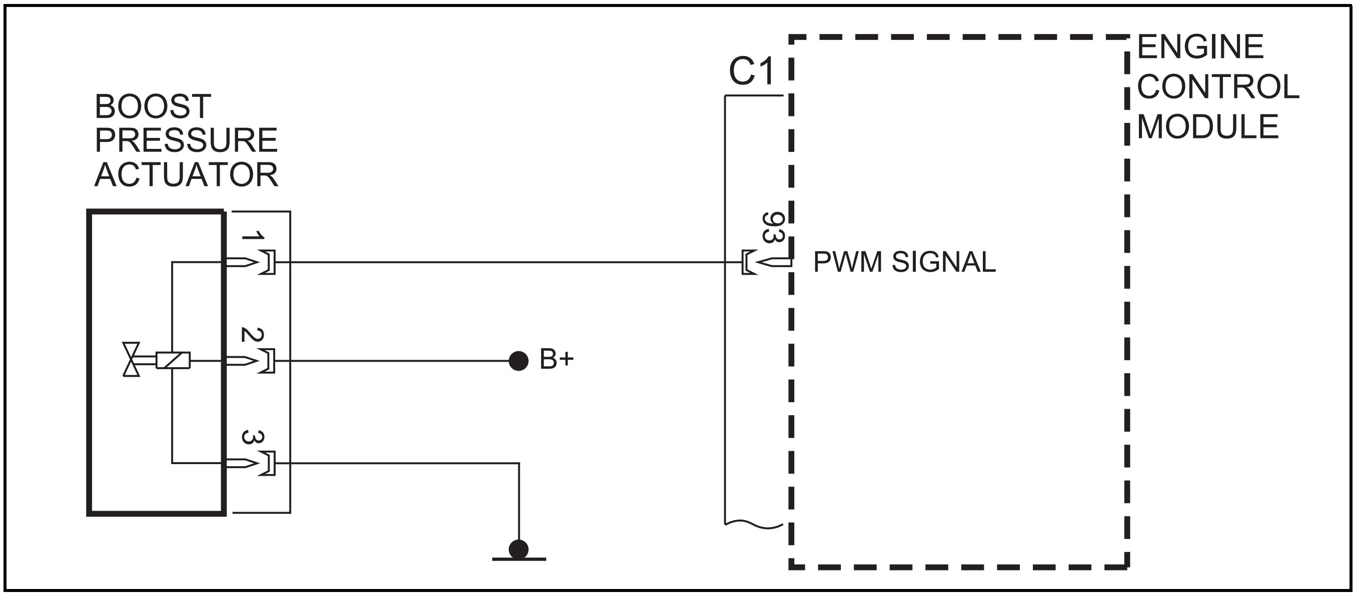


Figure 175 Boost Pressure Actuator Schematic

The boost pressure actuator is externally grounded and is supplied with battery power when the ignition is switched on. The boost pressure actuator ground and battery power supply circuits are shared with the EGR actuator.

Failure Modes

The ECM monitors the operation of the boost pressure actuator and stores fault codes related to the following conditions:

- Wire shorted to positive or wire shorted to ground/open circuit
- Boost pressure is too low or too high
- Activation On/Off ratio is too high

EGR VALVE ACTUATOR

The EGR valve actuator is mounted to the intake manifold (Figure 176).

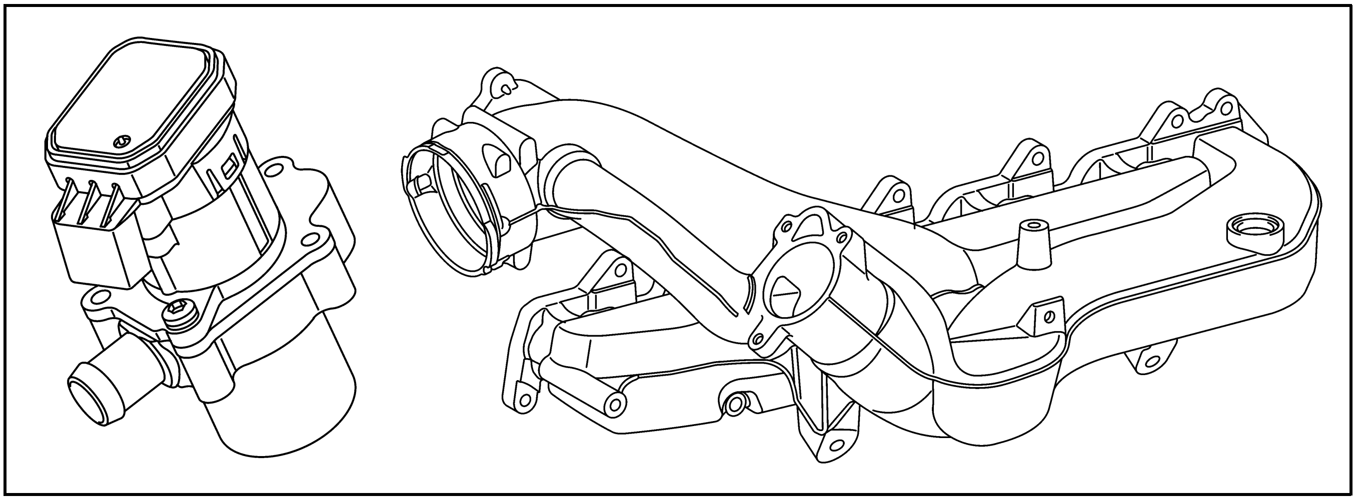


Figure 176 EGR Valve

Exhaust-gas recirculation (EGR) is a method for reducing the emissions of NOx. With EGR, a portion of the exhaust gases are diverted into the intake during part-load operation. Not only is the oxygen content reduced, but also the rate of combustion and the peak temperature at the flame front, which results in lower NOx emissions.
If too much exhaust gas is recirculated (exceeding 40% of the intake air volume), the particulates, CO, and HC emissions, as well as the fuel consumption rise due to the lack of oxygen.

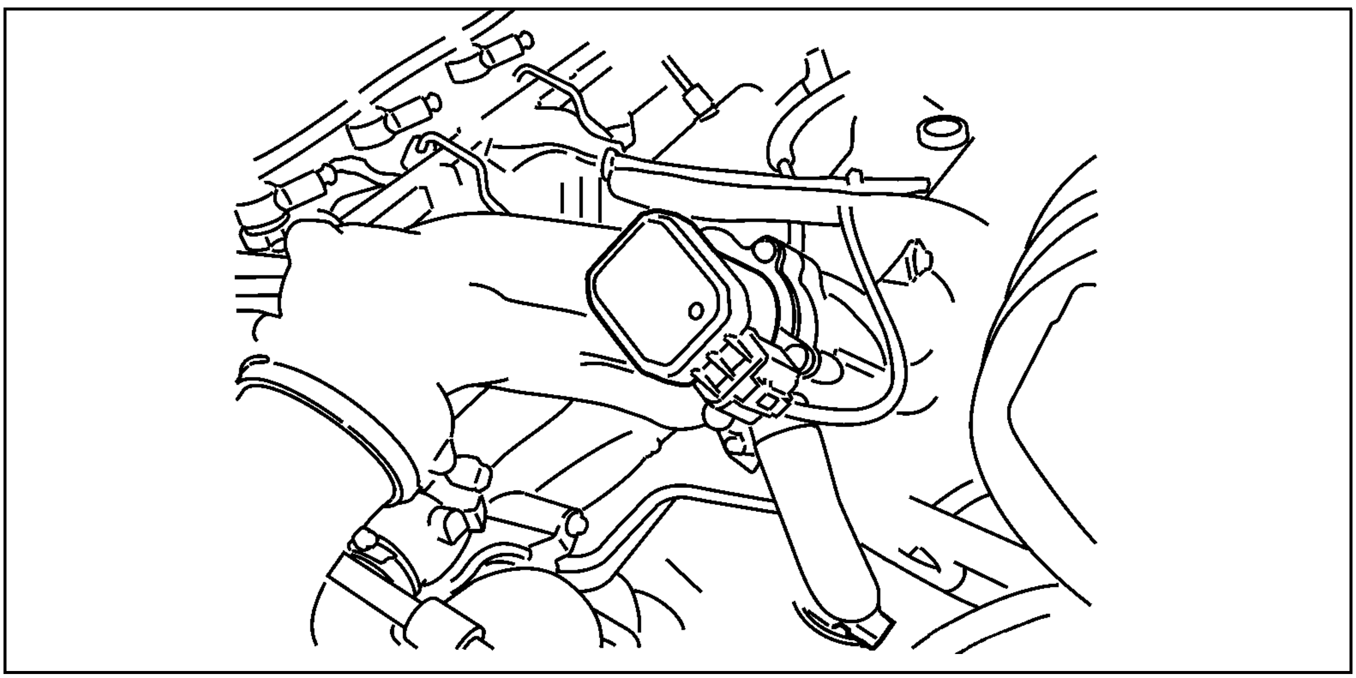
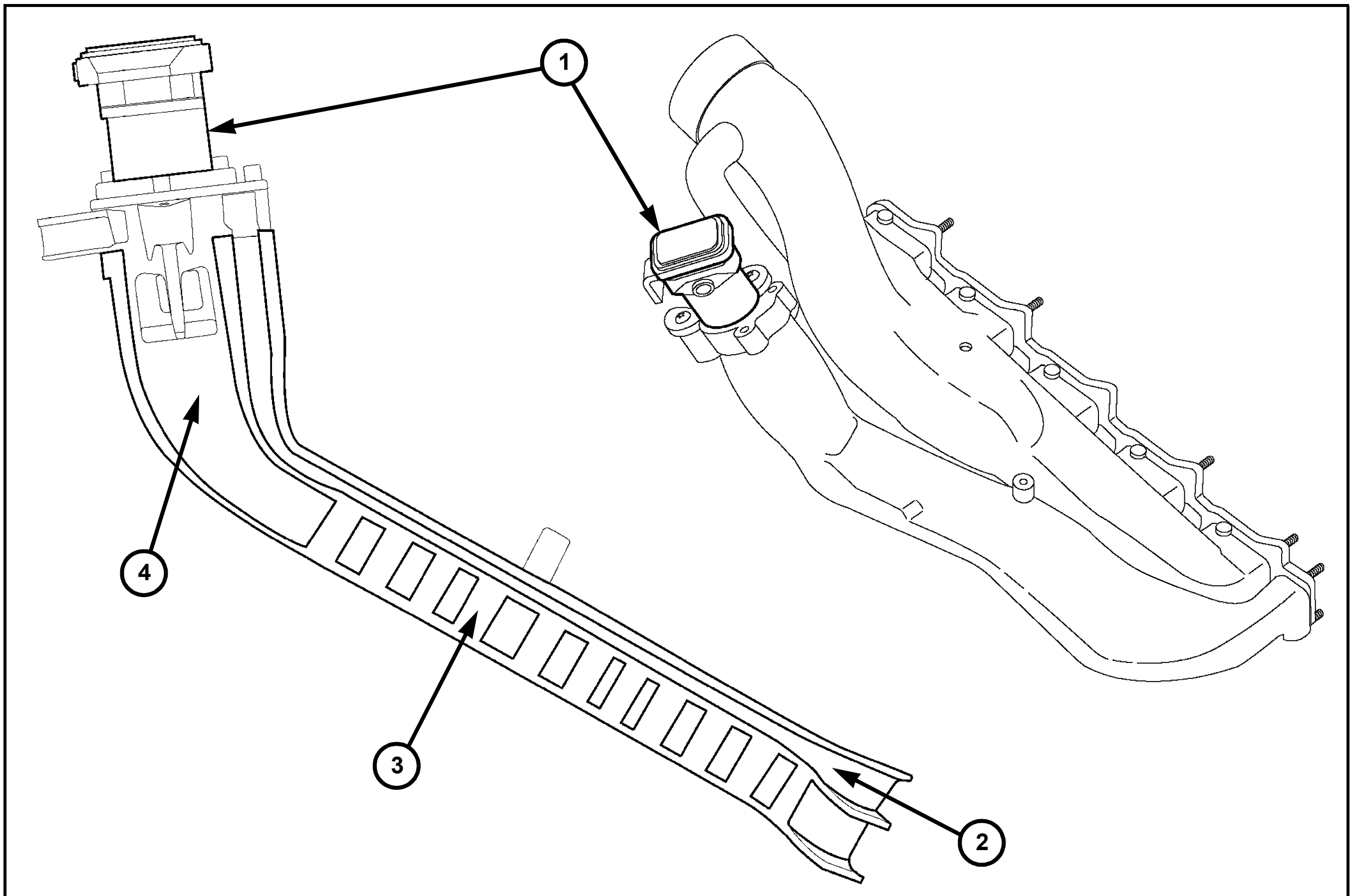


Figure 177 EGR Valve Location

The EGR system can provide up to 35% exhaust gas recirculation. The EGR operates during all engine speed and load conditions. At wide open throttle, it provides a 5% recirculation rate. The EGR shuts down during high engine idle to avoid carbon buildup on the valve (vehicles with the optional constant rpm feature). The EGR also deactivates if the EGR temperature is too high.

The intake manifold contains a finned EGR cooler. Coolant flows through the EGR cooler and around the EGR valve to lower the recirculated exhaust gas temperature. The reduced temperature achieved by the EGR cooler improves EGR operation at high engine load.

The recirculated exhaust gas temperature must be reduced significantly for emissions. The exhaust gases reach temperatures of approximately 700°C (1292°F). The temperature is reduced 200°C (392°F) by flowing through the cylinder head internal passage. The exhaust gases are led through the water cooled manifold, which reduces the exhaust gas temperature by another 200°C (392°F). As a result, the temperature of the exhaust gas being recirculated is approximately 300°C (572°F).



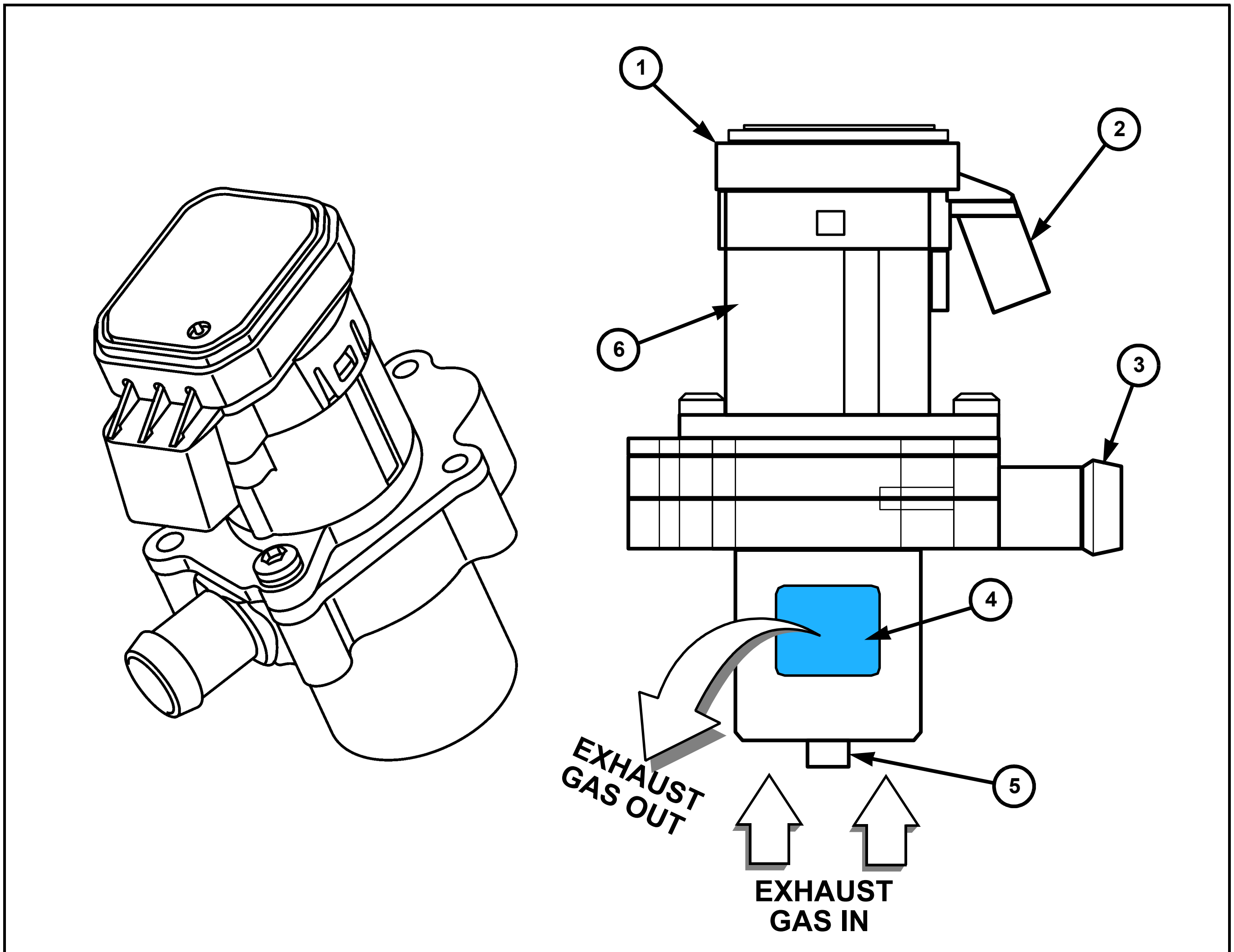
1	EGR Valve	3	Cooling Fins
2	Coolant Passage	4	Exhaust Gas Passage

Figure 178 EGR Water-Cooled Duct

Construction

The EGR valve is an electrically operated, rotary-type valve. Similar to the boost pressure actuator, the EGR valve is considered to be a smart actuator. Smart actuators have integrated electronics that allow them to measure and process data in order to perform tasks. The EGR valve housing contains the following subassemblies (Figure 179):

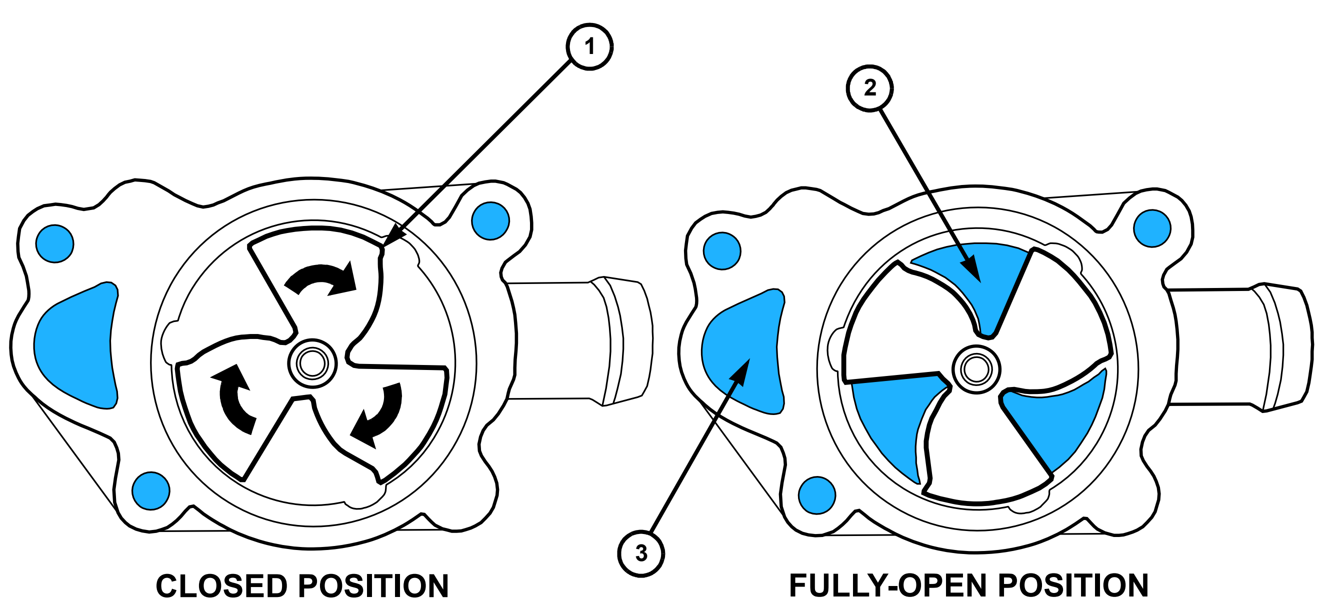
- **End cover—**Contains the electronic circuit using thick film hybrid technology. A thick film hybrid is a combination of film circuits and other elements, such as capacitors and integrated circuits on a ceramic substrate. The electronic circuit is mounted to a heat sink and covered with thermal gel. The end cover is a sealed unit and is not serviceable.
- **Motor subassembly—**Contains the torque motor, which turns the rotary valve. The torque motor turns the rotary valve up to a maximum of 70° from its fully closed position. The motor consists of a single stator, an armature with a permanent magnet and an SmCo magnetic ring for position feedback.
- **Coolant jacket—**Provides the path between the engine's coolant circuit and the EGR cooling duct.
- **Rotary valve subassembly—**Contains the rotary valve, valve shaft, return spring and EGR inlet and outlet ports. With a rotary valve arrangement, the position of the valve does not change due to boost pressure pulsations and the effects of varnish and soot build-up are reduced.



1	End Cover With Electronic Circuit	4	EGR Outlet Port
2	Electrical Connector	5	EGR Inlet Port (Rotary Valve)
3	Coolant Port	6	Torque Motor

Figure 179 EGR Valve

The EGR actuator turns the rotary valve to increase or reduce the opening at the inlet port. The position of the rotary valve determines the amount of exhaust gases flowing back into the combustion chambers.



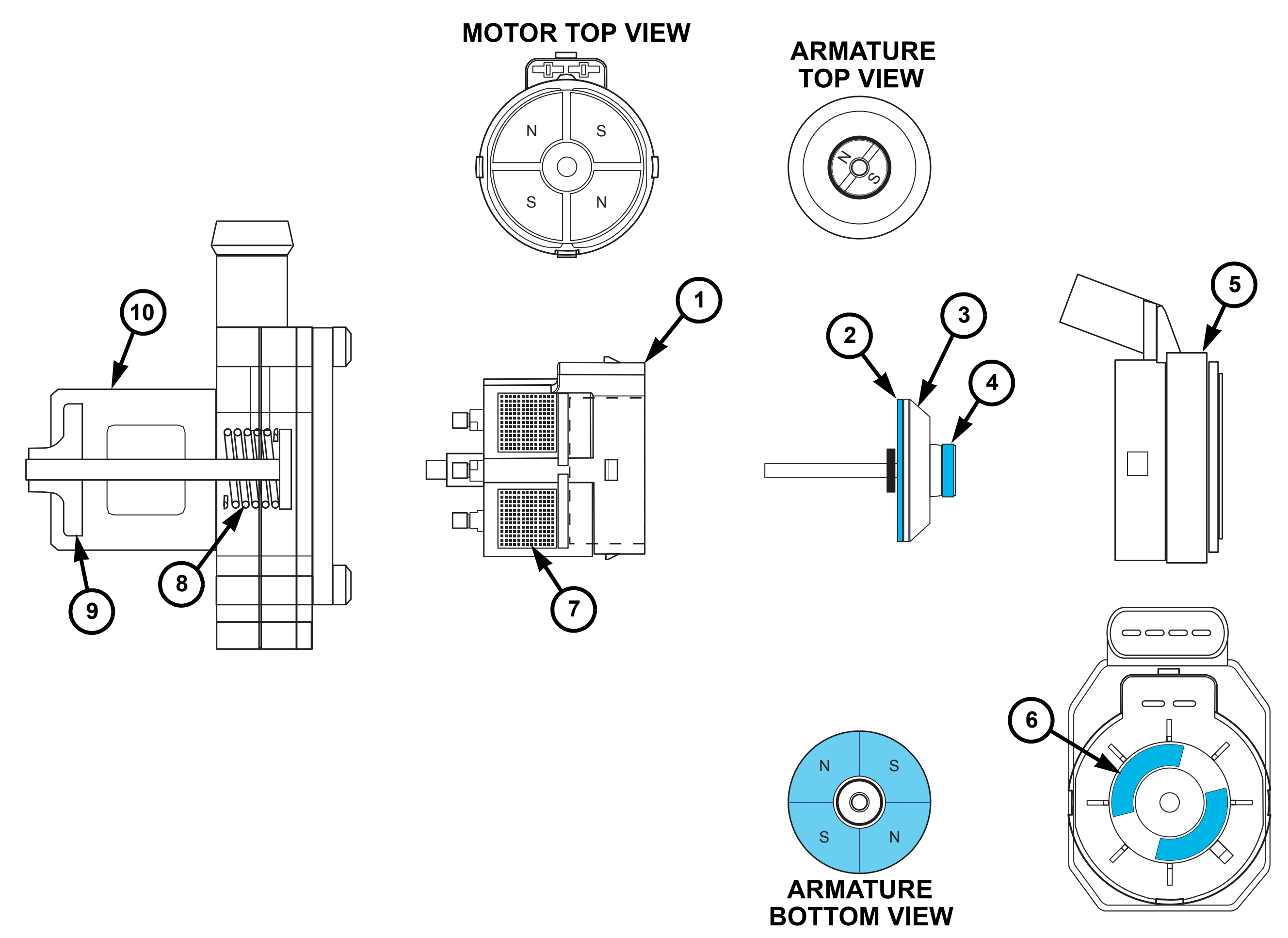
1	Rotary Valve	3	Coolant Jacket
2	EGR Inlet Port		

Figure 180 EGR Valve Bottom View

Operation

The ECM calculates the EGR rate based on a combination of various sensor signals instead of relying only on the MAF value as the control parameter. Such signals include boost pressure, air temperature, and engine speed. The calculation allows for a precise EGR rate, as well as better correction of the target value in case of changes in air density or ambient temperature.
The ECM evaluates these values and outputs a PWM signal in accordance with one of the maps stored in it. The signal is sent to the exhaust gas recirculation valve actuator. The map is formulated to keep the NOx as low as possible.

The electronic circuit within the EGR valve evaluates the PWM signal, and based on this input, generates a current signal to drive the torque motor. The angle of rotation of the valve is determined by the amount of current flowing through the torque motor stator. As current increases, a stronger magnetic field is produced. The armature increases its angle of rotation, which opens the valve further. Increasing the angle of rotation increases the amount of exhaust gases flowing back into the combustion chambers. When the current is reduced, the tension of the return spring overcomes the magnetic field strength, which closes the rotary valve.



1	Torque Motor	6	Position Sensing Elements
2	Permanent Magnet	7	Stator Windings
3	Armature	8	Return Spring
4	Position Feedback Magnet Ring	9	Rotary Valve
5	End Cover	10	Valve & Coolant Jacket Housing

Figure 181 EGR Valve Exploded View

The angle of rotation is monitored by an integrated position feedback control circuit. A samarium cobalt (SmCo) magnet ring is fixed to the top of the torque motor armature. The magnet ring has diametrically opposed poles, and when the armature turns, the direction of the magnetic field changes. The change is detected by a hall-effect sensing element within the end cover.

The EGR actuator is externally grounded and is supplied with battery power when the ignition is switched on. The ECM supplies a pulse width modulated (PWM) signal to the actuator.

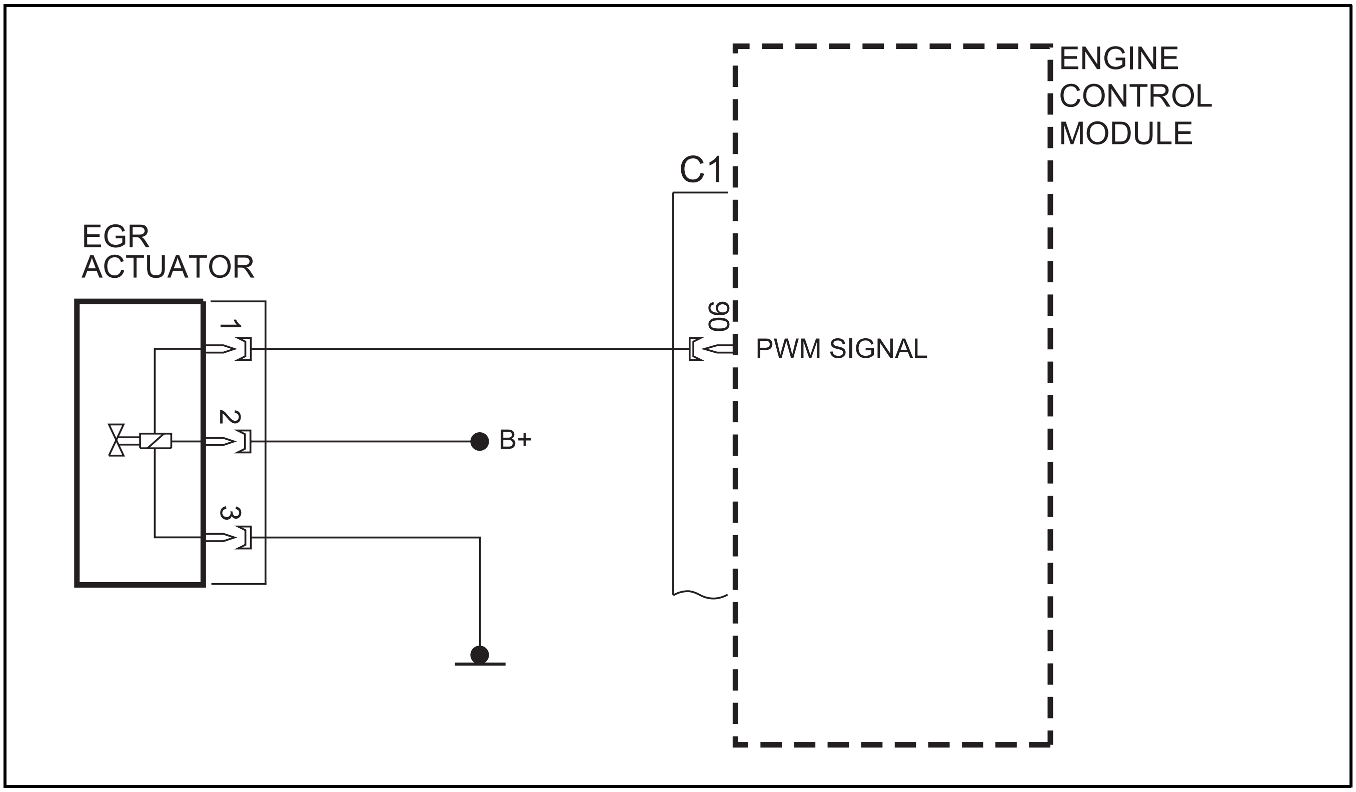


Figure 182 EGR Actuator Schematic

Self-Cleaning Function

The ECM provides the EGR valve with a self-cleaning function, which opens and closes the valve twice after the engine has been switched off to eliminate soot deposits. During the cleaning cycle, the valve turns a few degrees past the fully-open position to wipe off any carbon deposits.

Failure Modes

The ECM monitors the operation of the EGR valve and stores fault codes related to the following conditions:

- Open circuit
- Wire shorted to positive or shorted to ground
- Exhaust gas recirculation rate too high
- Exhaust gas recirculation rate too low
- Exhaust gas recirculation flow check

O2 SENSOR HEATER

The O2 sensor heater element is integrated in the sensor housing. The heater element burns off deposits from the sensor and allows the O2 sensor to reach its operating temperature.

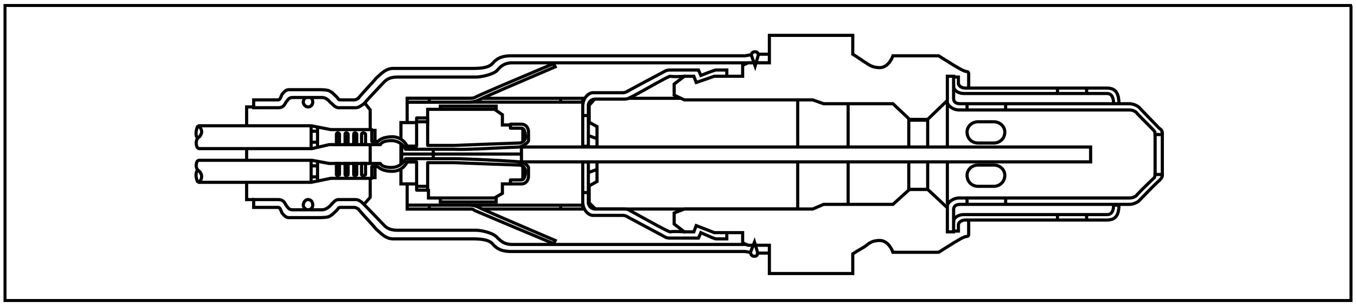


Figure 183 O2 Sensor Cutaway View

The ECM activates the integral heater element to raise the temperature of the sensor to 700°C (1292° F) for the ZrO_2 to become conductive. The heater element is designed to reach this temperature in approximately 8 seconds and maintain it at this level. In cold temperatures and engine idling, the ECM can delay the activation of the heater element for up to 5 minutes to avoid water condensate in the exhaust system from contacting and destroying the heated ceramic coating of the sensor.

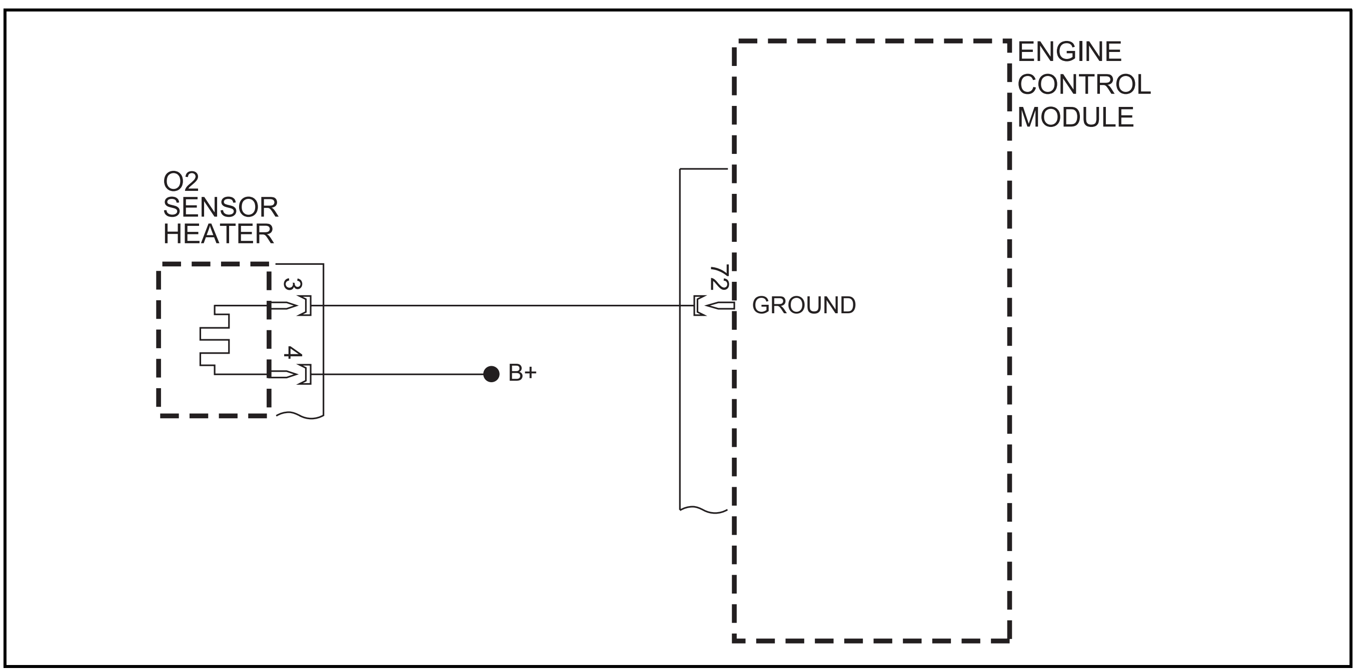


Figure 184 O2 Sensor Heater Schematic

The O2 sensor heater is supplied with battery power when the ignition is switched on. The ECM controls the activation of the O2 sensor heater by modulating the ground side. The ECM generates a PWM signal with a fixed frequency of 100 Hz. During open-loop conditions, the PWM duty cycle is held at about 1-2% (heater off). To activate the heater, the ECM increases the duty cycle. The ECM regulates heater temperature by controlling the duty cycle, which ranges between 30-60%, depending on engine operating conditions.

ENGINE SPEED (TACH) SIGNAL

The engine speed output is a digital signal, which is derived from the crankshaft position sensor (CKP) signal. The engine speed output is hardwired to the DLC connector. The square-wave signal has a fixed on/off ratio of 50% with a frequency that depends on crankshaft speed. The maximum current is of approximately 20 mA.

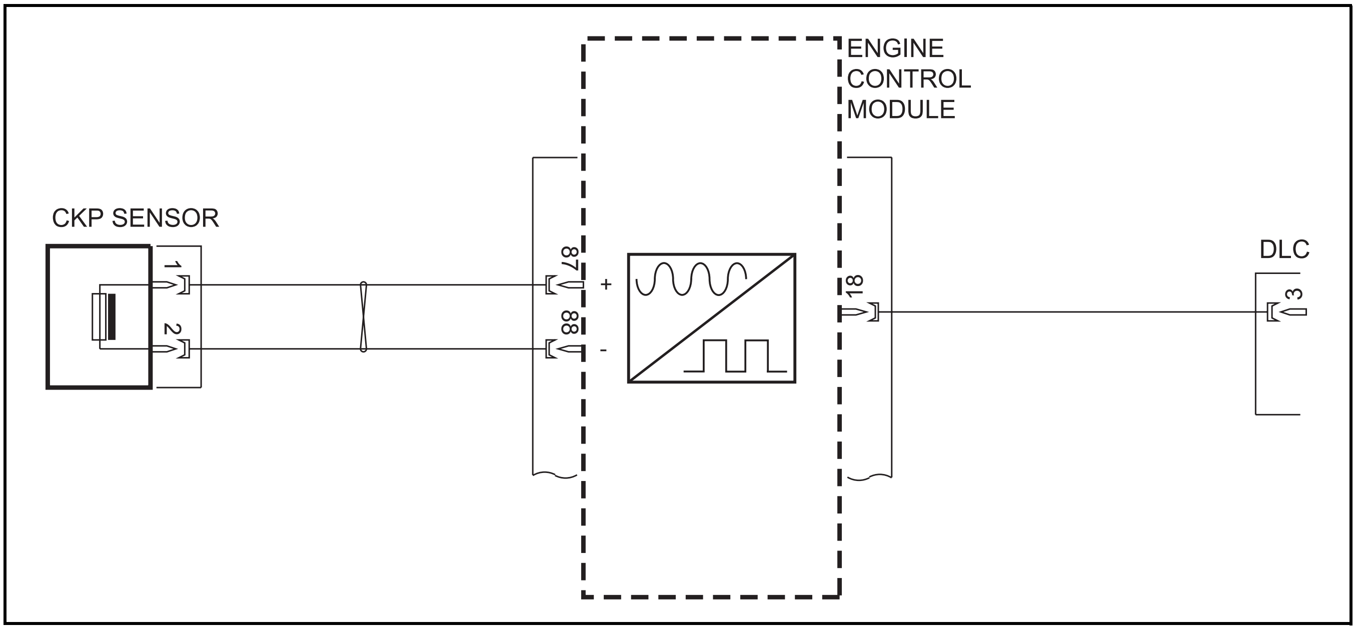


Figure 185 Engine Speed (Tach) Signal Schematic

The signal produced by the crankshaft position sensor (CKP) is conditioned by the ECM and converted into a digital squarewave signal of 6 pulses per engine revolution.

$$\textit{1 Crankshaft revolution} = \frac{\textit{58 teeth + 2 missing teeth}}{\textit{10 (divide by 10 counter)}} = 6$$

The frequency of this signal is therefore equal to one tenth of the actual engine speed value. For example, with the engine idling at 680 rpm, the speed signal frequency is calculated as follows:

680 rpm × 6 pulses = 4080 pulses per minute

4080 ÷ 60 seconds = 68 pulses per second (Hz)

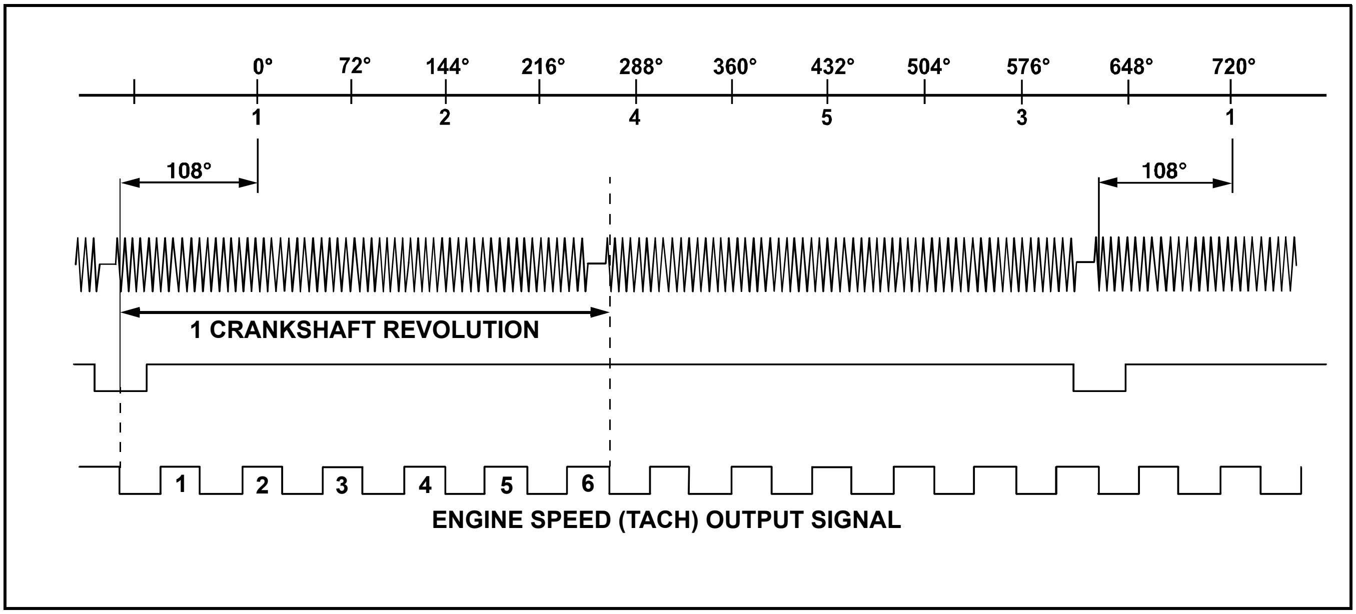


Figure 186 Engine Speed (Tach) Signal

CRANKCASE BREATHER HEATER

The crankcase breather heater is located in the crankcase breather hose between the three-stage oil separator and the turbocharger.

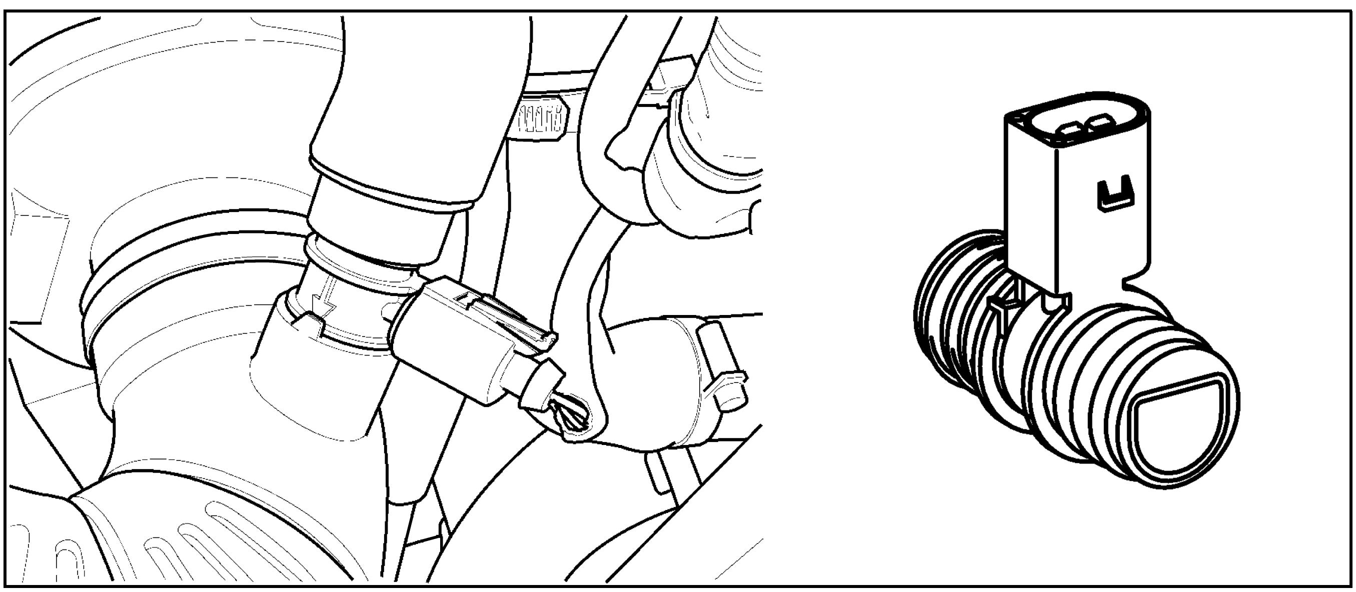


Figure 187 Crankcase Breather Heater

The ECM activates the breather heater to avoid a potential blockage of the crankcase ventilation hose due to freezing of water condensation at low temperatures.
To activate the crankcase breather heater, the ECM supplies both power and ground to the heating element.

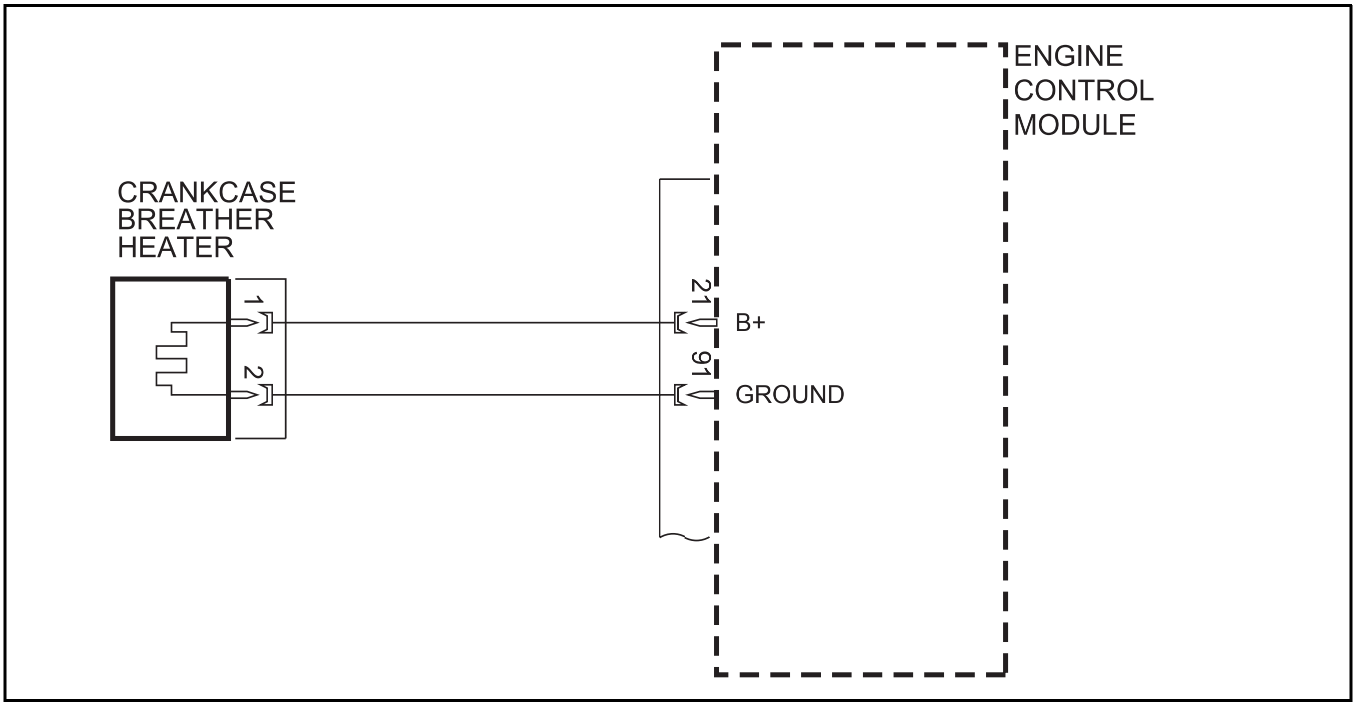


Figure 188 Crankcase Breather Heater Schematic

MIL LAMP

The engine malfunction indicator lamp is activated prior to the engine being started, with ignition ON (bulb check) and goes out after engine starts provided no fault exists. An emission-related fault may cause the lamp to stay illuminated. Not all failures ensure the illumination or the MIL lamp however.

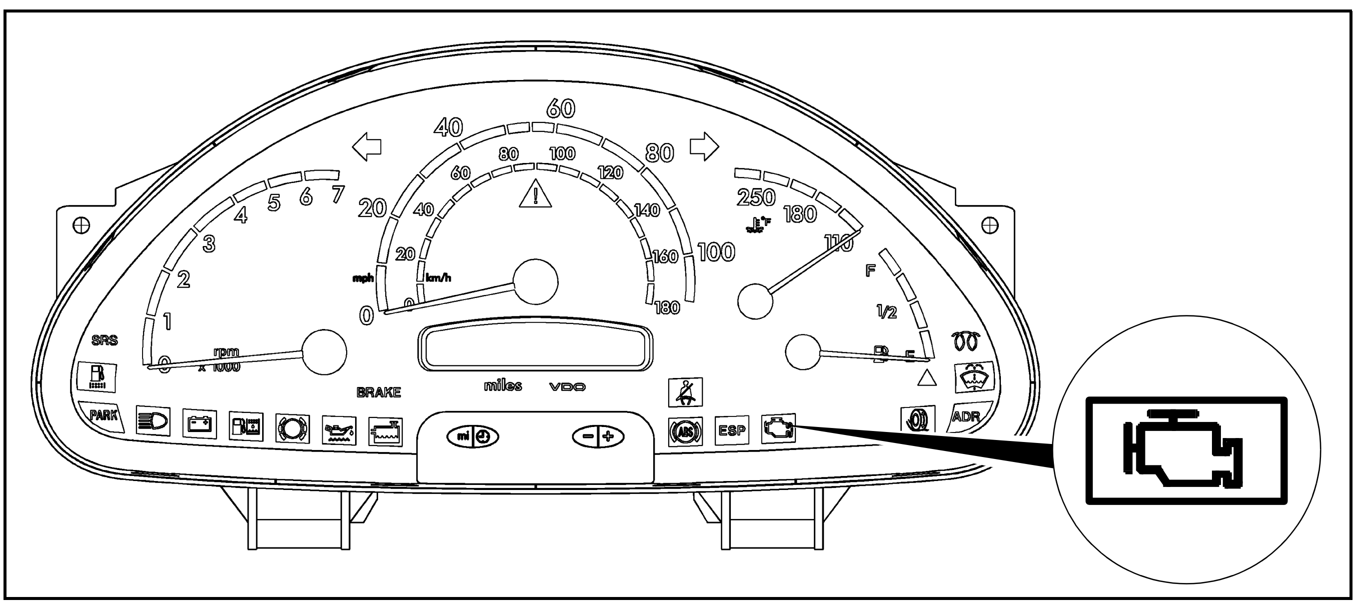


Figure 189 MIL Lamp

DATA LINK CONNECTOR

The Data Link Connector (DLC) is located under the instrument panel, on the left side of the driver's leg room area. When connected to the DLC, the diagnostic scan tool is able to establish communication with various control modules through individual diagnostic lines (K-Lines). A K-Line is a single wire that allows bi-directional data to be transmitted between control modules and a scan tool.

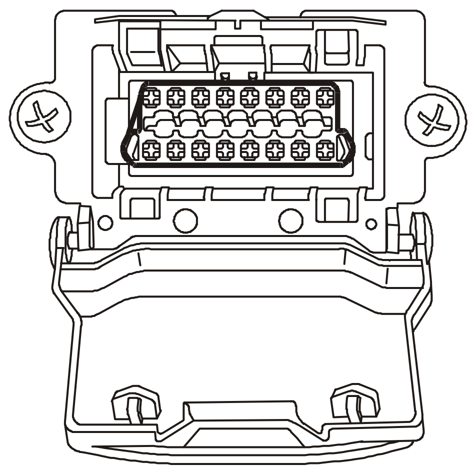


Figure 190 DLC Connector

The K-Line wiring is not connected to the CAN data bus. The K-Line is used for diagnostic and monitoring functions, while the CAN data bus is a communications link used exclusively for control module data exchange.

CAN BUS OUTPUTS

The ECM transmits information via the CAN bus to various control modules.

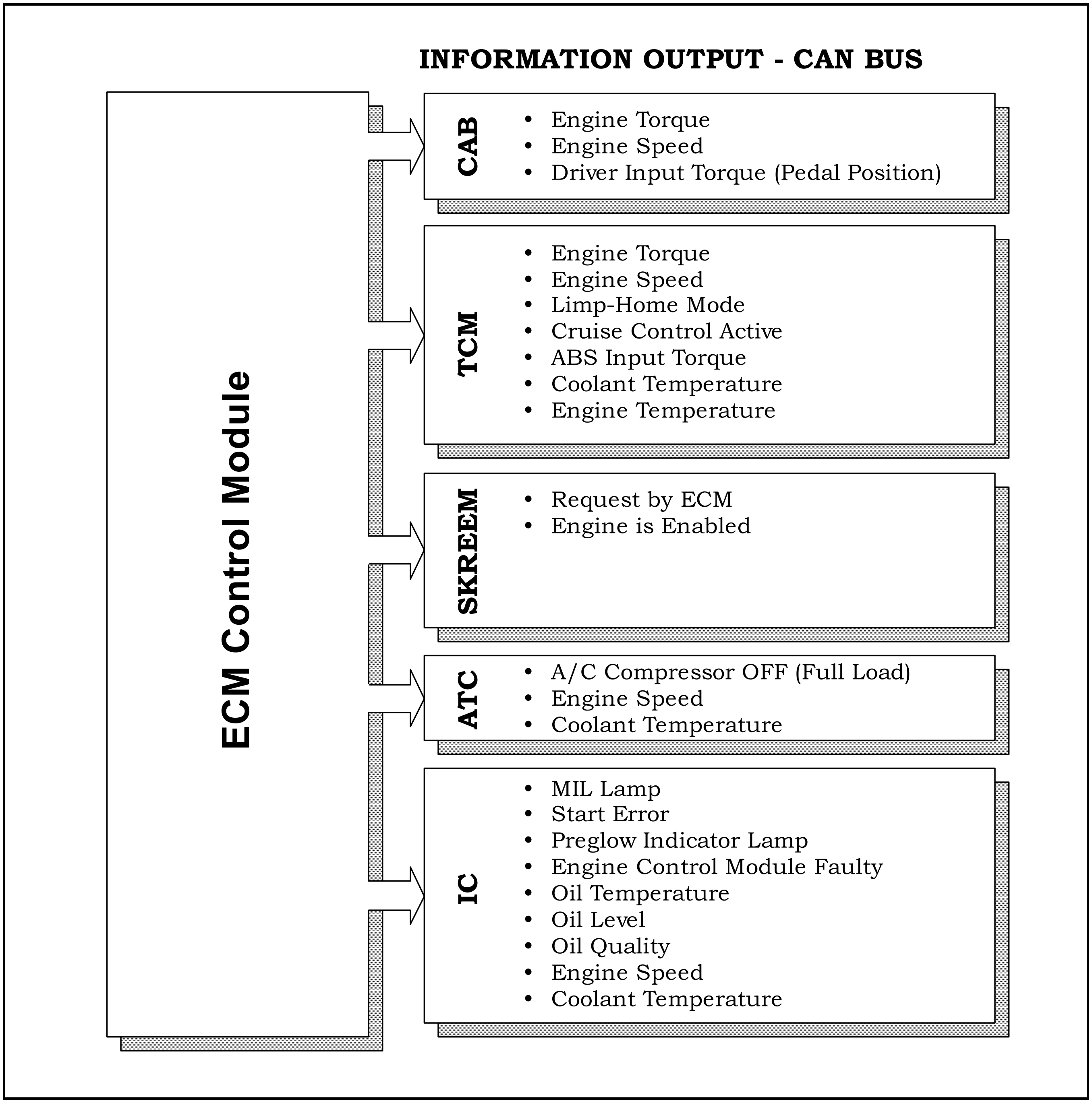


Figure 191 CAN Bus Outputs

ACTIVITY 5.4 ACTIVATIONS OF INTAKE/EXHAUST DEVICES

The purpose of this activity is to familiarize the student with injector open circuit faults and performing the EGR valve actuation test with the DRB III scan tool.

TASK 1 INJECTOR OPEN CIRCUIT

1. Simulate an open circuit by disconnecting an injector with the ignition OFF. Attempt to start the engine after disconnecting the injector and record your findings in the chart below.

MIL lamp ON (YES/NO)	Limp-In Mode (YES/NO)	Engine Does Start (YES/NO)	Engine Stalls (YES/NO)
YES	**YES - 2500 rpm**	**YES**	**NO**

2. Reconnect the injector.

TASK 2 MAF SENSOR

1. Start engine and view MAF sensor reading at idle. Record your reading below.
   Around 455 mg/strk
2. What is the MAF spec? Record your reading below.
   N/A
3. Unplug MAF. What is the status of the engine light?
   MIL lights up after 2nd start
4. Are there any associated codes?
   2067-002 signal too low, 2067-004 sign. short/open, 2068-004 sign. out of range
5. Reconnect the MAF. With the engine running. Perform EGR actuation and record results below. Clear stored faults.
   5 % *554* mg/strk (OPEN)
   95 % *254* mg/strk (CLOSED)
6. Of the above readings, which of the two is introducing the most exhaust gas?
   95% (EGR is open)
7. Shut off engine

TASK 3 INSTRUCTOR LEAD

8. Allow the engine to idle. Go to actuator tests and select the EGR positioner.
9. What is the EGR positioner value displayed?

____

10. What is the mass air value displayed?

    ____

11. Raise the engine speed and observe the readings.
12. Did the mass air flow value increase with increased engine speed? YES__NO __
13. Did the boost value increase with increased engine speed? YES ____ NO _____
14. What correlation do you see between boost and EGR values?

    As the EGR rate increases, the boost pressure decreases.

    ____

MODULE 6 ENGINE DIAGNOSIS

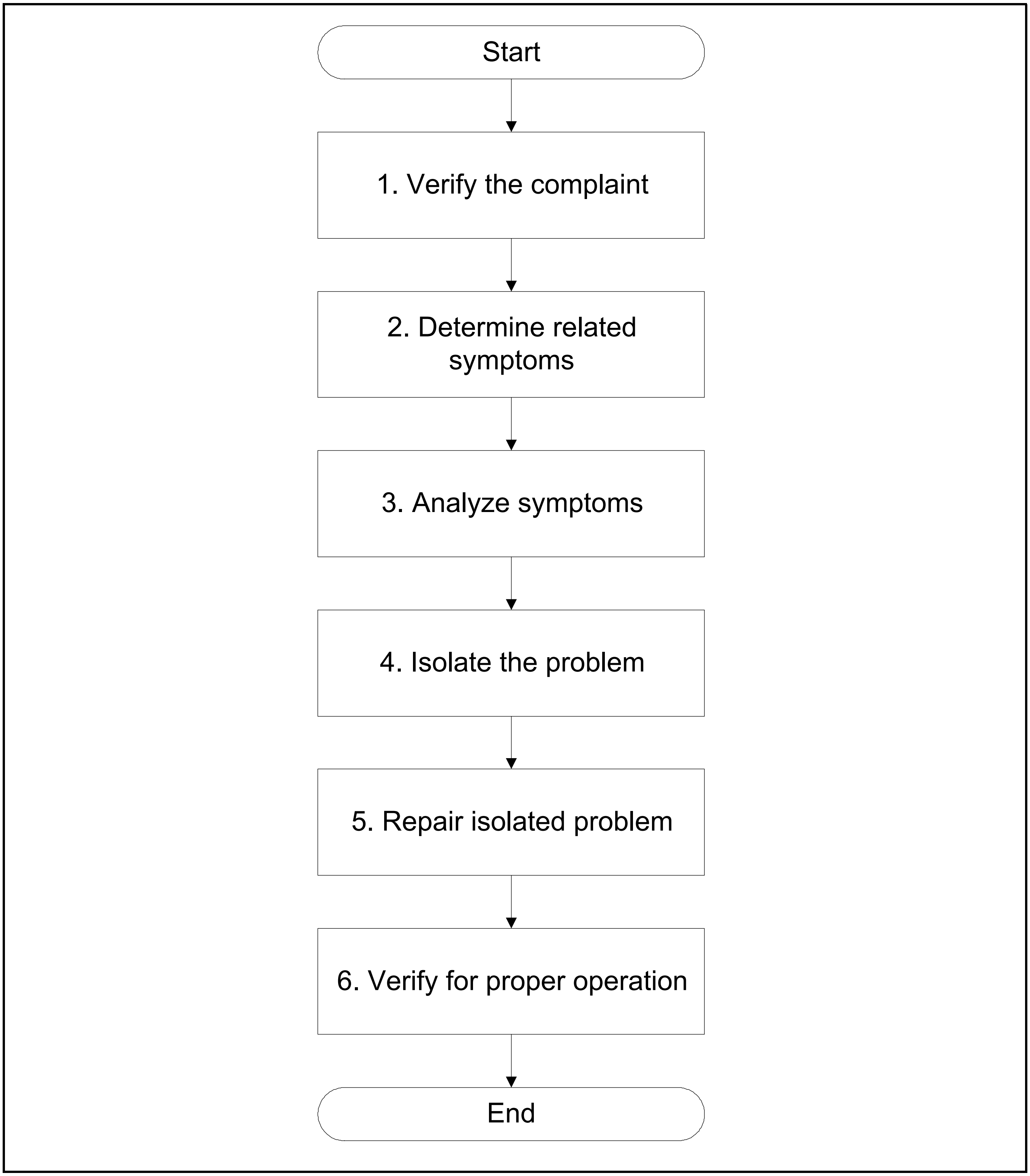


Figure 192 Flow Chart, Six-Step Diagnostic Process

SIX-STEP DIAGNOSTIC PROCESS

Step 1: Verify the Customer Concern

Verifying the customer concern is the first step in the Six-Step Diagnostic Process. This step actually begins with the Service Writer/Advisor. The Service Writer/Advisor must get as much information as possible from the customer. It is important to know if the condition is constant or varies with road speed, is weather or temperature dependent (happens when cold or when raining, etc.), or only occurs when certain equipment is being used such as the air conditioning or radio with power booster.
As a technician, the first thing you must do is accurately interpret the information. This may require talking to the customer and Service Writer/Advisor. Always duplicate the concern before attempting to correct it. Understanding and duplicating the symptom is important. It may be necessary to have the customer's help in duplicating the concern.

Step 2: Determine Related Symptoms

The next step in the Six-Step Diagnostic Process is troubleshooting the problem to determine if there are any related symptoms. The goal of this step is to gather information and associate the concern with a specific component.
Once the primary symptom is identified, check to see if there are other customer concerns which may be related. Check the vehicle's service history to determine if any other repairs were performed for similar symptoms. Review any Technical Service Bulletins (TSBs) to determine if any relate to the symptoms described by the customer. Perform a thorough visual inspection, including checking for non-factory installed accessories that may be causing the concern. Road testing a vehicle also may be necessary.

Step 3: Analyze the Symptoms

The next step in the Six-Step Diagnostic Process is to analyze the symptoms. The goal of this step is to justify the customer's claim and to classify the symptoms.
Confirming that the vehicle has a problem is important. Attempting to repair a normal condition can convince the customer that a true problem exists when it doesn't. Knowing correct system operation helps to satisfy the customer when the condition is normal.

Step 4: Isolate the Concern

The next step in the Six-Step Diagnostic Process is to isolate the concern. The goal of this step is to use the results of the road and in-shop tests to help identify the actual cause and location of the customer concern.
Isolating components from each other to determine which component is the cause of a vehicle concern is the basis of most diagnostic tests. Isolation may be as simple as lis-

tening to a suspect component with a mechanic's stethoscope, or running the vehicle with the suspect component removed.
Use the Diagnosis Charts in the Service Manual to develop an action plan to determine which checks to make. Document any additional problems with the customer's vehicle. Pay particular attention to other concerns and problems that can cause an unsafe condition.

Step 5: Repair the Concern

The fifth step in the Six-Step Diagnostic Process is to make the necessary adjustments and repairs to correct the problem. The Service Manual may help when performing these operations.
Always look for the cause of component damage. If you replace the component that is causing the symptom but do not try to determine what caused that component to fail, the failure is likely to recur.

Step 6: Verify Proper Operation

The last step in the Six-Step Diagnostic Process is to verify that the vehicle operates properly. Eliminating or isolating the problem is the optimal goal. If the customer must tolerate the concern, thoroughly explain to the customer why the condition exists. It is possible that fixing one concern may reveal another. Take the time to road test and verify that no further problems exist. Studies show that almost one out of three service visits requires a return visit to fully correct the problem.

TYPES OF EXHAUST SMOKE

The High-Pressure Common Rail (HPCR) diesel engine should emit very little smoke. White smoke is not considered normal. The different types of exhaust smoke indicate different problems. Following is a brief discussion of black, blue, and white exhaust smoke.

Black Smoke

Black smoke is created by incomplete combustion. The reason for the fuel being only partially burned often relates to one of the following problems:

- Excess fuel in the combustion chamber
- Insufficient air supply (clogged air filter, kinked hoses, faulty turbo)
- Advanced injection timing due to poor diesel fuel quality not recommended being used in the vehicle

Black smoke is caused by too much fuel or poor fuel quality and not enough air or time to burn the fuel. Black smoke is not considered normal and is often related to low power or poor fuel economy problems.

Blue Smoke

Blue smoke is an indication of engine oil burning in the combustion chamber. Blue smoke is usually accompanied by excessive oil consumption. Any of the following conditions can cause excessive oil consumption:

- Overfilled crankcase
- Worn piston rings
- Failed valve stem seals
- Failed turbocharger seals

White Smoke

White smoke is caused by particles of fuel passing through the combustion chamber without burning and exiting with the exhaust gas. Fuel not burning is often related to low combustion chamber temperature. At light loads, the temperature in the combustion chamber may drop to 260°C (500°F). The lower temperature delays combustion, causing some fuel to be partially burned and blown out with the exhaust gas.

NO DTC DIAGNOSIS

When diagnosing diesel driveability concerns in the absence of codes, use the symptom-based diagnostic tables in the Service Information. Always follow the Six-Step Diagnostic Process when diagnosing a customer concern.

HIGH-PRESSURE DIAGNOSIS

The high-pressure fuel system can be diagnosed using a DRBIII. The DRBIII will show the fuel pressure setpoint and the actual pressure. If the actual pressure and the fuel pressure setpoint values are about the same, a concern with the high-pressure fuel system may not be present. If a small leak is suspected in the high-pressure lines, check them by using the cardboard test.

WARNING: THE HIGH-PRESSURE FUEL PUMP SUPPLIES FUEL WITH PRESSURES AS HIGH AS 1600 BAR (23,205 PSI) TO EACH INJECTOR THROUGH THE HIGH-PRESSURE LINES. FUEL UNDER THIS AMOUNT OF PRESSURE CAN PENETRATE THE SKIN AND CAUSE PERSONAL INJURY. WEAR SAFETY GOGGLES AND ADEQUATE PROTECTIVE CLOTHING AND AVOID CONTACT WITH FUEL SPRAY WHEN CHECKING HIGH-PRESSURE LINES FOR LEAKS

DIAGNOSIS WITH RELATED FAULT CODES

The ECM stores diagnostic information in the EEPROM. When fault codes are present, follow the proper diagnostic steps in the service information.

COMMON POINT ANALYSIS

Certain failures can affect several circuits, causing multiple fault codes, which can lead to excessive diagnosis time. These types of faults should be treated as a whole, instead of individually. First, find if the faults displayed share a common circuit. For example, a customer complains his engine doesn't start (Start Error) and the horn doesn't work. If properly diagnosed, these complaints can be quickly narrowed down to a burnt fuse which supplies power to these components.

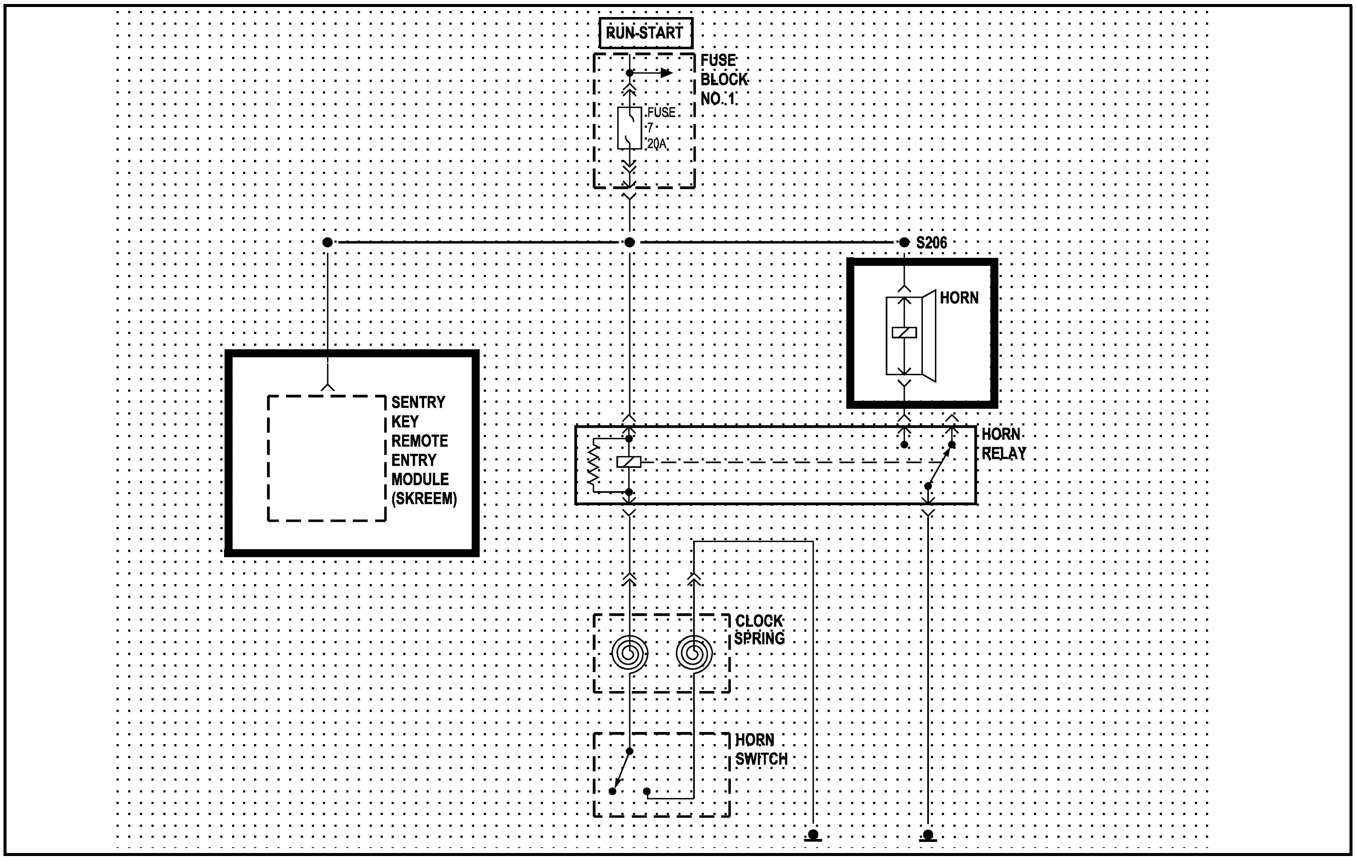


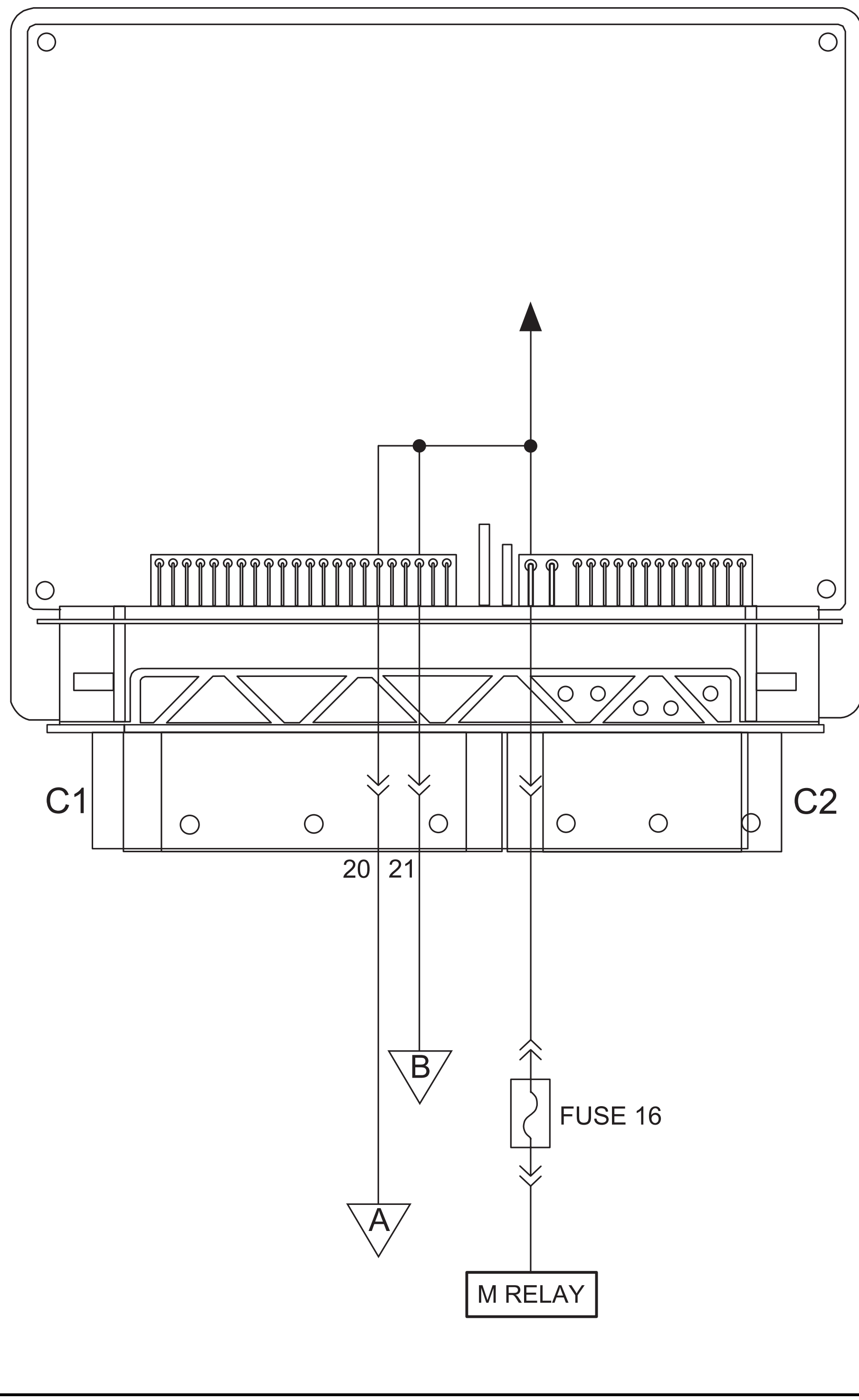
Figure 193 Common Point Analysis

ECM Internal Power and Ground Distribution

When diagnosing the common rail fuel system, the internal power supply and ground structure of the ECM must be taken into account. The ECM uses the power supply and distributes it among various inputs and outputs, both 12 volts and 5 volts. The ECM incorporates the following circuits:

- Two 12-volt power supplies
- Three regulated 5-volt power supplies (Reference 1, 2 and 3)
- Ground distribution

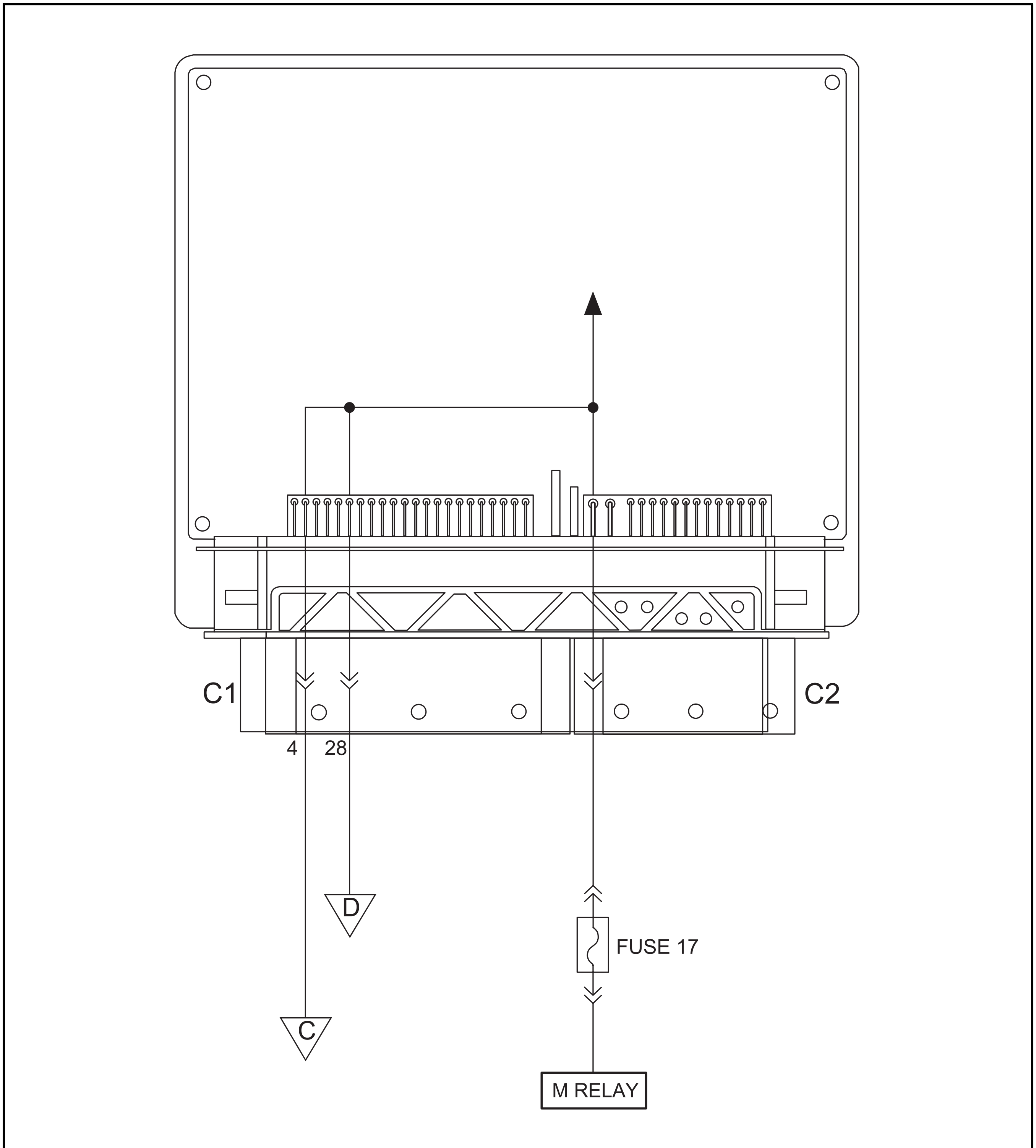
Internal Common Point Analysis, 12-Volt Power Supply Distribution



A	Water in Fuel Sensor 12 V Supply
B	Crankcase Ventilation Heater 12 V Supply

Figure 194 ECM, 12 Volt Supply 1

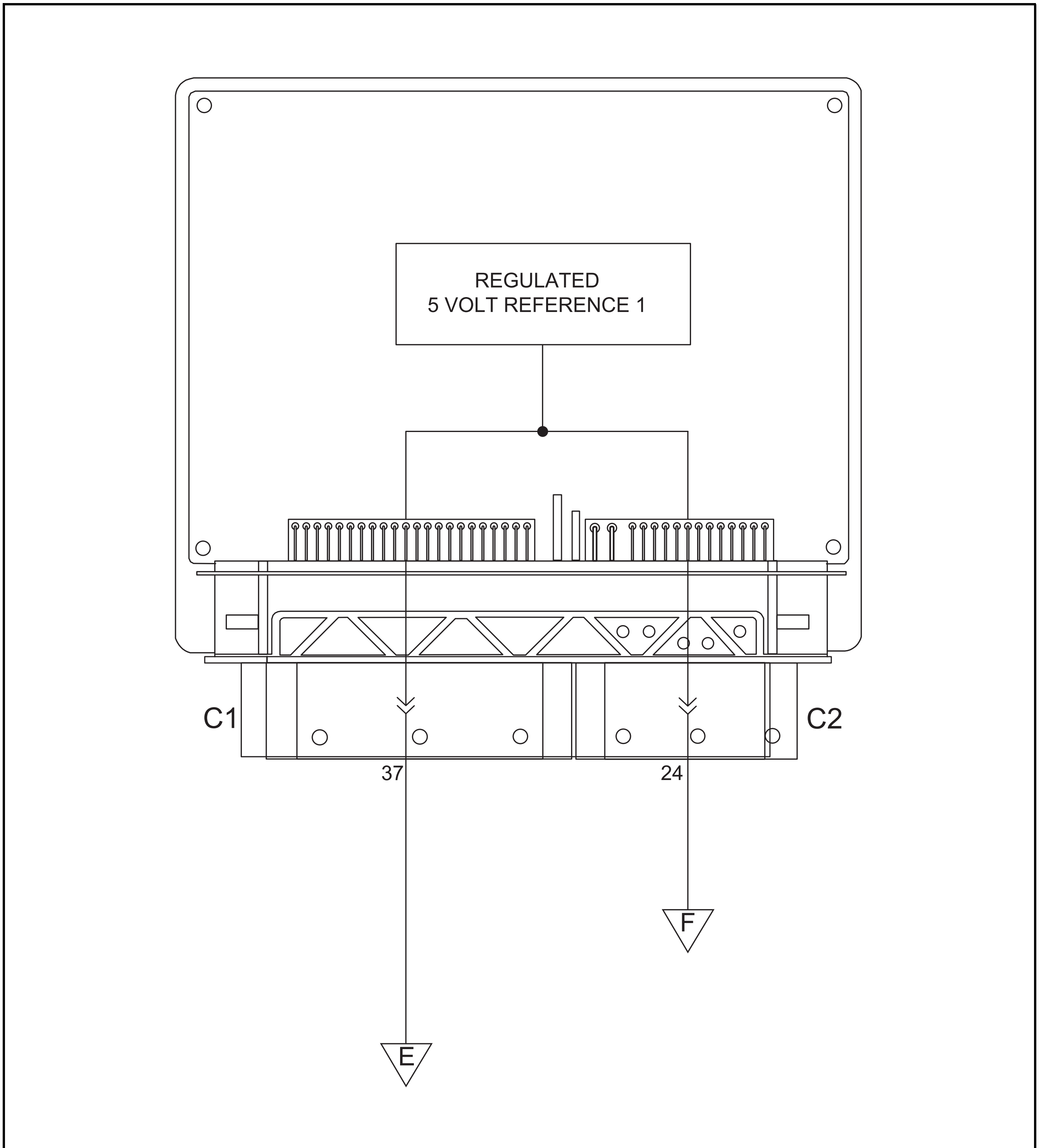
Internal Common Point Analysis, 12-Volt Power Supply Distribution



C	Fuel Pressure Solenoid 12 V Supply
D	Fuel Quantity Valve (Engine Management Valve) 12 V Supply

Figure 195 ECM, 12 Volt Supply 2

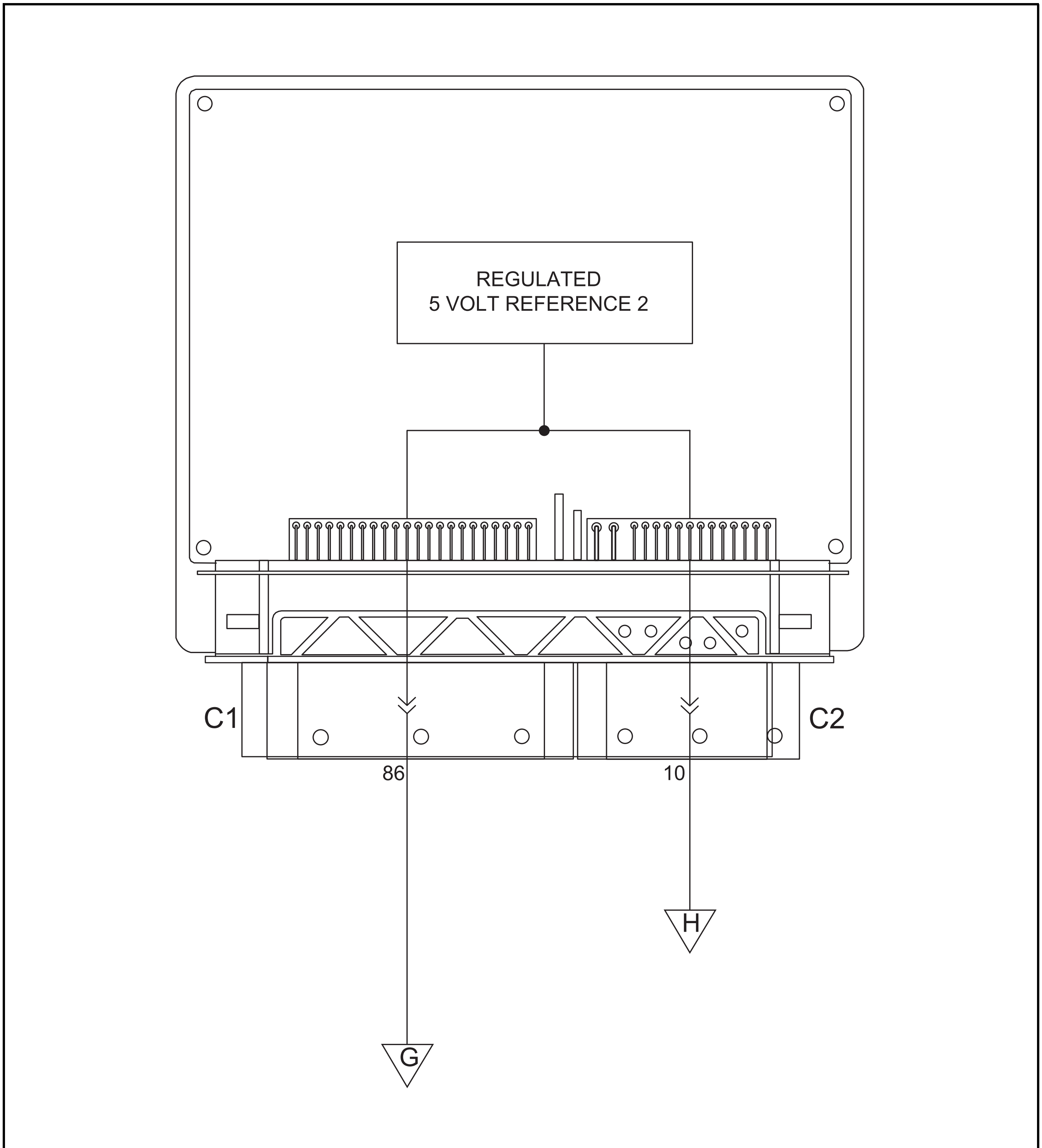
Internal Common Point Analysis, 5 Volt Reference 1



E	Camshaft Position Sensor 5V Supply
F	Accelerator Pedal Position Sensor (APP) 5 V Supply

Figure 196 ECM, 5 Volt Reference 1

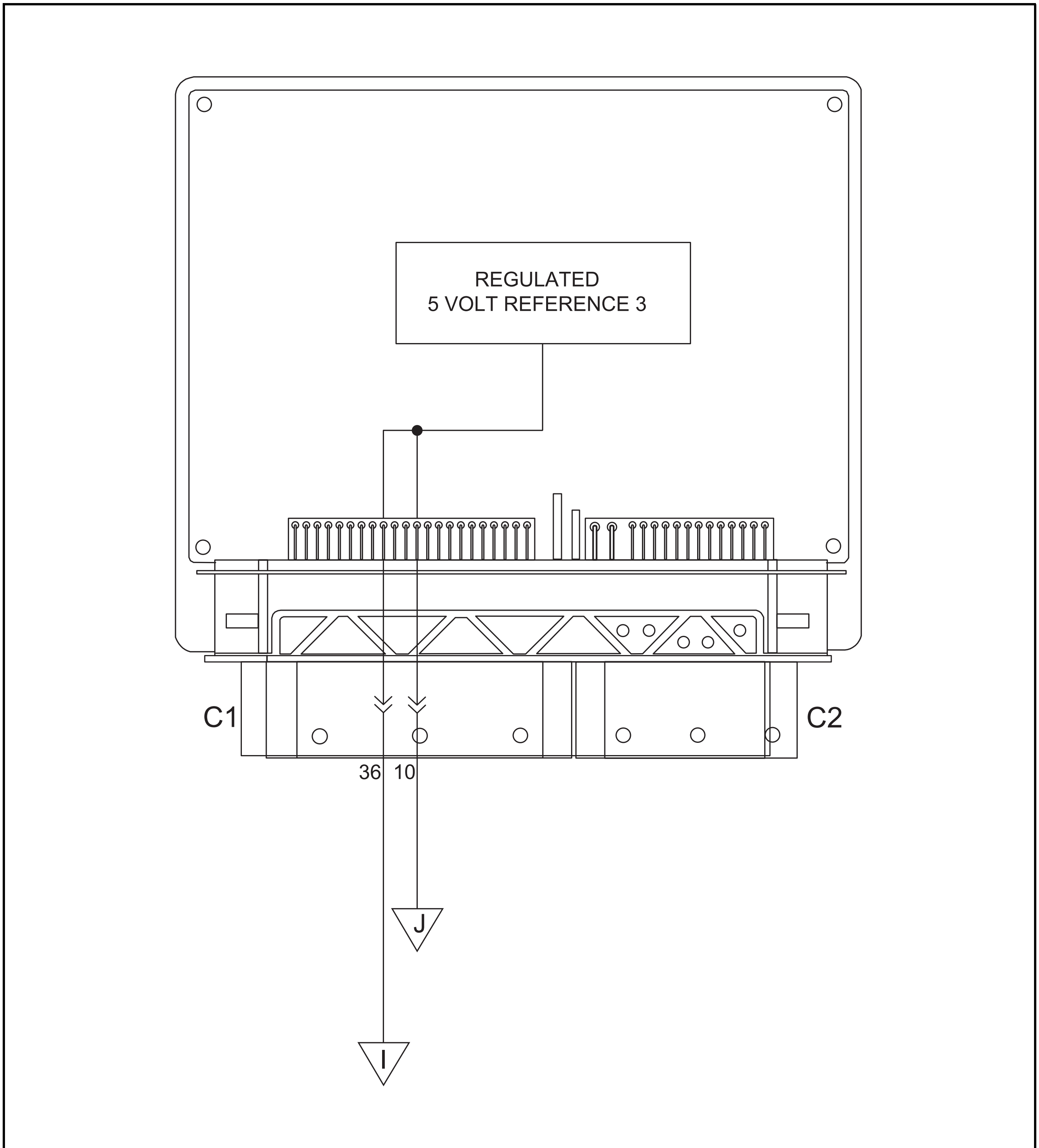
Internal Common Point Analysis, 5 Volt Reference 2



G	Fuel Rail Pressure Sensor 5V Supply
H	Boost Pressure Sensor 5 V Supply

Figure 197 ECM, 5 Volt Reference 2

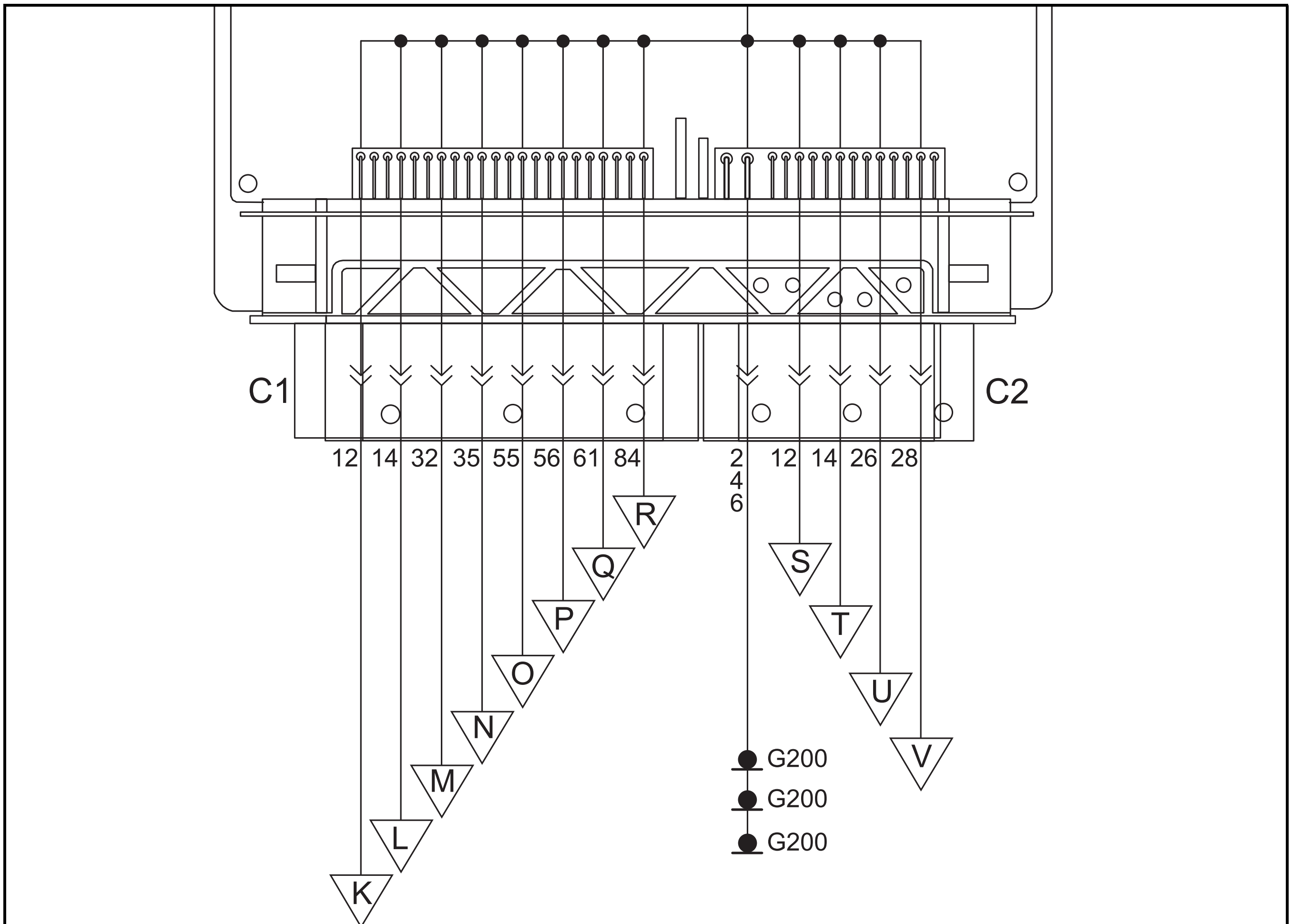
Internal Common Point Analysis, 5 Volt Reference 3



I	Intake Air Pressure Sensor 5V Supply
J	Engine Oil Sensor 5V Supply

Figure 198 ECM, 5 Volt Supply (3)

Internal Common Point Analysis, Grounds



K	Intake Air Pressure Sensor Ground
L	Camshaft Position Sensor Ground
M	Fuel Temperature Sensor Ground
N	Engine Oil Sensor Ground
O	Water In Fuel Sensor Ground
P	Coolant Temperature Sensor Ground
Q	MAF Sensor Ground
R	Fuel Rail Pressure Sensor Ground
S	Boost Pressure Sensor Ground
T	Accelerator Pedal Position Sensor 2 Ground
U	Accelerator Pedal Position Sensor 1 Ground
V	Boost Air Temperature Sensor Ground

Figure 199 ECM, Ground

DIAGNOSIS WITHOUT RELATED FAULT CODES

Following a systematic routine is essential when dealing with driveability complaints that have no related fault codes. The six-step diagnostic process allows the technician to remain focused and eliminates unnecessary work.

The following are examples of complaints without related fault codes.

COMPLAINT: ROUGH IDLE/ENGINE KNOCKS AT IDLE

Possible cause: injector malfunction

Troubleshooting Steps

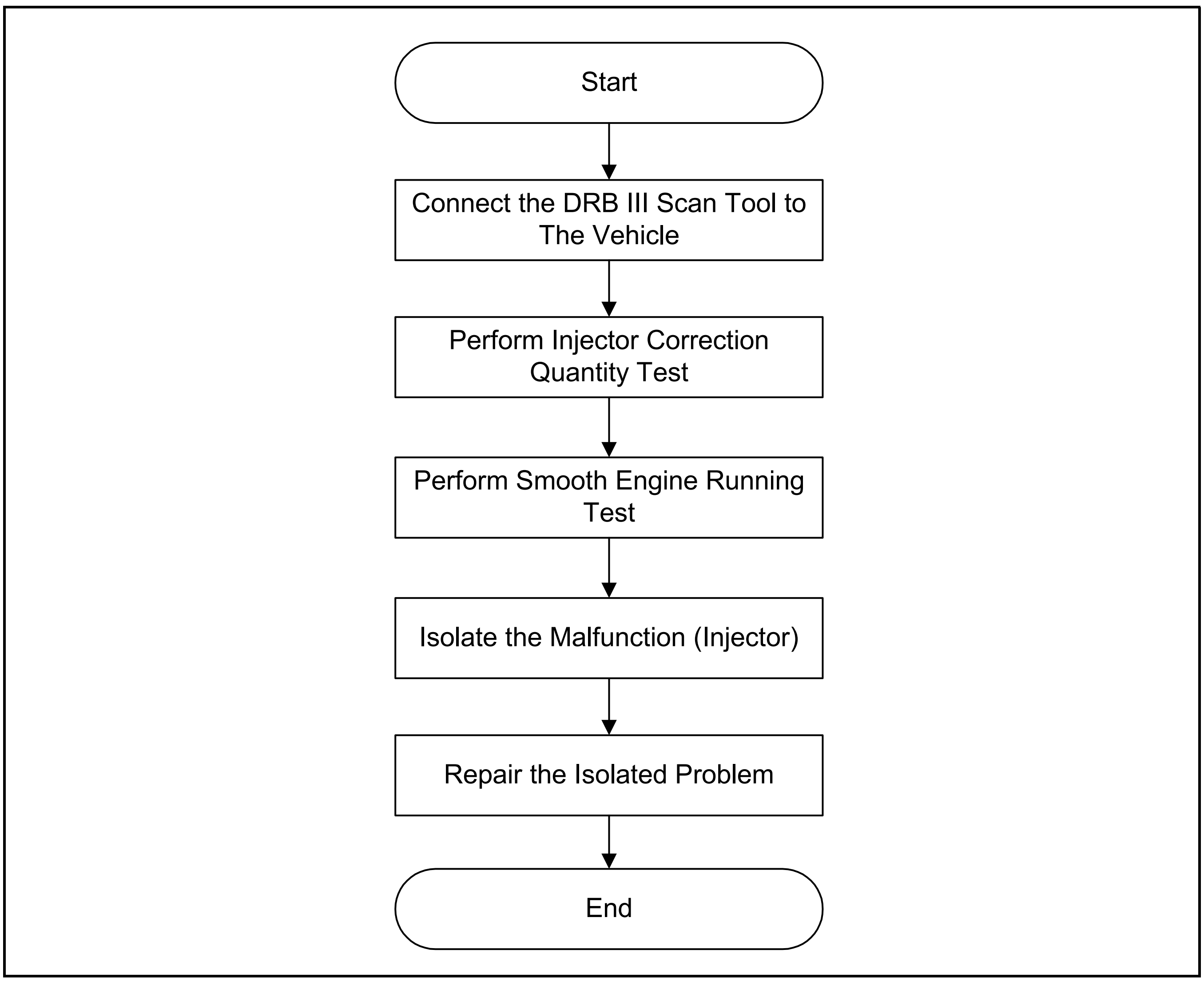


Figure 200 Rough Idle/Engine Knock

COMPLAINT: ENGINE CRANKS, BUT DOESN'T START

Possible causes:

- Insufficient fuel pressure – low or high pressure circuits
- Insufficient Low pressure pump output
- Fuel pressure sensor malfunction
- Fuel pressure solenoid malfunction
- Leaking injector
- High pressure pump failure
- CPS pulse ring or flex plate damage

Troubleshooting Steps

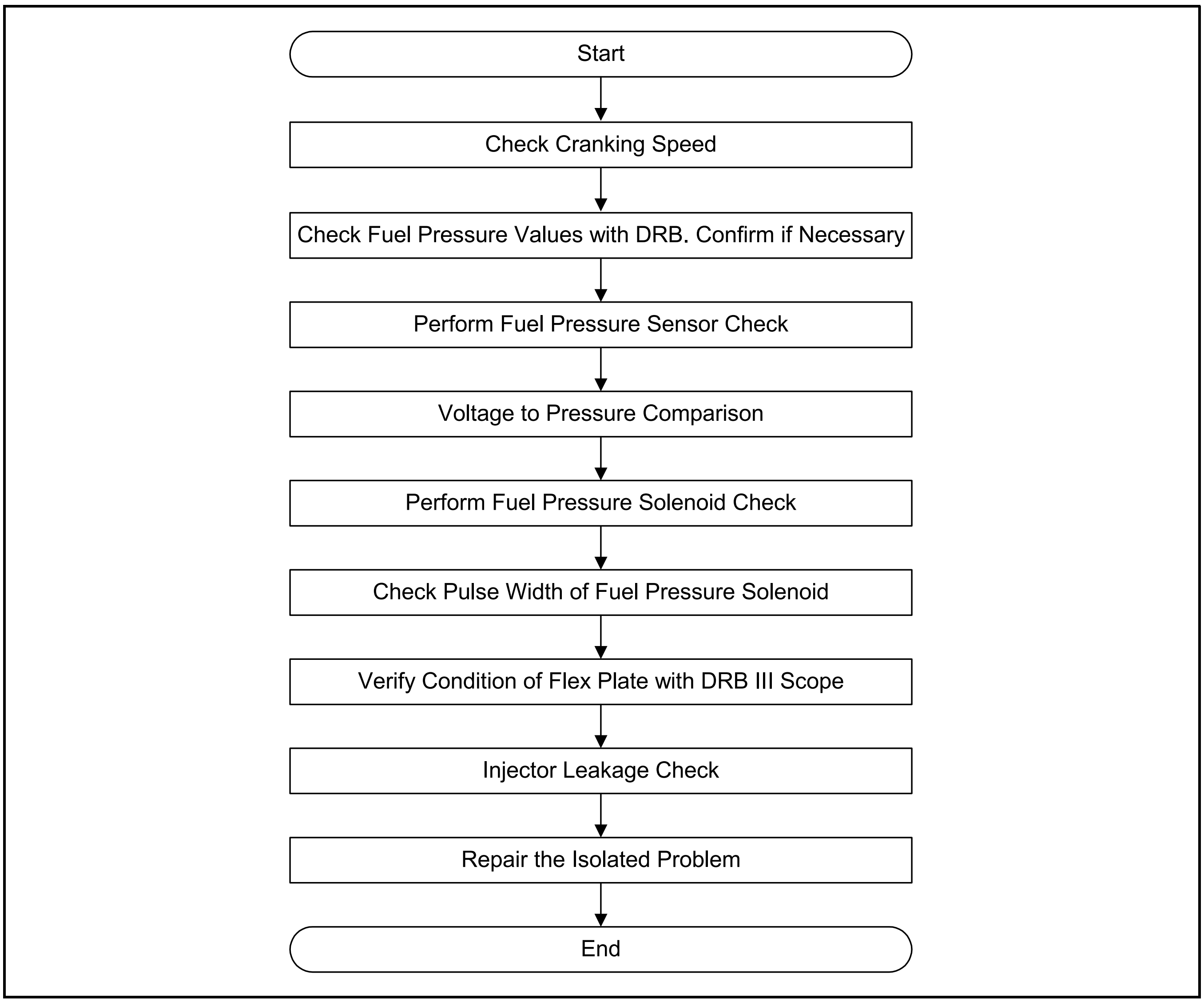


Figure 201 Engine Does Not Start

COMPLAINT: POWER LOSS/ENGINE DIES UNDER LOAD

Possible causes:

- Injector malfunction
- Fuel pressure solenoid malfunction
- High pressure pump fluctuates under load

Troubleshooting Steps

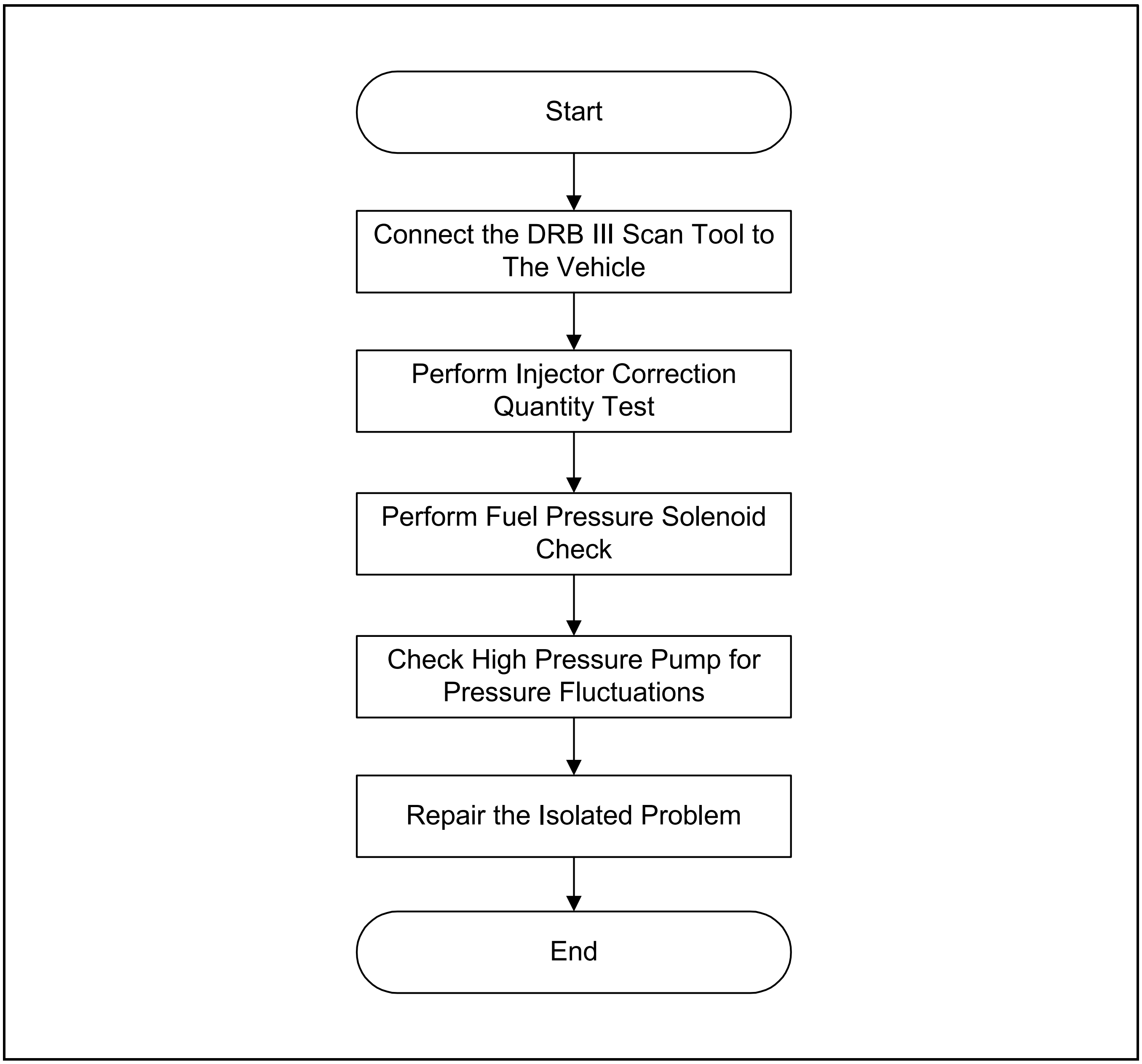


Figure 202 Power Loss/Engine Dies

COMPLAINT: BLACK SMOKE

(Smoke diagnosis review)
Possible cause: rail pressure sensor malfunction

Troubleshooting Step

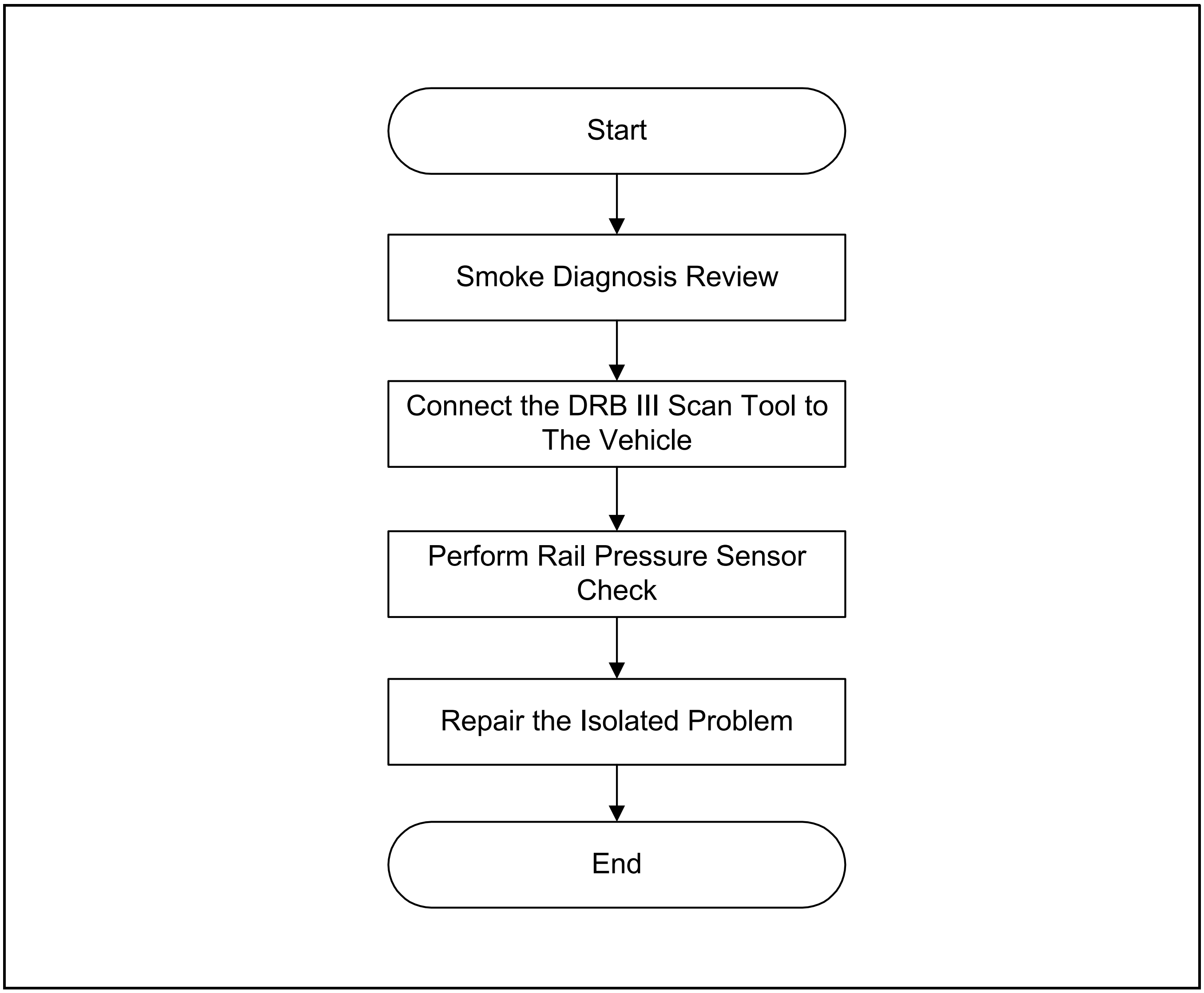


Figure 203 Black Smoke

COMPLAINT: ENGINE RPM DROPS INTERMITTENTLY

Possible cause: stop lamp switch misadjusted/malfunction

Troubleshooting step

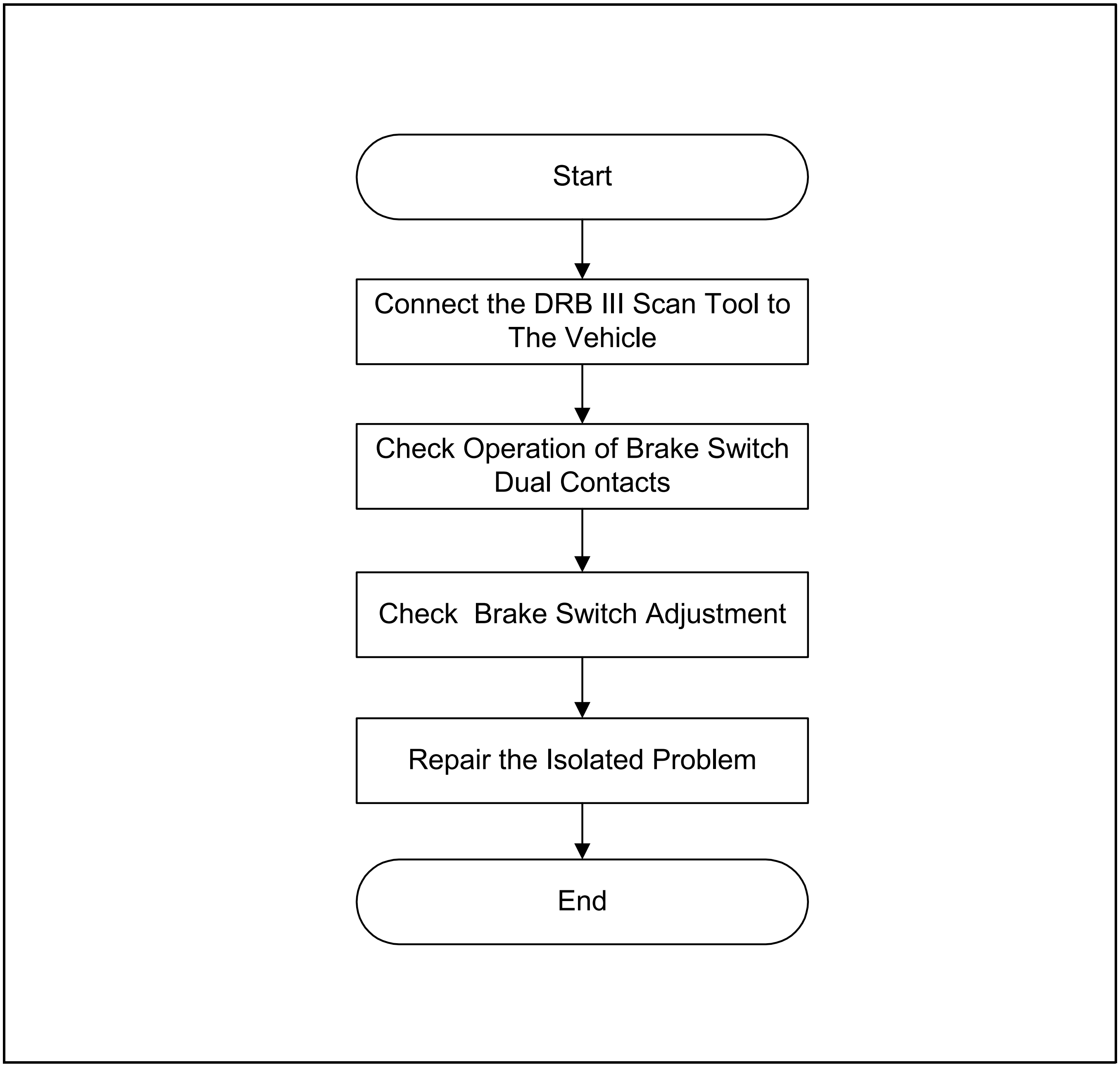


Figure 204 Engine RPM Drop

ACTIVITY 6.1 : TROUBLESHOOTING PROBLEMS ON VEHICLE

The purpose of this activity is to allow the students to perform driveability troubleshooting procedures using the diagnostic scan tool and the six-step diagnostic process.

TASK 1 <u>COMPLAINT</u>: NO CRANK - AUXILIARY FAN STAYS ON

1. Go to the shop vehicle assigned by your instructor. The hood is to remain closed during the analysis.
2. Write down a detailed diagnostic step procedure for troubleshooting this condition.

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3. What is the possible root cause of this driveability complaint?
   Blown fuses 16 and 17 in fuse block 1
   ____
4. Inform your instructor of the results of your troubleshooting procedure.

TASK 2 <u>COMPLAINT</u>: ENGINE CRANKS BUT DOESN'T START

1. Go to the shop vehicle assigned by your instructor. The hood is to remain closed during the analysis.
2. Write down a detailed diagnostic step procedure for troubleshooting this condition

3. What is the possible root cause of this driveability complaint?

   Fuel pressure solenoid malfunction

4. Inform your instructor of the results of your troubleshooting procedure

TASK 3 COMPLAINT: ENGINE RUNS ROUGH

1. Go to the shop vehicle assigned by your instructor. The hood is to remain closed during the analysis.
2. Write down a detailed diagnostic step procedure for troubleshooting this condition

3. What is the possible root cause of this driveability complaint?

   Injector malfunction

4. Inform your instructor of the results of your troubleshooting procedure

TASK 4 <u>COMPLAINT</u>: ENGINE HAS NO POWER

1. Go to the shop vehicle assigned by your instructor. The hood is to remain closed during the analysis.
2. Write down a detailed diagnostic step procedure for troubleshooting this condition

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3. What is the possible root cause of this driveability complaint?

   Air filter clogged

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4. Inform your instructor of the results of your troubleshooting procedure

APPENDIX

OM647 ENGINE WIRING SCHEMATIC

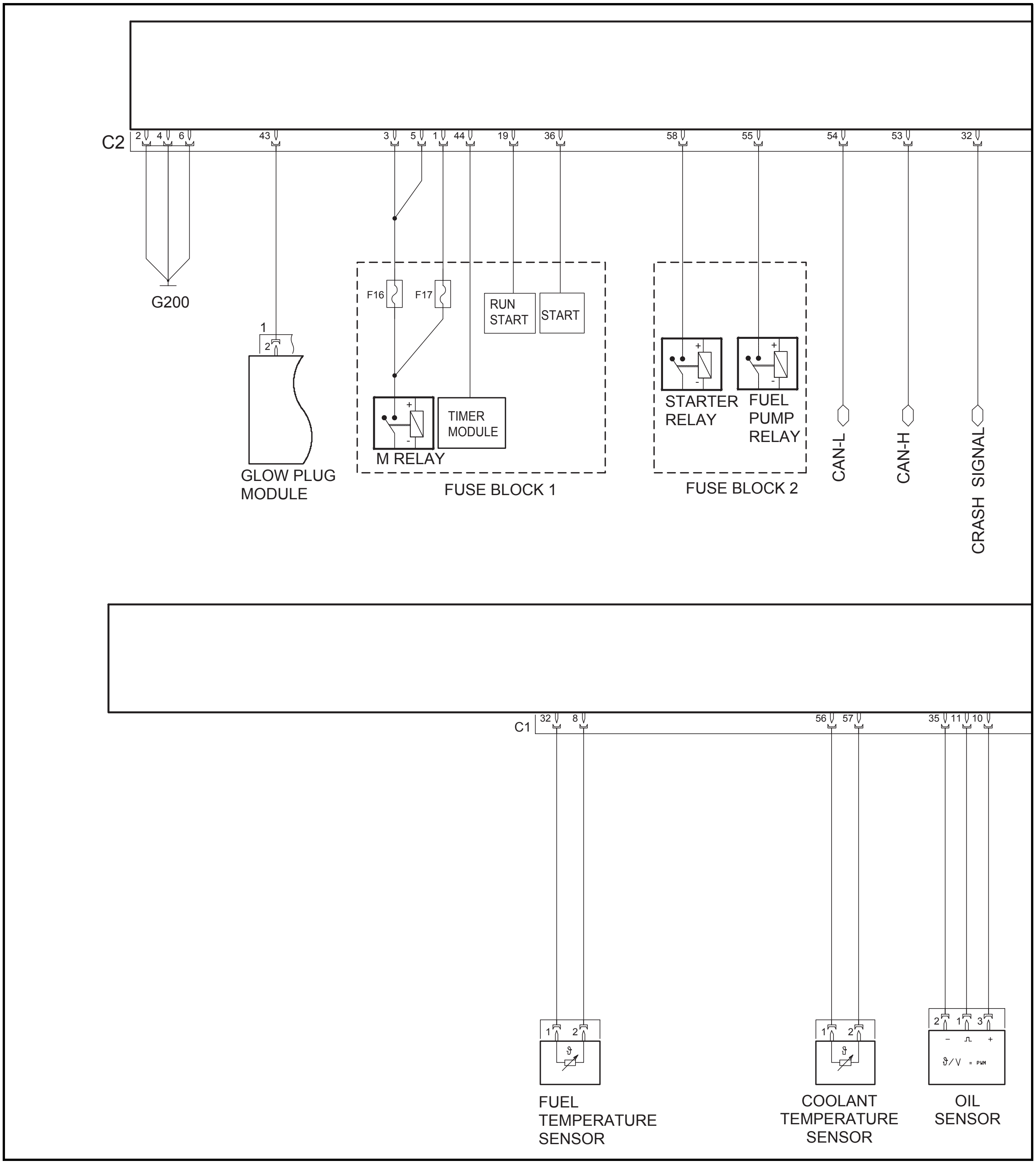


Figure 205 Engine Wiring Schematic

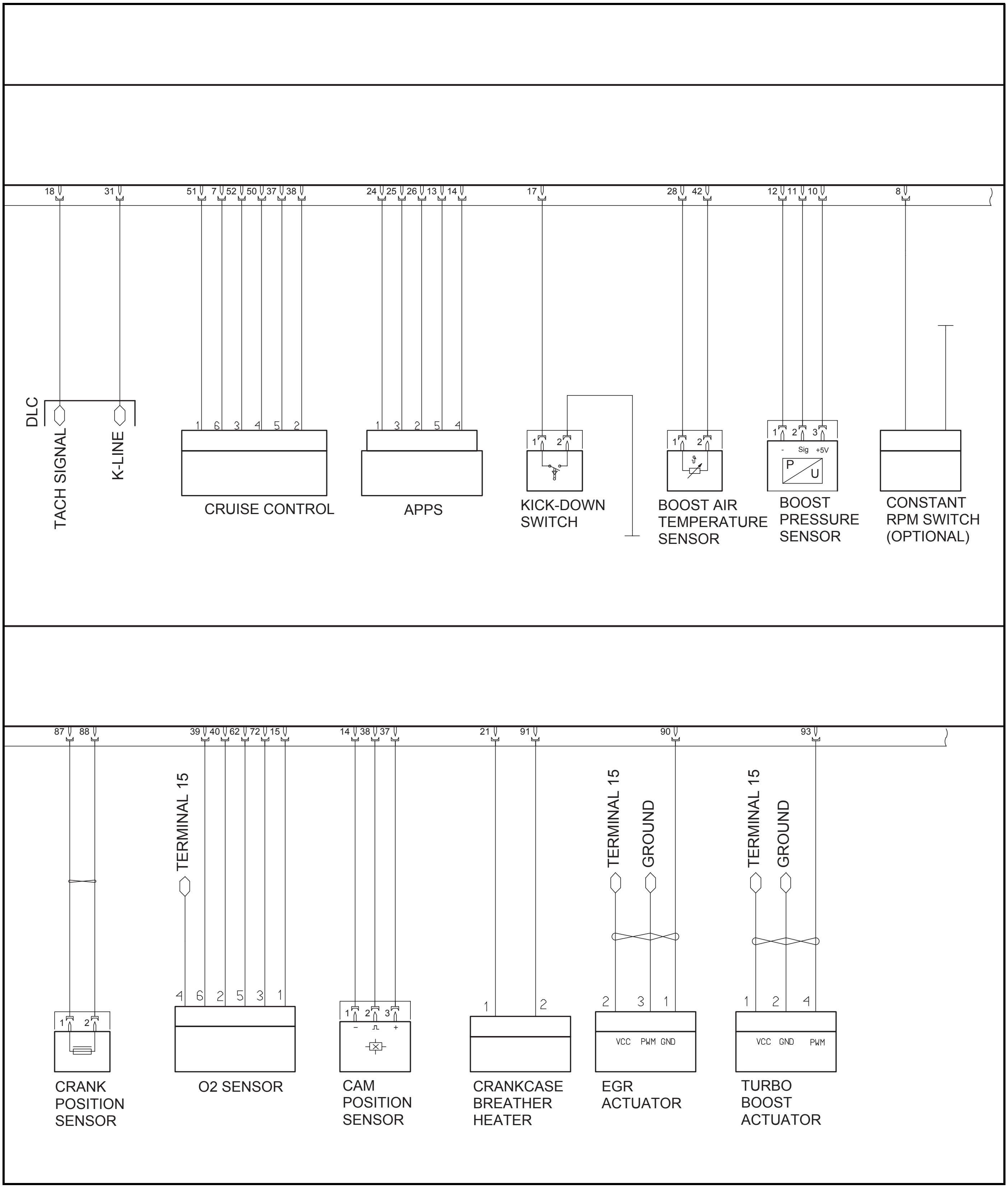


Figure 206 Engine Wiring Schematic (continued)

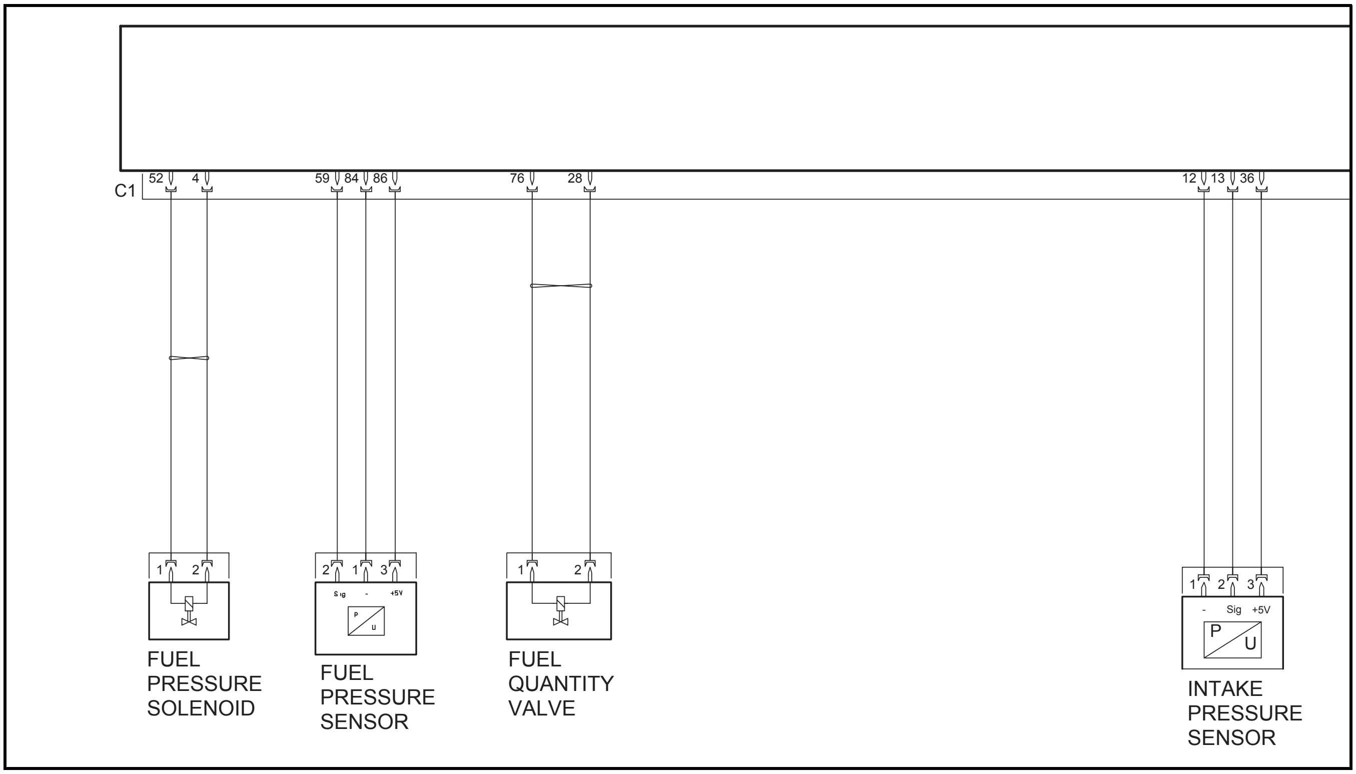


Figure 207 Engine Wiring Schematic (continued)

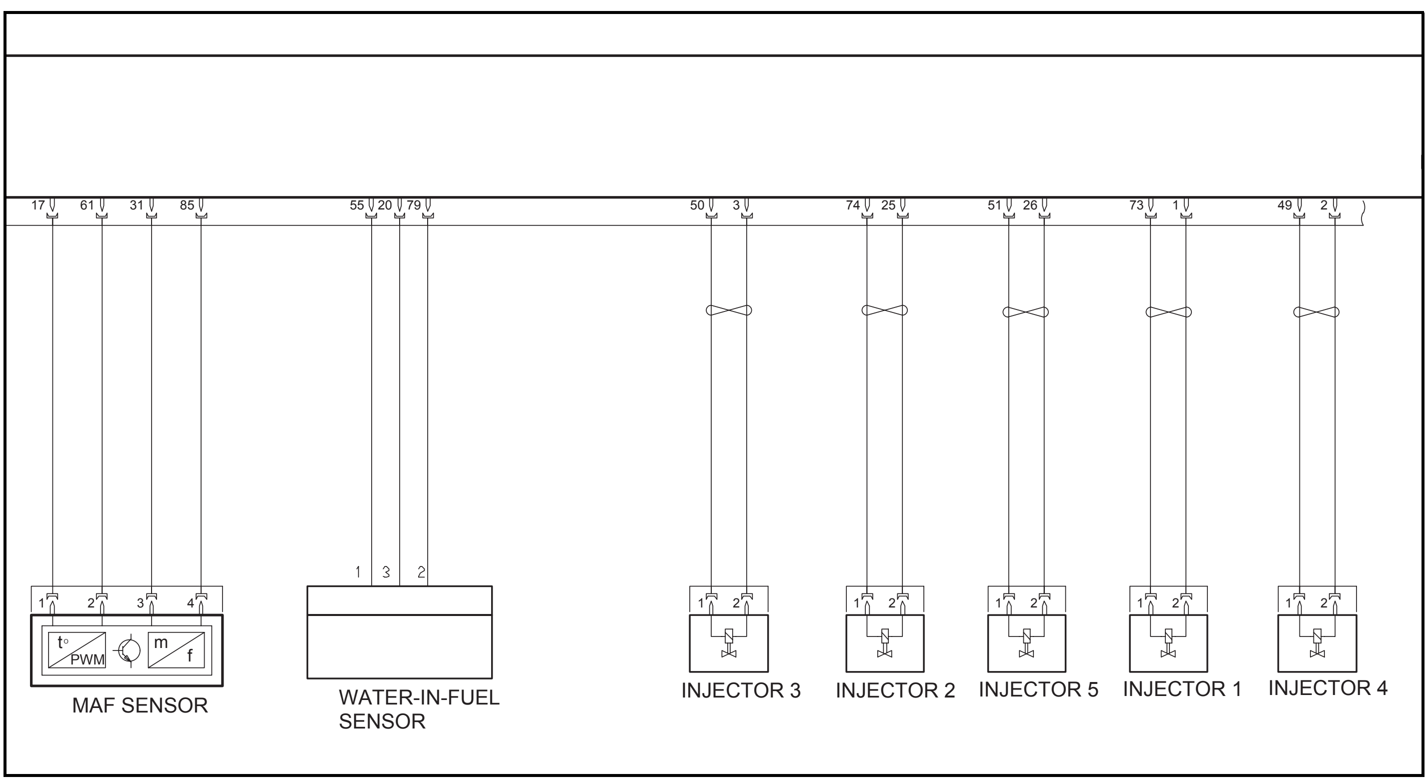


Figure 208 Engine Wiring Schematic (continued)

OSCILLOSCOPE PATTERNS

CRANK AND CAM SIGNALS

Figure 209 shows the pattern of the crankshaft position sensor (CKP)at idle speed. Notice the voltage gap resulting from the two missing teeth on the flywheel.

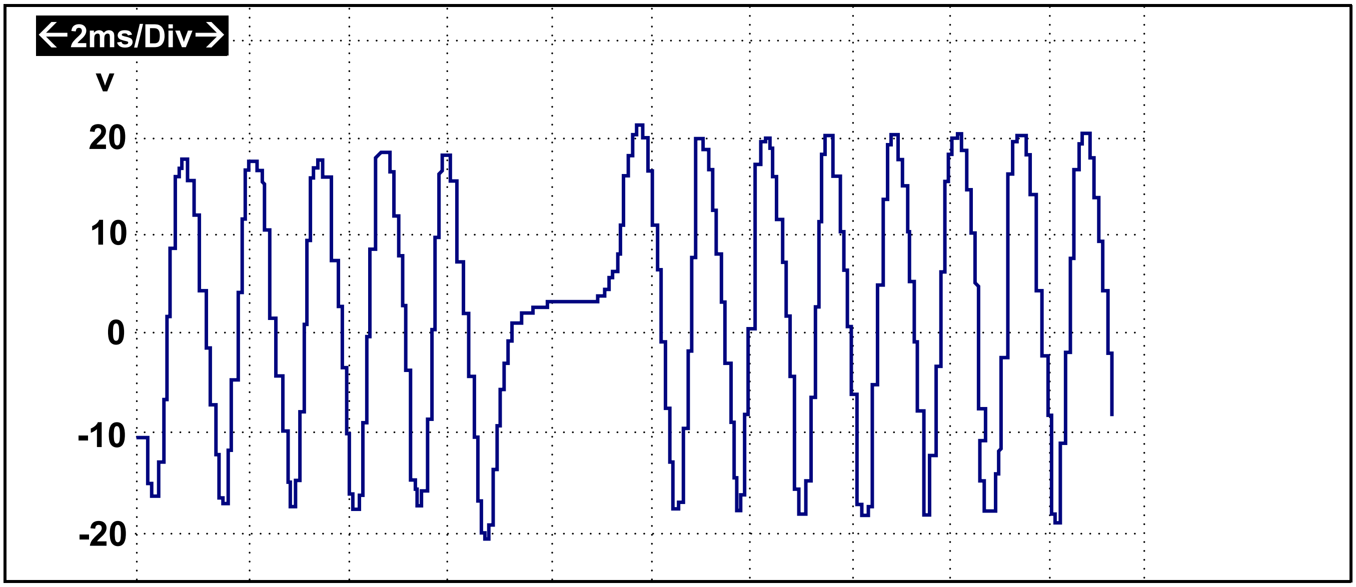


Figure 209 Crankshaft Position Sensor Signal

Figure 210 shows the pattern of the camshaft position sensor at idle speed. The 5-volt signal switches to a low voltage level when the segment for identification of cylinder No.1 is detected.

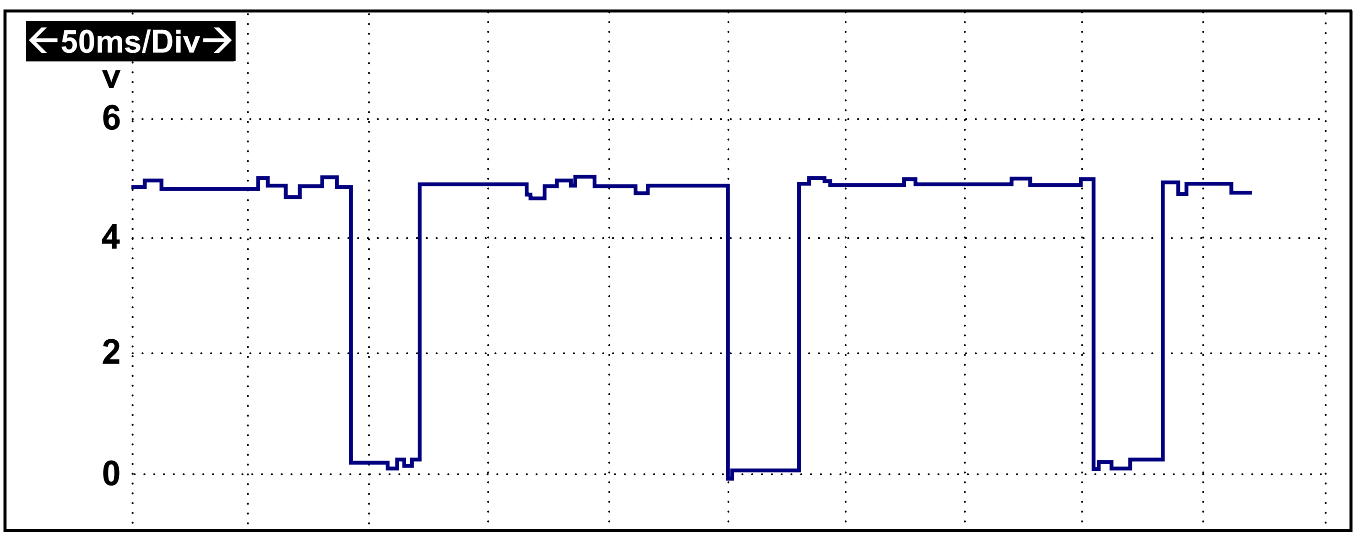


Figure 210 Camshaft Position Sensor Signal

Figure 211 shows the relationship between the CKP and CMP sensor signals

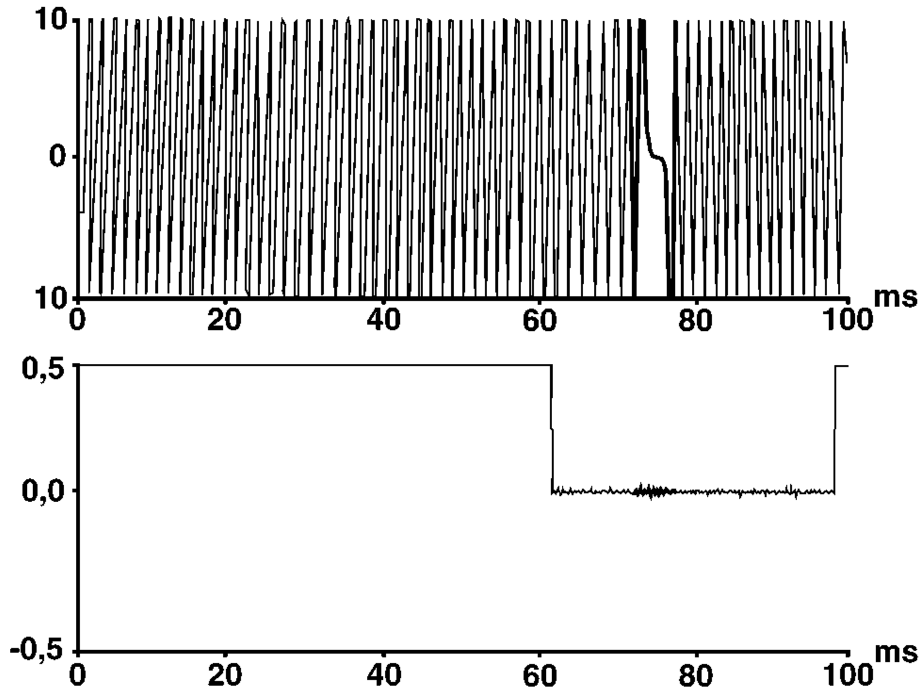


Figure 211 Crank (CKP) and Cam (CMP) Signals

Figure 212 shows the normal pattern of the CMP (Channel 1) and CKP (Channel 2) signals at idle.

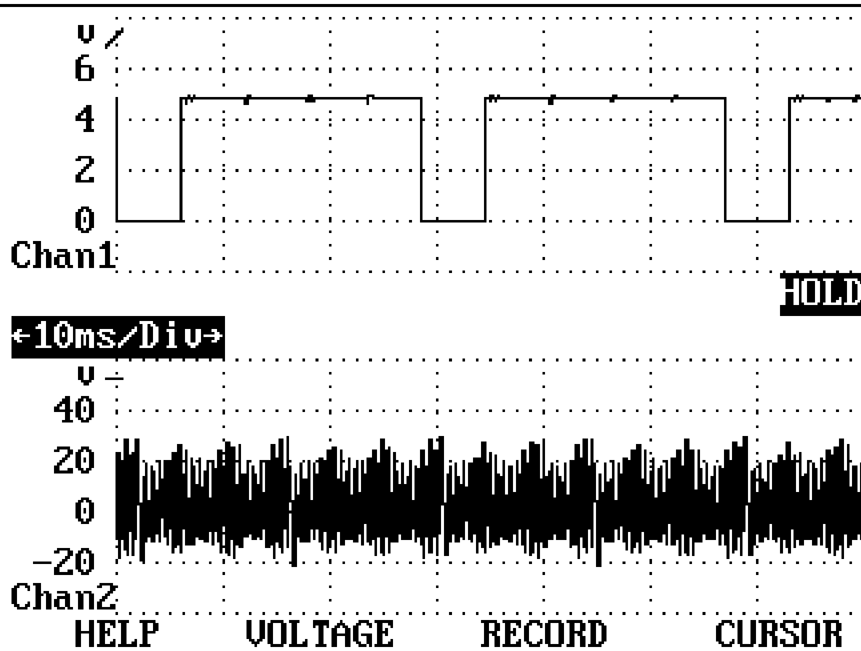


Figure 212 Fuel Injector Signal

Figure 213 shows the normal pattern of the CKP sensor (wires 1 and 2).

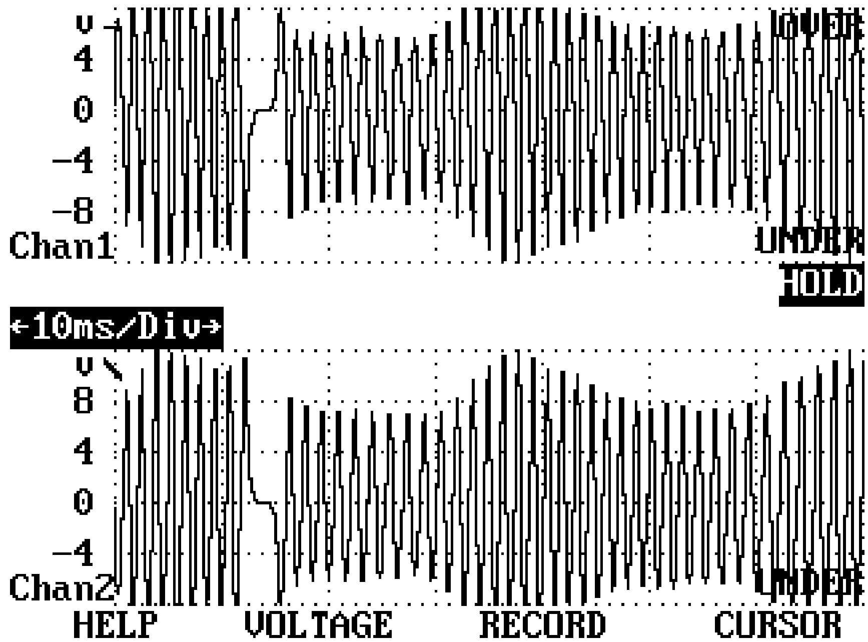


Figure 213 Crank (CKP) Sensor Signal

Figure 214 shows the Crank (CKP) Sensor pattern. Channel 2 shows the sensor wire No. 1 is shorted to ground.

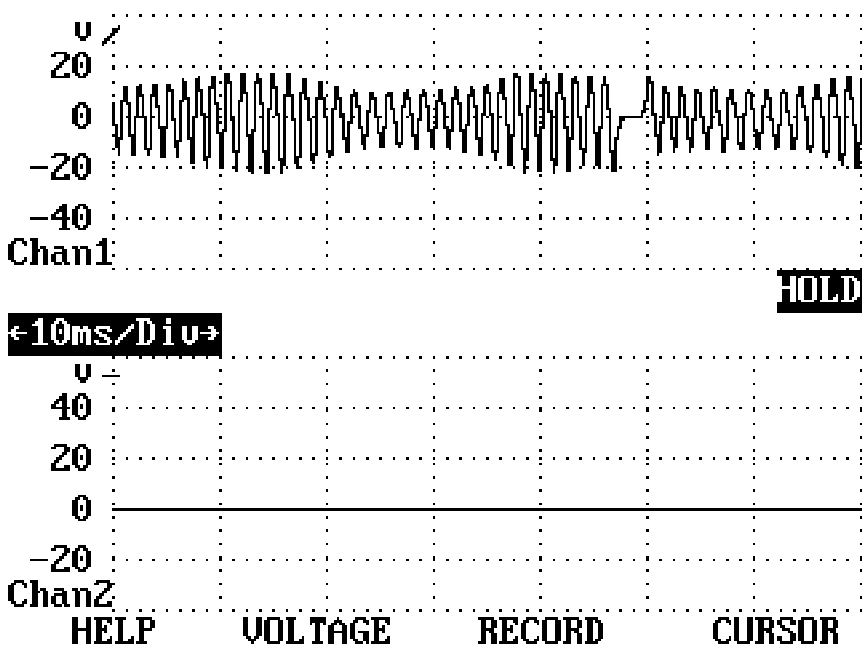


Figure 214 Shorted Crank Signal

MASS AIR FLOW (MAF) SENSOR SIGNAL

Figure 215 shows the pattern of the signal of the mass air flow sensor (MAF) at idle speed.

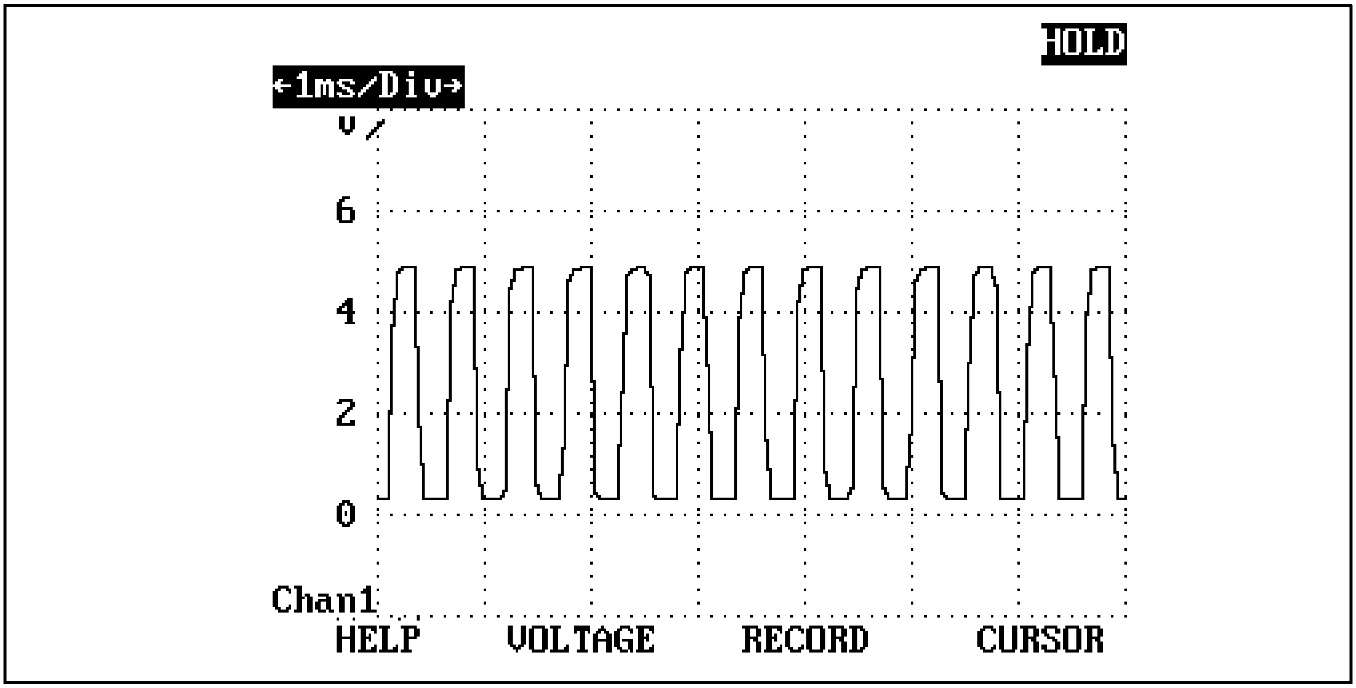


Figure 215 Mass Air Flow (MAF) Sensor Signal at Idle

Figure 216 shows the pattern of the mass air flow sensor (MAF) signal at 2000 rpm.

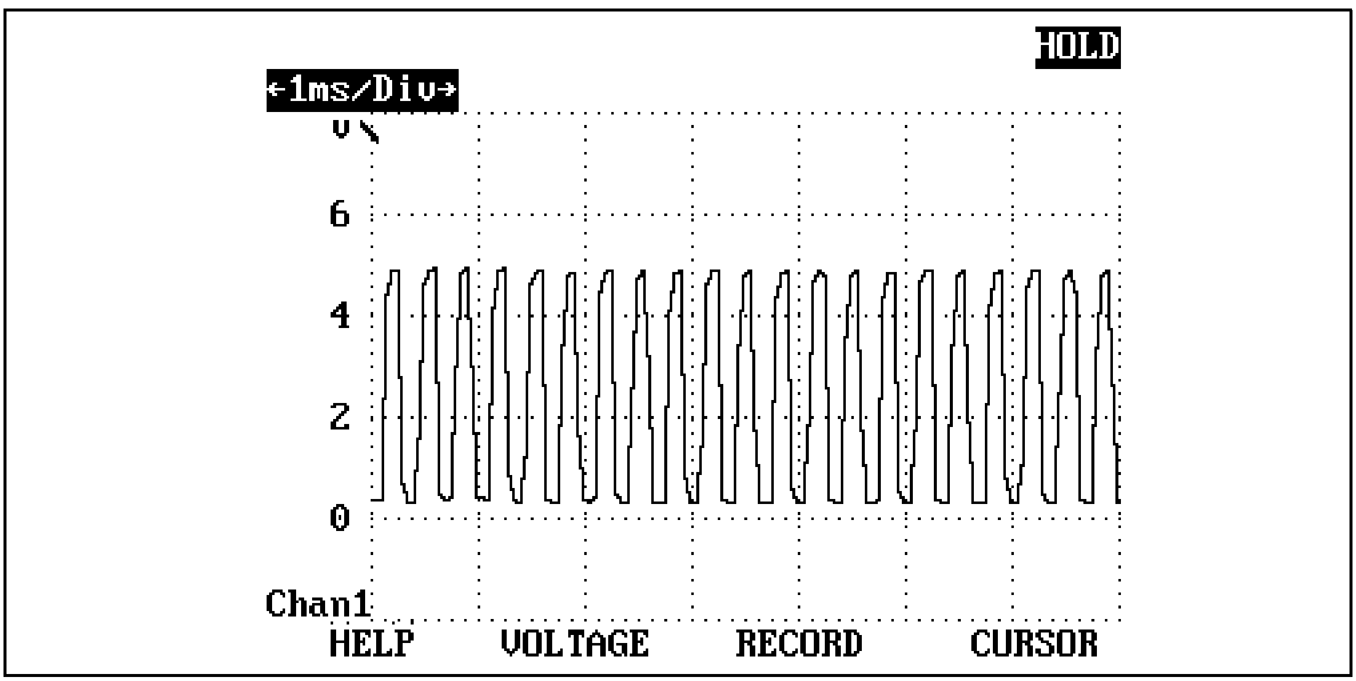


Figure 216 Mass Air Flow (MAF) Sensor Signal at 2000 rpm

FUEL RAIL PRESSURE SENSOR SIGNAL

Figure 217 shows the pattern of the rail pressure sensor signal at different stages: ignition off, ignition on, idle speed and snapping the throttle.

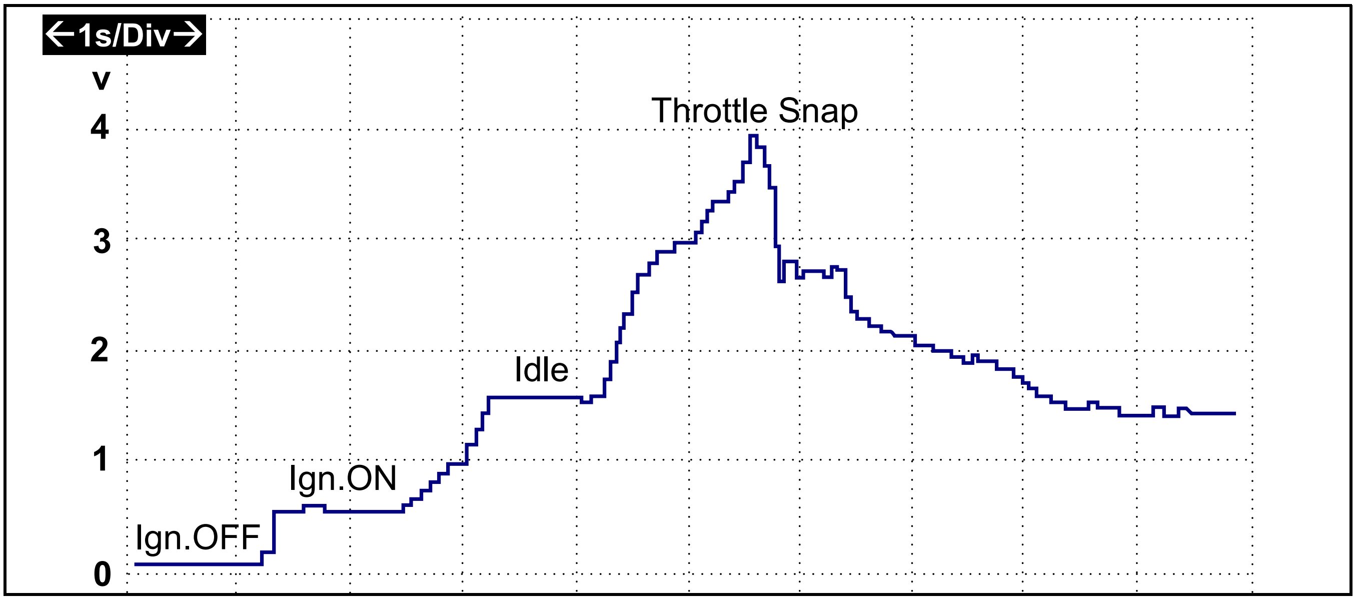


Figure 217 Rail Pressure Sensor Signal

FUEL INJECTOR PATTERN

Figure 218 shows the pattern of an injector at idle speed. The first voltage spike indicates the pilot injection phase, the second voltage spike indicates the main injection phase and the third spike indicates the post injection phase. Notice the longer injection time during the main injection phase.

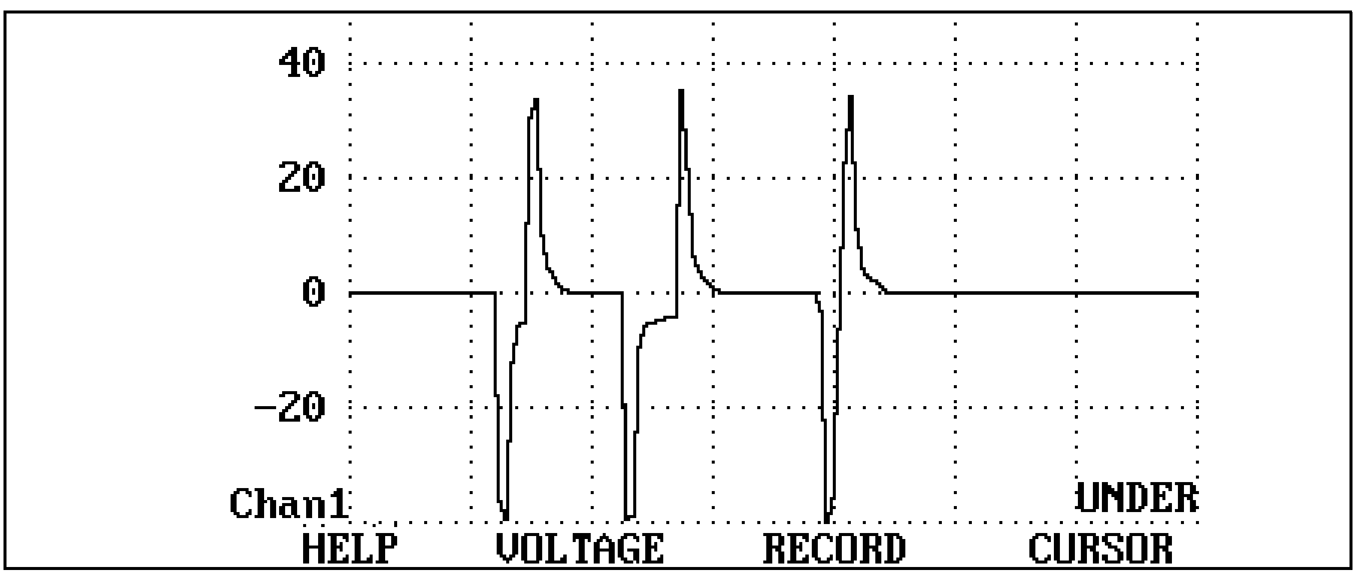


Figure 218 Fuel Injector Signal

FUEL PRESSURE SOLENOID

Figure 219 shows the pattern of the fuel pressure solenoid at idle speed.

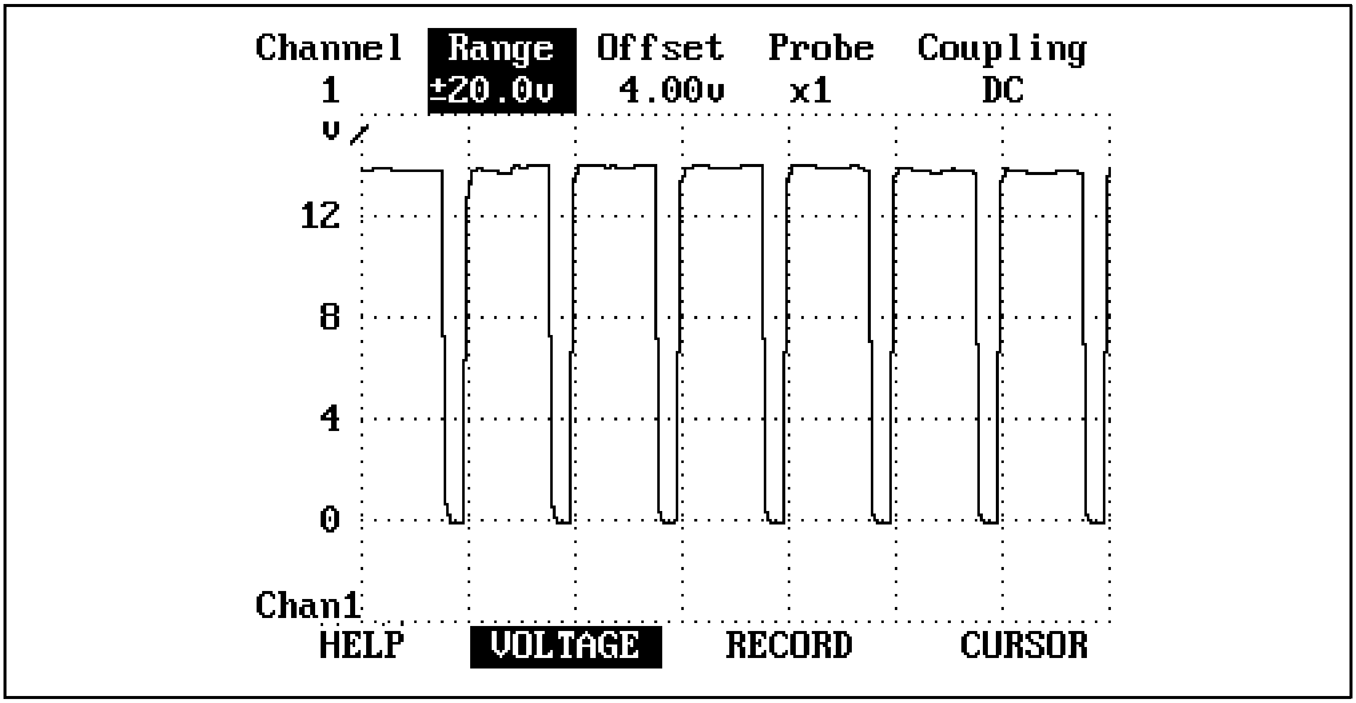


Figure 219 Fuel Pressure Solenoid Signal at Idle

Figure 220 shows the pattern of the fuel pressure solenoid at 2000 rpm.

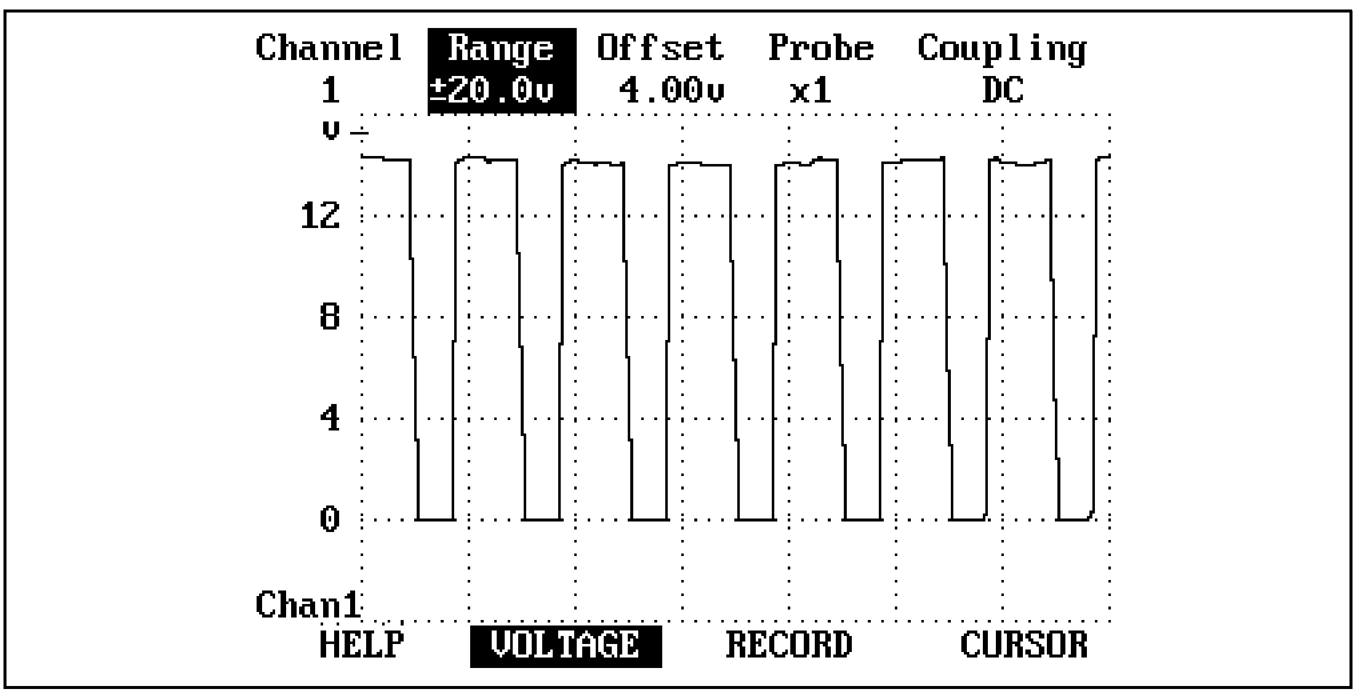


Figure 220 Fuel Pressure Solenoid Signal at 2000 RPM

Figure 221 shows the pattern of the fuel pressure solenoid during the ECM power-off phase.

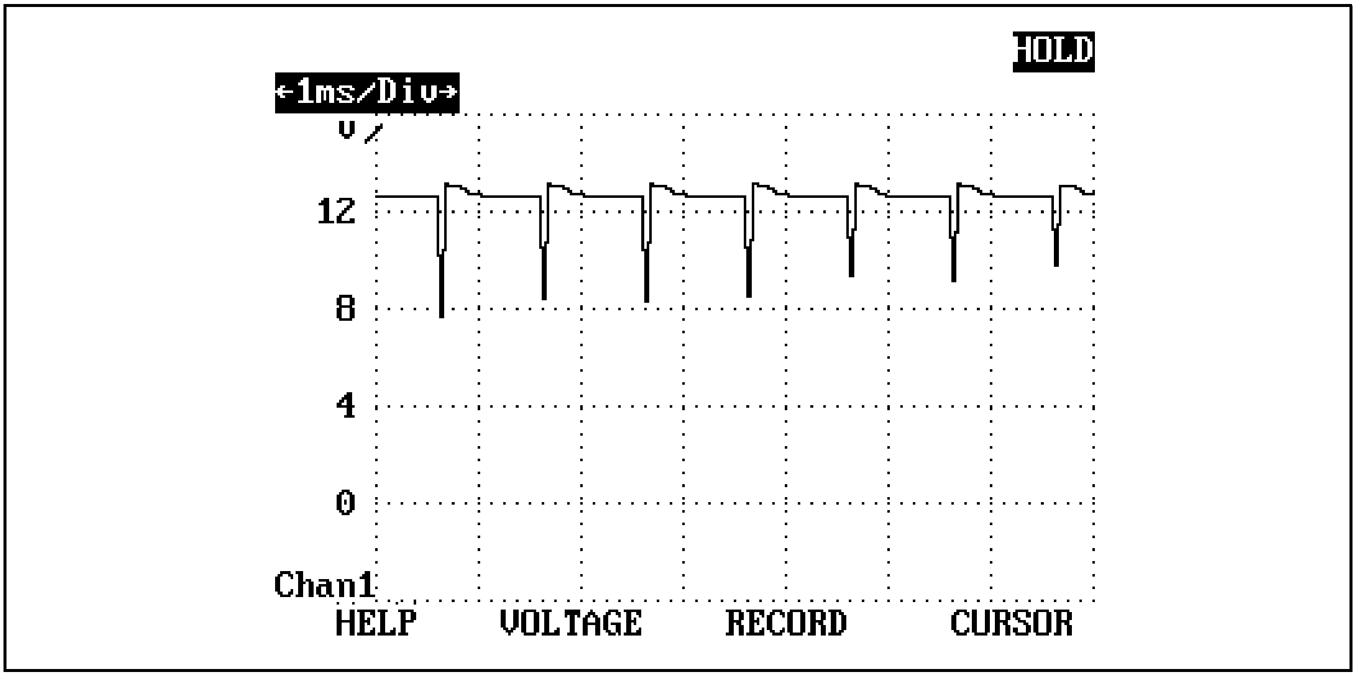


Figure 221 Fuel Pressure Solenoid Signal, ECM Power-Off Phase

FUEL QUANTITY VALVE

Figure 222 shows the pattern of the fuel quantity valve at idle speed.

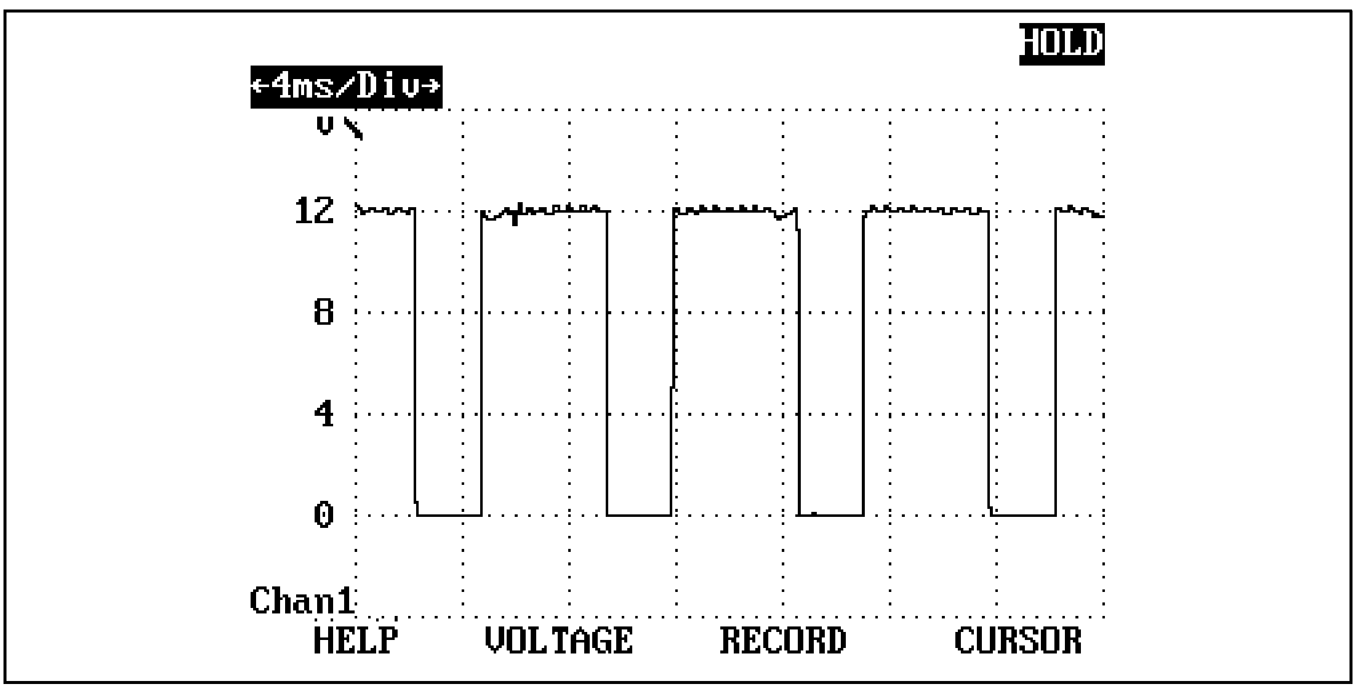


Figure 222 Fuel Quantity Valve Signal at Idle

EGR VALVE

Figure 223 shows the PWM signal to the EGR valve with the engine off/key on.

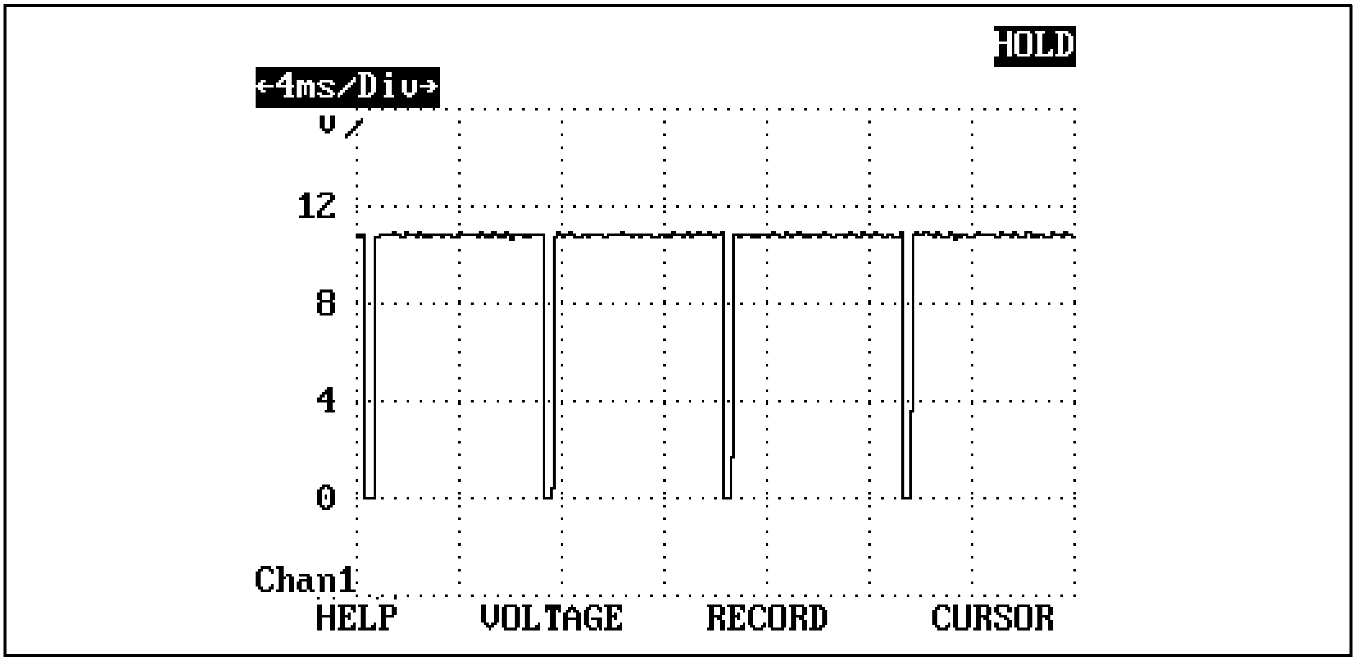


Figure 223 EGR Valve PWM Signal, Engine OFF/Key ON

Figure 224 shows the EGR valve signal with the engine at idle.

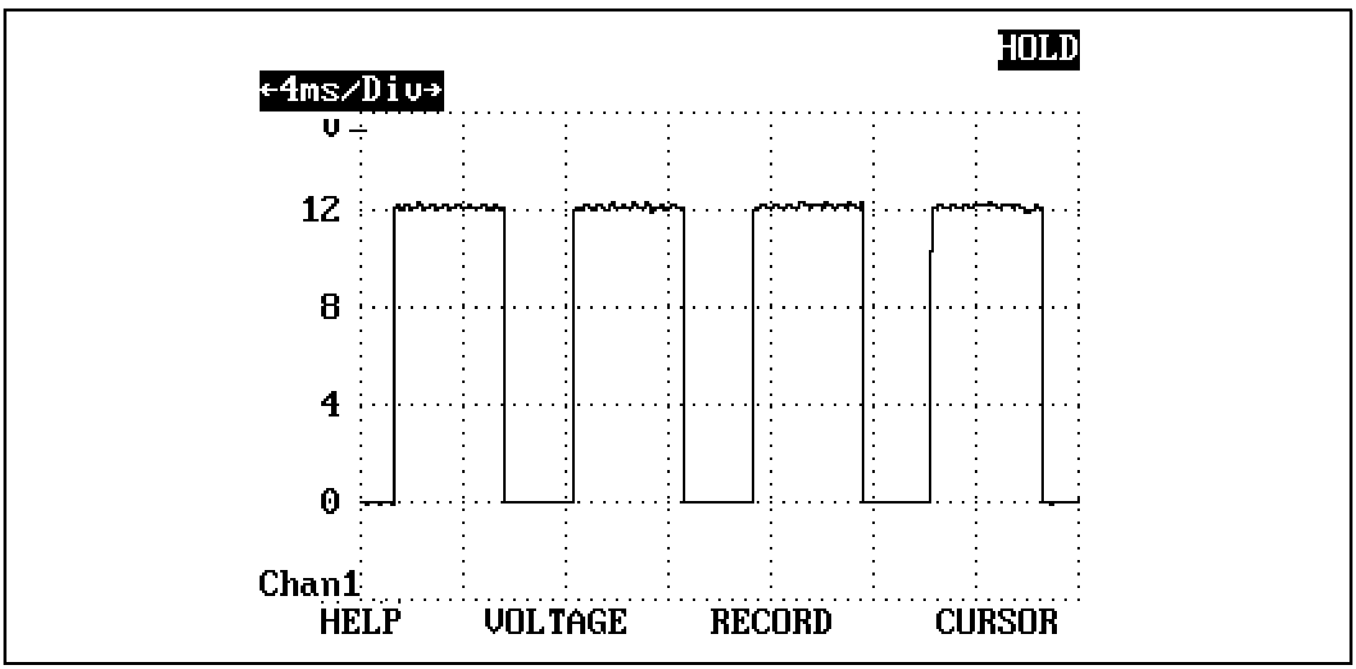


Figure 224 EGR Valve PWM Signal at Idle

Figure 225 shows the EGR valve signal with the engine under acceleration.

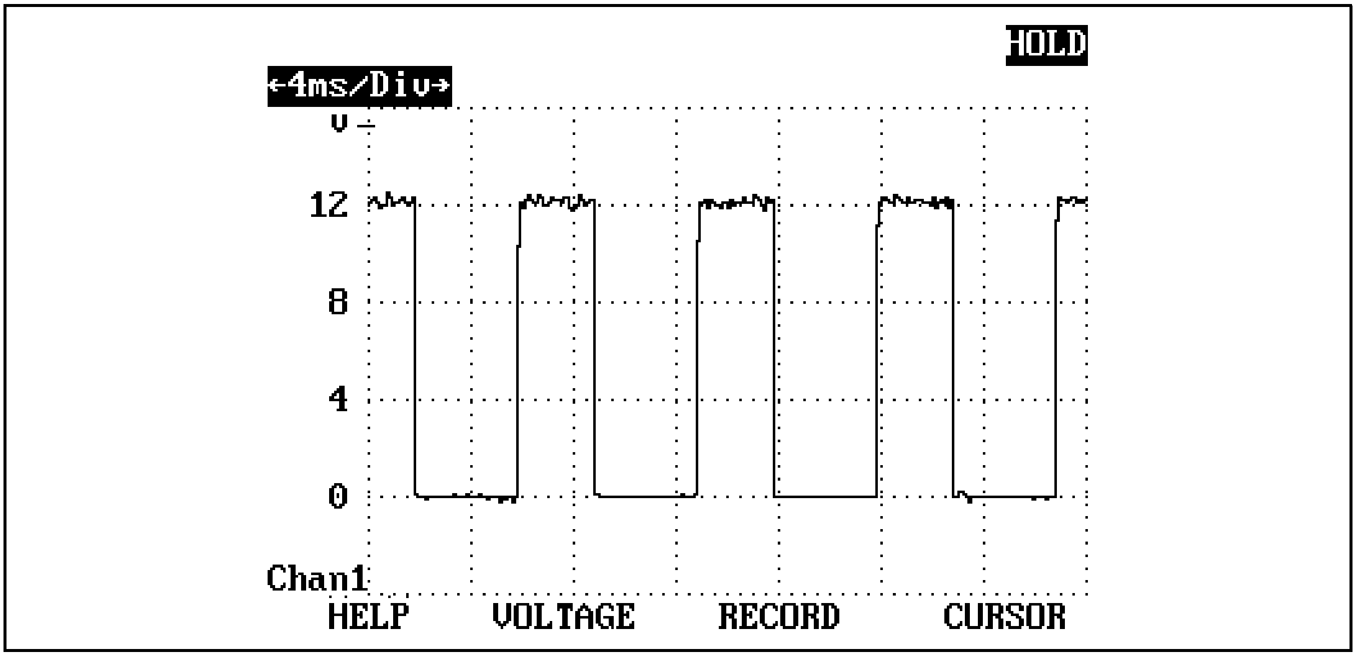


Figure 225 EGR Valve PWM Signal Under Acceleration

BOOST PRESSURE ACTUATOR

Figure 226 shows the PWM signal to the Boost Pressure Actuator with the engine off/ key on.

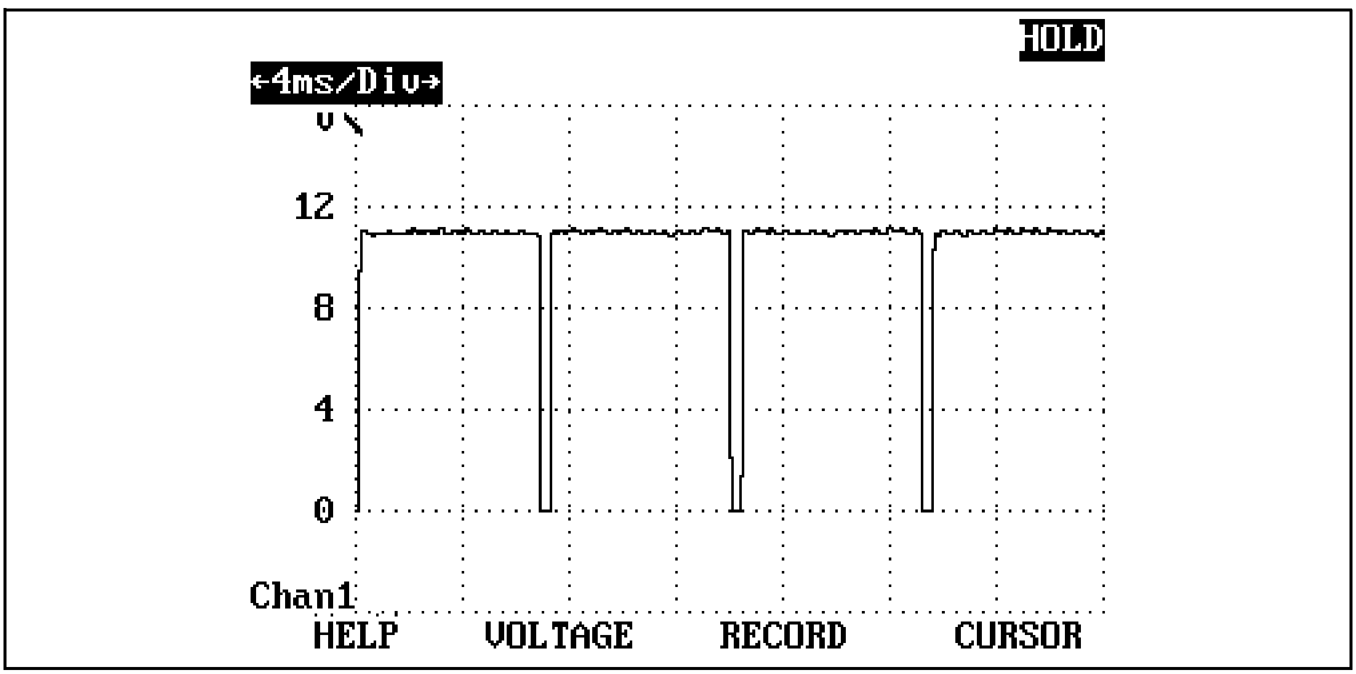


Figure 226 Boost Pressure Actuator PWM Signal, Engine OFF/Key ON

Figure 227 shows the Boost Pressure Actuator signal with the engine at idle.

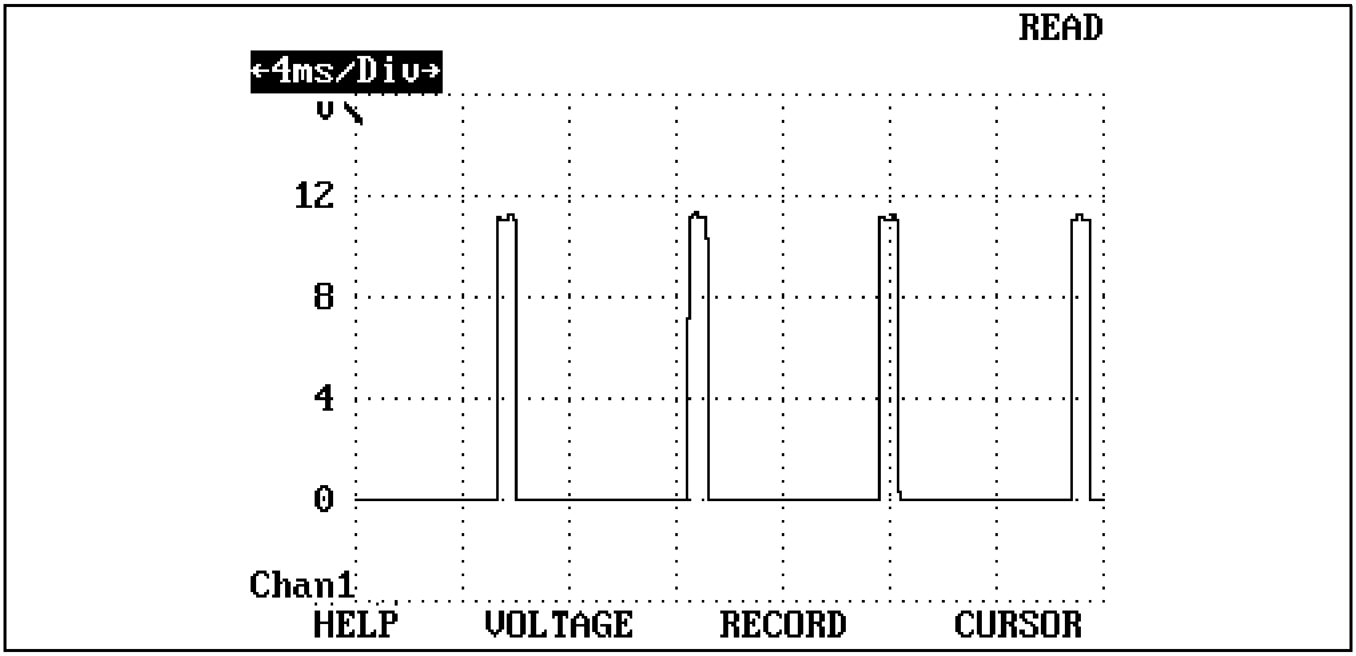


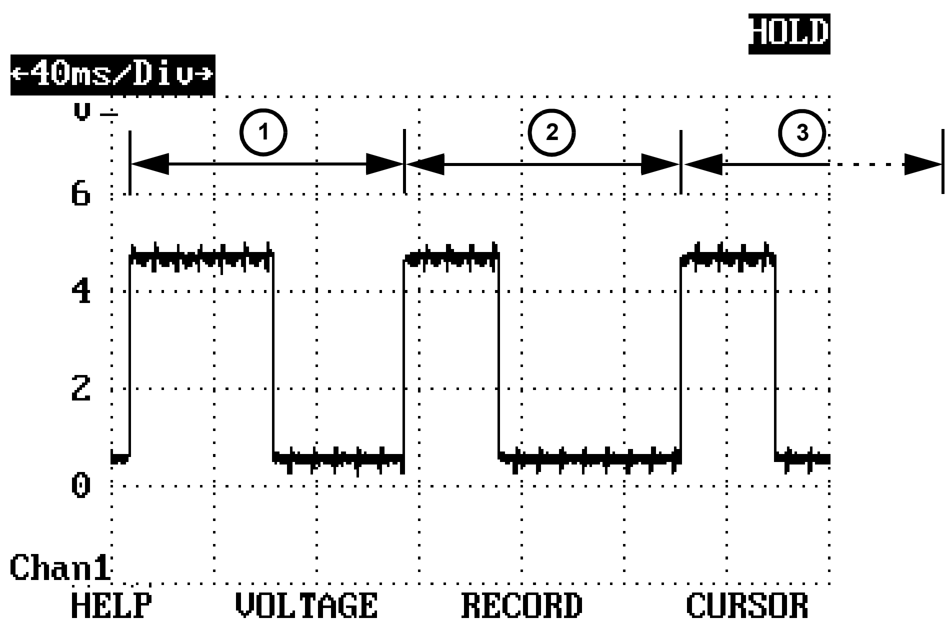
Figure 227 Boost Pressure Actuator PWM Signal at Idle

ENGINE OIL SENSOR

Figure 228 shows the pattern of the oil sensor. The first waveform (1) represents the oil temperature. The duty-cycle lower limit is 20%, which indicates an oil temperature of -40°. The upper limit is 80%, which indicates an oil temperature above 160°C.

The second waveform (2) represents the oil level value. The duty-cycle lower limit is 20%, which indicates an oil level of 0. The upper limit is 80%, which indicates an oil level of 80mm.

The third waveform (3) represents the dielectric number of the oil. The duty-cycle lower limit is 20%, which indicates a dielectric number of 1. The upper limit is 80%, which indicates a dielectric number of 6. The typical value is around 40%, indicating an oil quality of 2.7.



1	Oil Temperature Waveform
2	Oil Level Waveform
3	Dielectric Number of Oil Waveform (Oil Quality)

Figure 228 Oil Sensor Signal

GLOW PLUG MODULE

Figure 229 shows the digital pattern (PWM) in the signal wire between the glow plug module and the engine control module (ECM).

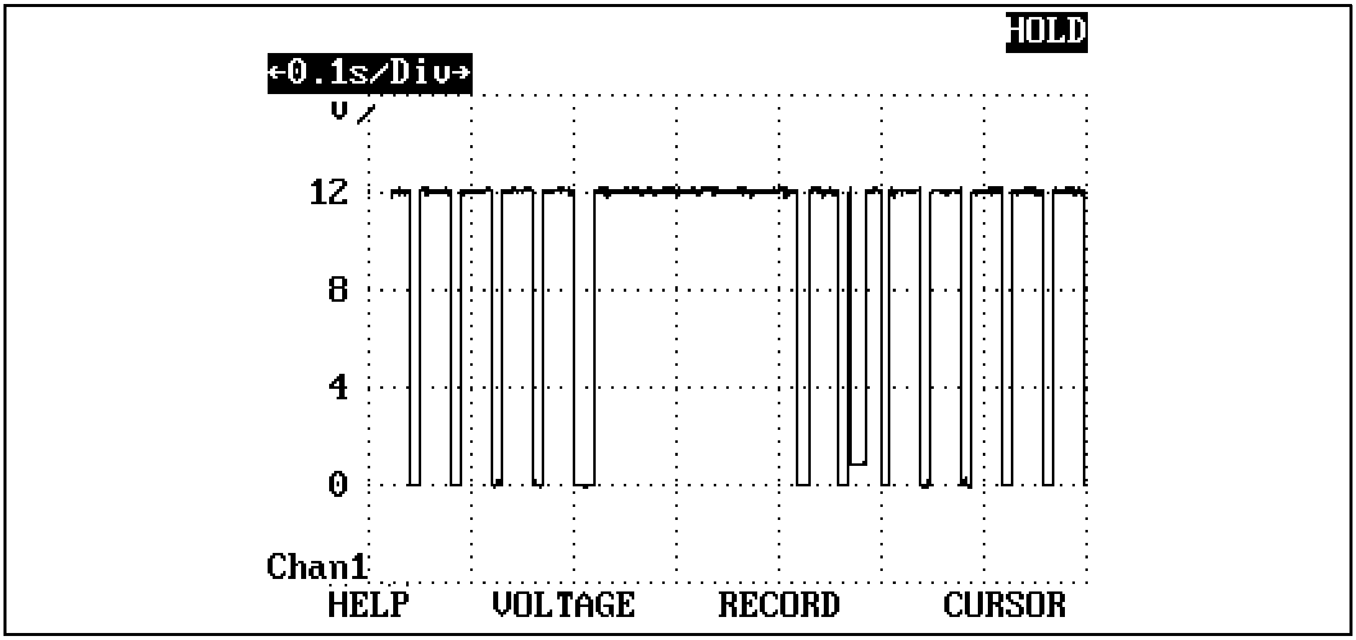


Figure 229 Glow Plug Module Signal

RETROFITTING SPEED CONTROL

This retrofit consists of installing a speed control switch in the steering column and changing the version coding of the engine control module (ECM) to enable the speed control feature.

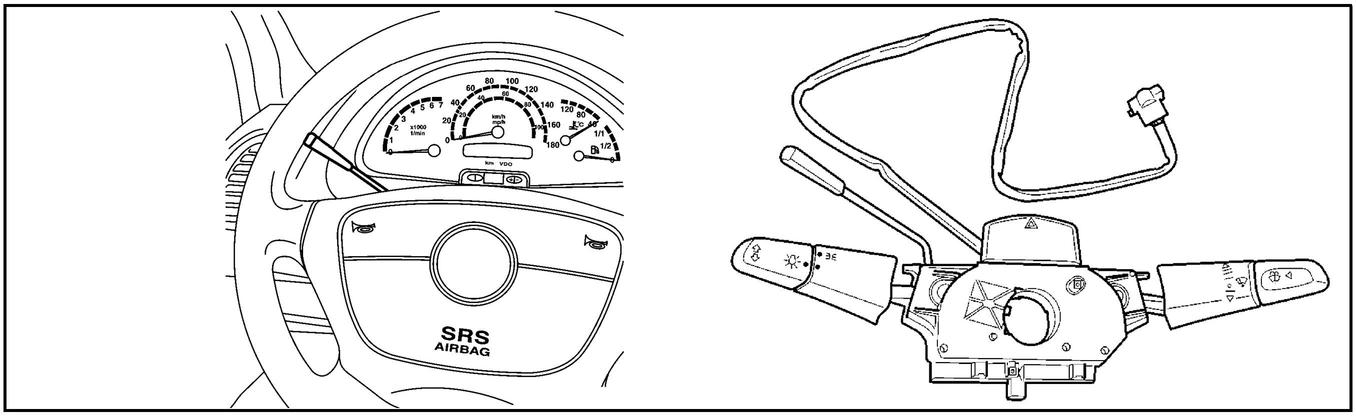


Figure 230 Speed Control Switch

PARTS REQUIRED

Following is the list of parts. The electrical wires listed must be purchased locally. It is strongly recommended to adhere to the color coding of the wires. It simplifies service procedures, troubleshooting of the electrical system, and is consistent with shop documentation and electrical wiring schematics.

NOTE: The parts list below may be issued in kit form in the near future.

Mopar Part Number	Description	Qty.
05103744AA	Speed control switch	1
05126175AA	Screw	1
05120786AA	Six-pin connector	1
05103882AA	Electrical terminal	6
05161275AA	Electrical terminal, ECM connector	6
- purchase locally -	Red electrical wire, 18 AWG	1 ft.
- purchase locally -	Black electrical wire, 18 AWG	1 ft.
- purchase locally -	Blue electrical wire, 18 AWG	1 ft.
- purchase locally -	Yellow electrical wire, 18 AWG	1 ft.
- purchase locally -	Dark green electrical wire, 18 AWG	1 ft.
- purchase locally -	Gray electrical wire, 18 AWG	1 ft.

Table 1 Parts List

PROCEDURE

1. Disconnect the cable from the negative battery post.
2. Remove fuse panel cover (1) by turning slotted screw 90° from position A to B (Figure 231).

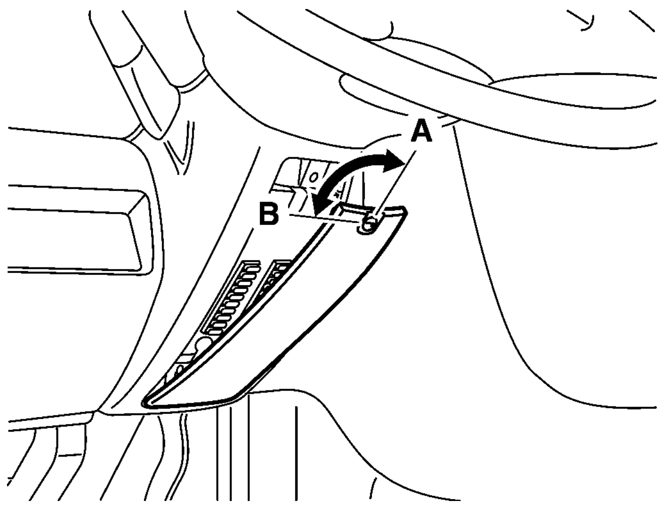


Figure 231 Removal of Fuse Panel Cover

3. Unscrew Phillips screws and nut (Figure 232). Remove steering column cover. Remove M relay for better access to steering column bracket.

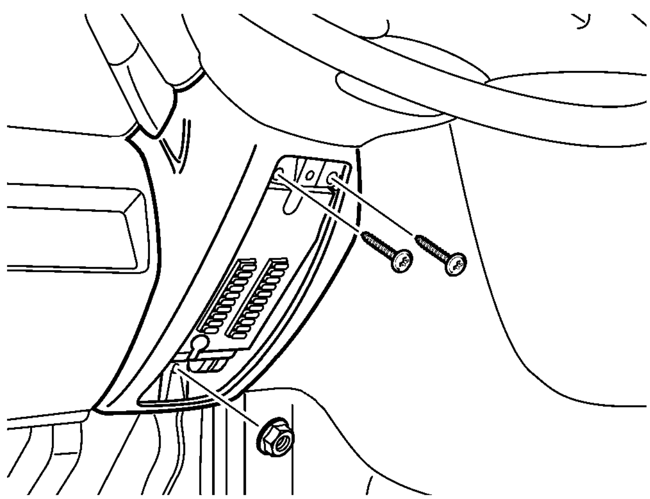


Figure 232 Removal of Steering Column Cover and M Relay

4. Unscrew both Phillips screws and remove upper cover (Figure 233).

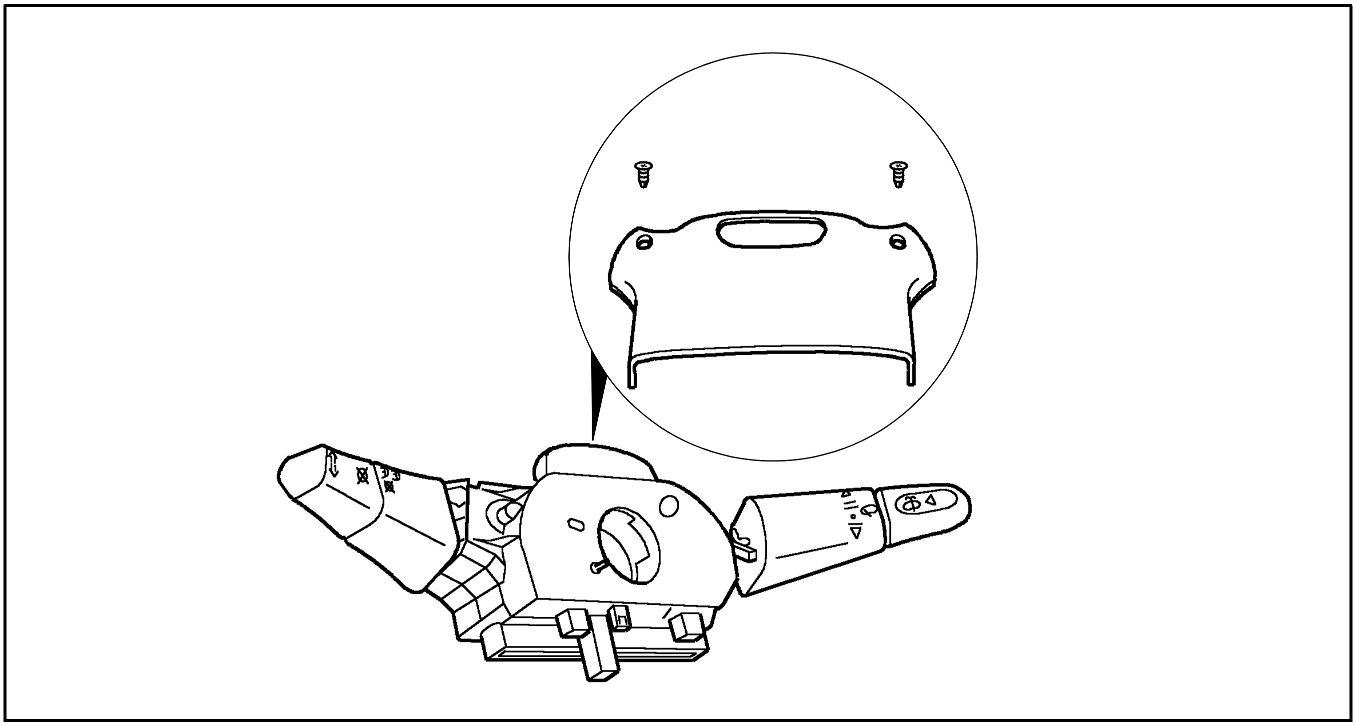


Figure 233 Removal of Phillips Screws and Upper Cover

5. Detach brake pedal spring from steering column (Figure 234).

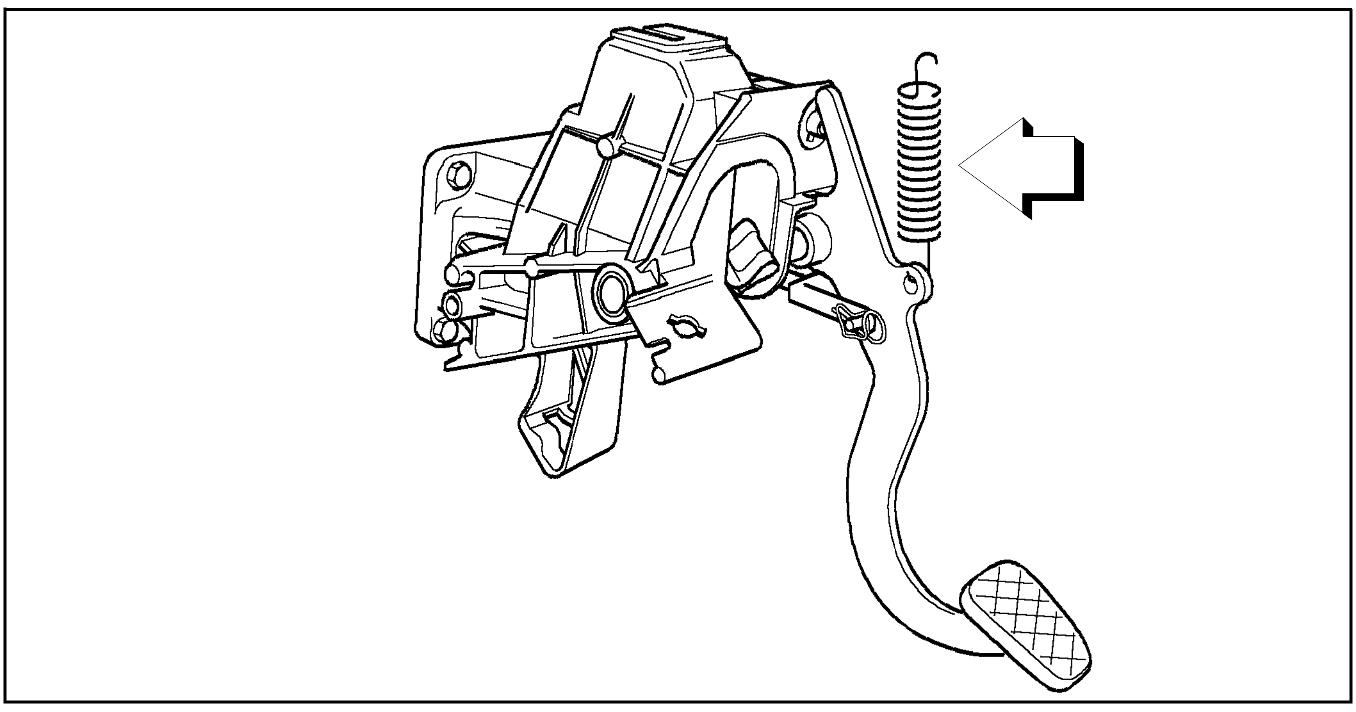


Figure 234 Brake Pedal Spring

6. Remove steering column bracket bolts (Figure 235).

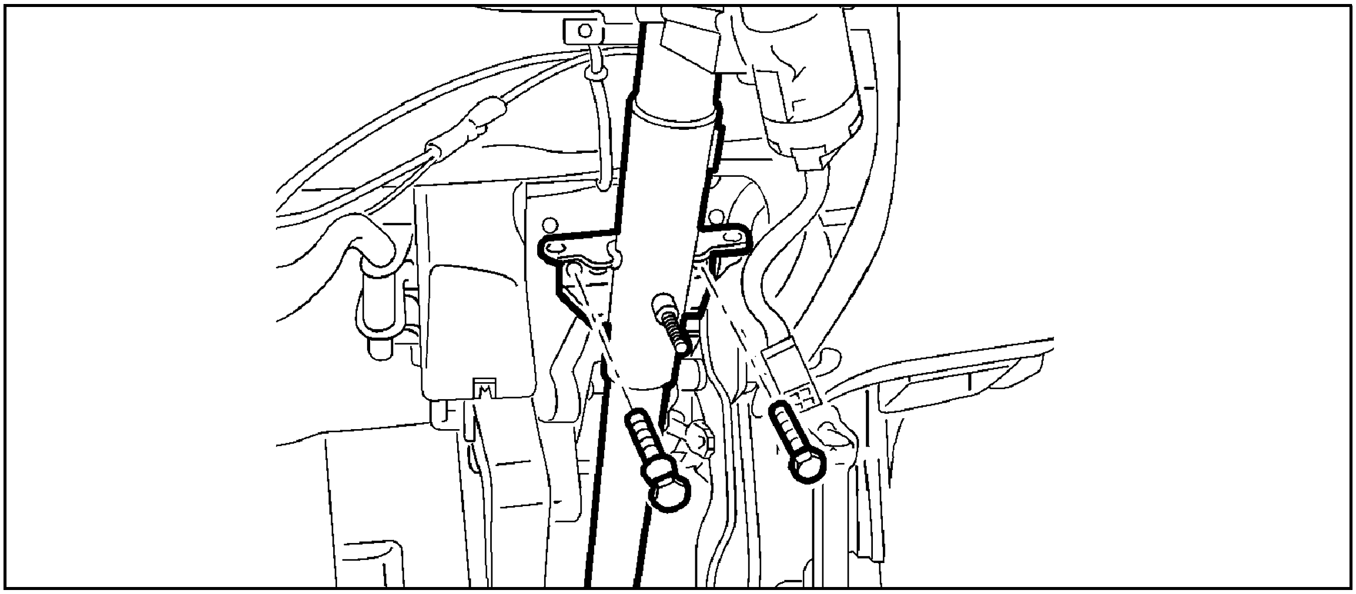


Figure 235 Removing Steering Column Bracket Bolts

7. Gently lower steering column about 6 inches (Figure 236).

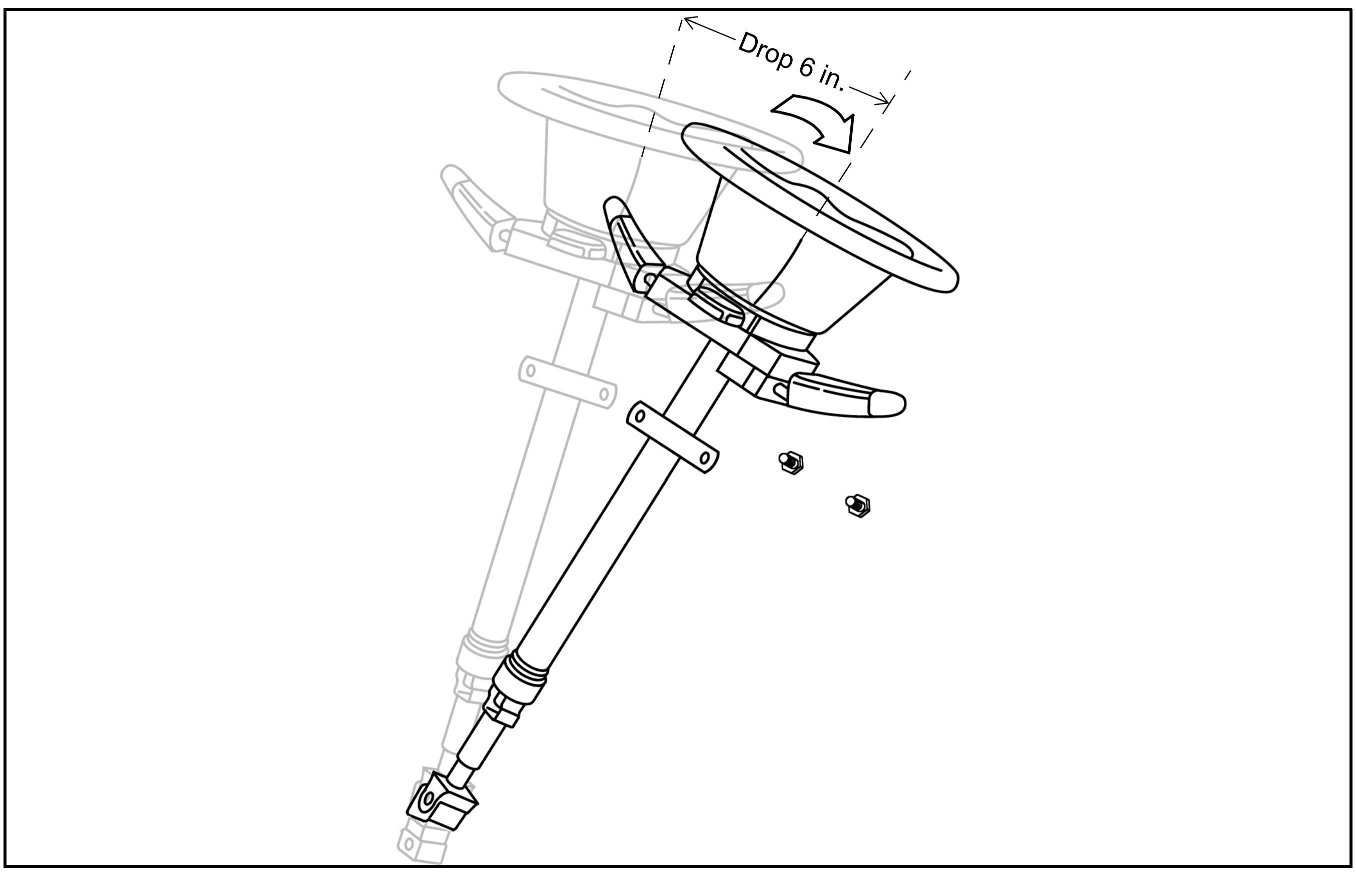
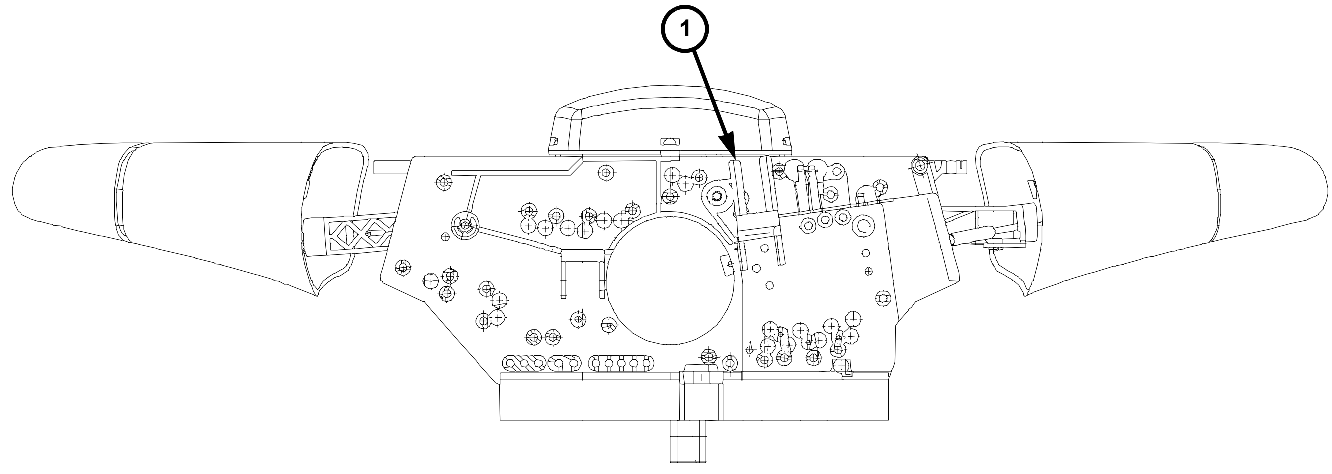


Figure 236 Lowering The Steering Column

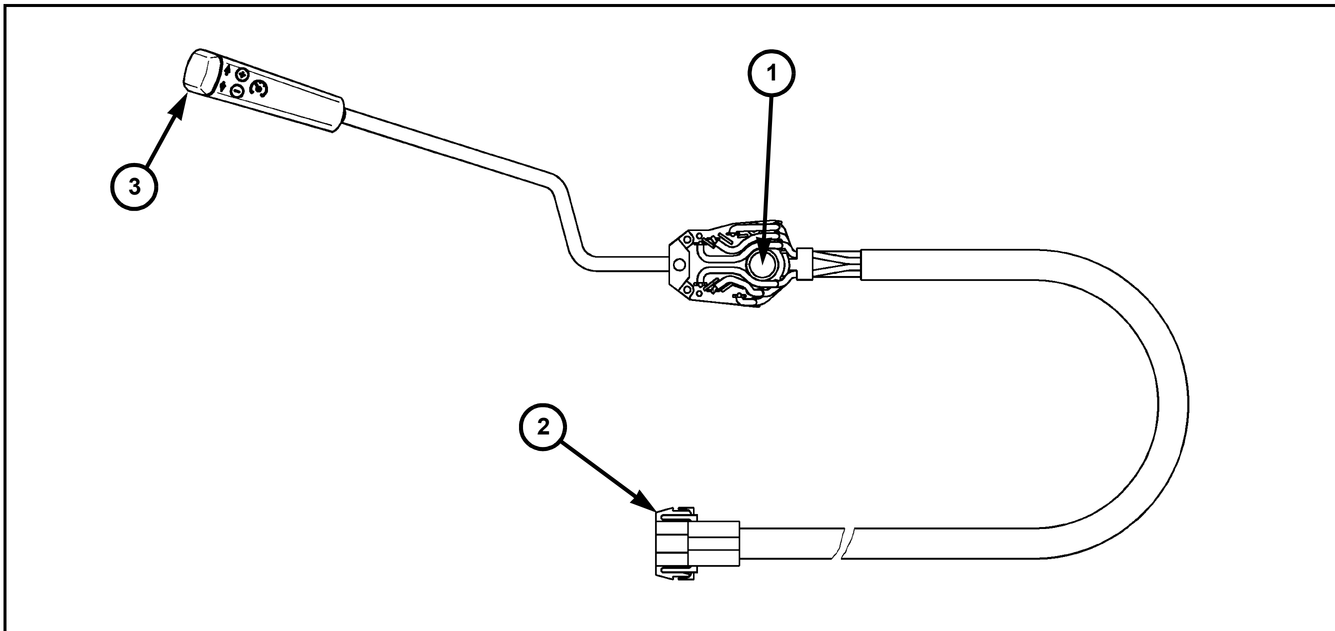
8. Locate the speed control switch mounting base (arrow) on the back of the combination switch (Figure 237).



1	Speed Control Switch Mounting Base

Figure 237 Location of Speed Control Switch Mounting Base

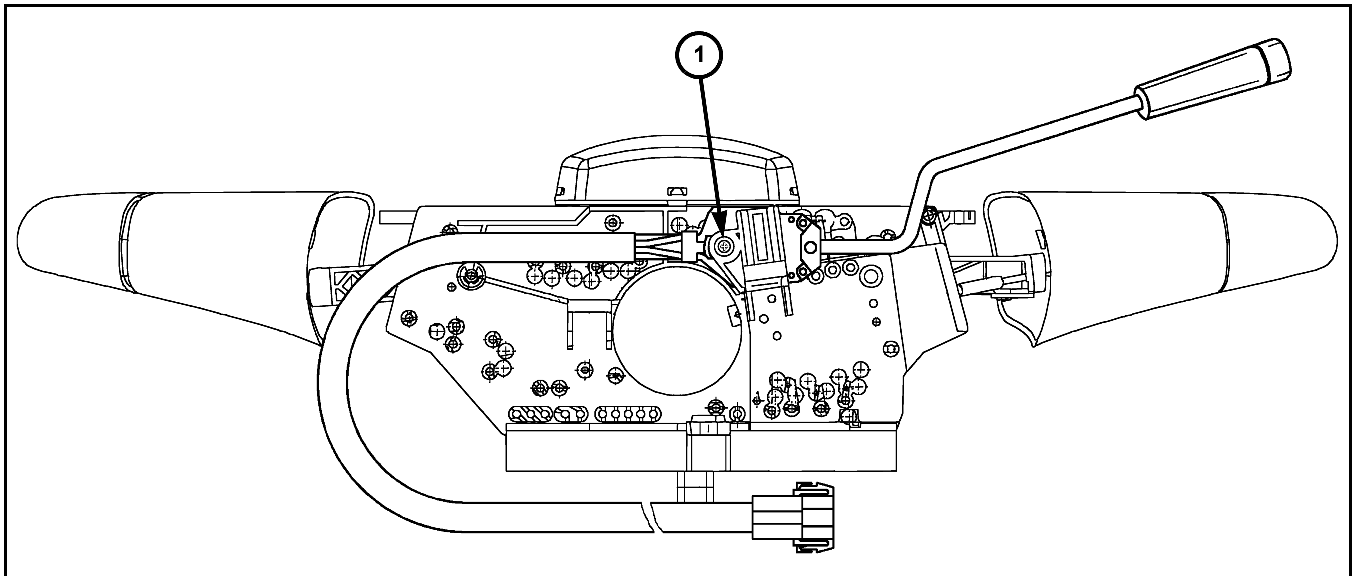
The speed control switch slides into the combination switch mounting base. A hole in the speed control switch lines up with a hole in the mounting base. A screw is inserted through the mounting hole to fasten the speed control switch.



1	Switch Mounting Hole	3	Switch Lever
2	Switch Harness 6-Pin Connector		

Figure 238 Speed Control Switch

9. Insert the speed control switch, part 05103744AA into its mounting base. Secure the switch with holding screw, part 05126175AA. See Figure 239.



1	Speed Control Switch Holding Screw

Figure 239 Speed Control Switch Installation

10. Ensure all connectors on the back of Fuse Block No.1 are tight. Gently raise the steering column and reinstall the column bracket bolts (Figure 240). Tighten the bolts to 25 Nm (18 lb.ft).

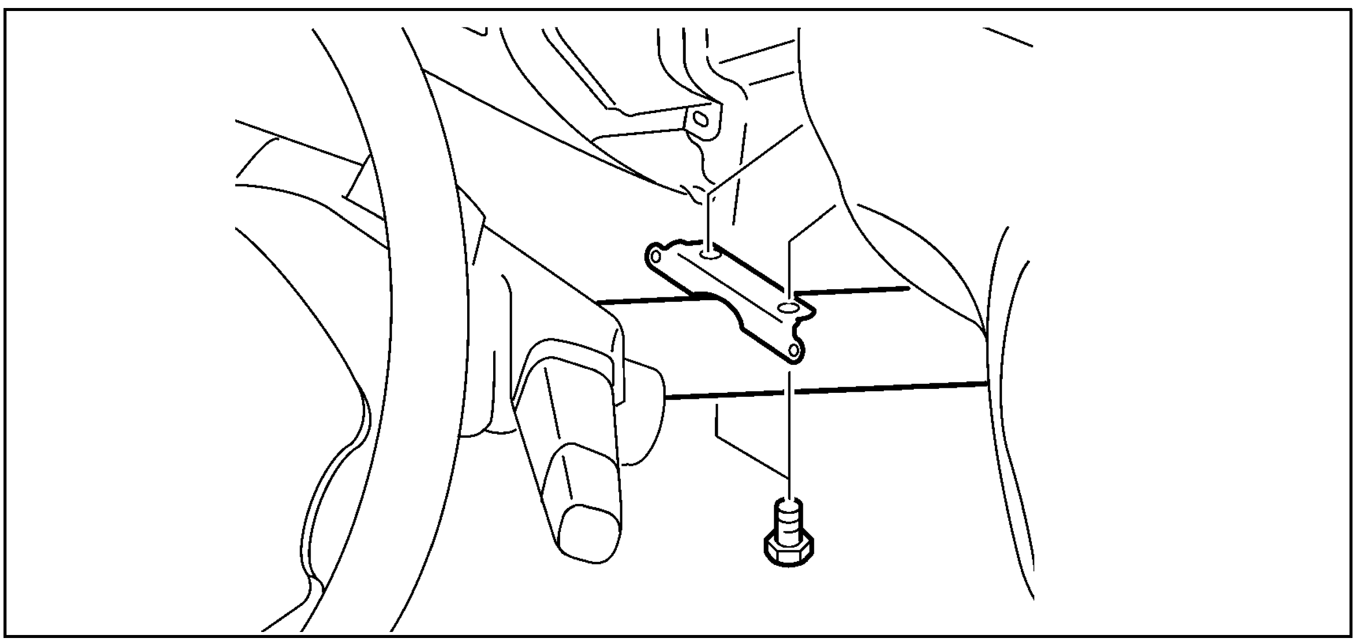


Figure 240 Raising the Steering Column and Reinstalling Bracket Bolts

11. Reinstall the brake pedal spring (Figure 234).

12. Route the speed control switch cable down the steering column towards the engine control module (ECM). See Figure 241.

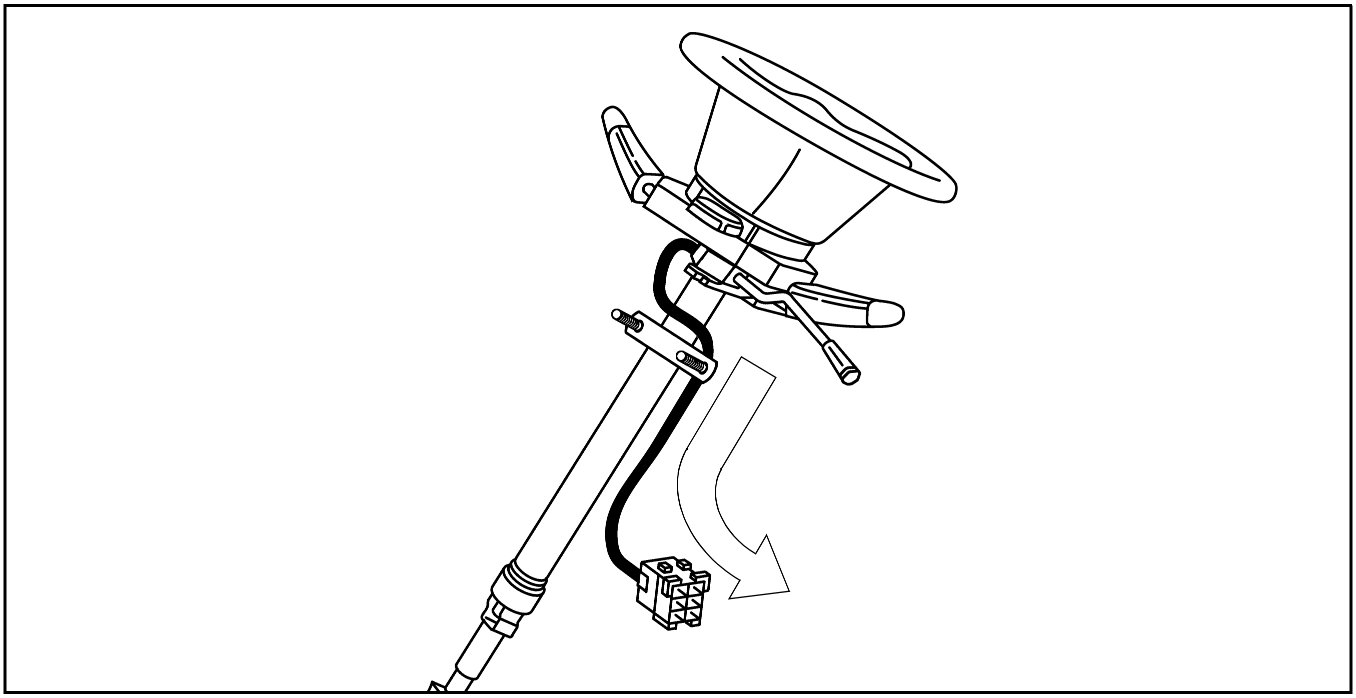


Figure 241 Routing of the Speed Control Switch Wiring Harness

13. Locate the engine control module (ECM) below the left knee protection next to the steering column (Figure 242). Pull the ECM down at the connection side until it releases. Pull it forward and out of the mounting bracket.

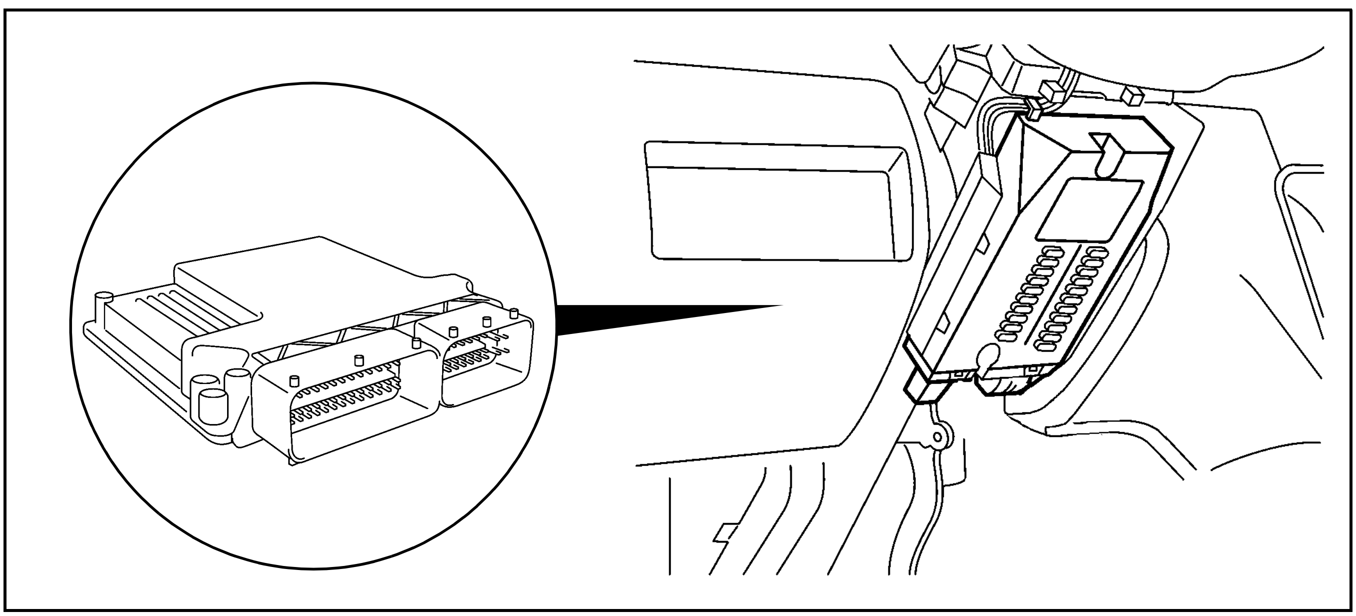
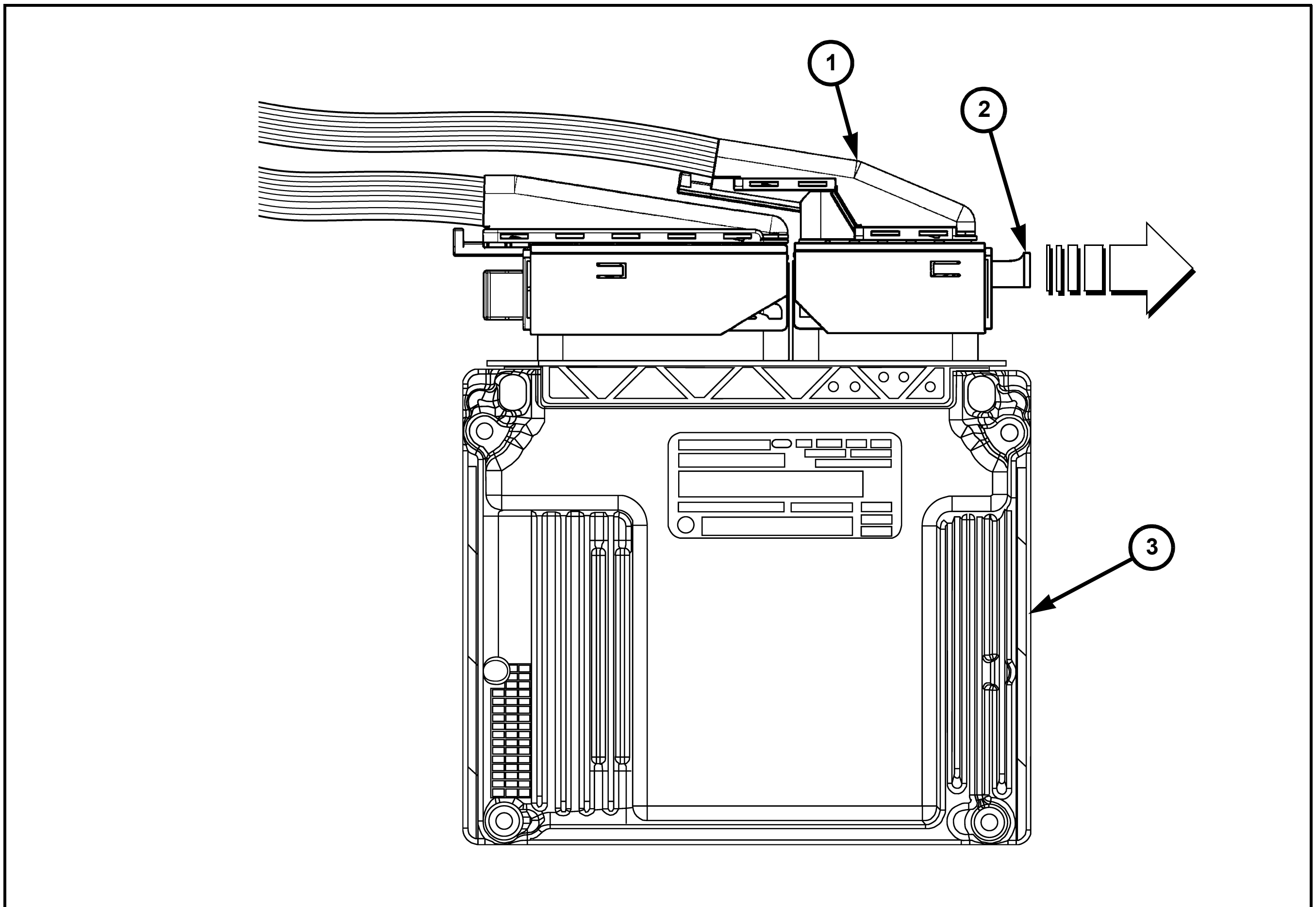


Figure 242 Location of the Engine Control Module (ECM)

14. Remove the 58-pin plug-in connector (marked F) from the ECM. To remove the plug-in connector, pull the slide lock sideways to the end of its travel and lift the plug-in connector.

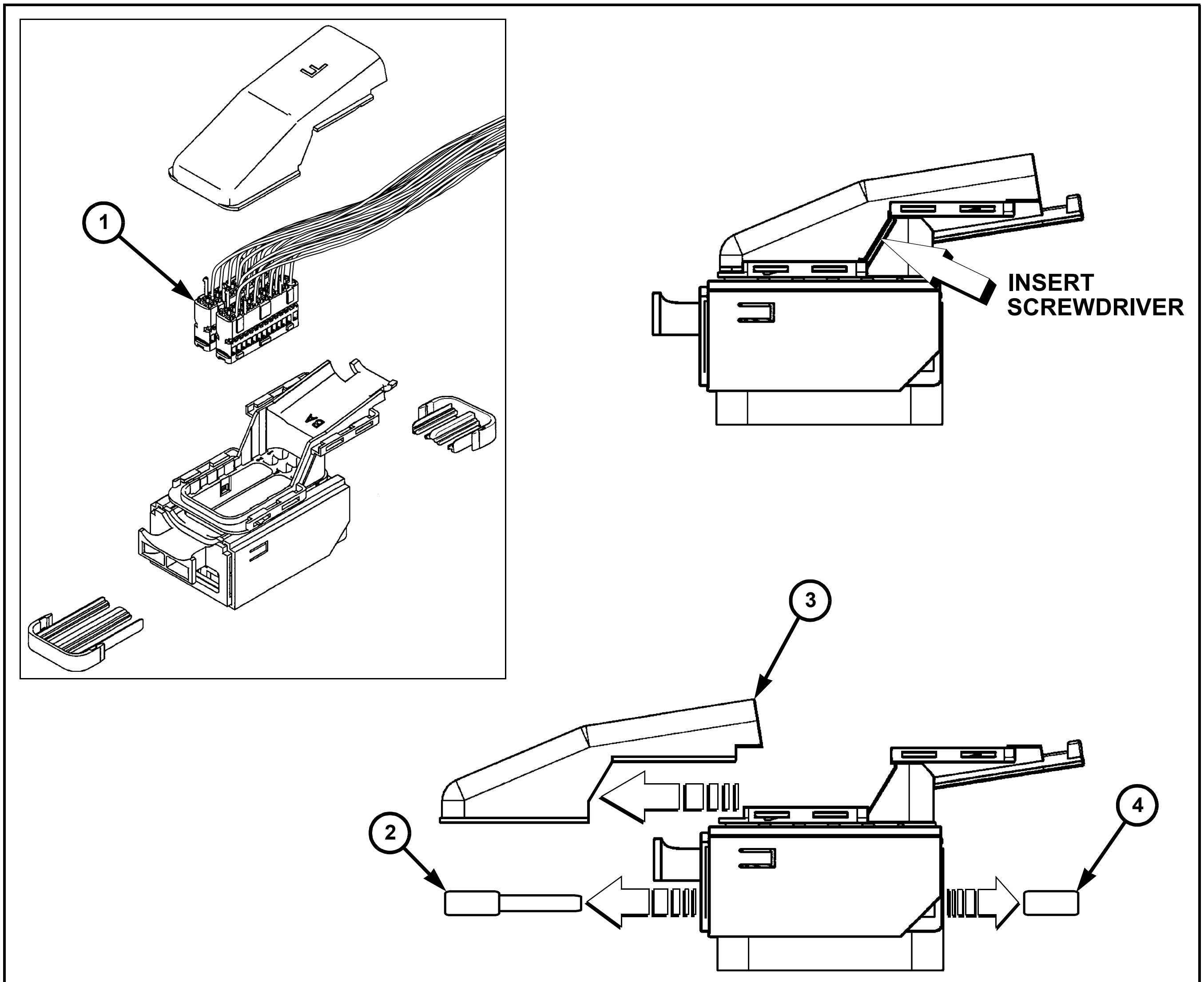


1	58-Pin Plug-In Connector	3	Engine Control Module (ECM)
2	Slide Lock		

Figure 243 Vehicle Harness 58-Pin Plug-In Connector

15. Carefully disassemble the plug-in connector to expose the wire insertion end of the connector. Remove the protective cap by inserting a wide blade screwdriver in the wedged area between the connector housing and protective cap (arrow). Alternating between both sides of the connector, gently twist on the screwdriver handle to separate the protective cap from the connector housing. Slide the protective cap away from the housing (Figure 244).

NOTE: If you require additional clearance for inserting the wires you may remove the electrical terminal holders. The electrical terminal holders are held in place with two locking pins. Carefully remove both locking pins with a small screwdriver and pull them out.



1	Electrical Terminal Holders	3	Protective Cap
2	Front Locking Pin	4	Rear Locking Pin

Figure 244 Vehicle Harness Connector Disassembly

16. Assemble an extension harness with the color-coded wires described in the parts list (Figure 245). Cut one piece out of each wire color, 12 inches long, and strip both ends of wire. Install six terminals, part 05103882AA, to one end of the wires, and six terminals, part 05161275AA, to the other end.

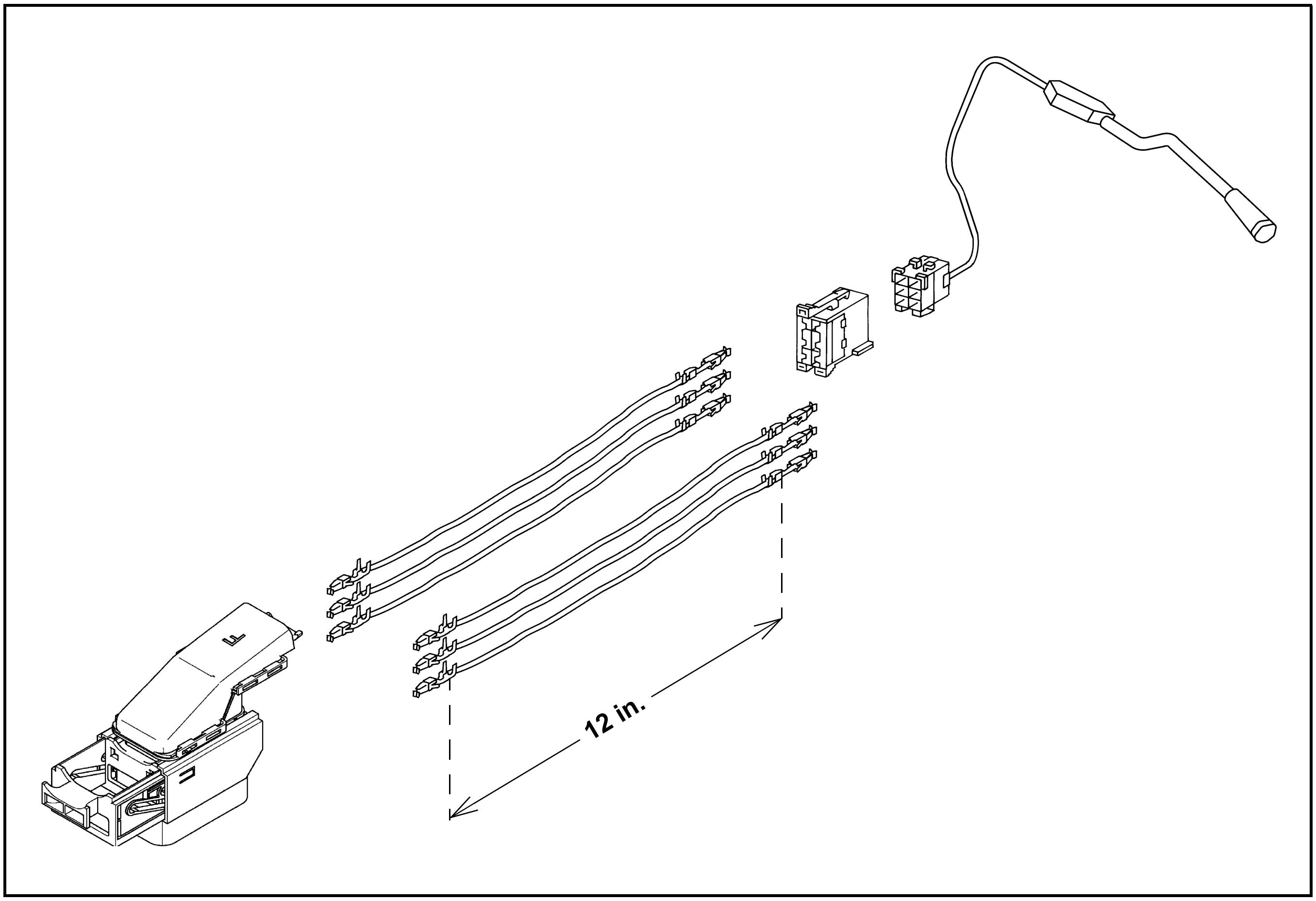
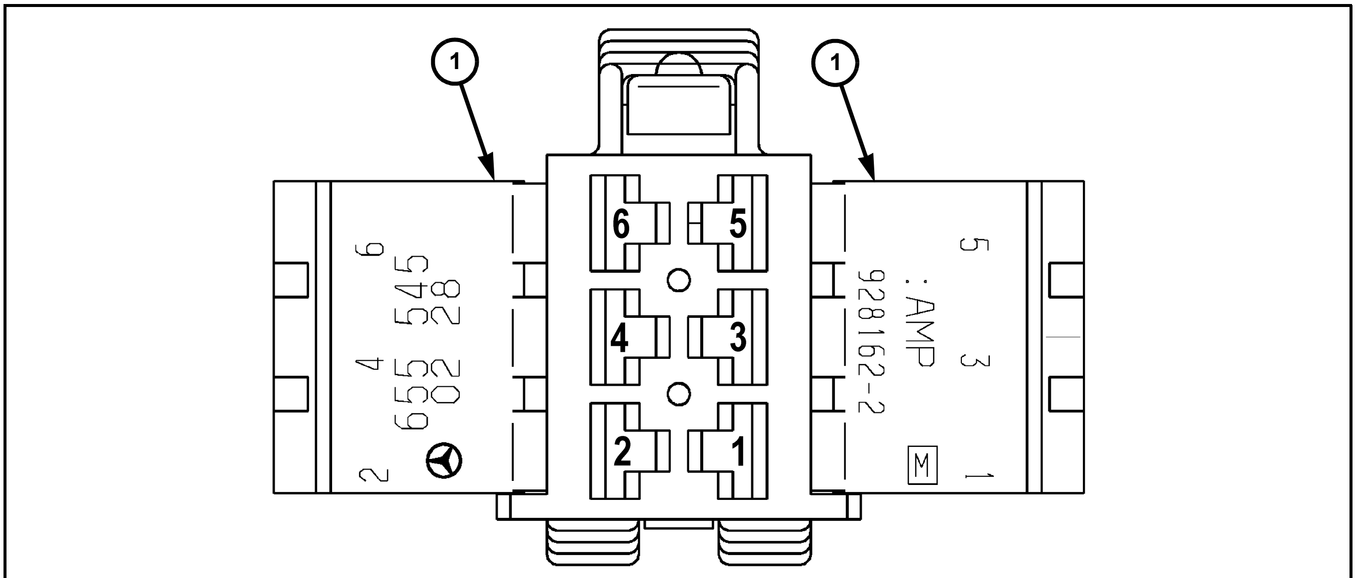


Figure 245 Assembling the Extension Harness to the Engine Control Module

17. Release the six-pin connector (05120786AA) secondary locks. Insert the terminals, part 05103882AA, into the cavities of the connector as follows: gray wire into cavity #1; black wire into cavity #2; blue wire into cavity #3; yellow wire into cavity #4; green wire into cavity #5, and red wire into cavity #6. Insert the wires until they click into place. Gently tug on the wires to make sure they are secure and fasten both secondary locks (Figure 246).



1	Secondary Lock

Figure 246 Six-Pin Connector Front View

18. Insert the other end of the wires with terminals, part 05161275AA, into the cavities of the 58-pin connector of the engine control module (ECM) as follows: gray wire into cavity #51; black wire into cavity #38; blue wire into cavity #52; yellow wire into cavity #50; green wire into cavity #37, and red wire into cavity #7. Insert the wires until they click into place. Gently tug on the wires to make sure they are secure.

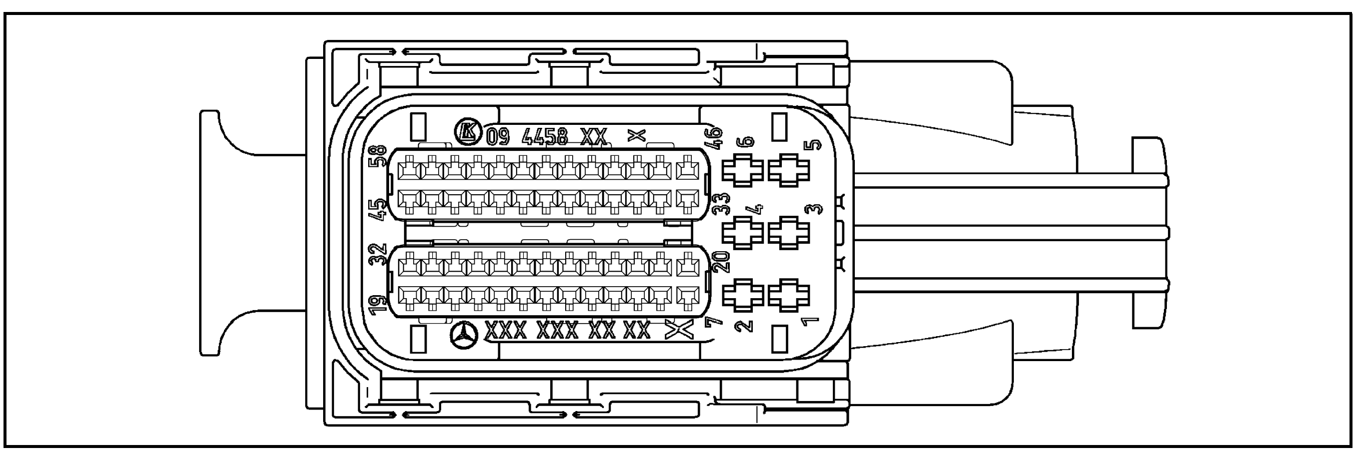


Figure 247 Vehicle Harness 58-Pin Connector Front View

19. Check the wires and cavities for proper position with the wiring diagram below (Figure 248). Plug the six-pin connector to the speed control switch connector. Reassemble the 58-pin connector. Install the connector back to the engine control module (ECM) and push the module back into its mounting bracket. Ensure the ECM is properly held in place by means of the tensioning spring clips.

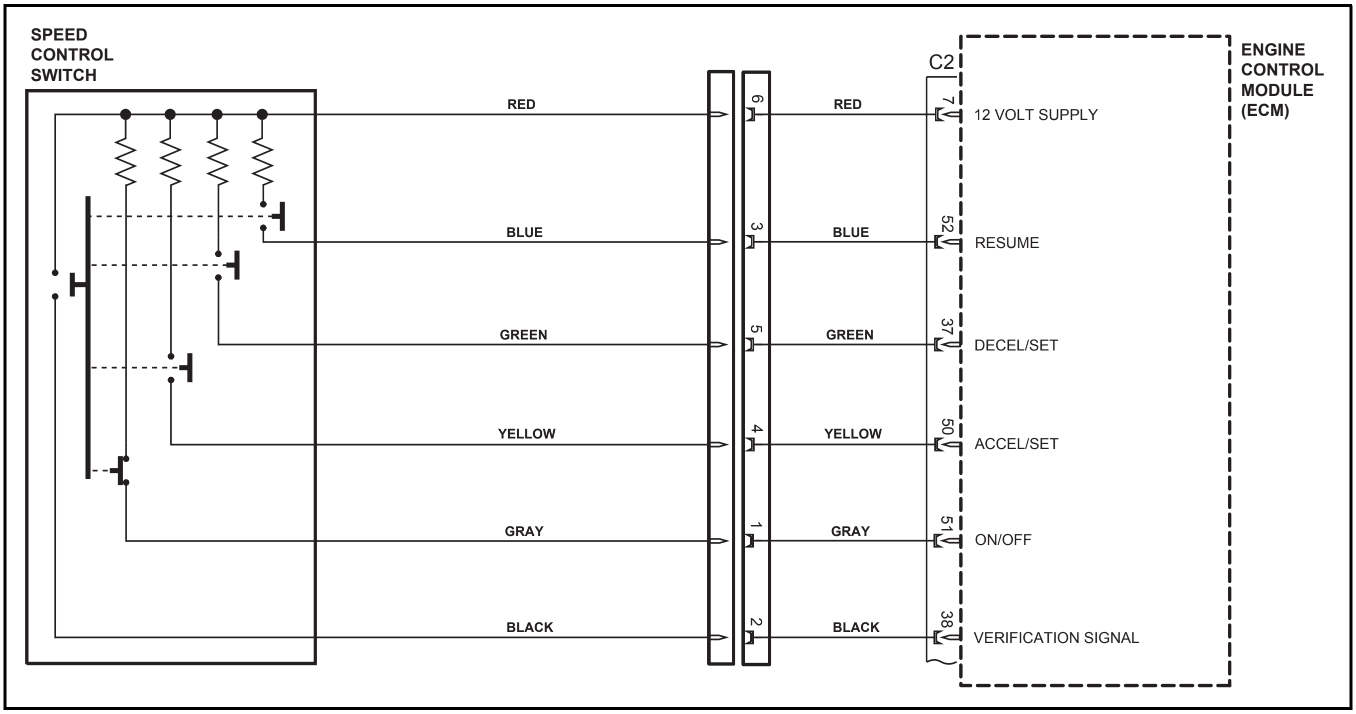


Figure 248 Wiring Diagram, Speed Control Circuit

20. Reinstall Fuse Block No. 1 and upper and lower steering column covers (Figure 249). The upper cover has a slot on the back (arrow) for the speed control switch lever. Reinstall the M relay and the fuse block locking cover.

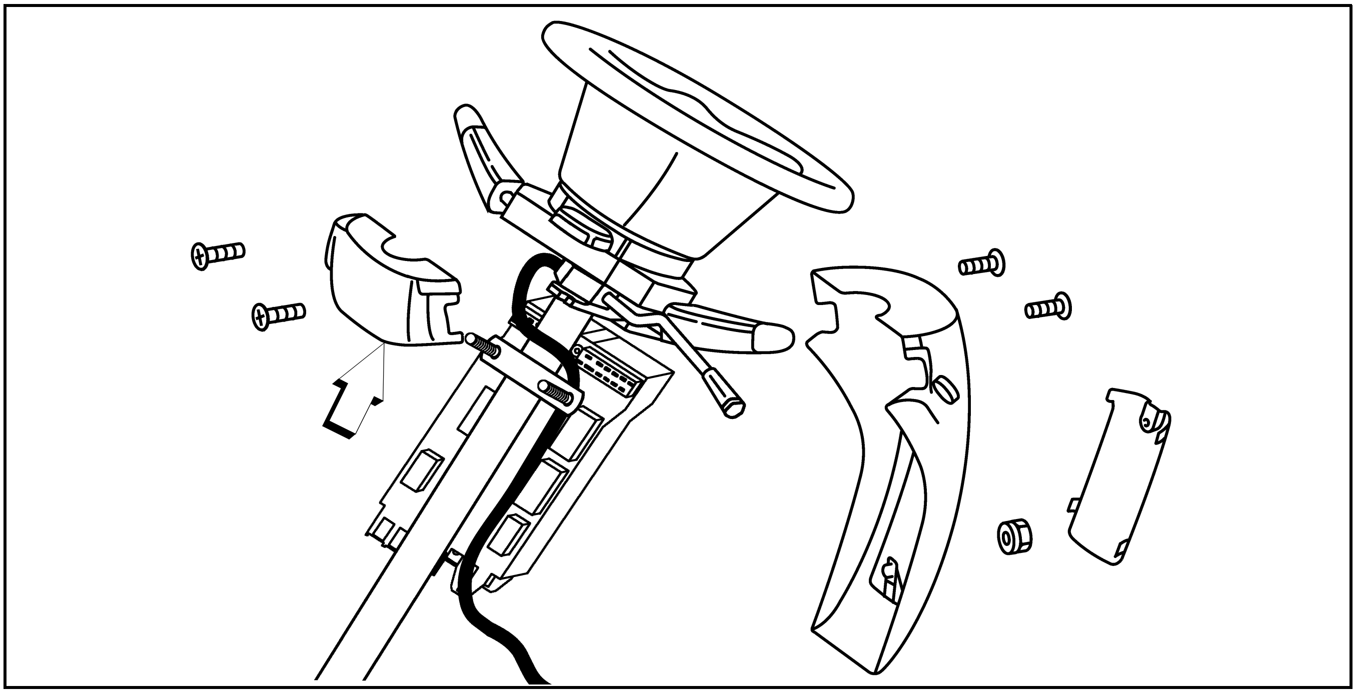


Figure 249 Reinstalling Fuse Block 1 and Upper and Lower Steering Column Covers

21. Reconnect the battery and code the radio if necessary. Connect the diagnostic scan tool to the vehicle.

NOTE: The following steps are for changing the ECM version coding. Follow the proper procedure with DRB III or DAS. Test drive the vehicle after completing the coding to ensure proper operation of the speed control switch (Figure 250).

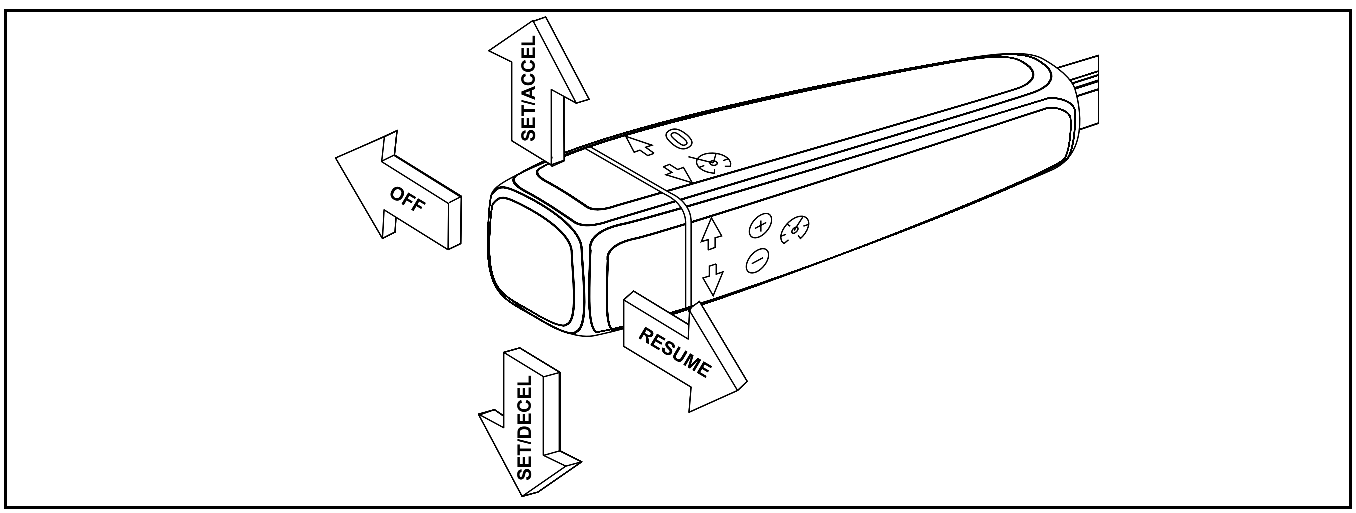


Figure 250 Speed Control Switch Operation

CHANGING THE ECM VERSION CODING WITH DRB III

1. Choose Engine in the System Select screen and Miscellaneous Functions in the Select Function screen (Figure 251).

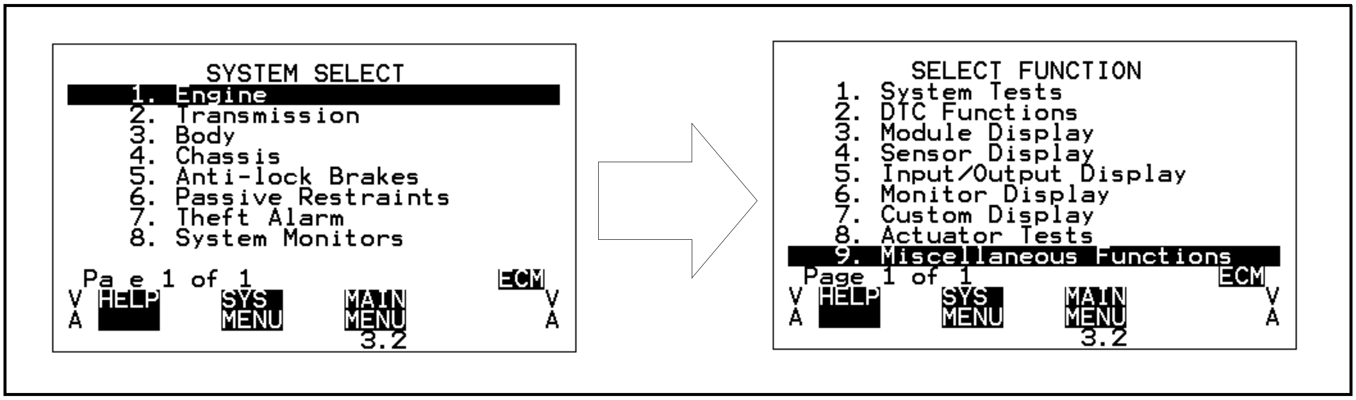


Figure 251 Selecting Engine and Miscellaneous Functions

2. Select Configuration in the Miscellaneous Functions screen. When asked, select Cruise Control Installed (Figure 252).

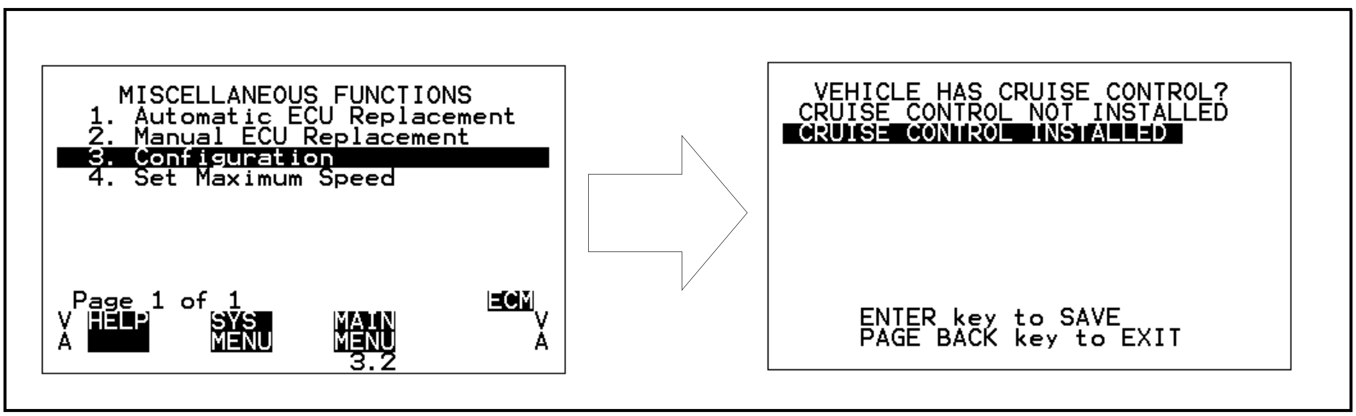


Figure 252 Selecting Configuration

3. Switch the ignition OFF and wait for the progress bar to indicate the completion of the configuration process (Figure 253).

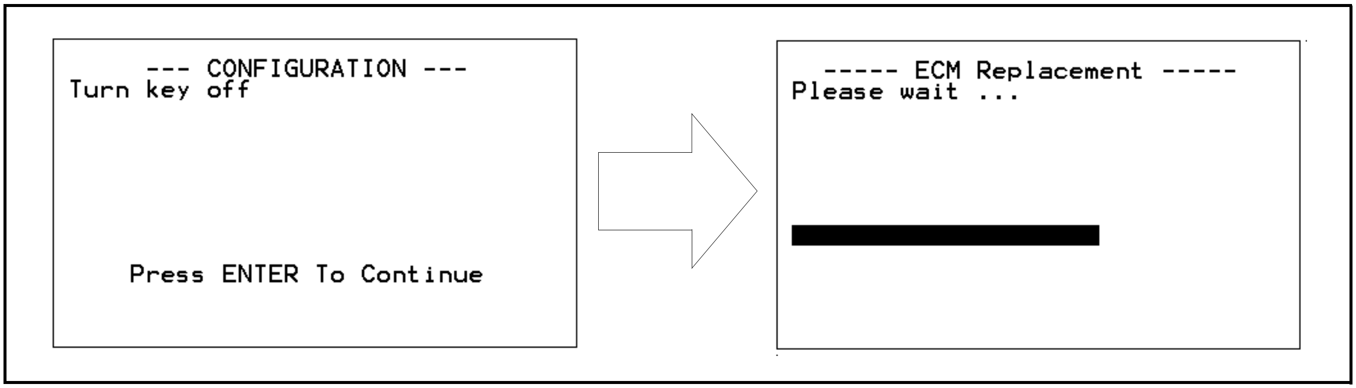


Figure 253 Key Off and Progress Bar Screens

4. Switch the ignition ON (Figure 254). The speed control installation is now complete.

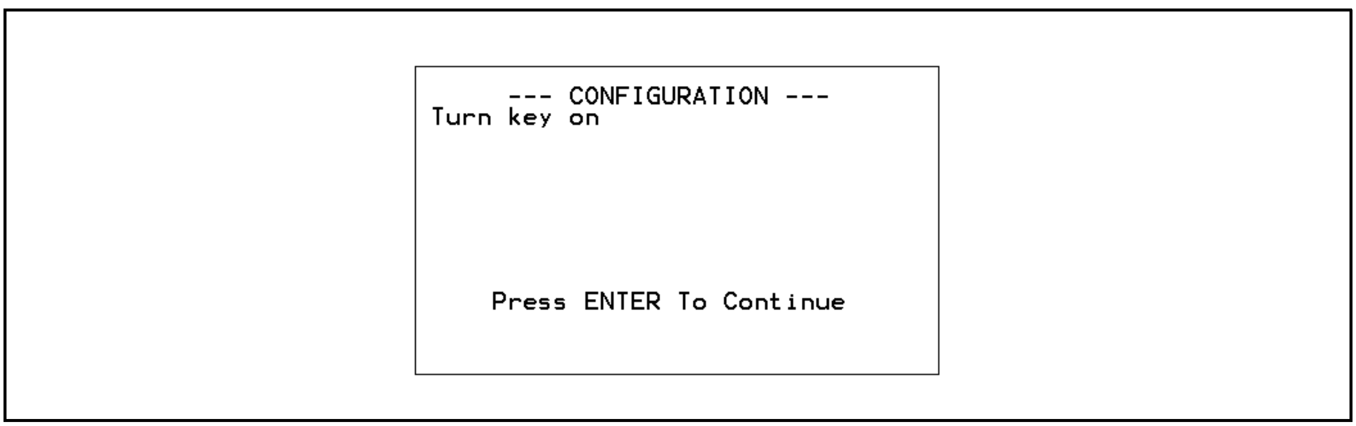


Figure 254 Key ON Screen

CHANGING THE ECM VERSION CODING WITH DAS

1. Select the CR Common Rail option in the Current Short Test screen. In the Common Rail screen select Control Unit Adaptations (Figure (255).

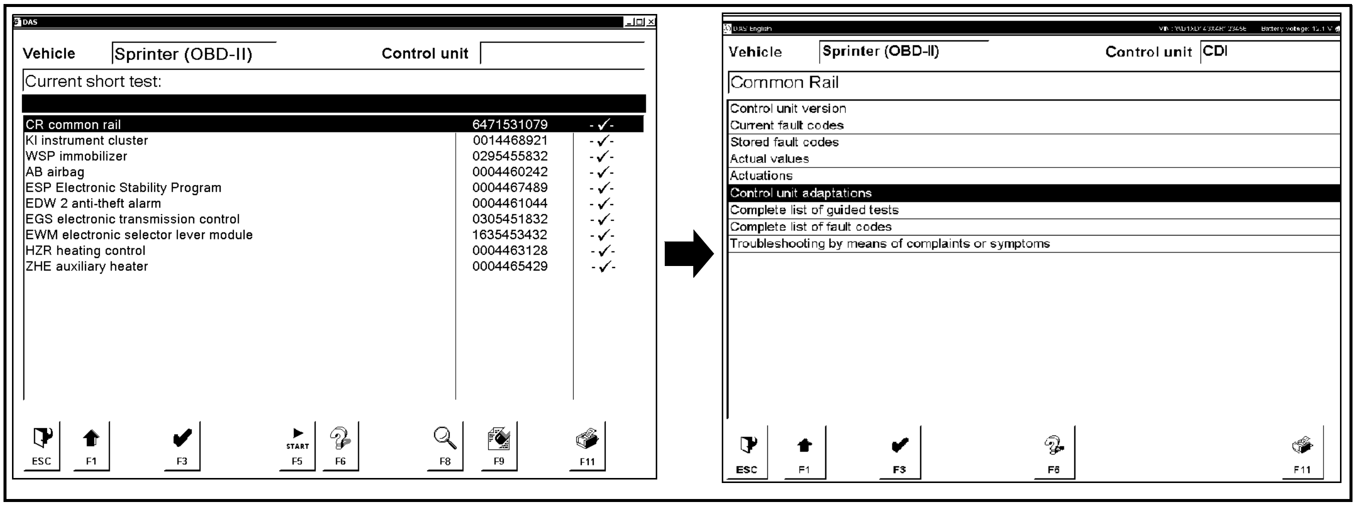


Figure 255 Current Short Test and Common Rail Screens

2. In the Control Unit Adaptations screen select SCN Coding. In the SCN Coding screen select Determine Vehicle Data for SCN Coding (Figure 256).

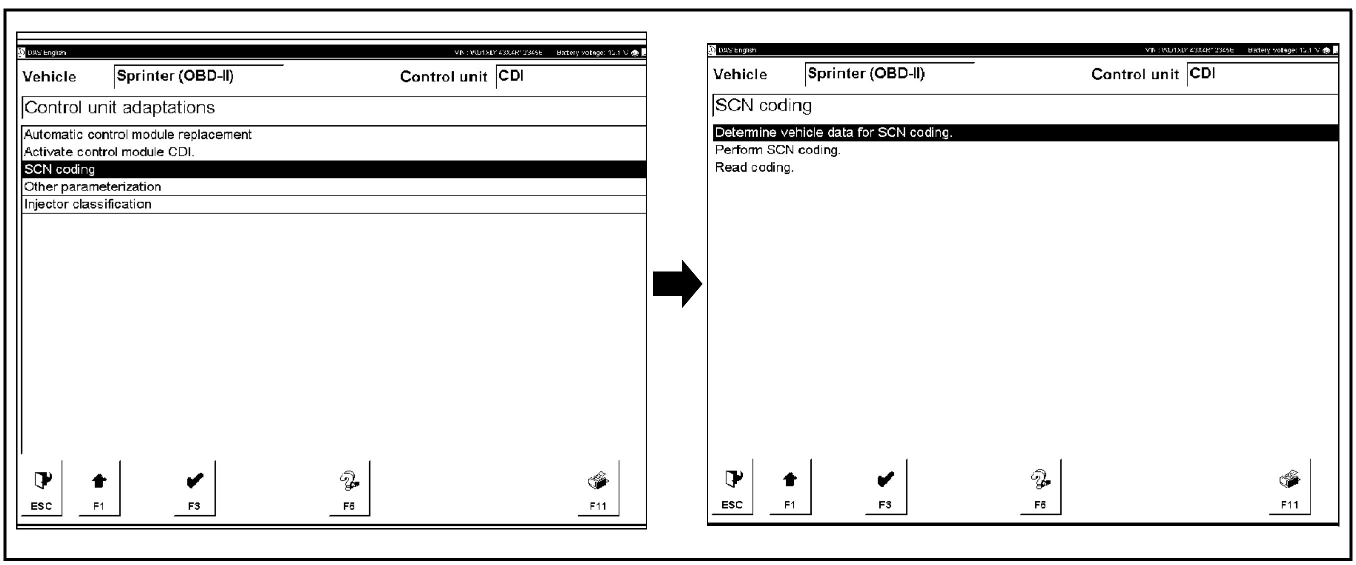


Figure 256 Control Unit Adaptations and SCN Coding Screens

3. Print or record the vehicle data (VIN, MB Code Number and Check Digit). You need to contact the Sprinter Technical Support Line (1-866-769-8092) to get a new SCN code. Provide the Support Line Representative with the vehicle data. The Technical Support Line Representative will issue a new Coding String, SCN and Check Digit. Return to the SCN Coding Screen and select the option Perform SCN Coding.

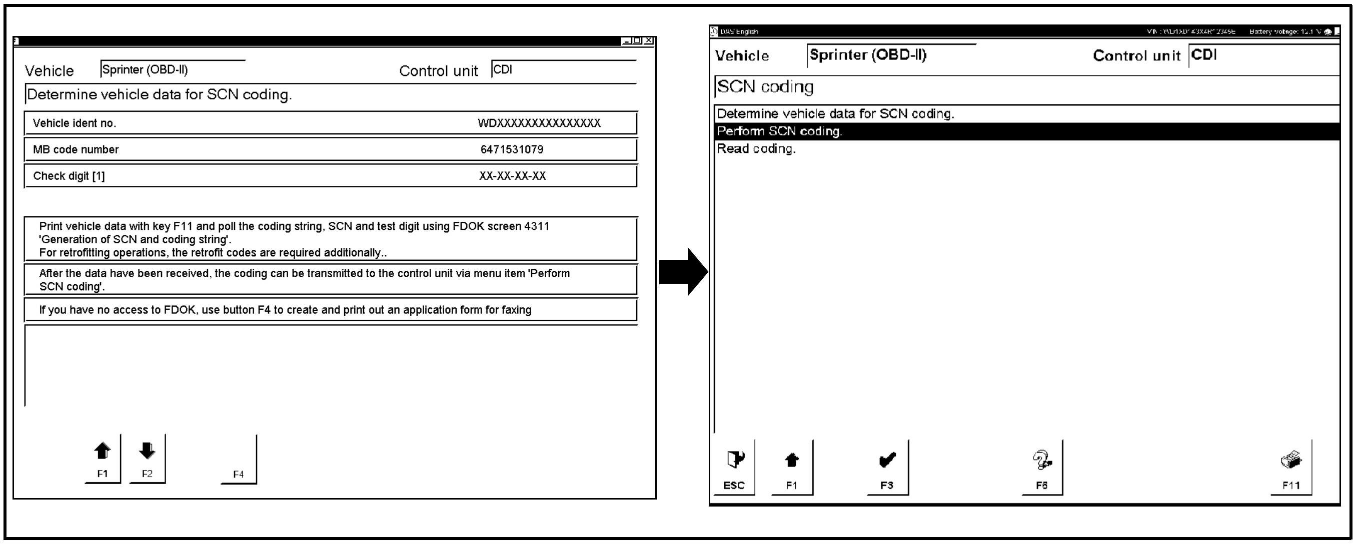


Figure 257 Determine Vehicle Coding and SCN Coding Screens

4. Enter the VIN and the new Coding String, SCN and Check Digit in the appropriate input fields (Figure 258). Press the YES button to complete the SCN coding.

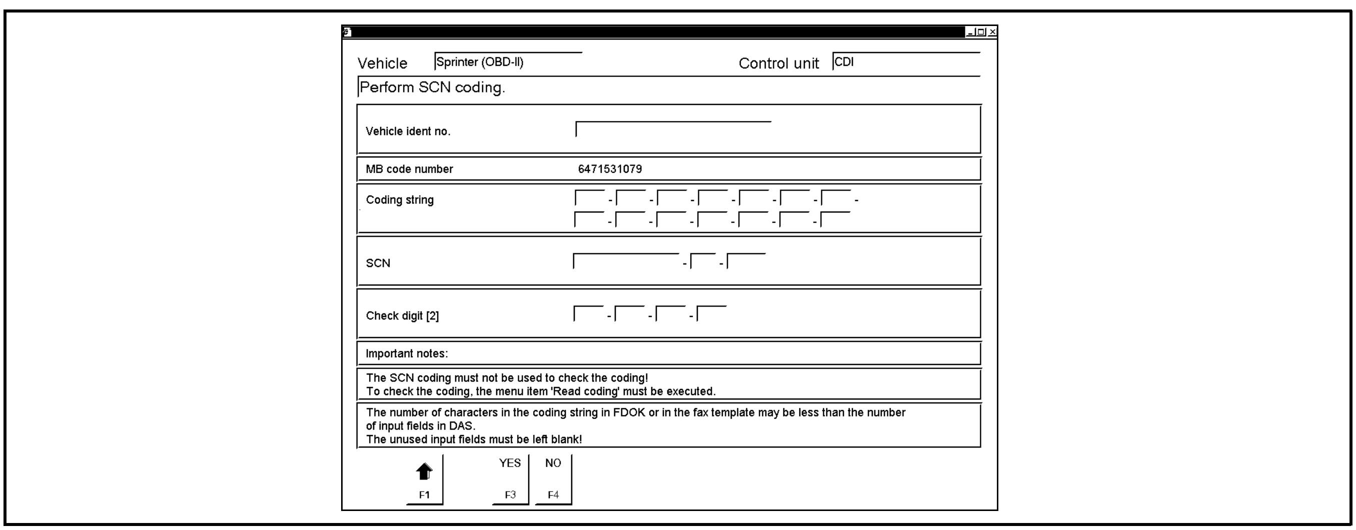


Figure 258 Perform SCN Coding Screen