ENGINE SERVICE MANUAL

EGES-390

2007

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Foreword

International Truck and Engine Corporation is committed to continuous research and development to improve products and introduce technological advances. Procedures, specifications, and parts defined in published technical service literature may be altered.

This *Service Manual* provides a general sequence of procedures for out-of-chassis engine overhaul (removal, inspection, and installation). For in-chassis service of parts and assemblies, the sequence may vary.

NOTE: Photo illustrations identify specific parts or assemblies that support text and procedures; other areas in a photo illustration may not be exact.

See vehicle manuals and Technical Service Information (TSI) bulletins for additional information.

Technical Service Literature is revised periodically and mailed automatically to “Revision Service” subscribers. If a technical publication is ordered, the latest revision will be supplied.

NOTE: To order technical service literature, contact your International dealer.

Technical Service Literature

1171897R1	International® MaxxForce™ 5 Engine *Operation and Maintenance Manual*
EGES-390	International® MaxxForce™ 5 *Service Manual*
EGES-395	International® MaxxForce™ 5 *Diagnostic Manual*
EGED-410	International® MaxxForce™ 5 Electronic Control Systems Diagnostic Form

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Service Diagnosis

Service diagnosis is an investigative procedure that must be followed to find and correct an engine application problem or an engine problem.

If the problem is engine application, see specific vehicle manuals for further diagnostic information.

If the problem is the engine, see specific *Engine Diagnostic Manual* for further diagnostic information.

Prerequisites for Effective Diagnosis

- Availability of gauges and diagnostic test equipment
- Availability of current information for engine application and engine systems
- Knowledge of the principles of operation for engine application and engine systems
- Knowledge to understand and do procedures in diagnostic and service publications

Technical Service Literature required for Effective Diagnosis

- *Engine Service Manual*
- *Engine Diagnostic Manual*
- Diagnostics Forms
- Electronic Control Systems Diagnostics Forms
- Service Bulletins

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Safety Information

This manual provides general and specific service procedures essential for reliable engine operation and your safety. Since many variations in procedures, tools, and service parts are involved, advice for all possible safety conditions and hazards cannot be stated.

Read safety instructions before doing any service and test procedures for the engine or vehicle. See related application manuals for more information.

Disregard for Safety Instructions, Warnings, Cautions, and Notes in this manual can lead to injury, death or damage to the engine or vehicle.

SAFETY TERMINOLOGY

Three terms are used to stress your safety and safe operation of the engine: Warning, Caution, and Note

Warning: A warning describes actions necessary to prevent or eliminate conditions, hazards, and unsafe practices that can cause personal injury or death.

Caution: A caution describes actions necessary to prevent or eliminate conditions that can cause damage to the engine or vehicle.

Note: A note describes actions necessary for correct, efficient engine operation.

SAFETY INSTRUCTIONS

Vehicle

Make sure the vehicle is in neutral, the parking brake is set, and the wheels are blocked before doing any work or diagnostic procedures on the engine or vehicle.

Work area

- Keep work area clean, dry, and organized.
- Keep tools and parts off the floor.
- Make sure the work area is ventilated and well lit.
- Make sure a first aid kit is available.

Safety equipment

- Use correct lifting devices.
- Use safety blocks and stands.

Protective measures

- Wear protective safety glasses and shoes.
- Wear correct hearing protection.
- Wear cotton work clothing.
- Wear sleeved heat protective gloves.
- Do not wear rings, watches or other jewelry.
- Restrain long hair.

Fire prevention

- Make sure charged fire extinguishers are in the work area.

NOTE: Check the classification of each fire extinguisher to ensure that the following fire types can be extinguished.

1. Type A — Wood, paper, textiles, and rubbish
2. Type B — Flammable liquids
3. Type C — Electrical equipment

Batteries

Batteries produce highly flammable gas during and after charging.

- Always disconnect the main negative battery cable first.
- Always connect the main negative battery cable last.
- Avoid leaning over batteries.
- Protect your eyes.
- Do not expose batteries to open flames or sparks.
- Do not smoke in workplace.

Compressed air

- Use an OSHA approved blow gun rated at 207 kPa (30 psi).
- Limit shop air pressure to 207 kPa (30 psi).
- Wear safety glasses or goggles.
- Wear hearing protection.
- Use shielding to protect others in the work area.
- Do not direct compressed air at body or clothing.

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Tools

- Make sure all tools are in good condition.
- Make sure all standard electrical tools are grounded.
- Check for frayed power cords before using power tools.

Fluids under pressure

- Use extreme caution when working on systems under pressure.
- Follow approved procedures only.

Fuel

- Do not over fill the fuel tank. Over fill creates a fire hazard.
- Do not smoke in the work area.
- Do not refuel the tank when the engine is running.

Removal of tools, parts, and equipment

- Reinstall all safety guards, shields, and covers after servicing the engine.
- Make sure all tools, parts, and service equipment are removed from the engine and vehicle after all work is done.

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Engine Identification

Engine Serial Number

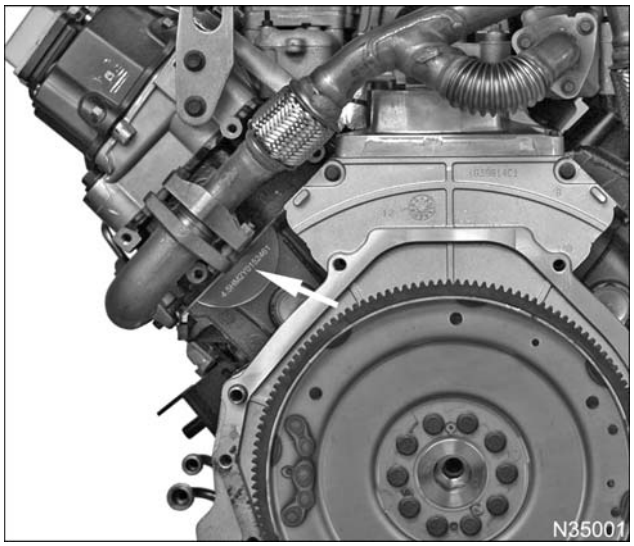

Figure 1 Engine serial number

The engine serial number is stamped on the crankcase pad, on the rear left side below the cylinder head.

Engine Serial Number Example

4.6HM2YXXXXXXX

4.6 – International® MaxxForce™ 5
H – Diesel, turbocharged, air intercooled and electronically controlled
M2 – Motor truck or **U2** power unit and OEM (Sold to original equipment manufacturer)
Y – United States, Huntsville
7 digit suffix – Sequence number

Emission Labels

An Environmental Protection Agency (EPA) Engine Emission Label is issued for the International® MaxxForce™ 5 diesel engine.

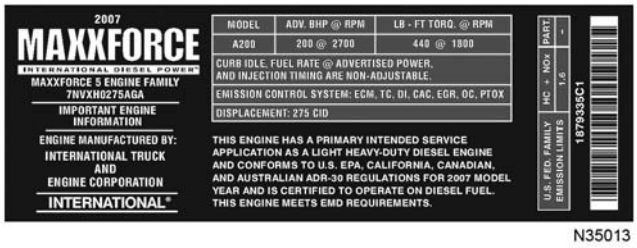

Figure 2 Example of U.S. Environmental Protection Agency (EPA) emission label (50 state)

The EPA exhaust emission label is on top of the crankcase breather, on the left valve cover. The label includes the following:

- Advertised brake horsepower ratings
- Engine model code
- Service applications
- Emission family and control systems
- Year the engine was certified to meet EPA emission standards

Engine Accessories

The following engine accessories may have manufacturers' labels or identification plates:

- Air conditioning compressor
- Alternator
- Cooling fan clutch
- Dual turbocharger assembly
- Power steering pump
- Starter motor

Labels or identification plates include information and specifications helpful to vehicle operators and technicians.

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Component Locations

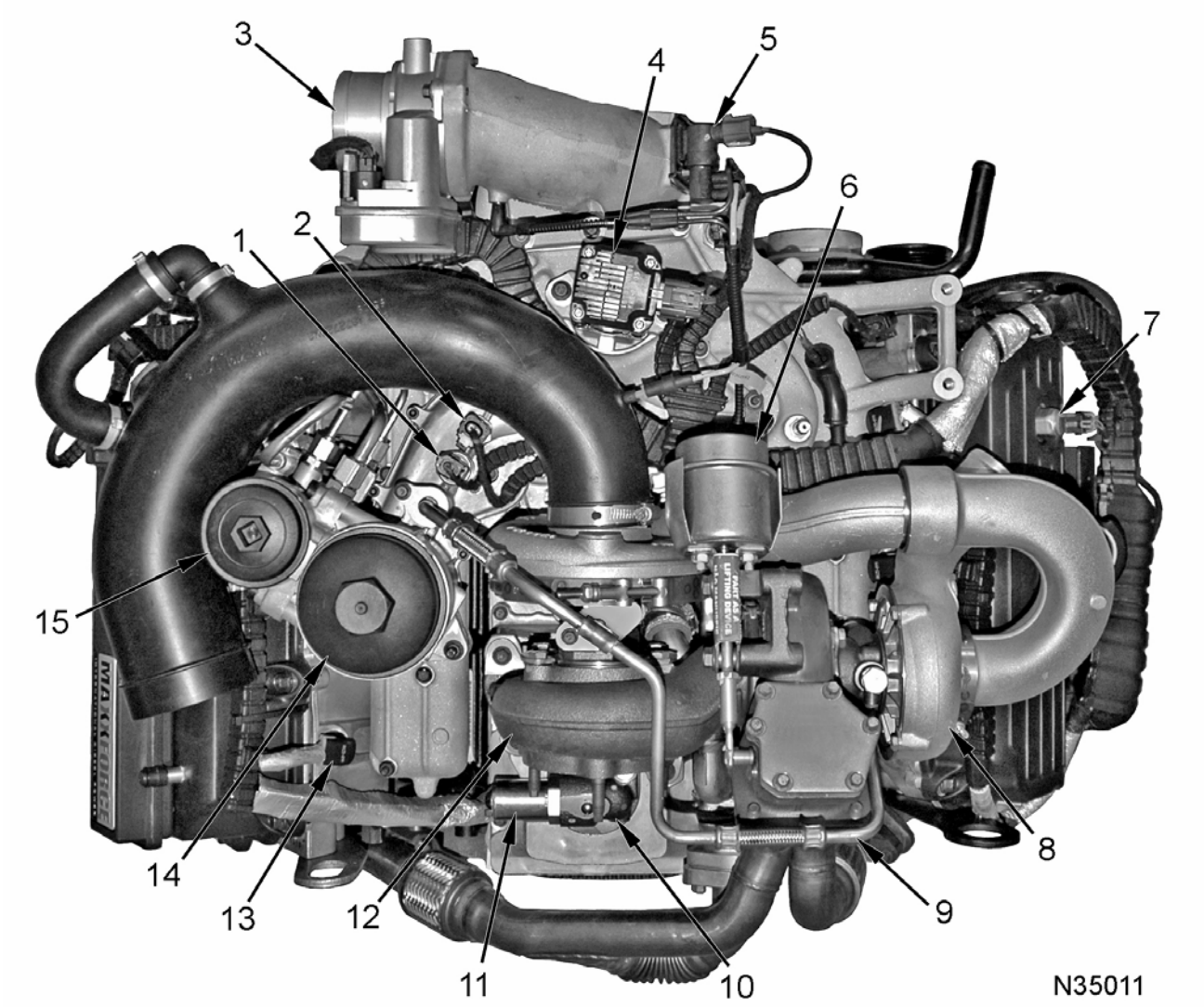

Figure 3 Top

1. Engine Oil Pressure (EOP) switch
2. Engine Oil Temperature (EOT) sensor
3. Intake Throttle Valve (ITV) assembly
4. Exhaust Gas Recirculation (EGR) valve
5. Boost Control Solenoid (BCS)
6. Turbocharger pneumatic actuator
7. Injection Control Pressure (ICP) sensor
8. Turbocharger high-pressure compressor
9. Turbocharger oil supply tube assembly
10. High-pressure oil pump assembly
11. Injection Pressure Regulator (IPR) valve
12. Turbocharger low-pressure turbine
13. Injector connection (6)
14. Oil filter housing assembly
15. Secondary fuel filter assembly

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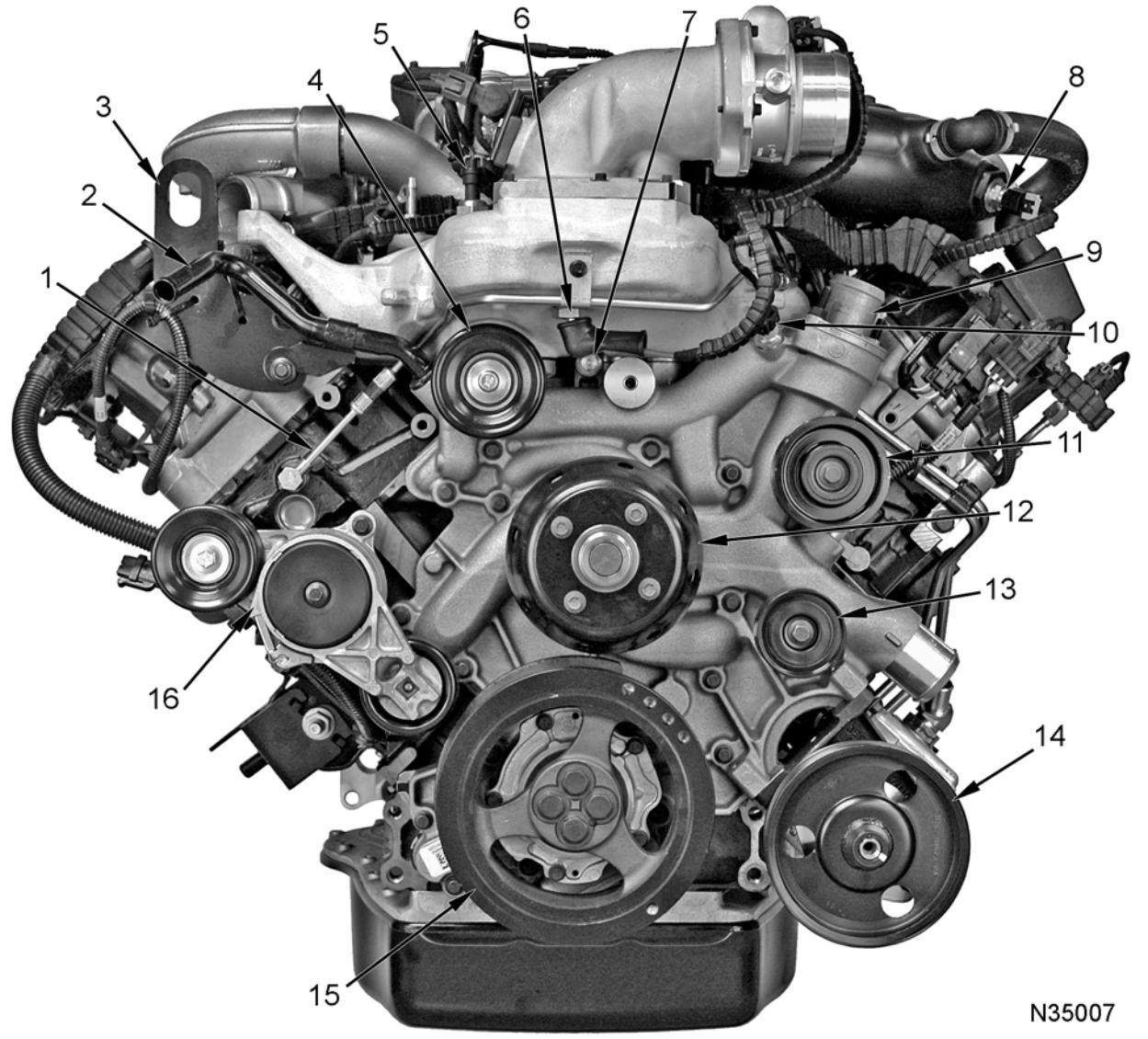

Figure 4 Front

1. Fuel filter to right cylinder head tube
2. Heater feed tube assembly
3. Lifting eye
4. Flat idler pulley
5. Manifold Absolute Pressure (MAP) sensor
6. Inlet Air Heater (IAH) element
7. Diagnostic port (oil cooler)
8. Intake Air Temperature (IAT) sensor
9. Thermostat assembly
10. Engine Coolant Temperature (ECT) sensor
11. 8-groove idler pulley
12. Water pump / fan drive pulley
13. Smooth idler pulley
14. Power steering pulley
15. Vibration damper
16. Belt tensioner assembly

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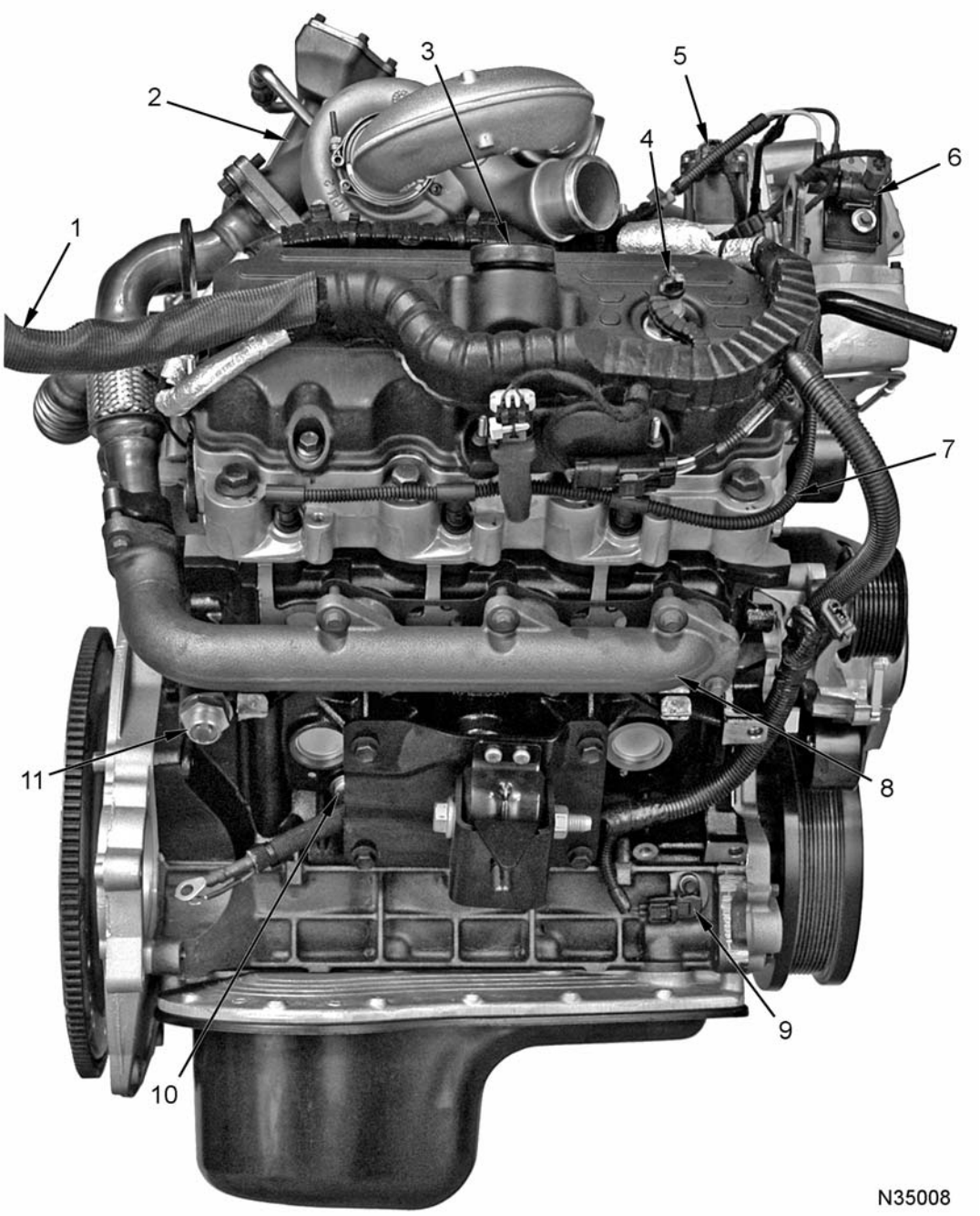

Figure 5 Right

1. Sensor wiring harnesses to chassis mounted ECM, IAH and glow plug relays
2. Dual turbocharger assembly
3. Oil fill cap
4. Injection Control Pressure (ICP) sensor
5. Exhaust Gas Recirculation (EGR) valve
6. Boost Control Solenoid (BCS)
7. Glow plug harness assembly (right)
8. Exhaust manifold (right)
9. Crankshaft Position (CKP) sensor
10. Crankcase coolant drain plug (right)
11. Coolant heater

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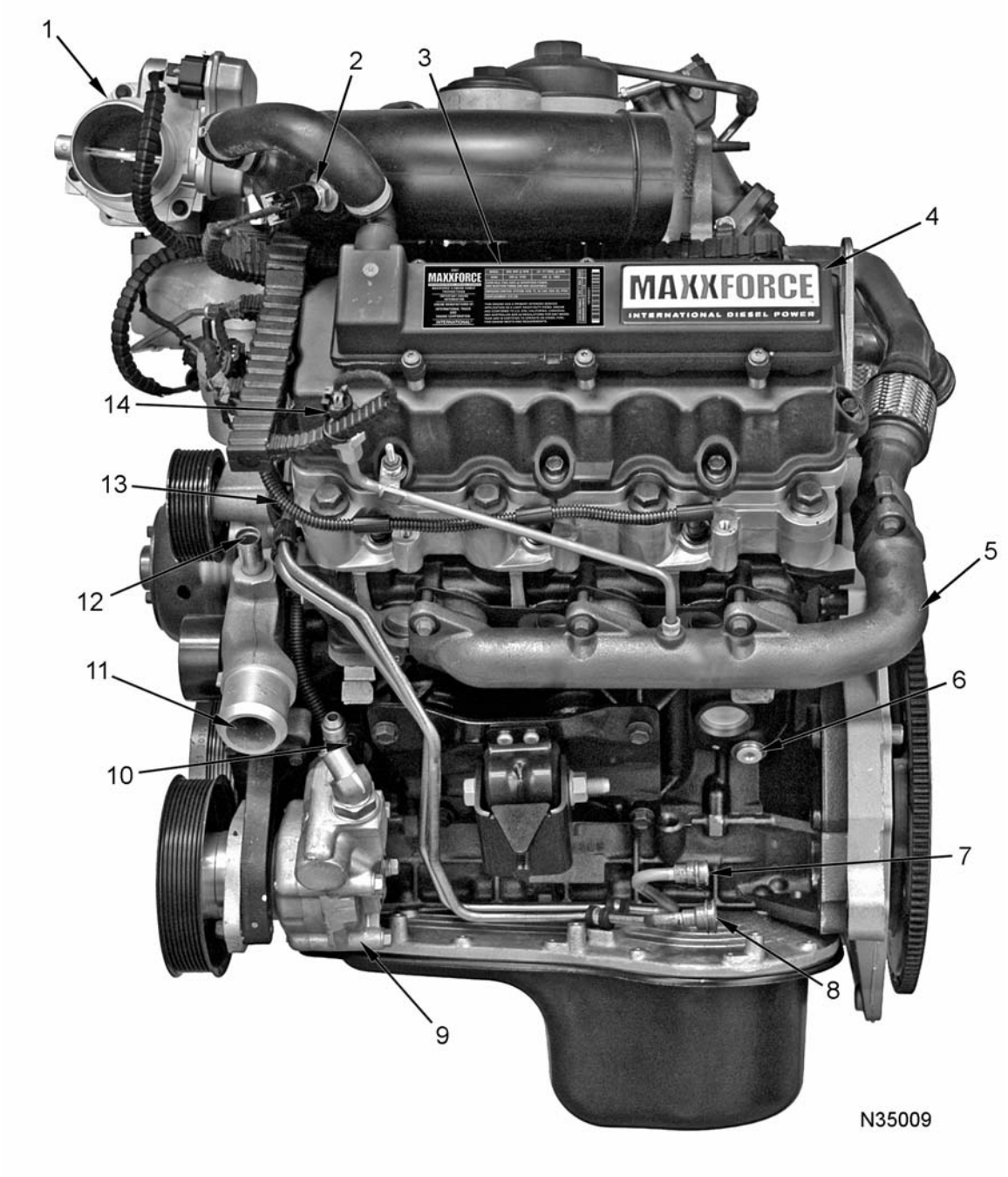

Figure 6 Left

1. Intake Throttle Valve (ITV) assembly
2. Intake Air Temperature (IAT) sensor
3. Exhaust emission label
4. Crankcase breather assembly
5. Exhaust manifold (left)
6. Crankcase coolant drain plug (left)
7. Fuel return to HFCM
8. Fuel supply to filter tube
9. Power steering pump
10. Camshaft Position (CMP) sensor
11. Coolant inlet
12. Heater return port
13. Glow plug harness assembly (left)
14. Exhaust Back Pressure (EBP) sensor

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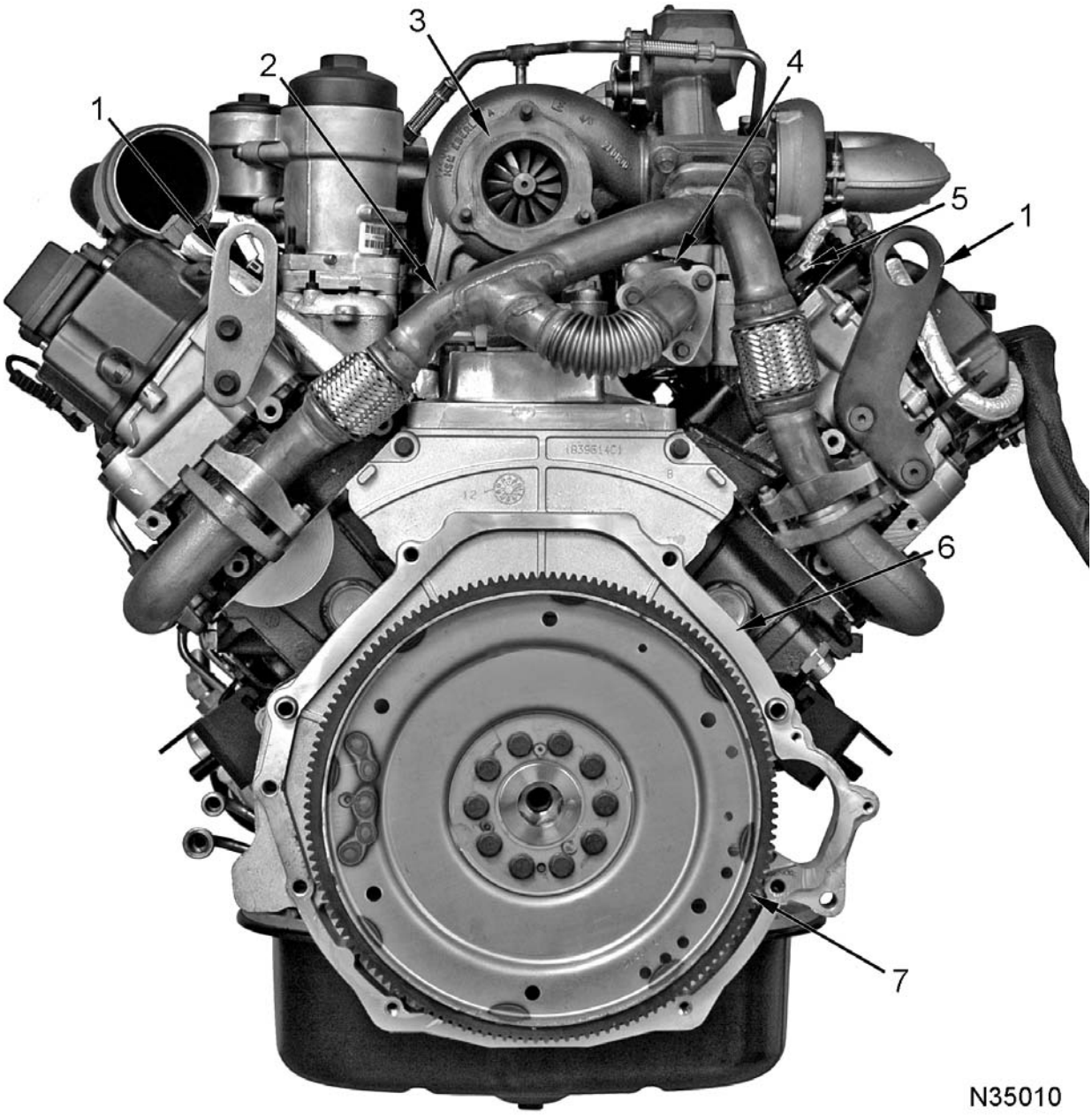

Figure 7 Rear

1. Lifting eye
2. Exhaust tube assembly
3. Turbocharger/exhaust outlet
4. Exhaust Gas Recirculation (EGR) cooler
5. Injector connector (6)
6. Rear cover
7. Flywheel assembly

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Engine Description, Specifications, and Features

Table 1 International® MaxxForce™ 5 Description and Specifications

Engine configuration	4 stroke V6 diesel, 4 valves/cylinder
Displacement	4.5 liters (275 in^3)
Bore (sleeve diameter)	95 mm (3.74 in.)
Stroke	105 mm (4.134 in.)
Compression ratio	18.0:1
Aspiration	Dual turbocharged and Charge Air Cooled (CAC)
Advertised brake horsepower @ rpm	See EPA exhaust emission label
Peak torque @ rpm	See EPA exhaust emission label
Engine rotation (facing flywheel)	Counterclockwise
Combustion system	Direct injection turbocharged
Fuel system	International® electro-hydraulic generation 2 injection
Cooling system capacity (engine only)	11 liters (12 quarts US)
Lube system capacity (including filter)	13 liters (14 quarts US)
Lube system capacity (overhaul only, with filter)	14 liters (15 quarts US)
Firing order	1-2-5-6-3-4

Engine Features

Table 2 International® MaxxForce™ 5 Standard and Optional Features

Standard Features	**Optional Features**
Four valves per cylinder	Coolant heater wiring harness
Primary balancer shaft assembly	**Chassis Mounted Features**
Dual timing sensors	Horizontal Fuel Conditioning Module (HFCM)
Two-piece crankcase	Diamond Logic® Engine Control
One-piece aluminum alloy pistons	Inlet air heater relay
Fracture cap joint connecting rods	Glow plug relay
International® electro-hydraulic generation 2 injection system	Charge Air Cooler (CAC)
Dual turbocharger assembly	
Secondary fuel filter	

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Engine Description

Cylinder Heads

Each cylinder head has four valves per cylinder for improved air flow. The overhead valve train includes hydraulic roller tappets, push rods, rocker arms, and valve bridges to operate the four valves. Each fuel injector is centrally located between the four valves, directly over the piston combustion bowl, for improved performance and reduced emissions.

Crankcase Assembly

The crankcase assembly consists of an upper crankcase and a lower crankcase. The upper crankcase assembly includes the cylinders, main bearing saddles, and cast or machined coolant passages. The lower crankcase, a structural plate that mates to the upper crankcase, has machined main bearing caps for improved load retention and alignment.

Aluminum alloy pistons are mated to fractured cap joint connecting rods. Piston pins, secured with retaining rings, are free floating for lateral movement in the connecting rod and piston.

The crankshaft is supported by four main bearings with fore and aft thrust controlled at the upper half of the number 3 main bearing. Two connecting rods, attached to each crankshaft rod journal, are offset to minimize vibration.

The camshaft is supported by four bushings pressed into the crankcase. The camshaft is crankshaft driven and thrust is controlled by a plate mounted behind the number four cam journal.

A closed crankcase breather system separates crankcase vapors and oil. Vapors are vented through a hose to the air inlet duct, while oil drains back to the crankcase.

Fuel System

The Horizontal Fuel Conditioning Module (HFCM) includes an electric fuel pump, primary fuel filter, Diesel Thermo Recirculation Module (DTRM), fuel heater, water drain plug, and a Water In Fuel (WIF) sensor. An amber Water In Fuel lamp is illuminated when a predetermined quantity of water has accumulated.

- The HFCM is mounted on the inside of the frame rail (operator's side) for Cab Forward (CityStar™) vehicles
- The HFCM is mounted near the transmission and frame rail (passenger side) for stripped chassis vehicles.

A secondary fuel filter assembly (engine mounted) includes outlets for the fuel lines to each cylinder head fuel rail, a fuel pressure regulator, an Engine Fuel Pressure (EFP) switch, and an air bleed orifice to discharge air if the vehicle runs out of fuel.

The International® electrohydraulic generation 2 injection system includes a high-pressure oil pump, cast iron oil rail assemblies, and fuel injectors.

An Electronic Control Module (ECM) processes signals from the Crankshaft Position (CKP), Camshaft Position (CMP), exhaust aftertreatment, and other sensors. The ECM sends voltage pulses to opening and closing coils of each injector to control injection timing, quantity, and duration.

Lubrication System

The engine lubrication system is pressure regulated, full flow cooled, and full flow filtered. A crankshaft driven gerotor lube oil pump delivers oil through an oil filter element and oil cooler to engine components and an oil reservoir for the high-pressure fuel system. An oil pressure regulator, in the front cover, maintains the desired system pressure.

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Air Management System

A dual stage turbocharger provides boost pressure for a variety of engine speeds and load conditions. An electronic Boost Control Solenoid (BCS) and a pneumatic actuator control the turbocharger.

A Charge Air Cooler (CAC), an air-to-air heat exchanger, cools and increases the density of the air charge from the turbocharger. The cooled dense air flows to the intake manifold. An intake throttle valve restricts air flow to help heat exhaust gas during aftertreatment regeneration.

An Exhaust Gas Recirculation (EGR) system includes an EGR cooler and EGR valve. Some exhaust from the exhaust tube assembly flows through the EGR cooler into a passage in the intake manifold and to the EGR valve. When the EGR valve opens, cooled exhaust gases enter the intake manifold.

The Inlet Air Heater relay and glow plug relay work together to improve cold weather engine performance and starting. An Intake Air Heater (IAH) element, mounted in the intake manifold under the inlet air elbow, is controlled by an inlet air heater relay (chassis mounted). Six glow plugs are controlled by a glow plug relay (chassis mounted).

An Aftertreatment System processes engine exhaust to meet EPA emissions requirements.

- An oxidation catalyst burns oxygen and hydrocarbons in the exhaust stream.
- A Diesel Particulate Filter (DPF) captures and burns particulates in the exhaust stream.

Optional Features

Although a 1250 watt coolant heater is standard equipment, an optional 120 volt cable is available for operation. The coolant heater raises coolant temperature around the cylinders to improve cold engine starts.

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Engine Systems Interaction Diagram

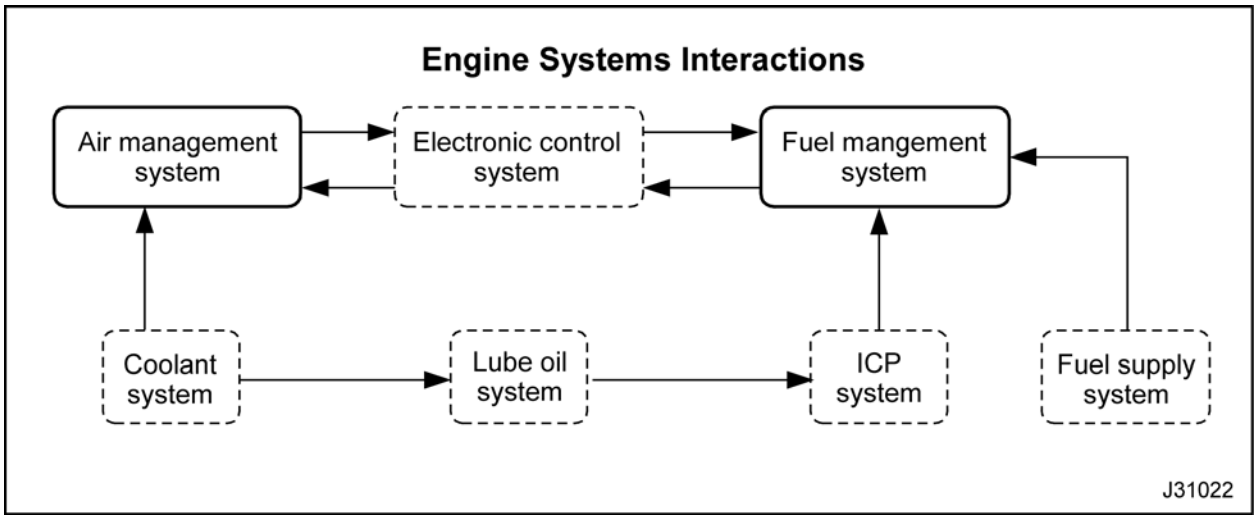

Figure 8 Engine systems interactions

The primary engine systems are air management and fuel management which share some subsystems or have a subsystem that contributes to their operation.

- The electronic control system controls the air management system and fuel management system.
- The Coolant System provides heat transfer for crankcase and cylinder sleeves, cylinder head, EGR gases, and lubrication oil.
- The lube oil system provides lubrication and heat transfer for engine components.
- The Injection Control Pressure (ICP) system uses engine oil to actuate the fuel injectors.
- The fuel supply system pressurizes fuel to the fuel injectors.

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Air Management System

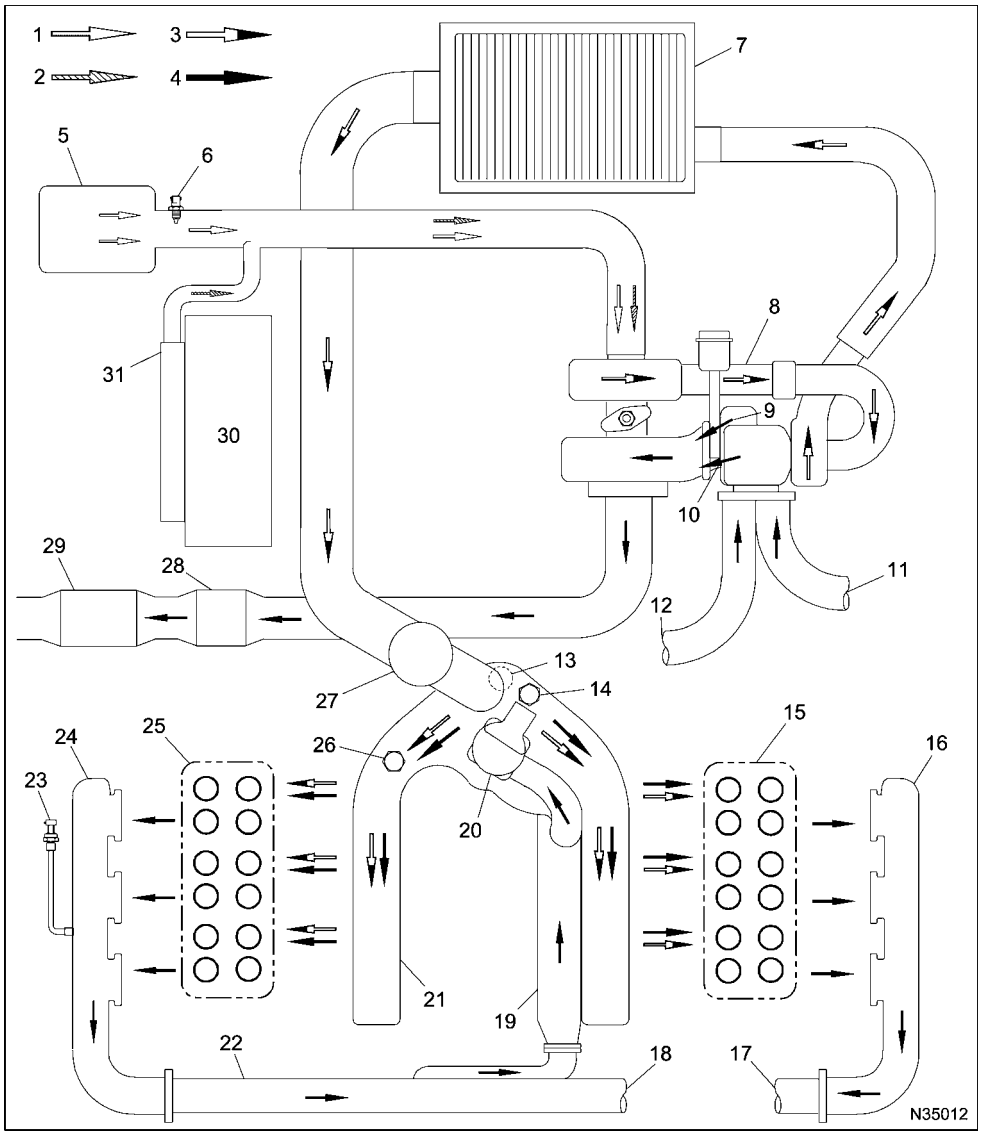

Figure 9 Air management system components and flow

1. Air flow
2. Crankcase gas flow
3. Compressed air and crankcase gas flow
4. Exhaust gas flow
5. Air filter
6. Intake Air Temperature (IAT) sensor
7. Charge Air Cooler (CAC)
8. Dual turbocharger
9. Exhaust flow (bypass closed)
10. Exhaust flow (bypass open)
11. Exhaust in from right cylinders
12. Exhaust in from left cylinders
13. Intake Air Heater (IAH)
14. Manifold Absolute Pressure (MAP) sensor
15. Right cylinder head
16. Right exhaust manifold
17. Exhaust out from right cylinders
18. Exhaust out from left cylinders
19. Exhaust Gas Recirculation (EGR) cooler
20. EGR valve
21. Intake manifold
22. Exhaust tube assembly
23. Exhaust Back Pressure (EBP) sensor
24. Left exhaust manifold
25. Left cylinder head
26. Manifold Air Temperature (MAT) sensor
27. Intake throttle assembly
28. Diesel Oxidation Catalyst (DOC)
29. Diesel Particulate Filter (DPF)
30. Left valve cover
31. Crankcase breather

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Air, Exhaust, and Crankcase Gas Flow

Ambient air is initially drawn through the air filter assembly past the IAT sensor and into the air inlet duct.

A crankcase breather and hose are used to draw crankcase gasses from the engine.

Air continues to flow through the low-pressure turbocharger compressor (larger turbo), where it is compressed and discharged to the high-pressure turbocharger compressor (smaller turbo). The high-pressure compressor compresses discharge air to a higher pressure and temperature before it enters the CAC.

As the compressed air (hot) flows through the CAC, ambient air flows across the CAC and heat is exchanged to the atmosphere. This heat exchange allows cooled (denser) air to enter the engine with enough pressure to give the correct air to fuel ratio.

During cold weather startups, an inlet air heater warms the incoming air. The Electronic Control Module (ECM) controls the inlet air heater relay. The inlet air heater relay controls the operation of the inlet air heating element depending on ambient temperature and atmospheric pressure.

Air flow continues in the intake manifold, past the intake valves and into the cylinders. After combustion, hot exhaust gases are forced through the exhaust manifolds and into the exhaust piping.

Most of the hot exhaust gas flows into the turbocharger high-pressure turbine (smaller turbo), spinning the high-pressure turbine wheel. Exhaust continues to flow onto the low pressure turbine (larger turbo), spinning the low-pressure turbine wheel before exiting the turbocharger to the exhaust system.

A portion of the hot exhaust gas is routed through the EGR cooler and EGR valve where it is metered into the intake manifold to blend with filtered incoming air. This helps reduce combustion temperatures and Oxides of Nitrogen (NO_x).

Exhaust flows through the exhaust piping, aftertreatment, and out the exhaust pipe.

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Exhaust Gas Recirculation (EGR) System

The EGR system reduces Nitrogen Oxide (NO_x) emissions. NO_x gas forms when nitrogen and oxygen react during high combustion temperatures. Mixing exhaust with inlet air reduces combustion temperature and NO_x gas formation.

Some exhaust from the exhaust tube assembly flows through the EGR cooler, intake manifold EGR passage, and to the EGR valve. The Electronic Control Module (ECM) commands the EGR valve to open, when needed, allowing cooled exhaust gases to enter the intake manifold to mix with intake air.

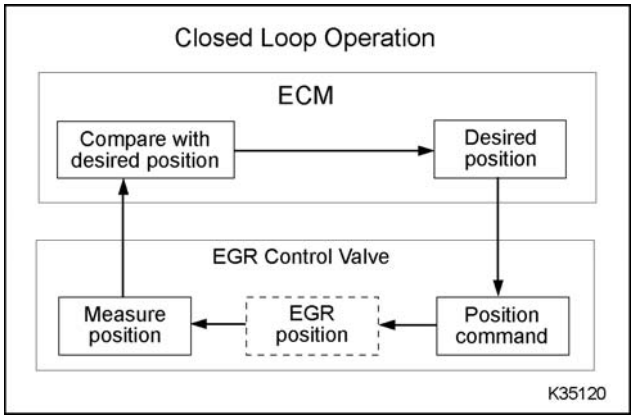

Figure 10 EGR closed loop operation

The ECM commands EGR valve position based on engine speed, Exhaust Back Pressure (EBP), Manifold Air Temperature (MAP), and Manifold Air Pressure (MAT) sensor input. The EGR valve provides feedback to the ECM on current valve position.

Figure 11 EGR valve

The EGR valve assembly consists of three major components; a dual poppet valve, a DC motor, and an Integrated Circuit (IC). The IC has three Hall effect position sensors to monitor valve movement. The EGR valve uses a DC motor to control the position of the valve assembly. The valve assembly has two valve heads on a common shaft.

The EGR valve is installed in the front of the intake manifold.

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Dual Stage Turbocharger Assembly

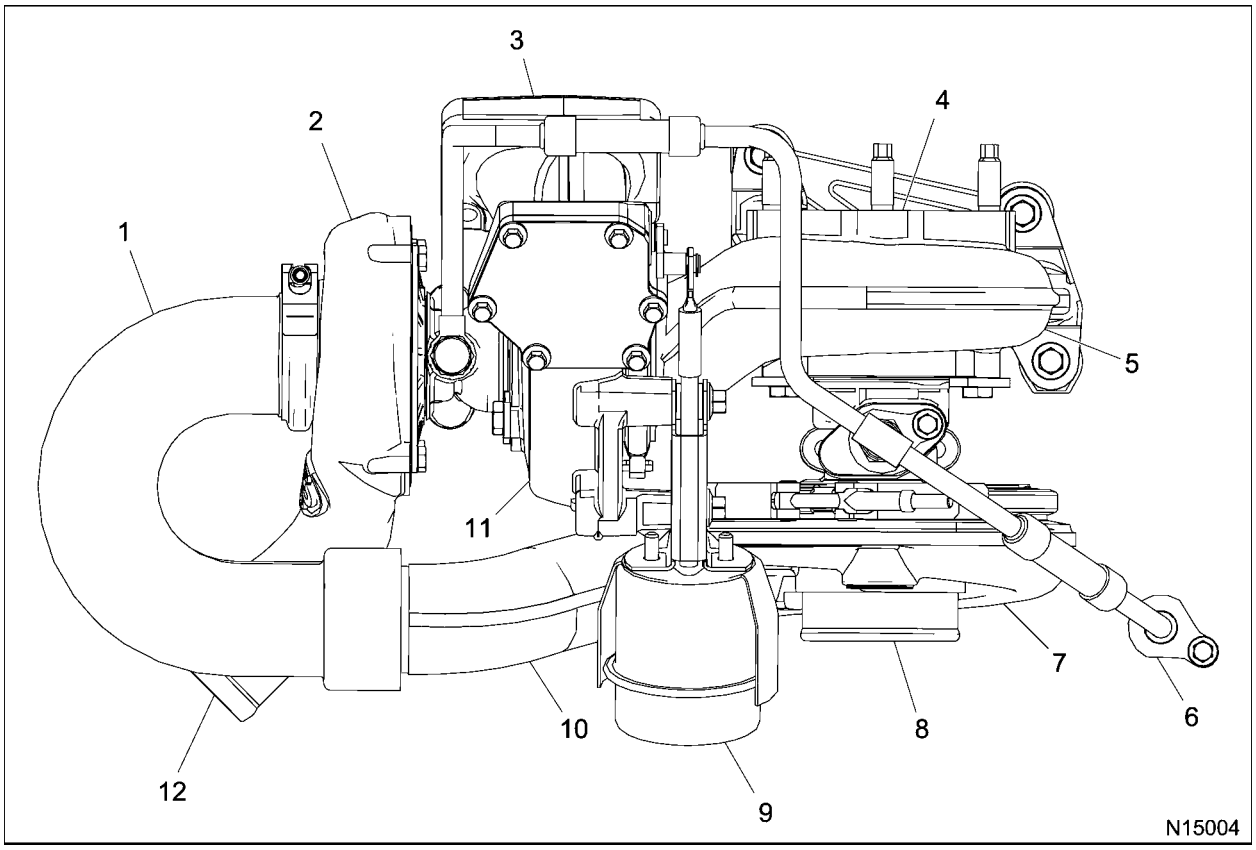

Figure 12 Dual stage turbocharger

1. Crossover tube
2. High-pressure compressor
3. Exhaust inlet
4. Exhaust outlet
5. Low-pressure turbine
6. Oil supply tube
7. Low-pressure compressor
8. Air inlet
9. Pneumatic actuator
10. Low-pressure compressor outlet
11. High-pressure turbine
12. High-pressure compressor discharge

The dual stage turbocharger responds to engine loads. During heavy loads, an increased flow of exhaust gasses turn the turbine wheels faster. Turbine wheel speed controls compressor boost pressure. As engine rpm and load decrease, less fuel and air enter the cylinders. Exhaust temperature and pressure decrease; lower exhaust energy decreases turbine and compressor speed which lowers the pressure and temperature of compressed air.

During light loads, all exhaust flows through the high-pressure turbine and low-pressure turbine. When boost pressure reaches a predetermined value, the pneumatic actuator opens the bypass valve, allowing some exhaust to bypass the high-pressure turbine and flow directly to the low-pressure turbine; maximum boost pressure is limited. The dual stages of the turbocharger contribute to lower exhaust emissions.

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Aftertreatment (AFT) System

The AFT System processes engine exhaust to meet emissions requirements. The aftertreatment system consists of the Diesel Oxidation Catalyst (DOC), Diesel Particulate Filter (DPF), three Exhaust Gas Temperature (EGT) sensors, and a Exhaust Gas Differential Pressure (EGDP) sensor. The Electronic Control Module (ECM) monitors aftertreatment and engine sensors to control AFT regeneration cycles. During a regeneration cycle the exhaust is heated to clear soot accumulation.

AFT Control System

The control system performs the following functions:

- Monitors exhaust gases, the aftertreatment system, and controls engine operating parameters for emission processing and failure recognition
- Cancels regeneration in the event of catalyst or sensor failure
- Monitors the level of soot accumulation in the Diesel Particulate Filter (DPF) and adapts engine operating characteristics to compensate for increased back pressure
- Controls engine operating parameters to make regeneration automatic.
- Maintains vehicle and engine performance during regeneration

Diesel Oxidation Catalyst (DOC)

The DOC does the following:

- Oxidizes hydrocarbons and carbon monoxide (CO)
- Provides heat for exhaust system warm-up
- Aids in system temperature management for the DPF
- Oxidizes NO into NO_2 for passive DPF regeneration

Diesel Particulate Filter (DPF)

The DPF does the following:

- Captures and temporarily stores carbon-based particulates in a filter
- Allows for oxidation (regeneration) of stored particulates once loading gets to a particular level (pressure drop)
- Stores noncombustible ash

Sensors

Sensors produce an electronic signal based on temperature and pressure and are used by the ECM to monitor aftertreatment function and control regeneration.

AFT Conditions and Responses

The operator is alerted audibly or with instrument panel indicators of AFT system status. Automatic or manual regeneration is required when levels of soot exceed acceptable limits. For additional information see the applicable vehicle *Operator's Manual* and the vehicle visor placard.

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Fuel Supply System

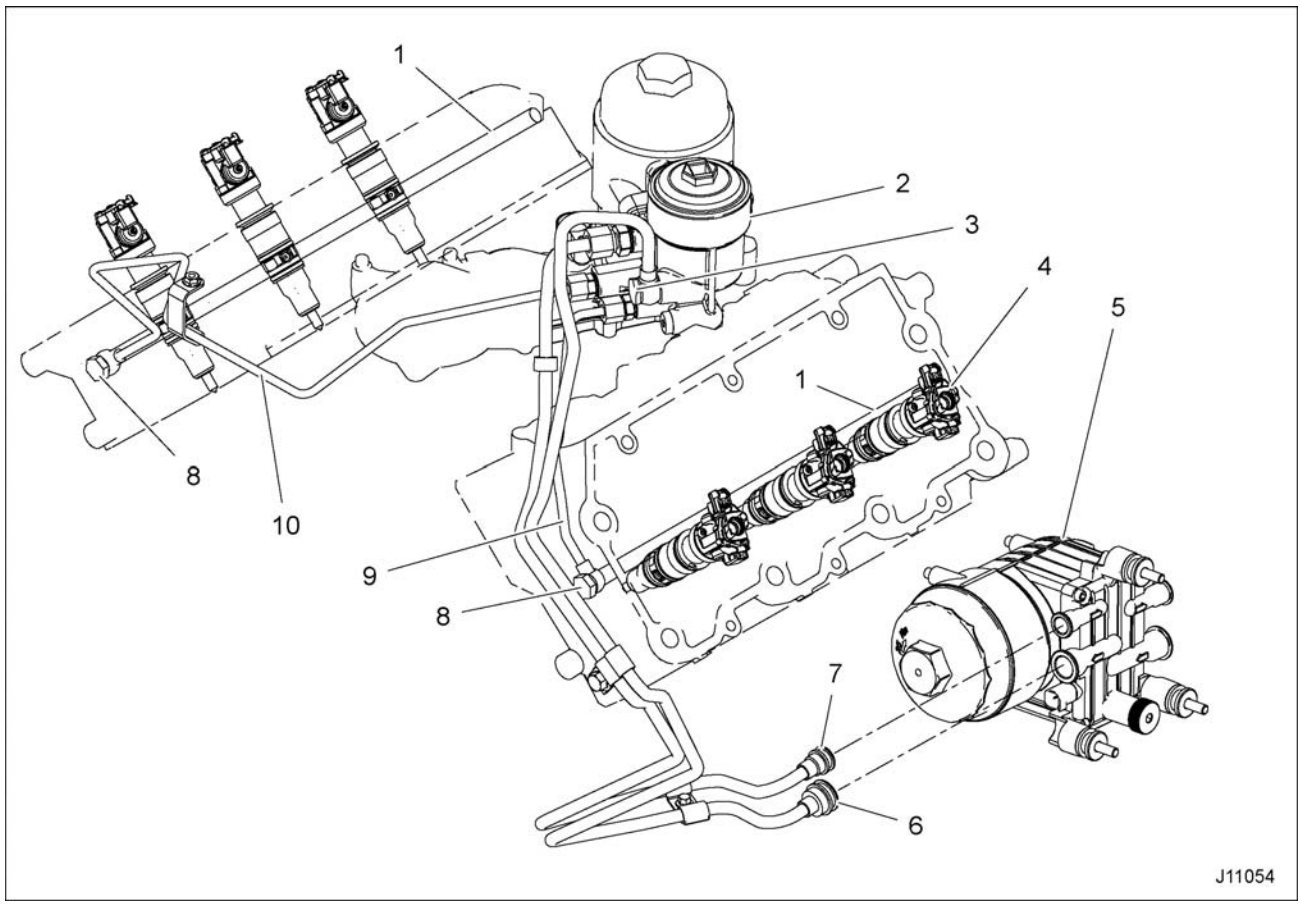

Figure 13 Fuel supply system

1. Drilled passage to fuel injectors (2)
2. Secondary fuel filter assembly
3. Banjo bolt (fuel supply)
4. Fuel injector (6)
5. Horizontal Fuel Conditioning Module (HFCM) (chassis mounted)
6. Fuel line (supply from HFCM)
7. Fuel line (return to HFCM)
8. Banjo bolt with check valve (2)
9. Fuel line (supply left cylinder head)
10. Fuel line (supply right cylinder head)

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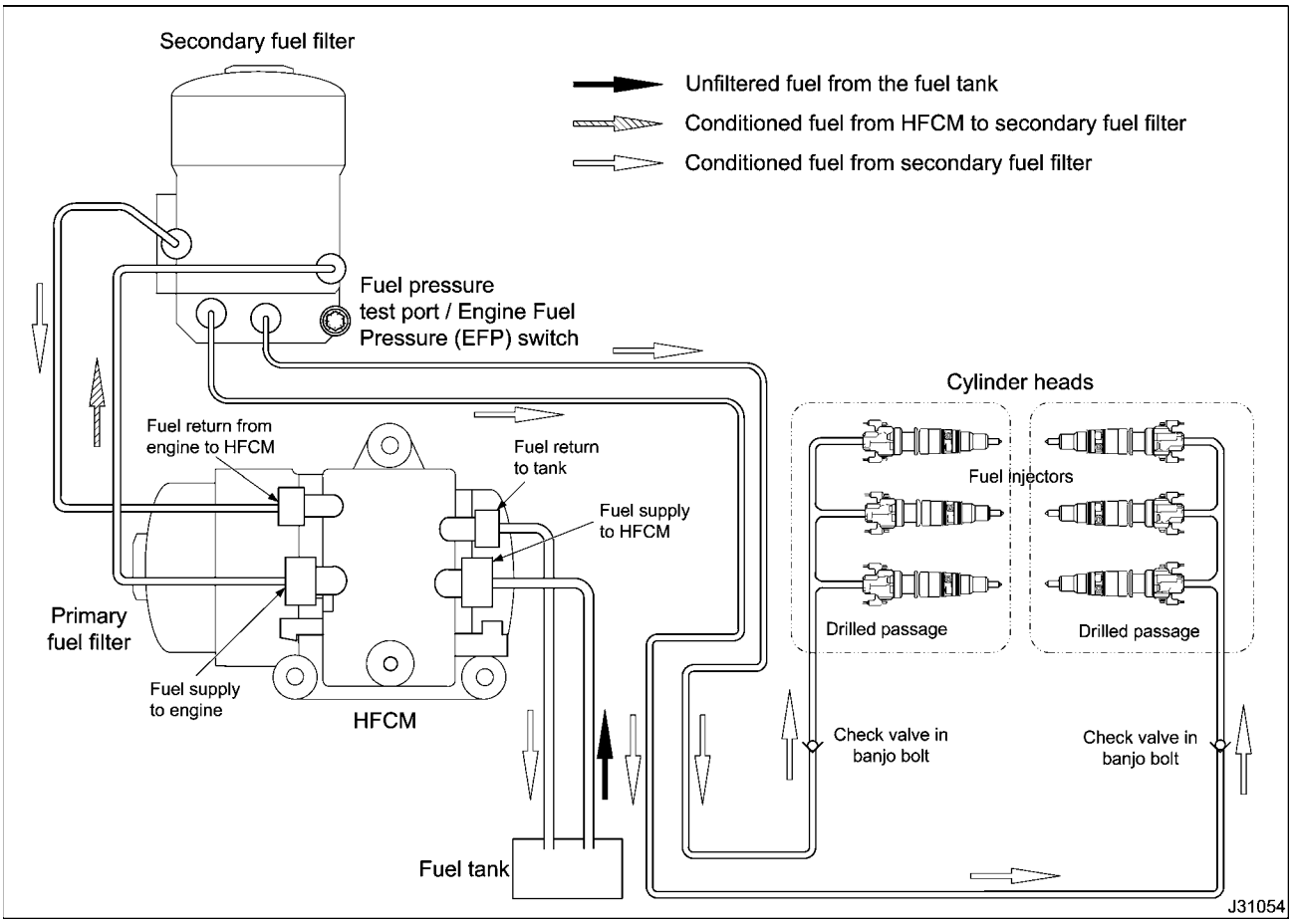

Figure 14 Fuel supply system flow

Fuel Flow

The fuel pump in the HFCM draws fuel through a fuel line from the fuel tank. The HFCM heats, filters, and pressurizes the fuel. Conditioned fuel flows from the HFCM through the supply line to the secondary fuel filter assembly.

The secondary fuel filter assembly conditions, maintains system pressure, and deaerates fuel. Fuel flows through each fuel line and a banjo bolt connecting the fuel line to the cylinder head. Fuel flows through drilled passages in each cylinder head to the fuel injectors. When the fuel injectors are activated, fuel flows into three inlets in each injector. Fuel does not return to the fuel supply system from the injectors or cylinder heads; this is a deadhead fuel system.

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Horizontal Fuel Conditioning Module (HFCM)

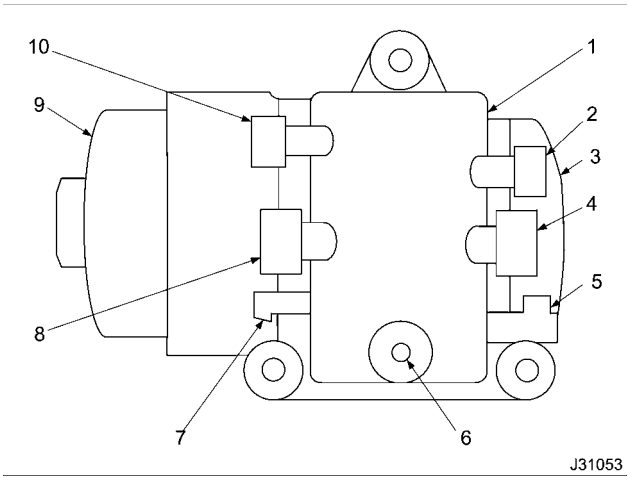

Figure 15 HFCM

1. Cover plate assembly
2. Fuel return to tank
3. Electric fuel pump
4. Fuel supply to HFCM
5. Water In Fuel (WIF) sensor connector
6. Water drain plug
7. Fuel heater connector
8. Fuel supply to engine
9. Primary filter cap
10. Fuel return from secondary filter

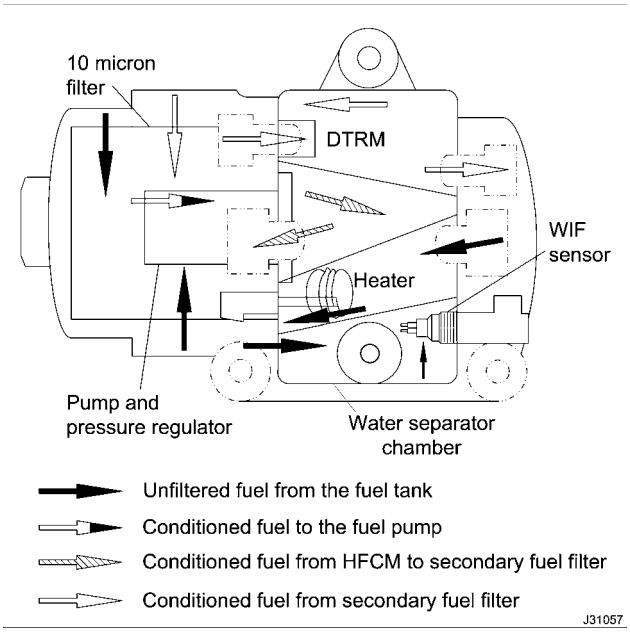

Figure 16 HFCM - fuel flow

The HFCM fuel pump draws fuel from the fuel tank, across an electric fuel heater and through a 10 micron fuel filter. The electric fuel heater is activated when the incoming fuel temperature is below 10 °C (50 °F) and is deactivated when incoming fuel temperature reaches 27 °C (80 °F). A 10 micron fuel filter/water separator separates particles and water from the incoming fuel before reaching the pump. The conditioned fuel is then pumped to the secondary fuel filter assembly. The outlet fuel pressure is controlled by a pressure relief valve located within the fuel pump. When the water separated from the incoming fuel accumulates in the water sump a Water In Fuel (WIF) sensor sends a signal to the Electronic Control Module (ECM) and illuminates the amber WATER IN FUEL lamp.

During cold temperature operation, the Diesel Thermo Recirculation Module (DTRM), located in the HFCM, redirects the warm fuel returned from the secondary fuel filter assembly back into the unfiltered side of the HFCM filter. When the incoming fuel temperature is below 30 °C (85° F), a portion of the return fuel will be redirected into the HFCM to increase the supply fuel temperature. When the incoming fuel temperature reaches 38 °C (100 °F) the DTRM will divert all the return fuel back to the tank.

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Secondary Fuel Filter Assembly

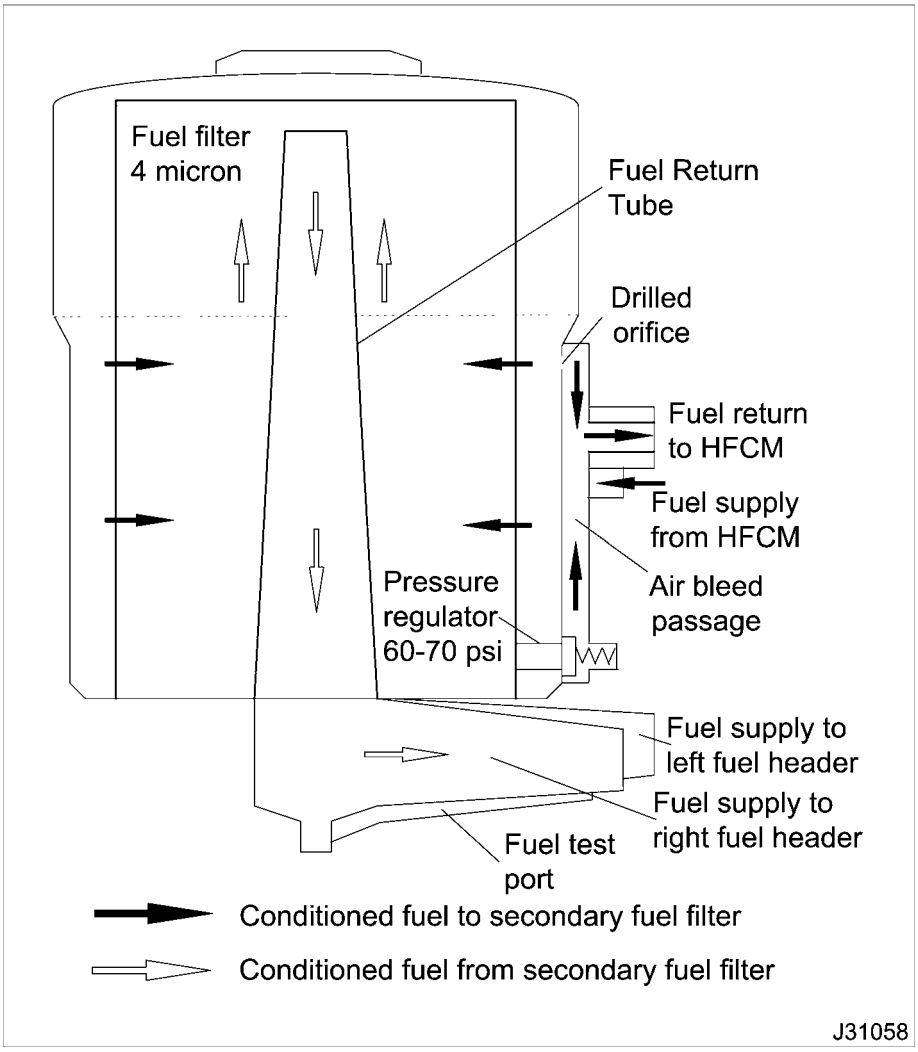

Figure 17 Secondary fuel filter assembly - fuel flow

Conditioned fuel flows through a fuel return tube to the two fuel supply ports to the cylinder heads and the fuel test port.

An orifice is drilled through the side of the secondary fuel filter housing, to the return fuel passage on the side of the secondary fuel filter. Air trapped in the housing is returned through the return fuel passage.

During idle and low engine loads most of the fuel is cycled between the fuel filter housing and HFCM. When engine load increases, engine fuel consumption increases; fuel flows through the filter with little or no cycling.

A banjo bolt, with check valve, connects each fuel line to each cylinder head. The check valve prevents fuel return to the secondary fuel filter and keeps the drilled passages full. Fuel flows through drilled passages to the fuel injectors in each cylinder head. When the fuel injectors are activated, fuel flows into three inlets in each injector. Fuel does not return to the fuel supply system from the injectors; this is a deadhead fuel system.

A four micron filter element in the fuel filter separates particles in the fuel.

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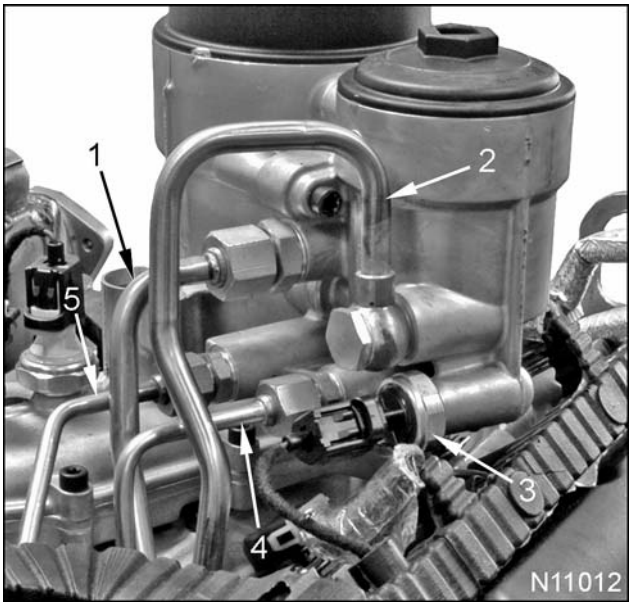

Figure 18 Fuel lines connected to the secondary fuel filter assembly

1. Fuel return to fuel pump
2. Fuel supply from fuel pump
3. Engine Fuel Pressure (EFP) switch
4. Conditioned fuel to left cylinder head
5. Conditioned fuel to right cylinder head

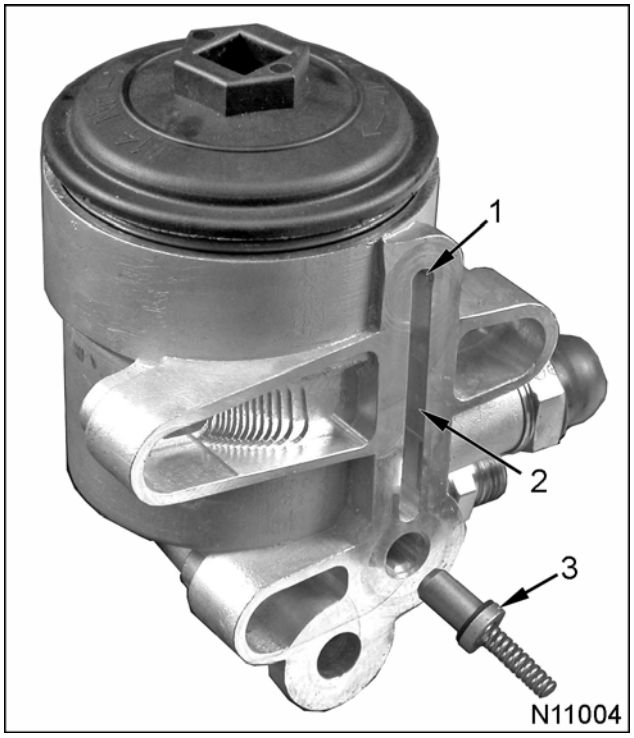

Figure 19 Secondary fuel filter assembly

1. Orifice
2. Return fuel passage
3. Poppet valve (fuel pressure regulator)

The fuel pressure regulator is a spring loaded poppet valve used to regulate and relieve excessive fuel pressure. Fuel passing through the pressure regulator returns to the HFCM.

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Fuel Management System

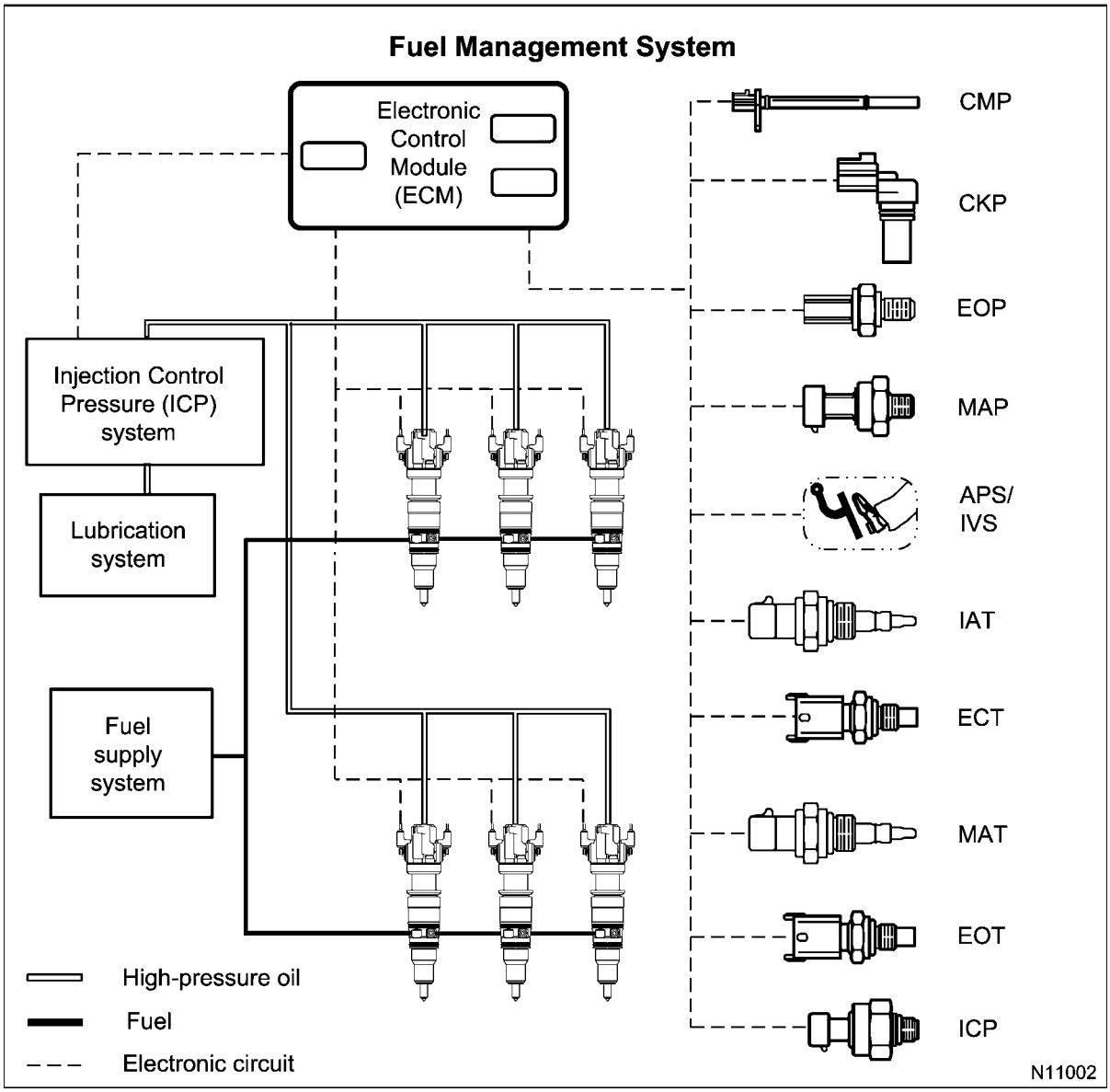

Figure 20 Fuel management system components and sub-systems

The fuel system uses high-pressure oil to increase fuel pressure inside the injectors for high-pressure fuel injection.

The ECM uses sensor input signals to determine timing and quantity of fuel for the injectors. The ECM uses CMP and CKP input signals to calculate engine speed and valve train position.

The ECM distributes current to the injectors and controls engine fueling by sending voltage pulses to the OPEN and CLOSE coils of the injectors. The ECM has a dual output DC to DC converter which supplies current for generating injection pulses. The DC to DC converter boosts ECM input working voltage to a high level voltage (max 50 V) and a low level voltage (max 24 V). The two voltages are used to achieve the peak and hold injector current waveform.

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High-pressure Oil Flow

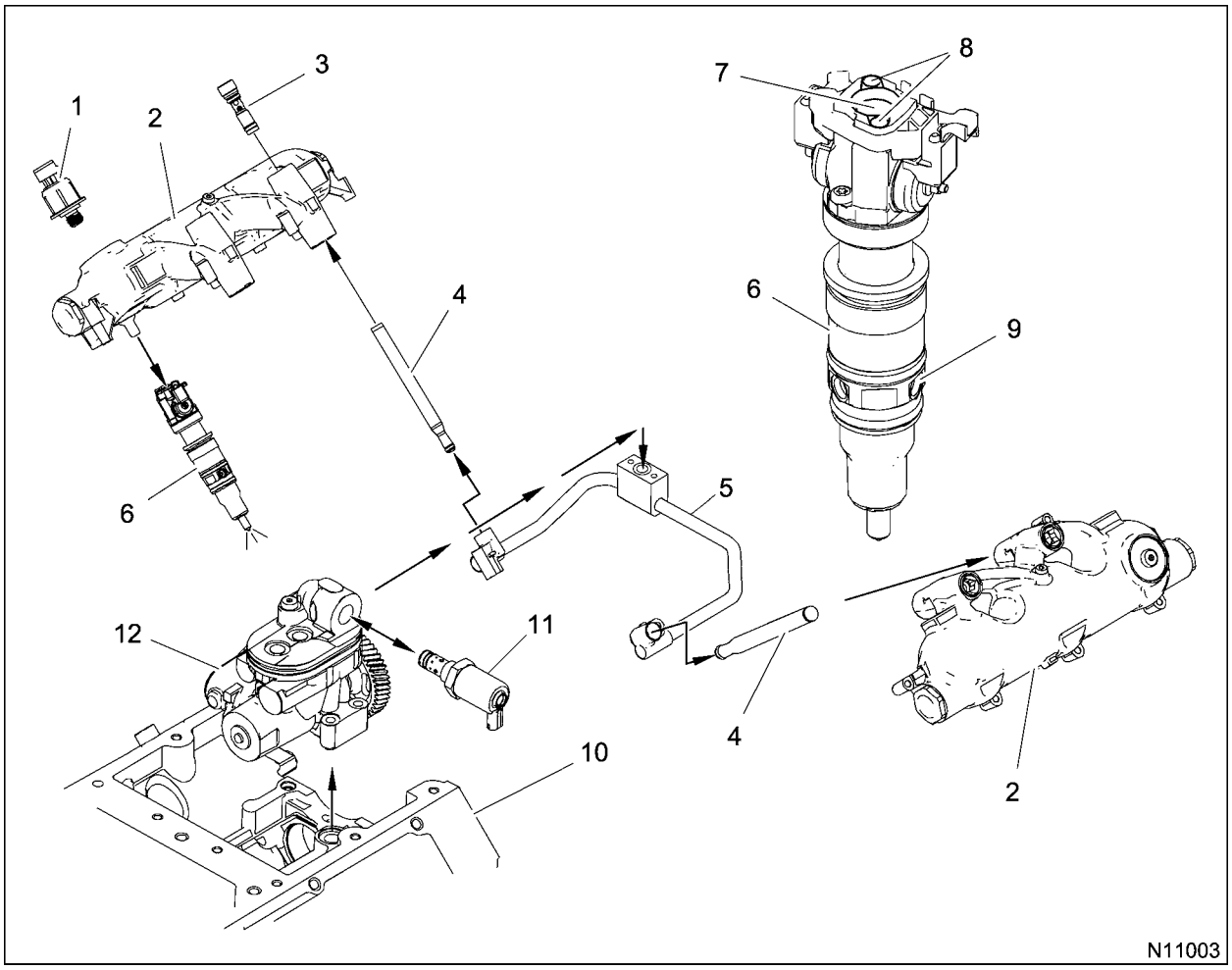

Figure 21 High-pressure oil flow and components

1. Injection Control Pressure (ICP) sensor
2. High-pressure oil rail assembly
3. Case-to-head tube plug (2)
4. Case-to-head tube assembly
5. Branch tube assembly
6. Fuel injector (6)
7. High-pressure oil inlet (injector)
8. Oil exhaust ports
9. Fuel inlet (4)
10. Crankcase
11. Injection Pressure Regulator (IPR) valve
12. High-pressure pump assembly

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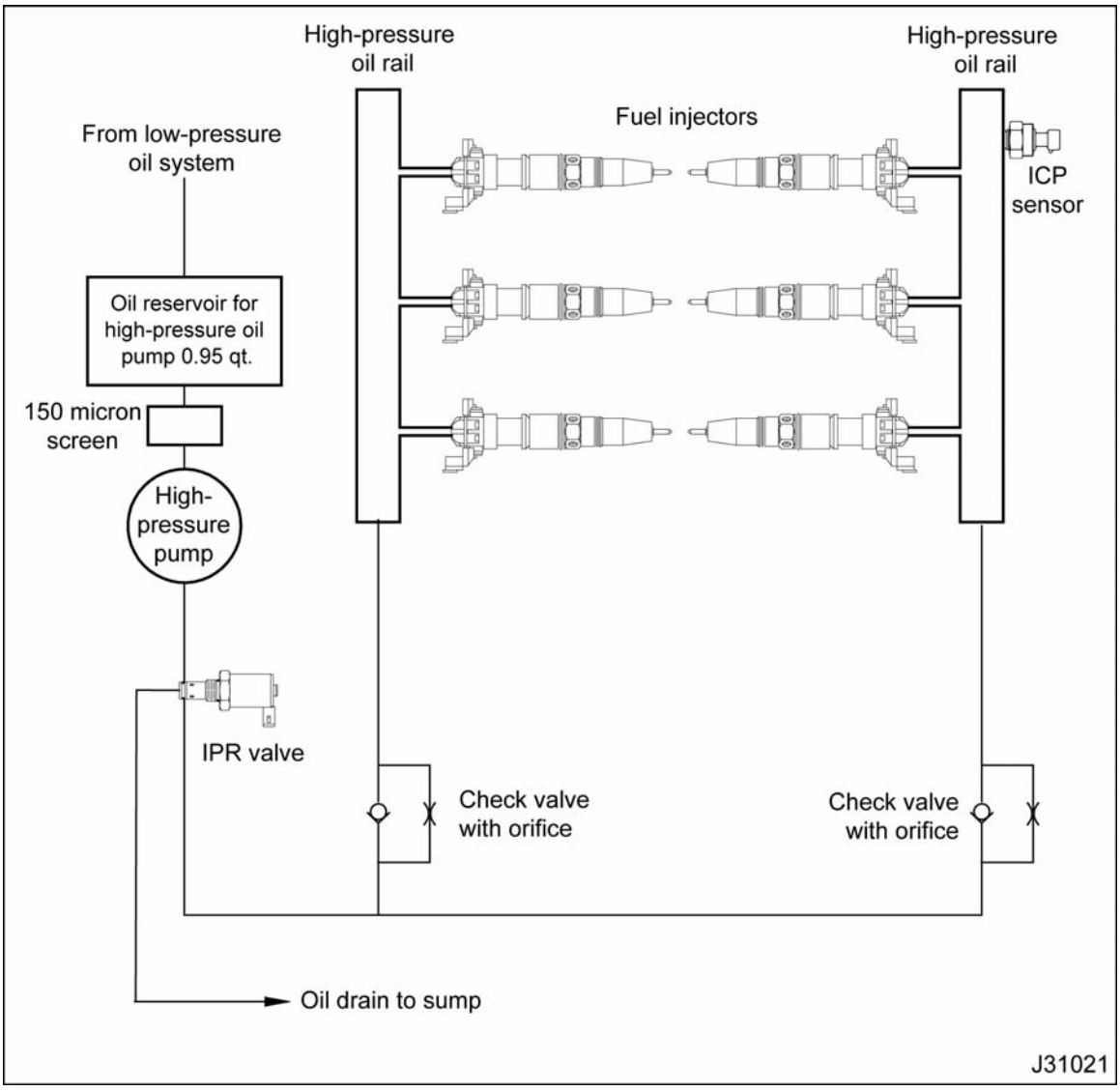

Figure 22 High-pressure oil flow schematic

The lubrication system constantly refills the oil reservoir located in the top of the crankcase below the oil cooler. The reservoir provides oil for the high-pressure oil pump.

A gear-driven, high-pressure oil pump is mounted on the top rear of the crankcase under the turbocharger. The high-pressure oil pump draws oil through a screen from the oil reservoir.

High-pressure oil flows from the high-pressure oil pump to the branch tube assembly, to both case-to-head tube assemblies and then to each high-pressure oil rail. High pressure oil from the high-pressure oil rails enter the fuel injector oil inlet ports in the top of each fuel injector.

High-pressure oil is used by the fuel injectors to pressurize, inject, and atomize fuel in the cylinders. Injection begins when the OPEN coil for each fuel injector is energized. The CLOSE coils are energized to end injection. Injector exhaust oil exits through two outlet ports in the top of each injector and drains back to the oil pan.

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Injection Control Pressure (ICP) System

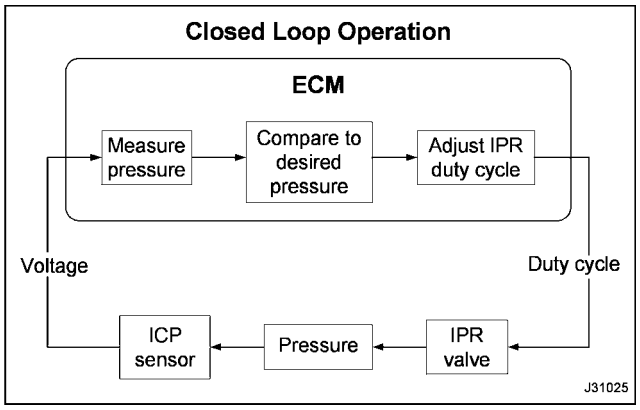

Figure 23 ICP closed loop system

The ICP system is a closed loop system that uses ICP sensor voltage to provide feedback to the Electronic Control Module (ECM). The ECM commands IPR valve duty cycle to open or close to maintain ICP pressure by dumping excess high-pressure oil back to the crankcase sump.

ICP System Control

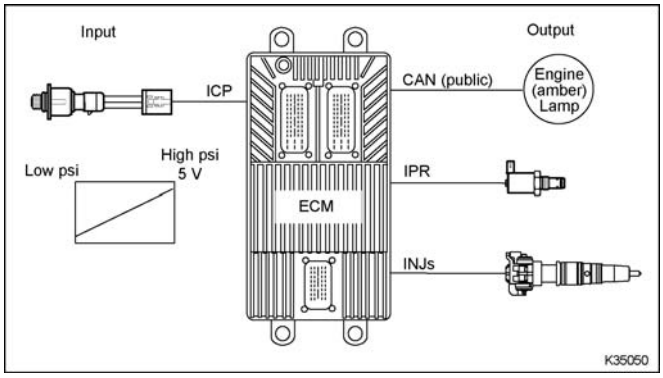

Figure 24 ICP system

The IPR solenoid receives pulse width modulated signals from the ECM to control IPR valve on and off time. The pulse is modulated to control ICP pressure in a range from 4.5 MPa (650 psi) up to 27 MPa (3,920 psi). Maximum pressure relief occurs at about 31 MPa (4,500 psi).

The IPR valve is mounted in the body of the high-pressure oil pump.

As demand for ICP increases, the ECM increases the pulse - width modulation to the IPR solenoid. When ICP demand decreases, the ECM decreases the duty cycle to the solenoid, allowing more oil to flow from the drain orifice.

If the ICP signal is out of range the ECM will set one or more Diagnostic Trouble Code (DTC). The ECM will ignore ICP signals that are out of range and the IPR valve will operate from programmed default values. This is called an Open Loop operation.

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Fuel Injector Assembly

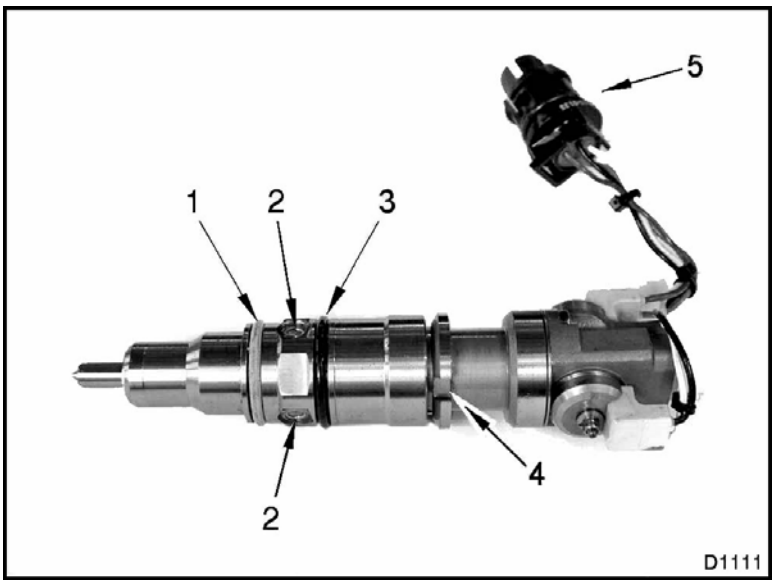

Figure 25 Fuel injector assembly

1. Lower O-ring
2. Fuel inlet screens (3)
3. Upper O-ring
4. Clamp alignment slot
5. Harness connector

Fuel Injector Features

Two 48 volt, 20 amp coils control a spool valve that directs oil flow in and out of the injector. The injector coils are turned on for approximately 800 µs (microseconds). Each injector has a single four pin connector that couples to the engine sensor wiring harness through the rocker arm carrier.

Injector Coils and Spool Valve

An OPEN coil and a CLOSE coil on the injector move the spool valve from side to side using magnetic force. The spool has two positions:

- When the spool valve is open, oil flows into the injector from the high-pressure oil manifold.
- When the spool valve is closed, oil exits from the top of the fuel injector and drains back to the oil pan.

Intensifier Piston and Plunger

When the spool valve opens, high-pressure oil enters the injector and pushes down the intensifier piston and plunger. The intensifier piston is 7.1 times greater in area than the plunger so, injection pressure is 7.1 times greater than injection control pressure.

Plunger and Barrel

Fuel pressure builds at the base of the plunger in the barrel. When the intensifier piston pushes the plunger down, the plunger increases fuel pressure in the barrel 7.1 times greater than injection control pressure. The plunger has a hardened coating to resist scuffing.

Injector Needle

The injector needle opens inward when fuel pressure overcomes the Valve Opening Pressure (VOP) of 20 MPa (2,900 psi). Fuel is atomized at high-pressure through the nozzle tip.

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Fuel Injector Operation

Injector operation has three stages:

- Fill
- Injection
- End of injection

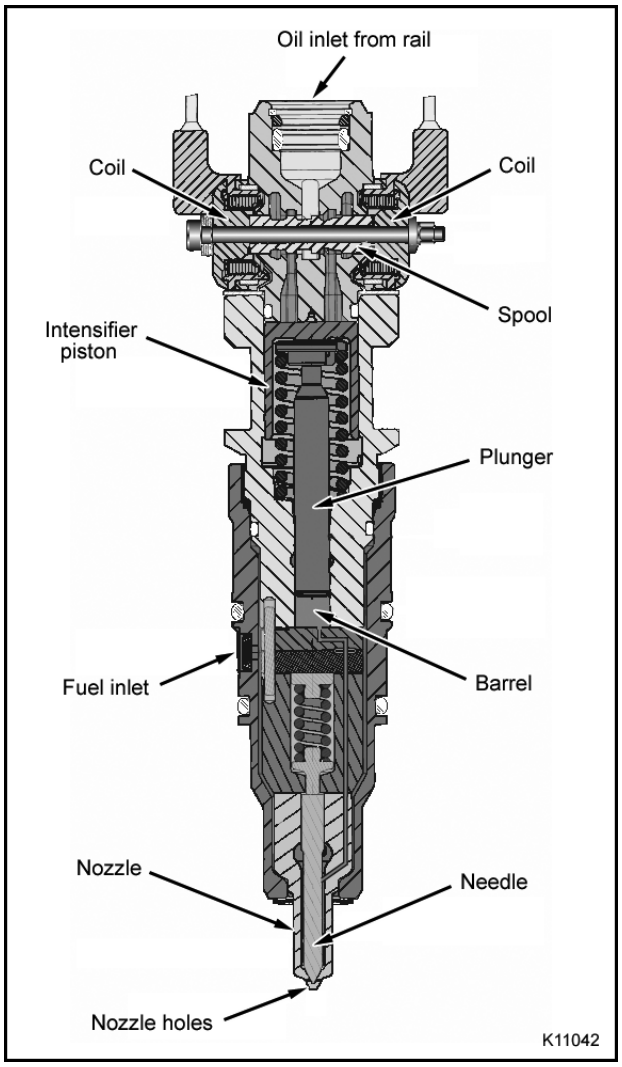

Figure 26 Fuel injector cross section

Fill

During Fill, both coils are de-energized and the spool valve is closed. High-pressure oil from the high-pressure oil manifold is stopped at the spool valve.

Low-pressure fuel fills the three ports and enters through the fuel inlet screens on its way to the chamber beneath the plunger. The needle control spring holds the needle onto its seat to prevent fuel from entering the combustion chamber.

Injection

1. A pulse-width controlled current energizes the OPEN coil. Magnetic force moves the spool valve open. High-pressure oil flows past the spool valve and onto the top of the intensifier piston. Oil pressure overcomes the force of the intensifier piston spring and the intensifier starts to move down. An increase in fuel pressure under the plunger seats the fuel inlet check ball, and fuel pressure starts to build on the needle.
2. The pulse-width controlled current to the OPEN coil is shut off, but the spool valve remains open. High-pressure oil from high-pressure oil manifold continues to flow past the spool valve. The intensifier piston and plunger continue to move and fuel pressure increases in the barrel. When fuel pressure rises above Valve Opening Pressure (VOP), the needle lifts off its seat and injection begins.

End of Injection

1. When the ECM determines the correct injector on-time has been reached (the correct amount of fuel has been delivered), the ECM sends a pulse-width controlled current to the CLOSE coil of the injector. The current energizes the CLOSE coil and magnetic force closes the spool valve. High-pressure oil is stopped against the spool valve.
2. The pulse-width controlled current to close the coil is shut off, but the spool valve remains closed. Oil above the intensifier piston flows past the spool valve through the exhaust ports. The intensifier piston and plunger return to their initial positions. Fuel pressure decreases until the needle control spring forces the needle back onto its seat.

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Engine Lubrication System

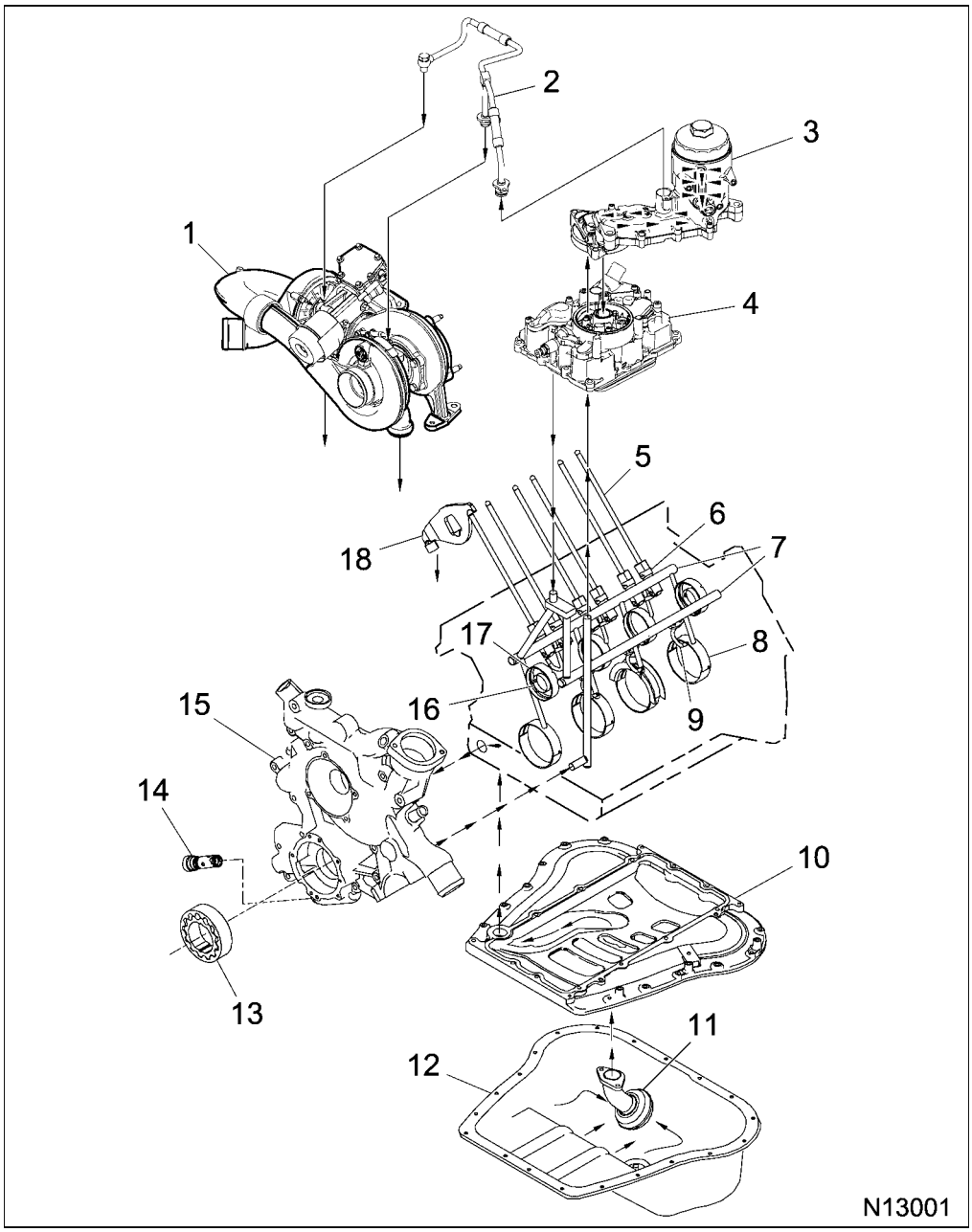

Figure 27 Lubrication system

1. Dual stage turbocharger assembly
2. Turbocharger oil supply line
3. Oil filter assembly
4. Oil cooler assembly
5. Push rod (12)
6. Hydraulic roller follower (12)
7. Oil galleries
8. Crankshaft main bearing (4)
9. Piston cooling tube (6)
10. Upper oil pan
11. Oil pickup tube
12. Oil pan
13. Rotor assembly (gerotor oil pump)
14. Oil pressure regulator
15. Front cover
16. Primary balancer shaft bushing (2) (inside camshaft)
17. Camshaft bushing (4)
18. Rocker arm assembly (12)

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Oil Flow Diagram

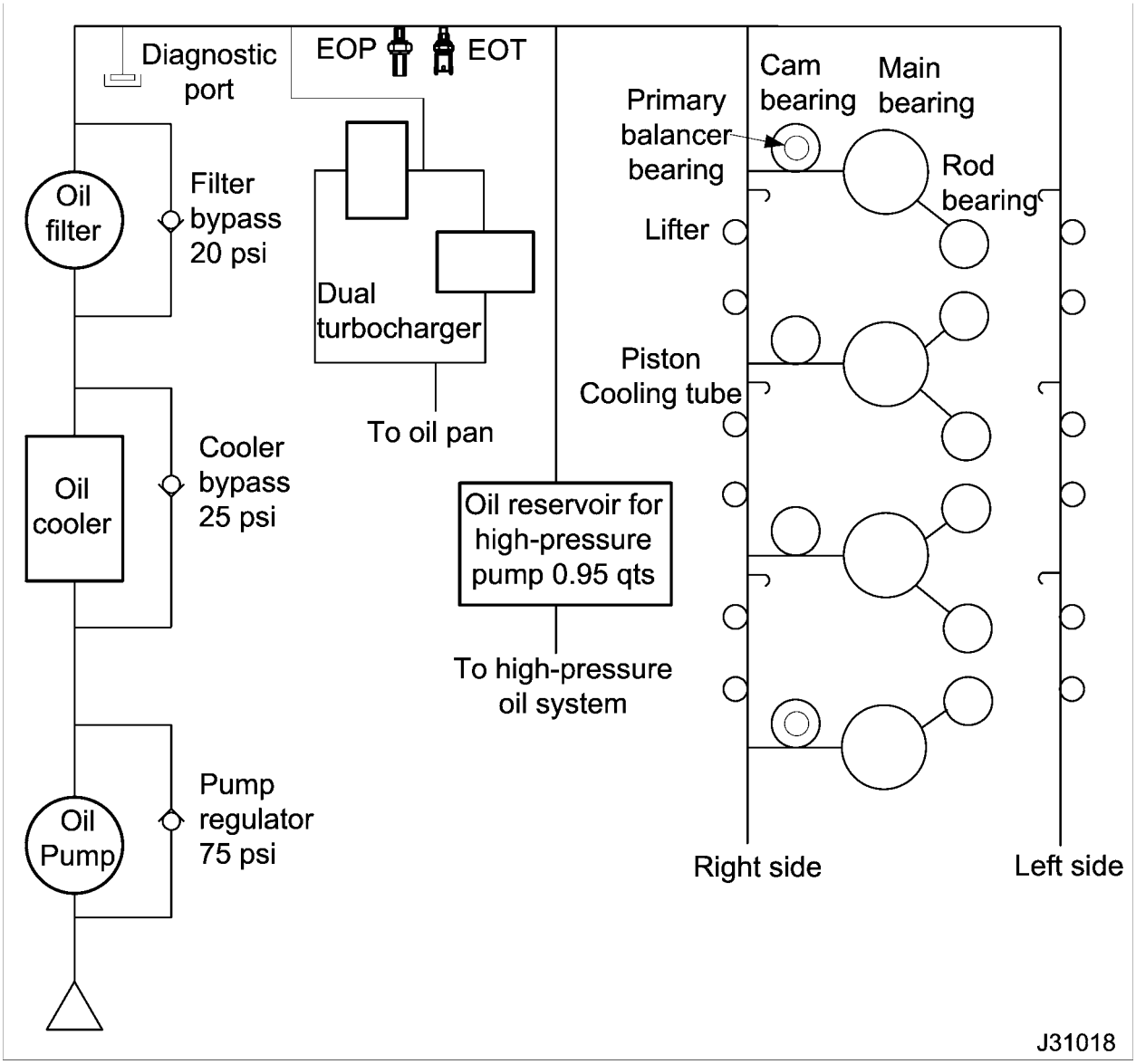

Figure 28 Lubrication system schematic

A gerotor oil pump draws oil from the oil pan through an oil pickup tube bolted to the upper oil pan. Oil flows through passages in the upper oil pan, in the lower crankcase, and in the front cover to the oil pump. The oil pump includes the front cover assembly, rotor assembly (inner and outer gears), and the gerotor housing cover. The crankshaft drives the inner rotor gear of the gerotor pump. Discharge oil flows through a passage in the front cover through the regulator valve to the gerotor pump suction.

The Electronic Control Module (ECM) monitors Engine Oil Pressure (EOP) switch and Engine Oil Temperature (EOT) sensor signals.

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Oil Cooler and Filter Assemblies

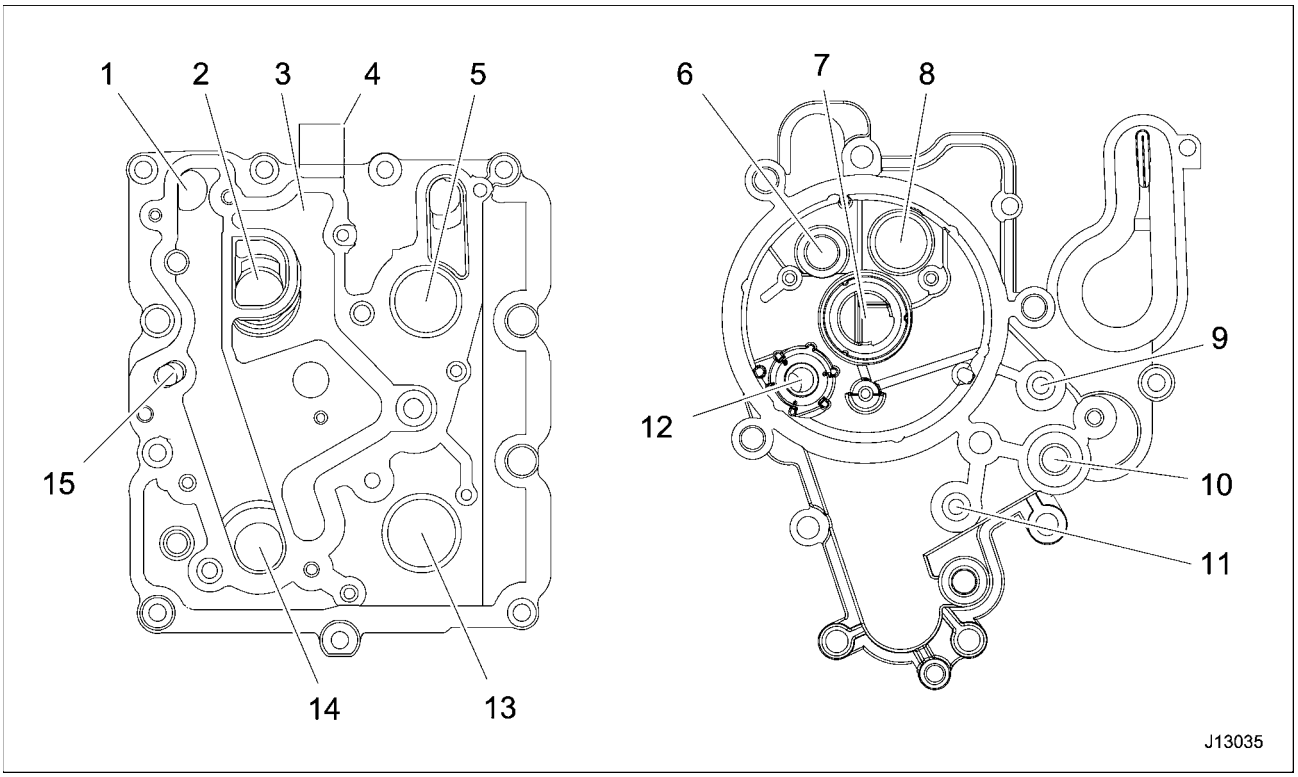

Figure 29 Oil cooler cover and oil filter base

1. Unfiltered oil flow from pump
2. Oil cooler outlet (oil)
3. Filtered oil to reservoir
4. Oil pressure test port fitting
5. Coolant inlet
6. Oil cooler bypass valve
7. Filtered oil to crankcase galleries
8. Unfiltered oil inlet
9. Oil temperature sensor port
10. Turbocharger oil supply port
11. Oil pressure sensor port
12. Oil filter drain to sump
13. Coolant outlet
14. Oil cooler inlet (oil)
15. Oil drain to sump

Pressurized oil from the oil pump flows through a passage in the front cover, through a passage in the upper crankcase, to the oil cooler cover. Passages in the oil cooler cover direct lube oil and coolant. Oil flows through plates in the oil cooler from the back to the front, cools, and flows back to the oil cooler cover.

If the oil cooler is restricted, a bypass valve in the oil filter base opens, oil bypasses the oil cooler, and flows to the oil filter base.

Oil flows through the oil filter base to the oil filter element outside to inside, up the outside of the filter stand pipe and down the inside of the stand pipe, and back to the oil filter base. If the oil filter element is restricted, a bypass valve in the oil filter return line opens, oil bypasses the oil filter element, and flows to the oil filter base.

Both bypass valves ensure full flow of oil to the engine, if the filter or cooler is restricted.

The oil filter base directs filtered oil to the turbocharger oil supply tube, EOP switch, EOT sensor, diagnostic port, and to the oil cooler cover. Lubricating oil from the turbocharger drains back to the oil pan through the high-pressure oil pump cover.

When the oil filter is removed, oil flows from a drain valve in the oil filter base back to the oil pan.

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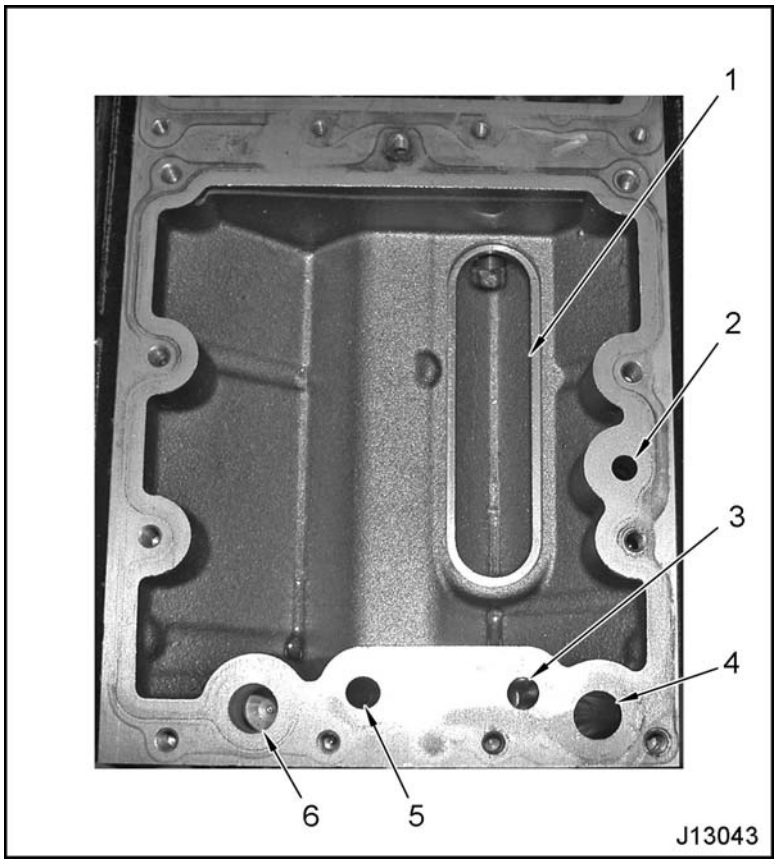

Figure 30 Oil reservoir in crankcase

1. Oil feed to high-pressure oil pump
2. Oil filter drain to pan
3. Oil feed to left side of main lube oil gallery
4. Oil feed to oil cooler cover
5. Oil feed to right side of main lube oil gallery
6. Coolant feed to oil cooler

The oil cooler cover and oil cooler base direct filtered oil in three ways:

- One passage supplies oil to the reservoir in the crankcase for the high-pressure oil pump and ICP system. A screen in the oil reservoir catches debris before oil goes to the high-pressure oil pump.
- One passage supplies filtered oil to the left side for the main lube oil gallery, push rod and rocker arms, piston cooling tubes, and lifters.
- One passage supplies filtered oil to the right side for the main lube oil gallery, push rods and rocker arms, piston cooling tubes, camshaft bushings, crankshaft main bearings, connecting rod bearings, primary balancer shaft bushings, and lifters.

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Cooling System

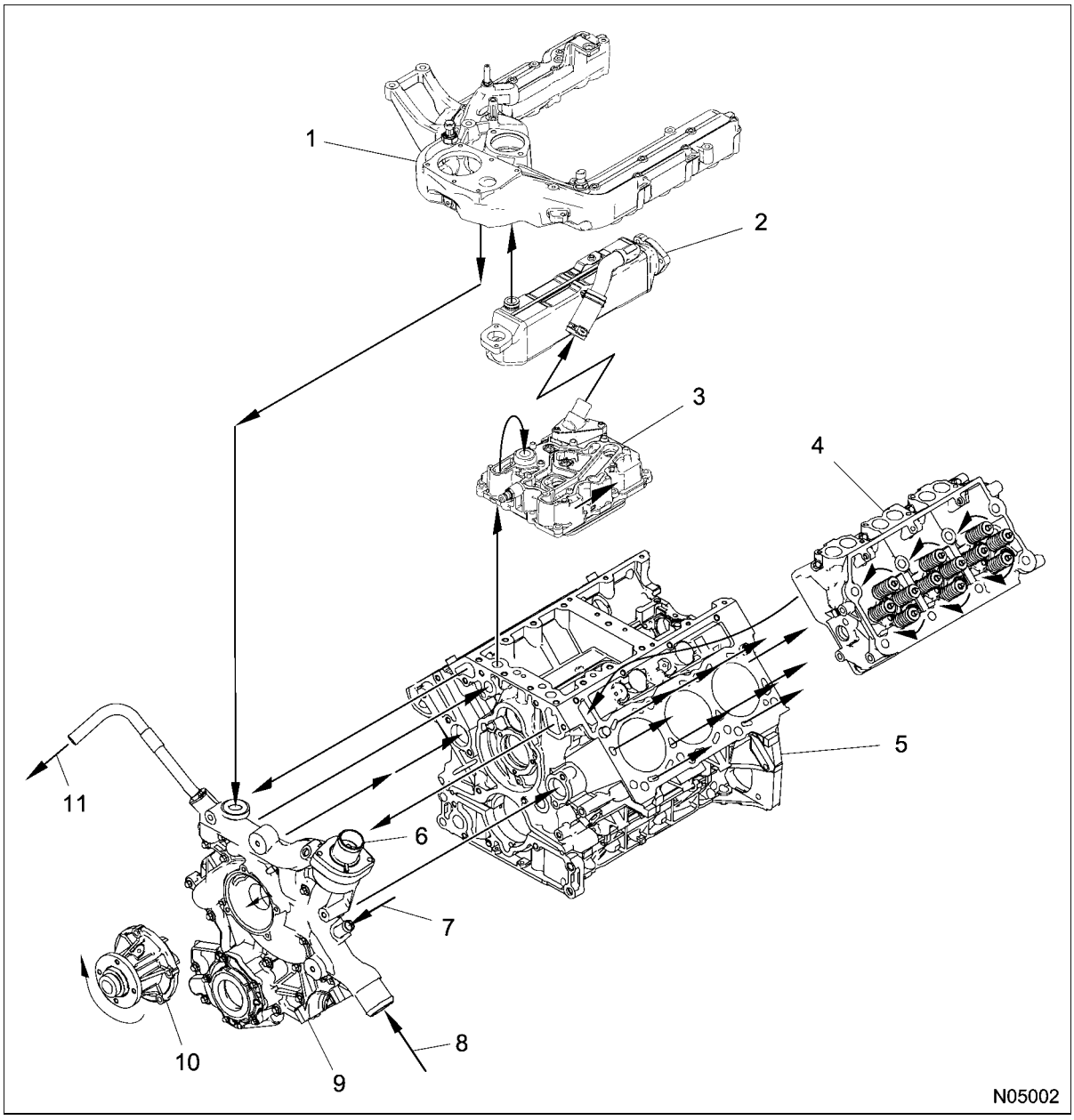

Figure 31 Cooling system components and flow

1. Intake manifold
2. EGR cooler assembly
3. Oil cooler
4. Cylinder head (2)
5. Crankcase
6. Thermostat assembly (coolant outlet to radiator)
7. Coolant return (from heater)
8. Coolant inlet (from radiator)
9. Front cover assembly
10. Water pump assembly
11. Coolant supply (to heater)

The cooling system circulates coolant to keep the engine within a designated temperature range. A centrifugal water pump (hub and impeller) is mounted in the pump housing of the front cover.

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Front Cover Coolant Flow

The water pump draws coolant from the radiator through the front cover coolant inlet. Coolant flows from the water pump through three passages in the front cover. Two passages (left and right) direct coolant into the crankcase coolant jackets (front to rear) to cool the cylinder walls and the cylinder heads. The third passage directs coolant through a passage in the crankcase to the oil cooler cover.

NOTE: If an oil cooler seal is damaged, weep holes in the oil filter base allow coolant to seep from the cooler cover.

Coolant returns through three front cover passages. Returned coolant is directed to the thermostat by the front cover. If the engine has reached operating temperature and the thermostat is open, coolant flows to the radiator to be cooled. If the thermostat is closed, coolant is returned to the water pump through a bypass passage in the front cover.

Crankcase and Cylinder Head Coolant Flow

Coolant flows through passages in the front cover to the left and right sides of the crankcase. Coolant flows through the front of both sides of the crankcase, evenly distributing coolant around the cylinders, and exits the crankcase flowing up to the cylinder heads.

Coolant flows from the rear of the cylinder heads to the front, exits down a passage in the crankcase, and returns to the front cover.

For increased performance in cold weather, an optional power cord can be connected to the coolant heater installed in the crankcase.

Oil Cooler and EGR Cooler Coolant Flow

The front cover directs coolant to passages in the crankcase. Coolant flows from the crankcase to the front of the oil cooler cover. The oil cooler and the oil filter base direct coolant to the front of the oil cooler. Coolant flows through the oil cooler from the front to rear and exits through the EGR cooler supply tube.

Coolant flows from the rear of the EGR cooler to the front returning to the front cover though a passage in the intake manifold.

A deaeration port is on top of the intake manifold.

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Thermostat Operation

The thermostat has two outlets. One directs coolant to the radiator when the engine is at operating temperature. The other directs coolant to the water pump until the engine reaches operating temperature. The thermostat begins to open at 89 °C (192 °F) and is fully open at 104 °C (219 °F).

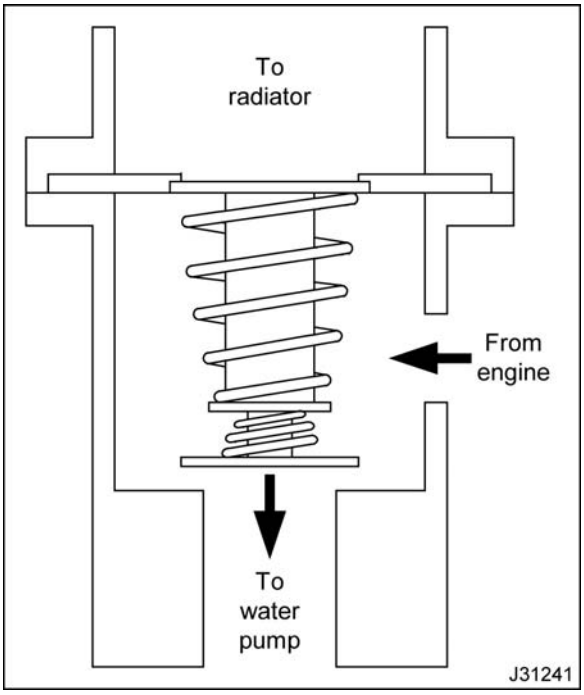

Figure 32 Coolant flow - thermostat closed

When engine coolant is below operating temperature the thermostat is closed, blocking flow to the radiator. Coolant is forced through a bypass port back to the water pump.

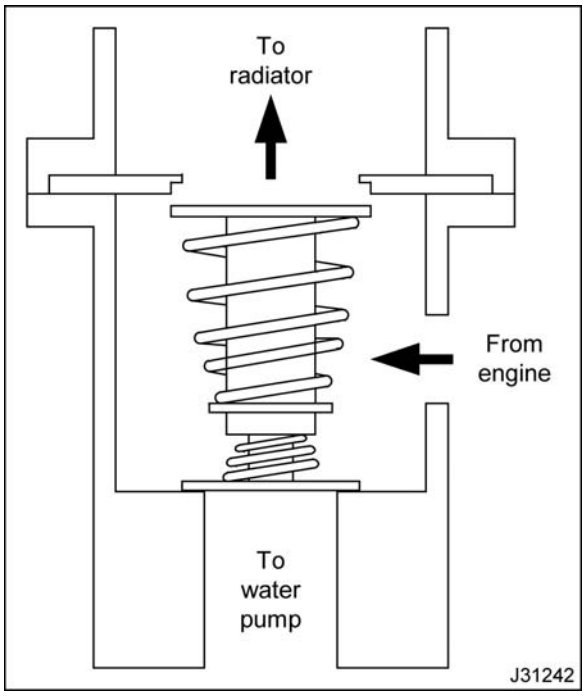

Figure 33 Coolant flow - thermostat open

As coolant temperature reaches opening temperature the thermostat starts to open allowing some coolant to flow to the radiator. When coolant temperature reaches operating temperature, the lower seat blocks the water pump port directing full coolant flow to the radiator.

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Electronic Control System

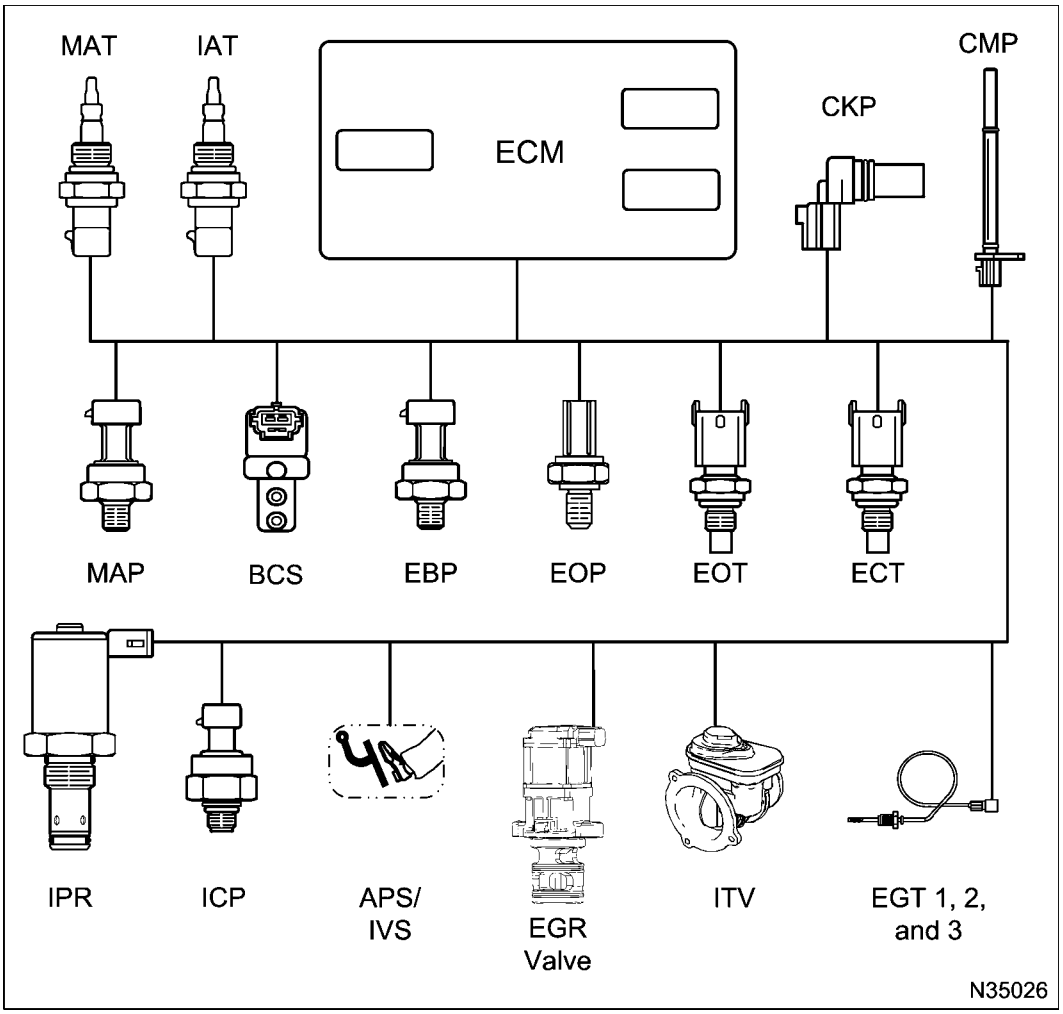

Figure 34 Electronic Control System components

Table 3 The Electronic Control System includes the following:

Electronic Control Module (ECM)	Engine Oil Temperature (EOT) sensor
Manifold Air Temperature (MAT) sensor	Engine Coolant Temperature (ECT) sensor
Intake Air Temperature (IAT) sensor	Injection Pressure Regulator (IPR) valve
Crankshaft Position (CKP) sensor	Injection Control Pressure (ICP) sensor
Camshaft Position (CMP) sensor	Accelerator Pedal Position Sensor and Idle Validation Switch (APS/IVS)
Manifold Absolute Pressure (MAP) sensor	Exhaust Gas Recirculation (EGR) valve
Boost Control Solenoid (BCS)	Intake Throttle Valve (ITV) assembly
Exhaust Back Pressure (EBP) sensor	Exhaust Gas Temperature (EGT) sensors
Engine Oil Pressure (EOP) sensor	

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Electronic Control System Operation and Function

The Electronic Control Module (ECM) monitors sensor input signals and controls engine performance with actuators and relays to ensure maximum performance while adhering to emissions standards. The ECM also has an internal barometric air pressure sensor which measures atmospheric pressure to compensate for changes in elevation.

The ECM has four primary functions:

- Provides Reference Voltage (VREF)
- Conditions input signals
- Processes and stores control strategies
- Controls actuators

Reference Voltage (VREF)

The ECM supplies a 5 volt VREF signal to input sensors in the electronic control system. By comparing the 5 volt VREF signal sent to the sensors with their respective returned signals, the ECM determines pressures, positions, and other variables.

The ECM supplies two independent circuits for VREF:

- VREF A supplies 5 volts to engine sensors
- VREF B supplies 5 volts to vehicle sensors

Signal Conditioner

A signal conditioner in the ECM converts analog signals to digital signals, squares up sine wave signals, or amplifies low intensity signals.

Microprocessor

The ECM microprocessor stores operating instructions (control strategies) and value tables (calibration parameters). The ECM compares stored instructions and values with conditioned input values to determine the correct operating strategy for all engine operations.

Continuous calculations in the ECM occur at two different levels or speeds: Foreground and Background.

- Foreground calculations are faster than background calculations and are critical for engine operation. Engine speed control is an example.
- Background calculations are variables that change at slower rates. Engine temperature is an example.

Diagnostic strategies are also programmed into the ECM. Some strategies monitor inputs continuously and command the necessary outputs for correct performance of the engine. If inputs or conditions are not within expected values, the microprocessor sets a Diagnostic Trouble Code (DTC).

The ECM microprocessor includes Read Only Memory (ROM) and Random Access Memory (RAM).

ROM stores permanent information for calibration tables and operating strategies. Permanently stored information cannot be changed or lost by turning the ignition switch OFF or when ECM power is interrupted. ROM includes the following:

- Vehicle configuration, modes of operation, and options
- Engine Family Rating Code (EFRC)
- Engine warning and protection modes

RAM stores temporary information for current engine conditions. Temporary information in RAM is lost when the ignition switch is turned to OFF or when ECM power is interrupted. RAM information includes the following:

- Engine temperature
- Engine rpm
- Accelerator pedal position

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Actuators

The ECM controls engine operation with the following:

- Intake Air Heater (IAH) relay
- Glow plug relay
- Fuel pump relay
- Injection Pressure Regulator (IPR) valve
- Boost Control Solenoid (BCS)
- Exhaust Gas Recirculation (EGR) valve
- Intake Throttle Valve (ITV) assembly

Actuators are controlled in the following ways:

- Switched on or off
- Pulse Width Modulation (PWM)
- Controller Area Network (CAN) digital signals
- Duty cycle (percent time on/off)

The ECM controls actuators by applying a low level signal (low side driver) or a high level signal (high side driver). When switched on, both drivers complete a ground or power circuit to an actuator.

Intake Air Heater (IAH) Relay

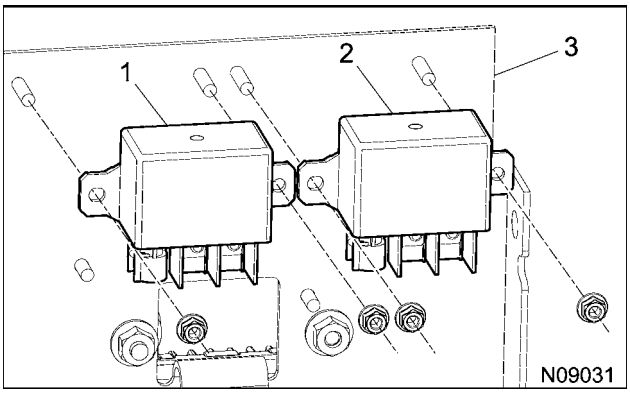

Figure 35 IAH and glow plug relays

1. Glow plug relay
2. IAH relay
3. ECM bracket

The IAH heats incoming air to aid cold starting and engine performance.

The ECM controls the IAH relay by switching on a voltage source. The relay delivers VREF to the Intake Air Heater for up to 30 seconds KOEO, depending on Engine Oil Temperature and altitude. Ground is supplied through pin–1 of the 16–pin connector to battery ground at all times. After the engine starts the IAH can stay on up to 30 minutes in cold conditions.

Glow Plug Relay

The glow plug system heats the engine cylinders to aid cold engine starting and to reduce exhaust emissions during warm-up.

The ECM controls the glow plug relay by switching on a voltage source. The relay delivers VREF to the glow plugs for up to 120 seconds, depending on engine coolant temperature and atmospheric pressure. Ground is supplied through pin–1 of the 16–pin connector to battery ground at all times.

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Fuel Pump Relay

The fuel pump is installed inside the Horizontal Fuel Conditioning Module (HFCM). Power to the fuel pump is supplied through the fuel pump relay.

The ECM controls the fuel pump relay by switching on a voltage source.

Injection Pressure Regulator (IPR) Valve

The IPR valve releases excess high-pressure oil to regulate Injection Control Pressure (ICP).

The ECM controls the IPR valve with Pulse Width Modulation (PWM) signals in response to ICP sensor input.

Boost Control Solenoid (BCS)

The BSC assembly is a two position valve that controls intake manifold boost pressure to the turbocharger pneumatic actuator. The pneumatic actuator controls the turbocharger bypass valve and turbocharger boost pressure.

The ECM controls the BCS by setting its duty cycle to 100% or 0%.

Exhaust Gas Recirculation (EGR) Valve

The EGR valve controls the flow of cooled exhaust gases into the intake air stream to reduce NOx emissions by reducing combustion temperatures.

The EGR valve changes valve position in response to private Controller Area Network (CAN) digital signals from the ECM.

Intake Throttle Valve (ITV) Assembly

The ITV assembly restricts inlet air flow to control air/fuel ratio and increase exhaust temperature during aftertreatment regeneration. The ITV also restricts air flow for engine shutdowns due to Engine Warning and Protection System (EWPS) or Idle Shutdown Timer (IST) features, where the engine is shut-off without turning the key-off.

The ECM controls the ITV with Pulse Width Modulation (PWM) signals through H-bridge circuitry. The ITV contains an integral position sensor which monitors valve position and sends a position signal to the ECM.

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Sensors and Switches

Thermistor Sensors

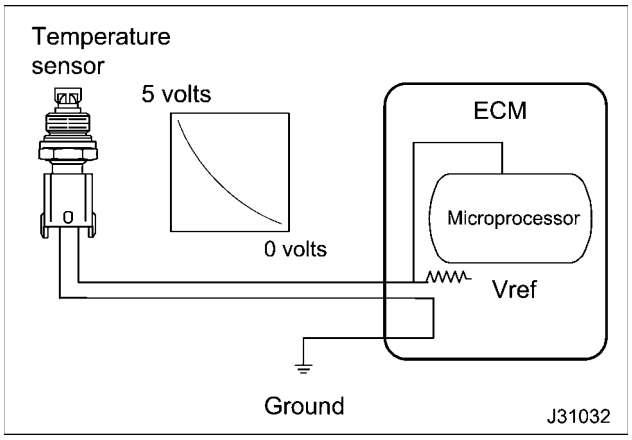

Figure 36 Thermistor

Thermistor sensors:

- Engine Oil Temperature (EOT)
- Engine Coolant Temperature (ECT)
- Manifold Air Temperature (MAT)
- Intake Air Temperature (IAT)
- Exhaust Gas Temperature (EGT)

Thermistor sensors change electrical resistance with changes in temperature. Resistance in the thermistor decreases as temperature increases, and increases as temperature decreases. Thermistors work with a resistor that limits current in the ECM to form a voltage signal matched with a temperature value.

The top half of the voltage divider is the current limiting resistor inside the ECM. Thermistor sensors have two electrical connectors, signal return and ground. The output of a thermistor sensor is a nonlinear analog signal.

Engine Oil Temperature (EOT) Sensor

The ECM monitors the EOT signal to control fuel quantity and inlet air heater operation. The EOT signal allows the ECM to compensate for differences in oil viscosity as oil temperature changes. The EOT sensor is installed in the oil filter base.

Engine Coolant Temperature (ECT) Sensor

The ECM monitors the ECT signal and uses this information for the instrument panel temperature gauge, coolant compensation, Engine Warning Protection System (EWPS), and glow plug operation. The ECM will use ECT sensor input as a backup, if EOT sensor values are out of range. The ECT sensor is installed in the left side of the front cover assembly.

Manifold Air Temperature (MAT) Sensor

The ECM monitors the MAT signal for EGR operation. The MAT sensor is installed in the left side of the intake manifold.

Intake Air Temperature (IAT) Sensor

The ECM monitors the IAT signal to control fuel timing and rate during cold starts. The IAT sensor is mounted in the turbocharger air intake, between the inlet of the turbocharger and the air filter.

Exhaust Gas Temperature (EGT) Sensors

Three EGT sensors are used in the aftertreatment system.

The EGT1 sensor provides a signal to the ECM indicating Diesel Oxidation Catalyst (DOC) inlet temperature. The EGT1 sensor is the first temperature sensor installed past the turbocharger and just before the DOC.

The EGT2 sensor provides a feedback signal to the ECM indicating Diesel Particulate Filter (DPF) inlet temperature. The EGT2 sensor is the second temperature sensor installed past the turbocharger and just after the DOC.

The EGT3 sensor provides a feedback signal to the ECM indicating DPF outlet temperature. The EGT3 sensor is the third temperature sensor installed past the turbocharger and just after the DPF.

During catalyst regeneration, the ECM monitors all three EGT sensors and adjusts the Intake Throttle Valve (ITV) and Exhaust Gas Recirculation (EGR) valve as needed.

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Variable Capacitance Sensors

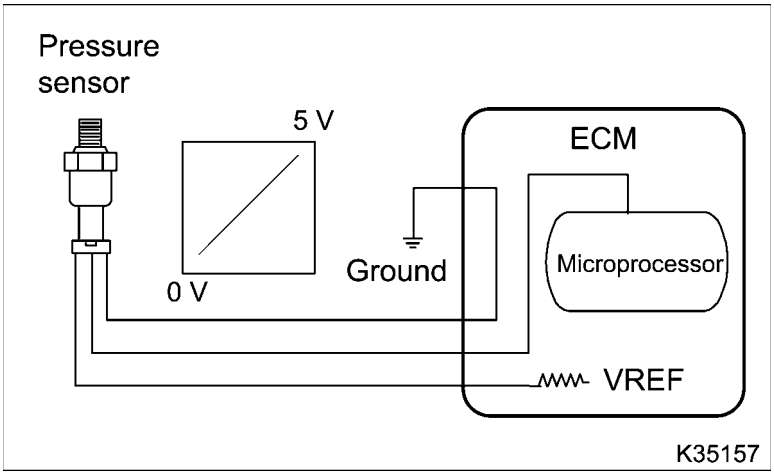

Figure 37 Variable capacitance sensor

Variable capacitance sensors:

- Exhaust Gas Differential Pressure (EGDP) sensor
- Exhaust Back Pressure (EBP) sensor
- Manifold Air Pressure (MAP) sensor

Variable capacitance sensors measure pressure. When pressure is applied to the sensor a ceramic material is forced closer to a thin metal disk which changes the capacitance of the sensor.

Variable capacitance sensors are connected to the ECM by three wires:

- VREF
- Signal
- Signal ground

The sensor receives the VREF and returns an analog signal voltage to the ECM. The ECM compares the voltage with pre-programmed values to determine pressure.

The operational range of a variable capacitance sensor is linked to the thickness of the ceramic disk. The thicker the ceramic disk the more pressure the sensor can measure.

Exhaust Gas Differential Pressure (EGDP) Sensor

The EGDP sensor provides a signal to the ECM indicating the pressure difference between the inlet and outlet of the Diesel Particulate Filter (DPF). During catalyst regeneration, the ECM monitors this sensor, three Exhaust Gas Temperature (EGT) sensors, the EGR System, and the Intake Throttle Valve (ITV).

The EGDP sensor is a differential pressure sensor with two tap-offs installed past the turbocharger. A tap-off is located before and after the DPF.

Exhaust Back Pressure (EBP) Sensor

The ECM monitors exhaust back pressure to control turbocharger, EGR, and intake throttle systems. The EBP sensor is installed in a tube connected to the left exhaust manifold.

Manifold Air Pressure (MAP) Sensor

The ECM monitors the MAP signal to determine intake manifold pressure (boost). This information is used to control the turbocharger boost. The MAP sensor is installed in the intake manifold, left of the MAT sensor.

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Micro Strain Gauge (MSG) Sensor

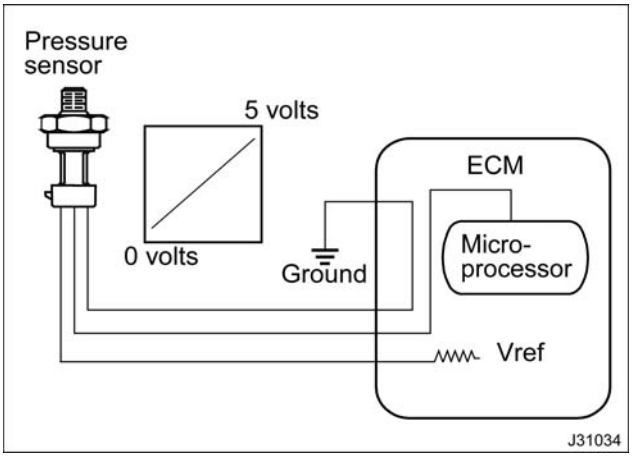

Figure 38 MSG sensor

Micro strain gauge sensor:

- Injection Control Pressure (ICP)

A Micro Strain Gauge (MSG) sensor measures pressure. Pressure exerts force on a pressure vessel that stretches and compresses to change resistance of strain gauges bonded to the surface of the pressure vessel. Internal sensor electronics convert the changes in resistance to a ratiometric voltage output.

The Micro Strain Gauge (MSG) sensor is connected to the ECM by three wires:

- VREF
- Signal
- Signal ground

The sensor is powered by VREF received from the ECM and is grounded through the ECM to a common sensor ground.

Injection Control Pressure (ICP) Sensor

The ICP sensor measures injection control pressure. The ECM monitors the ICP signal for closed loop control of the Injection Pressure Regulator (IPR) valve. The ICP sensor is installed through the right side valve cover in the oil high-pressure oil rail.

Potentiometer

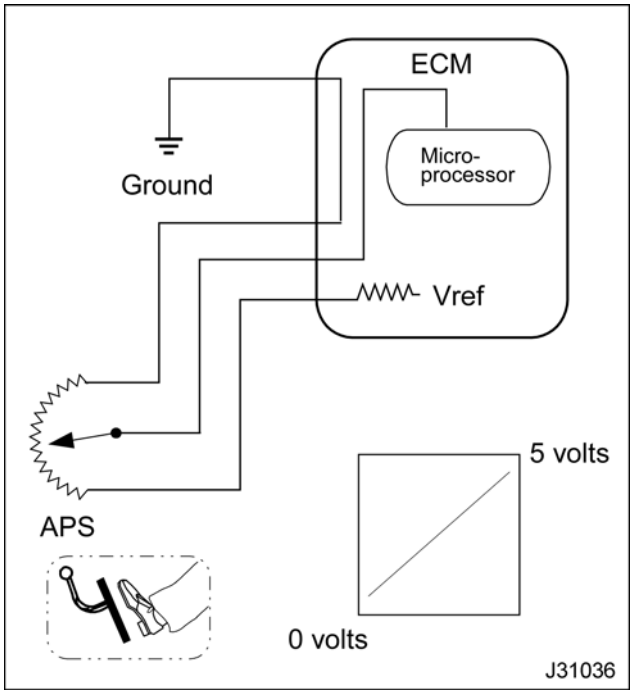

Figure 39 Potentiometer

Potentiometer:

- APS

A potentiometer is a variable voltage divider that senses the position of a mechanical component. A reference voltage is applied to one end of the potentiometer. Mechanical rotary or linear motion moves the wiper along the resistance material, changing voltage at each point along the resistive material. Voltage is proportional to the amount of mechanical movement.

Accelerator Position Sensor (APS)

The APS provides the ECM with a feedback signal (linear analog voltage) that indicates the operator's demand for power. The APS is mounted in the accelerator pedal.

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Magnetic Pickup Sensors

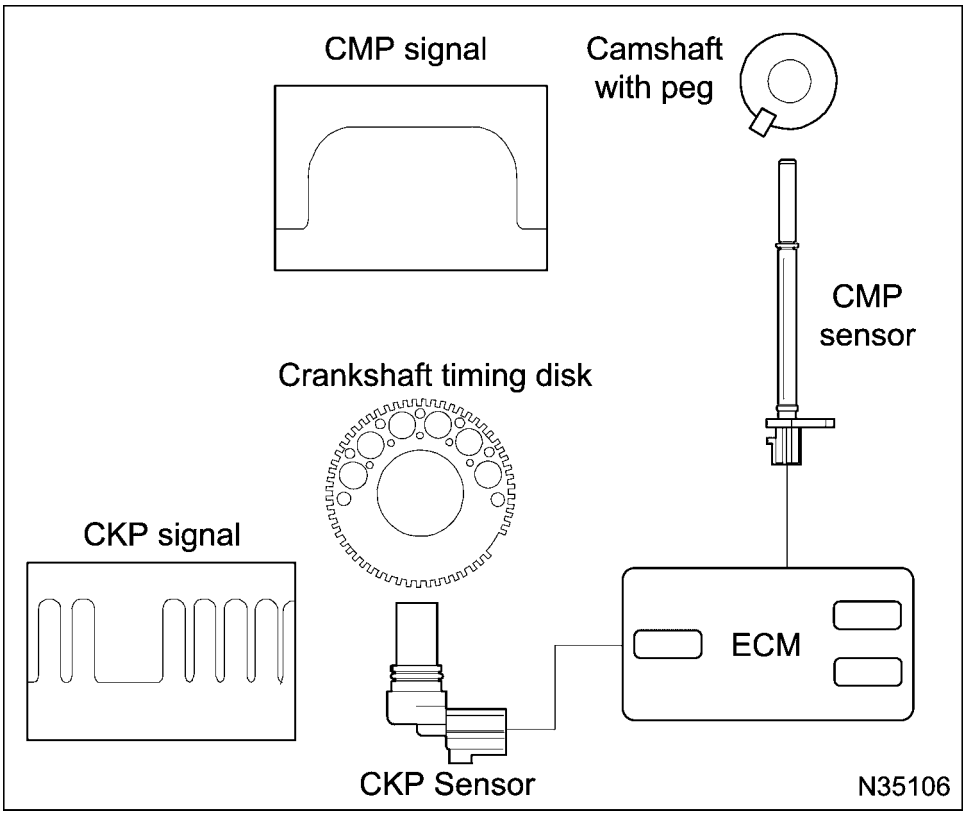

Figure 40 Magnetic pickup

Magnetic pickup sensors:

- Crankshaft Position (CKP)
- Camshaft Position (CMP)

Magnetic pickup sensors generate an alternating frequency that indicates speed. Magnetic pickups have a two wire connection for signal and ground. This sensor has a permanent magnetic core surrounded by a wire coil. The signal frequency is generated by the rotation of gear teeth that disturb the magnetic field.

Crankshaft Position (CKP) Sensor

The CKP sensor provides the ECM with a signal that indicates crankshaft speed and position. As the crankshaft turns the CKP sensor detects a 60 tooth timing disk on the crankshaft. Teeth 59 and 60 are missing. By comparing the CKP signal with the CMP signal, the ECM calculates engine rpm and timing requirements. The CKP is installed in the front right side of the lower crankcase.

Camshaft Position (CMP) Sensor

The CMP sensor provides the ECM with a signal that indicates camshaft position. As the cam rotates, the sensor identifies the position of the cam by locating a peg on the cam. The CMP is installed in the front left side of the lower crankcase.

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Switches

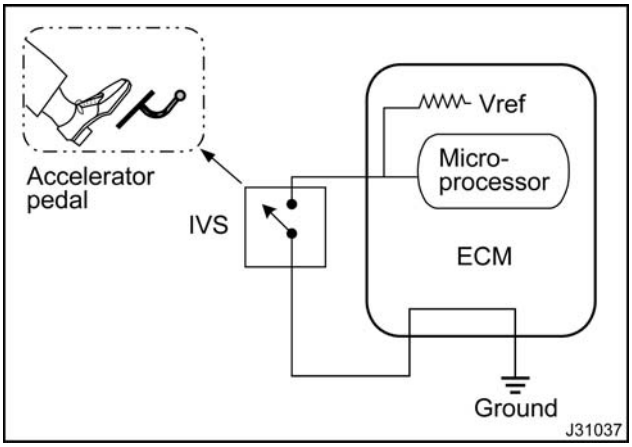

Figure 41 Switch

Switches:

- Driveline Disengagement Switch (DDS) (transmission select)
- Idle Validation Switch (IVS)
- Water In Fuel (WIF)
- Engine Oil Pressure (EOP)
- Engine Coolant Level (ECL)
- Engine Fuel Pressure (EFP) switch

Switches indicate position or condition. They operate OPEN or closed, allowing or preventing the flow of current. A switch can be a voltage input switch or a grounding switch. A voltage input switch supplies the ECM with a voltage when it is closed. A grounding switch grounds the circuit when closed, causing a zero voltage signal. Grounding switches are usually installed in series with a current limiting resistor.

Driveline Disengagement Switch (DDS)

The Transmission Control Module (TCM) monitors the transmission shifter position. A signal from the TCM functions as the DDS signal to the ECM. A manual transmission application will have a clutch switch for the DDS signal.

Idle Validation Switch (IVS)

The IVS is a redundant switch that provides the ECM with a signal that verifies when the APS is in the idle position.

Water In Fuel (WIF) Switch

A WIF switch detects water in the fuel filter of the HFCM. When enough water accumulates in the filter housing, the WIF switch sends a signal to the ECM. The ECM sets a Diagnostic Trouble Code (DTC) and illuminates the amber water in fuel lamp (fuel pump next to a fuel tank) on the right side of the instrument panel. The WIF switch is installed in the HFCM.

Engine Oil Pressure (EOP) Switch

The ECM monitors the EOP signal for reference only. The ECM uses the EOP signal to control EWPS warning and lights the red Stop Engine Lamp for low oil pressure. The EOP switch closes a circuit to ground when the engine oil pressure reaches 34 to 48 kPa (5 to 7 psi). The EOP switch is installed in the oil filter base assembly.

Engine Coolant Level (ECL) Switch

The ECL is part of the Engine Warning Protection System (EWPS). The ECL switch is used in plastic deaeration tanks. When a magnetic switch is OPEN, the tank is full.

If engine coolant is low, the red Stop Engine Lamp on the instrument panel is illuminated.

Engine Fuel Pressure (EFP) switch

The ECM monitors the EFP to detect low fuel supply pressure. If fuel supply pressure drops below 30 psi, due to a fuel filter restriction or other problem, the ECM reduces ICP pressure to 14 MPa. The EFP is installed in the secondary fuel filter housing.

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Glow Plug System

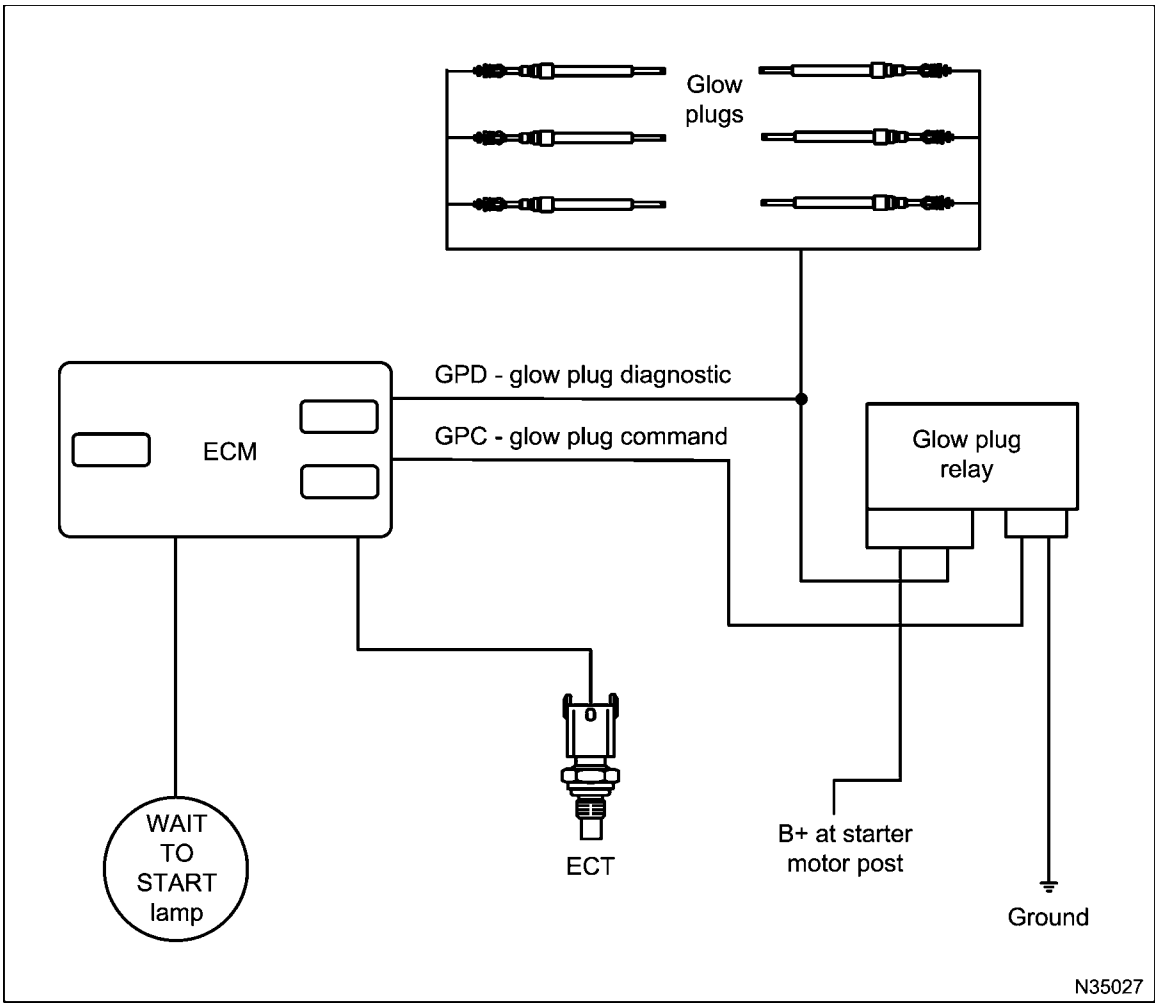

Figure 42 Glow plug system

The glow plug system warms the engine cylinders to aid cold engine starting and reduce exhaust emissions during warm-up.

The ECM energizes the glow plugs, by energizing the glow plug relay, while monitoring engine coolant temperature and atmospheric pressure. Glow plug activation time is increased, if the engine is cold and barometric pressure is low (high altitude).

The ECM monitors battery voltage and uses information from its internal barometric pressure sensor and the ECT sensor to determine WAIT TO START lamp ON time and the activation of the glow plug relay. The ECM controls the WAIT TO START lamp and the glow plug relay separately. The glow plugs are self-limiting and do not require cycling on and off. The glow plug relay will cycle on and off repeatedly if system voltage is greater than 14.0 volts.

The engine is ready to start when the WAIT TO START lamp is turned off by the ECM. The glow plugs can remain on up to 120 seconds while the engine is running to reduce exhaust emissions during engine warm-up.

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Inlet Air Heater System

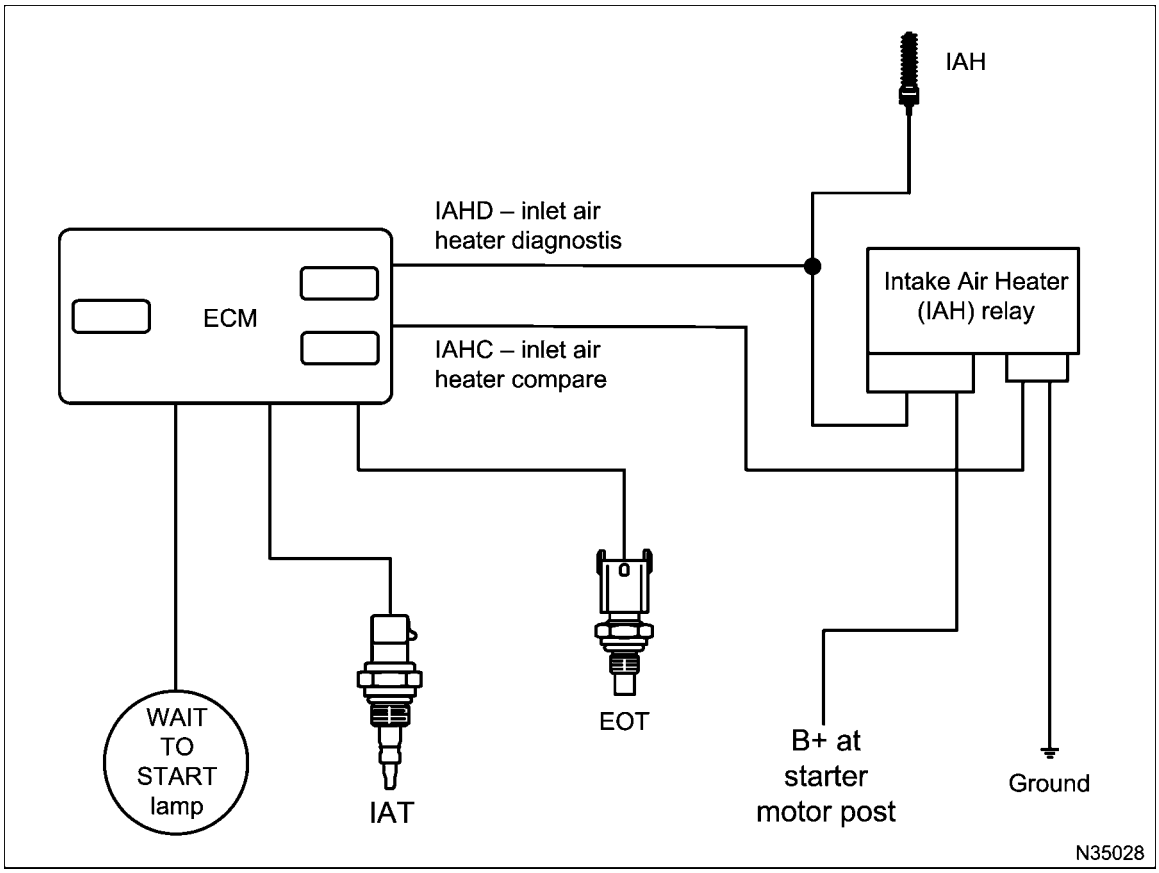

Figure 43 Inlet air heater system

The inlet air heater system warms the incoming air to aid cold engine starting and reduce exhaust emissions during warm-up.

The ECM energizes the inlet air heater, by energizing the inlet air heater relay, while monitoring programmed conditions for engine oil temperature, inlet air temperature, and atmospheric pressure.

The ECM controls the WAIT TO START lamp and inlet air heater relays separately.

The engine is ready to start when the WAIT TO START lamp is turned off by the ECM. The ECM will turn the inlet air heater on for a predetermined amount of time, based on EOT, IAT, and BAP. The inlet air heater can remain on while the engine is running to reduce exhaust emissions and white smoke during engine warm-up.

If the EOT is above 70 °C (158 °F), the inlet air heater will not reactivate when restarting the engine unless the IAT is 15 °C (59 °F) or colder.

Once the engine starts to crank, the IAH is turned off. Depending on factory calibration, once the engine starts the IAH can be reactivated for a calibrated amount of time.

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Engine Preparation

NOTE: See vehicle service publications for engine removal.

WARNING: To prevent personal injury or death, read all safety instructions in the "Safety Information" section of this manual.

WARNING: To prevent personal injury or death, wear safety glasses with side shields. Limit compressed air pressure to 207 kPa (30 psi).

WARNING: To prevent personal injury or death, do not let engine fluids stay on your skin. Clean skin and nails using hand cleaner, and wash with soap and water. Wash or discard clothing and rags contaminated with engine fluids.

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a threat to the environment. Recycle or dispose of engine fluids and filters according to applicable regulations. Never put engine fluids in the trash, on the ground, in sewers or bodies of water.

NOTE: Refer to engine stand and engine stand bracket manufacturer's instructions for specific directions on their safe use.

Clean Engine

1. Cap all engine openings to prevent water and degreasing agents from entering engine.
2. Cover exposed electrical connectors and the ECM using plastic and duct tape.
3. Use an appropriate detergent mixed in the correct ratio and apply to engine using a hot pressure washer or similar cleaning equipment.

Drain Engine Oil and Coolant

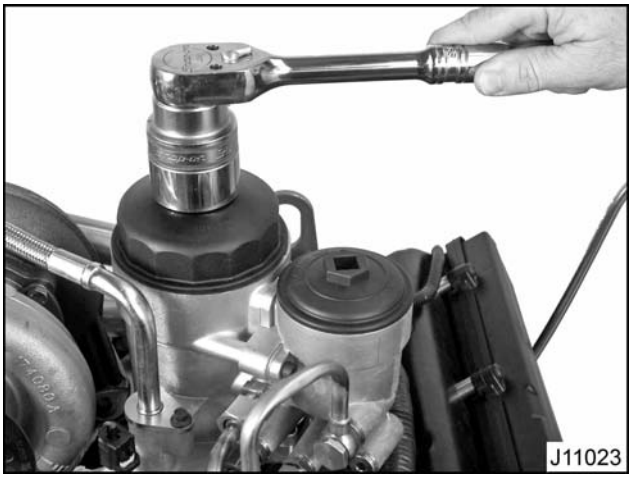

Figure 44 Oil filter cap removal

1. Remove oil filter cap from filter housing to allow oil to drain back into the oil pan. This must be done before removing the oil drain plug.

Figure 45 Oil drain plug removal

2. Remove the oil pan drain plug and drain oil into a suitable container.

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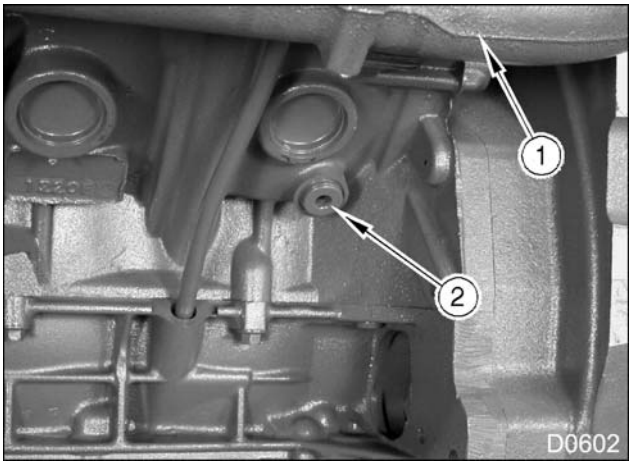

Figure 46 Coolant drain plug – left side

1. Exhaust manifold
2. Coolant drain plug

3. Remove the left side coolant drain plug and drain coolant into a suitable container.

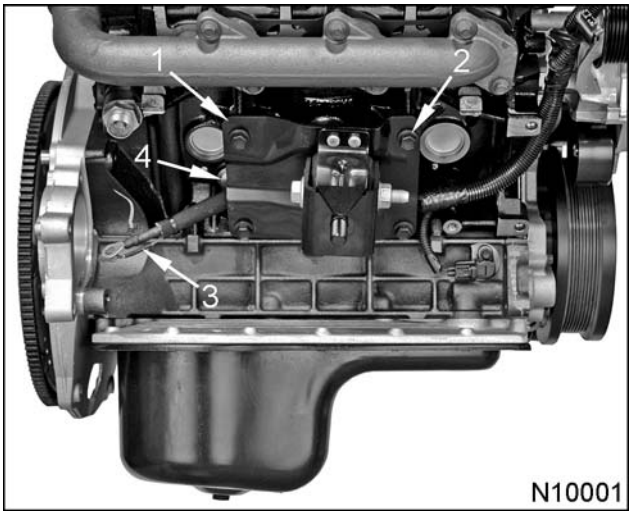

Figure 47 Right side engine mount and coolant drain plug

1. Right engine mount
2. M10 x 20 bolt (4)
3. Starter wiring
4. Coolant drain plug

4. Remove four M10 x 20 bolts and the right side engine mount.
5. Remove the right side coolant drain plug and drain coolant into a suitable container.
6. Install new O-rings on the coolant and oil drain plugs.
7. After oil and coolant have drained, install drain plugs in the crankcase and oil pan. Tighten oil and coolant drain plugs to special torque (page 56).

Removal

1. Remove the electrical cable and wires from the starter motor.
2. Remove bolts holding the starter motor to the rear cover and remove the starter.
3. Rotate the belt tensioner clock wise to relieve tension and remove the serpentine drive belt.
4. Remove bolts holding the Freon® compressor to the engine and remove the compressor.

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Mounting Engine on Engine Stand

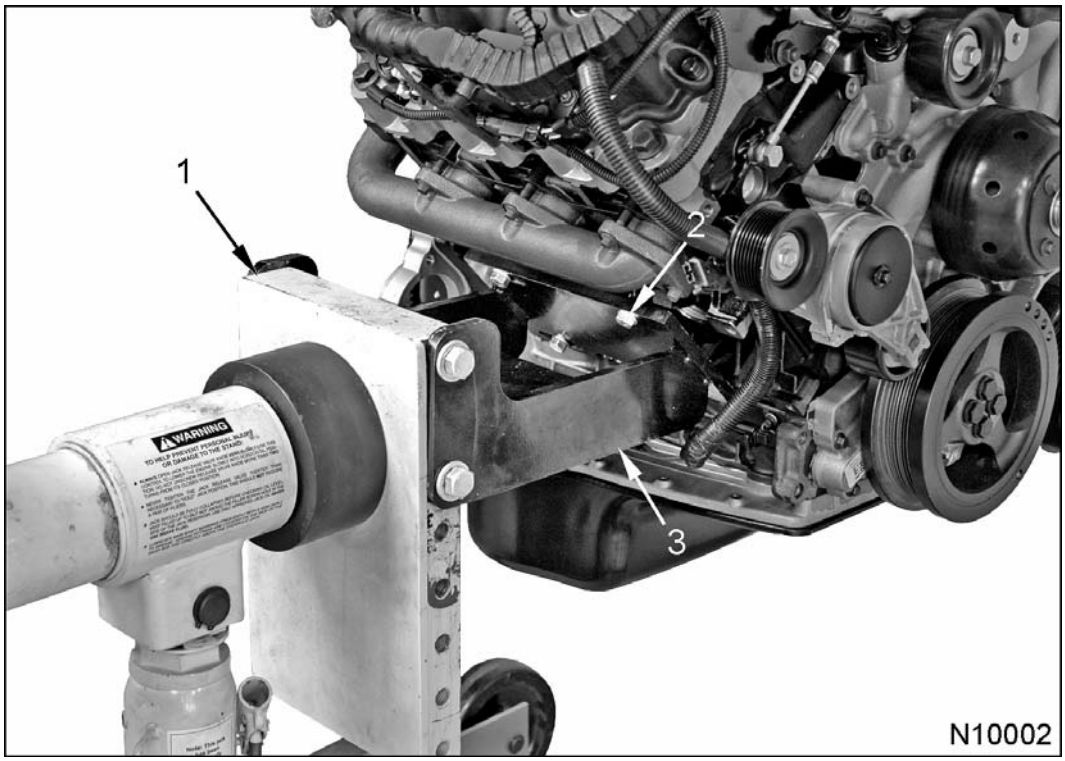

Figure 48 Engine Stand and Engine Stand Bracket

1. Engine Stand
2. Class 10.9 M10 bolt (4)
3. Engine Stand Bracket

WARNING: To prevent personal injury or death, use a minimum three ton rated chain hoist, equipped with safety hooks to lift the engine from factory installed lifting eyes.

WARNING: To prevent personal injury or death, use metric Class 10.9 or SAE grade 8 bolts when mounting the Engine Mounting Bracket to the engine and Engine Stand. See instructions included with Engine Stand and Engine Mounting Bracket.

1. Lift engine from factory installed lifting eyes using a minimum three ton rated chain hoist equipped with safety hooks.
2. Match Engine Stand Bracket (page 56) holes with bolt holes in the right side of the crankcase and install four Class 10.9 M10 bolts.
3. Tighten four M10 bolts to standard torque (page 400).
4. Raise or lower the engine to the approximate height of the Engine Stand (page 56).
5. Mount engine and Engine Stand Bracket on the Engine Stand using four Class 10.9 M16 bolts.
6. Tighten M16 engine stand bolts to standard torque (page 400).
7. Slowly release tension from engine hoist.
8. Remove hoist safety chain hooks from engine lifting eyes.

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Special Torque

Oil pan drain plug	44 N·m (32 lbf·ft)
Crankcase coolant drain plug	20 N·m (15 lbf·ft)

Special Service Tools

Engine Stand Bracket	ZTSE4507
Engine Stand	OTC1750A

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Electronic Component Locations

Electronic Components – Top

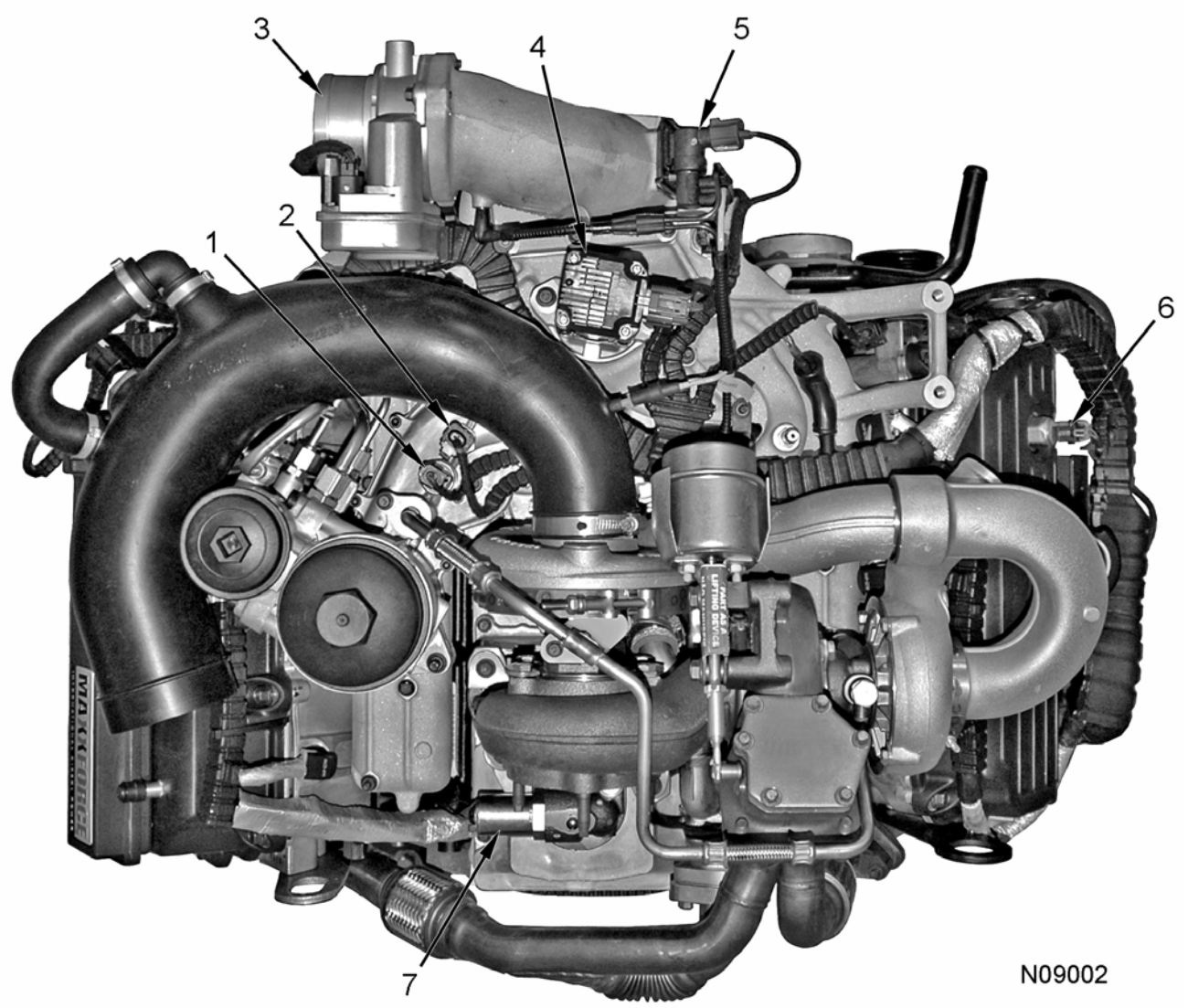

Figure 49 Sensor and switch locations – top (typical)

1. Engine Oil Pressure (EOP) switch
2. Engine Oil Temperature (EOT) sensor
3. Intake Throttle Valve (ITV) assembly
4. Exhaust Gas Recirculation (EGR) valve
5. Boost Control Solenoid (BCS) assembly
6. Injection Control Pressure (ICP) sensor
7. Injection Pressure Regulator (IPR) valve

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Electronic Components – Front

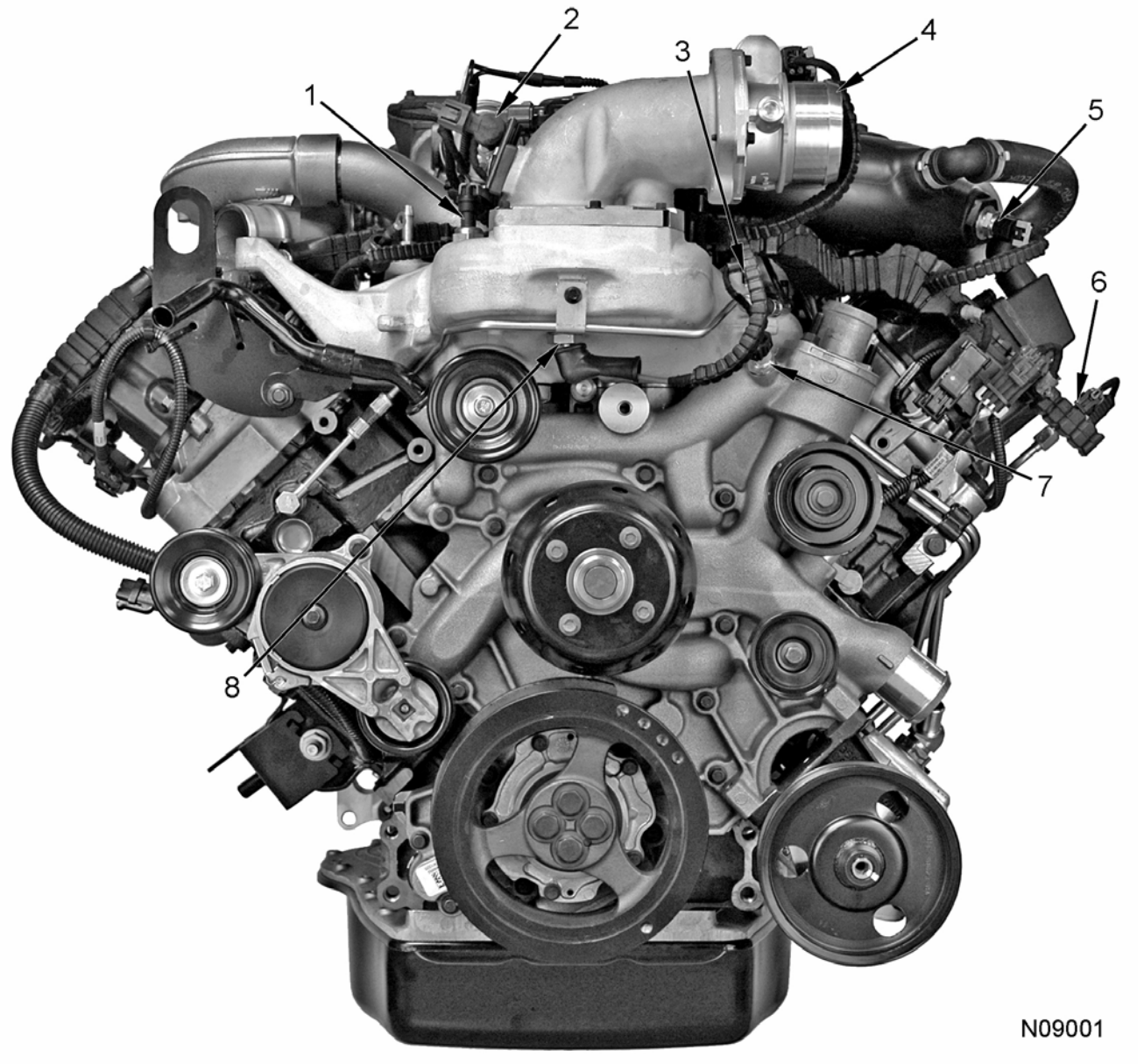

Figure 50 Sensor locations – front (typical)

1. Manifold Absolute Pressure (MAP) sensor
2. Boost Control Solenoid (BCS) assembly
3. Manifold Air Temperature (MAT) sensor
4. Intake Throttle Valve (ITV) Assembly
5. Intake Air Temperature (IAT) sensor
6. Exhaust Back Pressure (EBP) sensor
7. Engine Coolant Temperature (ECT) sensor
8. Intake Air Heater (IAH) element

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Electronic Components – Right

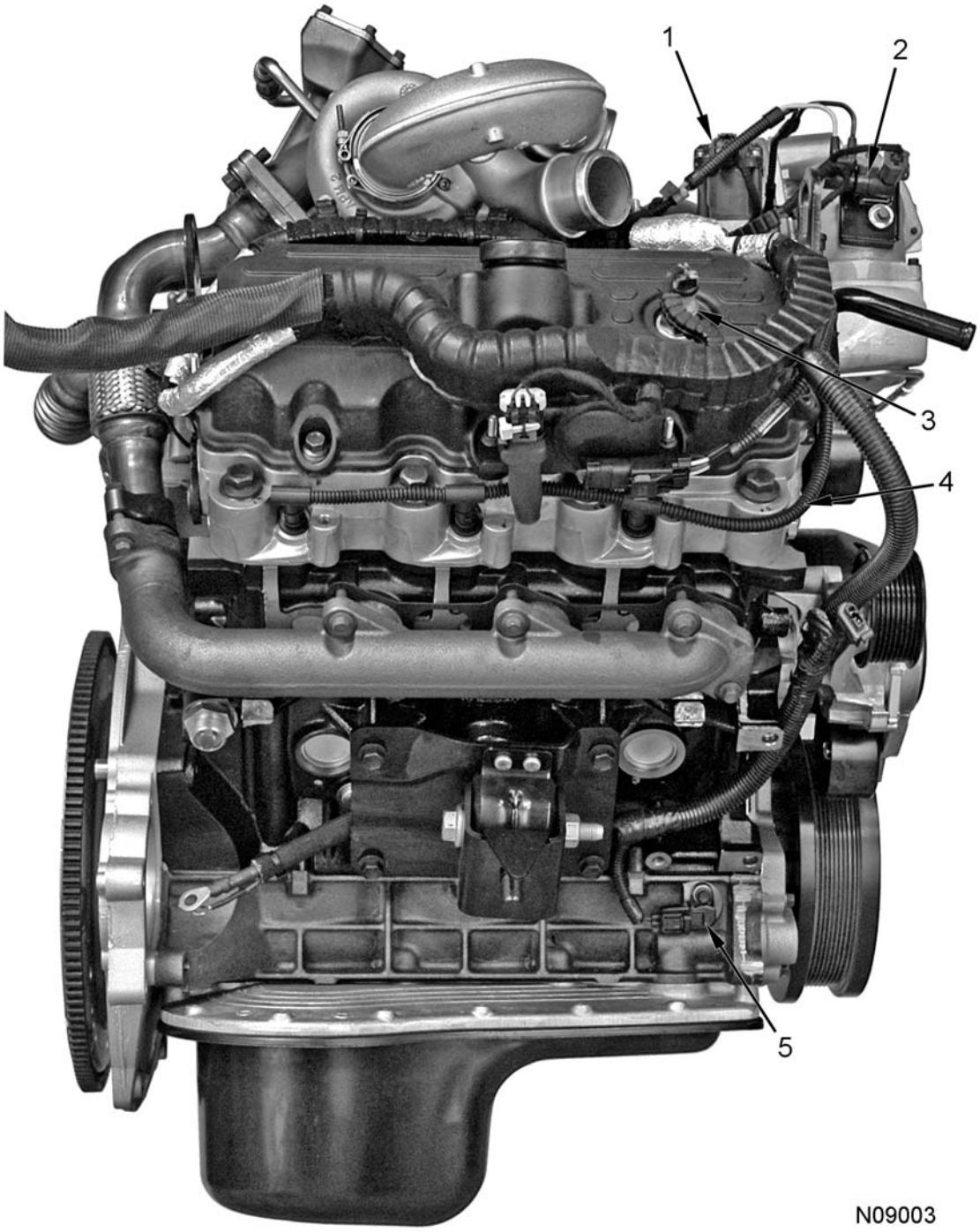

Figure 51 Sensor locations – right (typical)

1. Exhaust Gas Recirculation (EGR) valve
2. Boost Control Solenoid (BCS) assembly
3. Injection Control Pressure (ICP) sensor
4. Glow plug harness (right)
5. Crankshaft Position (CKP) sensor

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Electronic Components – Left

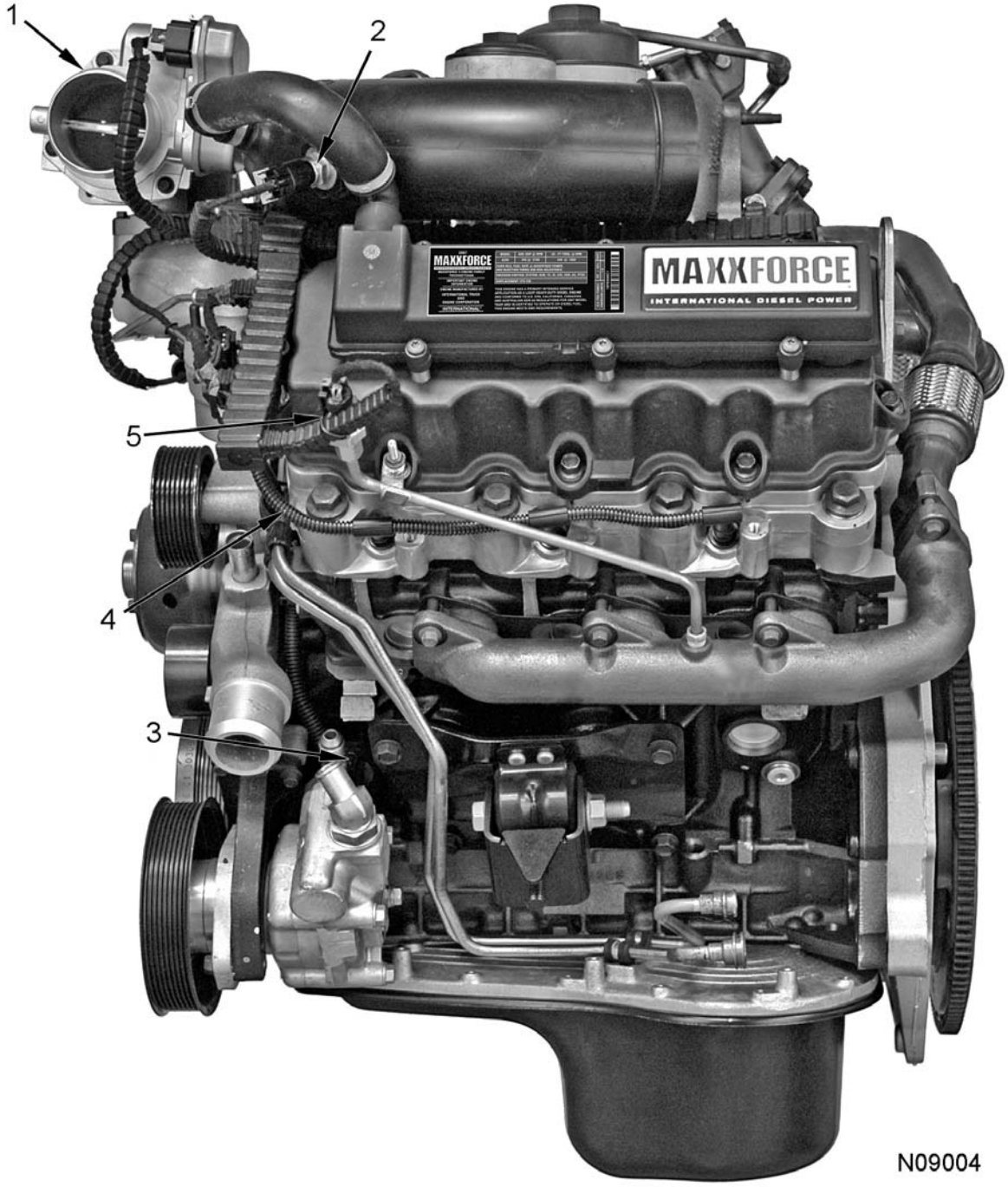

Figure 52 Sensor locations – left (typical)

1. Intake Throttle Valve (ITV) Assembly
2. Intake Air Temperature (IAT) sensor
3. Camshaft Position (CMP) sensor
4. Glow plug harness (left)
5. Exhaust Back Pressure (EBP) sensor

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Description of Engine Sensors, Valves, and Actuators

NOTE: For information on diagnostics and troubleshooting, refer to the following publications:

- EGES-395, International® MaxxForce™ 5 *Diagnostic Manual*
- EGED-410, International® MaxxForce™ 5 Electronic Control Systems Diagnostic Form

Camshaft Position (CMP) Sensor

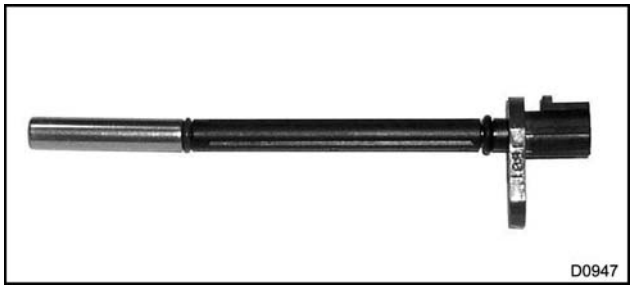

Figure 53 CMP sensor

The CMP sensor, a magnetic pickup sensor, indicates camshaft speed and position.

The CMP sensor sends a pulsed signal to the ECM when a single peg on the camshaft rotates past the CMP sensor once during each revolution of the camshaft. The ECM calculates camshaft speed and position from CMP signal frequency.

The CMP sensor is installed in the left front of the crankcase.

Crankshaft Position (CKP) Sensor

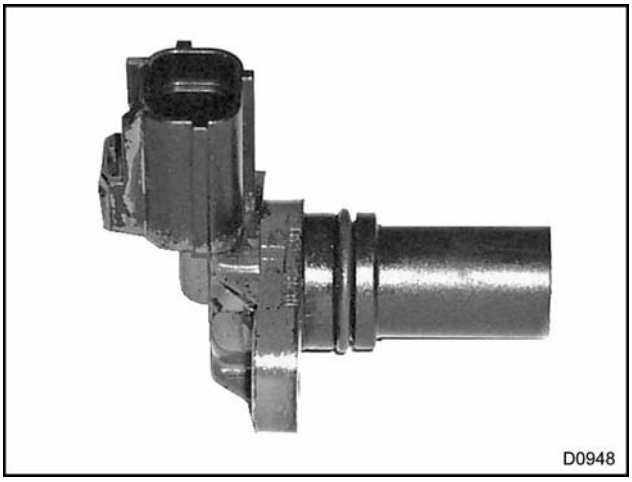

Figure 54 CKP sensor

The CKP sensor, a magnetic pickup sensor, indicates crankshaft speed and position.

The CKP sensor sends a pulsed signal to the ECM as the crankshaft turns. The CKP sensor reacts to a 60 tooth timing disk rotating on the crankshaft. For crankshaft position reference, teeth 59 and 60 are missing. By comparing the CKP signal with the CMP signal, the ECM calculates engine rpm and timing requirements.

The CKP is installed in the right front side of the crankcase.

NOTE: There will be no RPM readings without both CMP and CKP signals.

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Exhaust Back Pressure (EBP) Sensor

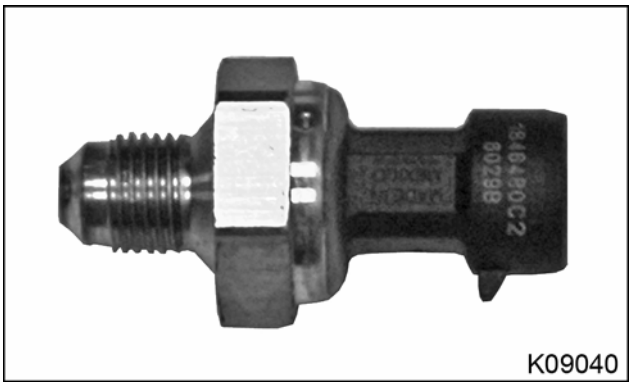

Figure 55 EBP sensor

The EBP sensor, a variable capacitance sensor, measures exhaust back pressure before the turbochargers.

The EBP sensor provides feedback to the ECM for closed loop control of the turbocharger Boost Control Solenoid (BCS), EGR rate calculations, and Intake Throttle Valve (ITV) control.

The EBP sensor is installed in a tube connected to the left exhaust manifold.

Boost Control Solenoid (BCS)

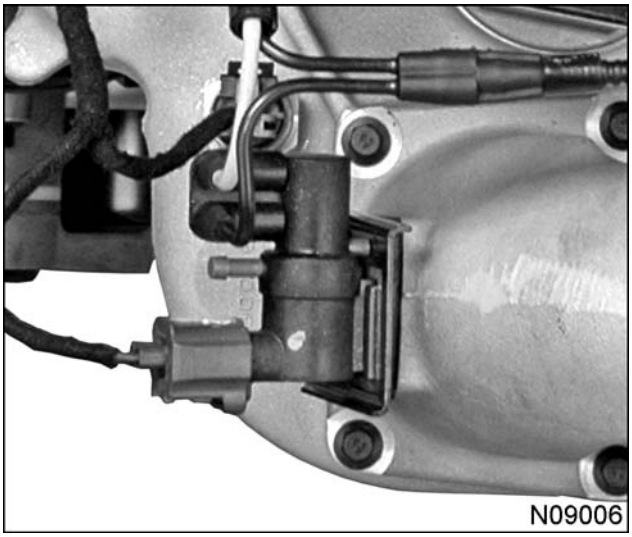

Figure 56 BCS assembly

The BSC assembly is a two position valve that controls intake manifold boost pressure to the turbocharger pneumatic actuator.

The ECM sends signals to the BCS assembly to control the turbocharger pneumatic actuator which controls the turbocharger bypass valve and turbocharger boost.

The BCS is mounted on the air inlet elbow.

Engine Coolant Temperature (ECT) Sensor

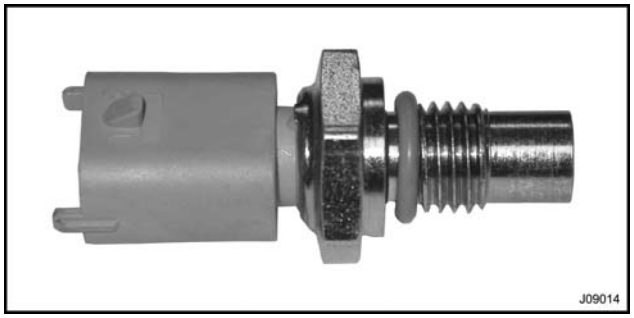

Figure 57 ECT sensor

The ECT sensor, a thermistor sensor, detects engine coolant temperature.

The ECT signal is monitored by the ECM for operation of the instrument panel temperature gauge, coolant temperature compensation, optional Engine Warning Protection System (EWPS), glow plugs, and the wait to start lamp. The ECM will use ECT sensor input as a backup, if EOT sensor values are out of range.

The ECT sensor is installed in the left side of the front cover, above the water pump.

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Engine Oil Temperature (EOT) Sensor

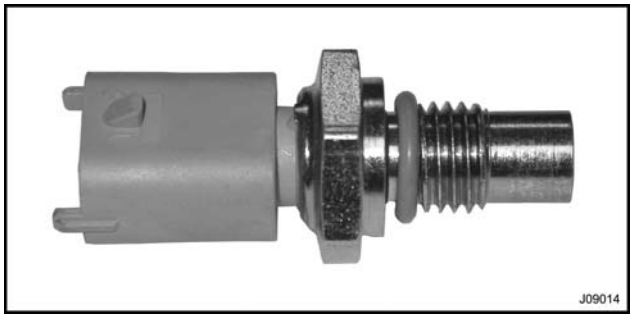

Figure 58 EOT sensor

The EOT sensor, a thermistor sensor, detects engine oil temperature.

The EOT signal is monitored by the ECM for inlet air heater operation and engine fueling calculations. The EOT signal allows the ECM to compensate for differences in oil viscosity, due to temperature changes.

The EOT sensor is installed in the oil filter base.

Engine Oil Pressure (EOP) Switch

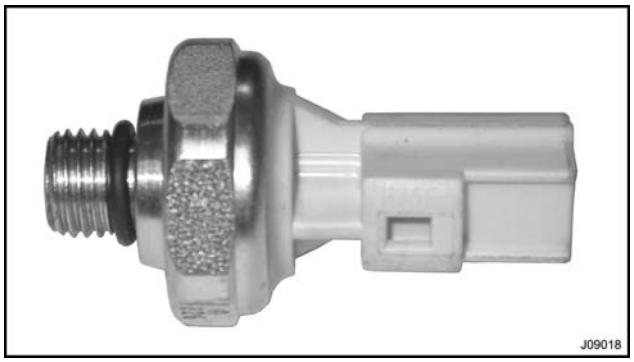

Figure 59 EOP switch

The EOP switch, a ceramic diaphragm switch, detects engine oil pressure.

The EOP signal is monitored by the ECM for operation of the low oil pressure warning lamp and optional EWPS. The EOP switch completes a circuit to ground when engine oil pressure is 31 kPa to 52 kPa (4.5 psi to 7.5 psi) or greater.

The EOP sensor is installed in the oil filter base assembly.

Manifold Absolute Pressure (MAP) Sensor

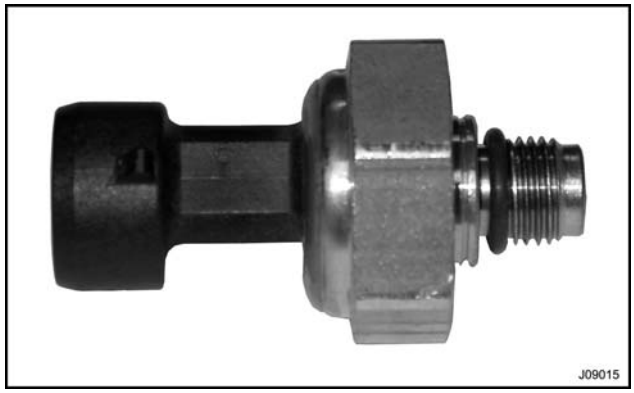

Figure 60 MAP sensor

The MAP sensor, a variable capacitance sensor, measures intake manifold boost pressure.

The MAP signal is monitored by the ECM for BCS, EGR valve, and engine fueling calculations.

The MAP sensor is installed in the right front top of the intake manifold next to the air inlet elbow.

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Intake Air Temperature (IAT) Sensor

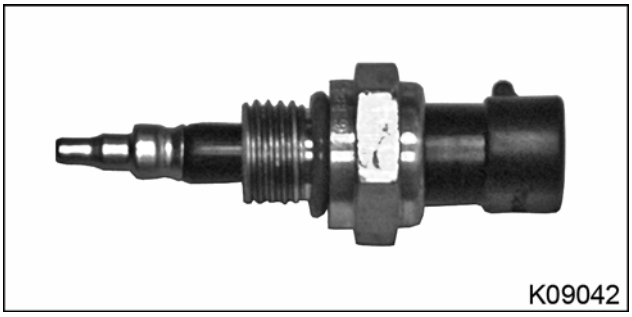

Figure 61 IAT sensor

The IAT sensor, a thermistor sensor, detects intake air temperature.

The IAT signal is monitored by the ECM for fuel rate and timing during cold starts.

The IAT sensor is installed in the turbocharger air intake duct.

Manifold Absolute Temperature (MAT) Sensor

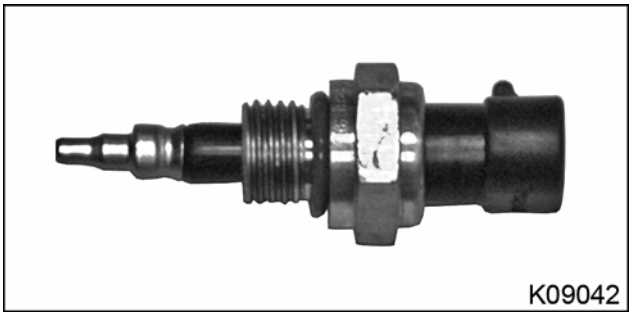

Figure 62 MAT sensor

The MAT sensor, a thermistor sensor, detects intake manifold air temperature.

The MAT signal is monitored by the ECM for EGR operation.

The MAT sensor is installed in the left side of the intake manifold toward the front of the engine.

Engine Fuel Pressure (EFP) switch

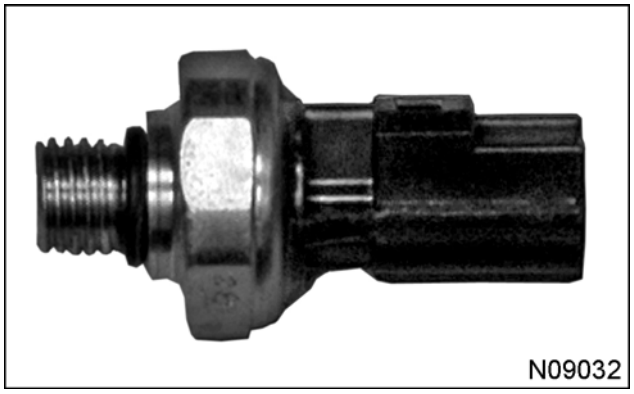

Figure 63 EFP switch

The EFP, a ceramic diaphragm switch, detects fuel supply pressure.

The EFP signal is monitored by the ECM for engine protection in case a fuel filter restriction or other problem results in low fuel supply pressure. The ECM reduces ICP pressure to 14 MPa if the fuel supply pressure drops below 30 psi.

The EFP is installed in the secondary fuel filter housing.

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Injection Control Pressure (ICP) Sensor

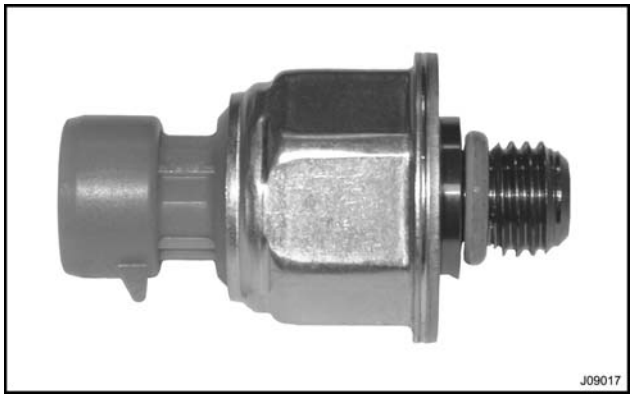

Figure 64 ICP sensor

The ICP sensor, a micro-strain gauge sensor, measures injection control pressure.

The ICP signal is monitored by the ECM for closed loop control of the IPR valve and engine fueling calculations.

The ICP sensor is installed through the right side valve cover in the right high-pressure oil rail.

Injection Pressure Regulator (IPR) Valve

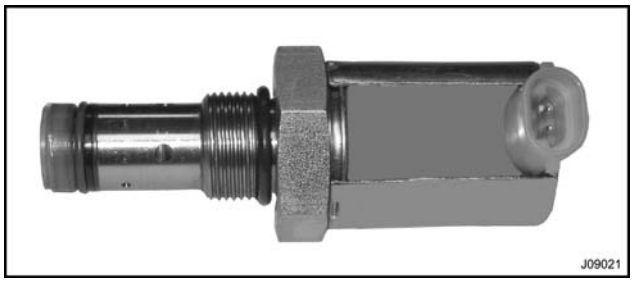

Figure 65 IPR valve

The IPR valve, a variable position Pulse Width Modulated (PWM) valve, regulates injection control pressure.

The IPR valve is controlled by a ground circuit in the ECM in response to ICP sensor input. Voltage is supplied through the ignition switch. The IPR valve includes a high-pressure relief valve which releases excessive injection control pressure.

The IPR valve is installed in the left rear side of the high-pressure oil pump.

Intake Throttle Valve (ITV) Assembly

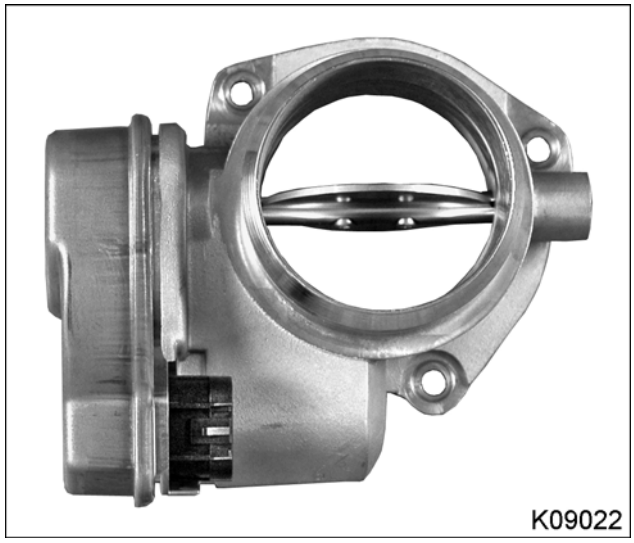

Figure 66 Intake throttle assembly

The ITV assembly, a variable position actuator, restricts inlet air flow to control air/fuel ratio and increase exhaust temperature during aftertreatment regeneration. The ITV also restricts air flow for engine shutdowns due to Engine Warning and Protection System (EWPS) or Idle Shutdown Timer (IST) features, where the engine is shut-off without turning the key-off.

The ITV assembly changes valve position in response to Pulse Width Modulated (PWM) signals from the ECM.

The ITV assembly is mounted on the air intake elbow.

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Exhaust Gas Recirculation (EGR) Valve

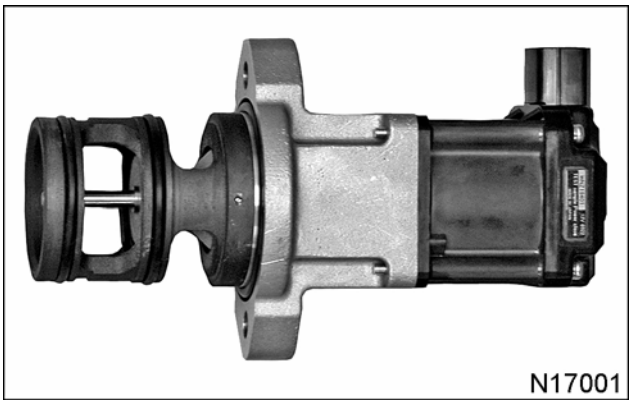

Figure 67 EGR valve

The EGR valve, a variable position electromechanical valve, recirculates cooled exhaust gases into the intake air stream to reduce NOx emissions by reducing combustion temperatures.

The EGR valve changes valve position in response to private Controller Area Network (CAN) digital signals from the ECM.

The EGR valve has three major components: a dual poppet valve assembly, a DC motor, and an Integrated Circuit (IC). The IC has three Hall effect position sensors that monitor valve movement.

The EGR valve is installed in the front of the intake manifold behind the air inlet elbow.

Glow Plug

Figure 68 Glow plug

Glow plugs are compact electric heating devices that heat the cylinders to aid cold engine starting and reduce exhaust emissions during warm-up. There are three glow plugs installed in each cylinder head, one for each cylinder.

Intake Air Heater (IAH) Element

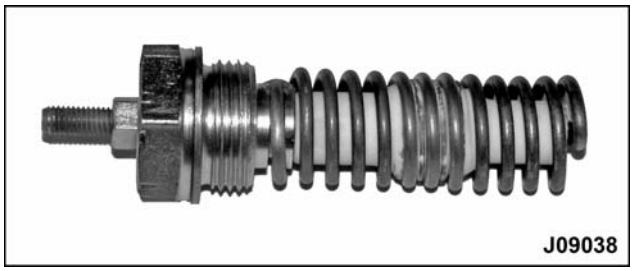

Figure 69 IAH element

The IAH element is a ceramic coiled heating element used to warm incoming air to aid cold engine starting and reduce exhaust emissions during warm-up.

The ECM energizes the IAH relay, while monitoring programmed conditions for Engine Oil Temperature (EOT), Inlet Air Temperature (IAT), and barometric pressure.

The IAH element is installed in the front bottom center of the intake manifold.

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Removal

WARNING: To prevent personal injury or death, read all safety instructions in the "Safety Information" section of this manual.

WARNING: To prevent personal injury or death, shift transmission to park or neutral, set parking brake, and block wheels before doing diagnostic or service procedures.

WARNING: To prevent personal injury or death, disconnect the main battery negative terminal before disconnecting or connecting electrical components.

CAUTION: To prevent engine damage, do not tug on wiring harnesses; if resistance is felt, find the problem and free connectors or clips.

WARNING: To prevent personal injury or death, do not let engine fluids stay on your skin. Clean skin and nails using hand cleaner, and wash with soap and water. Wash or discard clothing and rags contaminated with engine fluids.

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a threat to the environment. Recycle or dispose of engine fluids and filters according to applicable regulations. Never put engine fluids in the trash, on the ground, in sewers or bodies of water.

Alternator

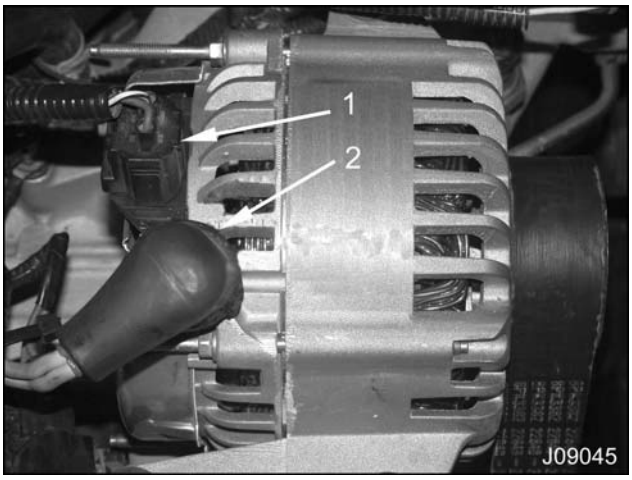

Figure 70 Alternator and sensor harness connections

1. Alternator control harness connector
2. Alternator power connector

1. Disconnect battery ground cable.
2. Rotate belt tensioner clock wise to release belt tension and remove drive belt from alternator pulley.
3. Push in the control connector tab and pull the alternator control harness connector off the alternator.
4. Pull back the rubber boot and remove the nut and alternator power connector from the alternator.
5. Remove three M10 x 80 bolts holding the alternator to the intake manifold and remove alternator.

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Intake Air Temperature (IAT) Sensor

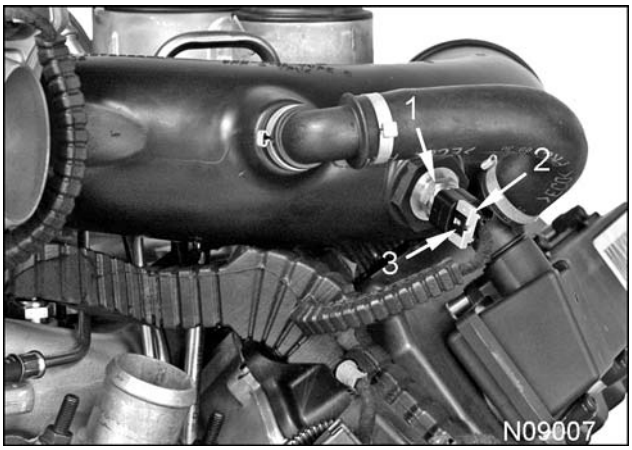

Figure 71 IAT sensor and harness connector

1. IAT sensor
2. Locking tab (locked position)
3. Release tab

1. Pull out the harness connector locking tab.
2. Push in the release tab and pull the 2-pin sensor harness connector off the IAT sensor, installed in the turbocharger air inlet duct.
3. Remove the IAT sensor and discard O-ring.

Injection Pressure Regulator (IPR) Valve Connector

1. Cut zip tie and remove IPR harness connector heat shield.

Figure 72 IPR valve and harness connector (connector heat shield removed)

1. IPR valve
2. IPR harness connector

2. Release the IPR valve harness connector wire retainer or tabs and pull 2-pin connector off the IPR valve.
3. See “High-pressure Oil System” for IPR valve removal.

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Exhaust Back Pressure (EBP) Sensor

Figure 73 EBP assembly

1. EBP sensor harness connector
2. EBP sensor
3. Zip tie

1. Cut zip tie holding sensor harness to EBP sensor.
2. Pull the EBP sensor harness connector tab out and pull 3-pin connector off the EBP sensor.
3. Remove EBP sensor from tube assembly.

Camshaft Position (CMP) Sensor

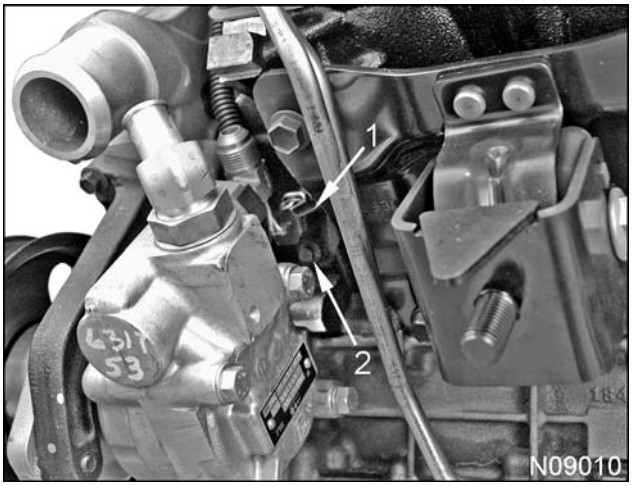

Figure 74 CMP sensor and harness connector

1. CMP sensor harness connector
2. M6 x 14 bolt

1. Push in the connector release tab and pull the 2-pin sensor harness connector off the CMP sensor, installed in the left front side of the crankcase.
2. Remove the M6 x 14 sensor retaining bolt.
3. Pull the CMP sensor out of the crankcase and discard O-ring.

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Glow Plug Wiring Harness – Left

Figure 75 Left glow plug harness

1. Connector locking tab
2. Left glow plug harness
3. Glow plug harness connector release tab

1. Slide glow plug harness connector locking tab to the side to unlock connector.
2. Push in the release tab and pull the 3-pin glow plug harness connector off the sensor harness connector.
3. Disconnect the glow plug harness from the connection point on the front of the left valve cover under the sensor harness.

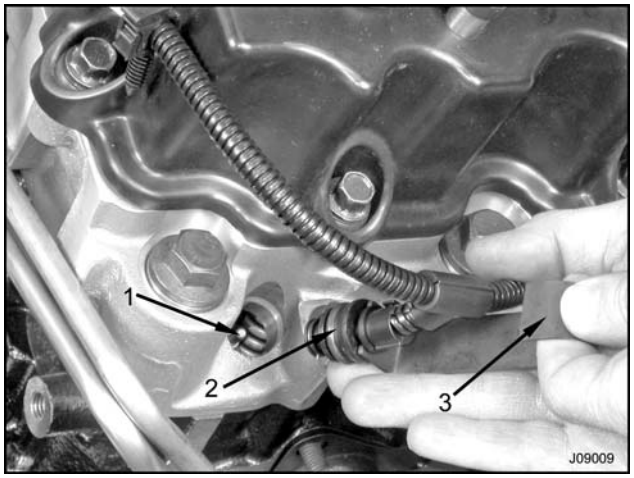

Figure 76 Glow Plug Connector Installer / Remover

1. Glow plug
2. Glow plug harness connector
3. Glow Plug Connector Remover / Installer

4. Remove each glow plug connector using the Glow Plug Connector Installer / Remover (page 101) tool.
5. Remove and discard O-rings from glow plug harness connectors.
6. See “Cylinder Head” for glow plug removal.

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Injector Harness Connectors – Left

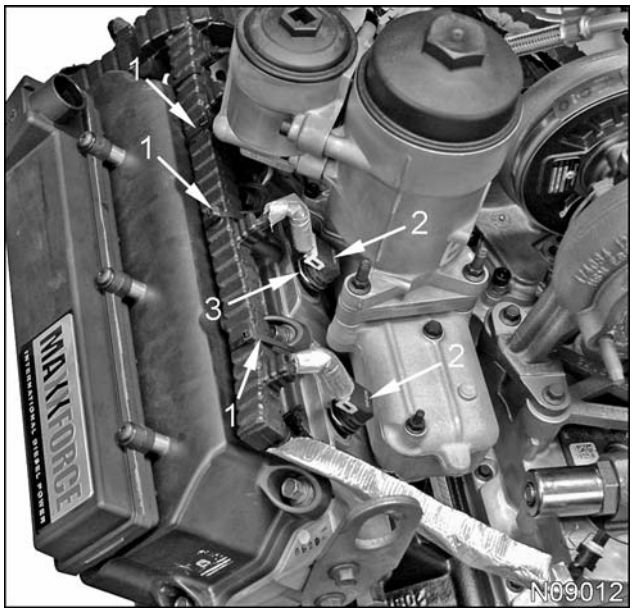

Figure 77 Left injector harness connectors

1. Zip tie
2. Injector harness connector
3. Snap ring

1. Cut three zip ties holding the sensor harness to the left valve cover.

NOTE: Do not pull snap rings out of injector harness connectors.

2. Push each snap ring into its harness connector and lift up to remove each of the three left side injector connectors.

Engine Fuel Pressure (EFP) switch

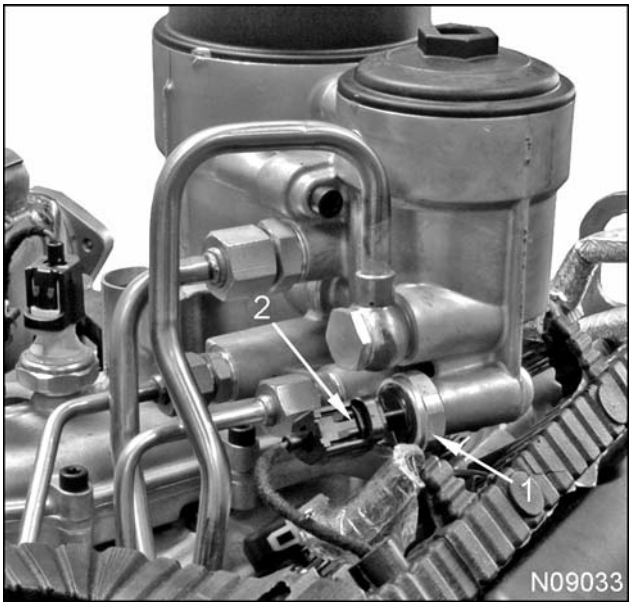

Figure 78 EFP switch

1. EFP switch
2. Release tab

WARNING: To prevent personal injury or death, do not smoke and keep fuel away from flames and sparks.

1. Place a suitable container under the secondary fuel filter housing to catch draining fuel.
2. Push in the connector release tab and pull the 1-pin sensor harness connector off the EFP switch, installed in the secondary fuel filter housing.
3. Remove the EFP switch and discard O-ring.

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Manifold Air Temperature (MAT) Sensor

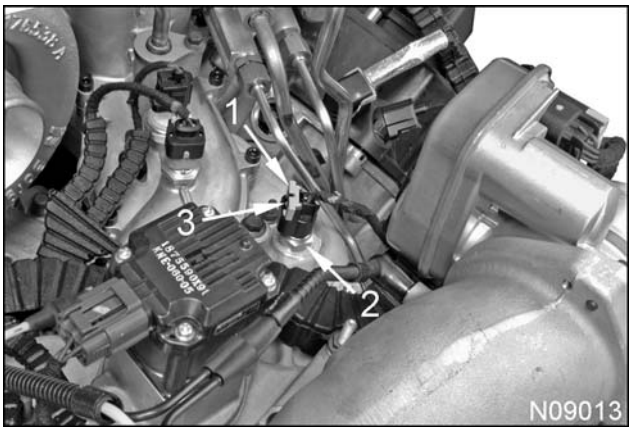

Figure 79 MAT sensor and harness connector

1. Locking tab (locked position)
2. MAT sensor
3. Release tab

1. Pull up the harness connector locking tab.
2. Push in the release tab and pull the 2-pin sensor harness connector off the MAT sensor, installed in the left front of the intake manifold.
3. Remove the MAT sensor and discard O-ring.

Engine Coolant Temperature (ECT) Sensor

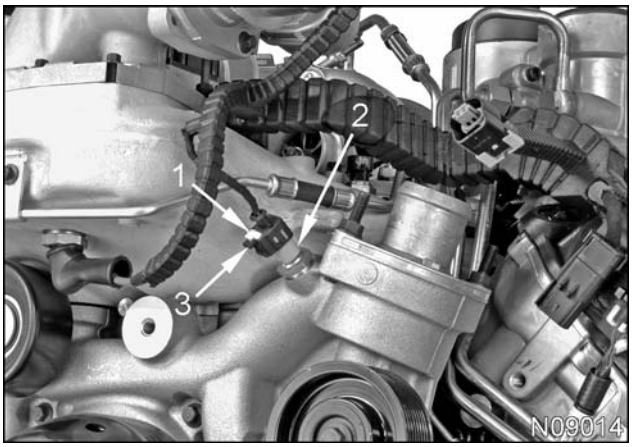

Figure 80 ECT sensor and harness connector

1. Locking tab (locked position)
2. ECT sensor
3. Release tab

1. Pull out the harness connector locking tab.
2. Push in the release tab and pull the 2-pin sensor harness connector off the ECT sensor, installed in the top left of the front cover.
3. Remove the ECT sensor and discard O-ring.

Intake Air Heater (IAH)

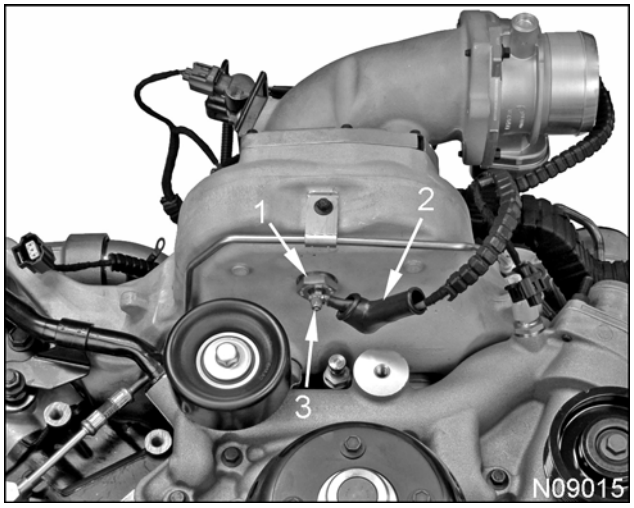

Figure 81 IAH element and harness connection

1. IAH element
2. Rubber boot
3. M5 nut

1. Pull back rubber boot covering intake heater nut, on the bottom front of the intake manifold.
2. Loosen and remove intake heater M5 nut and cable.
3. Remove IAH element from the intake manifold.

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Intake Throttle Valve (ITV) Assembly Connector

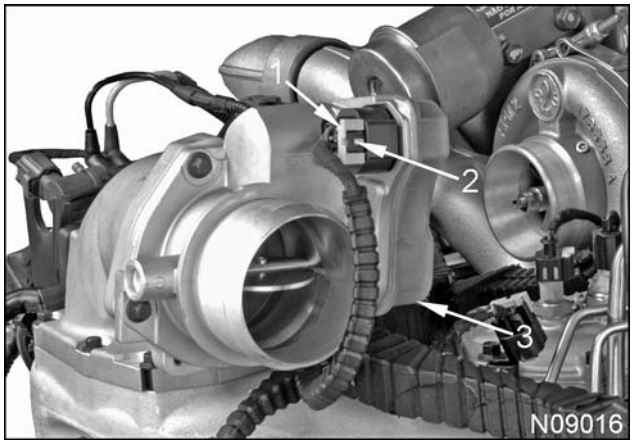

Figure 82 ITV assembly and harness connector

1. Locking tab (locked position)
2. Release tab
3. ITV assembly

1. Pull out the harness connector locking tab.
2. Push in the release tab and pull the sensor harness connector off the ITV assembly.
3. See “Manifolds and Exhaust Gas Recirculation” for ITV removal.

Engine Oil Temperature (EOT) Sensor and Engine Oil Pressure (EOP) Switch

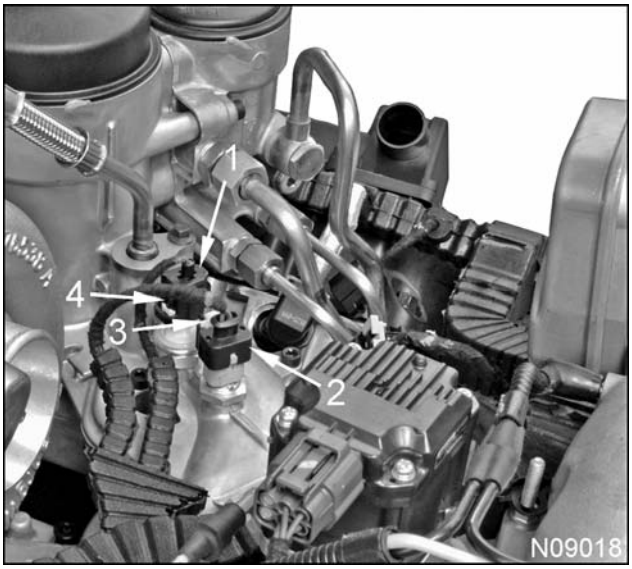

Figure 83 EOT sensor and EOP switch

1. EOP switch harness connector
2. EOT sensor harness connector
3. EOT locking tab (locked position)
4. EOP release tab

1. Pull up the EOT harness connector locking tab.
2. Push in the EOT connector release tab and pull the 2-pin harness connector off the EOT sensor, installed in the oil filter base assembly.
3. Push in the EOP connector release tab and pull the 1-pin harness connector off the EOP switch.
4. Remove the EOP switch and the EOT sensor.
5. Remove and discard O-rings.

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Boost Control Solenoid (BCS) Assembly

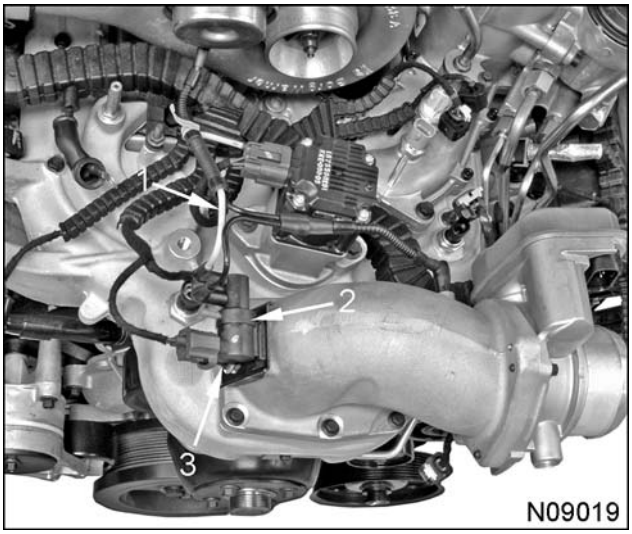

Figure 84 BCS, harness connector, and tube assembly

1. BCS tube assembly
2. BCS assembly
3. M6 x 30 bolt

1. Push in the BCS connector release tab and pull the 2-pin harness connector off the BCS assembly, installed on the air inlet elbow.
2. Pull the BCS tube assembly off the BCS assembly, air inlet elbow, turbocharger phonemic actuator, and air inlet duct.
3. Remove the M6 x 30 bolt securing the BCS assembly to the air inlet elbow and remove the BCS.

Manifold Absolute Pressure (MAP) Sensor

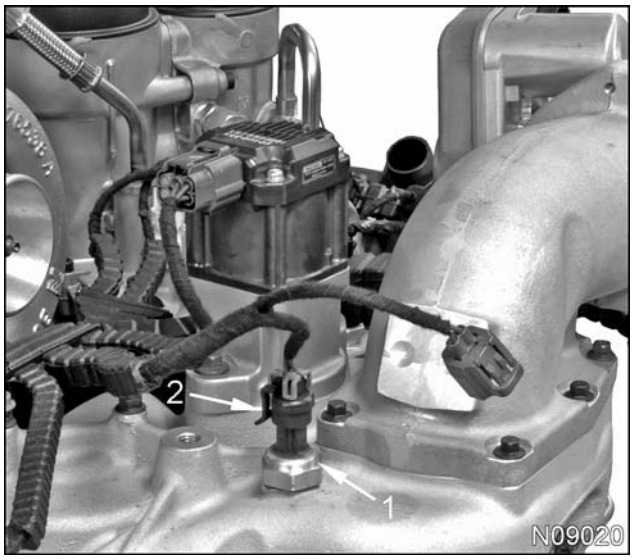

Figure 85 MAP sensor and harness connector

1. MAP sensor
2. Connector release tab

1. Pull the connector release tab up and pull the 3-pin sensor harness connector off of the MAP sensor, installed in the right front of the intake manifold.
2. Remove MAP sensor and discard O-ring.

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Exhaust Gas Recirculation (EGR) Valve Connector

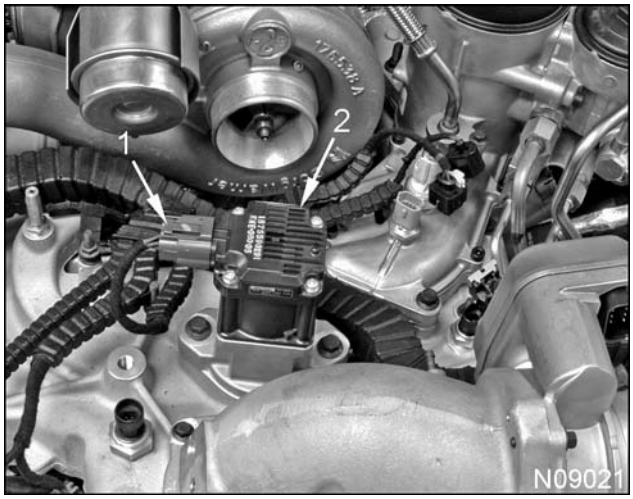

Figure 86 EGR valve and harness connector

1. Connector release tab
2. EGR valve

1. Push down the EGR valve connector release tab and pull the connector off the EGR valve, mounted in the front of the intake manifold.
2. See “Manifolds and Exhaust Gas Recirculation (EGR)” for EGR valve removal.

Injector Harness Connectors – Right

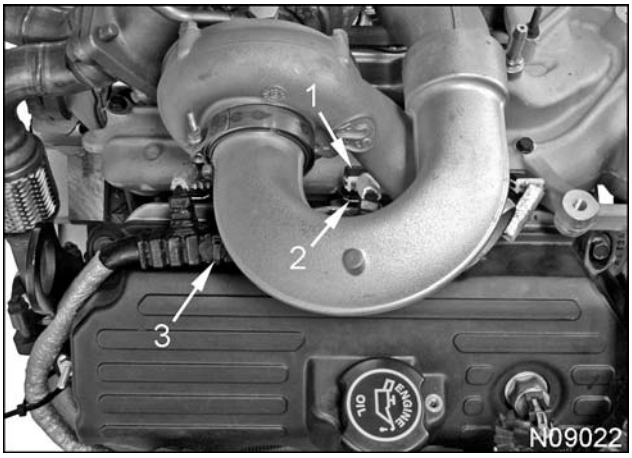

Figure 87 Right injector harness connectors

1. Injector harness connector
2. Snap ring
3. Zip tie

1. Cut three zip ties holding the sensor harness to the right valve cover.

NOTE: Do not pull snap rings out of injector harness connectors.

2. Push each snap ring into its harness connector and lifting up to remove each of the three right side injector connectors.

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Crankshaft Position (CKP) Sensor

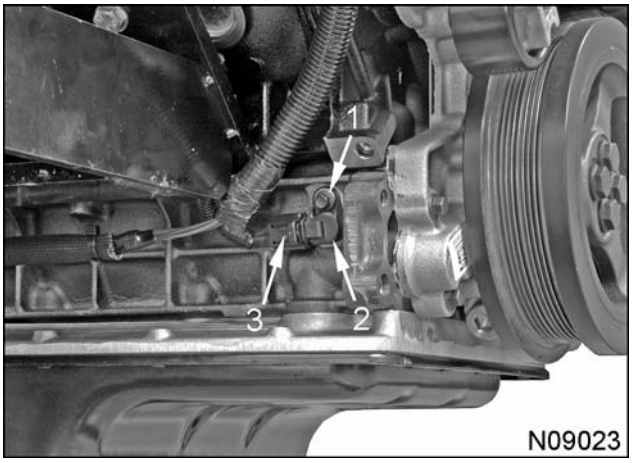

Figure 88 CKP sensor and harness connector

1. M6 x 14 bolt
2. CKP sensor
3. Connector release tab

1. Push down the connector release tab and pull the 2-pin harness connector off the CKP sensor, mounted in the right side of the crankcase.
2. Remove the M6 x 14 sensor retaining bolt.
3. Pull the CKP sensor out of the crankcase and discard O-ring.

Injection Control Pressure (ICP) Sensor

Figure 89 ICP sensor and harness connector

1. Connector release tab
2. ICP sensor

1. Pull the connector release tab up and pull the 3-pin sensor harness connector off the ICP sensor, installed in the right high-pressure oil manifold.
2. Remove ICP sensor and discard O-ring.

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Glow Plug Wiring Harness – Right

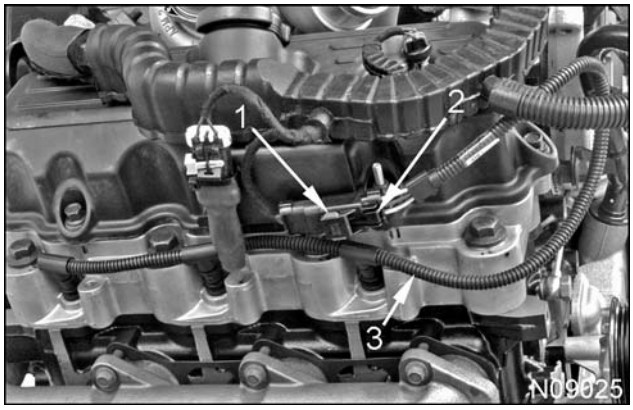

Figure 90 Right glow plug harness

1. Connector locking tab
2. Connector release tab
3. Right glow plug harness

1. Slide the connector locking tab to the side to unlock connector.
2. Push in the release tab and pull the 3-pin glow plug harness connector off the sensor harness connector.
3. Disconnect the glow plug harness from the connection point on the right front lifting eye.

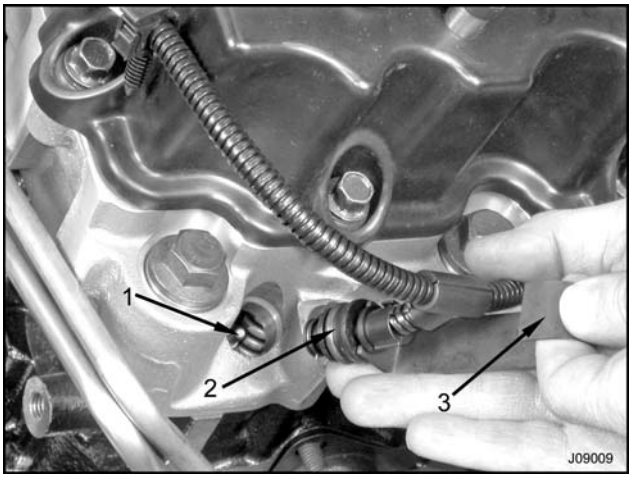

Figure 91 Glow Plug Connector Installer / Remover

1. Glow plug
2. Glow plug harness connector
3. Glow Plug Connector Remover / Installer

4. Remove each glow plug connector using the Glow Plug Connector Installer / Remover (page 101) tool.
5. Remove and discard O-rings from glow plug harness connectors.
6. See “Cylinder Head” for glow plug removal.

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Engine Sensor Wiring Harnesses

NOTE: Refer to Removal procedures for location photos of individual components.

1. Disconnect the main negative (-) battery cable.
2. Disconnect the alternator (page 69) harness connectors.
3. Disconnect the IAT sensor (page 70) harness connector.
4. Remove the turbocharger intake air duct.
5. Disconnect the IPR valve (page 150), EBP sensor (page 71), and CMP sensor harness connectors.

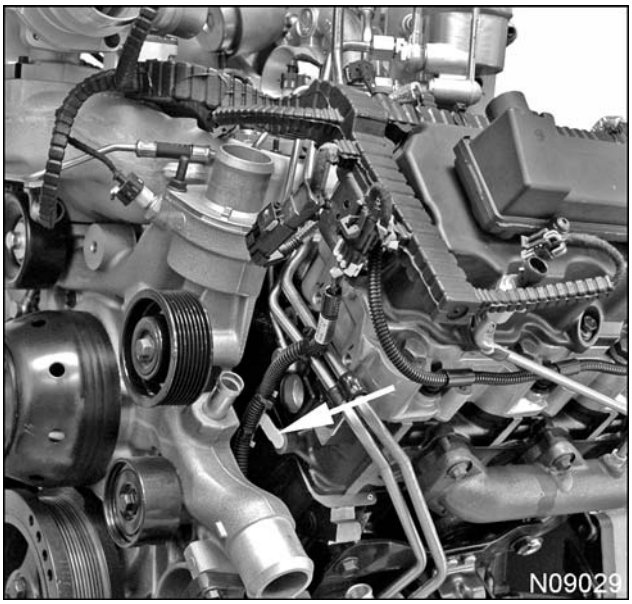

Figure 92 CMP sensor wiring harness connection point – left cylinder head

6. Disconnect the CMP sensor wiring harness from connection point on the left front cylinder head.
7. Remove left side glow plug harness (page 72).
8. Cut zip ties and remove sensor wiring harness from left side injector connectors (page 73).
9. Disconnect the EFP switch (page 73), MAT sensor (page 74), ECT sensor, IAH element, and ITV assembly (page 75) harness connectors.

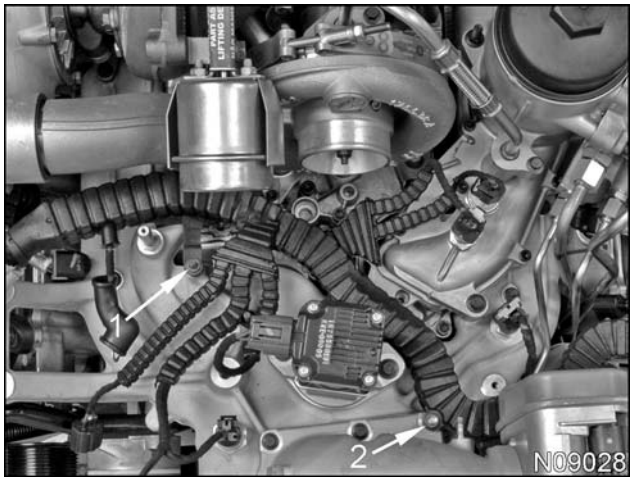

Figure 93 Sensor wiring harness connection points – intake manifold

1. M6 nut on stud in right front of intake manifold
2. M6 nut on air intake elbow stud

10. Remove the M6 nut holding the sensor wiring harness to the air intake elbow stud.
11. Disconnect the EOT sensor and EOP switch (page 75) harness connectors.
12. Disconnect the BCS assembly (page 76), MAP sensor, and EGR valve (page 77) harness connectors.
13. Remove the M6 nut holding the sensor wiring harness to the top right front of the intake manifold.
14. Cut zip ties and remove sensor wiring harness from right side injector connectors (page 77).
15. Disconnect wiring harness connections from the starter.
16. Disconnect the CKP sensor (page 78) and ICP sensor harness connectors.
17. Cut zip ties and disconnect sensor wiring harness connection point on the front of the right cylinder head.
18. Remove the right glow plug harness (page 79).

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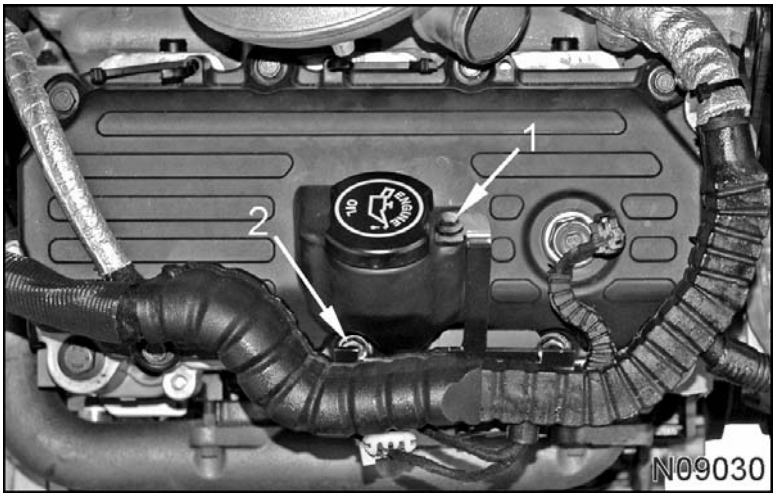

Figure 94 Sensor wiring harness connection points – right valve cover

1. M6 x 16 bolt
2. Stud bolts

19. Remove M6 x 16 bolt from right valve cover and remove the sensor wiring harness bracket from valve cover stud bolts.
20. Press two ECM sensor harness connector lever release tabs and carefully pull open the connector lever.
21. Pull out and disconnect the sensor harness connectors from the ECM.
22. Disconnect the IAH relay and the glow plug relay (page 83) harness connectors.

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Electronic Control Module (ECM)

1. Disconnect ground (-) cable from battery.

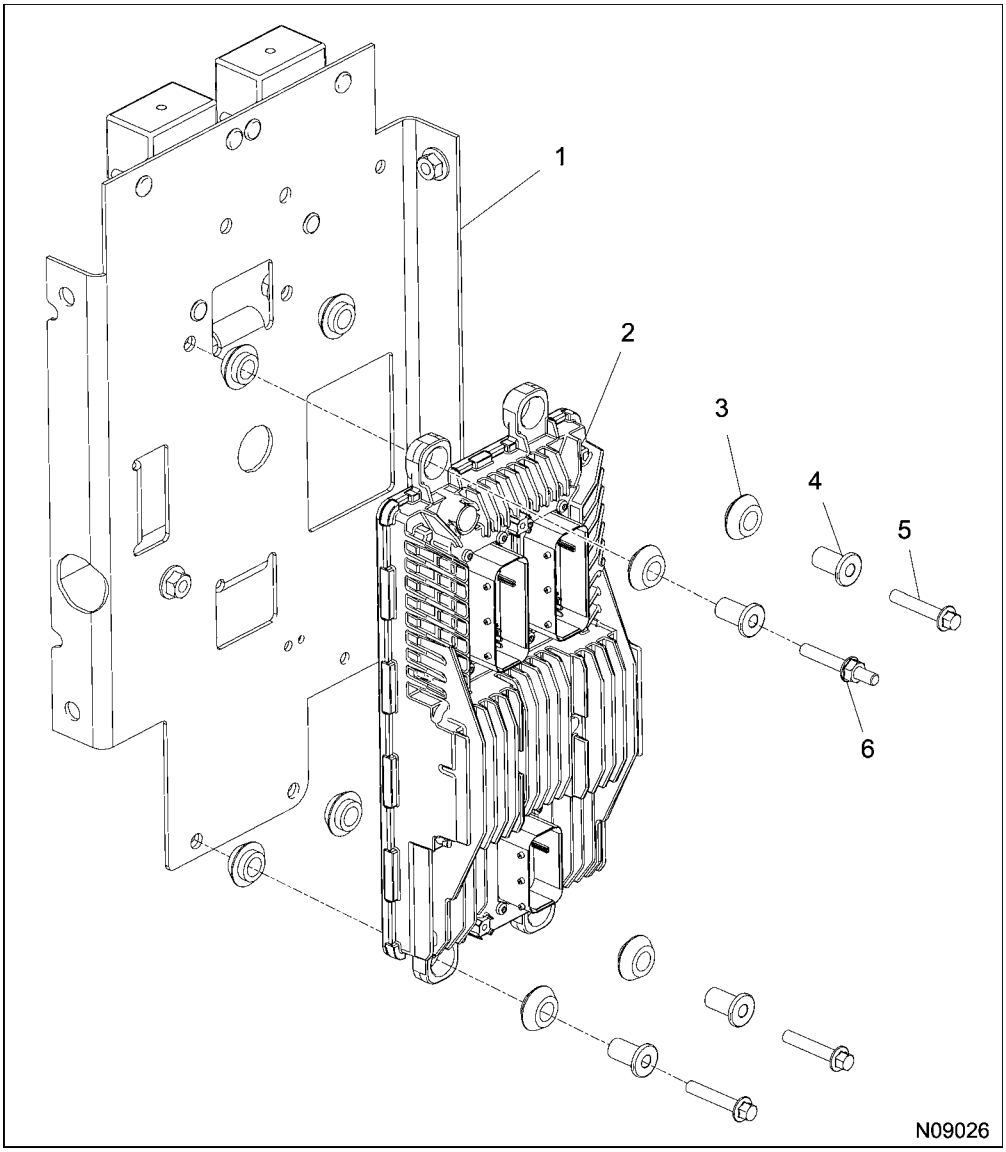

Figure 95 ECM and ECM mounting bracket

1. ECM mounting bracket (chassis mounted)
2. ECM
3. Vibration isolator grommet (8)
4. Vibration isolator bushing (4)
5. M8 x 45 bolt (3)
6. M8 stud bolt

2. Disconnect engine sensor harness and chassis harness connectors from the ECM. Press connector release tabs, rotate connector lever, and pull each connector out of the ECM.
3. Remove three M8 x 45 bolts, one M8 stud bolt and remove the ECM.
4. Remove the vibration isolator bushings and grommets.

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Glow Plug and Intake Air Heater (IAH) Relays

1. Disconnect ground (-) cable from battery.

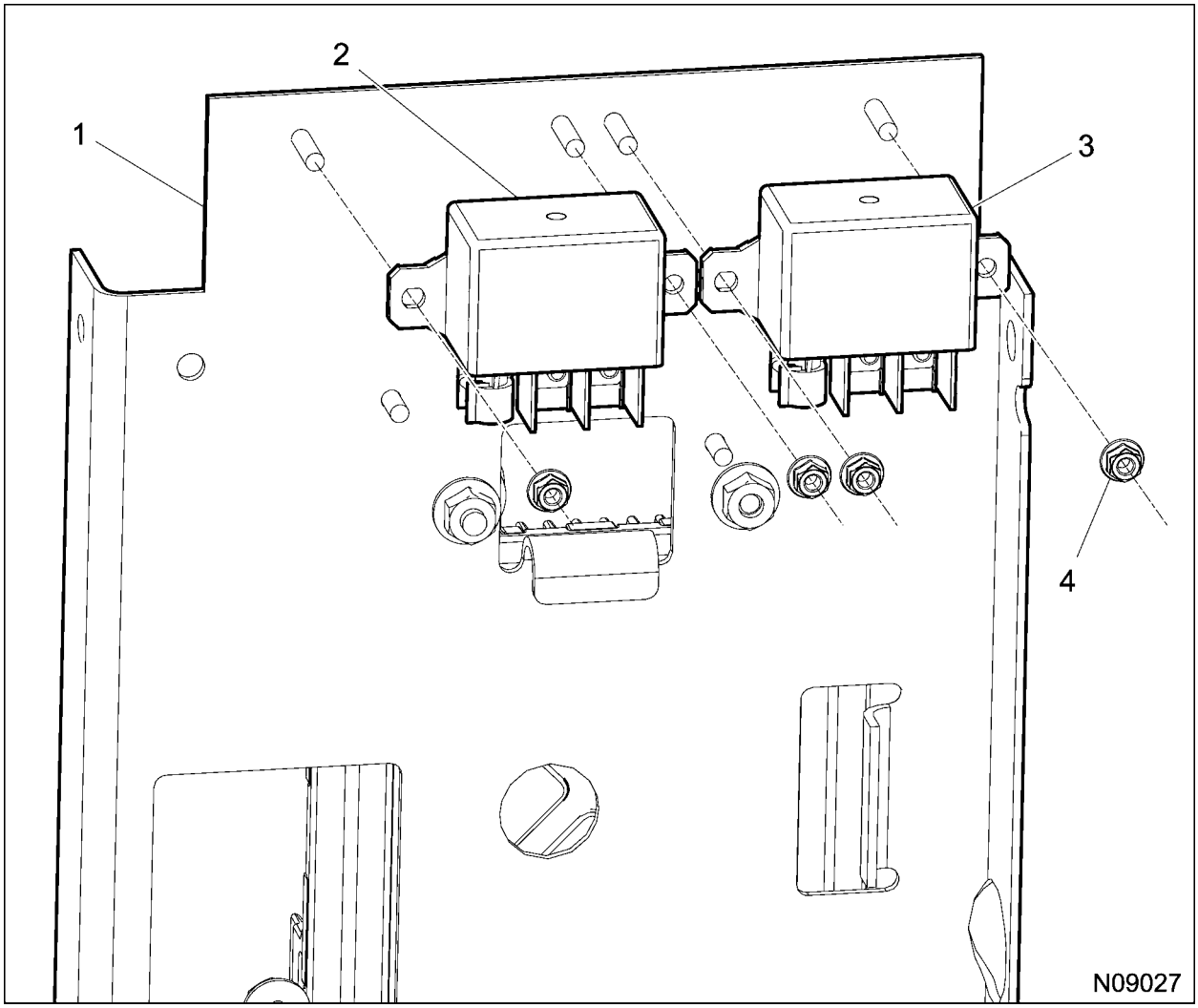

Figure 96 Glow plug relay and IAH relay

1. ECM mounting bracket
2. Glow plug relay
3. Intake Air Heater (IAH) relay
4. M6 nut (4)

2. Disconnect engine sensor harness from the glow plug relay and the IAH relay.
3. Remove four M6 nuts and remove the glow plug relay and the IAH relay.

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Cleaning and Inspection

NOTE: See EGES-395 *Diagnostic Manual* for further inspection and repair of engine electrical components and systems.

Engine Sensor Wiring Harness

1. Carefully inspect wiring harness for bent, missing or broken retaining clips, worn or cut conduit, frayed insulation, or heat damage to wires. Repair or replace as necessary.
2. Check engine wiring harness connectors, connector covers, seals, and cover shields for damage, cracks, cuts, or worn areas. Replace as required.
3. Inspect each sensor and actuator connector for the following, replace as required:
   - Chaffing
   - Cracked connector body.
   - Bent, missing, or broken socket pins.
   - Corroded connectors (green or gray) and white deposits on metal terminals.
   - Terminals incorrectly latched in connector body or “pushed back” relative to other terminals in same connector.
   - Damaged or missing O-rings or seals.

   NOTE: Make sure each connector has its ribbed seal in place. In some cases, upon disassembly, a ribbed seal may pull off of its connector and remain in the mating socket of a sensor or actuator. A connector that is assembled without the appropriate ribbed seal can become contaminated with moisture and corrode terminals, resulting in a poor electrical connection.

Sensors and Actuators

1. Check all connector pins on sensors and actuators. If any are bent or corroded, replace that sensor or actuator.
2. Remove any scale or carbon build up.
3. Check for sensor or actuator body cracks or other indications of leakage.
4. If any sensor orifices or actuators are plugged, replace sensor or actuator as necessary.

Glow Plug Harness

1. Inspect left and right glow plug wiring harness assemblies for defective or twisted O-rings and pin recesses that are corroded.
2. Wipe down glow plug harness assemblies with a shop towel. Do not use solvents. Inspect the glow plug harness for missing or damaged O-rings, replace as necessary.

ECM Assembly

1. Inspect rubber seal on harness connector and in ECM assembly pin recesses.
2. Check for bent pins in ECM assembly connections.

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Installation

Glow Plug and Intake Air Heater (IAH) Relays

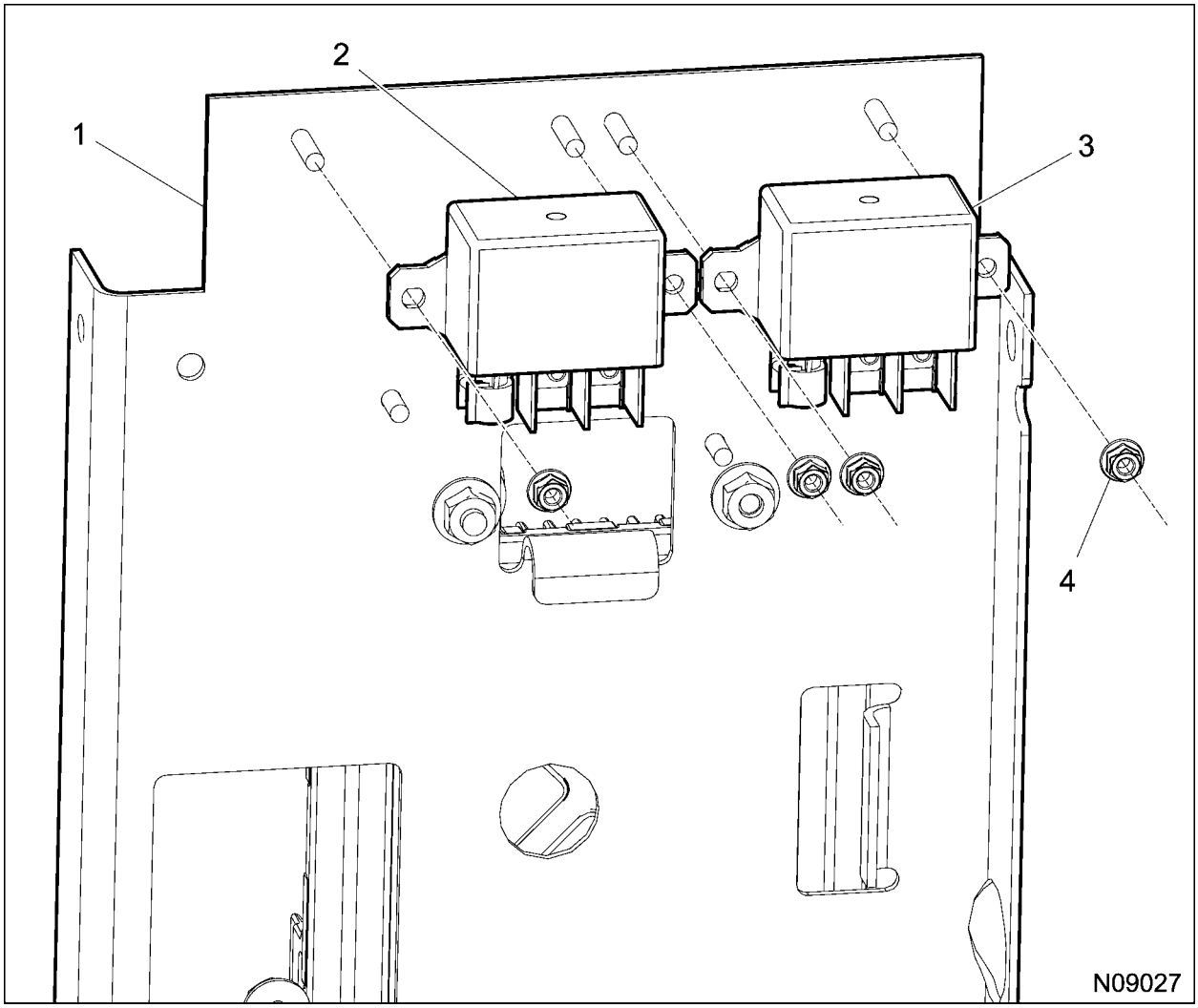

Figure 97 Glow plug relay and IAH relay

1. ECM mounting bracket
2. Glow plug relay
3. Intake Air Heater (IAH) relay
4. M6 nut (4)

1. Install the glow plug relay and the IAH relay on the ECM mounting bracket and install four M6 nuts finger tight.
2. Tighten M6 nuts to standard torque (page 400).
3. Connect the engine sensor harness to the glow plug relay and the IAH relay.

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Electronic Control Module (ECM)

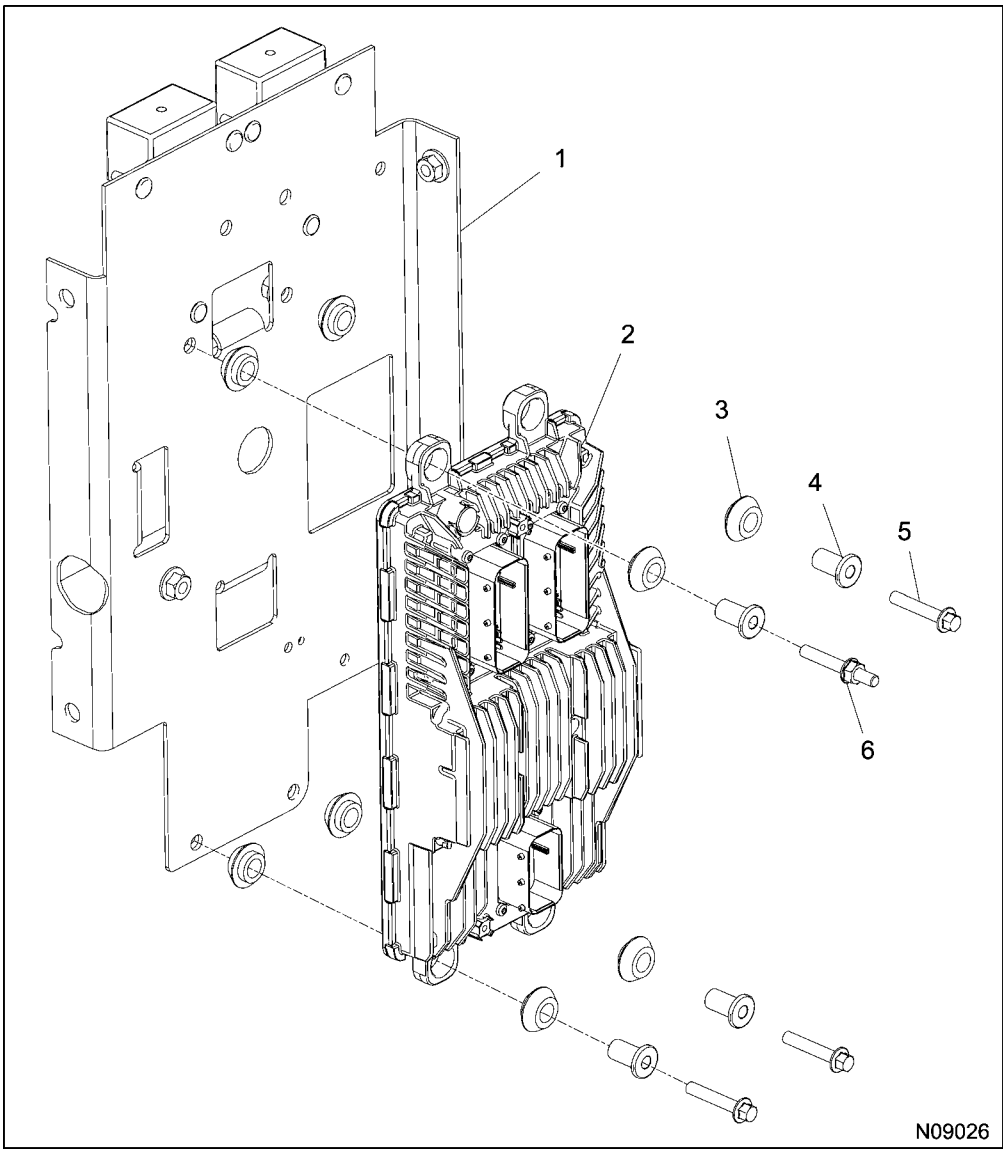

Figure 98 ECM and ECM mounting bracket

1. ECM mounting bracket (chassis mounted)
2. ECM
3. Vibration isolator grommet (8)
4. Vibration isolator bushing (4)
5. M8 x 45 bolt (3)
6. M8 stud bolt

1. Install eight vibration isolator grommets and four bushings on the ECM.
2. Install the ECM on the ECM mounting bracket and finger tighten three M8 x 45 bolts and one M8 stud bolt.
3. Tighten three M8 x 45 bolts and one M8 stud bolt to standard torque (page 400).
4. Install the sensor harness connector into the ECM and close the connector lever until it locks in place.

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Glow Plug Wiring Harness – Right

1. See “Cylinder Head” for glow plug installation.

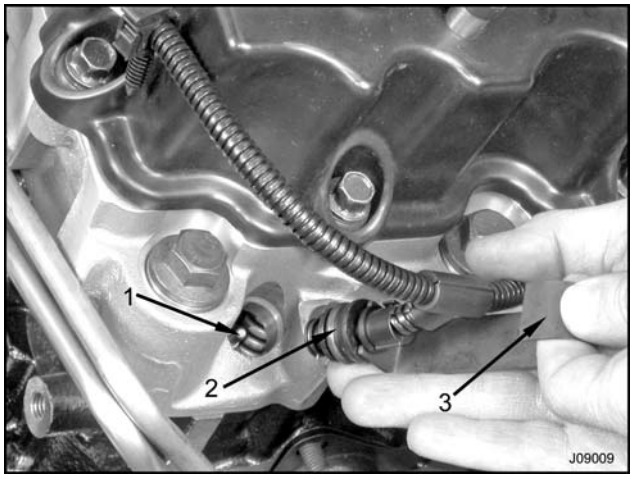

Figure 99 Glow Plug Connector Installer / Remover

1. Glow plug
2. Glow plug harness connector
3. Glow Plug Connector Remover / Installer

2. Install a new O-ring on each of the right glow plug harness connectors and lubricate with clean engine oil.
3. Install each glow plug connector using the Glow Plug Connector Installer / Remover (page 101) tool.

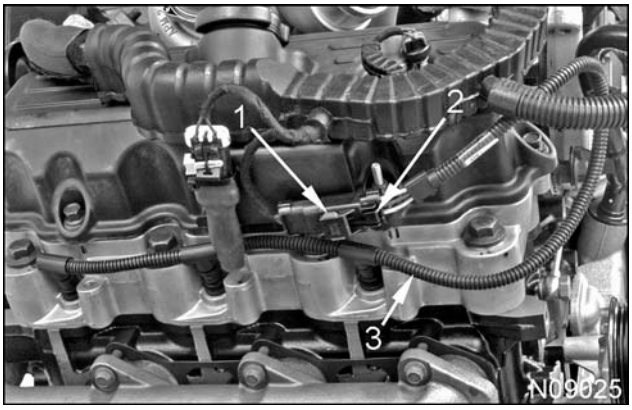

Figure 100 Right glow plug harness

1. Connector locking tab
2. Connector release tab
3. Right glow plug harness

4. Connect the 3-pin glow plug harness connector to the sensor harness connector.
5. Slide the connector locking tab in, to lock the connector.
6. Attach the glow plug harness to connection point on the right front lifting eye.

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Injection Control Pressure (ICP) Sensor

Figure 101 ICP sensor and harness connector

1. Connector release tab
2. ICP sensor

1. Install a new O-ring on the ICP sensor and lubricate with clean engine oil.
2. Install the ICP sensor into the right high-pressure oil manifold and tighten to special torque (page 101).
3. Connect the 3-pin sensor harness connector to the ICP sensor.

Crankshaft Position (CKP) Sensor

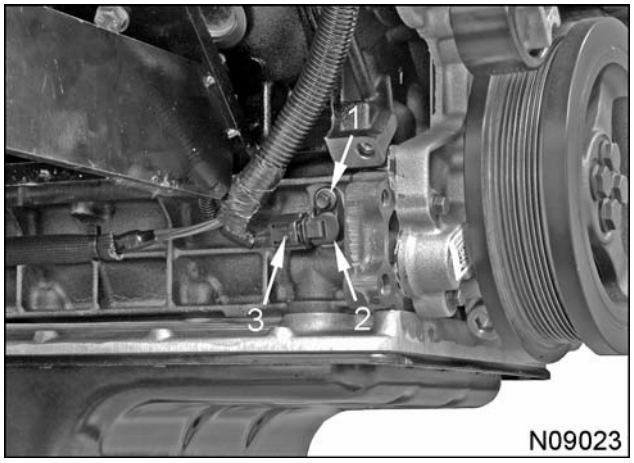

Figure 102 CKP sensor and harness connector

1. M6 x 14 bolt
2. CKP sensor
3. Connector release tab

1. Install a new O-ring on the CKP sensor and lubricate with clean engine oil.
2. Install the CKP sensor in the right side of the crankcase.
3. Install the M6 x 14 sensor retaining bolt and tighten to standard torque (page 400).
4. Connect the 2-pin sensor harness connector to the CKP sensor.

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Injector Harness Connectors – Right

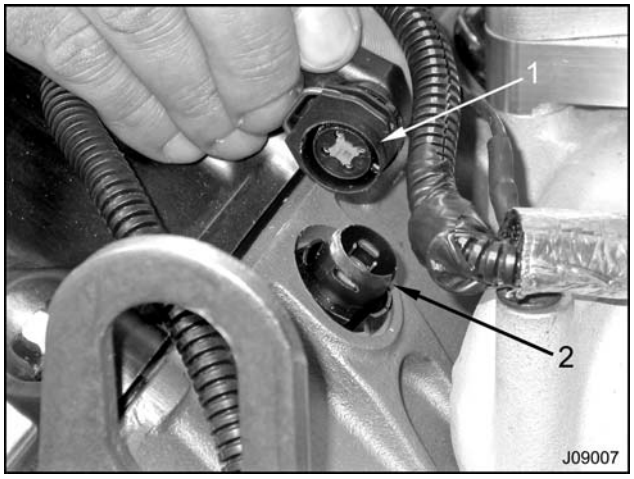

Figure 103 Injector and sensor harness connections

1. Sensor harness connector
2. Injector connector

1. Connect sensor harness connectors to three right side injector connectors, installed in the right rocker arm carrier. A “click” can be heard when connectors are seated.

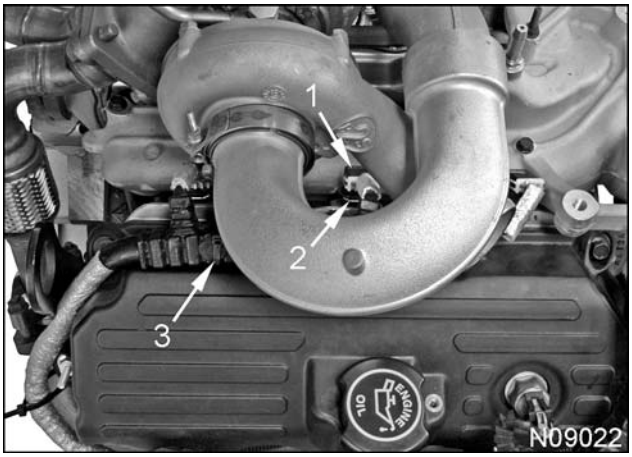

Figure 104 Right injector harness connectors

1. Harness connector
2. Snap ring
3. Zip tie

2. Install three zip ties to hold the sensor harness to the right valve cover.

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Exhaust Gas Recirculation (EGR) Valve Connector

Figure 105 EGR valve and harness connector

1. Connector release tab
2. EGR valve

1. See “Manifolds and Exhaust Gas Recirculation (EGR)” for EGR valve installation.
2. Connect the sensor harness connector to the EGR valve, installed in the front of the intake manifold.

Manifold Absolute Pressure (MAP) Sensor

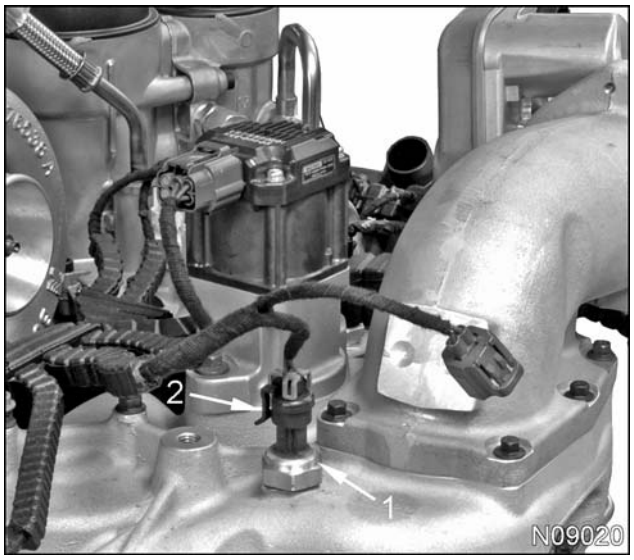

Figure 106 MAP sensor and harness connector

1. MAP sensor
2. Connector release tab

1. Install a new O-ring on the MAP sensor.
2. Install the MAP sensor into the right front of the intake manifold and tighten to special torque (page 101).
3. Connect the 3-pin sensor harness connector to the MAP sensor.

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Boost Control Solenoid (BCS) Assembly

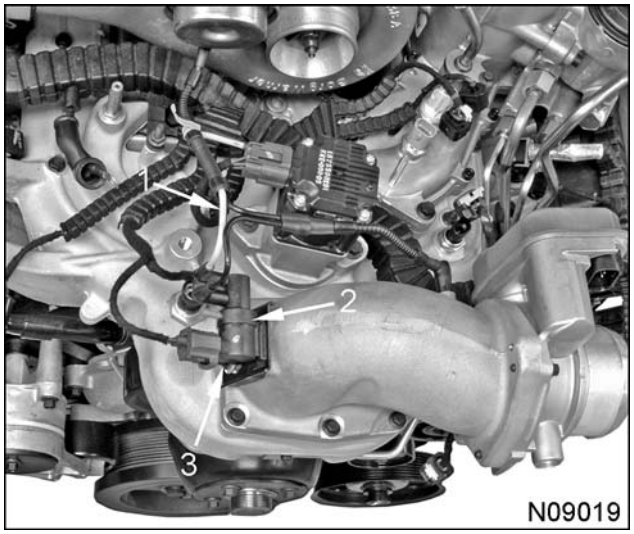

Figure 107 BCS, harness connector, and tube assembly

1. BCS tube assembly
2. BCS assembly
3. M6 x 30 bolt

1. Install the BCS assembly and M6 x 30 bolt on the air inlet elbow.
2. Tighten M6 x 30 bolt to standard torque (page 400).
3. Install the BCS tube assembly on the BCS assembly, air inlet elbow, turbocharger phonemic actuator, and air inlet duct.
4. Connect the 2-pin sensor harness connector to the BCS assembly.

Engine Oil Temperature (EOT) Sensor and Engine Oil Pressure (EOP) Switch

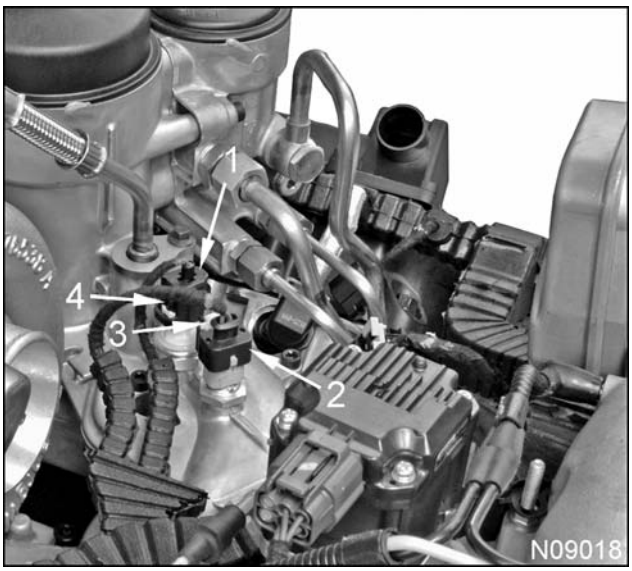

Figure 108 EOT sensor and EOP switch

1. EOP switch harness connector
2. EOT sensor harness connector
3. EOT locking tab (locked position)
4. EOP release tab

1. Install a new O-ring on the EOT sensor and EOP switch.
2. Lubricate O-rings with clean engine oil.
3. Install the EOT sensor and EOP switch into the oil filter base assembly and tighten each to its special torque (page 101).
4. Connect the 2-pin sensor harness connector to the EOT sensor and connect the 1-pin connector to the EOP switch.
5. Push in the EOT harness connector locking tab.

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Intake Throttle Valve (ITV) Assembly Connector

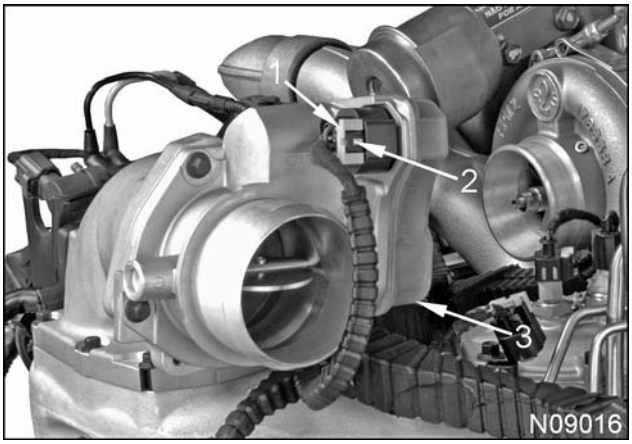

Figure 109 ITV assembly and harness connector

1. Locking tab (locked position)
2. Release tab
3. ITV assembly

1. See “Manifolds and Exhaust Gas Recirculation” for ITV assembly installation.
2. Connect the sensor harness connector to the ITV assembly.
3. Push in the harness connector locking tab.

Intake Air Heater (IAH)

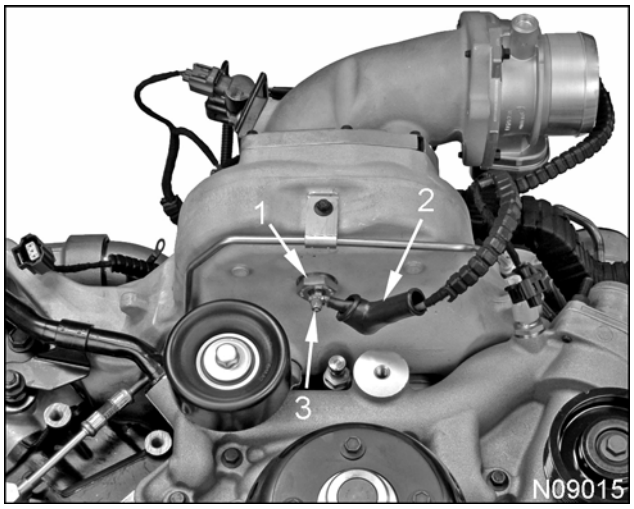

Figure 110 IAH element and harness connection

1. IAH element
2. Rubber boot
3. M5 nut

1. Install the IAH element into the intake manifold and tighten to special torque (page 101).
2. Install the intake heater M5 nut and cable.
3. Tighten M5 nut to special torque.
4. Install rubber boot covering intake heater nut.

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Engine Coolant Temperature (ECT) Sensor

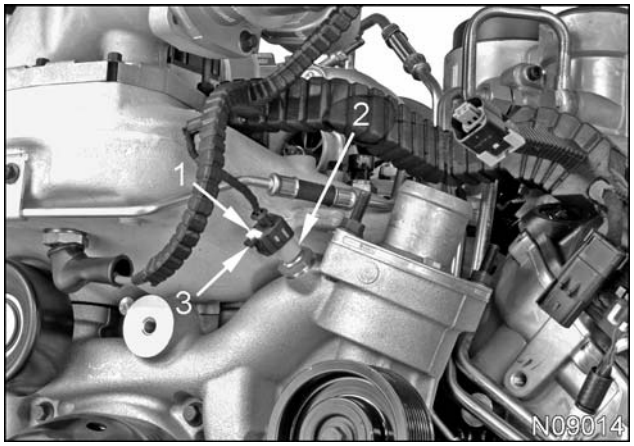

Figure 111 ECT sensor and harness connector

1. Locking tab (locked position)
2. ECT sensor
3. Release tab

1. Install a new O-ring on the ECT sensor.
2. Install the ECT sensor into the top left of the front cover and tighten to special torque (page 101).
3. Connect the 2-pin sensor harness connector to the ECT sensor.
4. Push in the harness connector locking tab.

Manifold Air Temperature (MAT) Sensor

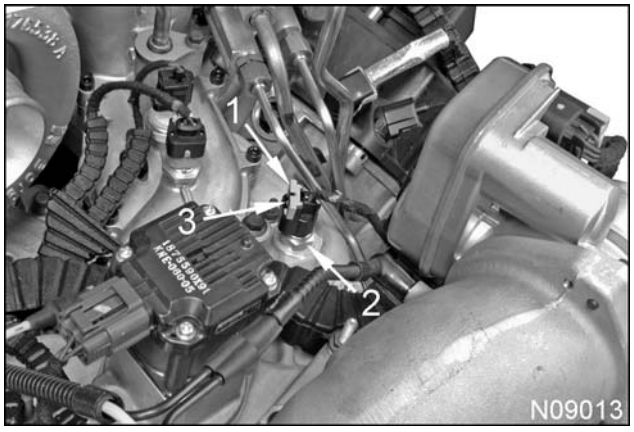

Figure 112 MAT sensor and harness connector

1. Locking tab (locked position)
2. MAT sensor
3. Release tab

1. Install a new O-ring on the MAT sensor.
2. Install the MAT sensor into the left front of the intake manifold and tighten to special torque (page 101).
3. Connect the 2-pin sensor harness connector to the MAT sensor.
4. Push in the harness connector locking tab.

Engine Fuel Pressure (EFP) switch

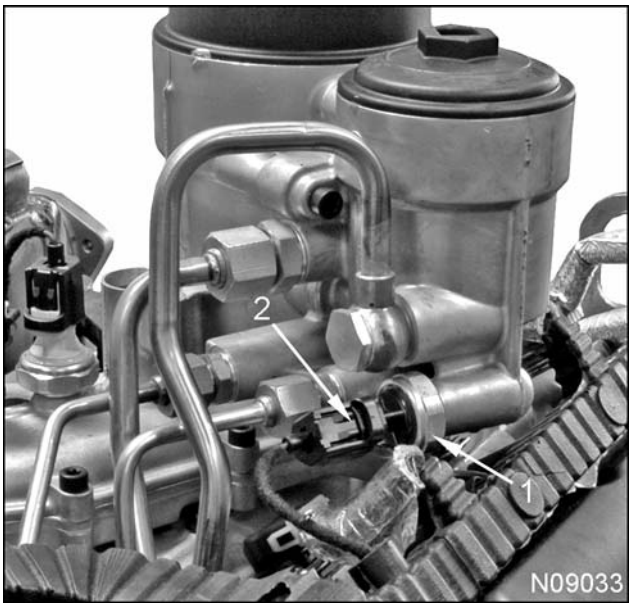

Figure 113 EFP switch

1. EFP switch
2. Release tab

WARNING: To prevent personal injury or death, do not smoke and keep fuel away from flames and sparks.

1. Install a new O-ring on the EFP.
2. Install the EFP into the secondary fuel filter housing and tighten to special torque (page 101).
3. Connect the 1-pin sensor harness connector to the EFP.

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Injector Harness Connectors – Left

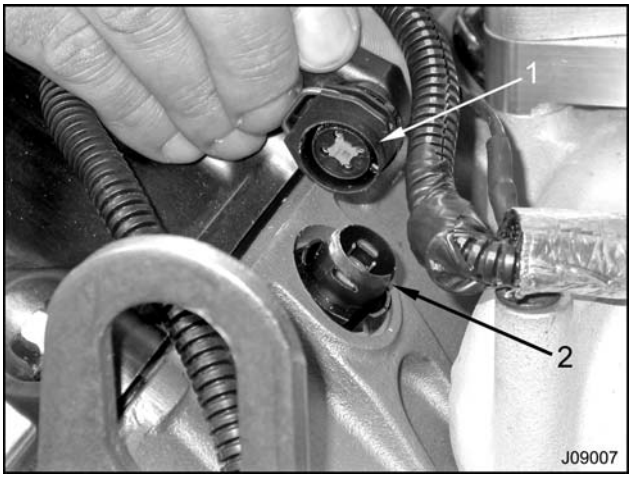

Figure 114 Injector and sensor harness connections

1. Sensor harness connector
2. Injector connector

1. Connect sensor harness connectors to three left side injector connectors, installed in the left rocker arm carrier. A “click” can be heard when connectors are seated.

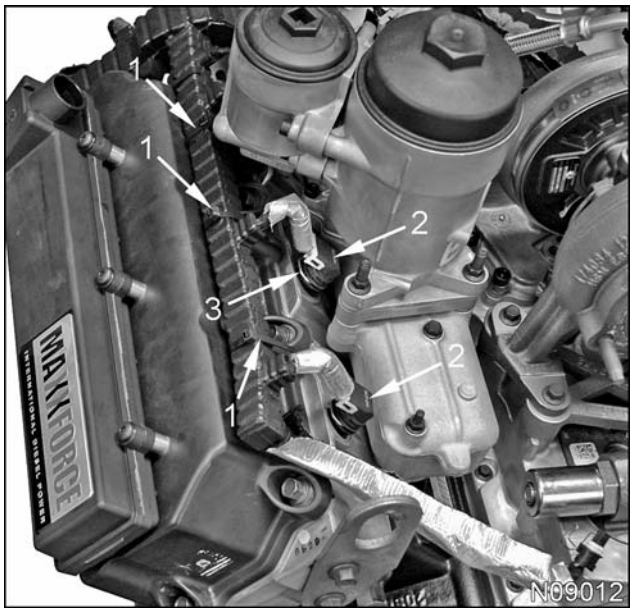

Figure 115 Left injector harness connectors

1. Zip tie
2. Injector harness connector
3. Snap ring

2. Install three zip ties to hold the sensor harness to the left valve cover.

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Glow Plug Wiring Harness – Left

1. See “Cylinder Head” for glow plug installation.

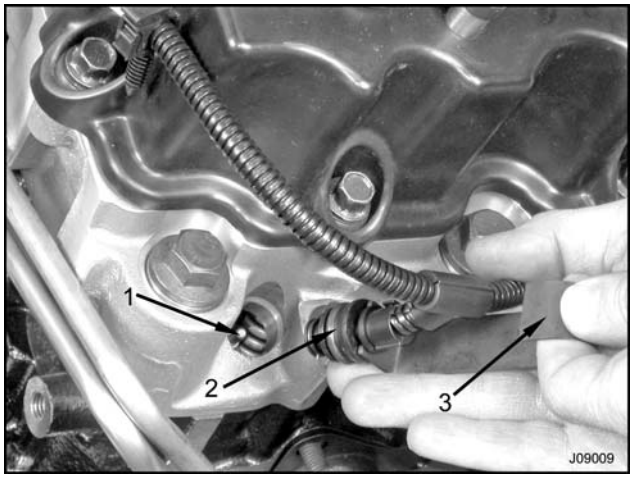

Figure 116 Glow Plug Connector Installer / Remover

1. Glow plug
2. Glow plug harness connector
3. Glow Plug Connector Remover / Installer

2. Install a new O-ring on each of the three left glow plug harness connectors and lubricate with clean engine oil.
3. Install each glow plug connector using the Glow Plug Connector Installer / Remover (page 101) tool.

Figure 117 Left glow plug harness

1. Connector locking tab
2. Left glow plug harness
3. Glow plug harness connector release tab

4. Connect the 3-pin glow plug harness connector to the sensor harness connector.
5. Slide the connector locking tab in, to lock the connector.
6. Attach the glow plug harness to connection point on the front of the left valve cover under the sensor harness.

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Camshaft Position (CMP) Sensor

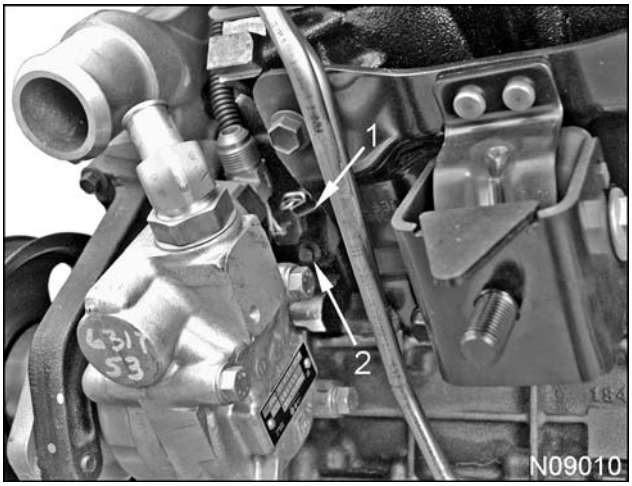

Figure 118 CMP sensor and harness connector

1. CMP sensor harness connector
2. M6 x 14 bolt

1. Install a new O-ring on the CMP sensor and lubricate with clean engine oil.
2. Install the CMP sensor in the left front side of the crankcase.
3. Install the M6 x 14 sensor retaining bolt and tighten to standard torque (page 400).
4. Connect the 2-pin sensor harness connector to the CMP sensor.

Exhaust Back Pressure (EBP) Sensor

Figure 119 EBP assembly

1. EBP sensor harness connector
2. EBP sensor
3. Zip tie

1. Install the EBP sensor into the tube assembly attached to the left exhaust manifold and tighten to special torque (page 101).
2. Connect the 3-pin sensor harness connector to the EBP sensor.
3. Attach a zip tie to hold the sensor harness to the EBP sensor.

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Injection Pressure Regulator (IPR) Valve Connector

1. See “High-pressure Oil System” for IPR valve installation.

Figure 120 IPR valve and harness connector (connector heat shield removed)

1. IPR valve
2. IPR harness connector

2. Install 2-pin IPR valve harness connector into the IPR valve.
3. Install IPR harness connector heat shield and secure heat shield with a zip tie.

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Intake Air Temperature (IAT) Sensor

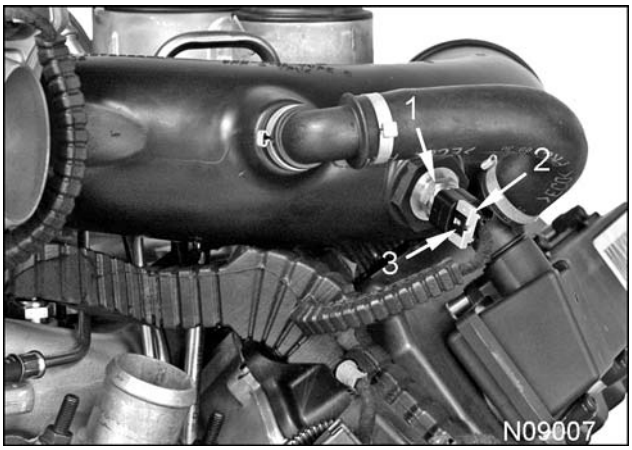

Figure 121 IAT sensor and harness connector

1. IAT sensor
2. Locking tab (locked position)
3. Release tab

1. Install a new O-ring on the IAT sensor.
2. Install the IAT sensor into the turbocharger air intake duct and tighten to special torque (page 101).
3. Connect the 2-pin sensor harness connector to the IAT sensor.
4. Push in the harness connector locking tab.

Alternator

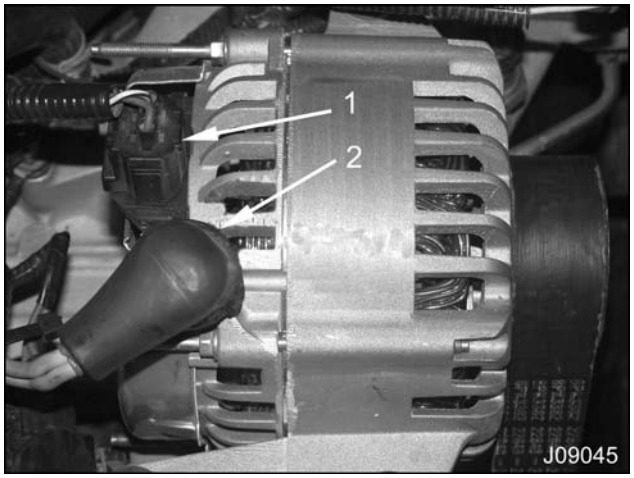

Figure 122 Alternator and sensor harness connections

1. Alternator control harness connector
2. Alternator power connector

1. Install three M10 x 80 bolts holding the alternator to the intake manifold.
2. Tighten three M10 x 80 bolts to special torque (page 101).
3. Install the alternator power connector nut and tighten to special torque.
4. Install the rubber boot over the power connector nut.
5. Install the alternator control harness connector.

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Engine Sensor Wiring Harnesses

NOTE: Refer to Installation procedures for location photos of individual components.

1. Connect the IAH relay and the glow plug relay (page 85) harness connectors.
2. Install the sensor harness connectors into the ECM (page 86) and close the connector lever until it locks in place.

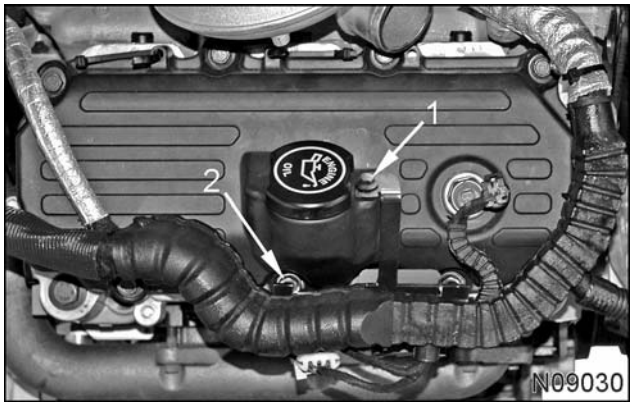

Figure 123 Sensor wiring harness connection points – right valve cover

1. M6 x 16 bolt
2. Stud bolt (2)

3. Install the sensor wiring harness bracket on the right valve cover stud bolts.
4. Install M6 x 16 bolt on the right valve cover and tighten to standard torque (page 400).
5. Install the right glow plug harness (page 87).
6. Connect the sensor wiring harness to connection point on the front of the right cylinder head and install zip ties.
7. Connect the ICP sensor (page 88) and CKP sensor harness connector.
8. Connect wiring harness connections to the starter.
9. Install sensor wiring harness to the right side injector connectors (page 89) and install new zip ties.

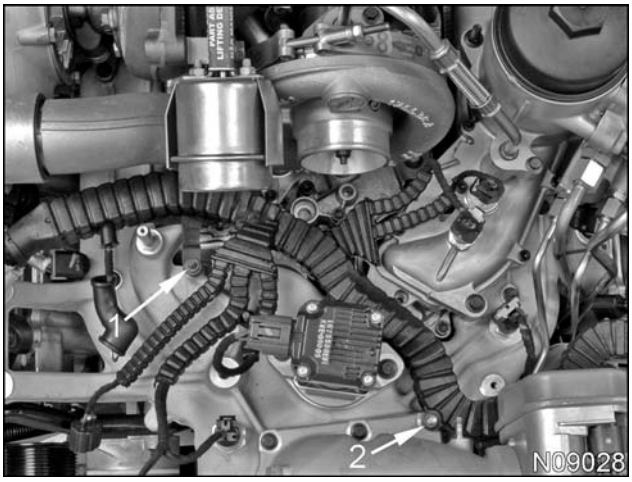

Figure 124 Sensor wiring harness connection points – intake manifold

1. M6 nut on stud in right front of intake manifold
2. M6 nut on air intake elbow stud

10. Install M6 nut holding the sensor wiring harness to the top right front of the intake manifold. Tighten M6 nut to standard torque (page 400).
11. Connect the EGR valve (page 90), MAP sensor, BCS assembly (page 91), EOT sensor, and EOP switch harness connectors.
12. Install the M6 nut holding the sensor wiring harness to the air intake elbow stud. Tighten M6 nut to standard torque (page 400).
13. Connect the ITV assembly (page 92), IAH element, ECT sensor (page 93), MAT sensor, and EFP switch harness connectors.

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14. Install sensor wiring harness on the left side injector connectors (page 94) and install new zip ties.
15. Install left side glow plug harness (page 95).

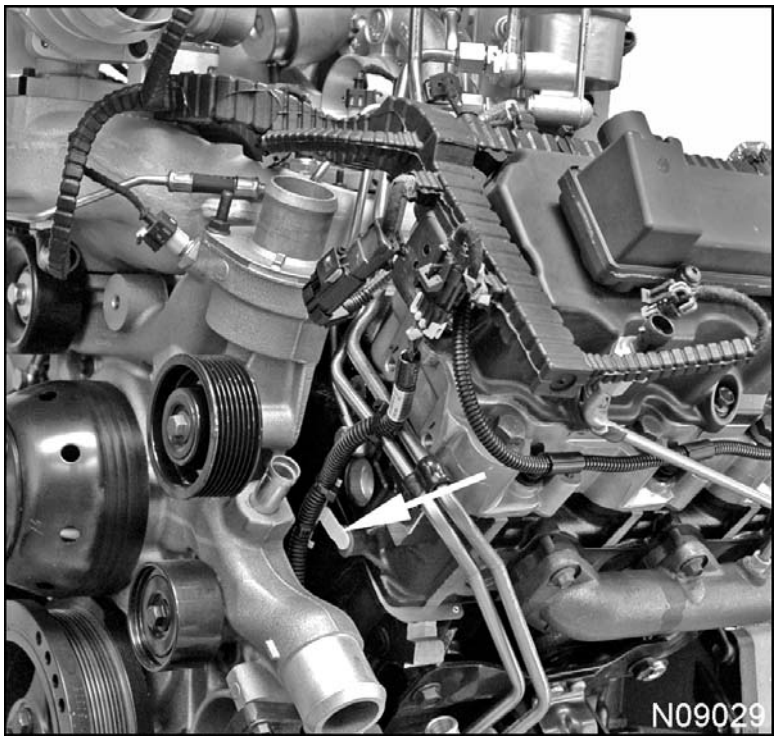

Figure 125 CMP sensor wiring harness connection point – left cylinder head

16. Connect the CMP sensor wiring harness to connection point on the left front cylinder head.
17. Connect the CMP sensor (page 96) , EBP sensor, and IPR valve (page 97) harness connectors.
18. Install the turbocharger air intake duct.
19. Connect the IAT sensor (page 98) harness connector.
20. Connect the alternator (page 98) harness connectors.

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Specifications

Glow plugs	10.9 V to 11.1 V
Intake Air Heater (IAH)	60 Amps
Camshaft Position (CMP) sensor operating speed	30 rpm to 3000 rpm
Crankshaft Position (CKP) sensor operating actuator speed	15 rpm to 2000 rpm

Special Torque

Alternator M10 x 80 mounting bolts	48 N·m (35 lbf·ft)
Alternator power connector nut	8 N·m (71 lbf·in)
Engine Coolant Temperature (ECT) sensor	17.5 N·m (154 lbf·in)
Engine Oil Pressure (EOP) sensor	14 N·m (124 lbf·in)
Engine Oil Temperature (EOT) sensor	17.5 N·m (154 lbf·in)
Exhaust Back Pressure (EBP) sensor	20 N·m (178 lbf·in)
Engine Fuel Pressure (EFP) switch	14 N·m (124 lbf·in)
Injection Control Pressure (ICP) sensor	17 N·m (150 lbf·in)
Intake Air Heater (IAH) element	61 N·m (45 lbf·ft)
Intake Air Heater (IAH) element M5 cable nut	4 N·m (35 lbf·in)
Intake Air Temperature (IAT) sensor	14 N·m (124 lbf·in)
Manifold Absolute Pressure (MAP) sensor	11.5 N·m (101 lbf·in)
Manifold Air Temperature (MAT) sensor	14 N·m (124 lbf·in)

Special Service Tools

Glow Plug Connector Installer / Remover	ZTSE4670

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