



SUBARU®

Confidence in Motion

Technician Reference Booklet

Basic Fuel Injection Part 3



June 2016

MSA5P2410C

04L202009I

This Technician Reference Booklet (TRB) is designed to be used in a classroom environment or as a guide for self study.

The TRB is not intended to be used as a supplement or substitute for the Subaru Service Manual. Always consult the appropriate Service Manual when performing any diagnostics, maintenance or repair to any Subaru vehicle.

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Basic Fuel Injection Part 3

Student Objectives

The Subaru Technician will have completed the following objectives upon successful completion of the Basic Fuel Injection Part 3 Module:

- a. Explain the proper safety equipment and procedures used when working on the Subaru fuel injection system.
- b. Identify the properties of air composition and pressure.
- c. Explain the principals of combustion.
- d. Explain the operation of the fuel supply system.
- e. Explain the operation of the waste-spark and coil-over-plug ignition systems
- f. Explain the operation and testing of the air induction system.
- g. Identify the fuel system operating status.
- h. Explain the operation and testing of the fuel supply system.
- i. Explain the testing of the fuel injection system.
- j. Explain the properties and testing procedures of fuel.
- k. Explain the testing of the ignition system components.
- l. Explain the operation and testing of the PCV system.
- m. Explain the operation and testing procedures of the ETC and SI drive system.
- n. Explain the operation of the turbocharger system.

Basic Fuel Injection Part 3

Safety Precautions

Upon completion of this lesson you will be able to:

- Explain the proper safety equipment and procedures used when working on the Subaru fuel injection system.

Personal Protective Equipment Overview

The proper use of personal protective equipment is your best defense against common workplace injuries. Subaru recommends the use of safety goggles, protective gloves, and safety shoes to provide additional protection when handling batteries, gasoline, or other harmful chemicals. Personal safety should always be a high priority when working around or using hand or power tools.



1-1

Personal Protective Equipment

When servicing a fuel system, always adhere to the safety Cautions and Warnings as directed by the service manual, Subaru Technical Information System (STIS).

A CAUTION describes prohibited matters to prevent vehicle or component damage, or matters that require special attention during a service procedure.

A WARNING describes matters that may cause serious damage to the technician or another person, or that may cause damage or accident.

Basic Fuel Injection Part 3

Personal Injury Safety Precautions

Protect yourself and others around you by adhering to the following safety Cautions:

- Wear approved safety glasses while performing any repairs.
- Safety glasses are recommended in the shop area at all times.
- Safety glasses protect eyes from airborne debris and chemicals.



1-2

Protective Equipment In Use

- Position the vehicle in a clear, level, well-ventilated work area.
- Make sure there are no sources of spark or combustion near the work area.
- Perform work in a no-smoking area, or post no-smoking signs in the area selected.
- Have a fully functional Class ABC fire extinguisher of adequate size readily available.

Notes:

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- Extinguishers are checked annually to be sure they are fully charged and in good working condition.
- For proper safety procedures, be aware of where the fire extinguishers are located within the shop.
- Disconnect the ground cable from the vehicle's battery before performing any operation involving gasoline, gasoline tanks, or gasoline lines.
- When raising the vehicle to perform under-vehicle services, use proper hoisting or jacking equipment along with approved safety supports.
- Use a safety helmet when working under a vehicle to protect your head from impacts.
- Allow the vehicle to cool before performing any operation that could possibly expose gasoline or gasoline vapors to hot parts, such as catalytic converters, hot light bulbs, or similar components.
- Avoid inhaling gasoline fumes and prolonged skin contact with gasoline. Promptly wash any areas on your body that have been in contact with gasoline.
- When removing the gasoline from a fuel tank, use an Occupational Safety and Health Administration (OSHA) approved fuel pump that is specifically designed for handling gasoline.
- The fuel system is under pressure. Release fuel pressure before servicing the fuel system or fuel may contact eyes and skin, causing serious personal injury.
- Protect your hands from sharp objects, hot objects, and chemicals by using mechanic's gloves.
- Risk of explosive fumes can cause death or serious personal injury.
- Wear safety boots or shoes with an oil resistant sole to prevent slipping and protect your feet from falling objects.
- Refer to the Resources section of the course for Fuel System Cautions and Warnings. pdf for future reference.

Note: Fuel pump fuse location will vary by vehicle model.

Notes:

Notes:

This image shows a full page of blank, lined paper. It features approximately 30 horizontal black lines spaced evenly across the page, typical of notebook paper. The lines are thin and extend from the left edge to the right edge. There are no margins, text, or other markings on the page.

Basic Fuel Injection Part 3

Understanding the “Air” in the Air/Fuel Mixture

Upon completion of this lesson you will be able to:

- Identify the properties of air composition and pressure.
- Explain the operation and testing of the air induction system.

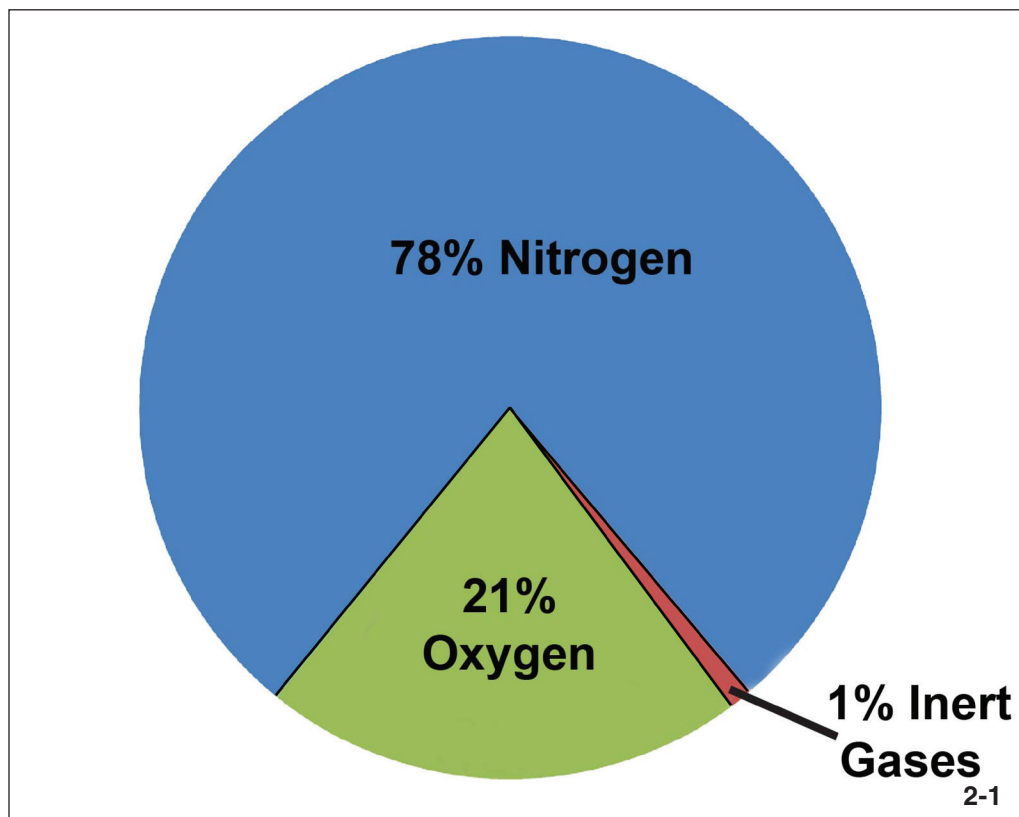
Identify the Properties of Air Composition and Pressure

Metering and monitoring the air supply to the combustion chamber is critical for efficient operation of the gasoline engine. Remember that air pressure changes with altitude, and the vacuum created when the piston moves downwards on naturally-aspirated engines pulls the air into the cylinders with the push from atmospheric pressure.

Introducing air into naturally-aspirated engines relies solely on the pressure differences between the atmosphere and the vacuum in the engine. On a turbocharged engine, during boost, the turbocharger impeller forces additional air into the cylinder.

Atmospheric pressure is the pressure formed by the air surrounding the Earth.

The atmosphere is composed of 78% nitrogen, 21% oxygen, and 1% inert gases.



Air Composition

Vacuum vs. Pressure

Vacuum is the difference between the air pressure of the engine's intake manifold and Earth's atmosphere. The pressure of the atmosphere at sea level is 14.7 psi (101.4 kPa).

Atmospheric pressure is monitored by a sensor in the ECM. On late model vehicles a component within the evaporative emissions system is used to provide this information.

Basic Fuel Injection Part 3

A vacuum gauge is calibrated to read 0 at atmospheric pressure, meaning the vacuum gauge reads pressure relative to atmospheric pressure. A typical vacuum reading for an engine in good running condition at idle and at sea level is 18–22 inHg (457–559 mmHg).

Engine vacuum readings vary with a change in altitude. For every 1000 ft (304.8 m) above sea level, vacuum decreases about 1 inch of mercury (25.4 mmHg). The decrease in vacuum is directly proportional to the atmospheric pressure gauge (14.7 psi at sea level) (101.4 kPa) being reduced by 1 psi (6.9 kPa) per 1000 ft (304.8 m) of altitude increase (a drop in atmospheric pressure equates to a lower volume of air per square inch).

Altitude	Vacuum (in. Hg)	Vacuum (mmHg)
Sea Level	18 – 22	457 – 559
1000 – 2000 ft.	17 – 21	439 – 533
2000 – 3000 ft.	16 – 20	406 – 508
3000 – 4000 ft.	15 – 19	381 – 483
4000 – 5000 ft.	14 – 18	356 – 457
5000 – 6000 ft.	13 – 17	330 – 432 ²⁻²

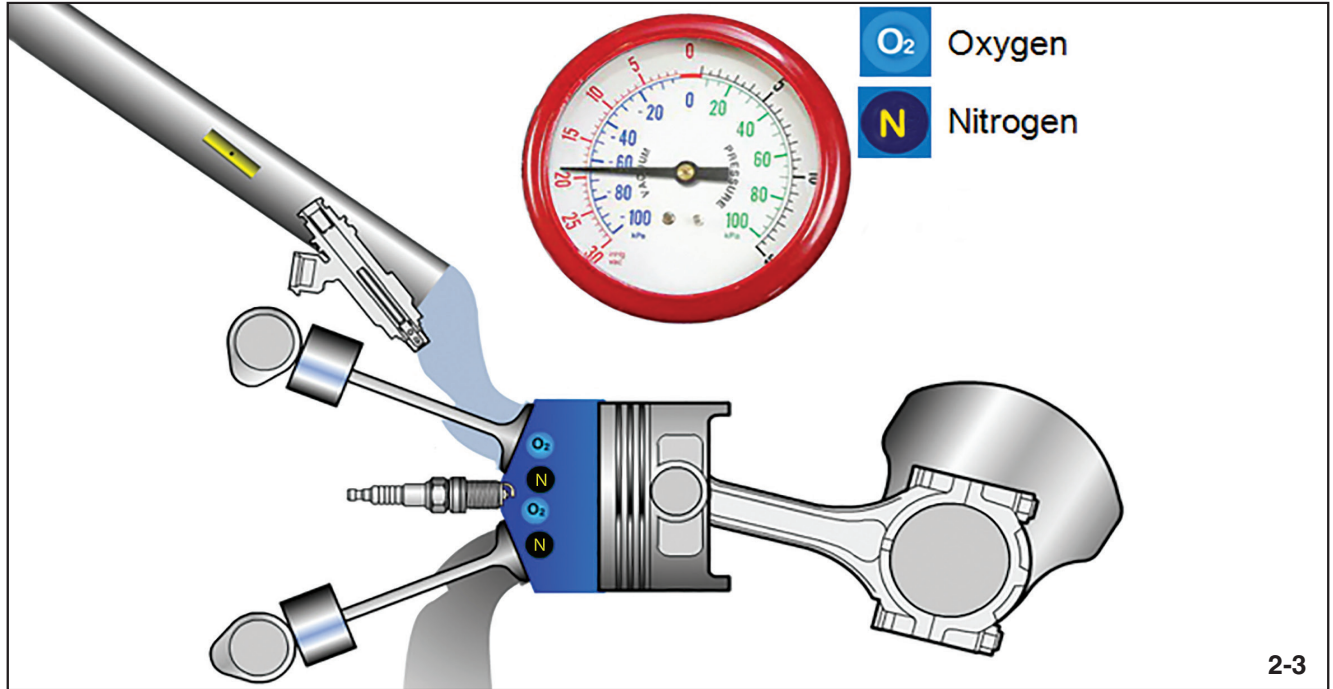
Vacuum vs. Altitude (Absolute Pressure)

Notes:

Basic Fuel Injection Part 3

Vacuum and How it is Generated

When the engine is running at idle, the piston is pulling air in through the intake valves, intake manifold, and throttle plate. The piston generates a vacuum within the intake manifold when the piston is on its downward stroke, and the throttle plate is closed because the piston is no longer taking up volume in the cylinder. The vacuum can be measured using the vacuum gauge, which displays a measurement of the difference between intake pressure and atmospheric pressure.



Vacuum Generation

When the engine is at wide open throttle, the throttle plate is fully open; pressure within the intake manifold is at 0 inHg (0 mmHg) or atmospheric pressure, allowing maximum airflow. The pressure difference is minimal.

Note: When a turbocharged engine is operating in a boosted condition, pressure within the intake measures above atmospheric pressure.

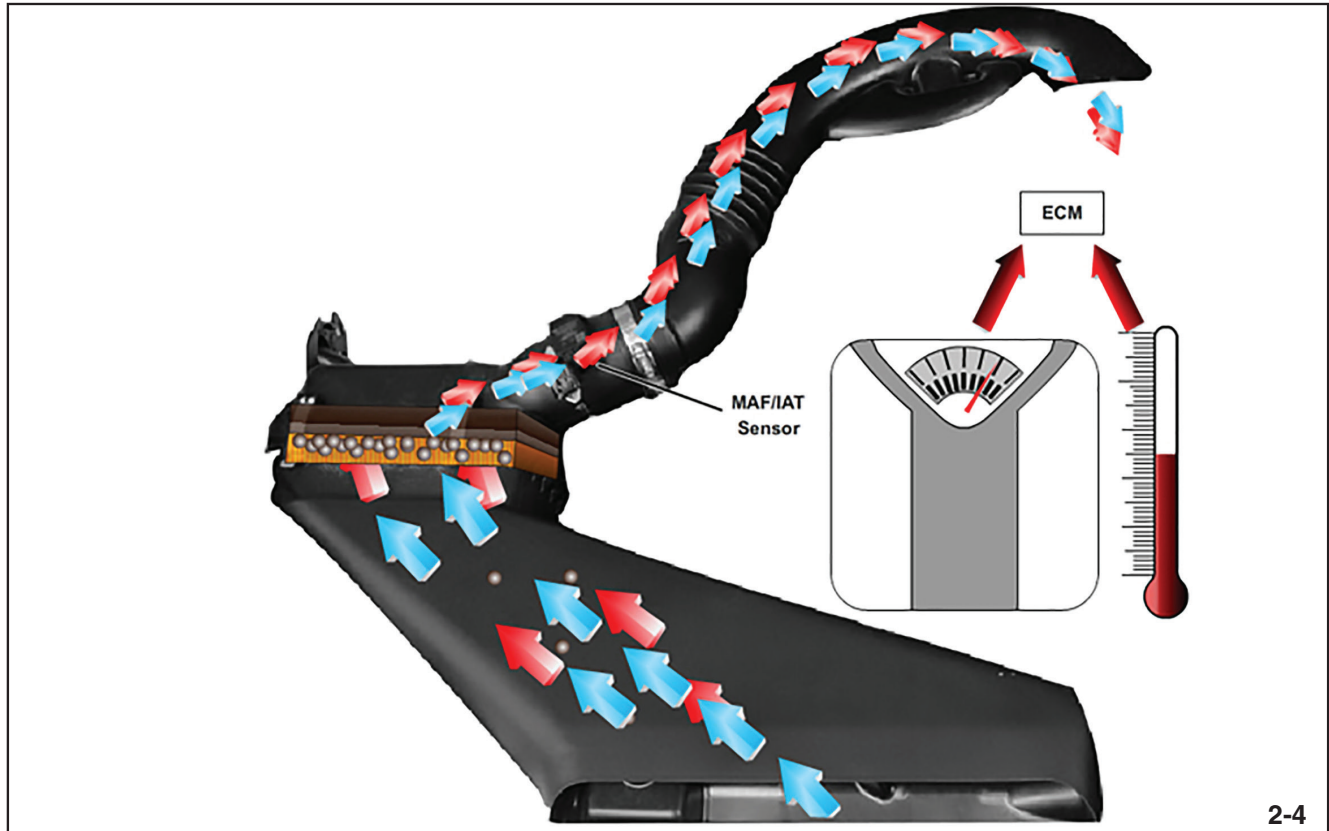
Notes:

Basic Fuel Injection Part 3

Induction System Components

The air induction system includes the following air inlet components: the air inlet ducts, air filter and housing, Mass Air Flow (MAF) sensor, resonator, throttle body, Tumble Generator Valve (TGV) system, intake manifold, and Manifold Absolute Pressure (MAP) sensor.

The air induction system filters, measures, and detects the temperature of the incoming air. The air induction system is equipped with sensors to provide data to the Engine Control Module (ECM). The ECM uses this information to help calculate the proper air/fuel ratio.



Induction System

Once the air has entered the induction system, it must be measured. Over the years, Subaru has used two different systems either together or separate. The decision to use one or both systems mainly depends on the government regulations set forth for a given year and model type.

These two systems are: the air flow meter and the manifold pressure sensor.

In either case, the goal of the air measurement is to provide the ECM with the information necessary to match the amount of air coming into the engine with the correct amount of fuel. This provides a stoichiometric burn of the air/fuel mixture, and provides the correct engine speed and power for any given vehicle condition or driver demand.

Notes:

Basic Fuel Injection Part 3

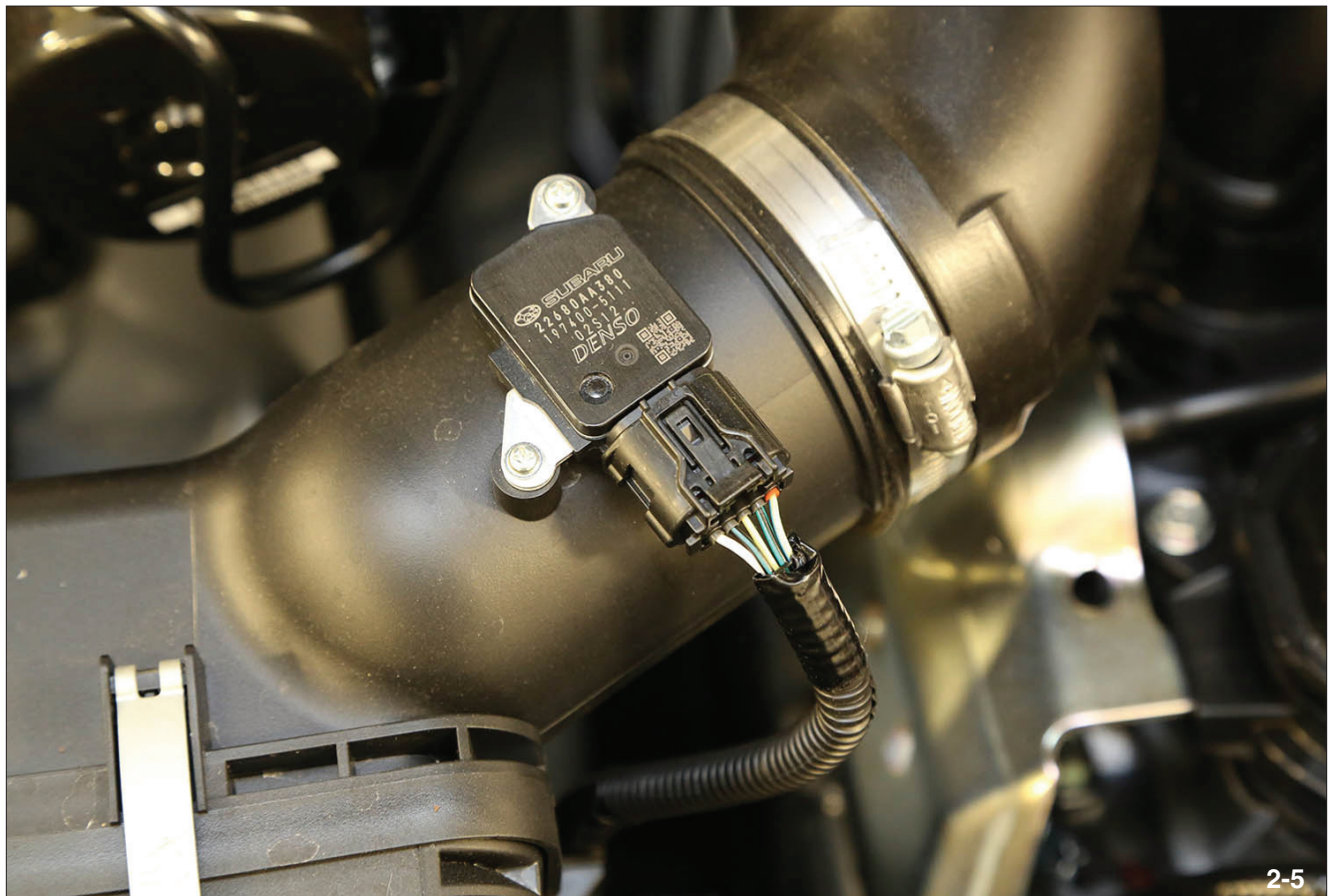
Mass Air Flow Sensor

The MAF and MAP sensors have changed many times since their introduction, but the results have stayed the same. The characteristics of the airflow meter show that it provides a very sensitive and very accurate measurement of the inducted air as long as the volume remains at a somewhat constant level, such as cruising.

Conversely, manifold pressure sensors show their best results during changes from one level of operation to another, such as going from cruising to wide open throttle. Using both sensors ensures that all operations and conditions of the vehicle are monitored to the most possible accurate means available.

The resonator is attached to the air cleaner housing and reduces the intake air noise level. The air inlet duct directs filtered and measured air to the throttle body.

The mass airflow sensor is located in the inlet air tube or air filter cover opening and includes the Intake Air Temperature (IAT) sensor. The engine control module monitors the mass airflow sensor output voltage on the signal circuit to adjust fuel injection amount and ignition timing.



Mass Air Flow Sensor

Notes:

Basic Fuel Injection Part 3

The input of the airflow sensor signal to the ECM determines the Quotient of Air (QA) value of the engine. The ECM compares this value to engine RPM to determine estimated engine load. Air entering the intake manifold from any source other than through the airflow sensor will result in lowered engine load values.

The construction of the mass airflow sensor consists of two reference resistors with fixed values, a cold wire or temperature offset resistor and a hot wire or hot film, and supporting operating circuits.

Note: The construction of the mass airflow sensor has changed over the years and it will be equipped with either the hot wire or the hot film-type sensor. The operational differences between the two are small. The following is a general description of operation for both types of airflow sensors.

During operation, the temperature offset resistor or cold wire and hot wire or hot film are exposed to the incoming airflow. Normal temperature of the hot wire or film is approximately 190–250 °F. As air flows across the cold and hot wire, heat is removed, which alters the resistance of each wire.

The cold wire has no self-generating heat capability, so its resistance is based on temperature. The cooler the cold wire becomes, the lower its resistance. The warmer the cold wire becomes, the higher its resistance. Positive Temperature Coefficient (PTC) effect.

The hot wire is designed to generate heat and alter its resistance with current flow, also a PTC effect.

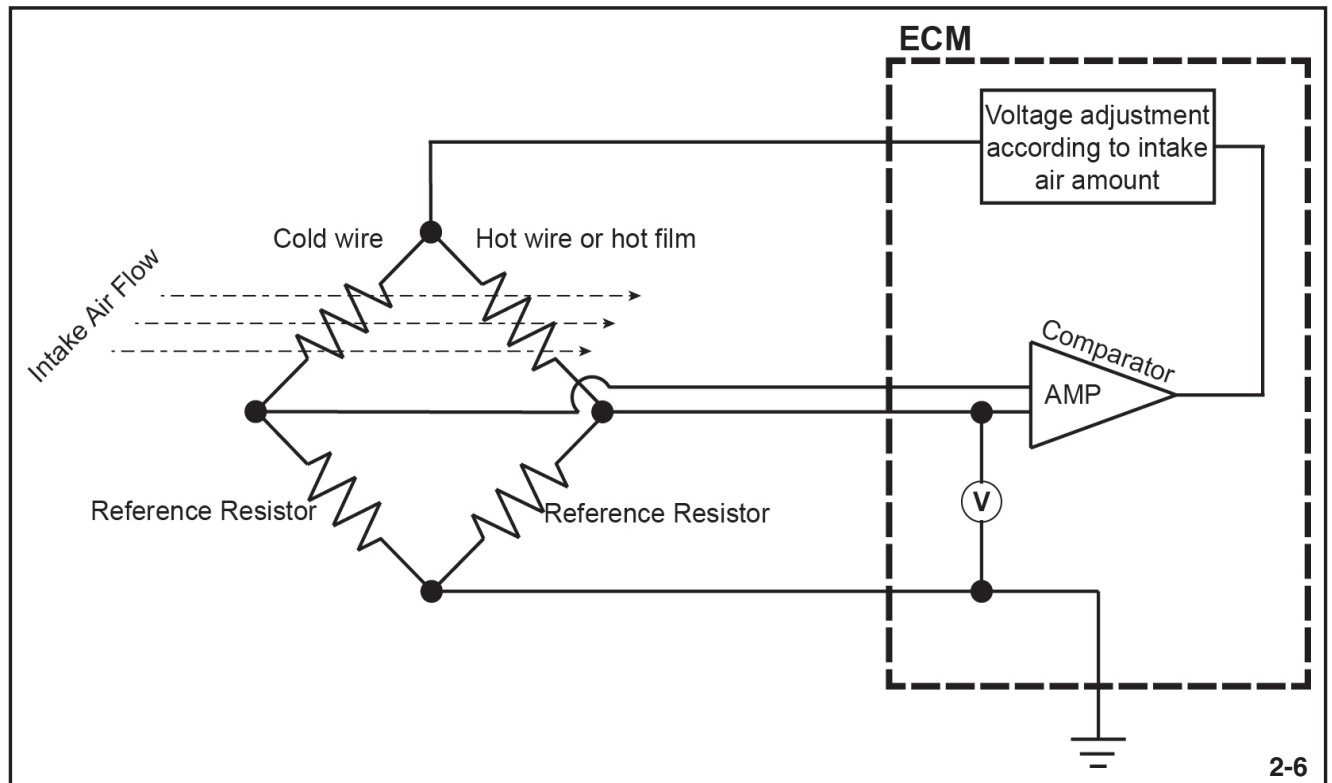
These two characteristics allow a set difference in temperature to exist between the cold and hot wire. Monitoring the voltage at the output side of the hot wire allows the ECM to determine airflow quantity or mass.

When the airflow is large, the temperature decrease will be high. Conversely, when the airflow is small and the heat taken away is small, the temperature will decrease little.

Based on this principle, in order to keep the hot wire within a certain temperature range, the larger the air volume, the more current the hot wire needs to maintain temperature.

Notes:

Basic Fuel Injection Part 3



Mass Air Flow Sensor Internal Circuit

The circuit shown provides two paths to body ground. On the cold wire side, the only thing preventing the voltage from shorting to ground is the resistance of the fixed reference resistor and the changing resistance of the cold wire.

On the hot wire side, the only thing preventing the voltage from shorting to ground is the resistance of the fixed reference resistor and the changing resistance of the hot wire.

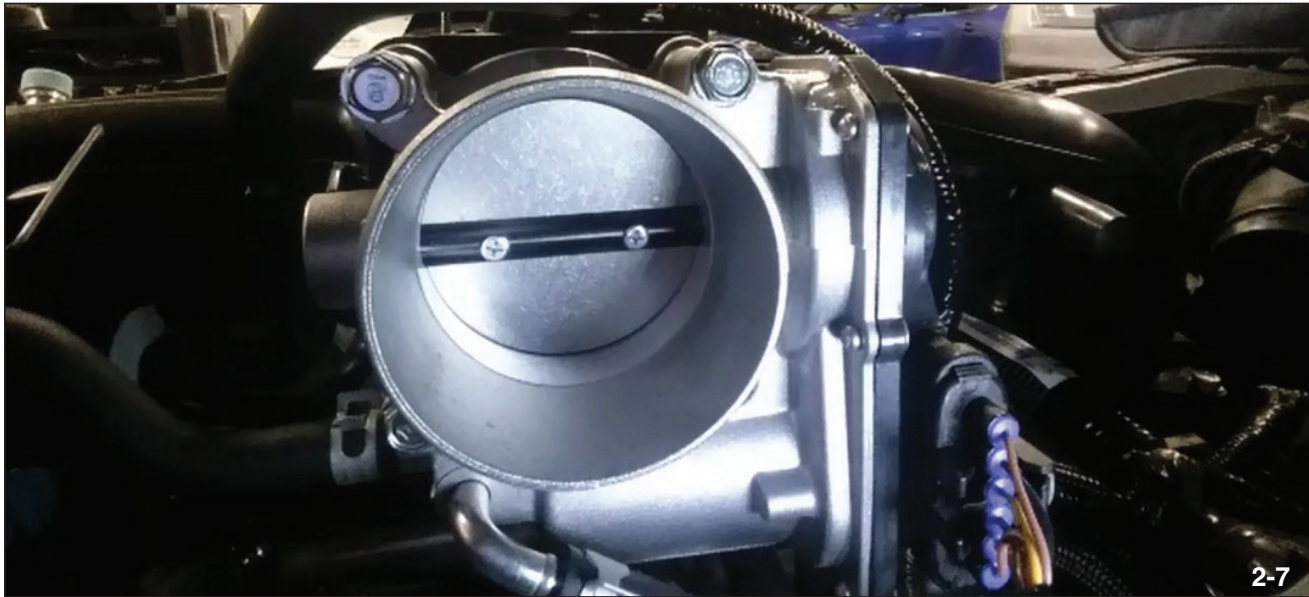
As the cold wire cools down, its resistance drops, which increases the voltage and current flow on the cold wire side. This lowers the voltage flow on the hot wire side, which lowers the hot wire resistance. This will then increase voltage and current flow through the hot wire and reduces voltage and current flow through the cold wire side.

This back and forth action occurs very rapidly to produce a steady input to the ECM.

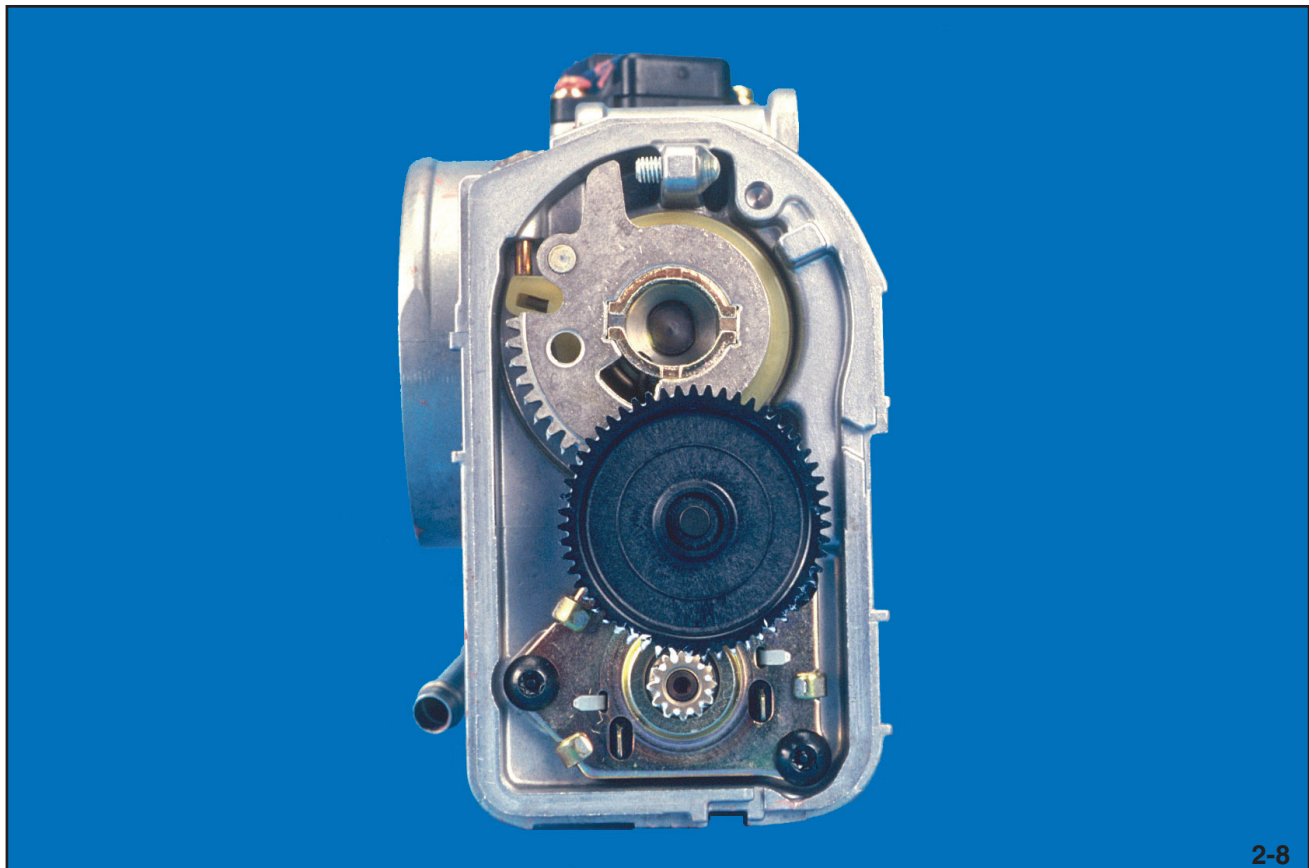
Notes:

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The throttle body is located at the central part of the intake manifold. The throttle body incorporates a throttle plate that controls or meters the air flowing into the engine. On electronic throttle bodies, a motor controls the position of the throttle plate based on the accelerator pedal sensor. The throttle position sensors are attached to the throttle shaft and monitor the position of the plate. As the plate opens, more air can flow into the engine, increasing engine speed. When the throttle plate closes, it restricts the airflow into the engine, reducing engine speed.



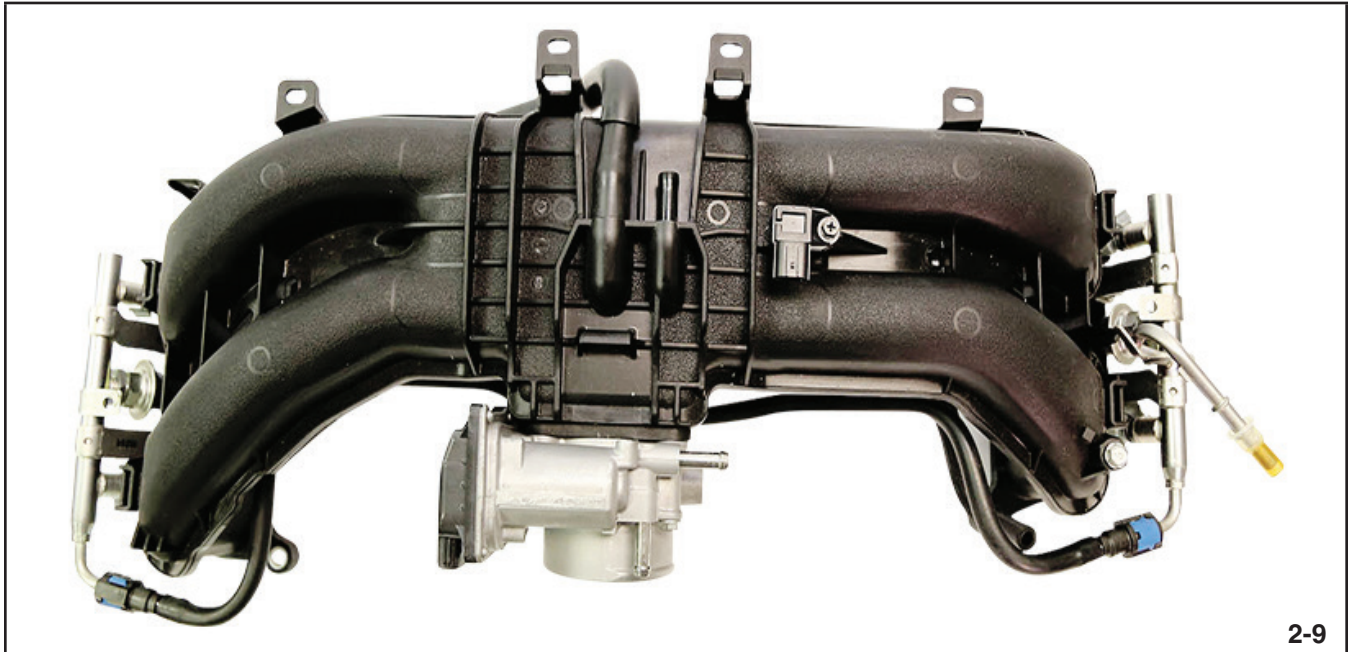
Throttle Body Assembly



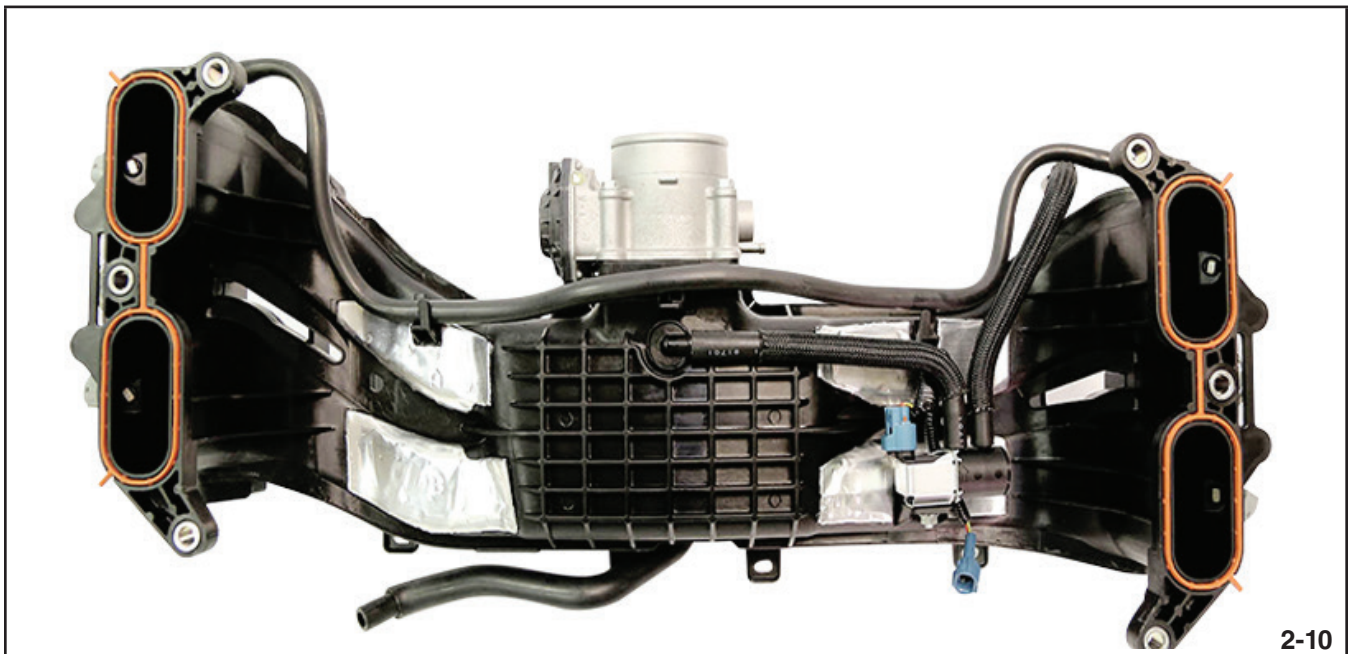
Throttle Actuator Motor and Gears

Basic Fuel Injection Part 3

The intake manifold is located on the top of the engine and is a series of tubes attached to the throttle body. It provides a passageway for air to flow into the cylinders. Even airflow distribution maximizes the efficiency and performance of the engine.



Intake Manifold Top View

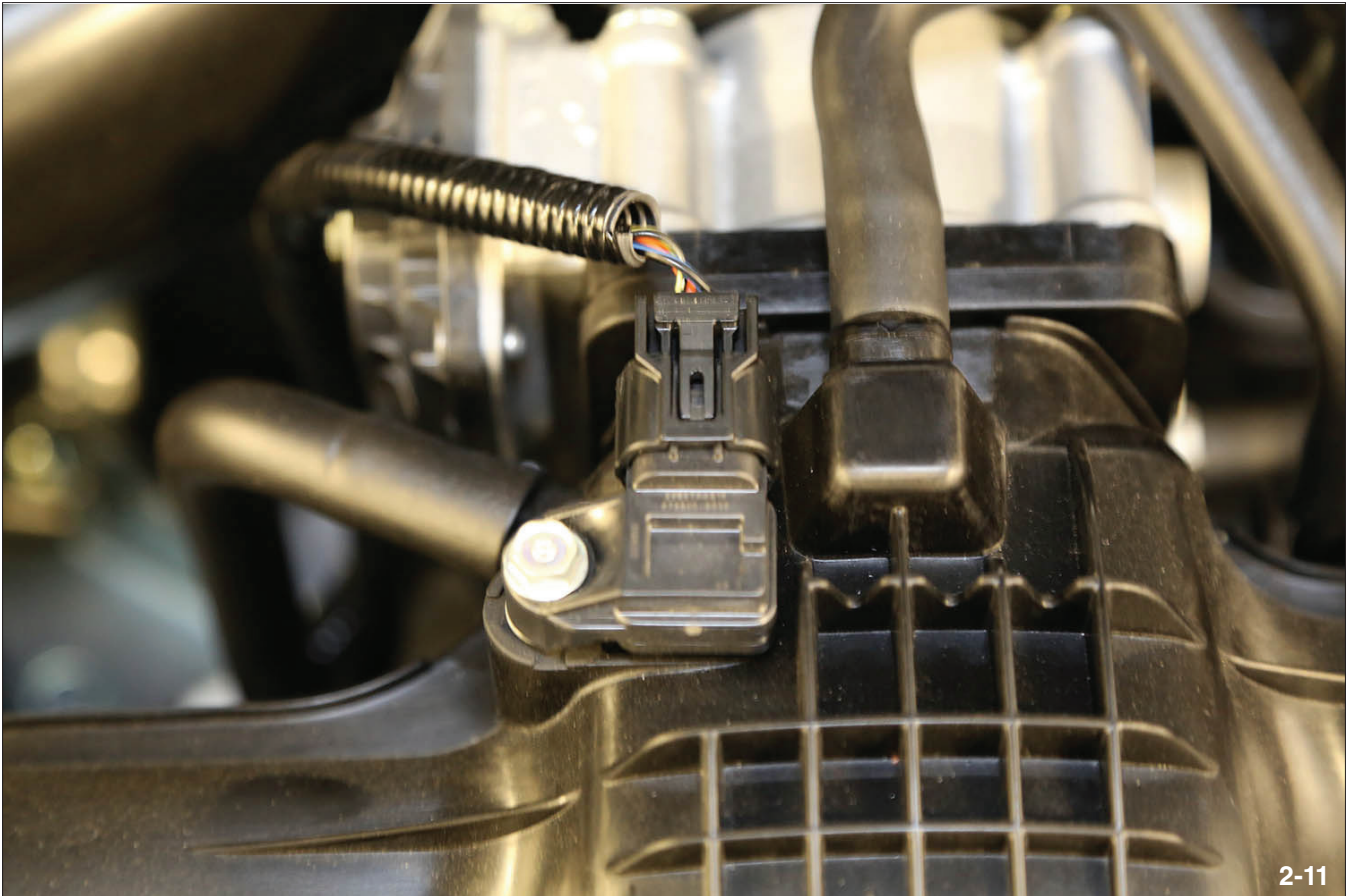


Intake Manifold Bottom View

Notes:

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The MAP sensor is located on the top of the intake manifold. The MAP sensor samples intake manifold pressure and converts the pressure value into electrical signals. Based on this signal and other signals from many other sensors, the ECM controls the fuel injection and ignition timing.



Manifold Absolute Pressure Sensor

Newer pressure sensors work by using a very small piece of a quartz crystalline structure that changes its electrical characteristics based on the amount of air pressure placed against it. The quartz structure provides an input to an integrated circuit, which then creates the signal that represents manifold pressure.

The integrated circuit is placed inside an airtight housing and is sealed to the intake manifold or throttle body with an O-ring and a fastener to hold it in position. The tip of the air-tight housing is placed so that it can sample the intake manifold pressure.

Notes:

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The Tumble Generator Valves (TGV) are located between the intake manifold and the cylinder head. The ECM controls the tumble generator valves; they are opened or closed based on coolant temperature, engine load, and engine runtime. When the engine is first started, the tumble generator valves are moved to the closed position.

With the valves in the closed position, the intake air flows at very high speeds, passing through narrowed passages in the directions determined by the individual intake air ports in the cylinder head. This creates an air tumbling effect in the cylinders, which promotes efficient atomization, lowering harmful exhaust emissions.

Each TGV assembly includes an actuator to move the valves' position and a position sensor to report the valves position to the ECM. The original type actuators have the actuator and sensor located separately, with the actuator at one end of the valve and the sensor at the other. Current type assembly's house this sensor internally.



Tumble Generator Valve

Fail-Safe Function

When a sensor or switch signal falls outside its normal operating parameters due to an open or short, the signal is judged as faulty by the ECM's on-board diagnostic system. When this occurs, the ECM will ignore the input and substitute a pre-programmed value to keep the vehicle operational (The control becomes degraded).

Example: If the coolant temperature sensor signal opens, the ECM will display the coolant temperature as -40 °F (-40 °C) and activate the cooling fans.

During fail-safe function, the ECM can substitute a known good value so the vehicle can be driven to a safe location. Engine performance may be compromised during fail-safe function.

Basic Fuel Injection Part 3

The following induction system sensors have a fail-safe mode strategy:

- MAF sensor
- MAP sensor
- TPS sensor
- ECT sensor
- Tumble generator

Fail-safe function example: If the MAF sensor malfunctions, the ECM will use the MAP sensor to calculate the air to fuel ratio.

Testing the Air Induction System

The air induction system must ensure the incoming air is cleaned and precisely metered for optimum fuel economy and engine performance. The induction system must be tightly sealed for an accurate measurement of the incoming air. Loose, cracked, or damaged ducts can result in un-metered air entering the engine and cause poor engine performance.

A vacuum gauge is used to measure the vacuum (negative pressure) within the intake manifold in inches of mercury (inHg) or kilopascal (kPa). The dial of a vacuum gauge is printed with many scales , but the most commonly used is inches of mercury (inHg).



Vacuum Gauge

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Normal Gauge Readings

When an engine is running properly, vacuum should measure (at idle) between 18–20 inHg (61–68 kPa) and the needle of the gauge should be steady.

The engine should be checked for a mechanical or valve timing issue if the vacuum within the engine is low or fluctuating.



Normal Vacuum Reading

Notes:

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Abnormal Gauge Readings

A vacuum gauge measures intake manifold pressure and can provide valuable information on engine performance. The vacuum gauge measures the difference between the outside atmospheric pressure and the amount of vacuum present in the intake manifold. The following are some examples of vacuum gauge readings and what may be wrong with the engine:

- Burnt and leaky valves (gauge fluctuates between 1–3 inHG)
- Weak valve springs (normal at idle speed, but excessive vibrations at higher rpm; 1–3 inHg)
- Restricted exhaust (normal at idle speed, but drops to near zero and rises to lower than normal)
- Intake system air leak (needle oscillates slowly, or drifts; between 3–9 inHg lower than normal)
- Sticking valve or misfire (irregular needle drop between 1–2 inHg; misfire or rich or lean air/fuel mixture)
- Low compression or late valve timing (low but steady, between 12–15 inHg)



Abnormal Gauge Reading

Newer Subaru vehicles are designed to retard the ignition timing during initial cold engine operation to promote faster heating of the catalytic converter; this process brings the engine vacuum closer to atmospheric pressure. Coolant temperature and a timer control the duration of retarded ignition timing.

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Performing an Intake Manifold Vacuum Test

To perform an engine vacuum test:

1. Warm up the engine.
2. Disconnect the brake booster vacuum hose from the intake manifold (or a reliable manifold vacuum source).
3. Connect the vacuum gauge to the intake manifold.
4. Keep the engine at idle speed and read the vacuum gauge.
5. Intake manifold vacuum (at idling, A/C OFF) is 60 kPa (450 mmHg [17.72 inHg]) or greater.



Manifold Vacuum Testing

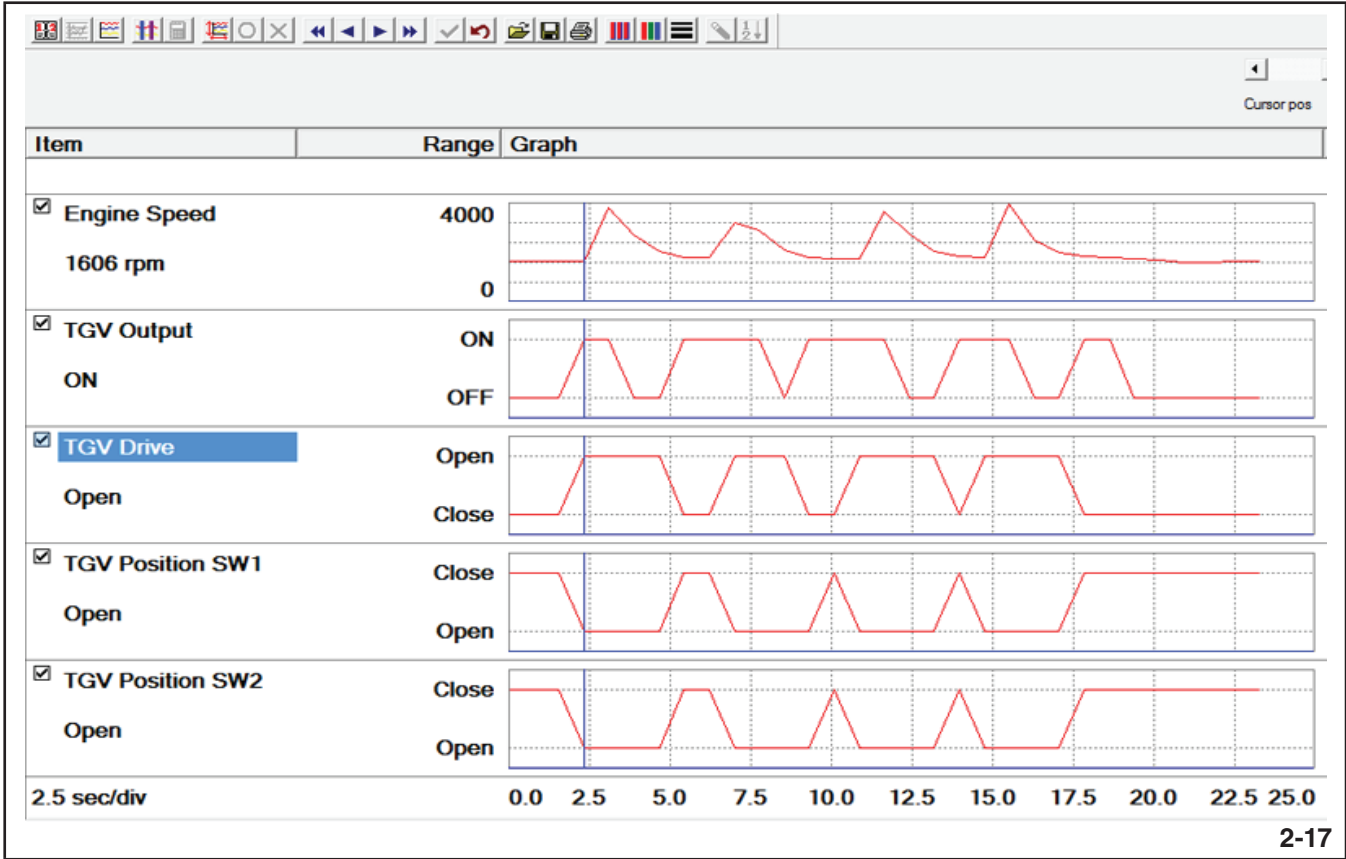
The condition of the engine can be diagnosed by observing the behavior of the vacuum gauge needle as described previously in the Abnormal gauge readings section.

Notes:

Basic Fuel Injection Part 3

Tumble Generator Valve

With the vehicle at idle, use the Subaru Select Monitor to view tumble generator valve data. With the engine at idle, the valves should be in the closed position, but when the throttle is rapidly accelerated, the valves should move to the open position and be synchronous in operation. The tumble generator valves should transition from open to closed smoothly without any binding or sticking.



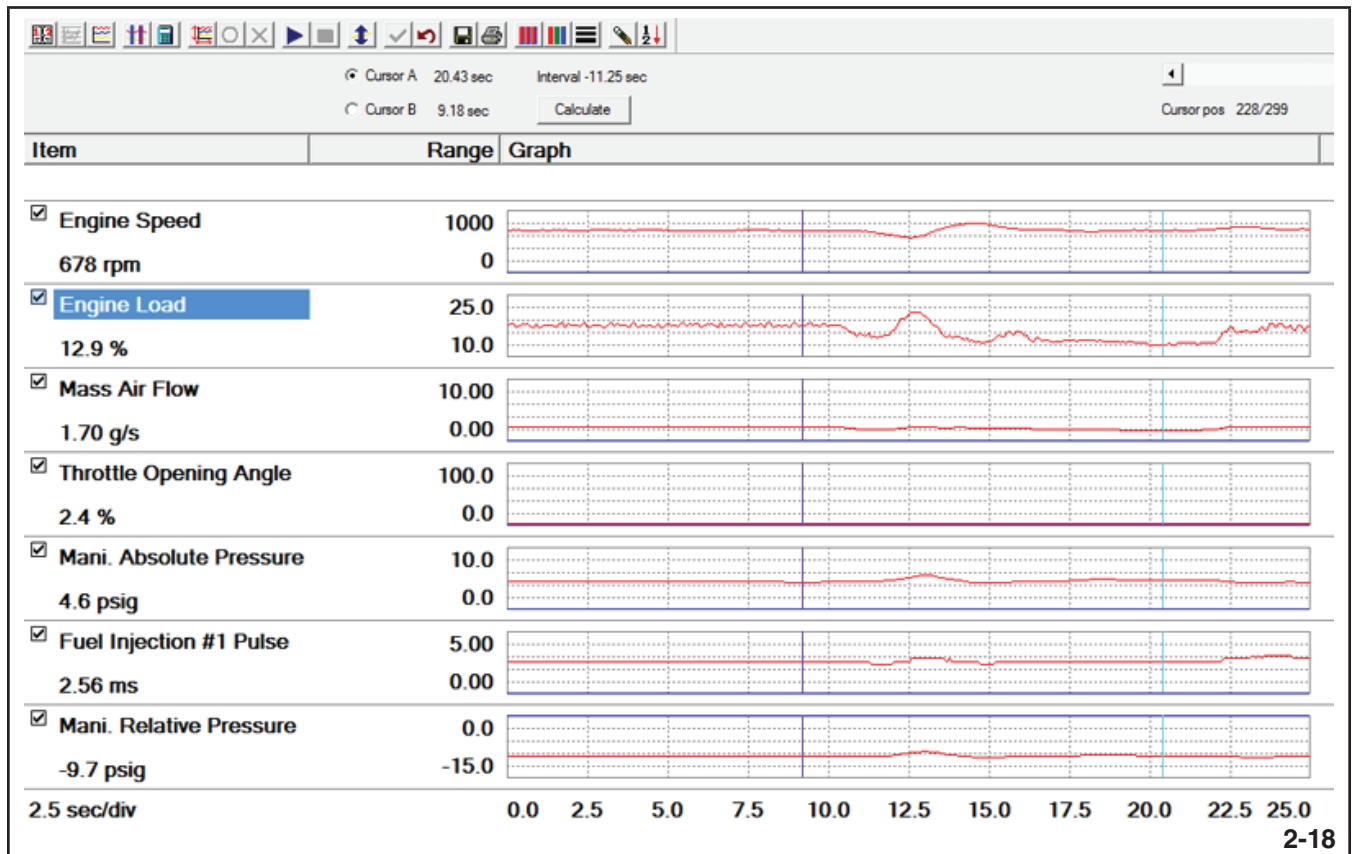
Testing the Tumble Generator Valve

Notes:

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Mass Air Flow Sensor Testing

The mass air flow sensor varies output voltage to the ECM as air flows past the hot wire. A malfunctioning mass air flow sensor can cause the engine to run too lean or too rich. It can also cause the engine control system to enter failsafe mode. Correct airflow across the sensor is critical for accurate operation. Debris, such as insects, that make it past the air filter can create insulation that changes the sensor operating characteristics. A concern with the mass air flow sensor can set mass air flow and fuel trim DTCs. The integrated intake air temperature sensor will set diagnostic trouble codes if a malfunction occurs.



Testing the Mass Air Flow Sensor

Validate MAF sensor operation by connecting the test as follows:

1. Disconnect the mass air flow sensor harness connector.
2. Remove the mass air flow sensor and position it near the battery.
3. Connect a fused jumper wire from the battery positive terminal to terminal 3 of the mass air flow sensor.
4. Ground terminal 4 of the mass air flow sensor to the battery negative terminal.
5. Set the Digital Volt Ohm Meter (DVOM) to volts.
6. Connect the DVOM positive lead (red) to terminal 5 of the mass air flow sensor.
7. Connect the DVOM ground terminal (black) to terminal 4 of the mass air flow sensor.

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8. Blow air into the mass air flow sensor unit from the air filter side.

CAUTION: Do not use compressed air pressure.

9. The voltage reading should increase from approximately .8 volts to over 2.5 volts when air is blowing across the sensor elements.

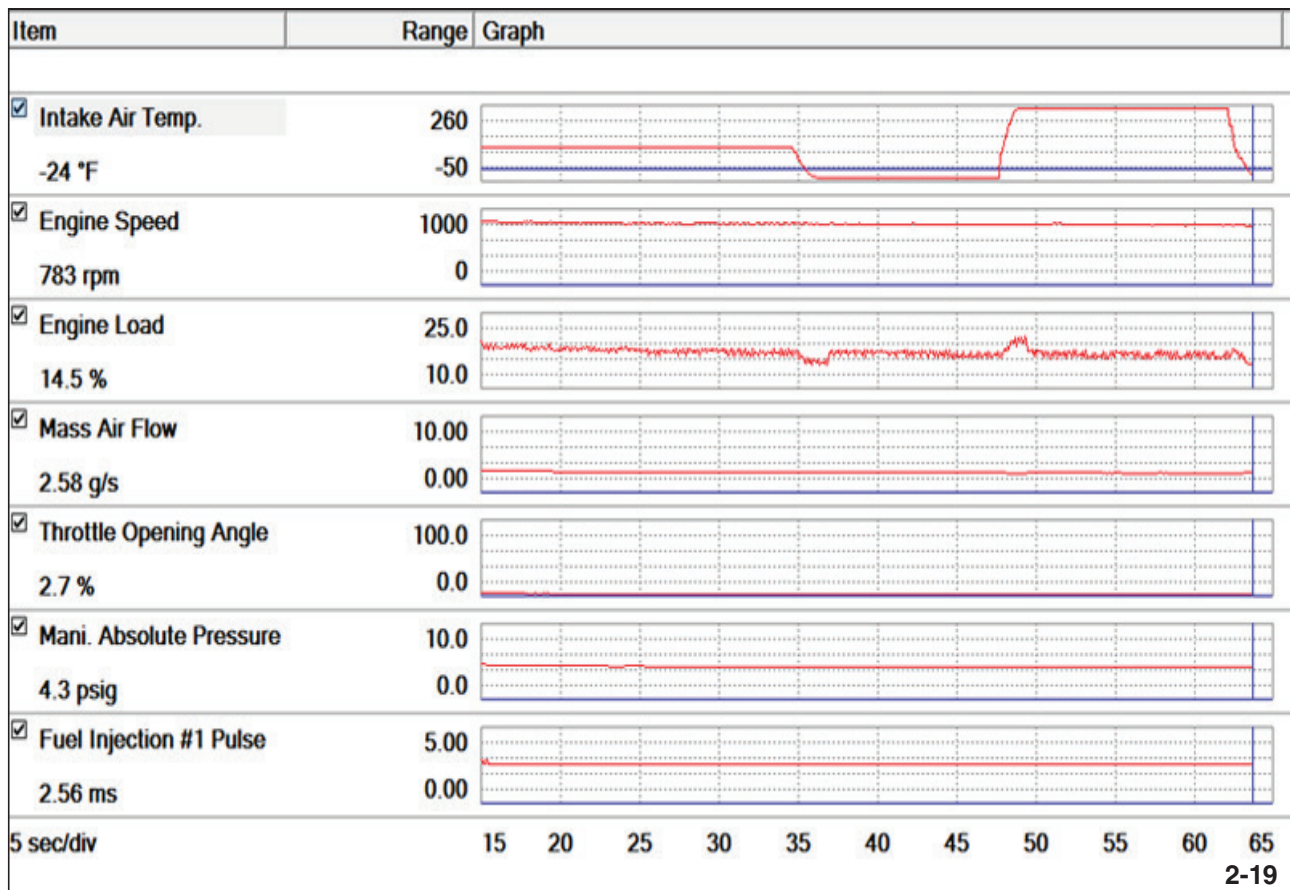
Note: This test is for example only. Always consult Subaru Technical Information System (STIS) for terminal identification.

Check to see if the mass air flow sensor voltage value changes when air is blown into the sensor. The air should be blown from the filter side.

The ECM uses the MAF value and engine rpm to determine the engine load calculation. Engine load values that are lower than normal at normal idle speed are an indicator that unmetered air is being introduced into the intake manifold.

Intake Air Temperature Sensor Testing

To test the IAT sensor, measure the resistance between intake air temperature sensor terminals and refer to the temperature vs. resistance chart in STIS.



Testing the Intake Air Temperature Sensor

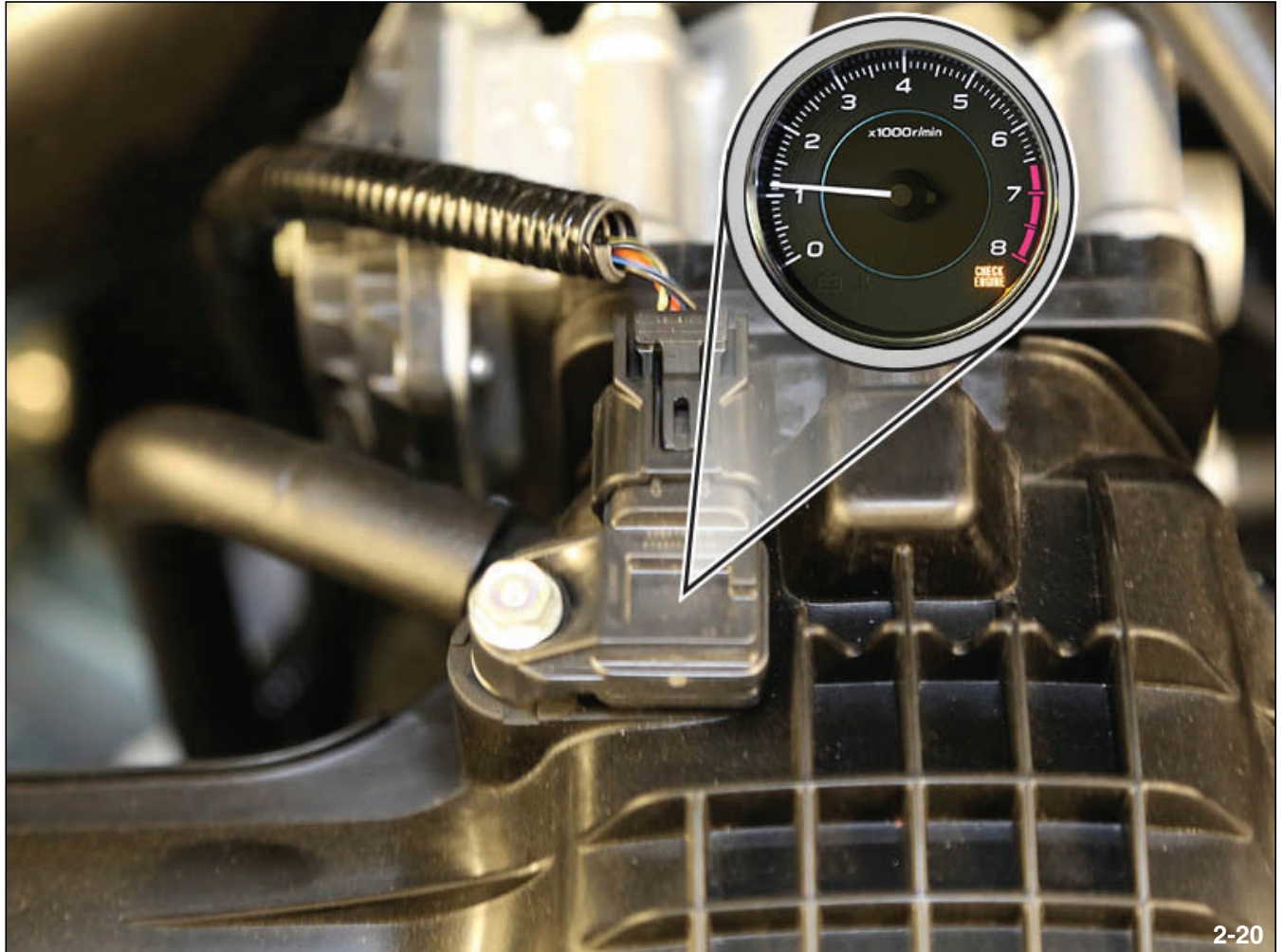
Notes:

Basic Fuel Injection Part 3

A disconnected sensor value on the scan tool will indicate -40 °F, while a shorted IAT temperature sensor value will indicate 248 °F. These extreme values are failsafe values and the ECM uses a predetermined IAT value where air temperature is a variable.

Manifold Absolute Pressure Sensor Testing

A malfunctioning MAP sensor can cause the engine to run too lean or too rich as it accelerates and decelerates. It can also cause the engine control system to enter failsafe mode. A concern with the MAP sensor can set MAP sensor and EGR DTCs.



Testing the Manifold Absolute Pressure Sensor

Inspect the MAP sensor for leaks caused by a missing or damaged seal.

The MAP sensor can be tested with a scan tool and hand held vacuum pump. Observe the data while applying a vacuum to the sensor. The data should change smoothly without any dropouts or spikes.

Use a DVOM to measure the circuit voltages and resistance as follows:

- The voltage supply wire should be 4.8–5.2 volts.
- The signal wire should be approximately 4.7–5.0 volts.
- Test the resistance of the ground circuit. The resistance should not exceed the specification in the service manual.

Notes:

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Basic Fuel Injection Part 3

Combustion Principles

Upon completion of this lesson you will be able to:

- Explain the principals of combustion.

A complete understanding of combustion principles is critical to ensure safe and efficient vehicle diagnosis and repair. Gasoline is combined with oxygen from the incoming air, making up the air to fuel ratio, which is ideally 14.7:1. When this mixture enters the cylinder, the spark plug ignites the air/fuel mixture, creating power to move the vehicle.

Note: Gasoline in Subaru vehicles should contain no more than 10% ethanol.

The term “stroke” refers to the movement of the piston through the length of the cylinder. The term “four-stroke engine” is used because the piston moves up and down the cylinder four times in one cycle.

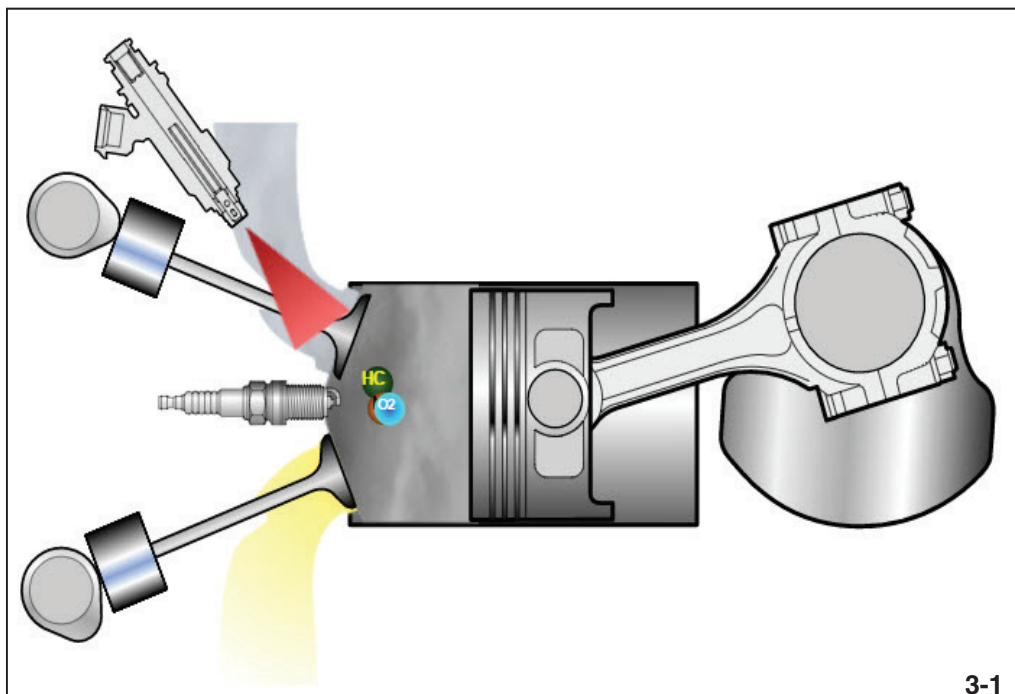
The four-strokes are:

- Intake
- Compression
- Power
- Exhaust

Intake Stroke

During the intake stroke, air from the atmosphere is drawn into the cylinders. On the intake stroke, the camshaft opens the intake valve while the piston moves downward. The atmospheric air pressure is then converted to manifold pressure after it passes by the throttle plate.

The intake stroke produces engine vacuum; the downward movement of the piston creates a low-pressure area above the piston.

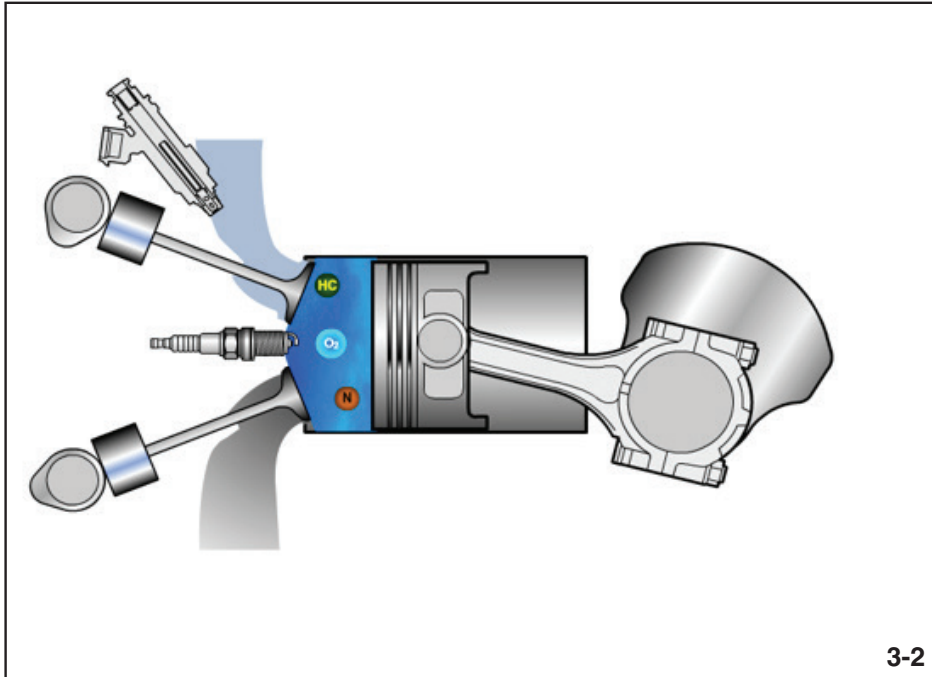


Intake Stroke

Basic Fuel Injection Part 3

Compression Stroke

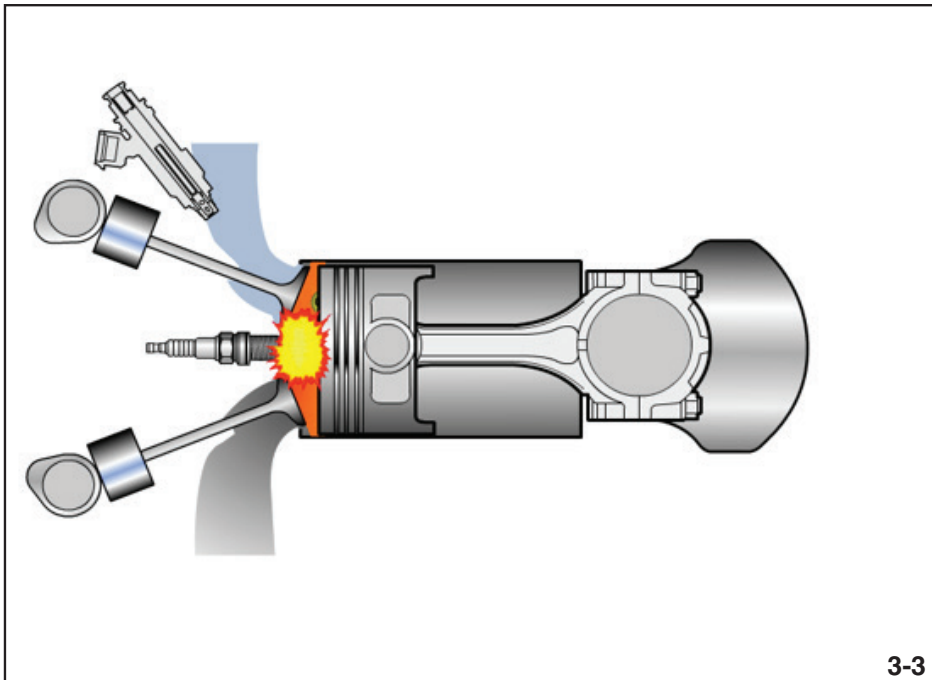
As the piston begins traveling upward, the intake and exhaust valves close, causing the air/fuel mixture to compress into a small volume at the top of the cylinder. In a gasoline engine, a spark plug ignites the air/fuel mixture just before top dead center, which is called spark ignition.



Compression Stroke

Power Stroke

On the power stroke, both intake and exhaust valves are closed, and the piston is forced downward in the cylinder during combustion.

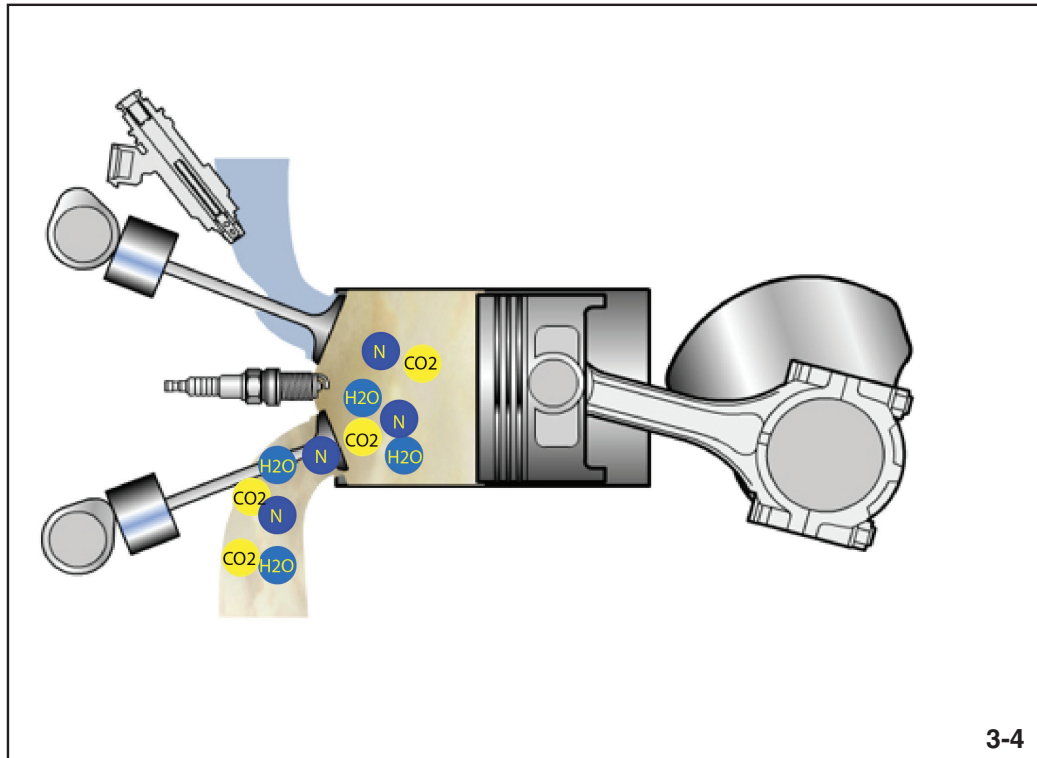


Power Stroke

Basic Fuel Injection Part 3

Exhaust Stroke

After the air/fuel mixture is ignited and burned from the power stroke, the camshaft opens the exhaust valve. The exhaust is pushed out of the cylinder and into the exhaust manifold as the piston moves upward.



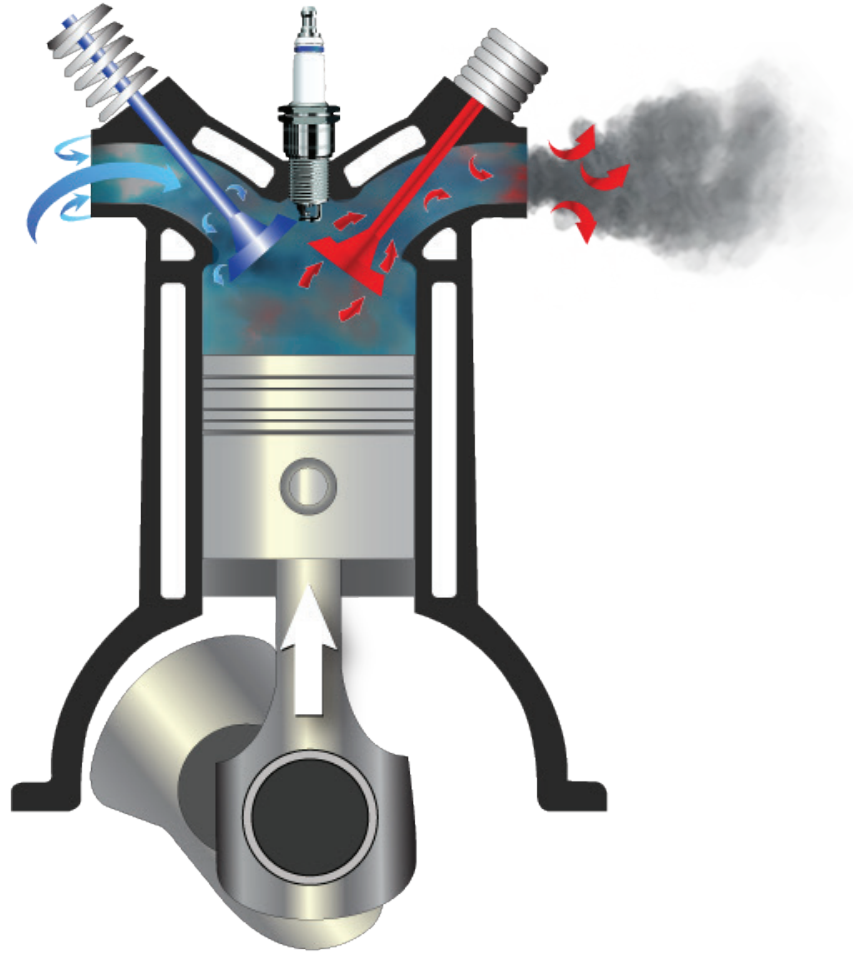
Exhaust Stroke

Notes:

Basic Fuel Injection Part 3

Valve Overlap

Valve overlap occurs when the intake and the exhaust valves are open at the same time. This is adjustable on engines with variable valve timing. Engines with fixed camshafts depend on the design and timing of the camshaft lobes. The purpose of valve overlap is to allow air scavenging to take place. When the exhaust leaves the cylinder a huge negative pressure area is created and this allows fresh air to rapidly fill the cylinder. This results in better combustion efficiency.



3-5

Valve Overlap

Notes:

Basic Fuel Injection Part 3

Fuel Supply System

Upon completion this lesson you will be able to:

- Explain the operation of the fuel supply system.
- Explain the operation and testing of the fuel supply system.

The purpose of the fuel supply system is to store and deliver fuel at a controlled pressure to the fuel injectors.



4-1

Typical Fuel System Pressure

Notes:

Basic Fuel Injection Part 3

The fuel tank is located at the rear underside of the vehicle near the rear differential and secured with hold-down bands. The fuel tank utilizes a two-compartment design called a saddle tank to ensure sufficient capacity without interfering with the rear differential.



Fuel Tank

Fuel is a hazardous material due to its high flammability characteristics. The fuel tank safely stores fuel for the vehicle. The fuel tank serviceable internal components include:

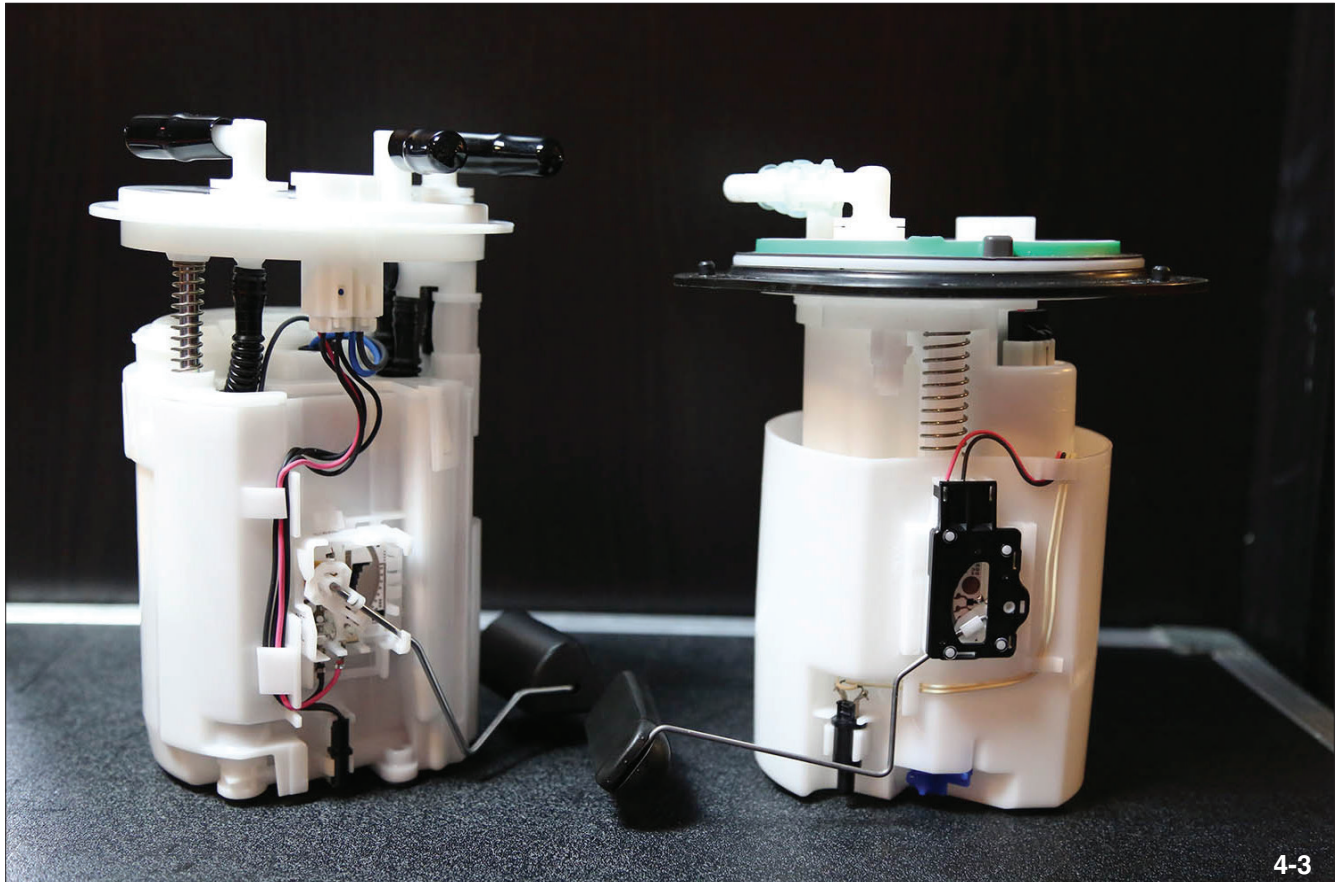
- A main fuel pump with jet pump and fuel level sensor assembly
- A sub-compartment fuel level sensor that detects the level of fuel in the sub side, which is the side without a fuel pump

When the jet pump is operating, the fuel in the sub side is drawn up and transferred to the fuel pump.

Notes:

Basic Fuel Injection Part 3

The main fuel pump is located toward the front passenger side of the fuel tank and is combined with the fuel level sensor in a single unit. The main fuel pump consists of a motor, impeller, pump casing, pump cover, check valve, and filter. When the engine and the fuel pump stop, the check valve closes the discharge port so the fuel pressure in the fuel delivery line is retained.



Main Fuel Pump

Notes:

Basic Fuel Injection Part 3

The jet pump is located inside the fuel tank, near the front passenger's side, and draws fuel from the pick-up on the driver's side sending unit. All-Wheel Drive (AWD) vehicles use a saddle-design fuel tank that requires a jet pump to siphon fuel from one side of the tank to the main fuel pump side.



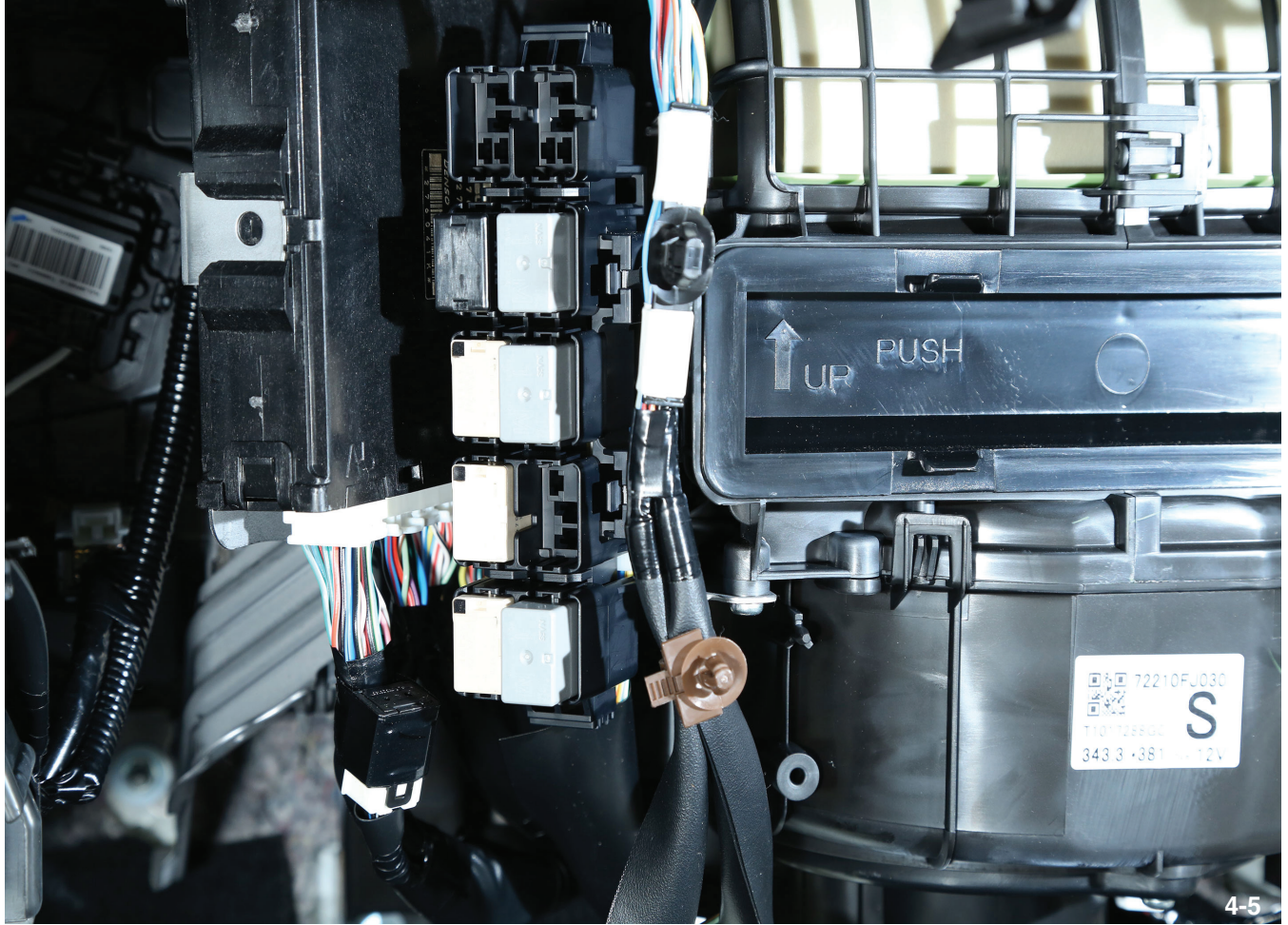
Jet Pump

The jet pump utilizes the velocity of fuel returning from the engine to produce a negative pressure. Using the pumping effect produced by the negative pressure, the jet pump transfers fuel from the sub side to the main side of the fuel tank.

The jet pump functions only while fuel is being returned to the fuel tank (during engine operation).

Basic Fuel Injection Part 3

The fuel pump relay location varies by vehicle model. The ECM controls the fuel pump relay.



Fuel Pump Relay Location

Fuel pump prime occurs when the ignition is turned ON. The engine control module grounds the control coil of the fuel pump relay for 2 seconds. The relay contacts close, completing the current path to the fuel pump motor (also for 2 seconds).

Notes:

Basic Fuel Injection Part 3

On a returnless-type fuel system, the fuel pressure is regulated at the pump inside the fuel tank. The fuel pressure regulator is an integral part of the fuel pump assembly and has one fuel line to the engine compartment. There is no return line from the fuel rail back to the tank.



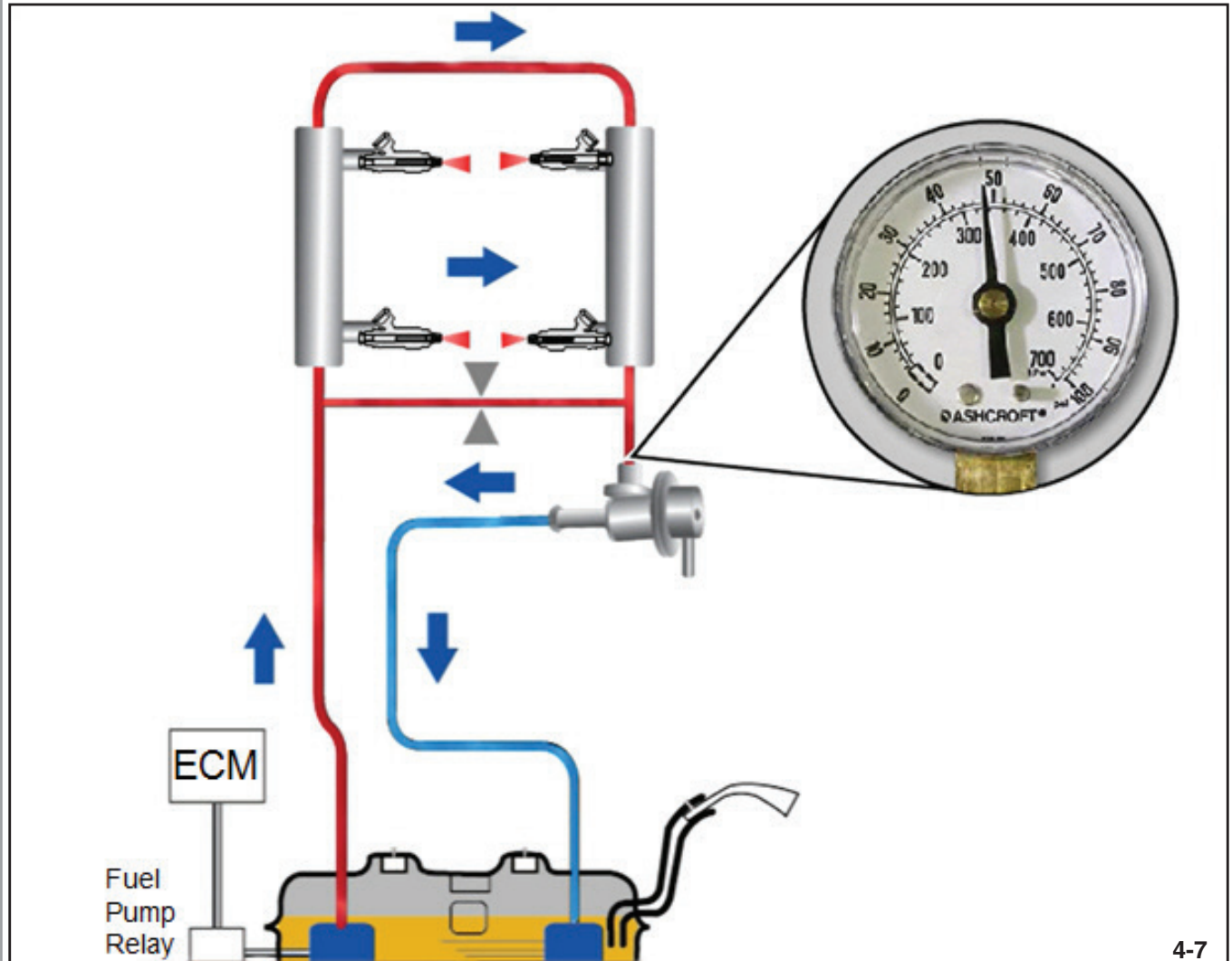
Fuel Pressure Regulator (Returnless)

Notes:

Basic Fuel Injection Part 3

On a return type system, the fuel pressure regulator maintains a constant fuel pressure to the fuel injectors. The fuel pressure regulator is located in the underhood area on the fuel supply line. The orifice between the fuel rails keeps the fuel pressure equal between both fuel rails.

On a return system, the fuel pressure regulator contains two chambers separated by a diaphragm, a spring, and a valve. These components control the amount of fuel returned to the tank.



Fuel Pressure Regulator (Return)

When the intake manifold vacuum is high, the diaphragm is pulled upward and the relief valve opens to decrease the fuel supply line pressure (or fuel injection pressure). When the intake manifold vacuum decreases, the spring pushes the diaphragm to increase the fuel supply line pressure. The difference between the fuel injection pressure and the intake manifold vacuum is maintained at a constant level to precisely control the amount of injected fuel.

Notes:

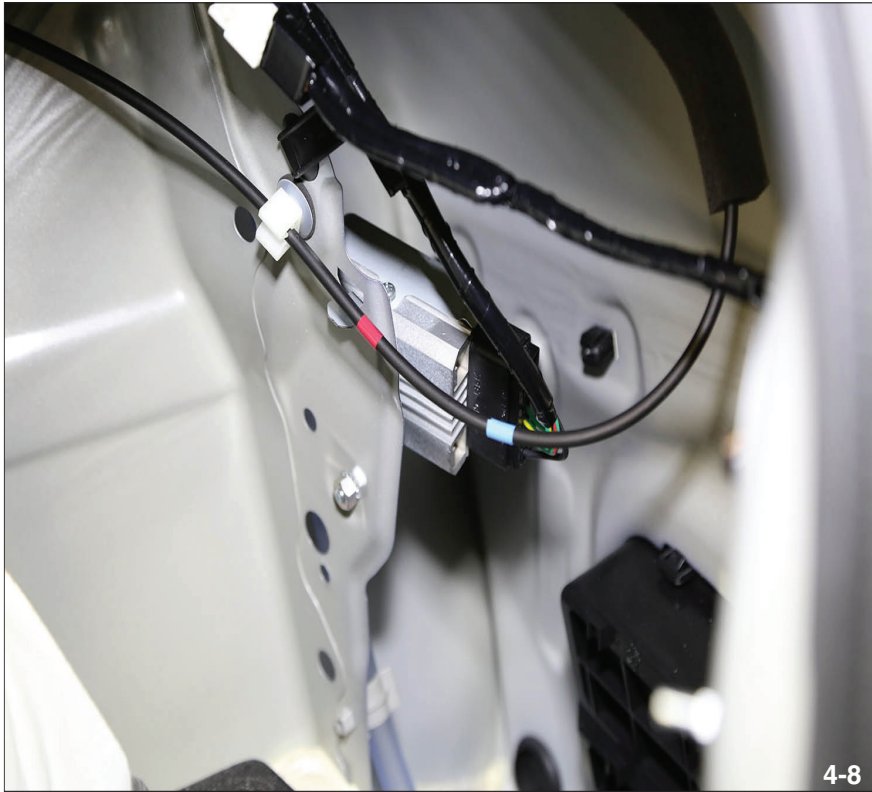
Basic Fuel Injection Part 3

Variable Speed Fuel Pump

Some Subaru vehicles are equipped with a variable speed fuel pump system. Diagnostics for the fuel pump circuit, including the fuel pump controller, are not covered in detail in the service manual. An understanding of the fuel pump circuit, including the fuel pump controller, will allow you to perform any diagnostics required.

This type of system requires the addition of a fuel pump controller that can vary the speed and volume output of the fuel pump. The control unit is typically located on the right side of the trunk or cargo area behind the trim panel. Always check STIS to determine the module location prior to removing any trim components.

Note: Currently, only turbocharged vehicles, six-cylinder vehicles, and vehicles equipped with direct injection are equipped with a fuel pump controller.



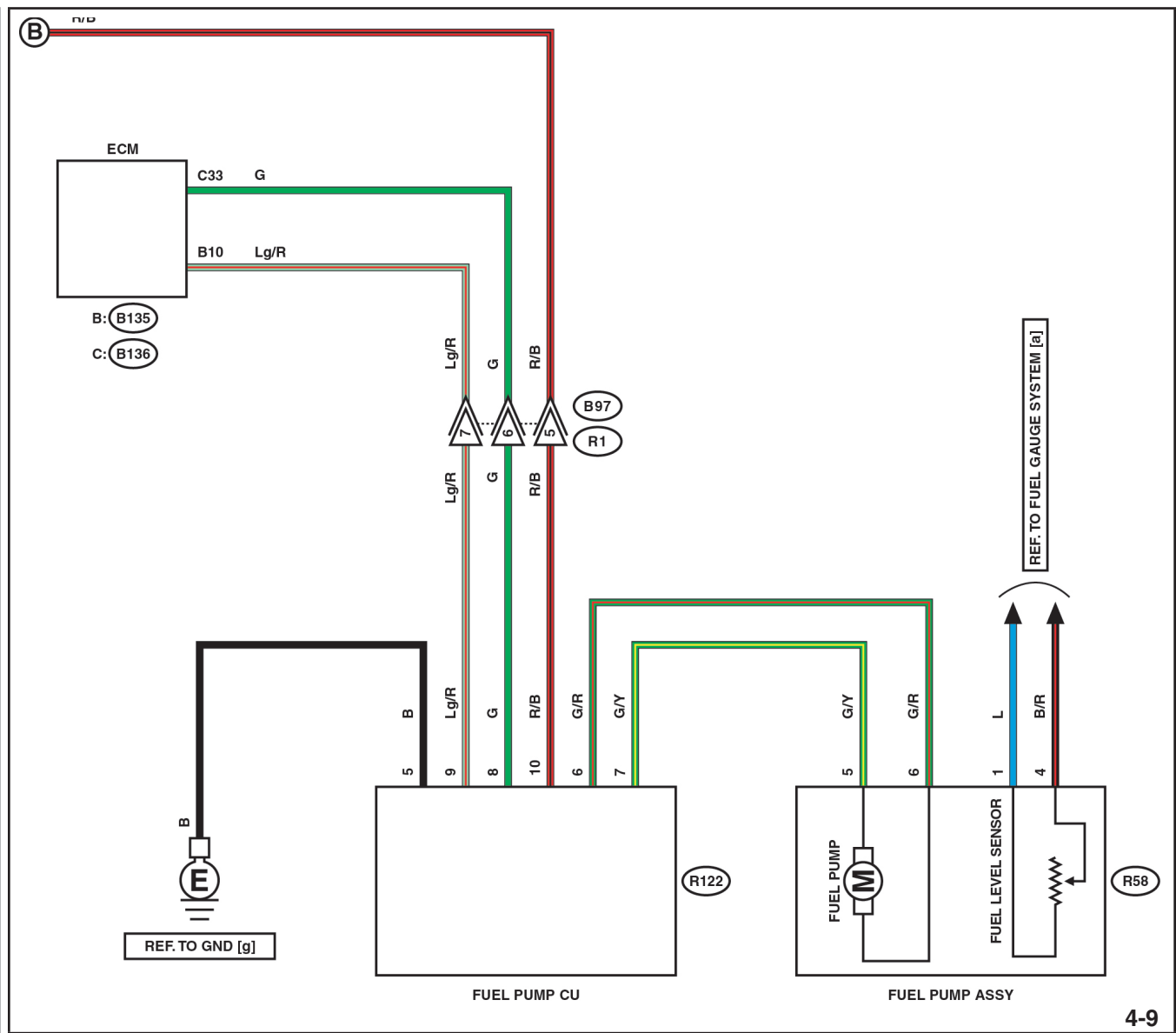
Variable Speed Pump Control Module

The ECM supplies a 4-volt duty ratio to the fuel pump controller. This duty ratio signal is based on engine loads. For example, engine start-up, cruising, and wide-open throttle each require different volumes of fuel, causing the duty-ratio to change to match the driving conditions.

When higher fuel pump volume is required for situations, such as full-throttle, the duty ratio can reach as high as 100%. The duty ratio is also 100% for 30 seconds on a warm or cold engine start-up.

Notes:

Basic Fuel Injection Part 3



Fuel Pump Controller Schematic

Fuel Pump Control Unit	Control	B136	33	0 or 5	0 or 5	Waveform
	Diagnostic signal	B135	10	Battery voltage	Battery voltage	—

4-10

Fuel Pump Controller I/O Chart

Notes:

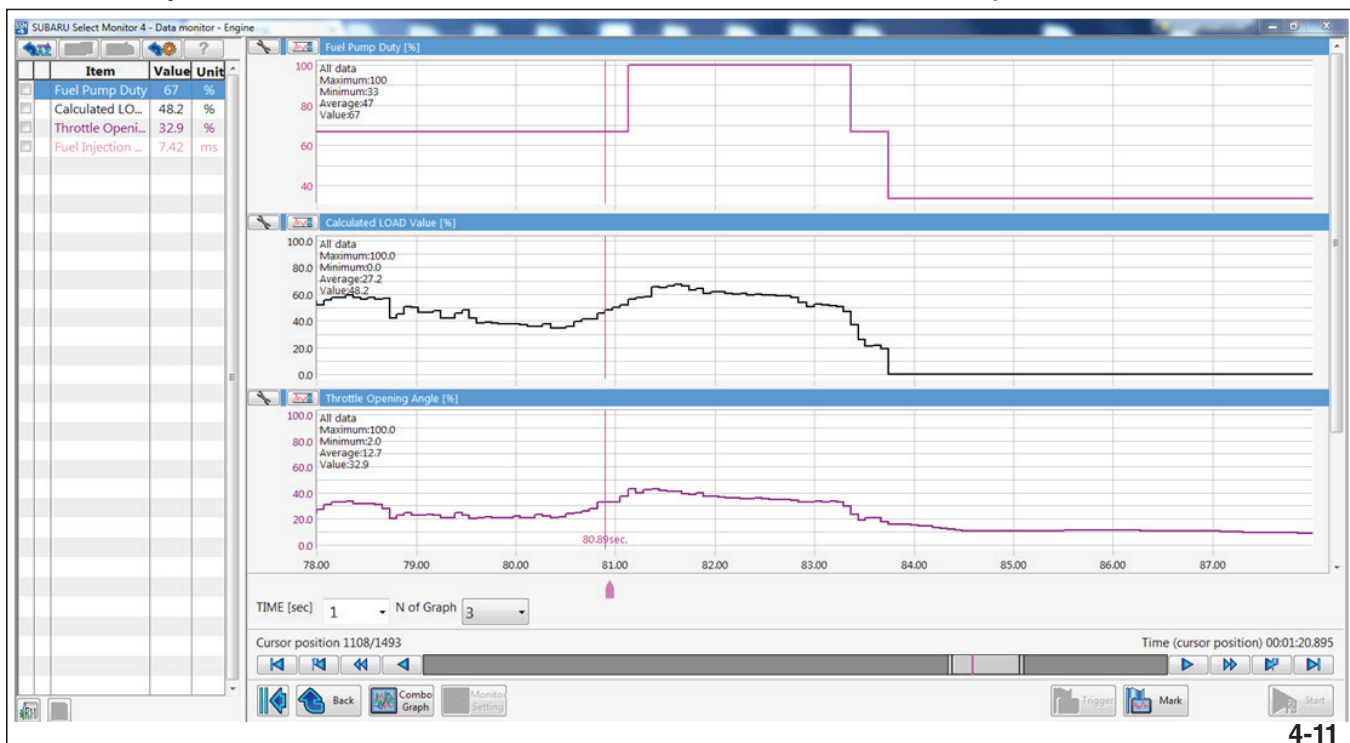
Basic Fuel Injection Part 3

The duty ratio changes the speed of the fuel pump by varying a voltage drop on the fuel pump ground circuit. A lower duty ratio operates the fuel pump at a slower speed, reducing the fuel volume to the injectors. For moderate fuel demands, the duty ratio input to the controller produces a 3–4 volt drop on the ground circuit of the pump. This equates to a duty ratio of 67%, which occurs during medium to heavy acceleration. For high demand situations, a .9-volt drop is produced on the fuel pump ground circuit. This level produces the fastest fuel pump speed and largest volume output. This duty ratio of 100% will remain until the rate of acceleration has been decreased.

A warm engine will idle at 33% duty ratio to the fuel pump controller, which produces approximately a 5-volt drop on the ground circuit of the fuel pump.

Monitor the fuel pump duty ratio while observing the fuel pump pressure (fuel pressure gauge). Fuel pressure should remain constant between speeds.

To monitor the three speeds, fully warm up the engine, apply the hand brake, set the foot brake, and place the transmission in Drive. At idle, the duty ratio will be 33%; check and record the fuel pressure. Slowly accelerate while continuing to press the foot brake. The duty ratio will increase to 67%; check and record the fuel pressure. Fully accelerate (stall speed) the engine and the duty ratio should increase to 100%; check and record the fuel pressure.



4-11

Variable Speed Fuel Pump Controller Testing

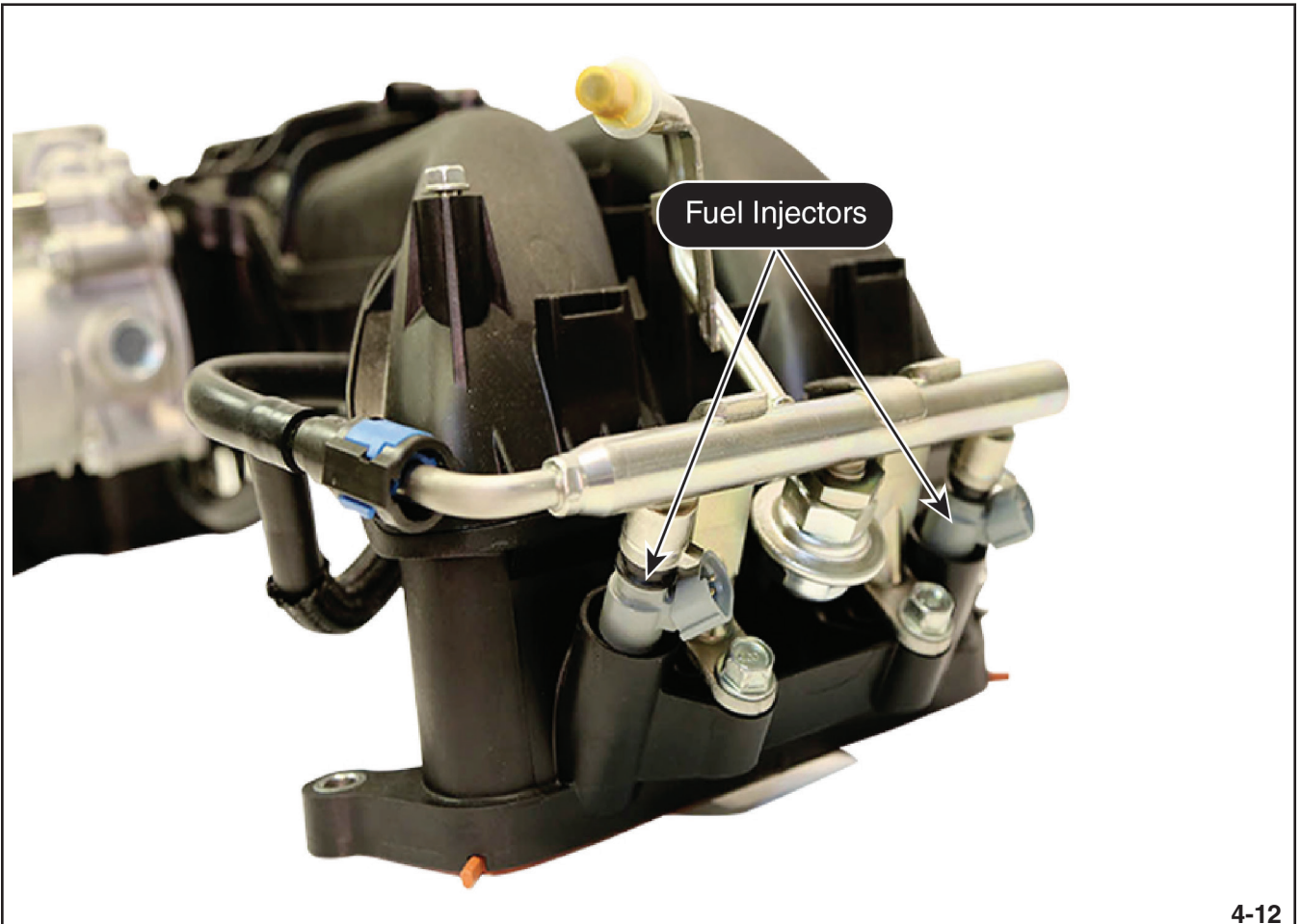
Note: For a manual transmission vehicle, you will need to drive the vehicle with an assistant to help perform this test. Operate the vehicle at light, medium, and heavy load conditions to achieve all three duty ratios.

Note: Rapid and heavy changes in manifold pressure will alter fuel pressure; do not confuse this normal operation with the vehicle having a fuel pump control unit concern.

Basic Fuel Injection Part 3

Fuel Injectors

The port fuel injector is located in the intake manifold runner near the cylinder head. This type of fuel injector has high heat resistance and low driving noise. A fuel injector is an electromechanical component that can deliver precise amounts of fuel to a cylinder during different operating conditions. A fuel injector delivers fuel to a cylinder; the ECM pulses an ON/OFF signal to the fuel injectors in milliseconds to open and close the pintle valve.



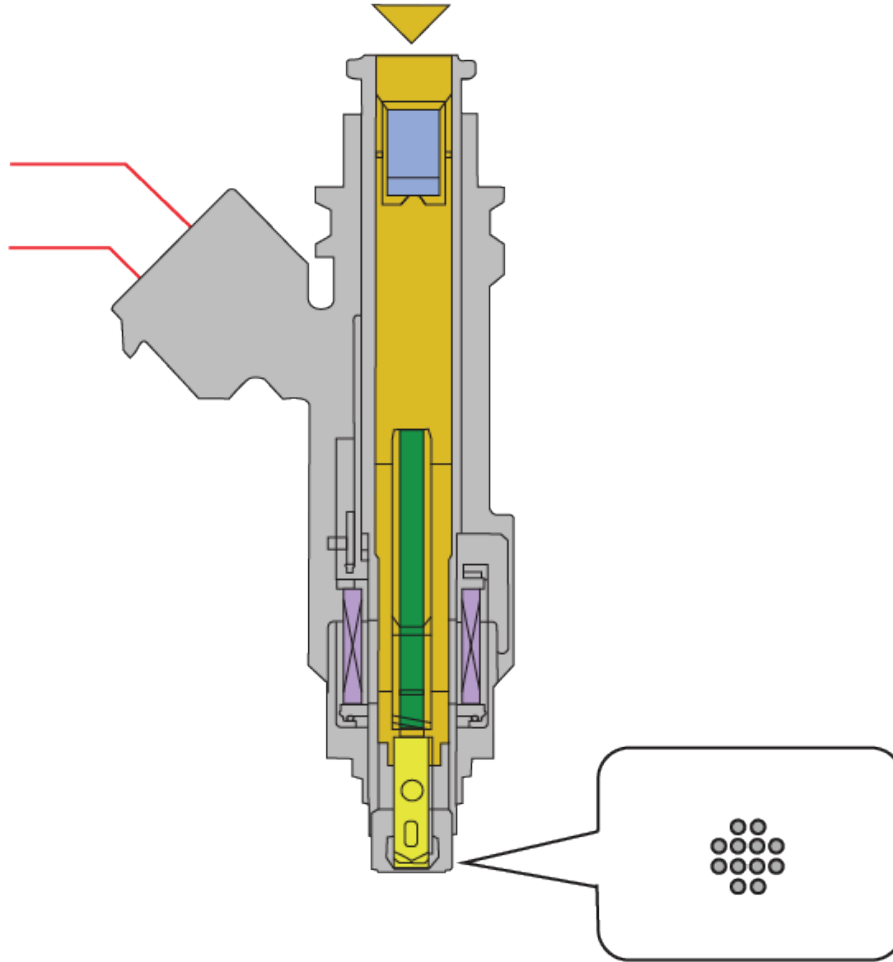
Fuel Injectors

Notes:

Basic Fuel Injection Part 3

The fuel injector supplies fuel to the cylinder according to the valve open signal from the ECM. A solenoid, energized by an ON signal, lifts the pintle valve off its seat.

The ECM varies the duration of the signal to control the amount of fuel injected into the cylinder. The multi-hole nozzle makes it possible for the injector to produce fine fuel particles, enhancing the combustion efficiency and output performance of the engine.



4-13

Fuel Injector Nozzle

Notes:

Basic Fuel Injection Part 3

Fuel Level Sensors

The primary fuel level sensor is located on the fuel pump module in the fuel tank. The fuel level sensor is integrated with the main fuel pump assembly. The fuel level sensor can be serviced separately from the fuel pump.

The fuel level sensor output is a voltage signal that varies with movement of a float to indicate the level of the fuel remaining in the tank.

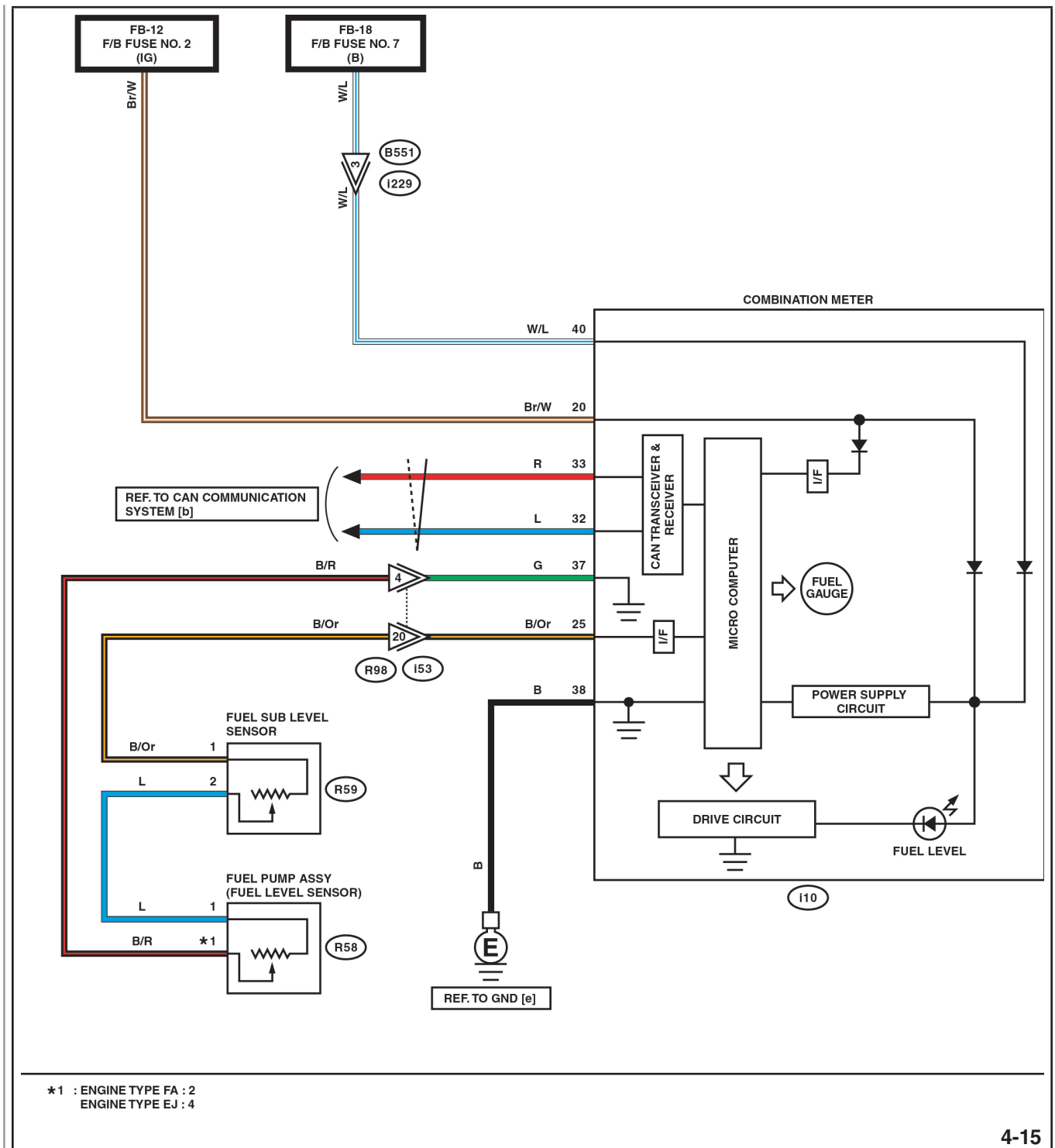
The combination meter supplies the fuel level sensor with a 5-volt signal.

The saddle tank design requires a secondary fuel level sensor, located on the driver's side of the tank. The secondary fuel sensor detects the level of the fuel in the sub-side of the fuel tank.



Primary and Secondary Fuel Level Sensors

Basic Fuel Injection Part 3



2016 WRX STI Fuel Level Indicator Circuit

The primary and secondary fuel level sending units are wired in series to provide the fuel gauge with information to show the correct fuel level.

Notes:

Basic Fuel Injection Part 3

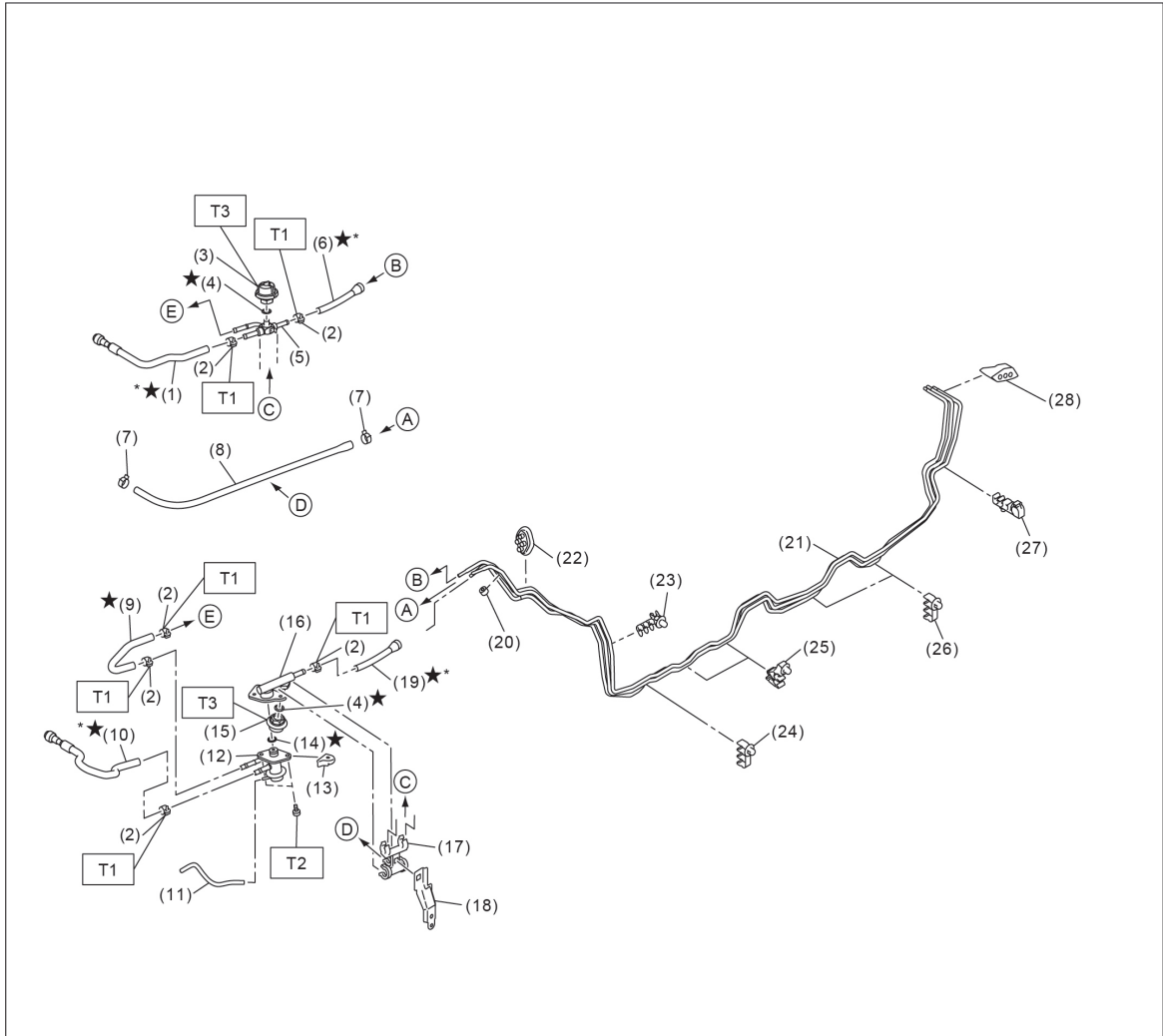
The construction and layout of the fuel supply and return lines and hoses have changed many times over the years. Always consult the service manual to determine if hoses and quick connectors can be reused.

General Description

FUEL INJECTION (FUEL SYSTEMS)

5. FUEL LINE

• Fuel line 1



- (1) Fuel delivery hose A
- (2) Clamp
- (3) Pulsation damper A
- (4) Fuel pipe gasket
- (5) Fuel by-pass pipe
- (6) Fuel delivery hose B
- (7) Clip
- (8) Evaporation hose
- (9) Fuel hose
- (10) Fuel return hose A
- (11) Vacuum hose

- (12) Pressure regulator
- (13) Fuel pipe protector
- (14) O-ring
- (15) Pulsation damper B
- (16) Fuel holder ASSY
- (17) Hose clamp
- (18) Hose clamp bracket
- (19) Fuel return hose B
- (20) Bushing
- (21) Fuel pipe ASSY
- (22) Fuel pipe front grommet

- (23) Pipe clamp
- (24) Pipe clamp
- (25) Pipe clamp
- (26) Pipe clamp
- (27) Pipe clamp
- (28) Fuel pipe rear grommet

Tightening torque: N·m (kgf-m, ft-lb)

T1: 1.25 (0.1, 0.9)

T2: 6.4 (0.7, 4.7)

T3: 21.6 (2.2, 15.9)

* It can be reused if the quick connector side is disconnected.

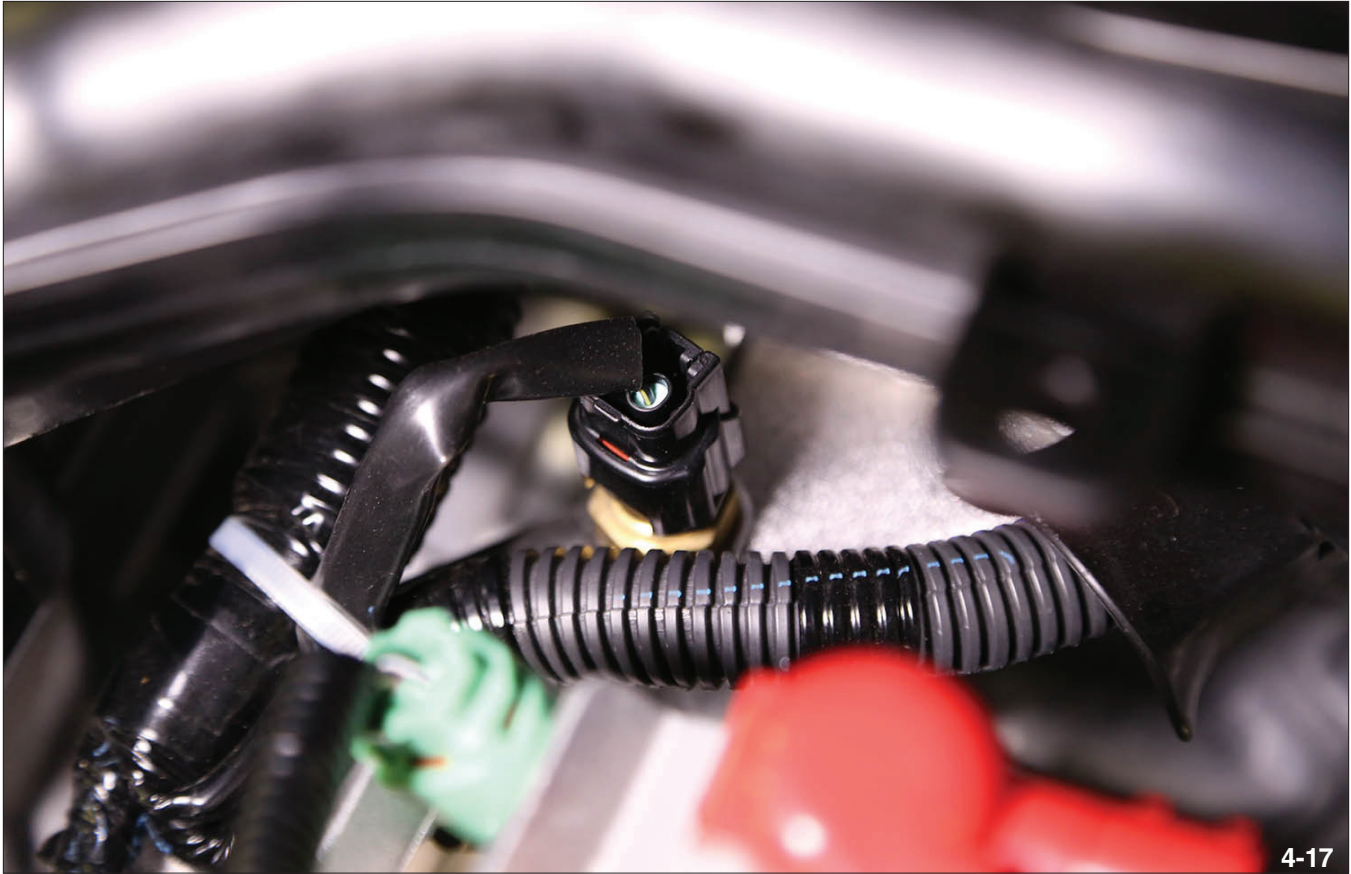
4-16

Fuel Lines

Basic Fuel Injection Part 3

Engine Coolant Temperature Sensor

The Engine Coolant Temperature (ECT) sensor is mounted in a coolant passage, near the intake manifold and alternator, and is monitored by the ECM.



Engine Coolant Temperature Sensor

The ECT sensor is a Negative Temperature Coefficient (NTC) thermistor that changes resistance inversely with temperature. Engine coolant temperature information is supplied to the ECM as voltage signals to adjust fuel enrichment, spark timing, purge control, and cooling fan operation.

Notes:

Basic Fuel Injection Part 3

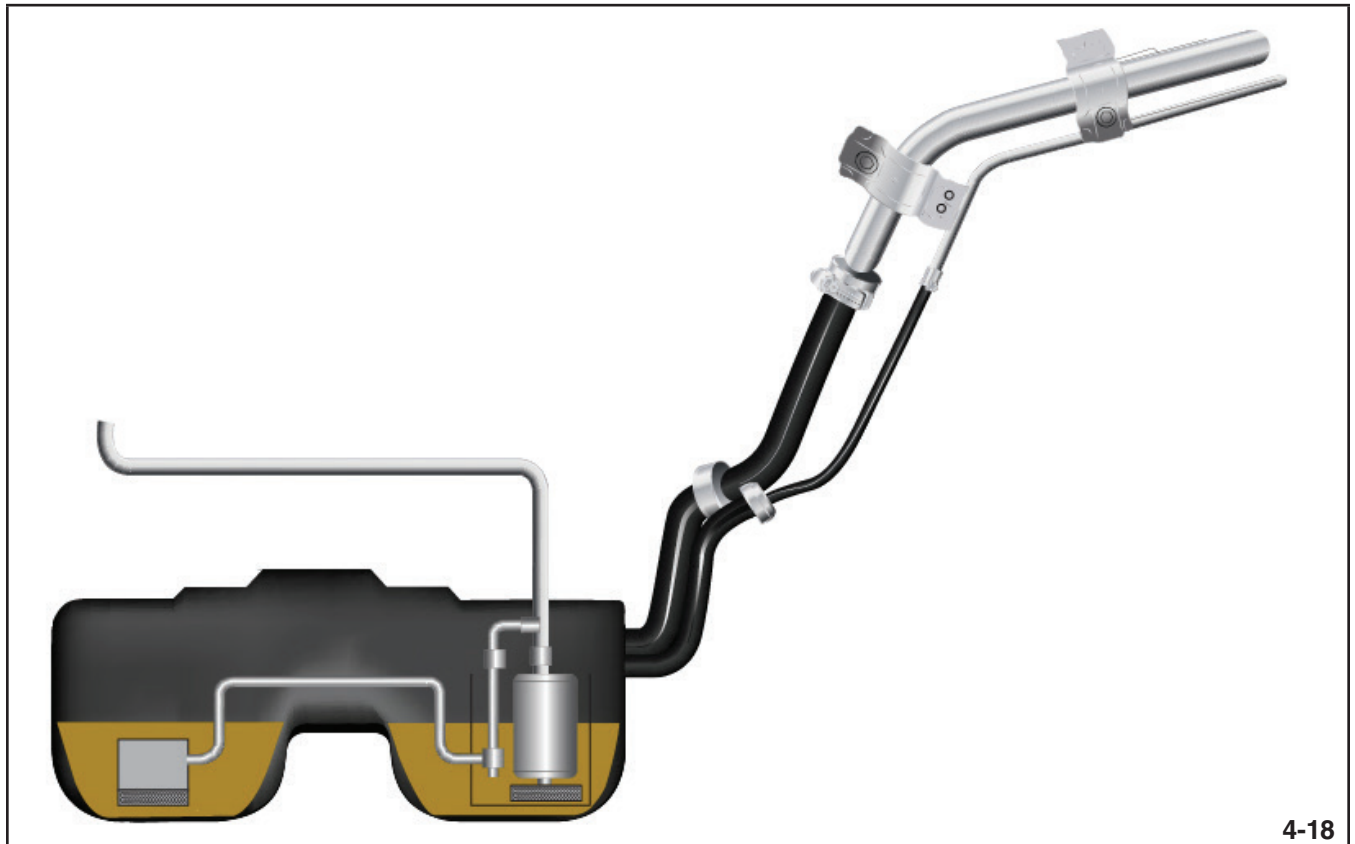
Diagnosing the Fuel Supply System

Subaru gasoline vehicles must safely deliver fuel to the fuel injector at the correct pressure and at precisely the right time. There are several sensors and components in the engine control and fuel delivery system to help accomplish this task.

Inspect Fuel Fill System

The fuel tank cap has a relief valve, which prevents development of vacuum in the fuel tank in the event of an issue with the fuel vapor line. Atmospheric pressure forces the spring down to open the valve, allowing outside air to flow into the fuel tank, balancing the pressure difference.

The fuel filler neck is connected at the gas tank with a rubber hose. Inspect the fuel filler neck and hose for leaks.



Fuel Fill System Testing

Inspect the Fuel Tank

Inspect the fuel tank for:

- Damage
- Cracks
- Leaks
- Dents

Basic Fuel Injection Part 3

Main Fuel Pump Operation

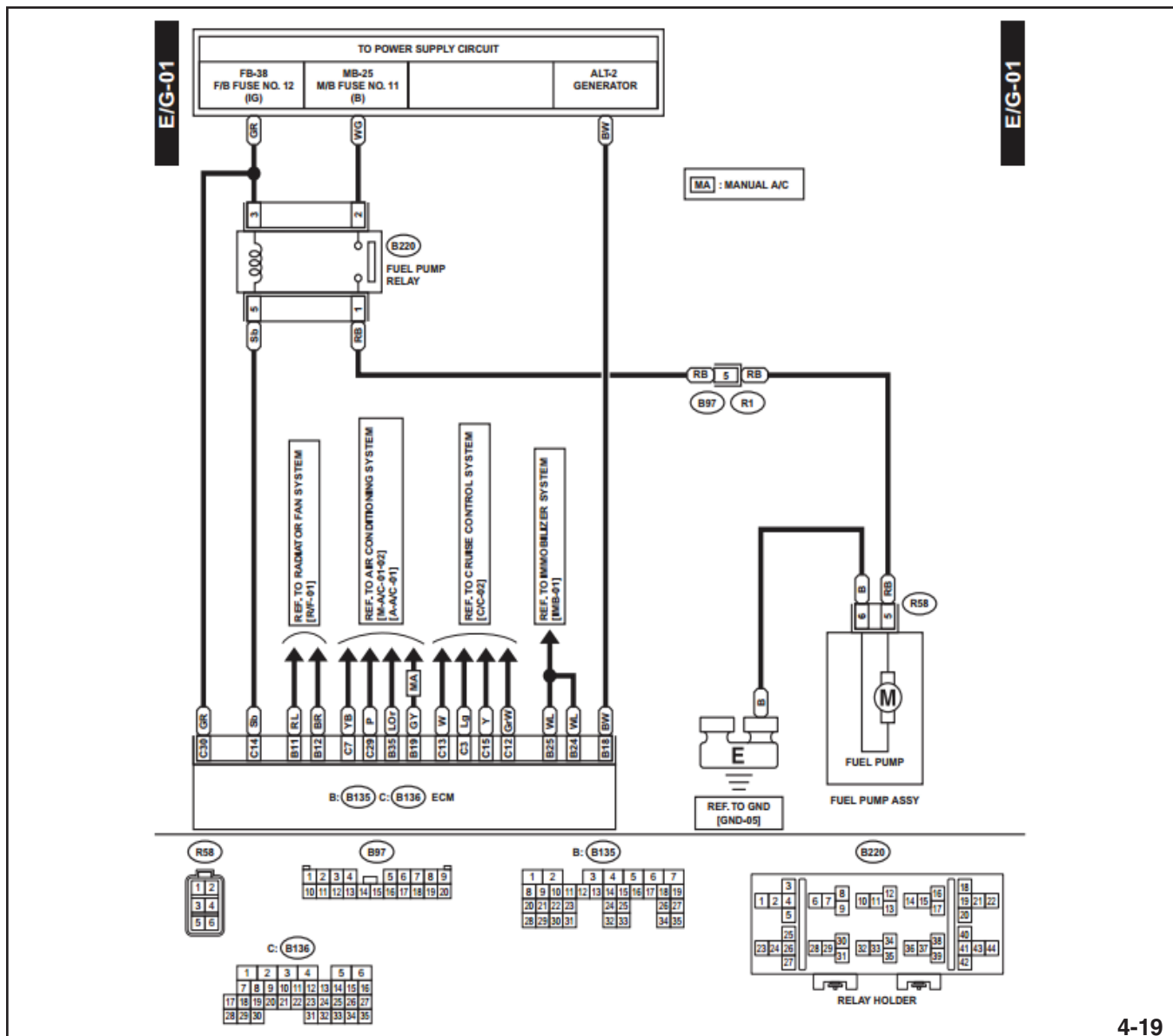
Diagnosis of the main fuel pump should include these steps:

1. Validate the crankshaft position sensor input for fuel pump relay or variable speed fuel pump controller operation.
2. Validate the proper circuit operation and voltages.
3. Validate the system pressure.
4. Use a fuel pressure gauge to measure fuel pump pressure and fuel pressure leak down.

Main Fuel Pump and Circuit Testing

Use a test light and service information wiring diagrams to test for power to the fuel pump.

Use a scan tool to command the relay ON and OFF. Listen for the fuel pump to run and observe the fuel pressure gauge for a pressure increase.



Main Pump Testing

4-19

Basic Fuel Injection Part 3

If the fuel pump does not operate:

- Test the fuel pump relay and circuits.
- Use the scan tool to monitor the fuel system electrical circuits (crankshaft signal and relay on/off signal) and retrieve any related diagnostic trouble codes.
- Diagnose related circuits using the service manual.

Fuel Pressure Regulator (Return System)

Fuel pressure regulators can leak internally or externally. External leaks are easy to find because of the presence of liquid fuel on the outside of the regulator.

An internal leak is usually caused by a deterioration of the diaphragm. Remove the vacuum hose to the regulator and check for liquid fuel in the vacuum line. This issue usually results in a customer concerns of long crank times, poor gas mileage, and rough idle.



Fuel Pressure Regulator Testing

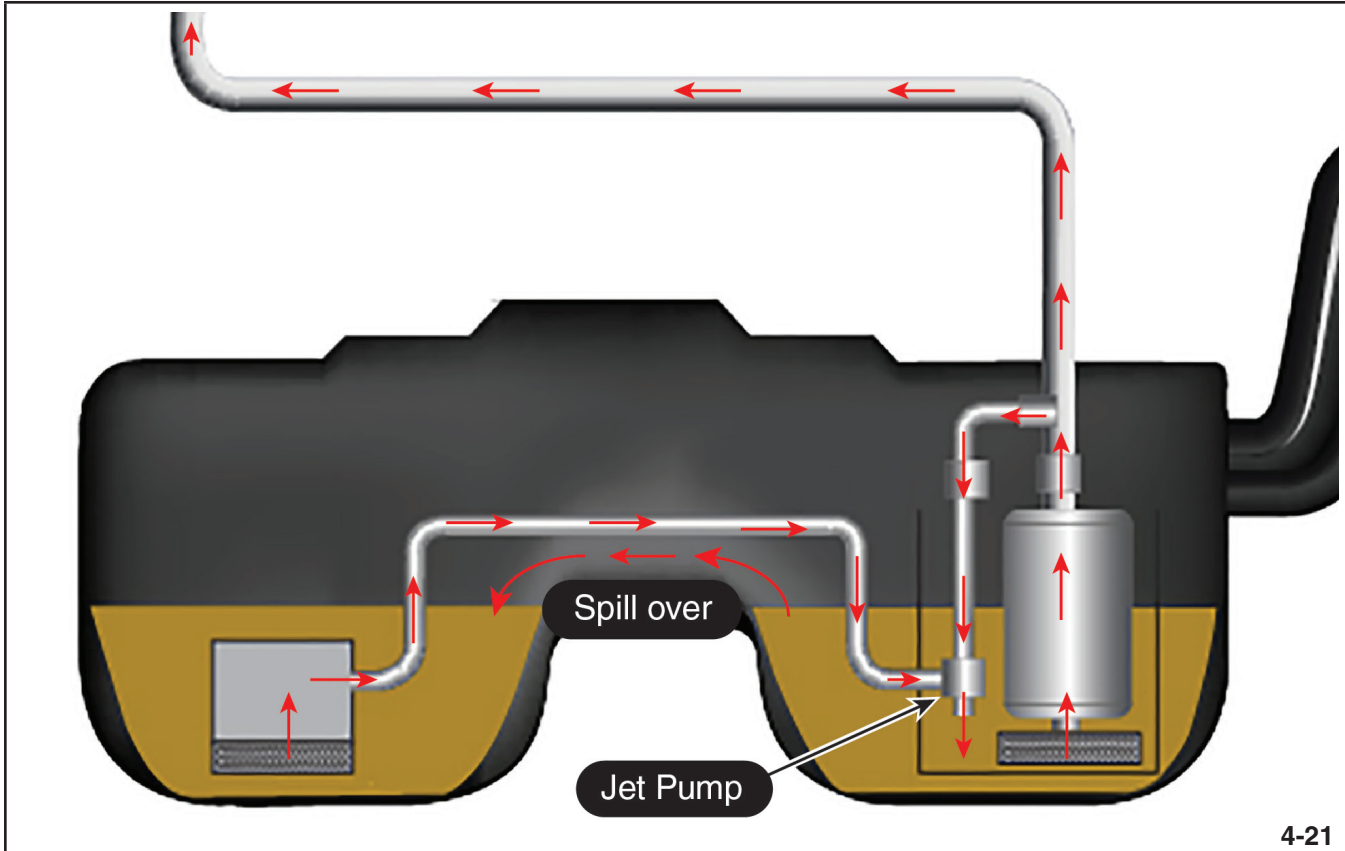
Fuel Pressure Regulator (Return-less System)

On a returnless fuel system, check the fuel pressure using the procedure in the service manual. Check the pressure at idle and stall speed. If the fuel pressure is not at the correct value or is leaking down after the vehicle is turned off, replace the fuel pump and fuel pressure regulator.

Basic Fuel Injection Part 3

Jet Pump Operation

The jet pump is a mechanical device that has no physical diagnostics. Diagnosis of the jet pump is based upon symptoms. The most common customer concerns would be “My vehicle seems like it has run out of fuel, but the fuel gauge still shows fuel in the tank,” or “My fuel gauge is not reading correctly.”



Jet Pump Testing

Notes:

Basic Fuel Injection Part 3

Inspect the Fuel Lines and Fittings

Inspect the fuel lines for:

- Leaks
- Damage
- Restrictions
- Kinks
- Proper routing



Fuel Line Release Tool 18371AA000



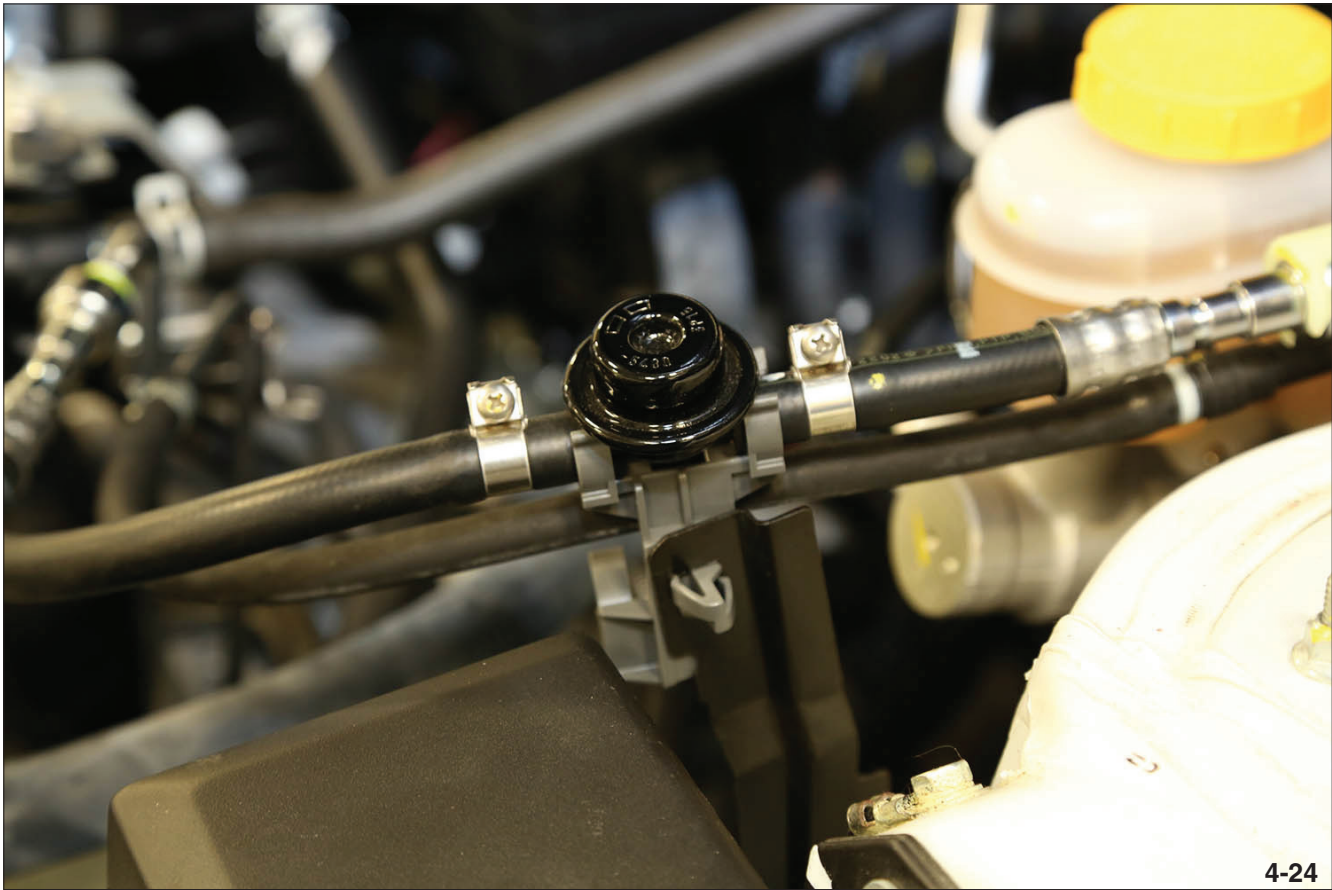
Fuel Line Release Tool 42099AE000

CAUTION: Follow the correct procedure in the service manual to remove fuel pressure from the system before removing any fuel system component.

Basic Fuel Injection Part 3

Fuel Pulsation Damper

A fuel pulsation damper is a device used to regulate the oscillation of fuel pressure noise caused by the injectors opening and closing. The damper reduces concerns of whistling, buzzing, humming, or moaning. If you suspect a damper is not operating correctly, replace it with a new one.



4-24

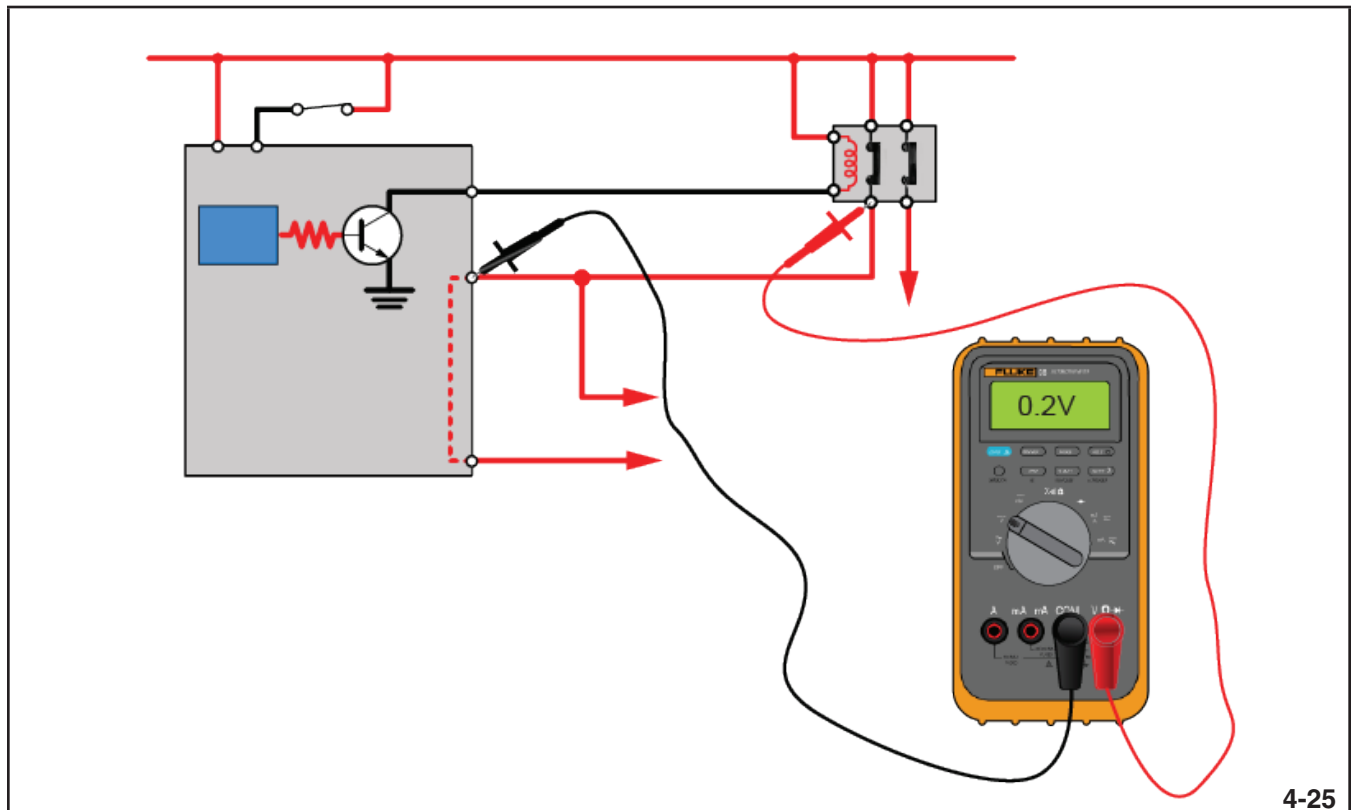
Testing Fuel Pulsation Damper

Notes:

Basic Fuel Injection Part 3

ECM Power and Ground Circuits

Verify the ECM power and ground connections using a DVOM and voltage drop testing. Consult the Input/Output (I/O) chart in STIS for power and ground terminal identification.



4-25

Testing ECM Power and Ground Circuits

Notes:

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Basic Fuel Injection Part 3

Ignition System

Upon completion of this lesson you will be able to:

- Explain the operation of the waste-spark and coil-over-plug ignition systems.

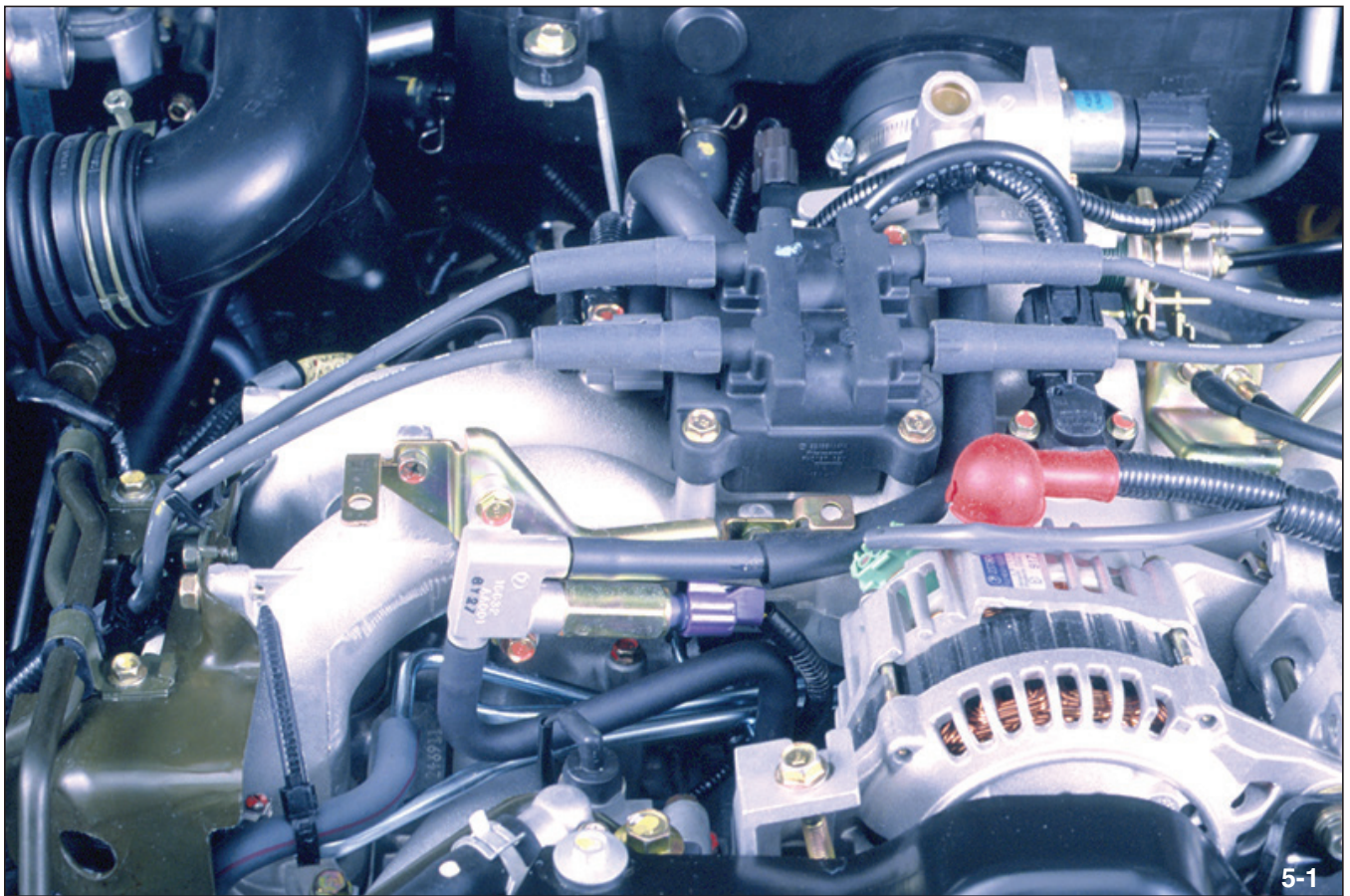
The ignition system has two basic functions. The first function is to control the spark timing; the spark plug must fire at precisely the right time to match varying engine requirements. The second function is to increase battery voltage to thousands of volts in order to provide a spark strong enough to fire the spark plug and ignite the air/fuel mixture.

Two types of ignition systems are found on Subaru vehicles:

- Waste spark system
- Coil-over-plug system

Waste Spark System Operation

The waste spark ignition system works by taking advantage of the engine design, two wires from the ECM send control signals to one coil pack which includes two separate coils. Each set of companion cylinders (1 and 2, 3 and 4) share a coil. The waste spark coil pack also includes two internal igniters.



Waste Spark Ignition Coil

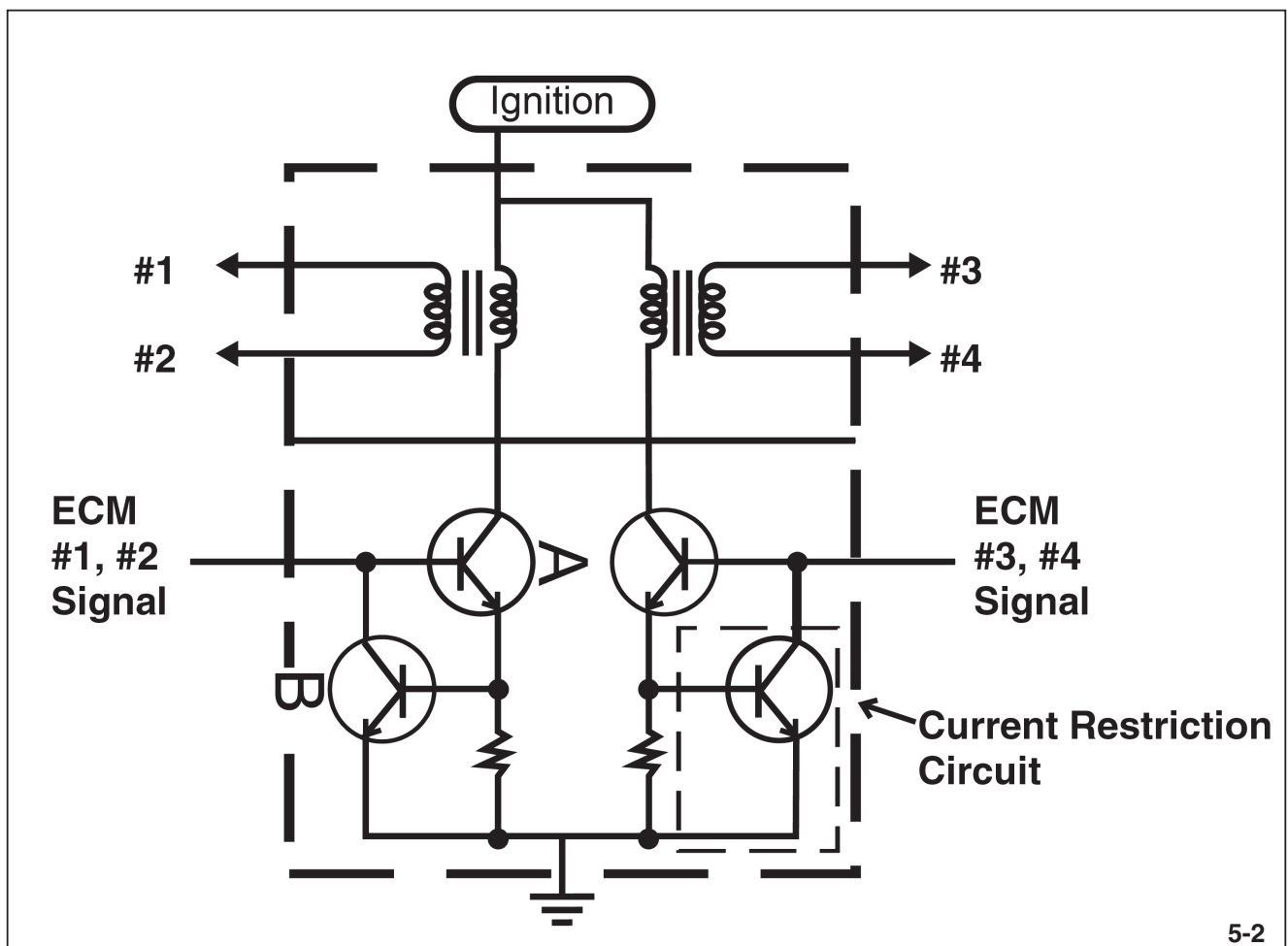
Basic Fuel Injection Part 3

The waste spark system amplifies battery voltage to over 10,000 volts, so the voltage can jump the spark plug gap and ignite the air/fuel mixture. The waste spark system fires the spark plug of the companion cylinder (on the exhaust stroke) at same time as the cylinder on the power stroke. Firing the companion cylinder on the exhaust stroke helps reduce emissions by combusting any unburned gases.

Testing the Waste Spark Ignition System

The waste spark ignition system includes:

- Engine control module
- Power feed and control circuits
- Ignition coil with integral igniter assembly



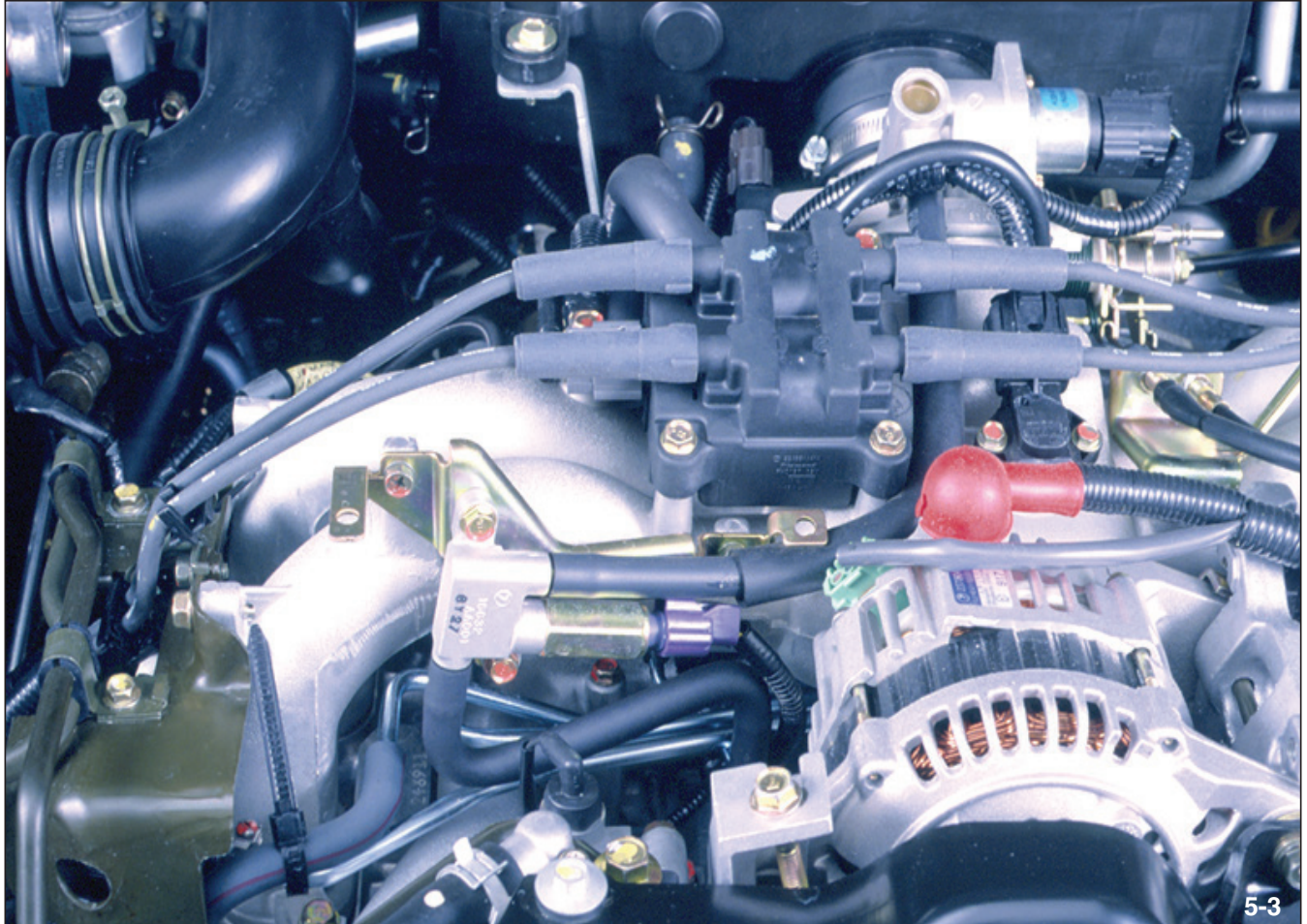
5-2

Waste Spark Schematic

Trouble within the waste spark system with a running engine will result in two possible conditions. If a fault in one side of the system, such as a leaking spark plug wire, is recent, you will observe a misfire in two cylinders. If this same concern is left long enough, the symptom may show only in one cylinder. This happens because the high voltage side of the system burns through the coil casing, finding its way to ground and allowing the companion cylinder to fire correctly.

Basic Fuel Injection Part 3

The best way to test the waste spark system is to verify the 12-volt supply to the ignition coil and validate the driver control from the ECM. Coil primary resistance cannot be measured because the internal transistor must be powered to complete the circuit. Refer to the service manual for ignition testing, cautions, procedures, and wiring diagrams.



Testing Waste Spark Ignition System

Tools used to diagnose the ignition components and circuits:

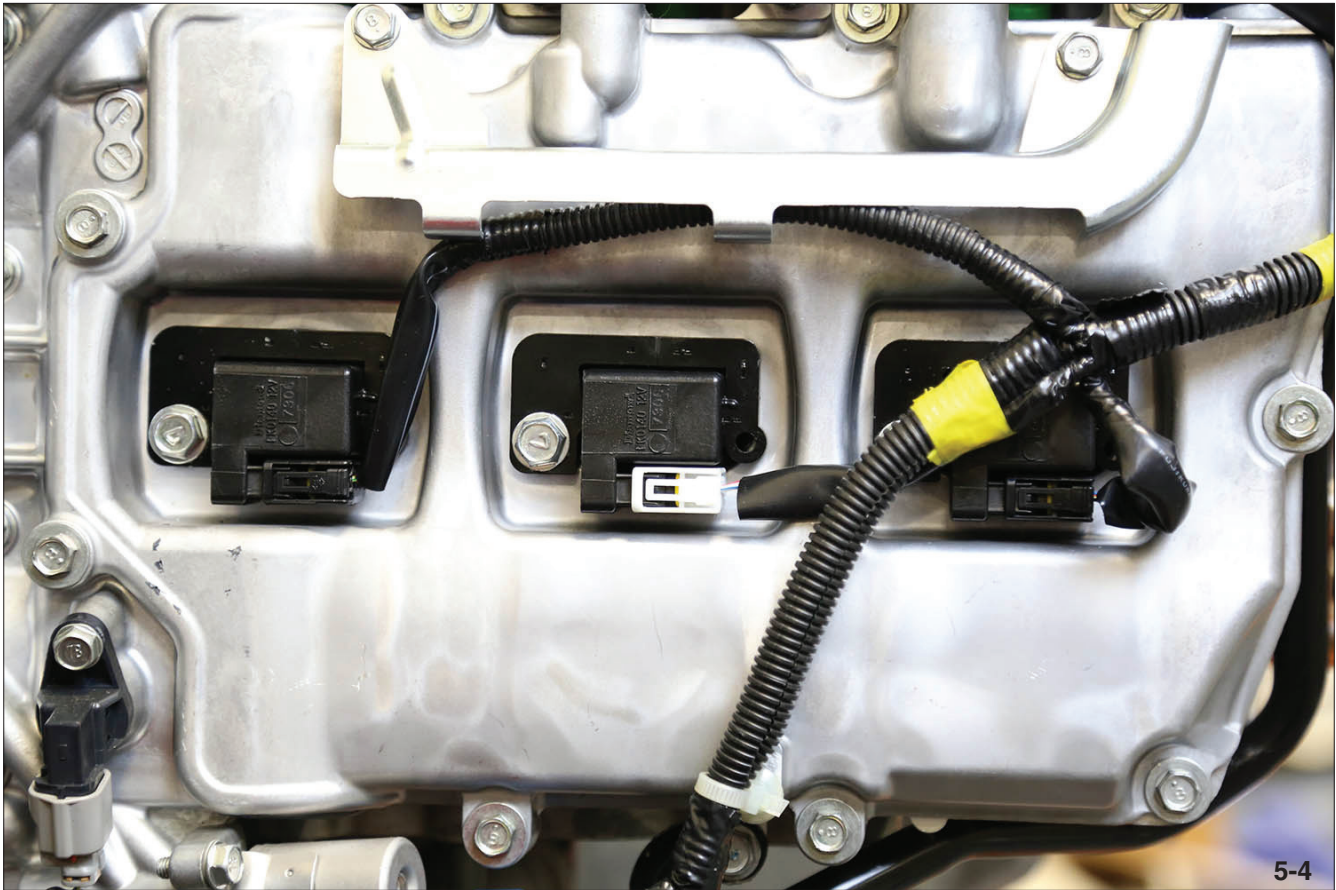
- Scan tool
- Test lamp
- DVOM
- Oscilloscope

Notes:

Basic Fuel Injection Part 3

Coil-Over-Plug System

The coil-over-plug ignition system has individual coil packs located at each spark plug. Wires from the ECM carry the control signals to the igniter, which is built into each coil.



Coil Over Plug Ignition Coil

The coil-over-plug ignition system:

- Converts low voltage to high voltage
- Supplies the high voltage to the spark plugs
- Is controlled by the ECM
- Contains an integrated igniter circuit

Note: The ignition coil electrical connector disengagement varies by model year. Consult STIS for the proper disengagement procedure.

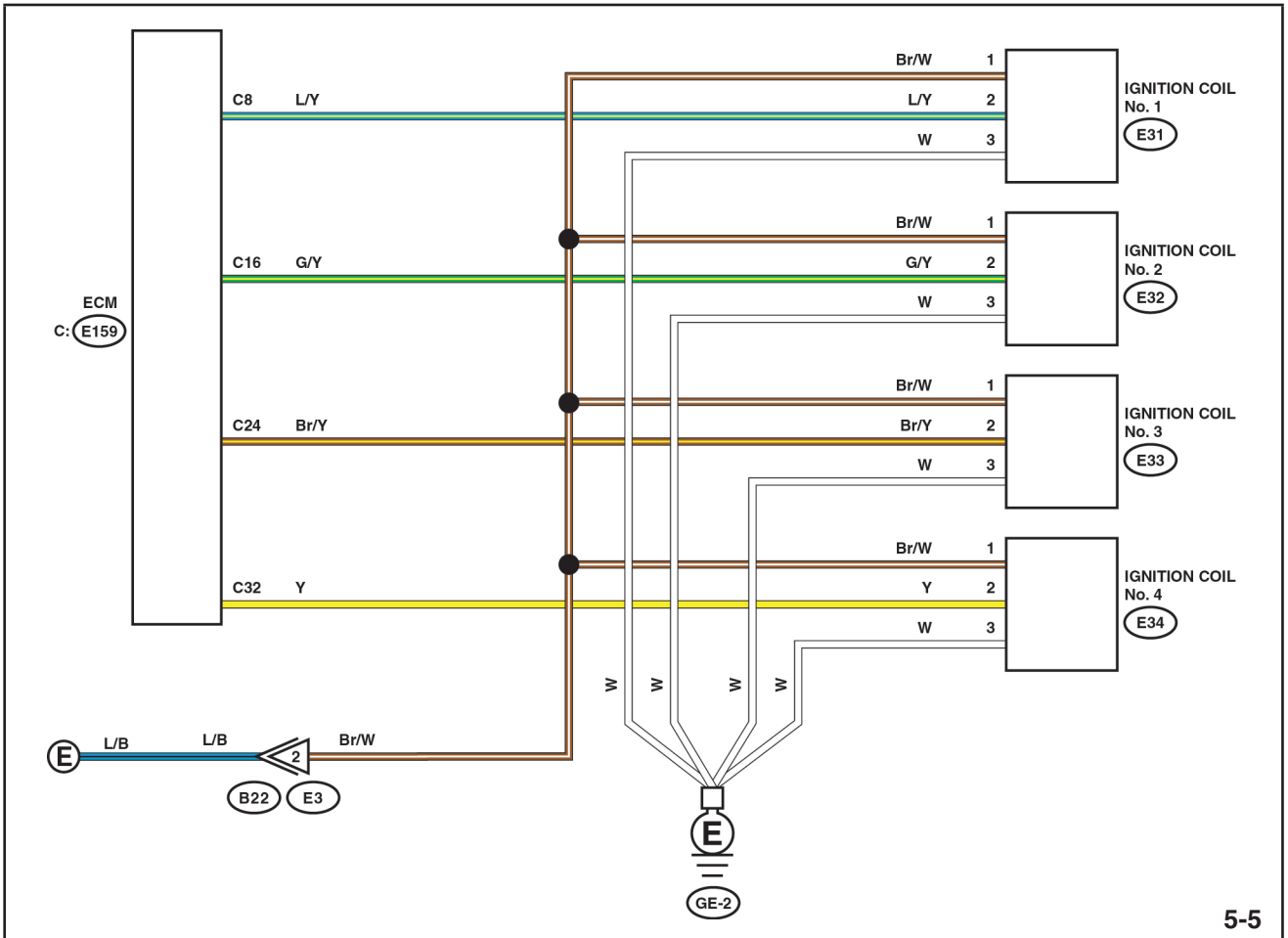
Testing the Coil-Over-Plug Ignition System

The coil-over-plug ignition system includes:

- Engine control module
- Power supply and control circuits
- Ignition coil with integral igniter assembly

Basic Fuel Injection Part 3

The coil-over-plug ignition system provides an ignition coil assembly for each cylinder of the engine; the malfunction of an individual coil assembly will create an issue with one cylinder only. The best way to test the coil over plug spark system is to verify the 12-volt supply to the ignition coil and validate the driver control from the ECM.



Coil-Over-Plug Ignition System Schematic

Tools used to diagnose the ignition components and circuits:

- Scan tool
- Test lamp
- DVOM
- Oscilloscope

Notes:

Basic Fuel Injection Part 3

Camshaft Position Sensor Types and Locations

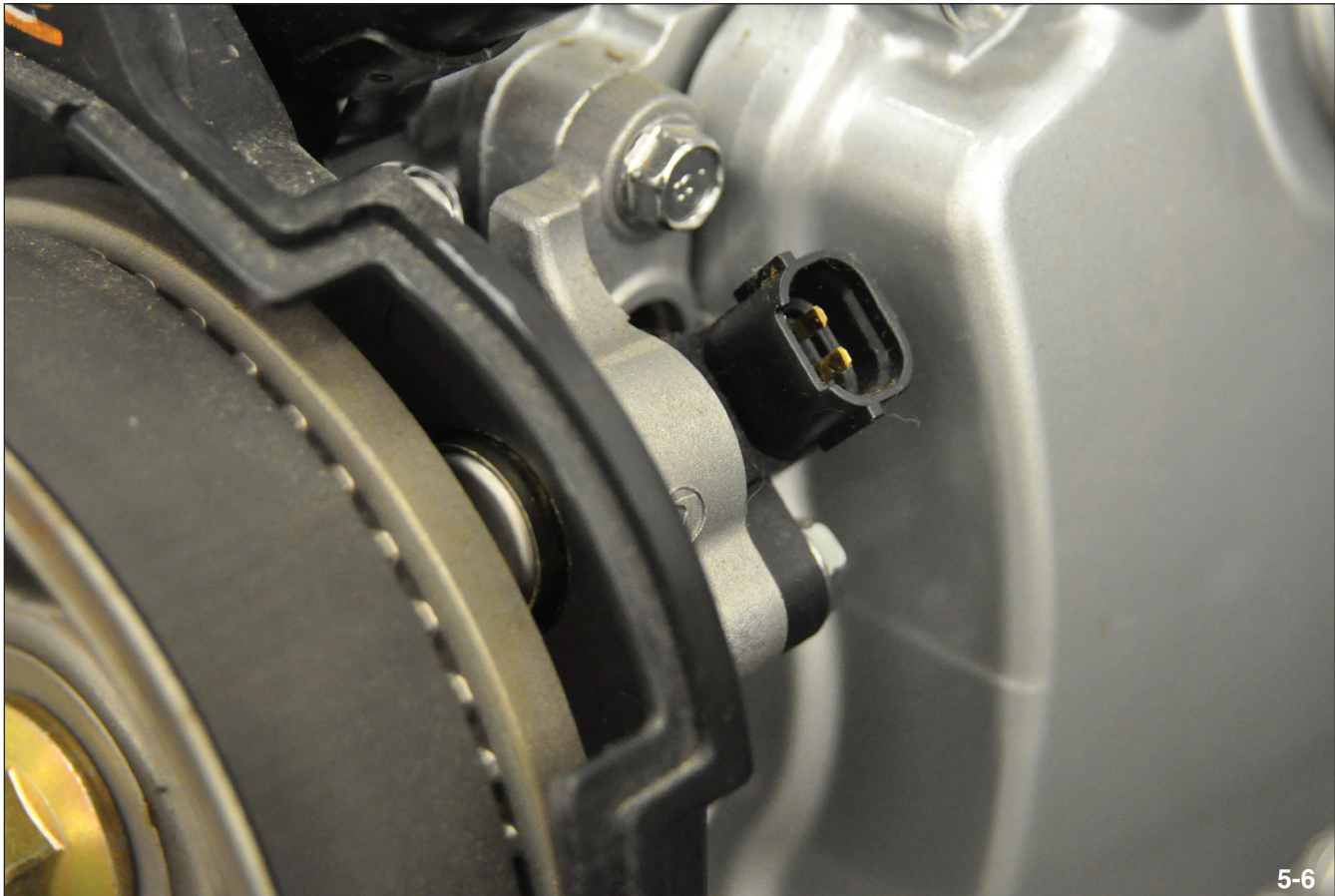
Gasoline engines use the ignition system to initiate combustion on the power stroke. The correct spark timing is calculated by an engine control module. The engine control module uses input data from the Camshaft Position (CMP) and Crankshaft Position (CKP) sensors for initial spark timing calculation.

There are two types of camshaft position sensors found on Subaru vehicles: inductive and Hall-effect. Both types of camshaft position sensors are located in the cylinder head and supply information about the camshaft position to the ECM.

Inductive Type

The inductive camshaft position sensor:

- Is voltage generating
- Requires a shield around its circuits
- Creates an AC sine wave from the rotating camshaft reluctor
- Provides signal to the ECM, which interprets camshaft position, ignition timing, and injector timing for each cylinder, and combines the camshaft signal with the crank angle sensor input to determine engine rpm



Inductive Type Camshaft Sensor

Basic Fuel Injection Part 3

Hall-Effect Type

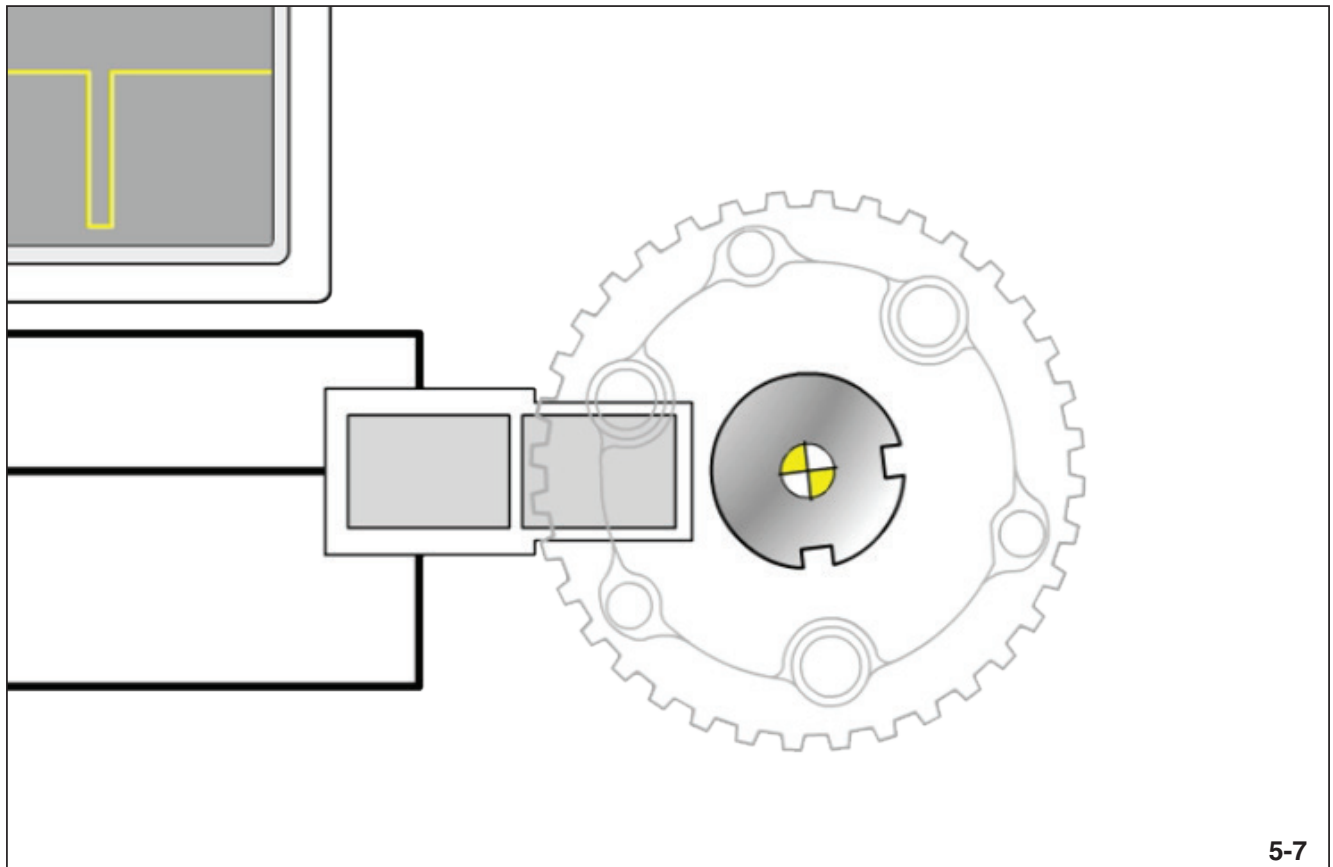
The Hall-effect camshaft position sensor creates a square wave signal off a rotating camshaft reluctor. The digital Hall-effect CMP sensor has three wires:

- 12-volt supply
- Signal
- Ground

With either type of sensor, the ECM receives camshaft position information which is used to trigger, ignition and injector timing for each cylinder. When combined with the crank angle sensor input, the ECM can determine engine rpm.

The camshaft reluctor(s):

- Rotates and has uniquely spaced teeth to identify cylinder number one
- Has a set air gap to the sensor
- Controls the shape and frequency of the camshaft sensor signal

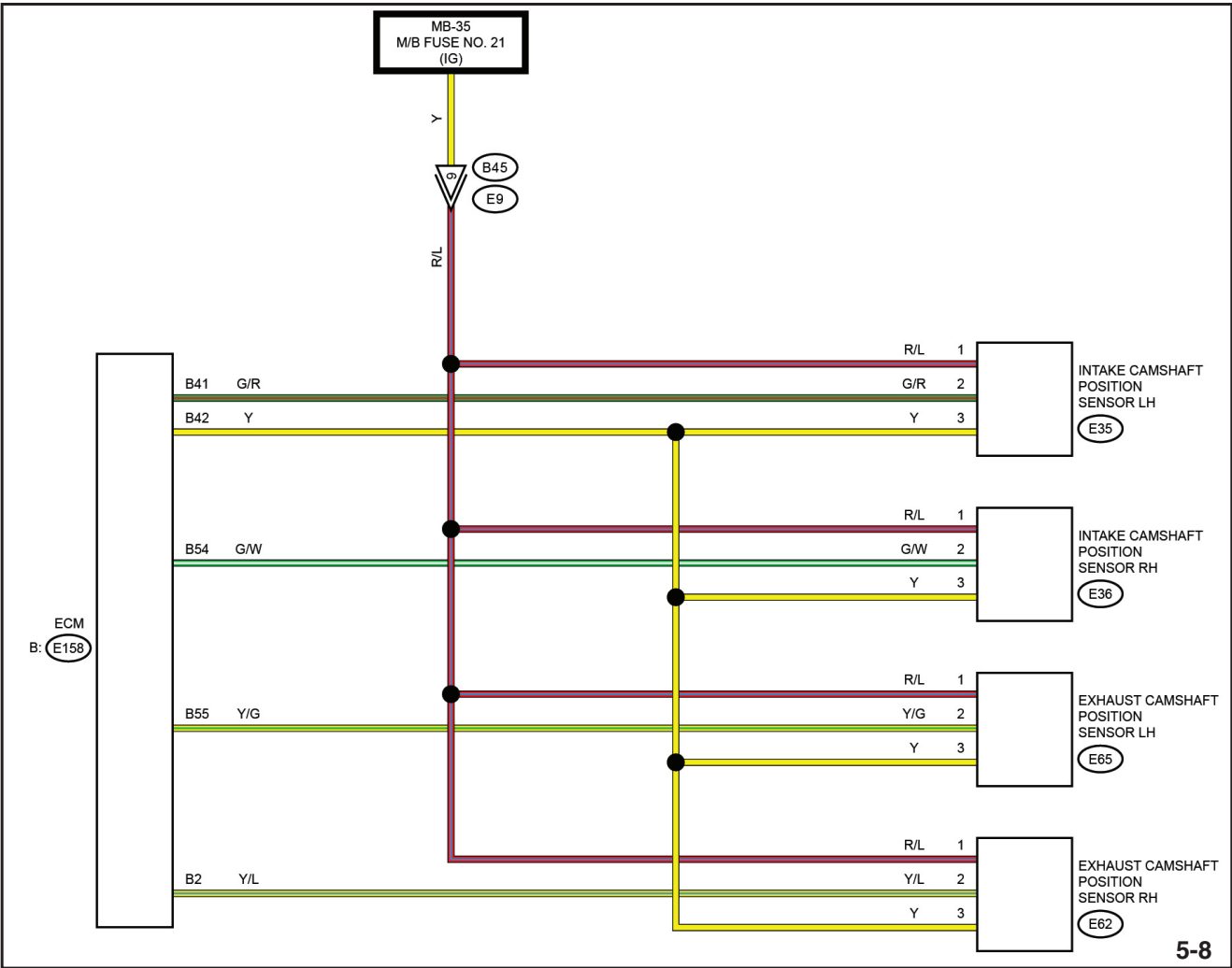


5-7

Camshaft Reluctor Wheel

The Hall-effect camshaft position sensor utilizes the 12-volt power supply and body ground to operate integrated circuits that are housed inside the sensor itself. When the ignition is on, 12 volts power from the main relay is supplied to the camshaft position sensor(in this example at R/L wire). The ground potential for the circuit is supplied through the ECM at B135 terminal 42 and is in a parallel circuit with the remaining camshaft position sensors of the engine.

Basic Fuel Injection Part 3



Camshaft Sensor Circuit Schematic

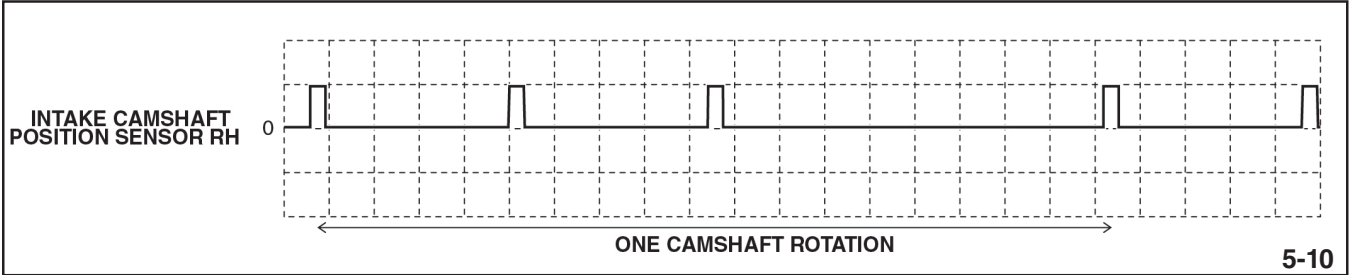
The ECM supplies a 5-volt signal to the camshaft position sensor through the signal wire(s) (41, 54, 55, and 2), which is changed to 0 volts and back to 5 volts as the camshaft reluctor rotates by the end of the sensor.

Intake camshaft position sensor (LH)	B135	41	0 or 5	0 or 5	*1: Waveform
Intake camshaft position sensor (RH)	B135	54	0 or 5	0 or 5	*1: Waveform
Exhaust camshaft position sensor (LH)	B135	55	0 or 5	0 or 5	*1: Waveform
Exhaust camshaft position sensor (RH)	B135	2	0 or 5	0 or 5	*1: Waveform
Camshaft position sensor ground	B135	42	0	0	— 5-9

Engine I/O Chart

Basic Fuel Injection Part 3

Normally, the waveform of the signal takes on the shape of the construction of the reluctor.



2014 Forester I/O

This design of the camshaft reluctor provides a 0-volt input while the taller outer circumference is traveling past the camshaft position sensor, and increases to 5 volts as a notch travels past.

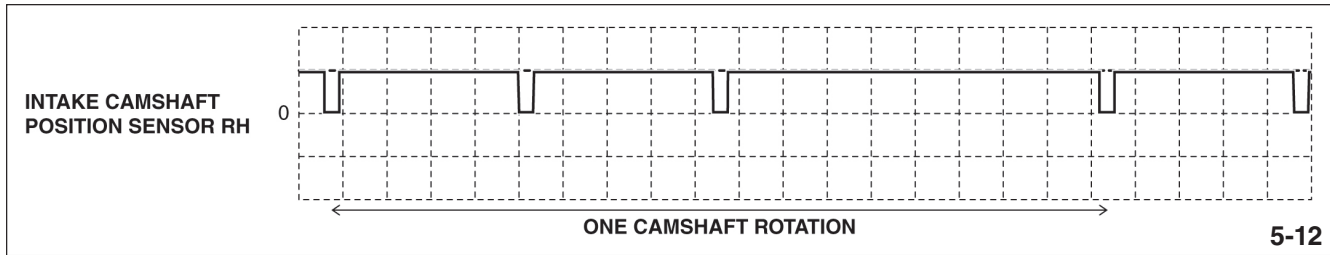


Sensor Plate

Notes:

Basic Fuel Injection Part 3

This design, with teeth protruding from the outer circumference of the camshaft reluctor, provides a 5-volt input while the shorter outer circumference of the camshaft reluctor travels past the camshaft position sensor, and increases to 5 volts as a tooth travels past.



2015 WRX and WRX STI I/O



15MY Sensor Plate

Both reluctor types rely on the proper air gap between the tip of the sensor and the smooth, straight rotation of the camshaft reluctor. A deviation in either part will result in the creation of poor signal or no signal at all. This can lead to hard start and drivability issues.

Note: Subaru Hall-effect camshaft and crankshaft position sensors rely on constant speed.

The edges of the signal tooth or notch are detected and timed as they go from an off to on to off condition. Large deviations in speed from off to on time compared to on to off time will result in the inversion of the waveform. This is most noticeable during an engine stall or nearing stall condition. This condition is considered normal and an operating characteristic of the sensors.

Basic Fuel Injection Part 3

Even though the signal is inverted, the ECM still receives the signal and determines it as normal during this condition. The waveform will return to normal with increased and steady rotational speed.

Crankshaft Position Sensor Characteristics and Location

There are two types of CKP sensors used on Subaru vehicles; inductive and Hall-effect. The location of the CKP sensor varies by model year and engine type. The sensor will be located at either the front or rear of the crankshaft.

The fuel delivery system uses the crankshaft position sensor input or ignition reference signals to indicate to the engine control module that the engine is either cranking or running.

Inductive Type

The inductive CKP sensors are voltage-generating sensors that create an analog signal that is sent to the ECM. The two wires carrying the signal to the ECM are shielded to protect signal integrity. The ECM determines the crankshaft position by counting the number of pulses supplied by the CKP sensor.



5-14

Crankshaft Sensor (Inductive)

Notes:

Basic Fuel Injection Part 3

Hall-Effect Type

The digital Hall-effect-type CKP sensor has three wires:

- 12-volt supply
- Signal
- Ground



5-15

Crankshaft Sensor (Hall-Effect)

Notes:

Basic Fuel Injection Part 3

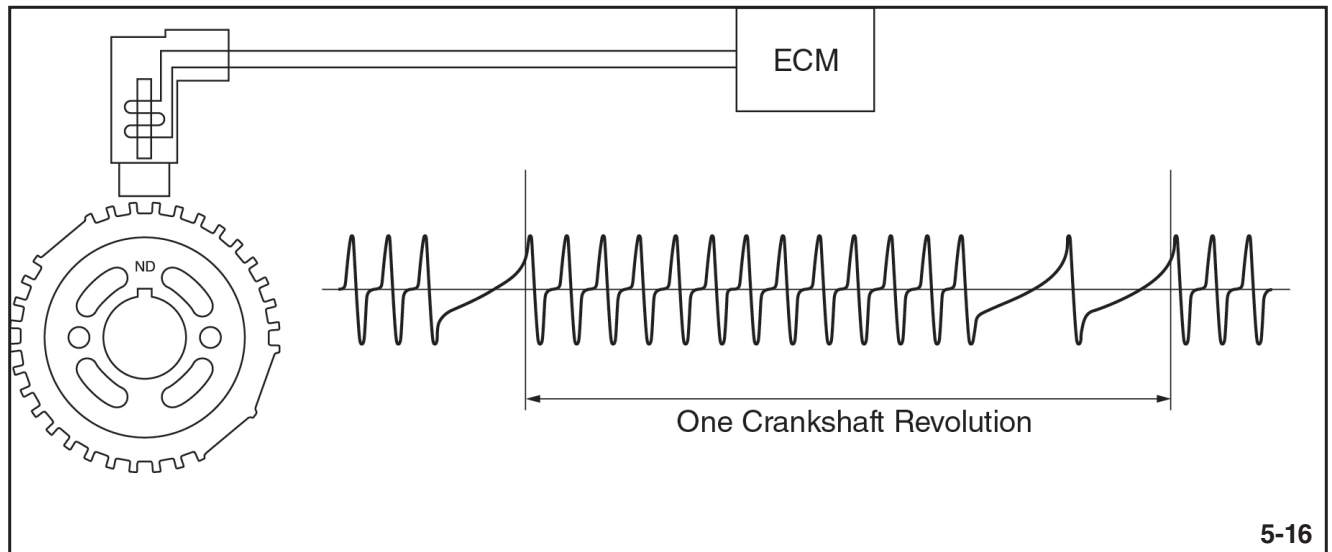
Crankshaft Reluctor Wheel

The crankshaft reluctor:

- Rotates and has uniquely spaced teeth to identify cylinder location
- Has a set air gap to sensor
- Controls the shape and frequency of the crankshaft sensor signal

The engine control module determines the crankshaft position by counting the number of pulses supplied by the crankshaft position sensor.

All sensor patterns can be located in the Input/Output (I/O) chart of the appropriate service manual. Compare the captured oscilloscope patterns against the pattern in STIS to confirm the correct signal output.



Crankshaft Reluctor Wheel

Tools used to diagnose the ignition components and circuits:

- Scan tool
- Test lamp
- DVOM
- Oscilloscope

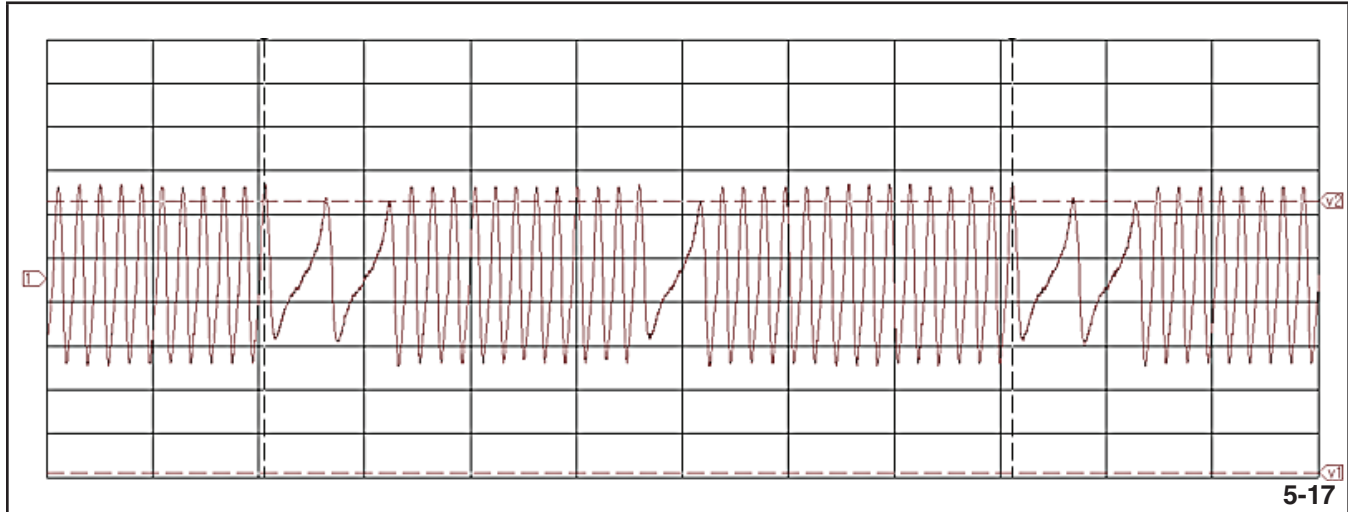
Notes:

Basic Fuel Injection Part 3

Inductive Crankshaft and Camshaft Sensor Operation

The inductive-style sensor is a two-wire sensor that generates a -7 to 7 volt sine wave. Review the test procedure, including use of the lab scope to validate a good analog signal, as shown in the diagram.

Note: Imperfections or irregularities with the reluctor teeth or air gap to the sensor will have an effect on the shape and amplitude of the generated signal.

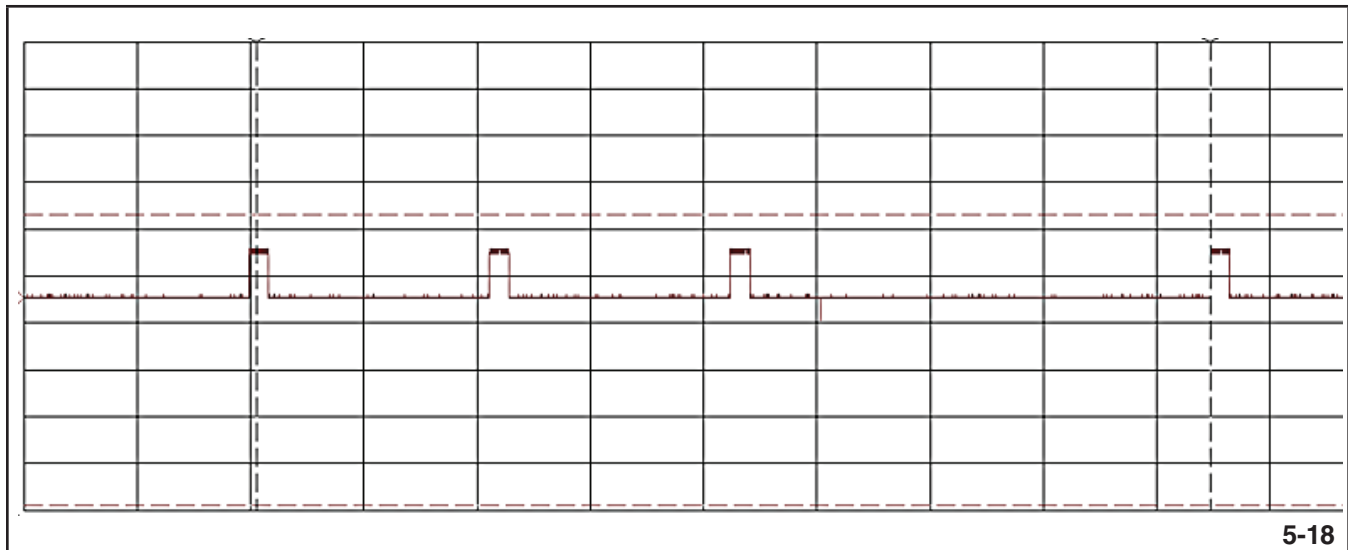


Typical Inductive Sensor Oscilloscope Pattern

Hall-Effect Crankshaft and Camshaft Sensor Operation

The hall-effect style sensor is a three-wire sensor that outputs a 0–5 volt square wave. Review the test procedure, including use of the lab scope to validate a good digital signal, as shown in the diagram.

Note: Imperfections or irregularities with the reluctor teeth or air gap to the sensor will have an effect on the shape of the output signal.

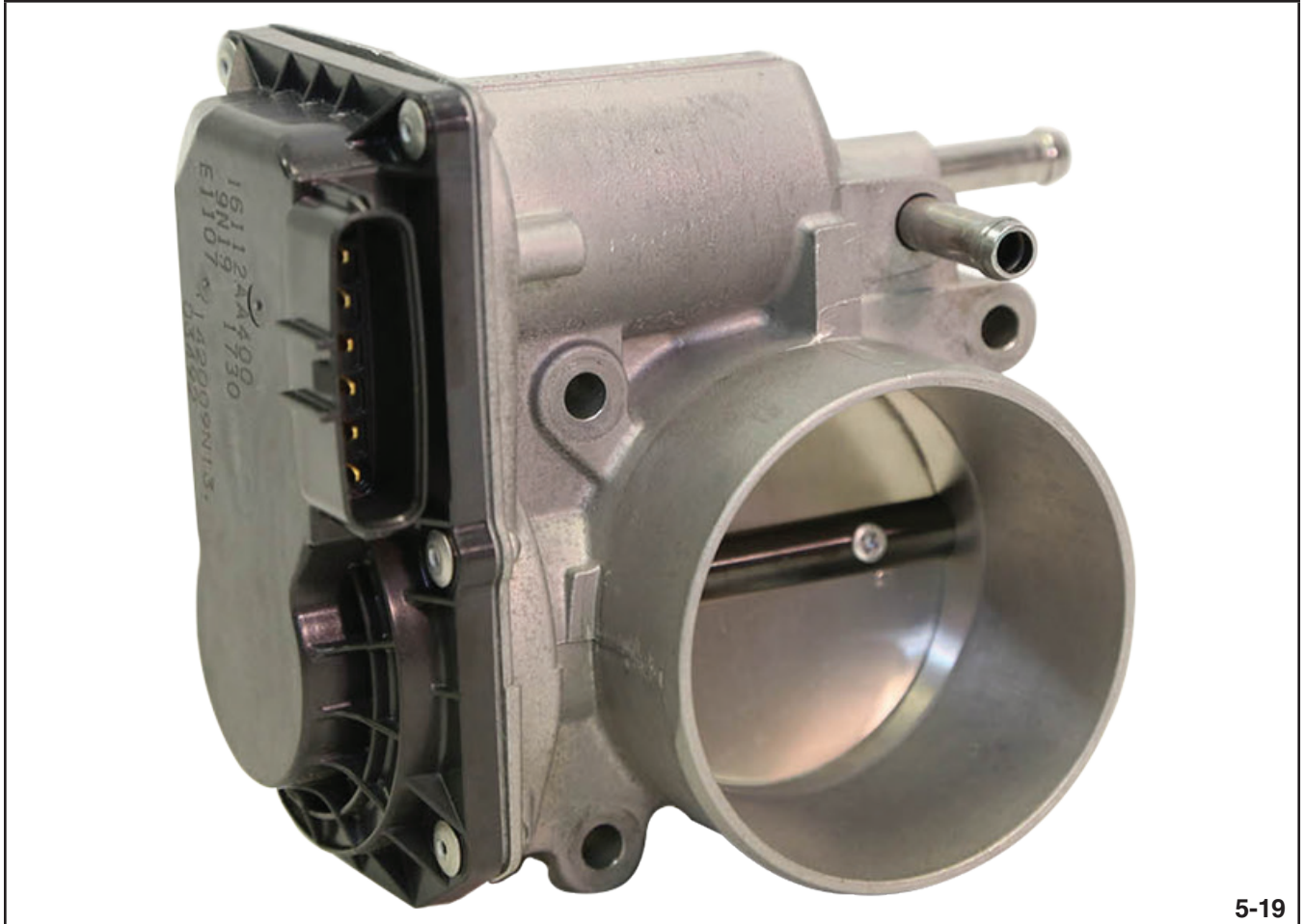


Typical Hall-Effect Sensor Oscilloscope Pattern

Basic Fuel Injection Part 3

Throttle Position Sensor Operation

The Throttle Position Sensors (TPS) are located on the throttle body and provide information to the ECM regarding the position of the throttle plate. The engine control module uses the sensors' signals input to calculate fuel delivery, spark timing, and other engine control module output functions.



Throttle Position Sensor

Notes:

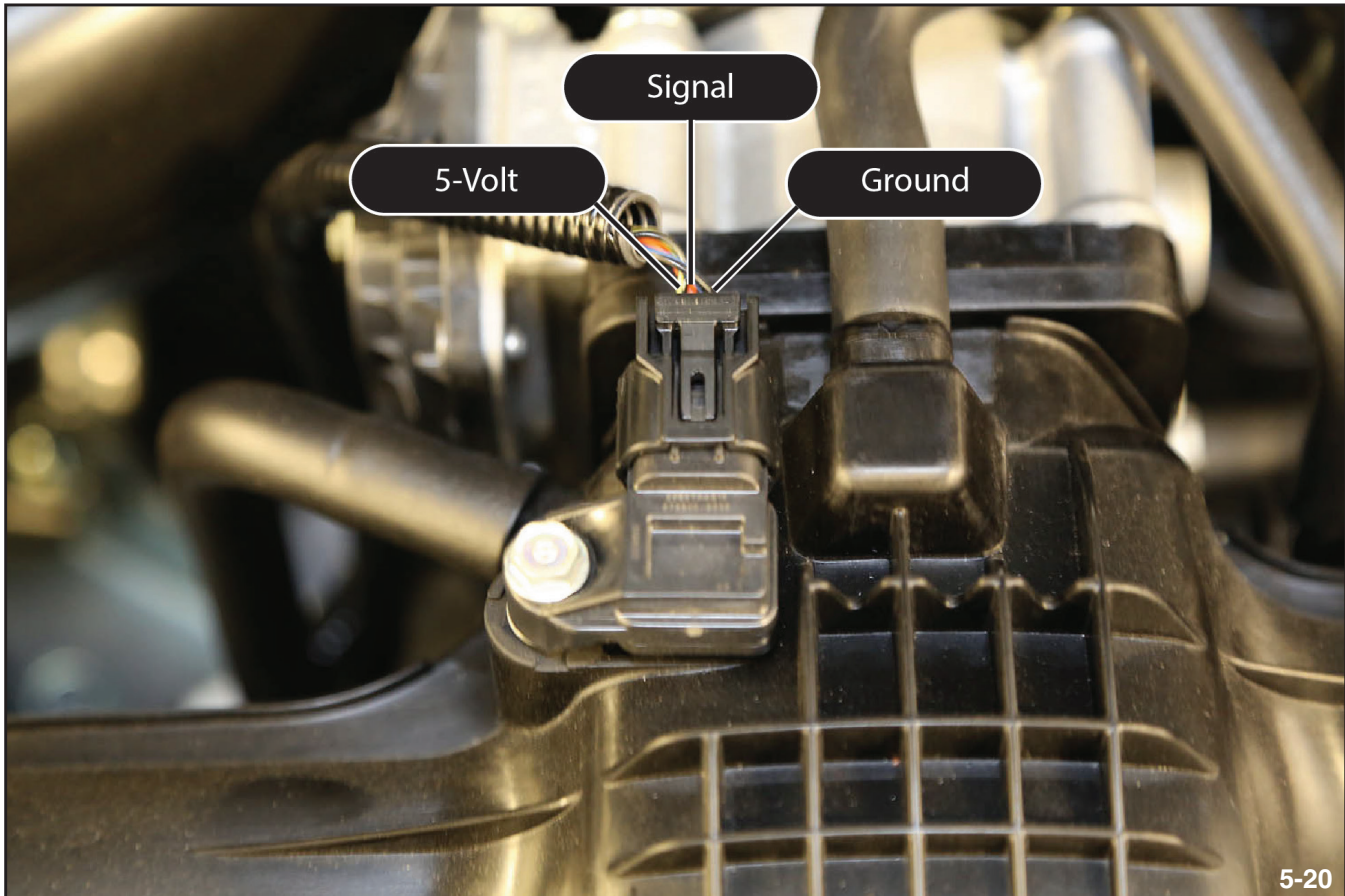
Basic Fuel Injection Part 3

Manifold Absolute Pressure Sensor Operation

The MAP sensor measures changes of the absolute air pressure in the intake manifold. The ECM uses this information to modify injector duration and monitor EGR operation.

The MAP sensor uses three wires:

- Voltage supply
- Signal
- Ground



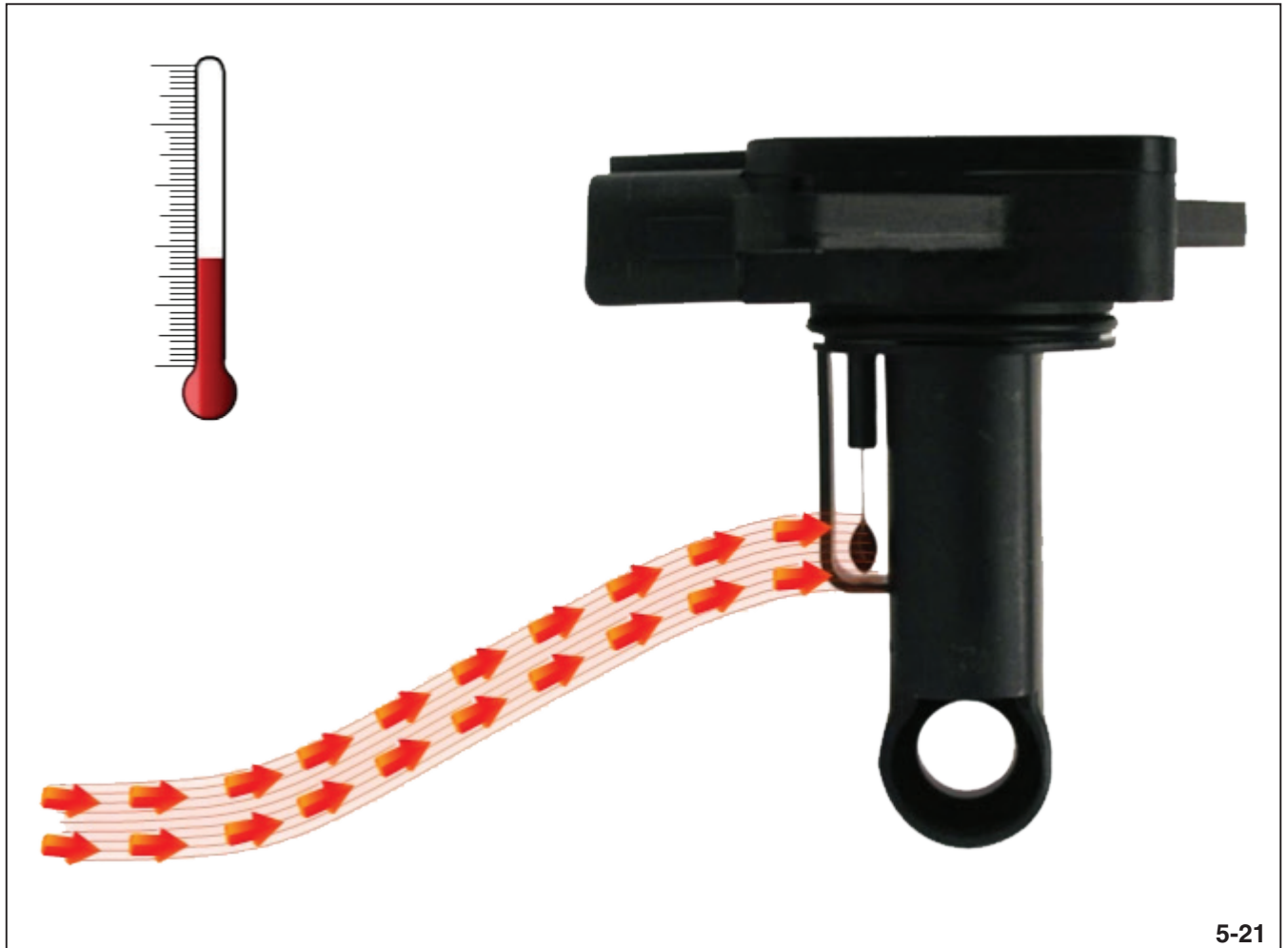
Manifold Absolute Pressure Sensor

Notes:

Basic Fuel Injection Part 3

Intake Air Temperature Sensor Operation

The IAT sensor is an NTC-type thermistor that changes resistance with temperature. The resistance change provides the ECM with a voltage signal. Based on this voltage value, the ECM can adjust fuel enrichment and spark timing.



Intake Air Temperature Sensor

Notes:

Notes:

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

Basic Fuel Injection Part 3

Fuel System Operating Status

Upon completion of this lesson you will be able to:

- Identify the fuel system operating status.

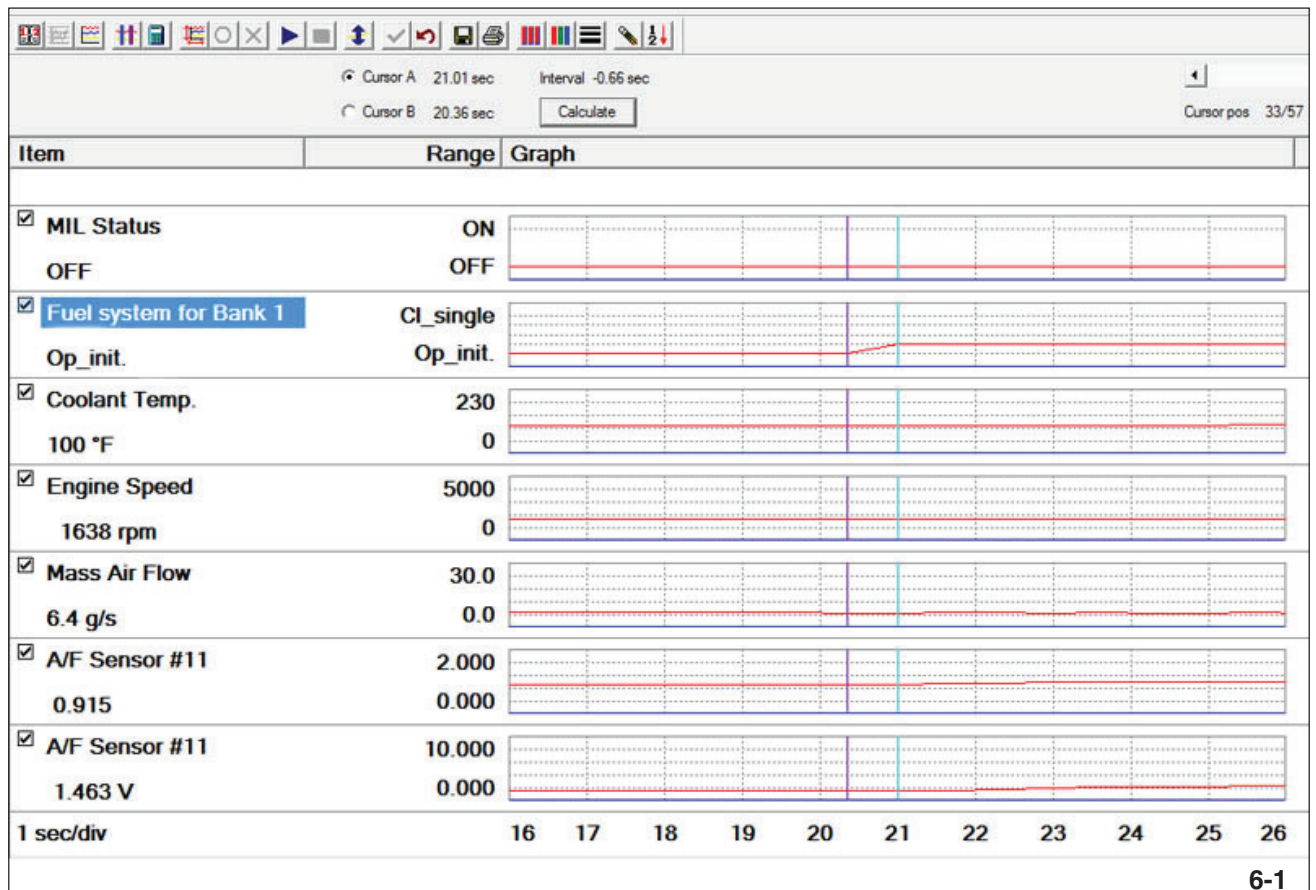
For proper combustion and maximum engine performance, the correct amount of fuel and air must be mixed together. There are many different strategies programmed in the ECM software to account for a cold, warm, or hot engine start.

Open-Loop Operation

Fuel system open-loop operation is a pre-programmed operating strategy used when the engine coolant is below a specific temperature.

Fuel system open-loop operation occurs when the engine management system provides the optimum operating conditions in which a different air/fuel ratio is required under certain situations, such as a cold engine, near full throttle, and fail-safe conditions.

To verify the fuel system is in open-loop, monitor the fuel system status parameter in the OBD II menu of the Subaru Select Monitor, and verify the parameter displays Op_init.



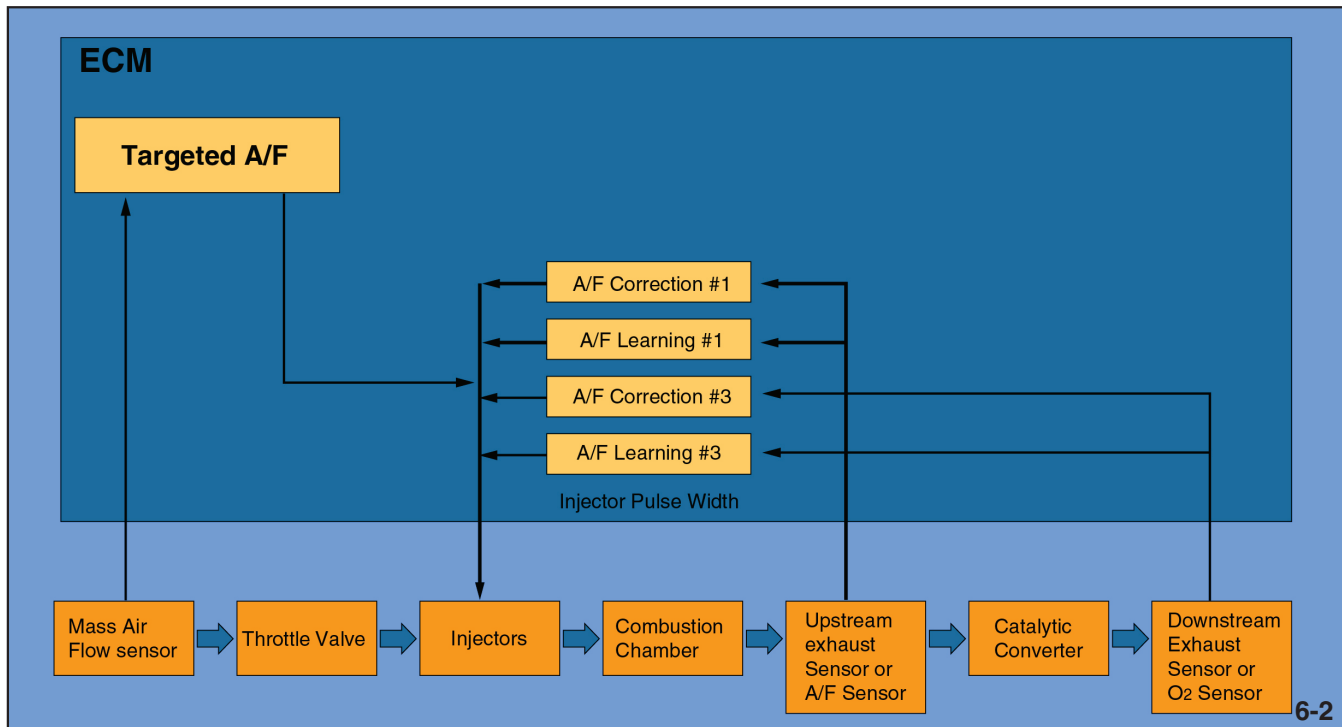
Open-Loop Operation

Note: The delivery mode fuse provides an input to the ECM to keep the vehicle in open loop operation. The delivery mode fuse is removed during the PDI process prior to vehicle delivery.

Basic Fuel Injection Part 3

Closed-Loop Operation

Fuel system closed-loop operation is an engine management strategy that uses system sensors to provide input for the required air/fuel ratio calculation. The engine management system uses the sensors to monitor the amount of air induced into the engine and the amount of oxygen within the exhaust stream, in order to adjust the air/fuel ratio as close to stoichiometric as possible (allowing complete combustion to occur). The correction and learning values, displayed on the Subaru Select Monitor, show current and past corrections to the amount of fuel injected.



Closed-Loop Operation

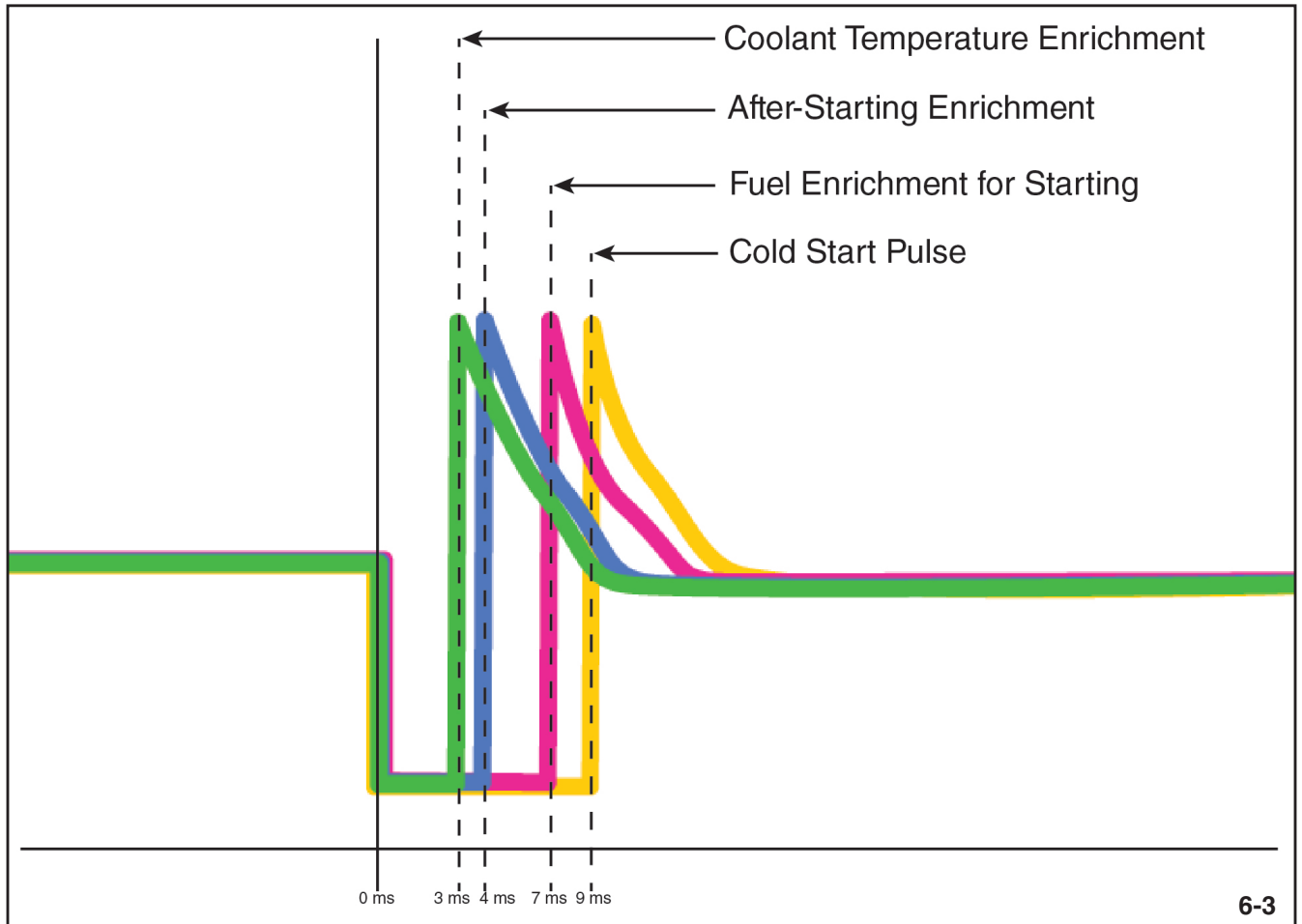
Notes:

Basic Fuel Injection Part 3

Cold Start Pulse

The cold start pulse determines the injection duration from the coolant temperature sensor. The following controls are performed to prevent the spark plugs from fouling and causing poor starting:

- The cold start pulse is gradually decreased during a long crank.
- The cold start pulse is decreased when depressing the throttle pedal.



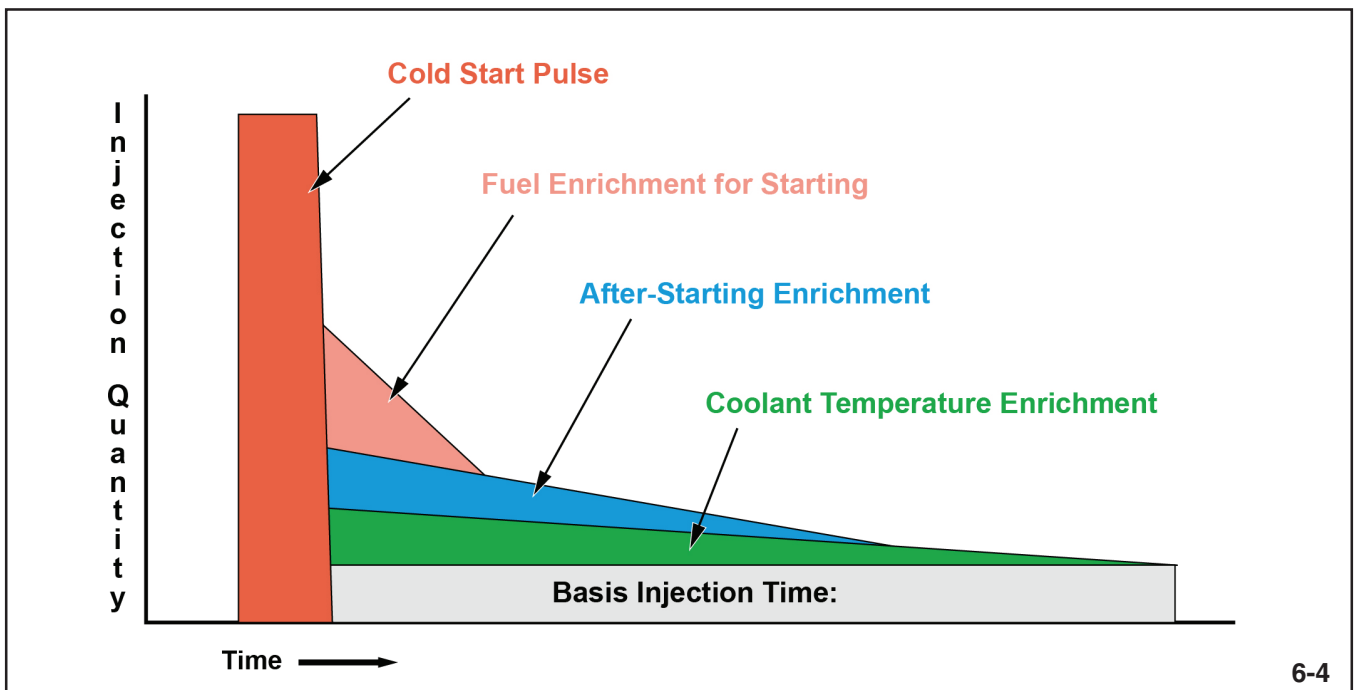
Cold Start Pulse

Starting Fuel Enrichment Mode

When starting the engine, the injection duration is increased to ensure an adequate quantity of vaporized fuel. This is due to the fuel vaporization rate being low, especially when the engine is cold and the airflow speed is low.

Notes:

Basic Fuel Injection Part 3



Injection Logic Graph

After starting the engine, the air and fuel vapors begin to travel in the intake manifold. With a cold intake manifold, the fuel clings to the inside walls of the manifold, creating a lean condition at the cylinders. To compensate, additional fuel is injected. The injection quantity is increased immediately after the engine starts and for a set period of time, which is determined according to the coolant temperature.

Coolant Temperature Enrichment

The quantity of fuel is incremental and set according to the engine coolant temperature while the engine is warming up, and until it is warmed up.

Hot Start Strategy

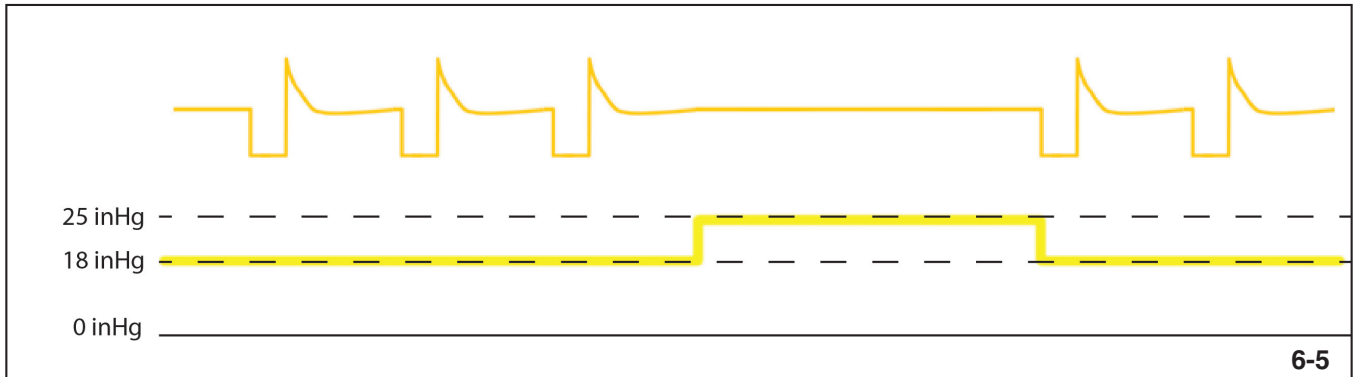
As the engine warms up, the amount of fuel injected to compensate for cold engine temperatures is reduced. After the engine reaches a preset temperature, which varies by model, no additional fuel will be injected to compensate for cold engine temperatures.

Notes:

Basic Fuel Injection Part 3

Fuel Cut Control

This control cuts off fuel to the engine when it is decelerating or under conditions such as high engine speeds. The injection pulse will be set to 0.



Fuel Cut Control

The ECM stops injection of fuel when the following conditions are met:

- The ignition switch is OFF.
- Engine speed has reached a preset value or higher regardless of vehicle speed.
- Engine speed has reached a preset value or higher for a set period of time while vehicle speed is zero.
- A torque control signal is received from the TCM, ABSCM or VDCCM.

Notes:

Basic Fuel Injection Part 3

ECT Sensor and Circuits

To test the ECT sensor, measure the resistance between engine coolant temperature sensor terminals and refer to the Temperature vs. Resistance chart in STIS.



Testing Engine Coolant Temperature Sensor and Circuits

A disconnected sensor value on the scan tool will indicate -40 °F, while a shorted ECT temperature sensor value will indicate 248 °F. These extreme values are fail-safe values, and the ECM uses a predetermined ECT value where coolant temperature is a variable.

Notes:

Basic Fuel Injection Part 3

Testing the Fuel Injector System

Upon completion of this lesson you will be able to:

- Explain the testing of the fuel injection system.

The fuel injectors must precisely atomize and deliver the fuel to each cylinder. The engine control module calculates fuel injector on-time. The on-time is based on inputs from different engine control sensors.

To perform a pressure test and leak down test, connect a pressure gauge to the fuel system and turn the key to the run position to allow pressure to build up. This is system pressure; verify it is within specification. Then, turn the key to the OFF position and watch the gauge. The pressure should not drop more than 1 psi (6.9 kPa) per minute. If it does, there is a leaking fuel injector or bad check valve in the fuel pump.

Fuel injector failures include:

- Excessive fuel pressure drop (leaking fuel injectors)
- Insufficient fuel delivery or volume flow (restricted fuel filter or weak fuel pump)

Perform the fuel pressure leak down test to verify a leaking fuel injector. Perform the fuel pressure test to verify a fuel delivery concern.

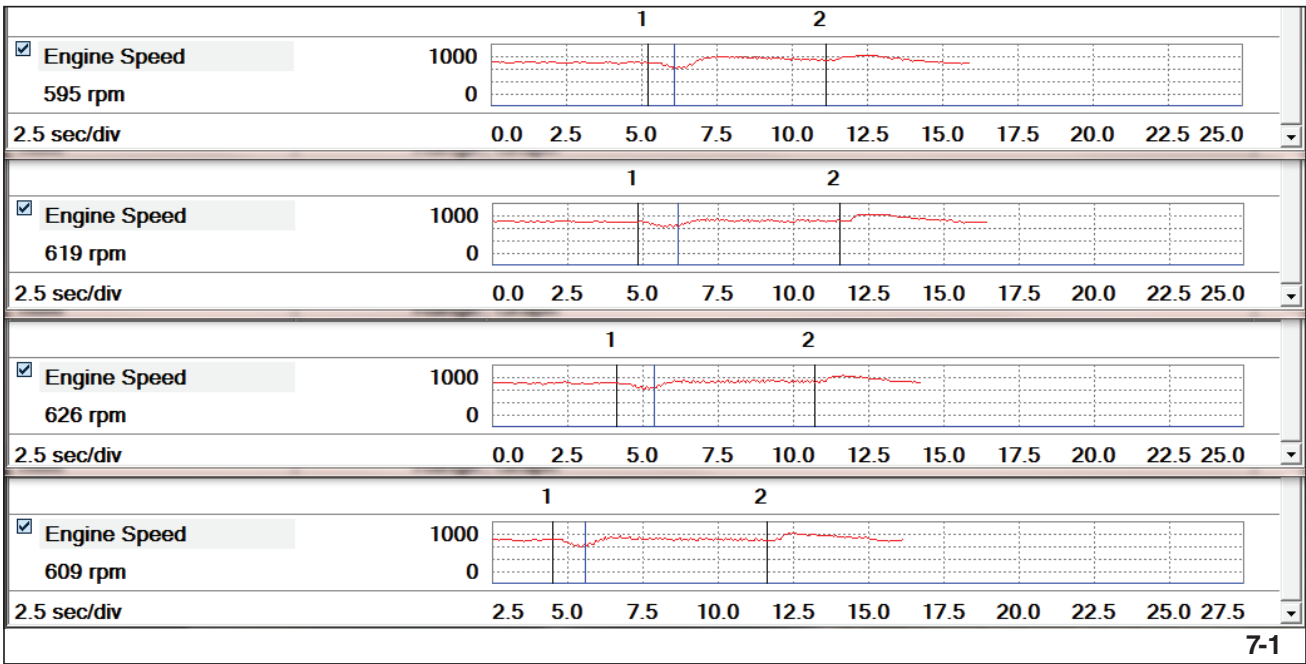
Notes:

Basic Fuel Injection Part 3

Fuel Injector Balance Test

To perform a balance test, use the scan tool to perform injection stop mode for each cylinder. Monitor and record rpm values before and during the test. Compare each cylinder's results to identify problem cylinders:

- Command the fuel injectors ON and OFF.
- View fuel system data.
- Save the data from each injector stop mode operation for comparison.



Fuel Injector Balance Test (Four separate recordings shown)

Notes:

Basic Fuel Injection Part 3

Injector Current Draw Test

A low-amp current probe can be used to measure the fuel injector current draw, and an oscilloscope verifies if the fuel injector electrical and mechanical attributes (injector pattern) are within specifications.



7-2

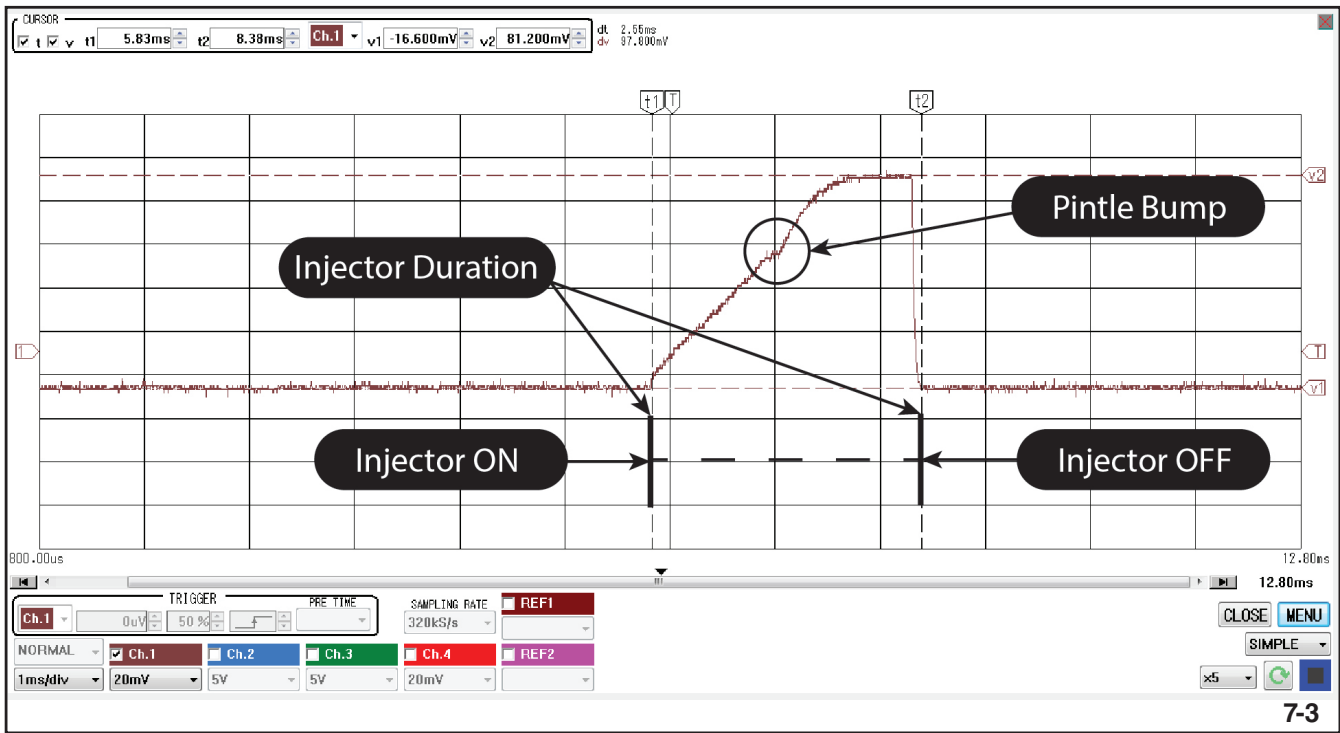
Injector Current Draw Test

Notes:

Basic Fuel Injection Part 3

Fuel Injector Signal Pattern

A normal injector pattern should show all of the characteristics of the pattern shown. Any deviation of the pattern would indicate a possible mechanical or electrical issue with the injector or its circuit.



Fuel Injector Signal Pattern

Notes:

Basic Fuel Injection Part 3

Testing Fuel

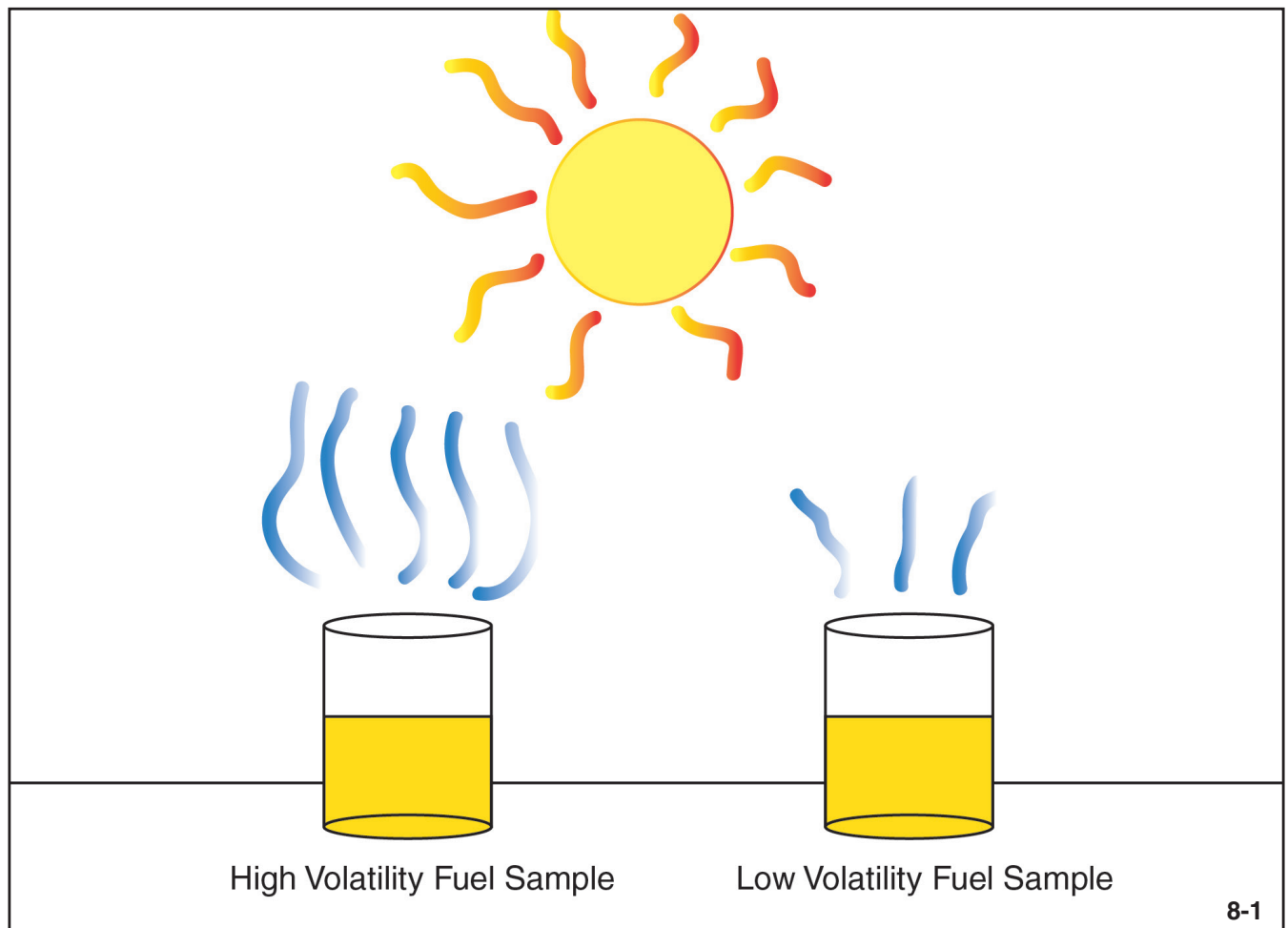
Upon completion of this lesson you will be able to:

- Explain the properties and testing procedures of fuel.

Diagnosis of the fuel system requires knowledge of the fuel delivery system components and basic troubleshooting skills, such as the ability to read and interpret scan tool data, DVOM values, oscilloscope waveforms, and characteristics of fuel and fuel quality.

Fuel Volatility

Volatility is gasoline's ability to change from a liquid to a vapor. The correct volatility allows air and fuel to properly pre-mix in the induction system prior to combustion. The correct volatility also prevents the fuel from evaporating prematurely, causing high emissions.



Fuel Volatility

The need for proper atomization must be balanced with the need to reduce hydrocarbon emissions. Fuels are adjusted seasonally and geographically, taking into account weather extremes. A vehicle containing fuel with the incorrect volatility will likely exhibit drivability concerns, such as hard starting, rough running, and hesitations.

Basic Fuel Injection Part 3

Octane Rating

Octane is also known as the Anti-Knock Index (AKI) and is the average of the Research Octane Number (RON) and Motor Octane Number (MON). $(R+M)/2$ laboratory tests determine RON and MON. Octane gives fuel resistance to self-ignition under compression. A high enough flash point prevents hot carbon deposits from igniting a second flame front.



Octane Rating

Reformulated and Oxygenated Fuel

Most gasoline is now reformulated. Reformulated fuels are blended with alcohol that chemically creates oxygen in the fuel. These fuels are called oxygenates; they burn cleaner, which keeps the air cleaner, improve catalytic converter efficiency, and produce less energy. Both Ethanol and Methanol raise the octane rating of hydrocarbon fuels.

Notes:

Basic Fuel Injection Part 3



Reformulated Fuels

Ethanol Fuel

Ethanol (ethyl or grain alcohol) and Methyl Tertiary Butyl Ether (MTBE) are also oxygenated blend fuels. To maintain good drivability, Subaru vehicles should use fuels that contain no more than 15% MTBE or 10% ethanol.

Methanol

Methanol (methyl or wood alcohol) is sometimes mixed with unleaded gasoline. Methanol can be used in Subaru vehicles **ONLY** if it:

- Does not exceed 5% of the fuel mixture
- Is accompanied by sufficient quantities of the proper co-solvents
- Contains enough corrosion inhibitors to prevent damage to the fuel system

Both ethanol and methanol raise the octane rating of hydrocarbon fuels.

Note: The specifications listed in this TRB for MTBE and methanol are identical to those listed in the Subaru owner's manuals. The use of MTBE has diminished over recent years and the use of methanol is not widely available for automotive use in the United States.

Basic Fuel Injection Part 3

Fuel Contamination

Fuel contamination is caused by debris, foreign materials, corrosion, water, and other unwanted substances mixed with the fuel in the tank.



Fuel Contamination

Contamination causes drivability symptoms, such as:

- Engine misfire
- Sluggish operation
- Poor engine performance
- Hard start conditions (not no-start concerns)

Too much alcohol in the fuel damages fuel system components, such as seals and O-rings.

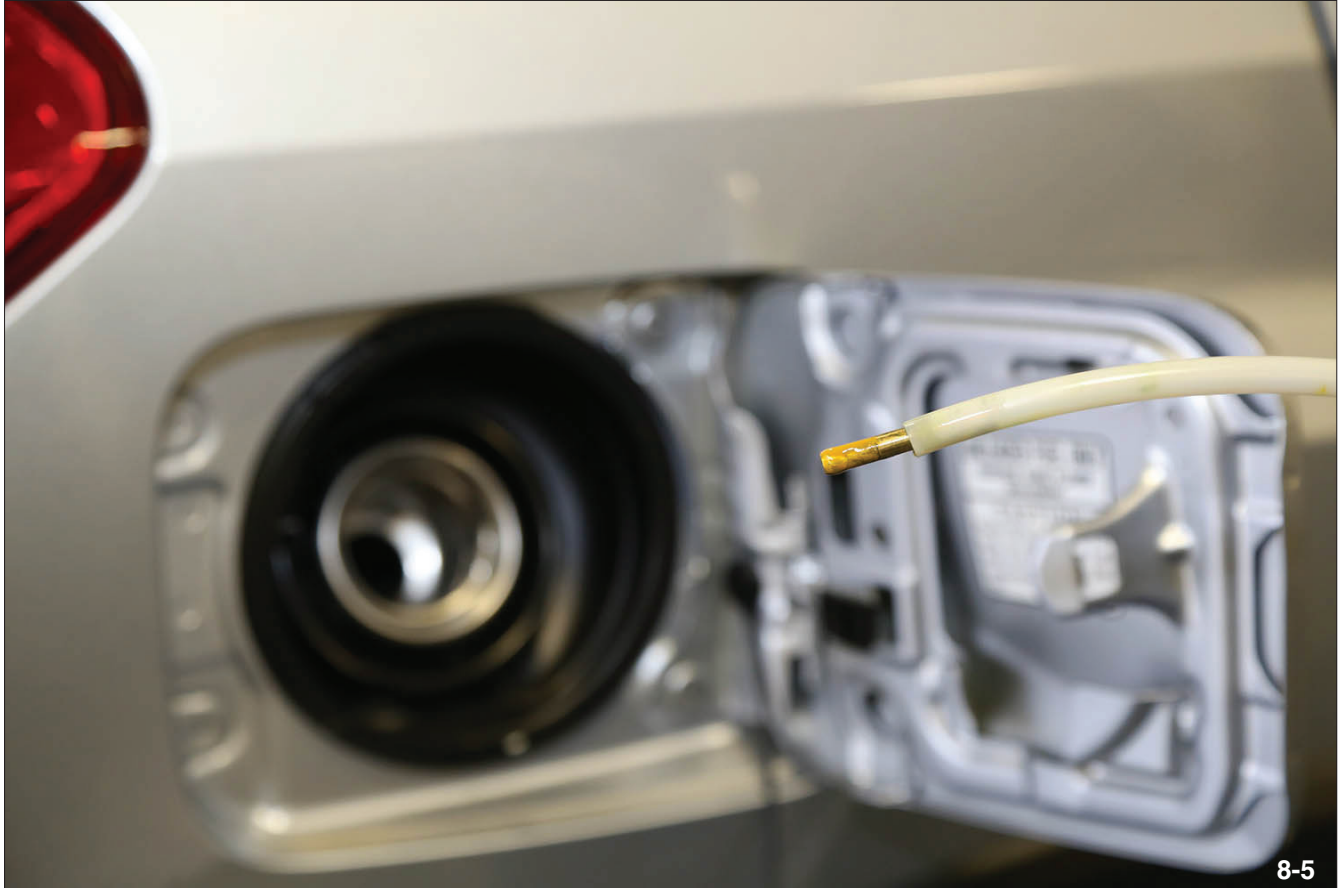
Notes:

Basic Fuel Injection Part 3

Testing for Water in Fuel

Analyze the fuel for water contamination with the water detection kit that is included in the Gas Test Kit, #J39383-A.

This kit consists of a dipstick and a special putty compound that turns red when exposed to water.



Water Test Being Performed

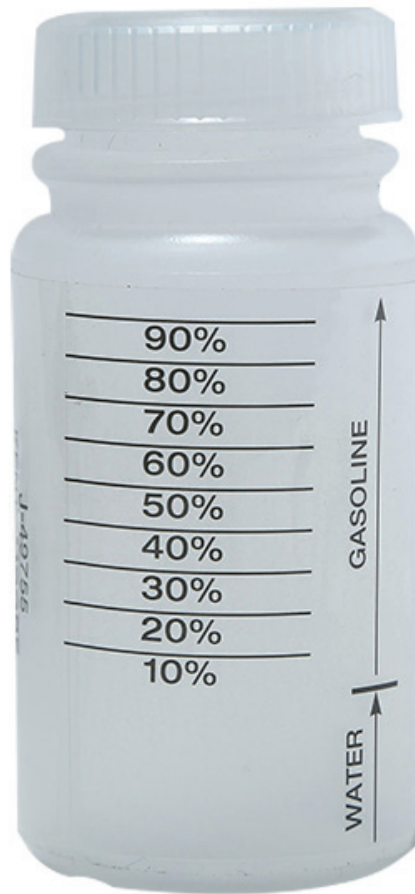
Perform the water test as follows:

- Put a small amount of putty on the end of the dipstick.
- Insert the dipstick through the vehicle fuel filler neck and into the tank, making sure the stick reaches the bottom of the tank.
- After letting the dipstick sit in the tank for a few moments, remove the stick and view the putty to see if it has changed color.
- If the putty has turned red, there is water present in the fuel tank. It will be necessary to drain and clean the tank.

Fuel Alcohol Content

Alcohols in fuel prefer water to gasoline. The alcohol will separate from gasoline and combine with water. This new alcohol-water mixture is heavier than gasoline and settles in the bottom of the tank. Eventually, enough water collects in the tank to cause a drivability problem.

Basic Fuel Injection Part 3



8-6

Testing Fuel Alcohol Content

This test will detect alcohol content in most cases, except Methyl-Butyl Ether (MBE) and methyl-tertiary-butyl, but it is not considered scientifically accurate, nor will it define the various alcohols that may be present. Use the instructions from the dealer kit as follows:

1. Fill the container with water to the water line.
1. Pour suspect gasoline into the container to the top of the gasoline arrow.
2. Install the cap onto the container.
3. Shake the container vigorously.
4. Let the mixture in the container settle for at least one minute
5. Look for any rise in the water level
6. The water level now indicates the percentage of alcohol in the tested gasoline.
7. The alcohol content should not exceed 10%.

Basic Fuel Injection Part 3

Reid Vapor Pressure Test

High Reid Vapor Pressure (RVP) fuel is used during the winter season. Low RVP fuel is used during the summer season. Using the incorrect seasonal fuel can cause engine starting and drivability concerns.

Use the Gasoline Test Kit, #J-39383-A, to check the reid vapor pressure level in the fuel.

Normal RVP values are as follows:

- AA - 7.8 psi (best for hot summer season)
- A - 9.0 psi
- B - 10.0 psi
- C - 11.5 psi
- D - 13.5 psi
- E - 15.0 psi (best for freezing winter season)

Higher volatility fuels evaporate faster than lower volatility fuels.

Subaru recommends the Gas Test Kit, #J39383-A, to test fuel RVP. The kit is available through the Subaru Dealer Tool web link. The fuel test kit contains the tools needed to measure fuel volatility, and indicate alcohol content and the presence of water.



8-7

Testing Fuel RVP

Notes:

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Basic Fuel Injection Part 3

The Positive Crankcase Ventilation System

Upon completion of this lesson you will be able to:

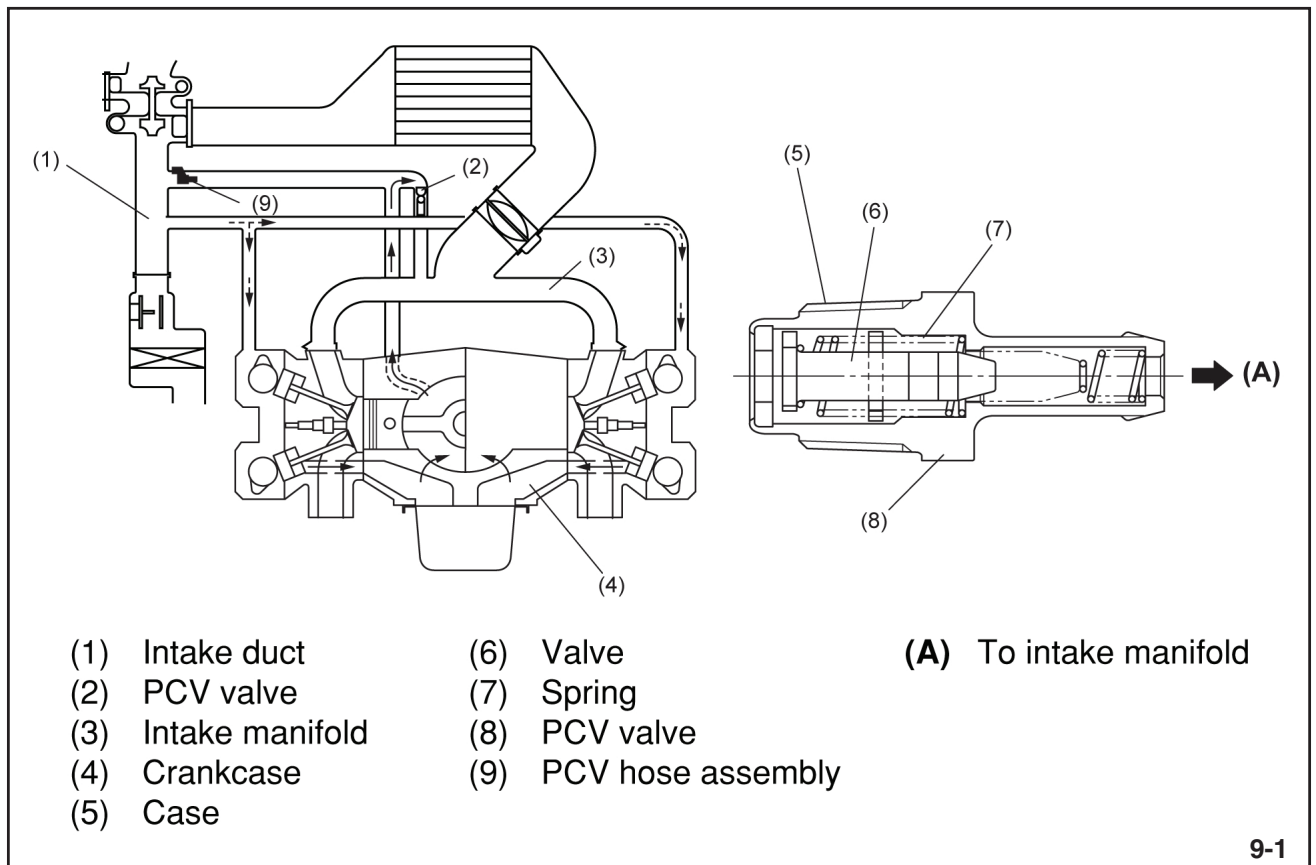
- Explain the operation and testing of the PCV system.

The Positive Crankcase Ventilation (PCV) system reduces crankcase blow-by emissions by rerouting them to the intake manifold, where they are recycled back into the combustion chamber.

Even in a correctly operating engine, some combustion gases force past the compression rings and end up in the crankcase. Cylinder leakage is referred to as blow-by. The PCV system removes blow-by gases from the crankcase before the contaminants can collect in the oil of engine components. Contaminants in the blow-by gases that are not removed from the crankcase react with the oil to form sludge, or attach and corrode internal engine components. The intake manifold vacuum draws the blow-by gases from the crankcase into the intake manifold. Blow-by gases are drawn from the intake manifold into the cylinders and are burned with the normal air/fuel charge.

The PCV meters the gases into the intake manifold. Incorrect metering of the PCV gases causes pressure to build in the crankcase, or an imbalance in the air/fuel ratio in the engine.

As gases are drawn from the crankcase, clean air is drawn into the crankcase from the intake air system. This prevents the creation of excessive vacuum in the crankcase. The PCV valve closes during a backfire, preventing the crankcase gases from igniting.



2008 Crankcase

Basic Fuel Injection Part 3

The crankcase emission control system functions to prevent blow-by gases from entering the atmosphere. Components include: sealed rocker covers, hoses, a PCV valve, and an air intake duct.

On turbocharged vehicles, operation is performed in two modes:

Mode one (Light engine load)

- Air flows into the air duct, and part of the air is routed to the rocker covers.
- Vapors and air entering the PCV because of the negative pressure at the valve.

Mode two (Heavy engine load)

- Air flows into the air duct, and part of the air is routed to the rocker covers.
- This action carries the vapors from the crankcase into the throttle body.

Permanent-type clamps maintain a more constant clamping tension of a PCV hose than a spring-type clamp. As a result, the potential for crankcase vapor escape is reduced. This aids in compliance with environmental regulations.



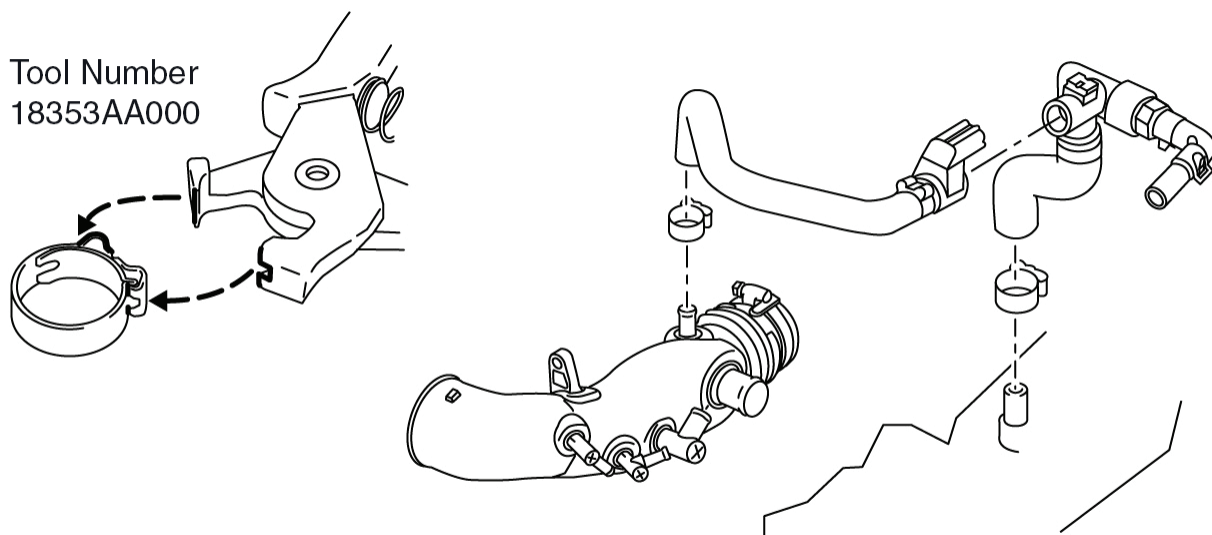
Permanent-Type Clamp



Spring-Type Clamp

9-2

Revised Clamps

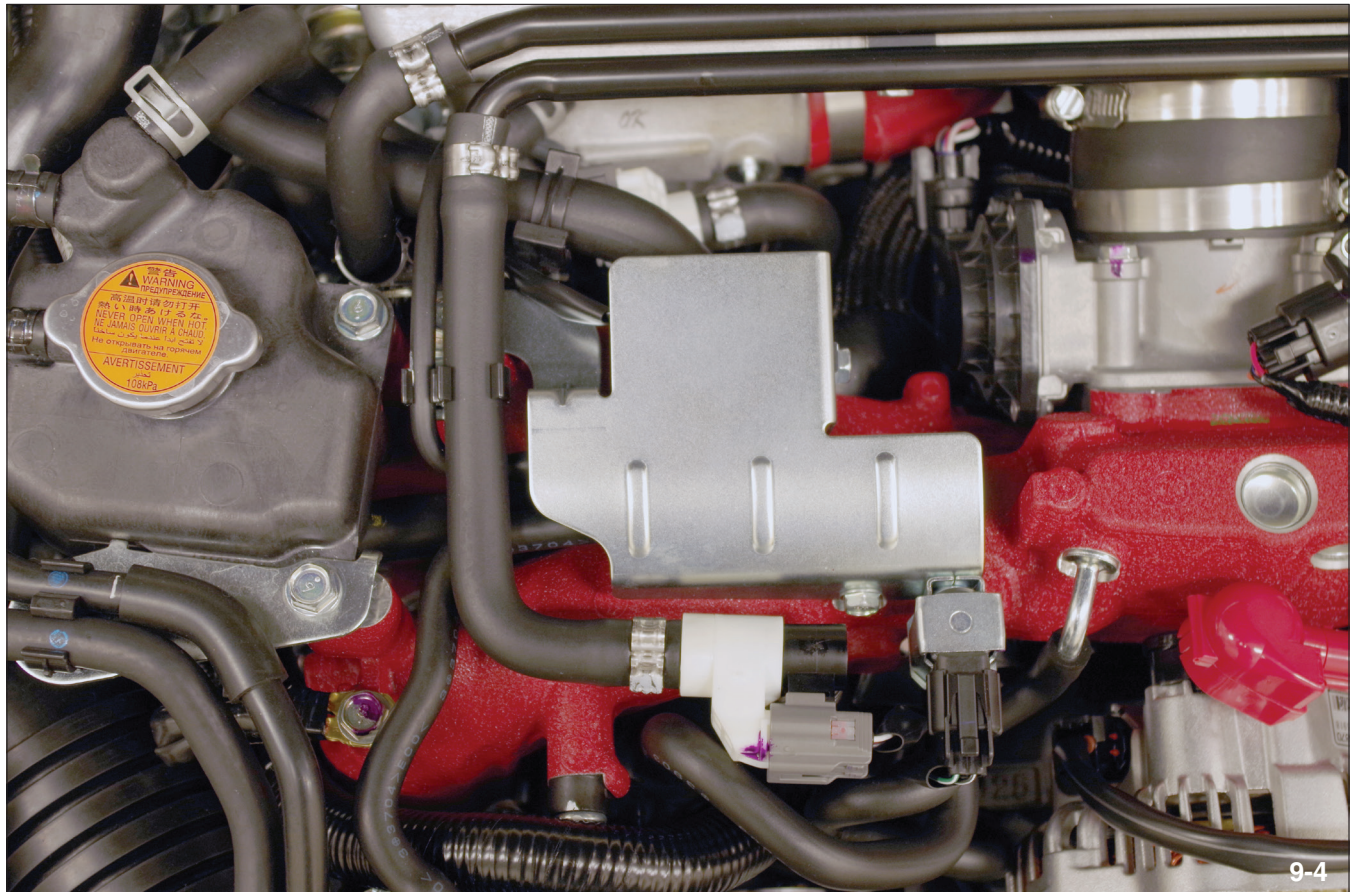


9-3

PCV Permanent Clamp Types

Basic Fuel Injection Part 3

A leak diagnosis connector is found in the PCV hose that connects the crankcase to the engine intake tract. This item provides the Engine Control Module (ECM) with a constant signal that the hose is connected. Internally, the Leak Diagnosis connector consists of two wires and a shorting bar.



Leak Diagnosis Connector

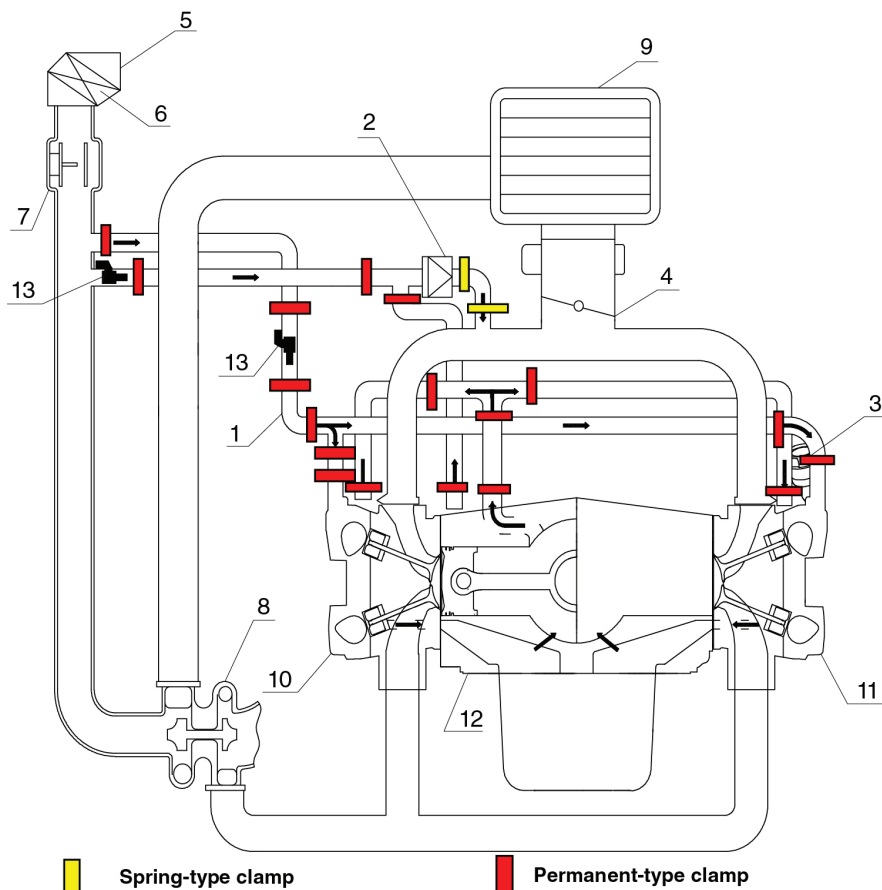
Note: Do not reuse any permanent-type hose clamp of the PCV system.

Notes:

Basic Fuel Injection Part 3

Beginning with the 2015 WRX STI, the number of permanent-type clamps has been increased.

Note: See the chart for new clamp locations; all clamps are the same size.



1	Connecting hose for crankcase ventilation system	8	Turbocharger
2	PCV Valve	9	Intercooler
3	Oil filler cap	10	Rocker cover(#1-#3)
4	Throttle body	11	Rocker cover(#2-#4)
5	Air filter case	12	Crank case
6	Air filter	13	Leak Diagnosis Connector
7	Mass Airflow (MAF) Sensor		

9-5

Clamp Placement Chart

Notes:

Basic Fuel Injection Part 3

Naturally Aspirated Engine PCV System Operation

The naturally aspirated Positive Crankcase Ventilation (PCV) system consists of the following components:

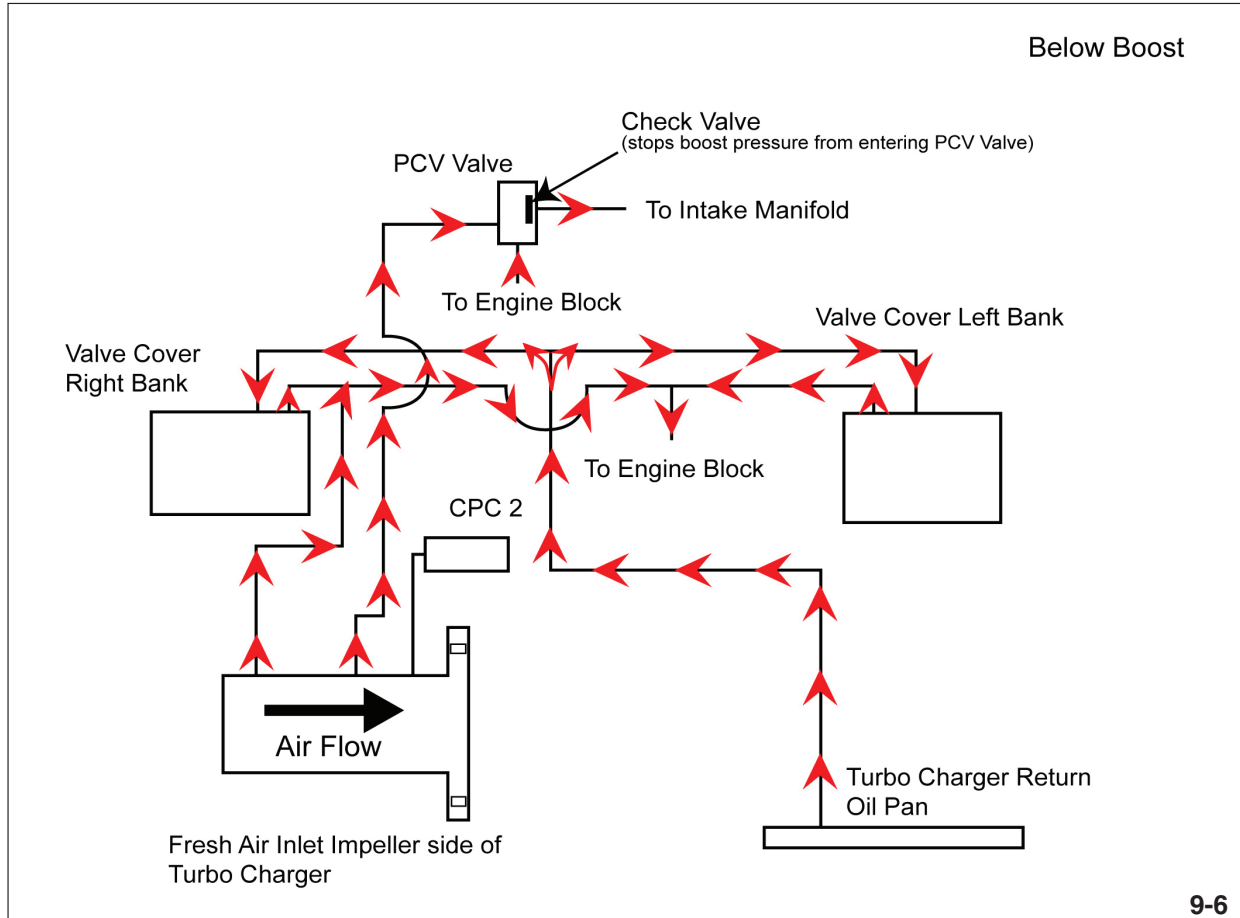
- Sealed oil filler cap
- PCV valve and chamber
- Air intake duct
- Rocker covers with fresh air inlet
- Hoses

Notes:

Basic Fuel Injection Part 3

Normal PCV System Operation

During idle or deceleration conditions, blow-by gases are drawn from the crankcase and directed into the intake manifold, and then routed to the cylinders where they are burned along with the normal air/fuel mixture. In a wide-open-throttle condition, the intake manifold vacuum is not strong enough to draw all the blow-by gases into the PCV system. Air flows into the air duct, and part of the air is routed to the rocker covers by the fresh air connecting hose.



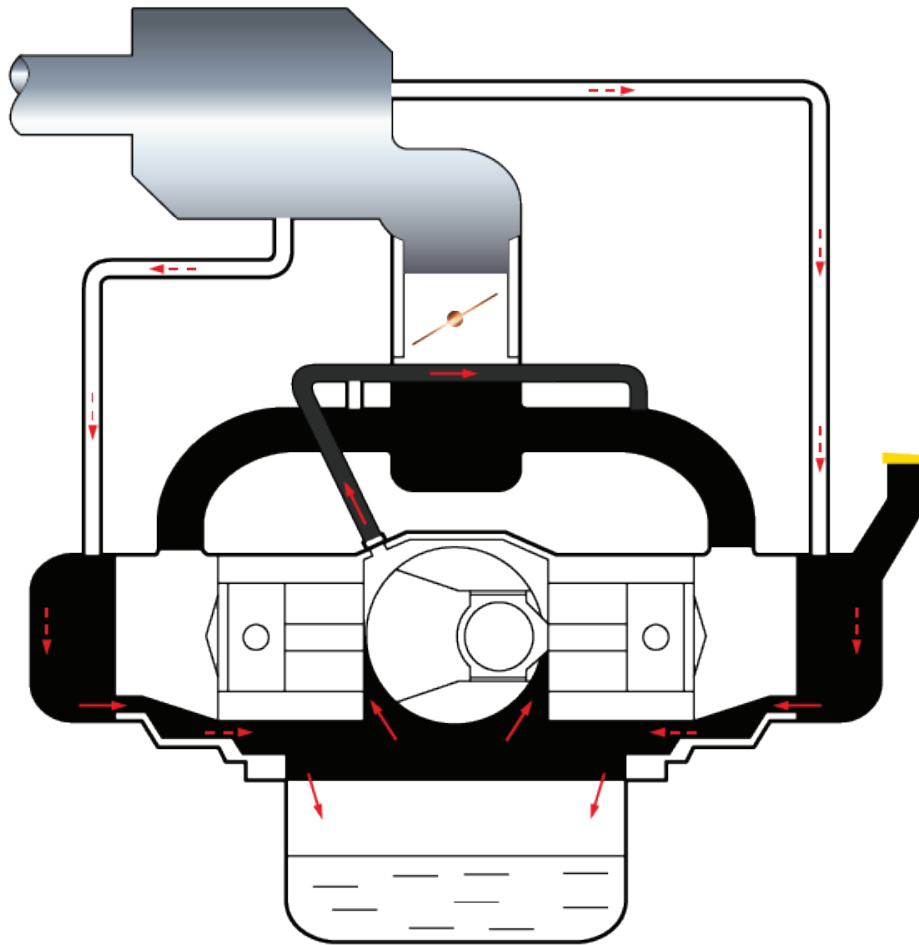
Idle Operation

PCV System Testing-Naturally Aspirated Engine

To test the PCV valve, remove it from the engine, attach the PCV valve to its hose, and start the engine. Check for the presence of vacuum at the crankcase side of the valve. Then, block the vacuum at the crankcase side with your thumb; you should feel the valve close. With the completion of this test, you are:

- Confirming proper operation
- Checking for blockage
- Checking for vacuum leak

Basic Fuel Injection Part 3



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Naturally Aspirated PCV System Testing

System Testing Turbocharged Engine

During light engine load, air flows into the air duct and part of the air is routed to the rocker covers. Vapors and air enter the PCV because of the negative pressure at the valve.

During heavy engine load, air flows into the air duct, producing a negative pressure at the rocker covers. This action carries the vapors from the crankcase into the throttle body.

Notes:

Notes:

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Basic Fuel Injection Part 3

Electronic Throttle Control System

Upon completion of this lesson you will be able to:

- Explain the operation and testing procedures of the ETC and SI drive system.

The Electronic Throttle Control (ETC) system opens and closes the throttle plate electronically, instead of using a conventional throttle cable.

The ETC system uses the following sensors and controls:

- Engine control module
- Throttle motor
- Accelerator pedal sensors
- Throttle position sensors
- ETC relay

ETC Sensor Description and Operation

The ETC system's, throttle position and accelerator position sensors are each comprised of two different sensors: a main and sub sensor. These sensors provide information on the movement and position of the accelerator pedal and throttle plate to the engine control module.

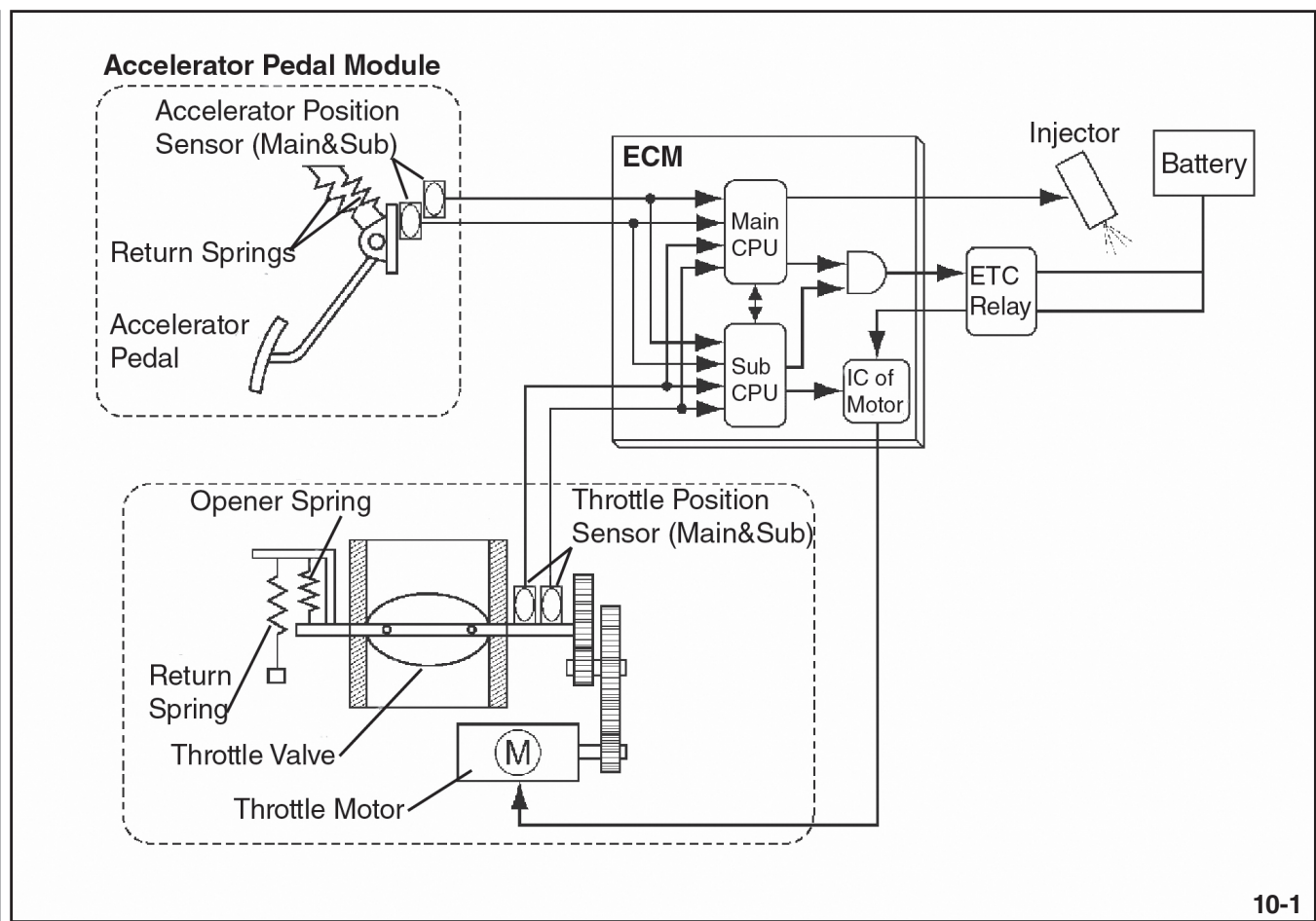
The engine control module monitors the signal circuits of each sensor to confirm pedal position and detect circuit malfunctions. The main and sub sensors' voltage output differs by model and model year. Previous model years maintained a difference in APS output. Newer models use output ranges from the sensors that are almost identical. Always consult the STIS, Input/Output (I/O) chart for the correct voltage output ranges.

Each sensor has three wires:

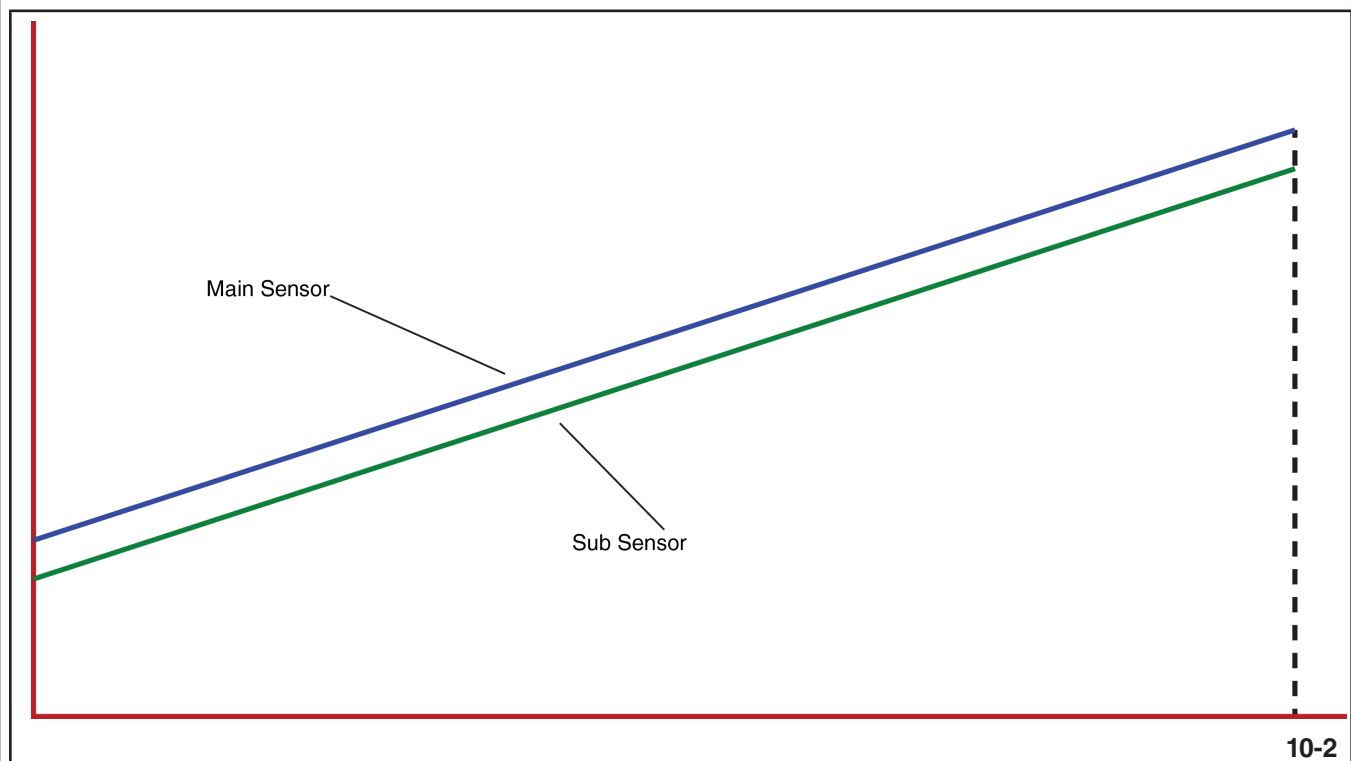
- 5-volt supply
- Signal
- Ground

Notes:

Basic Fuel Injection Part 3



ETC Block Diagram



Accelerator Position Sensors

Basic Fuel Injection Part 3

Use a scan tool to monitor the accelerator pedal and throttle position sensor signal. While observing the signal, depress and release the accelerator pedal. The signal should respond by changing smoothly without any dropouts or spikes. Monitor the diagnostic trouble code information; there should not be any accelerator pedal or throttle position diagnostic trouble codes set.

ETC Sensor Circuit Operation

Item	Value	Unit
☒ Engine Speed	686	rpm
☒ Accel. Opening Angle	0.0	%
☒ Throttle Opening Angle	1.6	%
☒ Main-Accelerator Sensor	0.68	V
☒ Sub-Accelerator Sensor	0.68	V
☒ Main-Throttle Sensor	0.62	V
☒ Sub-Throttle Sensor	1.50	V
☒ Throttle Motor Duty	-13	%
☒ Throttle Motor Voltage	14.2	V
☒ ETC Motor Relay	ON	
☒ Ban of Torque Down	ON	
☒ Request Torque Down VDC	OFF	
☒ Torque Permission Signal	ON	

< Idle Speed Control >

Target Engine Speed 1025 rpm

Engine Speed 686 rpm

Execution Cancel

10-3

APS Sensor Data

Use an oscilloscope or scan tool to graph the value of the main and sub sensors, and compare the accelerator position to throttle angle. Use a DVOM to measure the circuit voltages. The results should show clean linear change in the voltages of each sensor as the pedal is depressed slowly and steadily.

Throttle Body Motor Operation

The ECM controls the throttle body motor using a 12-volt pulse-width signal to position the throttle plate.

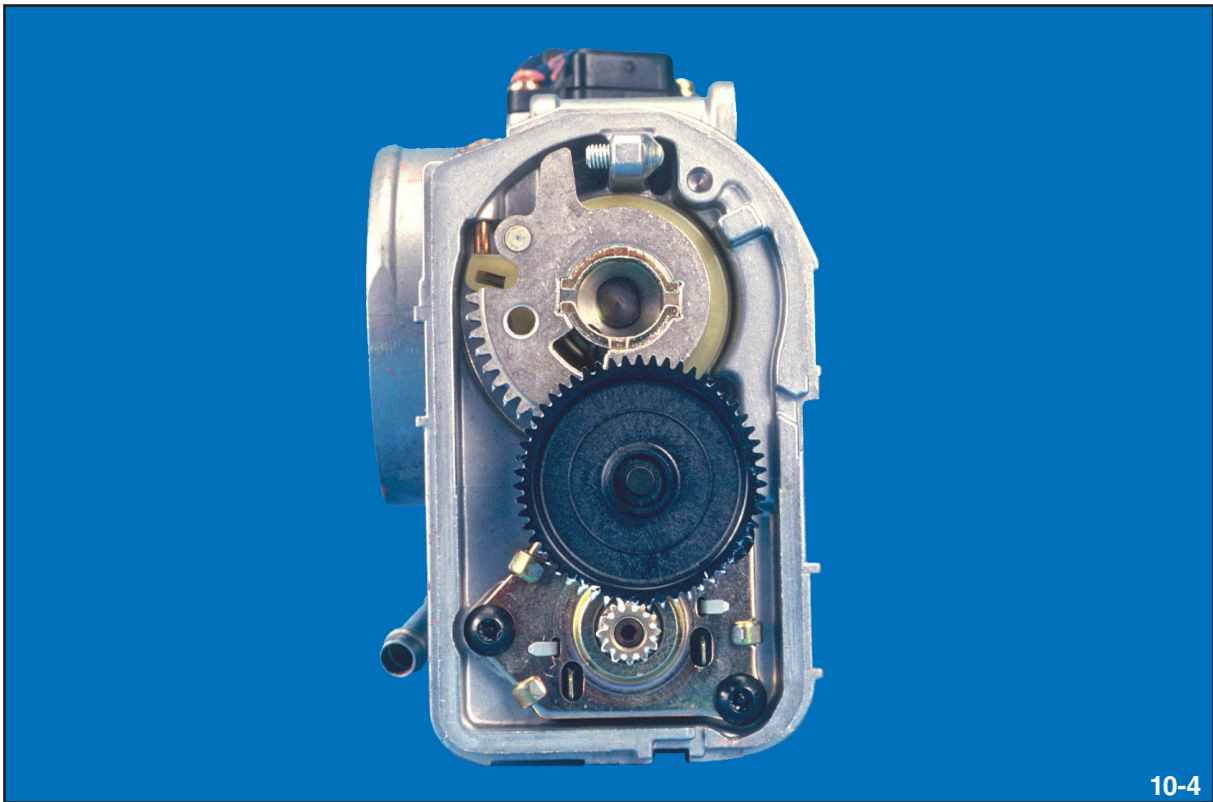
The motor power and ground circuits are:

- ETC Motor Command (+)
- ETC Motor Command (-)

The motor control circuits are shielded and provide the throttle motor with a bidirectional (open/close) signal.

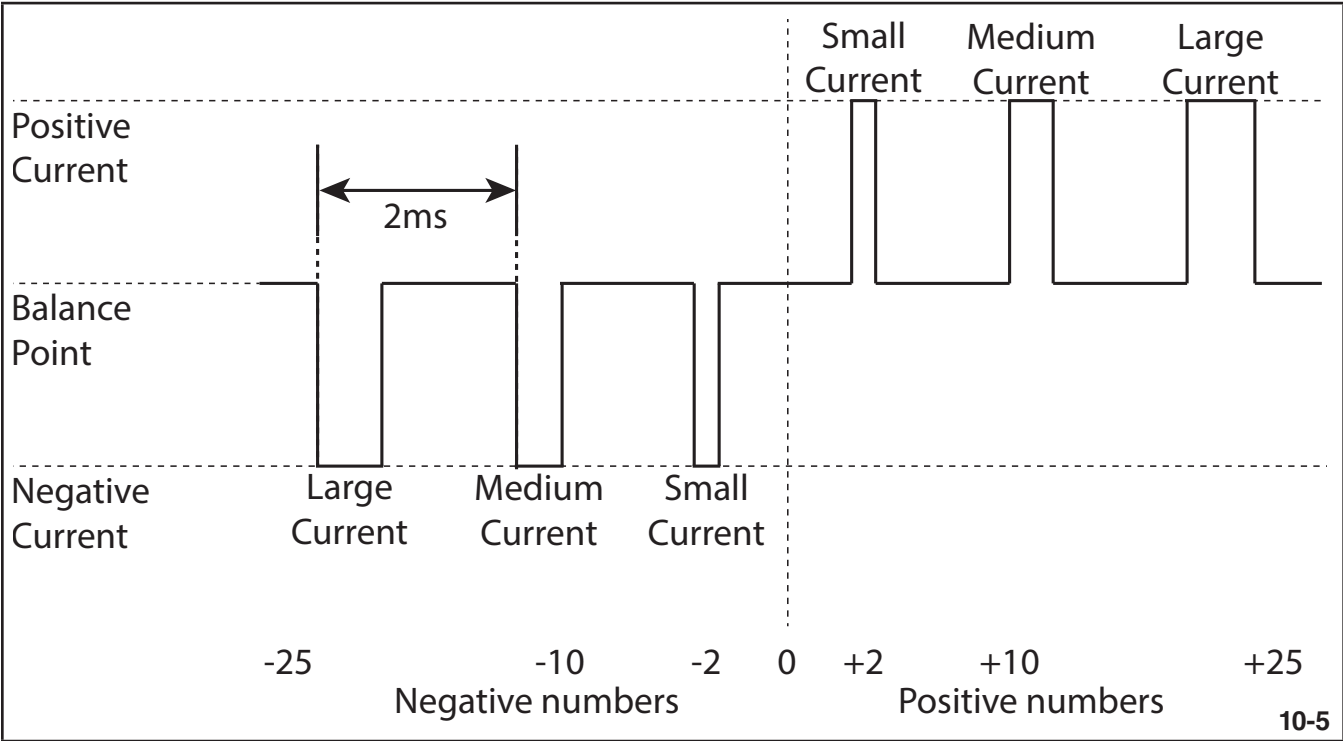
Notes:

Basic Fuel Injection Part 3



ETC Motor and Gears

A pair of springs (open and close) set the throttle plate to a point above idle, which is called the balance point. This requires the engine control module to supply a negative duty ratio to the throttle body motor, to move the throttle plate toward the closed or idle position. To open the throttle plate above the balance point require a positive duty ratio to the throttle body motor.

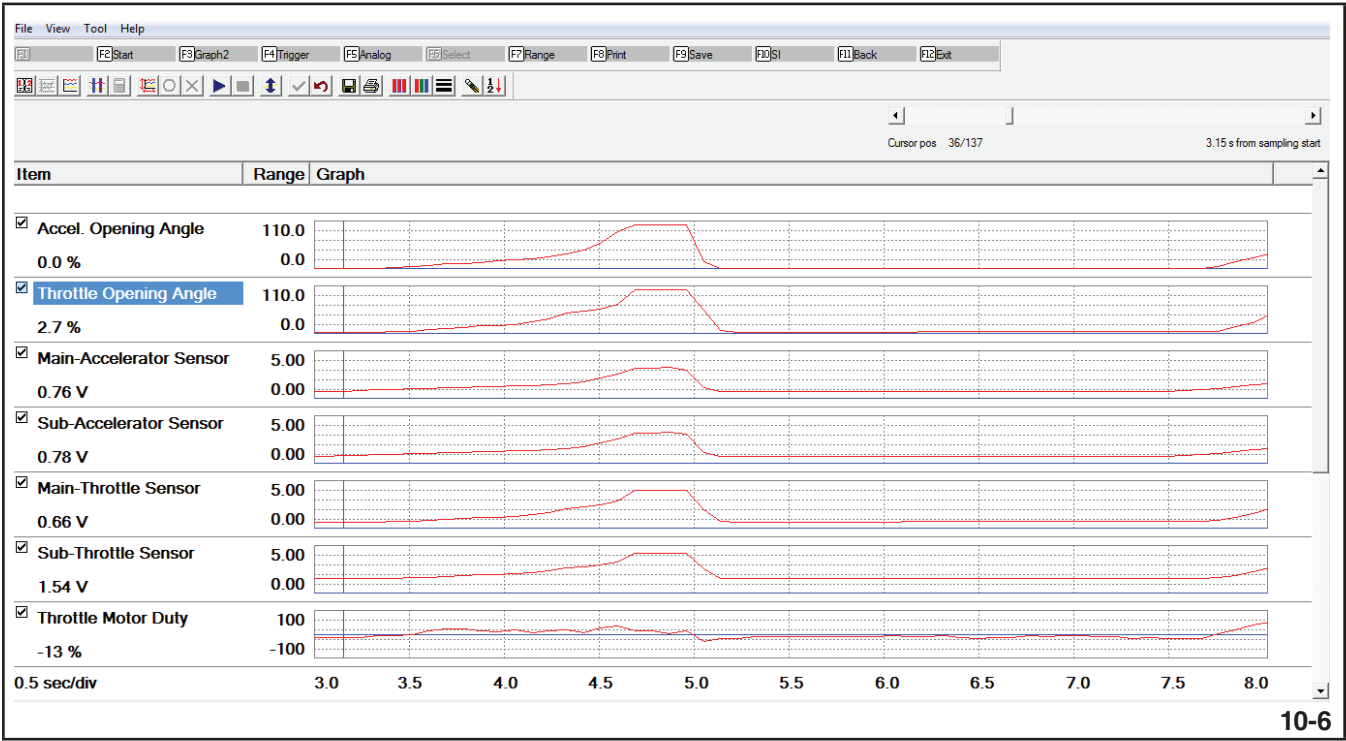


Throttle Body Motor Control

Basic Fuel Injection Part 3

Throttle Body Motor Circuit Operation

Use the SSM System Operation Check Mode and Idle Speed Control option to test throttle body motor operation. Monitor the operation for smooth changes in the throttle motor duty ratio, and output signals from the main and sub throttle position sensors.



Throttle Body Motor Circuit Operation

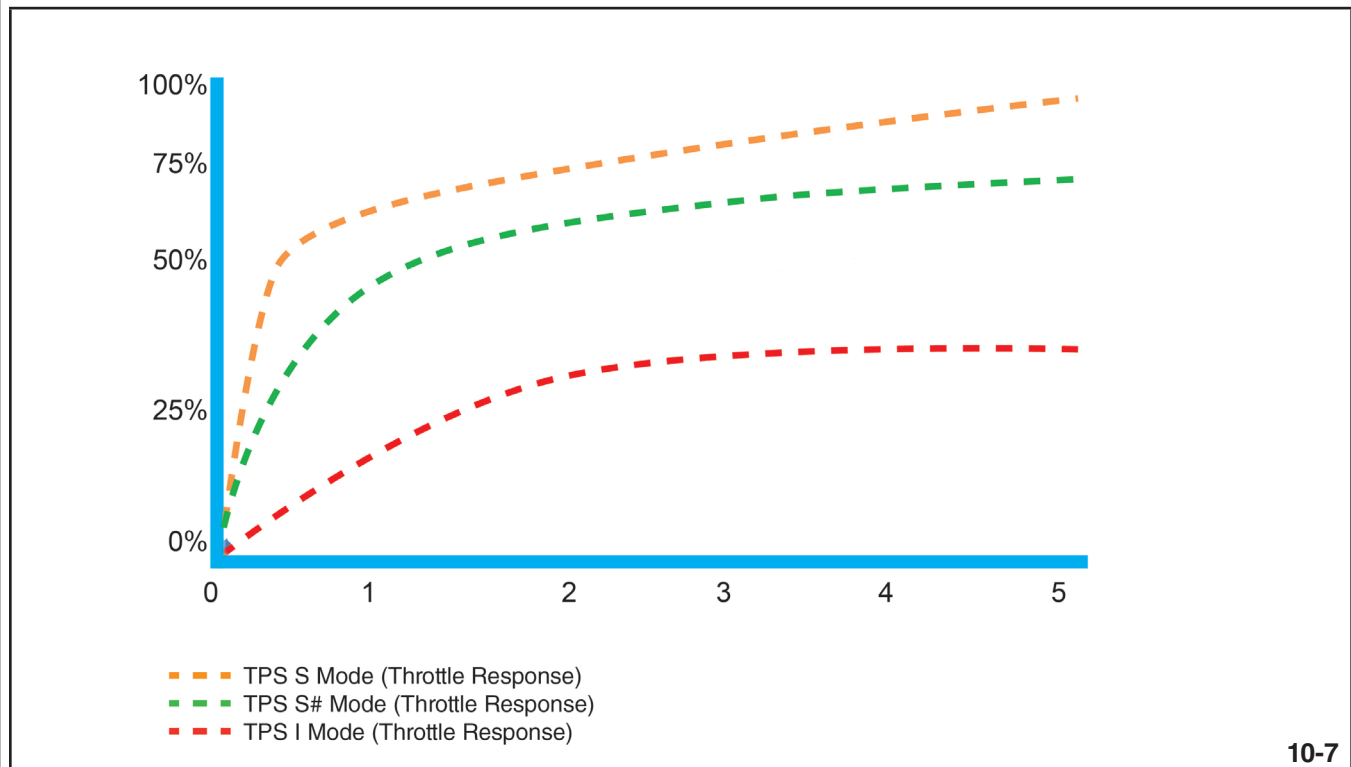
Notes:

Basic Fuel Injection Part 3

Subaru Intelligent Drive System

SI Drive enables three distinct modes of engine power characteristics. This is performed by fine-tuning the electronically-controlled throttle torque commands. A rotary switch, located in the center console, and ECM logic are all that is required to operate the system.

This graph shows the relationship of accelerator pedal movement to throttle response in each of the SI Drive modes. In each case, the accelerator pedal is depressed 100%.



APS vs. Throttle Response Chart

The varied resistance on the ground signal of the SI Drive switch is sent to the combination meter and enters the CAN circuit. The ECM controls the throttle according to the switch setting.

Note: There are no DTCs for SI Drive. Check the SI Drive switch and the corresponding indicator on the odometer for proper operation.

SI Drive Fail-Safe Operation

ECM operations are fixed to S mode at any of the engine conditions listed in the chart, even when the customer tries to activate S# and I mode.

ENGINE CONDITION	INDICATOR	ECM	TCM
MIL - ON	S	S	S
Coolant Temp > 248F Coolant Temp < 133F	S#, I	S	S
Reverse Gear	S#, I	S	S

10-8

SI Drive Logic Chart

Note: SI drive will enter S mode when engine coolant temperatures are greater than 248 °F or lower than 133 °F.



Notes:

This image shows a single page of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

Basic Fuel Injection Part 3

Turbocharger Description and Operation

Upon completion of this lesson you will be able to:

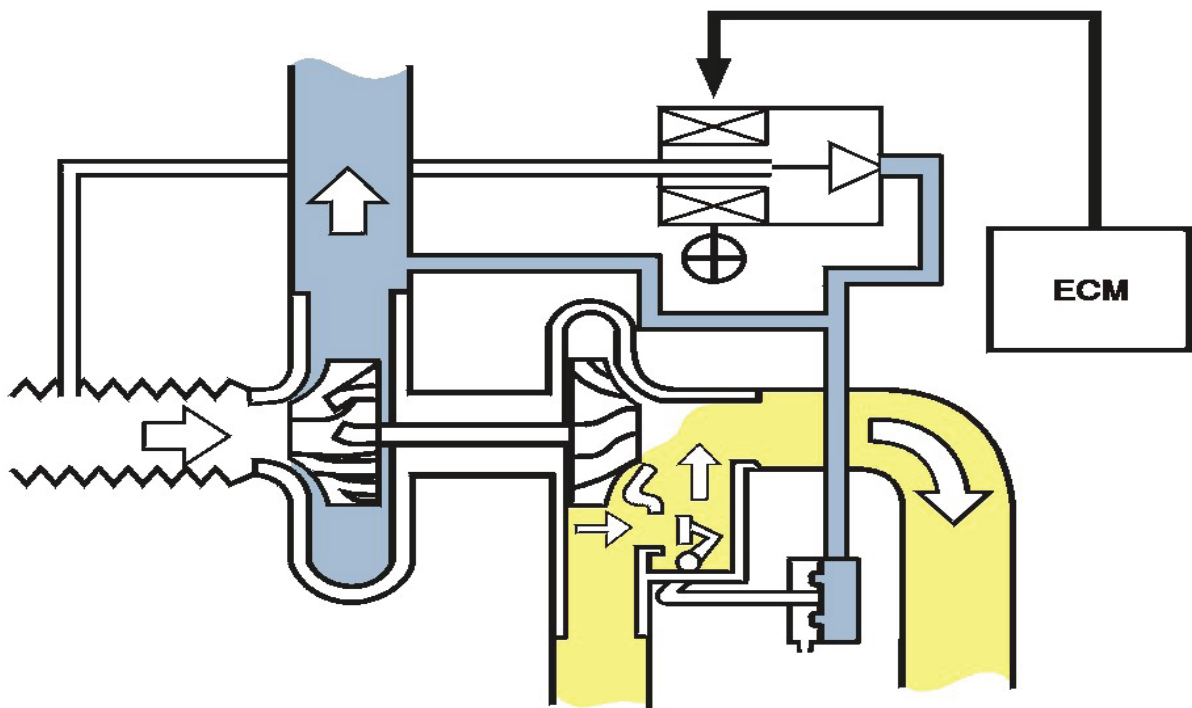
- Explain the operation of the turbocharger system.

The turbocharger compresses the intake air by using exhaust gas energy. The turbocharger turbine is driven by exhaust gas, which drives a compressor wheel. The compressor wheel compresses the intake air, increasing volumetric efficiency; as a result, engine power is greatly improved.

Due to the limited strength of the engine, there is a limit to the amount of boost pressure that can be used. The limiting of boost pressure is achieved by the use of a wastegate, which bypasses the exhaust gas around the turbine wheel when the desired level of boost is reached.

The ECM supplies a duty ratio to the wastegate solenoid to control and throttle the amount of opening. This duty ratio is called Primary Control. Higher levels of Primary Control duty ratio equate to more pressure bleeding off from the wastegate. This retards the mechanical opening of the wastegate and allows higher boost pressure to develop. The pressure bleed off from the wastegate is rerouted back to the inlet side of the turbocharger charger.

Boost Pressure Control



11-1

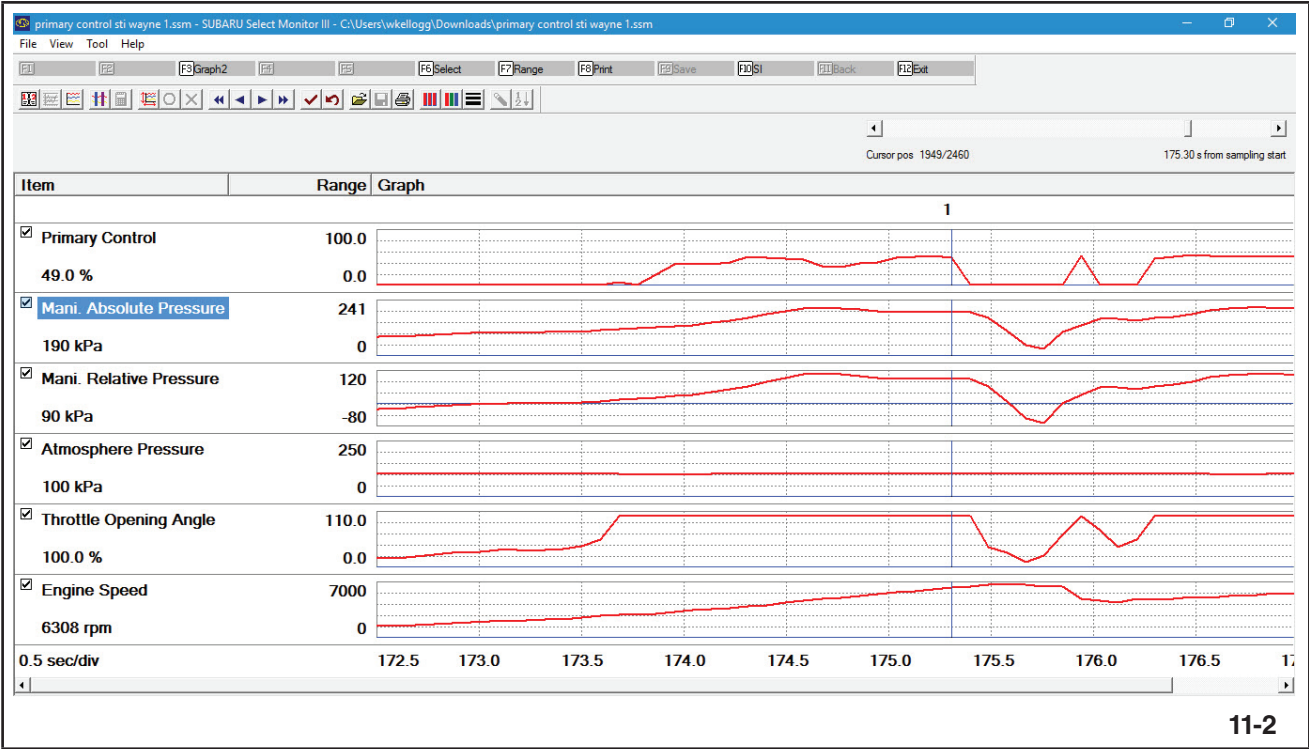
Boost Pressure Control

Primary Control duty ratio can be adjusted by the ECM to adjust for altitude, engine knock detection, or driveability conditions that would be amplified or cause engine damage, if high levels of boost were allowed to develop.

Basic Fuel Injection Part 3

The examples of Primary Control duty ratio shown below are provided to illustrate basic Primary Control. The first example is from a normally operating vehicle operating at sea level.

The value of the data at the mark on the graph shows 49% Primary control duty ratio at a boost pressure of 27.5 psi.

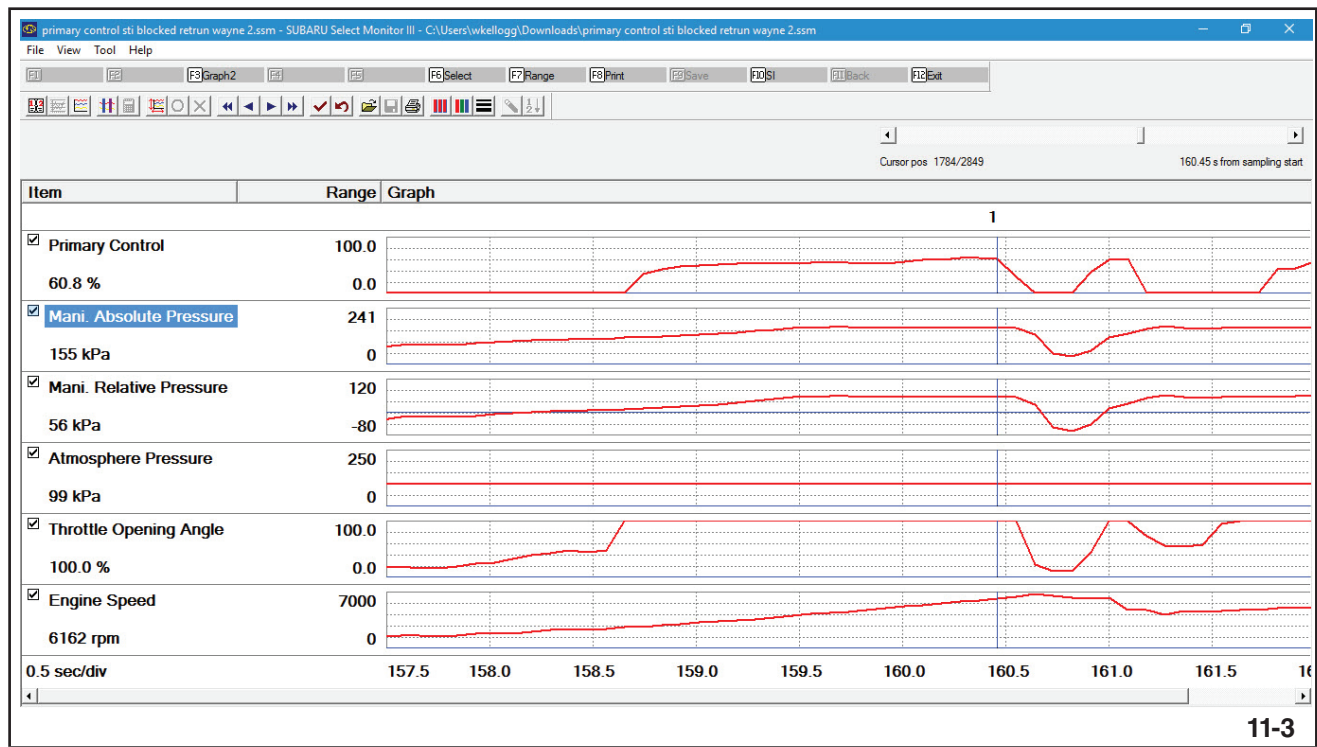


Normally Operating Vehicle at Sea Level

Notes:

Basic Fuel Injection Part 3

The second example is from the same vehicle with a restricted hose from the wastegate solenoid to the inlet side of the turbocharger. The value of the data at the mark on the graph shows 60.8% primary control duty ratio at a boost pressure of 22.5 psi. The ECM's response to a decrease in boost pressure is to attempt to bleed off more pressure from the wastegate. The primary duty ratio is increased, but the restriction prevents the reduction in wastegate pressure. In this case, diagnostics are best performed by checking the condition of each hose. Removing the restriction or pinch will return boost pressures to normal.



Vehicle with Restricted Wastegate Solenoid Hose

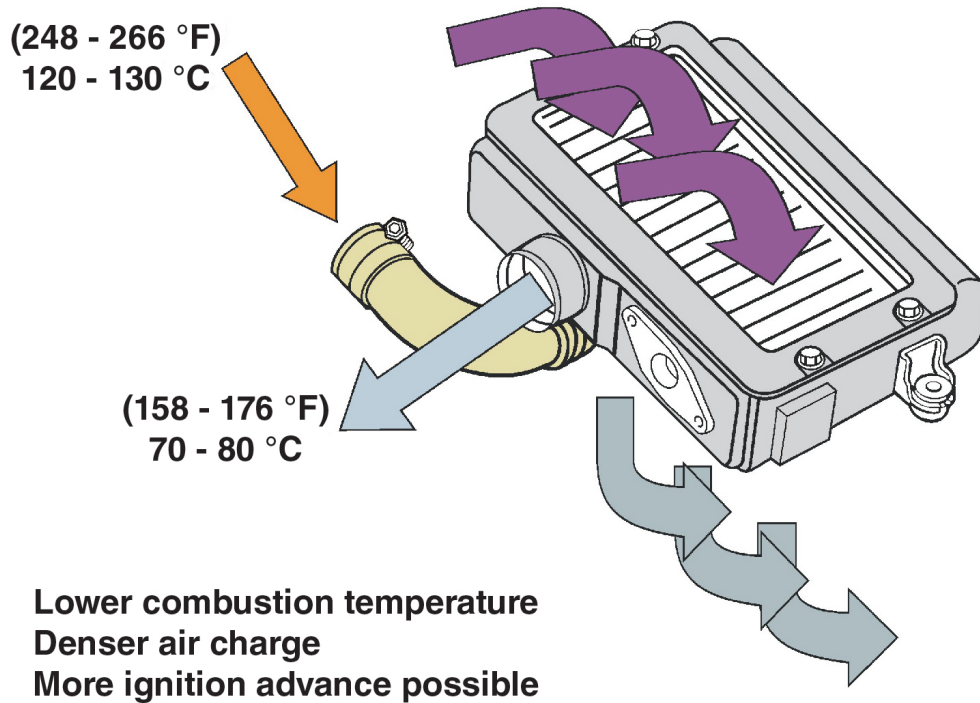
Note: Turbocharged vehicles are equipped with a control orifice that meters boost pressure to the wastegate. This provides smooth control of the wastegate by governing the boost pressure applied to the wastegate diaphragm. The size of the orifice is model-dependant. The orifice is installed to the hose leading from the turbocharger to the wastegate and cannot be ordered separately.

Notes:

Basic Fuel Injection Part 3

Turbocharger Intercooler Description and Operation

Effects of Intercooling



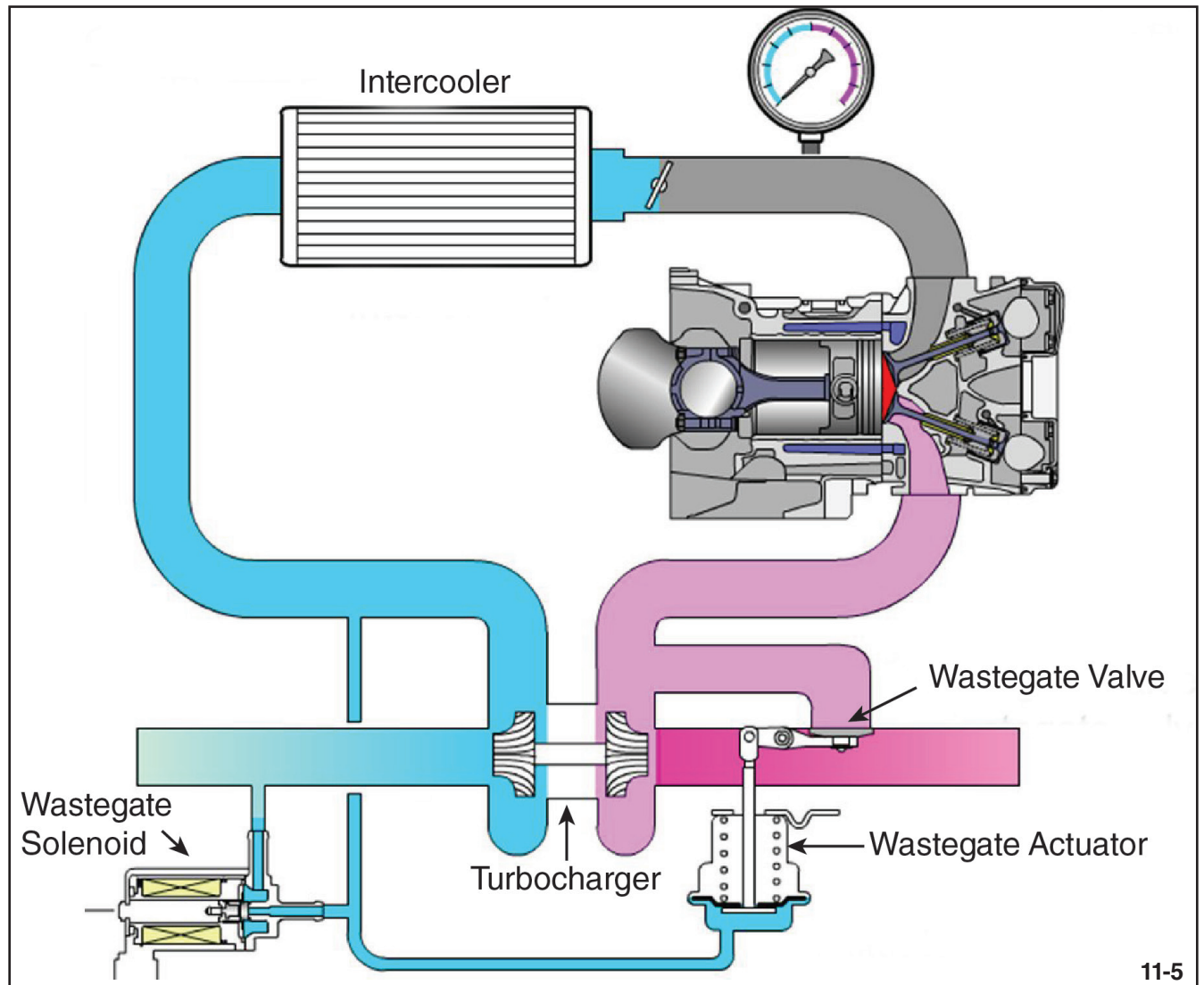
11-4

Effects Of Intercooling.

The compression of the intake air by the turbocharger compressor wheel causes an increase in air temperature, so an intercooler is located between the turbocharger and the intake manifold.

Notes:

Basic Fuel Injection Part 3



Turbocharger System

As the intake air passes through the intercooler tubes, ambient air passes through the intercooler fins and around the outside intercooler tubes, causing an air-to-air heat transfer. The cooling effect of the hot intake air creates a denser air stream for the combustion chamber air/fuel mixture, increasing the amount of energy generated when combustion take place. The result is that more of the air/fuel mixture can enter the cylinder.

Notes:

Basic Fuel Injection Part 3

Note: The MAP sensor detects the pressure increase in the intake manifold and the ECM increases the amount of fuel that is injected to allow complete combustion to take place.

Inspect the turbocharger intercooler fins for damage, such as debris, bent fins, or anything that could cause an airflow restriction.

The intercooler operates at the pressure produced by the turbocharger and must be tested for leaks at the same pressure ranges. An optional test tool that allows for this high pressure testing is the Redline High Pressure Smoke Machine (Part Number 697-95-0103-GM). Always follow the safety and operating instructions included with the tool.

During testing, the intercooler is blocked at one end with a sealing plug and sealed at the other end with a dual-purpose sealing plug. The dual-purpose sealing plug allows high pressure smoke to enter the intercooler, which helps to locate an existing leak. Look for leaks with a high intensity light source because the smoke has very little contrast with the metal construction of the intercooler. Replace the intercooler if a leak is detected.

Turbocharger Bypass Valve Description and Operation

The turbocharger bypass valve reduces air surges caused by a sudden throttle closure in the air passage between the turbocharger and throttle body. The bypass valve is located after the turbocharger and provides a bypass passage for the compressed intake air to return to the inlet side of the turbocharger.



Turbocharger Bypass Valve

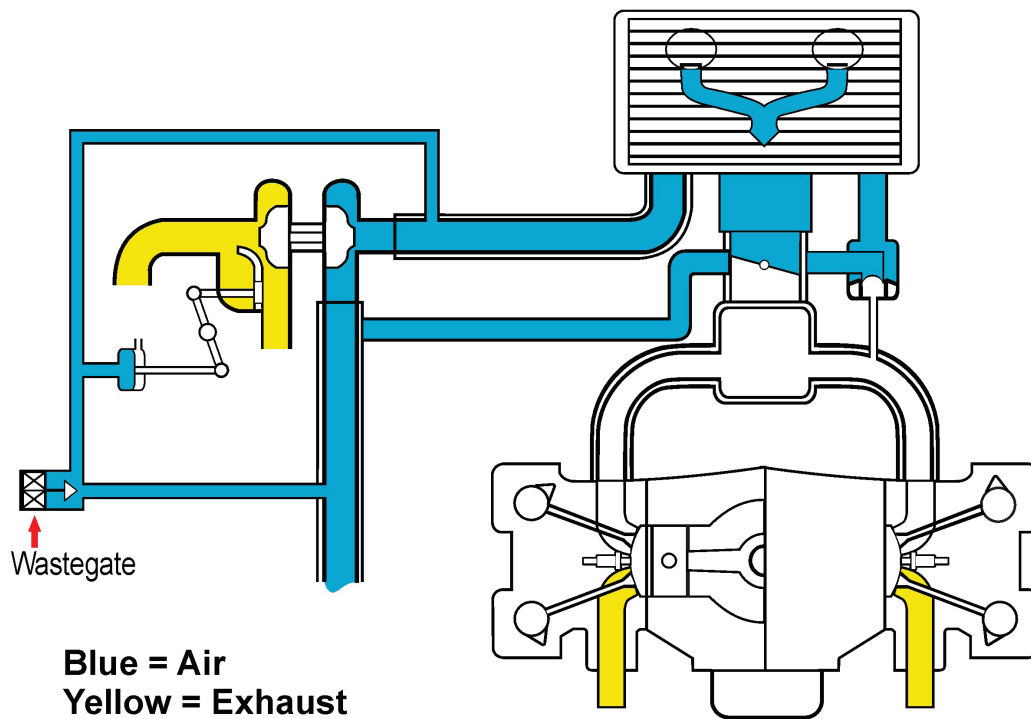
Operation of the valve can be tested by attaching a handheld vacuum pump to the intake manifold connection. The diaphragm should hold a vacuum and begin to open the valve. Continue to apply vacuum with the pump and confirm that the valve opens fully.

Basic Fuel Injection Part 3

Use a vacuum gauge to check the turbocharger bypass valve vacuum supply. The vacuum supply should be near manifold vacuum.

The air bypass valve is located after the turbocharger and provides a bypass passage for the compressed intake air back to the inlet side of the turbocharger. When deceleration occurs immediately after a period of high engine load (high boost pressure), a large pressure differential occurs at the compressor wheel of the turbocharger. This is due to the inertia of the turbocharger wheels, which are still generating boost pressure even though the throttle is fully closed. This high pressure may lead to increased noise and possibly damage the turbocharger due to the high pressure exerted at the compressor wheel.

Air By-Pass Valve Operation

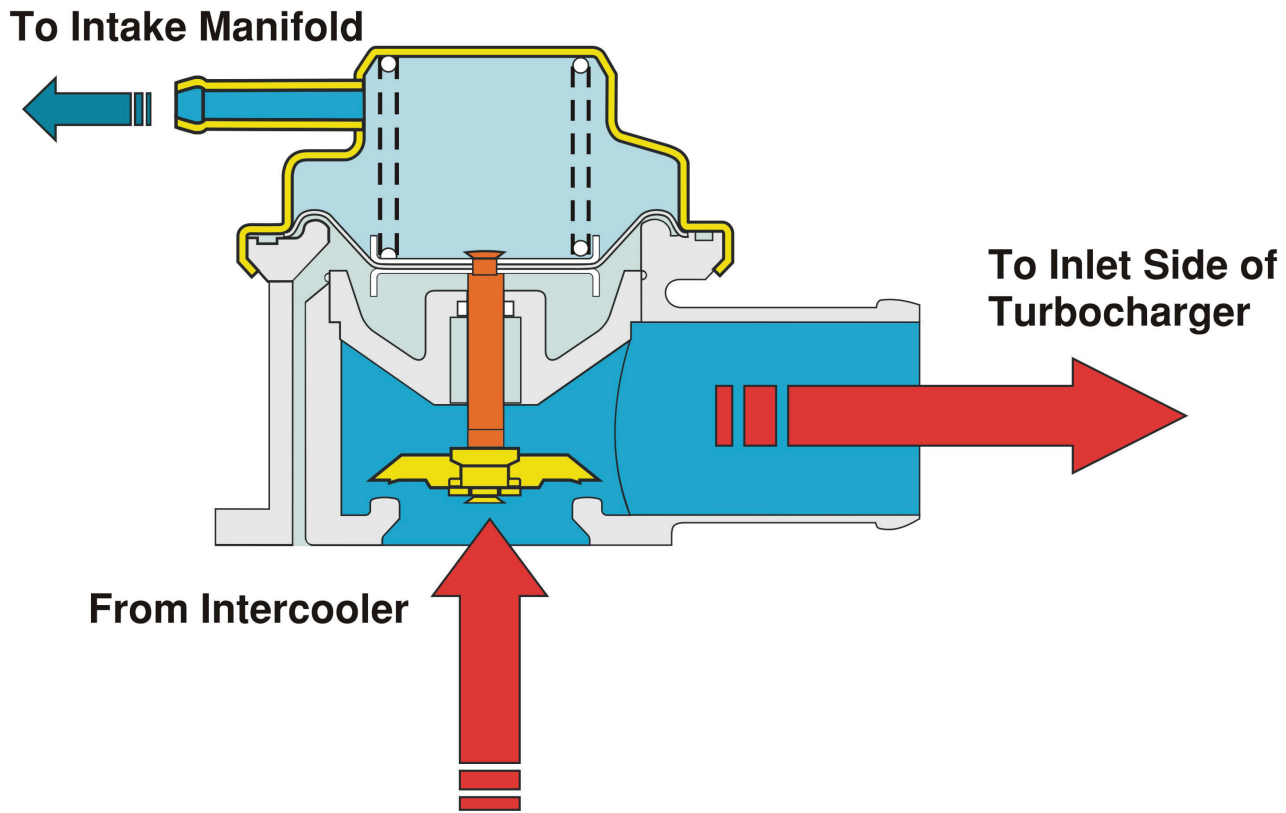


11-7

Air Bypass Valve Operation

Notes:

Air By-Pass Valve Operation



11-8

Air Bypass Valve Testing

The upper chamber of the bypass valve is connected to the intake manifold. The negative pressure (vacuum) created during deceleration opens the valve by acting on the diaphragm.

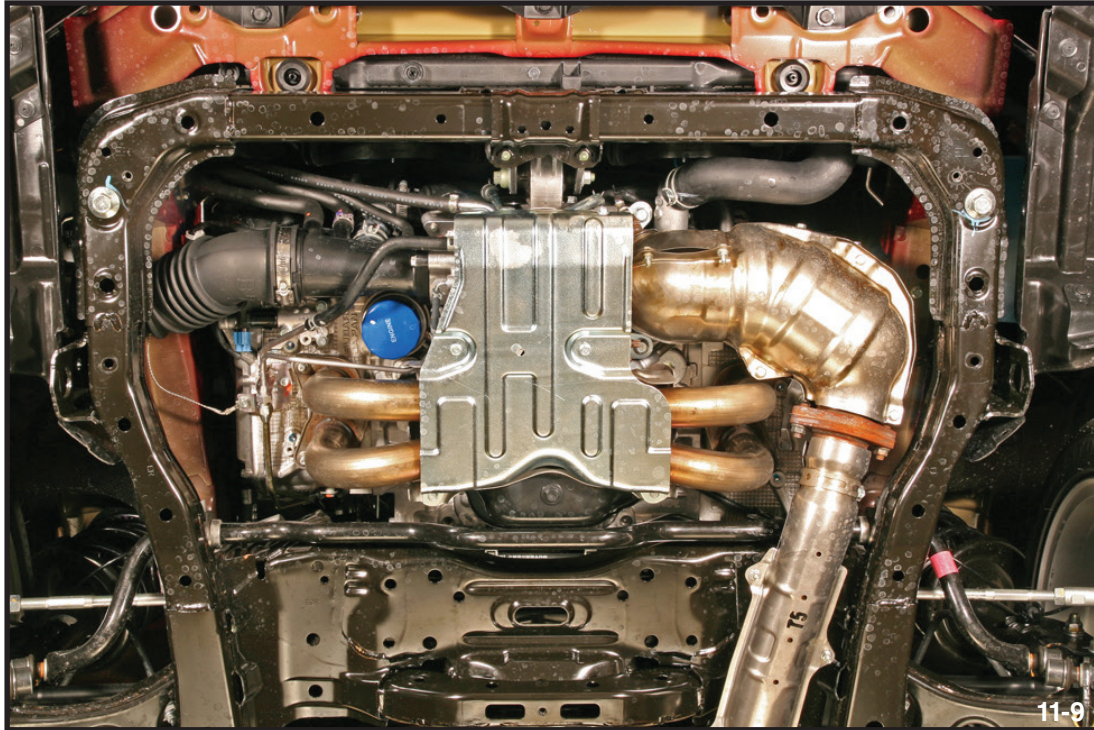
Operation of the valve can be tested by attaching a handheld vacuum pump to the intake manifold connection. Apply negative pressure with the pump and confirm that the valve opens.

Notes:

Basic Fuel Injection Part 3

2010 MY and Later Turbocharger Enhancements

The turbocharger for the 2010 Legacy is located in the front lower section of the engine compartment and is connected directly to the exhaust manifold. This improves turbocharger operation by shortening the distance between the turbine and the energy source that drives the turbocharger (turbo lag).



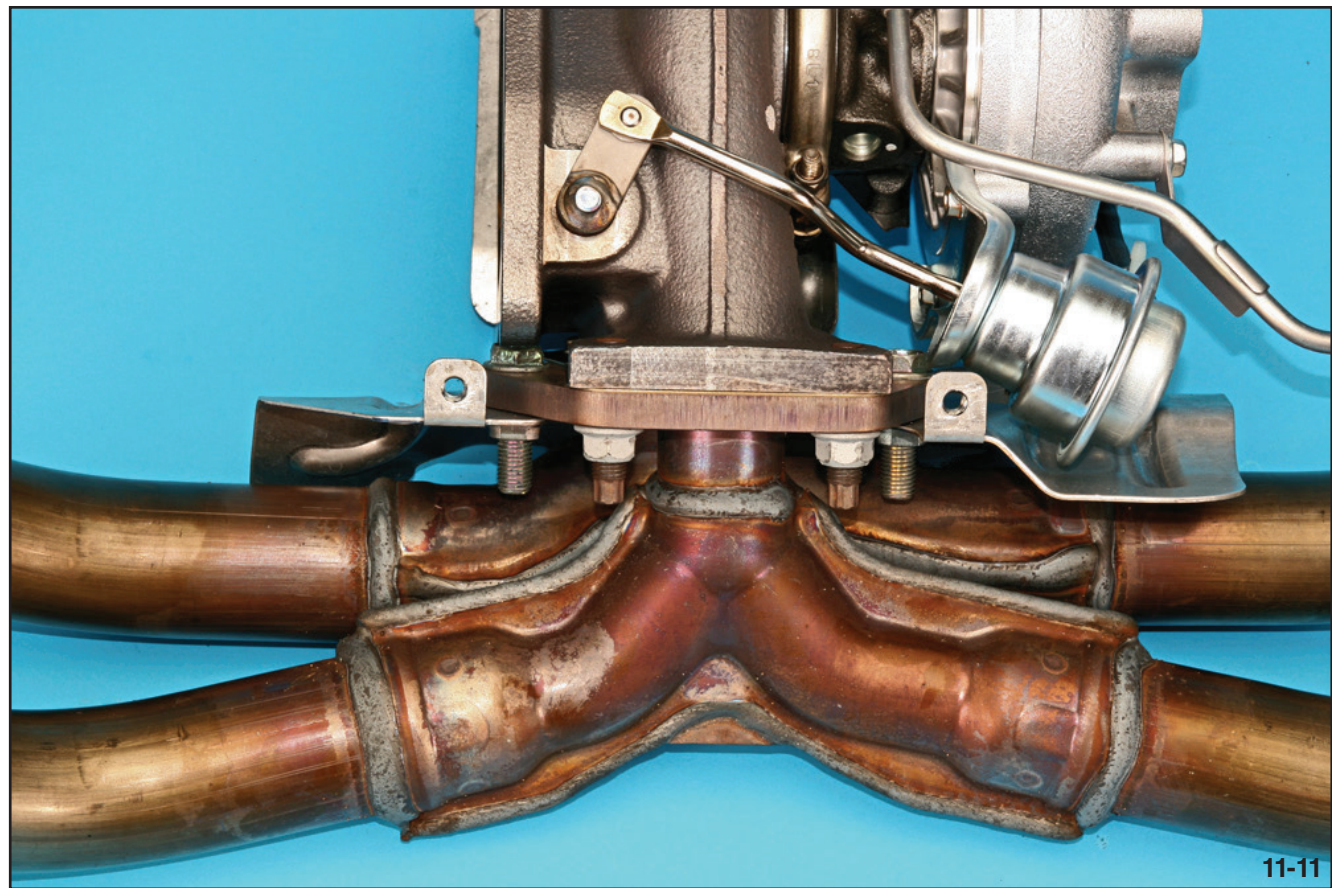
Turbocharger Location



Turbocharger with Heat Shields

Basic Fuel Injection Part 3

The catalytic converter is bolted to the outlet of the turbocharger. This brings the catalyst to operating temperature much faster and eliminates the need for a secondary air system (the secondary air system is not equipped on 2010 Legacy).

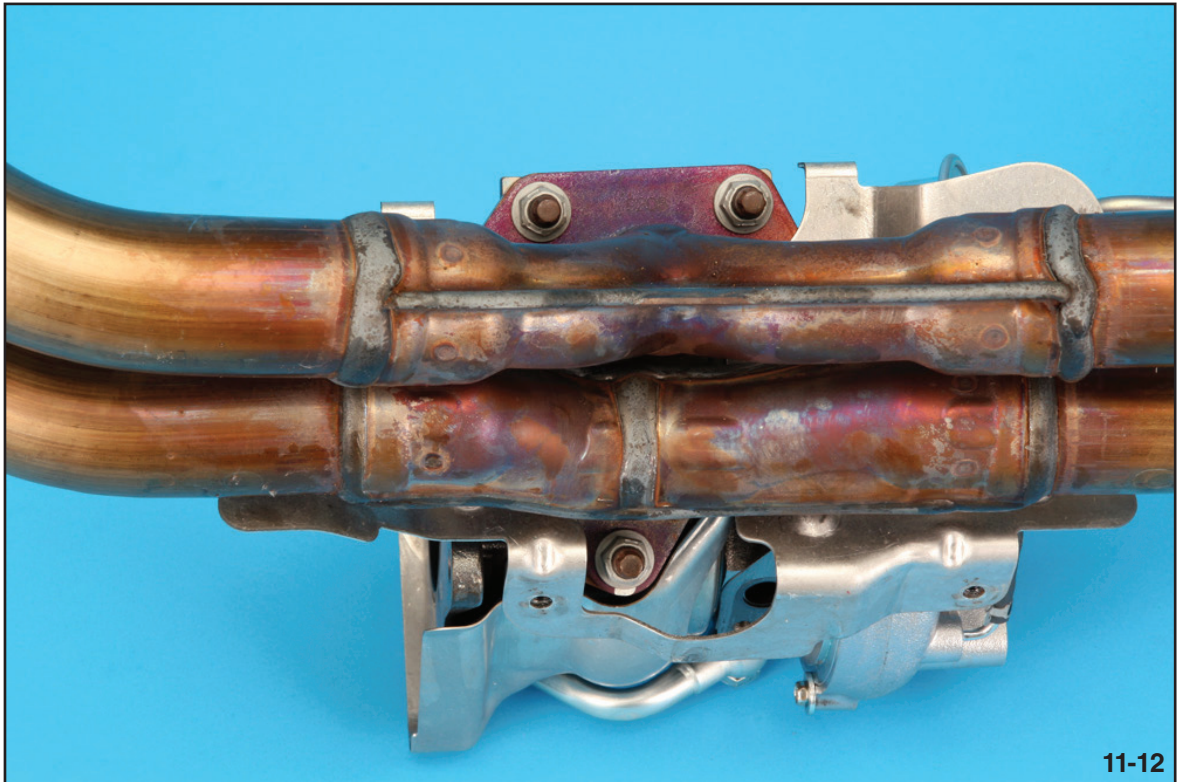


Exhaust and Turbocharger

Notes:

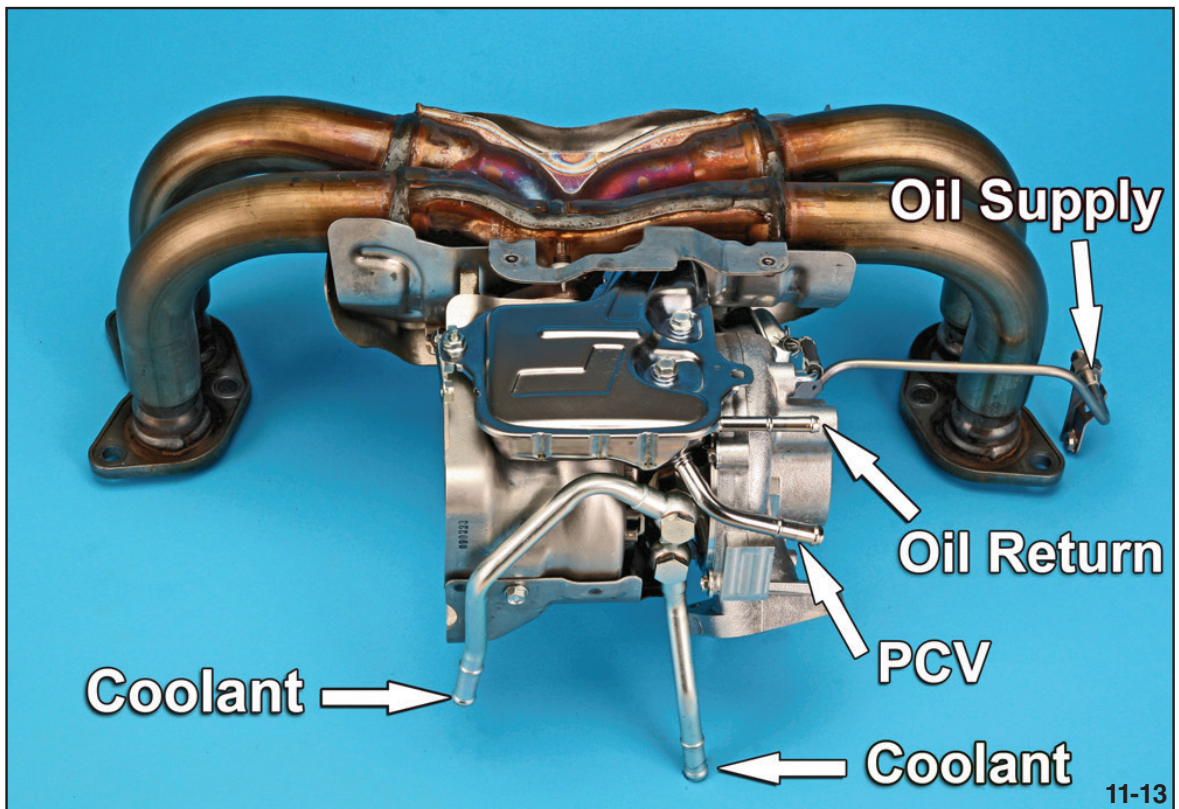
Basic Fuel Injection Part 3

Three studs secure the turbocharger to the collector of the right and left exhaust manifold.



11-12

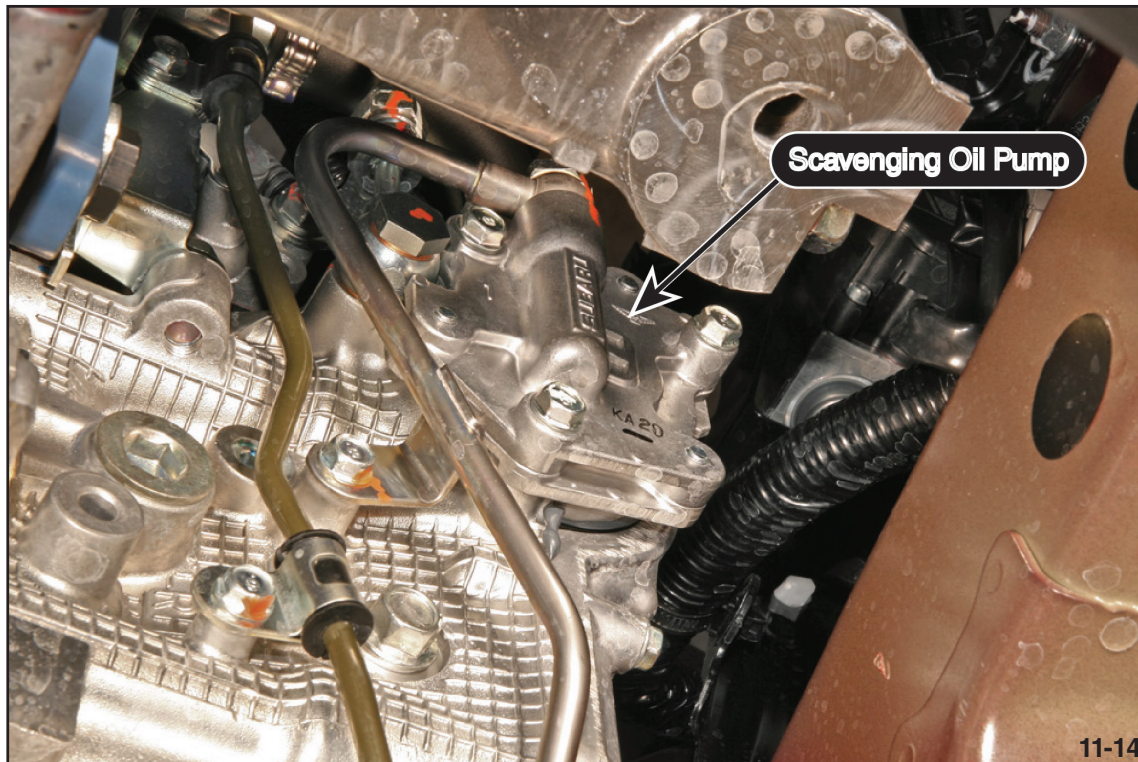
Turbocharger Mounting Bolts



11-13

Turbocharger Bottom View

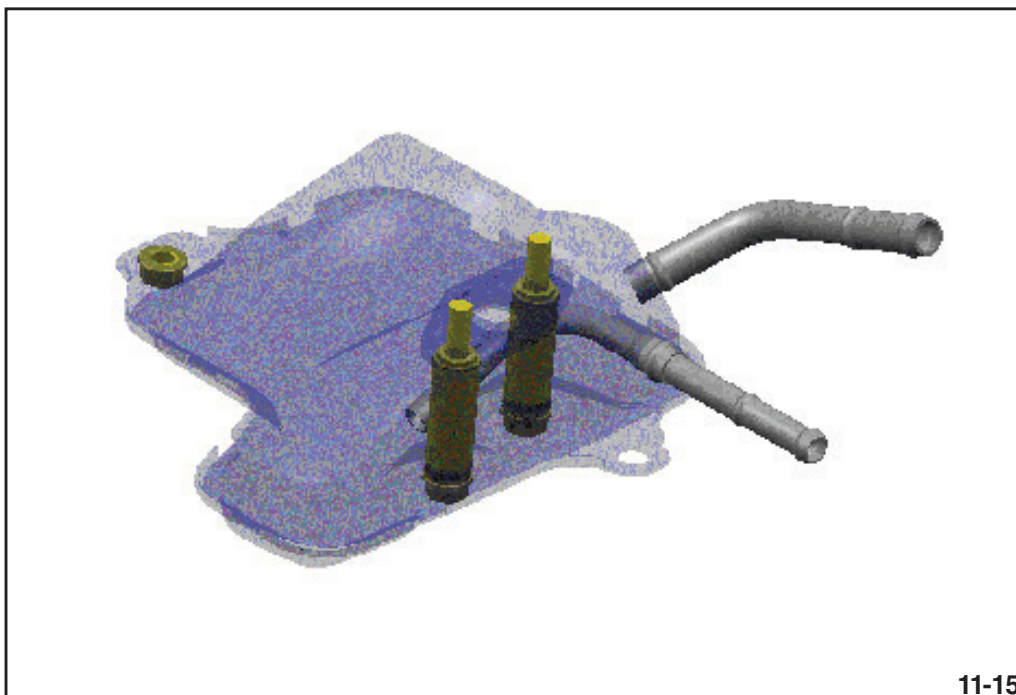
Basic Fuel Injection Part 3



Scavenging Oil Pump Mounted to Right Cylinder Head

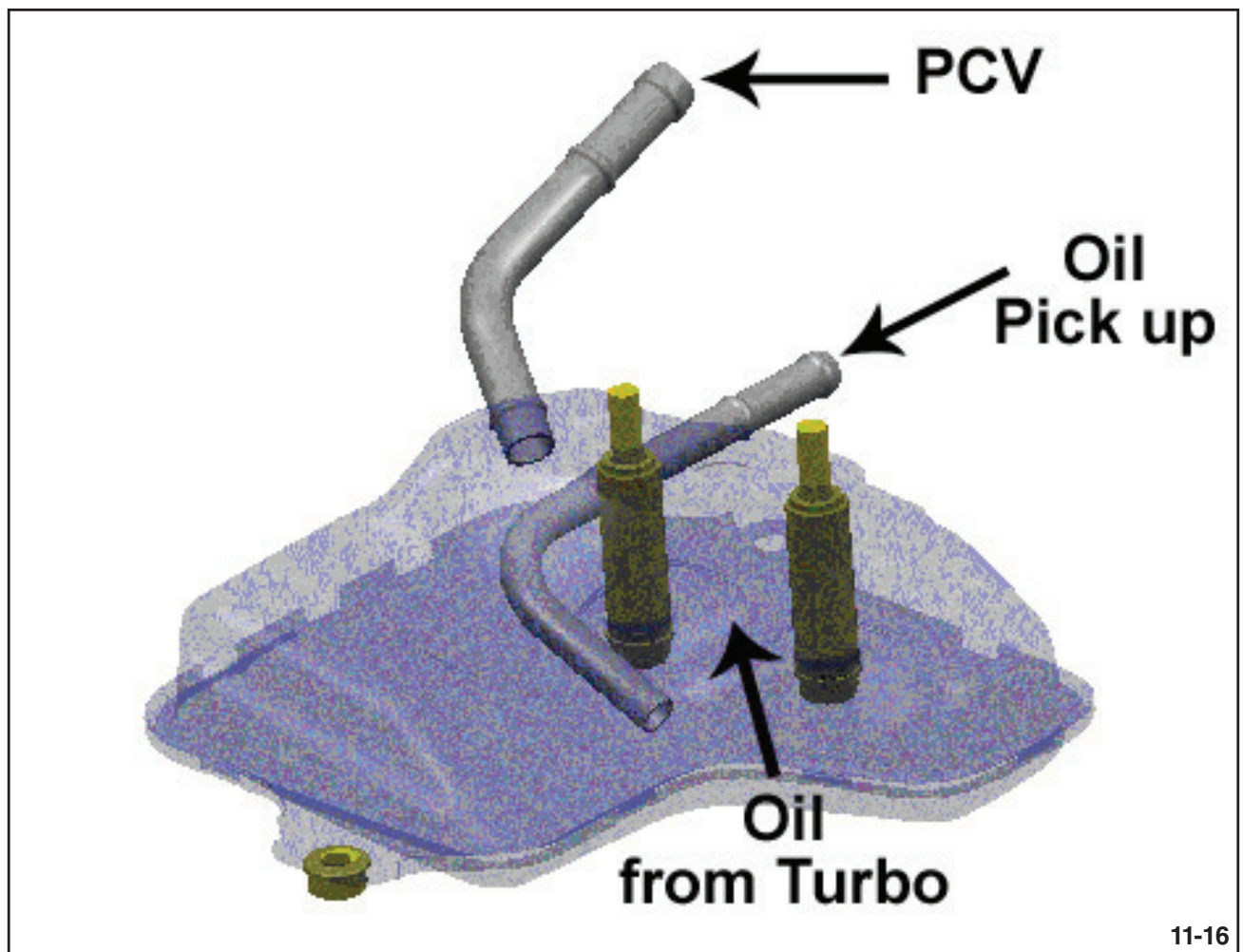
The turbocharger is the lowest point in the lubrication system and requires a scavenging oil pump to return oil that lubricates the turbocharger. The bottom of the turbocharger is equipped with a small oil pan that serves as a connection point for the scavenging oil pump pick up.

The scavenging oil pump is mounted to the back side of the right bank cylinder head and is driven from a slot at the rear of the intake camshaft.



Turbocharger Oil Pan with Pick-up (View 1)

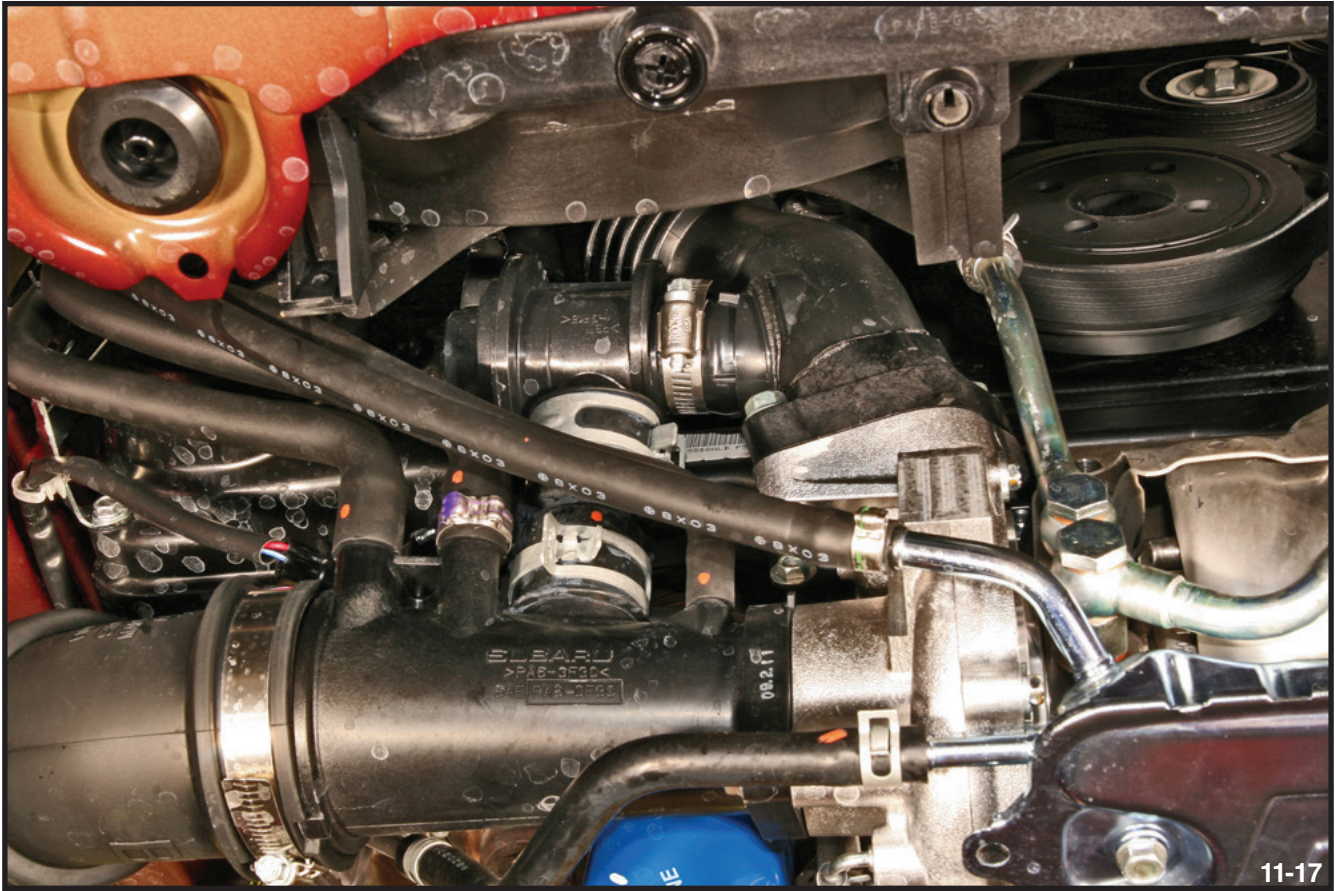
Basic Fuel Injection Part 3



Turbocharger Oil Pan with Pick-up (View 2)

Notes:

Basic Fuel Injection Part 3



Turbocharger Hoses and Lines

There are eight hoses or lines in the turbocharger area. The coolant system has a supply and return. The lubrication system has a supply and return. There are three PCV hoses and one hose for Canister Purge Control (CPC) 2 that connect to the fresh air intake connector at the inlet side of the turbocharger.

Note: The coolant expansion tank has been eliminated.

Notes:

Basic Fuel Injection Part 3



Bypass Valve



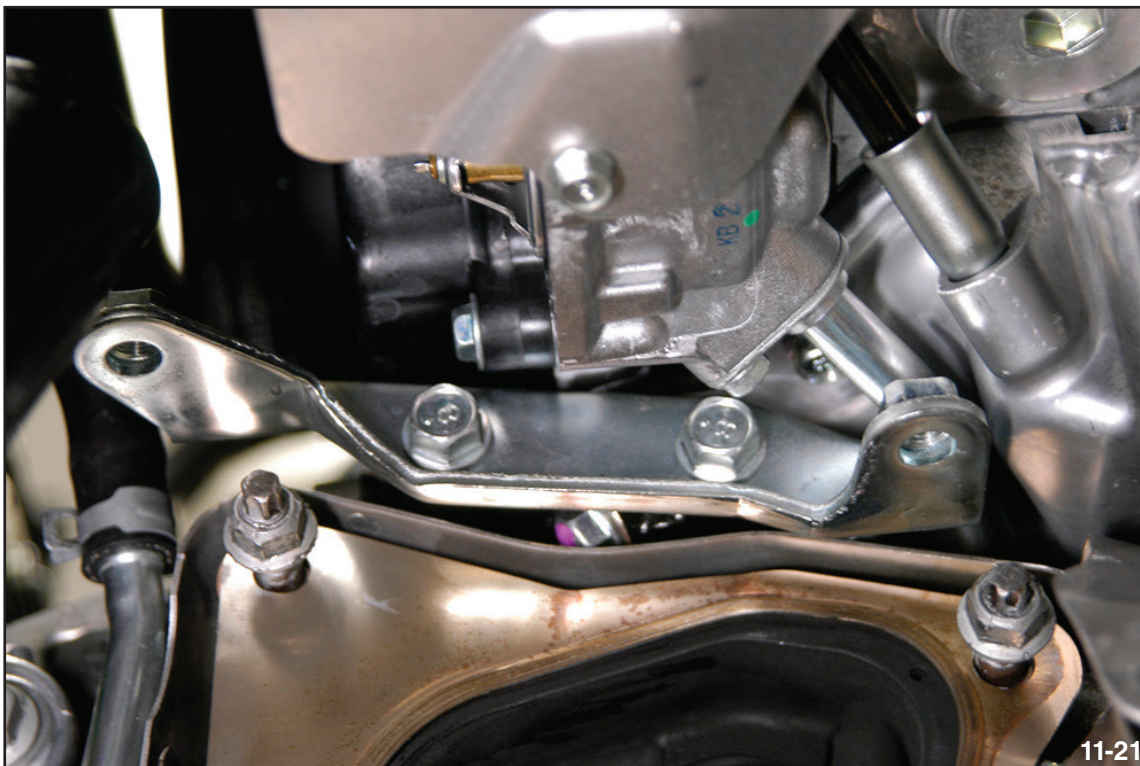
Wastegate Solenoid

Basic Fuel Injection Part 3



Wastegate Solenoid Mounted

The wastegate solenoid connects at the outlet side of the turbocharger, and a small hose connects to the vacuum “T” or “tee” between the compressor (outlet pressure) and the wastegate.



Top Bracket Mounting Plate

Basic Fuel Injection Part 3

The catalytic converter and the turbocharger share a mounting bracket. The top two studs of the turbocharger on the turbine side first go through an exhaust gasket then the catalytic converter. Before the nuts go into place, the mounting bracket is placed over the studs.



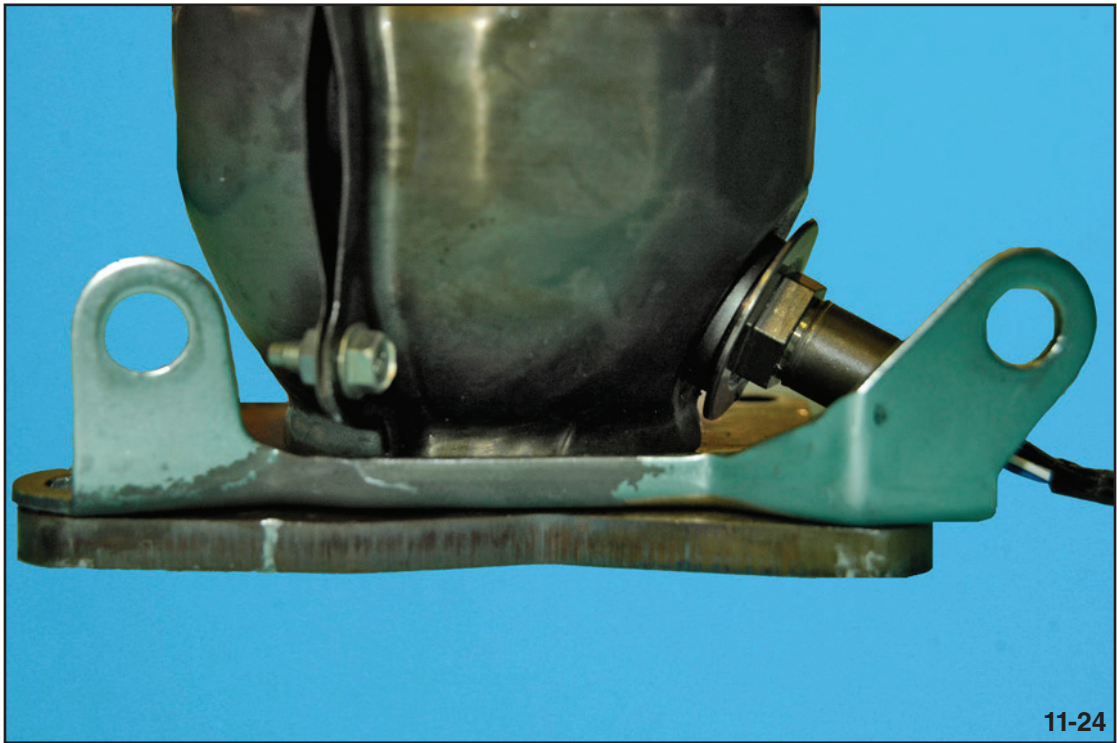
Top Bracket

The top holes of the bracket align with the threaded holes of the turbocharger/catalytic converter mount that is bolted to the side of the front engine mount.

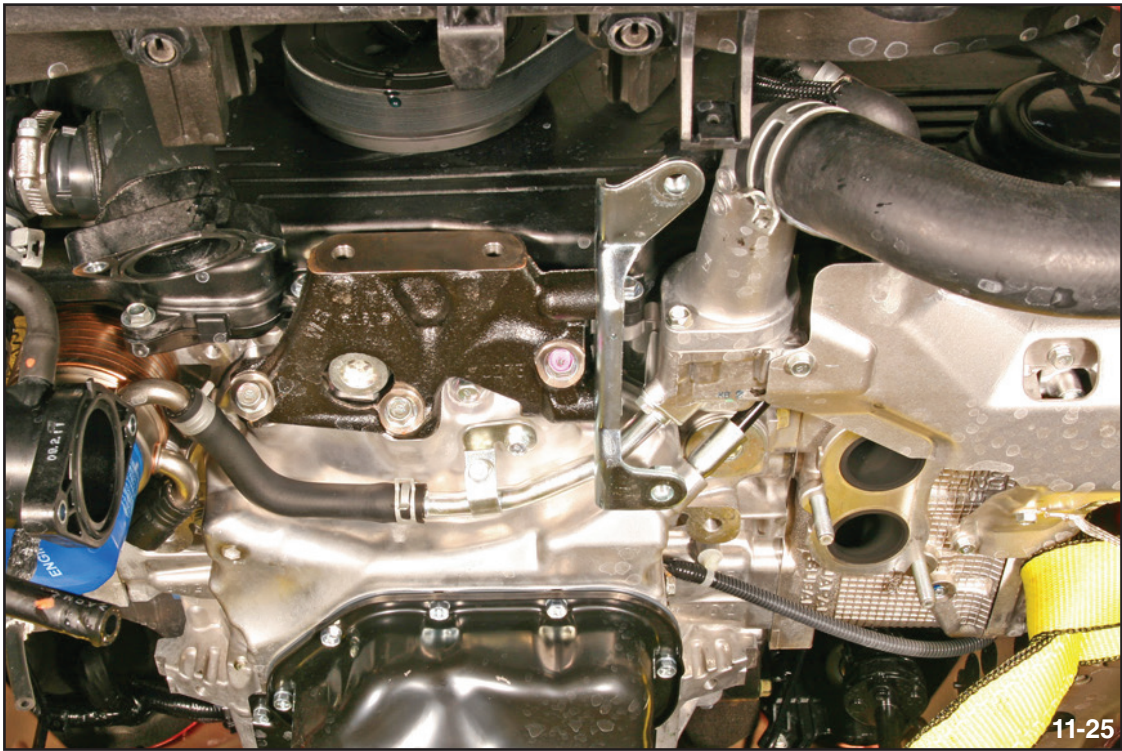


Top Bracket Mounted

Basic Fuel Injection Part 3



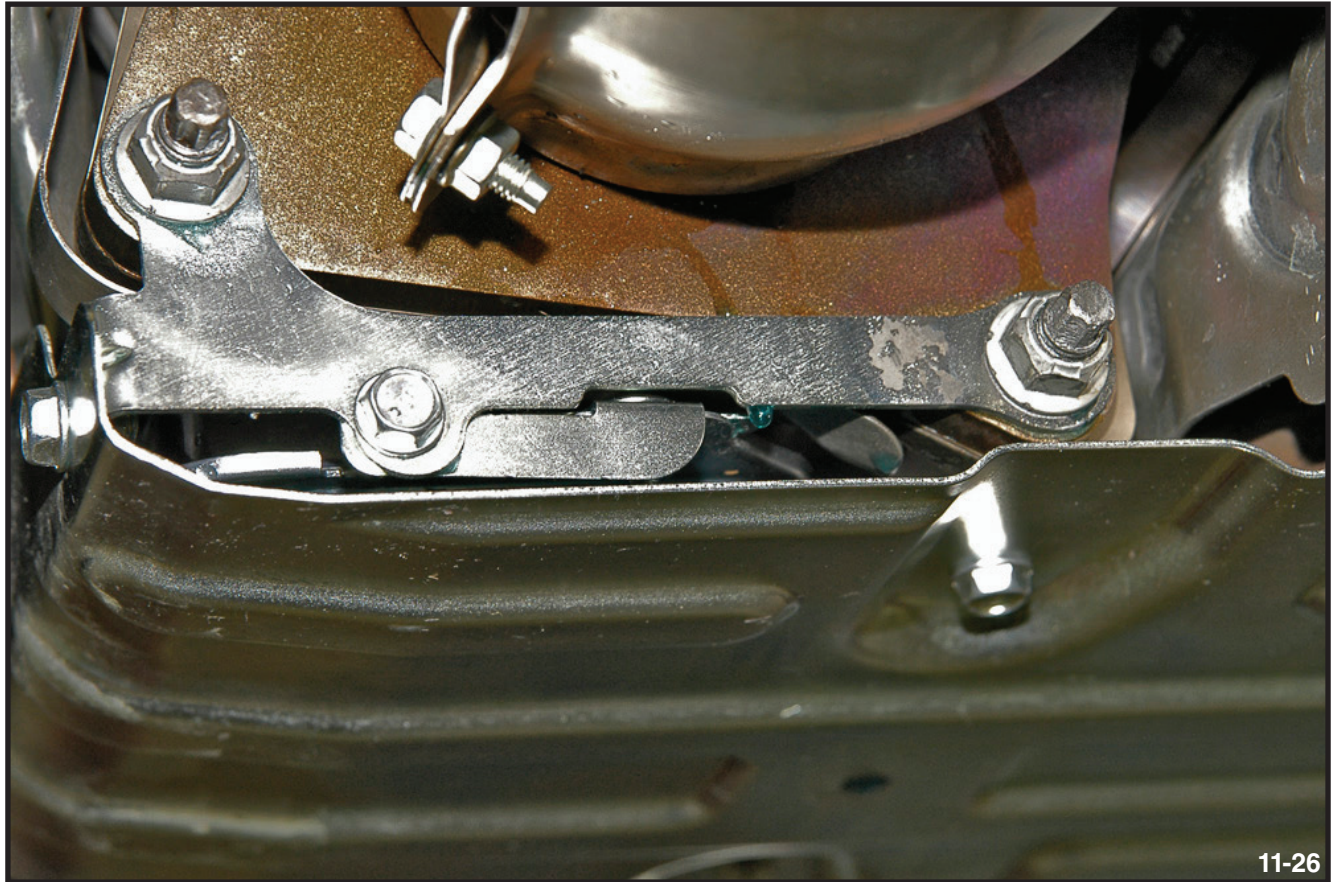
Top Bracket on Catalytic Converter



Top Bracket Mounting Plate Position

Notes:

Basic Fuel Injection Part 3



Turbocharger Bottom Studs

The bottom studs of the turbocharger pass through the exhaust gasket, catalytic converter, and a mounting bracket for the turbocharger heat shield. Both brackets must be removed before the catalytic converter can be removed.

Notes:

