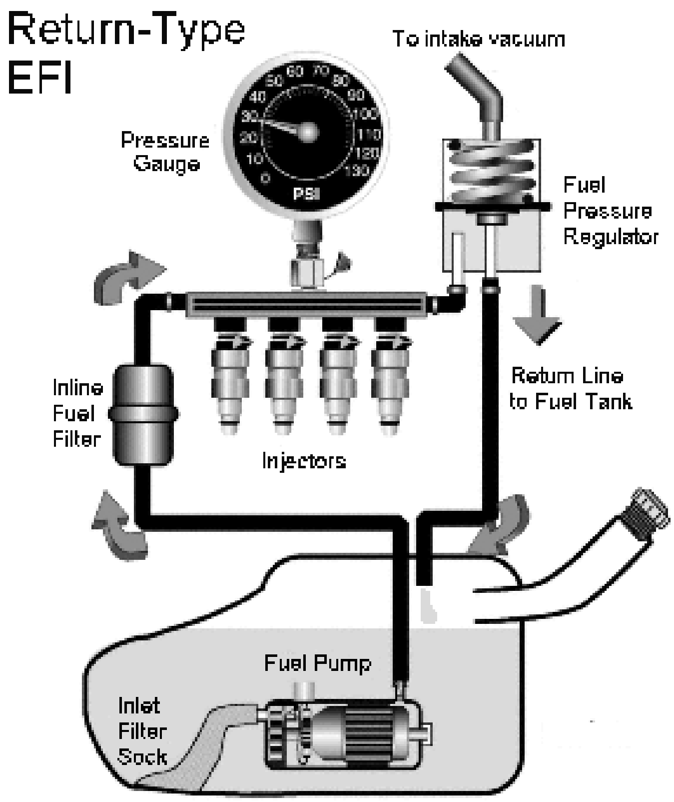


How Electronic Fuel Injection Works

By Larry Carley, Copyright 2019 AA1Car.com

Electronic fuel injection (EFI) replaced carburetors back in the mid-1980s as the preferred method for supplying air and fuel to engines. The basic difference is that a carburetor uses intake vacuum and a pressure drop in the venturi (the narrow part of the carburetor throat) to siphon fuel from the carburetor fuel bowl into the engine whereas fuel injection uses pressure to spray fuel directly into the engine.

> With a carburetor air and fuel are mixed together as air is pulled through the carburetor by the engine. The air/fuel mixture then travels through the intake manifold to the cylinders. One of the drawbacks of this approach is that the intake manifold is wet (contains droplets of liquid fuel) so fuel can puddle in the plenum area of the manifold when a cold engine is first started. The twists and turns of the intake runners can also

cause the air and fuel mixture to separate as if flows to the cylinders, resulting in uneven fuel mixtures between cylinders. The center cylinders typically run slightly richer than the end cylinders, which makes tuning for peak fuel economy, performance and emissions more difficult with a carburetor.

THROTTLE BODY INJECTION

With Throttle Body Injection (TBI), one or two injectors mounted in the throttle body spray fuel into the intake manifold. Fuel pressure is created by an electric fuel pump (usually mounted in or near the fuel tank), and the pressure is controlled by a regulator mounted on the throttle body. Fuel is sprayed into the engine when the engine computer energizes the injector(s), which occurs in a rapid series of short bursts rather than a continuous stream. This produces a buzzing noise from the injectors when the engine is running.

Because of this setup, the same fuel distribution issues that affect carburetors also affect TBI systems. However, TBI systems have better cold start characteristics than a carburetor because they provide better atomization and do not have a troublesome choke mechanism. A TBI system also makes it easier for an electronic engine control system to regulate the fuel mixture than an electronic feedback carburetor. Throttle Body Injection systems were only used briefly during the 1980s as US vehicle manufacturers transitioned from carburetors to fuel injection to meet emission regulations. By the late 1980s, most TBI systems were replaced with Multiport Injection (MPI) fuel injection systems.

MULTIPORT FUEL INJECTION

With MultiPort Injection systems, there is a separate fuel injector for each cylinder. The advantage of this approach is that fuel is sprayed directly into the cylinder head intake port. Since only air flows through the intake manifold, the intake manifold remains dry and there are no problems with fuel puddling when the engine is cold or fuel separation causing uneven fuel mixtures in the center and end cylinders. This allows the fuel mixture to be much more even in all of the cylinders for better fuel economy, emissions and performance.

Some early production multiport fuel injection systems were purely mechanical and date back to the 1950s (1957 Corvette with Rochester Fuel Injection , for example, and Bosch D-Jetronic and K-Jetronic systems with their mechanical fuel distributors and injectors). Later fuel injection systems such as the Bosch L-Jetronic systems of the late 1970s replaced mechanical injectors with electronic injectors. Today, all production EFI systems are fully electronic with computer controls and electronic injectors.

Most of the EFI systems that were offered in the late 1980s and early 1990s fire all of the injectors simultaneously, typically once every revolution of the crankshaft. The more sophisticated Sequential Fuel Injection (SFI) systems that came later fire each injector separately, usually just as the intake valve is opening. This allows much more precise fuel control for better fuel economy, performance and emissions.

GASOLINE DIRECT FUEL INJECTION

In the 2000s, some vehicle manufacturers began offering a new type of fuel injection system called Gasoline Direct Injection (GDI). With this setup, a separate injector is still used for each cylinder but the injectors are relocated on the engine to spray fuel directly into the combustion chamber rather than the intake port. This is similar to a diesel engine that sprays fuel directly into the cylinder. The advantage with this approach is a significant improvement (as much as 15 to 25 percent!) in fuel economy and power. However, it requires special high pressure fuel injectors and much higher operating pressures. Some current examples of direct fuel injection include VW TDI engines, Mazda direct injection engines, General Motors EcoTech engines and Ford EcoBoost engines.

FUEL INJECTOR PULSES

The relative richness or leanness of the fuel mixture in a fuel injected engine is determined by varying the duration of the injector pulses (called pulse width). The longer the pulse width, the greater the volume of fuel delivered and the richer the mixture.

Injector timing and duration is controlled by the engine computer. The computer uses input from its various engine sensors to regulate fuel metering and to change the air/fuel ratio in response to changing operating conditions. The primary sensor for fuel mixture control is the Oxygen sensor. The O2 sensor generates a RICH or LEAN signal that the engine computer uses to adjust the fuel mixture. For more information about feedback fuel control and fuel trim adjustments, see [What Is Fuel Trim?]

The computer is calibrated with a fuel delivery program that is best described as a three-dimensional map. The program directs the computer as to how long to make the injector pulses as engine speed and load change. During start-up, warm-up, acceleration and increased engine load, the map typically calls for a richer fuel mixture. When the engine is cruising under light load, the map allows for a leaner fuel mixture to improve fuel economy. And when the vehicle is decelerating and there is no load on the engine, the map may allow the computer to momentarily turn the injectors off altogether.

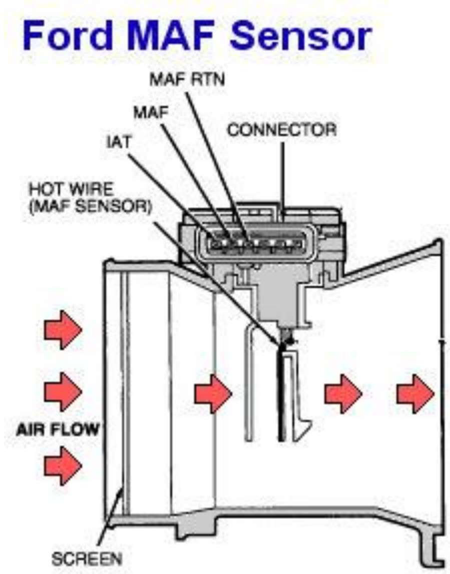
The programming that controls the EFI system is contained on a PROM (Program Read Only Memory) chip inside the engine computer. Replacing the PROM chip can change the calibration of the EFI system. This is sometimes necessary to update factory programming or to correct a drivability or emissions problem. The PROM chip on some vehicles can also be replaced with aftermarket performance chips to improve engine performance, too.

On many 1996 and newer vehicles, the programming is on an EEPROM (Electronically Ereasable Program Read Only Memory) chip in the computer. This allows the programming to be updated or changed by reflashing the computer. The new programming is downloaded into the computer through the OBD II Diagnostic Connector using a scan tool or J2534 reprogramming tool.

FUEL INJECTIN SENSOR INPUTS

Electronic fuel injection requires inputs from various engine sensors so the computer can determine engine speed, load and operating conditions. This allows the computer to adjust the fuel mixture as needed for optimum engine operation.

There are two basic types of EFI systems: Speed-Density systems and Mass Airflow systems. Speed density systems such as those found on many Chrysler engines and some GM engines do not actually measure airflow into the engine, but estimate airflow based on inputs from the Throttle Position Sensor (TPS), Manifold Absolute Pressure (MAP) sensor and engine RPM. The advantage with this approach is that the engine does not require an expensive airflow sensor, and the air/fuel mixture is less affected by small air leaks in the intake manifold, vacuum plumbing or throttle body.



A Ford mass airflow sensor also includes an Inlet Air Temperature (IAT) sensor inside.

With mass airflow systems, some type of airflow sensor is used to directly measure airflow into the engine. It may be a mechanical flap style airflow sensor, a hot wire airflow sensor or a vortex airflow sensor. The computer also uses inputs from all of its other sensors, but relies primarily on the airflow sensor to control the fuel injectors.

An EFI system will usually run without a signal from the MAP sensor, but it will run poorly because the computer has to rely on its other sensor inputs to estimate airflow. A common problem with MAF sensors is a buildup of dirt or varnish on the heated wire inside the sensor. Cleaning the MAF wire inside the sensor with electronics cleaner will often restore normal operation and cure a lean condition caused by a dirty airflow sensor.

On both types of systems (speed-density and mass airflow), input from the Heated Oxygen sensor (HO2) is also key for maintaining the optimum air/fuel ratio. The oxygen sensor (or Air/Fuel sensor on many newer vehicles) is mounted in the exhaust manifold and monitors unburned oxygen levels in the exhaust as an indicator of the relative richness or leanness of the fuel mixture. On V6 and V8 engines, there will be a separate oxygen sensor for each bank of cylinders, and on some straight six cylinder engines (BMW for example), there may be separate oxygen sensors for the first three cylinders and the last three cylinders. The feedback signal from the oxygen sensor or air/fuel sensor is used by the engine computer to constantly fine tune the fuel mixture to optimum fuel economy and emissions.

When the oxygen sensor tells the computer the engine is running lean (higher levels of unburned oxygen in the exhaust), the computer compensates by richening up the fuel mixture (increasing the pulse width of the injectors). If the engine is running rich (less oxygen in the exhaust), the computer shortens the pulse width of the injectors to lean the fuel mixture.

Input about the position of the throttle is provided by the Throttle Position Sensor (TPS). It is located on the side of the throttle body and uses a variable resistor that changes resistance as the throttle opens and closes.

Engine load is measured by the Manifold Absolute Pressure (MAP) sensor. It may be mounted on the intake manifold or attached to the intake manifold with a vacuum hose.

The temperature of the air entering the engine must also be monitored to compensate for changes in air density that occur (colder air is denser than hot air). This is monitored by an Inlet Ait Temperature (IAT) or Manifold Air Temperature (MAT) sensor, which may be built into the airflow sensor or mounted separately on the intake manifold.

Coolant temperature is monitored by the Coolant Temperature Sensor (CTS). This tells the computer when the engine is cold and when it is at normal operating temperature. The computer needs to know the temperature because a cold engine requires a richer fuel mixture when it is first started. When the coolant reaches a certain temperature, the engine goes into Closed Loop operation, which means it starts using inputs from the oxygen sensors to fine tune the fuel mixture. When it is operating in Open Loop (when cold or when there is no signal from the coolant sensor), the fuel mixture is fixed and does not change.

Faulty inputs from any of the engine's sensors may cause drivability, emissions or performance problems. Many sensor problems will set a Diagnostic Trouble Code (DTC) and turn on the Check Engine Light. Reading the code(s) with a scan tool will help you diagnose the problem.

EFI throttle body.

FUEL INJECTION IDLE SPEED CONTROL

Idle speed on fuel injected engines is computer controlled via an idle air bypass circuit on the throttle body. A small electric motor or solenoid is used to open and close the bypass orifice. The larger the opening, the greater the volume of air that can bypass the throttle plates and the faster the idle speed.

On newer vehicles with electronic throttle control, the computer also controls the opening of the throttle plate when the driver pushes down on the gas pedal. Position sensors in the gas pedal signal the computer how far to open the throttle plate.

Idle problems on EFI systems can be caused by varnish and dirt deposits in the throttle body idle control circuit. Cleaning the throttle body with throttle body cleaner can often solve idle problems (follow the directions on the product). Idle problems can also be caused by air leaks between the airflow sensor and throttle, the throttle body and intake manifold, and the intake manifold and cylinder head(s), or in the PCV or EGR systems, or vacuum hoses.

On most EFI systems, voltage is supplied directly to the injectors and the PCM energizes the injector by grounding the circuit.

INJECTORS

A fuel injector is nothing more than a spring-loaded solenoid pintle valve. When energized by the computer, the solenoid pulls the valve open. This allows fuel to spray out of the nozzle and into the engine. When the computer cuts the circuit that powers the injector, the valve inside the injector snaps shut and fuel delivery stops.

The total amount of fuel delivered is controlled by cycling the injector voltage on and off very rapidly. The longer the pulse width, the greater the volume of fuel delivered and the richer the fuel mixture. Decreasing the duration of the injector signal pulse reduces the volume of fuel delivered and leans out the mixture.

Dirty fuel injectors are a common problem. A buildup of fuel varnish deposits inside the tip of the injector spray nozzle can restrict fuel delivery and interfere with the creation of a good spray pattern. This can cause a lean fuel condition and misfiring. Cleaning the injectors with fuel injection cleaner, or removing the injectors and having them cleaned on a fuel injector cleaning machine can usually restore normal operation. Using a Top Tier gasoline that contains adequate levels of injector cleaner can also prevent varnish deposits from forming.

The fuel pressure regulator is usually mounted on the fuel rail that supplies the injectors.

FUEL PRESSURE CONTROL

Another important factor that helps determine how much fuel is delivered through an injector when it is pulsed, and that is the fuel pressure behind it. The higher the pressure behind the injector, the greater the volume of fuel that will spray out of the injector when it is opened.

Fuel pressure is generated by a high pressure electric fuel pump usually mounted inside or near the fuel tank. Pump output pressure may range anywhere from 8 to 80 lbs. depending on the application. The pump usually has an pressure valve to vent excess pressure and a check valve to maintain system pressure when the ignition is off.

In a multiport EFI system, the pressure differential between the fuel behind the injectors and the vacuum or pressure in the intake manifold is a constantly changing variable. Under light load or at idle, a relatively high vacuum exists in the intake manifold. This means less fuel pressure is needed to spray a given volume of fuel through the injector. Under heavy load, engine vacuum drops to near zero. Under these circumstances, more pressure is needed to deliver the same quantity of fuel through the injector. And in turbocharged engines, manifold vacuum can become 8 to 14 lbs. of positive pressure when turbo boost comes into play. Even more fuel pressure is required to force the same amount of fuel through the injector.

A means of regulating fuel pressure according to engine vacuum must be provided in a multiport EFI system to maintain the same relative pressure differential between the fuel system and intake manifold. This is done by the fuel pressure regulator. The regulator is mounted on the fuel rail that supplies the injectors. On returnless EFI systems, the regulator is part of the fuel pump assembly inside the fuel tank.

The fuel pressure regulator has a simple spring-controlled vacuum diaphragm with a vacuum connection to the intake manifold. The regulator decreases fuel pressure under light load and increases it under heavy load or boost conditions. The excess fuel pressure is shunted through a bypass port back to the fuel tank to maintain the desired pressure differential. Most systems are calibrated to maintain a pressure differential of somewhere between 40 and 55 psi.

On the older TBI systems, the regulator has an easier job because the injectors are mounted above the throttle plates. Since engine vacuum/boost has no effect on fuel delivery out of the injector on the TBI system, regulator only has to maintain an even pressure. On General Motors TBI applications, the pressure regulator is calibrated to maintain roughly 10 psi in the fuel system but most others run close to 40 psi.

Low fuel pressure will result in poor engine performance, possible misfiring and may prevent the engine from starting. Low fuel pressure can be caused by a weak fuel pump (a worn pump or low voltage to the pump that caused it to run slowly), restrictions in the fuel line, a plugged fuel filter, or a leaky fuel pressure regulator. Fuel pressure MUST be within specifications for the engine to run properly. Fuel pressure can be tested with a fuel pressure gauge connected to the service valve on the fuel rail, or teed into the fuel line.

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