TERMS AND DEFINITIONS OF FUEL INJECTION MANAGEMENT SYSTEMS

Throttle Body Assembly (TBA) — The throttle body assembly (also called air valve), controls the airflow to the engine through one, two or four butterfly valves and provides valve position feedback via the throttle position sensor. Rotating the throttle lever to open or close the passage into the intake manifold controls the airflow to the engine. The accelerator pedal controls the throttle lever position. Other functions of the throttle body are idle bypass air control via the idle air control valve, coolant heat for avoiding icing conditions, vacuum signals for the ancillaries and the sensors.

FUEL INJECTOR — There are basically three approaches in delivering the fuel to the engine:

- Above the throttle plate as in throttle body injection
- In the intake port toward the intake valves as in multi-port injection or central multi-port injection.
- Directly into the combustion chamber as in gasoline direct injection systems (GDI).

The fuel injector is continuously supplied with pressurized fuel from the electric fuel pump. The pressure across the metering orifice of the injector is maintained constant by the fuel pressure regulator. The fuel injector is an electromagnetic valve that when driven by the ECU delivers a metered quantity of fuel into the intake manifold (or combustion chamber in the GDI system). The ECU controls the fuel flow by pulse width modulation. The time the injector is driven into an open condition is determined by the following sensor inputs:

- Engine RPM
- Throttle position (TPS)
- Manifold absolute pressure or mass air flow
- Engine coolant temperature
- Oxygen sensor feedback voltage
- Intake air charge temperature
- Battery voltage

CENTRAL POINT INJECTION SYSTEM (CPI) — Electronic fuel Injection system consisting on a single fuel injector mounted in the throttle body.

DIGITAL FUEL INJECTION (DEFI OR DFI) — Electronic fuel injection system controlled by digital microprocessors as opposed to earlier systems that were of analog design. The analog input signals to the microprocessor are converted from analog to digital before being processed.

THROTTLE BODY INJECTION (TBI) — In TBI systems the throttle body assembly has two major functions: regulate the airflow, and house the fuel injectors and the fuel pressure regulator. The choices of throttle bodies range from single barrel / single injector unit generally sized for less than 150 HP to four barrel / four injector unit capable of supporting fuel and air flow for 600 HP. The injectors are located in an injector pod above the throttle valves. The quantity of fuel the injector spray into the intake manifold is continuously controlled by the ECU. Most of the TBI systems use bottom fed fuel injectors.

MULTI-POINT FUEL INJECTION (MPFI) — In the multi point fuel injection system an injector is located in the intake manifold passage. The fuel is supplied to the injectors via a fuel rail in the case of top fed fuel injectors and via a fuel galley in the intake manifold in the case of bottom fed fuel injectors. MPFI systems provide better performance and fuel economy as compared to TBI. Most of the MPFI systems use one injector per cylinder but in certain applications up to two injectors per cylinder are used to supply the required fuel for the engine.

CENTRAL MULTI-PORT FUEL INJECTION (CMFI) — This is a variation of MPFI system but in this case the injectors (usually one per cylinder) are located in a plastic molded pod and the fuel is distributed to the intake ports via a polymeric hose. To avoid fuel distribution variations a fuel pressure activated poppet valve is installed at the end of the hose. The injectors are activated via the ECU in a similar fashion as in the MPFI fuel systems.

TUNED PORT INJECTION (TPI) — A TPI is a fuel / air management system that has a tuned induction system to optimize airflow to each cylinder. This system was developed to obtain the broadest possible torque curve. A single throttle body and one injector per cylinder are used in this configuration. The intake manifold incorporates long runners whose length is tuned to the desired torque curve. For low and mid range torque longer runners are utilized in this application.

DIRECT FUEL INJECTION (DFI) — In a direct fuel injection system one injector is located in the cylinder head for each cylinder. The high-pressure fuel (single fluid) or low-pressure air / fuel mixture (dual fluid) is metered directly into the combustion chamber when the electromagnetic valve is activated by the ECU. This fuel injection system offers the latest in engine management systems and offers the best in engine performance, low exhaust emissions and fuel economy.

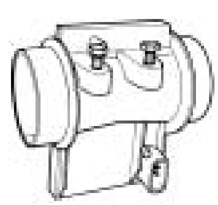
ELECTRONIC CONTROL UNIT (ECU) — The function of the ECU is to "tweak" or "fine tune" the engine operation to obtain the most complete and efficient combustion process. The ECU microprocessor receives input signals from various sensors from the engine and generates specific outputs to maintain optimum engine performance. The engine operating modes controlled by the ECU is the following:

- Cold and hot start
- Acceleration enrichment
- Battery voltage compensation
- Deceleration cut/off or enleanment
- Run mode (open loop or closed loop)

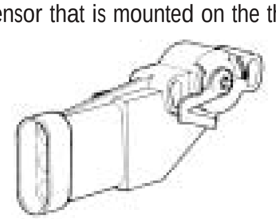
MANIFOLD ABSOLUTE PRESSURE SENSOR (MAP) — The MAP sensor is a three-wire sensor located on or attached to the intake manifold. The function of this sensor is to measure the changes in the intake manifold air pressure and generates an electric signal that is proportional to the change of pressure. This signal is fed into the ECU and is used to:

- Adjust the fuel delivery
- Spark ignition calculations
- Barometric pressure readings upon starting the engine

MASS AIR FLOW SENSOR (MAF) — The mass air flow sensor is positioned in the air intake duct or manifold and measures the mass of incoming air. From this acquired data the ECU calculates the required fuel for the specific air mass flow rate. The MAF works on the hot wire or hot film concept. The hot wire/film is maintained at a constant calibrated temperature. The passing air cools down the hot wire/film and the added energy required to maintain the calibrated temperature is directly proportional to the mass of air passing by the hot wire. The MAF also compensates for humidity as humid air, denser or cooler, absorbs more heat from the sensor, requiring more current to maintain the calibration temperature.



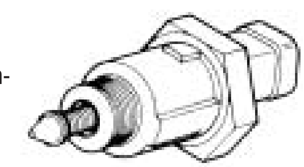
THROTTLE POSITION SENSOR (TPS) — The TPS is a three-wire sensor that is mounted on the throttle body assembly and is actuated by the throttle shaft. The TPS is basically a variable resistor (potentiometer) that sends a voltage signal to the ECU that is proportional to the throttle shaft rotation. When the throttle shaft is open the sensor emits a high voltage signal and when the throttle shaft is closed it emits a low voltage signal. The voltage signal from the TPS changes between 0.45 V at idle to 4.5 to 5.0V at wide open throttle.



OPEN LOOP — Open loop defines the engine operation where the fueling level is calculated by the ECU with only the input signals from the throttle position sensor (TPS), from the coolant and/or air charge temperature, and from the manifold absolute pressure (MAP) or the mass air flow sensor (MAF).

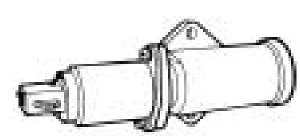
CLOSED LOOP — Closed loop defines the engine operation where the fueling level is calculated and corrected by the ECU based on the voltage signal from the O_2 sensor. When the O_2 sensor emits a voltage signal above 0.45V due to a rich mixture in the exhaust manifold, the ECU reduces the fueling level by reducing the pulse width of the injector. The O_2 sensor voltage is the feedback that modifies the fuel control program that is based on other signals.

IDLE AIR CONTROL VALVE (IACV OR IAC) — The IAC is located in the throttle body of the TBI, MPFI and CMFI systems. The valve consists of a stepper motor that adjusts the position of its pintle to vary the bypass air during idle and off idle conditions. During the closed throttle condition (idle), the ECU constantly compares actual engine speed with the programmed desired engine speeds. Discrepancy between these two values result in activation of the stepper motor increasing or decreasing the bypass air around the throttle plate(s) until desired engine speed is achieved. The following input signals or conditions determine the position of the valve:



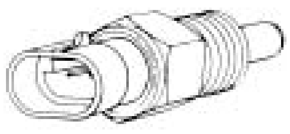
- Throttle position sensor
- Engine load (MAP/MAF, A/C compressor, power steering pressure switch, gear selection)
- Battery Voltage
- Engine coolant temperature

THROTTLE AIR BYPASS VALVE — The throttle air bypass valve is located on the throttle body of engine fuel management systems. This solenoid valve allows additional bypass air when the engine is subjected to certain load conditions or cold starts.



AIR CHARGE TEMPERATURE SENSOR — The air charge sensor is located in the engine air intake to sense the air induced into the engine manifold. The sensor consists of a thermistor, which generates a voltage signal, that is proportional to the air temperature. This voltage signal is used by the ECU to calculate the air density and using these results to adjust the fueling levels for a particular engine load. Other functions of the air temperature signal are:

- Adjust fueling during cold start
- Activation of the EGR valve
- Modify spark advance
- Regulate acceleration enrichment

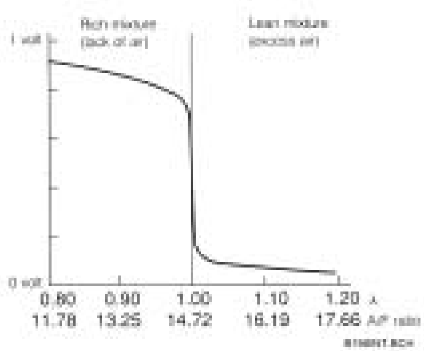


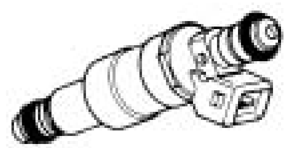
COOLANT TEMPERATURE SENSOR — The coolant temperature sensor is a two-wire sensor that is threaded into the engine block and is in direct contact with the coolant. The function of this sensor is to generate a signal that the ECU uses to adjust the fueling levels required for the operation of the engine and operate ancillaries. The thermistor contained in the sensor generates an electric signal that is proportional to the coolant temperature. At low temperatures the resistance is high (3800 ohms) generating a 5-volt signal in the ECU. At normal engine operating temperatures the resistance of the sensor is low (180–200 ohms) which generates 1–2 volt signal in the ECU. Other functions of the coolant temperature signal are:

- Idle speed adjustment via the IAC
- Modify spark advance
- Electric cooling fan operation
- Activation of the EGR
- Torque converter clutch application

Oxygen Sensor — The oxygen sensor is located in the exhaust manifold and its function is to measure the oxygen content in the exhaust gases. The sensor is an electrochemical cell, which develops a voltage signal between its two electrodes that is proportional to the oxygen content in the exhaust gases. The oxygen sensor adjusts and maintains an optimum air fuel mixture to control the exhaust emission and the fuel economy. When the oxygen content in the exhaust is high due to a lean mixture the output voltage of the sensor is close to zero. If the fuel air mixture is on the rich side, the oxygen content in the exhaust is low and the output voltage of the sensor approaches 1.0 volts. There are three types of oxygen sensors:

- One wire O_2 sensor (not heated)
- Three wire O_2 sensor (heated)
- Four wire O_2 sensor (heated)





TOP-FED FUEL INJECTOR — When the ECU activates this electromagnetic valve, the injector meters and atomizes fuel in front of the intake valve. The fuel enters the top and is discharged via the metering orifice at the bottom at high pressure. The spray geometry and cross sectional area is specific to the engine application. In general there are four major spray patterns:

- Pencil stream. Solid stream narrow angle spray.
- Split pencil stream. Two solid streams narrow angle sprays usually used in multi valve cylinder applications.
- Bend spray. Solid stream narrow angle spray being discharged in an angle with respect to the injector center axis. This application is used in engine applications where the injector package does not allow alignment of the injector axis with the spray target center axis.
- Oblong spray. This spray geometry consists of an elliptic or oblong cross-sectional area of the spray. This application is used in engine applications where the spray target requires a specific spray pattern.

BOTTOM FED FUEL INJECTOR — This electromagnetic valve meters fuel into the intake manifold in proportion to the air flowing into the engine. When the valve is energized the electromagnetic force generated by the solenoid lifts the pintle/ball from the seat. Fuel under pressure is then injected into the throttle body bore or the intake port. The spray configuration is application dependent. For throttle body injection a hollow conical spray is required while for port injection a narrow pencil stream is preferred to avoid wall wetting.

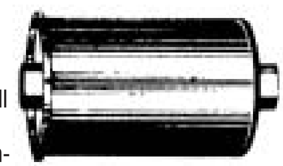
HIGH IMPEDANCE INJECTORS — Most injectors can be divided into two major categories: high impedance 12 to 16 Ohms and low impedance 1.2 to 4.0 Ohms. The high impedance injectors are used with ECUs that are designed with saturation drivers. The advantage of using saturation drivers is that the currents running through the ECU circuits and the injectors are relatively low thus generating less heat. The disadvantage of saturation drivers is that the driver has a slower response time, which could affect the full utilization of such a system at very high engine RPM.

LOW IMPEDANCE INJECTORS — The low impedance injectors are designed to be run with an ECU that employs peak and hold drivers (also called current sensing or current limiting drivers). The current ratio (peak to hold) is generally 4:1 and the most common drivers available are 4 A peak/1 A hold or 2 A peak/ 0.5A hold. The peak current is generated to overcome the inertia of the closed valve and once the valve is open the driver cuts down to 1/4 of the peak current to hold the injector open until the end of the metering event. Low impedance injector designs are mostly used in high flow applications.

ELECTRIC IN-LINE FUEL PUMP — The function of the electric fuel pump is to deliver pressurized fuel to the fuel injection system. The ECU activates the fuel pump relay to operate the fuel pump when the ignition switch is in the On or start position. The pumps are designed to match certain flow and pressure specification for the engine application. In TBI applications the fuel pump must supply enough fuel flow for the engine WOT output at 15 to 20 psi. In multi-port applications the fuel pump must be able to supply enough fuel at full engine load to maintain at least 43.5 psi at the fuel rail. At idle the fuel pressure regulator must be able to return the excess fuel to the tank and maintain the required system pressure. Most of the cars prior to 1987 use an in-line external electric fuel pump.

ELECTRIC IN-TANK FUEL PUMP — Almost all car applications after 1987 designed their fuel pump assembly inside the fuel tank. The advantage of having the fuel pump in the fuel tank is mainly lower noise, lower potential leakage problems, less mounting sensitivity of the pump with respect to lift of fuel from the tank is minimized. The in-tank pump went through several designs evolving from a simple "pump on a stick" to a complex in-tank fuel sending modules. The new designs combine the high-pressure electric fuel pump, noise isolation and a fuel level sensor into one compact modular package. This new design also helps reducing hydrocarbon emissions. The hot gasoline returning from the fuel system is returned to the reservoir surrounding the fuel pump. By returning the hot fuel to the reservoir heating of the bulk fuel in the fuel tank is avoided, thus reducing the evaporation of the high volatile portions in the fuel. At present all fuel tank modules are designed and serviced as a complete unit. If the pump or fuel level sensor fails the entire unit will have to be changed.

FUEL PUMP INLET FILTER — The function of this filter is to eliminate any impurities that might harm the fuel pump. In the in-line fuel pump type this filter is external to the fuel tank and is in a replaceable cartridge filter. In the in-tank fuel pumps the fuel filter is in the form of a sock and is directly attached to the pump in the "pump on a stick" version and attached to the fuel pump module in the module version.



MAIN FUEL FILTER — The function of this filter is to eliminate any contaminants after the fuel pump. These are either small enough to pass through the fuel filter of the pump inlet or are generated by the fuel pump. This fuel filter is also of the cartridge type but is designed to sustain much higher fuel pressures that the fuel pump inlet filter.

FUEL PRESSURE REGULATOR — Fuel system pressure is maintained by the regulator, while excess fuel is returned to the fuel tank. The regulator consists of two chambers separated by a diaphragm assembly. On the fuel side of the diaphragm a throttling valve is employed to expand or restrict fuel flow as the fuel pressure fluctuates. The other side contains a spring with an adjustment screw that is set at the factory for correct system pressure and flow. This chamber is connected to the intake manifold in MPFI systems to reference the vacuum in the manifold during engine operation. This pressure reference is required to maintain a constant differential pressure across the metering orifice of the fuel injector.

THE ENGINE APPLICATION AND THE SELECTION OF YOUR FUEL MANAGEMENT SYSTEM COMPONENTS.

INJECTOR FUEL FLOW

Engine output is in direct relation with fuel supplied to the engine, however installing injectors, which are too big, will not make more power. It is therefore very important to match the fuel injector flow characteristics to specific engine applications. Matching the fuel flow characteristics of fuel injectors is as important as matching the carburetor jets for a specific engine application. The fuel flow of the injectors and the carburetor has to be matched to the air flow requirements of the engine over a broad RPM operating range.

In the carburetor the operating range is usually divided into three sub-ranges: idle, mid-range and power. Three distinct fuel circuits supply the fuels for these three ranges. In MPFI systems one single injector has to cover all three ranges for individual cylinders from 500 RPM at idle to 8000 at WOT. The operating range in fuel injectors is normally referred to as the dynamic range of the injector. An injector with a wide dynamic range is capable not only to potentially cover several engine applications but also is a very sought after metering tool for high performance applications.

The dynamic range must encompass the minute quantities of fuel required at idle conditions and the large quantities of fuel required at maximum engine output. It must also cover the required fuel amounts during transient response. The dynamic range of the fuel injector is further stressed in turbo charged applications because of the additional fuel required due to the higher engine air mass flow rates generated by the turbocharger.

The following equation sizes fuel injectors for specific engine applications.

Injector Static Flow Rate [lb/hr] = (Engine HP * BSFC)/ (Number of injectors * DC of Inj.)

Engine HP = Realistic HP output estimate of the engine

BSFC = Brake Specific Fuel Consumption [lb/HP*hr]. Good approximation 0.50

Duty Cycle of Injector = Maximum opening time of injector/cycle time.

Maximum Duty Cycle= 0.90

Example:

Engine HP = 400HP

Number of Injectors = 8

Injector Static Flow Rate [lb/hr] = (400 * 0.50)/(8 *0.90) = >27.78 b/hr

Note: If the application requires a static flow rate that falls in between two available injectors always use the next injector with the higher flow rate.

For the example above if only 25 lb/hr and 30 lb/hr injectors are available, choose 30lb/hr injectors.

FUEL PRESSURE

In certain occasions matching of the injectors' fuel flow for a specific engine application cannot be done due to injector availability or the fuel flow step between the available injectors is too large. Since the fuel injector is a pressure/time-metering device, increasing the fuel pressure can increase the fueling level. Increasing the fuel pressure is limited mainly to four factors: burst pressure of the components in the fuel system, increase of opening time of the injector, reduced life expectancy of the fuel system components and limitations of the fuel pump. Most injectors are limited to a burst pressure of 125 psi. Reducing the fuel pressure to match the required fuel flow can be done but lower fuel pressures affect the atomization efficiency of the fuel injector nozzle. To project potential fueling levels by changing the fuel pressure, the following equation can be used:

$M1/M2 = \sqrt{P1} / \sqrt{P2}$

M1 = rated mass flow rate of the injector at fuel pressure P1 in lb/hr

M2 = new mass flow rate of the injector at fuel pressure P2 in lb/hr

P1 = existing fuel pressure setting in psi

P2 = new fuel pressure setting in psi

Example:

Rated mass flow rate M1 = 30 lb/hr

Existing fuel pressure P1 = 43.5 psi

Required fuel mass flow rate M2 = 35 lb/hr

$P2 = (M2/M1)^2 * P1$

$P2 = (35/30)^2 * 43.5$

P2 = 59.21psi = >60psi

To obtain a fueling level of 35 lb/hr the system pressure has to be increased to 60 psi.

After increasing the fuel pressure to obtain certain engine output, idle, off-idle and light load condition will have to be re-tested. Increasing the fueling level at the upper end, requires the fuel injector to run at smaller pulse widths at idle conditions. When running at pulse widths smaller than 1.8 ms the injector might be running in the non-n linear portion of its dynamic range. Such condition can lead to engine "hunting" during idle to hesitation during off-idle conditions.