

Fuel System Basics

Fuel System Open- and Closed-Loop Operation

The Fuel System of a vehicle is responsible for controlling the amount of fuel entering the combustion chamber at every cycle. The main component in the Fuel System is a software process which runs on the Engine Control Module (ECM). The ECM controls the Pulse-width of each electronic fuel injector using the data from various critical sensors and data stored in its memory by the manufacturer. The main input sensors that influence the fuel injector Pulse-width calculations are: the Manifold Absolute Pressure (MAP) sensor and/or the Mass Air Flow (MAF) sensor, the Intake Air Temperature (IAT) sensor, the Throttle Position (TP) sensor, the Oxygen Sensors, the Coolant Temperature (CT) sensor and the system voltage.

To minimize the engine's emissions released into the environment, the combustion (chemical reaction) must be close to stoichiometry. In other words, the emissions are reduced when the air/fuel mixture is almost all consumed by the combustion. However, a perfect combustion does not occur in the combustion chamber due to the high temperatures involved and several other factors. To reduce the emissions, a catalytic converter, located in the exhaust path(s), transforms the remaining partial reactants. The ideal Air-Fuel mixture for gasoline engines is an Air/Fuel ratio (A/F) of approximately 14.7:1. This corresponds to the point of maximum catalytic efficiency.

Closed-Loop Operation

The Fuel System has two main modes of operation, Open- and Closed-loop operation. Under Closed-loop operation, the ECM works to maintain the A/F at its ideal value for minimal emissions and maximum efficiency. The term "Closed-loop" implies that the Oxygen sensors are used to monitor the oxygen content in the exhaust and that the data is used as feedback for the ECM. The ECM uses the data from the Oxygen sensors to bring any corrections to the Air-Fuel mixture. The basic block diagram of the Closed-loop system is shown in Figure 1.

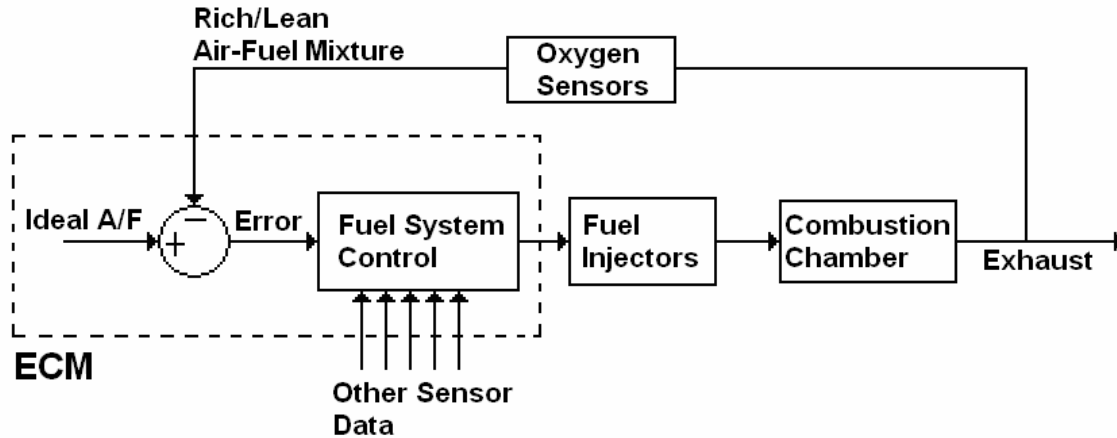


Figure 1: Closed-Loop Fuel System

Open-Loop Operation

Under Open-loop operation, the ECM does not work to maintain the ideal A/F. For this mode of operation, the ECM uses a fuel table located in its memory as well as other sensors to determine the amount of fuel required for each cycle. The Oxygen sensors are not used in the fuel calculations for this mode of operation. The system may be in Open-loop mode: at start-up, when the oxygen sensors are not in their operating temperature range (cold), when the vehicle is accelerating (A/F for maximum power), when it is decelerating, under heavy loads, at wide-open throttle or when an Oxygen sensor is malfunctioning. The basic block diagram of the Open-loop system is shown in Figure 2.

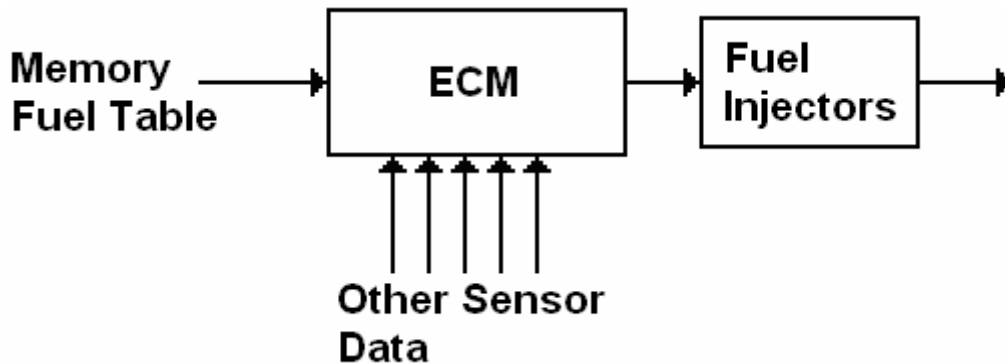


Figure 2: Open-Loop Fuel System

Oxygen Sensors

Like the name implies, an Oxygen sensor measures the amount of oxygen in the exhaust. The output signal of the sensor may be a voltage or a current depending on the type of sensor. A Bosch Oxygen sensor is depicted in Figure 3. There are different types of Oxygen sensors. The most common types are the Narrow Range Oxygen sensor and the Wide Range Oxygen sensor.



Figure 3: Narrow Range Bosch Oxygen Sensor

Oxygen sensors are used as the feedback source to the ECM when the Fuel System is operating in Closed-loop mode. In normal configurations, one Oxygen sensor is positioned upstream (before the catalytic converter) and another Oxygen sensor is positioned downstream (after the catalytic converter). Comparing the signals of the sensors in both positions, the ECM can monitor the efficiency of the catalytic converter.

Operating Temperature

The output signal of an Oxygen sensor is only valid when the sensor has reached its operating temperature. The operating temperatures for a Narrow and a Wide range Oxygen sensor are 400°C (750°F) and 650°C (1200°F) respectively. To maintain its operating temperature, the sensor has a built-in heater, controlled by the ECM.

Narrow Range Oxygen Sensor

The narrow range Oxygen sensor is the oldest style and the less expensive sensor. It is the most widely used in present automobiles. It is called “narrow” because of

its highly nonlinear response. A typical Narrow Range Oxygen sensor response to the A/F is shown in Figure 4. Because of its ultra sharp transition around the ideal A/F, a Narrow Range Oxygen sensor only indicates if a mixture is lean or if it is rich. Therefore, in Closed-loop operation, the A/F will oscillate between rich and lean about the stoichiometric point. Because of this inaccuracy, these types of Oxygen sensors are not used for performance tuning of the air/fuel mixture.

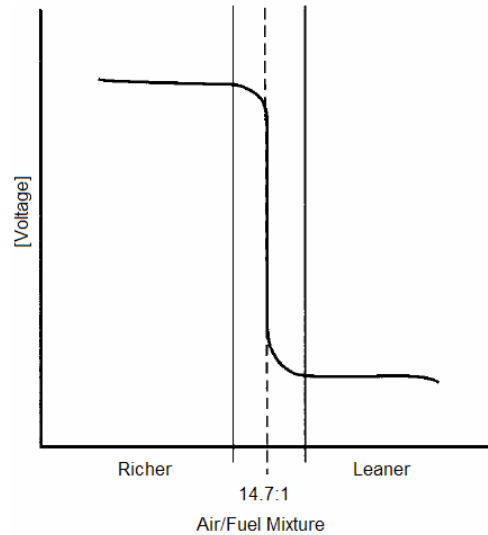


Figure 4: Narrow Range Oxygen Sensor Response

Wide Range Oxygen Sensor

The Wide Range Oxygen sensor is the new style sensor. It is also known as an A/F sensor for its ability to measure accurately the A/F. The Wide Range Oxygen sensor operates somewhat differently from the Narrow Range Oxygen sensor in the sense that the output signal is a current. A transimpedance amplifier converts the current signal into a voltage signal suitable for the ECM to read. The voltage sensor response to the A/F is depicted in Figure 5.

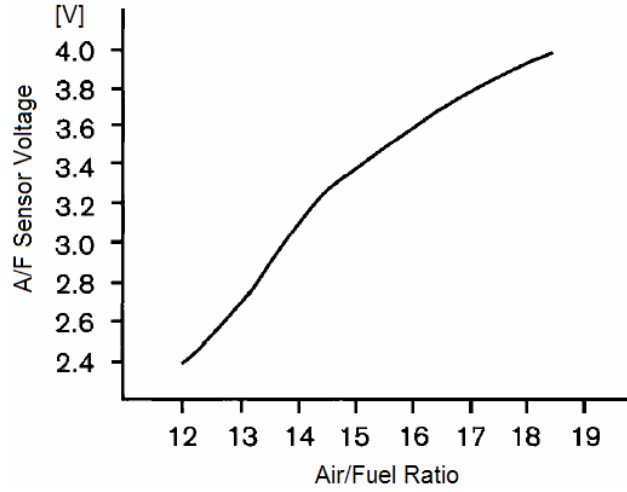


Figure 5: Wide Range Oxygen Sensor Response

Because of its quasi-linear response, the Wide Range Oxygen sensor may be used for performance tuning.

Fuel Trim

Because of the changing and the wearing of the engine the various sensors over time, as well as, the varying environment conditions, the ECM needs to adapt the injectors pulse duration to attain best performance and reduced emissions. A measurement of these compensations is the Fuel Trim. The Fuel Trim is expressed as a percentage relative to the base pulse duration.

Short Fuel Trim

The Short Fuel Trim (FT) is the small correction made to the base injector pulse duration at each cycle using the feedback of the Oxygen sensors. Therefore, it is only relevant when a Fuel System is in its Closed-loop mode. A positive Short FT value indicates that the mixture is lean and that the injector Pulse-width is increased. Conversely, a negative Short FT value indicates that the Air-Fuel mixture is rich and that the injector pulse width is decreased. Under normal operation, the Short FT will vary around a 0% mean and will remain within $\pm 20\%$.

Long Fuel Trim

The Long FT is the long term correction to the base injector pulse duration calculated using the fuel table. As soon as the ECM senses a considerable drift in the Short FT average (recurring correction for lean or rich Air-Fuel mixture), it changes the Long FT accordingly. Hence, the Short FT average returns to 0%. In simpler words, the Long FT is a positive or a negative offset value added to the base pulse duration. The Long FT is used for the fuel calculation even when the Fuel System is in its Open-loop operation. However, it can only be modified by the ECM once in Closed-loop operation. Unlike the Short FT, the Long FT is kept in the ECM's non-volatile memory and is therefore not erased when the ignition is turn-off. It is used during engine warm-up for the next driving cycle. Under normal operation, the Long FT value will vary between $\pm 10\%$. Its maximum range is from -25% to +25%.