Electronic petrol injection system (EPI)
Foreword
The electronic petrol injection (EPI) system ensures that the driver commands, e.g. acceleration, is translated into appropriate drive output of the spark ignition engine. It regulates all engine functions in such a way that the engine delivers the required level of torque yet achieving the best fuel consumption and exhaust emissions kept as low as possible.

The engine and emission control system is divided into 4 major sub-systems:
• Air intake system,
• Fuel delivery system,
• Electronic control system (covered in this training manuals)
• Emission control system.

Pre-requisites
GE02 Electrical / Electronics

Suzuki Technician curriculum

This training manual is part of the Non Suzuki Technician to Suzuki Technician curriculum. The curriculum consists of the following modules:

1. GE01 Suzuki Introduction
2. GE02 Electrical / Electronics
3. GE03 Diagnostics
4. EN02 Engine Mechanical part I
5. En03 Engine Mechanical part II
6. EN04 Engine Mechanical part III
7. EN05 Engine Auxiliary systems
8. DS01 Driveshaft/Axle
9. DS02 Driveshaft/Axle transfer case
10. BR02 Brake control systems
11. Manual transmission / transaxle
12. CS02 Control system / body electrical
13. CS03 Communication / bus systems

You are currently studying GE03 Diagnostics. This module consists of the following courses:

- Electronic Petrol Injection System
- EPI diagnostics [Practical activities]
Table of contents

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesson 1 – Introduction to EPI</td>
<td>4</td>
</tr>
<tr>
<td>Air/fuel ratio requirements of an engine</td>
<td>5</td>
</tr>
<tr>
<td>Functions of engine control</td>
<td>7</td>
</tr>
<tr>
<td>Intake air detection</td>
<td>7</td>
</tr>
<tr>
<td>Overview of control function</td>
<td>8</td>
</tr>
<tr>
<td>Fuel injection control</td>
<td>8</td>
</tr>
<tr>
<td>Ignition timing control</td>
<td>9</td>
</tr>
<tr>
<td>Idle speed control</td>
<td>9</td>
</tr>
<tr>
<td>EGR control</td>
<td>9</td>
</tr>
<tr>
<td>EVAP canister purge control</td>
<td>9</td>
</tr>
<tr>
<td>Fail safe function</td>
<td>9</td>
</tr>
<tr>
<td>Self diagnosis function</td>
<td>9</td>
</tr>
<tr>
<td>Engine inputs and functions overview</td>
<td>10</td>
</tr>
<tr>
<td>Engine control configuration</td>
<td>11</td>
</tr>
<tr>
<td>Intake air system</td>
<td>11</td>
</tr>
<tr>
<td>Fuel system</td>
<td>12</td>
</tr>
<tr>
<td>Ignition system</td>
<td>12</td>
</tr>
<tr>
<td>Exhaust system</td>
<td>13</td>
</tr>
<tr>
<td>Control system</td>
<td>13</td>
</tr>
<tr>
<td>Pulse Width Modulation (PWM)</td>
<td>15</td>
</tr>
<tr>
<td>Lesson 2 – Electronic control system</td>
<td>18</td>
</tr>
<tr>
<td>Sensors</td>
<td>19</td>
</tr>
<tr>
<td>IAT sensor</td>
<td>19</td>
</tr>
<tr>
<td>MAF sensor</td>
<td>21</td>
</tr>
<tr>
<td>MAP sensor</td>
<td>23</td>
</tr>
<tr>
<td>TP sensor</td>
<td>25</td>
</tr>
<tr>
<td>CKP sensor</td>
<td>28</td>
</tr>
<tr>
<td>CMP sensor</td>
<td>29</td>
</tr>
<tr>
<td>KS</td>
<td>32</td>
</tr>
<tr>
<td>ECT sensor</td>
<td>34</td>
</tr>
<tr>
<td>HO2S</td>
<td>36</td>
</tr>
<tr>
<td>Accelerator pedal position sensor</td>
<td>41</td>
</tr>
<tr>
<td>Barometric pressure sensor</td>
<td>43</td>
</tr>
<tr>
<td>A/C refrigerant pressure sensor</td>
<td>44</td>
</tr>
<tr>
<td>Brake switch</td>
<td>45</td>
</tr>
<tr>
<td>Power steering pressure switch</td>
<td>45</td>
</tr>
<tr>
<td>Electric load signal and current sensor</td>
<td>46</td>
</tr>
<tr>
<td>Vehicle speed sensor/signal</td>
<td>46</td>
</tr>
<tr>
<td>Actuators</td>
<td>47</td>
</tr>
<tr>
<td>Injectors</td>
<td>47</td>
</tr>
<tr>
<td>Throttle body</td>
<td>49</td>
</tr>
<tr>
<td>Idle air/speed control valve</td>
<td>52</td>
</tr>
<tr>
<td>Ignition coil</td>
<td>53</td>
</tr>
<tr>
<td>Oil control valve</td>
<td>54</td>
</tr>
<tr>
<td>Exhaust gas recirculation valve</td>
<td>55</td>
</tr>
<tr>
<td>Main relay</td>
<td>56</td>
</tr>
<tr>
<td>Abbreviations</td>
<td>58</td>
</tr>
</tbody>
</table>
Lesson 1

Introduction to EPI

The purpose of this lesson

This lesson introduces the basic principles of electronic petrol injection and engine management systems.

Learning outcomes

The contents of this chapter will enable learners to:

• Describe the three factors that influence engine performance.
• Explain the meaning of Air/Fuel ratio.
• Describe the effects of Air/Fuel ratio in engine performance with respect to power and economy.
• Describe the basic functions of engine control
• Explain the difference between EPI-D and EPI-L air detection techniques used in Suzuki EPI systems.
• Describe the basic engine control configuration functions.
• Name the inputs required for each engine control function.
• Explain what is meant by duty ratio.
1.1 Introduction

The factors that have an influence upon the performance of an engine, which is the heart of a vehicle, can be broadly divided into 3 elements:

- Good air/fuel mixture,
- Good compression and
- Good spark

In an engine, the atomized fuel mixes with air in proper ratio and produces an air mixture, subjected to proper compressive force and fires at proper timing. This process achieves the best out of an engine under various conditions of use and which is the prime purpose of an engine.

Out of these 3 elements, the role to produce a good air/fuel mixture is being taken over by an electronic-controlled fuel injection device from a carburetor, which is a device for mixing vaporized fuel with air.

SUZUKI, has given the name of EPI (a trademark) to this electronic-controlled device. The engine control system, including the fuel injection system, is also called the EPI system and the control unit is called the ECM (Engine Control Module).

EPI is an abbreviation for Electronic Petrol Injection.

1.2 Air/fuel ratio requirements of an engine

The air/fuel ratio of an air/fuel mixture is the ratio of the weight of air to fuel. The air/fuel ratio is one of the very important conditions to produce a good air/fuel mixture.

In figure 1 [Y] above, the fuel weight is represented by one black building block and air having the same weight of fuel is represented by one white building block. It is evident in this case that the weight ratio of the air to fuel, or in other words the air/fuel ratio, is 1:1.

Figure 1: [A] Air [F] Fuel

The air/fuel ratio of an air/fuel mixture is the ratio of the weight of air to fuel. The air/fuel ratio is one of the very important conditions to produce a good air/fuel mixture.

In figure 1 [Y] above, the fuel weight is represented by one black building block and air having the same weight of fuel is represented by one white building block. It is evident in this case that the weight ratio of the air to fuel, or in other words the air/fuel ratio, is 1:1.

Here, let us consider a gasoline engine. It will not be possible to have normal fuel combustion by producing an air/fuel mixture at this air/fuel ratio of 1:1. The reason is that more air is needed (minimum of 14.7 times in terms of mass ratio) for a complete combustion of fuel (petrol) to take place. The air/fuel ratio now becomes 14.7:1 (figure 1 [Z]). This air/fuel ratio is specially called "theoretical air/fuel. This ratio is also known as the stoichiometric ratio.
1.3 Air/fuel ratio at engine running conditions

The condition of an actual running engine undergoes changes from starting to low speed and to high speed, and from no-load to full load. For example, if you start a cold engine, the engine speed is still low and the compression temperature does not rise with the result that only a part of the fuel is vaporized. Therefore, a large quantity of fuel will be needed to produce a combustible air/fuel mixture. In other words, it will be necessary to supply a "rich" fuel mixture to run a cold engine.

The table below shows actual air/fuel ratio in different conditions.

<table>
<thead>
<tr>
<th>Driving condition</th>
<th>Air/Fuel ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold starting</td>
<td>1-5:1</td>
</tr>
<tr>
<td>Normal temperature starting</td>
<td>5 – 10:1</td>
</tr>
<tr>
<td>Low speed</td>
<td>14 – 15:1</td>
</tr>
<tr>
<td>Maximum output</td>
<td>12-13</td>
</tr>
<tr>
<td>Economy drive</td>
<td>16 – 17:1</td>
</tr>
</tbody>
</table>

1.4 Air/fuel ratio, engine output and fuel consumption

The relationship among the air/fuel ratio, engine output and fuel consumption in the figure 2 clearly shows that the air/fuel ratio highly affects the engine output and fuel consumption.

The ideal air/fuel setting over the everyday use region with partial load the air/fuel ratio should be the economy air/fuel ratio for an economy drive. Driving at full load region demands a high output, the air/fuel ratio is set to the output air/fuel ratio in order to get the maximum output.

Figure 2: Ratio between A/F & fuel consumption

[a] Output (Torque)
[b] Rate of fuel consumption
[A/F] Air/Fuel ratio
[A/F_0] Theoretical Air/Fuel ratio
[A/F_pow] Power Air/Fuel ratio
[A/F_clo] Economy Air/Fuel ratio
1.4 Functions of engine control

A microcomputer in the controller, used for the EPI control, performs overall control of an engine. In addition to controlling the fuel injection time, the controller also performs other engine controls that include the ignition timing control (ESA), idle speed control (ISC), exhaust gas recirculation (EGR) control.

1.4.1 Intake air detection

It is necessary to accurately detect the intake air volume in order to produce a proper air/fuel mixture in fuel injection control of EPI. Depending on the detection method of intake air volume, there are two techniques known as EPI-D and EPI-L techniques. "D" is an abbreviation for German language DRUCK (pressure) and "L" for LUFT (air). However, the service manuals do not classify these two techniques by using any special symbols inside the displays.

1.4.2 EPI-D technique (Speed density: Speed/air density detection technique)

In this EPI-D technique, pressure inside the air intake pipe and engine speed are detected, the ECM computes the intake air volume and determines the basic ignition time.

A semiconductor type pressure sensor detects the intake manifold absolute pressure. To this result is added a compensation factor corresponding to the intake air temperature and manifold absolute pressure in order to compute an accurate intake air volume.

1.4.3 EPI-L technique (Mass air flow: Airflow detection technique)

In this EPI-L technique, an airflow meter directly measures the engine intake air volume. The ECM determines the basic injection time that is based on the intake air volume of that time and engine speed.

In the potentiometer type air flow meter, ECM compensates the injection time according to the intake air temperature and hence more accurately computes the injection time.
As the hot wire type mass air flow sensor directly detects the mass of intake air flow, compensation is not needed regardless of intake air temperature and barometric pressure.

1.5. Overview of ECM control functions

The engine control functions include the functions to control the basic parts of an engine such as the fuel injection control, ignition timing control (ESA), idle speed control (ISC). Besides, the engine control function has other functions which operate in the event of failure of these controls. These functions include the following:

• Fail-safe function
• Back-up function
• Diagnosis function: It is useful at the time of repair.
• A function that allows to communicate the operating data with an outside diagnostic tool via the data link connector (DLC).

1.5.1 Fuel injection control (EFI: Electronic Fuel Injection)

Memory (ROM) in the ECM retains the fuel injection time equation and the optimum basic fuel injection time data (map) that corresponds to the engine states. The CPU in the ECM computes the most appropriate fuel injection time based on this data and from the signals of each sensor (intake mass air flow or manifold absolute pressure, engine speed, engine coolant temperature etc.,) to control the injectors.
1.5.2 Ignition timing control (ESA : Electronic Spark Advance)

Memory (ROM) in the ECM retains data on the optimum basic ignition timing that corresponds to the engine states. Based on this data and the signals (intake mass air flow or manifold absolute pressure, engine speed, engine coolant temperature etc.,) from each sensor, the CPU computes the most appropriate ignition timing and controls the ignition circuit.

1.5.3 Idle Speed Control (ISC)

The memory (ROM) in the ECM retains data on the target speed corresponding to the engine states. Based on the signals from each of the sensors (engine speed, engine coolant temperature, air-conditioner on/off etc.) the CPU controls the engine idle speed to obtain the target idle speed.

1.5.4 EGR control (EGR : Exhaust Gas Recirculation)

The memory (ROM) in the ECM retains the EGR operating conditions corresponding to the engine states. Based on the signals from the sensors (coolant temperature, engine speed etc.,) the CPU controls EGR to match the conditions.

1.5.5 EVAP canister purge control

The memory (ROM) in the ECM retains the purge condition of vaporized fuel corresponding to the engine states. The CPU performs the purge control matching those conditions, based on signals from the (engine speed, engine coolant temperature, vehicle speed etc.,) 

1.5.6 Fail-safe function

In order to prevent the engine from breaking down in the event of a trouble in the input and/or output signals of the ECM, the values are switched to the fixed values memorized in the memory (ROM). In the event of a major abnormality, the engine is stopped.

1.5.7 Self diagnosis function

In the event of an abnormality in the input/output signals of the ECM, the CPU detects the abnormality and memorizes in the memory (RAM) and, at the same time, sends a warning to the driver. The diagnosis codes that are related to normal operation are also set.
### 1.6 ECM Inputs & engine control functions

The tables below show the configuration of EPI sensors and actuators used by the ECM to control engine functions. *(Suzuki Kizashi A6B424)*

<table>
<thead>
<tr>
<th>Function</th>
<th>Output</th>
<th>Input</th>
</tr>
</thead>
</table>
| **Injection control** | Fuel injection | - Ignition mode status  
- Starter control status  
- ECT sensor  
- CKP sensor  
- CMP sensor  
- TP sensor  
- APP sensor  
- MAF sensor  
- IAT sensor  
- HO2S  
- Barometric pressure sensor  
- Battery voltage  
- Keyless start control module  
- Brake light switch  
- ESP® control module (wheel speed signal)  
- TCM (torque reduction request signal) (CVT model) |
| **Immobilizer control** | Fuel injection | - Ignition mode status  
- Starter control status  
- ECT sensor  
- CKP sensor  
- CMP sensor  
- TP sensor  
- APP sensor  
- MAF sensor  
- IAT sensor  
- Knock sensor  
- Barometric pressure sensor  
- Battery voltage  
- ESP® control module (wheel speed signal)  
- TCM (torque reduction request signal) (CVT model) |
| **Ignition control** | Ignition coil with igniter | - Ignition mode status  
- Starter control status  
- ECT sensor  
- CKP sensor  
- CMP sensor  
- TP sensor  
- APP sensor  
- MAF sensor  
- IAT sensor  
- Knock sensor  
- Barometric pressure sensor  
- Battery voltage  
- ESP® control module (wheel speed signal)  
- TCM (torque reduction request signal) (CVT model) |
| **Idle speed control** | Throttle actuator | - Ignition mode status  
- Starter control status  
- ECT sensor  
- CKP sensor  
- TP sensor  
- APP sensor  
- MAF sensor  
- IAT sensor  
- Barometric pressure sensor  
- Generator (field measured signal)  
- BCM (electric load signal and A/C ON request signal)  
- ESP® control module (wheel speed signal)  
- TCM (transmission shift position signal) (CVT model) |
| **Throttle valve control** | Throttle actuator | - Ignition mode status  
- Starter control status  
- ECT sensor  
- CKP sensor  
- TP sensor  
- APP sensor  
- IAT sensor  
- Barometric pressure sensor  
- BCM (electric load signal and A/C OFF / ON request signal)  
- ESP® control module (torque up/down request signal)  
- TCM (torque reduction request signal) (CVT model) |
| **Cruise control** | Throttle actuator | - Ignition mode status  
- Starter control status  
- ECT sensor  
- CKP sensor  
- TP sensor  
- APP sensor  
- IAT sensor  
- Barometric pressure sensor  
- Battery voltage  
- Cruise control switch  
- ESP® control module (wheel speed signal) |
| **Generator control** | Generator | - Ignition mode status  
- Starter control status  
- ECT sensor  
- CKP sensor  
- TP sensor  
- APP sensor  
- IAT sensor  
- Battery voltage  
- BCM (electric load signal)  
- ESP® control module (wheel speed signal) |
| **A/F sensor heater control** | A/F sensor | - Ignition mode status  
- ECT sensor  
- TP sensor  
- Battery voltage |
| **HO2S heater control** | HO2S | - Ignition mode status  
- ECT sensor  
- TP sensor  
- IAT sensor  
- Battery voltage |
1.7 Engine control configuration

1.7.1 Intake system

The intake system supplies air necessary to burn the fuel. The air which passed through the air cleaner is supplied to the engine after passing through the throttle body and surge tank. The intake system primarily incorporates the Idle Air Control (IAC) valve that regulates the idle engine speed and a fast idle control mechanism (if equipped) that regulates the engine idle speed in a auxiliary manner when the engine is cold. Some engines with rotary IAC valve or stepping motor IAC valve do not have fast idle control mechanism thanks to increase in controllable air flow.

![Figure 5: Denso intake air system](image-url)
1.7.2 Fuel system

The fuel pump is used to send fuel to the injectors under pressure. The fuel pressure applied on to the injectors is maintained at a pressure 200 to 300 kPa higher than the pressure inside the manifold by means of the pressure regulator. The quantity of fuel injection is controlled by the time the current flows through the injectors to turn on the injectors. The injectors spray the fuel inside the manifold for the ON time only under the control of the controller. There is an increase in the types of engines in which fuel is sequentially injected to individual cylinder thus replacing the simultaneous fuel injection system. Also, modularization of the fuel pumps has made progress. The modular unit includes the fuel pump, fuel filter, pressure regulator, 2-way valve, and fuel gauge. There is also Constant Pressure Injection (CPI) technique.

1.7.3 Ignition system

The ignition system is made up of ignition coil, igniter, distributor, and spark plugs. The ignition signal sent to the igniter from the ECM causes the spark plugs to fire a spark. The ignition confirmation signal is sent from the igniter to the ECM. In most current Suzuki EPI systems, the ignition systems employ Distributor-Less Ignition (DLI) type ignition system.

Figure 6(a): Fuel and EVAP system

Figure 6(b): DLI ignition system
1.7.4 Exhaust system

The exhaust system is made up of heated oxygen sensor installed in the exhaust manifold and three-way catalyst installed inside the exhaust pipe.

Since the three-way catalyst purifies all the three types of harmful components (CO, HC, NOx) present in the exhaust gases at the same time, it needs the heated oxygen sensor to demonstrate its performance. The EGR valve is installed in the intake manifold and admits a part of exhaust gases to the intake air. The EGR valve operates by receiving signals directly or indirectly from the ECM.

Figure 7: Exhaust system

1.7.5 Control system

The electronic control system consists of various sensors, switches, ECUs which detect the state of engine and driving conditions, and ECM which controls various electric control devices according to the signals from various sensors and various electric control devices.

Functionally, it is divided into the following subsystems:

- Fuel injection control system
- Ignition control system
- Electric throttle control system
- Fuel pump control system
- Radiator cooling fan control system
- Evaporative emission control system
- A/F sensor heater control system
- HO2S heater control system
- A/C control system
- Immobilizer control system
- Communication system among control modules

The ECM uses the CAN communication network to communicate with other control modules.
Figure 8: EPI control system (A6B424)
1.8 Pulse Width Modulation (PWM) signals

PWM signals are digital signals (square-wave signals) that have a constant frequency (Hz) but variable activation time. The pulse width is the duration of the active signal.

A **Duty cycle** is the ratio between the activation time and the deactivation time of a PWM signal and is expressed in percentages (%). The following terms are related to duty cycle:

- Duty ratio
- Duty operation
- Duty waveform
- ON duty (ratio)
- OFF duty (ratio)
- High duty (ratio)
- Low duty (ratio)
- Duty tester reading

1.8.1. Duty ratio

If we look at the signal in figure 9, the signal is ON for half a second, and OFF for the remainder of the second. When this is expressed as duty ratio, it would be 50%. If the signal was ON for 0.25 of a second and OFF the remainder of the second, the duty ratio would be 25%.

1.8.2 Duty waveform

In an electronic control, a voltage or current waveform that repeats periodically between high (Hi) and low (Lo) values, as shown in the figure, is called a "duty waveform".
1.8.3 ON duty, OFF duty, Hi duty, Low duty

In a circuit that undergoes a duty operation, the percentage of time a current is passed through the load is "ON duty ratio", and the percentage of time a current does not pass through the load is "OFF duty ratio".

Let us consider potentials at a point where the duty waveform can be viewed (for example, point P of Figures 11 (A) and (B)) in a circuit undergoing the duty operation. The percentage of time a duty waveform is "high" is called a "Hi duty ratio", and the percentage of time the duty waveform is "low" is called a "Lo duty ratio".

In Figures (A) and (B), let us consider the relationship between ON/OFF duty focusing on the load operation, and between the Hi/Lo duty paying attention to the potential at point P.

In Figure (A), the potential at point P is Lo (0V) when the transistor is ON. Therefore, the ON duty becomes equal to the Lo duty in the circuit of Figure (A).
Conversely, the potential at point P in figure B is Hi (+12V) when the transistor is ON. Therefore, the ON duty becomes equal to the Hi duty in the circuit of figure (B). This is how the relationship between the ON duty, OFF duty and between Hi duty, Lo duty is different depending on the circuit configuration.

Figure 11: Duty waveform

[T] One Duty cycle
[L] Load
[P] Measuring point using oscilloscope
[Hi] Voltage at point P is high (12V)
[Lo] Voltage at point P is low (0V)
Summary

• The three factors that influence engine performance are good air/fuel mixture, good compression, and good spark.
• The ideal theoretical air/fuel mixture is 14.7:1. This means, 14.7 parts of air mixed with 1 part of fuel.
• Actual air/fuel mixture fluctuates according to the engine operating conditions and driver requirements.
• The two types of intake air detection techniques are EPI-D and EPI-L techniques.
• In the EPI-D technique, a MAP sensor is used to detect the pressure in the intake manifold.
• In the EPI-L technique, a MAF sensor is used to detect the mass of air flow into the intake.
• The ECM controls five engine sub-systems, the: intake system, fuel system, ignition system, exhaust system, and control system.
• The ECM uses inputs from different sensors and switches to control functions that enable the engine to operate efficiently in all conditions.
• A duty ratio is the ratio of the ON and OFF times of a PWM signal. Some actuators such as the stepper motor are controlled via duty cycles.
Lesson 2

Electronic control system

The purpose of this lesson
In this lesson, we will study the electronic control system of the Suzuki electronic petrol injection (EPI) system.

Learning outcomes

The contents of this lesson will enable the learners to:
• Describe the basic tasks and functions of sensors used in the EPI system
• Describe the basic tasks and functions of switches used in the EPI system
• Describe the operating principles of each of the sensors used in the EPI system.
• Describe the basic electrical data for each of the sensors used in the EPI system.
• Describe the basic operating principles ECM controlled actuators.
2.1 Sensors

The engine control module (ECM) is the heart of the engine management system. Inputs and outputs are connected to the ECM. The ECM controls the outputs based on the signals received from the inputs.

The following sensors form part of the inputs used in Suzuki EPI systems.

- Intake Air Temperature sensor (IAT)
- Mass Air Flow sensor (MAF)
- Manifold Absolute Pressure sensor (MAP)
- Throttle Position sensor (TP)
- Camshaft Position sensor (CMP)
- Crankshaft Position sensor (CKP)
- Knock sensor (KS)
- Engine Coolant Temperature sensor (ECT)
- Air/Fuel sensor (A/F)
- Heated exhaust gas oxygen sensor (HO2S)
- Accelerator Pedal Position sensor (APP)
- A/C refrigerant pressure sensor
- Brake switch
- PSP switch
- Electric load current sensor

Intake Air Temperature (IAT) sensor

Task and function

The intake air temperature sensor is used for the detection of intake air temperature. The intake air temperature signal is used by the ECM to control amongst other functions the:

- Calculation of intake air mass since density of air changes with temperature.
- Oxygen sensor heater control
- Fuel Injection, ignition, idle speed and throttle valve control functions.

Depending on the type of engine management system, the IAT can be installed as a stand-alone component or integrated in the Mass Air Flow sensor assembly.

![Figure 2: IAT sensor installation position (AMF310)](image)

[1] Intake Air Temperature (IAT) sensor
[2] Intake air pipe
Operating principle
The IAT sensor operates according to the NTC principle. It incorporates a thermistor. Changes to intake air temperature are detected by corresponding changes to the resistance of thermistor. The lower the intake air temperature, the higher is the resistance of thermistor, and conversely, higher the temperature, the lower is the resistance.

Figure 3 below shows the characteristics curve of the IAT sensor.

The IAT (2) is connected to the ECM as shown in figure 4 below. In this case, the IAT is integrated in the MAF, but it has its own circuitry and can be tested independently from the MAF.

Service note:
When the IAT sensor is integrated in the MAF sensor assembly, the IAT sensor cannot be renewed separately, renew MAF sensor assembly in the event of fault in the IAT sensor.
Electrical data for IAT

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference voltage</td>
<td>5V</td>
</tr>
<tr>
<td>Sensor type</td>
<td>Thermistor</td>
</tr>
<tr>
<td>Signal type</td>
<td>Analog DC Voltage</td>
</tr>
<tr>
<td>Signal range</td>
<td>0.4 V – 4.6V</td>
</tr>
<tr>
<td>Resistance range</td>
<td>13.6 - 18.4 kΩ at -20ºC</td>
</tr>
<tr>
<td></td>
<td>2.21 - 2.69 kΩ at 20ºC</td>
</tr>
<tr>
<td></td>
<td>0.439 - 0.667 kΩ at 60ºC</td>
</tr>
</tbody>
</table>

Task and function

The MAF detects the intake air flow in the unit of gram/sec. This signal is used by the ECM for the following functions:

- Fuel injection control
- Ignition control
- Idle speed control

Figure 5: MAF mounting position (A6B424)

[1] MAF sensor (integrated IAT)
[2] Air cleaner housing
[3] MAF sensor mounting screws
Operating principle

The MAF sensor consists of heat resistor, control circuit, metering duct and straightening net. The heat resistor is an element used for the detection of air flow. The control circuit in the MAF sensor controls the heat dissipation (current flow to the heat resistor) to keep the heat resistor at a constant temperature, outputs this control value as a voltage signal, and measures the air intake flow on MAF sensor.

The source voltage is supplied to the airflow meter via the main relay. If intake air flow changes, the voltage at terminal MAF will change.

When a hot wire energized with a constant current (resistance wire heated by a current to a high temperature (200°C above IAT) is placed in the air flow channel, its heat is absorbed by the air flow and the temperature of the hot wire is reduced (heat is absorbed by the air). The less air flow, the less heat is dissipated (absorbed) from the hot wire and the more air, the more heat is dissipated to the hot wire. Therefore, if the temperature of the hot wire is maintained constant by regulating the amount of electric current flowing to the hot wire, the amount of air flow (intake air) can be measured by the amount of flowing current, for the amount of current corresponds to that of the intake air.

The hot wire temperature is detected by the circuit in which the hot wire and reference resistor are connected. Also, as the hot wire temperature is affected by the air temperature, the intake air temperature is detected by the circuit in which the cold wire and reference resistor are connected so as to compensate the changes in hot wire temperature. And by putting these two circuits in the bridge structure, the current flowing to the hot wire is regulated and corresponds to the amount of the intake air and thus the hot wire temperature is kept constant. Then the current flowing to the hot wire, as a voltage signal, is transmitted to ECM. As it corresponds to the amount of the intake air as described above, the voltage rises higher as the air flow increases.

Figure 6: MAF (hot wire type)

[1] Air temperature sensor
[2] Hot wire
[3] Air bypass duct
**MAF sensor signal characteristics curve**

![Graph of MAF characteristics curve]

**Electrical data for MAF**

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply/reference V</td>
<td>12V or 5V</td>
</tr>
<tr>
<td>Sensor principle</td>
<td>Hot film principle</td>
</tr>
<tr>
<td>Signal type</td>
<td>DC Voltage</td>
</tr>
<tr>
<td>Signal range</td>
<td>0.1 – 4.5 V</td>
</tr>
</tbody>
</table>

**Manifold Absolute Pressure (MAP) sensor**

**Task and function**

The MAP sensor measures the absolute pressure inside the intake manifold. A transistorized pressure transducer inside the MAP sensor makes use of a property in which the electrical resistance changes with pressure (piezo-resistance effect). A MAP sensor is normally installed on the intake manifold as shown in figure 8.

![Figure 8: MAP sensor location (AZH412)](image)

[1] MAP sensor
[2] Intake manifold
Operating principle

Manifold absolute pressure is guided to the sensor. Vacuum is always maintained inside the sensor unit. A silicon chip is installed on a shielded wall with the intake manifold pressure chamber. When the air intake pressure acts on the sensor at the silicon chip, the silicon chip receives stress that is the pressure difference with respect to the vacuum chamber. It changes the resistance of the silicon chip. This change of resistance in the silicon chip is converted into voltage change, amplified and output to the ECM. The output voltage becomes proportional to the manifold absolute pressure. The pressure detected by MAP sensor is absolute pressure with respect to absolute vacuum. Meanwhile, 5V power is supplied to the MAP sensor for amplifier in the sensor. This signal is primarily used for computing the basic injection time and ignition timing. The MAP sensor is connected to the ECM as shown in figure 9.
This MAP sensor signal value indicates how much correction is necessary to keep the air/fuel mixture stoichiometric. The signal from the MAP sensor is used by the ECM to control the following functions:
- Injection control
- EVAP purge control
- Ignition control
- HO2S heater control
- Idle speed control

### Electrical data for MAP sensor

*(Reference: AMF310)*

<table>
<thead>
<tr>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supply voltage</strong></td>
</tr>
<tr>
<td><strong>Sensor principle</strong></td>
</tr>
<tr>
<td><strong>Signal type</strong></td>
</tr>
<tr>
<td><strong>Signal range</strong></td>
</tr>
</tbody>
</table>

---

**Throttle Position (TP) sensor**

**Task and function**

The throttle position sensor is located on the throttle body housing and is used to detect the opening of the throttle valve. The throttle position signal detected by TP sensor is primarily used in the power enriching compensation, a synchronous injection at acceleration, and advancing compensation at acceleration.

The ECM also uses the signals from the TP sensor to control the following functions: Injection control, Ignition control, Idle speed control, Throttle valve control, HO2S heater control, EVAP purge control and VVT control.

---

Figure 11: TP sensor (with idle switch)
Operating principle

The TP sensor is a potentiometer. It consists of a strip of resistor with variable resistance values. The ECM sends reference voltage to this resistor. The movable contacts that are linked with the throttle shaft move on the resistive body. This mechanism makes it possible to obtain output voltage according to the throttle valve opening. Regarding changes in the output voltage, the larger the opening of throttle valve, the higher becomes the output voltage.

TP sensor with idle switch

This type of throttle sensor is made up of 2 movable contacts (for throttle opening signal and for idle signal) linked to the throttle valve, resistive body printed on a board, and 4 terminals. The idle switch signal is related to various controls. It is one of the implementation conditions of the control of a synchronous injection, fuel cut, ISC etc.

Voltages near 0V and 5V are not output since these voltages are used for detection of abnormality in TP sensor circuit.

TP sensor without idle switch

In the recent models, idle switch is not equipped. In this type, some other methods are used to identify the idle state such as the throttle full-close learning value, air intake flow learning value at idle, coolant temperature, vehicle speed and so on.

TP sensor with two signal outputs

In some engine management systems, the TP sensor has two resistance tracks to ensure highly accurate and reliable control of the throttle valve.

This type of sensor produces two signals of different ranges to the ECM. The signals are usually named the “main” and the “sub” signals.
Characteristics curve of the double signal TP sensor.

The TP sensor is connected to the ECM as shown in the circuit diagram below. (single signal output type shown)

### Electrical data for TP sensors

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference voltage</td>
<td>5V</td>
</tr>
<tr>
<td>Sensor principle</td>
<td>Potentiometer</td>
</tr>
<tr>
<td>Signal type</td>
<td>DC voltage</td>
</tr>
<tr>
<td>Signal range</td>
<td>0.3 V – 4.7 V</td>
</tr>
</tbody>
</table>
Crankshaft Position (CKP) sensor

Task and functions
The CKP sensor is mounted directly opposite a pulse wheel mounted on the crankshaft or on the crankshaft pulley. As the pulse wheel rotates, the teeth and the gaps pass the tip of the CKP sensor causing a change in the magnetic flux in the sensor. This changes of the magnetic flux results in generation of a signal which is used by the ECM to calculate engine speed, and based on the signal from the CMP and CKP, the ECM judges which cylinder piston is in the compression stroke.

Operating principles

Inductive CKP sensor
This sensor is made of a magnet and a coil and placed at a specified air gap between the sensor tip and the pulse wheel. As the pulse wheel rotates in-front of the sensor tip, AC voltage is generated by the inductive CKP sensor. The inductive type CKP sensor does not require a reference voltage supply. An electromotive force is generated in the sensor coil as the magnetic field builds-up and collapses around the coil. This sensor produces a sinusoidal wave pattern.
Active CKP sensor
The active type CKP sensor has a built-in hall element. The hall element converts changes in the magnetic flux caused by rotation of the sensor plate into digital electric pulse signals. The amplitude of the output signal is not dependent on the rotational speed of the pulse wheel. This makes it possible for very low speeds to be sensed.

Crankshaft Position (CMP) sensor
Task and function
The CMP sensor located on the cylinder head consists of signal generator (magnetic sensor) and signal rotor (fixed to the camshaft). The signal generator generates reference signal by teeth on the signal rotor which turns together with the camshaft. Based on CMP sensor signal and CKP sensor signal, ECM judges which cylinder piston is in the compression stroke.
Operating principle

The CMP sensor has a built-in hall element (element which generates voltage from changes in magnetic flux) and a wave forming circuit. A toothed sensor rotor is mounted on the camshafts and rotates together with the camshaft. The CMP sensor is positioned in-front of the toothed sensor rotor.

Figure 19. CMP sensor & camshaft signal rotor configuration

Figure 19
[a] CMP sensor is opposite of signal rotor (Output voltage = 0V)
[b] Projection of signal rotor away from CMP sensor (Output voltage = 5V)

Figure 20. CMP and CKP signal pattern (AZH412)

[1] Exhaust CMP sensor signal
[2] Intake CMP sensor signal
[3] CKP sensor signal
The CKP and CMP sensors are connected to the ECM as shown by the circuit diagram below.

![Circuit Diagram](image)

**Figure 21. CKP and CMP circuit diagram (A6B424)**

- [1] CMP sensor
- [2] CKP sensor
- [3] ECM
- [4] CMP signal rotor
- [5] CKP sensor plate

<table>
<thead>
<tr>
<th>Sensor principle</th>
<th>Inductive or Hall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>12V (Hall type)</td>
</tr>
<tr>
<td></td>
<td>No supply voltage (Inductive type)</td>
</tr>
<tr>
<td>Signal type</td>
<td>Square wave digital signal (Hall type)</td>
</tr>
<tr>
<td></td>
<td>Analog AC voltage (Inductive type)</td>
</tr>
<tr>
<td>Signal range</td>
<td>Dependent on speed (Inductive type)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value</th>
<th></th>
<th>Value</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor principle</td>
<td>Inductive or Hall</td>
<td>Supply voltage</td>
<td>12V (Hall type)</td>
</tr>
<tr>
<td></td>
<td>No supply voltage (Inductive type)</td>
<td>Signal type</td>
<td>Square wave digital signal (Hall type)</td>
</tr>
<tr>
<td></td>
<td>Analog AC voltage (Inductive type)</td>
<td>Signal range</td>
<td>Dependent on speed (Inductive type)</td>
</tr>
</tbody>
</table>
Knock Sensor (KS)

Task and function
The knock sensor is installed directly on to the cylinder block. It detects the vibrations generated due to engine knocking that are transmitted to the cylinder block. The signal from the knock sensor is used by the ECM for ignition control.

Operating principles
The knock sensor (resonant type sensor) is composed of a vibration plate of resonant frequency that is almost the same as the knock vibration frequency (6 kHz to 8 kHz) and a piezo electric element that detects vibrations of the vibration plate, and converts them into electrical signals.

At the time of knocking, the vibration plate resonates and produces high voltages. For protection of engine when knocking is detected, the ignition timing is controlled for as early ignition timing as possible by retarding the ignition timing over the range where knocking does not occur.
The knock sensor signal waveform, shown in figure 24, is the sensor output when an impact is given to the cylinder block by using a hammer at engine stop.

The KS is connected to the ECM as shown in the circuit diagram below.

![Circuit Diagram]

**Figure 25: Knock sensor circuit diagram**

- [1] Knock sensor
- [2] Shield wire
- [3] ECM
- [A1] Knock sensor signal circuit
- [A2] Knock sensor ground circuit

**Electrical data for the KS**

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>None</td>
</tr>
<tr>
<td>Sensor principle</td>
<td>Piezo effect</td>
</tr>
<tr>
<td>Signal type</td>
<td>mV</td>
</tr>
<tr>
<td>Signal range</td>
<td>Increases as engine knock increases</td>
</tr>
<tr>
<td>Frequency</td>
<td>4KHz – 18KHz</td>
</tr>
</tbody>
</table>
Engine Coolant Temperature (ECT) sensor

Task and function
Mounted on the coolant passage, the engine coolant temperature sensor is used to detect the temperature of the engine coolant. The ECM uses the signal from the ECT sensor to control amongst other functions, fuel injection, Ignition control, Idle speed control, throttle valve control, generator control, heater elements of the oxygen sensors, VVT, A/C compressor, Radiator cooling fan control and EVAP purge control.

Operating principle
The ECT sensor has a built-in thermistor. Its resistance undergoes a rapid change with the coolant temperature change therefore the change in temperature of the coolant is detected by change in resistance of the thermistor. The resistive characteristic is different from that of a conductive metal. In conductive metals, the resistance rises as the material temperature rises and its resistance does not undergo a rapid change. A thermistor therefore is suitable to detect temperature changes. The temperature signal is also used in the warming-up enriching compensation and engine coolant temperature compensation of ignition timing in order to improve drivability when cold.

Figure 26: ECT location (AMF310)

Figure 27: Characteristics curve of the ECT (AMF310)

[a] Resistance of ECT thermistor
[b] Temperature of ECT thermistor
The ECT is connected to the ECM as shown in the circuit diagram below.

**Electrical data of the ECT**

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference voltage</td>
<td>5V</td>
</tr>
<tr>
<td>Sensor principle</td>
<td>Thermistor</td>
</tr>
<tr>
<td>Signal type</td>
<td>Voltage</td>
</tr>
<tr>
<td>Signal range</td>
<td>0.4 V @100°C – 3.8 V @ 0°C</td>
</tr>
<tr>
<td>Resistance</td>
<td>See figure 26</td>
</tr>
</tbody>
</table>

![ECT circuit diagram](image)

**Figure 28: ECT circuit diagram**

Heated Oxygen Sensor (HO2S)

Task and function
The heated oxygen sensor is used for the detection of oxygen concentration in the exhaust gases. The oxygen sensors are installed in the exhaust system. The signal from the oxygen sensor installed upstream of the catalytic converter (also known as air/fuel (A/F) sensor) is used by the ECM to maintain the air fuel ratio to the theoretical value of 14.7:1.

Operating principle
Inside the sensor is a zirconia element in the shape of a test tube with both surfaces coated with platinum. The zirconia element has a characteristic to generate an electromotive force when there is a difference in oxygen concentration on its two surfaces.

Figure 28
[1] Sensor housing
[2] Ceramic support tube
[3] Electrical connection
[4] Protective with slots
[5] Active sensor ceramic
[6] Contact element
[7] Protective sleeve
[8] Heating element
[9] Clamp type connection for heating element

Figure 29: HO2S

Figure 30: HO2S sensor tip

[1] Zirconia element/Ceramic element
[2] Exhaust side platinum electrode
[4] Exhaust gas
[6] Electromotive force

The inside of the sensor is exposed to the atmosphere (5) and is filled with air (air contains 21% oxygen) and the outside of the sensor tip is exposed to exhaust gases. The Zirconia or Ceramic element is a solid state electrolyte. When the difference in oxygen content in the two sides of the electrolyte is large, the EMF generated will be large.
When the oxygen concentration on both sides of the electrolyte is small, the EMF generated will be very small.

**Heating element**

The electrolyte element (Zirconia or ceramic elements) is conductive for oxygen ions from a temperature of approximately 350°C. The temperature of the element influences its ability to conduct the oxygen ions and thus the shape of the output-volt curve as a function of the excess-air factor. The response times at ceramic temperatures below 350°C are in the seconds range, at optimum temperatures of around 600°C the sensor responds in less than 50ms. When the engine is starter therefore, the Lambda control is switched off until the minimum operating temperature of about 350°C is reached. During this period, the engine is open loop controlled. The heated oxygen sensor is fitted with a heater element that assists in increasing the temperature of the ceramic element quickly.

**Lambda (λ)**

Lambda is a mathematical calculation representing air/fuel ratio. The figure is derived by dividing air/fuel ratio of the engine by the theoretically correct value of 14.7:1.

\[
\text{Actual A/F ratio} = \frac{14.7 : 1}{14.7 : 1} = 1
\]

Rich mixture produce Lambda values that are below 1 (λ <1)
Lean mixtures produce Lambda values above 1 (λ >1)

**Rich mixture**

The oxygen content in the exhaust gas is approx. 0%, the voltage generated is approx. 900mV

**Lean mixture**

The oxygen content in the exhaust gas is approx. 4%, the voltage generated is approx. 100mV

**Normal mixture**

The oxygen content in the exhaust gas is approx. 1%, the voltage generated is approx. 450mV
The oxygen sensor produces a wave form as shown in figure 31.

The oxygen sensor is connected to the ECM as shown in the circuit diagram below.

**Broadband oxygen sensor**

Up until this point, we have described the basic operation of the Two-step Lambda oxygen sensor. There is also a wide-band Lambda oxygen sensor which is used across a very extensive range to determine the oxygen concentration in the exhaust gases. The wide-band/broadband sensor makes precise measurements not only at the stoichiometric point where Lambda = 1, but also in the lean range and in the rich range.

**General operation**

- The zirconia element generates the electromotive force depending on the oxygen concentration difference between the detection chamber and the oxygen reference chamber.
- ECM controls the intensity and the direction of the pump current to zirconia element so as to maintain the certain voltage between both electrodes of zirconia element (between “LFUN” and “LFVM” terminals).
  
  In other words, ECM intends to maintain the oxygen concentration to a specified value in the detection chamber via the pump current in order to generate the electromotive force of zirconia element at specified value.
- ECM calculates the A/F ratio in the exhaust emission by the intensity and the direction of the pump current.
At the lean state, the exhaust emission contains a large amount of oxygen. At this state, ECM calculates the A/F ratio as follows.

- As the exhaust emission enters the detection chamber, the electromotive force generated by zirconia element is reduced.

- ECM intends to reduce the oxygen concentration in the detection chamber to a specified value via the pump current in order to generate the electromotive force of zirconia element at a specified value. (The oxygen ion flows from the detection chamber to the zirconia element.)

- ECM calculates the A/F ratio by the intensity and the direction of the pump current.
At the rich state, the exhaust emission contains a small amount of oxygen. At this state, ECM calculates the A/F ratio as follows.

- As the exhaust emission enters the detection chamber, the electromotive force generated by zirconia element is increased.
- ECM intends to increase the oxygen concentration in the detection chamber to a specified value via the pump current in order to generate the electromotive force of zirconia element at a specified value. (The oxygen ion flows from zirconia element to the detection chamber.)
- ECM calculates the A/F ratio by the intensity and the direction of the pump current.

The pump current is proportional to the exhaust-gas oxygen concentration and at lambda 1, pump current is 0mA.

---

**Electrical data for HO2S**

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supply voltage</strong></td>
<td>12V (Heater element)</td>
</tr>
<tr>
<td></td>
<td>12V (Broadband HO2S sensor element)</td>
</tr>
<tr>
<td></td>
<td>No supply voltage for two-step HO2S sensor element</td>
</tr>
<tr>
<td><strong>Sensor principle</strong></td>
<td>Galvanic principle</td>
</tr>
<tr>
<td><strong>Signal type</strong></td>
<td>Voltage (two-step HO2S)</td>
</tr>
<tr>
<td></td>
<td>mA (broadband HO2S)</td>
</tr>
<tr>
<td><strong>Signal range</strong></td>
<td>0.1V to 1.0V (two-step HO2S)</td>
</tr>
<tr>
<td></td>
<td>-0.1mA to 0.10mA (idle speed AMF310)</td>
</tr>
<tr>
<td><strong>Resistance</strong></td>
<td>Approx. 5 – 6.4Ω @ 20°C</td>
</tr>
</tbody>
</table>

---

**Figure 36: Broadband sensor pump current**
Accelerator Pedal Position (APP) sensor

Task and function
The APP sensor is installed in vehicles equipped with the electric throttle control system. The APP sensor measures the position of the accelerator pedal. The ECM uses the APP sensor signal and other engine operating conditions to calculate the optimum throttle valve opening. The APP sensor has two sensors (main and sub) to ensure highly accurate and reliable control of the throttle valve.

Operating principle
The APP sensor has a built-in potentiometer. The resistance track is supplied with a reference voltage and ground. As the pedal is being depressed, a wiper moves across the face of the resistance track. When the APP is at rest (idle) position, the wiper is on the greater side of the resistor and thus the signal voltage is low. When the accelerator pedal is fully depressed, the wiper is on the smallest part of the resistor and thus the signal voltage is high. The main sensor and the sub sensor of the APP always produce signals of different ranges.

Signal voltage is low. When the accelerator pedal is fully depressed, the wiper is on the smallest part of the resistor and thus the signal voltage is high. The main sensor and the sub sensor of the APP always produce signals of different ranges.

Figure 36: APP sensor

Figure 37: APP sensor main & sub output voltages (AZH414)

[a] APP sensor, main
[b] APP sensor, sub
[c] Voltage output
[d] Accelerator pedal, idle position
[e] Accelerator pedal, fully depressed position
The APP sensor is connected to the ECM as shown in the circuit diagram below.

Service note:

- When the APP sensor is replaced, perform calibration of the throttle valve position.

Electrical data for APP sensor

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>5V</td>
</tr>
<tr>
<td>Sensor principle</td>
<td>Potentiometer</td>
</tr>
<tr>
<td>Signal type</td>
<td>Voltage</td>
</tr>
<tr>
<td>Signal range</td>
<td>Main: 0.7V – 3.85V</td>
</tr>
<tr>
<td></td>
<td>Sub: 0.33V – 2.0V</td>
</tr>
<tr>
<td>(A6B424 data)</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 38: APP sensor circuit diagram (A6B424)

[A1] APP sensor, main, power supply circuit
[A2] APP sensor, main, signal circuit
[A3] APP sensor, main, ground circuit
[B1] APP sensor, sub, power circuit
[B2] APP sensor, sub, signal circuit
[B3] APP sensor, sub, ground circuit
[1] APP Main sensor
[2] APP Sub sensor
[3] Sensor shield
[4] ECM
Barometric Pressure sensor (BARO)

Task and function
The barometric pressure sensor is located inside the engine control module, measures the atmospheric pressure and is used for altitude correction of the fuel injection quantity.

At sea level, the atmospheric pressure is 101.325 KPa. The atmospheric pressure at high altitudes is lower than at sea level, therefore the ECM must maintain optimum operation of the engine at different altitudes. The ECM uses the barometric pressure sensor signal to control functions such as; Idle speed control, throttle valve control, ignition control and fuel injection control.

Operating principles
The measurement principle is based on four piezo-resistors located on a membrane which are connected to a Wheatstone bridge. Beneath the membrane a thin cavity encloses vacuum. The applied barometric pressure leads to a deflection of the membrane which causes a change in the resistors’ value. The resulting signal is amplified and temperature compensated by an electronic circuit which is integrated on the same chip with the sensor element.

Service note:
In Suzuki vehicles, the barometric pressure sensor is integrated in the engine control module housing and can not be renewed or tested separately. The ECM must be renewed in the event of faults.

Figure 39: Barometric pressure sensor
A/C refrigerant pressure sensor

Task and function
The function of the A/C pressure sensor is to detect the pressure in the air-conditioning refrigerant lines. When the air-conditioning is turned on, the compressor starts running and the engine load increases. The pressure in the air-conditioning lines also increase. The ECM uses the signal from the pressure sensor to control the radiator cooling fan and the A/C compressor.

The A/C pressure sensor is connected to the ECM as shown in the circuit diagram below.

The A/C pressure sensor produces a voltage signal (A) which increases as the pressure in the refrigerant line (B) increases, as shown in figure 39.

![Figure 41: A/C refrigerant pressure sensor signal (A6B424)](image)
Brake switch

Task and function
The brake switch is installed on the brake pedal assembly and functions as an ON/OFF switch. When the brake pedal is depressed, the contacts in the brake switch close, allowing current to flow to the ECM. The ECM uses this information to control functions such as fuel injection, cruise control and the OCV of the VVT.

Figure 40 below shows an example of how the brake switch is connected to the ECM.

Power Steering Pressure (PSP) switch

Task and function
Power steering pressure switch is installed on the power steering pump body. When the steering wheel is turned and the oil pressure in the pump exceeds the specified value (depending on the vehicle), the pressure switch is turned ON and the signal is sent to ECM. The ECM uses this signal as one of the information used for controlling idle speed. Generally, ECM increases bypass air flow when ECM receives PSP switch signal to prevent drop in engine idle speed due to increase in engine load when the power steering pump is operating. The PSP switch is connected to the ECM as shown in the circuit diagram below. In some engine management systems, the signal is sent to the ECM via CAN.

Figure 43: Brake switch circuit (A6B424)
Electric load signal & current sensor

Task and function
When the electric load such as blower fan, headlights (position lamps), rear defogger is operated, the electric load signal slightly increases the bypass air flow via IAC valve and prevents the drop in the idle speed. In vehicles with electronically controlled throttle valve, the ECM performs idle speed control via the throttle actuator. Depending on the engine management system, the ECM also controls the alternator based on the electric load signal. The ECM receives information on the electrical load from the BCM via CAN. In some models, an electric load current sensor is installed on the negative terminal of the battery. This sensor measures the actual current consumption of the vehicle’s electrical system and the ECM uses this information to control the generator.

Vehicle speed sensor

Task and function
The vehicle speed signal is sent to the ECM by the vehicle speed sensor. In vehicles equipped with ABS/ESP, the vehicle speed signal is sent to the ECM by the ABS/ESP control module based on inputs from wheel speed sensors. The vehicle speed signal is used by the ECM for (depending on the engine management system): fuel injection control, Ignition control, Idle speed control, throttle valve control, cruise control, alternator control, EVAP purge control and the A/C compressor control.

Operating principle
- Inductive
- Hall effect

Figure 44: Electric load current sensor [1]
2.2 Actuators

In the EPI system, the signals from the inputs (sensors and switches) are used to control engine functions by controlling actuators. The actuators controlled by the ECM include:

- Fuel injectors
- Ignition coils
- Throttle actuator
- HO2S heater
- ISC valve
- EGR valve
- IMT valve actuator
- A/C compressor relay
- Radiator cooling fan relay
- Main relay
- Fuel pump relay

### Fuel Injectors

**Task and function**

Fuel injectors are used for atomizing and precise metering of the quantity of fuel required by the engine for combustion. Fuel injectors used in Suzuki vehicles are electromagnetic (solenoid-controlled) fuel injectors. Figure 1 below shows an example of a fuel injector.

![Fuel Injector Diagram]

**Figure 1: Fuel injector**

[1] Filter  
[2] Solenoid coil  
[3] Ball valve  
Operating principle

Voltage is applied to the injector coil, based on the injection signal computed by ECM, and energizes the coil. Plunger and needle valve are attracted to the coil and the fuel is injected. The amount of needle movement is constant at this time. As for the injector operation, there are only two phases:

- fuel injection by the valve fully open and
- No injection by the valve fully closed.

Since the aperture area and fuel pressure applied on to the injectors are constant, the amount of injection is determined by the time the needle valve is open i.e., the time for which the current is applied to the coil.

![Fuel injector circuit](image)

Figure 2: Fuel injector circuit (A6B424)

|------------------|--------------------------------------|

**Electrical data for injectors (solenoid type)**

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
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<tbody>
<tr>
<td>Supply voltage</td>
<td>12V</td>
</tr>
<tr>
<td>Actuator principle</td>
<td>Solenoid</td>
</tr>
<tr>
<td>Signal type</td>
<td>Injection signal (from ECM)</td>
</tr>
<tr>
<td>Resistance</td>
<td>11.6 – 12.4Ω @ 20°C (A6B424 data)</td>
</tr>
</tbody>
</table>

Figure 3: Fuel injector signal [1]
Throttle body

Task and function
The throttle body is used to control the flow of air taken into the engine. The throttle body is composed of the throttle valve linked with the accelerator pedal, and a bypass passage to send a small amount of air at idle. The throttle body mounts the throttle position sensor to detect throttle valve opening.

In vehicles equipped with the electronic throttle control system, the ECM controls the opening and closing of the throttle valve using an electrical actuator integrated in the throttle body assembly. A DC motor and two TP sensors are integrated in the throttle body assembly.

Electronic throttle control system
The electric throttle control system consists of the following items.
- Throttle body assembly incorporated with the throttle valve, throttle actuator and TP sensors (main/sub)
- Accelerator pedal assembly incorporated with APP sensors (main/sub)
- Throttle actuator control relay
- ECM

Figure 3: Electronic throttle body assembly

Figure 4: Electronic throttle control system

[6] CPU  
[7] Throttle actuator  
[9] From “THR MOT” fuse  
[10] From main relay  
[11] APP sensor (Main)  
[12] APP sensor signal (Sub)  
[13] TP sensor signal (Main)  
[14] TP sensor signal (Sub)  
[15] Drive circuit for throttle actuator  
[16] Power supply for throttle actuator  
[17] Drive circuit-actuator relay
Operating principle

ECM (5) detects to what extent the accelerator is depressed based on the signal voltage of the APP sensor (1). Using that data and engine operation condition, ECM calculates the optimum throttle valve opening. On the other hand, it detects the throttle valve opening based on the signal voltage of the TP sensor (3) in the throttle body assembly (2) and compares it with the above calculated optimum throttle valve opening. When there is a difference between them, ECM controls the duty ratio (0% – 100%) of throttle actuator control according to this difference to drive the throttle actuator (4) in the throttle body. When there is no difference, ECM controls the duty ratio of throttle actuator control to about 15% to maintain the throttle valve opening. In this way, the throttle valve (17) is opened and closed to achieve the optimum throttle valve opening.

In this system, TP sensor and APP sensor have 2 sensors (main and sub) each to assure highly accurate and highly reliable control and abnormality detection. Also, when ECM detects an abnormality in the system, it turns off the throttle actuator control relay (8) to stop controlling the throttle actuator. When the throttle actuator control relay is turned off, the throttle valve is fixed at the opening of about 7° (default opening) from its completely closed position by the balance of the return spring and open spring in the throttle body. This throttle body is not equipped with IAC valve for idle speed control. Idle speed control is performed by the throttle actuator by adjusting the throttle valve opening.

Figure 5: Electronic throttle control system (A6B424)
Electrical data for electronic throttle actuator

<table>
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<tr>
<td>Supply voltage</td>
<td>12V Throttle actuator</td>
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<td>5 V TP sensors</td>
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<td>Actuator principle</td>
<td>DC motor / stepper motor</td>
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<td>Signal type</td>
<td>PWM signal</td>
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<td>Signal range</td>
<td>Duty cycle 0% - 100%</td>
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</table>

Service note:
It is necessary to perform calibration of the electronic throttle body after performing the following job activities:
- Replacement of the APP
- Replacement of the throttle body assembly
- Clearance of DTC’s related to throttle control system
- Replacement of the ECM
- Disconnecting the battery
Refer to current service manuals for electronic throttle body calibration procedure.
Idle Speed Control (ISC)

Task and function
In engine systems with mechanical throttle control, the throttle valve closes the air passage when the accelerator is not depressed (idle position) in such a way that there is not enough air flowing to the intake manifold. Without an air bypass system, the engine switches off. To avoid unintended engine cut off, an air bypass tube is installed around the throttle valve. An ISC valve is installed in a position to control the air bypass and maintain engine idle speed when the accelerator is not depressed.

Operating principle
Depending on the model, the ISC valve is can either be a stepper motor or electromagnetic valve (solenoid valve). The ECM controls the opening and closing of the ISC valve to meet different engine operating conditions.

Example: At idle speed after engine warm up and A/C off, the ECM actuates the ISC valve with a duty cycle of between 10 – 55% to maintain an engine speed of 830 – 930 rpm (Alto AMF310 data). The ISC valve is connected to the ECM as shown in figure 9 below.

![Figure 8: Air bypass chamber with ISC valve (AMF310)](image)

![Figure 9: ISC valve circuit diagram (AMF310)](image)

- [3] Throttle body
- [4] Idle Speed Control valve
- [6] Throttle valve
- [7] Intake air flow
**ISC valve signal**

![ISC valve duty cycle signal, Idle speed after engine warm up (AMF310)](image)

**Electrical data for ISC valve (amf310)**

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</tr>
<tr>
<td>Actuator principle</td>
<td>Solenoid or stepper motor</td>
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<tr>
<td>Signal type</td>
<td>PWM signal</td>
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**Ignition coil**

**Task and function**

The ignition coil is used to generate the high voltage/current necessary for the ignition of the spark plugs. The ignition coil is made of a primary coil and a secondary coil. The secondary coil is then connected to the spark plug.

![Ignition coil circuit diagram](image)

**Electrical data for ignition coil**

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<td>Pulse signal</td>
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</table>

**Figure 10:** ISC valve duty cycle signal, Idle speed after engine warm up (AMF310)

**Figure 11:** Ignition coil circuit (A6B424)

[1] Ignition coil power supply circuit
[2] Ignition coil ground circuit
[3] Ignition coil drive circuit
[4] Primary coil
[5] Secondary coil
Oil Control Valve

The OCV is installed in vehicles equipped with the VVT system. It is used to control oil flow to the CMP actuator.

Operating principle
The OCV is a solenoid type actuator. It is controlled by the ECM via PWM duty cycle. The OCV is connected to the ECM as shown in the circuit diagram below.

Electric data for OCV

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<td>Actuator principle</td>
<td>Solenoid</td>
</tr>
<tr>
<td>Signal type</td>
<td>PWM signal</td>
</tr>
<tr>
<td>Resistance</td>
<td>6.7 – 7.7 Ω @ 20°C</td>
</tr>
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</table>
Exhaust Gas Recirculation (EGR) valve

Task and function
The EGR valve is installed between the exhaust and the intake manifold. It controls exhaust gas flow to the intake manifold by opening and closing the air recirculation passage of the exhaust gas recirculation system.

Operating principle
The EGR system uses different actuator techniques to open and close the valve, such as: stepper motor technique, VSV technique (this consists of an EGR modulator and EGR solenoid vacuum valve). In the AMF 310 engine, for example, the EGR valve (if equipped) is a stepper motor that consists of four sets of coils, each actuated by the ECM.

The circuit diagram below shows how the EGR valve is connected to the ECM (AMF310)

Figure 15: EGR circuit diagram (AMF310)

Electrical data for EGR valve

<table>
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<td>Supply voltage</td>
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</tr>
<tr>
<td>Actuator principle</td>
<td>Stepper motor</td>
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<tr>
<td>Signal type</td>
<td>PWM signal</td>
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<tr>
<td>Resistance</td>
<td>20 - 24Ω</td>
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</table>
Relays

The following relays can also be controlled by the engine control module depending on the engine management system used:

- Fuel pump relay
- Radiator cooling fan relay
- A/C compressor relay, etc.
- Main relay

When a relay is controlled by the ECM, the ground side of the relay solenoid is connected to the ECM. The ECM switches on and off the relay by controlling the ground circuit of the solenoid. Example: in figure 16, the main relay (6) and the fuel pump (7) relay is controlled by the ECM (9).

Main relay

Task and function
The main relay is controlled by the ECM and it supplies battery power to many components including the following:

- A/C compressor relay
- Fuel pump relay
- Oxygen sensor heater relay
- ECM
- Throttle actuator relay
- Radiator fan relays
- Fuel injectors
- MAF sensor
- CMP sensor
- CKP sensor

Figure 16: EGR valve, stepper motor type (AMF310)
Summary

- Sensors are devices convert for example mechanical and chemical parameters into electrical signals.
- Intake air system sensors include the MAF sensor, IAT sensor, TP sensor.
- The sensors installed on the engine are: CMP sensor, CKP sensor, Knock sensor.
- Exhaust system sensors include; A/F sensor, heated exhaust gas oxygen sensor.
- Actuators convert electrical signals to other forms of energy such as mechanical, heat.
- Actuators such as the throttle valve actuator, idle air control valve, injectors, convert electrical signals to mechanical movements.
- The ECM also uses inputs from other control modules to control some actuators to ensure optimum engine performance.
### Reference

The following abbreviations can be used in this training manual

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
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<tr>
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<td>CAN</td>
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<td>After Bottom Dead Center</td>
<td>Crankshaft Position</td>
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<td>Anti-lock Brake System</td>
<td>CMP</td>
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<td>Alternating Current</td>
<td>Camshaft Position</td>
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<td>Air Conditioning</td>
<td>CO</td>
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<td>Automatic-Emergency Locking Retractor</td>
<td>Carbon Monoxide</td>
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<td>A/F</td>
<td>Air Fuel Ratio</td>
<td>CO2</td>
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<td>ALR</td>
<td>Automatic Locking Retractor</td>
<td>Carbon Dioxide</td>
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<td>API</td>
<td>American Petroleum Institute</td>
<td>CPP</td>
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<td>APP</td>
<td>Accelerator Pedal Position</td>
<td>Clutch Pedal Position</td>
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<td>A/T</td>
<td>Automatic Transmission, Automatic Transaxle</td>
<td>CPU</td>
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<td>After Top Dead Center</td>
<td>Central Processing Unit</td>
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<td>ATF</td>
<td>Automatic Transmission Fluid, Automatic Transaxle Fluid</td>
<td>CVT</td>
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<td>All Wheel Drive</td>
<td>Continuously Variable Transmission, Continuously Variable Transaxle</td>
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<td>EBD</td>
<td>Electronic Brake Force Distribution</td>
</tr>
<tr>
<td>ECM</td>
<td>Engine Control Module</td>
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<tr>
<td>ECT</td>
<td>Engine Coolant Temperature</td>
</tr>
<tr>
<td>ECU</td>
<td>Electronic Control Unit</td>
</tr>
<tr>
<td>EEPROM</td>
<td>Electrically Erasable Programmable Read Only Memory</td>
</tr>
<tr>
<td>EFE</td>
<td>Early Fuel Evaporation Heater</td>
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<tr>
<td>EGR</td>
<td>Exhaust Gas Recirculation</td>
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<td>EGT</td>
<td>Exhaust Gas Temperature</td>
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<td>ELR</td>
<td>Emergency Locking Retractor</td>
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<td>EPS</td>
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<td>Intake Air Temperature</td>
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<td>Intake Manifold Tuning</td>
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<tr>
<td>ISC</td>
<td>Idle Speed Control</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
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<tr>
<td>JIS</td>
<td>Japanese Industrial Standards</td>
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<td>J/B</td>
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<td>J/C</td>
<td>Junction Connector</td>
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**Other**

|       | 2WD     | 2-Wheel Drive |
|       | 4WD     | 4-Wheel Drive |

Note: ESP is a trademark of Daimler AG

DPF® is a trademark of HJS Fahrzeugtechnik GmbH & Co KG and Suzuki is the trade mark licensee.
Well done, you have now completed the “Electronic Petrol Injection” training course!

Please complete the online exam