

TROUBLESHOOTING AUTOMOTIVE COMPUTER SYSTEMS

Automotive Computers, Sensors & Network

**HAPPYSON GAVI &
CHARMAINE GAVI**

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By

Happyson Gavi

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Chapter 1

1.1 PCM in a BUS Network

The abbreviation PCM stands for Power Control Module. PCM is the main automotive computer used to achieve various purposes mostly oriented toward transmission, engine management and performance. The PCM is one of the several on-board computers that are interconnected in an automotive vehicle forming a network system called CAN BUS, (CAN) for Controller Area Network, BUS is a form of network topology in which different in board computers / modules on different locations are connected to the main cable. BUS network topology is similar to passengers inside a bus sitting on seats that are located on different locations but sharing the same passage. CAN network provide an intercommunication system of various vehicle computers to make a CAN BUS system. The CAN BUS system shares data to each computer connected to the data link. Each computer in the data link is sometimes called a node. The PCM which is the main computer has the ultimate control of the Data BUS.

In brief the PCM's primary function is to manage Powertrain. This includes the ignition system, fuel system and emission system. **PCM's ultimate goal is to ensure that the sensors work properly and that the car is non-polluting.**

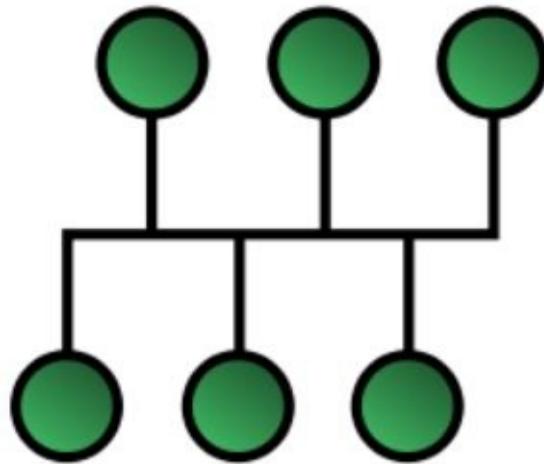


Fig1.1: A diagram illustrating a general BUS network topology.

1.2 What is BUS topology?

In such type of topology, a long backbone cable (twisted pair cable in CAN BUS) is used to link all the devices in the network. Wires are twisted to eliminate electrical noise. Twisted pair cable is used to link all the devices in the network. Drop lines and taps are used to connect different nodes/modules to this backbone. This topology allows only one device to transmit at a time since all nodes on the network share a common BUS. The node to transmit next is determined by distributed access protocol. This network topology helps to eliminate redundant wiring to the modules / ECU 's that need the same sensor information.

1.2.1 Advantages of BUS topology

Requires less cabling and therefore less expensive as compared to mesh, star and tree topologies.

Easier to install than other topologies

Weight reduction due to fewer components

1.2.2 Disadvantages of BUS topology

It's difficult to add new devices
It's difficult to do reconfiguration
It's difficult to isolate faults in nodes
Limited cable length required
Limited number of nodes that can be connected

The number of accessories inside automobile increased rapidly in the last three decades. A typical late model vehicle will have 10 or more modules. This therefore implies that the number of actuators, sensors, navigation, entertainment, climate control *etc.* and their corresponding electronic control modules increased as well. Since modern electronics is almost completely digital this therefore implies for the need for efficient communication that is immune to interruption and noise using defined protocol. The communication between all on-board computers requires a network. This network allows all on-board computers to communicate with each other as well as scan tool communications. Engineers noted that BUS network topology was an effective mode of communication and came up with CAN BUS system

Chapter 2

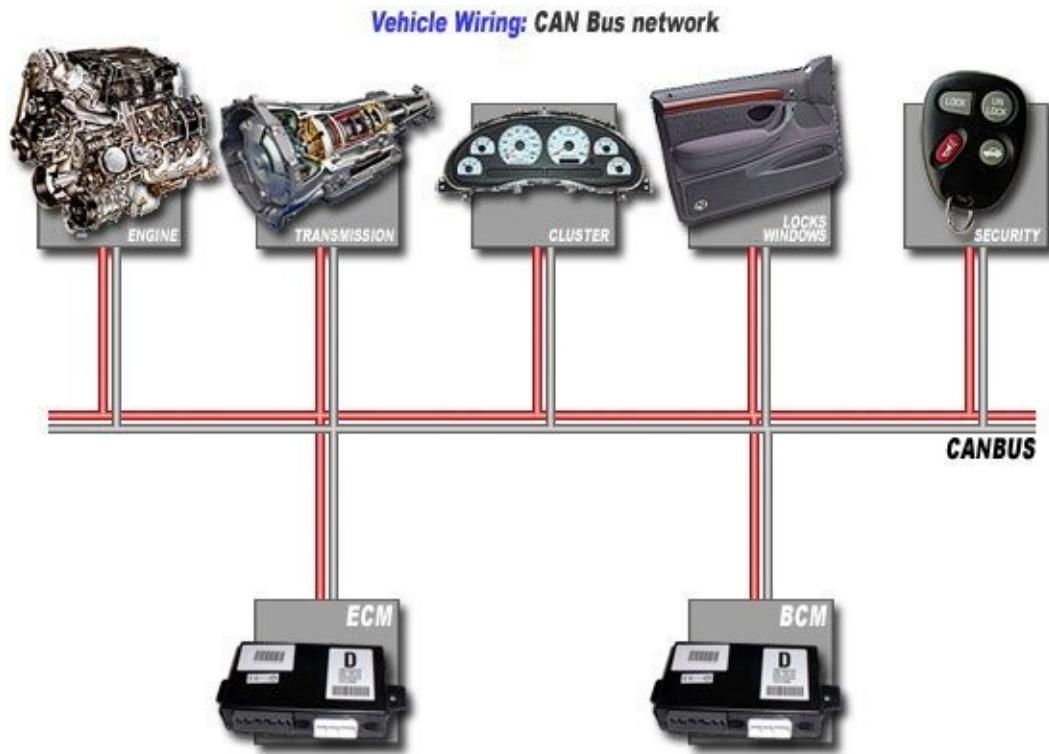
2.1 CAN BUS system

A serial BUS that was developed in 1983 by Robert Bosch GmbH and was officially released in 1986 at the Society of Automobile Engineers (SAE) congress in Detroit Michigan for in-vehicle network in cars. CAN BUS employ twisted wires to eliminate radio frequency interference (RFI) and electromagnetic interference (EMI) from entering the system. The twisted wire is terminated at each end with 120 Ohm resistor called a Termination Resistor. The total resistance of the two terminating resistors connected in a twisted pair BUS sums up to 60 Ohms since the 2-resistors are connected in parallel. If one end of a twisted pair wire is open a 120 Ohm will be measured across pin 6 and 14 of the data link connector (DLC) with the ignition switch turned off and negative battery terminal being disconnected. If both wires are open an **OL** will be indicated on a DMM. Such CAN BUS is not reliable for data transmission and in many cases it might fail to operate.

CAN is the fastest network and its twisted wire can transmit at speeds up to one million bits per second.

CAN network allow different modules to share common sensor data like vehicle speed, outside air temperature, coolant temperature and density of air. Such information is essential for fuel trim and transmission shifting. Examples of modules that were programmed to use same vehicle speed signal are powertrain control module (PCM), cruise control module (CCM), anti-lock brake control module (ABS) and driver 's door module (DDM) CAN system was also designed to function in the harsh automotive / truck environment. The CAN BUS is one of the 5-protocols used in the on-board diagnostics or OBD2 diagnostic standard. The OBD2 has been maintained for all cars and light truck

sold in the USA since 1986.



2.1.1 Why 120 Ohms terminating resistor?

The 120Ω came up as a result of considering the Transmission Line Theory of Physics. This theory takes into consideration the length of BUS wires.

The length is determined in terms of wavelengths.

The terminating resistors prevent signal reflections causing interference. All devices in the network have to conform to the BUS impedance. When CAN BUS is at 60Ω (meaning two 120Ω in parallel as shown in Fig 2.1.1) the BUS can absorb all energy for maximum efficiency of the system.

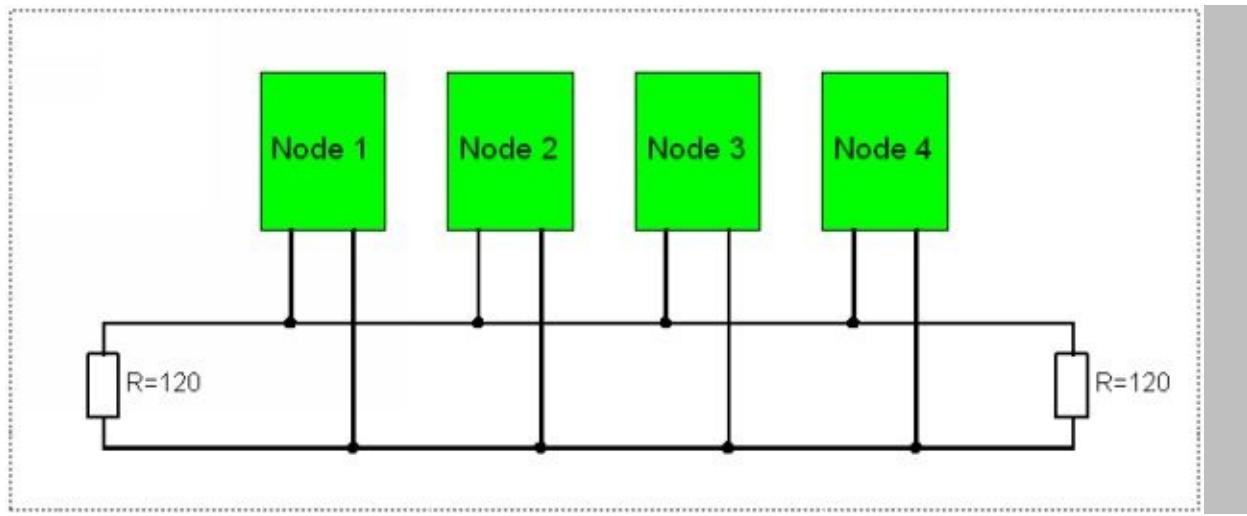


Fig 2.1.1: illustration of a CAN BUS network with 120 ohm terminating resistors

2.2 CAN Communications Protocols

Protocols are a system of digital rules or procedures for data exchange within or between computers. More precisely Protocols have more to do with the way data is formatted, transmitted and received.

[**ISO9131-2**](#)

[**ISO13230-4 \(Keyword Protocol 2000\)**](#)

[**ISO15765-3SAE J2480**](#)

[**J1859 PWM \(Class B\)**](#)

[**J1859 VPW**](#)

2.2.1 Classes of CAN Network

Class A = one wire low speed data, less than 10 Kbs, generally used for trip computers and entertainment.

Class B = two wire mid speed data, 10-125Kbs, generally used for information transfer among modules such as temperature sensor data.

Class C = twisted 2-wire high speed for PCM, ECM, Airbags, Antilock brakes.

Class is basically 100 times faster than Class B. Class 6 & 14 of the DLC

Class D = is at speeds of up to 1.0 Mbit / second and appears on some late model cars.

When CAN communication is possible or communicates with the scan tool it implies no wiring problems. The technician's job dealing with CAN BUS network is to ensure that:

- The CAN BUS network is in good condition. The battery has proper B+ voltage 12.6V -13.5V
- No loose connection exists on a wire harness
- All the control units are operating properly
- Good ground on B- (GND) pin 4 & 5 of DLC
- Proper B+ voltage on pin 16 of DLC

If all the above conditions are met then the CAN BUS system can be relied on such that trouble shooting and repair won't be a big deal. I will explain that in the proceeding chapters. Problems that normally occur in the BUS communication are opens, shorts, and unwanted resistance. Diagnosing and troubleshooting these problems requires a DMM and an analogue meter. I will explain the diagnosis and troubleshooting procedures in the accompanying chapters.

2.2.2 Summary of CAN features

Faster than other BUS communication protocols, with maximum speed of 1000 000 bps.

Cost effective because it eliminates redundant wiring and it is an easier system to use as compared to others Less affected by EMI and RF due to twisted wires

Message based rather than address based which makes it easier to expand No wake up needed because it is a 2-wire system

Supports up to 15 modules including a scan tool

Uses a $120\ \Omega$ terminating resistor at the ends of each pair to reduce electrical noise Applies 2.5V on both wires:

A CAN_H (High) signal exists from 2.5V to a high approximately 3.5V when active A CAN_L (Low) signal exists from 2.5 V to a low approximately 1.5V when active Possibility of assigning priority to messages and guaranteed maximum latency times[1]

Detection of possible permanent failures of nodes and automatic switching off of defective nodes[2]

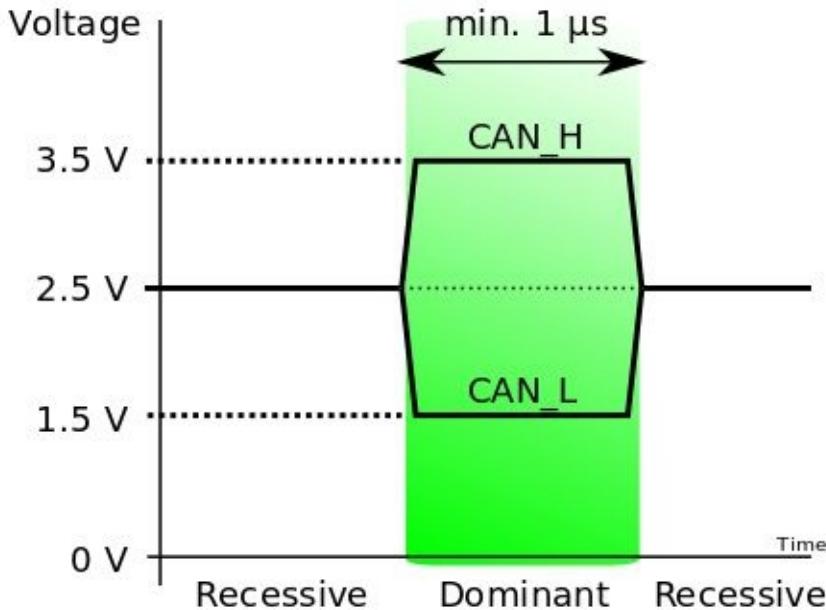
2.3 Voltage levels of CAN BUS Digital Signals

CAN uses a differential type of module communication where the voltage of one wire is equal but opposite to voltage of another wire. When no communication occurs both wires have a voltage of 2.5V applied. So 2.5V is a reference level. If there is no data being sent the voltage at CAN_H (High) and CAN_L (Low) will be 2.5V if the DMM is connected to the chassis GND which happens to be pin 4.

The voltage difference between the peak of CAN_H (+) and the peak of CAN_L (-) ≈ 2 Volts in amplitude.

Peak CAN_H (+) - Peak CAN_L(-) ≈ 2 Volts

When communication is occurring, CAN_H (High) goes by 1Volt up to 3.5 Volts and CAN_L (Low) goes down 1 Volt to 1.5 Volt.



2.3.1 CAN Electron Current

Current carrying wire has magnetic field around it, such fields induces voltage but in opposite direction according to Lenz's Law of electromagnetism. This induced voltage termed voltage spike can destroy electronic components that are fundamental to an automotive system and therefore twisted pair cable is a good idea to curb such problems. CAN_H and CAN_L wires are twisted pair and therefore the electron signal current will flow in different directions and that signal is in a state of balanced. This makes the CAN BUS immune to electrical noise since any electrical noise and induced voltage present in one wire exists in the other but in opposite directions and therefore cancellation effect will occur. This will minimise signal loss and increase signal conductivity of the lower level of the CAN signal.

2.3.3 Measuring the Resistance of CAN BUS network

The rule of thumb says measure the resistance when no current is flowing. Measuring the resistance of the CAN network is done on pin 6 & 14 of the DLC. Extreme caution should be exercised whenever dealing with the DLC since the pins on DLC are very delicate and vulnerable. The following steps to

be taken when measuring the resistance of the CAN network;

- Before measuring the CAN network resistance disconnect **B-** of the battery first. This is because some voltage will still be present on pin 6 & 14 even at Key Off. The **B-** is disconnected first because electric current flows from negative to positive.
- Wait for maximum of 10 minutes before probing pin 6 & 14 with a DMM to ensure that voltage is negligible.
- Measure the resistance on pin 6 & 14 after you are sure that voltage does not exist on those pins
- The DMM test leads should be on pin 6 & 14, red test lead on CAN_H (High) and black test lead on CAN_L (Low)

2.3.4 CAN BUS network resistance values interpretation

- If both wires are open an “ **OL** ” will be indicated on a DMM
- If one end of a twisted pair wire is open a 120Ω will be measured across pin 6 and 14 of the data link connector (DLC), this shows that the two terminating resistors are no longer connected in parallel.
- A $0.0\ \Omega$ or very low resistance far much less than $60\ \Omega$ implies that the twisted wires are shorted together
- The data bus will remain operational when one of the two modules containing a terminating resistor is not connected to the network.
However the data bus will fail when both terminating resistors are not connected to the network.

Do a thorough visual inspection and look for network wire insulation damage, repair or even replace the wire if possible, look for loose connections as well. Repair the damaged resistors if possible. A reading of $60\ \Omega$ implies a perfect connection between different control units and the CAN BUS.

2.3.5 Measuring Voltage of CAN BUS network

The rule of thumb says measure voltage when current is flowing in the circuit. This is done to monitor communications and to check the CAN BUS for proper

operation. The following steps are to be taken when measuring voltage of the CAN network;

- Check the battery voltage, the battery voltage should be at least 75% state of charge before Measuring Voltage of CAN BUS network
- Use a DMM set to DC volts
- Pin 4/5, 6 & 14 to be used for voltage measurements
- 0.0 Volts indicates short-to-ground, check for the short by disconnecting one module at a time until a module causing problems is found.
- When no communication occurs both wires have a voltage of 2.5V applied and this phenomenon is called recessive state.
- Signal that is 12 Volts all the time indicates short-to-voltage, the BUS circuit could be shorted to 12 Volts. Check the repair history of the car with the customer before doing anything, and then start unplugging one module at a time until a problem is found.
- Variable voltage indicates a normal operation of the CAN BUS; this usually indicates that messages are being transmit sent (Tx) and received (Rx) by a transceiver circuit embedded in different modules.

Battery Voltage	State of charge
12.66	100%
12.45	75%
12.24	50%
12.06	25%
11.89	0%

Summary of network communication diagnosis

Check the battery voltage, the battery voltage should be at least 75% state of charge before doing any electrical diagnosis.

Do a thorough visual inspection to check accessories that do not function properly as this will help to identify a module or a BUS circuit at fault. A power window that does not work properly can be due to a BCM problem. A miscommunication between an engine and transmission can be attributed to a TCM in some cars. I remember fixing a Nissan extera 2001 model that had such problem, it was cranking with no start condition.

Use a scan tool usually a factory scan tool to perform module status test. Check if the components/ systems/ actuators can be controlled by the scan tool Check CAN BUS network for voltages

Disconnect the PCM terminals and check for corrosion, spray anti-corrosion solvent to remove rust on PCM pins, W40 is a good solvent to achieve that. Corrosion causes PCM intermittent malfunction.

Check for loose terminals in a connector

Check for loose ground connections

Check owner's manual for procedures and steps to fix BUS network problems

2.4 No network communication diagnosis

- Check the battery voltage, the battery voltage should be at least 75% state of charge before doing any electrical diagnosis
- Check pin 16 of the DLC for the presence of **B+** voltage. At least 10Volts should be available at pin 16 during cranking when the battery is good. If no voltage is found on pin 16 check the (1) B+ cable to the PCM if properly connected, if properly connected check for (2) a damaged PCM fuse or circuit breaker, PCM fuses are normally damaged when the B+ polarity is reversed. The B+ pin which is fused maintains the PCM's volatile memories such as KAM and DTC's memories when the ignition is turned off. If (1) & (2) is valid check for any loose connections in the wire harness that might cause a no communication. If the above mentioned steps are valid the following procedures listed below may be done:

- Be sure that your scan tool is not a problem; you may as well test it on a different car.
- **Test for 5 volt reference signal from any accessible sensors like MAF, TPS and MAP.** The 5 volt reference originates from the PCM. If the 5 volt reference signal is present then the PCM is partially operational, and if no 5 volt reference exists then one of the sensors is shorted to ground, implying that it pulls all the 5 volt reference to the ground. The best procedure to deal with that problem will be to disconnect one sensor after the other until the 5volt reference appears on line. This could be very monotonous but we have to do it.
- In some cases check the PCM relay
- Check the PCM for any external damages, PCM can be damaged by overcharging alternator, alternator with shorted rotor excessive moisture or any catastrophic occurrences
- Use an oscilloscope to check for voltage measurements on testing points, in this exercise you have to open the PCM before the testing and then afterwards run the testing whilst the ignition is running.
- Consult a PCM connector diagram to determine the configuration of the connector pins

Manifold Absolute Pressure (MAP) Sensor

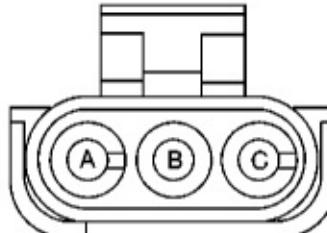
			
Connector Part Information		<ul style="list-style-type: none"> • 12020403 • 3-Way M WeatherPack Sealed (DK GRN) 	
P in	Wire Color	Cir cuit No.	Function
A	ORN/BLK	469	Low Reference
B	LT GRN	432	MAP Sensor Signal
C	GRY	2704	5 Volt Reference

Fig2.4: A schematic diagram of a MAP sensor of one of the GM cars. The MAP sensor has 3-wires as signified by A,B & C. Wires C which is grey in colour is the 5-volt reference signal that is used for testing described above. The above diagram can be pulled from ALLDATA online program. For those without access to the internet and subscriptions to ALLDATA a T-pin together with a DMM can be used to identify the 5-Volt reference signal. That grey wire can be inspected to check if not shorted to the ground[3].

2.5 Effects of bad PCM grounds

Bad PCM grounds can cause serious problems to the computer due to incorrect voltage drop. The PCM was designed to work with 5V reference implying that any voltage drop will affect the normal operation of a computer. Listed below are some of the problems caused by poor PCM ground: No start conditions

Abnormal PCM reference voltage

Wondering trouble codes

Intermittent driveability problems

Poor engine performance

2.6 OBD2 Data Link Connector (DLC)

DLC or Data Link Connector is an OBDII standardized and has got 16 pin configurations. It has been used in all automobiles manufactured since 1996. DLC design and location depends on the manufacturer however most vehicles have DLC located under the dash. Some pins function is standard like pin (4,5, 6,14 & 16) and required by all manufacturers, while others like (1,8 & 12) are left to the individual manufacturer's discretion. DLC is very delicate and vulnerable and extra care and caution is required whenever dealing with it.

DLC has pins 1-8 running on the upper segment of DLC and 9-16 running on the lower segment of the DLC as shown below:

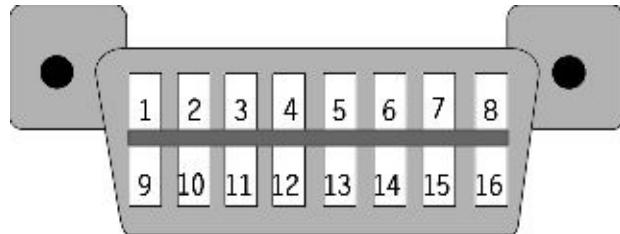


Fig 2.6: A diagram showing standard OBDII Data Link Connector with 16 pin configurations

2.6.1 The DLC allows you to:

- Turn ON / OFF actuators using a bidirectional scan tool

- Test Signal & Chassis ground
- Testing of computer network system, protocol communication & signalling
- Provides power to the Scan tool
- In brief it is a diagnostic tool

1 OEM COMM

2 BUS +ve line (square wave signal)

3 OEM reserved

4 Chassis ground

5 Signal / Sensor ground

6 CAN_ H

7 K Line ISO 9141 Protocol

8 OEM reserved

9 OEM COMM

10 BUS –ve

11, 12 & 13 OEM reserved

14 CAN_L

15 L Line ISO 9141 Protocols

16 B+ voltage

Different modules have different network speeds. Network speeds are classified into different classes *i.e.* Class A, Class B, Class C & Class D. Electrical pulses which are square wave Signals are used to communicate on a Serial line.

Electrical pulses are a series of 0's and 1's. Logic "1" is at 5V and Logic "0" is at 0V. TTL (Transistor-Transistor- Logic) is the Logic circuitry language inside various computers, its voltage levels are represented by a "1" or "0", Logic '1" being at 5V & "0" being at 0V.. Each of the Logic "1" or "0" is called a **bit**. A byte is made up of 8-bits. Each byte represents a small amount of information or

data. A chain of bytes constitute to a message when it is sent to a CAN BUS network. The “1’s” or “0’s” dictates the *type, origin & importance* of the signal. The frame of information is broken down to start, identifier & priority sections. The priority section is indicated by “1” or “0”. A signal with “0” has high priority than a signal with “1”. This is done to prevent collision problems within a network and allows signals from modules like the ABS Controller to have a higher priority than modules for power seat, power window and climate control.

2.6.2 Accessing OBD2 Data Link Connector (DLC) pins

Breakoutbox (BOB) offers easy access to DLC pins for diagnostic measurements. The BOB is a true reflection of the DLC. The BOB protects the possible damage of DLC if probed with DMM test leads. BOB has 16 pins that match the 16 pins on the DLC. Pin 2,4,5,6,7,10 & 16 have LEDs that light up. LEDs are used to indicate status of power, grounds and communication activity on each of the pins listed above of the DLC.

Pins 2, 6, 7, 10 light up to identify vehicle data OBD-II protocol and activity. A CAN_H & CAN_L voltage appears on pin 6 & 14 of DLC respectively. Pin 16 has B+ voltage at Key ON and charging voltage at Key ON Engine ON. The intensity of brightness of LED on pin 16 increases during charging as compared to Key ON. The diagram below illustrates the BOB with the 16 pins configurations and two connectors. One connector will be connected to the DLC and the other to the scan tool.

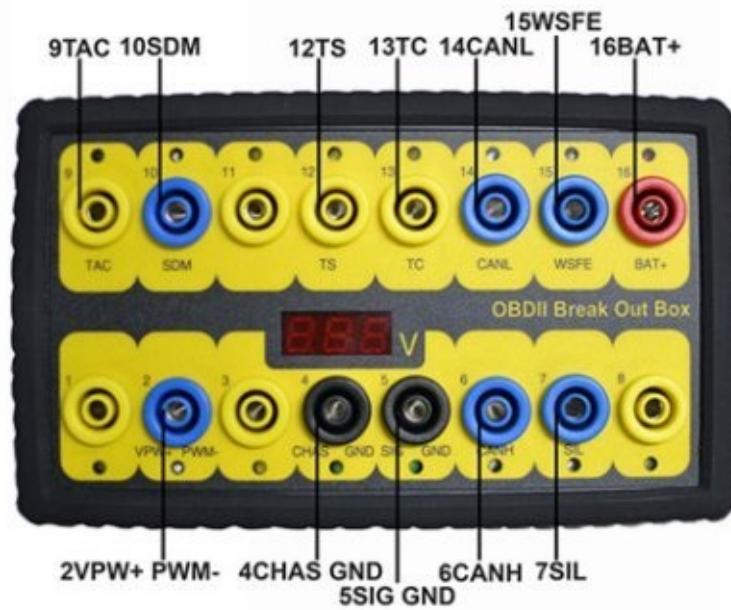


Fig2.6.2: illustration of OBD2 Breaker - out - box

Chapter 3

3.1 Onboard diagnostics OBDI & OBDII

OBDI was the generation of automotive engine control system instituted by the government. OBDI was meant to keep track of limited amount of information making use of O₂ sensor, EGR sensor and fuel trim unlike OBDII which is more complex and makes use of various sensors OBDII is a second generation of automotive engine control system instituted by the government with much stricter standards and uniformity. To be more precise OBDII was designed to detect electrical, chemical and mechanical failures in the vehicle emission control system that might threaten emission levels. This book is going to focus only on OBDII automobiles.

Ideal emission levels after combustion in a vehicle:

O₂ = 0.5%

CO₂ = 12-15 %

CO = 0.5%

3.1.1 OBD II Monitors

OBDII checks the entire system unlike OBDI. It runs a series of tests called monitors. OBDII monitors checks information from various sensors for rationality such process is called a rationality check.

3.1.2 What exactly are OBDII MONITORS?

Monitors are experiments, when you perform an experiment in a lab you expect to get some results, analyse the results and draw some conclusions. This is analogous to the concept of operation of monitors. Monitors have the ability to run tests of multiple components and make judgements about system efficiency.

To be more precise we can safely say that monitors are carefully planned experiments done by the PCM to verify if the sensors in a subsystem are working together to produce acceptable emissions. Below is a list of examples of monitors that may be run by the OBDII system:

Comprehensive component monitors Misfire detection monitors Fuel system monitors

Heated Catalyst monitors

Catalyst Efficiency monitors EGR system monitors

Evaporative system monitors Heated Oxygen sensor monitors Air injection monitors

3.1.3 When do monitors run?

The following 3-monitors run *continuously*:

- Comprehensive component monitor (**CCM**)
- Misfire Detection monitor (**MDM**)
- Fuel system monitor (**FSM**)

CCM – Check computer controlled devices for opens, rationality & shorts-to-grounds.

MDM – Prevents the conditions that threatens the efficiency of the catalytic converter **FSM** - Prevents the conditions that threatens the efficiency of the catalytic converter The remaining monitors run once per ***trip***. The next chapter will explain the meaning of the term ***trip*** as used in OBDII system.

The sole purpose of running monitors continuously is to protect a catalytic converter from imminent threats such as over fuelling and engine misfire. These two threats can completely destroy the catalytic converter and that will pose a

serious threat to our environment. I regard OBDII as one of the greatest scientific invention done in the USA considering the threats posed by fossil fuels to the environment. Global warming is causing catastrophic weather changes across the globe and if we don't take serious step the whole world will be very much inhabitable. Thanks to the scientist who came up with the idea of OBDII.

3.1.4 When do other remaining monitors run?

Depends on the enabling criteria like for example it is wise to test an O2 sensor during a closed loop status otherwise fuel trim is not accurate. In similar fashion it is wise to test EGR flow with the engine running since the EGR is closed at idle. Most of the tests have to be done when the coolant is under normal operating temperatures otherwise the tests won't be rational. The PCM has to wait for normal operating conditions to be met before running the monitors.

The following monitors run *non-continuous*

Heated Catalyst monitors
Catalyst Efficiency monitors
EGR system monitors
Evaporative system monitors
Heated Oxygen sensor monitors
Air injection monitors

3.1.5 How does the PCM know when conditions are right to run the tests?

Enabling criteria should be right to run a monitor. The tests are run during a ***trip***. ***Trip*** definition differs and usually depends on the type of monitor that the PCM wants to run. In simple terms ***Trip*** is defined as Key ON Engine ***RUN*** Key OFF cycle.

NOTE; A Trip exists once the Key is set ON whilst Engine is RUNNING under certain conditions to meet enabling criteria so that monitors RUN and then Key OFF / Engine OFF.

The enabling criteria is managed by the computer software sometimes called task manager

Enabling Criteria summary

Trip

Warm up cycle

MIL condition: OFF

MIL condition: ON Steady

MIL condition: Flashing

MIL: OFF

3.1.6 What is a readiness monitor?

If a test has been completed, the system status will be reported "ready." An uncompleted test will be reported "not ready" and therefore an OBDII vehicle will not pass the annual inspection unless the required monitors are "ready." The Vehicle Inspection Report from the test equipment will identify monitors that are not ready. The US Environmental Protection Agency (EPA) guidelines allow up to ***two monitors*** to be in a "not ready" state for model year 1996 through 2000 vehicles and one monitor "not ready" for 2001 or newer model year vehicles.

3.1.7 What Causes a "Not-Ready" Report?

If the battery had been recently disconnected or replaced; or,

If the vehicle's computer requires a software update; or,

Recent vehicle repairs in which diagnostic trouble codes have been cleared with a scan tool; or, A pending problem has not yet illuminated the "check engine" light; or,

3.1.8 Generic Drive Cycle

1. The OBDII drive cycle begins with a cold start (coolant temperature below 122 degrees F and the coolant and air temperature sensors within 11 degrees of each other).
2. The ignition key must not be left on prior to the cold start – otherwise the heated oxygen sensor diagnostic may not run.
 - As soon as the engine starts, idle the engine in drive for two and one-half minutes, with the air conditioning (A/C) and rear defrost turned on, if equipped.
 - Turn the A/C and rear defrost off, and accelerate to 55 mph under moderate, constant acceleration. Hold at a steady speed of 55 mph for three minutes.
 - Decelerate (coast down) to 20 mph without braking (or depressing the clutch for manual transmissions).
 - Accelerate again back to 55 to 60 mph.
 - Hold at a steady speed of 55 to 60 mph for five minutes. Decelerate (coast down) to a stop without braking^[4].

3.2 Malfunction Indicator Lamp (MIL) / Check engine light





Figure 3.2: A typical malfunction indicator lamp (MIL) often called Check Engine Light.

3.2.1 What turns the MIL light ON?

Only Emission related DTCs will turn ON the MIL. MIL light turns ON after a single trip or two trips depending on the nature of the threat to the catalytic converter. A severe misfire like P0300 or electrical failure of a signal input is common single trip faults. Other faults will require a two trip before turning on MIL. The first detection of a failure that would set a two trip fault is stored in the PCM memory specifically RAM. The MIL light will turn ON unless the fault is repeated during the next consecutive trip when it matures. Fuel & Misfire DTCs require more trips to turn ON MIL. As soon as the MIL is requested ON the PCM turns ON the trip counter and start keeping track of how many trips are made after the faulty is recorded. In short a MIL is turned ON when a DTC is stored in a computer memory, the DTC should be mature and emission related. With KOEO the MIL stays ON for bulb check.

3.2.2 What is a DTC?

Diagnostic Trouble Codes includes numbers, letters or a combination of both generated by the PCM to help technicians to pinpoint problems with the computer systems, sensors, CAN BUS network, transmission issues and engine performance. DTCs will only tell technicians the problem area such as sensors,

actuators, circuit integrity and other factors concerning the basic operation of a vehicle.

3.2.3 Length of Period a DTC stays in a memory

It depends on the type of faulty and the system design of a vehicle. As soon as the MIL is requested OFF by the PCM after 3 good trips, a warm up counter will start. When a warm up counter gets to 40, the DTC will be erased provided the faulty has not been repeated during that time. However in some vehicles some faults may require more warm up cycles *e.g.* Fuel & Misfire faults may require 80 warm up cycles before a DTC and freeze frame is erased. A warm-up cycle is counted at Key ON / Engine Running / ECT @ 160 ° F < PCM has to see 40 ° F in ECT>

3.2.4 Flashing MIL

The MIL will flash if a misfire or fuel trim condition exists that can cause damage to the catalytic converter.

3.2.5 How to manually erase a DTC from a PCM?

The following steps as explained below are used to erase a DTC manually:

Disconnecting a negative terminal of a battery, a DTC will be lost since it is stored in volatile computer memory.

Erase a DTC using a scan tool

Removing a PCM fuse, a DTC will be lost since it is stored in volatile computer memory.

However the preferred method to clear diagnostic trouble codes (DTCs) is to use a scan tool.

3.2.6 DTC priority List

CARB mandated that all DTCs be stored according to individual priority. DTCs with a higher priority overwrite those with lower priority.

OBDII DTC priority list is shown below:

Priority 0 – Non emission related codes 1-trip failure of 2-trip fault for non-fuel

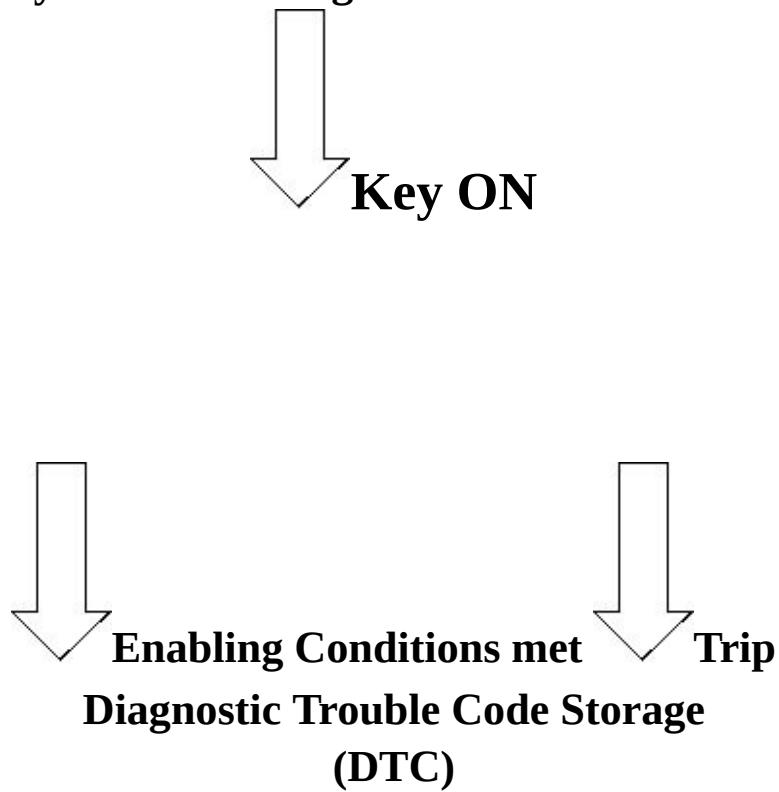
Priority1-1-trip failure of 2-trip fault for non-fuel, non-misfire codes

Priority2 - 1-trip failure of 2-trip fault for fuel or misfire codes

Priority3 - 2-trip failure or matured fault for non-fuel or non-misfire codes

Priority 4-2-trip failure or matured fault for fuel or misfire codes

3.2.7 Summary of DTCs storage



3.3 Freeze frame data

Stores the system condition at the instant a DTC is stored. Freeze frame is important in that it allows a technician to duplicate the conditions under which the fault occurred in the first place and to determine the reason the DTC was stored.

Typical Freeze frame data include:

Calculated load value

Engine Speed (RPM)
Short term & long term fuel trim %
Fuel system pressure (on some vehicles)
Vehicle speed (MPH)
Engine Coolant Temperature (ECT)
Intake Manifold Pressure (IMP)
Closed / Open loop status
Fault code that triggered the freeze frame code
If a misfire code is set identify which cylinder is misfiring

3.4 OBD II DTC Numbering System Designation

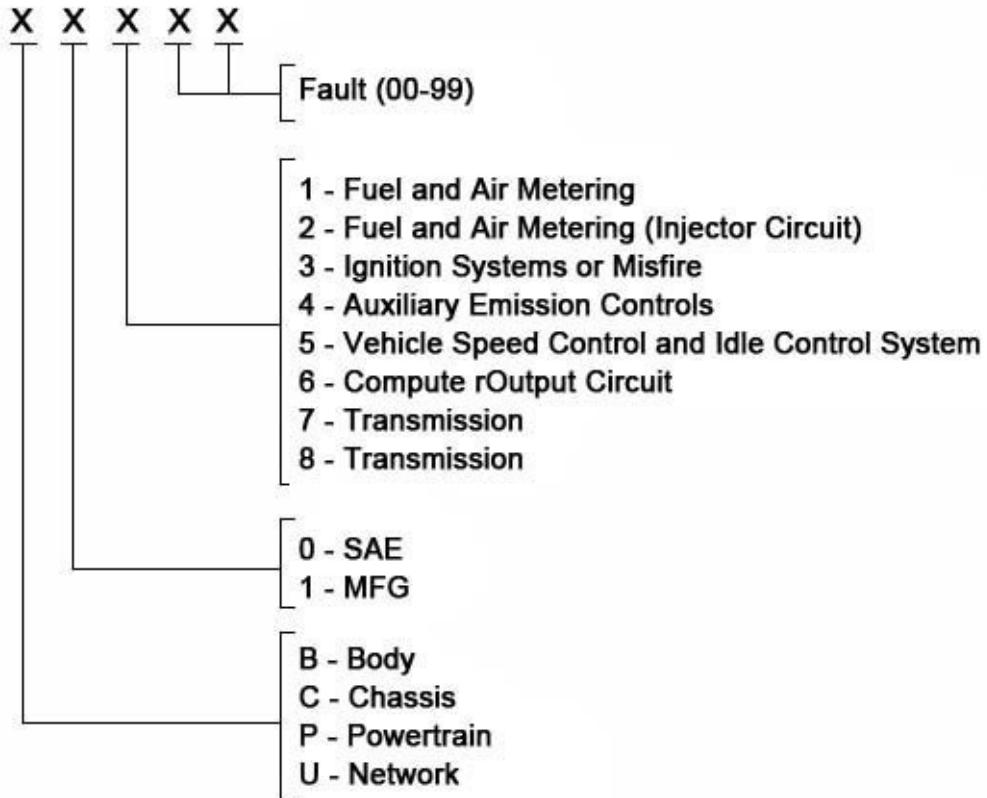


Fig3.4: OBDII DTC identification format [2]

3.4.1 DTC Numbering Explanation

P0100-Air metering fuel system fault
 P0200 – Fuel system (fuel injector only) fault
 P0300 – Ignition system / misfire
 P0400-Emission control system faulty
 P0500-Idle speed control, VS sensor
 P0600-Computer output circuit
 P0700-Transaxle, Transmission faults

A scan tool is used to retrieve the diagnostic trouble codes (DTCS)

3.5 What exactly is a scan tool?

An electronic displaying tool that allows technician to interface with the automotive computer system to retrieve information in regards to diagnosing and repairing computer operated vehicles. Data is transferred in serial format from the PCM to the Scan tool. The PCM receives electrical signals from various sensors, interprets those signals and then creates the serial data words it eventually sends to the scan tool. Scan tools can be aftermarket or Generic.

3.5.1 Scan tool function

Retrieve DTCs and Freeze Frame information

Allow live sensor data to be observed

Allow technicians to capture and record data for later diagnosis

Allow technicians to activate actuators such as relays, motors & solenoids

Erase DTCs

Reprogram PCM & BCM

3.6 Rationality

The PCM compares information from different sensors and expect them be within a programmed range. The PCM expect the information from some sensors to be logical when compared to one another.

3.6.1 How does a technician check for PCM rationality?

Using a scan tool check the ECT equals IAT after an overnight cold soak

Look carefully at all major sensors and compare the readings to the normal readings that would be accepted. Compare the charging voltage displayed on the instrument cluster with the one on the scan tool display; a technician might as well use a DMM to check the charging voltage. A labscope might be used by the technician as an alternative as well to check for voltage signals, other signals and temperature.

If a PCM fails to display correct values reprogramming / replacement might be necessary.

Chapter 4

4.1 Automotive Computer Fundamentals

Automotive computer has several names depending on the manufacturer. In this book we will be using the term PCM to designate automotive computer. Below is a list of names given to automotive main computer, they all mean the same thing.

PCM Power Control Module

OBDII ECA Engine Control Assembly

GM

Microprocessor

FORD

Engine Controller

CHRYSLER

PCM = ECM (Engine Control Module) + TCM (Transmission Control Module)

Given below is a diagram of a typical PCM found in many vehicles [\[5\]](#).



4.2 Automotive Power Control Module (PCM)

An automobile engine is controlled by three main factors *i.e.* (1) Compression (2) electric spark (3) Air Fuel mixture. *If an automobile engine loses any one of the listed factors it will misfire and more often than not it will not run at all. If an engine fails to run automatically the transmission will fail as well since the two coupled together. It therefore makes a lot of sense that if the fuel injection, ignition spark timing and emission controls has to be controlled and managed one has to alter any all of the above three mentioned factors that controls an automobile.*

PCM is responsible for managing four primary engine tasks:

Fuel injection

Ignition spark timing

Emission controls

Idle controls

Today's technological world is fully digital, automotive computer system is not

an exception to the ever evolving techworld. Digital computers are preferred to analog computers because digital computers process information fast and that will trigger responsive operation of spark controls, fuel delivery and emission controls. Most of the actuators in today's vehicle are PCM controlled. It is the PCM drivers that will be responsible for turning them ON/OFF *controlling Pulse Width Modulation (PWM) mechanism*. *Technically speaking, PCM drivers are solid state components, specifically switching transistors. These transistors control either the Ground side Power side of actuators.* Below is a schematic of Mitsubishi charging system using both an internal voltage regulator controlled by the PCM. Notice the NPN driver transistor that controls the voltage regulator which in turn controls the field current. It is a driver because it drives current from the ground and allows it to flow through it up to the voltage regulator and then eventually to **B+**.

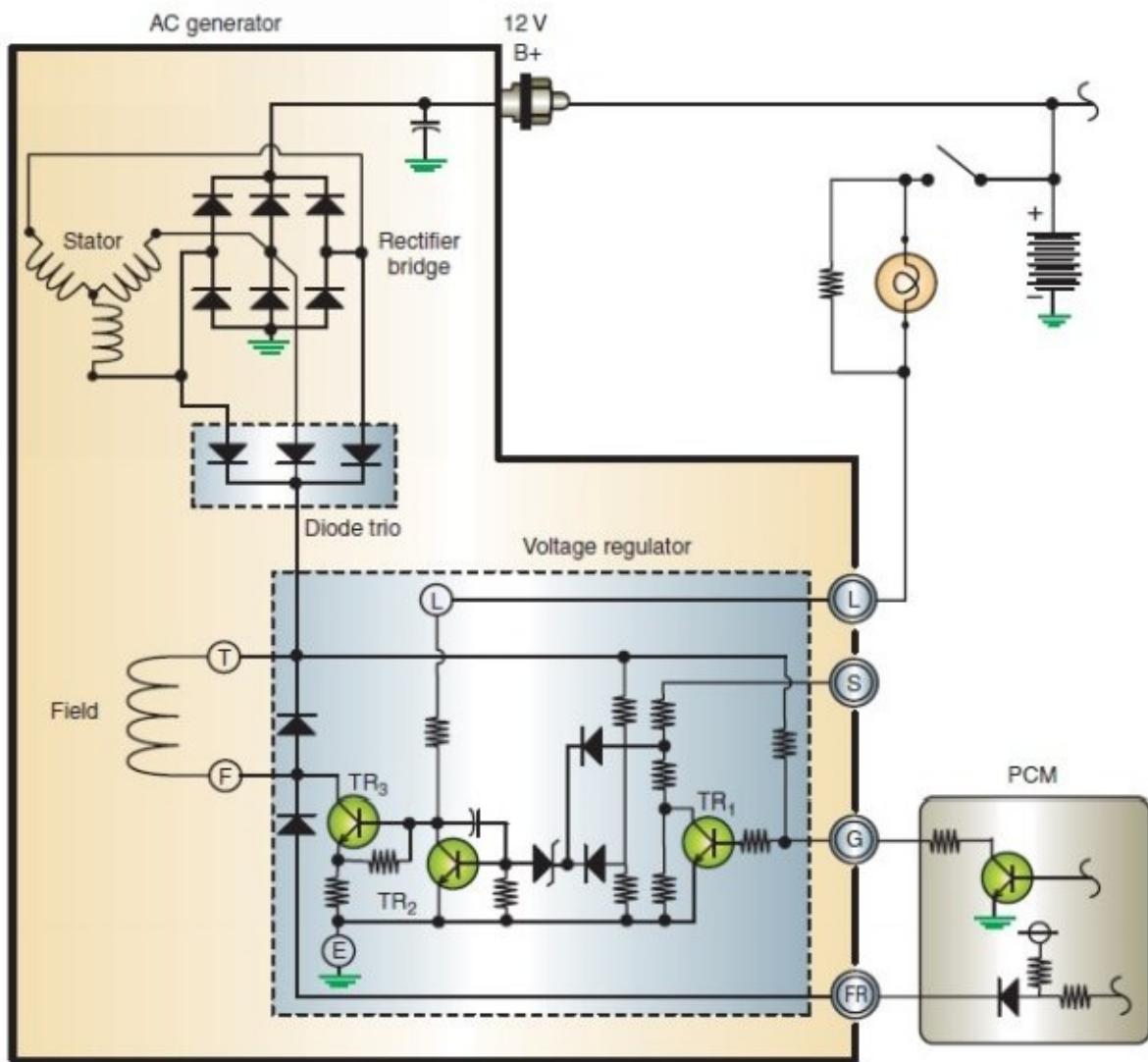


Fig4.2: An illustration showing NPN driver transistor that controls the voltage regulator of a Mitsubishi charging circuit.

4.2.1 In simple terms what does the PCM do?

Receives various sensor input

Calculate ignition system and fuel requirement like long term / short term

Controls actuators like relays, motors and solenoids

Receives power from the battery and ignition switch

Provides regulated and steady 5V-reference to many sensor circuits

Controls the charging system voltage by controlling the generator field current

Chapter 5

5.1PCM to Sensor Communication & Storage Devices

Sensors provide input to the PCM in regards to position, temperature, pressure and other physical characteristics of various components. The input to the PCM provided by each sensor is in form of voltage or frequency signal. The signal from each sensor will be sent to a specific pin on the connector of the PCM. Most sensors produce an analog signal; the analogue signal produced by most sensors is converted to digital signal through an analogue to digital converter (ADC) inside the PCM. This is because the PCM can only understand the digital language which is in form of “bits”. This is the language used by modern computer systems.

The processed information will be compared to programmed values and instructional programs that are stored in the PROM or other PCM memory. The main PCM objective will be to calculate correct output for fuel, spark timing and emission controls. The overall ultimate goal by the PCM is to protect the Catalytic converter from possible damage caused by excessive fuel injection and misfiring problem. The moment the PCM observes such threats it will turn ON a flashing MIL.

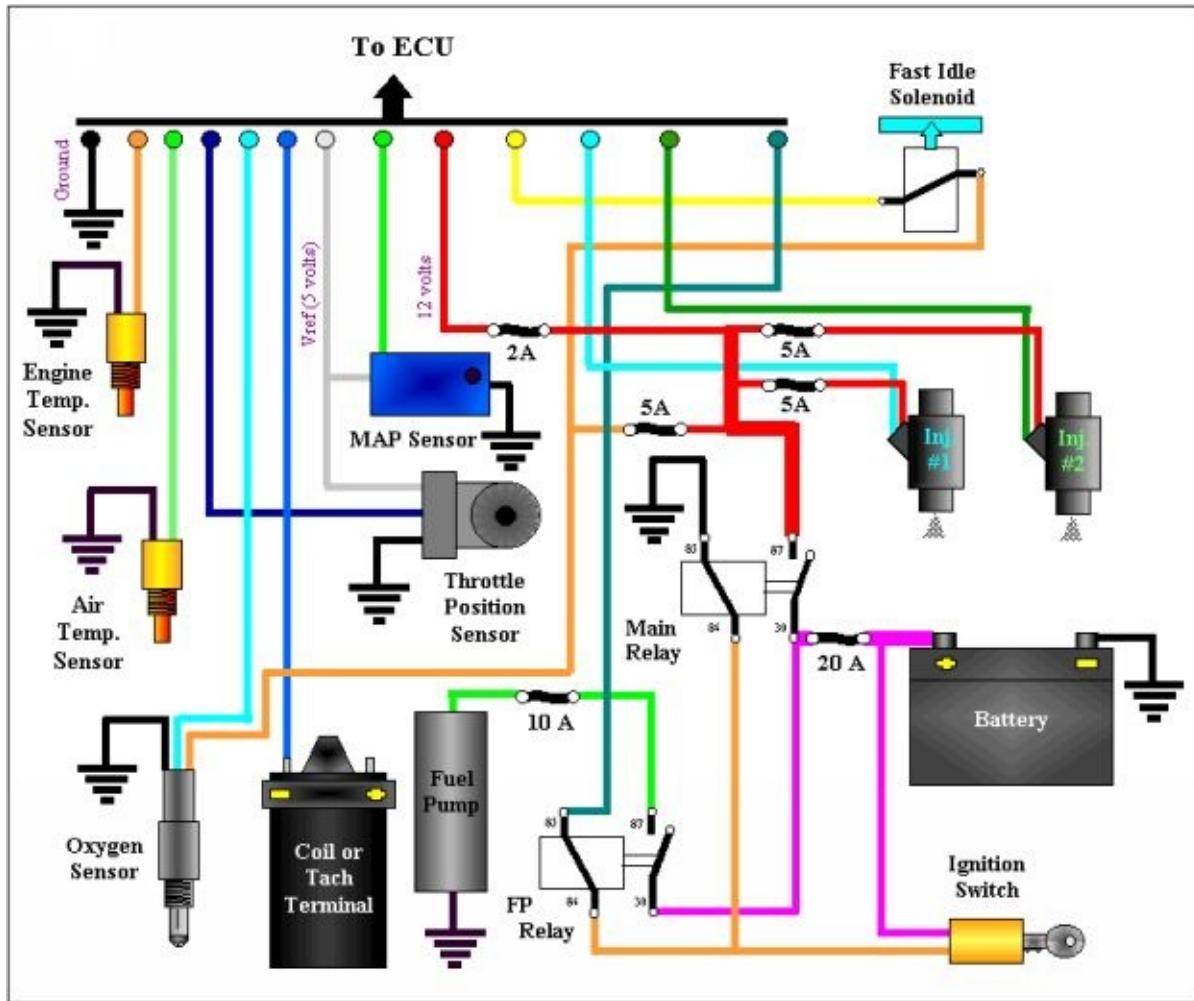


Fig5.1: An illustration of various sensors as input to the ECU.

In this diagram at KOEO, pin 86 of FP Relay receives power from the B+ and this will energise the coil creating magnetic field around it. The magnetic field created will reach pin 30 forcing it to connect to pin 87 which connect to the Fuel Pump, 12V will be delivered to the Fuel Pump turning it ON. The ground signal will be provided by the ECU terminal pin 85, we expect between 0.1-0.2V to be at pin 85 during that time. If we get 12V or close to battery voltage on pin 85 then either the relay is bad or the ECU. Fuel pump will start pumping out fuel from the tank to be sent to the injectors once the injector solenoids are REQUESTED to open by the ECU when certain conditions are met. Each

sensor in the above diagram generates a voltage or frequency signal that is sent to a specific pin of the connector of the ECU. Most sensors above produce analogue signals, therefore the analogue signals must be sent to an analogue to digital convertor inside the ECU so that the ECU can interpret the Language. The PCM takes the processed information using its memory and pre-programmed information and calculates correct output for fuel, spark timing and emission controls. The PCM will eventually COMMAND actuators to do the job. That is the point whereby we see inj. #1 and inj. #2 opening up, the pulse width depends on other sensor input such as TPS, MAP, ECT, ATS & HO₂ sensors (close loop). The PCM will COMMAND the ignition coil as well. This will happen very fast since most modern automotive computers are 32 bit. This means that they can process a piece of information consisting of 32 numbers & letters as a single piece of data. A 32 bit computer can store as much as 4GB in its internal memory.

5.1.1 OBDII DTCs associated with the PCM malfunction include:

P0600 Serial Communication Link

P0601 Internal Control Module Memory Check Sum Error

P0602 Control Module Programming Error

P0603 KAM error

P0604 RAM error

P0605 ROM error

P0606 ECM / PCM error

P0607 Control Module Performance

P0608 Control Module VSS output A

P0609 Control Module VSS output B

P0610 Control Module Vehicle Options Error

If you see any of the above codes when diagnosis a vehicle using a Scan tool

mostly likely the PCM is dead and need to be replaced. However if the MIL turns ON with the same codes after PCM replacement then there is still a problem with the vehicle, the problem is not the PCM. In that case further diagnosis may be required otherwise the PCM may not function properly.

5.2 What are sensors?

Sensors are mostly solid state components that provide input to the PCM pertaining to temperature of liquid or outside air, position or speed of rotating devices, pressure of liquid or air, oxygen content of exhaust *etc.*

5.3 What are actuators?

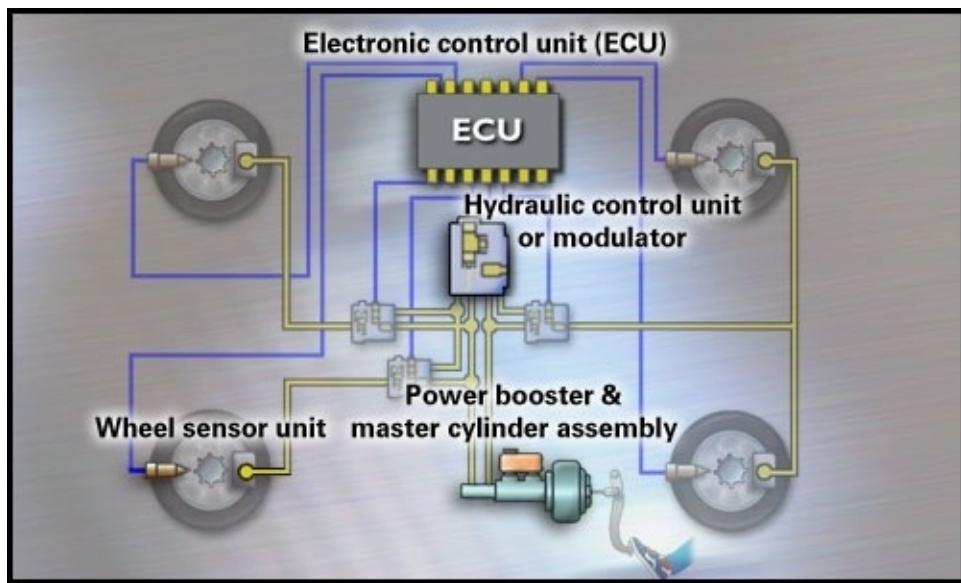
Actuators are output devices that actually do the job. Examples are fuel pump relay, control modules, idle speed motor, fuel injectors, ignition coils *etc.*

5.4 What is the difference between Body Control Module (BCM) and Power Control Module (PCM)?

BCM differs to PCM in that BCM is responsible for managing Body Electrically relating components like Courtesy Lights, Power Window, and Door Locks *etc.*

5.5 What is an ABS Module?

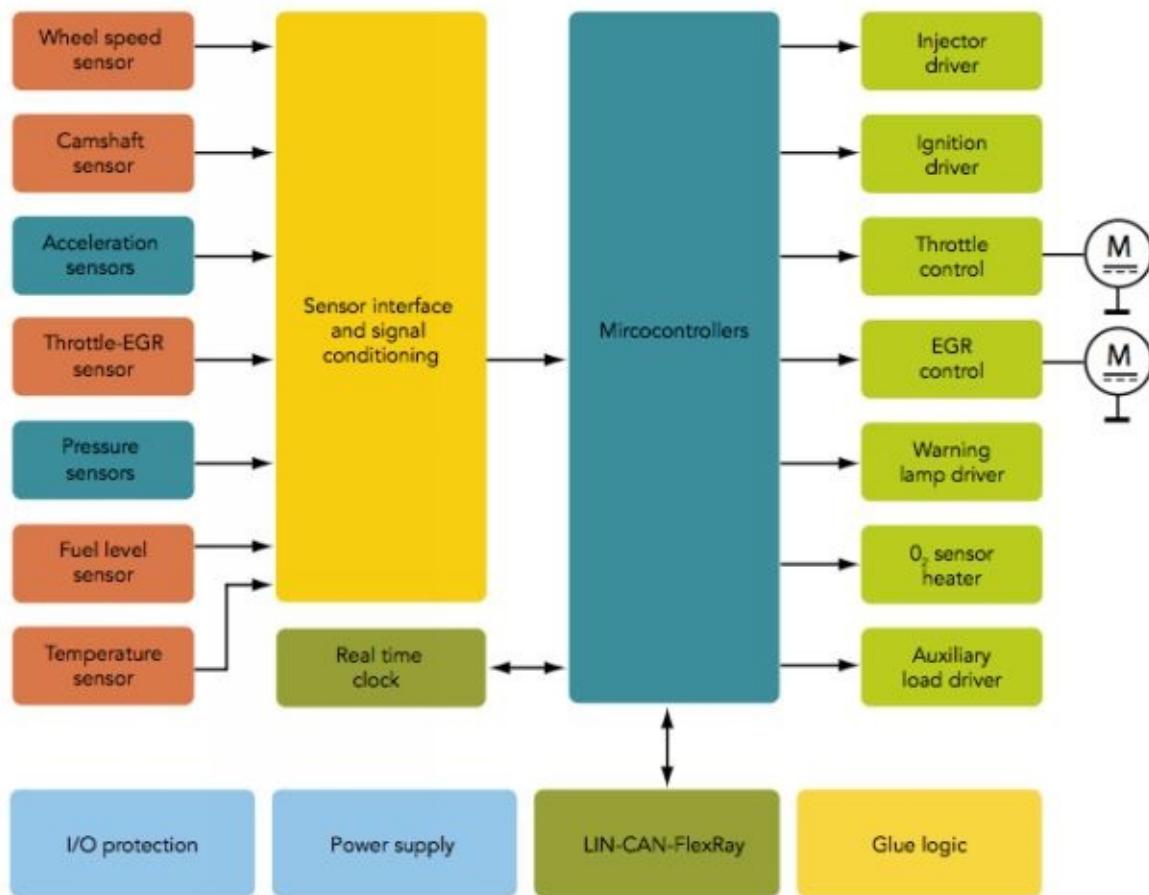
ABS stands for anti-lock brake system, it is sometimes called Hydraulic Control Unit as shown below; it is a computer responsible for managing anti-skid and traction control.



Chapter 6

6.1PCM Architecture

This section will talk about the internal part of the PCM and how each component that makes up the internal part relates to each other as shown in the diagram below;



Above is a simplified block diagram of interconnection of various sensors as input to the sensor interface & signal condition and then eventually to the microprocessor after being processed. A microprocessor evaluates the input processed information and compares it to stored reference data and determines the correct course of action using calculations. A clock crystal provides timing mechanism that ensures that all these calculations are synchronised and

processed in the correct order. The synchronisation allows all the various sensor input data to work in harmony. The clock will definitely improve the performance of microcontrollers. Eventually the microcontrollers will turn ON / OFF actuators.

6.1.1PCM interfaces

The PCM needs interfaces to handle its input and outputs. These interfaces do two main tasks:

- (1) Protect the CPU from voltage surges in electrical circuits
- (2) Converts analogue sensor inputs to binary code for the CPU

6.1.2 PCM internal structure

PCM is made up of four major components that include:

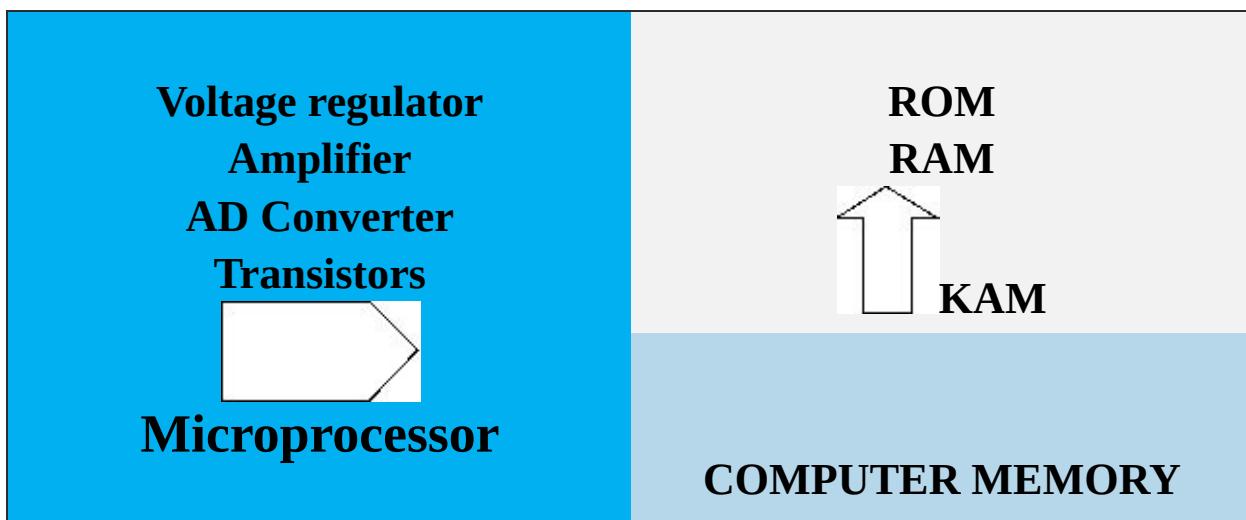
Voltage regulator

Amplifier

ADC

Transistors

Microprocessor



6.1.3 Voltage Regulator

Voltage goes above 12.6V during charging and slightly above 10V during cranking. It is imperative that voltage need to be regulated for stability. A PCM cannot work with fluctuating voltage. Voltage regulator provides 5V reference to most cars.

6.1.4 So what is the importance of 5 V-reference?

It is a signal sent to the sensors by the PCM; the signal will be modified by the sensors and then returned to the PCM so that the PCM knows the sensor value to determine the action to carry forward. It is important for a PCM to have good Ground and Power side connections otherwise there will be too much voltage drop and the reference voltage regulator will not function properly. A minimum of 9.6V is required as input to produce a voltage regulator output of 5V. A good battery is required as well to have a good 5V reference output.

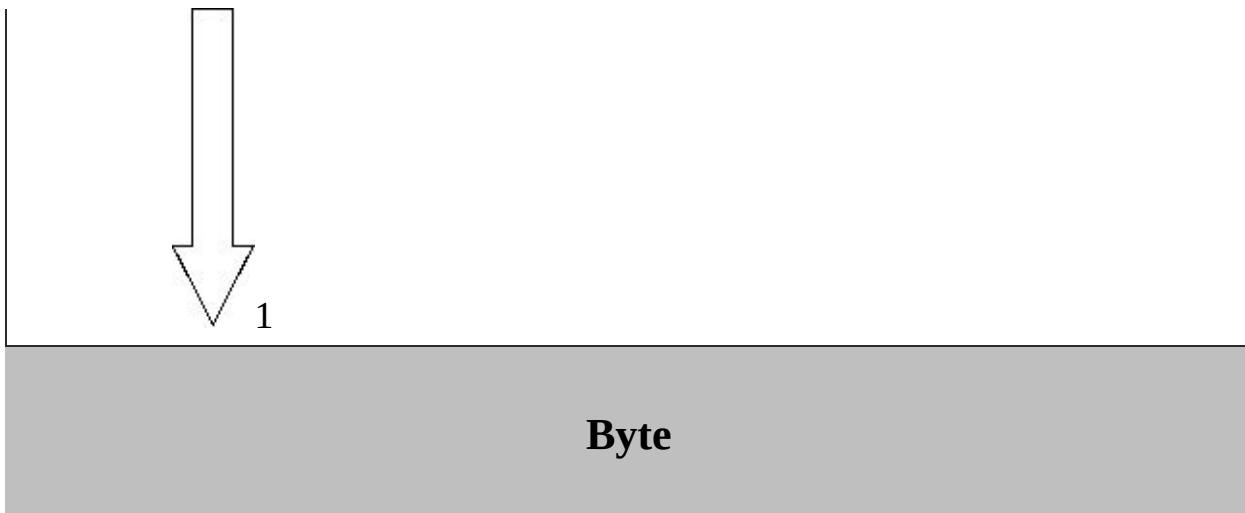
6.1.5 Amplifier

Strengthens and filter out any interference from sensor input signals. Micro processor needs a clean signal.

6.1.6 Analogue to Digital Converter

Takes Analogue sensor signals and converts them into Digital signals that the microprocessor can comprehend. Digital signals are conveyed as “bits” a stream of “1s” or “0s”.

0	1	0	1	0	0	1
---	---	---	---	---	---	---



Byte

Bit

8bits = 1 byte
1 word = 2bytes / 16 bits
2 word = 4bytes / 32 bits

Since there are 8bits it implies that we have $2^8 = 256$ different sequences for 1 byte ranging from 00000000 - 11111111. Characters, letters, decimal digits and special characters are replaced with bytes.

In essence an 8 bit computer has 256 different words in its language. What it means is that an 8 bit computer can divide an input voltage into 256 binary communication for its internal decision making. A TPS sensor has the following voltage specifications: 0.5V @ Closed Throttle (CT)

4.5 V @ Wide Open Throttle (WOT)

Idle = 10 % of WOT

A TPS sensor ranges from 0.5 - 4.5 V, 0 - 255 sequences may be assigned to

each voltage change within that range from 0.5 - 4.5V which are analogue signals. This is done in order to convert each specific analogue voltage reading to digital, the only language that a CPU can only understand.

6.2 Hexadecimal

Scan tools communicate with the PCM and other on-board computers using binary code. This binary code will be converted to hexadecimal values for ease in reading information. As a result scan tools display their information in hexadecimal numbering system. Hexadecimal values are generally referred to as “hexcodes” and may be identified by \$ sign in front of the value.

6.2.1 Binary-to- hex conversion

Binary	Hexadecimal Equivalent	Binary	Hexadecimal Equivalent
0000 =	0	1000 =	8
0001 =	1	1001 =	9
0010 =	2	1010 =	A
0011 =	3	1011 =	B
0100 =	4	1100 =	C
0101 =	5	1101 =	D
0110 =	6	1110 =	E
0111 =	7	1111 =	F

Binary numbers	0011	1111	0100	1101
----------------	------	------	------	------

Hex Codes	3	F	4	D
------------------	---	---	---	---

6.3Microprocessor (CPU)

Evaluates the sensor input information, compares it to stored reference data (Program) and determines the appropriate action. Different PCM memories is utilized *i.e.* ROM, RAM or KAM. The processed information then leaves the PCM in the form of output commands through the Drivers to the various actuators.

6.3.1ROM

ROM stands for read only memory, ROM is built into the PCM during manufacturing and has the primary control over the computer. Microprocessor can only read and not write to it. ROM is responsible for storage of permanent information the PCM uses moreover it contains lookup tables and MAPS and responds to signal inputs. ROM is a non-volatile kind of memory, meaning that it retains its information during Key OFF Engine OFF and even when the battery is disconnected. In brief we can say ROM “remembers” information when power is lost.

6.3.2RAM

RAM stands for Random Access Memory. Microprocessor can only Read / Write to it. RAM is also used by the microprocessor to do maths necessary to do the PCM output, including adaptive strategy value such as fuel trim and storage of accumulated mileage on vehicles with digital odometer. DTCs are also recorded in RAM. RAM exists in twofold; we have volatile and non volatile RAM. Volatile implies that during Key OFF Engine OFF, all information will be erased. In brief we can say volatile RAM “forgets” when power is lost and non

volatile RAM “remembers”.

6.3.3KAM

KAM stands for Keep Alive Memory. It is sometimes called volatile RAM. Similar to RAM except that it is direct connected to the Hot wire so that it receives constant power even at Key OFF Engine OFF. KAM constantly updates its memory and stores new data. This is important because this is where adaptive memory and learned values live. After doing major service like: Sensor replacement

Vacuum leaks

Replacement of clogged air *fuel* filter

It is a good idea to pull the PCM fuse to erase KAM. Otherwise, it will still be using all those learned values that it does not need any more, and may run badly.

6.3.4PROM

PROM stands for Programmable Read Only Memory. Earlier PROMs were removable from the PCM unlike in late model cars whereby it is soldered in PCM. PROM contains very specific engine family information. PROM cannot be written to by a microprocessor however it can be electrically erased and then reprogrammed by external equipment. PROMs have evolved to Electronically Programmable Read Only Memory or EPROMs and now to Electronically Erasable Programmable Read Only Memory or EEPROMs sometimes called Flash EPROMS. EEPROMs and EPROMs can be reprogrammed by external equipment. The information in these memories is protected during power loss.

6.4 Reprogramming a PCM

The PCM need good information to make good decisions. The information comes from various sensor inputs. The PCM need information to understand vehicle operating conditions. With age and high mileage sensors and harness

tend to age as well and therefore will not give good information to the PCM. It is imperative that a PCM will need to be reprogrammed at certain point in time.

6.4.1 Why is it important to reprogram a PCM at certain point in time?

Usually after 60 000 miles the intake vacuum changes; the EGR value takes some time to respond as it ages, therefore cleaning *replacing an EGR may not fix the problem*. A code P1406 is set that indicates the problem with EGR. Therefore a PCM will need reprogramming to flash the PCM with new instructions that allow more time for EGR response.

PCM measures air densities and temperature then stores them. As you drive it uses that stored information / data to decide fuel trim. This implies that during winter or rapid temperature changes the density of air changes and old settings becomes less efficient.

The intake vacuum decreases after 60 000 miles. This creates a rich fuel condition P0172 and P0175. The solution is to flash the PCM with new instruction Fix factory bugs

If a car sets false DTCs

To fix idle roughness problem

Stalling problems

Emission failure

Change the shift characteristics of an automatic transmission

Chapter 7

7.1 Sensing Devices

The PCM need good information all the time to make good decisions. The information comes from various sensor inputs. Sensors in automotive are divided according to three main physical quantities *i.e.*

Velocity

Load

Temperature

Velocity / Position Sensors	Load Sensors	Temperature Sensors
Transmission Turbine Shaft Speed Sensor (TSS)	Fuel Tank Pressure Sensor (FTP)	Engine Coolant Temperature Sensor (ECT)
Vehicle Speed Sensor (VSS)	A/C Pressure Sensor	Intake Air Temperature Sensor (IAT)
Camshaft Position Sensor (CMP)	Manifold Absolute Pressure (MAP)	Transmission Fluid Temperature Sensor (TFT)
Throttle Position Sensor (TPS)	Mass Air Flow Sensor (MAF)	
Crankshaft Position Sensor (CKP)		
	Knock Sensor (KS)	

	Heated Oxygen Sensor (HO ₂)	

7.2PCM inputs / outputs

The table below illustrates PCM inputs & outputs

PCM inputs	PCM outputs
CMP sensor	Fuel Pump Relay
CKP Sensor	MIL
MAP Sensor	IAC Motor
ECT Sensor	EGR Solenoid
IAT Sensor	TCC Solenoid
HO2 Sensor	Fuel Injectors
A/C Pressure Sensor	ICM
TFT Sensor	Ignition Coils
VSS Sensor	Generator Field Current
TPS Sensor	Fan Control relay
KS sensor	A/C Clutch Relay
	EVAP Solenoid
	TPC Solenoid
	TSS Solenoids

Most technicians are now mere parts changers just because they do not know basic electrical / electronic circuits. It is difficult to diagnose, troubleshoot and fix any modern car without having knowledge on sensors and PCM networking with various sensors. This table below gives a summary of various sensor applications and it is important for every technician to understand fully this table below.

Sensor	Application(s)
MAP	Measures manifold absolute Pressure / Vacuum
MAF	Measures the density and volume of air entering the intake manifold
ECT	Measures the engine coolant temperature at all the time
HO2S	Measures the O2 content in the exhaust
CKP	Measures the engine speed
CMP	Signals the position of the camshaft intake lobe relative to the CKP signal & the opening of the intake valve for fuel injection on each cylinder
A/C Pressure Sensor	Measures pressure of the high side A/C line
TFT	Measures the temperature of the transmission fluid
KS	It detects engine knock / detonation

VSS

Measures the transmission speed
which is the vehicle speed

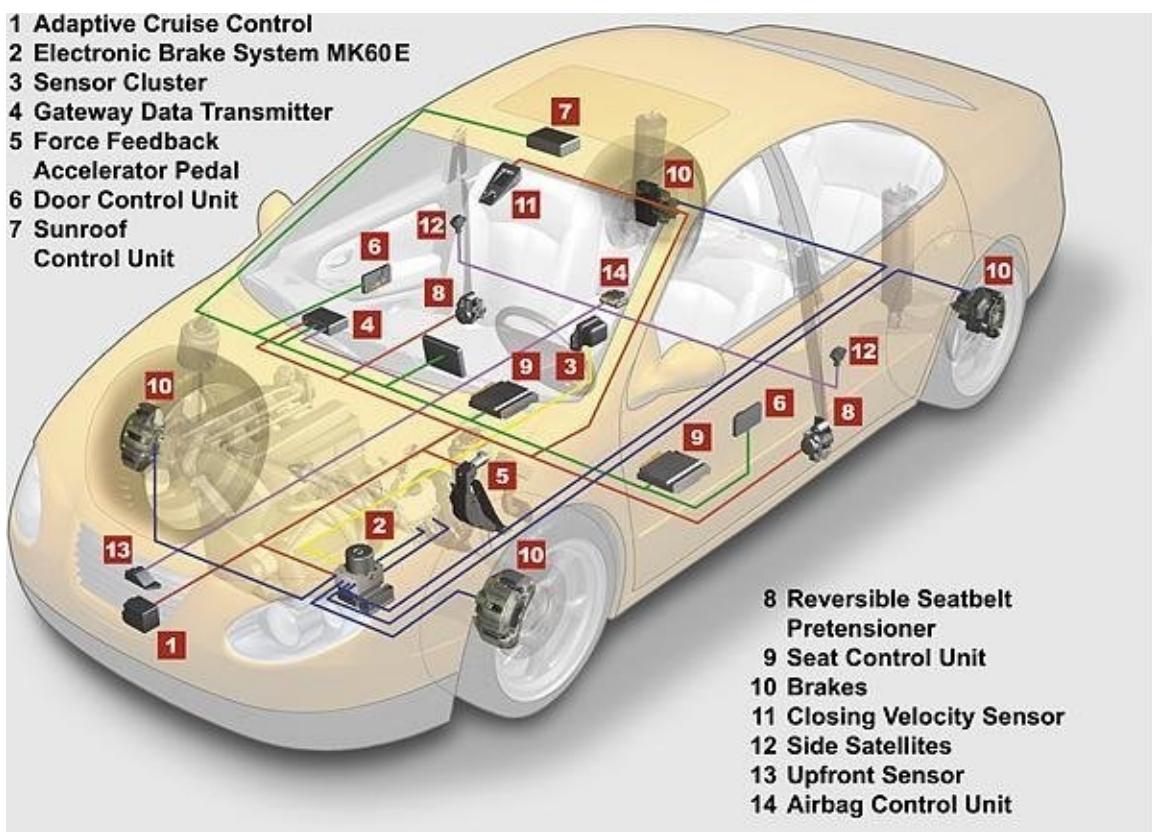


Fig 7.2.1: Network of sensors as found in various vehicles

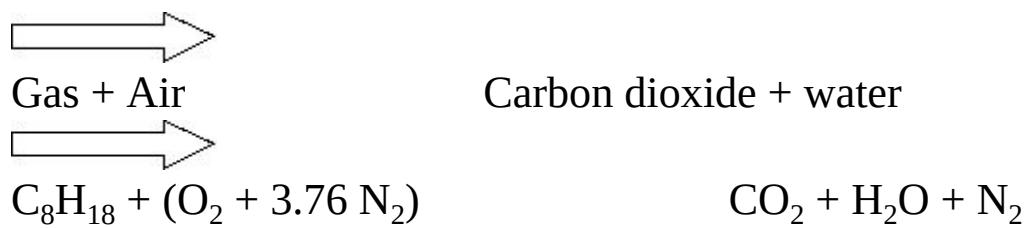
Chapter 8

8.1 Ideal Air / Fuel Ratio

Air is a mixture of gases mostly Nitrogen (N₂) = 78 %
& Oxygen (O₂) = 21 %

Therefore every molecule of O₂ we have 3.76 N₂

The equation of combustion says:



After balancing the equation we have:



$$\frac{(12.5 \cdot 16.2) + 12.5(3.76 \cdot 28)}{8(12) + 1(18)}$$

$$= 15: 1$$

Assumptions made

Octane is not pure. We assumed that it's pure.

Nitrogen cannot be exactly 79%

Because of those assumptions the ideal air / fuel ratio becomes 14.7: 1

The 14.7:1 ratio implies that we have 14.7 parts of air to 1 part of fuel as measured by weight. This ratio has to be maintained in a vehicle under all the various driving conditions like cold start, idling in heavy traffic, cruising on a freeway, driving up an inclined surface *etc.*

8.1.1 So why 14.7:1 air / fuel ratio in modern cars

Provides low emissions since by maximising the production of CO_2 & H_2O and therefore this minimises the potential production of CO, HC & NO_x

Good fuel economy

Provides enough power for the engine load

In brief we can say that the ideal fuel ratio ensures that we do not have O_2 & fuel left over after combustion process. Lean mixture can damage the engine due to the longer residence time of combustion taking place in the cylinder. Moreover lean mixture lead to the overproduction of NO_x this will cause uncontrolled engine overheating problems which may lead to engine destruction.

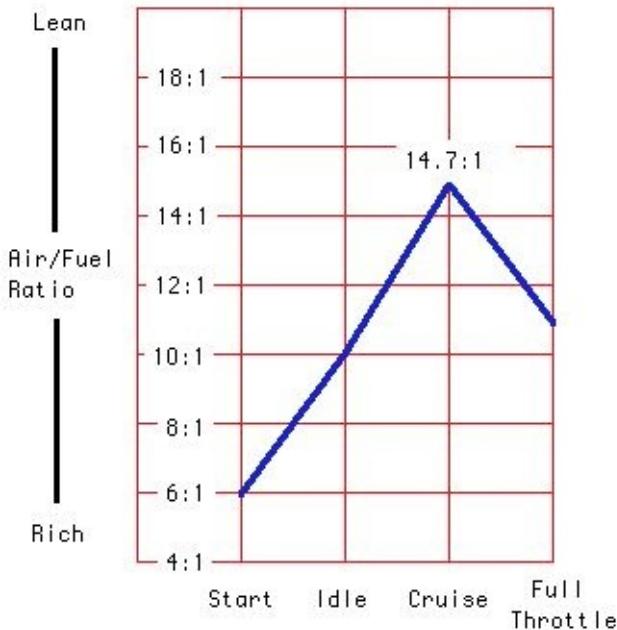


Fig 8.1.1: Summary of air-fuel ratios at different vehicle modes, the ideal air fuel ratio is achieved during cruising mode.

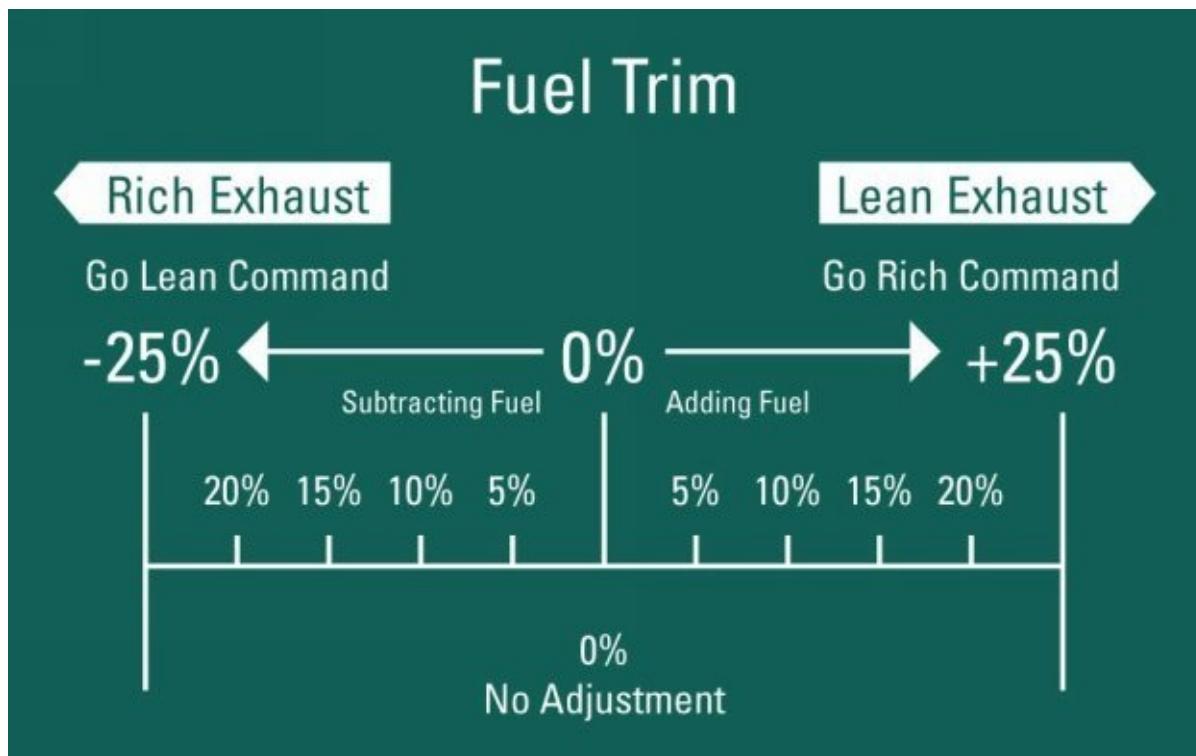
8.1.2 Fuel trim

Most fuel problems are caused by defective MAP, MAF, IAT, TPS and vacuum leaks. A proper understanding of sensors and fuel trims can result in quicker diagnosis and alert the technician of any pending problem with your car.

Most fuel trim numbers are expressed as either positive or negative. A PCM is designed to achieve ideal and chemically perfect 14.7: 1 air / fuel ratio. This is the ratio that we assume a complete combustion of hydrocarbons and oxygen.

A +15% number indicates that PCM is adding 15% more fuel than originally calculated to achieve ratio 14.7 : 1 for a particular driving cycle. A +15% fuel trim is a response to the engine lean conditions. A -15% number indicates that the PCM is subtracting fuel. GM motors use a different numerical system in which 128 is considered zero fuel trim. Numbers above 128 indicates that PCM is adding fuel and numbers below 128 indicates that the PCM is subtracting fuel. The process of adding or subtracting fuel to achieve a chemically perfect

14.7 : 1 air / fuel ratio is known as fuel trim. Fuel trim can be categorised as short term fuel trim (STFT) or long term fuel trim (LTFT). The HO2S are the drivers of fuel trim such that changes in HO2S voltages will cause a direct change in fuel injection. When fuel trim consists of more than two digits number being added / subtracted a DTC will be set.



8.1.3 STFT

STFT1 is specifically for bank 1

STFT2 is specifically for bank 2

STFT is the PCM's immediate response to adjust the air / fuel ratio up to a certain optimum level whereby there is no more fluctuations between lean and rich. It is at this point that the LTFT is introduced. STFT occurs several times per second.

+ve fuel trim is fuel addition in response to a lean condition

-ve fuel trim is fuel subtraction in response to a rich condition

STFT is a quick response to O2 sensor input. STFT is not stored in KAM implying that at Key off Engine Off all information will be lost and automatically resets to zero for the next drive cycle

8.1.4 LTFT

LTFT1 is specifically for bank 1

LTFT is specifically for bank 2

LTFT is learned over a period of time whilst in close loop. To be more precise LTFT is defined as changes in STFT averaged over a long period of time. It is stored in the KAM so that it can be used for open loop calculation like cold start, WOT, *etc.*

NOTE: It is good to evaluate fuel trim at idle or at rpm between 2000 - 2500 for meaningful results.

8.1.5 What is the normal STFT & LTFT?

A STFT should generally fluctuate between negative and positive single digits maximum of 3times / second. Usually STFT stays around 5% if the engine is still good. However it might go up to close 10% as the engine ages, components ages, vacuum leaks and some other variable factors. A normal LTFT since it is the average of STFT over a long period of time. Under normal engine operating conditions LTFT should be close to zero or negative or positive single digits.

LTFT fluctuates very slowly almost static unlike STFT that do many times per second. A double digit STFT will set a DTC. An engine running lean will set a DTC, P0171 or P0174. Conversely if the engine is running rich a DTC, P0172 or P0175 will be set.

8.1.6 Explaining STFT and LTFT of an engine running lean

If a car has a vacuum leak leading to unmetered air reaching the intake manifold, the HO2S will detect too much O2 in the exhaust manifold and will run lean. The PCM will notice abnormality in the waveform and will compensate to that by adding more fuel.

As the fuel is added by the PCM the STFT will start to increase immediately. While the PCM is adding the fuel it has to simultaneously monitor the HO2S until the HO2S no longer indicates the lean condition and ideal air / fuel ratio is met. The PCM will maintain this further fuel addition until the leakage is corrected. The scan tool will show both STFT and LTFT with readings greater than 10%.

NOTE: PCM can only trim fuel to a maximum calibration of 25%.

8.1.7 Importance of fuel trim

Once we have a +ve fuel trim make us aware of the vacuum leak in the intake manifold, bad HO2S, low fuel pressure due to restriction, bad pump, bad fuel regulator *etc.*

-ve fuel trim respond to rich condition due to leaking fuel injector, a faulty pressure regulator, a bad HO2S *etc.*

Fuel trim gives a quick overview of the courses of engine under performance
Fuel trim help to fix a problem if no DTC is set in a vehicle

8.2 A rich fuel condition

8.2.1 Causes of rich condition

Leaking fuel injector

A faulty pressure regulator leading to uncontrolled pressure

A faulty ECT

A stuck open thermostat

Dripping fuel injectors

Damaged or disconnected vacuum line to the intake manifold

Stuck open purge solenoid of EVAP canister

Exhaust leaks like pinholes before the HO2S

Low compression
Incorrect camshaft timing
MAF sensor problems

NOTE: If intake manifold is loose *vacuum line damaged* left disconnected this will lead to a lean mixture, the PCM will notice a difference in the air / fuel ratio. The PCM will then compensate for the lean mixture by holding the injector open for longer period of time resulting in an enriched mixture.

8.2.2 Symptoms of rich / fuel condition

Black exhaust smoke
Fouled spark plugs
Poor engine performance
Poor fuel economy

8.3 A lean fuel condition

A lean fuel condition occurs when air / fuel ratio is more than 14.7:1.

8.3.1 Causes of lean condition

Fuel delivery issues
Water contaminated fuel
Low fuel pressure
Restricted fuel pressure
MAF problems
HO2S faults
Vacuum leaks from intake gaskets / hoses
Unmetered air
Clogged or dirty fuel injectors

Exhaust restrictions causing back pressure

Exhaust leaks

Loose HO2S thereby allowing extra O₂ into the exhaust manifold

Typically the check engine light is illuminated if the 10% is added / subtracted from the ideal ratio.

8.3.2 Diagnosis of a lean condition using freeze frame data

RPM	850	2 500
STFT	+20%	+2%
LTFT	+13%	-1%
MAF	1.4 g/s	37.2 g/s
ECT	195 ° F	195 ° F
TPS	1.0%	15%
GEAR	P	P

The above data was taken from a vehicle equipped with a 4 cylinder engine. The vehicle has an illuminated MIL and stored system too lean (Bank1) DTC. So we are to verify the causes of the problem using STFT & LTFT data analysis.

The fuel trim correction at idle is very positive indicating a lean condition. At higher engine RPM there is very little trim correction. This problem is caused by unmetered air entering the intake manifold system and is mostly predominant at low engine RPM. At higher engine RPM more air enters the intake manifold

system and the leak becomes insignificant. In conclusion the causes of this problem are a vacuum leak. A regulated smoke gas is supposed to be injected into the system to check the leak.

Chapter 9

9.1 Sensors used to calculate air / fuel ratio

A PCM uses the following sensors as input to calculate air / fuel ratio:

ECT Engine Coolant Temperature

IAT Intake Air Temperature

TPS Throttle Position Sensor

HO2S Heated O2 Sensor (**Fuel trim**) MAP Manifold Absolute Sensor

Inputs	PCM	Outputs
HO2S		Injector # 1
 MAP		Injector # 2
ECT		Injector # 3
IAT		Injector # 4
TPS		Injector # 5
		Injector # 6

9.1.1 ECT

ECT is a variable resistor sensor commonly called NTC thermistor. The sensor voltage changes according to temperature of the engine coolant stream. The resistance of the sensor decreases with increasing coolant temperature or vice versa. This means that the sensor decreases in resistance as engine warms up to operating temperature. The sensor values range from -40°F to 248°F (-40°C to 120°C). At 212°F (100°C), the sensor reading is 0.46 volts and resistance around

177Ω . The ECT sensor voltage increases with increasing resistance, the voltage signal will be sent to the PCM.

The ECT sensor maintains engine operating temperature and is located in the coolant stream usually around thermostat housing or the intake manifold. This sensor senses the engine coolant temperature all the time.

Temperature ° F	Temperature ° C	Sensor Voltage	Ohms Ω
248	120	0.25	—
212	100	0.46	177
176	80	0.84	332
150	66	1.34	—
140	60	1.55	667
104	40	2.27	1 459
86	30	2.60	2 238
68	20	2.93	3 520
32	0	3.59	9 420
-4	-20	4.24	28 680
-40	-40	4.90	100 70

Fig4: Temperature, Voltage and Resistance relationships of ECT, IAT sensors.

9.1.2 Importance of the ECT input signal to the PCM

Input of the ECT may be used by the PCM for the following control functions:

- Start up fuel enrichment on fuel injected engines. When PCM receives a cold signal from ECT it increases the PW of an injector to create a richer fuel mixture.

- Purge Solenoid of EVAP to remain closed until engine warm up
- Idle speed control. The PCM will usually increase idle speed when cold engine is first started to prevent stalling
- Operation of the cooling fan depends entirely on the ECT
- The ECT signal controls the TCC. Solenoid is energized when engine coolant temperature reaches 150 ° F (66 °C) & vehicle is at 40 mph

9.1.3 DTCs associated with ECT failures

P0116 Engine Coolant Temperature Circuit Range/Performance

P0117 Engine Coolant Temperature Circuit Low Input

P0118 Engine Coolant Temperature Circuit High Input

9.1.4 ECT Sensor diagnosis

- Perform visual inspection to check for corrosion, shorts and loose connections
- Use a DMM to check for resistance and compare to specifications, low resistance shorted sensor, high resistance open sensor. Such a sensor should be replaced.
- If the resistance of ECT is OK but the engine fails to enter closed loop status, then the fault is with wiring / PCM.

9.2 IAT

Intake Air Temperature sensor is an NTC thermistor that changes its resistance according to intake air temperature. The PCM will provide a rich air fuel ratio as cool air passes the sensor. This is because cool air is denser than warm air. IAT sensor just like the ECT sensor increases in voltage reading as the temperature drops.

9.2.1 Problems caused by bad IAT

- Extended starting time

- Miscalculation of air/fuel mixture
- Affect the EGR valve opening in some cars

9.2.2 DTCs associated with ECT failures

P0111 IAT sensor 1 circuit, range / performance problem
P0112 IAT sensor 1circuit, low input

P0113 IAT sensor circuit, high input

P0114 IAT sensor circuit, intermittent failure

IAT diagnosis steps are just similar to ECT diagnosis steps above.

9.3 TPS

Throttle Position Sensor (TPS) is a 3 wire non-adjustable potentiometer that indicates throttle angle to the PCM. As the throttle angle varies voltage varies as well. Voltage reading varies from 0.45V-4.5V.

Closed throttle = 0.45V

WOT = 4.5V

Closed throttle = 10% WOT

The information above will be used to control injector pulse width & timing. The fuel injectors and ignition timing are adjusted by the PCM as the throttle plate is moved. If a vehicle is accelerated to WOT the PCM would read 4.5V signal.

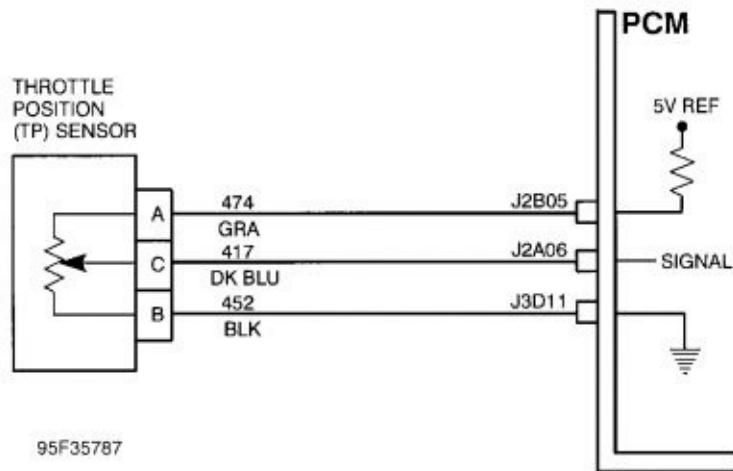


Fig9.3: A 1996 Saturn TPS connected to the PCM. Gray wire being the 5V-ref, Dark wire being the signal & Black wire being the ground.

9.3.1Common symptoms of a bad TPS sensor

Delayed acceleration

Random stalling, this may occur during idling / engine running

Sudden surge in car's speed especially in highway

Difficult to change gears

Poor fuel economy

Rough idling

Bucking and jerking in the vehicle

Transmission shifting problems

9.3.2Diagnosis of a bad TPS sensor

- Check the TPS adjustment before you do anything.
- Check for terminal corrosion and loose connections
- Check the voltage changes on a scan tool using live data at idle, closed throttle and WOT.
- Check for good ground & 5V-reference using a DMM.

9.3.2 TPS waveforms

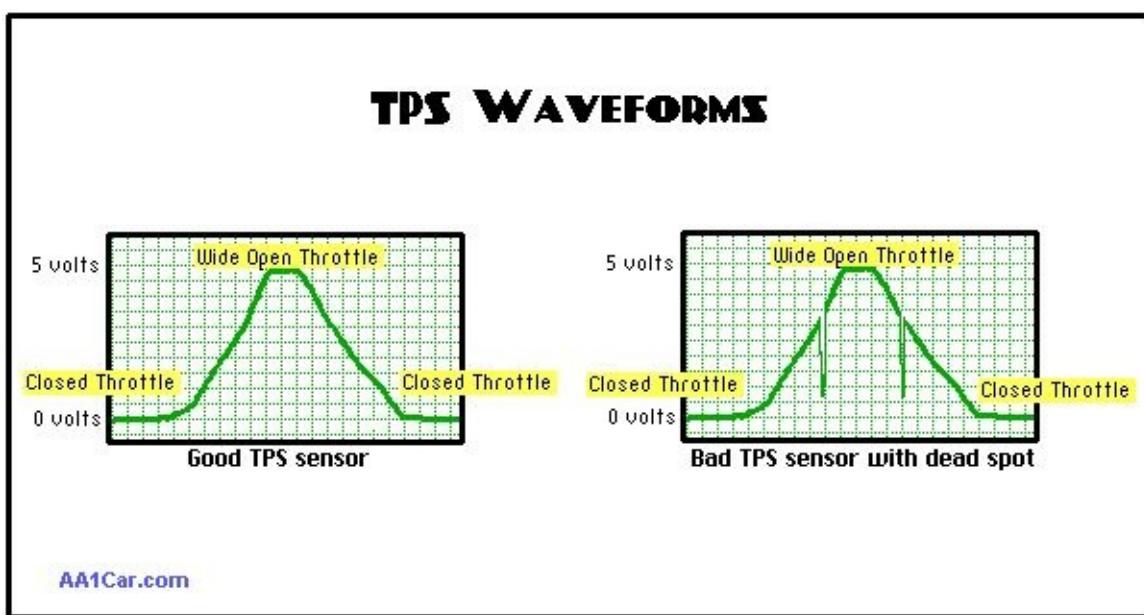


Fig 9.3.2: illustration of TPS waveforms[\[6\]](#)

9.4 O2 Sensor

Lean is low O2: 0 - 0.45V

Rich is high: 0.45 - 1.0V

KOEO: 0V

The O2 sensor provides a voltage signal between 0 & 1 Volt. This voltage varies according to the O2 content in the exhaust system.

Once O2 sensor reaches 600 ° F it begins to create its own voltage, this is a closed loop status. In closed loop mode the PCM attempts to maintain 14.7: 1. O2 sensors contain zirconium or titanium and two different plates. One plate is exposed to the atmosphere and the other exposed to the exhaust manifold. Amount of voltage generated depends on an imbalance between the O2 in the ambient air and O2 inside the exhaust. If the difference is high, sensor generates a higher voltage, more fuel combine with O2; less is left in the exhaust manifold. If the difference is low, sensor generates low voltage implying lot of O2 in the exhaust manifold and usually indicates lean fuel / air mixture.

Most O2S have 3 / 4 wires, usually Grey / Black wire stand for signal and white stand for heater.

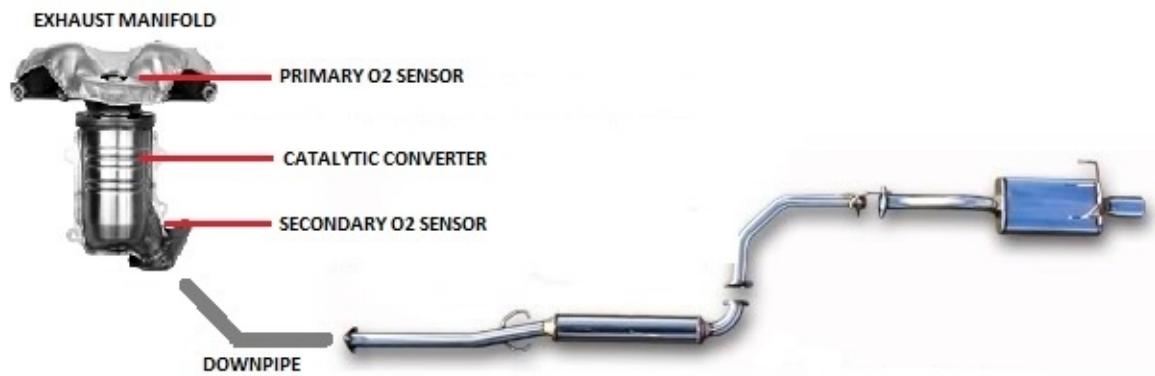
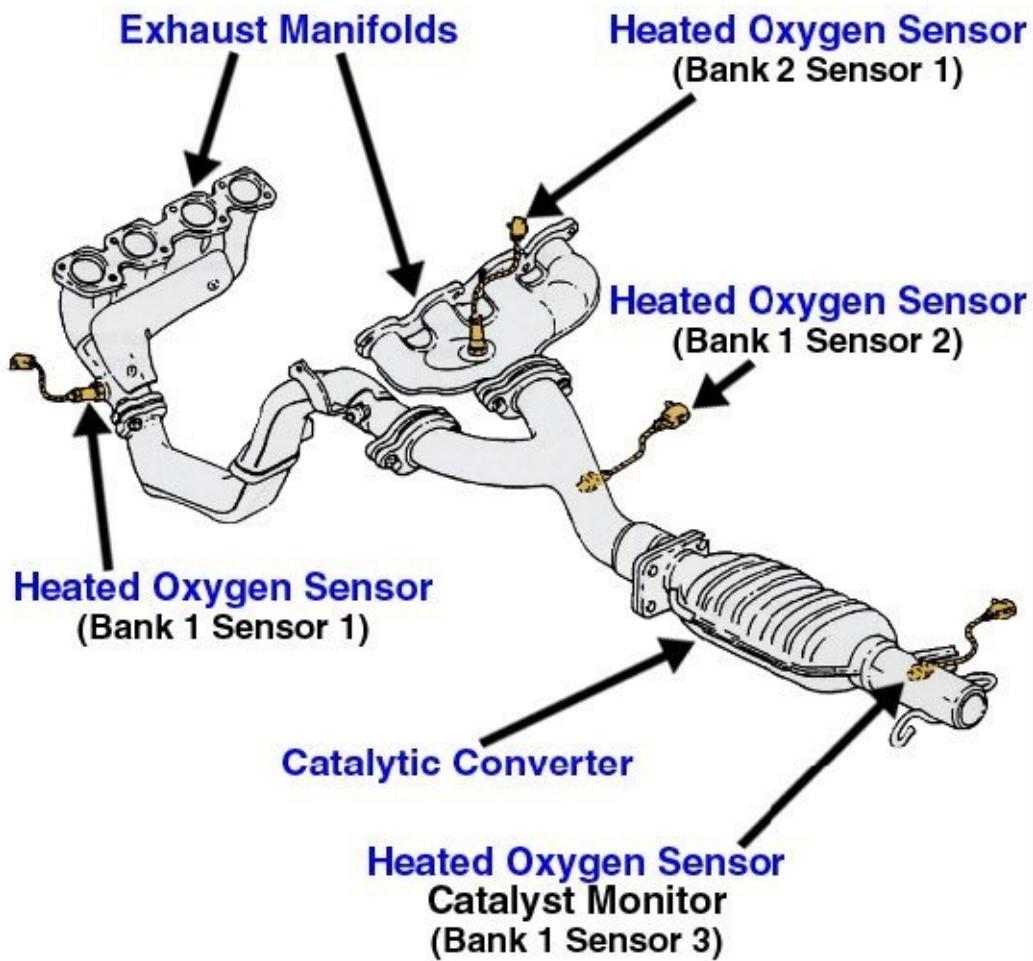


Fig9.4: An illustration of an exhaust manifold.

9.4.1 HO2 Sensor locations



According to the above diagram, **Bank 1 Sensor 1**, **Bank 1 Sensor 2** & **Bank 2 Sensor 1** (Upstream sensors) are used for closed operation and OBDII monitoring. **Bank 1 Sensor 3** (Downstream sensor) and is used for OBD II monitoring of catalytic converters. Catalytic Converter has to be hot for a while before attaining a good signal output.

9.4.2 Symptoms of a bad HO2S

Poor fuel economy. A defective HO2S will likely cause air / fuel mixture to be rich

Stalling

Hesitation during acceleration

Spark knock

9.4.3 Causes

A faulty HO2S

Loose electrical wiring connections

Bad ground

Burnt HO2S fuse

High resistance in the circuit

Opens / shorts in the circuit

PCM problems

9.4.4 Troubleshooting HO2S problems

If a code related to HO2S is set a technician should do the following steps listed below in order to mitigate the problem: The first thing to do is to check the integrity of HO2S fuse

If fuse is not blown then check for a loose electrical connections and unwanted resistances as well. If everything is OK then you have to disconnect the sensor and measure the resistance across the heater, an open indicates a damaged heater and low resistance below the specs indicates a shorted heater. If the resistance of the HO2S is according to spec then the following should be done: Reconnect the HO2S and back probe the ground and signal wire of the HO2S and measure the voltage changes at idle (cold), idle (warm), acceleration and deceleration using DMM. The test results should correspond to the values given below:

Condition	Voltage across HO2SS & SRTN
KOEoff	0V
Idle (cold)	0 V
Idle (warm)	0 - 1.0V

Acceleration	0.5V - 1.0V
Deceleration	0 - 0.5V

If the voltage readings are approximately equal to those in the table, then the sensor is okay.

If the readings are different then replace the HO2S, if the problem still persists after sensor replacement then check the PCM.

It is advisable to buy a new HO2S from a dealer because aftermarket HO2S may give lousy voltage readings. A scan tool can be used as well to check the voltage changes of an HO2S.

NOTE: If a car is found to have a defective head gasket or a cracked head an HO2S sensor might have to be replaced since additives in conventional coolant such as silicates and phosphates can coat the HO2S causing the sensor to give false readings.

9.4.5 Oxygen sensor waveforms

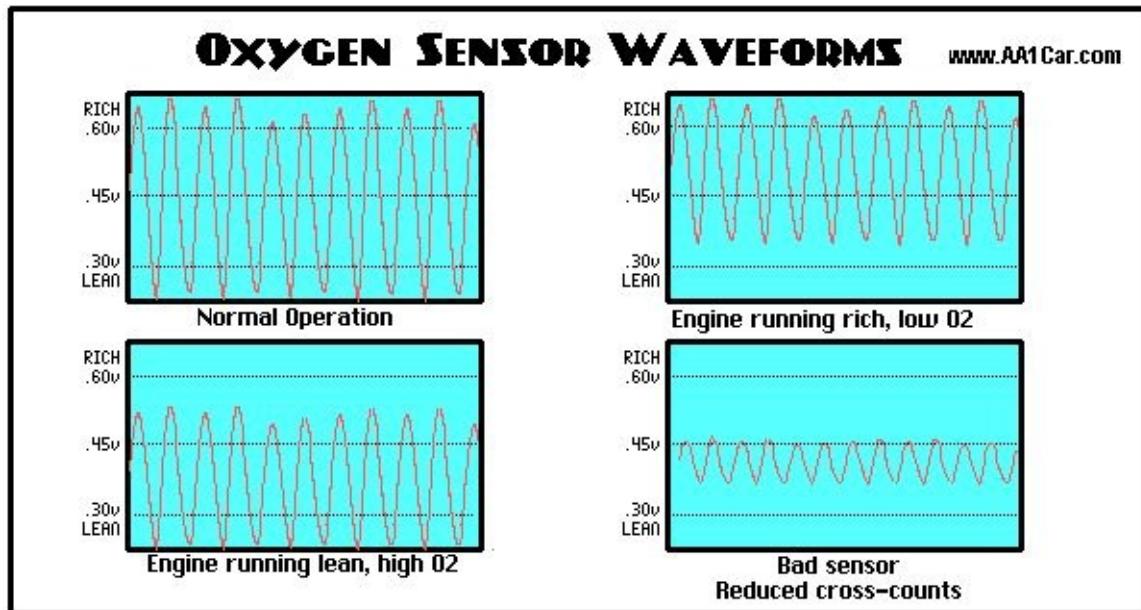


Fig 9.4.5: illustration of various oxygen sensor waveforms [7]

9.5 Closed & Open loop mode

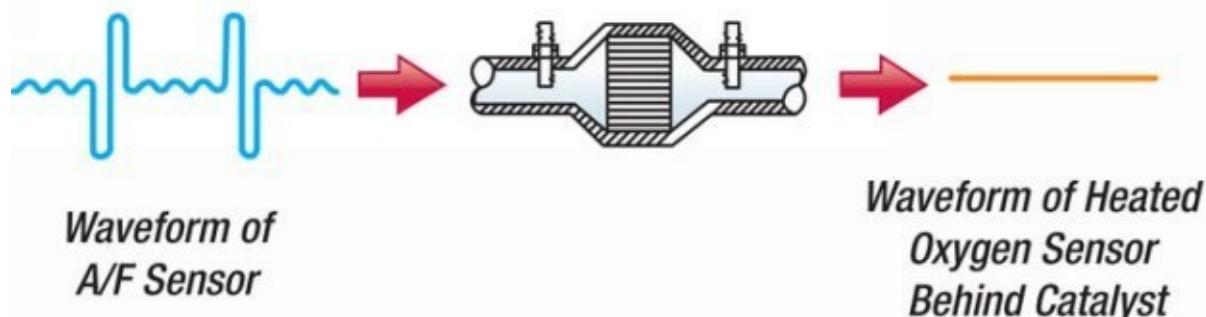
During closed loop O2 sensor start communicating with the PCM. The system goes on open loop mode on cold, WOT and high load conditions. The HO2S signal is ignored by the PCM; the PCM will enrich the mixture to accommodate immediate demand. In open mode fuel injector pulse width is calculated from various sensors combined with the engine speed.

9.6 PCM does not go to close loop

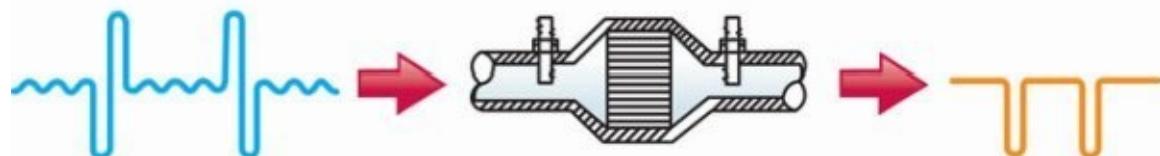
Chances are high that the ECT / HO2S is not working properly. A technician should perform a thorough visual inspection on those sensors.

9.7 Signal output as a result of a good / bad Catalytic Converter

Normal Catalyst



Abnormal Catalyst



9.7.1 Testing for the integrity of catalytic converters

An infra red thermometer may be used, large differences in temperatures at a point before and after the catalytic converter illustrates a bad catalytic converter,

acceptable temperature difference should be between 25 - 50 ° F.

A vacuum gauge may be used to check the integrity of a catalytic converter, when a needle drops steady during acceleration is an indication of a failed catalytic converter.

A failed catalytic converter will cause numerous driveability problems.

A bad catalytic converter will give wrong information to the HO2S which will then misinform the PCM

A scan tool data can be used, STFT, LTFT & HO2S information can be used to verify the integrity of catalytic converters.

Downstream HO2S can tell us the efficiency of the catalytic converters

NOTE: A clogged catalytic converter causes excessive backpressure in the exhaust manifold; this may trick the MAP sensor into indicating there is a load on the engine. This may result in rich condition.

A restricted exhaust does not set a DTC.

9.7.2 Diagnosis of catalytic inefficiency using sensor live data

RPM	3000	HO2S
Sensors	CLSD	
HO2S11 (mV)		HO2S21 (mV)
680		545
HO2S12 (mV)		HO2S22 (mV)
730		690
STFT 1 (%)		STFT 2 (%)
-5		10
LTFT 1 (%)		LTFT 2 (%)
-30		28
FUEL PW1 (mS)		FUEL PW1 (mS)
9.6		14.9

The above information shows sensor live data of a certain car that can be used to diagnose catalytic inefficiency. The LTFT of Bank 2 indicates that the Bank 2 primary catalytic converter is clogged. A clogged catalytic converter causes a backpressure, this effect will make a MAP sensor into thinking that the car is under an extra load and thus the PCM will command the injectors to lengthen their ON time and hence the LTFT & STFT will indicate a rich condition as shown in the table above.

9.8 MAP / BARO Sensor

MAP sensor stand for manifold absolute pressure, it measures pressure / vacuum changes inside the intake manifold when the engine is running. Pressure inside the intake manifold indicates engine load. Vacuum is created during intake stroke whereby air is drawn in during this process. Vacuum is defined as a pressure less than 14.7 psi which is the atmospheric pressure.

$$14.7 \text{ psi} = 101.3 \text{ KPa}$$

Barometric Pressure - MAP reading = intake manifold vacuum

A PCM supplies 5V to the MAP sensor, a resistor inside the MAP moves relative to the intake manifold pressure between 1 - 4.5V depending on intake manifold pressure which signifies engine load. The voltage signal will be returned to the PCM to indicate manifold absolute pressure / vacuum.

9.8.1 MAP principle of operation

Engine mode	Pressure	Vacuum	Voltage Signal
WOT	↑	↓	↑

Idle	↓	↑	↓
CT	= 101.3 KPa	= 0 ↓	= 4.0 V ↑

9.8.2 MAP sensor voltage, vacuum & pressure relationships

Vacuum at sea level (Inc. Hg)	Manifold Absolute Pressure (kPa)	Sensor Voltage	Fuel Mixture
0	101.3	4.0	
3	91.2	3.5	Rich
6	81.0	3.0	
9	70.8	2.5	
12	60.7	2.0	
15	50.5	1.5	
18	40.4	1.0	
21	30.2	0.5	↓
24	20.0	0.0	Lean

The table above shows that as the manifold absolute pressure increases the car will start to run rich. This is because the engine load increases with increase in manifold pressure and hence the PCM has to command the injector pulse width to be prolonged to compensate for this load increment. The diagram below is an

electrical wiring diagram of a MAP sensor connected to the PCM. Inside the MAP sensor is a variable resistor that changes its resistance relative to engine pressure. When the pressure is high the diaphragm pushes the variable resistor close to the 5V-reference. However when the pressure is low the variable resistor reads far lower than the 5V-reference signal, the diaphragm will be pulled by vacuum in the opposite direction. The measured signal will be sent back to the PCM via the MAP sensor signal. If the pressure is high the PCM will command the fuel injectors to open up over a period of time so that the engine produces more power. At the same time the PCM will retard the ignition slightly to prevent detonation that can completely destroy the engine and affect its performance. If the pressure is low (high vacuum) the PCM will command the injectors to open over short period of time so that the engine produces less power. At the same time the PCM will advance the ignition timing for good fuel economy. The MAP sensor signal is also used by a transmission computer to help to decide when to shift the gears. Some GM cars use a MAP sensor for this purpose. I remember having a hard shift on my transmission of Chevrolet Malibu 2003 model for a while, after a thorough visual inspection and scan tool live data analysis I discovered that the MAP sensor was disconnected. By reconnecting the MAP sensor I then fixed the hard shifting problem.

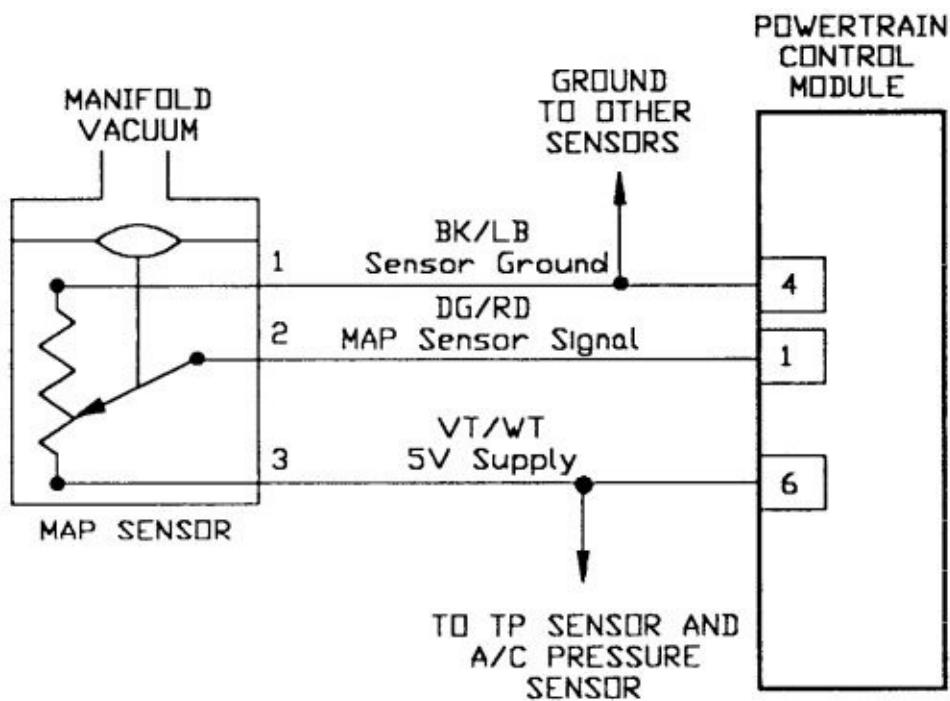


Fig 9.8.2: illustration of internal components of MAP sensor

9.8.3 Symptoms of a bad MAP sensor

DTC P0170 is present

Bad fuel economy

Extended cranking time

Black smoke coming out of the tailpipe

Hesitation during acceleration

Gear shifting problems

Rough idle

Spark plug fouling due to rich condition

9.8.4Most common causes

A bad MAP sensor

Loose or broken electrical wiring connections

Engine with low compression

A fuel pump not supplying not enough volume

A timing belt that is not synchronised correctly

A bad PCM

Loose / damaged vacuum hose

Shorted MAP sensor

Bad EGR / EGR leaks

Clogged air filter

Chapter 10

10.1 Introduction to Emission Control

An internal combustion engine emits 3-major pollutants into the air: hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x).

Moreover an internal combustion engine also gives off many small liquid or solid particles such as sulphur, lead, carbon and other particles which contribute to pollution.

10.1.1 Hydrocarbons (HC)

Hydrocarbons are the main components that make up all fossil fuels. Gasoline is a fossil fuel and therefore made up of hydrocarbons. The three major sources of hydrocarbon emissions in an automobile are as follows: [1]

Fuel system evaporation - 20%

Crankcase vapors - 20%

Engine exhaust - 60%

10.1.2 Carbon monoxide (CO)

CO gas is a product of incomplete combustion of hydrocarbons. A rich mixture will often result in incomplete combustion. To make a complete combustion the ideal stoichiometric ratio of 14.7:1 should be met in the combustion process in order to produce a required CO₂.

10.1.3 Oxides of Nitrogen (NO_x) Air is a mixture of gases: 78% Nitrogen,

21% Oxygen and 1% other gases. When the combustion chamber temperature reaches 2 500 ° F (1 371 ° C) or greater, the Nitrogen and Oxygen in the air-fuel mixture combine to form large quantities of oxides of nitrogen (NO_x). This chemical reaction requires large amount of temperatures since Nitrogen molecule is made up of triple bonds that requires large quantities of energy to break. NO_x & HC levels have to be monitored to avoid pollution and some other environmental degradation.

NO_x can be lowered by cooling the combustion chamber through the use of EGR and HC levels can be lowered by the use of the PCV and the EVAP system. This chapter will explain exactly how these major pollutants can be reduced.

Chapter 11

11.1 Automotive Emission Controls

Automotive emission controls employs the EVAP System, PCV System and the EGR System.

11.1.1 EVAP System

Evaporative emission controls (EVAP) system controls the evaporation of HC vapors from the fuel tank, pump, carburetor and fuel lines from escaping into the atmosphere. It achieves that by containing, storing & sending evaporative gas mixed with air to the intake manifold for combustion purposes in order to keep the environment clean and improve gas economy. The EVAP system is made up of the following listed below components: Non-vented gas cap

Sealed fuel tank

Purge canister solenoid

Vent solenoid

Storage carbon canister

Fuel tank pressure sensor

Fuel evaporates within the tank and the vapors need to be safely removed, drawn through the lines to the carbon canister storage. When the engine is running these gases are purged from the canister to the intake manifold. The process happens as follows: At WOT, the PCM commands the purge and vent solenoid to open, when the purge opens fuel is drawn from the tank and storage canister, canister vent allow air in to mix with the gas in the carbon canister.

Once at KOEO the PCM waits a predetermined amount of time before it proceeds to check the pressure sensor. If the pressure inside the tank is greater than ≈ 1.5 in. H₂O then the test is aborted. If the pressure is within the range the

pressure sensor by the PCM and the canister vent solenoid is commanded to close sealing the EVAP system. All this happens at KOEO.

The PCM monitors any pressure drop inside the tank and if everything is OK, the PCM commands normal operation. If the PCM detects a drop in pressure it knows that there is a leak somewhere within the EVAP system. To determine the size of the leak it sets a pending code until a drive cycle / trip is completed. If the problem exists after the trip MIL will be illuminated. Pressure changes can be caused by a loose gas cap, some external leakages on the EVAP system and rapid temperature changes. A vehicle with enhanced EVAP system will turn ON MIL due to small leak. The gas cap contains a vacuum and pressure relief valve; a small leak will be indicated.

11.1.2 Common EVAP DTCs

P0440 - vacuum deficiency

P0441 - no flow during purge cycle

P0442, P0456, P0457 - small leak

P0455 - large leak

P0443, P0446, P0449 - purge solenoid (blocked / inactivated)

11.1.3 Dealing with common EVAP DTCs

If you find a P0440 & P0455 DTC, first check to verify if the gas cap is tightly closed, a click sound is normally heard if the cap is tightly closed.

If the above condition is met remove the gas cap to check for any form of damage.

After doing the above and if still the problem persists replace the gas cap. If it doesn't solve the problem, check for leaks using a smoke machine. Smoke is passed through a green port of the EVAP system in some other car like GM motors.

P0443, P0446 and P0449 DTC, first check the resistance of the purge solenoid to verify if the resistance is according to spec. A good solenoid's resistance should

normally not exceed 50Ω

NOTE: Cracked / disconnected hoses would result in vapor odor.

If the EVAP system purges vapors from the canister at idle, rough idle will result.

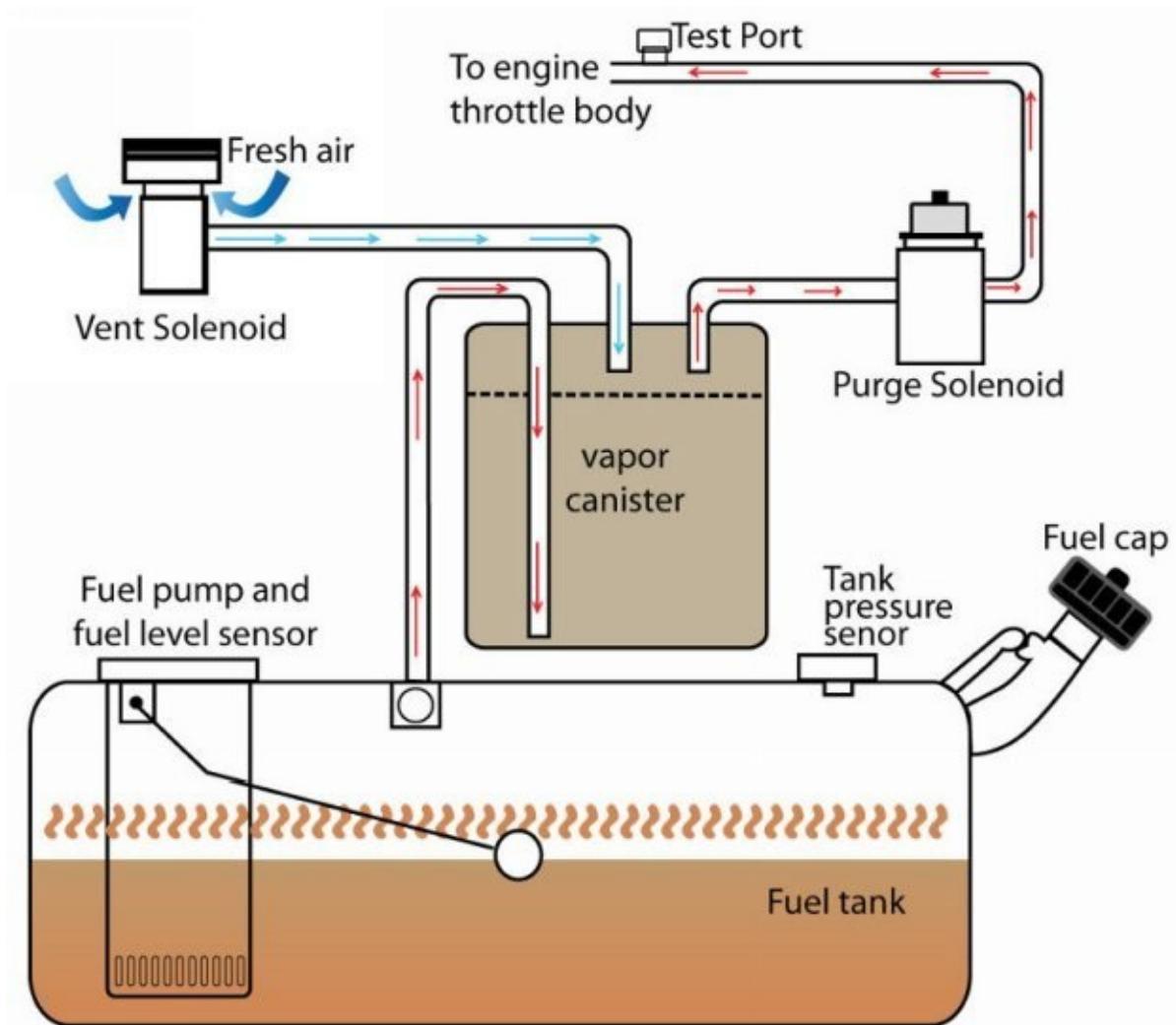


Fig 11.1.3: A diagram illustrating EVAP system made up of different

components.

EVAP System components include:

Purge valve

The purge valve is responsible for venting the evaporative gas into the intake manifold. This is done by the PCM after certain conditions are met. A stuck open purge valve would cause the engine to run richer than normal due to extra fuel added to the engine and this can eventually ruin the catalytic converter.

Fuel tank pressure sensor

An input used by the PCM to indicate if the EVAP system is discharging evaporative gas into the atmosphere.

Vent valve

Vent valve allows fresh air to enter the canister. The valve is used by the PCM to assist in monitoring purge valve operation. The vent valve is used on enhanced OBDII EVAP systems.

Charcoal canister

Charcoal absorbs and retains hydrocarbons until they are blended into the air/fuel mixture, this happens in the closed loop mode.

Gas cap

The gas cap contains an integral vacuum and pressure relief valve so as to stop deformation of the gas tank.

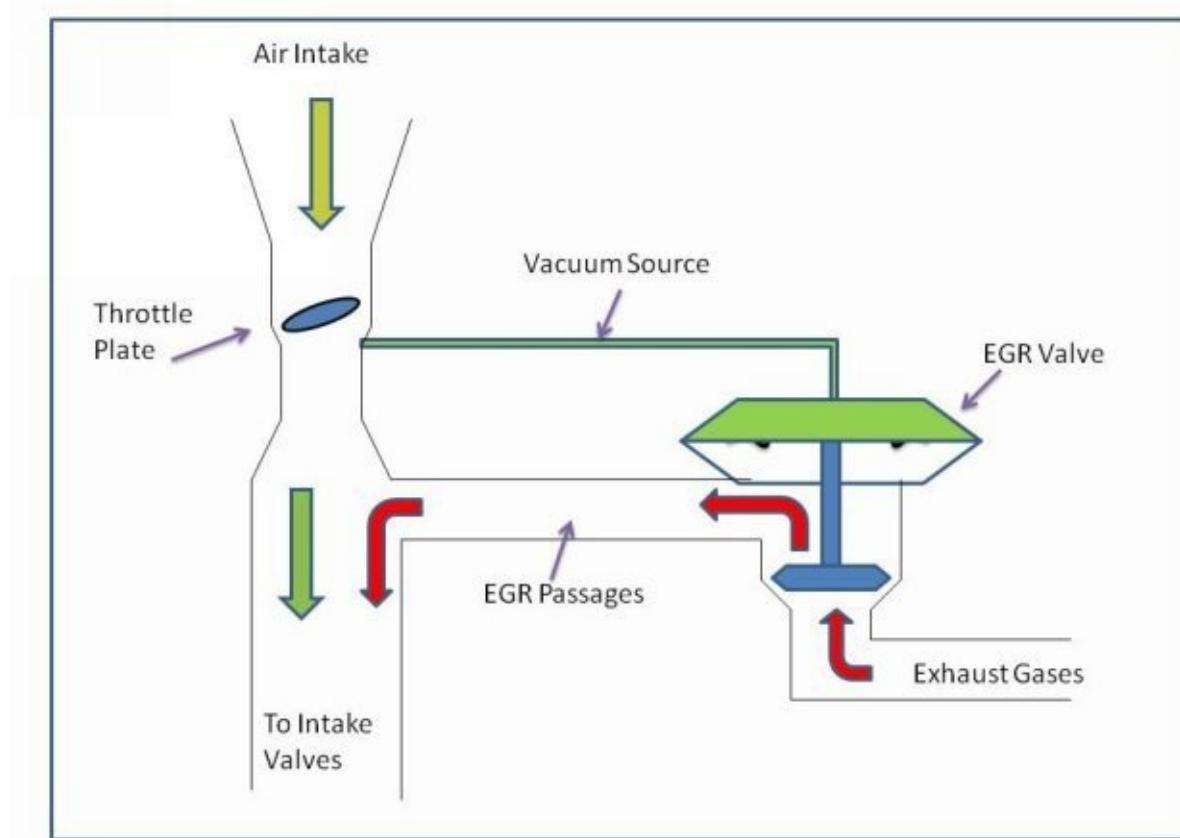
Fuel tank

The tank does not fill all the way to the top to allow space for expansion. Overfilling the gas tank may damage the canister or may cause leakages in the EVAP system.

11.2 Exhaust gas recirculation (EGR) Valve

An EGR is not a sensor but a valve. Its primary purpose is to relocate the exhaust gas back to the intake manifold thereby cooling down the engine by minimizing NO_x . Most late model vehicles use a PCM to actuate a solenoid.

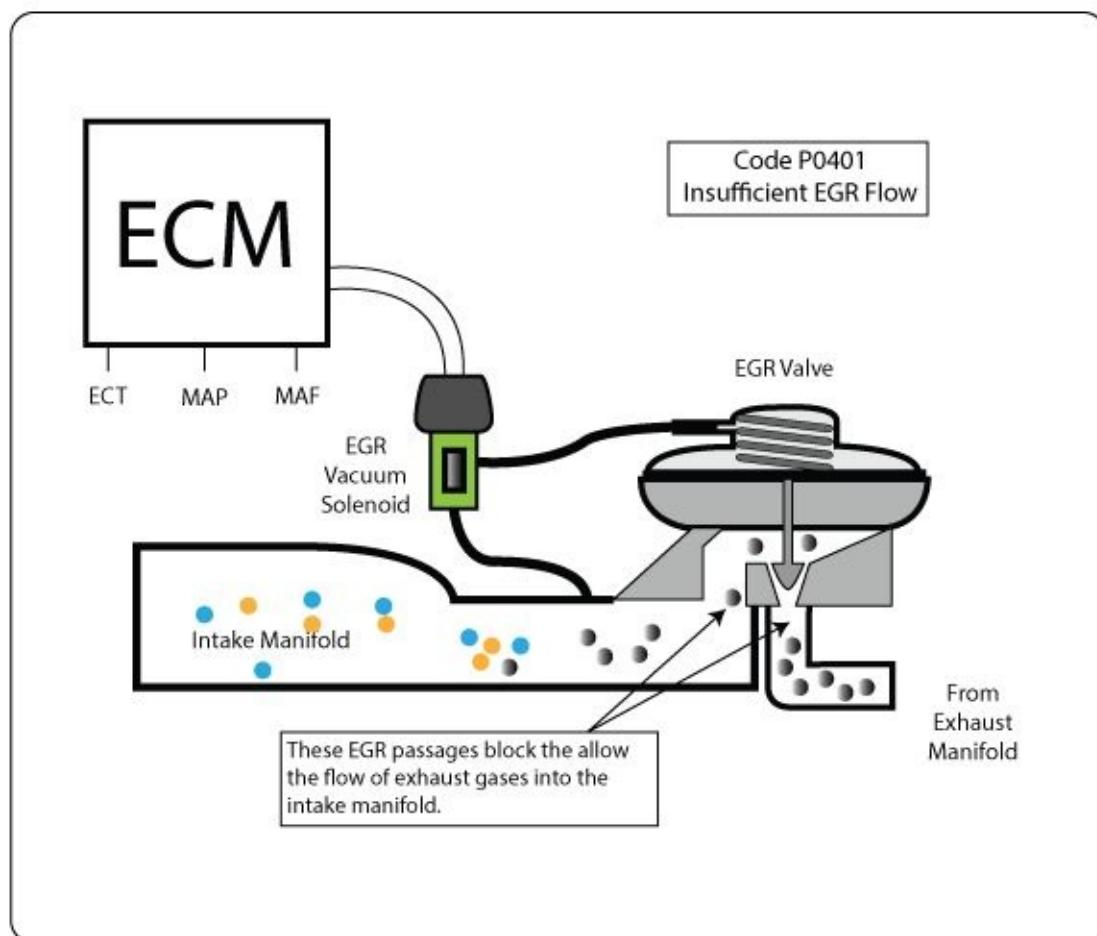
This will allow engine vacuum to go to the valve when requested thereby allowing exhaust gases to recirculate to the intake manifold. A diagram below is simplified to illustrate EGR principle of operation.



11.2.1 Problems associated with malfunctioning EGR

A stuck open EGR valve will result in excessive exhaust gas flow into the intake manifold. This results in engine stumble at idle. The reason of idling is due to the fact that exhaust gas dilutes O₂ molecules concentration and therefore affects air / fuel mixture in the combustion chamber.

A stuck closed EGR valve will result in excessive NO_x emissions and this will manifest as engine knocking or detonation. An EGR can be stuck closed due to failed solenoid, PCM and blocked EGR passages. A common DTC associated with EGR blockage is P0401. A diagram below illustrates the symptoms of P0401. P0401 is a stuck closed EGR. Cleaning the EGR passages usually solves the problem.



NOTE: In some late model cars a defective break switch may cause EGR malfunctioning.

Chapter 12

12.1 Dealing with Common DTCs

12.1.1 P0107

When DTC P0107 is set, the PCM sees a MAP registering a low voltage / low pressure. It will command fuel injectors to extend its duty cycle and hence the vehicle will run rich.

12.1.2 Troubleshooting P0107

- First check that the manifold vacuum is within the specifications, at idle you should expect vacuum between 18" - 21" inch.Hg.
- Check for loose connections and corroded terminals
- Check for any shorted wires
- Check for good ground and 5V-reference using a DMM.
- Vacuum pump @ KOEO, the MAP voltage reading should fall as seen from the scan tool.

12.2 P0171 & P0174

P0171 and P0174 mainly apply to V6 and V8 with 2-Banks since a 4-cylinder engine is just 1-Bank. However there are a few expectations.

P0171 - fuel system too lean Bank 1

P0174 - fuel system too lean Bank 2

12.2.1 Symptoms associated with P0171 & P0174

- MIL ON
- Engine performance problems
- Rough idling when engine is warm and at stoplight

- Misfiring
- Lack of power during acceleration
- Bad smelling due to misfire

12.2.2 Common causes of P0171 & P0174

- Lack of PCM software update, as the engine ages it wears and vacuum leaks, changes in piston-cylinder clearance etc are inevitable and therefore the PCM fuel software inaccurately compensates vacuum leaks and some engine changes.
- Vacuum leaks (Intake manifold, Vacuum hoses, PCV hoses, Cracks inside an engine block etc)
- Defective MAF sensor especially if both P0171 & P0174 codes are set simultaneously.
- Plugged / dirty fuel injectors
- Stuck closed fuel injectors
- High resistance on fuel injector connections
- Plugged fuel filter
- Under-performing fuel pump due to sometimes low voltage reaching the pump

12.2.3 Troubleshooting P0171 & P0172

- First check that the manifold vacuum is within the specifications, at idle you should expect vacuum between 18" - 21" inch.Hg. If between 5' - 10' Hg. inches is recorded then an intake vacuum leak is detected
- Connect scan tool and check for STFT & LTFT
- Do visual inspections to check for damaged PCV and vacuum hoses
- Check for loose connections and corroded terminals of MAF sensor
- Check for any shorted wires of MAF sensor
- Check for good ground and 5V-reference using a DMM
- Check voltage drop measurements across the fuel pump.
- Check and verify that fuel pressure & delivery are at spec. In some cars

the fuel pressure & delivery can be checked on Schrader valve located on the fuel injector rail, keep in mind that some late model cars do not have Schrader valves.

NOTE: Fuel pressure & delivery is irrelevant on some cars that have a fuel pump that is pulse width modulated PWM.

12.3 Dealing with DTC P0300

P0300 random / multiple cylinder misfire is a common DTC which might cause low power to the engine, poor shifting, rough idling, poor performance of the engine and worst case engine shacking whilst running. Random misfire is the lack of or loss of combustion in two or more cylinders. When a misfire happens raw fuel is dumped into the converter. The converter temperature rises to dangerous level elevating HC output and sometimes causing a flashing Check engine light as seen on an instrument cluster.

Random misfire is mostly caused by ignition, fuel and engine mechanical problems. A misfire is said to be random when it involves multiple cylinders simultaneously. In actual fact two or more cylinders lead to P0300. P0300 is the most common problem experienced by many motorists in the USA.

12.3.1 What happens to the PCM and HO2S sensor during random misfire?

- The HO2S will detect excess amount of raw fuel in the exhaust
- The excess O2 that was not used during the combustion process results in rapid switching of the HO2S sensor and in most cases PCM will lose fuel trim control

12.3.2 What causes random misfire?

- Worn or malfunctioning ignition components like ignition coils, ignition

wires, ignition spark plugs and ignition control module (ICM)

- Leak, restricted or malfunctioning fuel injectors, fuel filter, defective pump and fuel pressure switch.
- Mechanical factors like low compression on multiple cylinders, blown head gasket and skipped timing belts / chain and water in the combustion chamber
- Vacuum leak
- Bad battery

12.3.3 P0300 misfire diagnostics

- First check for the presence of spark in all the spark plugs
- Check the condition of spark plugs, check the spark gap if it is according to spec, check the spark plug for fuel and oil fouling. If they are bad replace them.
- Check for vacuum leaks and restriction by checking for cracks, kinks and looseness of the vacuum hose
- Spray penetration oil around the intake manifold, engine has to be idle; if the idle speed changes then a leak is present in the intake manifold. A vacuum gauge can be used to probe for an intake manifold leakage. A reading of 5-10 Hg. Inc at idle shows a leakage in the intake manifold.
- Check for fuel pressure using a fuel pressure gauge
- If any of the above steps doesn't solve the problem measure the compression of each cylinder

Chapter 13

13.1 Charging system

The generator / alternator is the source of DC voltage needed by the battery, all accessories, electrical and electronic components of a car. The generator produces DC voltage by the action of diodes inside a diode bridge. Most generators have six diodes in order to obtain a full wave rectification. The process of converting AC - DC voltage is called rectification. The generator charges the battery when the engine is running; this is possible since battery and generator are always connected in parallel. A good generator produces DC charging voltage at the B+ output terminal which is normally in the range of 13.8V 15.1V.

The charging system has drastically changed in the last decade to a computerised one. In the past years the voltage regulator used to be inside the generator, nowadays a charging system is controlled by on board computer. The charging system is a heart bit of a modern vehicle that you might think of, it therefore needs to be properly checked and regulated. If the charging voltage is operating too high the battery will suffer from overcharging and that will eventually destroy the battery. If the charging voltage is too low all electrical / electronic circuits in on board computers will be unable to function at their full potential and that will cause a lot of driveability concerns. Modern cars charging system depends mainly on the engine load, engine and air temperature and vehicle speed. Various sensors and switches are input to the PCM so as to generate a signal(s) that will control the charging system depending on various conditions as shown in fig 13. The faster the car moves (engine rpm increases) the higher the output voltage of a generator. The slower the car moves (engine rpm

decreases) the lower the output voltage of a generator.

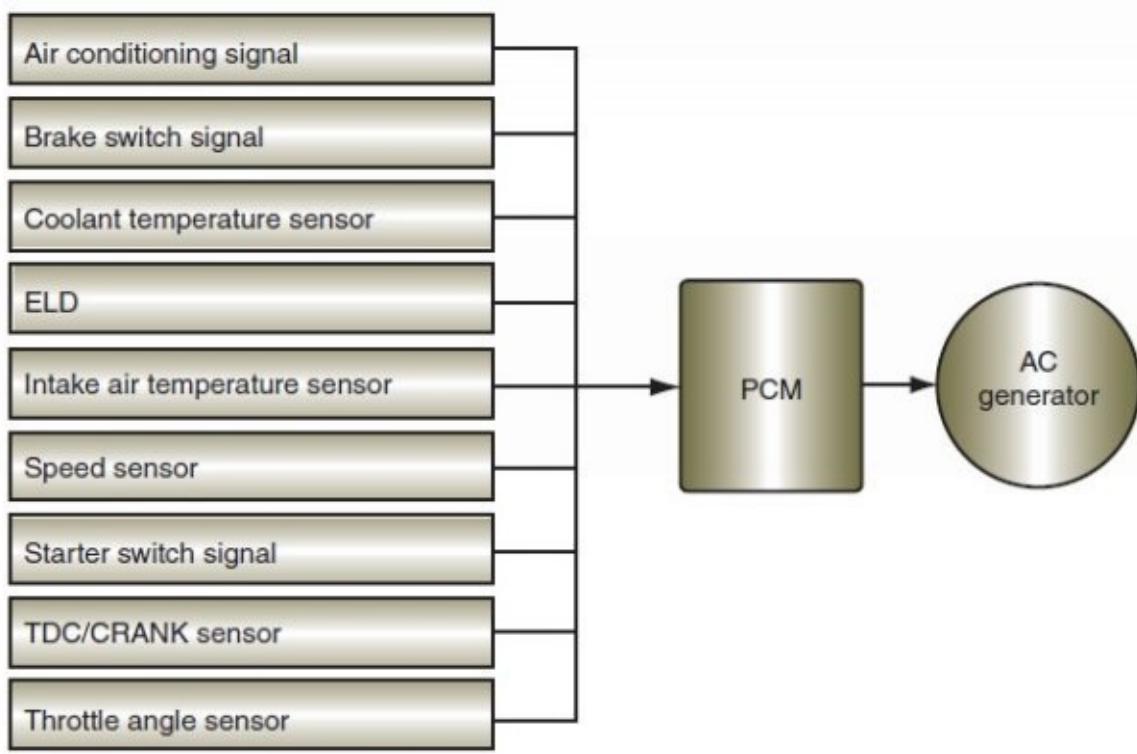


Fig13.1: Various sensors and switches that controls the performance of the charging system.

13.2 Inside the Charging system

There are four major components that make up a generator. Fig 13.2 shows a composite schematic of the internal parts of a basic generator.

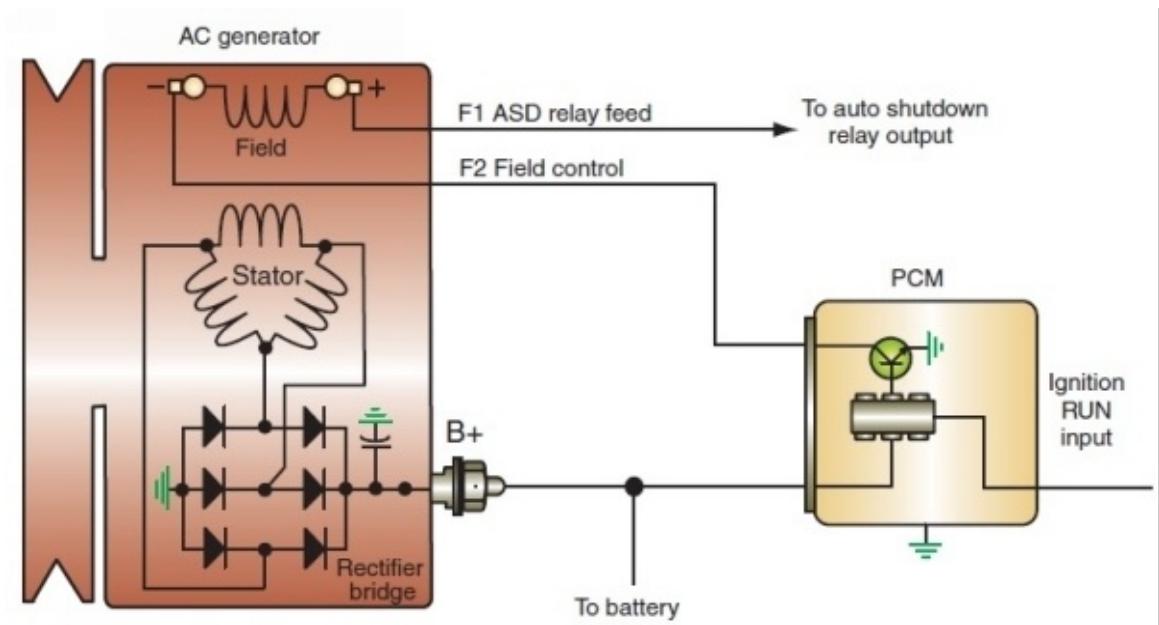


Fig 13.2: illustration of the internal assemblies of a generator.

The main components that make up a generator include:

Rotor (field) winding

Stator winding

Diode Bridge

PCM (Voltage regulator)

The Rotor winding is controlled by the voltage regulator. The voltage regulator in this case is an NPN driver transistor inside the PCM that turns ON and OFF the current through the Field winding. The voltage regulator regulates the current that goes into the Rotor windings. The more current that flows into the Rotor windings implies that more electromagnetic field is produced around the Rotor windings. The less current that flows into the Rotor windings implies that less electromagnetic field is produced around the Rotor windings. As long as the current flows through the Rotor windings, the Rotor will always be an

electromagnet. The rotating Rotor enables electrical energy to be induced the three stator windings by electromagnetic induction. AC current is produced in the Stator winding during this process. The AC current produced is rectified by the Diode Bridge. The Diode Bridge consists of six diodes divided into three legs among the three Stator windings. Each Stator winding has a (+) Diode and a (-) Diode connected in series. The AC current enters each series diode leg at the common junction point of the two diodes.

The faster the Rotor winding spins the higher the output of the generator. The slower the Rotor winding spins the lower the output of the generator. The Stator winding is always stationary, and the one shown on Fig 13.2 is called a 3-phase Stator because of its 3-windings. The Rotor/Field winding is mounted inside the Stator winding and rotates as the generator pulley is rotated by the serpentine belt. Most common generator failures are as result of Diode failures due to overheating.

13.3 The charging Voltage

The charging voltage produced by the generator is the voltage across the battery terminals when the engine is running. The charging voltage varies mostly with engine speed and ambient temperature. The PCM containing the voltage regulator takes information from various sensors to determine vehicle operating conditions and ensures the generator is required to supply voltage required by the electrical system.

13.4 Range of charging voltage according to ambient temperature

15.10V: The maximum charging voltage that should ever appear in a vehicle operating with 14V electrical / electronic system. This voltage is not acceptable especially in hot weather since it can completely ruin the PCM.

14.80V -14.40V: Range of charging voltage in cold winter weather **14.20V -**

13.80V: Cool - mild warm weather

13.60V - 12.80V: Hot weather

13.00V - 12.80V: Low charge condition

12.66V: Battery voltage, generator under performing **Less than12.66V:**

Generator is dead, all the electrical / electronic systems running on battery voltage.

13.5 Factors that affect the charging voltage

Charging voltage is not a fixed value, it entirely depends on temperature, load, speed and vehicle make and model.

13.5.1 Make and Model of a vehicle

Make and model of a vehicle affects charging voltage. The charging voltage set at factory is calculated to match the type of battery the manufacturer installs for an original equipment battery. Vehicles using maintenance free battery tends to have voltage that ranges between 0.5V -1.0V higher than low maintenance.

13.5.2 Generator electrical load

High electrical load implies that the charging voltage decreases because increased electrical load pulls the charging voltage down. Conversely, generator output current increases as electrical circuits demand more current to run efficiently.

Low electrical load implies that the charging voltage increases because decrease electrical load will definitely cause the charging voltage to rise. Conversely, generator output current decreases underload as circuits being powered by the generator will be OFF implying less current demand.

13.5.3 Ambient temperature

Ambient temperature affects charging voltage. In cold weather the charging

voltage increases to overcome battery's higher internal resistance. In hot weather the charging voltage decreases because hot battery is easier due to lower internal resistance.

13.5.4 Engine speed

Engine speed affects charging voltage. The faster the car moves (engine rpm increases) the higher the output voltage of a generator. The slower the car moves (engine rpm decreases) the lower the output voltage of a generator.

13.6 The charging voltage diagnosis

Testing for undercharge condition

Set DMM to 20V and connect test leads to battery post

Run the engine at 1500 rpm

Turn ON all accessories

Hold this test for 30 seconds

If an undercharge condition is suspected hold this test for 3-5 minutes and watch for voltage drop across the battery. Look for not less than 13.50V underload. Less than 13.50V indicates possible undercharge unless ambient temperature is hot.

Less than 12.66V means the generator is dead

Testing for overcharge condition

Set DMM to 20V and connect test leads to battery post

Run the engine at 2000 rpm

Turn OFF all accessories

Hold this test for 30 seconds

If an overcharge condition is suspected hold this test for 3-5 minutes and watch for voltage increase across the battery. Expect charging voltage in the range of 14.00V -14.60V.

More than 15.20V indicates a faulty voltage regulator, bad wire connection or bad wire.

13.7 Alternator voltage drop measurements

Whenever the charging voltage is overcharged or undercharged, the first thing to do is to look for a bad wire or connection. The diagrams below illustrate voltage drop test of the voltage side and ground side of the charging system. **Both of these tests are taken whilst the engine is running and ALL accessories turned OFF.** A good voltage drop reading should not be more than 0.2V.

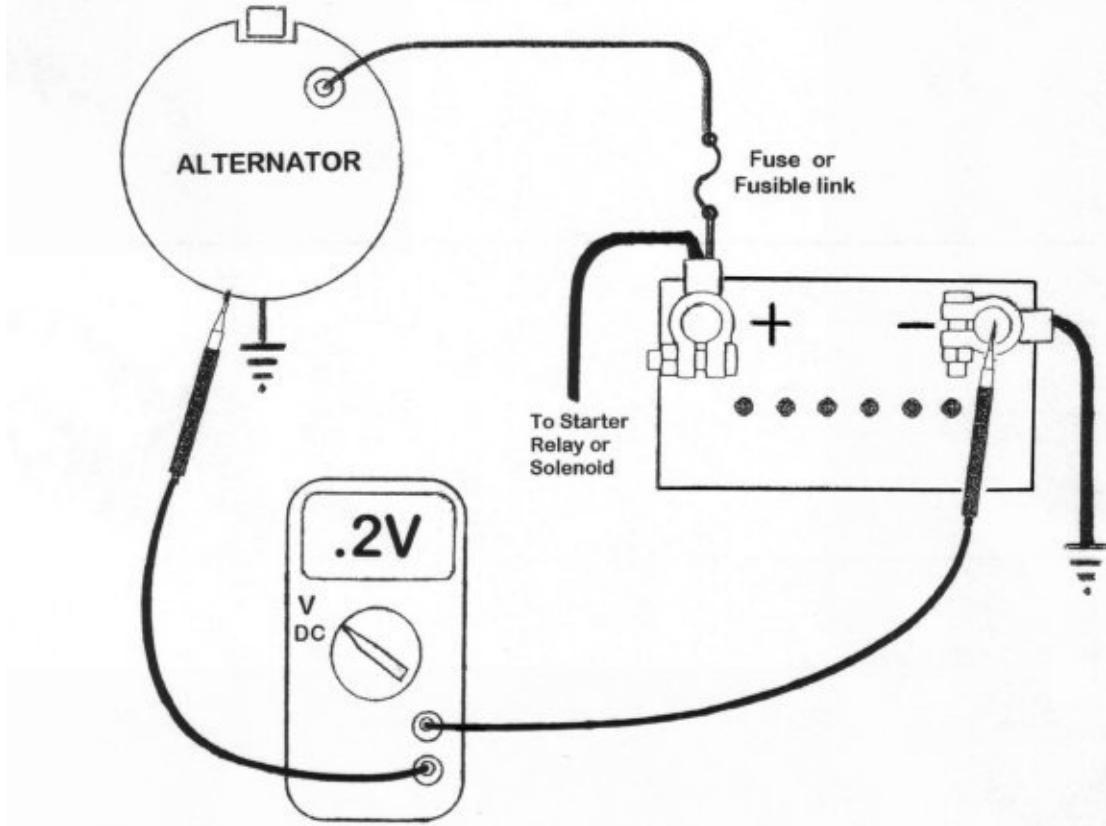


Fig 37.1: Checking voltage drop measurement on the ground side of charging system

According to Fig 37.1, Connect a Red test lead to -BATT and Black test lead to -GEN. The DMM reading should be less than 0.2V. More than 0.2 indicates an electrical problem. Look for corroded terminals, bad connections or damaged wiring.

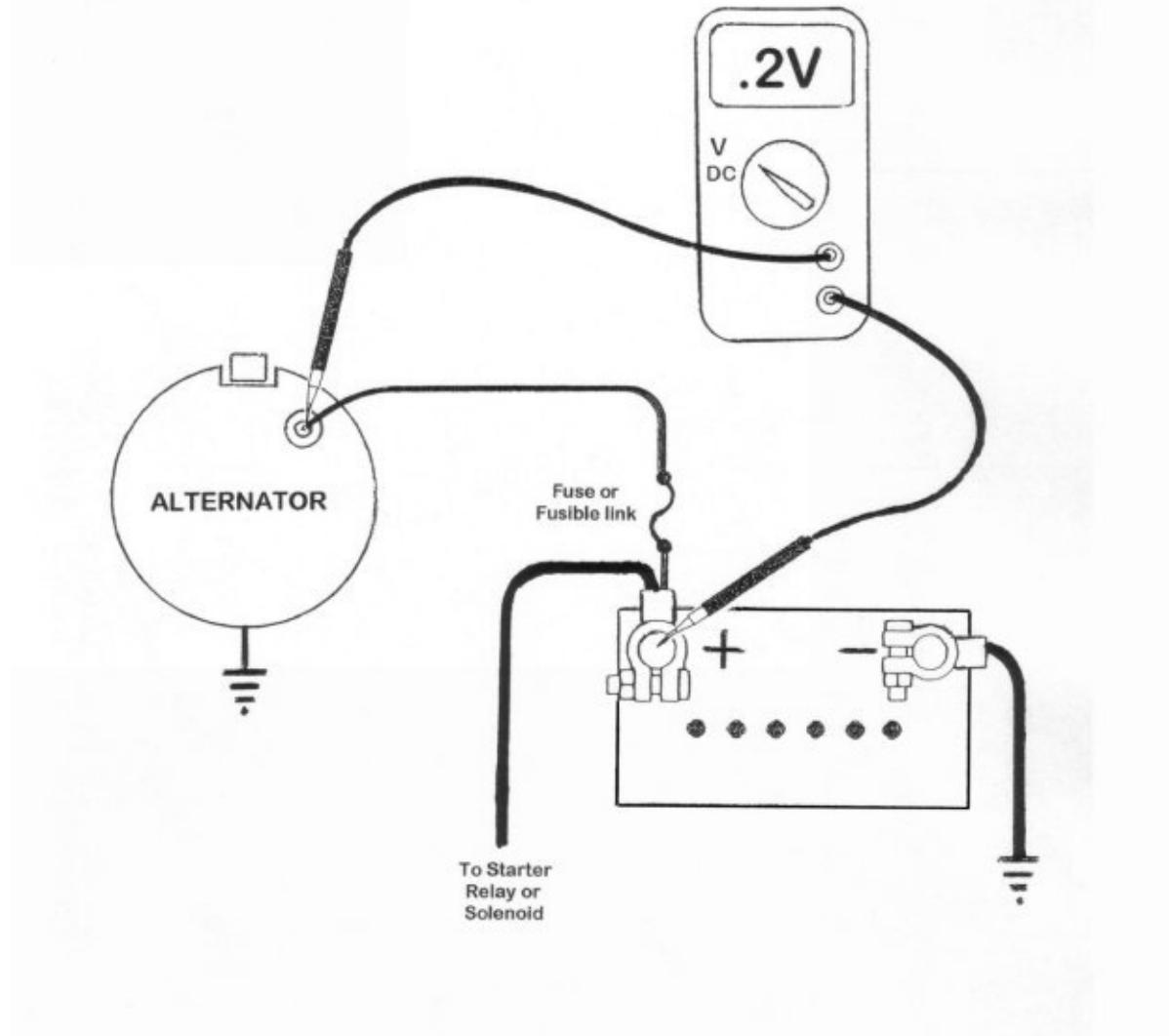


Fig 37.2: Checking voltage drop measurement on the voltage side of charging system

According to Fig 37.2, connect a Red test lead to +GEN and Black test lead to +BATT. The DMM reading should be less than 0.2V. More than 0.2 indicates an electrical problem. Look for corroded terminals, bad connections or damaged wiring.

Problems associated with Generator voltage too high or too low

Higher charging voltage produce higher current causing the battery to overcharge and boil away electrolyte. This definitely results in shorter battery life.

Higher charging voltage will cause computer to fail and some other electronic / electrical appliances such as lamps and relays.

Higher electric current cause melting of wire harness causing short to ground, short to voltage, OPEN and intermittent failures. Low charging voltage cause low current flow causing a lot of drivability issues such as poor transmission shift, problems with air / fuel mixture ratio maintenance, sluggish fuel injector operation, low engine power and various electrical problems.

- [1] Marco Di Natale, Understanding using the Controller Area Network, 2008
- [2] Marco Di Natale, Understanding using the Controller Area Network, 2008
- [3] Diagram obtained from ALLDATA online program
- [4] NEW YORK STATE DEPARTMENT OF MOTOR VEHICLE
- [5] Ford Power Train Control Module
- [6] www_AA1Car.com
- [7] www_AA1Car.com