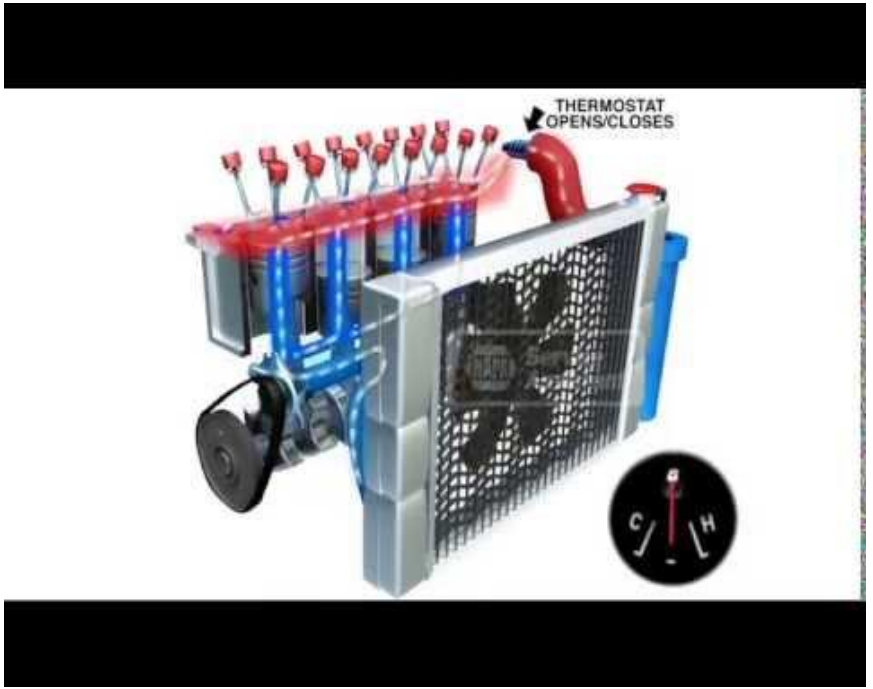
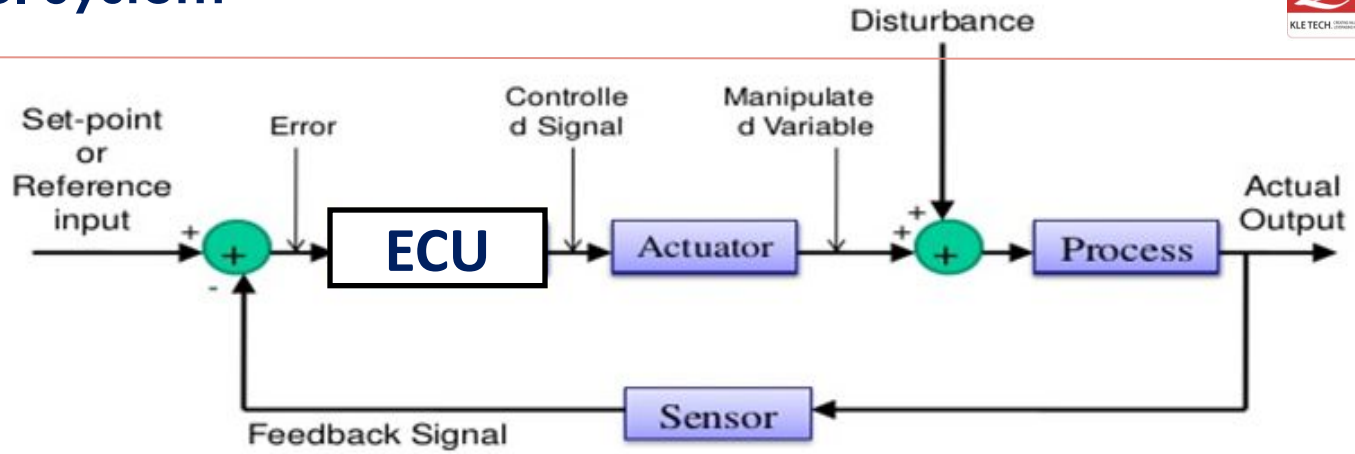
Chapter 3:
Sensors & Actuators

What these system mean??



Control System



In any control system,

Sensors provide measurements of important plant variables in a format suitable for the digital microcontroller.

Actuators are electrically operated devices that regulate inputs to the plant that directly control its output.

For example, as we shall see, fuel injectors are electrically driven actuators that regulate the flow of fuel into an engine for engine control applications.

Automotive manufacturers are continuously increasing the use of electronics systems to,

- ✔Improve vehicle performance
- ✔Safety
- ✔Passenger comfort.

Sensors and actuators are integrated with automotive control computers to help optimize vehicle performance while improving reliability and durability.

Sensors and Actuators

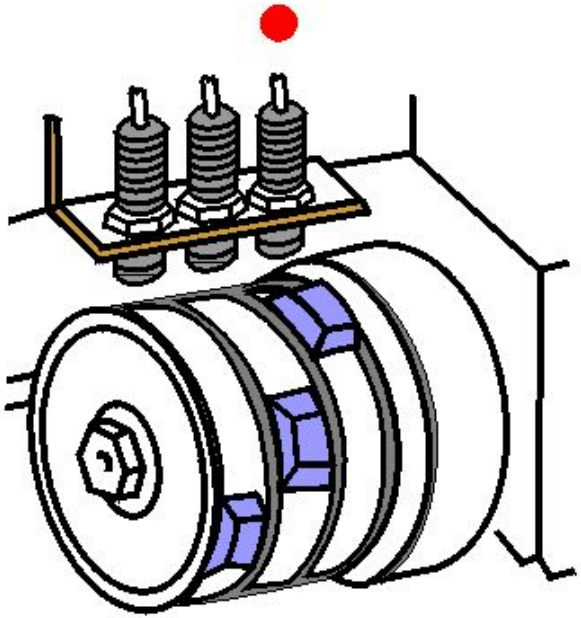
On completion of this session the student would have understood

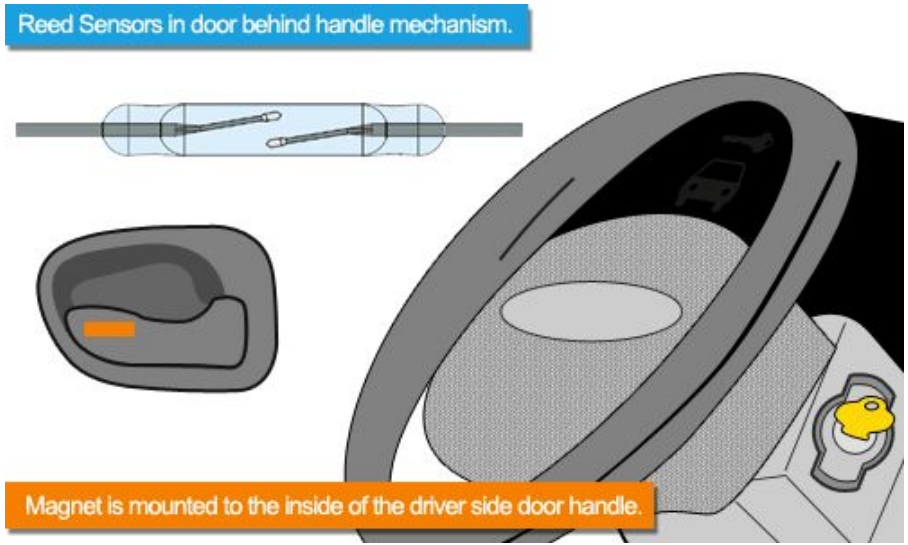
✔The various sensors and actuators that are used in automotive electronics

✔Their working principles

✔Their various uses in automotive electronic systems

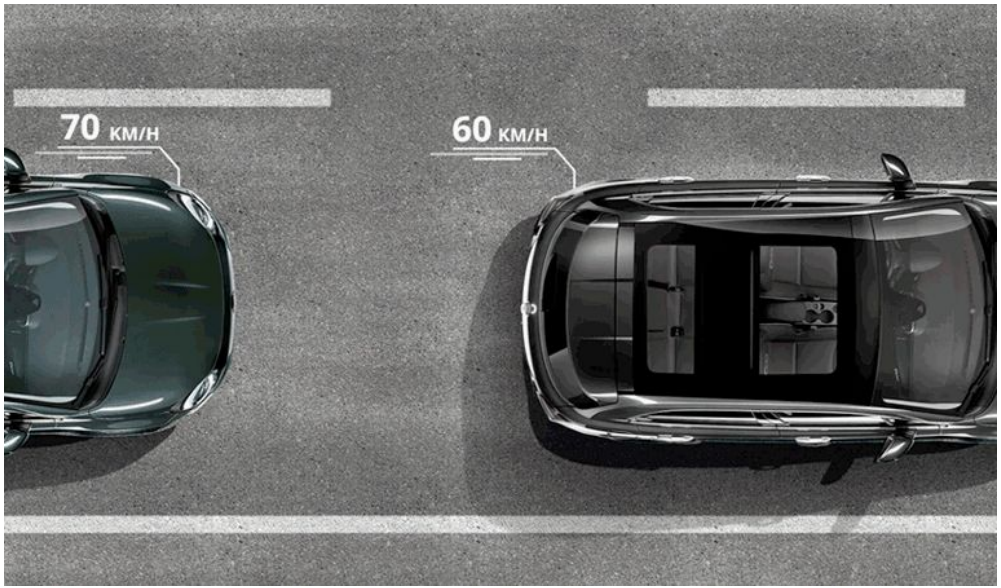
Physical Systems





Physical System

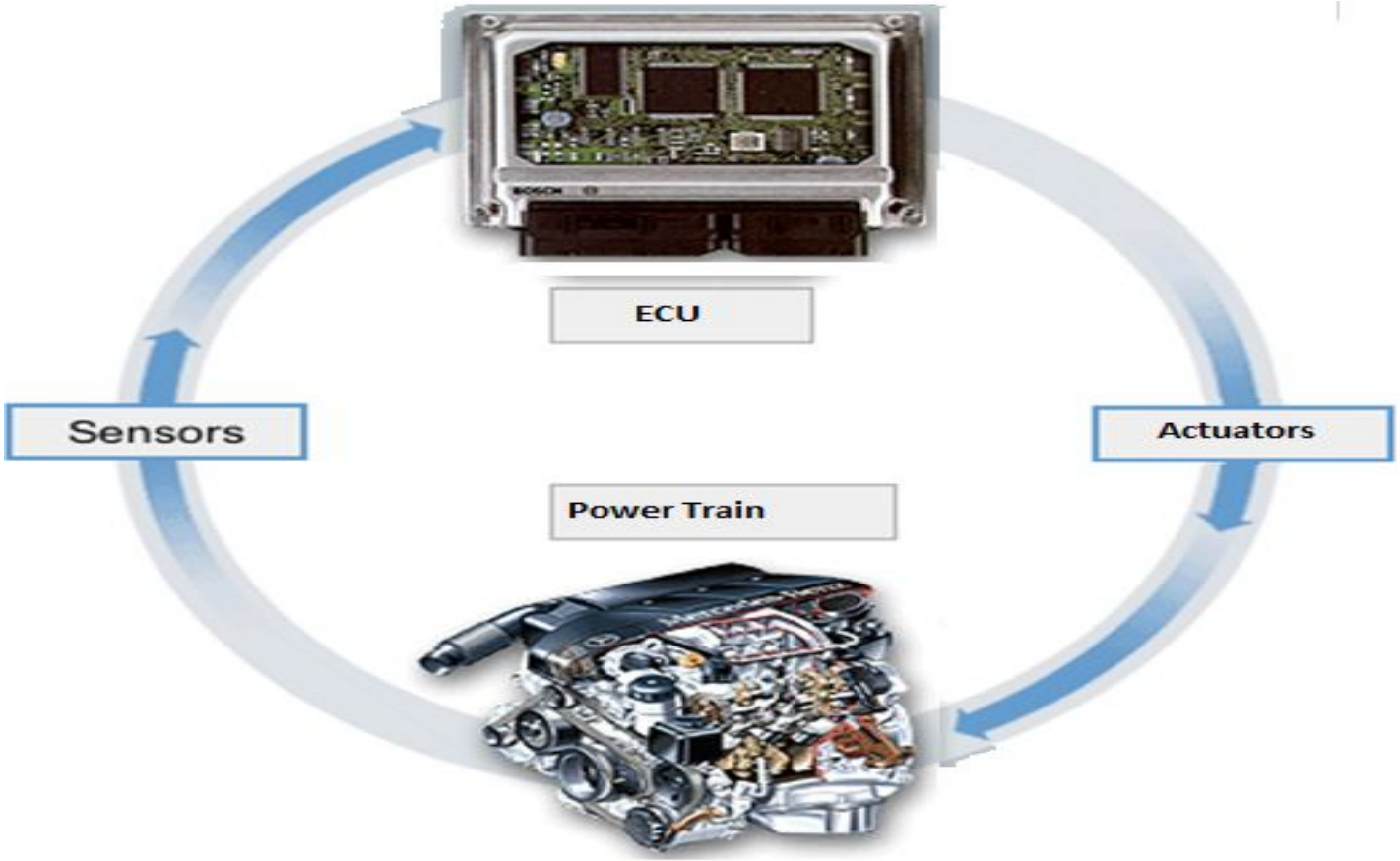
Speed and Distance sensor



Acceleration and Throttle

Cruise Control

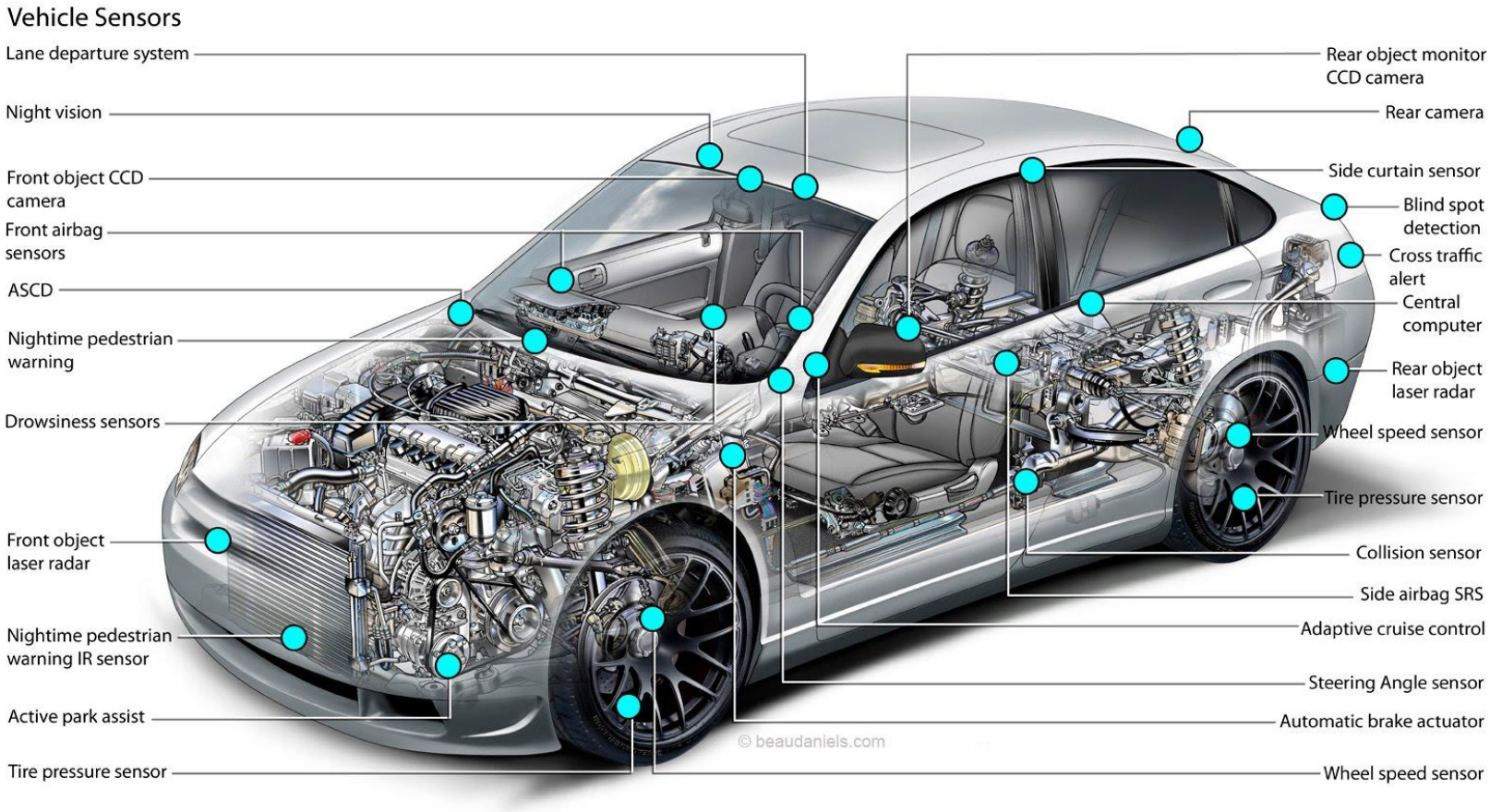
Contd..



Selection Criteria

- ✔ What is to be measured
- ✔ Magnitude, range, dynamics of measured quantity
- ✔ Required resolution, accuracy
- ✔ Cost
- ✔ Environment
- ✔ Interface Requirements
  - ✔ Output quantity (voltage, current, resistance,…)
  - ✔ Sensitivity
  - ✔ Signal conditioning
  - ✔ A/D requirements (#bits, data rate)

Typical Sensors: Car



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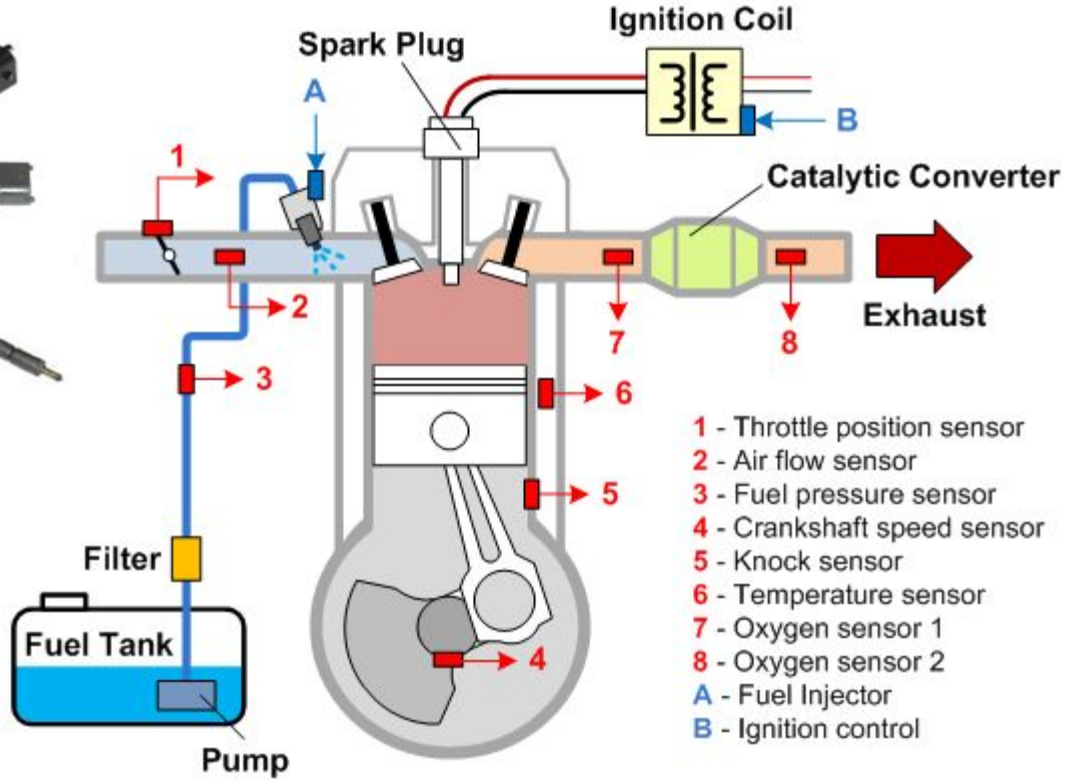
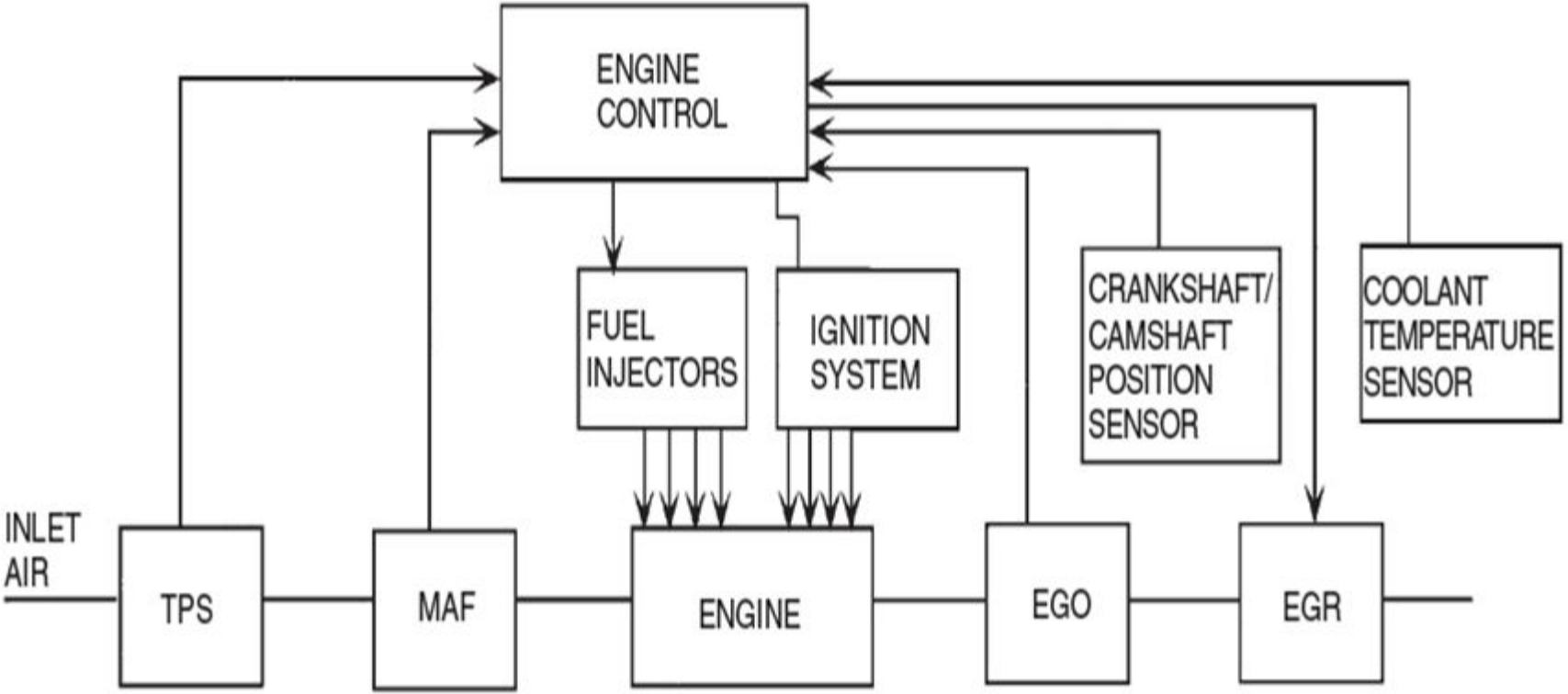
Sample: Sensor mounting



Typical Electronic Engine Control System



Throttle position sensor

Mass air flow

Exhaust gas oxygen

Exhaust gas recirculation

Sensors and Actuators

The superset of variables sensed in engine control includes the following:

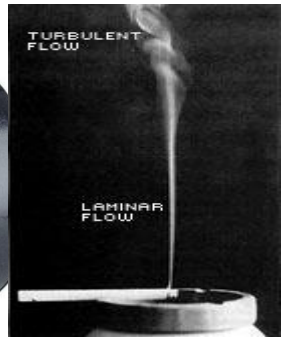
1. Mass air flow (MAF) rate
2. Exhaust gas oxygen concentration (possibly heated)
3. Throttle plate angular position
4. Crankshaft angular position/RPM
5. Coolant temperature
6. Intake air temperature
7. Manifold absolute pressure (MAP)
8. Differential exhaust gas pressure
9. Vehicle speed
10. Transmission gear selector position

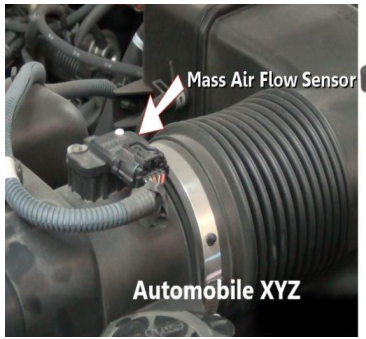
Switches include the following:

1. Air conditioner clutch engaged
2. Brake on/off
3. Wide open throttle
4. Closed throttle

Mass Air Flow Sensor (MAF)

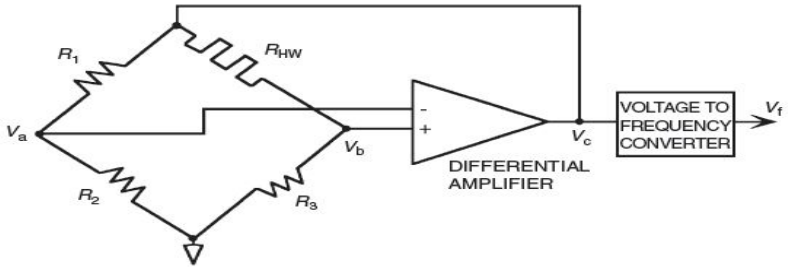
- ✔ The correct operation of an electronically controlled engine operating with government-regulated exhaust emissions requires a measurement of the mass flow rate of air (*Rm*) into the engine.
- ✔ **The Mass Air Flow Sensor (MAF)** is a computer-controlled sensor that calculates the volume and density of the air taken in by the engine.
- ✔ This is normally mounted as part of the **air cleaner assembly**, where it measures air flow into the intake manifold.

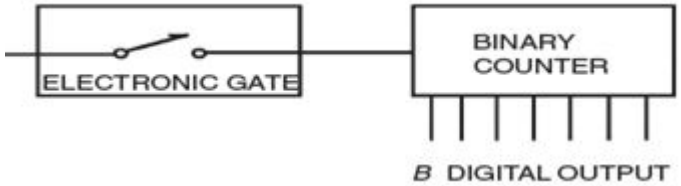


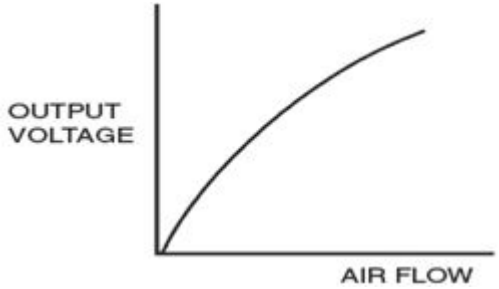


Mass Air Flow Sensor (MAF): contd..

- ✔ The MAF sensor is a variation of a classic air flow sensor that was known as a hot wire anemometer: **Wheatstone bridge** configuration
- ✔ The **BC counts** (in binary) at the instantaneous frequency of the v/f, which is proportional to the amplifier **output voltage vf** , which in turn varies with **mass air flow rate.**







where $B = f\,t$

B = BC count

f = frequency of v/f

t = duration of closure of electronic gate

Engine control system and its sensors

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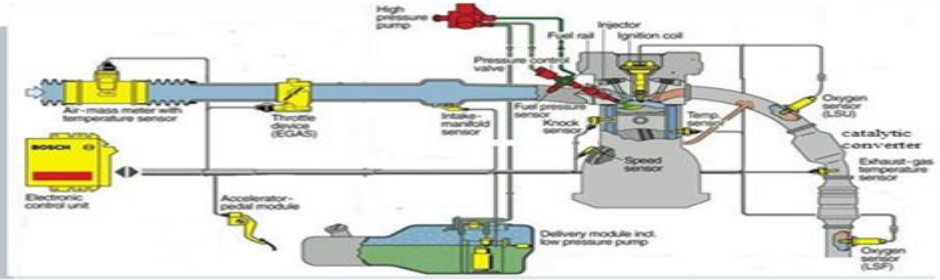
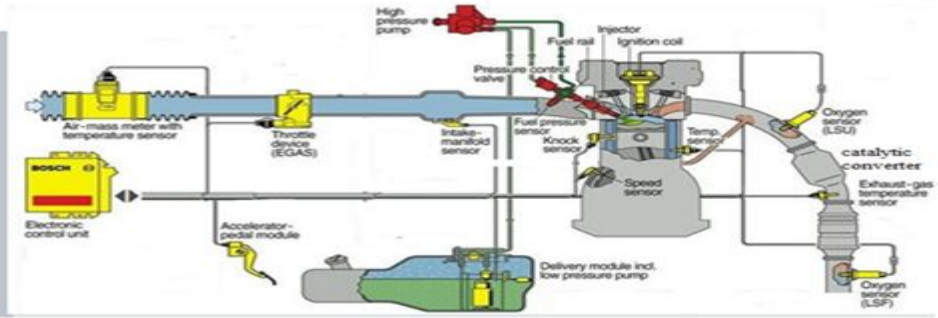
Air Mass Flow sensor



Air Mass Flow sensor

Air Mass Flow sensor



- ✔ Contains a hot film inside
- ✔ Hot film Cools down as air enters inside
- ✔ Voltage increases as it cools down
- ✔ ECM determines air quantity based on this

Pressure Sensors

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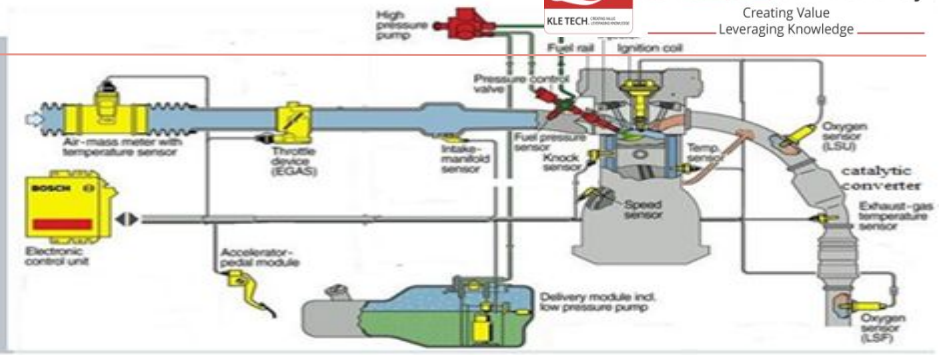
Pressure Sensors



What is pressure ?

Pressure is the strength per unit area

✔The SI unit for pressure is the pascal.

✔Non-SI measures such as pounds per square inch and *bars* are used in some parts of the world, primarily in the United States of America.

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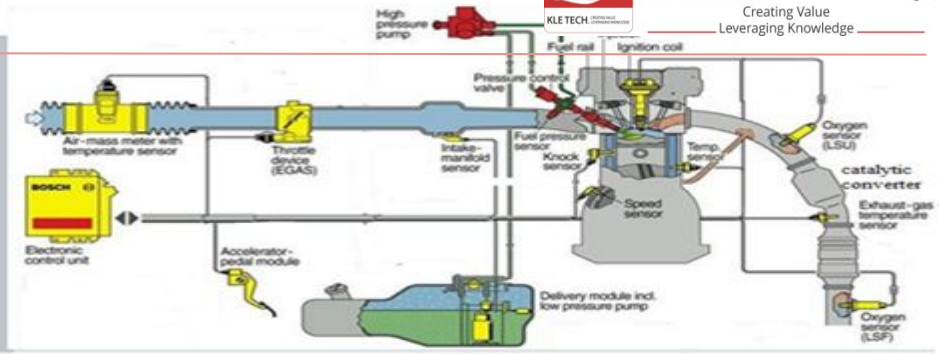
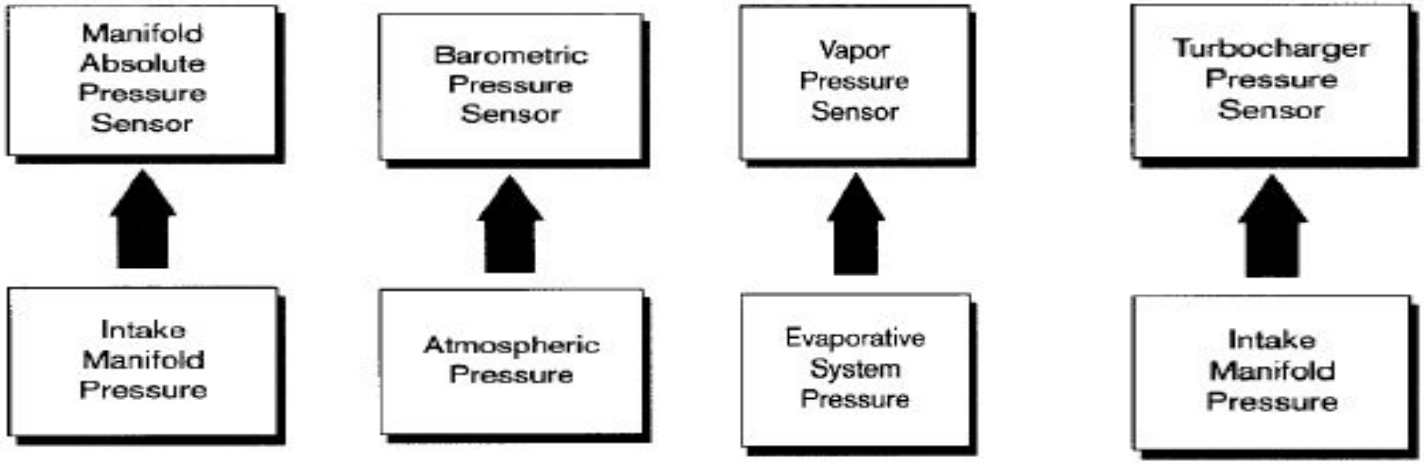
Pressure Sensors





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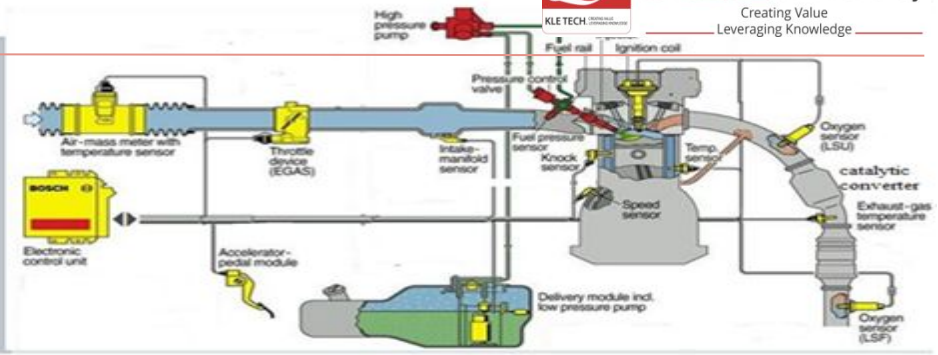
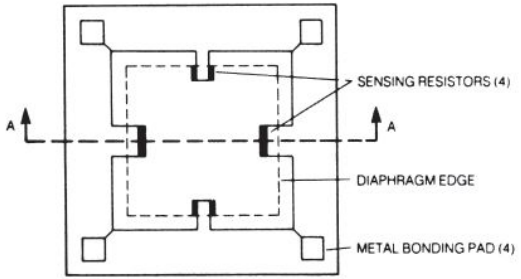
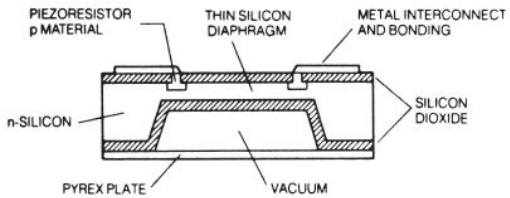
Manifold Absolute Pressure Sensor(MAP)



Manifold Absolute Pressure Sensor



a Top View



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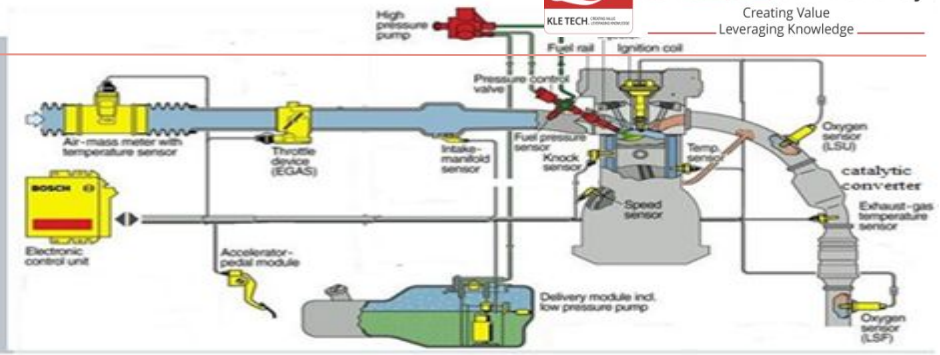
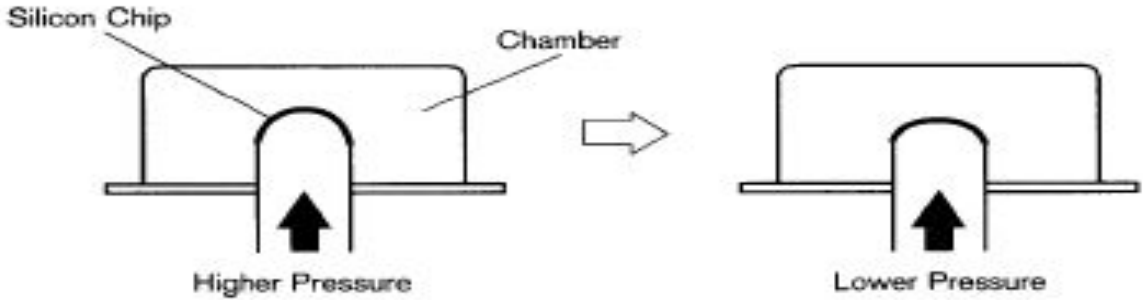
Manifold Absolute Pressure Sensor(MAP)



Pressure Sensing

The silicon chip flexes as pressure changes. The amount the silicon chip flexes determines the output voltage signal.



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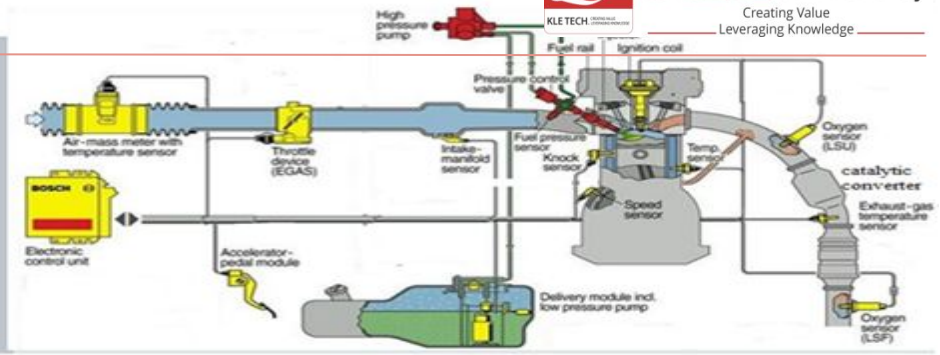
Manifold Absolute Pressure Sensor(MAP)



MAP Sensor Circuit

The ECM measures this voltage signal at the PIM terminal. This sensor receives 5 Volts from the ECM on the VC (or VCC) line. The ground for the sensor is through a ground wire to the ECM (usually terminal E2).

The PIM signal will be 5 Volts if the PIM wire is disconnected.

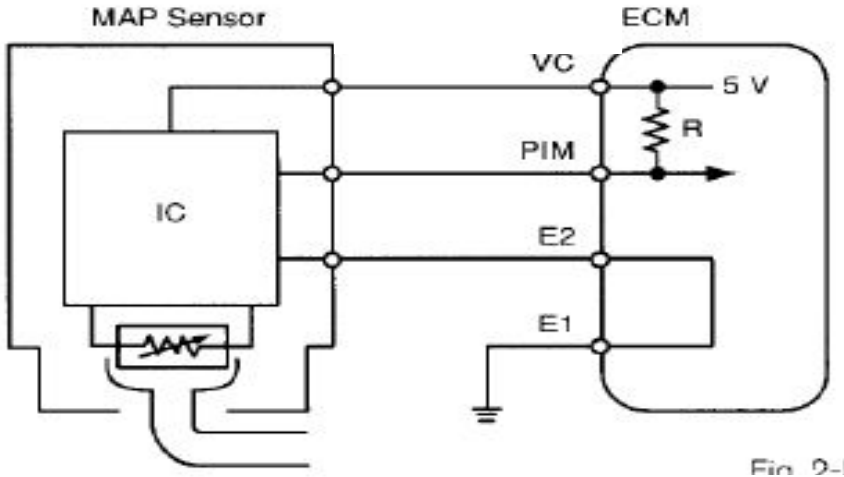


Fig. 2-54

Sensors and Actuators

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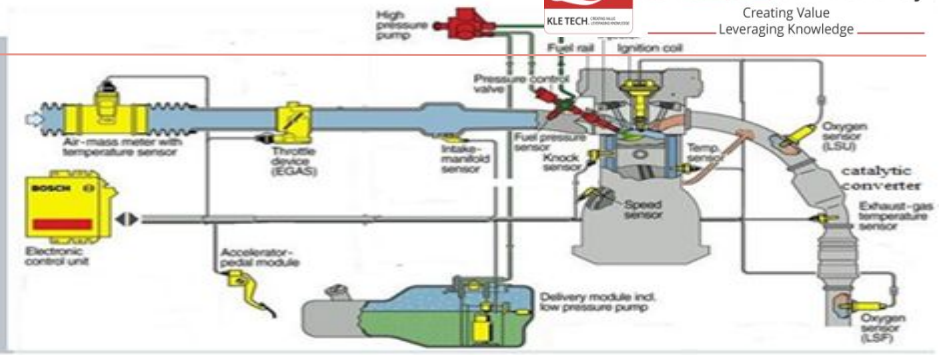
Barometric Pressure Sensor



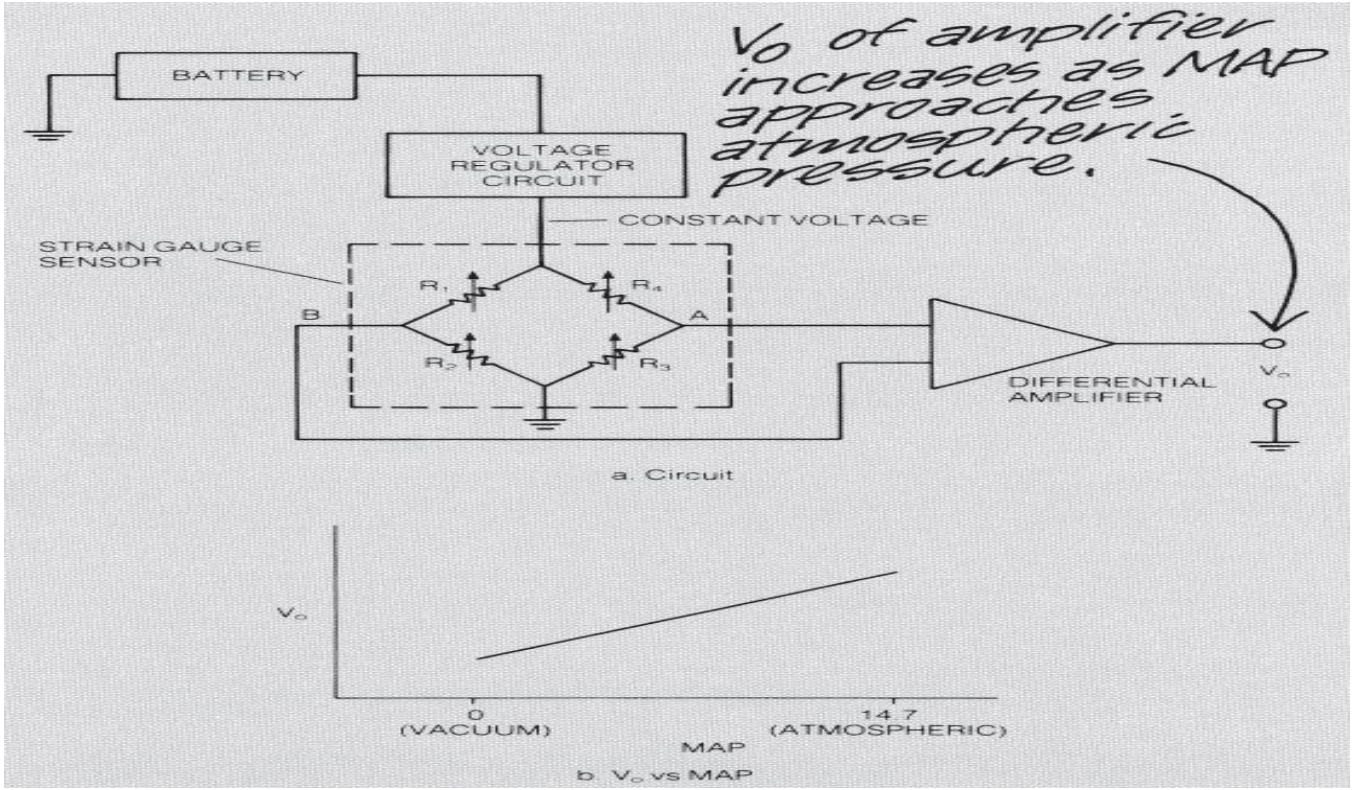
Barometric pressure sensor

Senses the atmospheric Pressure.

- Tells the ECM about present pressure.
- Allowing the PCM to sense the altitude at which the vehicle is operating.
- Its signal affects, spark advance for altitude compensation

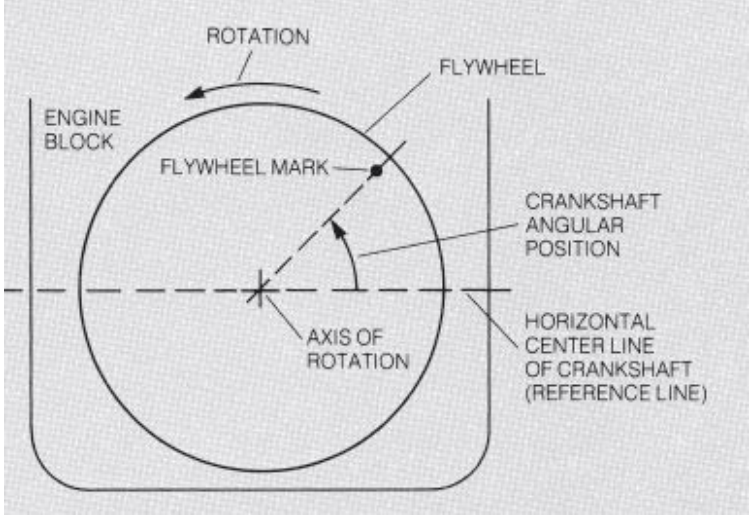
Contd..

Circuit Diagram for MAP Sensor Using Strain Gauges



ENGINE CRANKSHAFT ANGULAR POSITION SENSOR

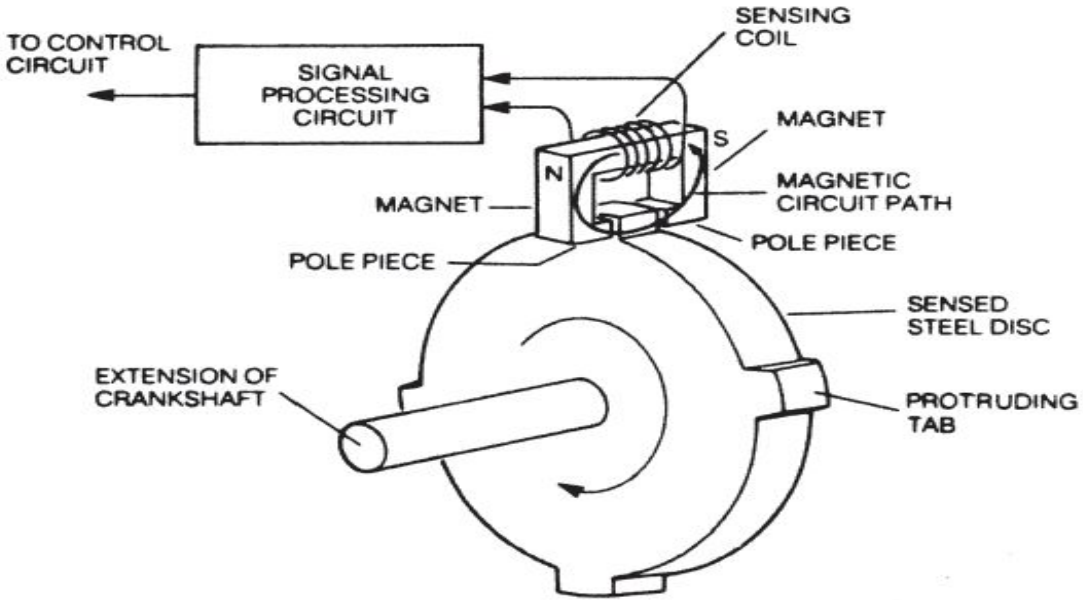
- ✔ Crankshaft angular position is an important variable in automotive control systems, particularly for controlling ignition timing and fuel injection timing.
- ✔ It is desirable to measure engine angular position with a non contacting sensor to avoid mechanical wear and corresponding changes in accuracy of the measurement.
- ✔ The two most common methods for noncontact coupling to a rotating shaft employ **magnetic fields or optics**.

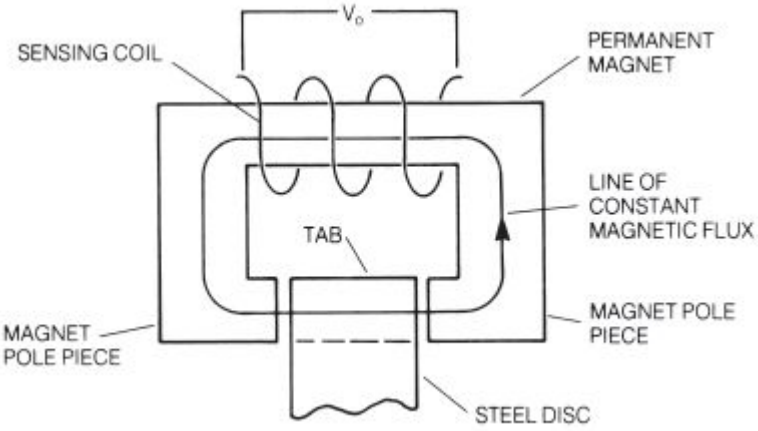


ENGINE CRANKSHAFT ANGULAR POSITION SENSOR

Magnetic Reluctance Position Sensor

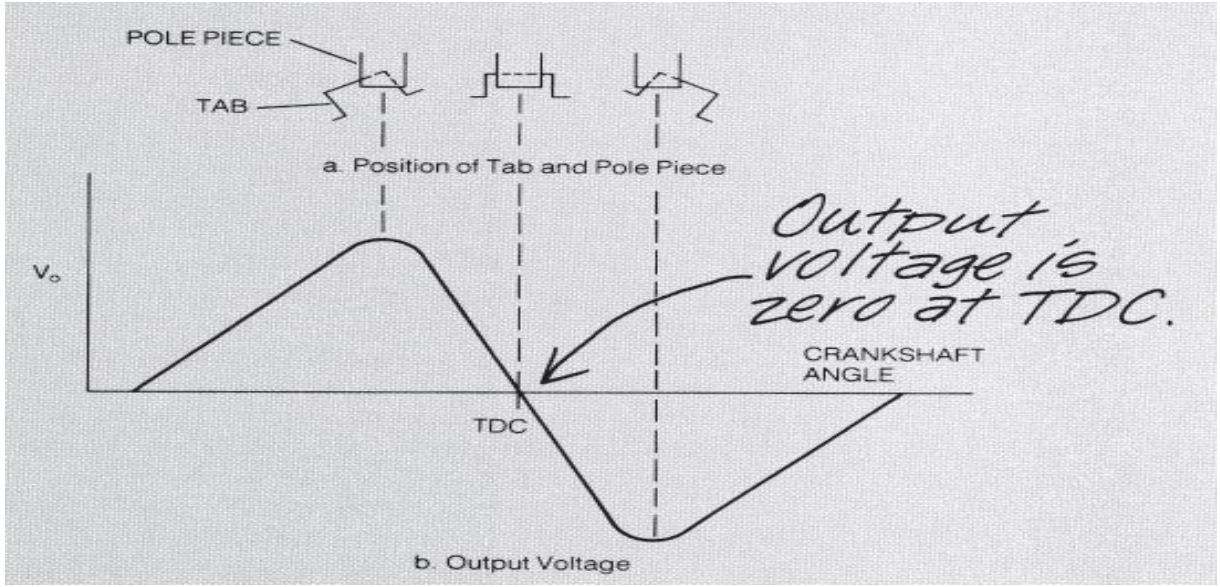
- ✔ This sensor consists of a permanent magnet with a coil of wire wound around it. A steel disk that is mounted on the crankshaft
- ✔ The passage of each tab can correspond to the **TDC position** of a cylinder on its power stroke





Contd..

- ✔ The change in **magnetic flux** induces a **voltage, Vo**, in the sensing coil that is proportional to the rate of change of the magnetic flux.
- ✔ Vo, begins to increase from zero as a tab begins to pass between the pole pieces, reaches a maximum, then falls to zero when the tab is exactly between the pole pieces



Engine Speed Sensor

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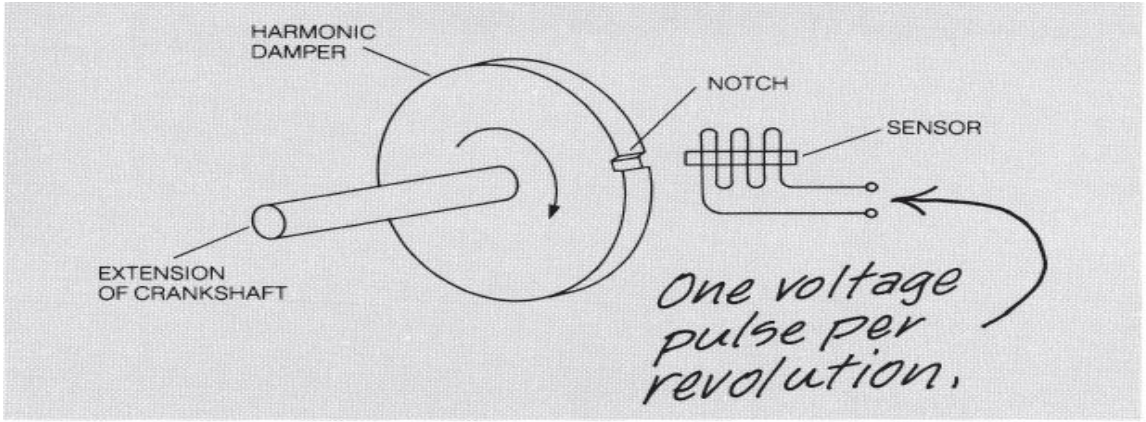
✔ Engine speed can be calculated in a number of ways. Digital circuits use counters and crankshaft sensors to calculate actual engine speed.

Crankshaft Position Sensor



As the camshaft rotates, the notch passes under the sensor once for every two crankshaft revolutions. The magnetic flux abruptly decreases, then increases as the notch passes the sensor. This generates a voltage pulse that can be used in electronic control systems for timing purposes.

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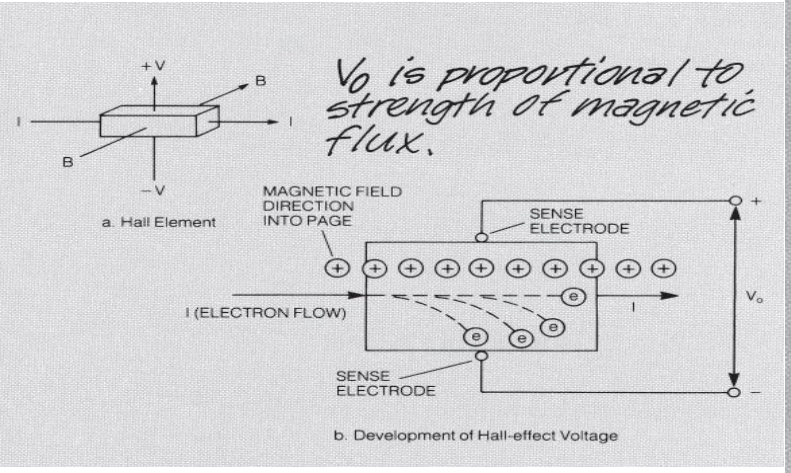
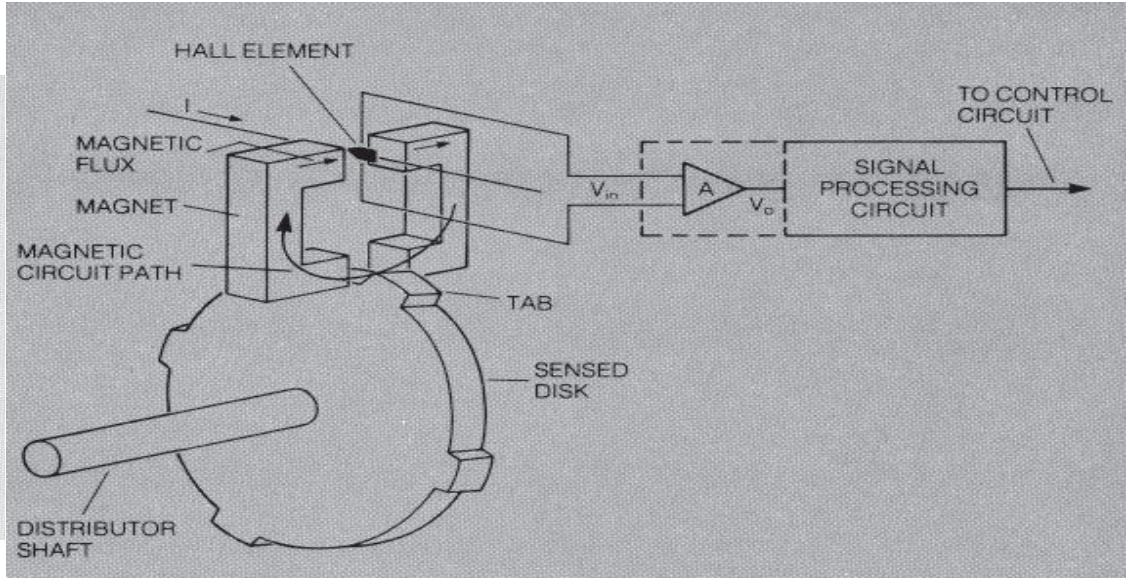
Hall-Effect Position Sensor

The Hall element is a thin slab of semiconductor material that is placed between the magnets so it can sense the magnetic flux variations as the tab passes. A constant current is passed through the semiconductor in one direction, and a voltage is generated that varies with the strength of the magnetic flux.





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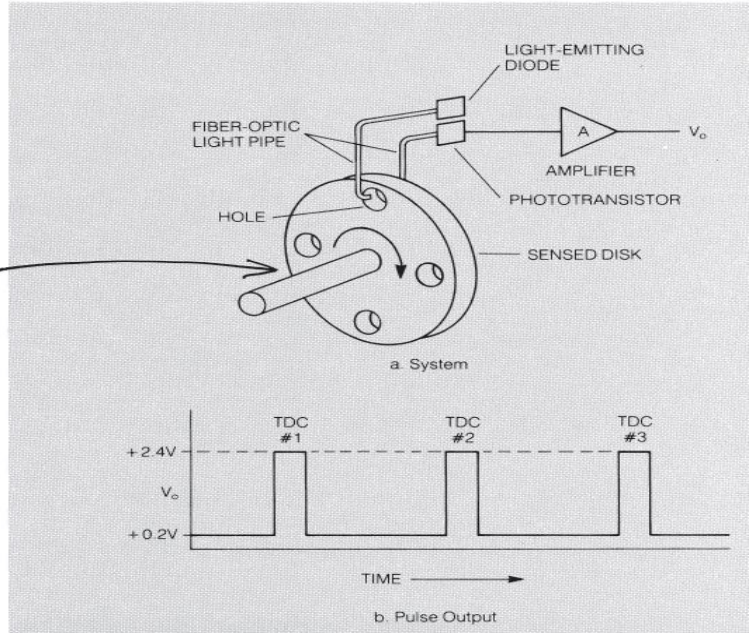
- ✔ In the **optical crankshaft position sensor**, a disk coupled to the crankshaft has holes to pass light between the LED and the phototransistor.
- ✔ An output pulse is generated as each hole passes the LED.

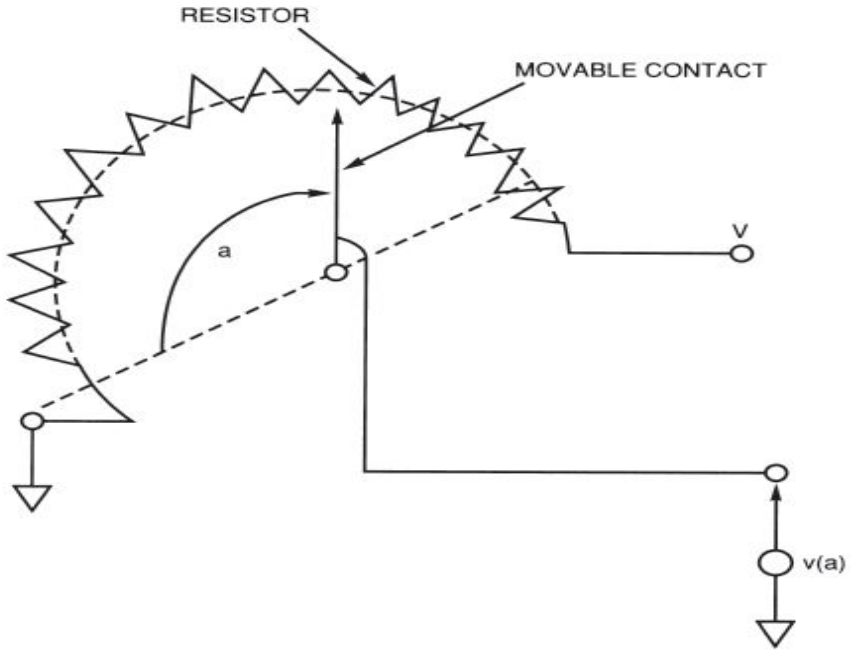
Figure 6.14
Optical Position Sensor



Rotation of disk causes alternate blocking and transmission of light.

THROTTLE ANGLE SENSOR

- ✔ The throttle plate is linked mechanically to the **accelerator pedal**
- ✔ Most throttle angle sensors are essentially potentiometers
- ✔ A **potentiometer** consists of a resistor with a movable contact



Temperature Sensor

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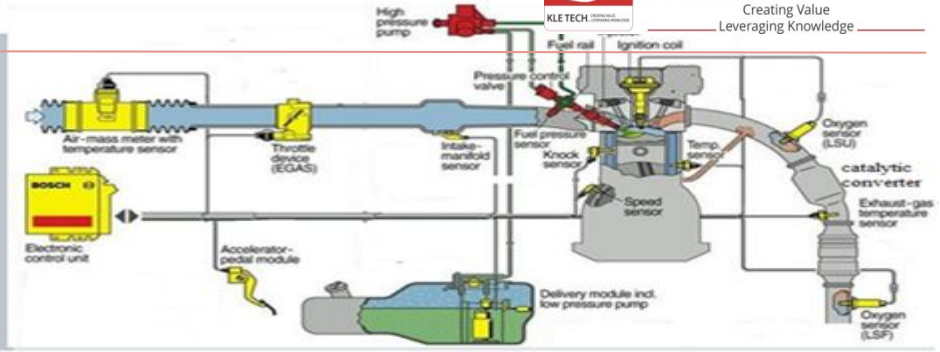
Temperature Sensors in ECM



- Engine Coolant Temperature Sensor
- Air Intake Temperature Sensor
- EGR Temperature Sensor

Sensors and Actuators

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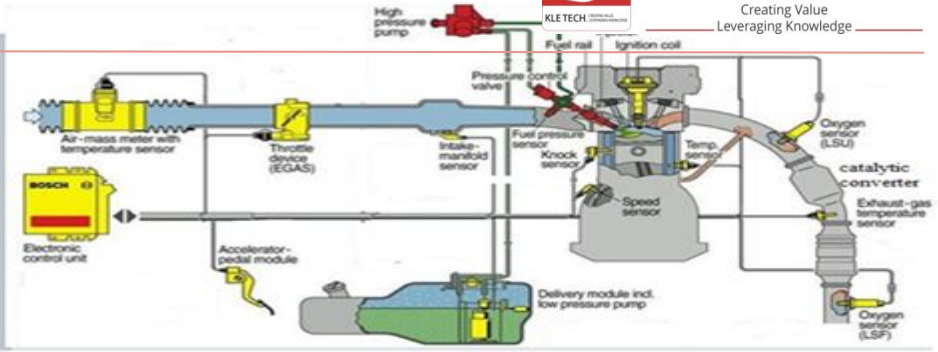
Temperature Sensors in ECM



Temperature Sensors are used in ECM

- Engine Coolant Temperature Sensor

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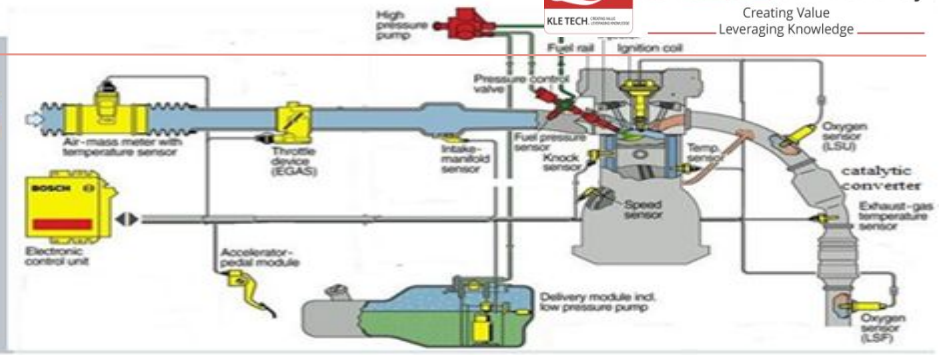
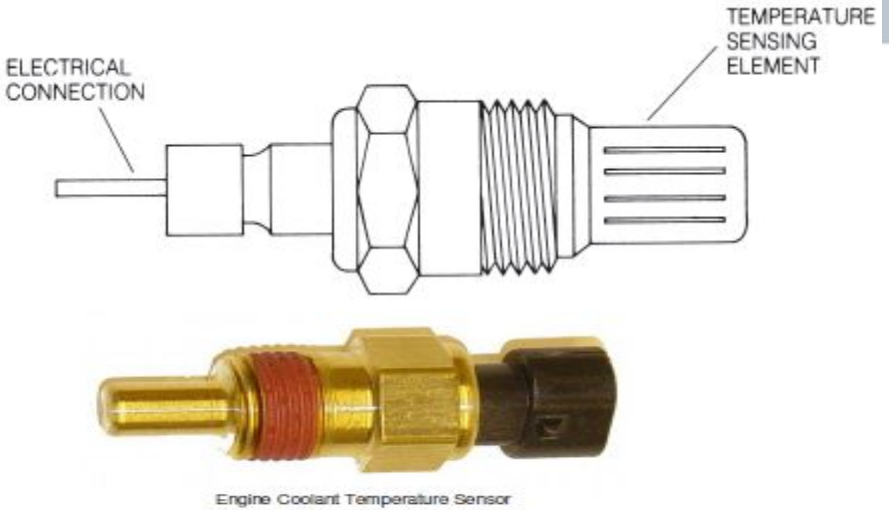
Engine coolant tempearture Sensor (ECT)





Engine Coolant Temperature Sensor

- Senses the coolant temp.
- Tells the ECM about the present temp.
- ECM instructs the radiator fan to turn on , if temp exceeds the threshold.
- The measuring range is usually from -40° to + 130°C.

Sensors and Actuators

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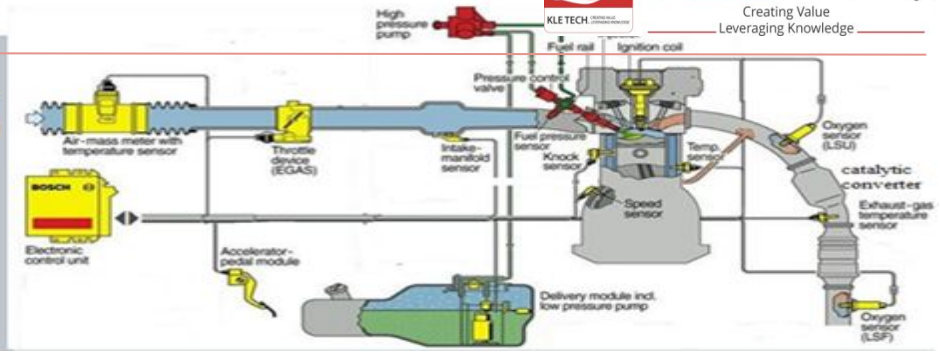
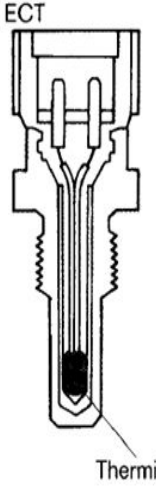
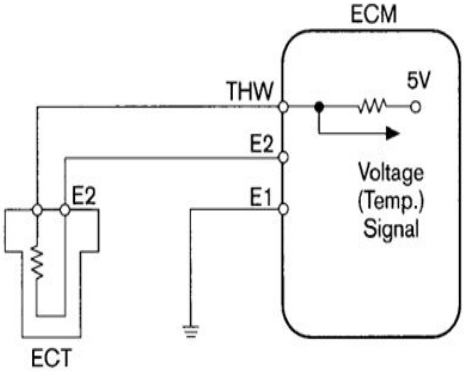
Engine coolant tempearture Sensor (ECT)



Coolant Sensor

ECT Circuit





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Thermistors

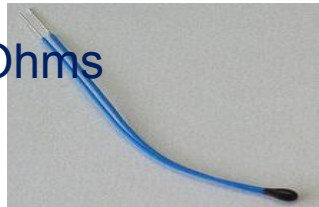
✔Commonly used for temperature measurement on vehicles.

✔They are made out of **semiconductor materials** such as cobalt or nickel oxides.

✔Change in temperature causes change in change in resistance of the thermistor.

✔Most of the thermistors are of the negative **negative temperature coefficient (NTC)** type

✔Resistance range – Several Kilo Ohms at 0oC to a few hundred Ohms hundred Ohms at 100o C. Thus it can be more sensitive.



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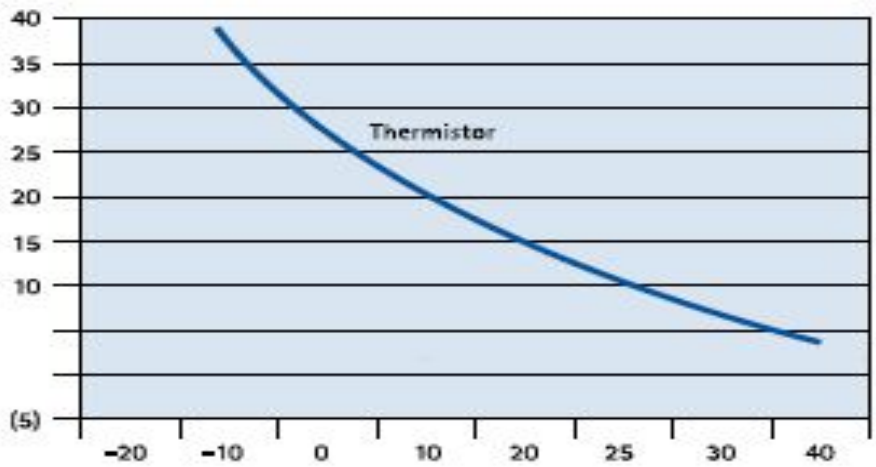

NTC Thermistor ‘s curve
(temp v/s Resistance)

SENSORS FOR FEEDBACK CONTROL: Oxygen Sensors

- ✔ It is also known as the **02** sensors.
- ✔ It is situated in the exhaust pipe.
- ✔ The sensor determines how much oxygen is left in the exhaust.
- ✔ It will point out whether the fuel is burning rich or lean.

Stoichiometry

- **Stoichiometry** in automotive terms is the principle that refers to the “ideal” air to fuel ratio being consumed in the cylinder.
- At **14.7 pound of air to 1 pound of fuel**, even pre-converter HC, CO and NO_x exhaust gases will be at their lowest levels.
- However, no vehicle can maintain a precise **14.7:1 mixture**.
- Constant changes in the throttle position, engine load, and vehicle speed cause the mixture to vary almost constantly.
- The feedback system has to adjust the mixture constantly to keep the mixture near optimum levels.

Stoichiometry

- ✔ The system keeps the **air/fuel mixture** close to the ideal by constantly switching back and forth on either side of stoichiometry.
- ✔ The engine management system is **responsible for maintaining stoichiometry** allowing the catalytic converter to operate at maximum efficiency while maintaining minimal emissions.
- ✔ The engine management system uses an **oxygen sensor** in the exhaust to determine if the air/fuel mixture is rich or lean and adjusts to compensate.

Oxygen Sensor Operation

The oxygen sensor plays a critical role in providing optimum engine performance with minimal emissions.

There are two basic types of oxygen sensors. They are the:

- Zirconia
- Titania

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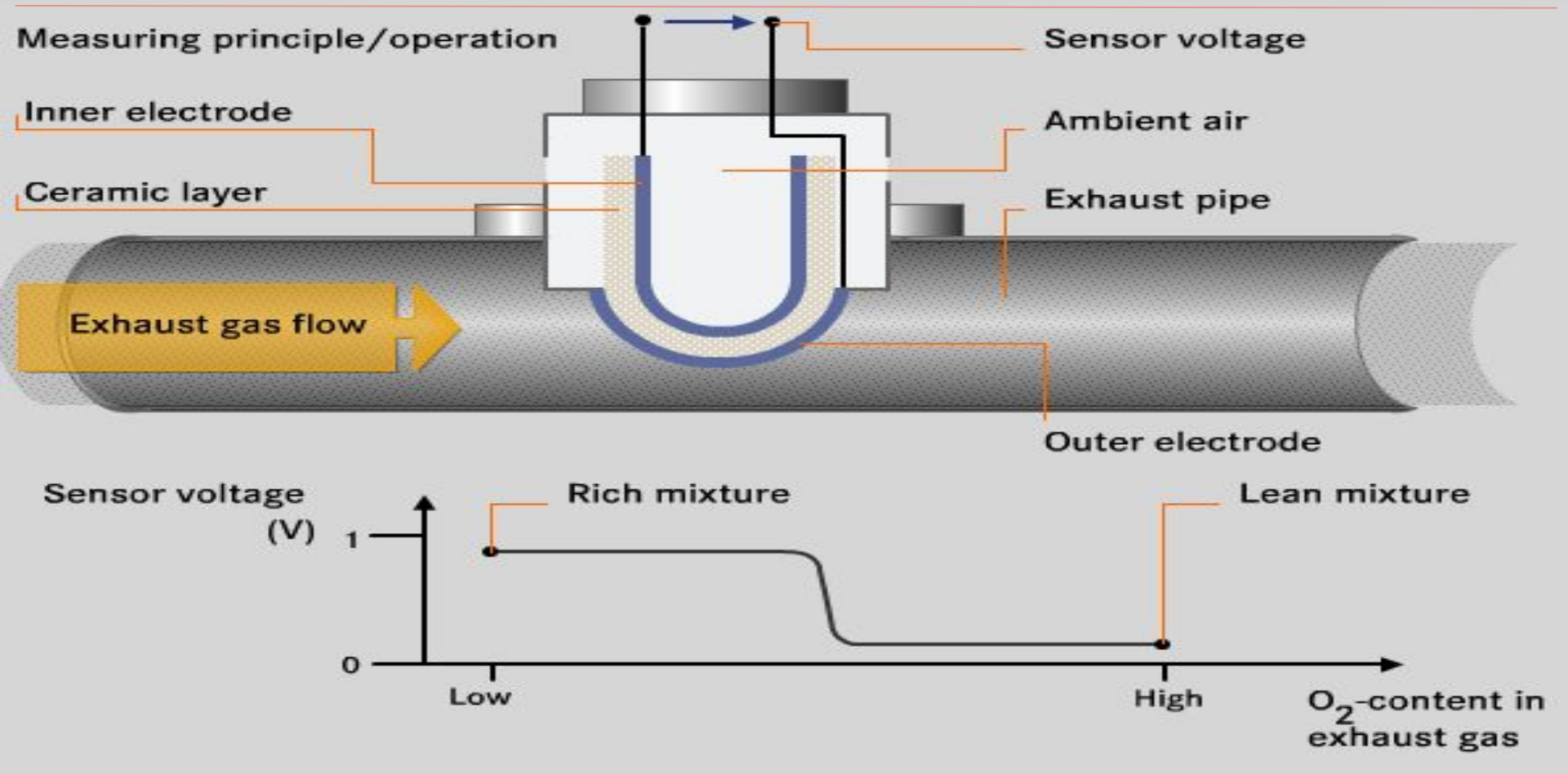

Measuring principle/operation
Sensor voltage
Inner electrode
Ambient air
Ceramic layer
Exhaust pipe
Exhaust gas flow
Outer electrode
Sensor voltage
(V)
1
0
Rich mixture
Lean mixture
Low
High
O_2-content in exhaust gas

Contd..

- This sensor is often called a **lambda sensor** from the Greek letter lambda (l), which is commonly used to denote the equivalence ratio:

$$\lambda = \frac{(\text{air/fuel})}{(\text{air/fuel at stoichiometry})}$$

  - Whenever the air/fuel ratio is at stoichiometry, the value for **l is 1**.
  - When the air–fuel mixture is too lean, the condition is represented by lambda greater than one (denoted **l > 1**).
  - When the air–fuel mixture is too rich, the condition is represented by an equivalence ratio of lambda less than one (**l < 1**).

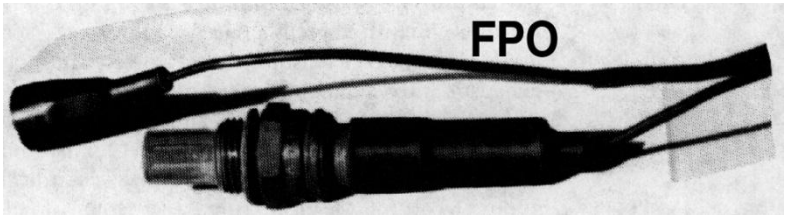
- The two types of EGO sensors that have been used are based on the use of **active oxides** of two types of materials.
  - **Zirconium dioxide (ZrO2)**
  - **Titanium dioxide (TiO2).**

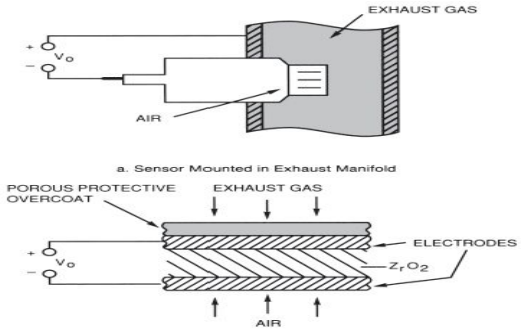
Desirable EGO Characteristics

- Abrupt change in voltage at stoichiometry
- Rapid switching of output voltage in response to exhaust gas oxygen changes
- Large difference in sensor output voltage between rich and lean mixture conditions
- Stable voltages with respect to exhaust temperature

Contd..

- The zirconium dioxide EGO sensor uses zirconium dioxide sandwiched between two platinum electrodes. One electrode is exposed to exhaust gas and the other is exposed to normal air for reference.
- The ZrO2 has a tendency to **attract the oxygen ions**, which accumulate on the ZrO2 surface just inside the platinum electrodes.
- The **platinum plate** on the air reference side of the ZrO2 is exposed to a much higher concentration of oxygen ions than the exhaust gas side.
- The air reference side becomes electrically more negative than the **exhaust gas side**; therefore, an electric field exists across the ZrO2 material and a **voltage, Vo**, results.





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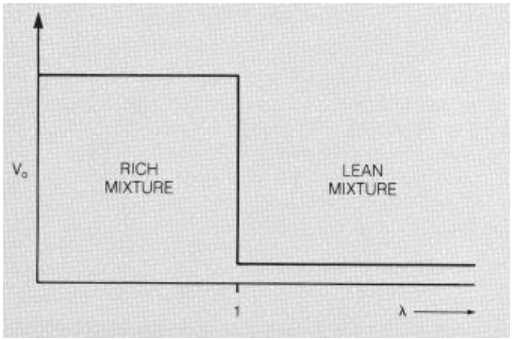
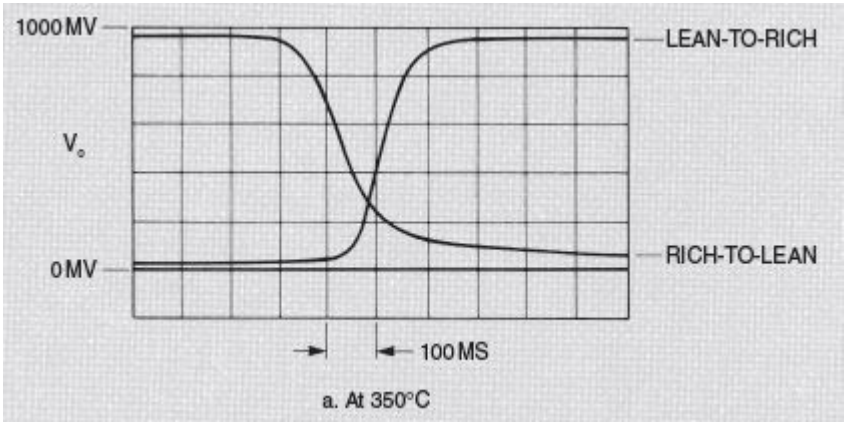
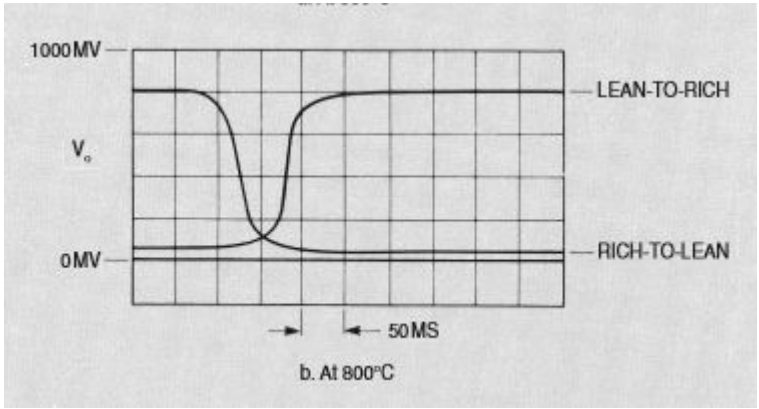


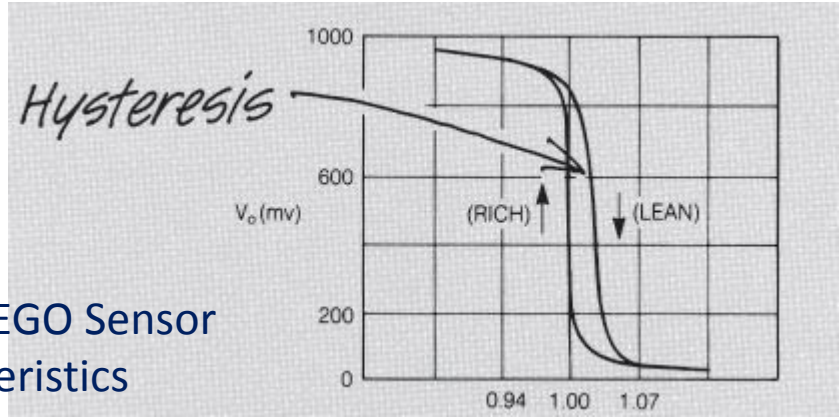
Ideal EGO Switching Characteristics

Typical Voltage Switching Characteristics of EGO Sensor





Typical EGO Sensor Characteristics



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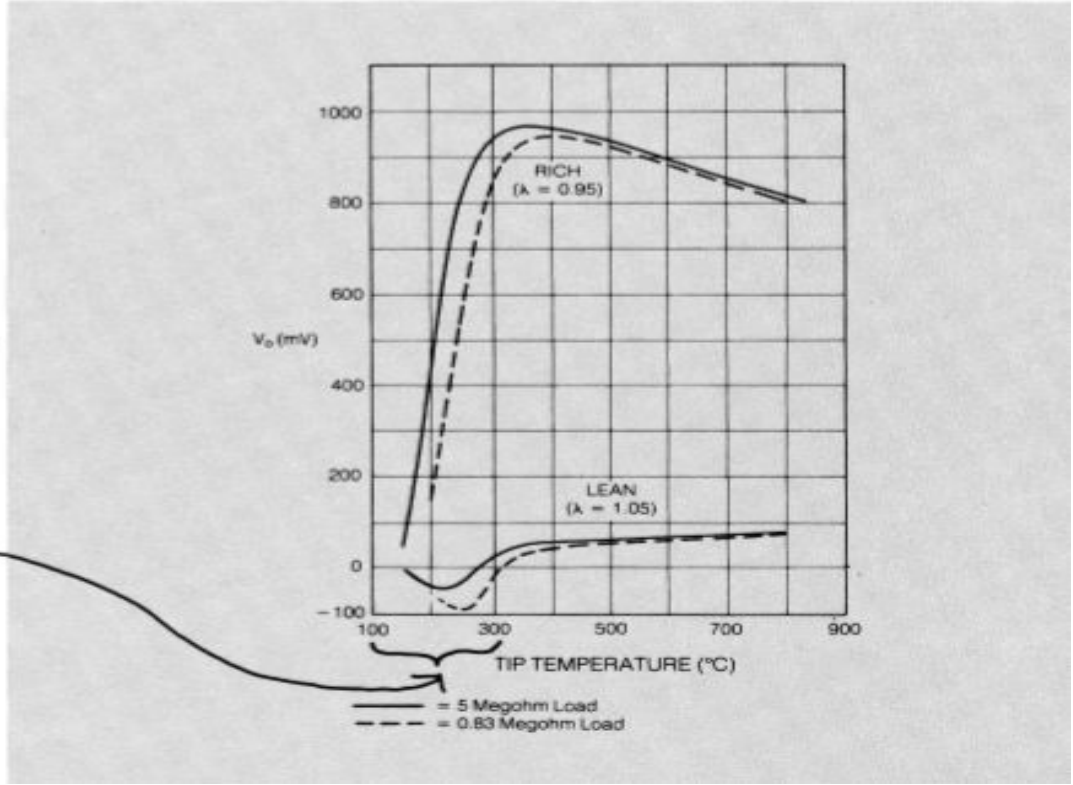
Typical Influence of Mixture and Temperature on EGO Output Voltage

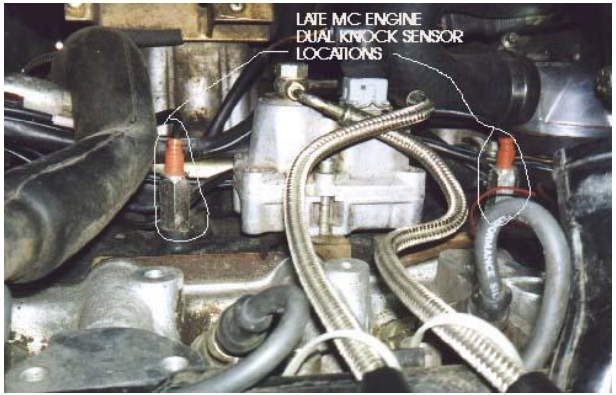


Knock Sensor

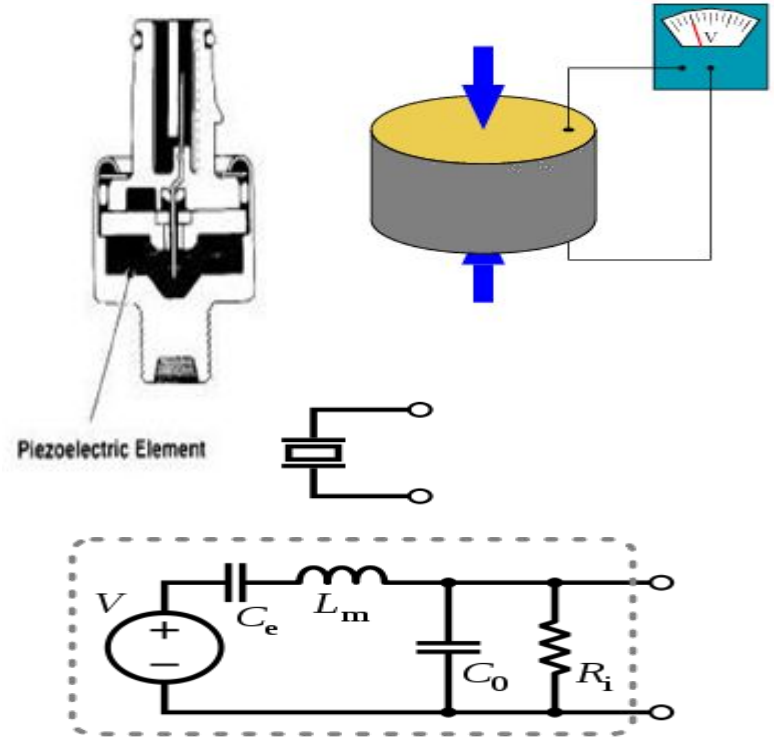
- **What are Knocks??** - high frequency vibrations caused by detonation, or the premature burning of fuel inside an engine's cylinders

- it can be described generally as a **rapid rise in cylinder pressure** during combustion.

- It occurs most commonly with high manifold pressure and excessive spark advance. It is important to detect knock and avoid excessive knock; otherwise, there may be damage to the engine.



How it works - Piezoelectric effect

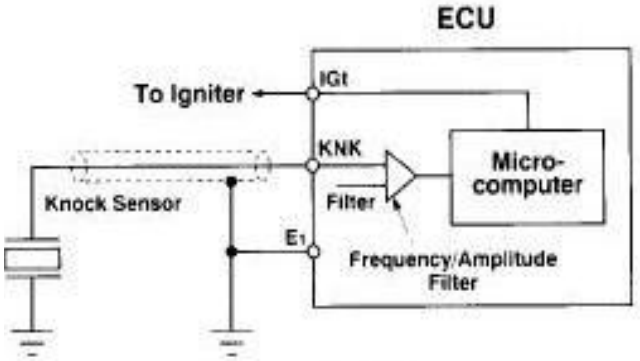


- ✔ Knock Sensors **generate a voltage when vibration** is applied to them utilizing the piezoelectric effect

- ✔ Due to the vibration, a counter weight inside the sensor is applying pressure on the piezo element, this pressure creates an **electric charge** in the piezo element which is the output signal of the sensor.

Contd..

✔ Once signs of knocking are detected, the knock sensor sends a voltage signal to the engine management computer, which retards the spark timing slightly to avoid detonation.



Benefits

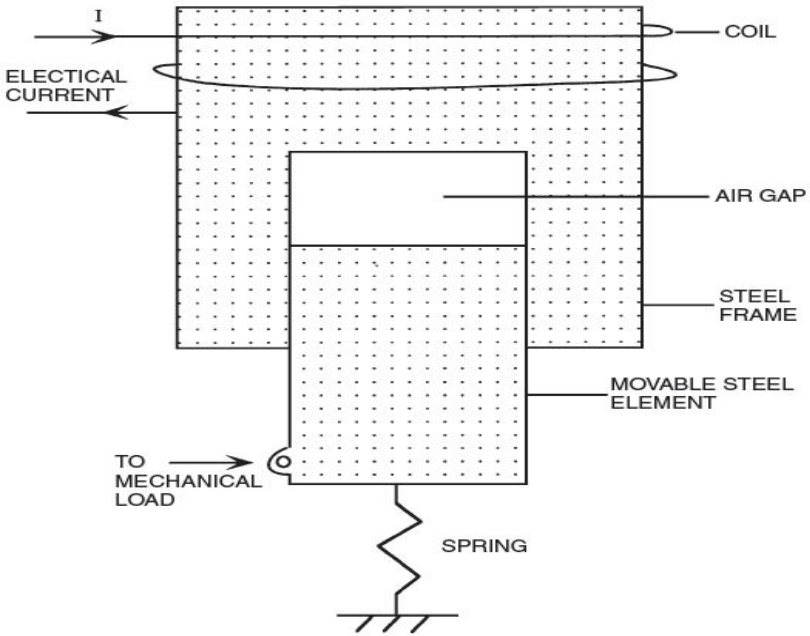
- Vehicle engines work more efficiently and produce more power when operating near the detonation limit.
- Although simple, knock sensors allow optimum engine performance and protect the engine from potential damage caused by detonation.

Challenges

- Piezoelectric elements can be sensitive to more than one physical dimension Ceramic materials lack long term stability
- Sensor can be fooled by things like bad water pump or alternator bearing, or a loose rod bearing

AUTOMOTIVE ENGINE CONTROL ACTUATORS

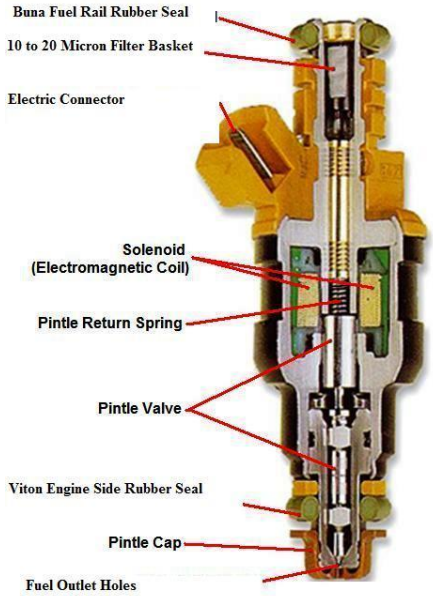
- An actuator is a device that receives an electrical input (e.g., from the engine controller) and produces a mechanical or thermal (or other) output.
- Some of the actuators are:
  - Solenoids
  - DC Motors
  - Stepper motors
  - Hydraulic/Pneumatic
  - Piezo Actuators and so on..



Schematic Drawing of a Solenoid

Contd..

- One of the examples of solenoid actuator is the one used in Fuel injector **Fuel injector.**
- A typical fuel injector solenoid has the following:
  - Stroke: 0.1mm
  - Open period range: 1.5 to 10.0 ms.
  - Coil resistance : 16 Ω
  - Time taken by an injector to open and close is critical in fuel injection.
  - The induction of the coil plays an important role in the reaction time for the solenoid. (Higher inductance -> longer reaction time, ballast resistors)
  - Another application of solenoid actuator is for **door locks**.



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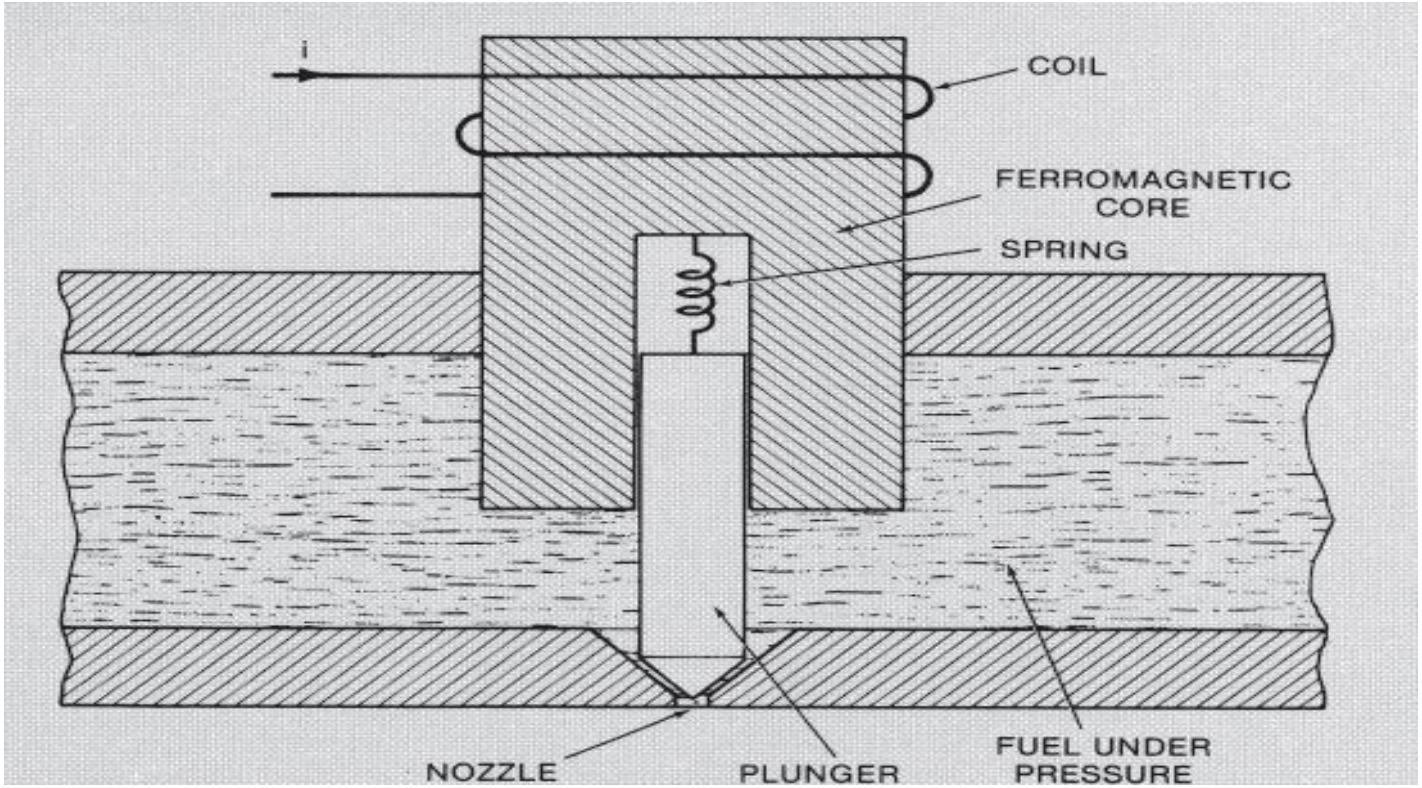
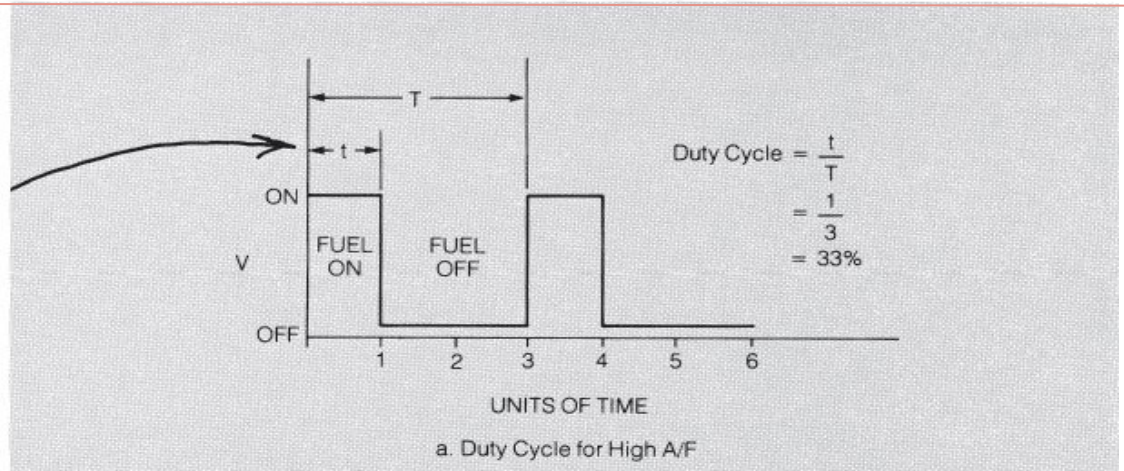
Schematic Drawing of Fuel Injector



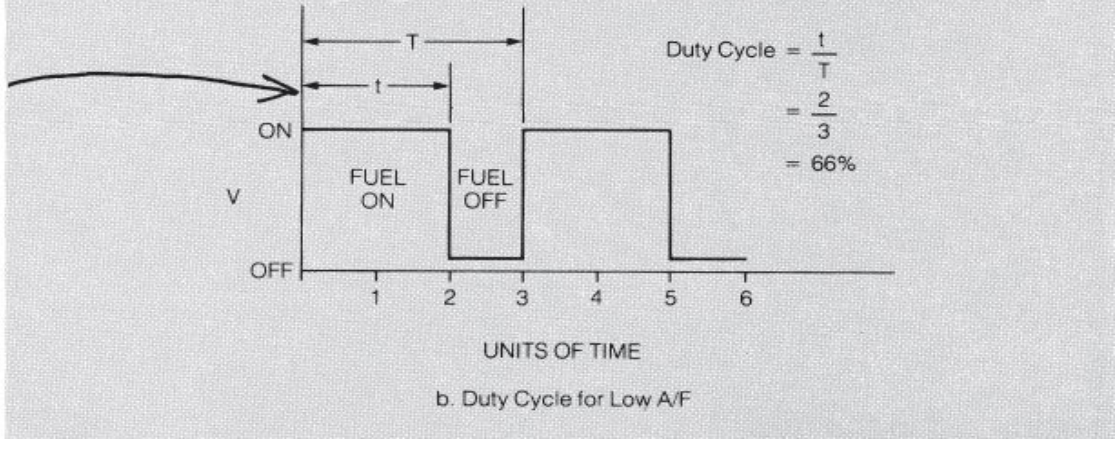
Pulse Mode Fuel Control Signal to Fuel Injector

High air-to-fuel ratio.



a. Duty Cycle for High A/F

Low air-to-fuel ratio.



b. Duty Cycle for Low A/F

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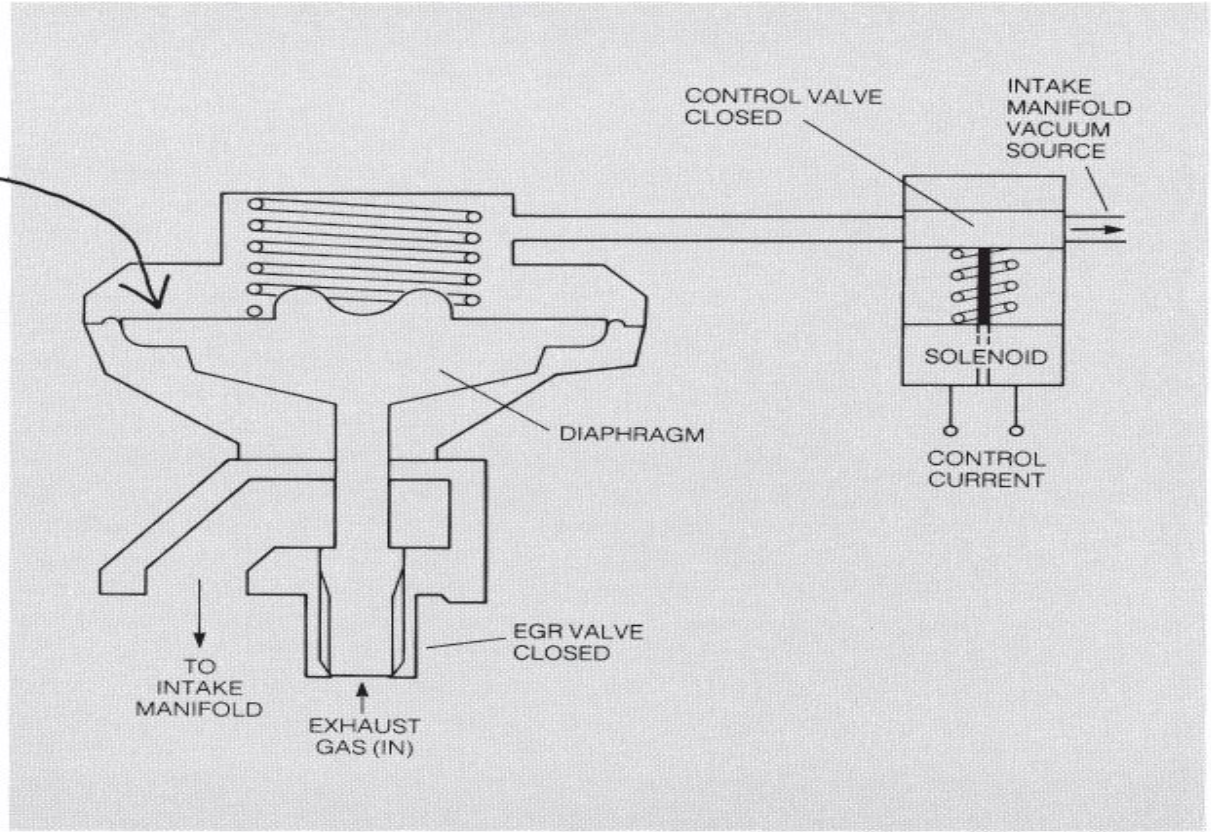
EGR Actuator Control

Vacuum pulls up diaphragm



Hydraulic/Pneumatic

Prime m

AC Motor

DC Motor

Diesel Eng

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– Clutches

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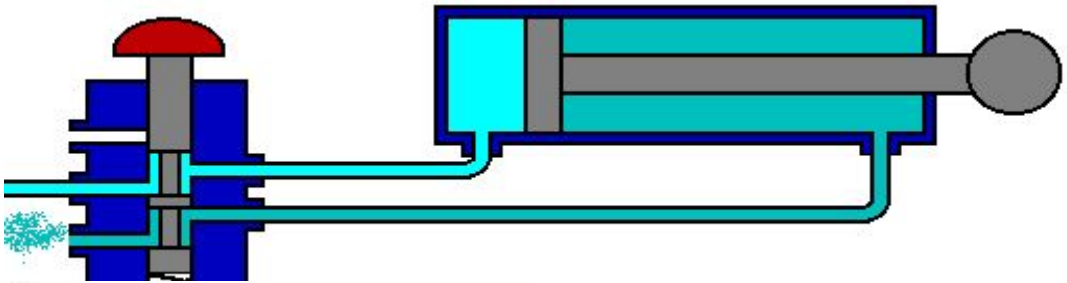

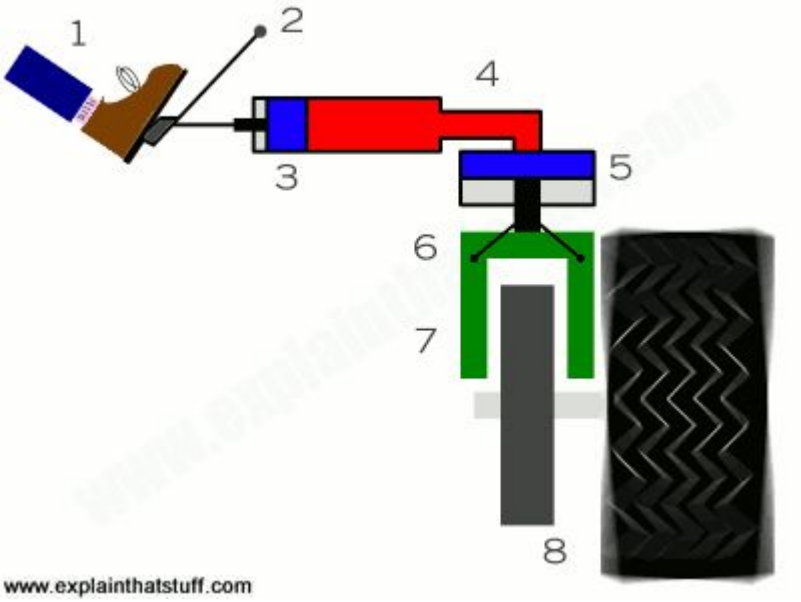
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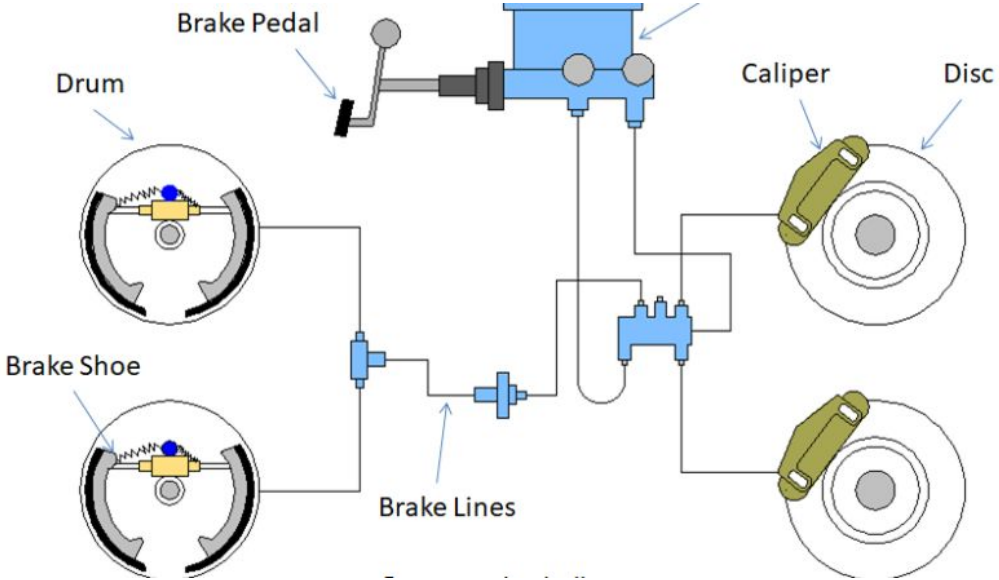
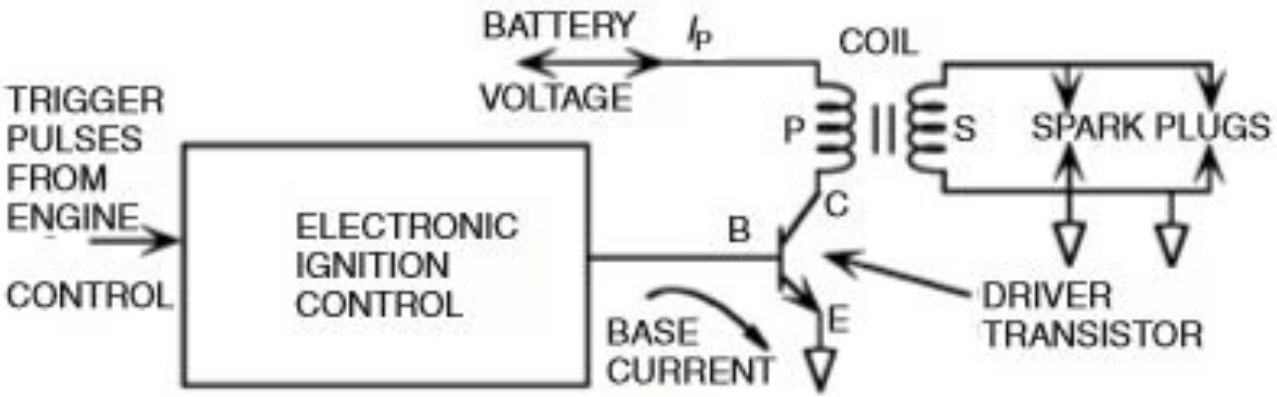
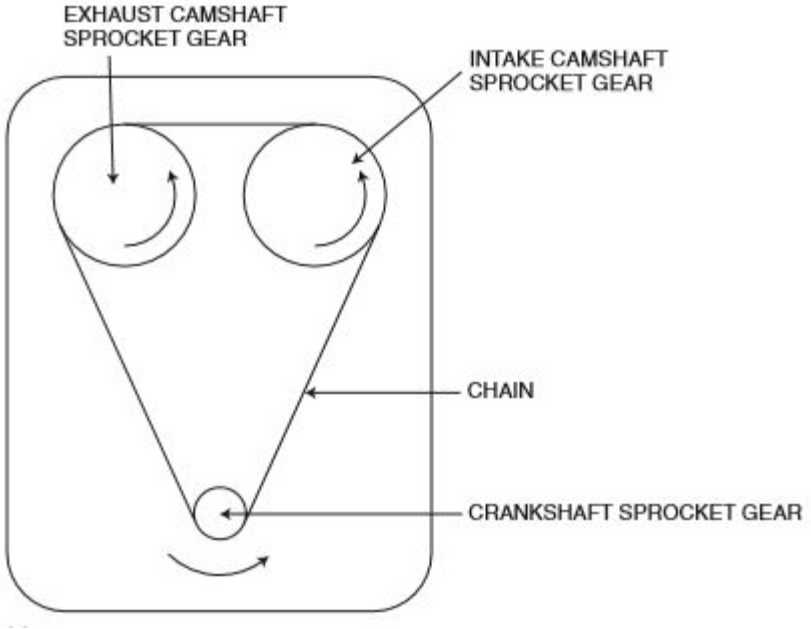
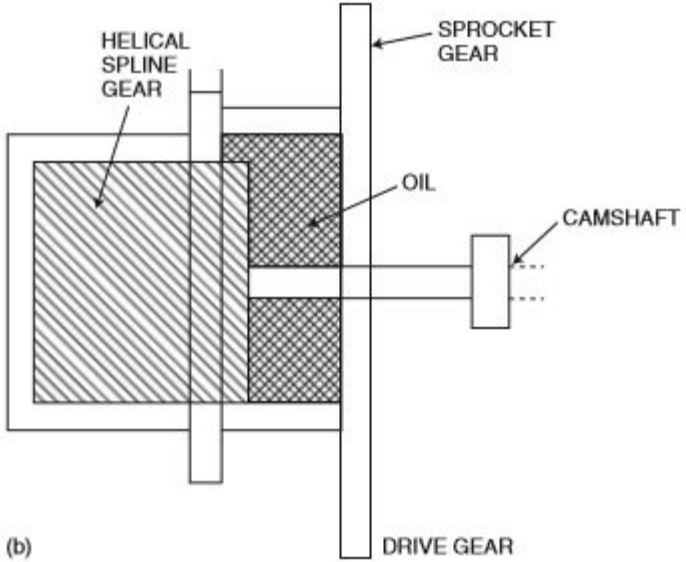

Brake Pedal
Drum
Caliper
Disc
Brake Shoe
Brake Lines

Ignition System

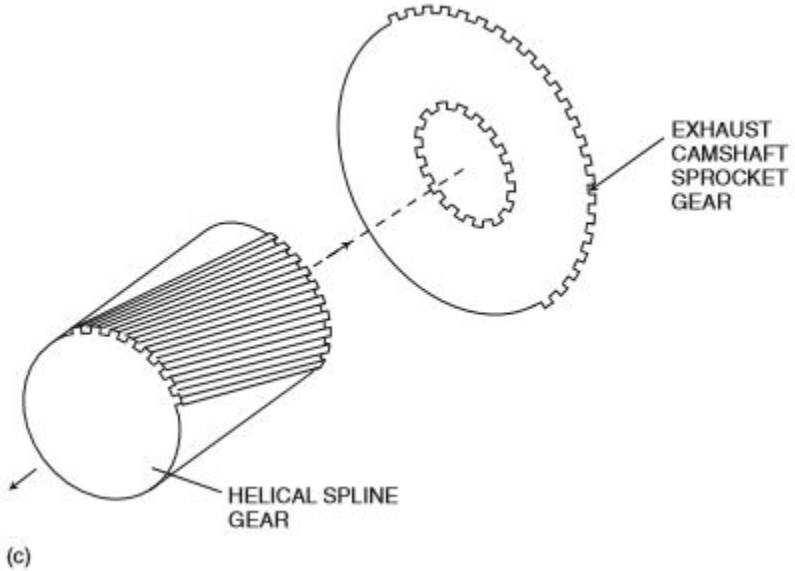


Variable valve Timing

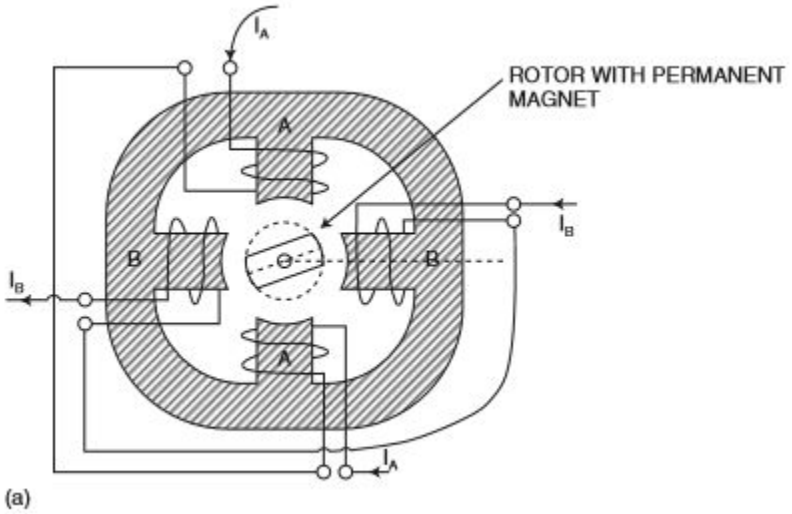


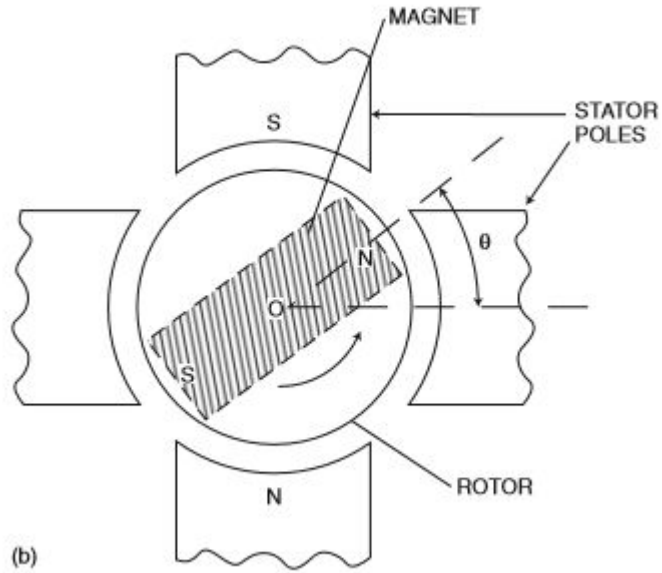


Variable Valve Timing

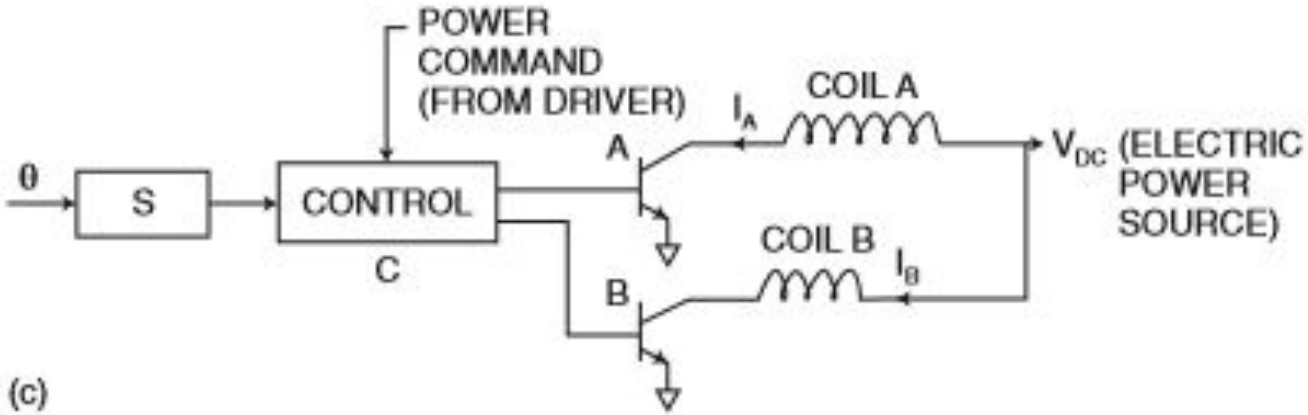


Brushless DC Motor





Brushless DC Motor



THANKS