AUTOMOTIVE SENSORS & ACTUATORS

Transducer

A device that converts energy of one form into energy of another form.

Examples: Sensors and Actuators

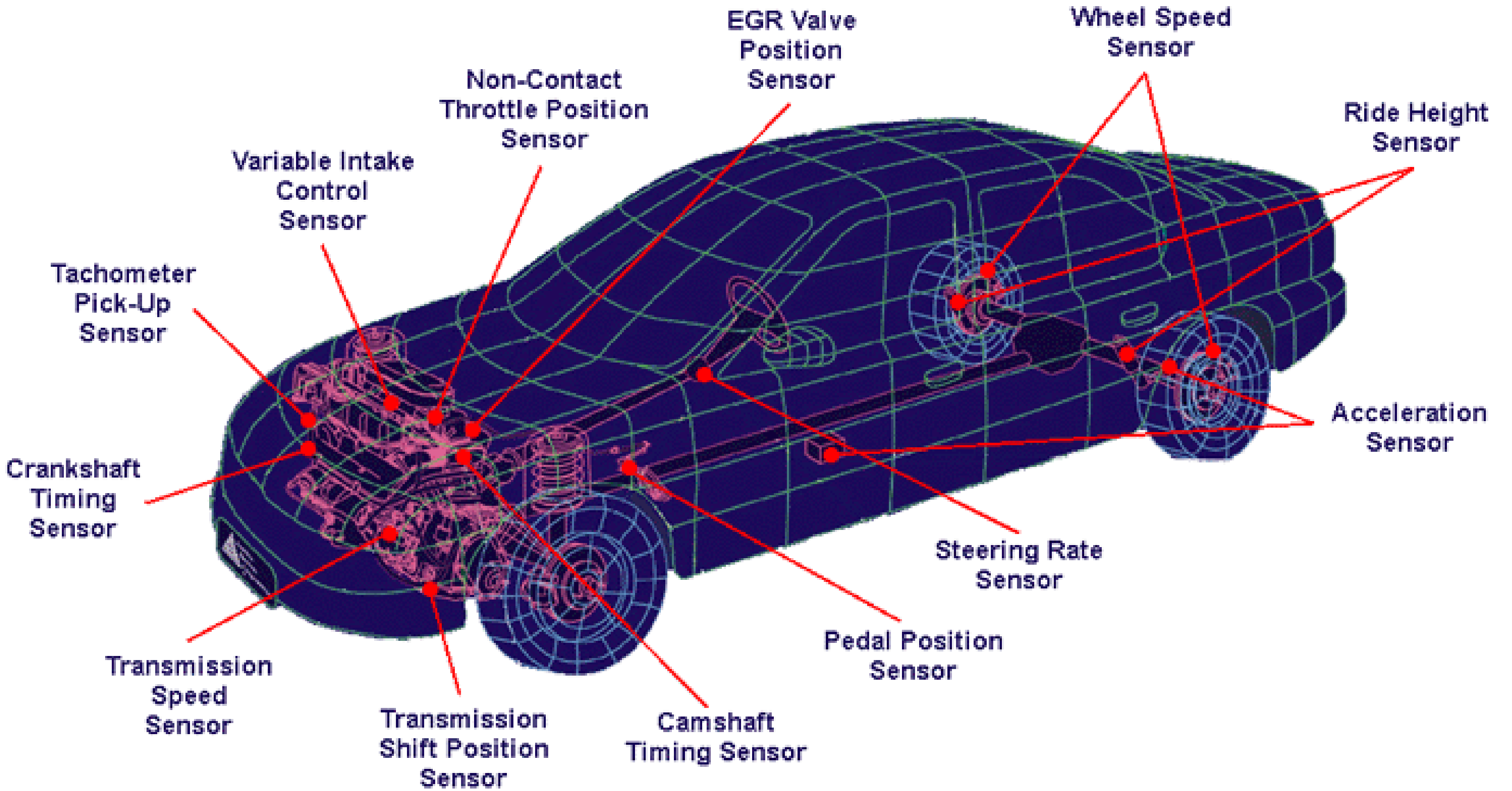
Sensor

A device that responds to a physical stimulus (measurand).

Actuator

A device or mechanism capable of performing a physical action.

Automotive Sensors



Classification of Sensors

- Active and Passive sensors
- Contact and non contact sensors
- Absolute and relative sensors
- Other schemes

Active and passive sensors

Active sensor : a sensor that requires external power to operate.

Examples : carbon microphone, thermistors, strain gauges, capacitive and inductive sensors, etc.

Other name: parametric sensors

Passive sensor: generates its own electric signal and does not require a power source.

Examples: thermocouples, magnetic microphones, piezoelectric sensors.

Other name: self-generating sensors

Contact and noncontact sensors

Contact sensor: a sensor that requires physical contact with the stimulus.

Examples: strain gauges, most temperature sensors.

Non-contact sensor: requires no physical contact.

Examples: most optical and magnetic sensors, infrared thermometers.

Absolute and relative sensors

Absolute sensor: a sensor that reacts to a stimulus on an absolute scale.

Examples: Thermistors, strain gauges, etc., (thermistor will always read the absolute temperature).

Relative scale: The stimulus is sensed relative to a fixed or variable reference.

Examples: Thermocouple measures the temperature difference, pressure is often measured relative to atmospheric pressure.

Other schemes

Classification by broad area of detection

- Electric sensors
- Magnetic
- Electromagnetic
- Acoustic
- Chemical
- Optical
- Heat, Temperature
- Mechanical
- Radiation
- Biological

Other schemes (contd..)

Classification by physical law

- Photoelectric
- Magnetoelectric
- Thermoelectric
- Photoconductive
- Magnitostrictive
- Electrostrictive
- Photomagnetic
- Thermoelastic
- Thermomagnetic
- Thermooptic
- Electrochermical
- Magnetoresistive
- Photoelastic

Other schemes (contd..)

Classification by specifications

- Accuracy
- Sensitivity
- Stability
- Response time
- Hysteresis
- Frequency response
- Input (stimulus) range
- Resolution
- Linearity
- Hardness (to environmental conditions, etc.)
- Cost
- Size, weight
- Construction materials
- Operating temperature

Other schemes (contd..)

Classification by area of application

- Consumer products
- Military applications
- Infrastructure
- Energy
- Heat
- Manufacturing
- Transportation
- Automotive
- Avionic
- Marine
- Space
- Scientific

Why do we need sensors?

- Information gathering
- Control
- Actuation

Information gathering

Provides data for display purposes to give an understanding of the current status of system parameters.

Example: Car speed sensor and speedometer.

Control

The signal from the sensor is input to a controller. Once this information is gathered by sensors, it is conditioned, and then input to the computer system to process and generate an appropriate response.

Actuation

The controller then provides an output to control the measured parameter to perform a physical action.

Example: Information from the wheel speed sensor in an anti-lock braking system is used to control applied brake pressure and thus stop the wheel skidding during braking.

Sensor Types

Automotive application

Angular position sensors

Function

Measure simple angular settings and changes in angle.

Automotive application

Throttle-valve-angle measurement for engine management on gasoline (SI) engines.

Rotational-speed sensors

Function

Measure rotational speeds, positions and angles in excess of 360°.

Automotive application

Wheel-speed measurement for ABS/TCS, engine speeds, positioning angle for engine management, measurement of steering wheel angle, distance covered, and curves/bends for vehicle navigation systems.

Spring-mass acceleration sensors

Function

Measure changes in speed, such as are common in road traffic.

Automotive application

Registration of vehicular acceleration and deceleration. Used for the Antilock Braking System (ABS) and the Traction Control System (TCS).

Bending-beam acceleration sensors

Function

Register shocks and vibration which are caused by impacts on rough/unpaved road surfaces or contact with kerb stones.

Automotive application

For engine management, detection of vibration on rough/unpaved road surfaces.

Piezoelectric acceleration sensors

Function

Measure shocks and vibration which occur when vehicles and bodies impact against an obstacle.

Automotive application

Impact detection used for triggering airbags and belt tighteners

Piezoelectric vibration sensors

Function

Measure structure-borne vibrations which occur at engines, machines, and pivot bearings.

Automotive application

Engine-knock detection for anti-knock control in engine-management systems.

Absolute-pressure sensors

Function

Measure the pressure ranges from about 50% to 500% of the earth's atmospheric pressure.

Automotive application

Manifold vacuum measurement for engine management. Charge-air-pressure measurement for charge-air pressure control, altitude pressure- dependent fuel injection for diesel engines.

Yaw sensors

Function

Measure skidding movements, such as occur in vehicles under road traffic conditions.

Automotive application

Used on the vehicle dynamics control (Electronic Stability Program, ESP) for measuring yaw rate and lateral acceleration, and for vehicle navigation sensors.

Differential-pressure sensors

Function

Measure differential gas pressures, e.g. for pressure compensation purposes.

Automotive application

Pressure measurement in the fuel tank, evaporative-emissions control systems.

Temperature sensors

Function

Measure the temperature of gaseous materials and, inside a suitable housing, the temperatures of liquids in the temperature range of the earth's atmosphere and of water.

Automotive application

Display of outside and inside temperature, control of air conditioners and inside temperature, control of radiators and thermostats, measurement of lube-oil, coolant, and engine temperatures.

Lambda oxygen sensors

Function

Determine the residual oxygen content in the exhaust gas.

Automotive application

Control of A/F mixture for minimization of pollutant emissions on gasoline and gas engines.

Air-mass meters

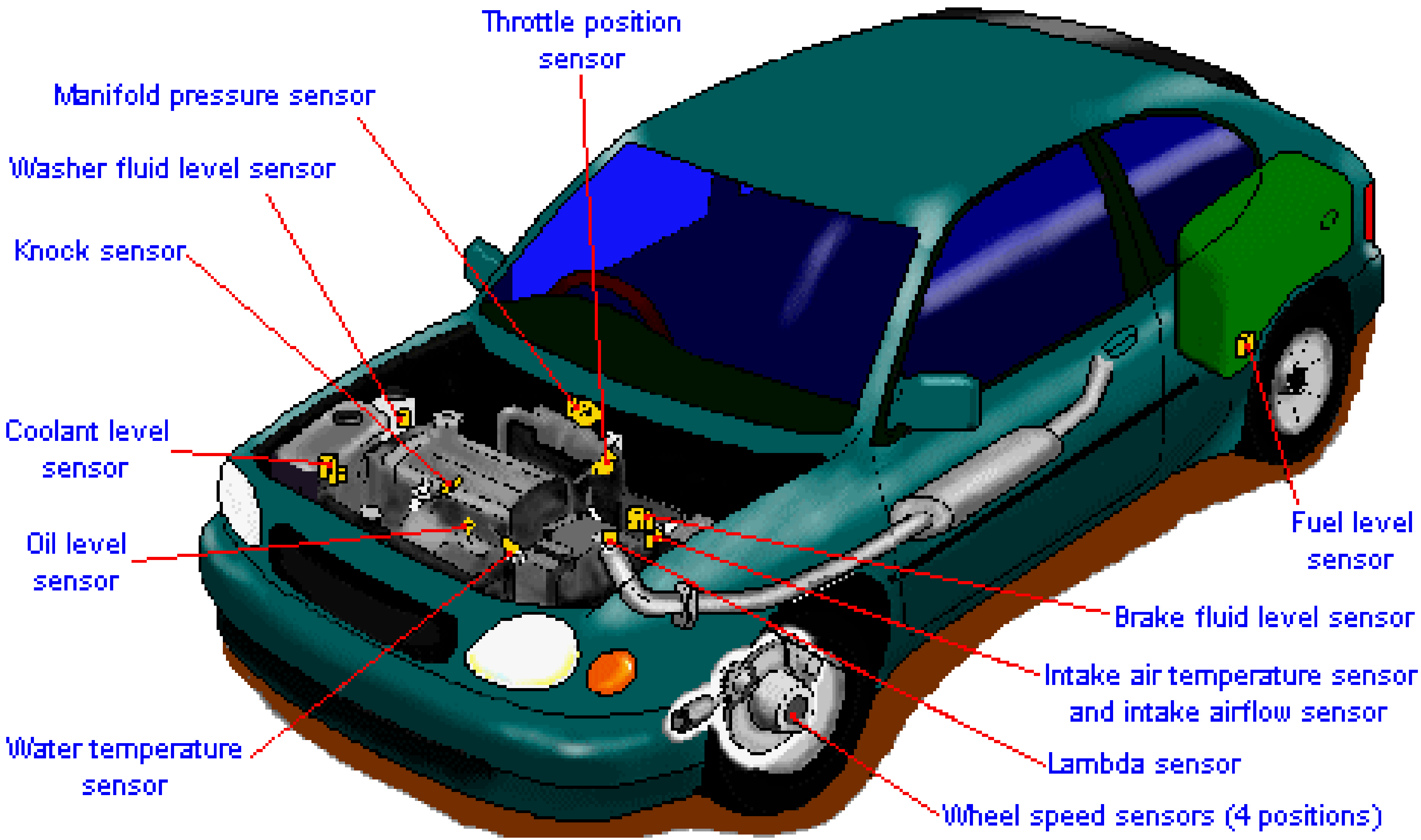
Function

Measure the flow rate of gases.

Automotive application

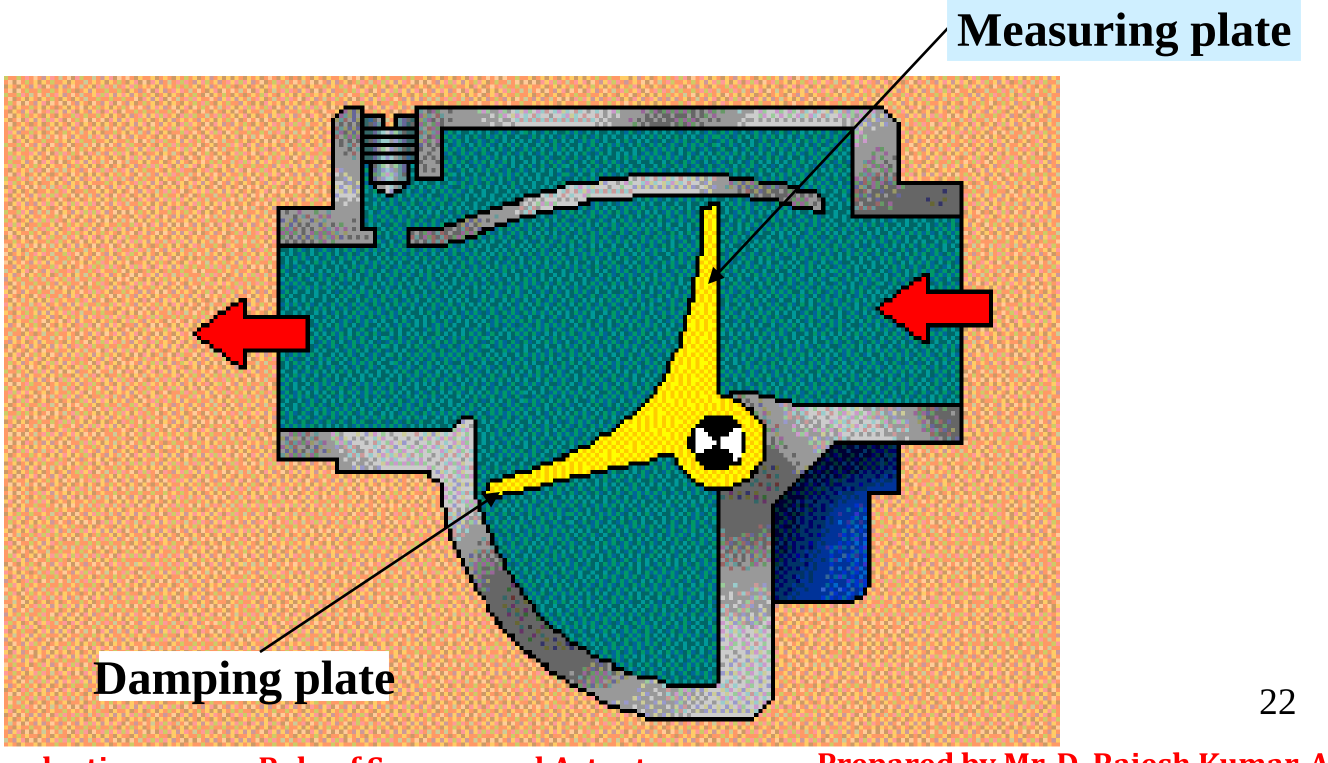
Measurement of the mass of the air drawn in by the engine.

Sensors used in a car



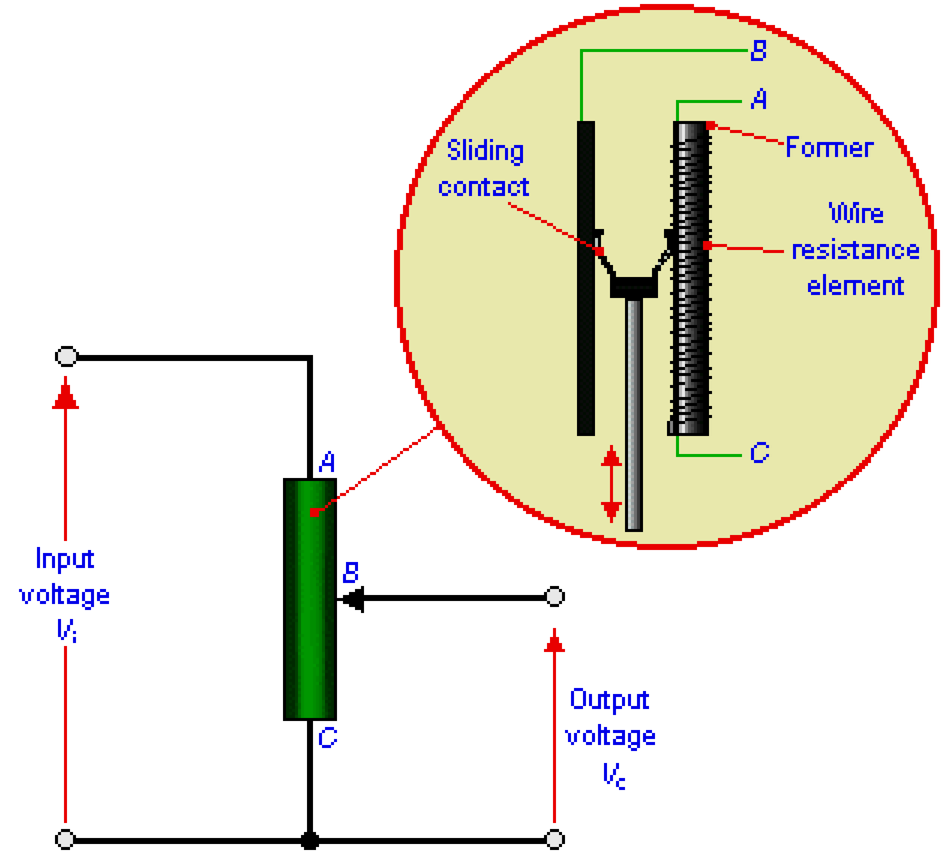
Airflow Sensor

- The air moving past the sensor turns the vanes against a spring.
- The position of the vanes is detected using a potentiometer.
- The vane that is out of the airflow is used to damp out any oscillations caused by the pulsed air



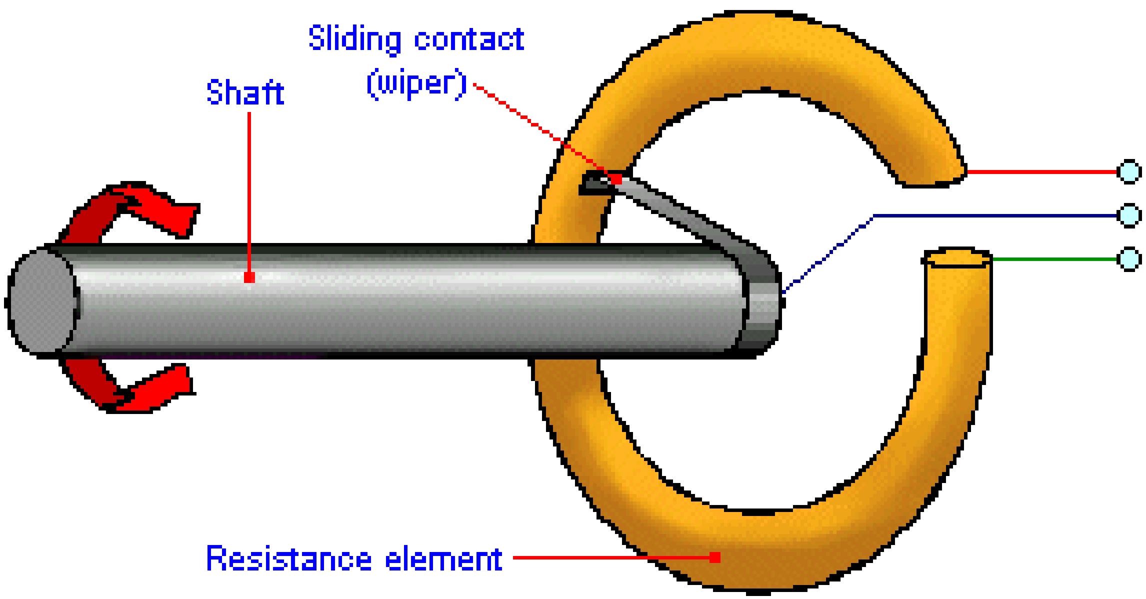
Linear potentiometer

- Potentiometers are a form of variable resistance.
- It consists of a wiper which moves over the length of a resistance element.
- This sliding contact connects to a plunger, whose displacement is to be measured.
- Resistance elements are commonly made of thin nickel or platinum wire.
- Resistance elements may also be made of films of carbon, metal, or conductive plastics to improve resolution.



Rotary potentiometer

- Rotary or angular potentiometers measure angular displacement.
- Rotary potentiometers work on the same principle as linear potentiometers.
- The output voltage is proportional to angular displacement, and will usually be displayed on a voltmeter calibrated in units of angular displacement.

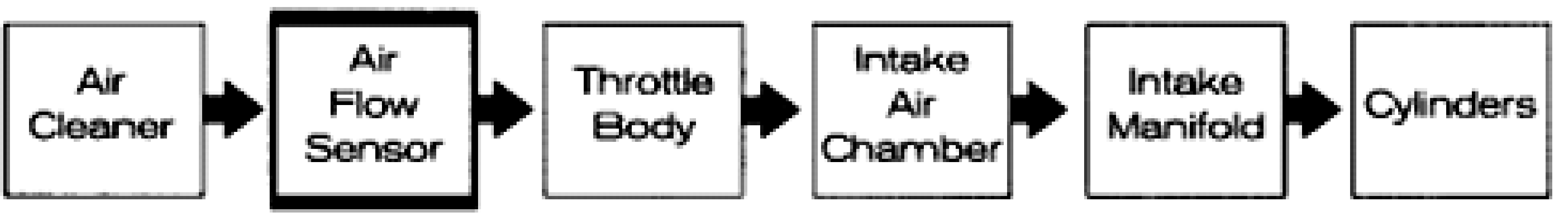


Mass Air Flow (MAF) Sensor

- The Mass Air Flow Sensors converts the amount of air drawn into a voltage signal.

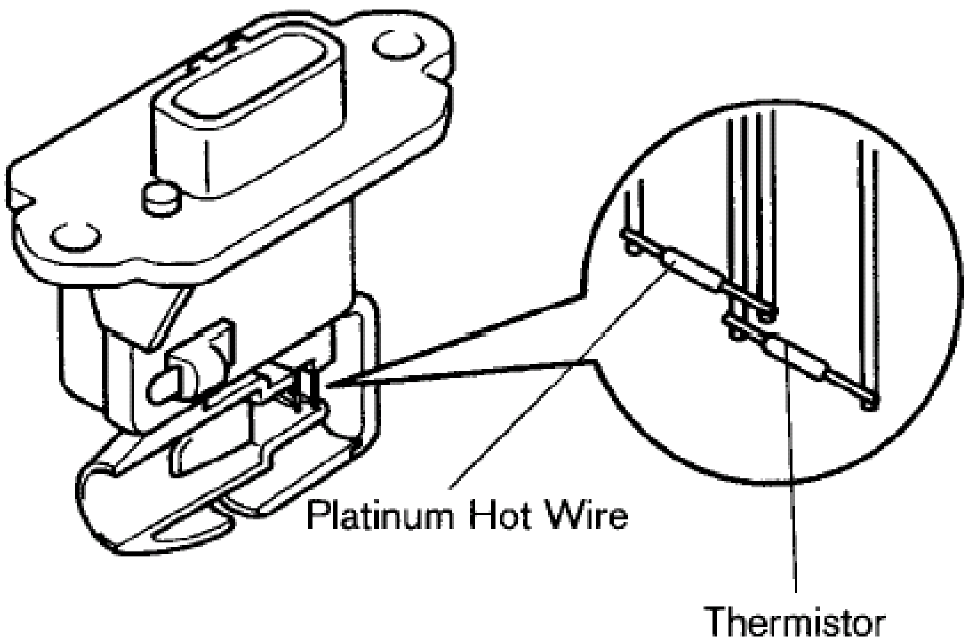
- This is necessary to determine how much fuel to inject, when to ignite, and when to shift the transmission.

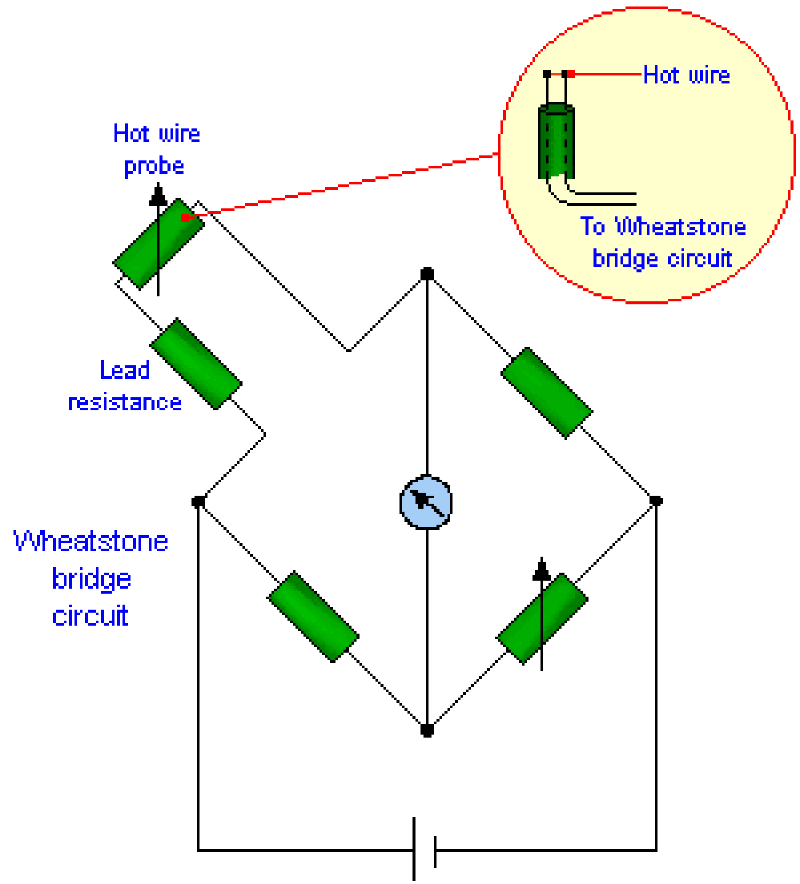
- The air flow sensor is located directly in the intake air system, between the air cleaner and throttle body.



Hot Wire MAF Sensor

- The primary components of the MAF sensor are a thermistor, a platinum wire, and an electronic circuit.
- MAF sensor also has an Intake Air Temperature Sensor as part of the housing assembly.





- The Thermistor measures the temperature of the incoming air.

- The hot wire is maintained at a constant temperature in relation to the thermistor by the electronic control circuit.

- An increase in air flow will cause the hot wire to lose heat faster and the electronic control circuitry will compensate by sending more current through the wire.

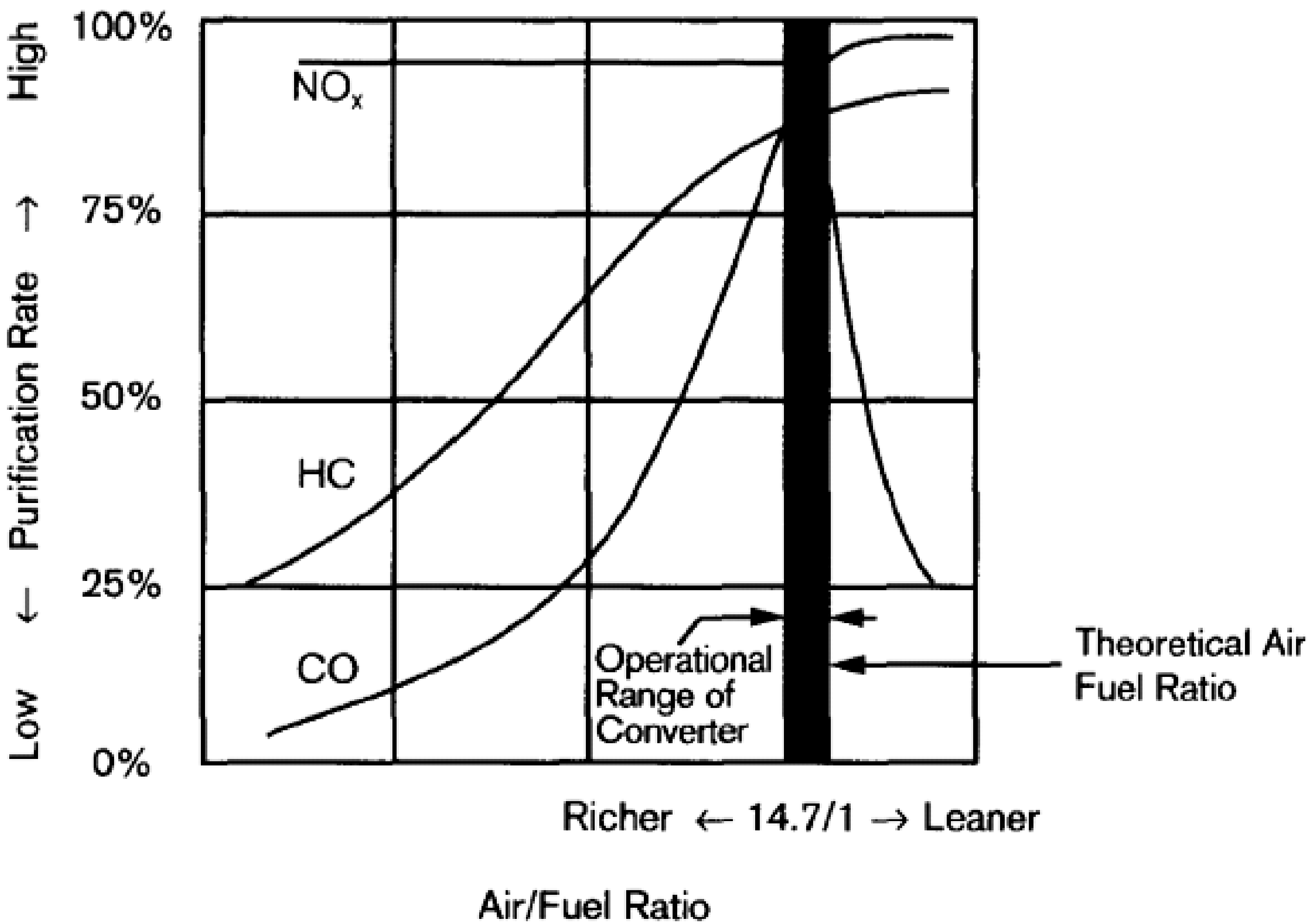
- The electronic control circuit simultaneously measures the current flow and puts out a voltage signal proportional to current flow.

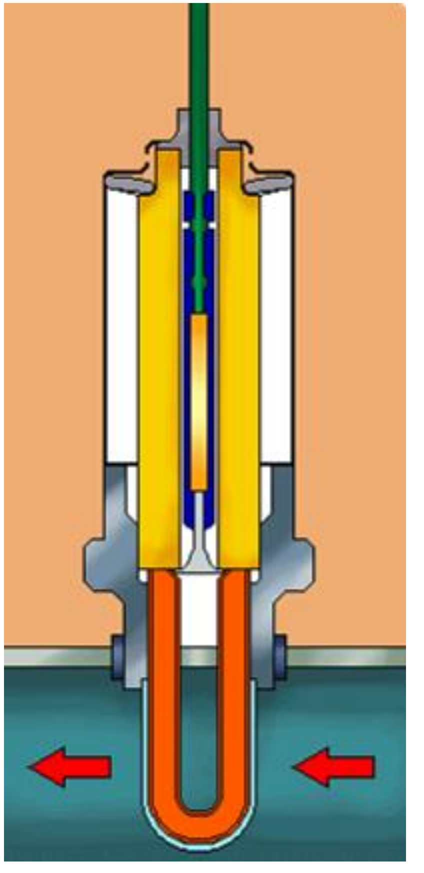
- Located after the catalytic converter.
- Used by the ECM primarily to determine catalytic converter efficiency.
- Based in the oxygen sensor signal, the ECM will adjust the amount.
- The fuel injected into the intake air stream.
- The output of the sensor is usually between 0 and 1.1 volts

Common Types

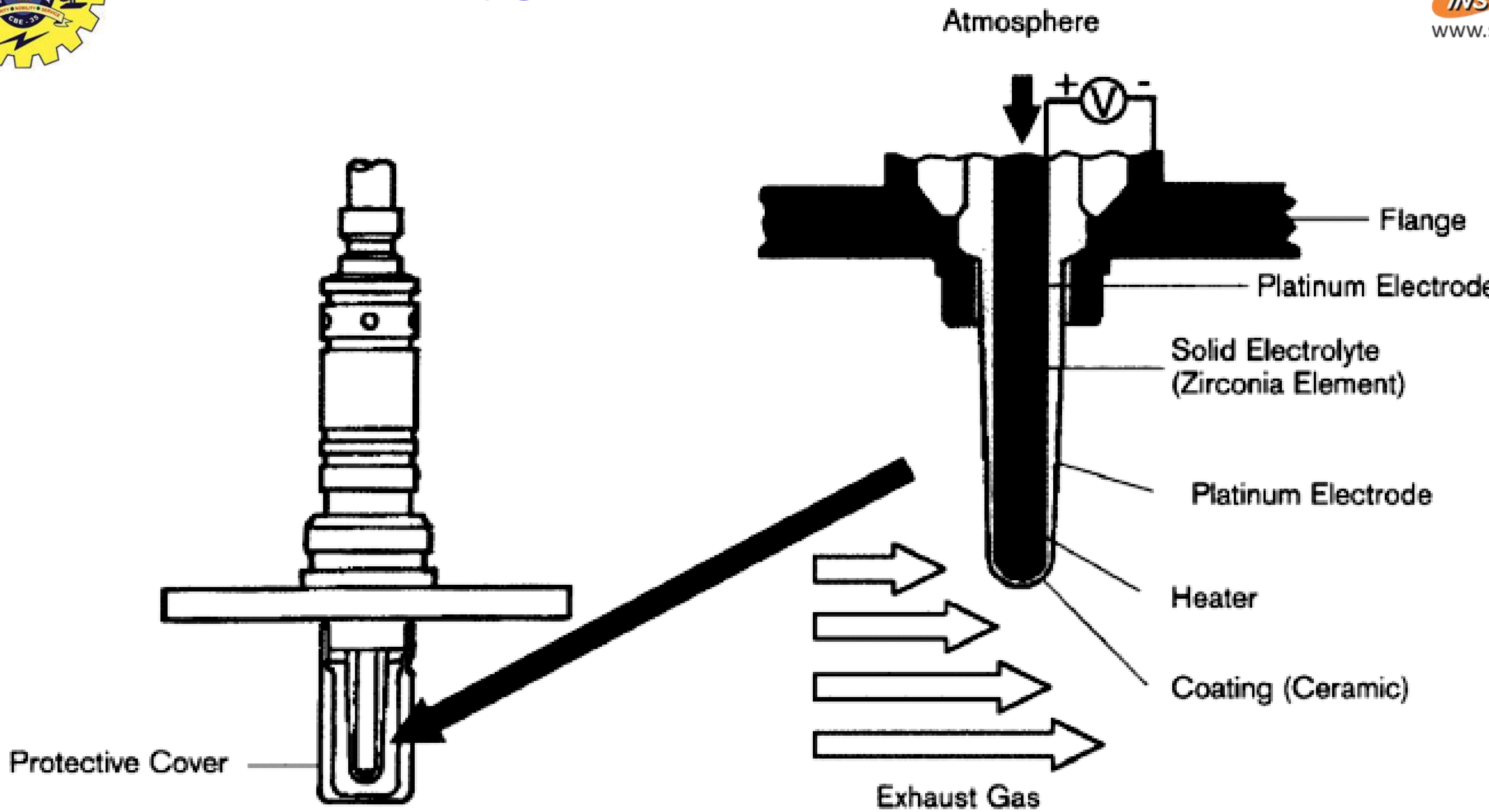
1. Narrow range oxygen sensor, simply called oxygen sensor

2. Wide range oxygen sensor, called air/fuel ratio (A/F) sensor


High
↑
Purification Rate
↓
Low
100%
75%
50%
25%
0%
NOx
HC
CO
Operational
Range of
Converter
Theoretical Air
Fuel Ratio
Richer ← 14.7/1 → Leaner
Air/Fuel Ratio



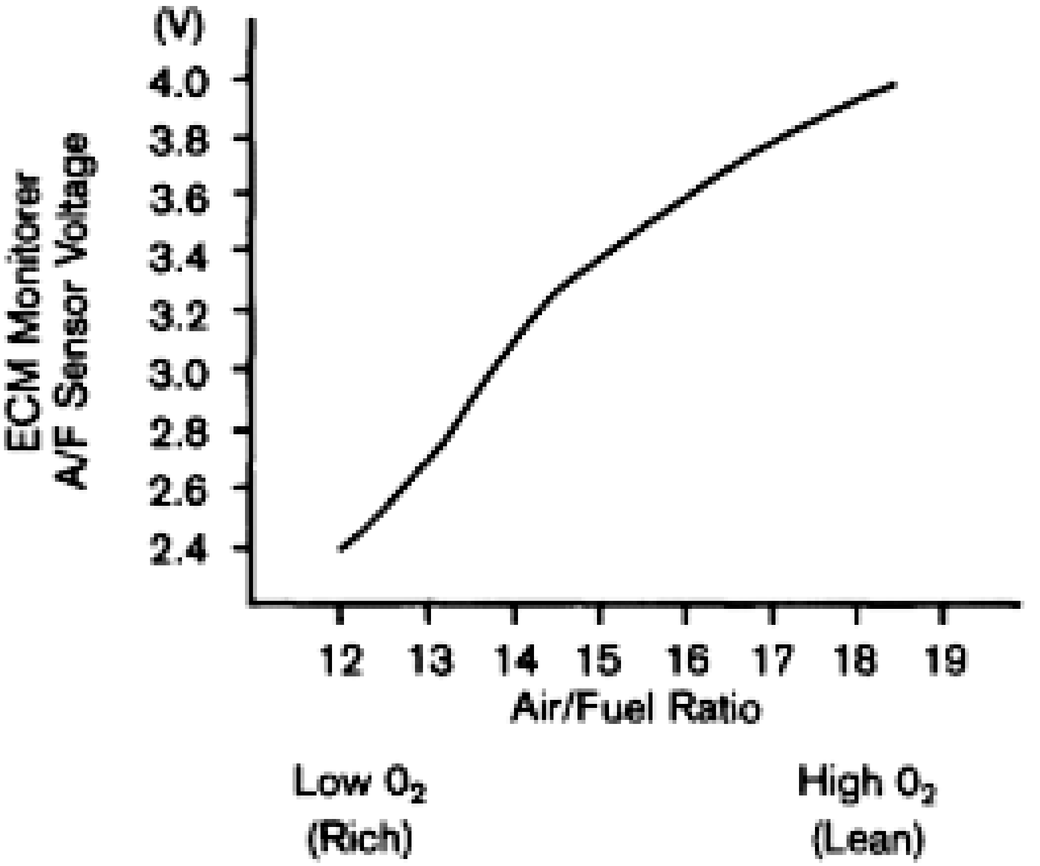
Oxygen Sensor Construction



Exhaust Oxygen Content		Oxygen Sensor Output		Air/Fuel Ratio Judged To Be
Low	→	High, Above 0.45 volts	→	Rich
High	→	Low, Below 0.45 volts	→	Lean

Air/ Fuel Ratio Sensor

- The A/F senor voltage signal is relatively proportional to the exhaust oxygen content.
- A/F ratio is leaner, the out put voltage is higher.

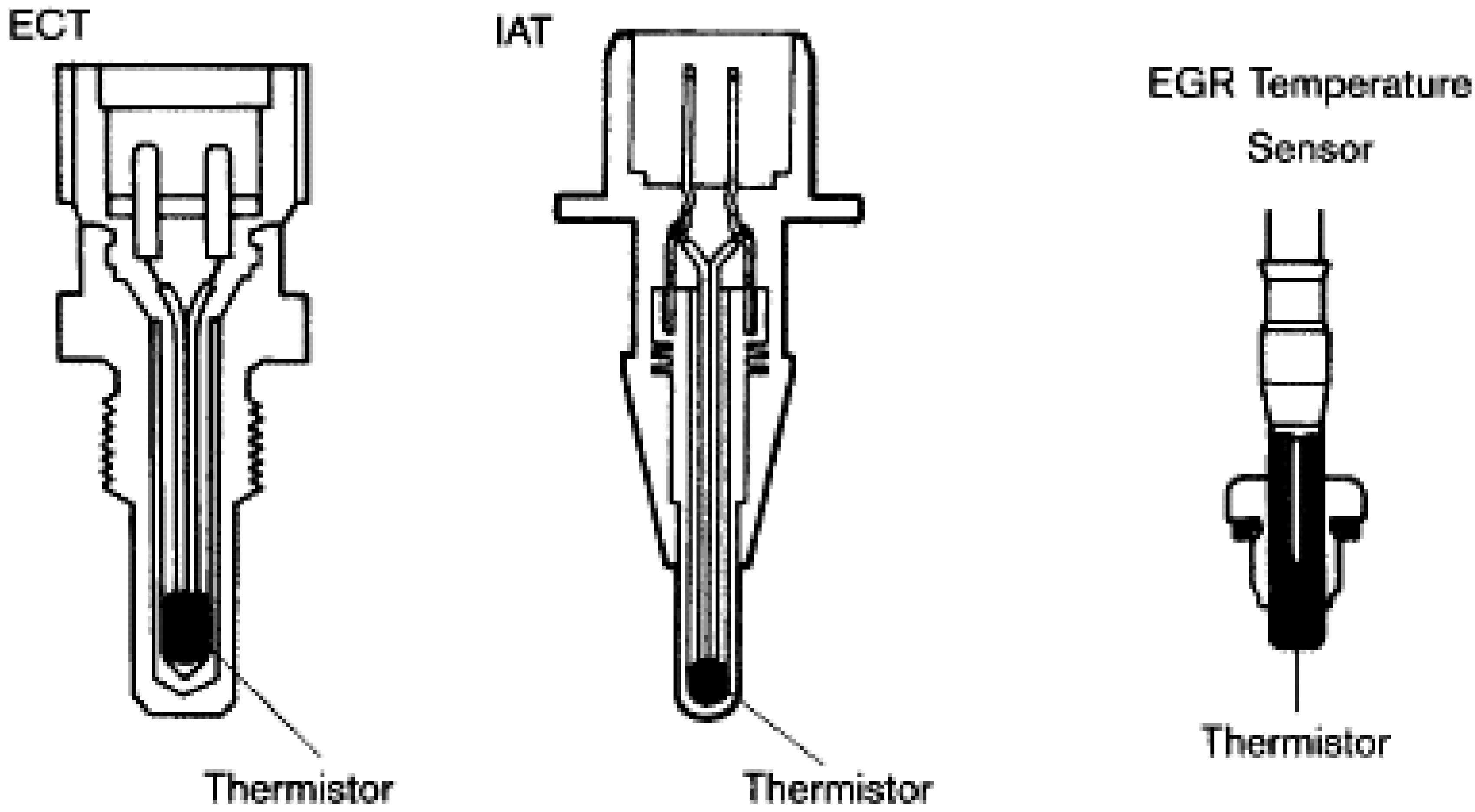


TEMPERATURE SENOSRS

- Measures air and liquid temperatures between –40 °C and +130 °C.
- For proper amount of fuel injection

Commonly used Automotive Temperature Sensors

1. Engine Coolant Temperature (ECT) Sensor
2. Intake Air Temperature (IAT) Sensor
3. Exhaust Recirculation Gas Temperature Sensor


ECT
Thermistor
IAT
Thermistor
EGR Temperature
Sensor
Thermistor

Engine Coolant Temperature (ECT) Sensor

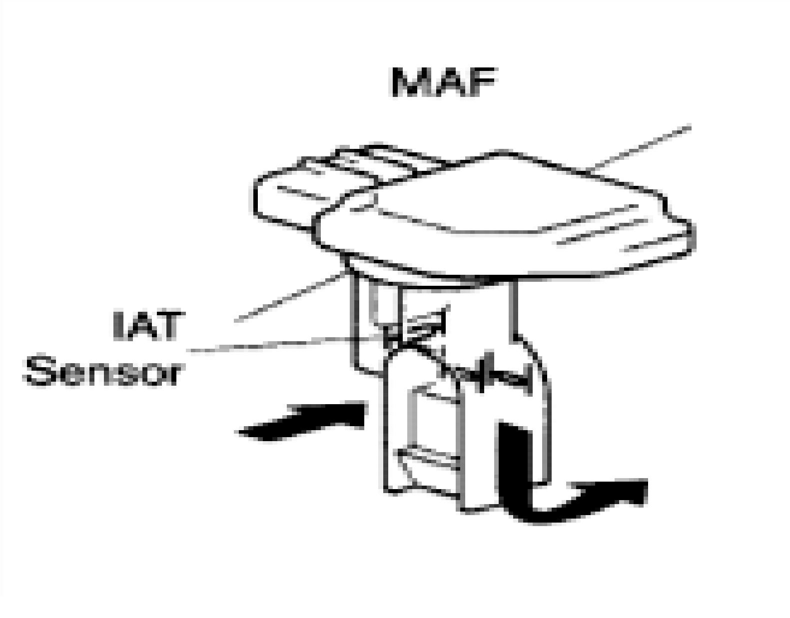
- Usually located just before the thermostat.
- Responds to change in Engine Coolant Temperature.
- Critical to many ECM functions such as fuel injection, ignition timing, variable valve timing, transmission shifting, etc.

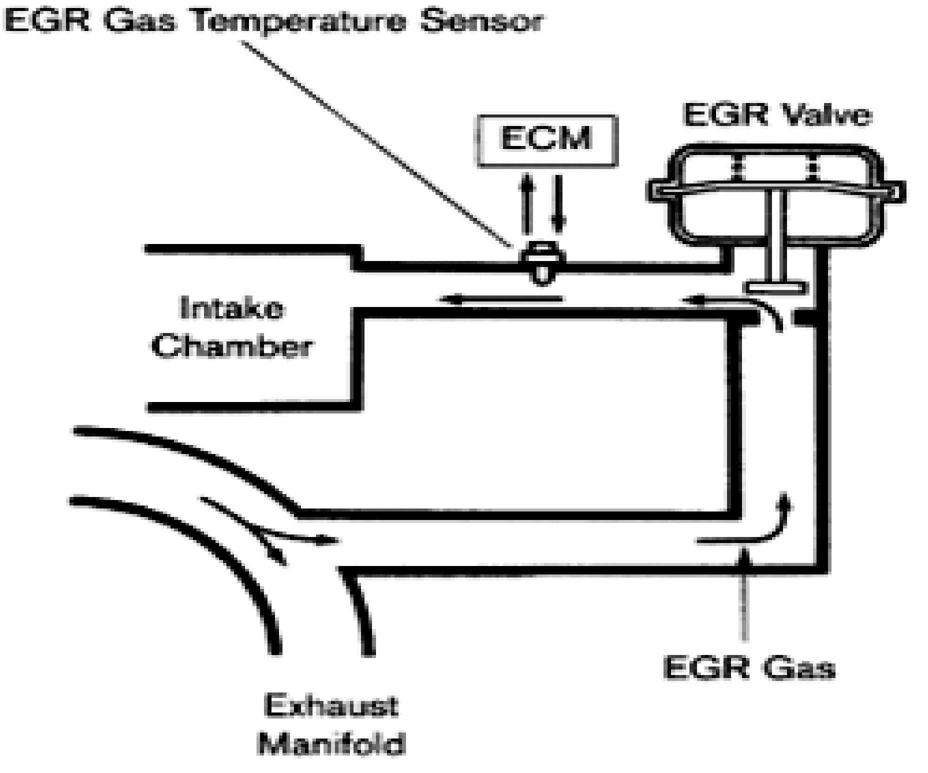
Intake Air Temperature (IAT) Sensor

- Detects the temperature of the incoming air stream.
- On a cold starts, heats up the incoming air.
- On vehicles equipped with a MAP sensor, the IAT is located in an intake air passage.
- On Mass Air Flow sensor equipped vehicles, the IAT is part it.

Exhaust Gas Recirculation (EGR) Temperature Sensor

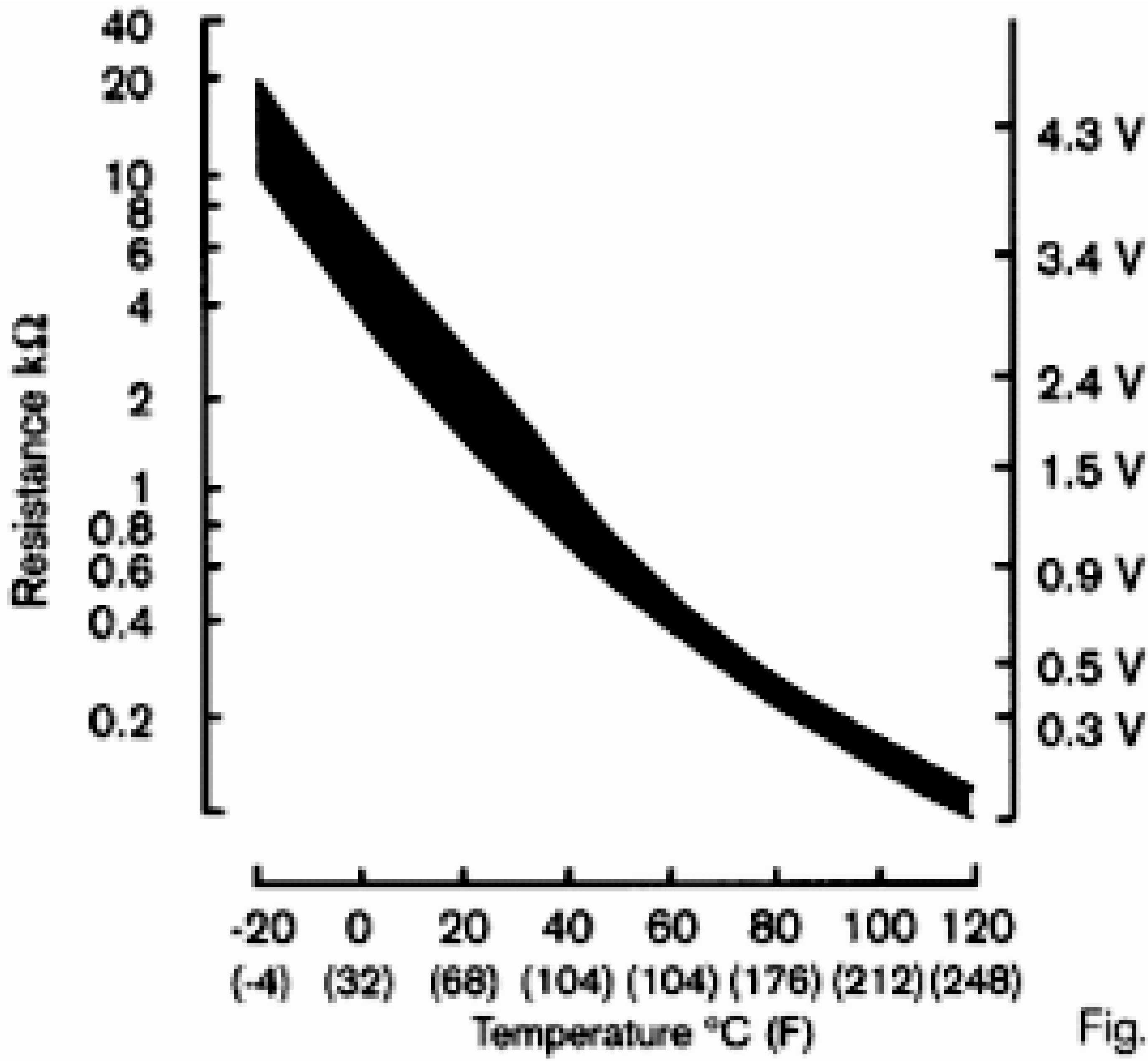
- The EGR Temperature Sensor is located in the EGR passage and measures the temperature of the exhaust gases.
- As the temperature increases, the ECM opens the EGR valve to allow the exhaust gases to flow into the intake manifold.





Thermistors

- For automotive applications, Thermistors (Negative Temperature Coefficient) are enclosed in a protective housing.
- If Thermistors are exposed to external heat, their resistance drops drastically and, provided the supply voltage remains constant, their input current climbs rapidly. This property is utilised for temperature measurement.
- It is possible to measure a wide range of liquid temperatures.
- Thermistors comprised of metal oxides and oxidized mixed crystals.
- This mixture is produced by sintering and pressing with the addition of binding agents.



Resistance kΩ
40
20
10
8
6
4
2
1
0.8
0.6
0.4
0.2
4.3 V
3.4 V
2.4 V
1.5 V
0.9 V
0.5 V
0.3 V
-20 0 20 40 60 80 100 120
(-4) (32) (68) (104) (104) (176) (212) (248)
Temperature °C (F)

Fig.

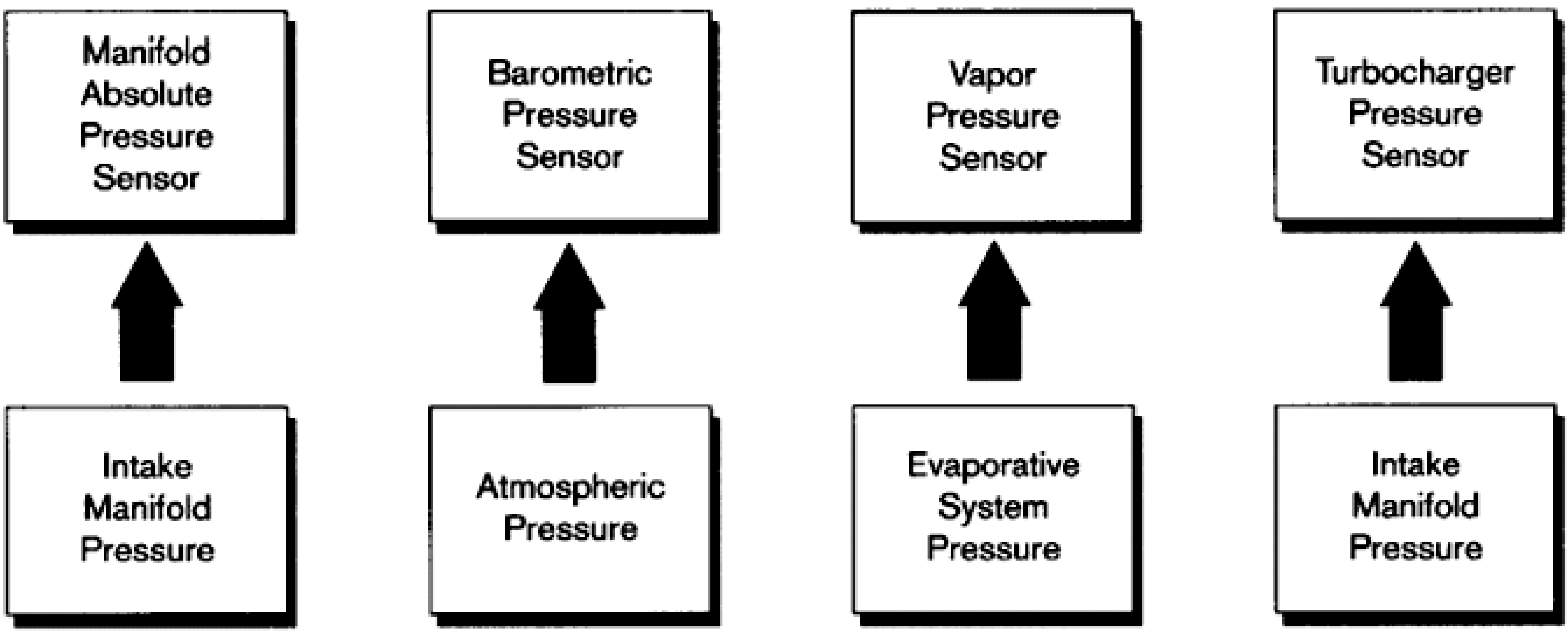
ECT, IAT, & EGR Temperature Sensor Operation

- As the temperature increases, the voltage signal decreases.
- The decrease in the voltage signal is caused by the decrease in resistance. The change in resistance causes the voltage signal to drop.
- When the sensor is cold, the resistance of the sensor is high, and the voltage signal is high.
- As the sensor warms up, the resistance drops and voltage signal decreases.
- From the voltage signal, the ECM can determine the temperature of the coolant, intake air, or exhaust gas temperature.

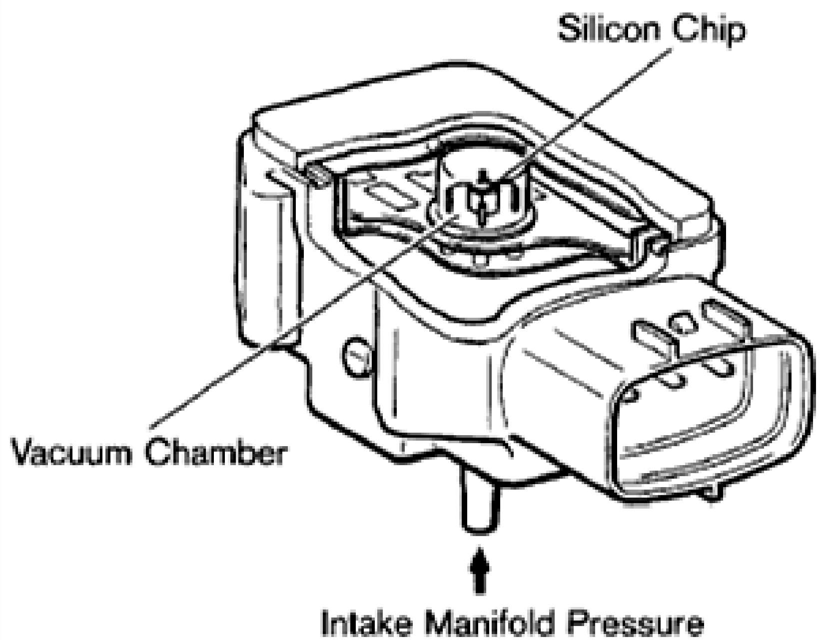
Pressure Sensors

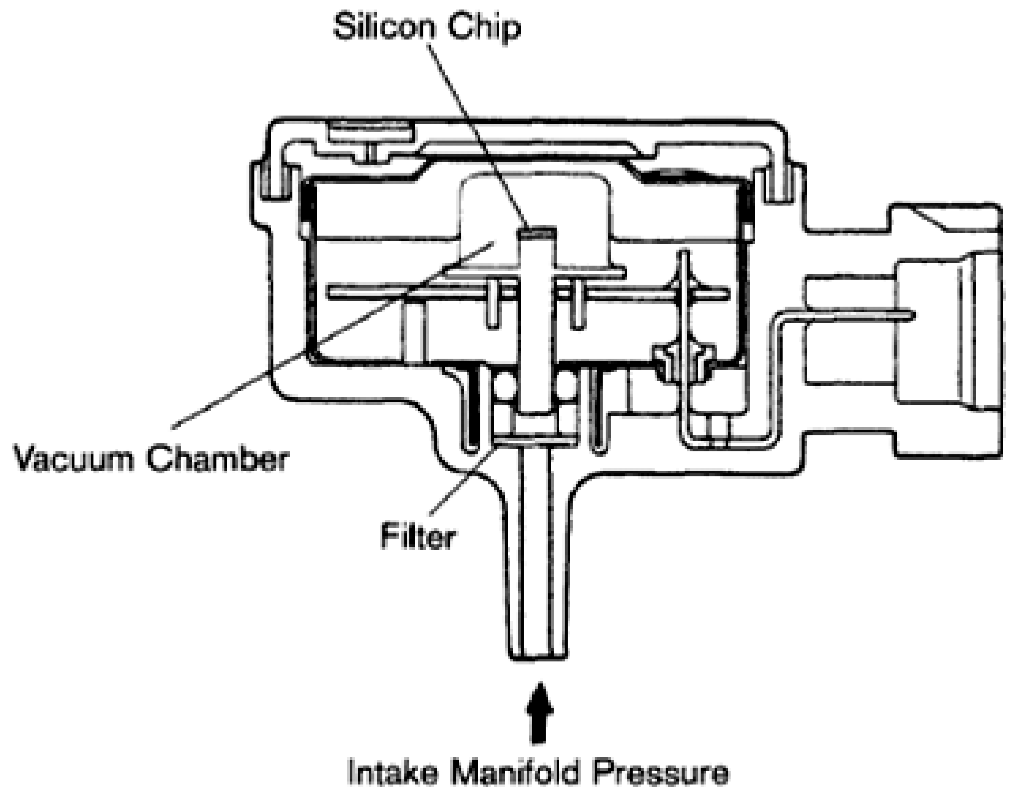
- Pressure sensors are used to measure intake manifold pressure, atmospheric pressure, vapour pressure in the fuel tank, etc.

- The operating principles are similar.



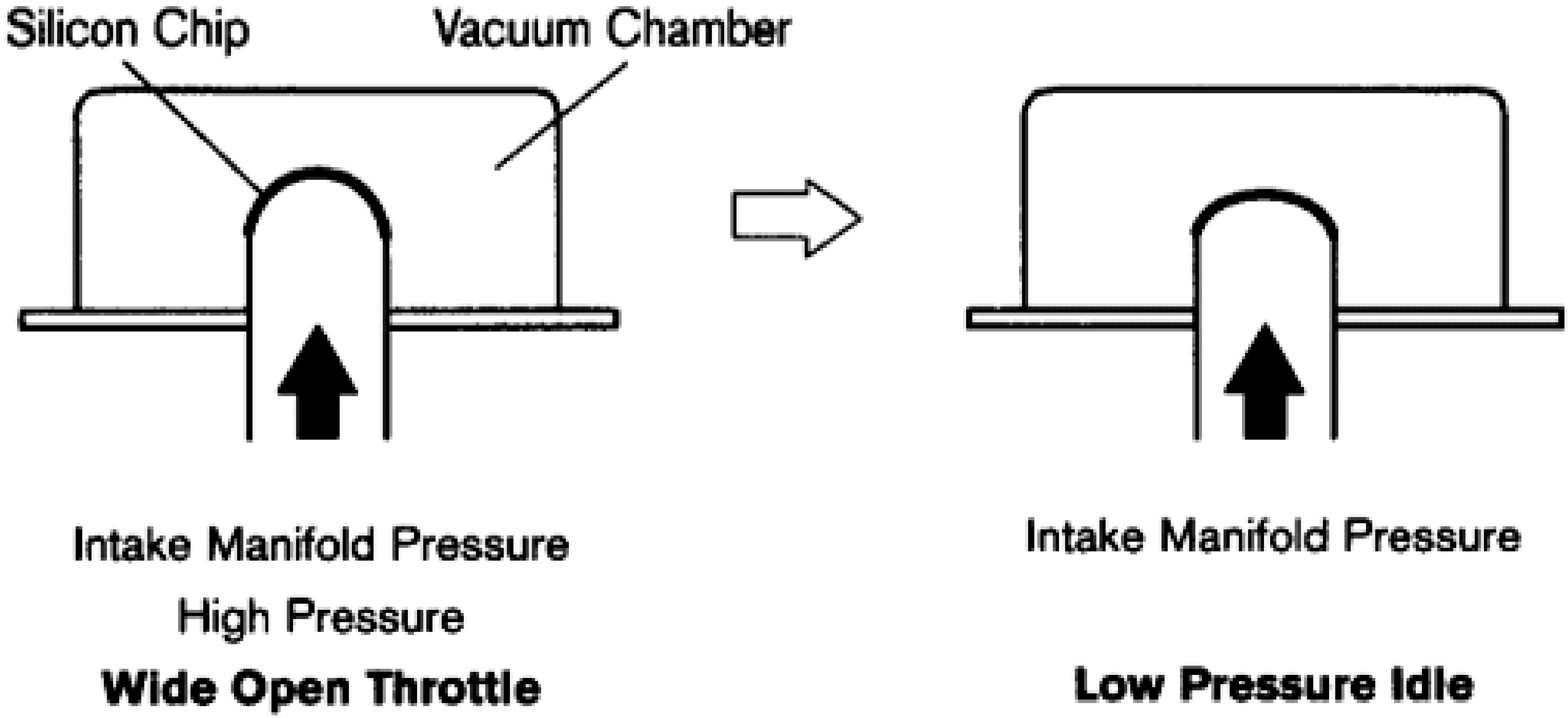
Manifold Absolute Pressure (MAP) Sensor





Location: Either directly on the intake manifold or mounted high in the engine compartment and connected to the intake manifold with vacuum hose.

Manifold Absolute Pressure (MAP) Sensor



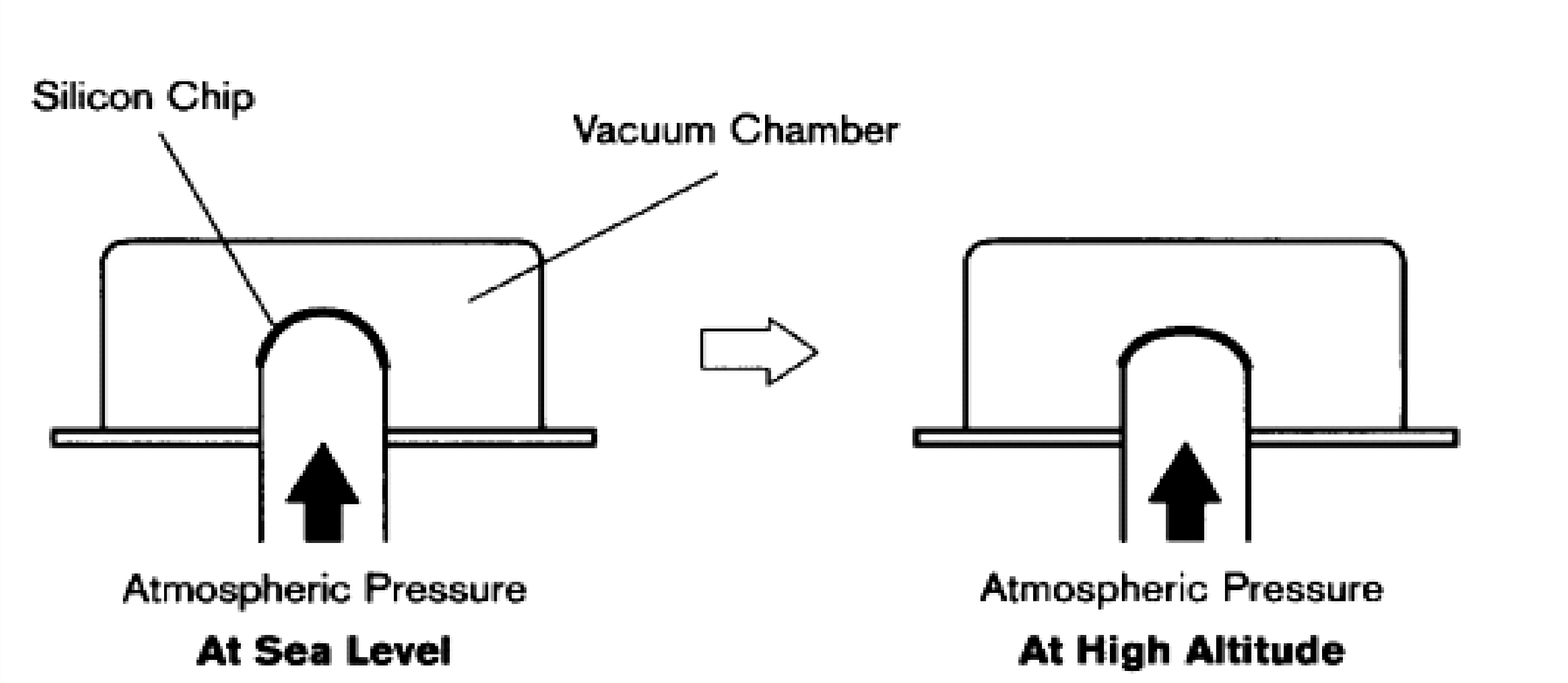
- Silicon chip mounted inside a reference chamber.
- On one side of the chip is a reference pressure (either a perfect vacuum or a calibrated pressure, depending on the application).
- On the other side is the pressure to be measured.

Operation

- Intake manifold pressure is a directly related to engine load. The ECM needs to know intake manifold pressure to calculate how much fuel to inject, when to ignite the cylinder, and other functions.
- The silicon chip changes its resistance with it is subjected to strain.
- Silicon chip flexes with the change in pressure, the electrical resistance of the chip changes. This change in resistance alters the voltage signal.
- The ECM interprets the voltage signal as pressure and any change in the voltage signal means there was a change in pressure.
- The MAP sensor voltage signal is highest when intake manifold pressure is highest and it is lowest when intake manifold pressure is lowest on deceleration with throttle closed.

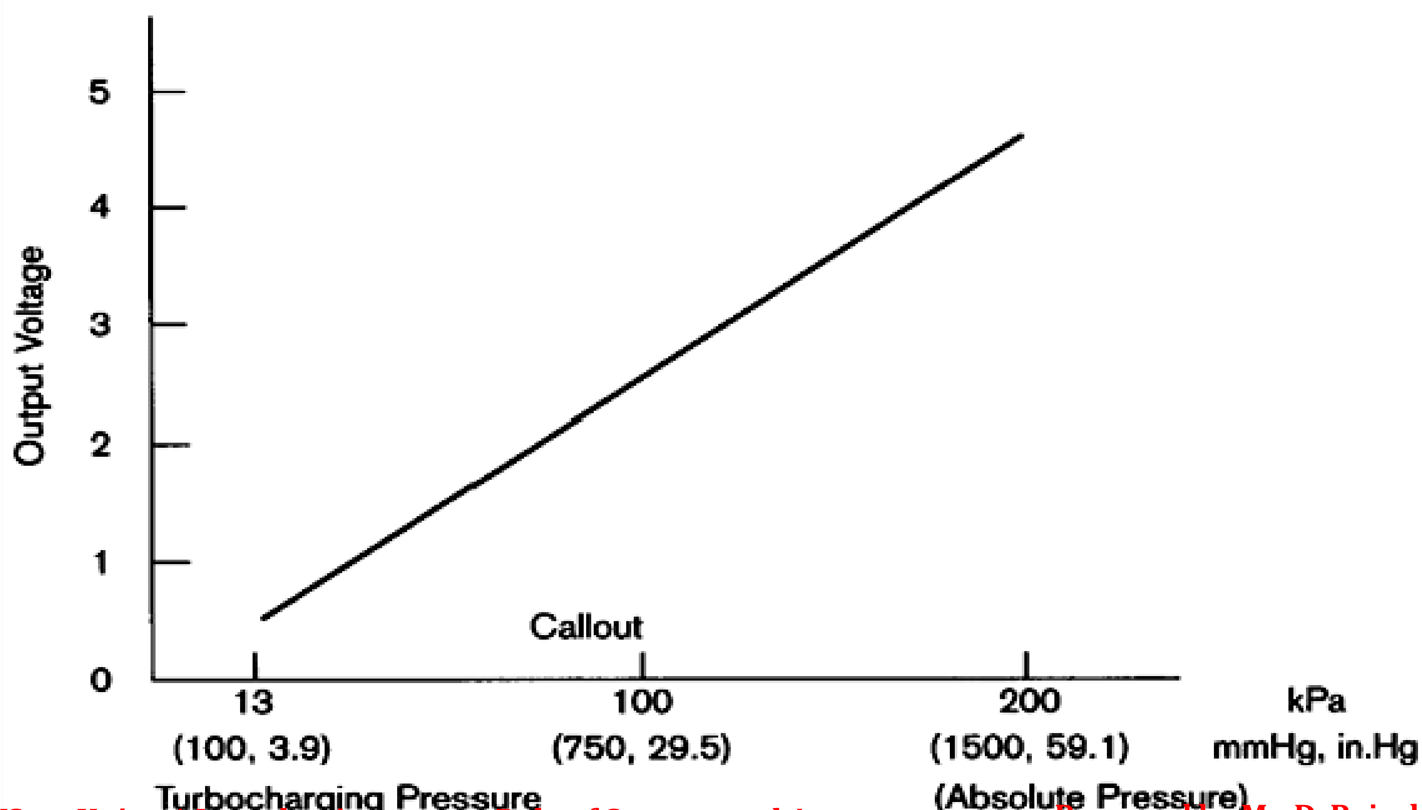
Barometric Pressure Sensor

- Sometimes called a High Altitude Compensator (HAC) measures the atmospheric pressure.
- Atmospheric pressure varies with weather and altitude.
- Operates same as the MAP sensor except that it measures atmospheric pressure.



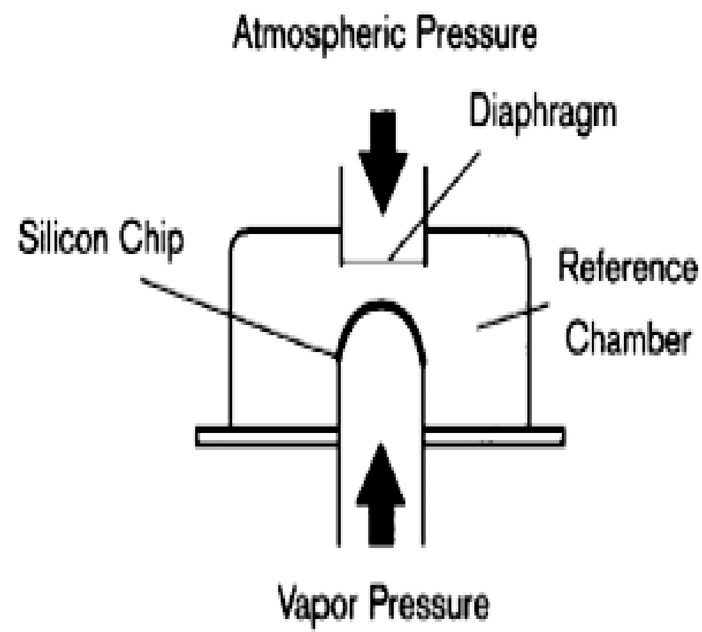
Turbocharging Pressure Sensor

- Operates identically to the MAP sensor.
- Used to measure intake manifold pressure when there is boost pressure.
- Voltage signal goes higher than on a naturally aspirated engine.



Vapor Pressure Sensor (VAP)

- Measures the vapor pressure in the evaporative emission control system.
- Located on the fuel tank, near the charcoal canister assembly, or in a remote location.
- The pressure inside the reference chamber changes with atmospheric pressure.
- The voltage signal out depends on the difference between atmospheric pressure and vapor pressure.



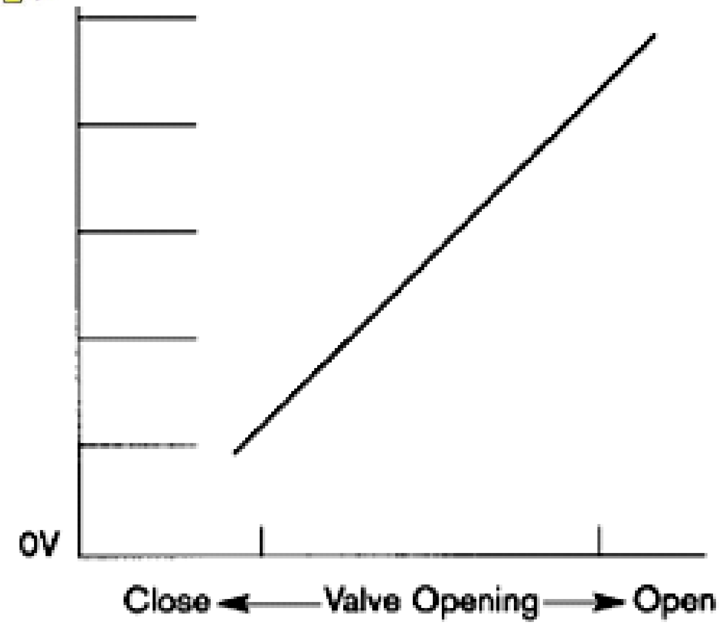
Position Sensors

- Throttle Position Sensor (TPS) indicates position of the throttle valve.
- Accelerator Pedal Position (APP) sensor indicates position of the accelerator pedal.
- Exhaust Gas Valve (EGR) Valve Position Sensor indicates position of the EGR Valve.

Throttle Position Sensor

- TPS is mounted on the throttle body and converts the throttle valve angle into an electrical signal.
- As the throttle opens, the signal voltage increases.
- The ECM uses throttle valve position information to know:

1. idle
2. part throttle
3. wide open throttle
4. air-fuel ratio correction
5. power increase correction
6. fuel cut control



- In linear / angular potentiometer as the wiper arm moves the signal voltage output changes.
- At idle, voltage is approximately 0.6 - 0.9 V on the signal wire.
- At wide open throttle, signal voltage is approximately 3.5 - 4.7 V

Accelerator Pedal Position (APP) Sensor

- The APP sensor converts the accelerator pedal movement.
- APP is identical in operation to the TPS.

EGR Valve Position Sensor

- EGR Valve Position Sensor is mounted on the EGR valve.
- It converts the movement and position of the EGR valve into an electrical signal.
- The ECM uses this signal to control EGR valve height.
- Operation is identical to the TPS.

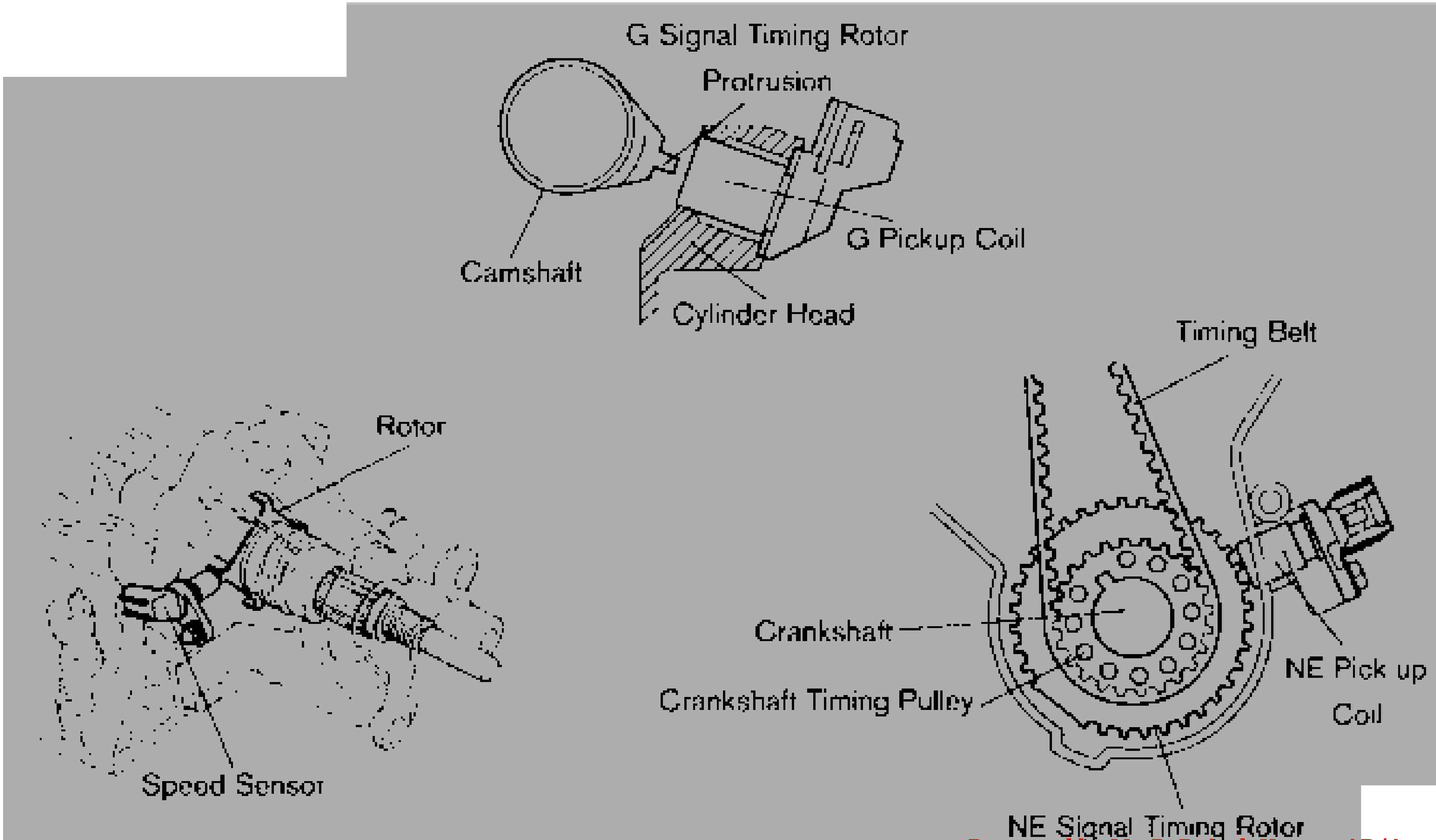
Position / Speed Sensors

Position/speed sensors provide information to the ECM about the

- position of a component,
- speed of a component, and
- change in speed of a component.

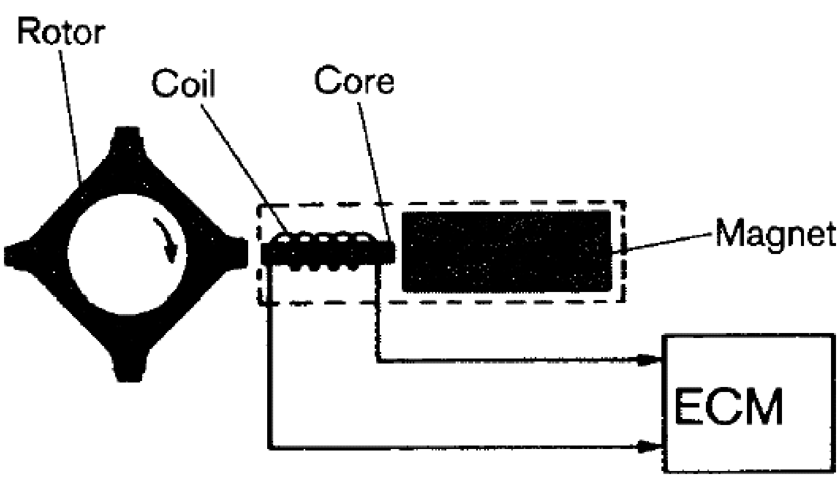
- Camshaft Position Sensor (also called G sensor).
- Crankshaft Position Sensor (also called NE sensor).
- Vehicle Speed Sensor.

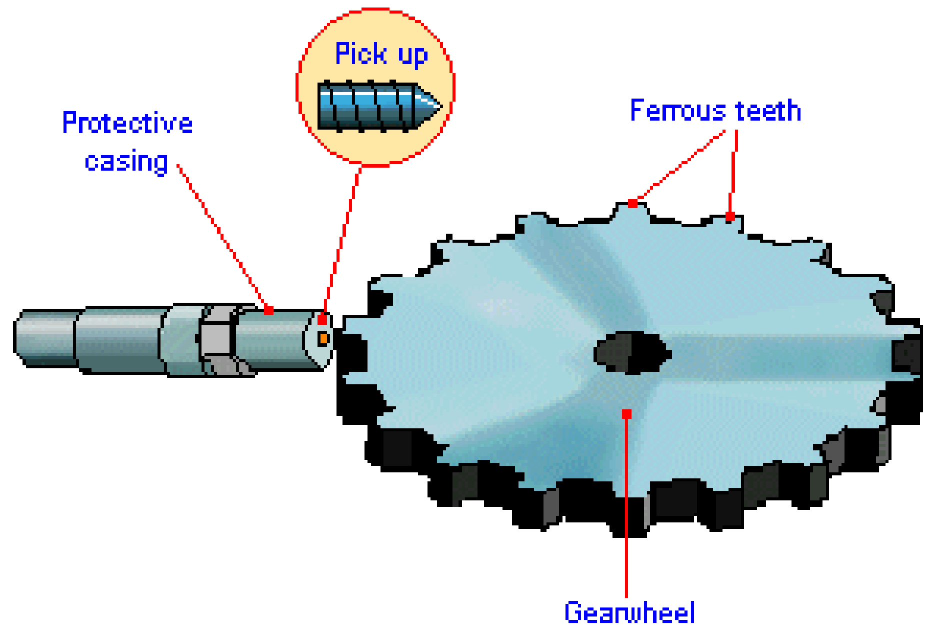
Position / Speed Sensors

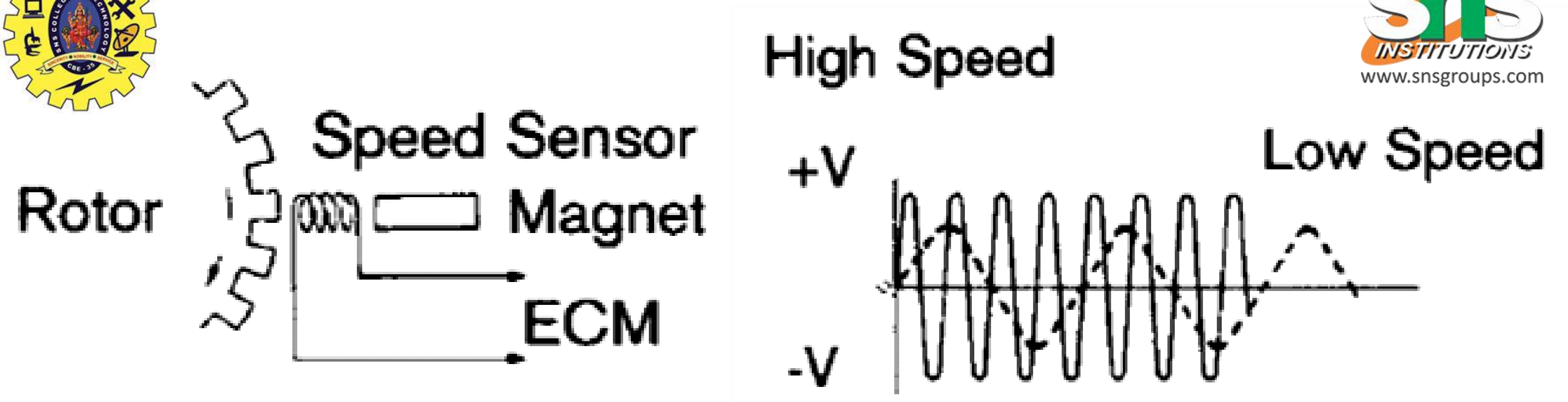


Pick-Up Coil (Variable Reluctance) Type Sensors

- It consists of a permanent magnet, yoke, and coil.
- It is mounted close to a toothed gear.
- The distance between the rotor and pickup coil is critical.



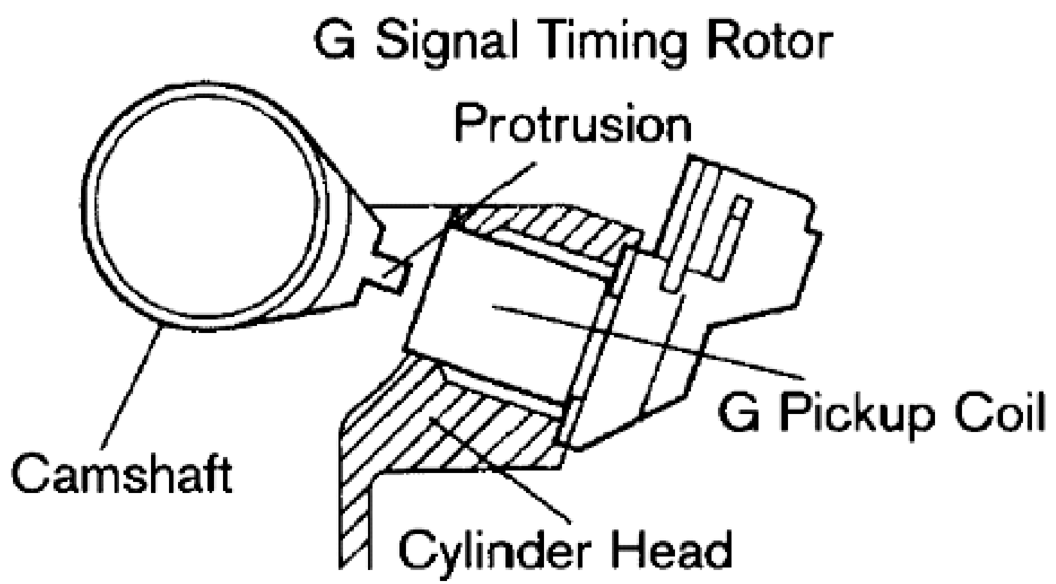




- AC voltage pulse is induced in the coil. Each tooth produces a pulse.
- The ECM determines the speed the component based on the number of pulses per unit time.
- As the gear rotates faster there more pulses are produced.
- The magnitude of the induced voltage increases with the speed.
- The voltage decreases as the distance (air gap) between the end of the sensor and the moving target gets larger.

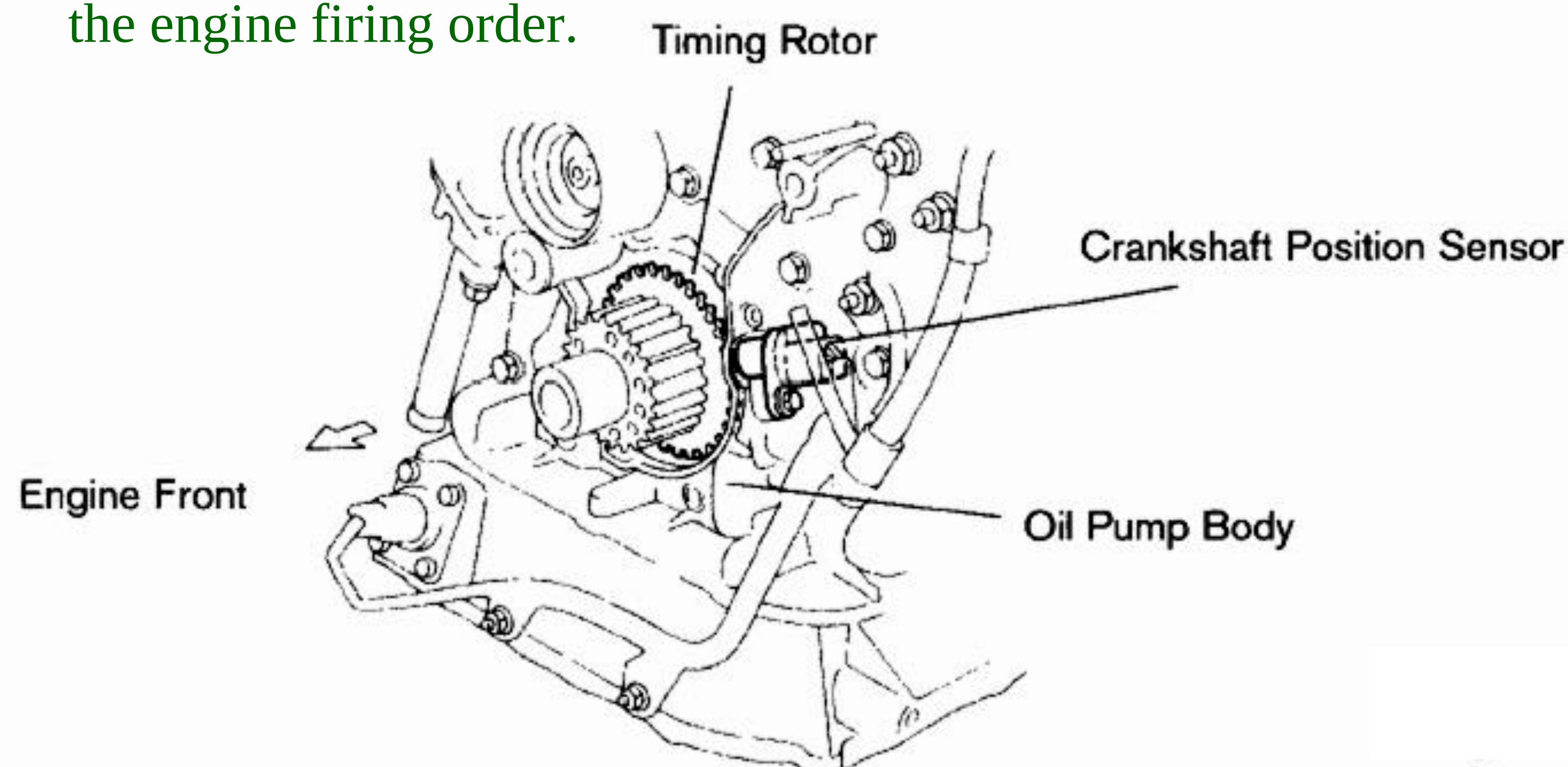
Camshaft Position Sensor (G Sensor)

- ECM can determine when cylinder No. 1 is on the compression stroke.
- The ECM uses this information for fuel injection timing, for direct ignition systems and for variable valve timing systems.
- Some variable valve timing systems call the Camshaft Position Sensor the Variable Valve Position Sensor.



Crankshaft Position Sensor (NE Sensor)

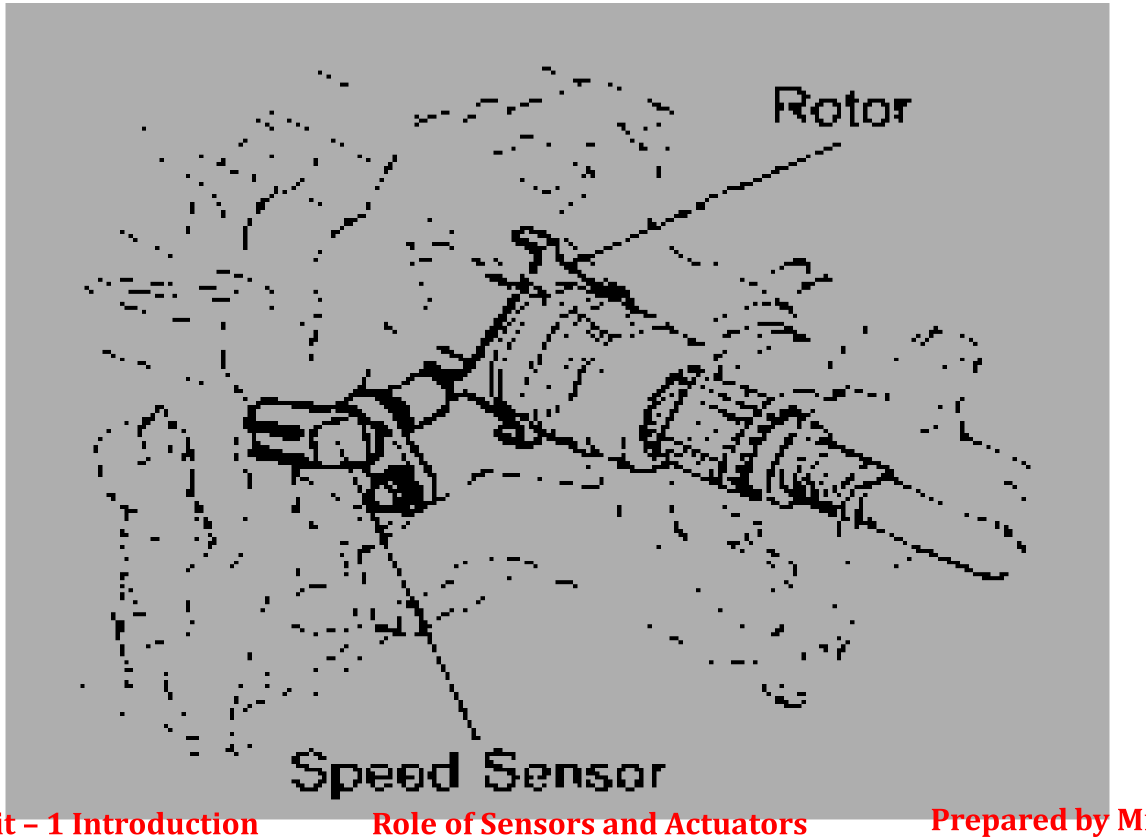
- To determine engine RPM, crankshaft position, and engine misfire.
- The NE signal combined with the G signal indicates the cylinder that is on compression and the ECM can determine from its programming the engine firing order.



Vehicle Speed Sensor (VSS)

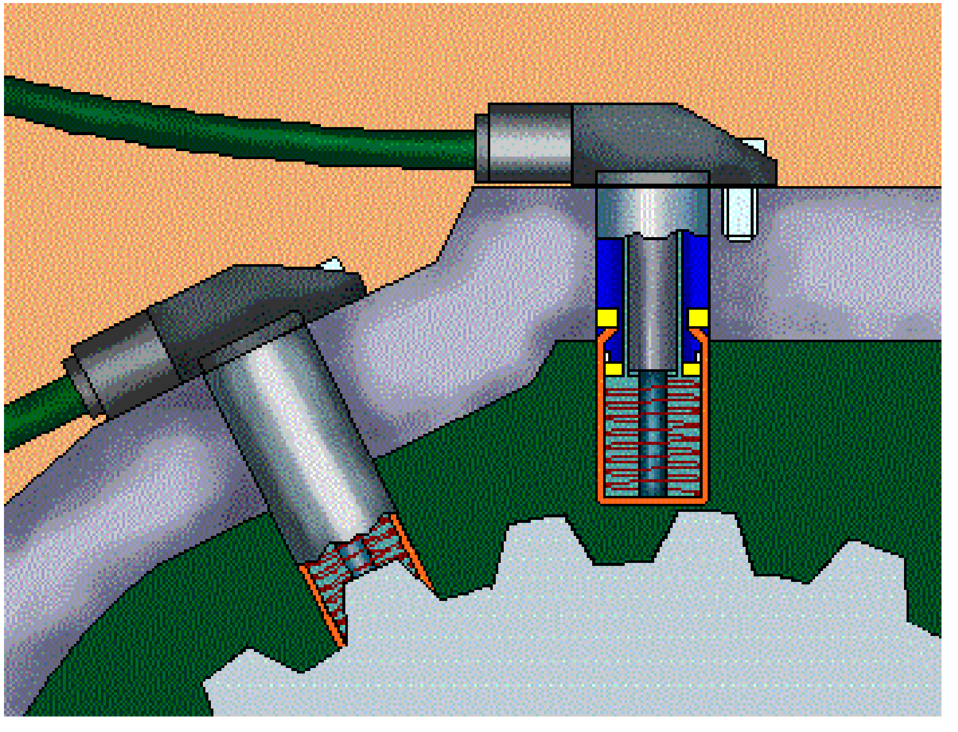
- The ECM uses the Vehicle Speed Sensor (VSS) signal to modify engine functions and initiate diagnostic routines.

- The VSS signal originates from a sensor measuring transmission / transaxle output speed or wheel speed.

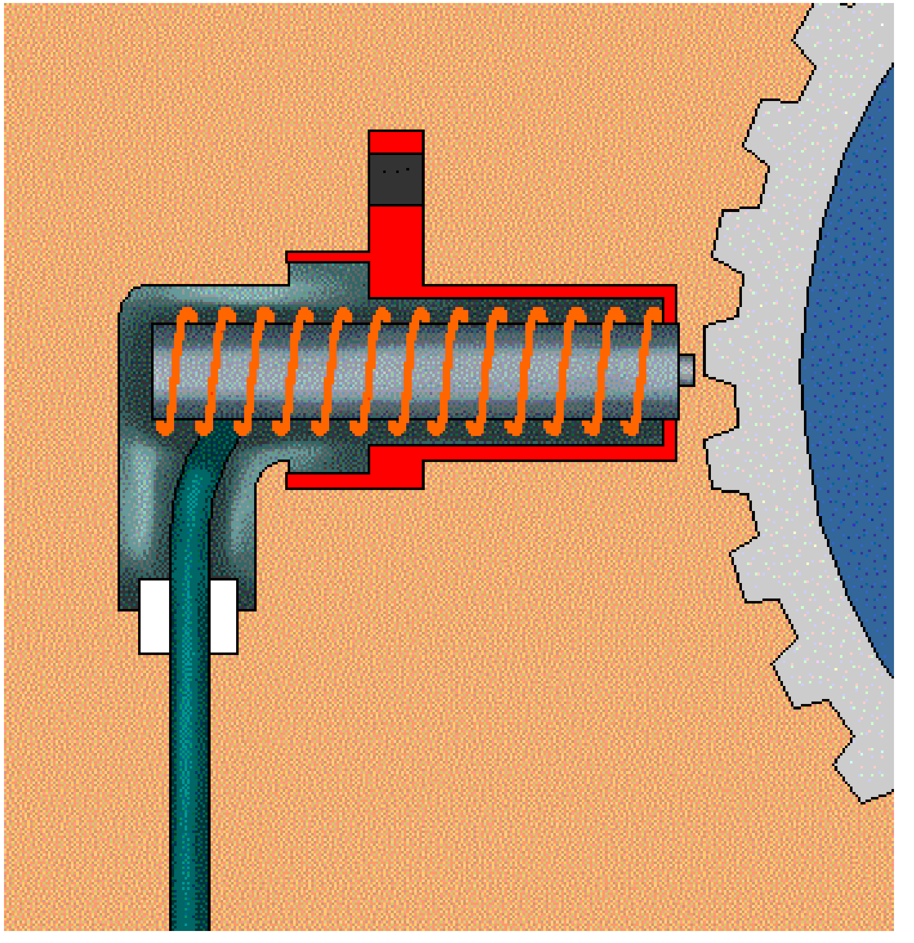


Timing Sensor (Variable reluctance proximity sensors)

- The crankshaft has two timing sensors fixed to it.
- The left hand sensor gives one pulse per revolution and provides an index for the other transducer.
- The right hand sensor picks up many pulses per revolution from the teeth on the flywheel and gives an accurate value for the angle of the crankshaft.



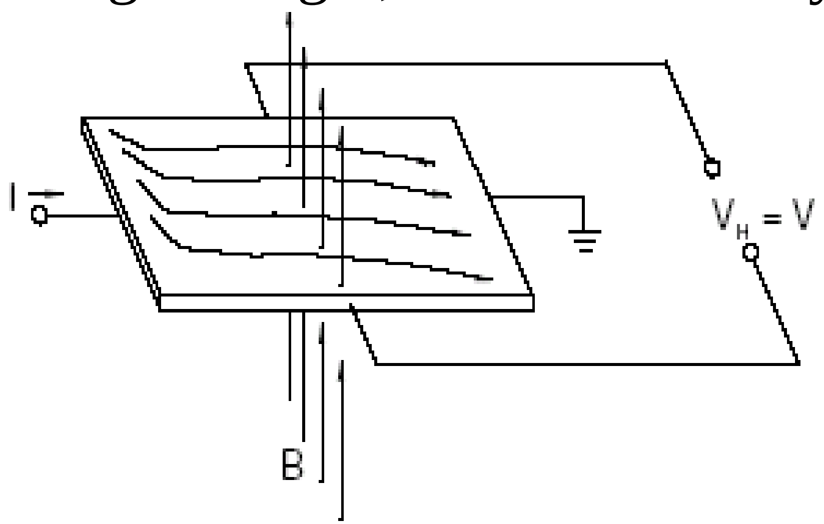
Wheel Rotation Sensor

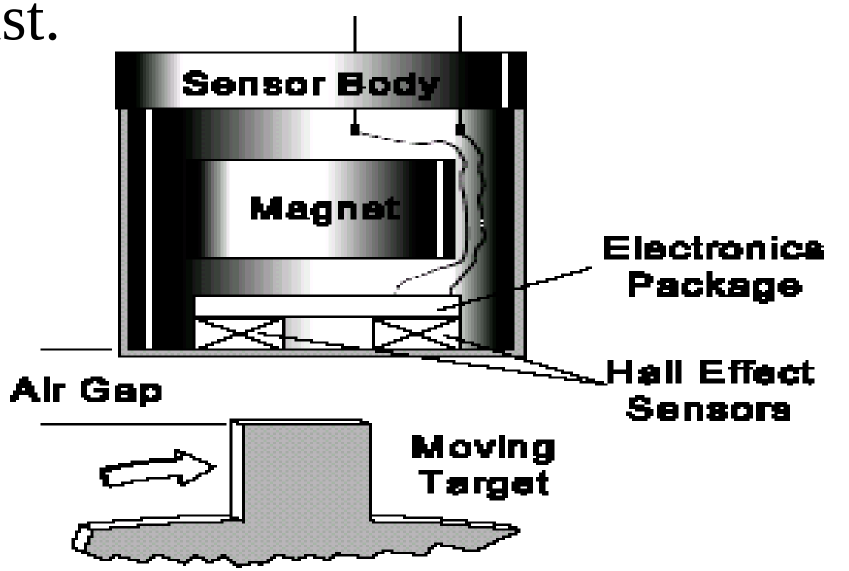


- Used in anti-lock braking and traction control systems.
- If one wheel speeds up significantly compared to the other three then the brakes are momentarily applied on that wheel to stop it spinning.
- It uses an inductive proximity detector to pick up the rotation of the toothed wheel.
- In an inductive sensor, the magnetic field around a permanent magnet changes if a ferrous target (eg. a toothed wheel) is moved in front of the sensor.

Differential Hall Effect Sensors

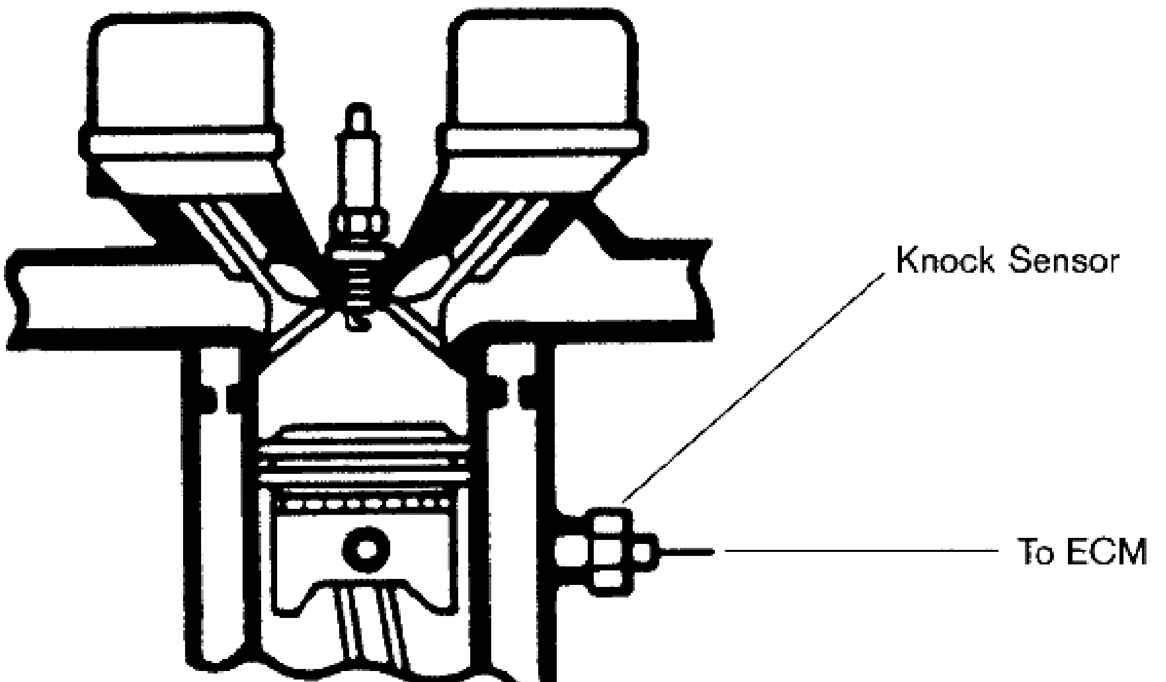
- Applications : wheel speed and camshaft position measurement
- A Hall effect element is a small sheet of semiconductor material arranged with a constant current flowing across it.
- In a magnetic field, a voltage, which is proportional to the field strength and at right angles to the current flow, is generated across the element.
- The magnetic field is supplied by a permanent magnet in the sensor.
- light weight, reliable and very robust.

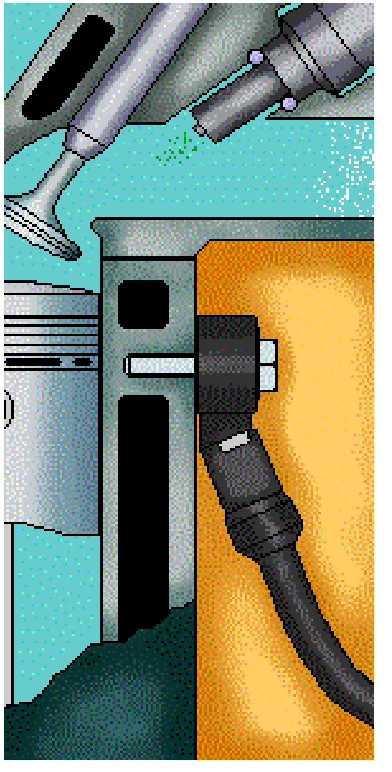


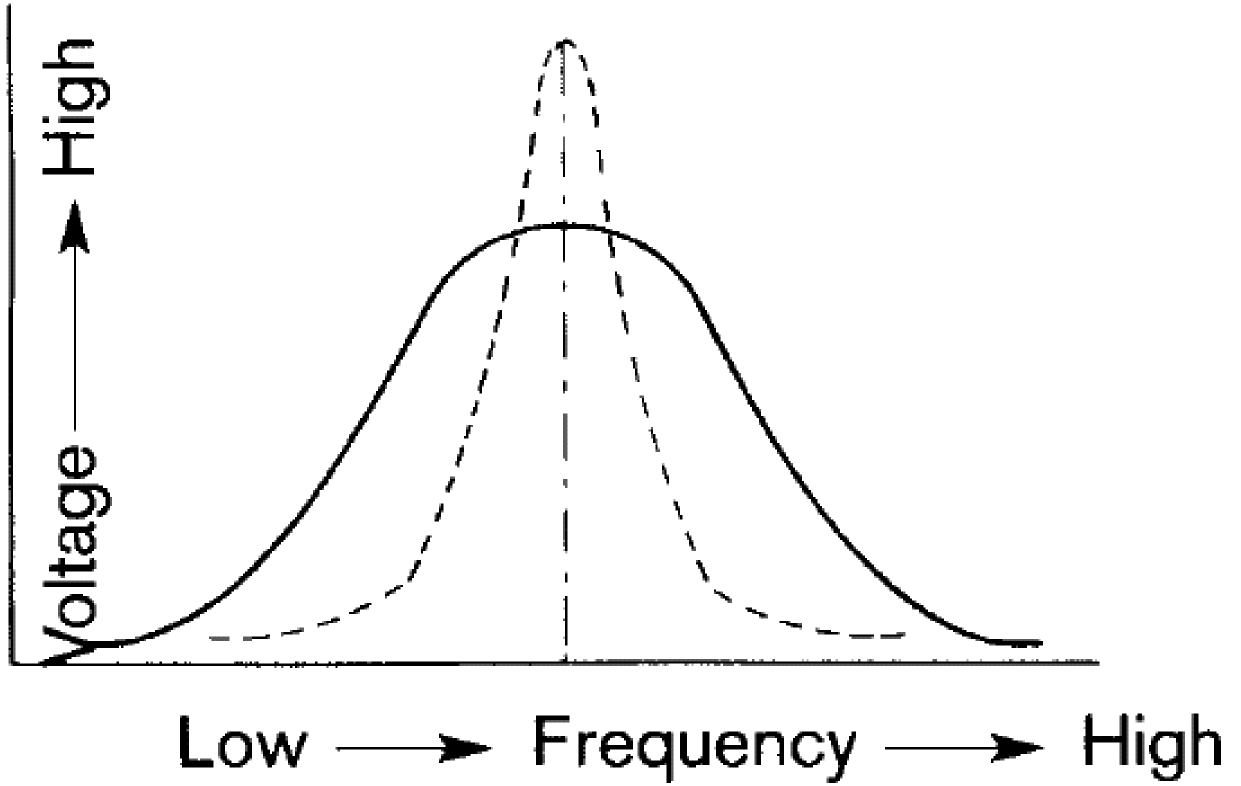


Knock Sensor

- Knock Sensor is located in the engine block, cylinder head, or intake manifold.
- Knock sensor is a piezoelectric element.
- The ECM uses the Knock Sensor signal to control timing.
- Piezoelectric elements generate a voltage when pressure or a vibration is applied.







- The vibrations from engine knocking vibrate the piezoelectric element generating a voltage.

- The voltage output from the Knock Sensor is highest at the time of knocking.

Classification of actuators

By type of motion

- Linear
- Rotary
- One-axis
- Two-axes
- Three-axes

Classification of actuators

Based on power consumption

- Low power actuators
- High power actuators
- Micropower actuators

Classification of actuators

Based on actuation

- Electromechanical Actuators
- Fluid Power Actuators
- Active Material Based Actuators

Electromechanical Actuators

1. **Solenoids**
2. **Relays**
3. **Electrical Motors**
   - DC motor
     - » Brushed DC motor
     - » Brushless DC motor
     - » Permanent Magnet (PM) Motors
     - » Coreless DC motor
   - AC motor
     - » Asynchronous (or induction) AC motor
     - » Synchronous AC motor
   - Stepper Motor

ACTUATORS

- Fluid Power Actuators

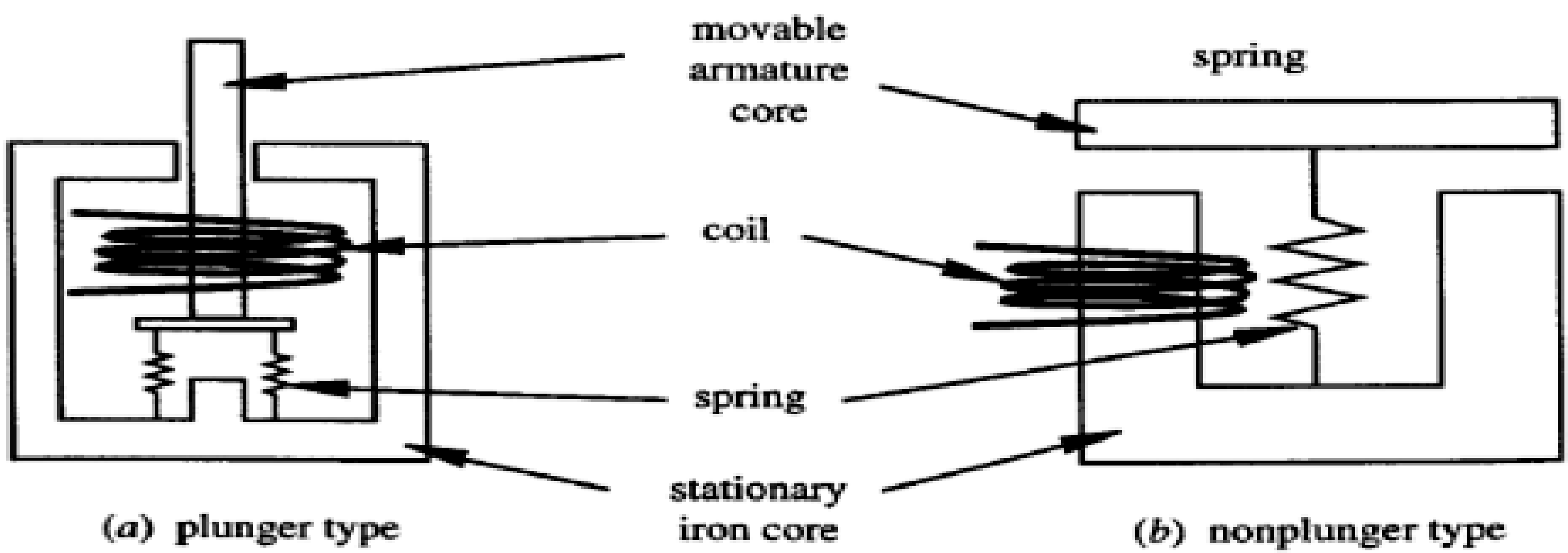
    1. Pneumatic Actuator
    2. Hydraulic Actuator

- Active Material Based Actuators

    1. Piezoelectric Actuator
    2. Memory Metal Actuator
    3. Magnetostrictive Actuator
    4. Chemical Actuator

Solenoids

- Like stepper motors, solenoids are digital actuators.
- When energized, the solenoid may extend a plunger or armature to control functions such as vacuum flow to various emission-related systems or fuel injection.



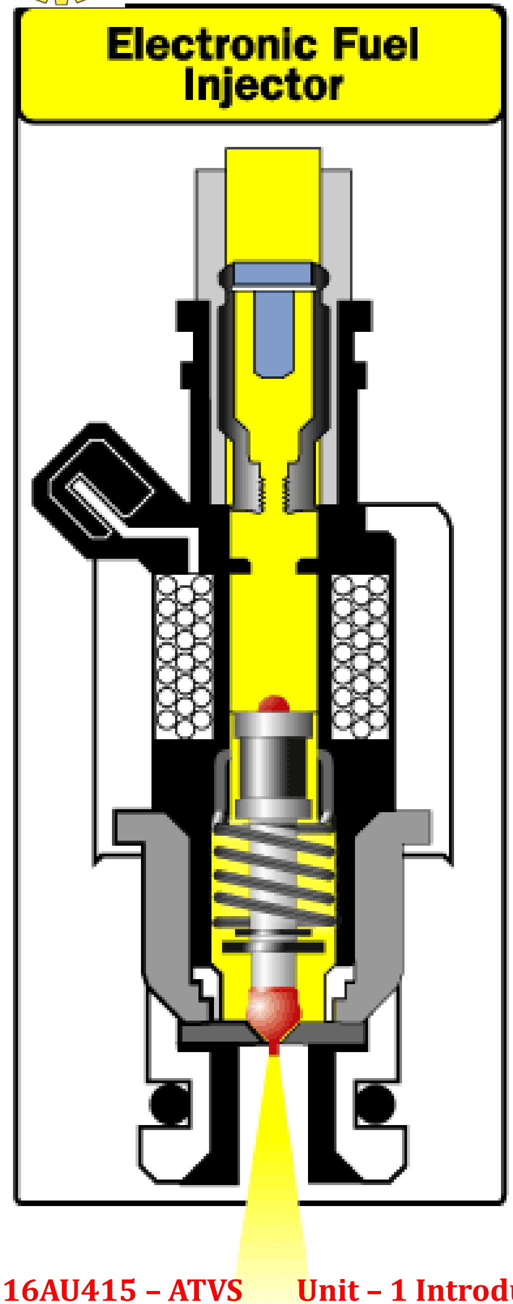
Solenoids

- Solenoids are controlled two ways:
  - » pulse width or duty cycle
- An example of pulse width is a fuel injector, which is turned on for a determined length of time and then shut off.
- A duty cycle solenoid in ABS is designed to be on and off for a specific time according to a selected ratio-on for 20% of the time and off the other 80%.
- Idle speed control valves can be constructed with a solenoid instead of a stepper motor.

Relay

- Relay is a solenoid used to make or break mechanical contact between electrical leads.
- A small voltage input to the solenoid controls a potentially large current through the relay contacts (usually for enable/disable circuits).

Solenoid operated Electronic Fuel Injector



- Fuel injector is an electronically controlled valve.
- It is supplied with pressurized fuel by the fuel pump.
- When the injector is energized, an solenoid moves a plunger that opens the valve, allowing the pressurized fuel to squirt out through a tiny nozzle.
- The amount of fuel supplied to the engine is determined by the amount of time the fuel injector stays open. This is called the **pulse width**, and it is controlled by the ECU.

A simplified calculation of the fuel injector pulse width.

- Example: our equation will only have three factors, whereas a real control system might have a hundred or more.
- **Pulse width = (Base pulse width) x (Factor A) x (Factor B)**
- ECU first looks up the **base pulse width** in a lookup table. Base pulse width is a function of **engine speed** and **load**
- Let's say the engine speed is 2,000 RPM and load is 4. We find the number at the intersection of 2,000 and 4, which is 8 milliseconds.

RPM	Load				
	1	**2**	**3**	**4**	**5**
1,000	1	2	3	4	5
2,000	2	4	6	8	10
3,000	3	6	9	12	15
4,000	4	8	12	16	20

- Real control systems may have more than 100 parameters, each with its own lookup table.
- Next example: **A** and **B** are parameters that come from sensors.
- Let's say that **A** is coolant temperature and **B** is oxygen level.
- If coolant temperature equals 100 and oxygen level equals 3, the lookup tables tell us that Factor A = 0.8 and Factor B = 1.0.

pulse width = (base pulse width) x (factor A) x (factor B)

So,

The overall pulse width = 8 x 0.8 x 1.0 = 6.4 milliseconds

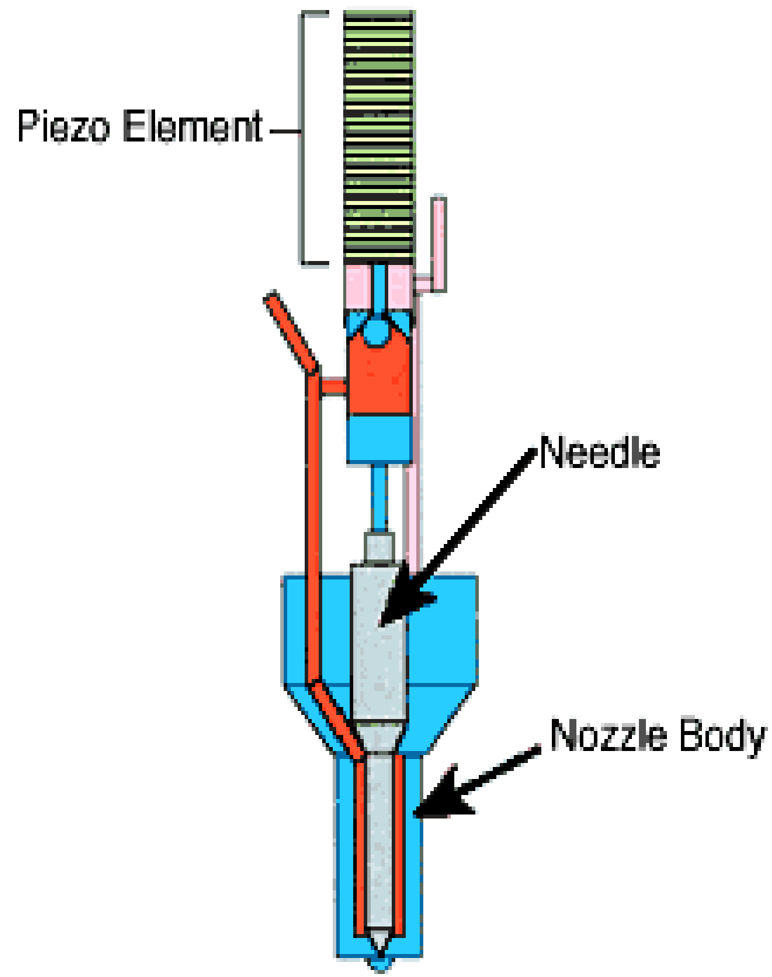
A	Factor A		B	Factor B
0	1.2		0	1.0
25	1.1		1	1.0
50	1.0		2	1.0
75	0.9		3	1.0
100	0.8		4	0.75

Piezoelectric operated Electronic Fuel Injector

- The piezoelectric effect, discovered by Pierre and Jacques Curie in 1880, causes electric charges of opposite polarity to appear on the faces of certain types of crystal when subjected to a mechanical strain. This charge is proportional to the strain.
- High-pressure fuel injection and volume of fuel must be controlled precisely to improve combustion efficiency.

Advantages

- Quick response
- High piezoelectric efficiency
- Excellent repeatability of fuel injection.

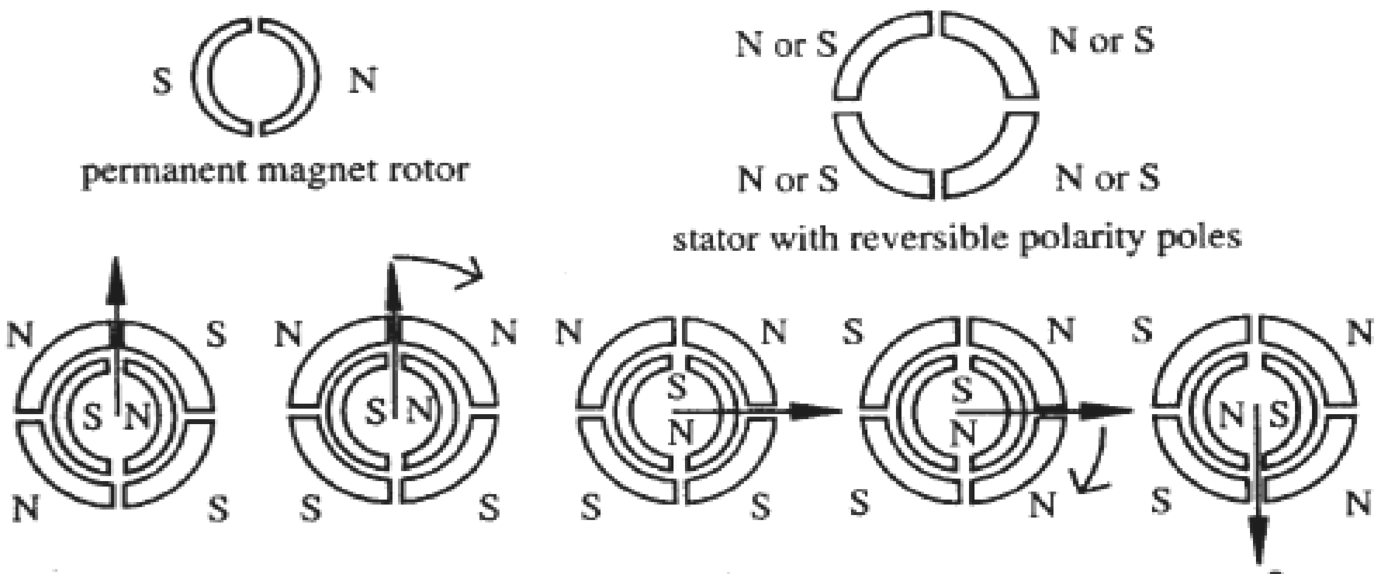


Camless Engines

Cams replaced by piezoelectric actuators and embedded controls

Stepper Motors

- Stepper motors are digital actuators.
- Rotation in both directions.
- Precision angular incremental changes without feedback sensors.
- Good holding torque at zero speed.
- Capability for digital control.



Stepper Motors

- A commercial stepper motor has a large number of poles that define a large number of equilibrium positions of the rotor.
- They move in fixed increments in both directions(over 120 steps).
- In most fuel injection systems, the stepper motor controls an idle speed control valve (ISCV), located in the air intake chamber.
- It rotates a valve shaft either in or out, which in turn increases or decreases the clearance between the valve and the valve seat, thereby regulating the amount of air allowed to pass through.
- The ISCV stepper motor allows 125 possible valve opening positions.

VCT (Variable Cam Timing)

- VCT closes and opens the engine valves at the optimal moment and reduces the harmful emissions with a computer.
- Perfect timing for opening and closing these valves depends on the number of engine revolutions per minute.
- As well as enhancing power and torque, the system offers smoother performance, improved fuel economy and fewer exhaust emissions across all of the engine rev range.

VCT