MODULE 1

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OBJECTIVES

1. Understand the basics of automobile dynamics
2. To learn the Basics of Electronic Engine Control

Module 1: Chapter 1: Automotive Fundamentals Overview

1.1.1 Evolution of Automotive Electronics

Electronics have been relatively slow in coming to the automobile primarily because of the relationship between the added cost and the benefits. Historically, the first electronics (other than radio) were introduced into the commercial automobile during the late 1950s and early 1960s. However, these features were not well received by customers, so they were discontinued from production automobiles.

Two major events occurred during the 1970s that started the trend toward the use of modern electronics in the automobile: (1) the introduction of government regulations for exhaust emissions and fuel economy, which required better control of the engine than was possible with the methods being used; and (2) the development of relatively low cost per function solid-state digital electronics that could be used for engine control.

Electronics are being used now in the automobile and probably will be used even more in the future. Some of the present and potential applications for electronics are

1. Electronic engine control for minimizing exhaust emissions and maximizing fuel economy
2. Instrumentation for measuring vehicle performance parameters and for diagnosis of on-board system malfunctions
3. Driveline control
4. Vehicle motion control
5. Safety and convenience
6. Entertainment/communication/navigation

1.1.2 The Automobile Physical Configuration

The earliest automobiles consisted of carriages (similar to those drawn by horses) to which a primitive engine and drive train and steering controls were added. Typically, such cars had a strong steel frame that supported the body of the car. The wheels were attached to this frame by a set of springs and shock absorbers that permitted the car to travel over the uneven road surfaces of the day while isolating the car body from much of the road irregularities. This same general configuration persisted in most passenger cars until sometime after World War II, although there was an evolution in car size, shape, and features as technology permitted.

This early configuration is depicted in Figure 1.1, in which many of the important automotive systems are illustrated. These systems include the following:

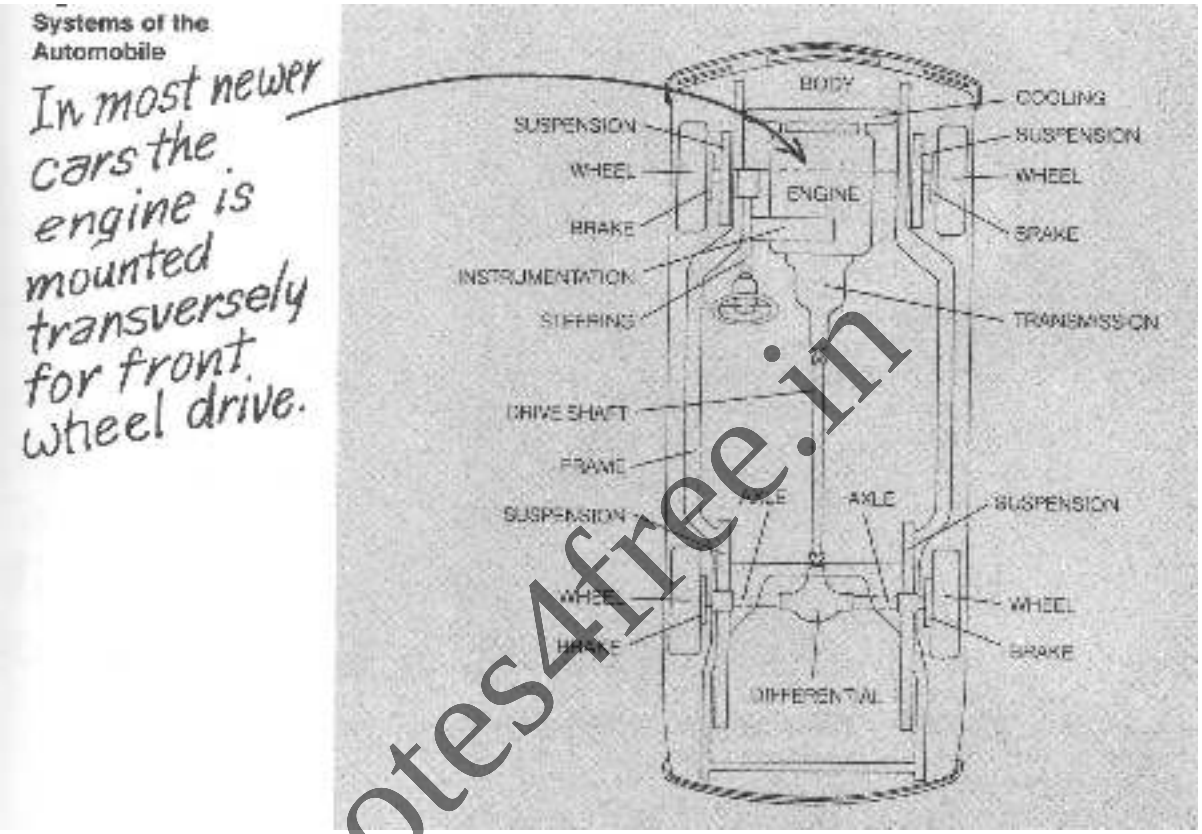
1. Engine
2. Drive Train (transmission, differential, axle)
3. Suspension
4. Steering
5. Brakes
6. Instrumentation
7. Electrical/electronic
8. Motion control
9. Safety
10. Comfort/convenience
11. Entertainment/communication/navigation

In Figure 1.1 the frame or chassis on which the body is mounted is supported by the suspension system. The wheels' brakes are connected to the opposite end of the suspension components. The steering and other major mechanical systems are mounted on one of these components and attached as necessary through mechanical components to other subsystems.

This basic vehicle configuration was used from the earliest cars through the late 1960s or 1970s, with some notable exceptions. The increasing importance of fuel efficiency and government-mandated safety regulations led to major changes in vehicle design. The body and frame evolved into an integrated structure to which the power train, suspension, wheels, etc., were attached.

Once again with a few notable exceptions, most cars had an engine in front configuration with the drive axle at the rear. While it is an advantage for several reasons (e.g., crash protection, efficient engine cooling) to have the engine in front, this location has a disadvantage from a traction standpoint. Because the engine is a relatively heavy component, its location influences weight distribution (fore and aft). Ideally, the engine should be located near the drive wheels for optimal drive traction. It is this fact that has led car makers to configure the front wheels as drive wheels. This change has led to the engine being mounted transversely (i.e., with the rotation axis orthogonal to the vehicle axis as opposed to along the vehicle axis). In automotive parlance the traditional engine orientation is referred to as *North-South,* and the transverse orientation as *East-West*. The transmission is mounted adjacent to the engine and oriented with its axis parallel to the engine axis. The differential and drive axle configuration is normally mounted in the transmission; the combined unit is thus called the *transaxle*.

For stability purposes the steering is still via the front wheels. The combination of steering and drive mechanisms results in a somewhat more complicated front-wheel system configuration than the traditional orientation. Apart from auto radios, some turn signal models, and a few ignition systems, there was very little use of electronics in the automobile until the early 1970s. Government-mandated emission regulations, fuel economy, and safety requirements motivated the initial use of electronics.



The dramatic performance improvements and relatively low cost of electronics have led to an explosive application of electronics in virtually every automotive subsystem. We will be exploring these electronic systems in great detail later in this book, but first it is helpful to review the basic mechanical configurations for each component and subsystem.

1.1.3 Survey of Major Automotive Systems

Basic mechanical configurations for each component and subsystem are reviewed here. Modern Automotive Electronics were first applied to control the Engine in order to reduce the exhaust emissions and somewhat later to improve fuel economy. Consequently, the Engine configuration is reviewed first in this survey.

1.1.3.1 THE ENGINE

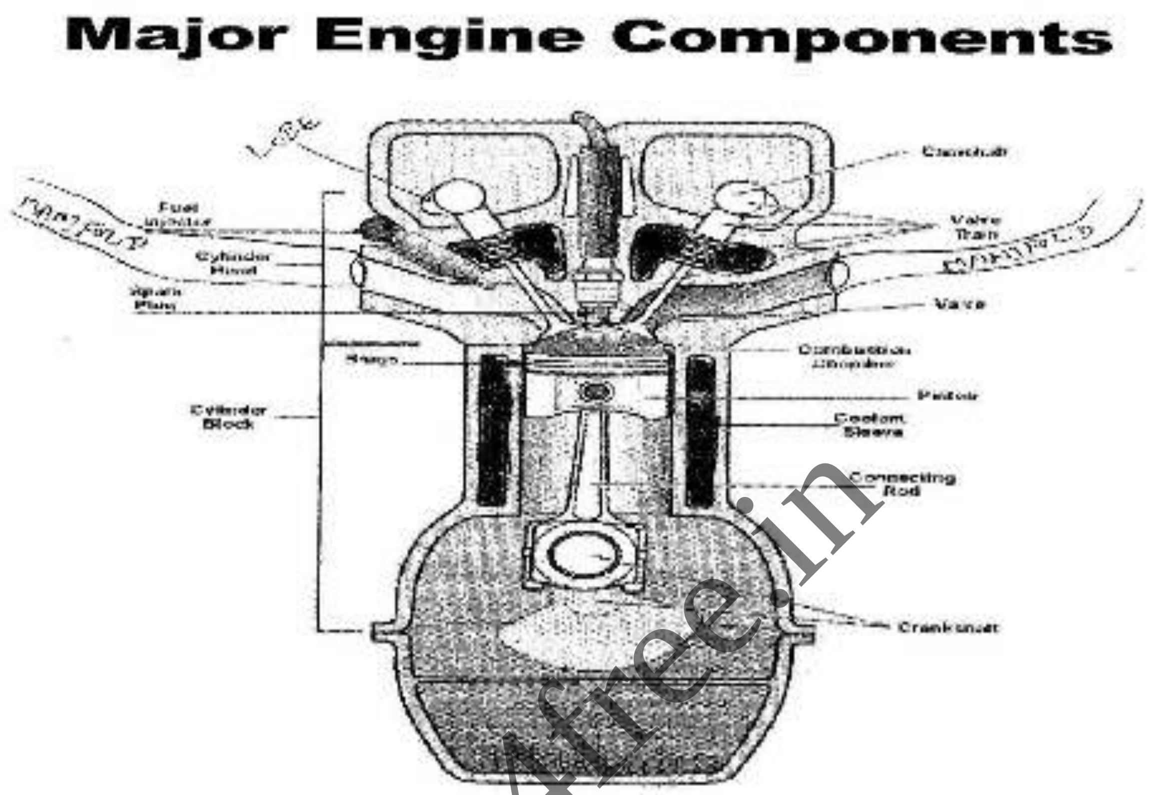
The engine in an automobile provides all the power for moving the automobile, for the hydraulic and pneumatic systems, and for the electrical system. A variety of engine types have been produced, but one class of engine is used most: the internal combustion, piston-type, 4-stroke/cycle, gasoline fueled, spark-ignited, liquid-cooled engine. This engine will be referred to as the spark-ignited, or SI, engine.

Although rapid technological advances in the control of the SI engine have been achieved through the use of electronics, the fundamental mechanical configuration has remained unchanged since this type of power plant was first invented. In addition, the introduction of modern materials has greatly improved the packaging, size, and power output per unit weight or per unit volume. In order that the reader may fully appreciate the performance improvements that have been achieved through electronic controls, we illustrate the engine fundamentals with an example engine configuration from the pre electronic era.

The major components of the engine include the following:

1. Engine block
2. Cylinder
3. Crankshaft
4. Pistons
5. Connecting rods
6. Camshaft
7. Cylinder head
8. Valves
9. Fuel control system
10. Ignition system
11. Exhaust system
12. Cooling system
13. Electrical System

Electronics play a direct role in only the fuel control, ignition, and exhaust systems. In order to meet government regulations for exhaust emissions and fuel economy, these systems combine to optimize performance within regulatory constraints. In the earliest days of government regulation, electronic controls were applied to existing engine designs. However, as electronic technology evolved, the engine mechanical configuration was influenced (at least indirectly) by the electronic controls that were intended to be applied.



Engine operation

One complete cycle requires two complete rotations of the crankshaft. As the crankshaft rotates, the piston moves up and down in the cylinder.

1.1.3.1.1 Engine Block

The cylinders are cast in the engine block and machined to a smooth finish. The pistons fit tightly into the cylinder and have rings that provide a tight sliding seal against the cylinder wall. The pistons are connected to the crankshaft by connecting rods, as shown in Figure. The crankshaft converts the up and down motion of the pistons to the rotary motion needed to drive the wheels.

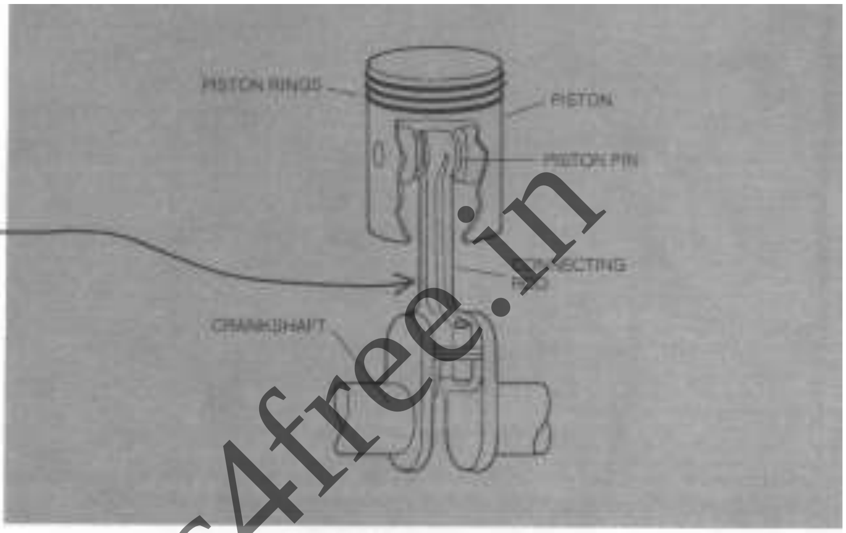
1.1.3.1.2 Cylinder Head

The cylinder head contains an intake and exhaust valve for each cylinder. When both valves are closed, the head seals the top of the cylinder while the piston rings seal the bottom of the cylinder.
The valves are operated by off-center (eccentric) cams on the camshaft, which is driven by the crankshaft as shown in Figure. The camshaft rotates at exactly half the crankshaft speed because

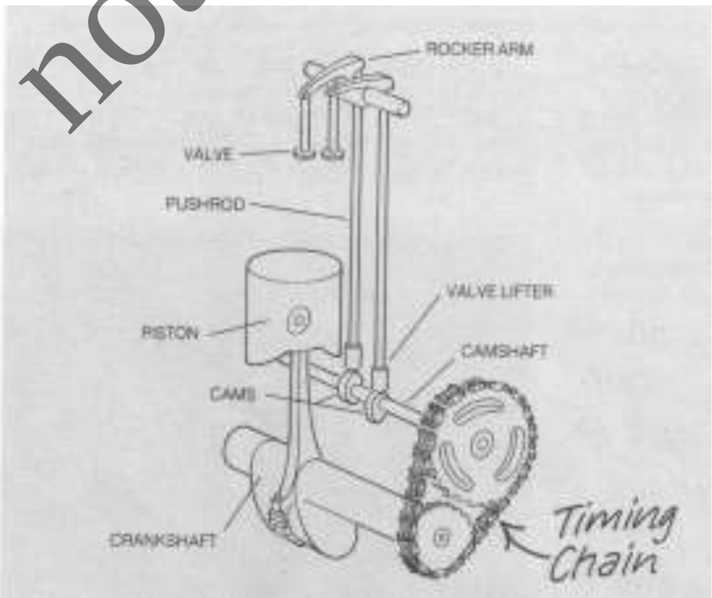
a complete cycle of any cylinder involves two complete crankshaft rotations and only one sequence of opening and closing of the associated intake and exhaust valves. The valves are normally held closed by powerful springs. When the time comes for a valve to open, the lobe on the cam forces the pushrod upward against one end of the rocker arm. The other end of the rocker arm moves downward and forces the valve open. (Note: Some engines have the camshaft above the head, eliminating the pushrods. This is called an *overhead cam* engine.)

Piston Connection to Crankshaft *(Source: Crouse)*

Force due to combustion pressure is applied through the connecting rod to produce torque at the crankshaft.



Valve Operating Mechanism *(Source: Crouse)*



1.1.3.1.3 The 4-Stroke Cycle

The operation of the engine can be understood by considering the actions in any one cylinder during a complete cycle of the engine. One complete cycle in the 4-stroke/cycle SI engine requires two complete rotations of the crankshaft. As the crankshaft rotates, the piston moves up and down in the cylinder. In the two complete revolutions of the crankshaft that make up one cycle, there are four separate strokes of the piston from the top of the cylinder to the bottom or from the bottom to the top. Figure illustrates the four strokes for a 4-stroke/cycle SI engine, which are called:

1. **Intake**
2. **Compression**
3. **Power**
4. **Exhaust**

There are two valves for each cylinder. The left valve in the drawing is called the ***intake valve*** and the right valve is called the ***exhaust valve***. The intake valve is normally larger than the exhaust valve. Note that the crankshaft is assumed to be rotating in a clockwise direction. The action of the engine during the four strokes is described in the following sections.

1. Intake

During the intake stroke the piston is moving from top to bottom and the intake valve is open. As the piston moves down, a partial vacuum is created, which draws a mixture of air and vaporized gasoline through the intake valve into the cylinder. In modern, electronically controlled engines, fuel is injected into the intake port and is timed to coincide with the intake stroke. The intake valve is closed after the piston reaches the bottom. This position is normally called ***Bottom Dead Center*** **(BDC).**

2. Compression

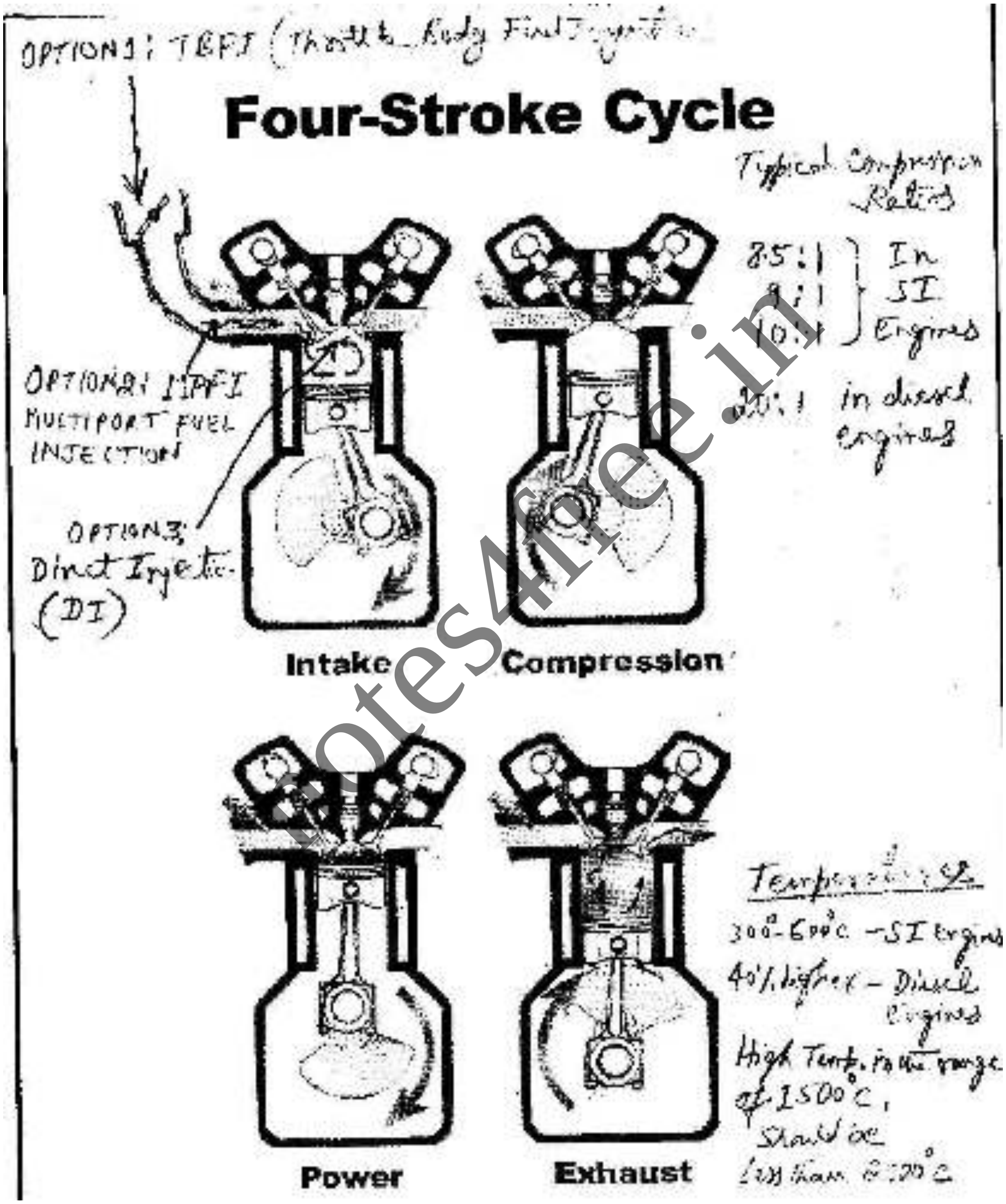
During the compression stroke (Figure 1.5b), the piston moves upward and compresses the fuel and air mixture against the cylinder head. When the piston is near the top of this stroke, the ignition system produces an electrical spark at the tip of the spark plug. The top of the stroke is normally called ***Top Dead Center*** (**TDC**). The spark ignites the air–fuel mixture and the mixture burns quickly, causing a rapid rise in the pressure in the cylinder.

3. **Power**

During the power stroke the high pressure created by the burning mixture forces the piston downward. It is only during this stroke that actual usable power is generated by the engine.

4. Exhaust

During the exhaust stroke the piston is again moving upward. The exhaust valve is open and the piston forces the burned gases from the cylinder through the exhaust port into the exhaust system and out the tail pipe into the atmosphere.



This 4-stroke cycle is repeated continuously as the crankshaft rotates. In a single-cylinder engine, power is produced only during the power stroke, which is only one-quarter of the cycle. In order to maintain crankshaft rotation during the other three-quarters of the cycle, a flywheel is used. The flywheel has traditionally been a relatively large, heavy, circular object that is connected to the crankshaft, although in modern engines the mass of the flywheel has been reduced relative to very early engines. The primary purpose of the flywheel is to provide inertia to keep the crankshaft rotating during the three non-power producing strokes of the piston.

In a multi cylinder engine, the power strokes are staggered so that power is produced during a larger fraction of the cycle than for a single-cylinder engine. In a 4-cylinder engine, for example, power is produced almost continually by the separate power strokes of the four cylinders. The shaded regions of Figure indicate which cylinder is producing power for each 180 degrees of Crank shaft rotation. (Remember that one complete engine cycle requires two complete crankshaft rotations of 360 degrees each, for a total of 720 degrees.)

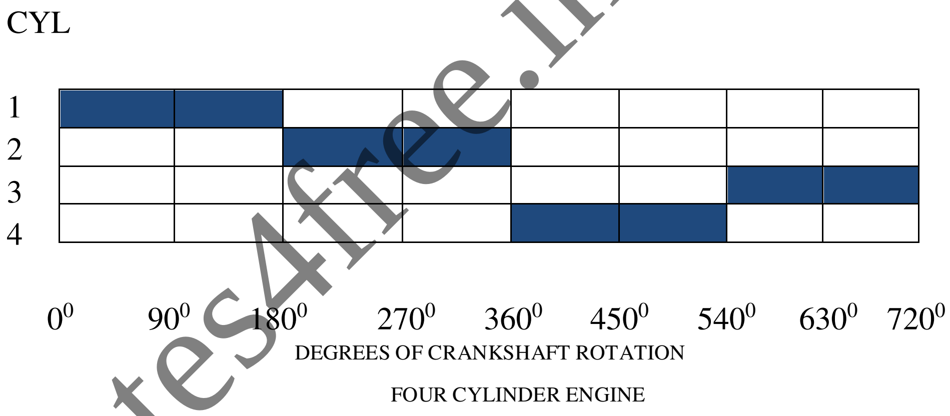


Figure: Power pulses from a 4-Cylinder Engine

1.1.4 ENGINE CONTROL

Control of the engine in any car means, regulating the power that it produces at any time, in accordance with the driving needs. The driver controls engine power via the accelerator pedal, which, in turn, determines the setting of the throttle plate via a mechanical linkage system. The throttle plate is situated in the air intake system The intake system is an assembly of pipes or Passage ways through which the air flows from outside into each cylinder. The air flowing into the engine flows past the throttle plate, which, in fact, controls the amount of air being drawn into the engine during each intake stroke.

The power produced by the engine is proportional to the mass flow rate of air into the engine. The driver then controls engine power directly by controlling this air mass flow rate with the throttle plate. Of course, the power produced by the engine depends on fuel being present in the correct proportions. Air combines with fuel in the fuel metering device. This device automatically delivers fuel in the correct amount as determined by the air flow. The classic fuel metering device was the carburetor, which is now virtually obsolete. In modern car engines, fuel injectors do the fuel metering. The amount of fuel delivered by a fuel injector is determined electronically in accordance with the air flow in such a way as to minimize pollutants in the exhaust gas.

1.1.5 IGNITION SYSTEM

To produce power, the gasoline engine must not only have a correct mixture of fuel and air, but also some means of initiating combustion of the mixture. Essentially the only practical means is with an electric spark produced across the gap between a pair of electrodes of a spark plug. The electric arc or spark provides sufficient energy to cause combustion. This phenomenon is called ***ignition***.

Once a stable combustion has been initiated, there is no further need for the spark. Typically, the spark must persist for a period of about a millisecond (one thousandth of a second). This relatively short period makes spark ignition possible using highly efficient pulse transformer circuits in which a circuit having a relatively low average current can deliver a very high-voltage (high peak power) pulse to the spark plug. The ignition system itself consists of several components: the spark plug, one or more pulse transformers (typically called *coils*), timing control circuitry, and distribution apparatus that supplies the high-voltage pulse to the correct cylinder.

1.1.5.1 Spark Plug

The spark is produced by applying a high-voltage pulse of from 20 kV to 40 kV (1 kV is 1,000 volts) between the center electrode and ground. The actual voltage required to start the arc varies with the size of the gap, the compression ratio, and the air–fuel ratio. Once the arc is started, the voltage required to sustain it is much lower because the gas mixture near the gap becomes highly ionized. (An ionized gas allows current to flow more freely.) The arc is sustained long enough to ignite the air–fuel mixture.

A typical spark plug configuration is shown in Figure. The spark plug consists of a pair of electrodes, called the *center* and *ground electrodes,* separated by a gap. The gap size is important and is specified for each engine. The gap may be 0.025 inch (0.6 mm) for one engine and 0.040 inch (1 mm) for another engine. The center electrode is insulated from the ground electrode and the metallic shell assembly. The ground electrode is at electrical ground potential because one terminal of the battery that supplies the current to generate the high-voltage pulse for the ignition system is connected to the engine block and frame.

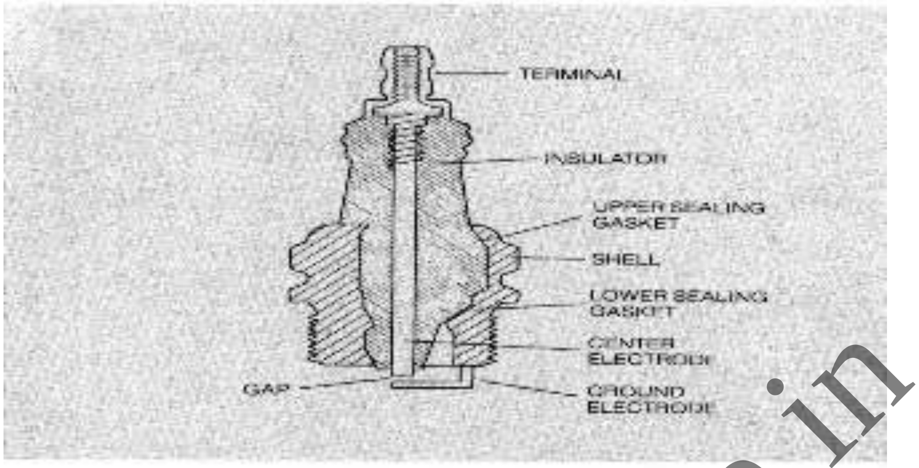


Figure: Spark Plug Configuration

1.1.5.2 High-Voltage Circuit and Distribution

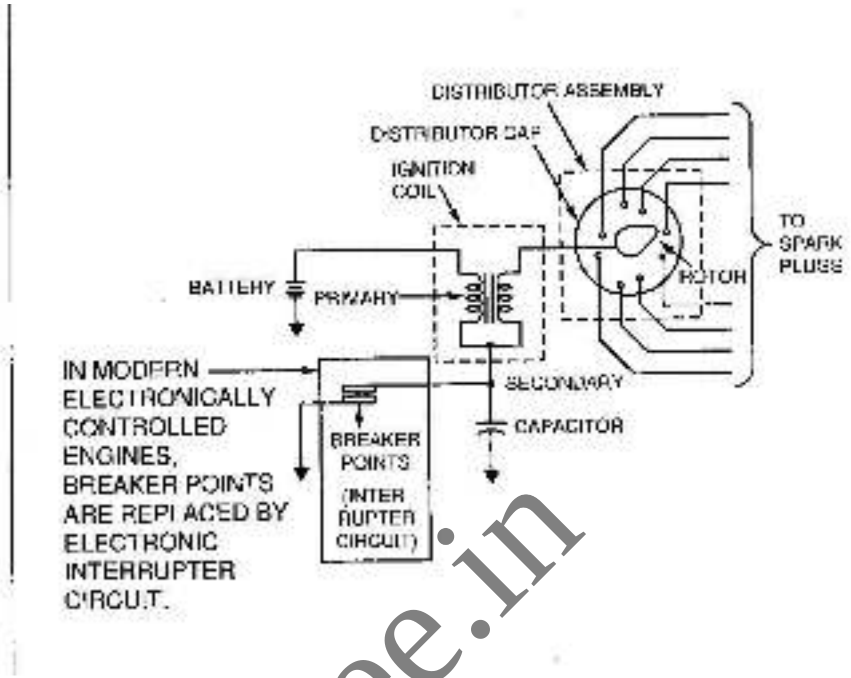
The ignition system provides the high-voltage pulse that initiates the arc. Figure shows the schematic of the electrical circuit for the ignition system. The high-voltage pulse is generated by inductive discharge of a special high-voltage transformer commonly called an ***ignition coil***. The high-voltage pulse is delivered to the appropriate spark plug at the correct time for ignition by a distribution circuit. Before the advent of modern electronic controls, the distribution of high-voltage pulses was accomplished with a rotary switch called the ***distributor.***

The center electrode is mechanically driven by the camshaft (via gears) and rotates synchronously at camshaft speed (i.e., one half of crankshaft speed). The distributor is an obsolete means for distribution of the spark to the appropriate spark plug, and is being replaced by multiple coils, typically one each for a pair of cylinders.

Once again, as in the case of fuel delivery, we explain spark distribution in terms of the distributor and spark initiation in terms of breaker points in order to provide a framework for the discussion of the modern distributor less ignition systems. In this way the reader can see the benefits of the electronic controls.

A set of electrical leads, commonly called *spark plug wires,* is connected between the various spark plug center terminals and the individual terminals in the distributor cap. The center terminal in the distribution cap is connected to the ignition coil secondary.

Schematic of the Ignition Circuit



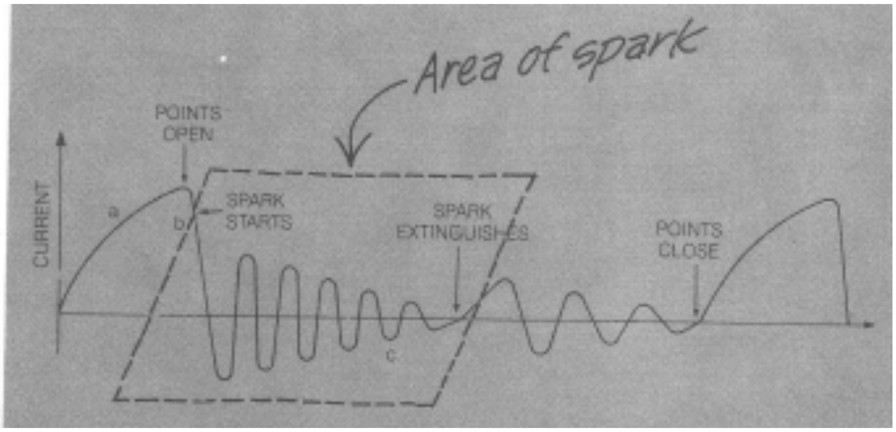
IN MODERN ELECTRONICALLY CONTROLLED ENGINES, BREAKER POINTS ARE REPLACED BY ELECTRONIC INTERRUPTER CIRCUIT.

1.1.5.3 Spark Pulse Generation

The actual generation of the high-voltage pulse is accomplished by switching the current through the primary circuit. The mechanism in the distributor of a traditional ignition system for switching the primary circuit of the coil consists of opening and closing the breaker points (of a switch) by a rotary cam in the distributor. During the intervals between ignition pulses (i.e., when the rotor is between contacts), the breaker points are closed (known as *dwell*). Current flows through the primary of the coil, and a magnetic field is created that links the primary and secondary of the coil.

At the instant the spark pulse is required, the breaker points are opened. This interrupts the flow of current in the primary of the coil and the magnetic field collapses rapidly. The rapid collapse of the magnetic field induces the high voltage pulse in the secondary of the coil. This pulse is routed through the distributor rotor, the terminal in the distributor cap, and the spark plug wire to the appropriate spark plug. The capacitor absorbs the primary current, which continues to flow during the short interval in which the points are opening, and limits arcing at the breaker points. The waveform of the primary current is illustrated in Figure.

Primary Current Waveform



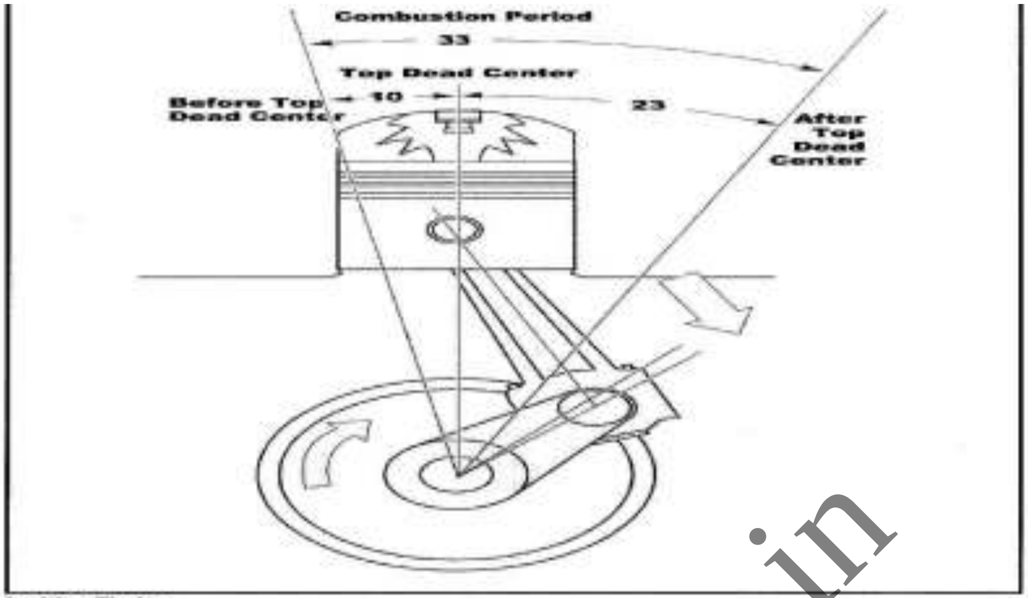
The primary current increases with time after the points close (point *a* on waveform). At the instant the points open, this current begins to fall rapidly. It is during this rapid drop in primary current that the secondary high-voltage pulse occurs (point *b*). The primary current oscillates (the "wavy'' portion; point *c*) because of the resonant circuit formed between the coil and capacitor.

In electronic ignition systems the breaker points are replaced by a solid-state switch (in the form of a transistor). A transistor in saturation is equivalent to a closed switch, and a cutoff transistor is equivalent to an open switch. The transistor state (i.e., saturation or cutoff) is controlled electronically in order to set dwell and spark timing.

1.1.6 IGNITION TIMING

Ignition occurs some time before top dead center (BTDC) during the compression stroke of the piston. This time is measured in degrees of crankshaft rotation BTDC. For a modern SI engine, this timing is typically 8 to 10 degrees for the basic mechanical setting with the engine running at low speed (low rpm). This basic timing is set by the design of the mechanical coupling between the crankshaft and the distributor. The basic timing may be adjusted slightly in many older cars by physically rotating the distributor housing.

As the engine speed increases, the angle through which the crankshaft rotates in the time required to burn the fuel and air mixture increases. For this reason, the spark must occur at a larger angle BTDC for higher engine speeds. This change in ignition timing is called ***spark advance***. That is, spark advance should increase with increasing engine rpm. In a conventional ignition system, the mechanism for this is called a ***centrifugal spark advance***



Ignition Timing

In addition to speed-dependent spark advance, the ignition timing needs to be adjusted as a function of intake manifold pressure. Whenever the throttle is nearly closed, the manifold pressure is low (i.e., nearly a vacuum). The combustion time for the air–fuel mixture is longer for low manifold pressure conditions than for high manifold pressure conditions (i.e., near atmospheric pressure). As a result, the spark timing must be advanced for low pressure conditions to maintain maximum power and fuel economy. The mechanism to do this is a ***vacuum-operated spark advance***.

Ignition timing significantly affects engine performance and exhaust emissions; therefore, it is one of the major factors that is electronically controlled in the modern SI engine. The performance of the ignition system and the spark advance mechanism has been greatly improved by electronic control systems. Because ignition timing is critical to engine performance, controlling it precisely through all operating conditions has become a major application of digital electronics.

Ignition timing refers to how early or how late the spark plug fire in relation to the position of piston on the compression stroke. For the engine to run efficiently and produce low emissions, the combustion process should be completed approximately 23° After Top Dead Center (ATDC). Since the combustion process always takes the same amount of time to complete, spark must occur sooner on the compression stroke as engine speed increases 10° Before Top Dead Center (BTDC).

In old vehicles, the timing control was accomplished through mechanical means i.e., by using spring and weights in combination with vacuum operated link, physically moved the distributor to provide the correct timing position. In new vehicles EST is made use of (ICM or PCM).

1.1.7 DIESEL ENGINE

Physically, the diesel Engine is nearly identical to the gasoline Engine and can be either 4-stroke or 2-stroke/cycle. The diesel engine fuel is supplied via a fuel is supplied via a fuel injection system that injects fuel either directly into the cylinder (Direct Injection System) or into the intake port during the intake stroke (Indirect Injection System). Diesel Engines are subject to exhaust emission regulations similar to those applied to gasoline engines. Emissions are influenced by the timing of the fuel injection relative to the compression and power strokes.

The difference between Petrol (Gasoline) Engine and Diesel Engine is that, o spark ignition is required in Diesel Engine. The ignition happens due to compression. The compression ratio is very high in comparison to gasoline Engine.

Diesel engines are used mostly in heavy-duty vehicles such as large trucks, ships, railroad locomotives, and earth-moving machinery.

1.1.8 DRIVE TRAIN

The engine drive train system of the automobile consists of the engine, transmission, drive shaft, differential, and driven wheels. We have already discussed the SI engine and we know that it provides the motive power for the automobile. Now let’s examine the transmission, drive shaft, and differential in order to understand the roles of these devices.

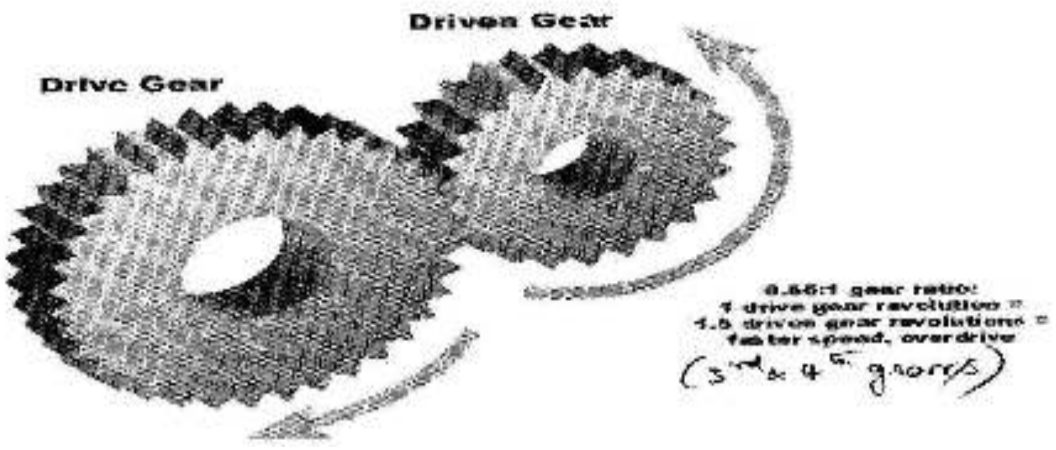
1.1.8.1 Transmission

The transmission is a gear system that adjusts the ratio of engine speed to wheel speed. Essentially, the transmission enables the engine to operate within its optimal performance range regardless of the vehicle load or speed. It provides a gear ratio between the engine speed and vehicle speed such that the engine provides adequate power to drive the vehicle at any speed.

To accomplish this with a manual transmission, the driver selects the correct gear ratio from a set of possible gear ratios (usually three to five for passenger cars). An automatic transmission selects this gear ratio by means of an automatic control system.

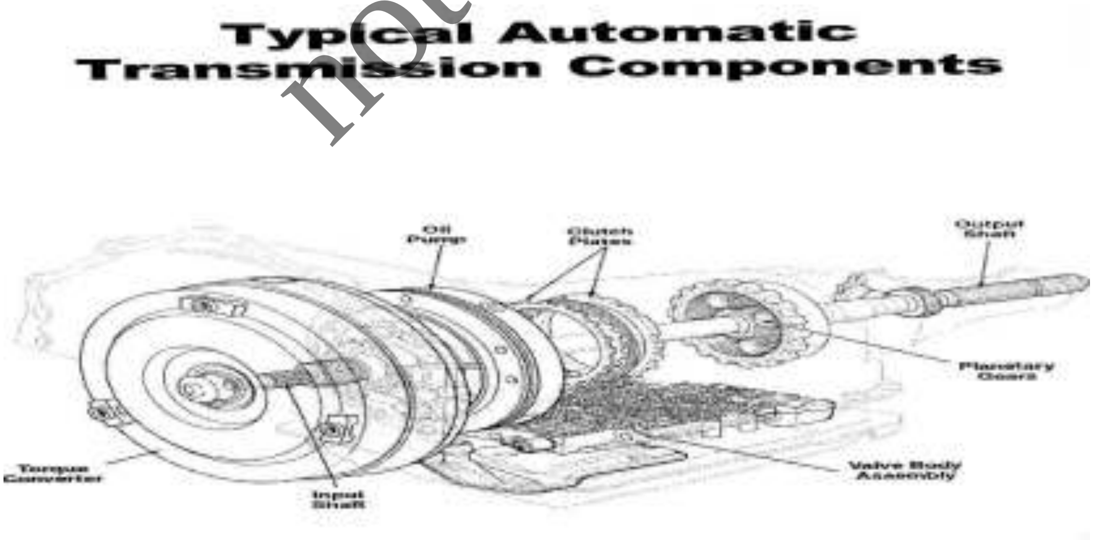
Most automatic transmissions have three forward gear ratios, although a few have two and some have four. A properly used manual transmission normally has efficiency advantages over an automatic transmission, but the automatic transmission is the most commonly used transmission for passenger automobiles in the United States. In the past, automatic transmissions have been controlled by a hydraulic and pneumatic system, but the industry is moving toward electronic controls. The control system must determine the correct gear ratio by sensing the driver-selected command, accelerator pedal position, and engine load. The proper gear ratio is actually computed in the electronic transmission control system. Once again, as in the case of electronic engine control, the electronic transmission control can optimize transmission control. However, since the engine and transmission function together as a power-producing unit, it is sensible to control both components in a single electronic controller.

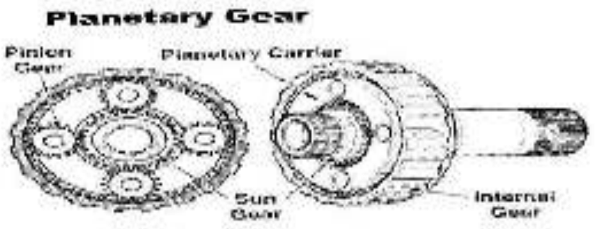
Example: A drive gear has 12 teeth and driven gate has 24 teeth, the drive gear must turn 2 times to turn the driven gear once. The gear ratio between the two gears is 2:1. If a 36 teeth gear drives a 24 teeth gear, the 24 teeth gear 1&1/2 times for every revolution of the 36 tooth gear. The gear ratio is 1:1.5 which is normally expressed as 0.66:1. A gear ratio <1 indicates overdrive condition. This means the driven gear is turning faster than the drive gear. Speed is high, but the output torque is low.

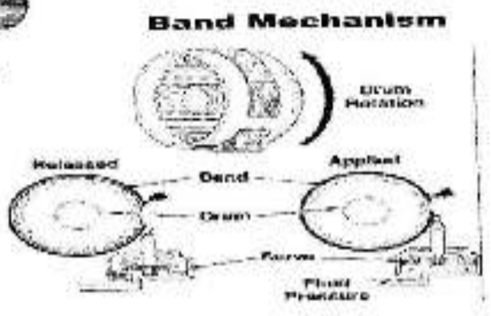


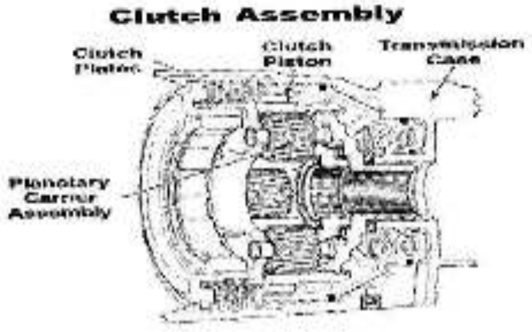
Transmission	
Manual Transmission (M/T)	**Automatic Transmission (A/T)**
1) Driver selects the correct gear ratio from a set of possible gear ratio (Usually 3 to 5)	1) A/T selects this gear ratio by means of an automatic control system.
2) A properly used M/T has efficiency advantages over an A/T	2) In the past A/T have been controlled by a hydraulic and pneumatic system, but there is a move towards electronic controls in the future. The control system must determine the correct gear ratio by sensing the driver select command, accelerator pedal position and engine load.
3) Shifted manually by driver from one gear ratio to another, the driver depresses a pedal called clutch and then moves gear shift lever.	3) Automatically shifted from one gear to another. It requires no action from the driver other than depressing the accelerator pedal. There is no clutch available here.

In case A/T Vehicles, no Clutch and Gear are available for the driver to operate. Instead of that there is a lever available besides driver which can select the options such as "**PRNDL"** which indicates Park, Reverse, Neutral, Drive and Low (1st Gear). In some vehicles it is **PRND2L** where 2 indicates 2nd Gear. In addition there will be a switch available on the same lever which indicates **O/D OFF** (Over Drive Off) which indicates that no operation of 3rd and 4th gear condition during 'Drive' mode.









1.1.8.2 Drive Shaft

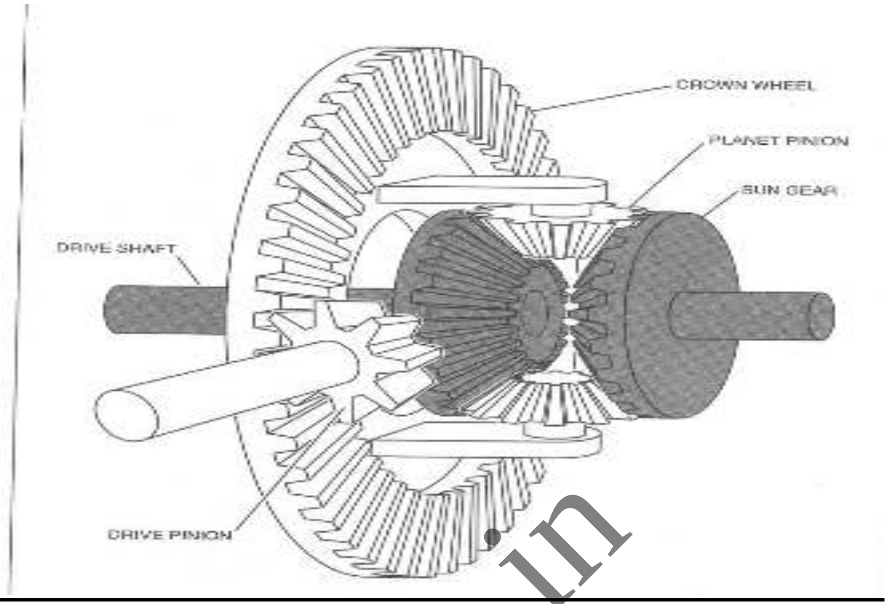
The drive shaft is used on front-engine, rear wheel drive vehicles to couple the transmission output shaft to the differential input shaft. Flexible couplings, called *universal joints*, allow the rear axle housing and wheels to move up and down while the transmission remains stationary. In front wheel drive automobiles, a pair of drive shafts couples the transmission to the drive wheels through flexible joints known as *constant velocity* (CV) *joints*.

1.1.8.3 Differential

The differential serves three purposes.

1. The most obvious is the right angle transfer of the rotary motion of the drive shaft to the wheels.
2. Second purpose is to allow each driver wheel to turn at a different speed. This is necessary because the 'Outside' wheel must turn faster than the 'Inside' wheel when the vehicle is turning a corner.
3. The third purpose is the torque increase provided by the gear ratio. This gear ratio can be changed to allow different torque to be delivered to the wheels while using the same engine and transmission. This gear ratio also affects fuel economy.

Schematic of a Differential



In front wheel drive cars, the transmission differential and drive shafts are known collectively as the *transaxle assembly*.

1.1.9 SUSPENSION

Another major automotive subsystem is the suspension system, which is the mechanical assembly that connects each wheel to the car body. The primary purpose of the suspension system is to isolate the car body from the vertical motion of the wheels as they travel over the rough road surface.

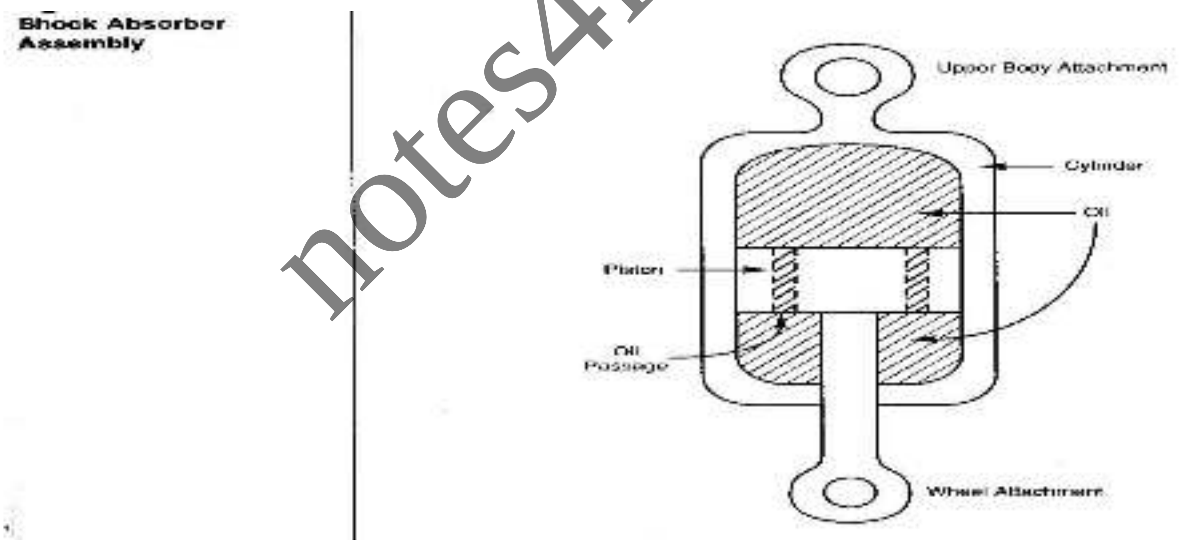
The suspension system can be understood with reference to Figure which illustrates the major components. Notice that the wheel assembly is connected through a movable assembly to the body. The weight of the car is supported by springs. In addition, there is a so-called *shock absorber* (sometimes a *strut*), which is in effect a viscous damping device. There is a similar assembly at each wheel, although normally there are differences in the detailed configuration between front and rear wheels.

The mass of the car body is called the *sprung mass,* that is, the mass that is supported by springs. The mass of the wheel assemblies at the other end of the springs is called *unsprung mass.*

All springs have the property that the deflection of the spring is proportional to the applied axial force. The proportionality constant is known as the *spring rate*. The springs are selected for each car such that the car body height is as desired for the unloaded car. Typically, the weight on the front wheels is greater than on the rear wheels, therefore, the front springs normally have a higher spring rate than the rear.

Similar to the springs, the shock absorbers (struts) also produce a force that acts to support the weight of the car. However, unlike the springs, the shock absorbers produce a force in response to the motion of the wheel assembly relative to the car body. Figure is an illustration of a typical shock absorber.

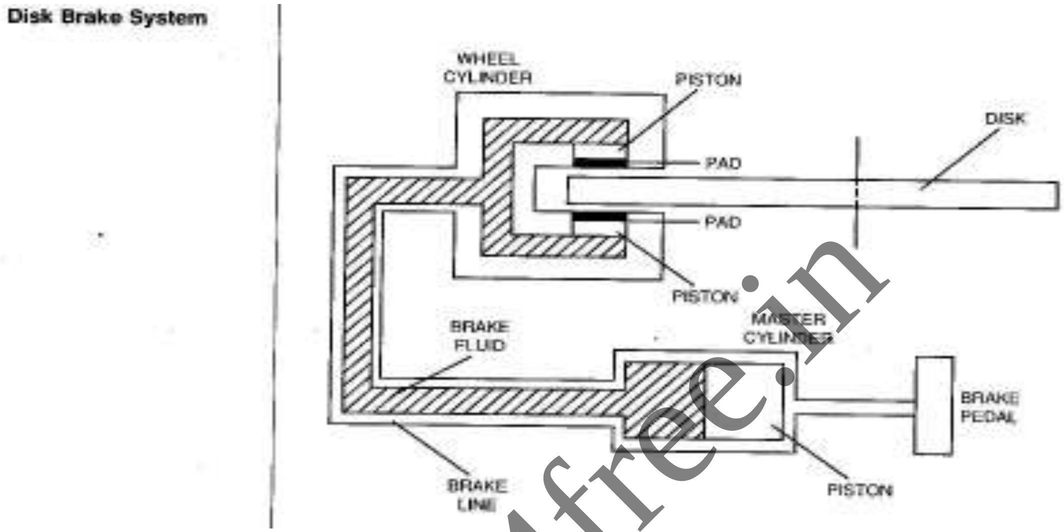
The shock absorber consists of a cylinder and piston assembly. The cylinder is filled with a viscous oil. There are small oil passages through the piston through which the oil can flow. As the wheel assembly moves up and down, the piston moves identically through the cylinder. The oil (which is essentially incompressible) flows through the oil passages. A force is developed in response to the piston motion that is proportional to the piston velocity relative to the cylinder. This force acts in combination with the spring force to provide a damping force. The magnitude of this force for any given piston velocity varies inversely with the aperture of the oil passages. This aperture is the primary shock absorber parameter determining the damping effect and influencing the car's ride and handling.



1.1.10 BRAKES

Brakes are as basic to the automobile as the engine drive train system and are responsible for slowing and stopping the vehicle. Most of the kinetic energy of the car is dissipated by the brakes during deceleration and stopping (with the other contributions coming from aerodynamic drag and tire rolling resistance).

There are two major types of automotive brakes: drum and disk brakes. Drum brakes are an extension of the type of brakes used on early cars and horsedrawn wagons. Increasingly, automobile manufacturers are using disk brakes. Consequently, it is this type that we discuss here.



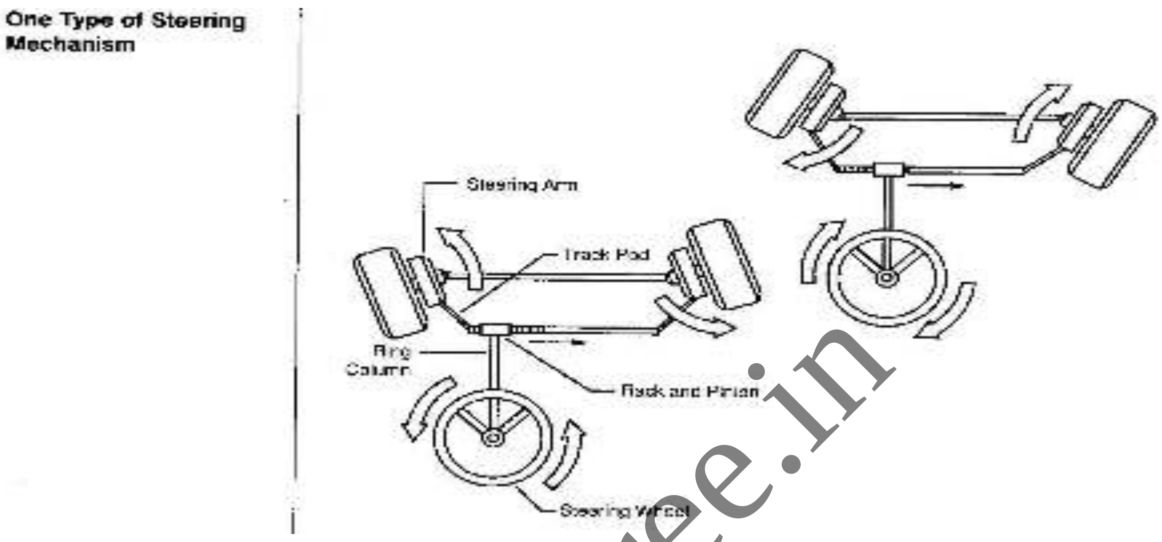
Disk brakes are illustrated in Figure. A flat disk is attached to each wheel and rotates with it as the car moves. A wheel cylinder assembly (often called a *caliper*) is connected to the axle assembly. A pair of pistons having brake pad material are mounted in the caliper assembly and are close to the disk.

Under normal driving conditions, the pads are not in contact with the disk, and the disk is free to rotate. When the brake pedal is depressed, hydraulic pressure is applied through the brake fluid to force the brake pads against the disk. The braking force that decelerates the car results from friction between the disk and the pads.

Electronic control of braking benefits safety by improving stopping performance in poor or marginal braking conditions. In later chapter explains the operation of the so-called *Antilock Braking System* (ABS) is explained.

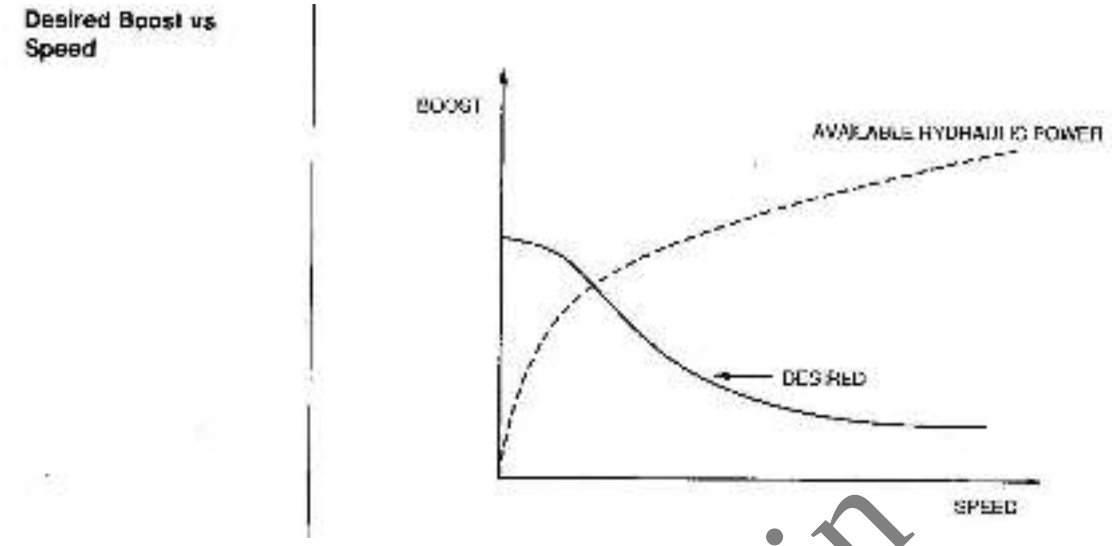
1.1.11 STEERING SYSTEM

A steering system is one of the major automotive subsystems required for operation of the car. It provides the driver control of the path of the car over the ground. Steering functions by rotating the plane of the front wheels in the desired direction of the turn. The angle between the front wheel plane and the longitudinal axis of the car is known as the *steering angle*. This angle is proportional to the rotation angle of the steering wheel.



Traditionally, automotive steering systems have consisted solely of mechanical means for rotating the wheels about a nominally vertical axis in response to rotation of the steering wheel. The inclination of this axis gives rise to a restoring torque that tends to return the wheels to planes that are parallel to the vehicle's longitudinal axis so that the car will tend to travel straight ahead. This restoring torque provides a steering stability for the car.

When steering the car, the driver must provide sufficient torque to overcome the restoring torque. Because the restoring torque is proportional to the vehicle weight for any given steering angle, considerable driver effort is required for large cars, particularly at low speeds and when parking.
In order to overcome this effort in relatively large cars, a power steering system is added. This system consists of an engine-driven hydraulic pump, a hydraulic actuator, and control valve. Whenever the steering wheel is turned, a proportioning valve opens, allowing hydraulic pressure to activate the actuator. The high-pressure hydraulic fluid pushes on one side of the piston.
The piston, in turn, is connected to the steering linkage and provides mechanical torque to assist the driver in turning. This hydraulic force is often called steering *boost*. The desired boost varies with vehicle speed, as depicted in Figure.



This graph shows that the available boost from the pump increases with engine speed (or vehicle speed), whereas the desired boost decreases with increasing speed. An electronic control system can adjust the available boost as a function of speed to desirable levels.

In addition to the automotive systems described above, electronics is involved in the implementation of cruise control systems, heating and air conditioning systems, as well as entertainment and some safety systems. Moreover, electronics is responsible for introducing new systems that could, in fact, not exist without electronics, such as navigation systems, communication systems, and electronic diagnostic systems.

1.1.12 STARTER BATTERY: Operating Principle

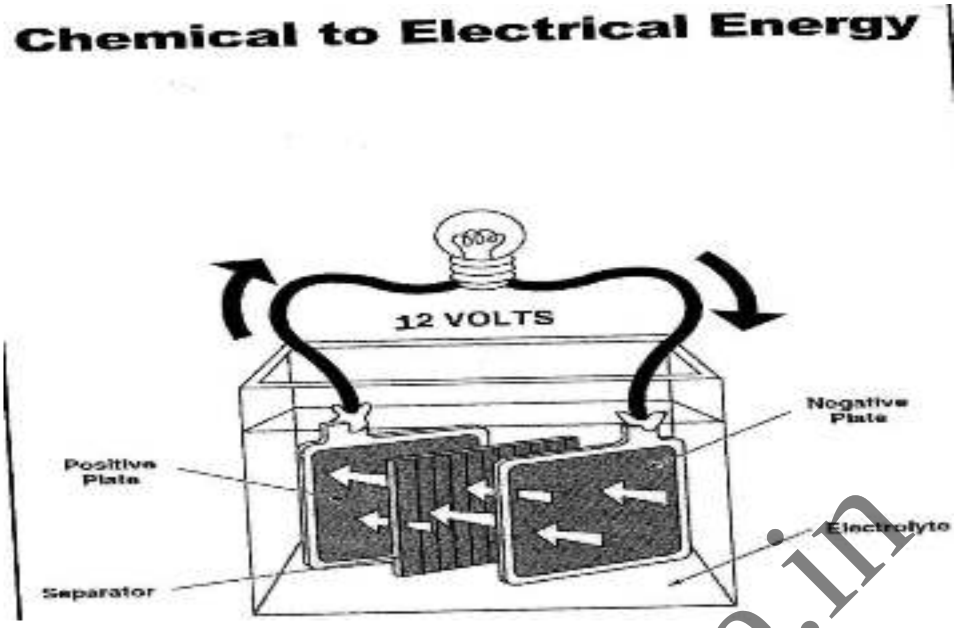
Battery is an electrochemical device for converting chemical energy to electrical energy. Battery performs four functions:

1. Supplies electrical energy for the accessories when the engine is not running.

2. Supplies energy for cranking motor and ignition system.

3. Intermittently supplies current for lights, radio, heater and other accessories, when the electrical demands of those devices exceed the output of the generator.

4. Acts as a voltage stabilizer in the electrical system.



Active materials within the battery react chemically to produce a flow of DC (direct current) whenever lights, radio, cranking motor or other current consuming accessories are connected to the Battery. This current is produced by a chemical reaction between the active materials of the plate and Sulfuric acid of the electrolyte.

Charging, Discharging & Recharging

During the life of a battery, it is either charging or discharging.

When a battery is supplying the electrical current to the accessories or cranking motor, it is said to be discharging.

When the engine is running at sufficient speed, the generator in the charging system supplies current to the battery and it is said to be charging.

Discharging occurs under following three conditions:-

1. The automobile engine is not running.
2. The automobile is running out at low RPM.
3. There is a fault in the charging system.

When a battery is nearly or completely discharged, recharging is required for the battery to provide proper service.

Recharging occurs when electrical current flows into the battery in the direction opposite to the current flow during discharge. This recharging current must come from an external source, such as an automobile charging system, an external charging unit or another battery.

Module 1: Chapter 2: Basics of Electronic Engine Control

Engine Control means regulating fuel and air intake as well as spark timing to acheve desired performance in the form of Torque or Power output.

1.2.1 Motivation for Electronic Engine Control

The motivation came from two government requirements. The first is from legislation to regulate automobile exhaust emissions and the second was to improve the national average fuel economy by government regulation.

1.2.1.1 Exhaust Emissions

The engine exhaust consists of the product of combustion of the air and gasoline mixture. Gasoline is a mixture of chemical compounds that are called hydrocarbons. The name is derived from the chemical formation of the various gasoline compounds, each of which is a chemical union of Hydrogen (H) and Carbon (C). In addition, the gasoline also contains natural impurities as well as chemicals added by the refiner. All of these can produce undesirable exhaust elements.

During the combustion process, the carbon and Hydrogen combine with oxygen from air, releasing heat energy and forming various chemical compounds. If the combustion were perfect, the exhaust gases would consist of only carbon dioxide (CO_2) and water (H_2O), neither of which is considered harmful in the atmosphere. In fact these are present in a human's breath.

Unfortunately, the combustion of the SI engine is not perfect. In addition to the CO_2 and H_2O, the exhaust contains amounts of carbon monoxide (CO), oxides of nitrogen (chemical unions of nitrogen and oxygen which are denoted NO_x), unburned hydrocarbons (HC), oxides of sulfur, and other compounds. Some of the exhaust constituents are considered harmful and come under the control of government. The exhaust emissions controlled by government are CO, HC and $NO_{x..}$

1.2.1.2 Fuel Economy

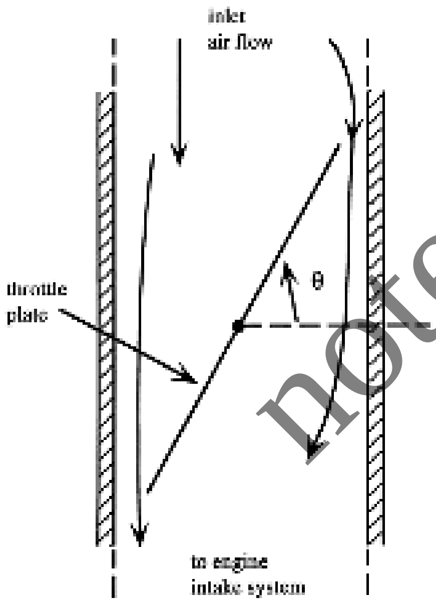
It is related to the number of miles that can be driven for each gallon of gasoline consumed. It is referred to as miles per gallon (mpg) or simply mileage. Just like Electronic Engine Control improves emission control, another important feature of it is to improve fuel economy.

The mileage of a vehicle is not unique. It depends upon size, shape, weight, and how the vehicle is driven. The best mileage is achieved under steady conditions. City driving, with many starts and stops, yields worse mileage than steady highway driving.

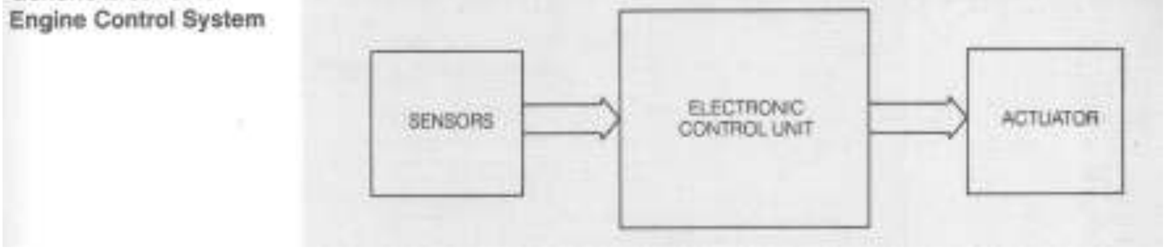
The government fuel economy standards are not based on just one car, but are stated in terms of the average rated miles per gallon fuel for the production of all models by a manufacturer by any year. This is known by the acronym CAFÉ (Corporate Average Fuel Economy). It is somewhat complex requirement and is based upon requirements of the fuel used during the prescribed, simulated standard driving cycle.

1.2.2 Concept *of an Electronic Engine Control System*

An electronic engine control system is an assembly of electronic and electromechanical components that continuously vary the fuel and spark settings in order to satisfy government exhaust emission and fuel economy regulations.

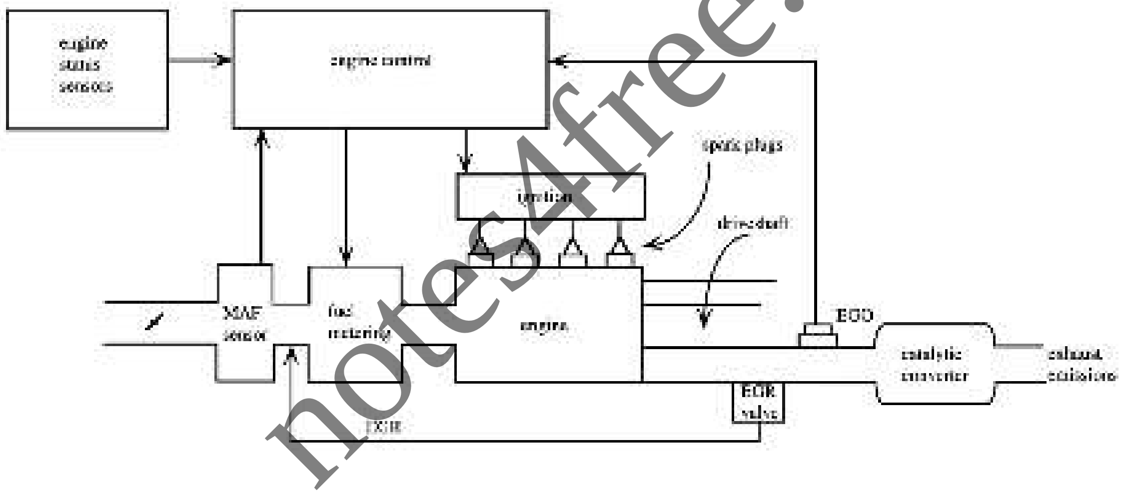


The Block diagram of a generalized Electronic Engine Control System is as shown below.



A control system requires measurement of certain variables that tell the controller the state of the system being controlled. The electronic engine control system receives input electrical signals from the various sensors which measure the state of the engine. From these signals, the controller generates output electrical signals to the actuators that determine the engine calibration.

The figure (a) below identifies the automotive functions that surround the engine in a bit more detail. There is a fuel metering system to set the air fuel mixture going into the engine through the intake manifold. Spark control determines when the air fuel mixture is ignited after it is compressed in the cylinders of the engine. The power is at the drive shaft, and the gases which result from combustion flow out of the exhaust system. In the exhaust system there is a valve to control the amount of exhaust gas being circulated back to the input and catalytic converter to further control emissions. As shown in figure (b), it appears that the automotive engine control system is evolving toward an intelligent digital system in which these subsystems are treated as separate functions of the same controller.



Before proceeding with the details of Engine Control Systems, we will define certain Terms.

The ***Terms*** are categorized into ***General Terms*** and ***Engine Performance Terms.***

1.2.3 Definition of General Terms

General Terms are further classified into ***Parameters*** and ***Variables.***

1.2.3.1 PARAMETER:

Parameter is a numerical value of some engine dimension that is fixed by design.

Examples:

- Bore – It is the Piston Diameter
- Stroke - The distance of the crankshaft level arm
- Throw - Length of the crankshaft level arm
- Bore & stroke determine the cylinder volume & displacement
- Displacement – It is the total volume of air that is displaced as the engine rotates through two complete revolutions.
- Compression Ratio – It is the ratio of cylinder volume at BDC to the volume at TDC
- Combustion chamber shape
- Crankshaft cam profile
- Intake & Exhaust valve size
- Valve timing

All of these design parameters are fixed by design and are not subject to control while engine is operating.

1.2.3.2 VARIABLE:

Variable is a quantity that changes or may be changed as the engine operates.

Examples: Mass Air Flow, Fuel Flow Rate, Spark Timing, Power, Intake Manifold Pressure etc.

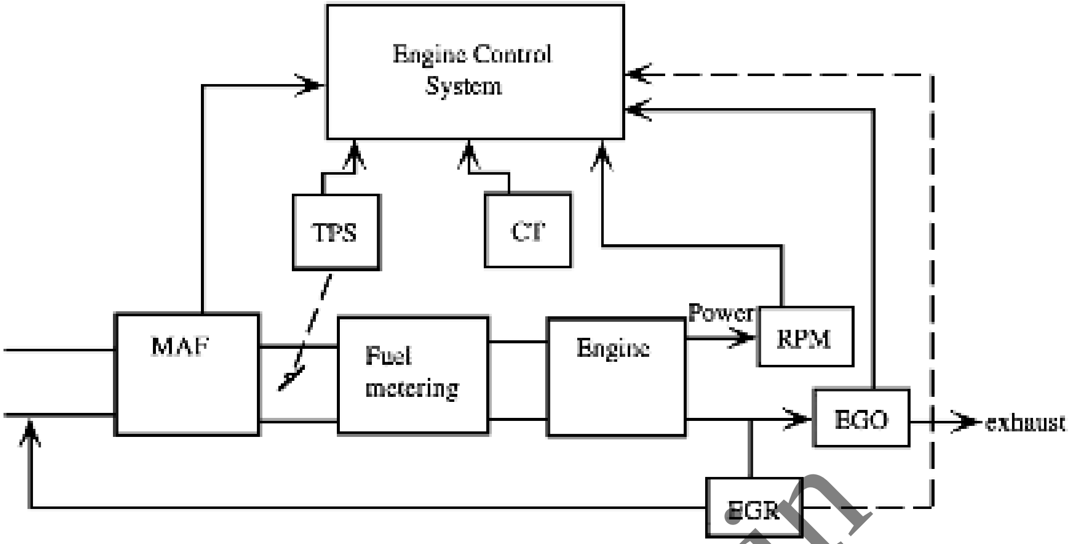
Inputs to Controllers

- Throttle position sensor(TPS)
- Manifold Absolute Pressure (MAP)
- Engine Temperature or Coolant Temperature
- Engine speed (RPM)
- Exhaust gas recirculation (EGR) valve position
- Exhaust gas oxygen (EGO) concentration

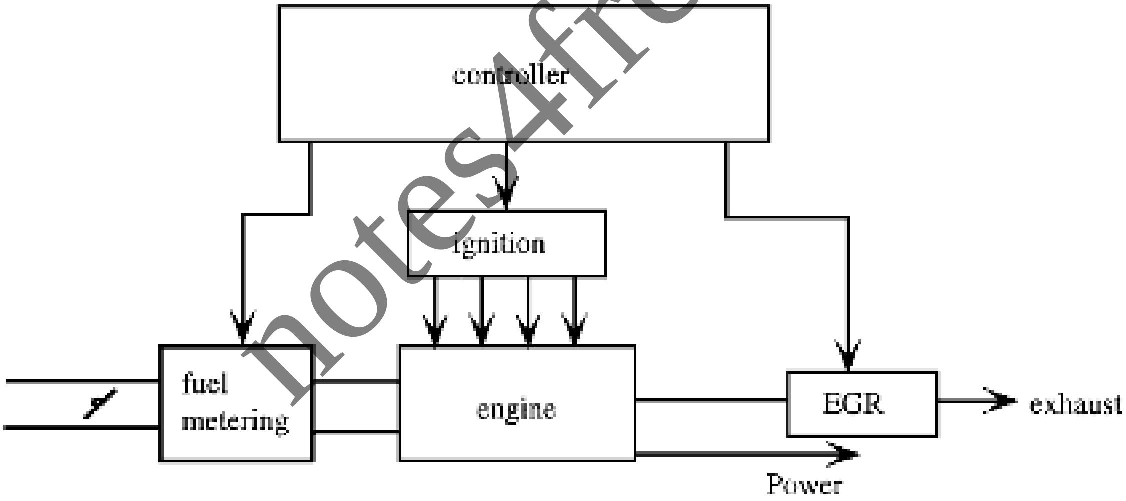
Outputs from Controllers

- Fuel metering control
- Ignition control
- Ignition timing
- Exhaust Gas Recirculation (EGR) control

The Major controller inputs from Engine are as shown in the diagram below.



The major controller outputs to Engine are as shown in the diagram below.



1.2.4 Definition of Performance Terms

1.2.4.1 Power

Power is a measurement of an engine ability to perform useful work. Brake power which is measured with an engine dynamometer, is the actual power developed by the engine minus losses due to internal friction.

$P_b = p_i$ - friction losses

Where, P_b = Brake Power and P_i = Indicated power

This is normally given in kilowatts or formerly in horse power (hp). The power is rate at which the engine is doing useful work. It varies with the engine speed and throttle angle. The power may be measured at the drive wheels or at the engine output shaft depending upon which is desired.

1.2.4.2 BSFC

BSFC is the measurement of an engine's fuel economy. It is a ratio of fuel flow to the brake power output of the engine.

BSFC = brake specific fuel consumption.

$$BSFC = \frac{r_f}{P_b} = \frac{Fuel\ Flow\ Rate}{Brake\ Power\ Output} = \frac{Kg/hr}{HP}$$

By improving the BSFC of the engine (reducing), the fuel economy of the vehicle in which it is installed is also improved.

1.2.4.3 Torque

Engine torque is a twisting force of an engine crankshaft by the cylinder pressure pushing on the piston during the power stroke. Torque is produced whenever a force is applied to a lever. The length of the lever in the engine is determined by the 'throw' of the crankshaft. The torque is expressed as a product of this force and the length of the lever. The unit of torque are N.m. (Newton meters) in the metric system or ft. lb. (foot founds) in the US system. One ft. lb. is the torque produced by one pound acting on a lever arm one foot long). The torque of a typical engine varies with RPM.

1.2.4.4 Volumetric Efficiency

The variation in torque with rpm is strongly influenced by the "Volumetric Efficiency" or "Breathing Efficiency". Volumetric efficiency actually describes how well the engine functions as an air pump, drawing air and fuel into the various cylinders. It depends upon various engine design parameters such as piston size, piston stroke, number of cylinders etc.

1.2.4.5 Thermal Efficiency

Thermal efficiency expresses the mechanical energy that is delivered to the vehicle relative to the energy content of the fuel. In the typical SI engine (spark ignited engine), 35% of the energy that is available in the fuel is lost as heat to the coolant and lubricating oil, 40% is lost as heat and un-burnt fuels in exhaust gases, 5% is lost in engine and drive train friction.

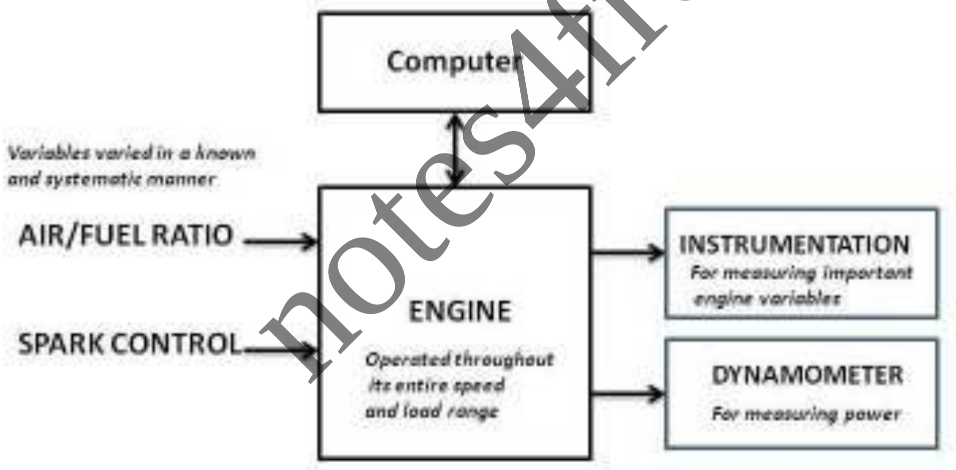
100 - (35+40+5) = 20% is available to drive the vehicle and accessories. These percentages vary with operating conditions.

1.2.4.7 Calibration

The definition of engine calibration is the setting of the air fuel ratio and ignition timing of the engine. With the new electronic control systems, calibration control is determined by the electronic engine Control System.

1.2.5 Engine Mapping

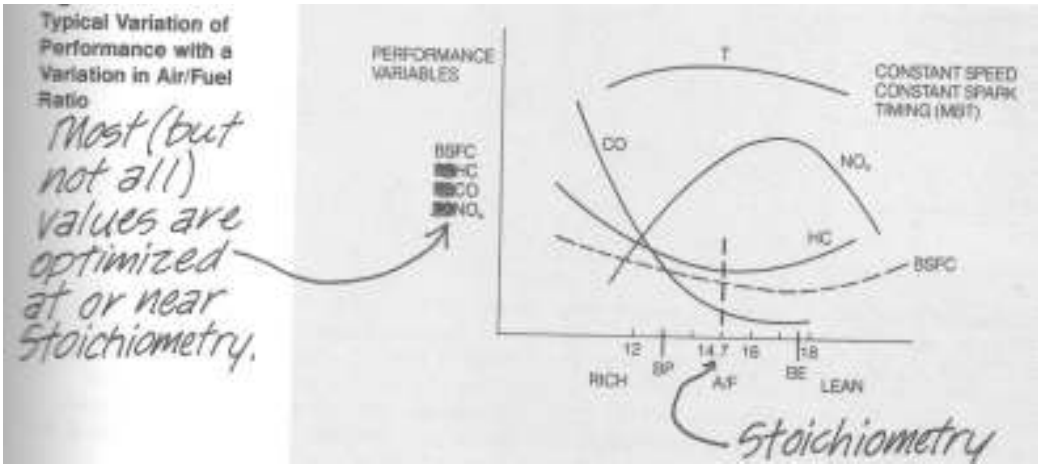
Engine Mapping is a process by which measurements are made of important engine variables while the engine is operated throughout its speed and load ranges.



From the above mapping, a mathematical model is developed, that explains the influence of every measurable variable and parameter on engine performance. The Control System designer must select a Control Configuration, Control Variables and Control Strategy which will satisfy all performance requirements (including stability) as computed from this model and which are within the other design limits such as cost, quality and reliability.

1.2.5.1 Effect of Air/Fuel Ratio on Performance

The graph shows the variation of performance variables with respect to Air to Fuel Ratio by keeping the Spark timing as constant. The torque is taken at constant speed.


Typical Variation of Performance with a Variation in Air/Fuel Ratio

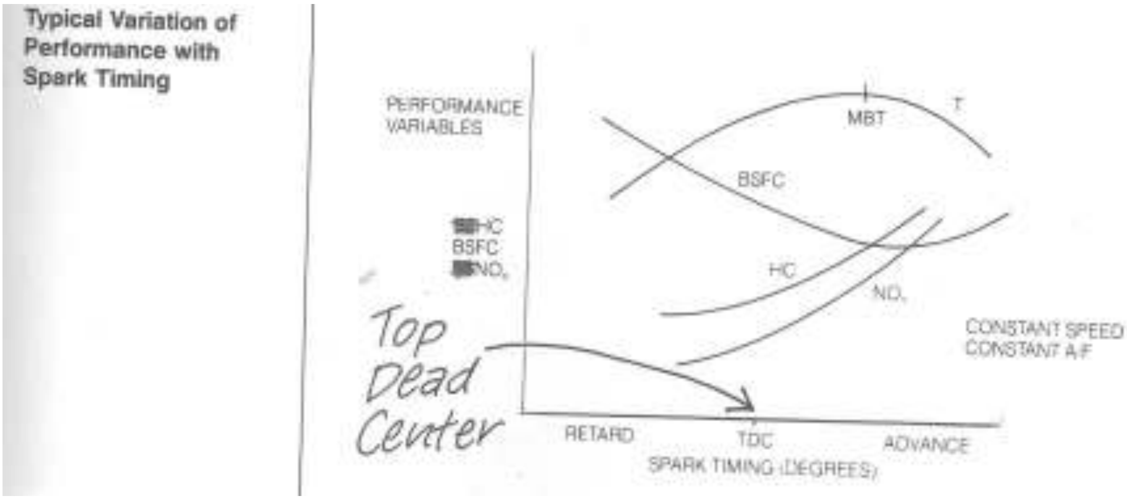
T = Torque, BSFC = Brake Specific Fuel Consumption, HC = Hydro Carbons, CO = Carbon Monoxide, NO_X = Oxides of Nitrogen.

Note that Torque (T) reaches a maximum in the air/fuel ratio of 12 to 16. The exact Air/Fuel ratio for which the torque is maximum, depends upon the engine configuration, engine speed and ignition timing.

The relative maximum which occurs in NO_X emissions is near the air/fuel ratio where torque is greatest. This characteristic of the engine causes some rather challenging problems in attempting to control exhaust emission while preserving vehicle performance.

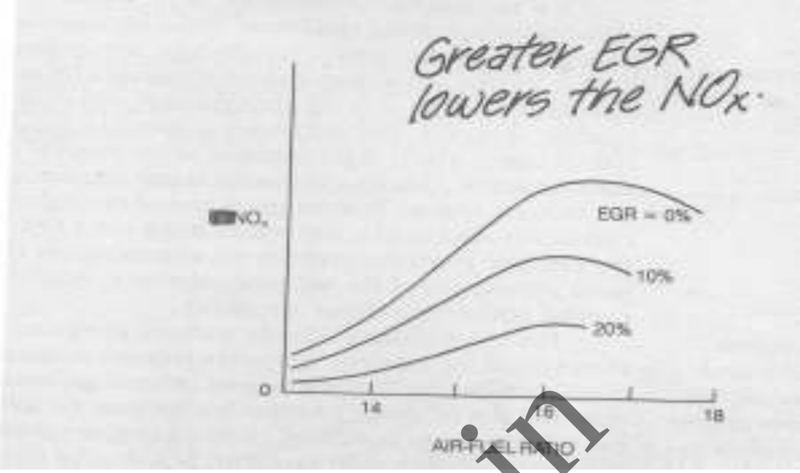
1.2.5.2 Effect of Spark Timing on Performance

Note that both NO_X and HC generally increase with increased advance in spark timing. BSFC and torque are also strongly influenced by timing. The graph below shows that maximum torque occurs at a particular advanced timing referred to as Minimum Advance for Best Timing (MBT).

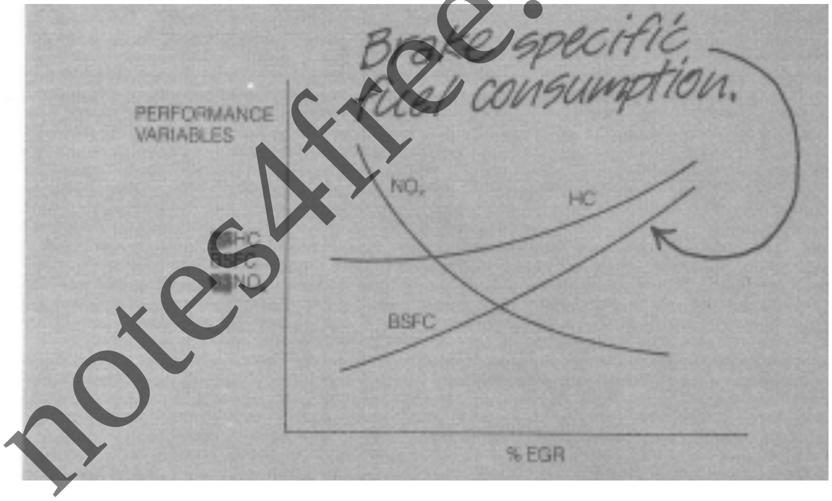

Typical Variation of Performance with Spark Timing

1.2.5.3 Effect of Exhaust Gas Recirculation on Performance

NO_x Emission as a Function of EGR at Various Air/Fuel Ratios



Typical Variation of Engine Performance with EGR



Increasing EGR tends to lower the peak combustion temperature, if all other variables remain fixed. Increasing EGR tends to lower this temperature; therefore, it tends to lower NO_x generation. But BSFC & HC will increase.

1.2.6 Control Strategy

It is the task of the electronic control system to set the calibration for each engine operating condition. There are many sets of possible control strategies to set the control variables for any given engine and each tends to have its own advantages and disadvantages. Moreover, each automobile manufacturer has a specific configuration that differs from competitive systems. However, the discussion is about a typical electronic control system that is representative of most of them. The typical system is the one that has catalytic converter in the exhaust system.

Essentially the catalytic converter reduces the concentration of undesirable exhaust gases coming out of tail pipe relative to engine out gases (the gases coming out of the exhaust manifold).

The EPA (Environmental Protection Agency) regulates only the exhaust gases that leave the tail pipe. Hence, if the catalytic converter reduces exhaust gas emission concentration by 90%, the engine exhaust gas emissions at the exhaust gas manifold can be about ten times higher than the EPA requirements. This has the significant benefit of allowing engine calibration to be set for better performance than would be permitted if exhaust emissions in the engine exhaust manifold had to satisfy EPA regulations. This is the type of system that is chosen for the typical electronic engine control system.

1.2.6.1 Catalytic Converter

Several type of catalytic converters are available for use of an automobile. The desired functions of a catalytic converter include:

1. Oxidation of hydrocarbon emissions to carbon dioxide (CO_2) and water (H_2O).
2. Oxidation of CO to CO_2.
3. Reduction of NO_X to Nitrogen (N_2) and Oxygen (O_2)

1.2.6.2 Oxidizing Catalytic Converter

The purpose of oxidizing catalyst (OC) is to increase the rate of chemical reaction, which initially takes place in the cylinder as the compressed air/fuel mixture burns, towards the exhaust gas that has a complete oxidation of HC & CO to H_2O & CO_2.

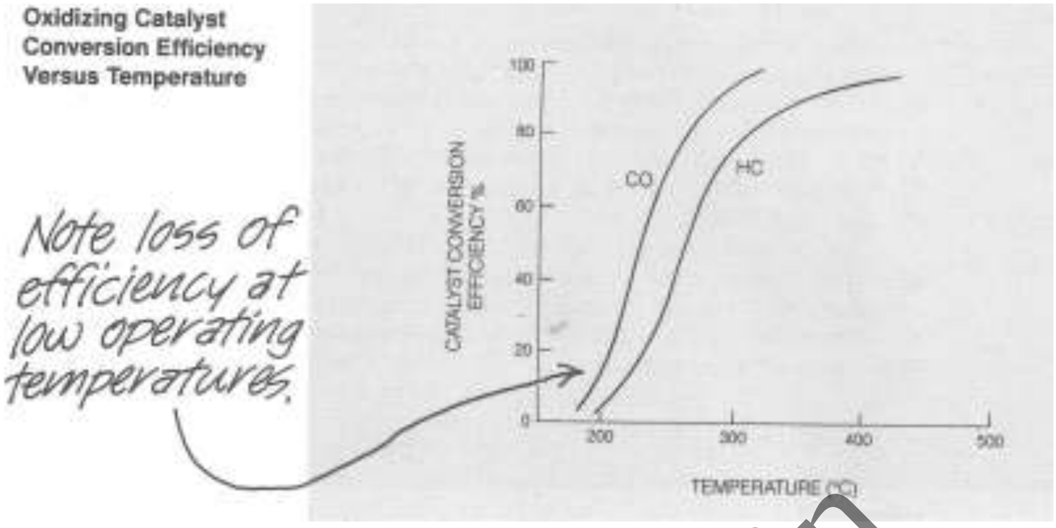
The extra oxygen required for this oxidation is often supplied by adding air to the exhaust system from an engine driven air pump. This air, called "Secondary air", is normally introduced into the exhaust manifold. The most significant measure of the performing the OC is its conversion efficiency, η_c.

$$\eta_c = \frac{Mo}{Mi}$$

Where, M_i = Mass air flow rate of gas into converter

M_o = Mass flow rate of gas leaving converter which has been oxidized

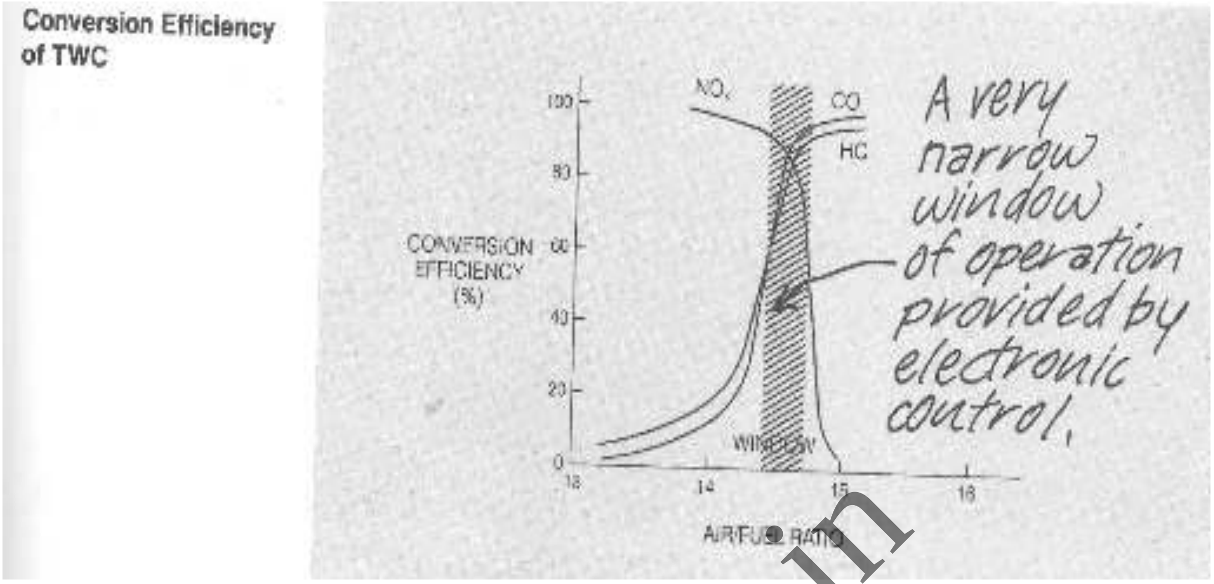
The conversion efficiency of the OC depends upon its temperature. Above about 300°C, the η_c approaches 98 to 99% for CO & more than 95% for HC.



1.2.6.3 The Three-Way Catalyst

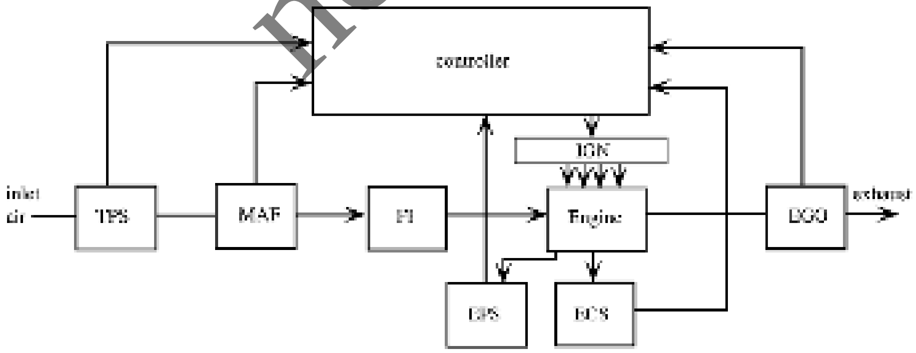
The Three Way Catalyst (TWC) is extremely important for modern emission control system. It uses a specific catalyst formulation containing Platinum, Palladium & Rhodium to reduce NO_X & oxidize HC & CO all at the same time. It is called three way because it simultaneously reduces the concentration of all three major undesirable exhaust gasses by about 90%.The conversion efficiency of the TWC for the three exhaust gasses depends mostly upon air/fuel ratio. Unfortunately, the air/fuel ratio for which NO_X conversion efficiency is highest corresponds to very low conversion efficiency for HC and CO and vice versa. However as shown in graph below, there is a very narrow range of air/fuel ratio (called the window) in which as acceptable compromise exists between NOx and HC/CO conversion efficiencies. The conversion efficiencies with in this window are sufficiently high to meet very stringent EPA requirements established so far.

Note that this window is only about 0.1 air/fuel ratio wide (+ or – 0.05 air/fuel ratio) and is centered at stoichiometry. The control of average air/fuel ratio to the tolerance of the TWC window is beyond the capabilities of a conventional carburetor. The operation of the three way catalytic converter is adversely affected by lead. Thus, in automobiles using any catalyst, it is necessary to use lead-free fuel.



1.2.7 Electronic Fuel Control System

For an understanding of the configuration of an electronic fuel control system, refer to the block diagram of Figure. The primary function of this fuel control system is to accurately determine the mass air flow rate into the engine. Then the control system precisely regulates fuel delivery such that the ratio of the mass of air to the mass of fuel in each cylinder is as close as possible to stoichiometry (i.e., 14.7).



The components of this block diagram are as follows:

1. Throttle position sensor (TPS)
2. Mass air flow sensor (MAF)
3. Fuel injectors (FI)
4. Ignition systems (IGN)

5. Exhaust gas oxygen sensor (EGO)
6. Engine coolant sensor (ECS)
7. Engine position sensor (EPS)

The EPS has the capability of measuring crankshaft angular speed (RPM) as well as crankshaft angular position when it is used in conjunction with a stable and precise electronic clock (in the controller).

The signals from the various sensors enable the controller to determine the correct fuel flow in relation to the air flow to obtain the stoichiometric mixture. From this calculation the correct fuel delivery is regulated via fuel injectors. In addition, optimum ignition timing is determined and appropriate timing pulses are sent to the ignition control module (IGN). There is an important property of the catalytic converter that allows for momentary (very short term) fluctuations of the air/fuel ratio outside the narrow window. As the exhaust gases flow through the catalytic converter they are actually in it for a short (but nonzero) amount of time, during which the conversions described above take place. Because of this time interval the conversion efficiency is unaffected by rapid fluctuations above and below stoichiometry (and outside the window) as long as the average air/fuel ratio over time remains at stoichiometry and provided the fluctuations are rapid enough. A practical fuel control system maintains the mixture at stoichiometry but has minor (relatively rapid) fluctuations about the average, as explained below. The electronic fuel control system operates in two modes: open loop and closed loop.. In the open-loop mode (also called feedforward), the mass air flow rate into the engine is measured. Then the fuel control system determines the quantity of fuel to be delivered to meet the required air/fuel ratio.

In the closed-loop control mode (also called feedback), a measurement of the controlled variable is provided to the controller (i.e., it is fed back) such that an error signal between the actual and desired values of the controlled variable is obtained. Then the controller generates an actuating signal that tends to reduce the error to zero.

In the case of fuel control, the desired variables to be measured are HC, CO, and NOx concentrations. Unfortunately there is no cost-effective, practical sensor for such measurements that can be built into the car's exhaust system. On the other hand, there is a relatively inexpensive sensor that gives an indirect measurement of HC, CO, and NOx concentrations. This sensor generates an output that depends on the concentration of residual oxygen in the exhaust after combustion. This sensor is called an *exhaust gas oxygen* (EGO) *sensor*. It will be shown that the EGO sensor output switches abruptly between two voltage levels depending on whether the input air/fuel ratio is richer than or leaner than stoichiometry. Such a sensor is appropriate for use in a limit-cycle type of closed-loop control. Although the EGO sensor is a switching-type sensor, it provides sufficient information to the controller to maintain the average air/fuel ratio over time at stoichiometry, thereby meeting the mixture requirements at the three-way catalytic converter.

In a typical modern electronic fuel control system, the fuel delivery is partly open loop and partly closed loop. The open-loop portion of the fuel flow is determined by measurement of air flow. This portion sets the air/fuel ratio at approximately stoichiometry. A closed-loop portion is added to the fuel delivery to ensure that time-average air/fuel ratio is at stoichiometry (within the tolerances of the window).

There are exceptions to the stoichiometric mixture setting during certain engine operating conditions, including engine start, heavy acceleration, and deceleration. These conditions represent a very small fraction of the overall engine operating times which explains the operation of a modern, practical digital electronic engine control system.

1.2.7.1 Engine Control Sequence

Engine Start -> The mixture is set rich by an amount depending on the Engine Temperature (measured via the Engine Coolant Sensor) -> Open Loop mode till the temperature raises to certain temperature -> Closed Loop Mode

1.2.7.2 Open Loop Control

The correct fuel mass that is injected with the intake air is computed by the electronic controller. Which is given by, $\mathrm{M_f} = \frac{\mathrm{M_f}}{\mathrm{M_a}} \times \mathrm{Ma} = \mathrm{r_{fa}}\ \mathrm{Ma}$

Where,

$\mathrm{r_{fa}}$ = defined ratio of fuel to air = $\frac{1}{14.7}$ = 0.068 and

Ma = Mass of air drawn into each cylinder during intake.

$$\therefore\ M_f = 0.068\, M_a$$

1.2.7.3 Closed Loop Control

The step by step events after the engine starts, begin with the system operating in the open loop mode. After a set of operating conditions are satisfied, the system is converted to closed loop configuration. The figure below shows a block diagram of closed loop fuel control system. It operates as follows. For any given set of operating conditions, the fuel metering actuator provides fuel flow to produce an air/fuel ratio set by the controller output. This mixture is burned in the cylinder and the combustion products leave the engine through the exhaust pipe. The exhaust gas oxygen (EGO) sensor generates a signal for the controller input that depends upon the air/fuel ratio. This signal tells the controller to adjust the fuel flow rate for the required air/fuel ratio, thus completing the loop.

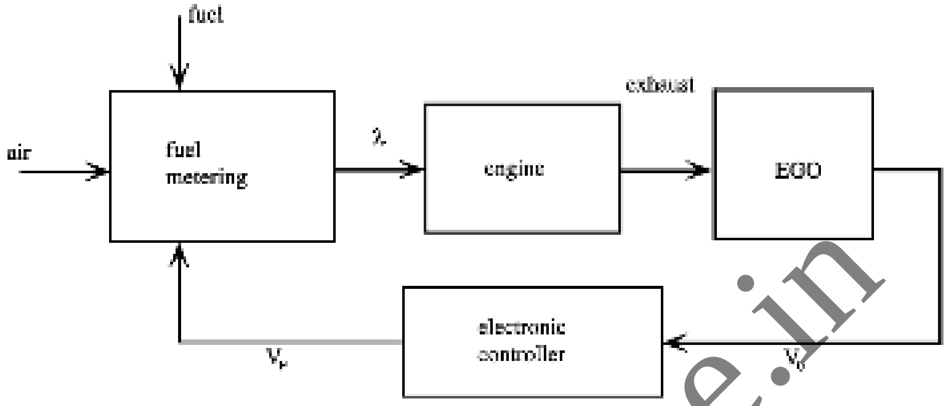


Figure: Simplified typical Closed loop fuel control system

1.2.7.4 Closed Loop Operation

The simplified waveforms in a closed loop fuel control system are as shown below. Take note that the straight line segments are used in order to simplifying explanation. In practice they may be curved and it may not be linear with time.

Reduced to its essential features, the engine control system operates as a limit-cycle controller in which the air/fuel ratio cycles up and down about the set point of stoichiometry, as shown in Figure. The air/fuel ratio is either increasing or decreasing; it is never constant. The increase or decrease is determined by the EGO sensor output voltage. Whenever the EGO output voltage level indicates a lean mixture, the controller causes the air/fuel ratio to decrease, that is, to change in the direction of a rich mixture. On the other hand, whenever the EGO sensor output voltage indicates a rich mixture, the controller changes the air/fuel ratio in the direction of a lean mixture.

Consider V_F, the output of the electronic controller. The fuel metering actuator is presumed to control fuel in such a way that the equivalent ratio λ (lambda) increases in projection to V_F, as shown in figure (b). If this were expressed as a transfer function mathematically, it would appear as,

$$\lambda - 1 = k_f V_f$$

Where, $\mathbf{k_f}$ is a constant for the fuel metering actuator.

When $V_F = 0$, $\lambda - 1 = 0$ which is $\lambda = 1$ and the input mixture is at stationary. As a V_f varies, λ varies.

When V_F is positive, $\lambda > 1$, which amounts to a LEAN mixture and

When V_F is negative, $\lambda < 1$, which amounts to a RICH mixture

1.2.8 Analysis of Intake Manifold Pressure

The air and fuel mixture enters the engine through the *intake manifold*, a series of channels and passages that directs the air and fuel mixture to the cylinders. One very important engine variable associated with the intake manifold is the manifold absolute pressure (MAP). The sensor that measures this pressure is the manifold absolute pressure sensor—the MAP sensor. This sensor develops a voltage that is approximately proportional to the average value of intake manifold pressure.

Figure is a very simplified sketch of an intake manifold. In this simplified sketch, the engine is viewed as an air pump drawing air into the intake manifold. Whenever the engine is not running, no air is being pumped and the intake MAP is at atmospheric pressure. This is the highest intake MAP for an unsupercharged engine. (A supercharged engine has an external air pump called a supercharger.) When the engine is running, the air flow is impeded by the partially closed throttle plate. This reduces the pressure in the intake manifold so it is lower than atmospheric pressure; therefore, a partial vacuum exists in the intake.

If the engine were a perfect air pump and if the throttle plate were tightly closed, a perfect vacuum could be created in the intake manifold. A perfect vacuum corresponds to zero absolute pressure. However, the engine is not a perfect pump and some air always leaks past the throttle plate. (In fact, some air must get past a closed throttle or the engine cannot idle.) Therefore, the intake MAP fluctuates during the stroke of each cylinder and as pumping is switched from one cylinder to the next. Each cylinder contributes to the pumping action every second crankshaft revolution. For an *N*-cylinder engine, the frequency fp, in cycles per second, of the manifold pressure fluctuation for an engine running at a certain RPM (Revolutions per minute) is given by

$$\boldsymbol{f_p = N \times \frac{RPM}{60\times2} = \frac{N\times RPM}{120}}$$

where, 60 = seconds per minute and 2 = No. of revolutions of Crankshaft in one cycle.

For a control system application, only average manifold pressure is required. The torque produced by an engine at a constant RPM is approximately proportional to the average value of MAP. The rapid fluctuations in instantaneous MAP are not of interest to the engine controller. Therefore, the manifold pressure measurement method should filter out the pressure fluctuations at frequency *f*p and measure only the average pressure. One way to achieve this filtering is to connect the MAP sensor to the intake manifold through a very small diameter tube. The rapid fluctuations in pressure do not pass through this tube, but the average pressure does. The MAP sensor output voltage then corresponds only to the average manifold pressure.

Measuring Air Mass

If the controlling has the correct value for air mass, the correct mass of fuel to be injected for stoichiometry can be determined, i.e., the ratio of air mass to fuel mass should be 14.7.

The average mass airflow rate can be obtained either directly using a mass air flow sensor or indirectly by calculation. The mass air flow sensor generates an output signal which is proportional to the average mass of air drawn into the engine over the few engine cycles.

1.2.9 ELECTRONIC IGNITION

The engine ignition system exists solely to provide an electric spark to ignite the mixture in the cylinder. As explained earlier in this chapter, the engine performance is strongly influenced by the spark timing relative to the engine position during the compression stroke. The spark advance (relative to TDC) is determined in the electronic engine control based on a number of measurements made by sensors. The optimum spark advance varies with intake manifold pressure, RPM, and temperature.
However, in order to generate a spark at the correct spark advance the electronic engine control must have a measurement of the engine position. Engine position is determined by a sensor coupled to the camshaft or the crankshaft, or a combination of each, depending on the configuration for the electronic ignition.

Electronic ignition can be implemented as part of an integrated system or as a stand-alone ignition system.. Based on measurements from the sensors for engine position, mass air flow or manifold pressure, and RPM, the electronic controller computes the correct spark advance for each cylinder. At the appropriate time the controller sends a trigger signal to the driver circuits, thereby initiating spark. In many modern electronic spark systems, spark plugs are fired in pairs through a common coil, or high-voltage transformer. Before the spark occurs, the driver circuit sends a relatively large current through the primary (P) of the coil. When the spark is to occur, a trigger pulse is sent to the driver circuit for the coil associated with the appropriate spark plug. This trigger causes the driver circuit to interrupt the current in the primary. A very high voltage is induced at this time in the secondary (S) of the coil. This high voltage is applied to the spark plugs, causing them to fire. Typically, one of the two cylinders will be in this compression stroke. Combustion will occur in this cylinder, resulting in power delivery during its power stroke. The other cylinder will be in its exhaust stroke and the spark will have no effect. Most engines have an even number of cylinders and there will be a separate driver circuit and coil for each pair of cylinders.

An ignition system such as this is often called a *distributor less ignition system* (DIS) because the multiple coil packs and drivers are a modern replacement for the (now essentially obsolete) distributor.

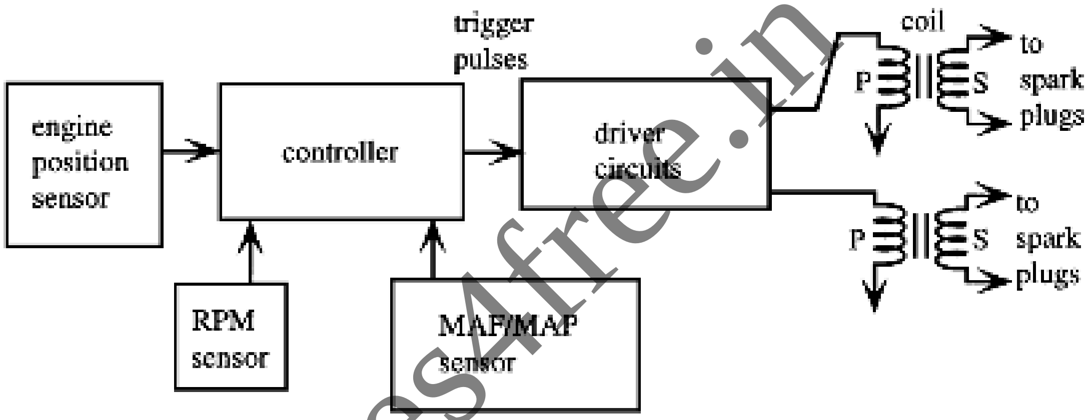


Figure: Electronic Distributor less Ignition System

OUTCOMES

At the end of the module, the students

1. understand the basics of automobile dynamics
2. learn the Basics of Electronic Engine Control

MODEL QUESTIONS

Module 1- Chapter 1 (Automotive Fundamentals Review)

1. With neat diagrams explain the four strokes of a typical SI Engine.
2. Briefly explain the working of a spark plug with neat diagrams of configuration and primary current waveform.
3. What are the important parts of an automobile? Show the position of each of them in a diagram.
4. Explain the working of Shock Absorber assembly and Disk Brake operation with relevant diagrams.
5. (a) What are the parts of a drive train?
   (b) What is transmission? Differentiate two types of transmissions.
   (c) What are the three purposes of differential?
6. Write a short note on Steering mechanism with relevant diagram and graph.

Module 1- Chapter 2 (The Basics of Electronic Engine Control)

1. What are the two government requirements for the motivation of Electronic Engine Control?
2. Write a diagram depicting Engine functions and control.
3. What are the six inputs to controller and four outputs from controller? Indicate these in diagram(s).
4. Define the following Engine performance terms: (a) Power, (b) BSFC, (c) Torque, (d) Volumetric Efficiency, (e) Thermal Efficiency, (f) Calibration
5. What do you mean by Parameters and Variables? Give five examples for each of them.
6. Discuss the effect of Air/Fuel Ratio, Spark timing and Exhaust Gas Recirculation on performance with the help of relevant graphs.
7. What are the three desired functions of Catalytic Converter? Discuss the Three Way Catalyst.
8. Discuss the Speed Density method of measuring air mass and write steps to calculate mass flow rate of fuel.
9. Write notes on Engine Mapping and Electronic Ignition.

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MODULE 2

2.0.0 Automotive Control System applications of Sensors and Actuators

2.0.1 Typical Electronic Engine Control System

2.0.2 Variables to be measured

Module 2: Chapter 1: AUTOMOTIVE SENSORS

- 2.1.1 Airflow rate sensor
- 2.1.2 Strain Gauge MAP sensor
- 2.1.3 Engine Crankshaft angular position sensor
- 2.1.4 Magnetic Reluctance Position Sensor
- 2.1.5 Hall effect Position Sensor
- 2.1.6 Shielded Field Sensor
- 2.1.7 Optical Crankshaft Position Sensor
- 2.1.8 Throttle Angle Sensor (TAS)
- 2.1.9 Engine Coolant Temperature (ECT) Sensor
- 2.1.10 Exhaust Gas Oxygen (O2/EGO) Lambda Sensors
- 2.1.11 Piezoelectric Knock Sensor

Module 2: Chapter 2: AUTOMOTIVE ACTUATORS

- 2.2.1 Solenoid
- 2.2.2 Fuel Injector
- 2.2.3 EGR Actuator
- 2.2.4 Ignition System

OBJECTIVES

1. Learn different Sensors and Actuators used in Automotives

Module 2: Sensors and Actuators

2.0.0 Automotive Control System Applications Of Sensors & Actuators

In control system applications, sensors and actuators are in many cases the critical components for determining system performance. This is especially true for automotive control system applications. The availability of appropriate sensors and actuators dictates the design of the control system and the type of function it can perform.

The sensors and actuators that are available to a control system designer are not always what the designer wants, because the ideal device may not be commercially available at acceptable costs. For this reason, often special signal processors or interface circuits are designed to adapt to an available sensor or actuator, or the control system is designed in a specific way to fit available sensors or actuators. However, because of the large potential production run for automotive control systems, it is often worthwhile to develop a sensor for a particular application, even though it may take a long and expensive research project to do so.

Although there are many subsystems on automobiles that operate with sensors and actuators, we begin our discussion with a survey of the devices for power train control. To motivate the discussion of engine control sensors and actuators it is helpful to review the variables measured (sensors) and the controlled variables (actuators). Figure 1 is a representative block diagram of a typical electronic engine control system illustrating most of the relevant sensors used for engine control. The position of the throttle plate, sensed by the throttle position sensor (TPS), directly regulates the air flow into the engine, thereby controlling output power. A set of fuel injectors (one for each cylinder) delivers the correct amount of fuel to a corresponding cylinder during the intake stroke under control of the electronic engine controller. A fuel injector is, as will presently be shown, one of the important actuators used in automotive electronic application. The ignition control system fires each spark plug at the appropriate time under control of the electronic engine controller.

The exhaust gas recirculation (EGR) is controlled by yet another output from the engine controller. All critical engine control functions are based on measurements made by various sensors connected to the engine in an appropriate way. Computations made within the engine controller based on these inputs yield output signals to the actuators. We consider inputs (sensors) to the control system first, then we will discuss the outputs (actuators).

2.0.1 Typical Electronic Engine Control System

In any control system, sensors provide measurements of important plant variables in a format suitable for the digital microcontroller. Similarly, 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.

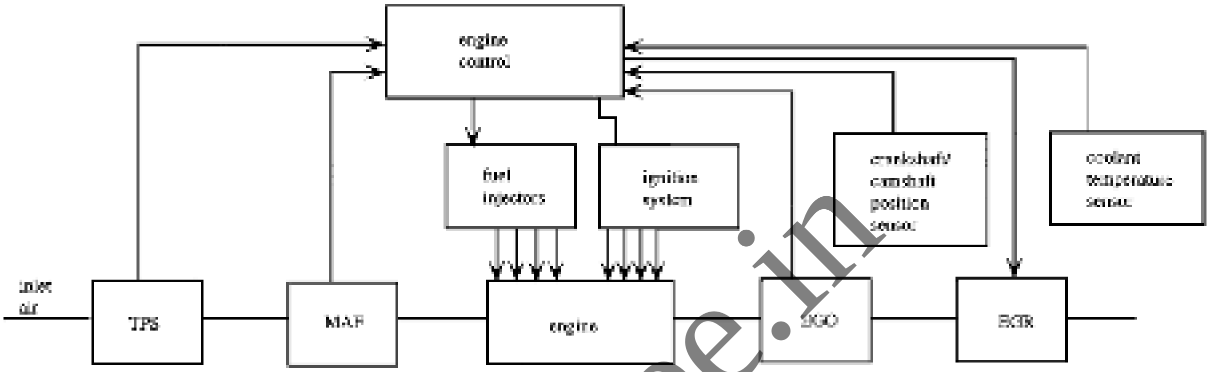


Figure 1 Typical Electronic Engine Control System

2.0.2 Variables to be measured

The set of variables sensed for any given engine is specific to the associated engine control configuration. Space limitations for this book prohibit a complete survey of all engine control systems and relevant sensor and actuator selections for all car models. Nevertheless, it is possible to review a superset of possible sensors, which is done in this chapter, and to present representative examples of practical digital control configurations, which is done in the next chapter.

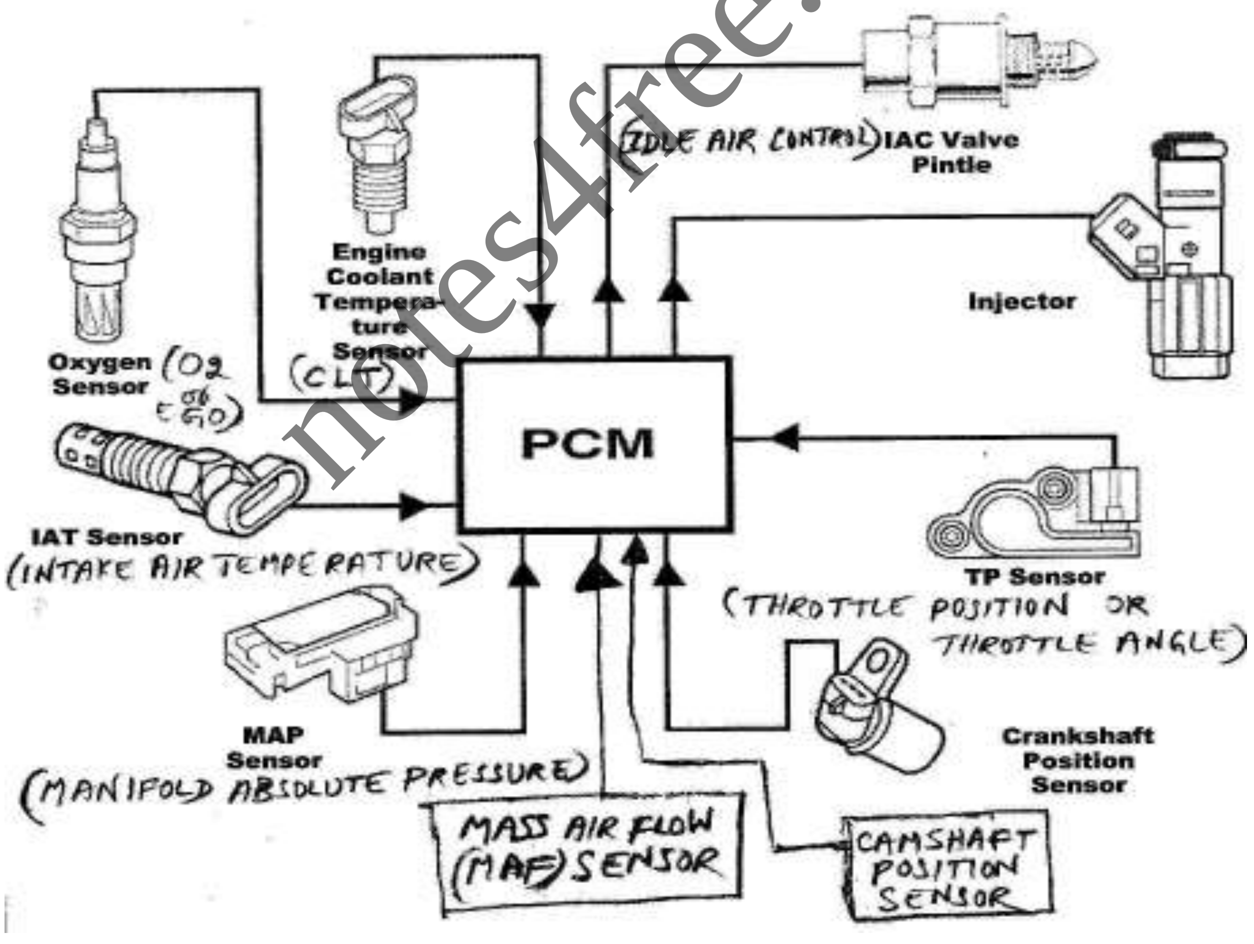
The superset of variables sensed in engine control includes the following:

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

In addition to measurements of the above variables, engine control is also based on the status of the vehicle as monitored by a set of switches. These switches include the following:

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

Common Inputs and Outputs

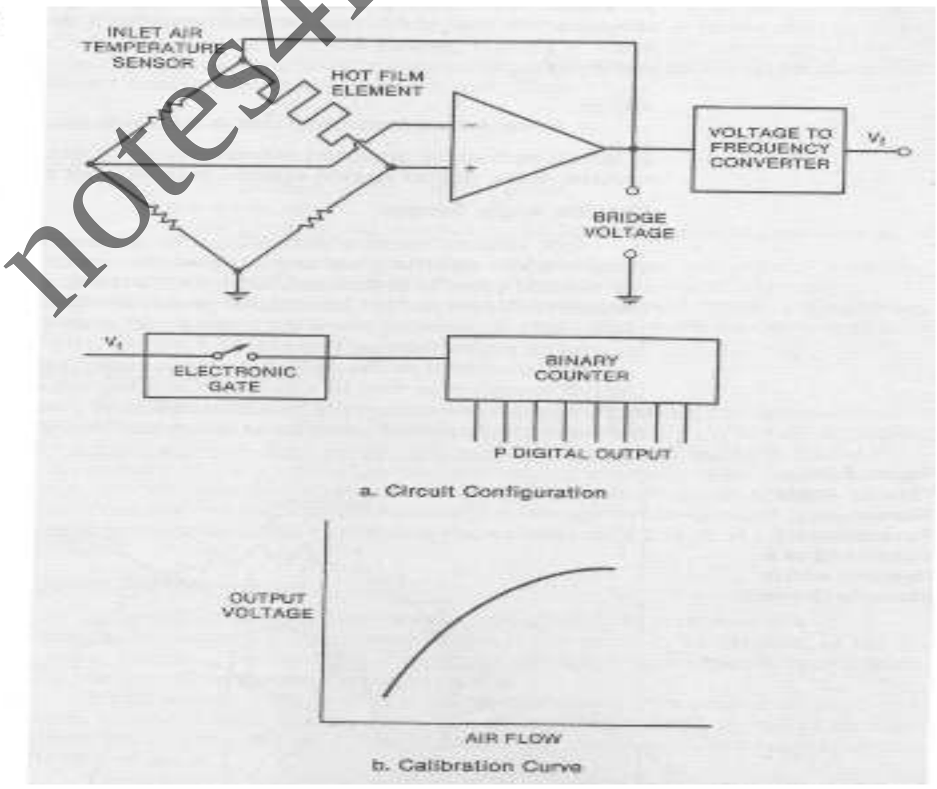


Module 2: Chapter 1: Automotive Sensors

2.1.1 Air Flow Rate Sensor

This is known as MAS (Mass Airflow Sensor) or MAF (Mass Air Flow sensor). The hot film element is electrically heated to constant temperature above that of inlet air. The latter air temperature is sensed using a solid state temperature sensor. The hot film element is incorporated in a wheat stone bridge circuit. The power supply for the bridge comes from an amplifier. As the air flows across the hot film, heat is carried away from the film by the moving air. The amount of heat carried away varies in proportion to the mass flow rate of the air. The heat lost by the film to the air tends to cause the resistance of the film to vary, which unbalance the bridge circuit, thereby producing an input voltage to the amplifier. The output o the amplifier is connected to the bridge circuit and provides the power to the circuit. The amplified voltage changes the resistance in such a way as to maintain a fixed hot film temperature relative to the inlet temperature. The amplifier output voltage varies with air mass flow rate and serves as a measure of R_{am} (Rate of air mass flow).

Mass Air Flow Sensor



a. Circuit Configuration

b. Calibration Curve

The conversion of voltage to frequency is advantageous in digital engine control application because the frequency is readily converted to digital format without requiring an A/D converter. The sensor output is connected to the electronic switch, the output of which is connected to a binary counter. The electronic switch is closed for an interval τ during which time the frequency is counted. At the end of the time interval, the binary counter contains a digital value P.

$$P = f\,\tau$$

Where f = sensor frequency that is known function of mass flow rate.

Manifold Absolute Pressure Sensor

MAP sensor concepts

Several MAP sensor configurations have been used in automotive applications. But none of the MAP sensors in use measure manifold pressure directly, but instead they measure the displacement of a diaphragm, which is deflected by manifold pressure.

These are frequency generating devices that are sensitive to pressure. MAP sensors have a hose that connects to an intake manifold vacuum port. Engine vacuum varies with load (high vacuum at idle/low load and low vacuum at acceleration/high load). The PCM/ECM uses this information in determining requirements for fuel metering.

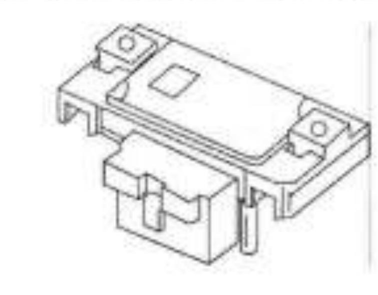
Manifold Pressure fluctuation (f_p) in cycles/second during stroke of each cylinder is given by,

$$f_p = \frac{N \times RPM}{120}$$

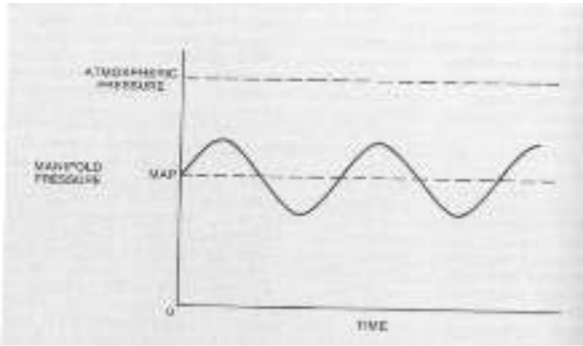
Where, N = No. of cylinders in engine and RPM = Speed of engine in Revolutions per minute.

This fluctuation should be filtered out and measure only average pressure. Filtering of fluctuation pressure is achieved by connecting the MAP sensor to the intake manifold through a very narrow tube (having small diameter). The rapid fluctuations in pressure do not pass through this tube, but the average pressure does. The MAP sensor output voltage then corresponds only to the average manifold pressure.

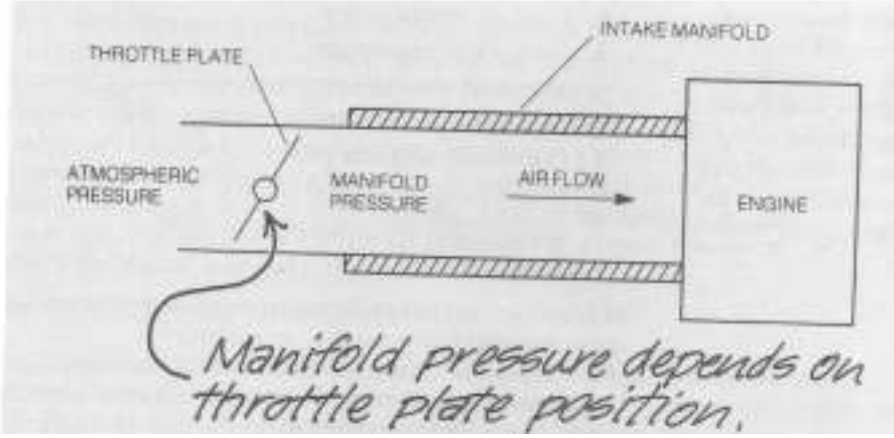
Manifold Absolute Pressure Sensor



Intake Manifold Pressure Fluctuations



Simplified Intake System

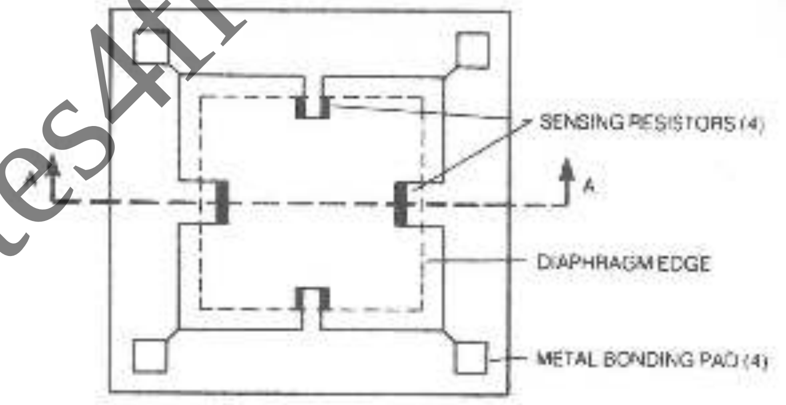


Apart from frequency generating sensors there are also other MAP sensors such as

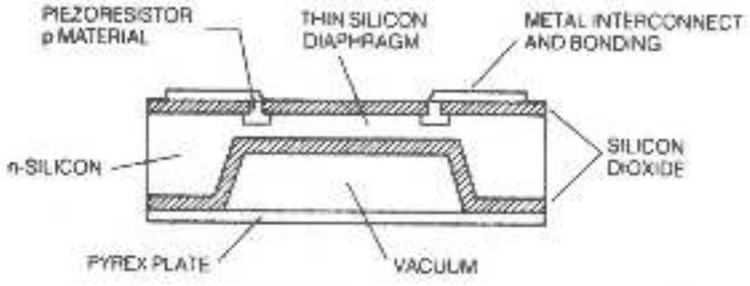
- Strain gauge MAP sensors
- Capacitor capsule MAP sensor

2.1.2 Strain Gauge MAP sensor

Typical Silicon-Diaphragm Strain Gauge MAP Sensor



a. Top View



b. Section A-A

When there is no strain on the diaphragm, $R_1 = R_2 = R_3 = R_4$, $V_A - V_B = 0$.

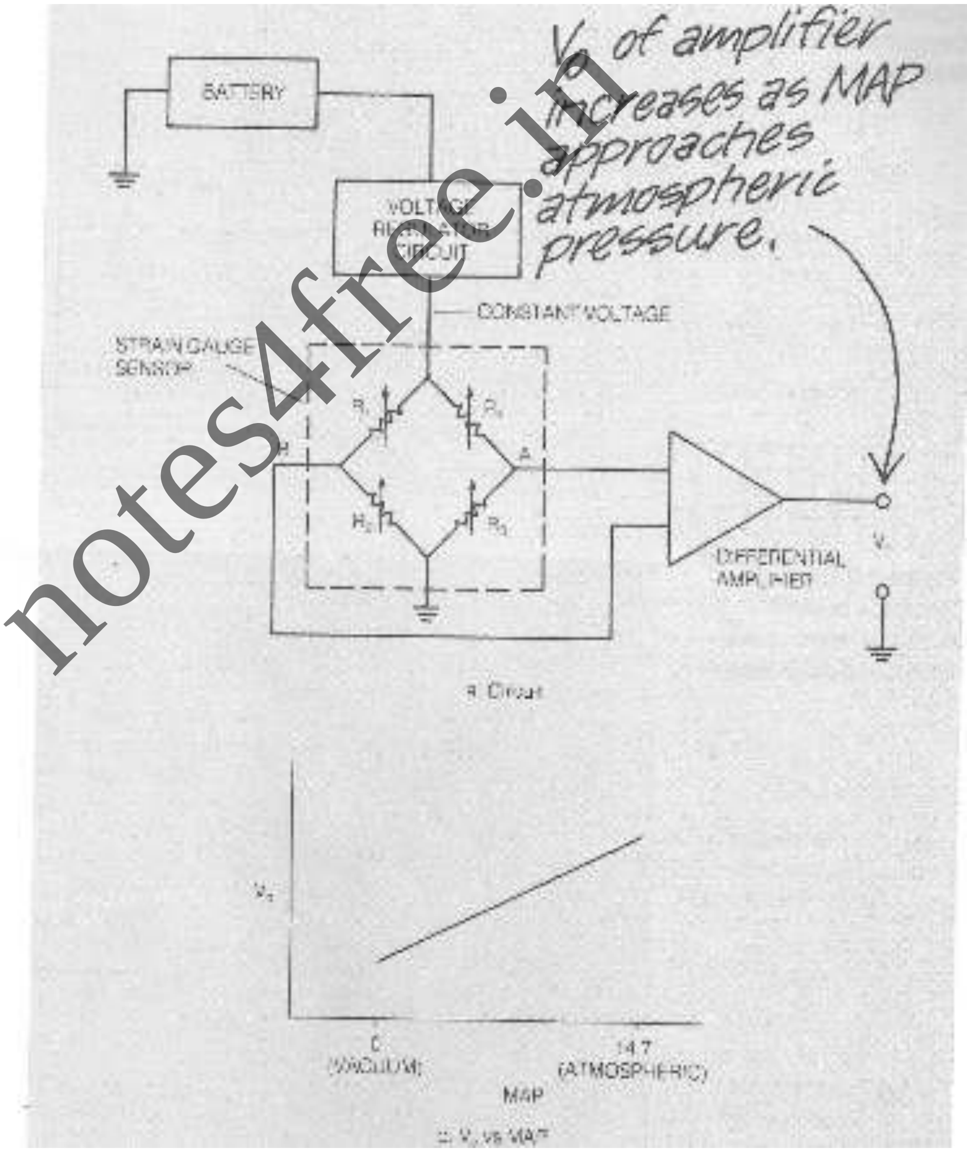
When pressure increases,

R_1 and R_3 increase by an amount proportional to the pressure.

R_2 and R_4 decrease by an identical amount.

This unbalances the bridge and net difference voltage will be present between A and B.

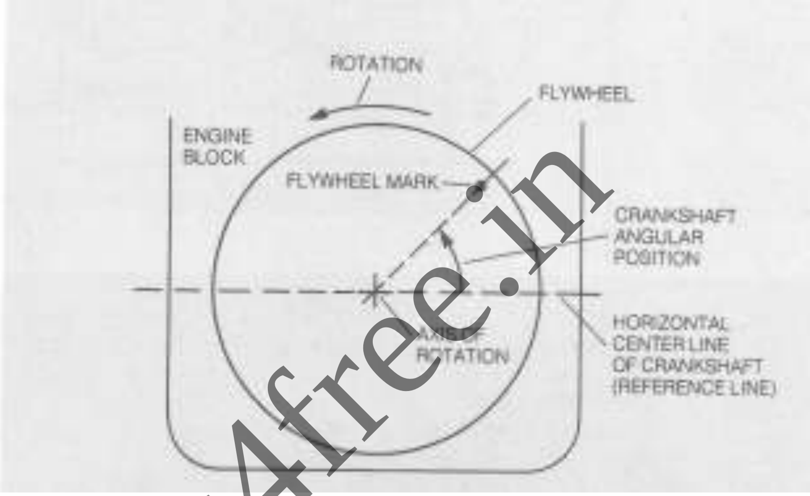
Circuit Using a Strain Gauge MAP Sensor



2.1.3 Engine Crankshaft angular position sensor (CKP)

Refer to the figure. As the crank shaft rotates, the angle increases from 0^{o} to 360^{o} in one revolution. However one full engine cycle from intake to exhaust requires two complete revolutions of the crank shaft that is one complete engine cycle corresponds to the crank shaft angular rotation going from 0^{o} to 720^{o}, During each cycle, it is important to make two crankshaft portion with reference to TDC for each cylinder .This information is used by the ECM to set the ignition timing and in some cases, to adjust the fuel control parameters.

Engine Crankshaft Angular Position Measurement



Both crankshaft or cam shaft sensing locations have been used in one electronic control system or another. The crankshaft location is superior for accuracy because of positional and gear backlash errors in the camshaft drive train. It is desirable to measure engine angular position with a non-contacting sensor to avoid mechanical wear and tear and corresponding changes in accuracy of measurement.

The two most common methods for contact coupling are (i) **Magnetic field (ii) Optics**

Under Magnetic field we have three sensors such as Magnetic reluctance position sensor, Hall effect position sensor, Shielded field sensor.

Under Optics we have optical crankshaft position sensor.

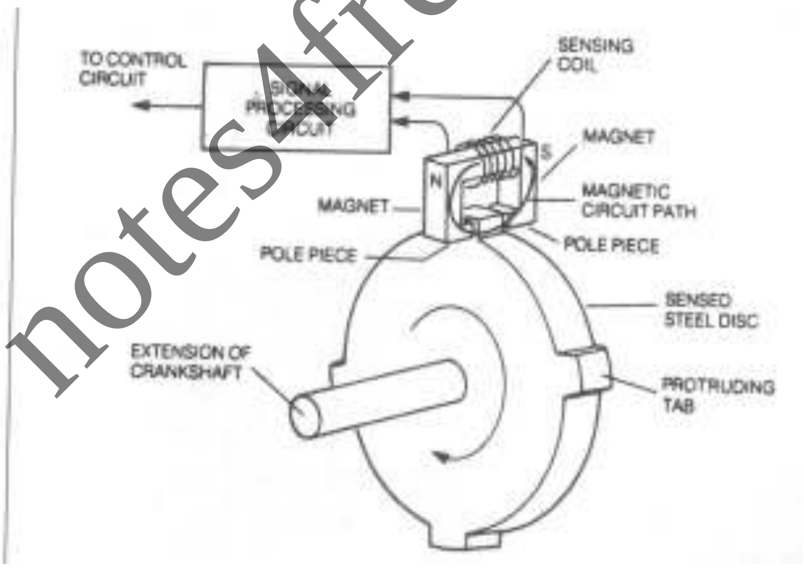
2.1.4 Magnetic Reluctance Position Sensor

Most CKP Sensors are variable reluctance devices. They generate a small AC current. This sensor works by rotating a reluctor through a magnetic field. It provides the PCM / ECM with engine speed data. Engine speed is needed to compute requirements for metering the fuel.

Refer to the figure. In that figure the steel disk has four protruding tabs, which is appropriate for an 8-cylinder engine. The passage of each tab can correspond to the TDC position of a cylinder on its power stroke. The steel disk is mounted on the crankshaft. The tabs pass between pole pieces of magnet. The permanent magnet with a coil of wire wound around it is sensor. This sensor is of the magnetic reluctance type and is based on the concept of a magnetic circuit.

Reluctance of a magnetic circuit is inversely proportional to the magnetic permeability of the material along the path.

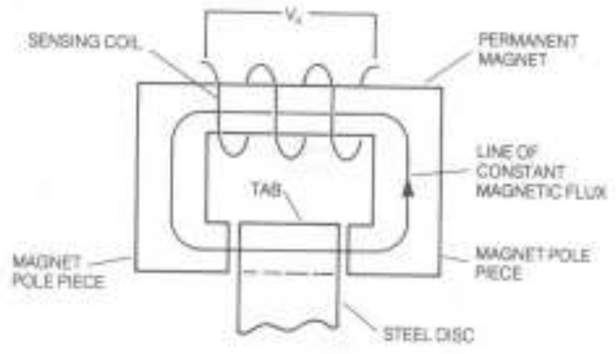
Crankshaft Position Sensor



Magnetic Reluctance Crankshaft Position Sensor

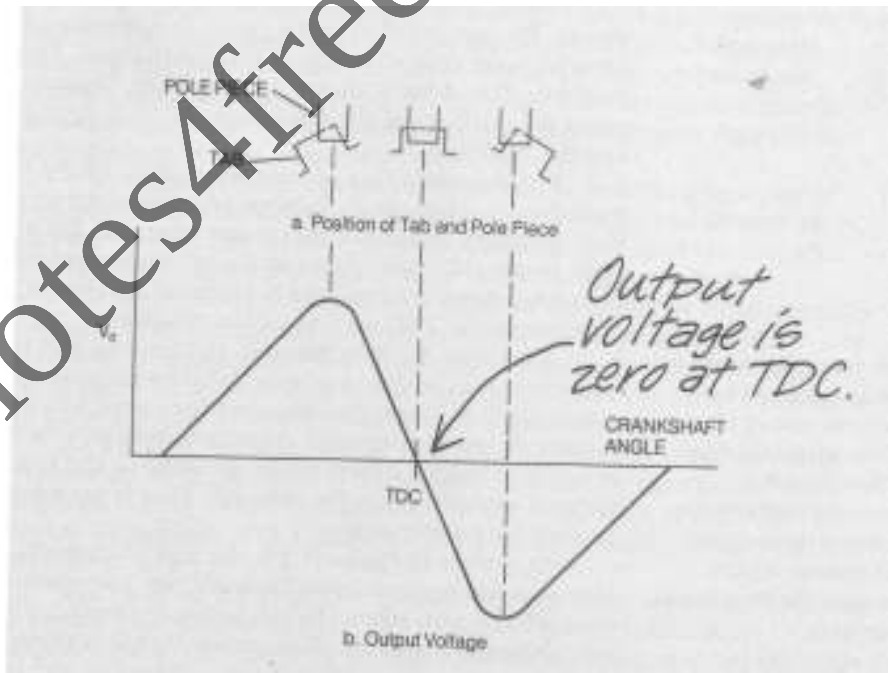
The voltage V_0 induced in the sensing coil by the change in magnetic flux which is proportional to the rate of change of the magnetic flux. Since the magnetic flux must be changing to induce a voltage in the sensing coil, its output voltage is zero whenever the engine is not running, regardless of the position of the crankshaft. This is a serious disadvantage for this type of sensor because the engine timing cannot be set statically.

Magnetic Circuit of the Reluctance Sensor



The magnetic flux is least when none of the tabs is near the magnet pole pieces. As a tab begin to pass through the gap, the magnetic flux increases. It reaches a maximum when the tab is exactly between the pole pieces, and then decreases as the tab passes out of the pole piece region. In most control systems, the position of maximum magnetic flux has a fixed relationship to TDC for one of the cylinders.

Output Voltage Waveform from the Magnetic Reluctance Crankshaft Position Sensor Coil



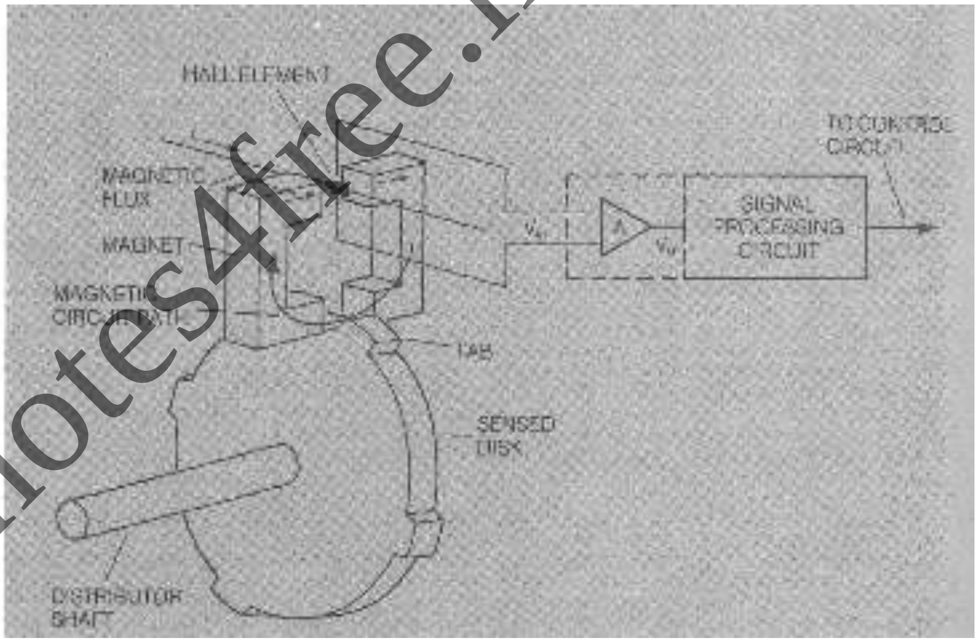
As shown in Figure, the coil voltage, V_0, begins to increase from zero as a tab begins to pass between the pole pieces, reaches a maximum, then falls to zero when the tab is exactly between the pole pieces (see figure a). (Note that although the value of magnetic flux is maximum at this point, the rate of change of magnetic flux is zero; therefore, the induced voltage in the sensing coil is zero). Then it increases with the opposite polarity, reaches a maximum, and falls to zero as the tab passes out of the gap between the pole pieces. The coil voltage waveform shown in

Figure (b) occurs each time one of the cylinders reaches TDC on its power stroke. It should be noted that if the disk is mounted on the crankshaft, then the number of tabs for this crankshaft position sensor always will be half the number of cylinders because it takes two crankshaft rotations for a complete engine cycle. That is why four tabs correspond to an eight cylinder engine.

2.1.5 Hall effect Position Sensor

As mentioned previously the main disadvantage of the magnetic reluctance sensor is its lack of output when the engine is not running. A crankshaft position sensor override this problem is the Hall effect position sensor. This sensor is normally located in the distributor where it measure camshaft piston rather than crankshaft position. This sensor is relatively inexpensive and requires only small modifications to a conventional distributor with ignition points to use it. In fact, with appropriate circuitry, this sensor can also be used to replace distributor ignition points.

Hall-Effect Position Sensor



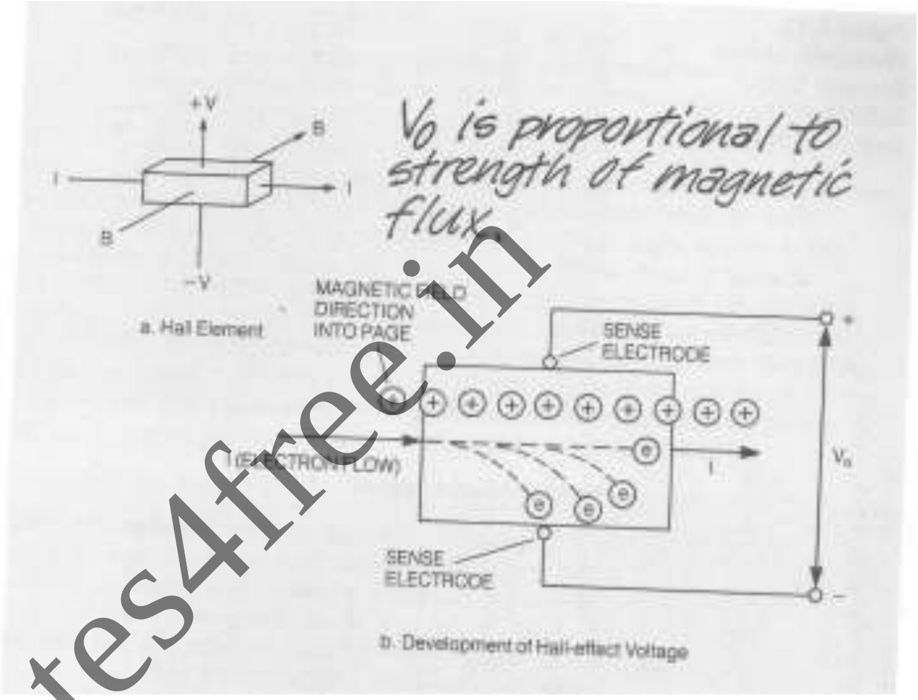
This sensor is similar to the reluctance sensor in that it employs a steal disk having protecting tabs and a magnet for coupling the disk to the sensing element. Another similarity is that the steel disk varies the reluctance of magnet path as the tab pass between the magnet pole pieces.

The Hall Effect

The Hall element is a small thin flat slab of semiconductor material. When current, I is passed through the slab by means of an external circuit as shown in figure (a) below, a voltage is developed across the slab perpendicular to the direction of current flow and perpendicular to the direction of magnetic flux. The voltage is proportional to both current and magnetic flux density which flows through the slab. This effect – the generation of voltage that is dependent on a magnetic field is called ***Hall Effect***.

In figure (b) below the current I is represented by electrons, e, which have –ve charge flowing from left to right. The magnetic field B is perpendicular to the page and into the page. This is indicated by arrow into the page of figure (b).

The Hall Effect



V_0 is proportional to strength of magnetic flux

a. Hall Element

b. Development of Hall-effect Voltage

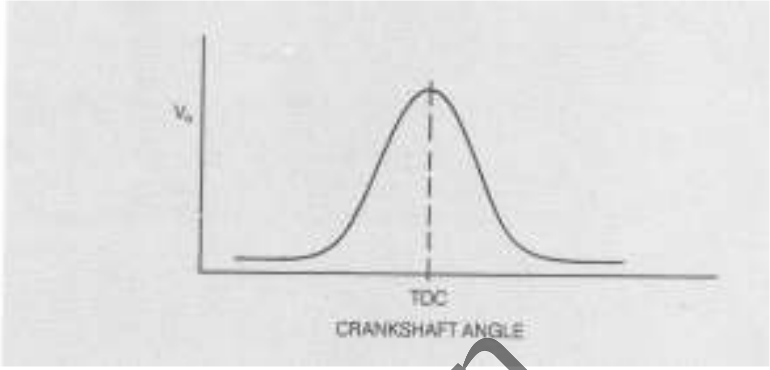
Whenever an electron moves through a magnetic field, a force (called the Lorentz force) is exerted on the electron which is proportional to the electron velocity and the strength of the magnetic flux. The direction of this force is perpendicular to the device in which the electron is moving. In figure (b) above the Lorentz force the direction is such that the electrons are deflected towards the lower sense electrode. Thus, this electrode is more negative than the upper electrode and a voltage exists between the electrode having the polarity shown in figure (b).

As the strength of the magnetic flux density increases more of the electrons are deflected downward. If the current, I, is held constant, then the voltage, V_0 is proportional to the strength of the magnetic flux density. This voltage tends to be relatively weak, so it is amplified as shown in figure.

Output waveform

V_0 is directly proportional to magnetic flux density which depends upon the position of tab. It reaches maximum when any of the tabs is symmetrically located between the magnetic pole pieces (i.e,. corresponding to the TDC of the cylinder). If the disk is driven by the crankshaft, then the disk must have as many tabs as the engine has cylinders. So the disk shown would be for 4-cylinder engine. It is important to realize that voltage output versus crankshaft angle is independent of engine speed. Thus the sensor can be used for setting the engine timing when the engine is not running.

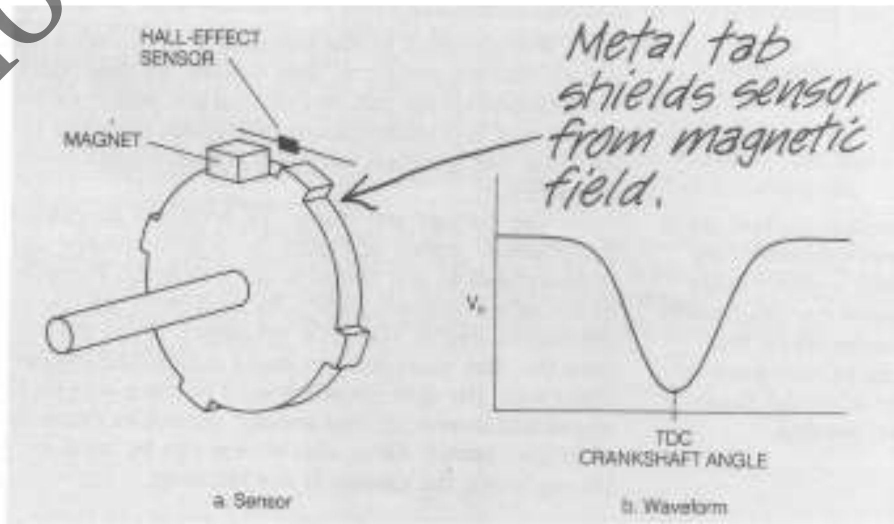
Waveform of Hall-Element Output Voltage for Position Sensor of Figure 5.15



2.1.6 Shielded Field Sensor

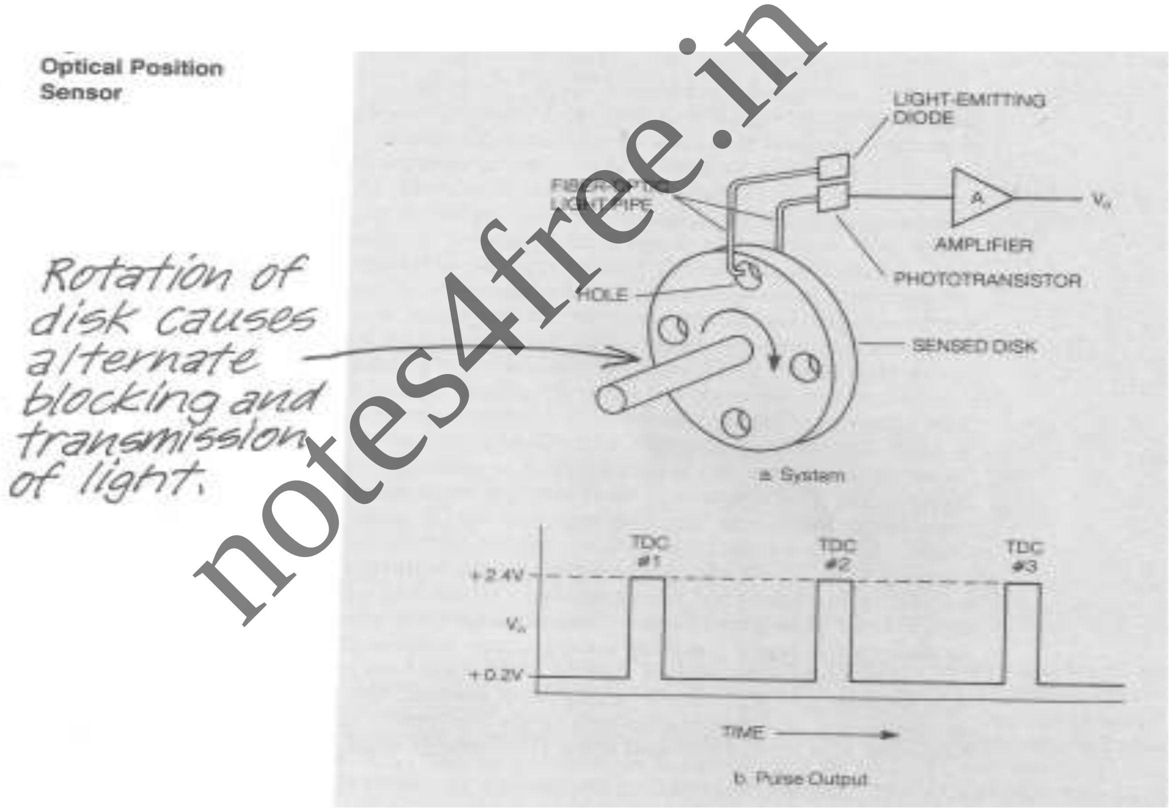
In this method the Hall element is normally exposed to a magnetic field and produces an output voltage. When one of the tabs passes between the magnet and the sensor element, the low reluctance of the tab and disk provides a path for the magnetic flux which bypasses the Hall Effect sensor element and the sensor output drops to near zero. This waveform is just opposite of the Hall Effect Sensor.

Hall-Effect Position Sensor that Shields the Magnetic Circuit


Metal tab shields sensor from magnetic field.

2.1.7 Optical Crankshaft Position Sensor

Shaft position can also be sensed using optical techniques. Again, as with the magnetic system, a disk is directly coupled to the crankshaft. This time, the disk has holes in it that correspond to the number of tabs on the disk of the magnetic system. Mounted on each side of the disk are fiber optic light pipes. The hole in the disk allows transmission of light through the light pipes from the LED source to the photo transistor used as a light sensor. Light would not be transmitted from source to sensor when there is no hole because the solid disk blocks the light. As shown in figure, the pulse of light is detected by the photo transistor and coupled to an amplifier to obtain a satisfactory signal level. The output pulse level can vary easily be standard transistor logic level of +2.4V for the high level and +0.2V for the low level. Used as pulses, the signal provide time referenced pulses which can be signal processed easily with digital integrated circuits.

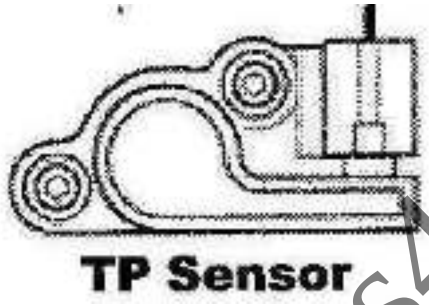


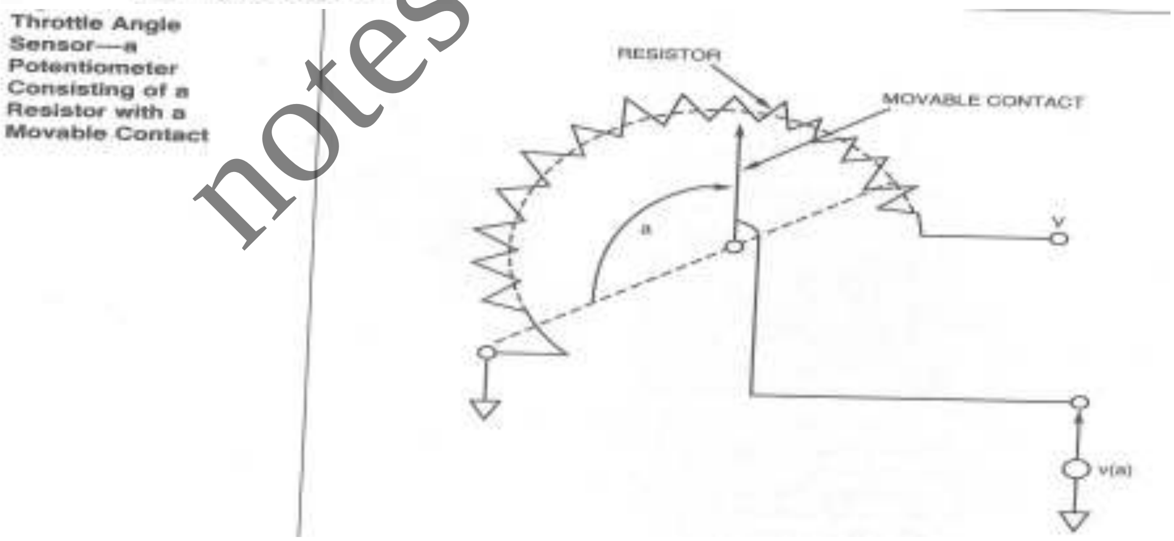
One of the problems with optical sensors is that they must be protected from dirt and oil; otherwise, they will not work properly. They have the advantage that they can sense

2.1.8 Throttle Angle Sensor (TAS) Or Throttle Position Sensor (TPS)

Most TA sensors are potentiometer style devices, resistance changes depending on the angle of a movable arm inside the sensor. The function of the TA sensor is to monitor the angle of the throttle plate and relay the data to the PCM / ECM. This data provides the PCM / ECM with information about the acceleration demands by the driver. This is useful in determining requirements for metering the fuel.

The throttle plate is linked mechanically to the accelerator pedal. When the driver depress the accelerator pedal this link causes the throttle plate angle to increase allowing more air to enter the engine thereby increasing the engine torque (power). Most throttle angle sensors are essentially potentiometers. A potentiometer consists of a resistance with movable contact as illustrated in figure.




Throttle Angle Sensor—a Potentiometer Consisting of a Resistor with a Movable Contact

A section of resistance material is placed in an automotive pivot axis for the movable contact. One end of the resistor is connected to the other to a fixed voltage (e.g. 5 Volts).The voltage at the contact point of the movable contact is proportional to the angle from the ground circuit to movable contact.

Then v(a) = Ka where, v(a) = voltage at the contact point, K = constant
a = angle of the contact point from the ground connection

For digital engine control, the voltage v(a) must be converted to digital format using an A/D converter.

2.1.9 Engine Coolant Temperature (ECT) Sensor

ECT is a thermistor device, resistance changes with temperature. It is typically mounted in a housing which is designed to be inserted in the coolant stream i.e., in an intake manifold coolant passage. This housing is typically threaded with pipe threads which seal against coolant leakage.

A thermistor is made of semiconductor material whose resistance varies inversely with temperature. For example at -40ºC, a typical coolant sensor has a resistance of 100,000 ohms. The resistance decreases to about 70,000 ohms at 130ºC.

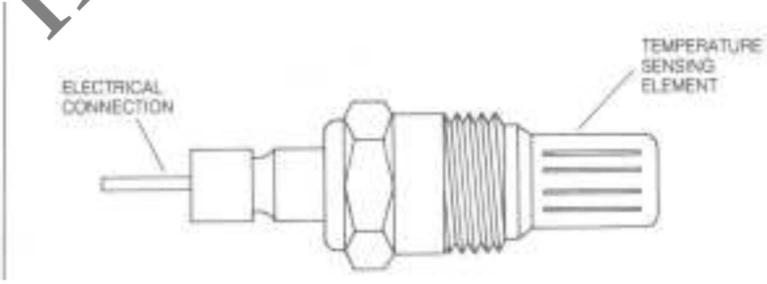
The sensor is typically connected in an electrical circuit like that shown in figure where the coolant temperature sensor resistance is denoted by R_T. The resistance is connected to a reference voltage through a fixed resistance R. The sensor output voltage, V_T, is given by:

$$V_T = \frac{R_T V}{R + R_T}$$

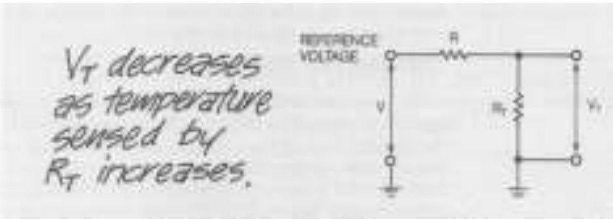
The sensor output voltage varies inversely with temperature; i.e., the output voltage decreases as the temperature increases.

It provides coolant temperature data information to PCM/ECM. This data helps the PCM/ECM determine requirement for metering a fuel. Temperature affects fuel vaporization and air density.

Coolant Temperature Sensor



Typical Coolant Temperature Sensor Circuit



Intake Air Temperature (IAT) Sensor

It is a thermistor device similar to ECT sensor. It is typically mounted in the air cleaner or the fresh air intake duct work. This has the same function as ECT sensor.

SENSORS FOR FEEDBACK CONTROL

The sensors that we have discussed to this point have been part of the open-loop (i.e., feed forward) control. We consider next sensors that are appropriate for feedback engine control. Feedback control for fuel delivery is based on maintaining the air/fuel ratio at stoichiometry (i.e., 14.7:1). The primary sensor for fuel control is the exhaust gas oxygen sensor.

2.1.10 Exhaust Gas Oxygen (O2/EGO) / Lambda Sensors

The function of oxygen (O_2) sensors is to measure the oxygen content in the exhaust. Exhaust gas oxygen content is used to measure combustion efficiency. The O_2 sensor sends a signal to the PCM / ECM , which uses this data to meter fuel. It is also known as EGO (Exhaust Gas Oxygen) sensor or LAMBDA sensor.

Oxygen causes fuel to burn. In a perfect combustion event (at Stoichiometry) all the oxygen and fuel is consumed, and exhaust stream contains only inert gases (such as H_2O - water vapors and CO_2 - Carbon dioxide).

RICH A/F Ratio means not enough oxygen to burn all of the fuel which will lead to unburned or partially burned HC (Hydro Carbons) and CO (Carbon Monoxide) at the exhaust -> Less or No oxygen content at the exhaust.

LEAN A/F Ratio means more than enough oxygen to burn all of the fuel which may lead to NOx produced at the exhaust once the temperature exceeds 2500ºC -> High or left over oxygen content at the exhaust.

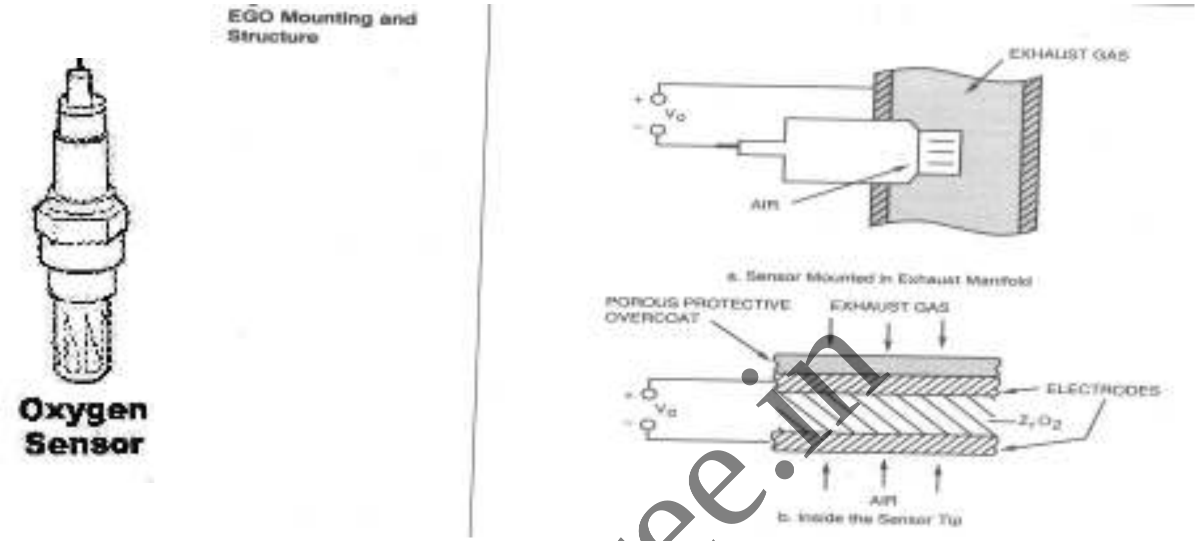
$$\boldsymbol{\lambda} = \frac{\boldsymbol{Air/Fuel}}{\boldsymbol{Air/Fuel(at\ Stoichiometry)}}$$

$\lambda = 1$ at Stoichiometry (Output of EGO Sensor = 450 mV)

$\lambda > 1$ for LEAN condition (Output of EGO Sensor = 0V to 300 mV)

$\lambda < 1$ for RICH condition (Output of EGO Sensor = 600 mV to 1V)

Oxygen Sensor is made up of Platinum Electrodes and Zirconium Oxide (Z_r O_2) in the centre with a porous protective overcoat.



An *ideal* EGO sensor would have an abrupt, rapid, and significant change in output voltage as the mixture passes through stoichiometry. The output voltage would not change as exhaust gas temperature changes.

Desirable EGO Characteristics

The EGO sensor characteristics that are desirable for the type of limit cycle fuel control system are as follows:

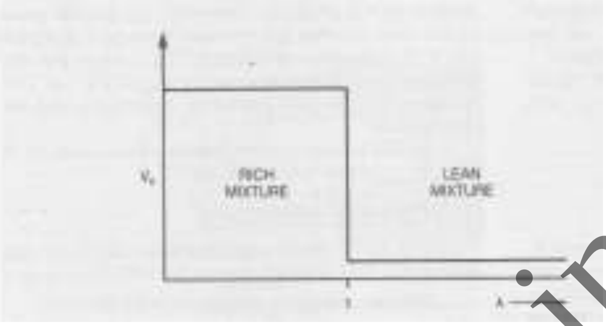
1. Abrupt change in voltage at stoichiometry
2. Rapid switching of output voltage in response to exhaust gas oxygen changes
3. Large difference in sensor output voltage between rich and lean mixture conditions
4. Stable voltages with respect to exhaust temperature

Switching Characteristics:

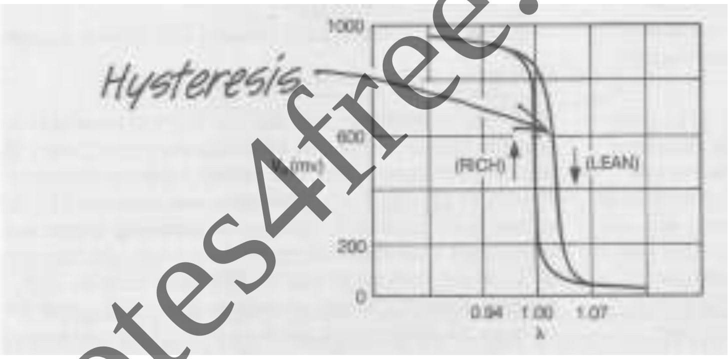
The switching time for the EGO sensor also must be considered in control applications. An ideal characteristic for a limit-cycle controller is shown in Figure. The actual characteristics of a new EGO sensor are shown in Figure. This data was obtained by slowly varying air/fuel ratios across stoichiometry. The arrow pointing down indicates the change in *V*o as the air/fuel ratio was varied from rich to lean. The up arrow indicates the change in *V*o as the air/fuel ratio was varied from lean to rich. Note that the sensor output doesn't change at exactly the same point for increasing air/fuel ratio as for decreasing air/fuel ratio. This phenomenon is called *hysteresis*.

Hysteresis is the difference in the switching point of the output voltage with respect to stoichiometry as a mixture passes from lean to rich, as contrasted to a mixture that passes from rich to lean.

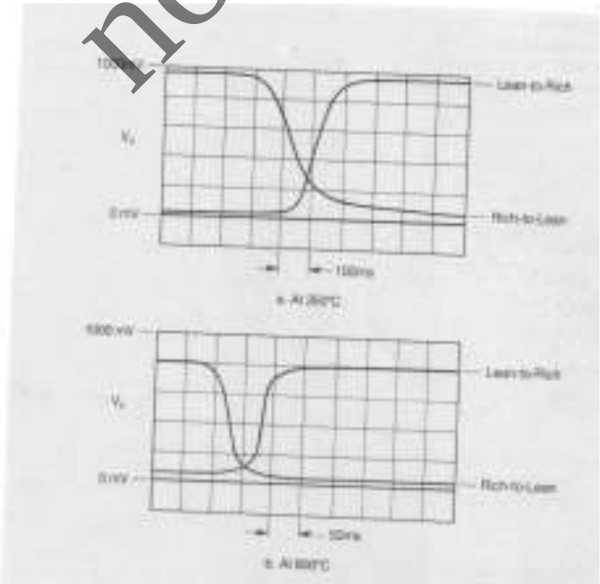
Ideal EGO Switching Characteristics

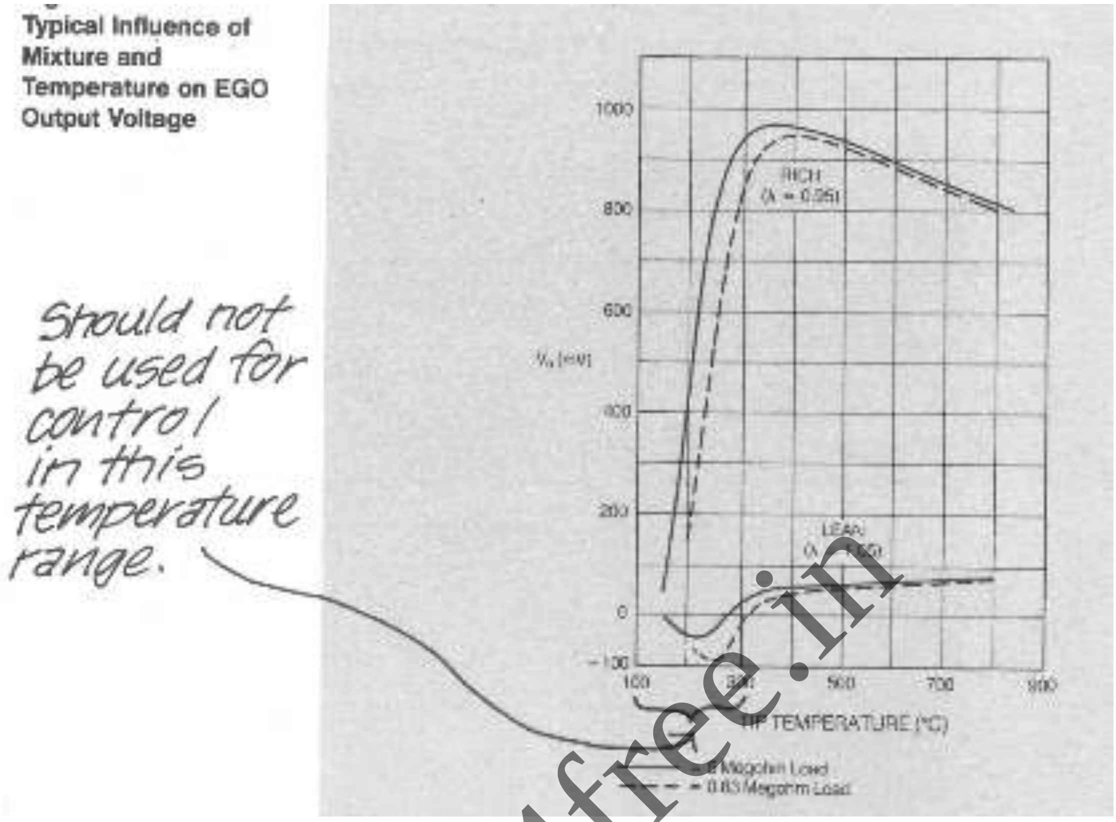


Typical EGO Sensor Characteristics



Typical Voltage Switching Characteristics of EGO





Typical Influence of Mixture and Temperature on EGO Output Voltage

Should not be used for control in this temperature range.

Temperature affects switching times as well as output voltages. Switching times at two temperatures are shown in Figure. Note that the time per division is twice as much for the display at 350°C as at 800°C. This means that the switching times are roughly 0.1 second at 350°C, whereas at 800°C they are about 0.05 second. This is a 2:1 change in switching times due to changing temperature.

The temperature dependence of the EGO sensor output voltage is very important. The graph in Figure shows the temperature dependence of an EGO sensor output voltage for lean and rich mixtures and for two different load resistances—5 mega ohms (5 million ohms) and 0.83 mega ohm. The EGO sensor output voltage for a rich mixture is in the range of about 0.80 to 1.0 volt for an exhaust temperature range of 350°C to 800°C. For a lean mixture, this voltage is roughly in the range of 0.05 to 0.07 volt for the same temperature range.

Under certain conditions, the fuel control using an EGO sensor will be operated in open-loop mode and for other conditions it will be operated in closed-loop mode. The EGO sensor should not be used for control at temperatures below about 300°C because the difference between rich and lean voltages decreases rapidly with temperature in this region. This important property of the sensor is partly responsible for the requirement to operate the fuel control system in the open-loop mode at low exhaust temperature. Closed-loop operation with the EGO output voltage used as the error input cannot begin until the EGO sensor temperature exceeds about 300°C.

Heated EGO Sensors

The increasingly stringent exhaust emission requirements for automobiles in the 1990s have forced automakers to shorten the time from engine start to the point at which the EGO sensor is at operating temperature. This requirement has led to the development of the heated exhaust gas oxygen (HEGO) sensor. This sensor is electrically heated from start-up until it yields an output signal of sufficient magnitude to be useful in closed-loop control.

The HEGO sensor includes a section of resistance material. Electrical power from the car battery is applied at start-up, which quickly warms the sensor to usable temperatures. This heating potentially shortens the time interval until closed-loop operation is possible, thereby minimizing the time during warm-up that air/fuel ratio deviates from stoichiometry and correspondingly reducing undesirable exhaust gas emissions.

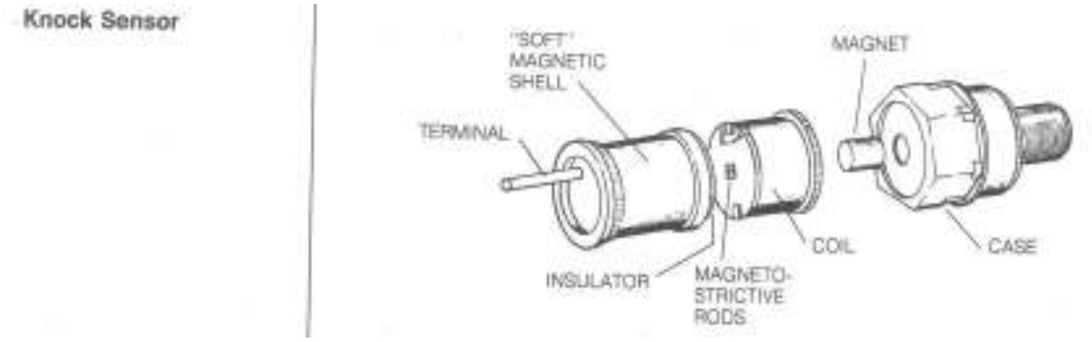
2.1.11 Piezoelectric Knock Sensor

For certain electronic engine control systems it is desirable to have a sensor which can detect an engine occurrence called '*Knock*'. It can be described generally as a rapid rise in cylinder pressure during combustion. It does not occur normally, but under special conditions. It occurs most commonly with high manifold pressure and excessive spark advance. It is important to detect knock and avoid excessive knock, otherwise there will be damage to the engine.

One way of controlling the knock is to sense when knocking begins and the retard the ignition until the knocking stops. A key to control loop for this is a knock sensor.

Knock sensor is made with three technologies viz. (i) Magnetostrictive technique in which the change the spark produces a voltage change in the coil. (ii) Piezo electric crystals (iii) Piezo resistance of a doped silicon semiconductor.

The problem of detecting knock is complicated by the presence of other vibrations and noises in the engine.



Module 2: Chapter 2: AUTOMOTIVE ACTUATORS

2.2.0 Introduction

In addition to the set of sensors, electronic engine control is critically dependent on a set of actuators to control air/fuel ratio, ignition, and EGR.

In general, 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. Examples of actuators include: various types of electric motors, solenoids, and piezoelectric force generators. In automotive electronic systems the solenoid is the most commonly used device because it is relatively simple and inexpensive.

2.2.1 Solenoid

The solenoid is used in applications ranging from precise fuel control to mundane applications such as electric door locks. A solenoid is in essence a powerful electromagnet having a configuration generally similar to that illustrated in Figure. The solenoid consists of a fixed steel (i.e., ferromagnetic) frame with a movable steel element. A spring holds the movable element in position such that there is a gap between the end of the movable element and the opening in the frame. A coil is wound around the steel frame, forming a powerful electromagnet.

When a current passes through the coil, a magnetic field is created that tends to pull the movable element toward the steel frame. When the magnetic field, which is proportional to the current, is sufficient to overcome the force at the spring holding the movable element, then it begins to move toward the frame. As this element moves, the size of the gap is reduced, causing an increase in the strength of the magnetic field. This increase causes the movable element to accelerate toward the frame until it reaches the stop.

This abrupt motion of the movable element is essentially in the form of a mechanical switching action such that the solenoid tends to be either in its rest position (as held by the spring) or against the mechanical stop. The movable element is typically connected to a mechanism that is correspondingly moved by the snap action of this element. Applications of solenoids in automotive electronics include fuel injectors and EGR valves.

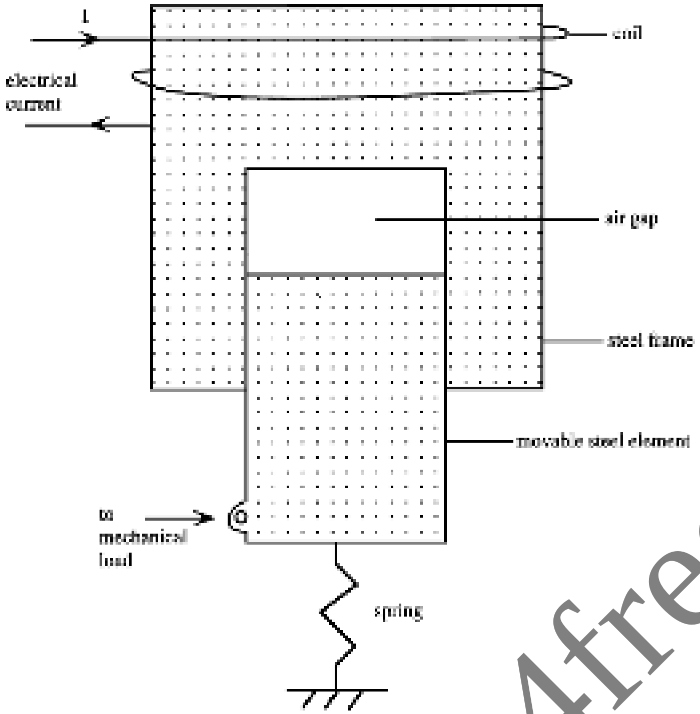


Figure: Schematic Drawing of a Solenoid

2.2.2 Fuel Injector

A fuel injector is (in essence) a solenoid-operated valve. The valve opens or closes to permit or block fuel flow to the engine. The valve is attached to the movable element of the solenoid and is switched by the solenoid activation.

In a fuel injector with no current flowing, the solenoid movable element is held down against the stop, covering the aperture or nozzle. Fuel is thereby blocked from flowing from the pressurized fuel chamber into the aperture. When current flows through the solenoid coil, the movable element is switched upward, the aperture is exposed, and fuel (under pressure) sprays through this aperture.

The fuel flow rate through the nozzle is constant for a given regulated fuel pressure and nozzle geometry; therefore, the quantity of fuel injected into the air stream is proportional to the time the valve is open. The control current that operates the fuel injector is pulsed on and off to deliver precise quantities of fuel.

Fuel Injector Signal

Consider an idealized fuel injector as shown in Figure 6.26, in which the injector is open when the applied voltage is on and is closed when the applied voltage is off. In this idealization, the control voltage operating the fuel injector is a binary pulse train (i.e., either on or off). For a pulse train signal, the ratio of on time *t* to the period of the pulse *T* (on time plus off time) is called the *duty cycle*. This is shown in Figure. The fuel injector is energized for time *t* to allow fuel to spray from the nozzle into the air stream going to the intake manifold. The injector is deenergized for the remainder of the period. Therefore, a low duty cycle, as seen in Figure (a), is used for a high air/fuel ratio (lean mixture), and a high duty cycle (Figure (b) is used for a low air/ fuel ratio (rich mixture).

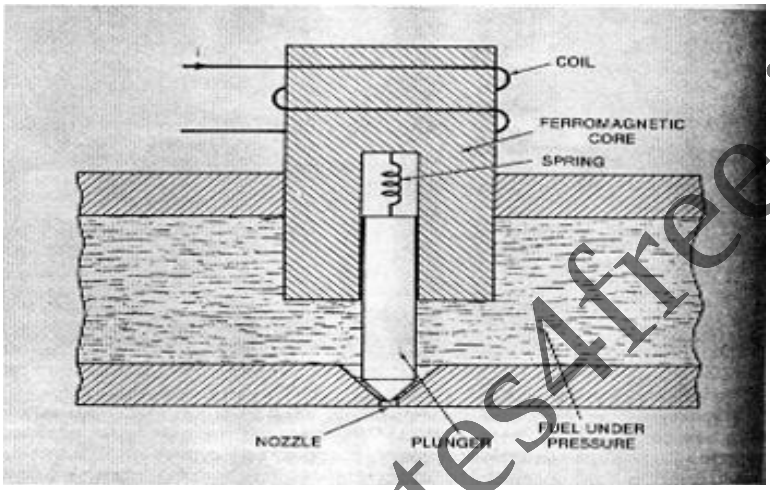


Figure: Schematic Drawing of Fuel Injector

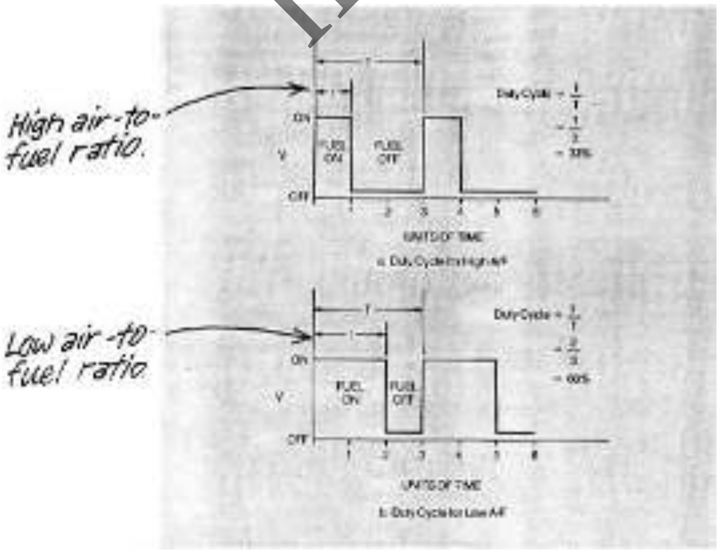


Figure: Pulse Mode Fuel Control Signal to Fuel Injector

2.2.3 EGR Actuator

Exhaust gas recirculation (EGR) is utilized to reduce NOx emissions. The amount of EGR is regulated by the engine controller. When the correct amount of EGR has been determined by the controller based on measurements from the various engine control sensors, the controller sends an electrical signal to the EGR actuator. Typically, this actuator is a variable-position valve that regulates the EGR as a function of intake manifold pressure and exhaust gas pressure. Although there are many EGR configurations, only one representative example will be discussed to explain the basic operation of this type of actuator.

The example EGR actuator is shown schematically in Figure. This actuator is a vacuum-operated diaphragm valve with a spring that holds the valve closed if no vacuum is applied. The vacuum that operates the diaphragm is supplied by the intake manifold and is controlled by a solenoid operated valve. This solenoid valve is controlled by the output of the control system.

This solenoid operates essentially the same as that explained in the discussion on fuel injectors. Whenever the solenoid is energized (i.e., by current supplied by the control system flowing through the coil), the EGR valve is opened by the applied vacuum.

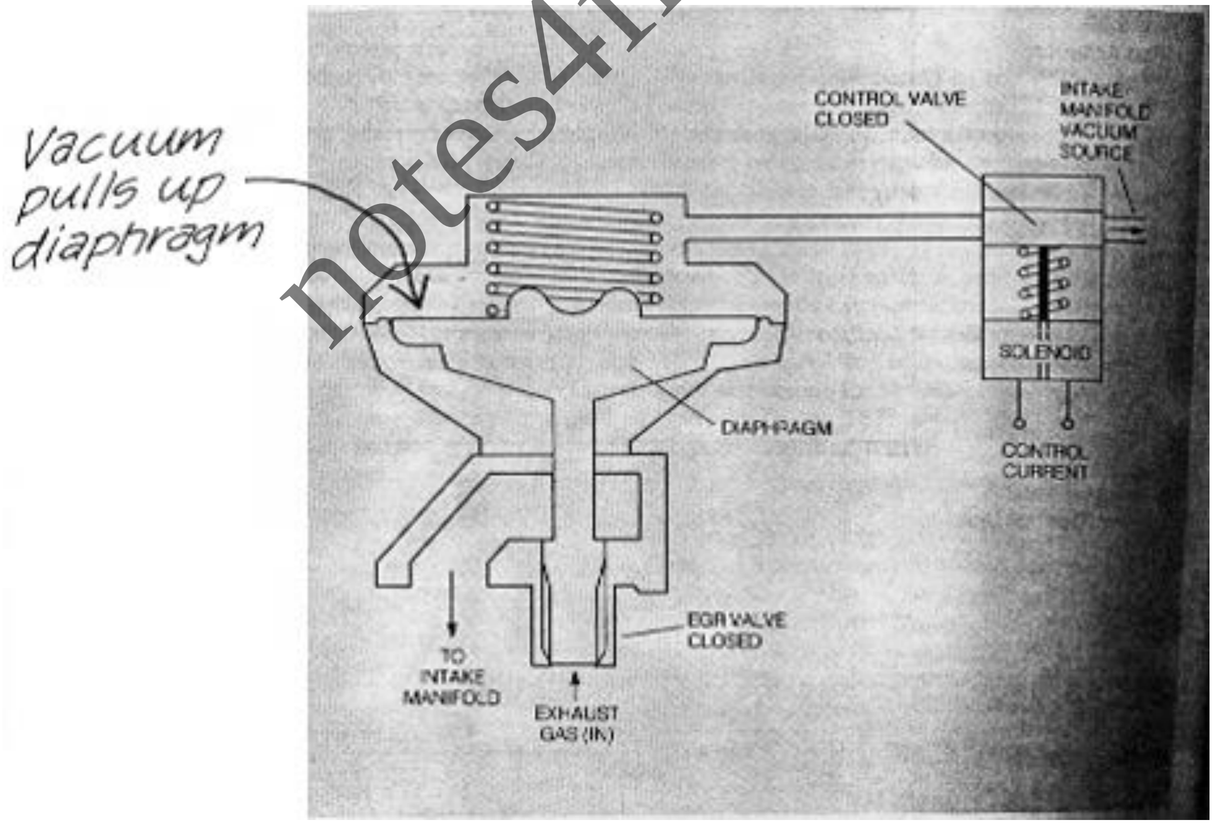


Figure: EGR Actuator Control

The amount of valve opening is determined by the average pressure on the vacuum side of the diaphragm. This pressure is regulated by pulsing the solenoid with a variable-duty-cycle electrical control current. The duty cycle (see discussion on fuel injectors) of this pulsing current controls the average pressure in the chamber that affects the diaphragm deflection, thereby regulating the amount of EGR.

Ignition System

The equivalent of an actuator for the ignition system on an engine is the combination of the spark plug, the ignition coil, and driver electronic circuits.

This is the subsystem that receives the electrical signal from the engine controller and delivers as its output the spark that ignites the mixture during the end of the compression stroke.

Figure shows a block diagram schematic drawing illustrating this subsystem. The primary circuit of the coil (depicted as the left portion P of the coil in Figure) is connected to the battery and through a power transistor to ground. For convenience, the collector, emitter, and base are denoted c, e, and b respectively. The coil secondary S is connected to one or more spark plugs.

The electronic controller supplies base current to the power transistor, rendering it fully conductive (i.e., in saturation). When it is conducting, the transistor acts essentially like a closed switch. A relatively large current (denoted *I*p) flows through the primary windings of the coil (P), creating a relatively large magnetic field that is linked to the secondary coil. At the appropriate time for ignition the controller switches off the base current, causing the transistor to be nonconducting. At this instant the primary current drops to zero very quickly, causing the magnetic field strength to drop rapidly also.

The very rapid drop in the magnetic field (linked to the secondary S) generates a very high voltage (20,000 to 40,000 volts), which, in turn, creates the spark across the spark plug electrodes, igniting the mixture and, finally, initiating the power stroke for the engine. It should be noted that the coil secondary is connected to a pair of spark plugs in Figure. Firing a pair of spark plugs on two separate cylinders has become commonplace today.

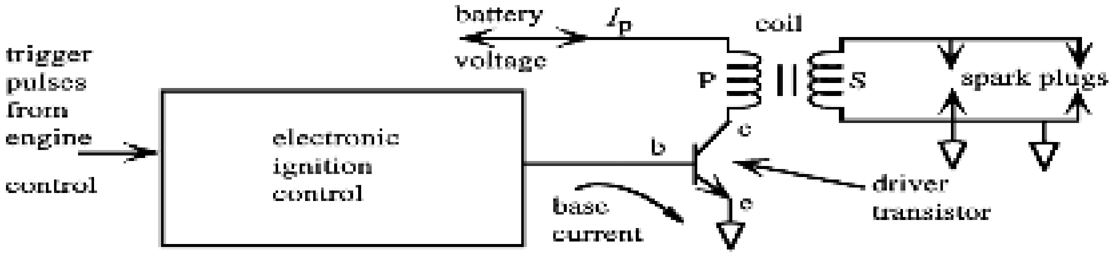


Figure: Electronic Ignition Subsystem

OUTCOMES

At the end of the module, the students

1. Learn different Sensors and Actuators used in Automotives.

MODEL QUESTIONS

Module 2- Chapter 1 (Automotive Sensors)

1. Write a diagram of typical Electronic Engine Control System showing sensors and Actuators.
2. With relevant diagrams explain the working of Mass Flow Sensor.
3. With relevant diagrams explain the working of Strain Gauge MAP sensor.
4. With relevant diagrams explain the working of Magnetic Reluctance Position sensor.
5. What is Hall Effect? Explain the working of Hall Effect position sensor with relevant diagrams.
6. What is the main disadvantage of the magnetic reluctance sensor which is avoided in Hall Effect Position Sensor? Explain the working of Shielded Field Sensor.
7. Explain the working of Optical Crankshaft Position Sensor with relevant diagrams.
8. What is the working principle of Throttle Angle Sensor? Explain with a diagram.
9. How does a typical coolant sensor work? Explain with diagrams.
10. Explain the working of Exhaust Gas Oxygen Sensor with relevant diagrams and its characteristic Curves.

Module 2- Chapter 2 (Automotive Actuators)

1. Explain the principle of working of a solenoid with the help of a diagram.
2. Explain the working of Fuel Injector with schematic drawing and waveforms for different duty cycles.
3. Explain the EGR Actuator working with relevant diagram.
4. Explain the Electronic Ignition System with relevant diagram.

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Module 3

DIGITAL ENGINE CONTROL SYSTEMS & CONTROL UNITS

3.1 Digital Engine Control Systems

3.2 Control Units

OBJECTIVES

1. Understand the features and Control Modes of Digital Engine Control Systems
2. Understand the functioning of EGR Control to reduce NOx, Closed loop Electronic Ignition Control for reducing emission and spark advance correction to reduce knock.
3. Learn about the method which will reduce the emissions further by some manipulations in exhaust chamber.

4. To increase economy and reduce emissions by utilizing the fuel which would otherwise have escaped to atmosphere.
5. To learn about the system diagnostics

Module 3 – Chapter 1

DIGITAL ENGINE CONTROL SYSTEMS

3.1 Digital Engine Control Systems

The motivation for development of the more sophisticated digital control systems has been the increasingly stringent exhaust emission and fuel economy regulations. It has proven to be cost effective to implement the power train controller as a multimode computer-based system to satisfy these requirements.

A multimode controller operates in one of many possible modes, and, among other tasks, changes the various calibration parameters as operating conditions change in order to optimize performance. To implement multimode control in analog electronics it would be necessary to change hardware parameters (for example, via switching systems) to accommodate various operating conditions. In a computer-based controller, however, the control law and system parameters are changed via program (i.e., software) control. The hardware remains fixed but the software are reconfigured in accordance with operating conditions as determined by sensor measurements and switch inputs to the controller.

This chapter will explain how the microcontroller under program control is responsible for generating the electrical signals that operate the fuel injectors and trigger the ignition pulses. This chapter also discusses secondary functions (including management of secondary air that must be provided to the catalytic converter EGR regulation and evaporative emission control) that have not been discussed in detail before.

3.1.1 Digital Engine Control Features

The components of a Digital Engine Control System are as shown in the figure. The microcontroller under program control generates output electrical signals to operate the fuel injectors and ignition drivers. In determining the correct fuel flow, the controller obtains a measurement or estimate of the mass air flow rate into the cylinder. Alternatively, the mass air flow rate is estimated (calculated) using the speed-density method. This estimate can be found from the measurement of the intake manifold absolute pressure (MAP), the RPM, and inlet air temperature. Using this calculation, the quantity of fuel to be delivered is determined by the controller in accordance with the *instantaneous control mode*. The quantity of fuel delivered by the fuel injector is determined by the operation of the fuel injector. A fuel injector is essentially a solenoid-operated valve. Fuel at a regulated pressure from the fuel pump is supplied to each fuel injector. In the earliest versions of electronic fuel control systems, the fuel metering actuator typically consisted of one or two fuel injectors mounted near the throttle plate so as to deliver fuel into the throttle body. **Throttle Body Fuel Injectors (TBFI)** were in effect as electromechanical replacement for the carburetor. Requirements for the TBFI were such that they only had to deliver fuel at the correct average flow rate for any given mass air flow. Mixing of the fuel and air, as well as distribution to the individual cylinders, took place in the intake manifold system.

The more stringent exhaust emissions regulations have demanded more precise fuel delivery than can normally be achieved by TBFI. These regulations and the need for improved performance have led to **Timed Sequential Port Fuel Injection (TSPFI)**. In such a system there is a fuel injector for each cylinder that is mounted so as to spray fuel directly into the intake of the associated cylinder. Fuel delivery is timed to occur during the intake stroke for that cylinder.

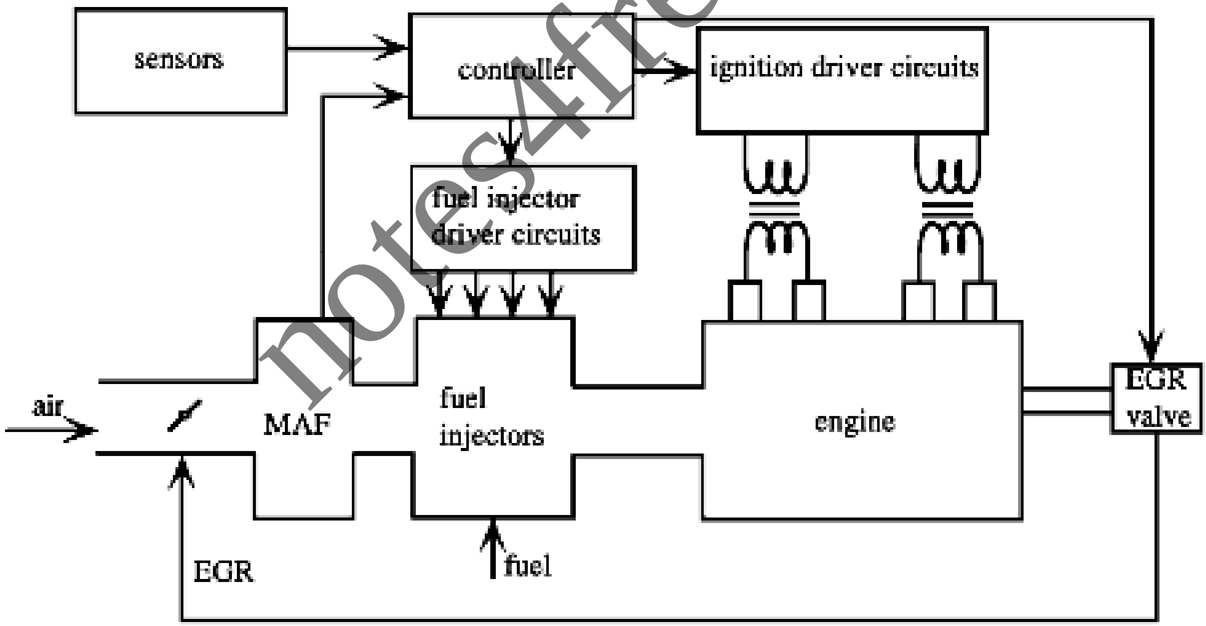


Figure: Components of an Electronically Controlled Engine

When the injector valve is opened, fuel flows at a rate R_f (in gm/sec) that is determined by the constant (regulated) pressure and by the geometry of the fuel injector valve. The quantity of fuel F delivered to any cylinder is proportional to the time T that this valve is opened.

$$F \, \alpha \, T$$

$$F = R_f\,T \text{ , where, } R_f = \text{constant (fuel flow rate)}$$

$$=> T = \frac{F}{R_f}$$

The controller then generates an electrical signal that opens the fuel injector valve for the appropriate time interval T to deliver this desired fuel quantity to the cylinder.

The controller also determines the correct time for fuel delivery to correspond to the intake stroke for the relevant cylinder. This timing is determined by measurements of crankshaft and camshaft position using sensors.

The control system selects an operating mode based on the instantaneous operating condition as determined from the sensor measurements. Within any given operating mode the desired air/fuel ratio $(A/F)_d$ is selected. The controller then determines the quantity of fuel to be injected into each cylinder during each engine cycle. This quantity of fuel depends on the particular engine operating condition as well as the controller mode of operation, as will presently be explained.

3.1.2 Control Modes of Fuel Control (Seven Modes)

The engine control system is responsible for controlling fuel and ignition for all possible engine operating conditions. However, there are a number of distinct categories of engine operation, each of which corresponds to a separate and distinct operating mode for the engine control system. The differences between these operating modes are sufficiently great that different software is used for each.

The sensors that measure various engine variables for control are as follows:

1. MAF Mass air flow sensor
2. CT Engine temperature as represented by coolant temperature
3. HEGO (One or two) heated exhaust gas oxygen sensor(s)
4. POS/RPM Crankshaft angular position and RPM sensor cycle
5. Camshaft position sensor for determining start of each engine cycle
6. TPS Throttle position sensor
7. DPS Differential pressure sensor (exhaust to intake) for EGR control

For a typical engine there are seven different engine operating modes that affect fuel control as follows:

1. **Engine crank Mode**: When the ignition key switched on low A/F ratio (more fuel) to present Stall during cool weather until engine coolant pump rises above some minimum valve stoichiometry.
2. **Engine warm-up Mode:** Once the engine RPM rises above cranking rate the control identifies the engine started mode.

3. **Open-loop control Mode:** When the coolant temperature rises and then monitors EGO output.

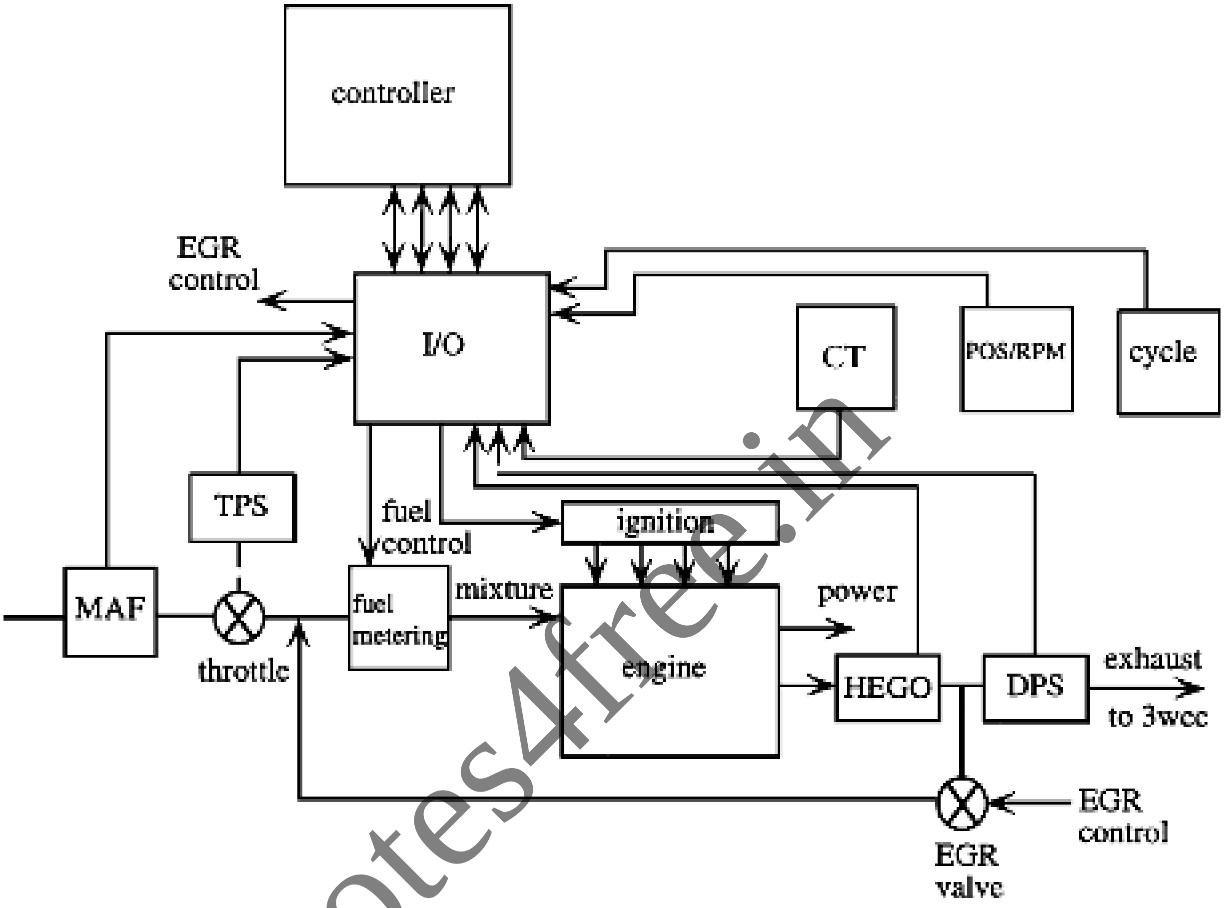


Figure: Digital Engine Control System Diagram

4. **Closed loop control Mode:** When the sensor has indicated rich at least once and after it has been in open loop mode for a specific time it remains have till and accordance in bioelectronics occurs. If sensor cools it will so back to open loop control.
5. **Hard acceleration Mode:** Rich air/fuel mixture for load accumulator heavy load returns to open loop or closed loop depending on conditions.
6. **Deceleration Mode:** Air/Fuel ratio increased to reduce emission of HC&CO program for mode control logic determines the engine operating mode from sensor date &timers.
7. **Idle Mode**: Engine speed is controlled to reduce engine roughness & stalling that might occur because the idle load has changed due to air conditioner compressor operation or gearshift positioning from park/neutral to drive.

3.1.2.1 Engine Crank Mode

While the engine is being cranked the fuel control system must provide an intake air/fuel ratio of anywhere from 2/1 to 12/1, depending on the engine temperature. Lower temperatures affect the ability of the fuel metering system to atomize or mix the incoming air and fuel. At low temperatures, the fuel tends to form into large droplets in the air which don't burn as efficiently as tiny droplets. The larger fuel droplets tends to increase apparent Air/Fuel ratio, because the amount of usable fuel (on the surface of droplets) in the air is reduced; therefore the fuel metering system must provide a decreased Air/Fuel ratio to provide the engine with a more combustible air/fuel mixture. During engine crank the primary issue is to achieve engine start as rapidly as possible. Once the engine is started the controller switches to an engine warm-up mode

During engine crank, the controller compares the value from the coolant temperature sensor with values stored in a lookup table to determine the correct air/fuel ratio at that temperature.

The computer reads the engine temperature through an ADC from a temperature sensor in the engine water coolant. A look up table is used to determine the proper A/F ratio at that temperature. The A/F ratio is determined and controlled as in the open loop mode. The main control concern is for reliable engine start, not for emission control or for fuel economy.

The output of the controller is a variable duty cycle pulse that meters the correct amount of fuel (i.e, that necessary to obtain the calculate A/F ratio). The average quantity of the fuel flowing into the engine is proportional to this duty cycle.

3.1.2.2 Engine Warm-upMode

While the engine is warming up, an enriched air/fuel ratio is still needed to keep it running smoothly, but the required air/fuel ratio changes as the temperature increases. Therefore, the fuel control system stays in the open-loop mode, but the air/fuel ratio commands continue to be altered due to the temperature changes. The emphasis in this control mode is on rapid and smooth engine warm-up. Fuel economy and emission control are still a secondary concern.

A diagram illustrating the lookup table selection of desired air/fuel ratios is shown in Figure. Essentially, the measured coolant temperature (*CT*) is converted to an address for the lookup table. This address is supplied to the ROM table via the system address bus (A/B). The data stored at this address in the ROM is the desired air/fuel ratio $(A/F)_d$ for that temperature. This data is sent to the controller via the system data bus (D/B).

There is always the possibility of a coolant temperature failure. Such a failure could result in excessively rich or lean mixtures, which can seriously degrade the performance of both the engine and the three-way catalytic converter (3wcc). One scheme that can circumvent a temperature sensor failure involves having a time function to limit the duration of the engine warm-up mode. The nominal time to warm the engine from cold soak at various temperatures is known. The controller is configured to switch from engine warm-up mode to an open-loop (warmed-up engine) mode after a sufficient time by means of an internal timer.

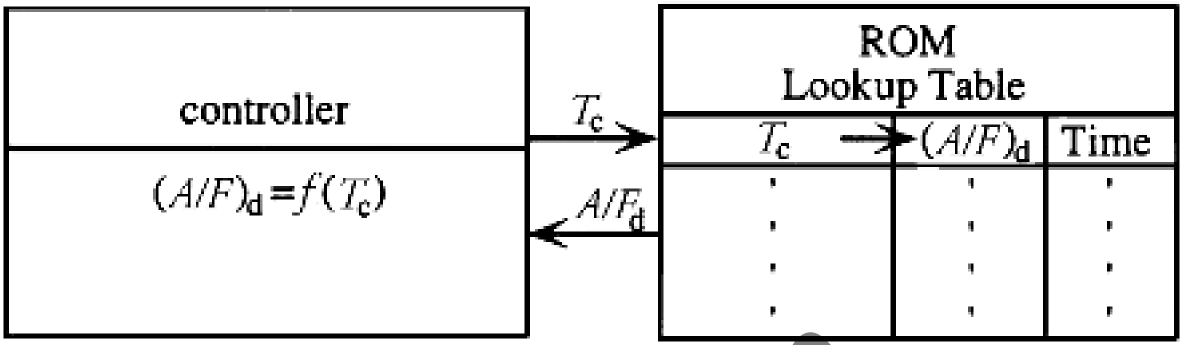


Figure: Illustration of Lookup Table for Desired Air/Fuel Ratio

It is worthwhile at this point to explain how the quantity of fuel to be injected is determined. This method is implemented in essentially all operating modes and is described here as a generic method, even though each engine control scheme may vary somewhat from the following. The quantity of fuel to be injected during the intake stroke of any given cylinder (which we call *F*) is determined by the mass of air (*A*) drawn into that cylinder (i.e., the air charge) during that intake stroke. That quantity of fuel is given by the air charge divided by the desired air/fuel ratio:

$$F = \frac{A}{(A/F)_d}$$

The quantity of air drawn into the cylinder, *A*, is computed from the mass air flow rate and the RPM. The mass air flow rate (MAF) will be given in kg/sec. If the engine speed in revolutions/minute is RPM, then the number of revolutions/second (which we call *r*) is $r = \frac{RPM}{60}$

Then, the mass air flow is distributed approximately uniformly to half the cylinders during each revolution. If the number of cylinders is *N* then the air charge (mass) in each cylinder during one revolution is: $A = \frac{MAF}{r(\frac{N}{2})}$

The quantity of air drawn into the cylinder, *A*, is computed from the mass air flow rate and the RPM. In this case, the mass of fuel delivered to each cylinder is: $F = \frac{MAF}{r\left(\frac{N}{2}\right)\left(\frac{A}{F}\right)_d}$

This computation is carried out by the controller continuously so that the fuel quantity can be varied quickly to accommodate rapid changes in engine operating condition. The fuel injector pulse duration *T* corresponding to this fuel quantity is computed using the known fuel injector delivery rate R_f: $T = \frac{F}{R_f} = \frac{MAF}{r\left(\frac{N}{2}\right)\left(\frac{A}{F}\right)_d R_f}$

This pulse width is known as the *base pulse width*. The actual pulse width used is modified from this according to the mode of operation at any time, as will presently be explained.

3.1.2.3 Open Loop Control Mode

After engine warm-up, open-loop control is used. The most popular method uses the mass density equation to calculate the amount of air entering the intake manifold.

For a warmed-up engine, the controller will operate in an open loop if the closed-loop mode is not available for any reason. For example, the engine may be warmed sufficiently but the EGO sensor may not provide a usable signal. In any event, as soon as possible it is important to have a stoichiometric mixture to minimize exhaust emissions. The base pulse width T_b is computed as described above, except that the desired air/fuel ratio $(A/F)_d$ is 14.7 (stoichiometry):

$$T_b = \frac{MAF}{r\,(N/2)(14.7)R_f}$$

Corrections of the base pulse width occur whenever anything affects the accuracy of the fuel delivery. For example, low battery voltage might affect the pressure in the fuel rail that delivers fuel to the fuel injectors. Corrections to the base pulse width are then made using the actual battery voltage.

3.1.2.4 Closed Loop Control Mode

The most important adjustment to the fuel injector pulse duration comes when the control is in the closed-loop mode. In the open-loop mode the accuracy of the fuel delivery is dependent on the accuracy of the measurements of the important variables. However, any physical system is susceptible to changes with either operating conditions (e.g., temperature) or with time (aging or wear of components).

In any closed-loop control system a measurement of the output variables is compared with the desired value for those variables. In the case of fuel control, the variables being regulated are exhaust gas concentrations of HC, CO, and NOx. Although direct measurement of these exhaust gases is not feasible in production automobiles, it is sufficient for fuel control purposes to measure the exhaust gas oxygen concentration. These regulated gases can be optimally controlled with a stoichiometric mixture. The EGO sensor is, in essence, a switching sensor that changes output voltage abruptly as the input mixture crosses the stoichiometric mixture of 14.7.

The closed-loop mode can only be activated when the EGO (or HEGO) sensor is sufficiently warmed. The output voltage of the sensor is high (approximately 1 volt) when the exhaust oxygen concentration is low (i.e., for a rich mixture relative to stoichiometry). The EGO sensor voltage is low (approximately 0.1 volt) whenever the exhaust oxygen concentration is high (i.e., for a mixture that is lean relative to stoichiometry).

The time-average EGO sensor output voltage provides the feedback signal for fuel control in the closed-loop mode. The instantaneous EGO sensor voltage fluctuates rapidly from high to low values, but the average value is a good indication of the mixture.

Fuel delivery is regulated by the engine control system by controlling the pulse duration (T) for each fuel injector. The engine controller continuously adjusts the pulse duration for varying operating conditions and for operating parameters. A representative algorithm for fuel injector pulse duration for a given injector during the *n*th computation cycle, $T(n)$, is given by

$$T(n) = T_b(n)\,(1 + C_L(n))$$

Where,

$T_b(n)$ = Base pulse width as determined from measurements of mass airflow rate R_a and the desired air/fuel ratio.
$C_L(n)$ = Closed loop correction factor.

For open loop operation, $C_L(n) = 0$

For closed loop operation, $C_L(n) = \alpha\, I(n) + \beta P(n)$

Where,

$I(n)$ = Integral part

$P(n)$ = Proportional part of the closed loop operation.

α & β = constants.

Whenever the EGO sensor indicates a rich mixture (EGO sensor voltage = HIGH), then the integral part is reduced by the controller for the next cycle.

i.e., $I(n+1) = I(n) - 1$ for a rich mixture.

Whenever the EGO sensor indicates a lean mixture (EGO sensor voltage = LOW), the controller increments $I(n)$ for the next cycle.

i.e., $I(n+1) = I(n) + 1$ for a lean mixture.

The integral part of C_L continues to increase or decrease in a limit cycle operation for continuous time operation.

The computation of the closed-loop correction factor continues at a rate determined within the controller. This rate is normally high enough to permit rapid adjustment of the fuel injector pulse width during rapid throttle changes at high engine speed. The period between successive computations is the computation cycle described above.

In addition to the integral component of the closed-loop correction to pulse duration is the proportional term. This term, $P(n)$, is proportional to the deviation of the average EGO sensor signal from its mid-range value (corresponding to stoichiometry). The combined terms change with computation cycle as depicted in Figure. In this figure the regions of lean and rich (relative to stoichiometry) are depicted. During relatively lean periods the closed-loop correction term increases for each computation cycle, whereas during relatively rich intervals this term decreases.

Once the computation of the closed-loop correction factor is completed, the value is stored in a specific memory location (RAM) in the controller. At the appropriate time for fuel injector activation (during the intake stroke), the instantaneous closed-loop correction factor is read from its location in RAM and an actual pulse of the corrected duration is generated by the engine control.

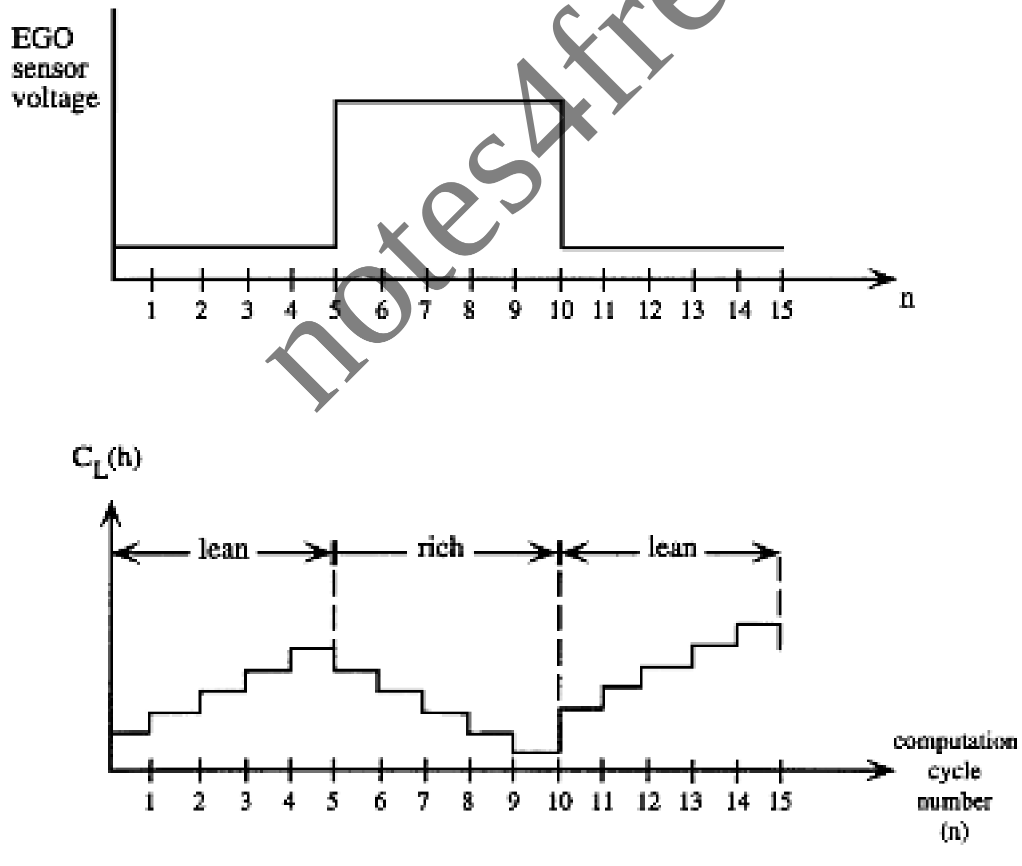


Figure: Closed-Loop Correction Factor

3.1.2.5 Hard Acceleration or Acceleration Enrichment

During periods of heavy engine load such as during hard acceleration, fuel control is adjusted to provide an enriched air/fuel ratio to maximize engine torque and neglect fuel economy and emissions. This condition of enrichment is permitted within the regulations of the EPA as it is only a temporary condition. It is well recognized that hard acceleration is occasionally required for maneuvering in certain situations and is in fact, related at times to safety.

The computer detects this condition by reading the throttle angle sensor voltage or from the MAP sensor. High intake manifold pressure or throttle angle corresponds to engine load. Enrichment of the air/fuel ratio of about 12:1 is sometimes used.

3.1.2.6 Deceleration Leaning

During periods of light engine load and high rpm such as during coast, the engine requires a very lean air/fuel ratio to reduce excess emissions of HC & CO. Deceleration is indicated by a sudden decrease in MAP & throttle angle. When these conditions are detected by the control computer, it computes a decrease in the duty cycle of the fuel metering signal. The fuel may even be turned off completely for very heavy deceleration.

3.1.2.7 Idle Speed Control

When the throttle angle reaches its closed position and engine RPM falls below a preset value, the controller switches to idle speed control. A stepping motor opens a valve, allowing a limited amount of air to bypass the closed throttle plate.

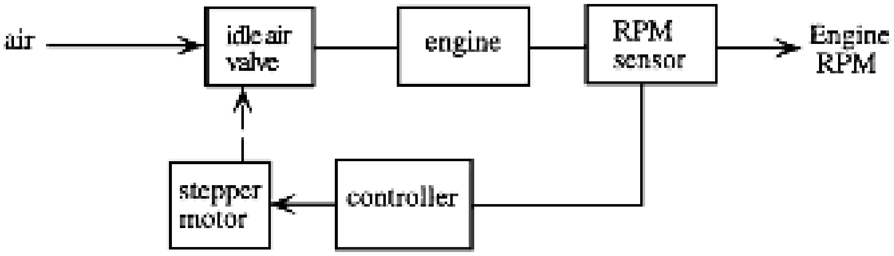
Idle speed control is used to prevent engine stall during idle. The goal is to allow the engine to idle at as low an rpm as possible, yet keep the engine from running rough and stalling when power takeoff accessories such as air conditioning compressors and alternators turn ON.

Idle speed is controlled by using an electronically controlled throttle bypass valve which allows air to flow around the throttle plate and produce the same effect as if the throttle had been slightly opened.

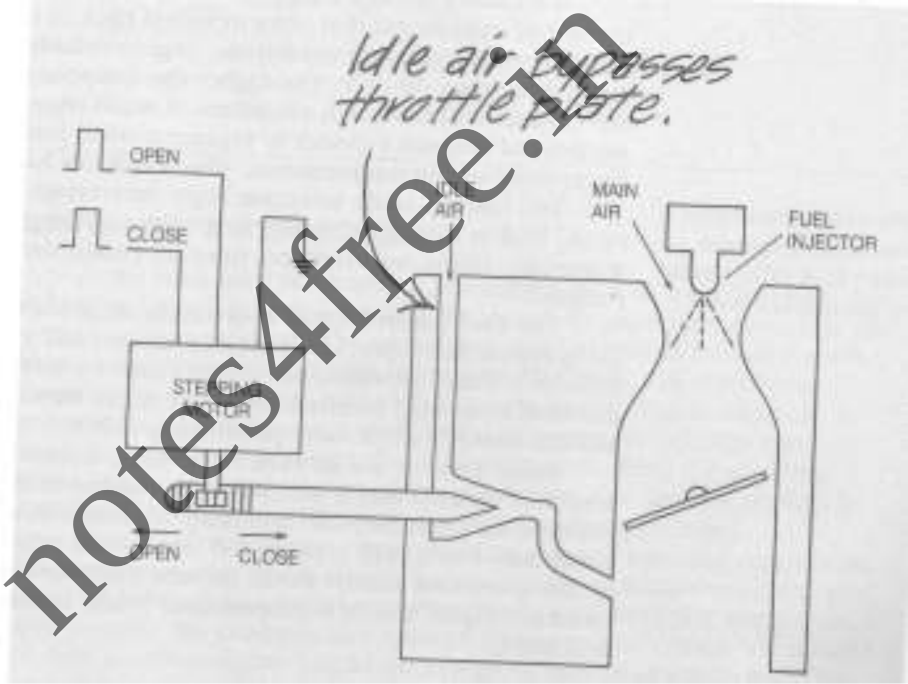
The simplest scheme is to use a solenoid to open or close a valve in the air bypass passage. By varying the duty cycle of the valve from a fully opened or fully closed it is possible to control the average flow rate of the bypass air. By controlling number of pulses, steps are provided to control the amount of opening/closing.

Idle speed is detected by rpm sensor and the speed is adjusted to maintain idle rpm constant. Air Condition, Clutch switch, Park/Neutral switch and battery charge indicator inputs indicate the load that is applied to engine during idle.

When the engine is not idling, the idle speed control valve is completely closed so that the throttle plate has complete control of intake air. During period of deceleration enhanced, the idle speed valve may be opened to provide extra air to increase the air/flow rate in order to reduce HC emissions.



Idle Air Control



3.1.3 EGR Control

A second electronic engine control subsystem is the control of exhaust gas that is recirculated back to the intake manifold. Under normal operating conditions, engine cylinder temperatures can reach more than 3000°F. The higher the temperature, the more chance the exhaust will have NOx emissions. A small amount of exhaust gas is introduced into the cylinder to replace normal intake air. This results in lower combustion temperatures, which reduces NO_x emissions.

The control mode selection logic determines when EGR is turned off or on. EGR is turned off during cranking, cold engine temperature (engine warm up), idling, acceleration, or other conditions demanding high torque.

Since exhaust gas recirculation was first introduced as a concept for reducing NOx exhaust emissions, its implementation has gone through considerable change. There are in fact many schemes and configurations for EGR realization. We discuss here one method of EGR implementation that incorporates enough features to be representative of all schemes in use today and in the near future.

Fundamental to all EGR schemes is a passageway or port connecting the exhaust and intake manifolds. A valve is positioned along this passageway whose position regulates EGR from zero to some maximum value. Typically the valve is operated by a diaphragm connected to a variable vacuum source. The controller operates a solenoid in a periodic variable-duty-cycle mode. The average level of vacuum on the diaphragm varies with the duty cycle. By varying this duty cycle, the control system has proportional control over the EGR valve opening and thereby over the amount of EGR.

In many EGR control systems the controller monitors the differential pressure between the exhaust and intake manifold via a differential pressure sensor (DPS). With the signal from this sensor the controller can calculate the valve opening for the desired EGR level. The amount of EGR required is a predetermined function of the load on the engine (i.e., power produced).

A simplified block diagram for an EGR control system is depicted in Figure. In this figure the EGR valve is operated by a solenoid-regulated vacuum actuator (coming from the intake). The engine controller determines the required amount of EGR based on the engine operating condition and the signal from the differential pressure sensor (DPS) between intake and exhaust manifolds. The controller then commands the correct EGR valve position to achieve the desired amount of EGR.

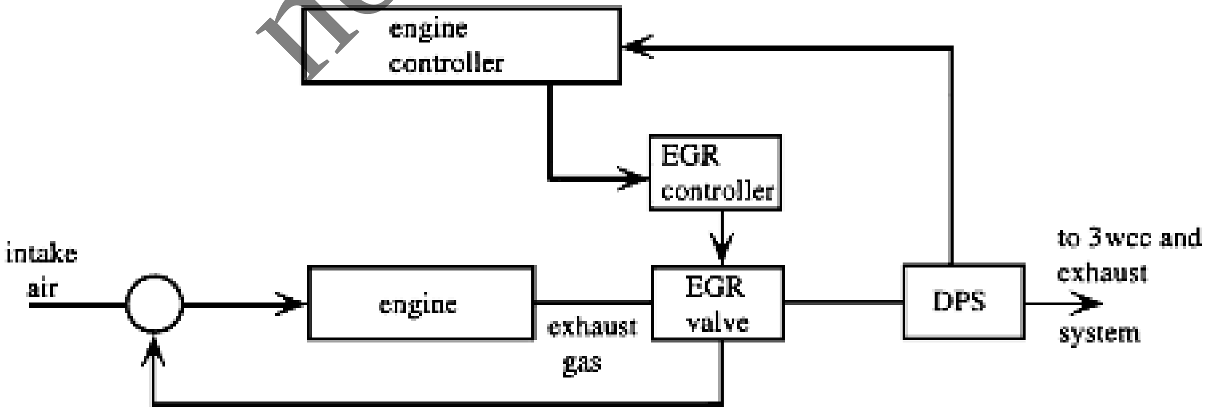


Figure: EGR Control

3.1.4 Electronic Ignition control

There are two types such as,

1. Open loop control

2. Closed loop control

3.1.4.1 Open loop Ignition control

An engine must be provided with fuel and air in correct proportions, and the means to ignite this mixture in the form of an electric spark. Before the development of electronic ignition the traditional ignition system included spark plugs, a distributor, and a high-voltage ignition Coil. The distributor would sequentially connect the coil output high voltage to the correct spark plug. In addition, it would cause the coil to generate the spark by interrupting the primary current (ignition points) in the desired coil, thereby generating the required spark. The time of occurrence of this spark (i.e., the ignition timing) in relation of the piston to TDC influences the torque generated.

In most present-day electronically controlled engines the distributor has been replaced by multiple coils. Each coil supplies the spark to either one or two cylinders. In such a system the controller selects the appropriate coil and delivers a trigger pulse to ignition control circuitry at the correct time for each cylinder. (Note: In some cases the coil is on the spark plug as an integral unit.)

Figure (a) illustrates such a system for an example 4-cylinder engine. In this example a pair of coils provides the spark for firing two cylinders for each coil. Cylinder pairs are selected such that one cylinder is on its compression stroke while the other is on exhaust. The cylinder on compression is the cylinder to be fired (at a time somewhat before it reaches TDC). The other cylinder is on exhaust.

The coil fires the spark plugs for these two cylinders simultaneously. For the former cylinder, the mixture is ignited and combustion begins for the power stroke that follows. For the other cylinder (on exhaust stroke), the combustion has already taken place and the spark has no effect.

The variables that influence the optimum spark timing at any operating condition include RPM, manifold pressure (or mass air flow), barometric pressure, and coolant temperature. The correct ignition timing for each value of these variables is stored in a ROM lookup table. For example, the variation of spark advance (SA) with RPM for a representative engine is shown in Figure (b).

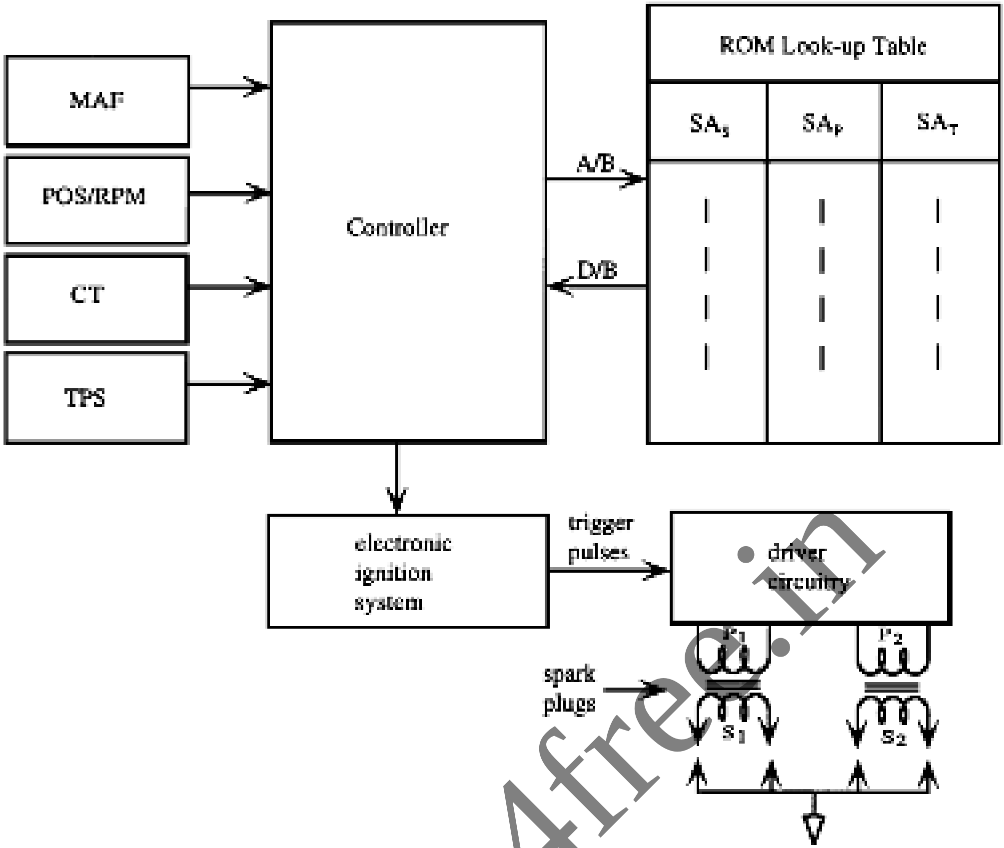


Figure (a) Distributorless Ignition System

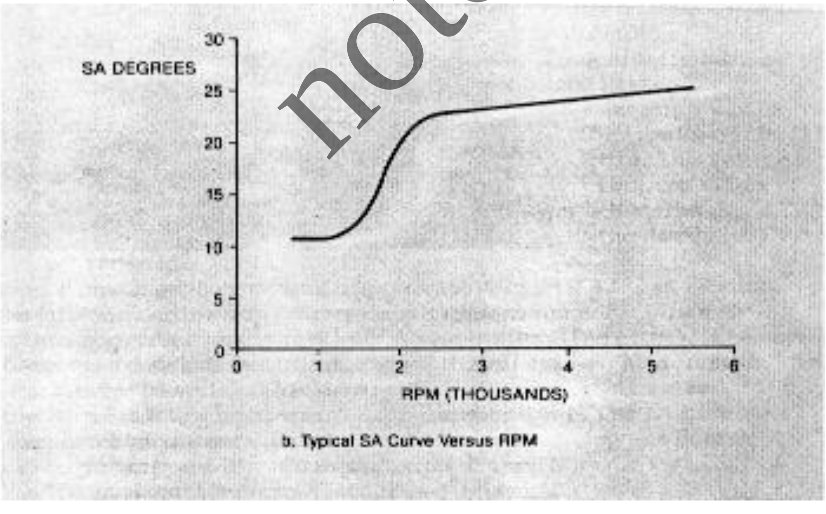


Figure (b) Typical SA curve versus RPM

The engine control system obtains readings from the various sensors and generates an address to the lookup table (ROM). After reading the data from the lookup tables, the control system computes the correct spark advance. An output signal is generated at the appropriate time to activate the spark.

Figure (a) is a schematic of a representative electronic ignition system. In this example configuration the spark advance value is computed in the main engine control (i.e., the controller that regulates fuel). This system receives data from the various sensors (as described above with respect to fuel control) and determines the correct spark advance for the instantaneous operating condition.

In the configuration depicted in Figure (a), the electronic ignition is implemented in a stand-alone ignition module. This solid-state module receives the correct spark advance data and generates electrical signals that operate the coil driver circuitry. These signals are produced in response to timing inputs coming from crankshaft and camshaft signals (POS/RPM). The coil driver circuits generate the primary current in windings P1 and P2 of the coil packs depicted in Figure (a). These primary currents build up during the so-called *dwell period* before the spark is to occur. At the correct time the driver circuits interrupt the primary currents via a solid-state switch. This interruption of the primary current causes the magnetic field in the coil pack to drop rapidly, inducing a very high voltage (20,000–40,000 volts) that causes a spark. In the example depicted in Figure (a), a pair of coil packs, each firing two spark plugs, is shown. Such a configuration would be appropriate for a 4-cylinder engine. Normally there would be one coil pack for each pair of cylinders.

The ignition system described above is known as a *distributorless ignition system* (DIS) since it uses no distributor. There are a number of older car models on the road that utilize a distributor. However, the electronic ignition system is the same as that shown in Figure (a), up to the coil packs. In distributor-equipped engines there is only one coil, and its secondary is connected to the rotary switch (or distributor).

In a typical electronic ignition control system, the spark advance SA (in degrees before TDC) is made by several components that are added together

$SA = SA_S + SA_P + SA_T$

ROM LOOK UP TABLE

SA_S	SA_P	SA_T
-------	--------	--------
-------	--------	--------
-------	---------	--------

The first component SA_S = Basic spark advance which is a tabulated function of RPM and MAP. The control system reads RPM and MAP, and then calculates the address in ROM of the SA_S that corresponds to these values.

Typically, from idle to 1200 RPM, increase in SA is relatively slow.

From about 1200 to 2300 RPM, increase in SA is relatively quick.

Beyond 2300 RPM, the increase in SA is again relatively slow.

Spark advance increases with RPM and MAP.

The second component SA_P **=** Contribution to spark advance due to Barometric Pressure. This value is obtained from ROM look up tables. Generally speaking, the SA is reduced as pressure increases.

The final component SA_T = Contribution to spark advance due to temperature. Spark advance decreases with increase in temperature after a certain predetermined temperature.

3.1.4.2 Closed Loop Ignition Timing

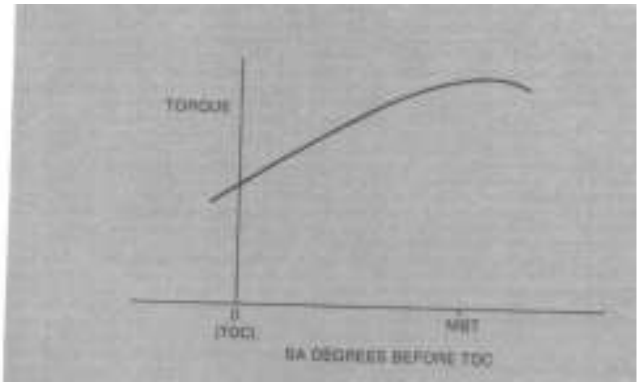
When the spark is advanced too far, an abnormal combustion phenomenon occurs that is known as 'knocking'. At the present time, knocking is not a fully understood phenomenon, although much is known about it. It is characterized by an abnormally rapid rise in cylinder pressure during combustion, followed by very rapid oscillation in cylinder pressure. A relatively low level of knock is generally beneficial to performance.

Excessive knock is unquestionably damaging to engine and must be avoided and control strategy for spark under closed loop control is to advance the spark timing until the spark level becomes unacceptable. At this point, the control system advances the spark advance (retarded spark) until acceptable levels of knock are achieved. A spark advance control scheme based upon limiting the levels of knocking requires a knock sensor. This sensor responds to acoustical energy in the spectrum of the rapid cylinder pressure oscillation as shown in figure.

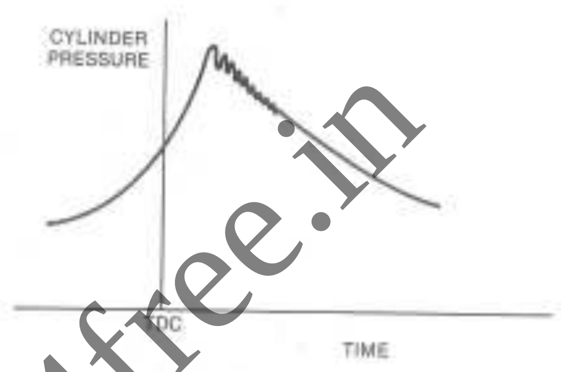
In the figure following the detector is an electronic gate that examines the knock sensor output at the time for which the knock amplitude is largest (i.e., shortly after TDC). The gate is, in essence, an electronic switch that is normally open, but is closed for a short interval (i.e., from 0 to t) following TDC. It is during this interval that the knocking signal is largest in relationship to engine noise. The probability of detecting successfully the knock signal is greatest during this interval.

Similarly, the possibility of mistaking engine noise for tone knock signal is smallest during this interval. The final stage in the knock measuring instrumentation is integration w.r.t. time. This can be accomplished using an OPAMP.

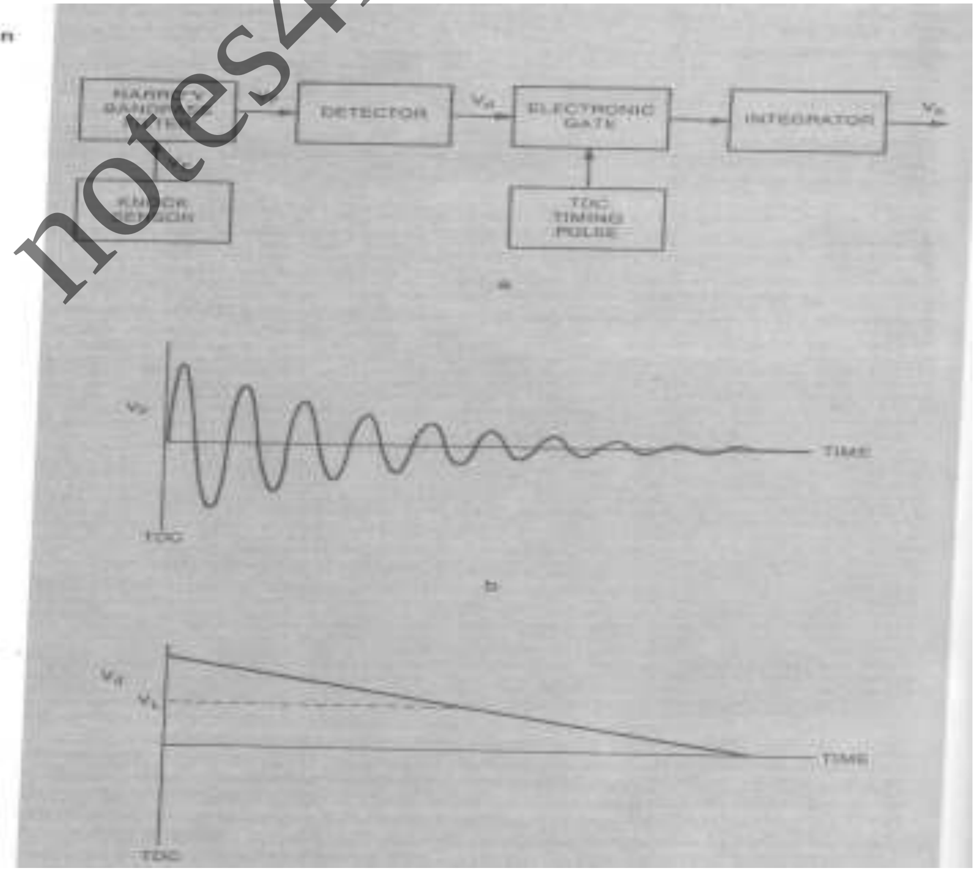
Torque Versus SA for Typical Engine



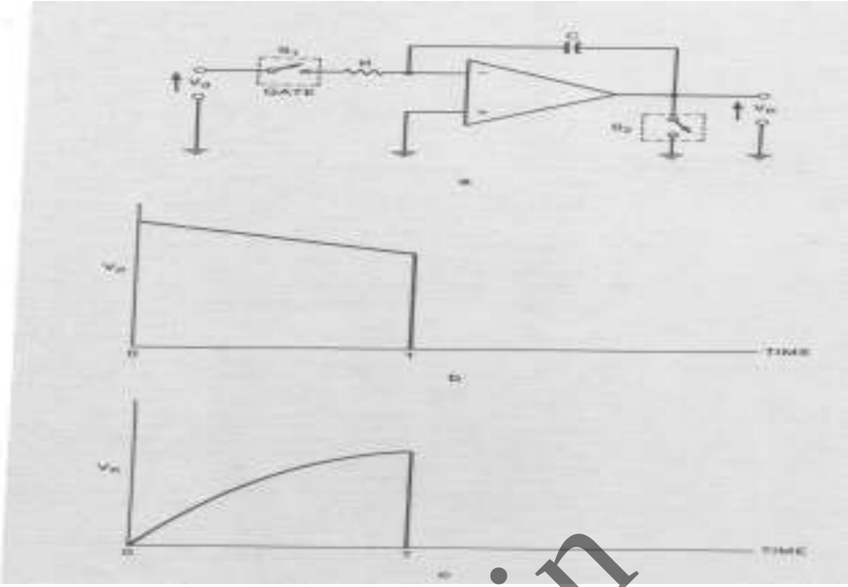
Cylinder Pressure (Knocking Condition)



Instrumentation and Waveforms for Ignition Control



Example Integrator Circuit Diagram

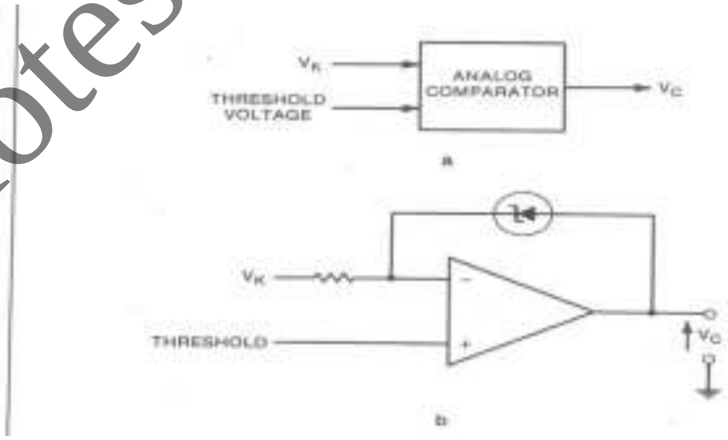


$V_k = -\frac{1}{RC}\int_0^T V_d(t)\ dt;$

If there is no knock, $V_k \cong 0$

The level of knock intensity is indicated by voltage $V_k(T)$ at the end of gate interval. The spark control system compares this voltage with a threshold voltage to determine whether knock has or has not occurred.

Knock Level Detector Circuit



Whenever $V_k(T)$ > threshold value, the comparator output is high indicating knock.

3.1.4.3 Spark Advance Correction Scheme

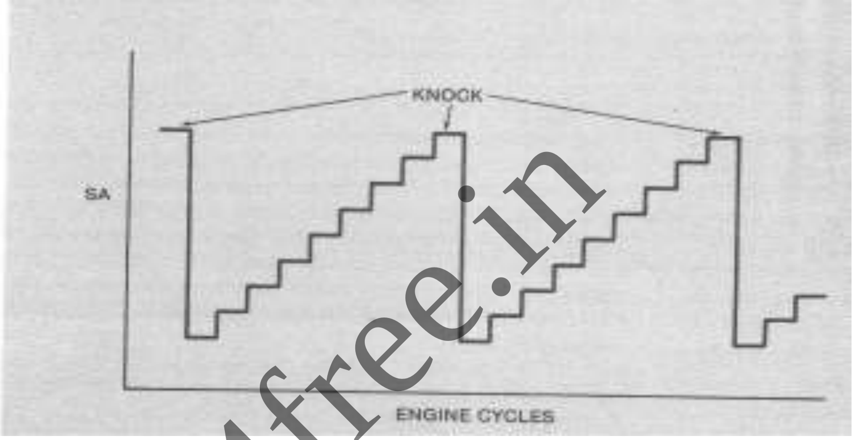
Whenever knock is excessive, a closed-loop spark advance system causes spark to retard. Although the details of spark advance control vary from manufacturer to manufacturer, there are generally two classes of correction that are used: *fast correction and slow correction.*

(i) **Fast Correction Scheme:**

In the fast correction scheme, the spark advance is decreased for the next engine cycle by a fixed amount (typically from 5° to 10°) whenever knock is detected. Then the spark advance is advanced in one degree increments every 5 to 20 crankshaft revolutions.

The fast correction ensures that minimum time is spent under heavy knocking conditions. Further, this scheme compensates for hysteresis (i.e., for one degree of spark advance to cause knocking, more than one degree must be removed to eliminate knocking). The fast correction scheme is depicted in Figure.

Fast Correction Spark Advance

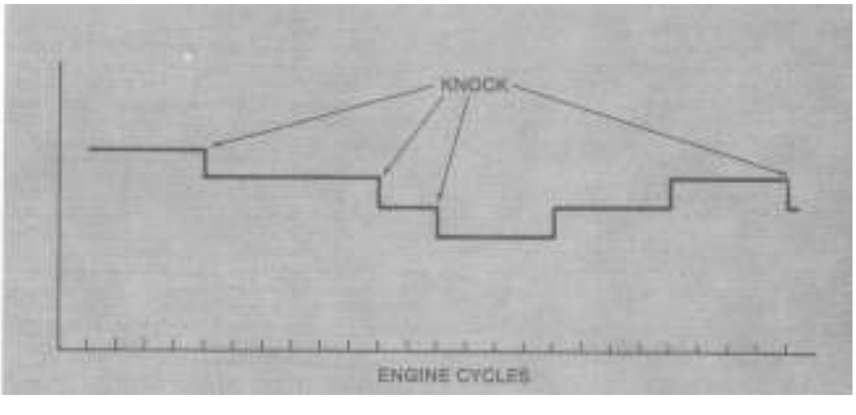


(i) Slow Correction Scheme:

In the slow correction scheme (Figure 7.16), spark advance is decreased by one (or more) degree each time knock is detected, until no knocking is detected. The spark advance proceeds in one-degree increments after many engine cycles.

The slow correction scheme is more of an adaptive closed-loop control than is the fast correction scheme. It is primarily employed to compensate for relatively slow changes in engine condition or fuel quality (i.e., octane rating).

Slow Correction Spark Advance



3.1.5 Integrated Engine Control System

Additional functions can be included in the Engine Control System other than the main functions such as Fuel Control, Spark Control and EGR. Several of these additional functions include the following:

1. Secondary Air Management
2. Evaporative Emissions Canister Purge
3. Automatic System Adjustment
4. System Diagnosis

3.1.5.1 Secondary Air Management

Secondary air management is used to improve the performance of the catalytic converter by providing extra oxygen rich air t either converter itself or to the exhaust manifold. The Catalyst temperature must be above about 300^0C to efficiently oxidize HC and CO and reduce NO_X. During engine warm up when the catalytic converter is cold, HC and CO is oxidized in the exhaust manifold by routing secondary air to the manifold. This creates extra heat to speed warm up of the converter and EGO sensor, enabling the fuel controller to go to the closed loop mode more quickly.

The converter can be damaged if too much heat is applied to it. This can occur if large amounts of HC and CO are oxidized in the manifold during periods of heavy loads which call for fuel enrichment, or during severe deceleration. In such cases, the secondary air is directed to the air cleaner where it has no effect on exhaust temperatures.

After warm up, the main use of secondary air is to provide an oxygen rich atmosphere in the second chamber of the three way catalyst dual chamber converter system. In the dual chamber converter, the first chamber contains rhodium, palladium and platinum to reduce NO_X and to oxidize HC and CO. The second chamber contains only platinum and palladium. The extra oxygen from the secondary air improves the converter's ability to oxidize HC and CO in the second converter chamber.

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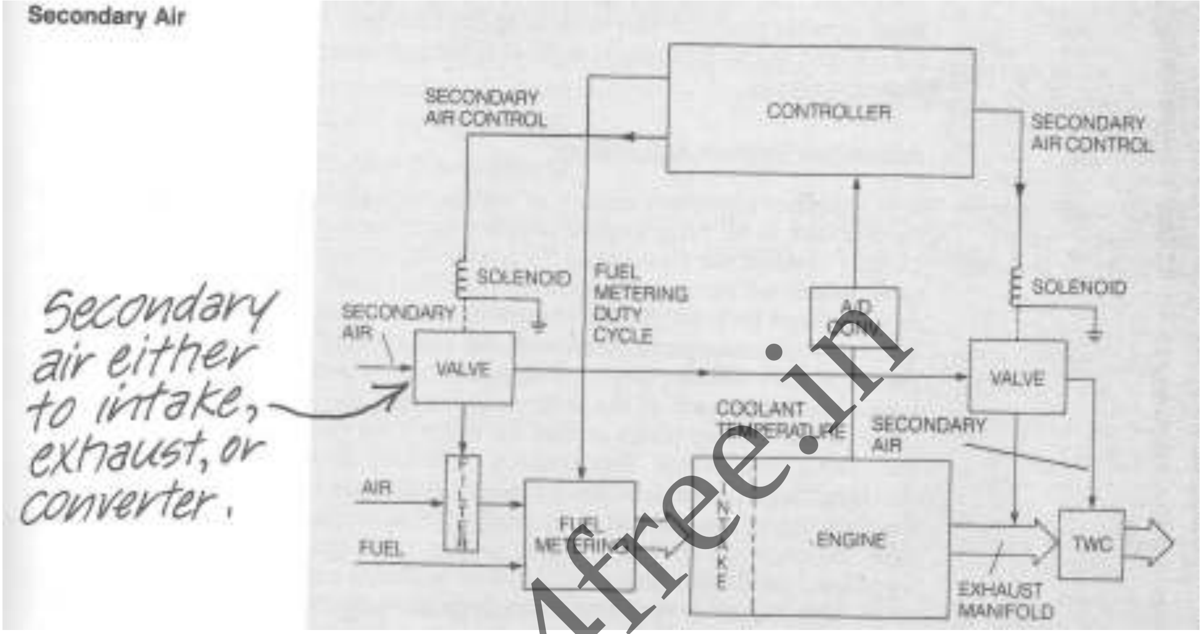
The computer program for the control mode selection logic can be modified to include the conditions for controlling secondary air. The computer controls secondary air by using two solenoid valves similar to EGR valve. One valve switches air flow to the air chamber or to the exhaust system. The other valve switches air flow to the exhaust manifold or to the converter. The air routing is based on engine coolant temperature and air/fuel ratio.



3.1.5.2 Evaporative Emissions Canister Purge

During engine OFF conditions, the fuel stored in the intake manifold tends to evaporate into the atmosphere. To reduce the HC emissions, they are collected by a charcoal filter in the canister. The collected fuel is released into the intake manifold through a solenoid valve controller by the computer. This is done during closed loop operation to reduce fuel calculation complications in the open loop mode.

3.1.5.3 Automatic System Adjustment

Another important feature of micro controller engine control system is their ability to be programmed to learn from their part experiences. Many Control systems use this feature to enable the computer to learn new look up table values for computing open loop mode, Air/fuel ratio. While the computer in the closed loop mode, the computer checks its open loop calculated air/fuel ratios and compares those with the closed loop average limit cycle values. If they match closely, nothing is learned and open loop look up tables are unchanged. If the difference is large, the system controller corrects the look up tables so that the open loop values more closely match the closed loop values. This updated open loop look up table is stored in memory which is always powered directly by the car battery so that the new values are not lost while the ignition key is turned OFF. The next time the engine is started, the new look up table values will be used in the open loop mode and will provide more accurate control of the air/fuel ratio. This feature is very important because it allows the system controllers to adjust to long term changes in engine and fuel system conditions. This feature can be applied in individual sub system control systems, or in the fully integrated control system. If not available initially, it may be added to the system by modifying its control program.

3.1.5.4 System Diagnosis

Another important feature of micro controller engine control systems is their ability to diagnose failures in their control systems and alert the operator. Sensor and actuator failures or miss adjustments can be easily detected by the computer. For instance, the computer will detect a malfunctioning MAP sensor if the sensors output goes above or below certain specified limits or fails to change for long periods of time. A prime example is the automatic adjustment system just discussed. If the open loop calculations consistently come up wrong, the engine control computer may determine that one of the many sensors used in the open loop calculations has failed.

If the computer detects the loss of a primary control sensors or actuators, it may close to operate in a different mode until the problem is repaired. The operator is notified of a failure by blinking lights or some other indicator on the dashboard. Because of the flexibility of the micro controller engine control systems, additional diagnostic programming might be added to accommodate different engine models that contain more or fewer sensors. Keeping the system totally integrated gives the controller the access to more sensor inputs so that they can be checked. Module 5 - Chapter 1 discusses system Diagnosis more fully.

SUMMARY OF CONTROL MODES:-

Parameter	**Engine crank (Start)**	**Engine Warm-up**	**Open Loop Control**	**Closed Loop Control**	**Hard Acceleration**	**Deceleration and Idle**
1.Engine RPM	at cranking speed	above cranking speed at command of driver	at the command of driver	at the Command of driver	Driver asking for sharp increase in RPM or in Engine Power, demanding Maximum Torque	RPM decreasing rapidly due to driver command or else held constant at idle.

2. Engine Coolant Temperature	at low Temperature	rises to Minimum threshold	above Warm up threshold	in normal range	in normal range	in normal range
3. A/F Ratio	Low (Rich mixture)	Low (Rich mixture)	Controlled by open Loop system 14.7:1	Average A/F ratio Controlled to 14.7±0.05	Rich mixture (Low)	Lean mixture (High)
4.Spark	Retarded	Timing set controller	Timing set by controller	Timing set by controller	Timing set by controller	Retarded
5.EGR	OFF	OFF	Controlled	Controlled	OFF	ON
6.Secondary Air	to exhaust manifold	to exhaust manifold	to catalytic converter	to catalytic converter	to intake	to intake
7.Fuel economy	not closely controlled	not closely controlled	controlled	tightly controlled	poor fuel economy	good fuel economy during deceleration and poor during idle but fuel consumption kept to minimum possible
8.Emissions	not closely controlled	not closely controlled	controlled	tightly controlled	Poor emission control	special mode to reduce emissions for both

Module 3- Chapter 2 – Control Units

3.2.0 INTRODUCTION:

FUNCTION OF CONTROL UNIT:

Receive electrical signals from the sensors - evaluate them - calculate triggering signals for actuators.

To perform above functions we should have control program,"software" is stored in special memory and implemented by microcontroller. The control unit and its components are referred to as hardware. "Motronic" is the name of the engine management system that facilitates open- and closed-loop control of gasoline engines with a single control unit.

Mo - movement or motion; *tronic* - Electronic

Autosar initiative (Automotive open systems architecture):-

Aut o s ar, in which various motor vehicle manufacturers suppliers participate, in working towards a standardization of electronics architecture with the aim of reducing complexity through increased reusability and interchangeablility of software modules.

FUNCTIONS OF MOTRONIC ENGINE MANAGEMENT SYSTEM:-

- To adjust the torque desired and input by the driver depressing the accelerator pedal.
- To operate the engine in such a way as to comply with the requirements of ever more stringent emissions control legislation.
- To ensure the lowest possible fuel consumption but at the same time.
- To generate high levels of driving comfort and driving pleasure.

3.2.1 OPERATING CONDITIONS:-

- Extreme ambient temperature -40 to +60....+125c
- Extreme temperature changes
- Indirect materials and supplies (oil, fuel etc)
- The effects of moisture
- Mechanical stress such as vibration from the Engine
- Must operate reliably when the vehicle is started with a weak battery (eg.cold start) and with high charge voltage (vehicle electrical system fluctuations)
- EMC (Electromagnetic compatibility)
- Immunity to electromagnetic interference (EMI)

3.2.2 DESIGN:-

The PCB with electrical components is installed in a housing of plastic or metal. A multiple plug connects the control unit to the sensors, actuators and electrical power supply.

The high performance driver circuits (using power transistors) that provide direct control of actuators are specially integrated within the housing to ensure effective heat transfer to the housing and surrounding air.

The majority of the electrical components are SMD (surface mounted device) technology type. This concept provides extremely efficient use of space in low weight packages. Only a few power components and the connectors use push through assembly technology.

Hybrid versions with extreme resistance to thermal attack are available for mounting directly on engine.

3.2.3 DATA PROCESSING:-

3.2.3.1 Input signals (from sensors) :-

- Analog input signals-A/D converter
- Eg:- Intake air mass battery voltage intake air temperature.
- Digital input signals-Directly fed
- Pulse type input signals (from inductive type sensors)
    - spurious pulses are suppressed
    - pulses converted to digital rectangular signals.

3.2.3.2 Signal conditioning:-

- Protective circuits limit the voltage to level suitable for processing
- Filters separate useful signal from interference signals
- When necessary, signals are then amplified to the input voltage required by microcontroller (0 to 5V)

3.2.3.3 Signal processing:-

Input signals provided by sensors and interface to other systems (such as CAN bus) are used as input variables and are subjected to further plausibility check in the computer. The control unit program supports generation of the output signals used to control the actuators.

3.2.3.4 Output signals:-

These are connected to actuators directly most of the times provide enough power required. It is also possible to activate certain output stage relays for consumers that use up a great deal of power (eg. motor fans).

3.2.3.5 Switching signals:-

Actuators can be switched ON and OFF using switching signals (eg. motor fans).

3.2.3.6 PWM (pulse width modulated) signals:

These are constant frequency rectangular signals with variable ON-times.

CONTROL UNIT INTERNAL COMMUNICATION:-

Address Bus, Data Bus (multiplexed or separate)

8 bit-256 addresses

16 bit -65,536 addresses

32 bit- 2^{32} addresses

Serial interfaces with single data line are used for data that does not have to be transmitted quickly (eg. fault data).

3.2.4 PROGRAMMING:

EOL (End Of Line) PROGRAMMING:-

This is to cater for extensive variety of vehicle variants with differing control programs and data records (calibration) with limited Hardware types. The flash EPROMS complete memory area can be programmed at the end of production with the program and the variant specific data record (calibration) is called End of line programming.

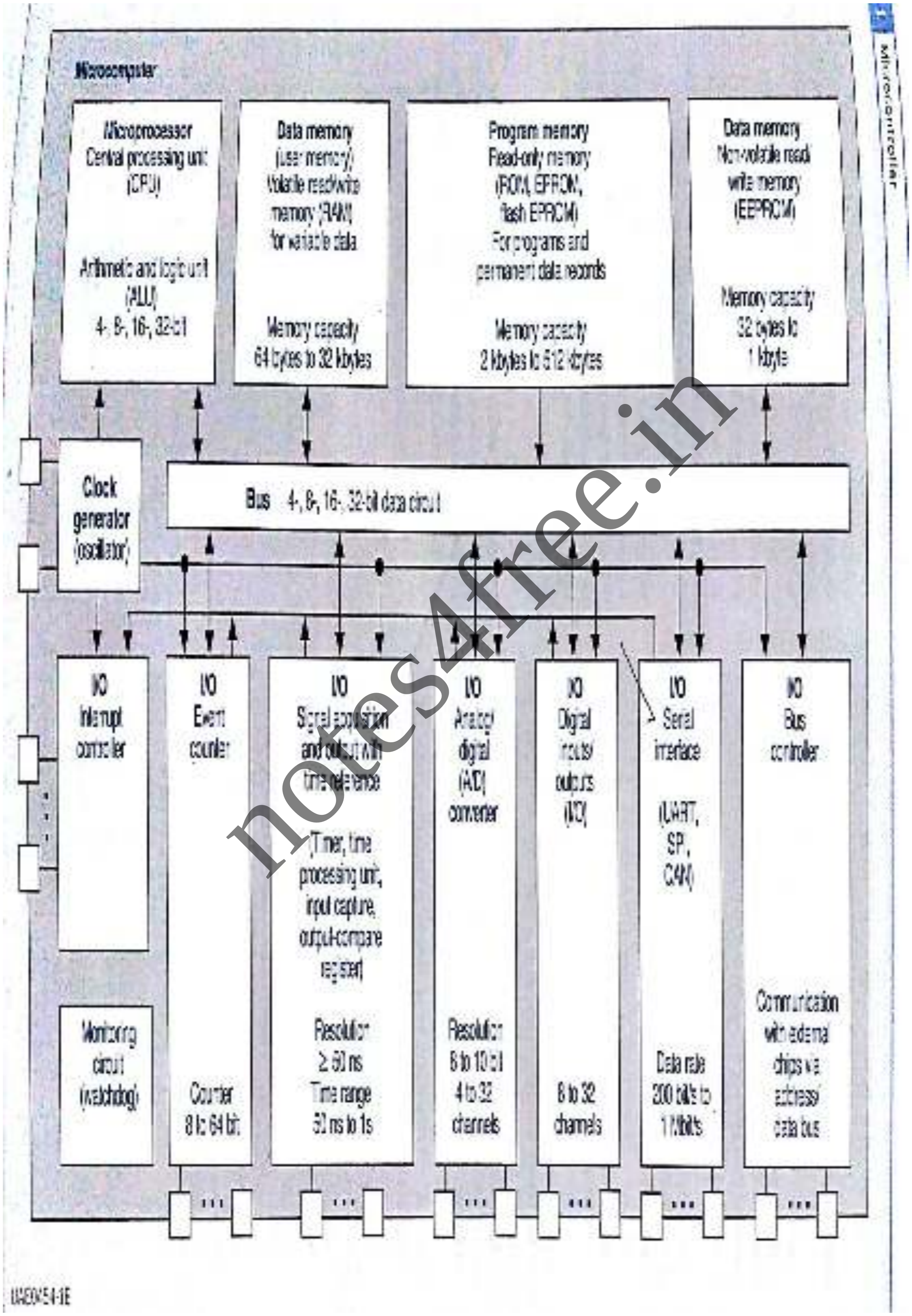
Another way of reducing the type diversity is to store several data variants in the memory which are then selected using coding at the end of the production line. This coding is stored in EEPROM.

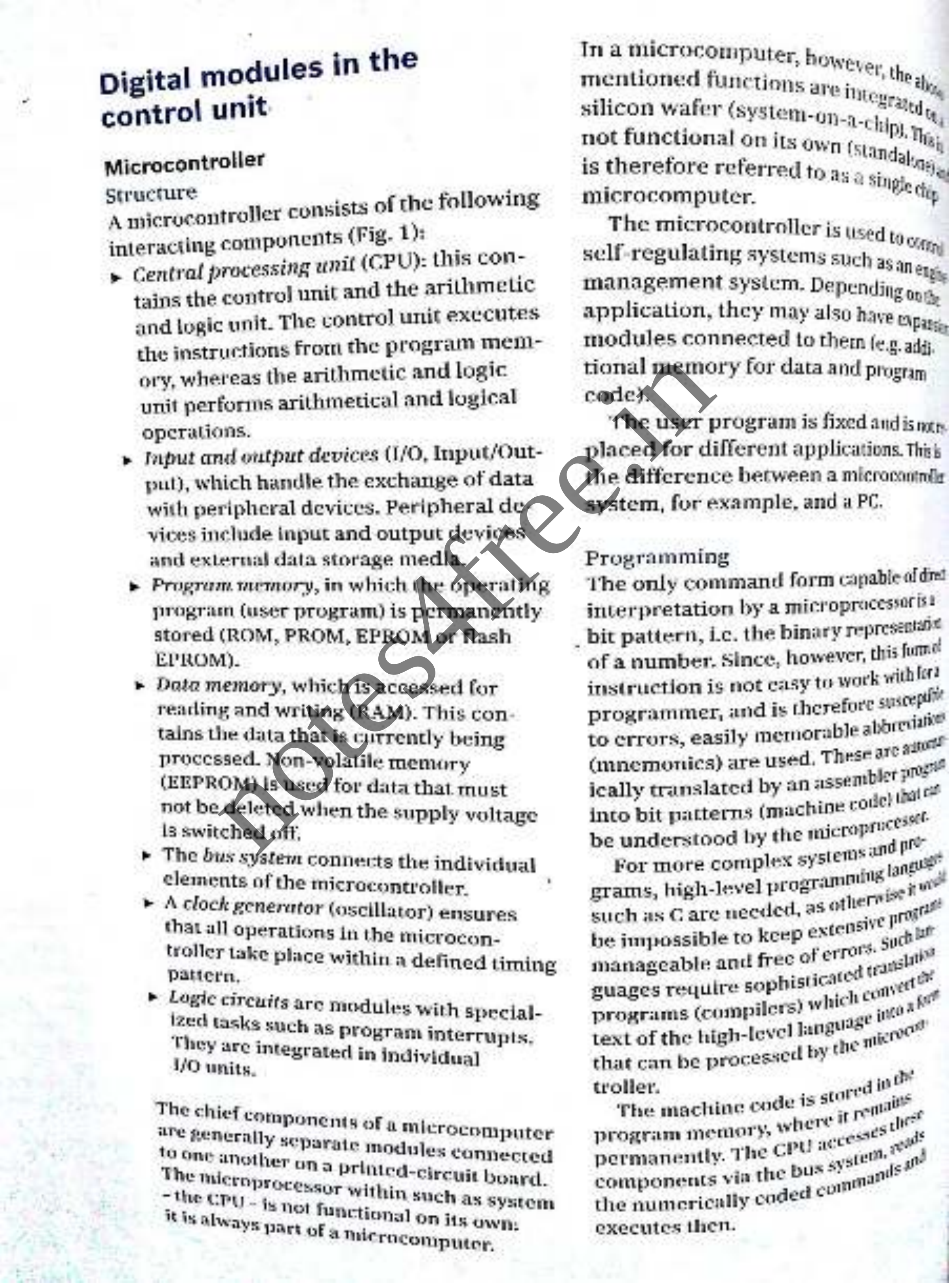
DEVELOPMENT OF ELECTRONIC CONTROL UNITS:-

The performance of ECU goes hand in hand with advances achieved in the field of Microelectronics. Initially only fuel injection was controlled. Later ignition system including knock control, EGR and whole variety of other systems were controlled.

3.2.5 DIGITAL MODULES IN THE CONTROL UNIT:

The figure shows different digital modules of Control unit.


Microcontroller
Microcomputer
Microprocessor
Central processing unit
(CPU)
Arithmetic and logic unit
(ALU)
4-, 8-, 16-, 32-bit
Data memory
(user memory)
Volatile read/write
memory (RAM)
for variable data
Memory capacity
64 bytes to 32 kbytes
Program memory
Read-only memory
(ROM, EPROM,
flash EPROM)
For programs and
permanent data records
Memory capacity
2 kbytes to 512 kbytes
Data memory
Non-volatile read/
write memory
(EEPROM)
Memory capacity
32 bytes to
1 kbyte
Clock
generator
(oscillator)
Bus 4-, 8-, 16-, 32-bit data circuit
I/O
Interrupt
controller
Monitoring
circuit
(watchdog)
I/O
Event
counter
Counter
8 to 64 bit
I/O
Signal acquisition
and output with
time reference
(Timer, time
processing unit,
input capture,
output-compare
register)
Resolution
≥ 50 ns
Time range
50 ns to 1s
I/O
Analog/
digital
(A/D)
converter
Resolution
8 to 10 bit
4 to 32
channels
I/O
Digital
inputs/
outputs
(I/O)
8 to 32
channels
I/O
Serial
interface
(UART,
SPI,
CAN)
Data rate
200 bit/s to
1 Mbit/s
I/O
Bus
controller
Communication
with external
chips via
address/
data bus
UAE0454-1E



Digital modules in the control unit

Microcontroller

Structure

A microcontroller consists of the following interacting components (Fig. 1):

- *Central processing unit* (CPU): this contains the control unit and the arithmetic and logic unit. The control unit executes the instructions from the program memory, whereas the arithmetic and logic unit performs arithmetical and logical operations.
- *Input and output devices* (I/O, Input/Output), which handle the exchange of data with peripheral devices. Peripheral devices include input and output devices and external data storage media.
- *Program memory*, in which the operating program (user program) is permanently stored (ROM, PROM, EPROM or flash EPROM).
- *Data memory*, which is accessed for reading and writing (RAM). This contains the data that is currently being processed. Non-volatile memory (EEPROM) is used for data that must not be deleted when the supply voltage is switched off.
- The *bus system* connects the individual elements of the microcontroller.
- A *clock generator* (oscillator) ensures that all operations in the microcontroller take place within a defined timing pattern.
- *Logic circuits* are modules with specialized tasks such as program interrupts. They are integrated in individual I/O units.

The chief components of a microcomputer are generally separate modules connected to one another on a printed-circuit board. The microprocessor within such as system – the CPU – is not functional on its own: it is always part of a microcomputer.

In a microcomputer, however, the above mentioned functions are integrated on a silicon wafer (system-on-a-chip). This is not functional on its own (standalone) and is therefore referred to as a single chip microcomputer.

The microcontroller is used to control self-regulating systems such as an engine management system. Depending on the application, they may also have expansion modules connected to them (e.g. additional memory for data and program code).

The user program is fixed and is not replaced for different applications. This is the difference between a microcontroller system, for example, and a PC.

Programming

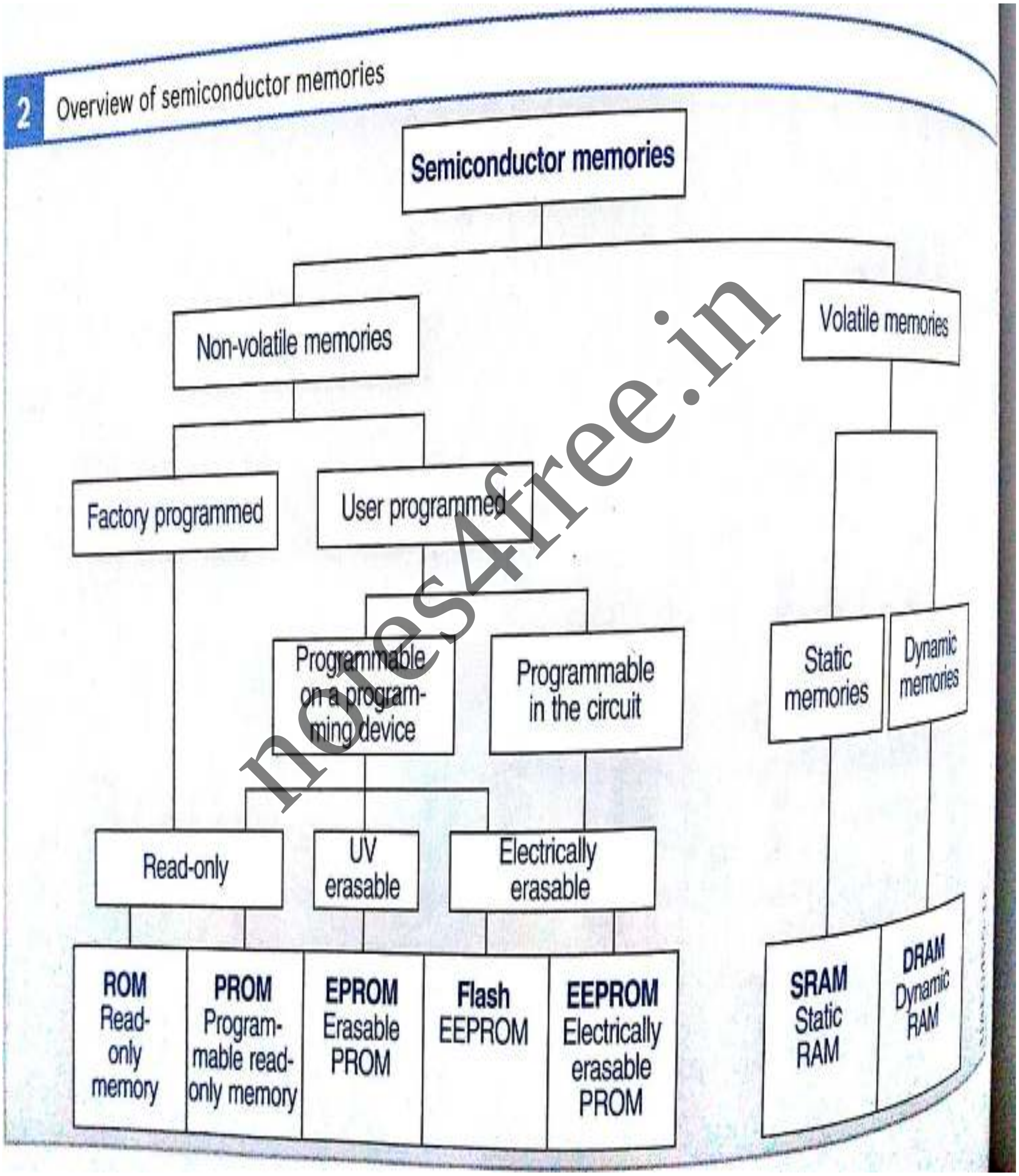
The only command form capable of direct interpretation by a microprocessor is a bit pattern, i.e. the binary representation of a number. Since, however, this form of instruction is not easy to work with for a programmer, and is therefore susceptible to errors, easily memorable abbreviations (mnemonics) are used. These are automatically translated by an assembler program into bit patterns (machine code) that can be understood by the microprocessor.

For more complex systems and programs, high-level programming languages such as C are needed, as otherwise it would be impossible to keep extensive programs manageable and free of errors. Such languages require sophisticated translation programs (compilers) which convert the text of the high-level language into a form that can be processed by the microcontroller.

The machine code is stored in the program memory, where it remains permanently. The CPU accesses these components via the bus system, reads the numerically coded commands and executes then.

3.2.5.1 OVERVIEW OF SEMICONDUCTOR MEMORIES:-

The figure shows different Semiconductor memories that can be used in Control unit.



The figure shows the explanation about different types of memories used.

Random-access memory (RAM)

Random-access memory or RAM is a short-term memory that allows direct access to any storage location. Information can be read/written from/to the memory any number of times.

Static RAM (SRAM)

Static RAMs use bistable switching elements as the data storage cells. Their functionality is similar to that of a flip-flop, a simple circuit with two transistors, of which either the one (logical "1") or the other (logical "0") conducts at any one time. In SRAM, the information remains stored until the storage cell concerned is addressed and overwritten, or the operating voltage is switched off. SRAM is therefore volatile memory.

Dynamic RAM (DRAM)

Unlike SRAM, the information is stored as an electrical charge in the gate capacity of a CMOS transistor in dynamic RAM (DRAM). As such capacitors are susceptible to leakage, the charge is gradually lost. In order to retain the information, the charge has to be refreshed at regular intervals (every few ms).

Read-only memory

Read-only memory (ROM) is permanent-storage memory that allows any memory location to be accessed directly but – as the name indicates – allows the information only to be read and not modified.

A ROM is nonvolatile memory, i.e. the information it contains is retained even when the operating voltage is switched off. It is usually used to store program code (control programs) and fixed data (function tables, encoding rules, engine characteristic data maps) that need to be retrievable at any time. The information may be indelibly entered in the memory by the manufacturer or the user by means of appropriate programming of specially prepared memories (PROMs or programmable ROMs).

Erasable ROM

There are also ROMs whose contents can be erased and reprogrammed as outlined below.

EPROM (Erasable PROM)

This type of erasable read-only memory can have its contents completely wiped by irradiation with UV light and can then be reprogrammed using a programming device.

EEPROM (Electrical EPROM)

The EEPROM (also known as E^2PROM) can be electrically erased and reprogrammed. Every storage cell of an EEPROM be individually overwritten. For this reason, this type of memory module can also be used as nonvolatile data memory (e.g. for learned information in engine management systems).

Flash EEPROM

A more sophisticated variant of the EPROM and EEPROM is flash EEPROM. In this case, electrical flash pulses are used to erase specific storage areas or the entire contents of the memory. The erased areas can subsequently be reprogrammed.

The flash memory can be reprogrammed on a programming station. However, the advantage of flash EEPROM is that is can also be reprogrammed while still inside the sealed control unit.

Flash EEPROM is used in cases where relatively large quantities of data need to be stored, but must also be modifiable (e.g. program memory in vehicle control units).

3.2.6 CONTROL UNIT SOFTWARE:

Real time capability:-

This means that control procedures must react to input signals within extremely short time. Eg:- ABS (Antilock Braking system).

Software structure:-

Normally Commands are executed sequentially. The time taken to read in and execute the command depends on the microcontroller that is used and the clock frequency. Current Microcontrollers that are used in vehicles can execute up to 1 million commands per second.

Priority based execution:-

Eg:- Time critical functions processed at high priority speed sensor that records engine speed and crankshaft position signals arrive at short intervals that can be a matter of milliseconds, depending on the engine speed other functions such as reading in the engine temperature are not as urgent, since the physical variable only changes extremely slowly in this case.

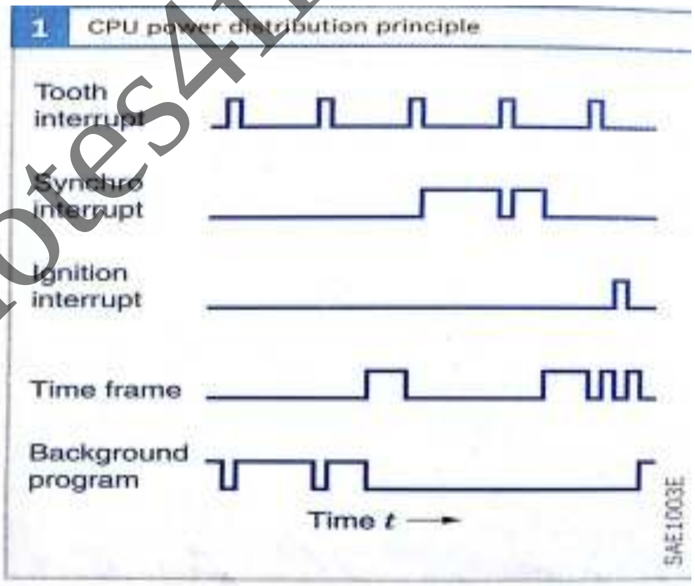


Fig. 1
Depiction of several program levels on the example of the software from a Motronic system

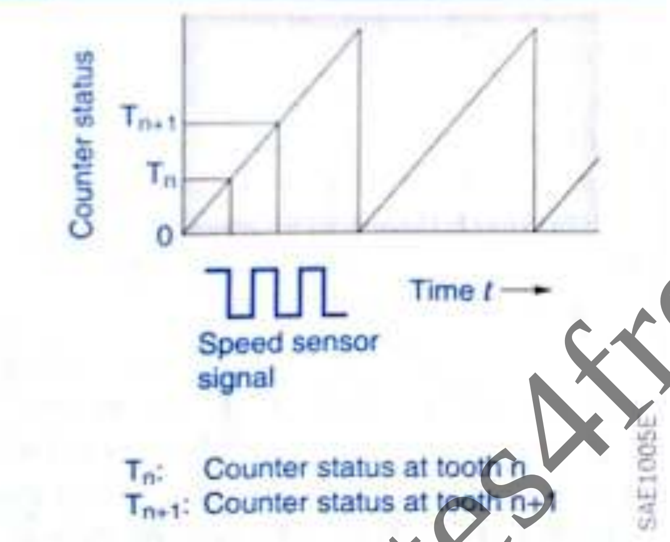
Interrupt control:-

As soon as an event occurs that requires an extremely rapid response (e.g. speed sensor pulse), the program that is currently running must be interrupted. Events can trigger a program execution interrupt, where upon the program jumps and executes the 'interrupt routine'. When this routine has been executed, the program resumes at the point at which it was interrupted.

An interrupt can be triggered by an external signal. Other interrupt sources are timers integrated in the signals can be generated (eg. ignition signal: Microcontroller ignition output is switched at a point in time that is calculated before hand). However, the timer can also generate internal time frames.

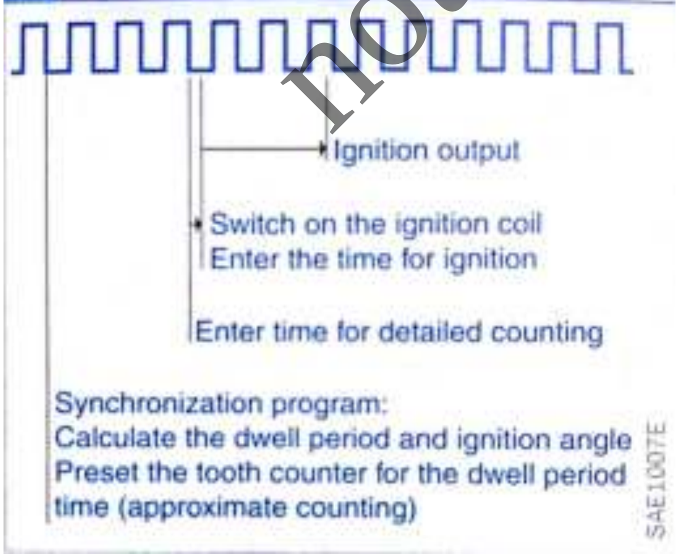
The control unit program reacts to several of these interrupts. An interrupt source can therefore request an interrupt while another interrupt routine is current being executed. Every interrupt source therefore has a fixed priority assigned to it. The priority controller decides which interrupt is allowed to interrupt another interrupt.

3 Time calculations via internal timer



4 Triggering the interrupt synchronously with combustion

5 Dwell and ignition time output



Tooth Interrupt:-

The crankshaft is equipped with a 'pulse wheel' that has a certain number of teeth on its circumference. The teeth are scanned by the speed sensor. This allows the crankshaft position to be recorded. The typical distance between a pair of teeth on the crankshaft sensor wheel is 6 degrees. In order to determine the crankshaft position, the control unit program must execute certain routines as each tooth is detected.

Combustion Synchronous Interrupt:

Some calculations have to be performed for every combustion cycle. For example, the ignition angle and the injection have to be calculated synchronously with combustion for each cylinder. The program does this by branching to the Synchronization Program after certain teeth.

Ignition Interrupt:

The ignition output takes place within a certain crankshaft range, depending on the value from the ignition map. Since the specified ignition angle has to be adhered to exactly, the ignition output to be controlled by an interrupt. Like the synchronization program, the ignition interrupt is also called up once per combustion cycle.

Time Frame:

Many Control algorithms have to run within a certain time frame, ***Lambda Control***, for example has to be processed with in a fixed time frame (e.g., 10 ms) so that the corresponding variables are calculated quickly enough.

Background Program:

All other activities that not run either in an interrupt routine or in a time frame are processed in a background program. At fast engine speeds, the synchronization program and the tooth interrupt are called frequently, having little CPU time for the background program, The Background program must therefore only contain low priority functions.

MODEL QUESTIONS

Module 3- Chapter 1 – Digital Engine Control Systems

1. What are the seven modes of Fuel Control?
2. Write the diagram of a Digital Engine Control System.
3. Explain Engine warm up mode with the help of relevant look up table and derive the equation of the fuel injector pulse duration in terms of MAF and A/F ratio.
4. Explain Open loop fuel control using speed density method with relevant diagram, look up table and equations.
5. Explain the closed loop fuel control using relevant equations and graphs.
6. Explain Idle Air Control using relevant diagrams.
7. Explain EGR Control using relevant diagram.
8. Explain Closed loop Ignition Control with the help of Instrumentation and waveforms.
9. Differentiate between two spark advance correction schemes with relevant graphs.
10. Explain Secondary Air Control System with the help of a diagram.
11. Write short notes on
    (a) Evaporative Emissions Canister Purge.
    (b) Automatic System Adjustment
    (c) System Diagnosis

Module 3- Chapter 2 – Control Units

1. What are the operating conditions to which the control unit is subjected?
2. What are the different types of input and output signals of the control unit? Explain briefly with example for each signal.
3. Write a diagram indicating the digital modules in the control unit.
4. What are the different types of semiconductor memories used in Control unit? Provide an overview of these.
5. What are the different program levels in the software of a Motronic System? Explain them briefly.

Module 4 – AUTOMOTIVE NETWORKING & VEHICLE MOTION CONTROL

Chapter 1: Automotive Networking

Chapter 2: Vehicle Motion Control

OBJECTIVES

1. To learn about Automotive Networking and Bus Systems used in Automotives such as CAN, LIN, MOST, Bluetooth, Flexray and Diagnostic Interfaces.
2. Understand Cruise Control and special sensors used for this particular application.
3. To learn about the principle and functioning of Antilock Braking System (ABS).

Module 4 – Chapter 1 - AUTOMOTIVE NETWORKING

4.1 Automotive Networking

Electrical and electronic systems in motor vehicles are often not independent of each other, but influence and complement each other. The increasing number of electronic systems rapidly increased demand for and the scope of information that was being exchanged. The number of signal lines and plug connections that is required increased accordingly, meaning that the technology that has so for been used was approaching the limit of items capability. The solution was provided by the development of serial bus system, with which large volumes of data from different sources can be transferred.

A serial bus system was first used in ac vehicle 1991, where the CAN bus was used in Mercedes Benz 500E. The demand for additional driving safety, convenience, economy and stricter legal requirements on the environment capability of motor vehicles can only be achieved with the aid of additional electronics. The number of electronic systems in vehicle is therefore increasing all the time.

Cross systems function:-

If we examine the signals that are processed in the individual systems, it becomes evident that many common signals are needed in several control units.

Examples of System encompassing functions: -

(1) *Driving speed:* - Is evaluated
  - in the ESP (electronic stability program) for vehicle dynamic control
  - In the engine management for the automotive speed control (cruise control)
  - Transmission control to change automatic gear
  - In the car sound system for the speed dependent volume control

The preparation of above variables from sensor signal requires computing power and therefore hardware and software resources. It is therefore advisable for these variables always to be calculated in one control unit and transmitted to other unit via communication network.

Intelligent sensors are also considered to be electronic systems that prepare the sensor signal in an evaluation circuit and put the information on the data bus via bus interface.

Pre-crash sensors detect a pending collision, for example, the airbag control unit sends the door modules and overhead control panel a request to close the windows the sliding roof. This protects the occupants from penetrating objects.

(2) Adaptive cruise control (ACC):- Involves:

- Radar sensor
- Engine management
- Electronic stability program (ESP)
- Transmission control

Distance control from the vehicle in front is adopted to the flow of traffic is made possible by means of

- Engine torque adjustments
- Automatic brake system intervention
- Gear selection

Coordination between individual systems is therefore required for cross system functions. Large volumes of data must be exchanged in case of powerful communication system and also low cost network that is suitable for automotive vehicle is required.

For this purpose special serial data bus signal has been developed.

Advantages of bus systems in comparison to a solution that uses conventional wiring:-

1. Reduced costs with less weight and installation space because of fewer cables in the wiring harness

2. Better reliability due to fewer plug-in connections

3. Simplifications of vehicle assembly during production

4. Multiple use of sensor signals

5. Simple connection of system components to a bus

6. Easier handling of equipment and special equipment variants in a vehicle

Requirements for bus systems:-

1. Data transfer rate

2. Interference immunity

3. Real Time capability

4. Number of network nodes

1) **Data transfer rate: -** Smallest unit of data is a bit. Data transfer rate is specified in bit / seconds. Alternate names for this are transfer rate, data rate, or bit rate. The bit rate is application dependent.

Example: - The switching of air conditioning compressor ON & OFF requires slower bit rate where as transfer of audio signals requires higher bit rate.

2) **Interference immunity: -** Immunity to Electromagnetic effect is required. These requirements depend on safety relevance of electronic system concerned. Comfort & convenience system requires less immunity compared ABS (Antilock Braking System). Hence the requirement is more in ABS.

To meet above requirements error detection is required. The methods adopted for this are either Parity bit or Checksum.

Parity bit: -

Odd *or* Even parity

Odd parity: - Total number of 1's in the transmitted byte + parity bit included is odd

Even parity: - Total number of 1's in the transmitted byte + parity bit included is even

According to the above, parity bit is selected. The received byte along with parity bit is checked for parity. If it matches transmitted parity then, number is correct otherwise it will be retransmitted by the Transmitter (Ack or Nack will be sent by receiver which is acknowledged or no acknowledgement)

Checksum: -

Here all the bytes are added and the resultant byte will sent as checksum byte. In the receiver side the process is repeated. If the checksum byte is different the process is repeated. If the checksum byte is matched then it is considered that transmitted data is correct, otherwise transmitter is asked to retransmit all the bytes.

3) Real time capability: - A real time system guarantees that is resyktsy are calculated with in fixed time interval. The duration of the time interval depends on the application ABS must react within a few milliseconds / wheel speed reduction) where as response time of 100 ms is adequate for actuating the power window motor. Human beings cannot perceive delay periods of less than 100 ms.

A) Soft real time requirement: - The system generally address to the specified response time, and if these times are occasionally exceeded, it does not produce any serious effect (e. g. image jerking during pictures transmission)

B) Hard real time requirement: - The time specification must be strictly adhered to. If the specified response time exceeded, the calculated result would not be able to be used. This can lead to serious problems in safety critical systems.

Example: - 1) If the allowance were exceeded in ABS system, the incipient locking of the wheels would not be detected soon enough and the pressure in the master cylinder would not be reduced in time. This would result in locked wheels

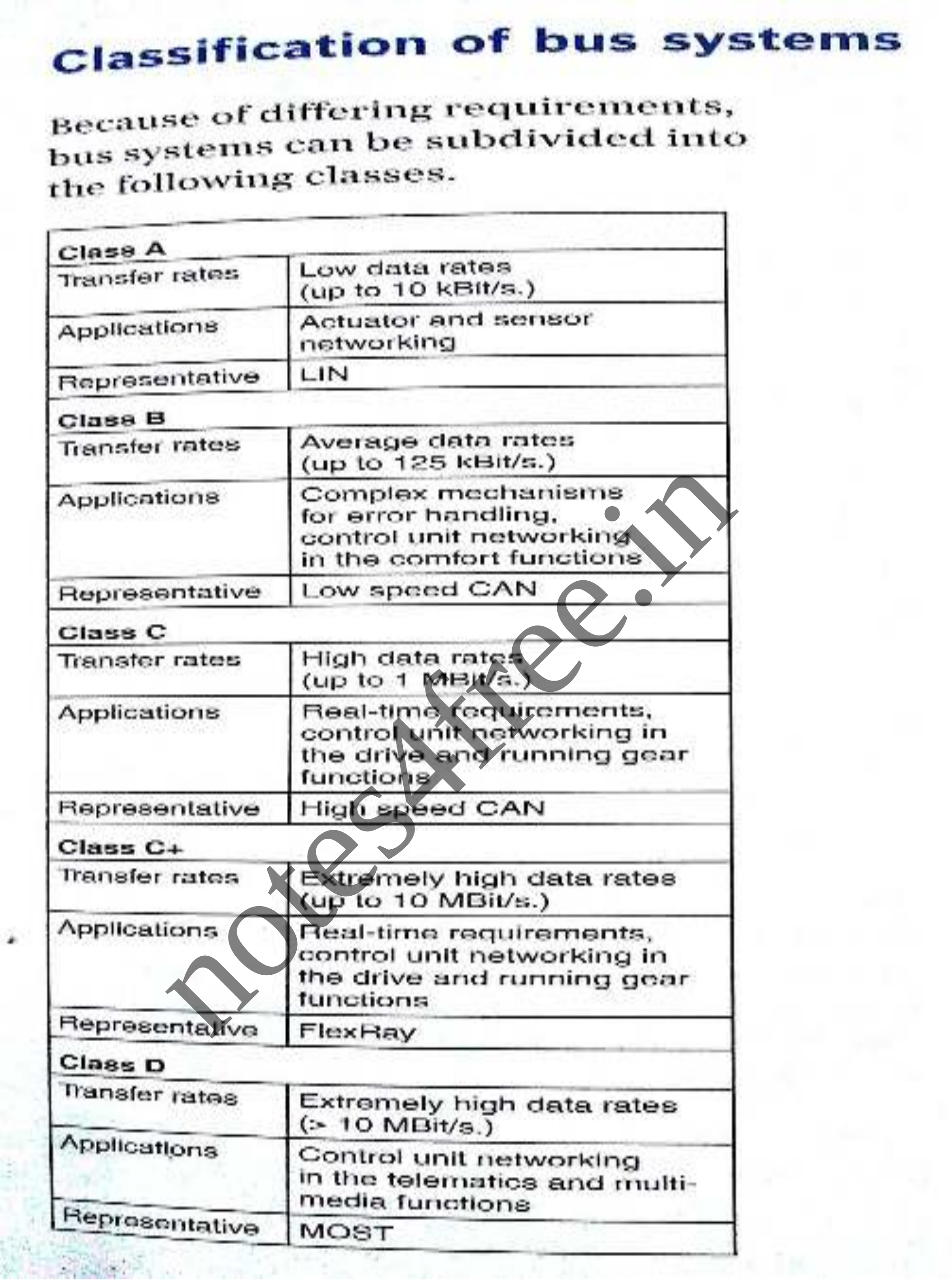
2) If time allowance not strictly adhered in engine management system functions, delays in transmitting injection and ignition signals could lead to engine judder) shake in a forceful way or vibrate with intensity = and even misfiring they represent potential danger

Hard real time requirement must therefore be adhered to, however this does not necessarily mean that the transmission of data via a bus system also has to be subject to there real tien requirements adherence to soft real time requirement is usually sufficient. If signals from other control units are needed for functions such as torque reduction request or during a shift operation the bus system must transfer data fast and with In a smaller time delay so that overall system complies with the specified real time requirements.

4. Number of network nodes: - The transmission no. Of nodes to be integrated varies for different areas of vehicle operation. The number of nodes for comfort and convenience may be high due to servo motor networking (e. g. Seat adjustment) and intelligent sensors (e. g. rain sensor). Several identical buses can be used if necessary

4.1.1.1 CLASSIFICATION OF BUS SYSTEM: -

The Bus system is classified as per the figure.



Classification of bus systems

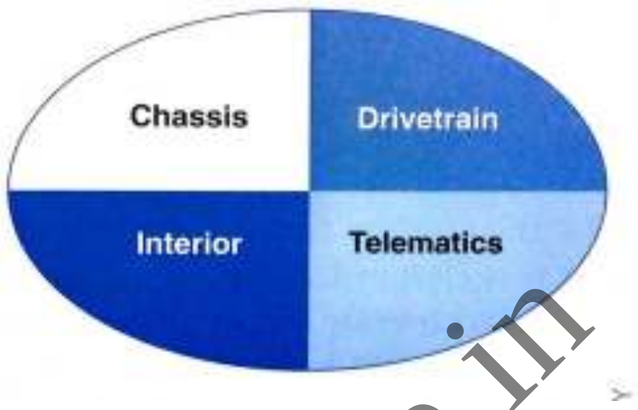
Because of differing requirements, bus systems can be subdivided into the following classes.

Class A	
Transfer rates	Low data rates (up to 10 kBit/s.)
Applications	Actuator and sensor networking
Representative	LIN
Class B	
Transfer rates	Average data rates (up to 125 kBit/s.)
Applications	Complex mechanisms for error handling, control unit networking in the comfort functions
Representative	Low speed CAN
Class C	
Transfer rates	High data rates (up to 1 MBit/s.)
Applications	Real-time requirements, control unit networking in the drive and running gear functions
Representative	High speed CAN
Class C+	
Transfer rates	Extremely high data rates (up to 10 MBit/s.)
Applications	Real-time requirements, control unit networking in the drive and running gear functions
Representative	FlexRay
Class D	
Transfer rates	Extremely high data rates (> 10 MBit/s.)
Applications	Control unit networking in the telematics and multi-media functions
Representative	MOST

4.1.1.2 APPLICATION IN THE VEHICLE:-

The overall vehicle system can be divided into four domains or functional areas from the point of view of electrics/electronics as shown in the figure.

3 Domains in the overall vehicle system



REAL TIME APPLICATION:-

500kb and high speed CAN

Examples:

*Engine management system - Motronic or electronic diesel control (EDC)

*Transmission control

*Antilock brake system (ABS)

*Vehicle dynamics control (e.g.: Electronic stability program, ESP)

*Chassis control system (e.g.: active body control, ABC)

*Support system (e.g.: adaptive cruise control, ACC)

MULTIPLEX APPLICATION:- (125kbit/s low speed CAN or 33kbit/s single wire CAN <20kbit/s low cost LIN)

Examples:

*Displays

*Lighting

*Access authorization with antitheft warning device

*Air conditioning

*Seat and mirror adjustment

*Door module (power-window unit, door mirror adjustment)

*Windshield wipers

*Headlamp adjustment

MULTIMEDIA NETWORKING: - (>10mbit/s -audio and video data, MOST data up to 125kbit/s - CD changer control and low speed CAN)

Examples:

*Car sound system

*CD changer

*Navigation system

*Driver information system

*Telephone

*Video system

*Voice input

*Internet, e-mail

*Back-up Camera

4.1.1.3 COUPLING OF NETWORKS:-

The network topologies and protocols that are must suitable for requirements are used for different application. However, the different network protocols are incompatible, meaning that data cannot be simply exchanged between networks. In this case, help is provided by a gateway.

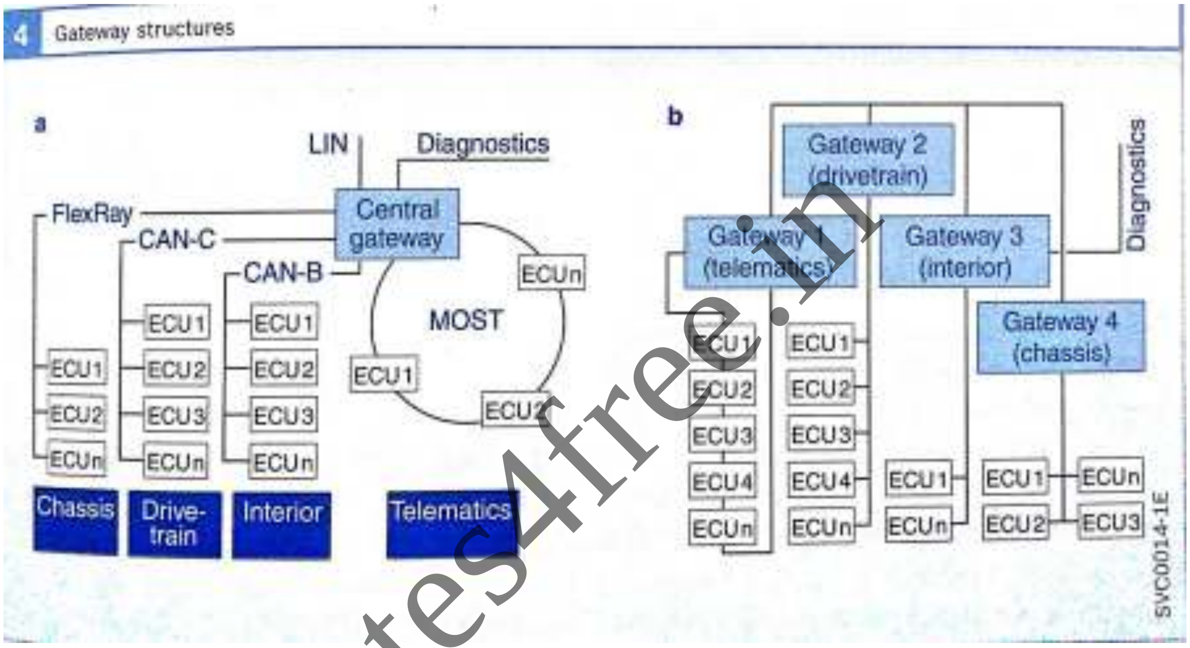
Network topology is the arrangement of a network including its nodes and connecting lines. There use two ways of defining network geometry: The physical topology and the logical (signal) topology.

LOGICAL TOPOLOGY refers to nature of the paths the signals follow from node to node.

Network protocols are formal standards and policies comprised of rules, procedures and formats that define communication between two or more devices over a network. They govern the end to end processes of timely, secure and manage data or network communication.

GATEWAY is a network node that connects two networks using different protocols together. Technically speaking a gateway is a computer that reads in the data that is transmitted by a network and converts it into another format. The use of gateways therefore makes it possible to exchange information between two networks.

A ***central gateway*** or several ***distributed gateways*** can be used to interconnect the bus systems. All bus lines are routed to central gateway. In case of distributed gateway, one gateway connects two or more gateways.



4.1.1.4 EXAMPLES OF NETWORKED VEHICLES:-

TOPOLOGY:-

The topologies of the communication networks differ considerably depending on the vehicle equipment. Networks can be designed differently for different vehicle classes. In some cases different car manufacturers use different bus systems for communication.

SIGNAL TRANSMISSION:

-Signal types

-Resolutions

-Output

1. SIGNAL TYPES: - Examples of the information which can be transmitted in a communication network in a vehicle are as under.

*Engine operating conditions (E.g.: Engine temperature, engine speed, engine load)

*Physical measurements recorded by sensors (E.g.: outside temperature)

*Control signals for activating sensomotors (E.g.: power window units)

*Control element switch positions (E.g.: for the window shield wiper)

2. RESOLUTION:

Switch position1 bit value

*0-open

*1-closed

Engine temperature sensors are calculated engine speed-1 byte or 2 byte values.

1 byte represents 256 values.

2 bytes represents 65,536 values

Sensor signals with voltage range 0 to 5 volt is approximately 20mV with 1 byte representation = 5V/256.

A resolution of 5mV requires a 10 bit data representation, $5V/256\times2^2 = 5V/1024$.

For engine speed N, a resolution of 30RPM, the value range is from 0 to 255×30 RPM = 7,650 RPM with a 1 byte representation.

For Idle speed control, an increment of 30 RPM may be too little on the other hand.

3. OUTPUT:

In event driven systems, the signals can be transferred on the data bus when an event occurs.

E.g.: - operation of switches for switching ON the air conditioning system or the Wind shield wiper.

ENGINE TEMPERATURE which changes slowly is cyclically measured in a fixed time frame by the engine control unit (e.g.:-1 sec).

ENGINE SPEED can change extremely rapidly. It depends on the crank shaft position. It is performed once per combustion cycle the times at which the engine management carries out measurements and calculations.

AT FAST ENGINE SPEEDS this corresponds to a time interval of a few m sec that is approximately 3.3 m sec at an engine speed of 6000 RPM for a 6 cylinder engine. Since this information need not to be sent as soon as it is calculated. A time frame of 10 ms is normal in the engine control area i.e. 100 times /sec.

DATA TRANSFER:-

Some of the examples of signals which are measured and evaluated in automotive system are: -

Driving speed, engine speed, turn signaling, wiper stage 1, load management, multimedia application.

4.1.2 Buses

The buses discussed here are CAN, LIN, MOST, Bluetooth, Flexray and Diagnostic Interfaces.

4.1.2.1 CAN Bus

In 1991 the CAN bus (controller area network) was the first bus system to be introduced to a motor vehicle in mass production. In imitation of other network types, such as local area network (LAN) wide area network (WAN) or personal area network (PAN), this bus system was given the name CAN.

CAN: High speed CAN (CAN-C) - ISO standard 11898-2 125K Bit/s-1M Bit/s bit rate

Low speed CAN (CAN-B)- ISO standard 11898-3 5 to 125K Bits/s -bit rate

CAN - C

->Engine management system (Motronic for gasoline Engines or EDC for diesel Engines)

->Electronic transmission control

->vehicle stabilization systems e.g. ESP (Electronic Stability Program)

- >Instrument cluster

CAN-B

->Control of the air-conditioning system

->Seat adjustment

->Power window unit

->Sliding sun-roof control

->Mirror adjuster

->Lighting system

->Control of the navigation system

Topology: - 1. Bus Topology

2. Star Topology

Bus Topology: - Need for a central control element eliminated.

->Failure of one station would not affect the functionality of data transmission system.

->Additional stations can be connected with little extra effort.

Star Topology: - Contains central coupler. Active as well as passive couplers can be used. The coupler simply forwards the messages to individual segments. The signal transmit times unchanged since the circuit length in case of star topology is the same for all the nodes.

DATA TRANSMISSION SYSTEM

Network nodes:-

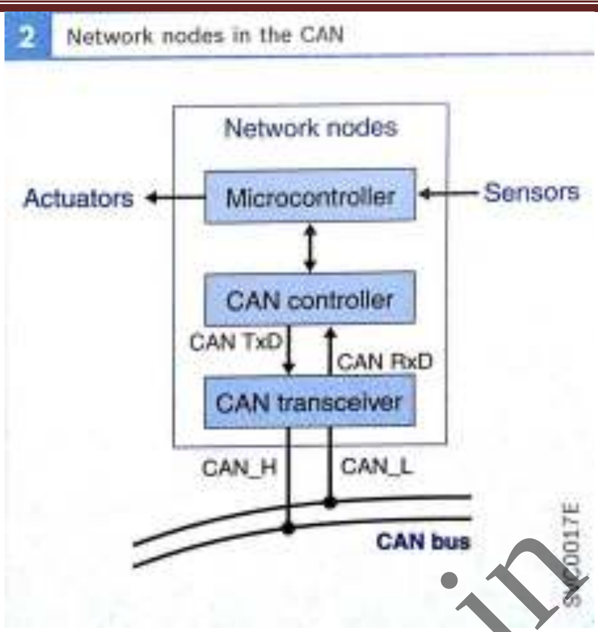
A network node comprises the microcontroller for the application software, the CAN controller and the CAN transceiver (Bus driver and receiver). CAN controller is responsible for transmit and receive nodes. It generates the bit stream for data communication from the binary data to be transmitted and forwards it to the transceiver on the TXD line. Transceiver amplifies the signals and generates voltage level required for differential data transfer and transmits the processed bit stream serially on the bus line (CAN-H and CAN-L). Incoming messages are processed and sent to CAN controller on the RXD line.

The microcontroller, which runs the application program (e.g. motronic or EDC), controls the CAN controller, prepares the data to be sent and evaluates the data received.

Logic bus states and coding:-

CAN uses two states for communication, `DOMINANT '& 'RECESSIVE', with which the information bits are transmitted. The Dominant state represents a binary "0" and the recessive a binary "1". NRZ (Non return to zero) is used as the encoding method for data transmission. With this method, there is no compulsory return to zero between two transmission states of the same value.

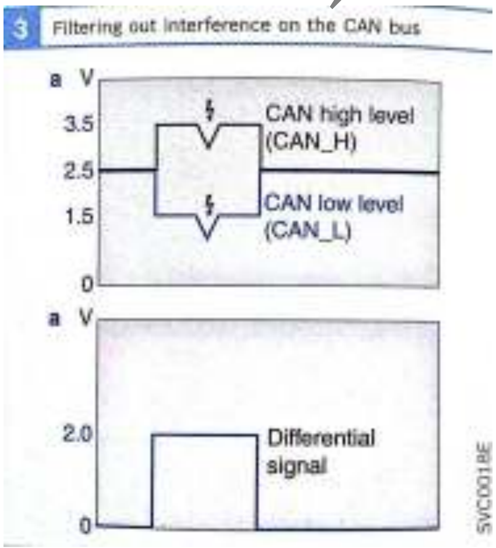
When it receives messages, the CAN transceiver converts the signal level back to logical states. In the process, a differential amplifier subtracts the CAN-L level from the CAN-H level.

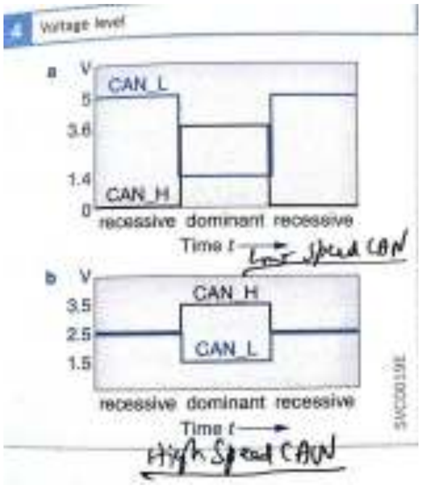

2 Network nodes in the CAN

If lines become twisted, disturbance pulses (e.g. from the ignition system) have the same effects on both lines. Differential data transfer therefore makes it possible to filter out interference on the line. Some transceivers also evaluate the voltage level on the CAN-H and CAN-L line separately. It would then be possible for operation to continue in single line mode if one of the two bus lines were to fail as consequence of a short circuit or a cable break. However the bus subscribers would have to share a common ground that would assume the function of the failed line.

Voltage level:-

The high speed & low speed CANs use different voltage levels for the transmission of dominant and recessive states.


3 Filtering out interference on the CAN bus


4 Voltage level

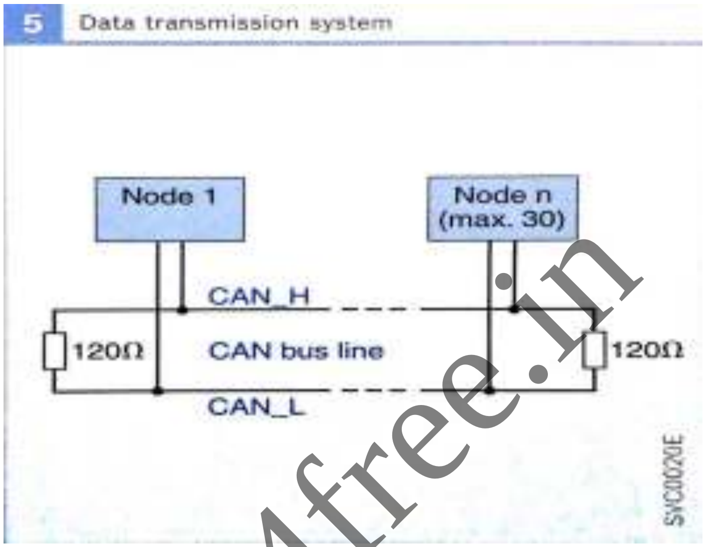
Low Speed CAN

High Speed CAN

Reflection Termination:-

Reflection of the electrical signals at open ends of line would interface with communication. To these reflections, the bus lines are terminated at each end with a resistor of 120 Ohm.

Alternatively, the terminating resistors may be integrated into the electronic control unit themselves.



ISO 11898 specifies the bit rate for a defined circuit length. The maximum permissible bit rate this depends on the total length of the bus. This will permit correct evaluation of bit transmission.

It is possible to connect at least 30 network nodes to the bus without the need for additional measures.

Recommendations:-

->1M Bits/S for 40m

->500K Bits/S up to 100m

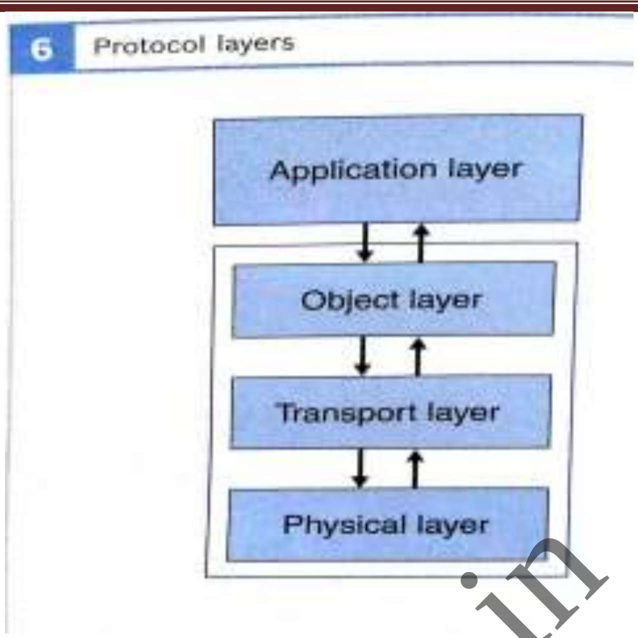
->250K Bits/S up to 250m

->125K Bits/S up to 500m

->40K Bits/S up to 1000m

CAN Protocol:-

Both CAN H/W &S/W are subdivided into four layers such as



->Information in the form of Data structures is used by application.

->Managing messages, decides which message to be sent at which time. For incoming messages, this layer is responsible for message filtering.

->Arbitration or Fault detection & signaling. Process messages sent by object layer in such a way that physical layer will be able to send these messages.

->Consists of physical components of the network, such as the wiring and the voltages used to send the information.

Multi master principle:-

The CAN protocol supports communication between network nodes without the need for a central control unit. Each node may attempt to send messages at any time.

Whether this attempt is successful or not essentially depends on two factors:

->Is the bus free before the start of transmission?

->Has the arbitration phase been passed successfully?

Content based Addressing: -

A station is able to broadcast a message to all other stations (broadcast) or selected stations (multicast). These stations read only those messages whose identifiers are stored in their acceptance list (message filtering). In this way, each station decides for itself whether or not it needs a message sent on the bus.

The identifier has 11bits (standard format, CAN 2.0A) or 29bits (extended format, CAN)

In standard format, it is possible to distinguish between 2048 & in the extended format, it is possible to distinguish between 536 million different CAN messages.

Network nodes are free to operate fully independent of each other.

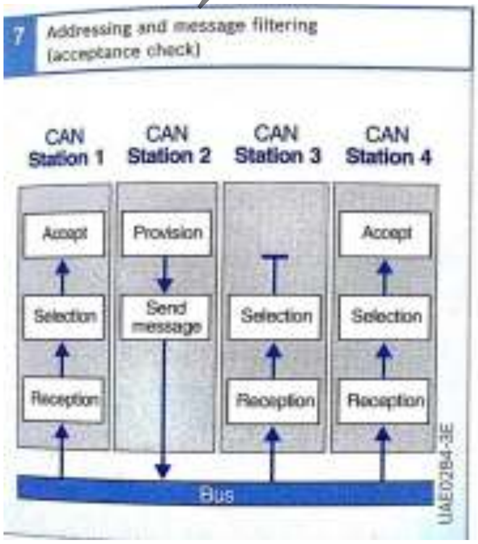
Controlling bus Access:-

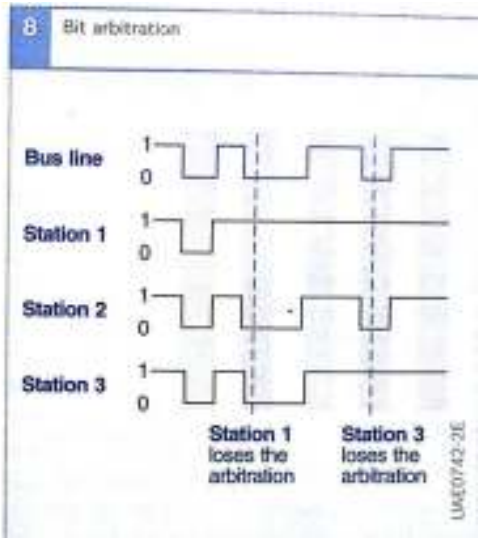
Arbitration phase:-

If the bus is unoccupied (recessive state) and messages are available for sending, each station is free to initiate sending of its message. The message begins with a dominant bit (start-of-frame bit), followed by the identifier.

When several stations start to transmit simultaneously, the system responds by employing "wire-and" arbitration to resolve the resulting conflicts over bus access. The message with the highest priority (lowest binary value of the identifier) is assigned first access, without any data loss or delay (non destructive protocol).

The arbitration principle permits the dominant bits transmitted by a given station to overwrite the recessive bits of the other stations. Each station outputs the identifier of its message on to the bus bit by bit, with the Most Significant Bit (MSB) first. The station with the lowest identifier, i.e., the highest priority, makes its way onto the bus without having to repeat the message (non destructive access control).The transmitters of lowest priority messages automatically become recipient of the message just sent by another station. They repeat their attempt to send as soon as the bus is free again. Without this access control, bus collisions would result in faults. To generate unequivocal (leaving no doubt) bus arbitration, therefore, it is not permissible for more than one node to send a message with the same identifier.


7 Addressing and message filtering (acceptance check)


8 Bit arbitration

Priority Assignments:-

An identifier corresponding to a low binary number has high priority and vice versa. It must not be possible for messages to have the same priority.

Message format:-

The message transfer on the CAN bus is based on four different frame formats - Data frame, remote frame, Error frame, overload frame.

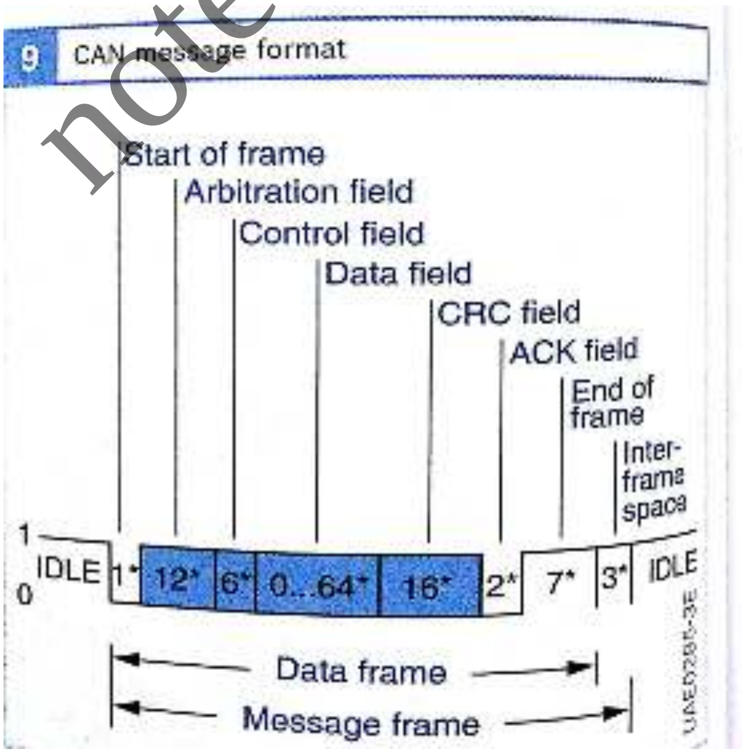
1. Data frame: - The transmitted message contains data (e.g. current engine speed) that is provided by the transmitting station (data source).

2. Remote frame: - Stations can request the data they need from data source (e.g. the windshield wiper requests how wet the windshield is from the rain sensor). The data source responds by sending the relevant data frame.

3. Error frame: - If a station detects a fault or error, it communicates this to the other stations using an error frame.

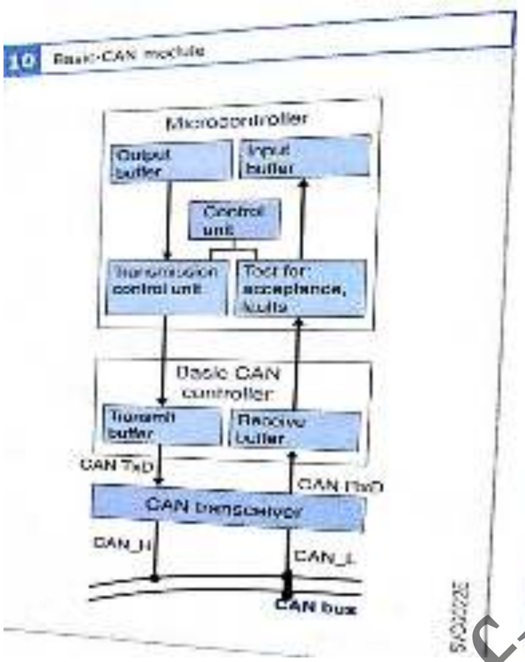
4. Overload frame: - This can be used to create a delay between a preceding and subsequent data frame or remote frame. The transmitting node reports that it cannot currently process another frame.

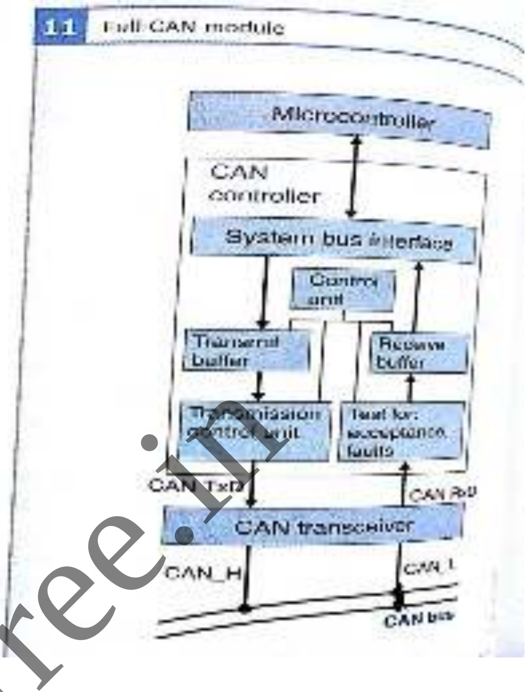
CAN Message Format: - It is as shown in the figure.



CAN Modules:

There are two types which are Basic CAN Module and Full Can Module.


10 Basic-CAN module


11 Full CAN module

Basic CAN Module: -

This is primarily suitable for low bit rates or for the transmission of messages but at higher bit rates.

Advantages: - smaller chip surface & lower manufacturing costs.

Full CAN Module: -

They relieve the burden on the local computer by performing all of the communication including message filtering in the controller. This is prepared in cases where a station has to manage several messages at high bit rates and the local computer has no free capacity for communication tasks.

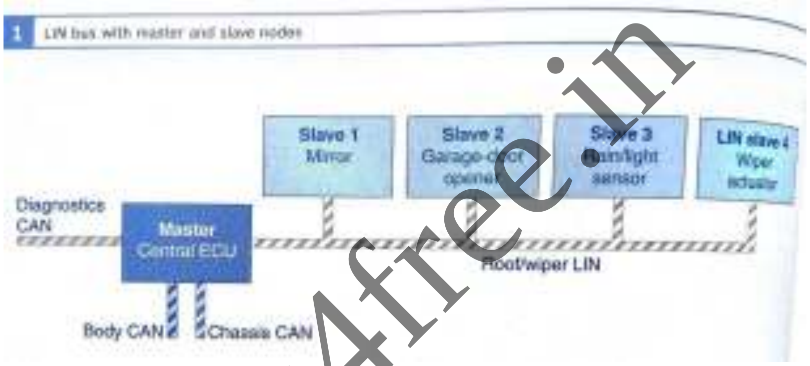
4.1.2.2 LIN Bus

The increasing use of systems in the motor vehicle gave rise to the idea of designing a cost effective bus system as an alternative to the low speed CAN. In 1998, several automotive manufacturers founded with the aim of developing a specification to a serial bus for the networking of sensors and actuators in the body electronics area. The work group's resulting LIN bus specification was introduced into Mass production with the Mercedes-Benz SL as early as 2001.

The name LIN (Local interconnect network) is derived from the fact that all electronic control units are located within a demarcated installation space (e.g. in the door). The LIN, therefore is a local sub system for supporting the vehicle network by means of super ordinate CAN networks.

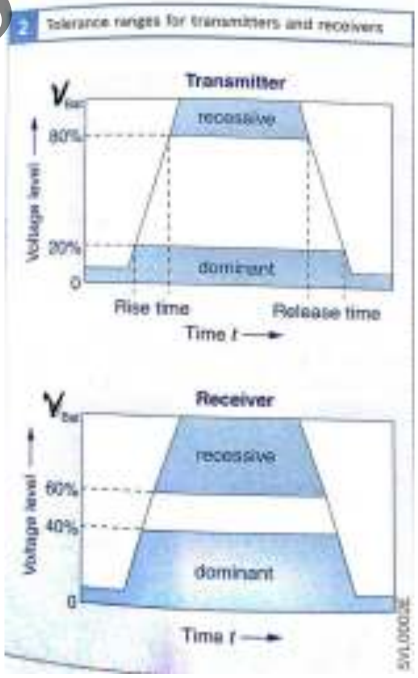
The LIN bus is suitable for low data rates of up to 20K bit/s and is typically limited to a maximum of 16 bus subscribers. The bus subscribers are usually arranged in a linear bus topology and connected to each other by a single wire line. This topology, however, is not explicitly specified.

Figure shows an example of a LIN network as a sub-bus in the roof/wiper area of the motor vehicle. Here the master also functions as a gateway to the chassis CAN, the body CAN and diagnostics CAN. Bus consists of master and four slaves.



The Tolerance Ranges:

The Voltage level tolerance ranges are as shown in the figure.

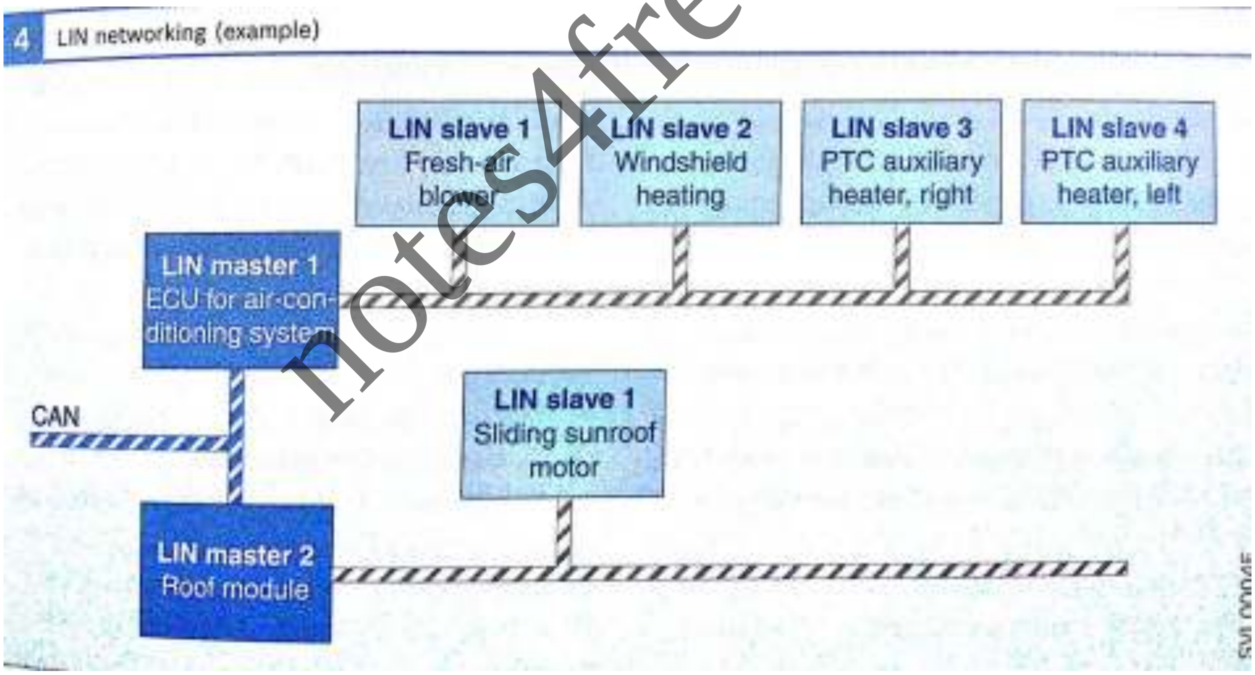


The LIN Message Format:

It is as shown in the figure. The standard bit rates of 2400 bits/S, 9600 bits/S & 19200 bits/S are recommended. The minimum possible value for the bit rate is 1k bit/S to prevent timeout conflicts. The edge itself is defined as 1 to 3 b/microseconds.

APPLICATIONS:-

One of the examples is as shown in the figure.



Some of the examples of LIN applications are:

-> Door module with door lock, power window drive and door mirror adjustment.

-> Control of the power sunroof drive unit.

-> Control of the wiper motor for the windshield wiper

-> Sensor for rain and light detection

-> Air conditioning system (transmission of signals from the control element, activation of the fresh air blower)

-> Lead light electronics

-> Control of motors for seat adjustment

-> Garage door opener

4.1.2.3 MOST Bus

The Most (Media oriented systems transport) was specifically developed for the networking of infotainment systems in motor vehicles. They provide functions such as radio tuners, CD players DVD, TV, route guidance capabilities and access to mobile communications and information.

Requirements:-

The transmission of the multimedia data both audio & video requires a high data rate and a synchronization of data transfer and the associated requirements of electromagnetic compatibility (EMC) must also be fulfilled.

MOST bus was developed in 1998.

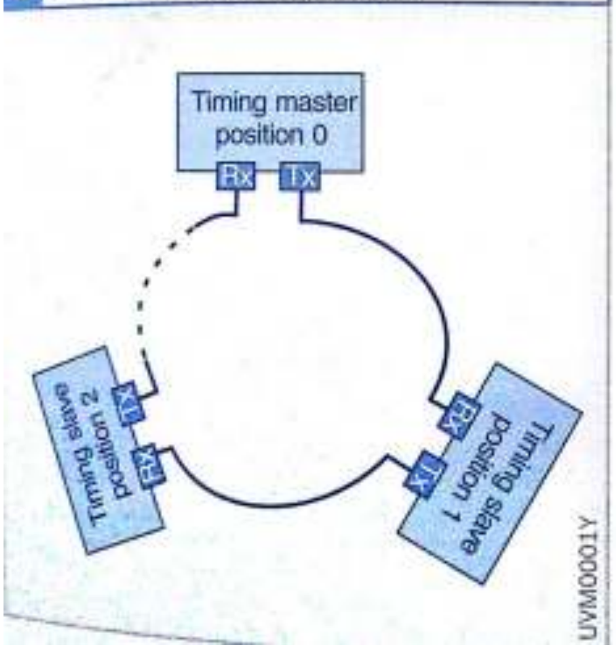
Features:-

The MOST bus supports the logical networking of up to 64 devices. It offers a data rate of 248M bit/S. (MOST 25), 50M bit/s (MOST 50) & 15pM bits/S (MOST 150).

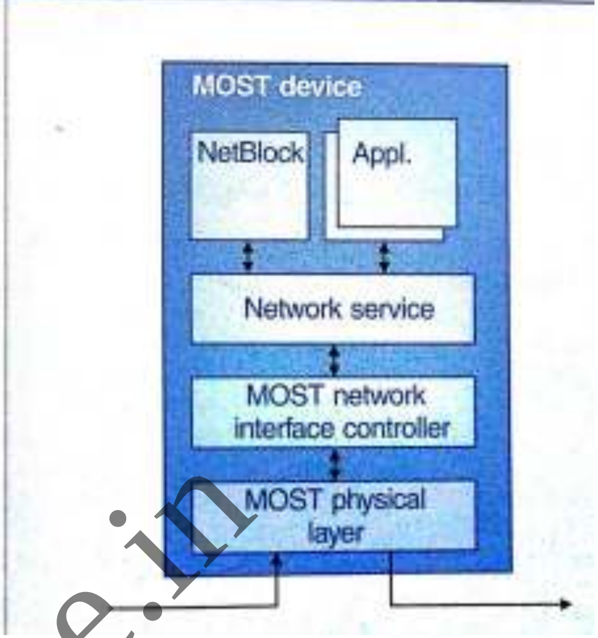
TOPOLOGY:-

Arranged in a ring structure where by a device is connected to its predecessor or successor in the ring by an input or output respectively. One of the devices acts as the "timing master" and generates data frames for data transfer with which the other devices synchronize. Each device has a bypass. When this is closed, the device forwards the signal directly and is therefore invisible to the MOST system.

1 Ring structure of the MOST system



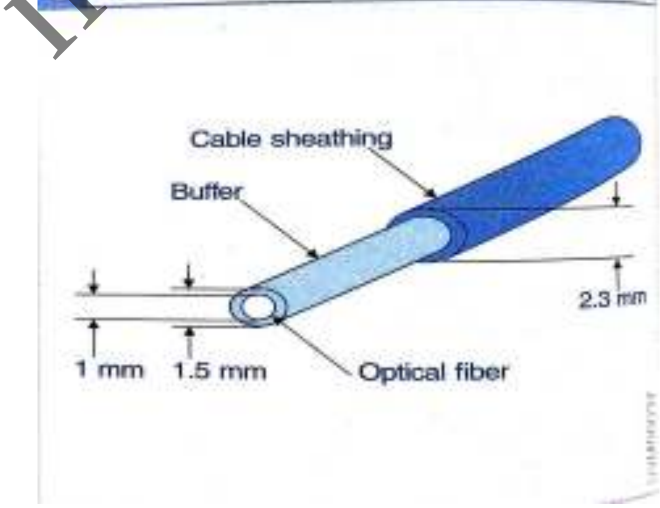
2 Model for a MOST device



Transmission Agent:-

POF (Plastic Optical Fibre) is used for transmission. TX-FOT (Fibre Optic Transceiver) has on LED on the transmit side with a wavelength of 650nm (in the red wavelength range). On the receive side, RX-FLOT the optical signal is converted back into an electrical signal by a PIN photo diode (P-Intrinsic-N)

POF cable

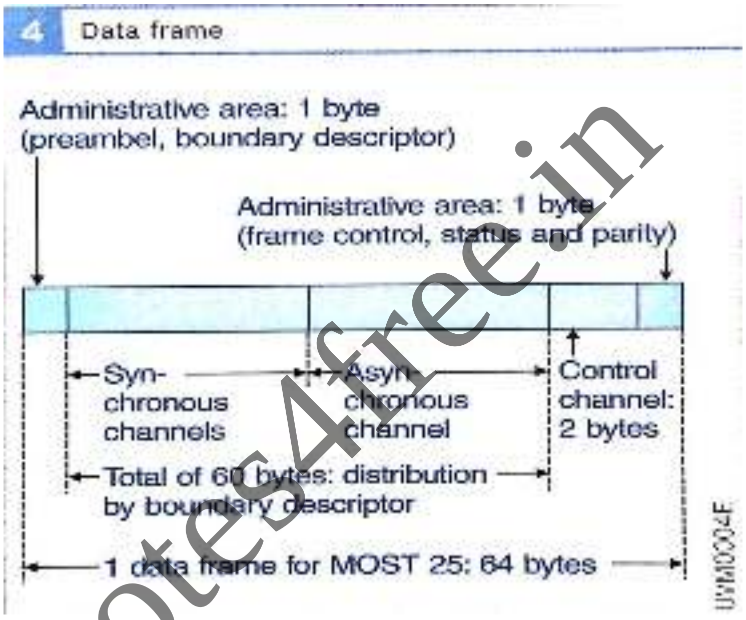


Data transmission channels:-

1. Control channel: - Simple transmission of control commands, for signaling of device status, for sending of messages necessary for system management.

2. Synchronous channel: - For the transmission of multimedia data (to carry both audio & video data) flexible no of channels.

3. Asynchronous channel: - Data is sent in packets, track information, software update.



4.1.2.4 Bluetooth

Bluetooth is an industry standard for the networking of mobile multimedia devices, such as the car sound system, cell phone, headset, PDA (personal digital assistant), PC and Peripheral equipment. it is used for simple exchange of data between portable terminals & the wireless transmission of audio & video signals for entertainment and information.

The short range wireless connectivity of bluetooth eliminates the need for connection cables between the cell phone &the hands free system.

Bluetooth version:-

V.1.0 was adopted in July 1999, 1.1 in 2001,1.2 in Nov 2003, 2.0 in Nov 2004 whose bit rate is 3M Bit/S & reduce power consumption with each new version, great emphasis was placed on backward compatibility with previous versions.

TRANSMISSION TECHNOLOGY: -

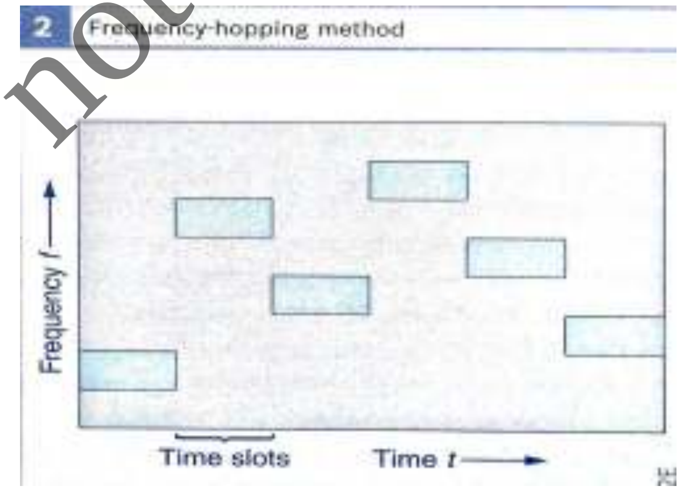
Frequency brand: -

Bluetooth operates in the worldwide license free 2.4GHz ISM Band (Industrial scientific medicine) without approval. For this reason, the possibility of interference from garage door openers, microwave ovens or other appliances which operate using the same frequency band has to be accepted. To minimize interference, the best possible use should be mode of the frequency spectrum. Devices that use the ISM band therefore implement "spread spectrum techniques ".

Frequency hopping method: -

Bluetooth divides the 2.4 GHz band into 79 channels at intervals of 1MHZ.(f=2.402+K, k=0..........78). The band is terminated at both the upper and lower end by two guard bands with a width of 3.5MHZ (upper guard band) and 2MHZ (lower guard band).

The transmission uses a combined frequency-lopping time division duplex (FH-TDD) method. The frequency looping spread spectrum (FHSS). The channels are switched 1600 times/second (i.e., 1÷1600=625 microseconds shots). The shots are assigned in accordance with the TDD method i.e. the transmitter and receiver are authorized to send alternately. The frequency looping method guarantees optional and uniform use of the ISM band and makes Bluetooth resistant to interference from other transmitters in the same frequency band (e.g. WLAN). In addition it also offers some security because a hacker would not know the destination of a frequency switch or indeed the time frame for which a particular frequency would be valid. This makes interception of a connection much more difficult.



Modulation method: -

Bluetooth uses the Gaussian frequency shift keying (GFSK) method of modulation.

Power classes:-

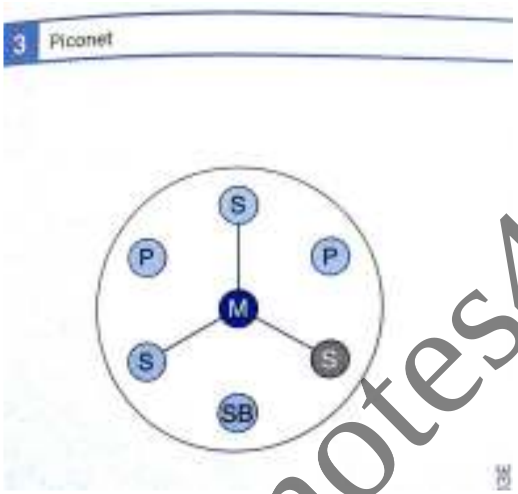
- class 1 (100mw-20dbm) transmission output for a range of 100 to 150m

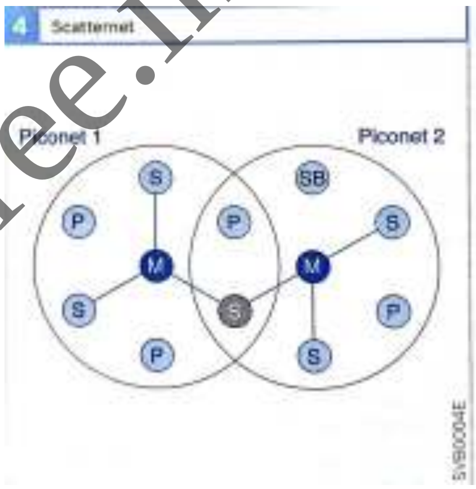
-class 2 (25mw-4dbm) -10 to 25m

- class 3 (1mw-0dbm) -10m range

Topology:-

Automatic configuration of ad-Hoc n/Ws. this means two or more devices are able to spontaneously form a n/w with no prior knowledge of each other. Bluetooth is based on master-slave principle. In principle any Bluetooth device may be a master or a slave. This n/w is known as "PICONET". With many piconets partly overlap to set up larger n/w it is called "SCATTERNET".





M->Master

S->Slave

P->Part mode

SB->stand by

4.1.2.5 FlexRay:

Flexray is a field that was designed to support open and closed loop control technology in the automotive sector. Development focused in the stability for use in active safety systems in particular. It has high bit rates and a fault tolerant design.

This was developed jointly by BMW and Daimler Chrysler. The main areas are drive train systems with no mechanical fall back level (X-by-wire). However, the areas of passive safety systems and comfort/convenience and body electronics are also supported.

The access method is FTDMA (Flexible time division multiple access). Flexray operates at a maximum bit rate of 10Mbit/s. A rate of up to 20Mbits/s is achievable if two channels are used without redundant access. Redundancy means duplication one channel ON-LINE & other standby. This is required since the application area is safety systems.

TOPOLOGY:-

1. Point-to-point (maximum distance between two nodes is 24m)

2. Bus Topology: - Between 4 and 22 nodes can be connected.

3. Star Topology: - Both active & passive couplers (central node) are supported.

4. Cascaded star Topologies: - Limited to three

5. Hybrid Topologies: - Blend of bus & star

6. Two channel Topologies: - Possible to implement both channels independently, with different topologies for each channel (can be star + bus).

Hardware:-

Hardware consists of one host processor, a communication controller (CC) and one bus driver (BD) for each channel. Optionally Bus Guardian (BG) for monitoring each bus driver is present.

Transmission Agents: -

Twisted pair where shielded (STP) or unshielded (UTP) cabling may be used, each channel has two wires designated Bus plus (BP) and Bus minus (BM).

Host processor gathers information from sensors, which is forwarded to communication controller for transmission. The information received from communication controller is forwarded to the actuators responsible for processing.

Communication controller is for scheduling, synchronizing with other n/w nodes creating macrotick signals, creating a bit stream from the information of the host or controlling bus access.

Bus driver assumes the role of a transceiver it converts logical information into physical voltages also protects against electrostatic discharge (ESD). Other functions are detecting faults and power management because functions of the node can be switched OFF. It processes wake up signals.

Bus Guardian will permit transmissions if the connected n/w node is authorized to send a message.

4.1.2.6 Diagnostic Interfaces

Diagnosis Legislation demands constant monitoring of emission-related components in various electronic systems (OBD- on Board Diagnosis). Faults (e.g. electrical short circuit of sensors, operating states) are stored in a fault memory in the control unit. These faults can be read using a scan tool (official testing station) or workshop tester. For this purpose, these is a socket in the foot well dashboard or centre console of the vehicle to which the tester is connected by means of a standard connector (ISO 15031-3). The pins of this diagnostic connector are as follows.

Pin 2 & 10 - Bus line (High & low)

Pin 7 & 15 - K line

Pin 6 & 14 - CAN-H & CAN-L

Pin 4 - Vehicle ground

Pin 5 - Signal Ground

Pin 16- Battery +ve

Pins 1, 9, 3, 11, 12, 13, 8 not used

Diagnostic protocols:-

KWP71 - K-line

KWP20000 - K-line

ISO 15765:- 1-3 - CAN

CARB (Californian environmental authority)

ISO 14230 -4 - K-line

ISO 15765 -4 - CAN

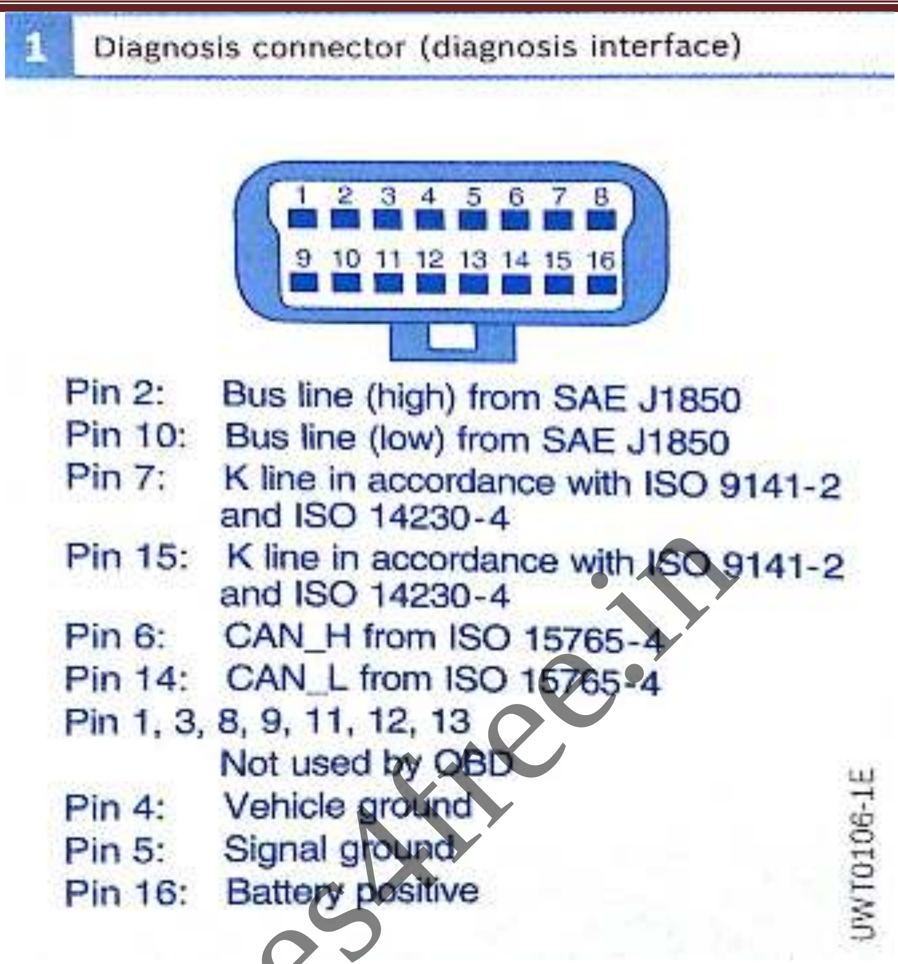
Application Protocols:-

For tuning & optimization of control units

1. Mc Mess- K- line

2. CCP (CAN calibration protocol)

The Diagnostic connector is as shown in the figure.



1 Diagnosis connector (diagnosis interface)

Pin 2: Bus line (high) from SAE J1850
Pin 10: Bus line (low) from SAE J1850
Pin 7: K line in accordance with ISO 9141-2 and ISO 14230-4
Pin 15: K line in accordance with ISO 9141-2 and ISO 14230-4
Pin 6: CAN_H from ISO 15765-4
Pin 14: CAN_L from ISO 15765-4
Pin 1, 3, 8, 9, 11, 12, 13 Not used by OBD
Pin 4: Vehicle ground
Pin 5: Signal ground
Pin 16: Battery positive

UWT0106-1E

Module 4 – Chapter 2 - VEHICLE MOTION CONTROL

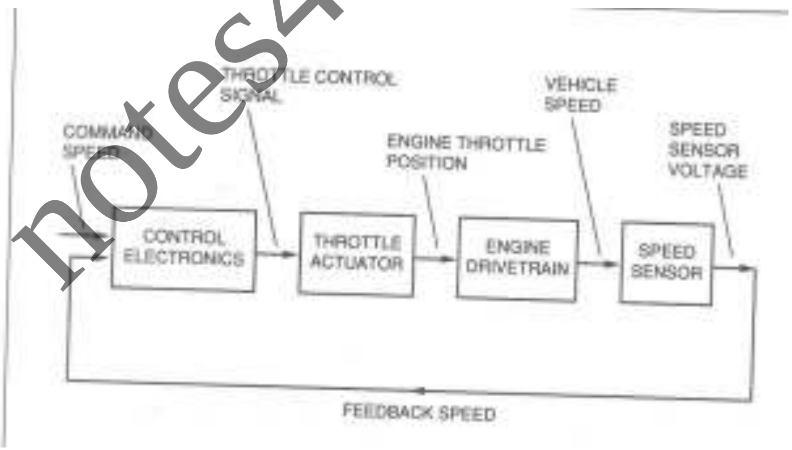
4.2.1 Cruise Control System

The purpose of Cruise control system is to maintain a constant vehicle speed on the high way without driver input (i.e. no foot on the gear pedal). The driver selects the desired speed and activates the cruise control by means of switches.

4.2.1.1 Typical Cruise Control System

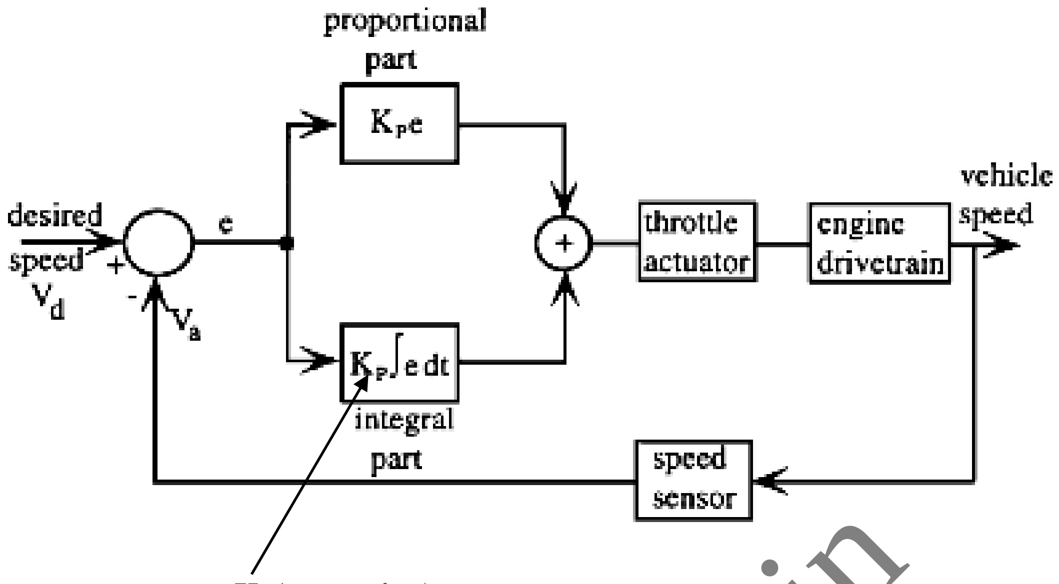
The essential features of a typical cruise control are as shown in the diagram. The electronic control system has two inputs: command speed which indicates desired speed and a feedback speed which indicates actual speed. The control electronic system indicates the difference between the inputs (the error) and produces a throttle control signal that is sent to the throttle actuator. The throttle actuator sets the throttle engine position which alters the engine speed to correct for the vehicle speed error detected by the control electronics. The vehicle speed is detected by the speed sensors and is converted to an electrical voltage proportional to vehicle speed. The control system is operating closed loop because the speed signal is fed back to control electronics to be compared to command signal.

Block Diagram of Cruise Control



The controller has to take into the account the time lag between its newly command drive force and the resulting final speed. The vehicle speed can become unstable and oscillate (vary up and down), if the controller tries to correct speed error, too quickly.

Most vehicle speed controllers use a type of control electronics known as proportional-integrated control (PI control). One of the major draw backs of using proportional control alone is the size of the steady state error due to disturbances allowed by proportional control systems. The dual error depends on the proportional gain/constant. To reduce the dual error to very small difference requires a large control effort or gain.



K_I (correction)

On a PI control system, the control signal is actually the sum of two signals. The proportional gain block K_P provides a control signal that is proportional to the error signal ‘e’. The other block, the integrator block, generates an output that is proportional to the integral of the error. The integrator output voltage increases or decreases linearly with time depending on whether e is +ve or -ve respectively. The gains K_P and K_I are chosen such that the system has quick response, high accuracy, and no instability or oscillations. The integral control block always drives the final error towards zero. The time required to drive the error to zero is determined by the integral control gain.

4.2.1.2 Digital Cruise Control System (Using Microprocessor)

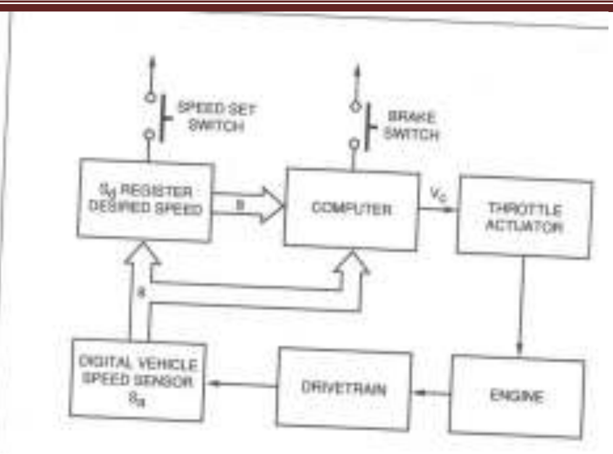
The diagram of Digital Cruise Control system using microprocessor is as shown in the figure.

The vehicle speed sensor is digital. When the car reaches the desired speed s_d, the driver activates the speed set switch. At this time, the output of the vehicle speed sensor is transferred to a storage register.

The computer continuously reads the actual vehicle speed S_a and generates an error, e_n, at the sample time t_n (n is an integer), $e_n = S_d - S_a$ at time t_n. A control signal, d, is computed which has the form: $d_n = K_P e_n + K_I \sum_{m=1}^{M} E_{n-m}$

The symbol $\sum in$ this equation means to add the M previously calculated errors to the present error. The control signal is actually the duty cycle of a square wave ($v_{c)}$) which is applied to the threshold actuator the throttle opening increases or decreases as d increases or decreases.

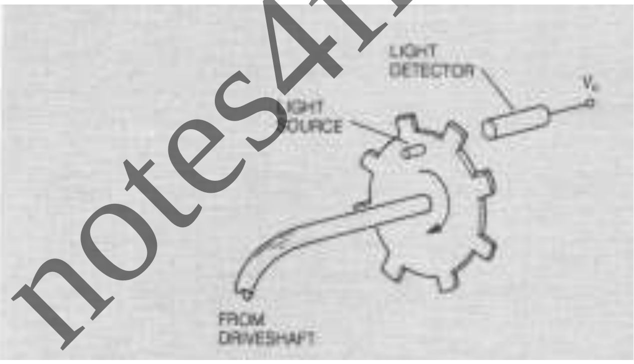
Digital Cruise Control System



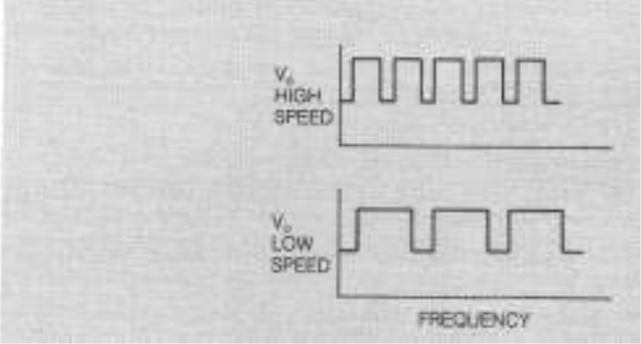
4.2.1.3 Digital Speed Sensor

For the hypothetical optical sensor, a flexible cable drives a slotted disk that rotates between a light source and a light detector. The placement of the source, disk, and detector is such that the slotted disk interrupts or passes the light from source to detector, depending on whether a slot is in the line of sight from source to detector. The light detector produces an output voltage whenever a pulse of light from the light source passes through a slot to the detector.

Digital Speed Sensor



Digital Speed Signal



The number of pulses generated per second is proportional to the number of slot in the disk and the vehicle speed:

$$F \propto NS \text{ or } F = NSK$$

Where,

f = the frequency in pulse per second

N = the number of slots in the sensor disk

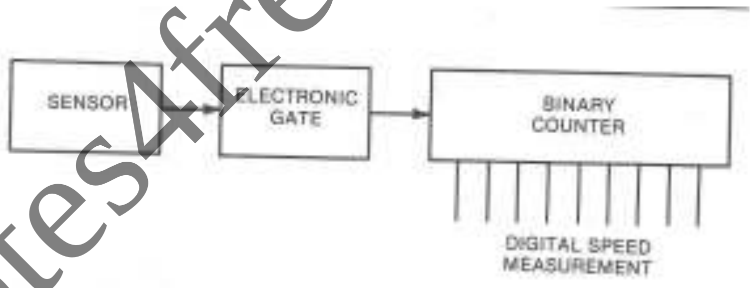
S = the vehicle speed

K = proportionality constant that accounts for differential gear ratio and wheel size

P = t NSK, where, t = time that the electronic gate is open & closed

The output pulses are passed through a sample gate to a digital counter. The gate is an electronic switch that either passes the pulses to the counter or does not pass them depending on whether the switch is closed or open. The time interval during which the gate is closed is precisely controlled by the computer. The digital counter counts the number of pulses from the light detector during time *t* that the gate is open. That is, the number *P* is proportional to vehicle speed *S*. The electrical signal in the binary counter is in a digital format that is suitable for reading by the cruise control computer.

Digital Speed Measurement System

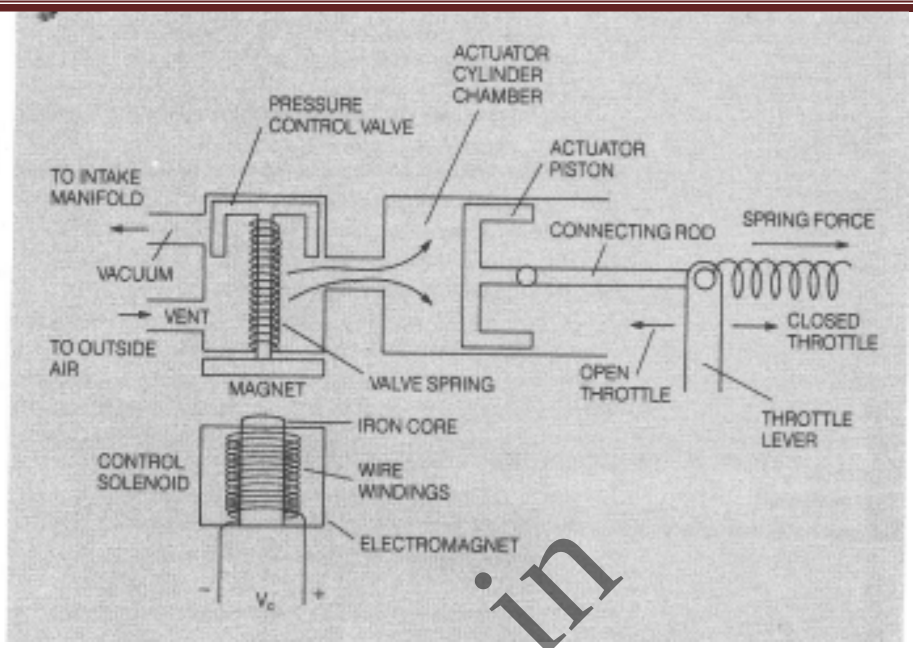


4.2.1.4 *Throttle Actuator*

An actuator which is important to cruise control system that was not covered previously is the throttle actuator system, In all previous discussions it was assumed that the throttle is being activated by vehicle driver who is outside the electric control system. With cruise control, however, throttle actuation is a part of electronic control system.

Many cruise control throttle actuator use a type of pneumatic piston arrangement that is driven from the intake manifold vacuum. The piston connecting rod assembly is attached to the throttle lever. There is also a spring attached to the lever. If there is no force applied by the piston, the spring pulls the throttle closed. When an actuator input signal energizes the electromagnet in the control solenoid, the pressure control valve is pulled down and changes the actuator cylinder pressure by providing the path to manifold pressure. Manifold pressure is lower than atmospheric pressure, so the actuator cylinder pressure quickly drops, causing the piston to pull against the throttle lever to open the throttle.

Vacuum Operated Throttle Actuator



The force exerted by the piston is varied by changing the average pressure in the cylinder chamber. This is done by rapidly switching the pressure control valve between the outside air port, which provides atmosphere, and the manifold pressure port, the pressure of which is lower than atmospheric pressure. The actuator control signal V_c is a variable-duty-cycle type of signal like that discussed for the fuel injector actuator. A high V_c signal energizes the electromagnet; a low V_c signal de-energizes the electromagnet. Switching back and forth between the two pressure sources causes the average pressure in the chamber to be somewhere between the low manifold pressure and outside atmospheric pressure. This average pressure and consequently the piston force are proportional to the duty cycle of the valve control signal V_c.

This type of duty-cycle-controlled throttle actuator is ideally suited for use in digital control systems. If used in an analog control system, the analog control signal must first be converted to a duty-cycle control signal.

4.2.2 Antilock Braking System (ABS)

ABS is a safety-related feature that assists the driver in deceleration of the vehicle in poor or marginal braking conditions (e.g., wet or icy roads). In such conditions, panic braking by the driver (in non-ABS-equipped cars) results in reduced braking effectiveness and, typically, loss of directional control due to the tendency of the wheels to lock. In ABS-equipped cars, the wheel is prevented from locking by a mechanism that automatically regulates braking force to an optimum for any given low-friction condition. The physical configuration for an ABS is shown in Figure.

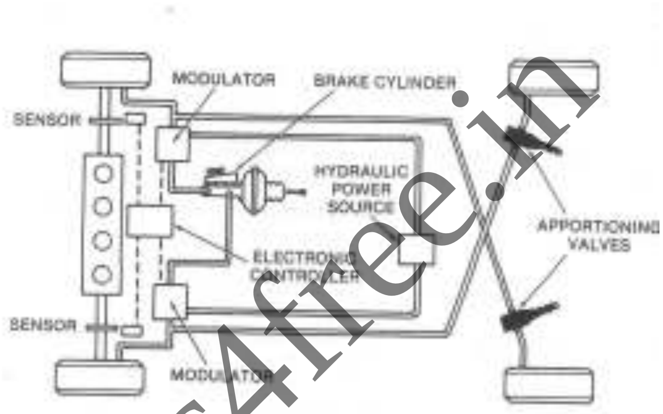
In addition to the normal brake components, including brake pedal, master cylinder, vacuum boost, wheel cylinders, calipers/disks, and brake lines, this system has a set of angular speed sensors at each wheel, an electronic control module, and a hydraulic brake pressure modulator (regulator).

To understand the ABS operation, it is first necessary to understand the physical mechanism of wheel lock and vehicle skid that can occur during braking. Figure illustrates the forces applied to the wheel by the road during braking.

The car is traveling at a speed U and the wheels are rotating at an angular speed w, with

$w = (\pi\ x\ RPM)\ /30$ where RPM is the wheel revolutions per minute.

Antilock Braking System



When the wheel is rolling (no applied brakes), U = w R , where R is the tire radius.

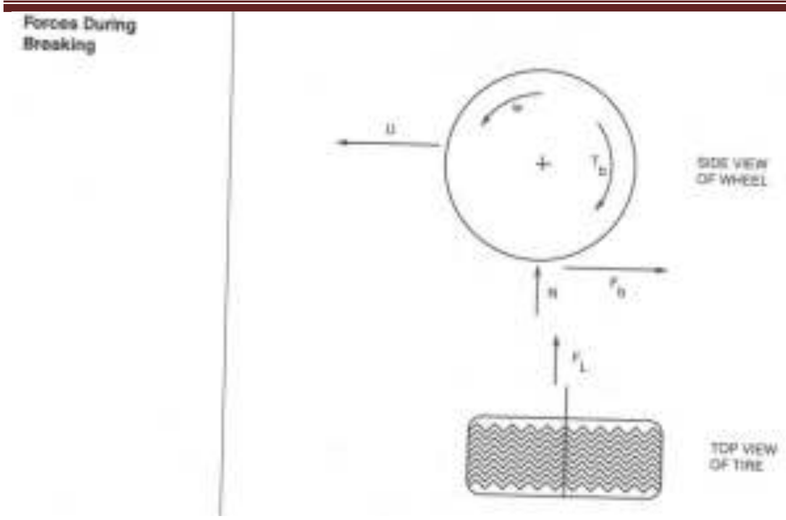
When the brake pedal is depressed, the calipers are forced by hydraulic pressure against the disk. This force acts as a torque T_b in opposition to the wheel rotation.

The actual force that decelerates the car = F_b

The lateral force that maintains directional control of the car = F_L

The wheel angular speed begins to decrease, causing a difference between the vehicle speed U and the tire speed over the road (i.e., wR). In effect, the tire slips relative to the road surface. The amount of slip (S) determines the braking force and lateral force. The slip, as a percentage of car speed, is given by S = $\frac{U-wR}{U} \times 100\%$

A rolling tire has slip S% = 0 (since U = wR), and a fully locked tire has S = 100% (since wR = 0).



The Braking Force (Fb) and Lateral Force (F_L) are proportional to the normal force acting on the tire/road surface and the friction coefficients for braking force (F_b) and lateral force (F_L).

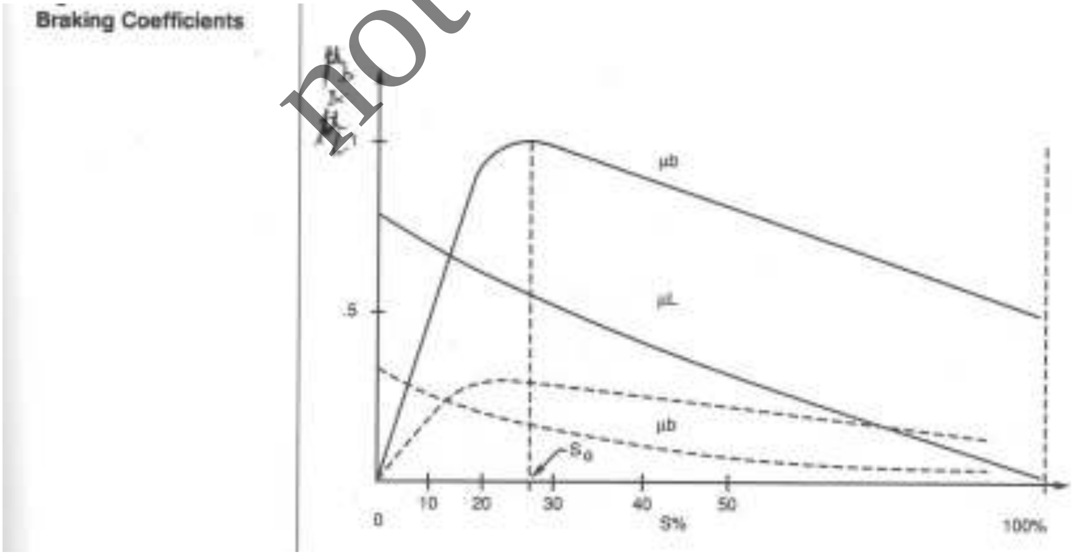
$$F_b \propto N ==> F_b = N\mu_b$$

$$F_L \propto N ==> F_L = N\mu_L$$

μ_b = Braking friction coefficient.

μ_L = Lateral friction coefficient.

These coefficients depend markedly on slip as shown in figure.



Solid curves are for dry road, and dashed curves are for wet/icy road.

As the brake pedal force is increased from zero, slip increases from zero. For increasing slip, μ_b increases to S = S_o. Further increase in slip actually reduces μ_b thereby reducing braking effectiveness. On the other hand μ_L decreases steadily with increasing S such that for fully locked wheels, the lateral force has its lowest valve. For wet roads, μ_L at S% = 100%, so low that the lateral force is insufficient to maintain directional control of the vehicle. However, directional current can often be maintained even in poor braking conditions if slip is optimally controlled. This is essentially the function of ABS. This should be noted in passing that experienced drives can achieve control by "pumping" the brakes to avoid wheel lockup.

The ABS system shown in figure regulates or modulates brake pressure to maintain slip as near to optimum as possible. The operation of this ABS is based upon estimating the Torque T_w applied to the wheel at the road surface by the braking force $F_{b...}$

Wheel Torque $T_W = R\ F_{b.}$

In opposition to this torque is the braking torque T_b applied to the disk by the calipers in response to the brake pressure P.

Braking torque $T_b = K_b P$ where K_b is constant for given brakes.

The difference between the two torques acts to decelerate the wheel.

In accordance with basic Newtonian mechanics, the wheel torque T_w is related to braking torque and wheel deceleration by

$T_W = T_B + I_W W$, where I_w = wheel moment of inertia and W = Wheel decelaration (dw/dt)

During heavy braking under marginal conditions, insufficient braking force is applied to cause wheel lock (in the absence of ABS control). As brake pressure is applied, T_b increases and W decreases causing slip to increase.

Wheel torque $\propto\ \mu_b$ which reaches a peak at slip $S_{o,}$ Consequently, the wheel torque reaches a maximum value. (assuming sufficient brake force is applied).

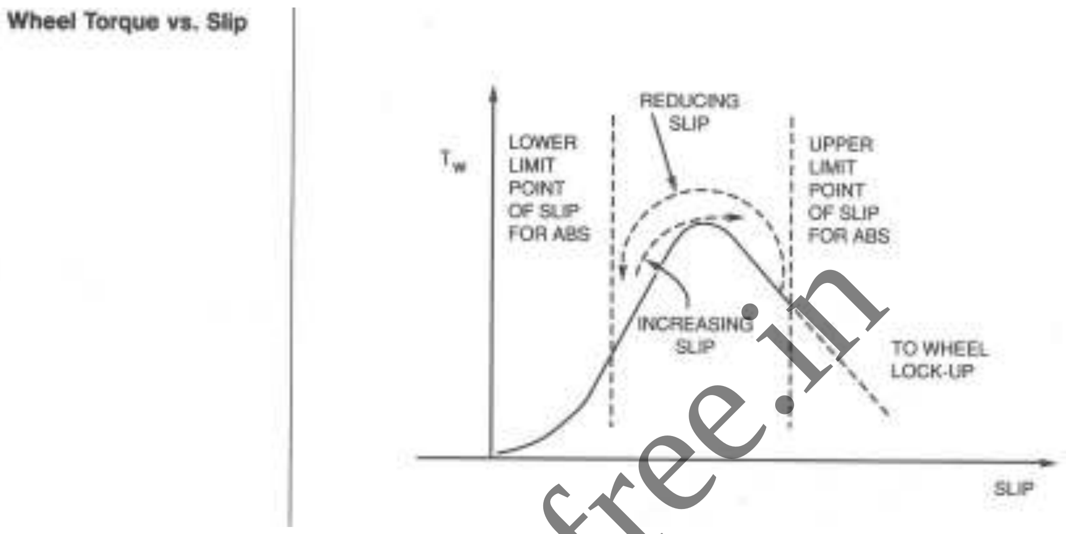
$T_w = R\ F_b$

But, $F_b\ =\ N\mu_b$

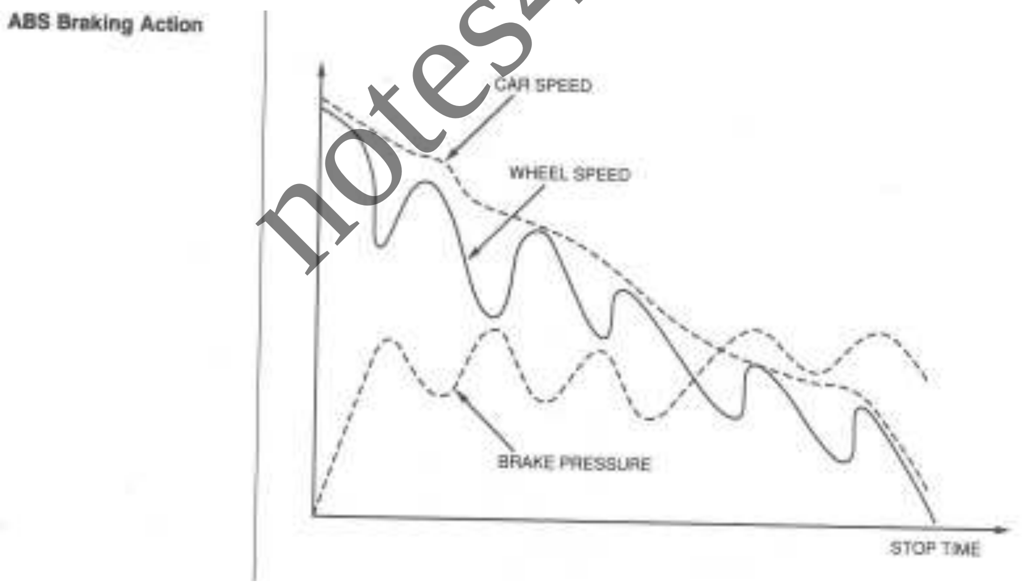
$\therefore\ \mathrm{T_w}\ = \mathrm{R\ N}\ \mu_b$, where N = Normal force acting on tire by the road surface and R = tire radius.

i.e. $\mathrm{T_w}\ \propto \mu_b;\ Also\ \ F_b\ \alpha\ N\ with\ only\ 'R'as\ constant.$

After the peak wheel torque is sensed electronically, the electronic control system commands that brake pressure be reduced (via the brake pressure modulator). This point is indicated in the figure above as the limit point of slip for the ABS. As the brake pressure is reduced, the slip is reduced and the wheel torque again passes through maximum. The wheel torque reaches a value below the peak on the low slip side and at this point brake pressure again increased. The system will continue to cycle maintaining slip near the optimal value as long as the brakes are applied and braking conditions are poor.



The ABS braking action is as shown in the figure below.



OUTCOMES

At the end of this module, the students

1. have a fair idea regarding Automotive Networking and about Bus Systems used in Automotives such as CAN, LIN, MOST, Bluetooth, Flexray and Diagnostic Interfaces.
2. understand Cruise Control and special sensors used for this particular application.
3. learn about the principle and functioning of Antilock Braking System (ABS).

MODEL QUESTIONS

*Module 4- Chapter 1 (***Automotive Networking***)*

1. Explain the various requirements for Bus Systems with examples.
2. In the form of a table provide how and under which criteria the bus systems have been classified.
3. What are the four domains from the point of view of electric/electronics the overall vehicle system can be divided? Provide five examples each Real time, multiplex and multimedia applications.
4. What is the use of a gateway? Write diagrams of two gateway structures.
5. Show how the data transfer takes place for Driving Speed and Engine Speed between various networks and gateway.
6. Explain the wired-and arbitration scheme as well as filtering out interference with the aid of relevant waveforms in CAN bus. What are the four frames used in CAN? Indicate their use. What are the applications of CAN-C and CAN-B?
7. Explain LIN bus indicating its salient features such as its tolerance ranges, protocol (message format), applications and LIN Networking example.
8. Explain MOST bus indicating the requirements, features, data transmission channels, Topology and Transmission agent.
9. Explain Bluetooth indicating its transmission technology, modulation, power classes and topology.
10. Write a note on Diagnosis Interfaces.

Module 4- Chapter 2 (Vehicle Motion Control)

1. Explain Digital Cruise Control System using Microprocessor with control electronics in detail with relevant diagrams.
2. Explain Throttle Actuator as well as Digital Speed Sensor of Digital Cruise Control System with relevant diagrams.
3. Explain ABS with relevant diagrams, graphs and equations.

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MODULE 5 – AUTOMOTIVE DIAGNOSTICS & FUTURE AUTOMOTIVE ELECTRONIC SYSTEMS

5.1 AUTOMOTIVE DIAGNOSTICS

5.1.0 Introduction
5.1.1 Timing Light
5.1.2 Engine Analyzer
5.1.3 Electronic Control System Diagnostics
5.1.3.1 On-board diagnostics
5.1.3.2 Off-board diagnostics
5.1.4 Expert Systems
5.1.5 Occupant Protection Systems – Accelerometer based Air Bag systems

5.2 FUTURE AUTOMOTIVE ELECTRONIC SYSTEMS

5.2.1 Alternative Fuel Engines
5.2.2 Electric and Hybrid Vehicles
5.2.3 Fuel Cell Powered Cars
5.2.4 Collision avoidance RADAR warning system
5.2.5 Low tire-pressure warning system
5.2.6 Heads up Display
5.2.7 Speech synthesis
5.2.8 Automotive Navigation Systems – Inertial, Radio, Signpost, Dead Reckoning
5.2.9 Voice recognition cell phone dialing
5.2.10 Advanced Cruise Control
5.2.11 Stability Augmentation
5.2.12 Automatic Driving Control

OBJECTIVES

1. Understand different types of diagnostics in case of Automotive Electronic Systems
2. To learn about the safety systems incorporated in Automotives.
3. To learn about alternate mode of running of Automotive Engines other than gasoline and diesel.
4. To learn about the Automotive Electronic Systems that may hit the market in near future.

MODULE 5 – CHAPTER 1 - AUTOMOTIVE DIAGNOSTICS

5.1.0 Introduction

The change from traditional fluidic/pneumatic engine controls to microprocessor-based electronic engine controls was a direct result of the need to control automobile emissions. In electronically controlled engines the diagnostics requires a fundamentally different approach than that for traditionally controlled engines because it requires more sophisticated equipment than was required for diagnostics in pre-emission-control automobiles. In fact, the best diagnostic methods use special-purpose computers that are themselves microprocessor based. However, before launching into a discussion of electronic control system diagnostics, there are two non microprocessor diagnostic instruments that are still used in garages and repair shops (particularly for older-model cars) that should be discussed: the timing light and the engine analyzer.

5.1.1 Timing Light

The timing light is used to measure and set ignition timing. It is a special stroboscopic light source that generates very short duration light pulses, the timing of which coincides with ignition pulses. The timing of these pulses is obtained from a special probe connected to a spark-plug wire. The block diagram of a typical timing light is also shown in figure. The probe generates a very short duration voltage pulse each time the spark plug fires. The pulse is amplified and then operates a trigger electrode on a flash lamp that is a gas discharge tube. When triggered, a current pulse flows through the flash lamp, generating a short burst of light. In timing the ignition, the light from the flash lamp is directed at the pulley on the front end of the crankshaft. Adjacent to the pulley is a pointer, such as seen in Figure. On the pulley are several marks. The relationship between the pointer and these marks corresponds to specific crankshaft angular positions relative to top dead center (TDC). The relationship of the pointer and crankshaft pulley marks at the time of ignition can be seen by viewing the pulley using the light from the flash lamp. When the ignition timing is correct, the pointer will align with the correct pulley mark.

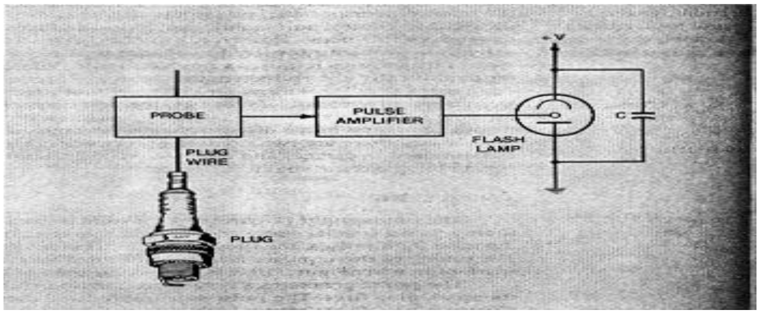


Figure: Timing Light Block Diagram

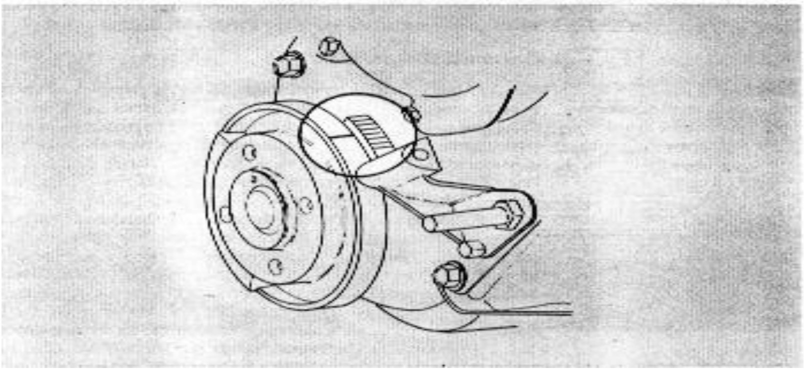


Figure: Timing Marks

5.1.2 Engine Analyzer

The engine analyzer is an instrument that has existed for many years and continues to be used in garages for several tune-up tasks. It provides, for example, a means for optimally setting the gap for ignition points (in cars that still have them, of course) by measuring the so-called dwell. *Dwell* is essentially the fractional duration that the ignition points are closed. However, an engine analyzer's role in diagnosing cars that have digital engine control systems is markedly different than its role in the diagnosis of cars that have analog or mechanical control systems. For example, ignition points have virtually been eliminated in digitally controlled cars. Nevertheless, the concept of dwell is still applicable, only today it represents the amount of time current flows through the coil primary circuit before this circuit is interrupted. In addition, in certain cases ignition timing can be measured by measuring the relative strength (peak voltage) of ignition pulses. Although the engine analyzer continues to be a useful instrument, it is not adequate for diagnosing problems in electronically controlled systems.

5.1.3 ELECTRONIC CONTROL SYSTEM DIAGNOSTICS

Each microprocessor-based electronic subsystem has the capability of performing some limited self-diagnosis. A subsystem can, for example, detect a loss of signal from a sensor or detect an open circuit in an actuator circuit as well as other failures. As long as the subsystem computer is still functioning it can store fault codes for detected failures. Such diagnosis within a given subsystem is known as *on-board diagnosis*.

However, a higher level of diagnosis than the on-board diagnosis is typically done with an external computer-based system that is available in a service shop. Data stored in memory in an on-board subsystem is useful for completing diagnosis of any problem with the associated subsystem. Such diagnosis is known as *off-board diagnosis* and is usually conducted with a special-purpose computer.

In order for fault code data to be available to the off-board diagnosis computer, a communication link is required between the off-board equipment and the particular subsystem on board the vehicle. Such a communication system is typically in the form of a serial digital data link. A serial data link transmits digital data in a binary time sequence along a pair of wires (one of which is normally ground).

5.1.3.1 On-board Diagnostics

Limited diagnostic capability is provided in any modern microprocessor based electronic control system. These diagnostic functions are performed by the microprocessor under the control of stored programs, and are performed only when the microprocessor is not fully committed to performing normal control calculations.

During the normal operation of the car, there are intermittent periods during which various electrical and electronic components are tested. Whenever a fault is detected, the data is stored in memory using a specific fault code. At the same time, the controller generates or activates a warning lamp (or similar display) on the instrument panel, indicating that service is required.

The on-board diagnostic functions have one major limitation—they cannot detect intermittent failures reliably. For the system to detect and isolate a failure, the failure must be nonreversible. In most on-board diagnostics, the electronic control module stores trouble codes that are automatically cleared by the microprocessor after a set number of engine cycles have occurred without a fault reappearing.

The on-board diagnostic capabilities can be manually activated by causing the engine controller to enter a diagnostic mode. The method for accomplishing this task varies from car to car. For example, in certain older model fuel-injected Cadillac cars, the diagnostic mode is entered by first switching on the ignition, then simultaneously depressing the Off and Warmer buttons on the climate control system. The use of on-board diagnostics can easily be illustrated by outlining typical procedures and using the Cadillac system as an example system. Although display of the fault codes varies from car to car, in each case the codes must be readable as a numeric code. A typical method involves flashing the “Check Engine’’ light. The mechanic enters the display mode and then counts the number of times that this light is flashed, in two-digit groups. For example, a fault code 24 would be given by 2 flashes then 4 flashes. After a short time interval the next code would similarly be flashed in two-digit sequence. At one time Cadillac used the environment controller to display a two-digit code. Figure shows a drawing of a Cadillac environmental system displaying code 88. This particular code is used to check that all display segments are working correctly and is the first display shown when the diagnostic mode is entered. After verifying that all display segments are working, the fault codes for all component failures are displayed in sequence, beginning with the lowest and proceeding to the highest. The mechanic notes the fault codes that are displayed and, using a reference manual, identifies the failed components. After all fault codes have been displayed, the number 70 appears on the climate control head, and the engine control system awaits further action by the mechanic. Typically, the “Check Engine” light on the instrument panel is illuminated whenever any fault occurs.

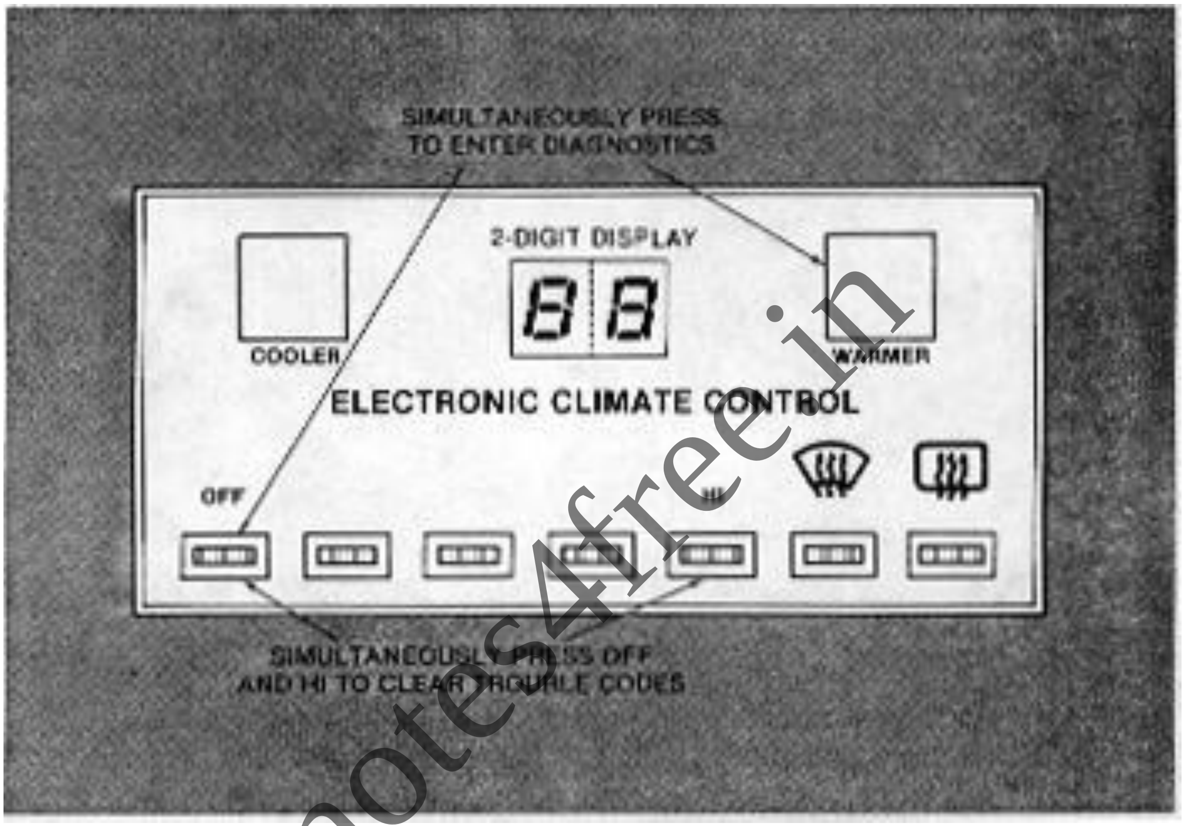


Figure: Fault Code Display

5.1.3.2 Off-board Diagnostics

An alternative to the on-board diagnostics is available in the form of a service bay diagnostic system. This system uses a computer that has a greater diagnostic capability than the vehicle-based system because its computer is typically much larger and has only a single task to perform—that of diagnosing problems in engine control systems.

An example of a service bay diagnostic system is General Motors’ CAMS (Computerized Automotive Maintenance System). This system was capable of detecting, analyzing, and isolating faults in late-model GM vehicles that are equipped with a digital engine control system. This system, commonly called the *technicians’ terminal,* has a modem equivalent that operates in essentially the same way as the CAMS.

The technicians' terminal is mounted on a rugged portable suitable for use in the garage. It connects to the vehicle through the assembly line data link (ALDL). The data required to perform diagnostics are obtained by the terminal through this link. The terminal has a color CRT monitor (similar to that of a typical home computer) that displays the data and procedures. It has a touch-sensitive screen for technician input to the system. The terminal features a keyboard for data entry, printer for hard copy output and modem for a telephone link to a network that collects and routes GM-CAMS information.

The GM system also features a mainframe computer system at the General Motors Information Center (GMIC) that contains a master database that includes the most recent information relating to repair of applicable GM cars. This information, as well as computer software updates, is relayed throughout the network. Mechanics can also obtain diagnostic assistance by calling the GM-CAMS Customer Support Center.

When using the GM-CAMS, the mechanic enters the vehicle identification number (VIN) via the terminal. The computer responds by displaying a menu in which several choices are presented. To select a particular choice the technician touches the portion of the display associated with that choice. Next, the computer displays an additional menu of further choices; this continues until the mechanic has located the desired choice.

Among the many capabilities of the technicians' terminal is its ability to store and display the diagnostic charts that appear in the shop manual. Whenever a fault is located, the appropriate chart(s) are automatically displayed for the mechanic. This capability greatly increases the efficiency of the diagnostic process. In addition, the GM-CAMS computer can store all of the data that is associated with the diagnostic procedures for several vehicles and then locate and display, virtually instantaneously, each specific procedure as required. Furthermore, updates and the most recent service bulletins are brought into the mechanics' terminal over the phone network so that mechanics lose no time trying to find the most recent data and procedures for diagnosing vehicular electronic systems.

In addition to storing and displaying shop manual data and procedures, a computer-based garage diagnostic system can automate the diagnostic process itself. In achieving this objective, the technicians' terminal has the capability to incorporate what is commonly called an *expert system*.

5.1.4 Expert System

An expert system is a computer program that employs human knowledge to solve problems normally requiring human expertise. The theory of expert systems is part of the general area of computer science known as artificial intelligence (AI). The major benefit of expert system technology is the consistent, uniform, and efficient application of the decision criteria or problem-solving strategies.

The diagnosis of electronic engine control systems by an expert system proceeds by following a set of rules that embody steps similar to the diagnostic charts in the shop manual. The diagnostic system receives data from the electronic control system (e.g., via the ALDL connector in the GM-CAMS) or through keyboard entry by the mechanic. The system processes this data logically under program control in accordance with the set of internally stored rules. The end result of the computer-aided diagnosis is an assessment of the problem and recommended repair procedures.

The use of an expert system for diagnosis can significantly improve the efficiency of the diagnostic process and can thereby reduce maintenance time and costs. The development of an expert system requires a computer specialist who is known in AI parlance as a *knowledge engineer*. The knowledge engineer must acquire the requisite knowledge and expertise for the expert system by interviewing the recognized experts in the field. In the case of automotive electronic engine control systems the experts include the design engineers as well as the test engineers, mechanics, and technicians involved in the development of the control system. In addition, expertise is developed by the mechanics who routinely repair the system in the field. The expertise of this latter group can be incorporated as evolutionary improvements in the expert system. The various stages of knowledge acquisition (obtained from the experts) are outlined in Figure.

It can be seen from this illustration that several iterations are required to complete the knowledge acquisition. Thus, the process of interviewing experts is a continuing process. Not to be overlooked in the development of an expert system is the personal relationship between the experts and the knowledge engineer. The experts must be fully willing to cooperate and to explain their expertise to the knowledge engineer if a successful expert system is to be developed. The personalities of the knowledge engineer and experts can become a factor in the development of an expert system.

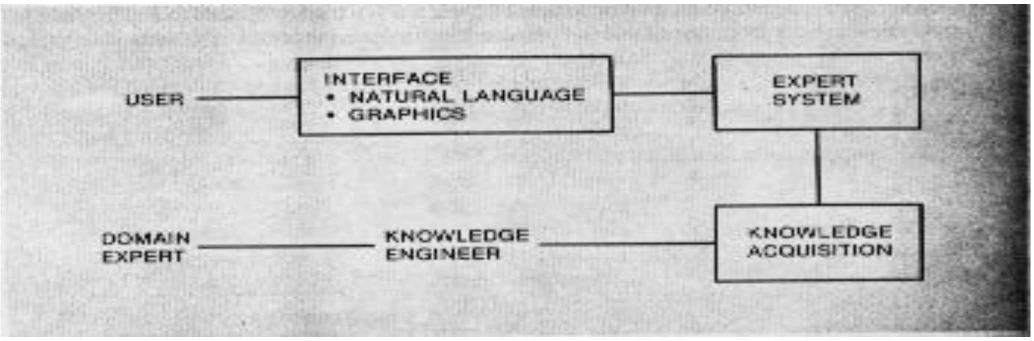


Figure: Environment of an Expert System

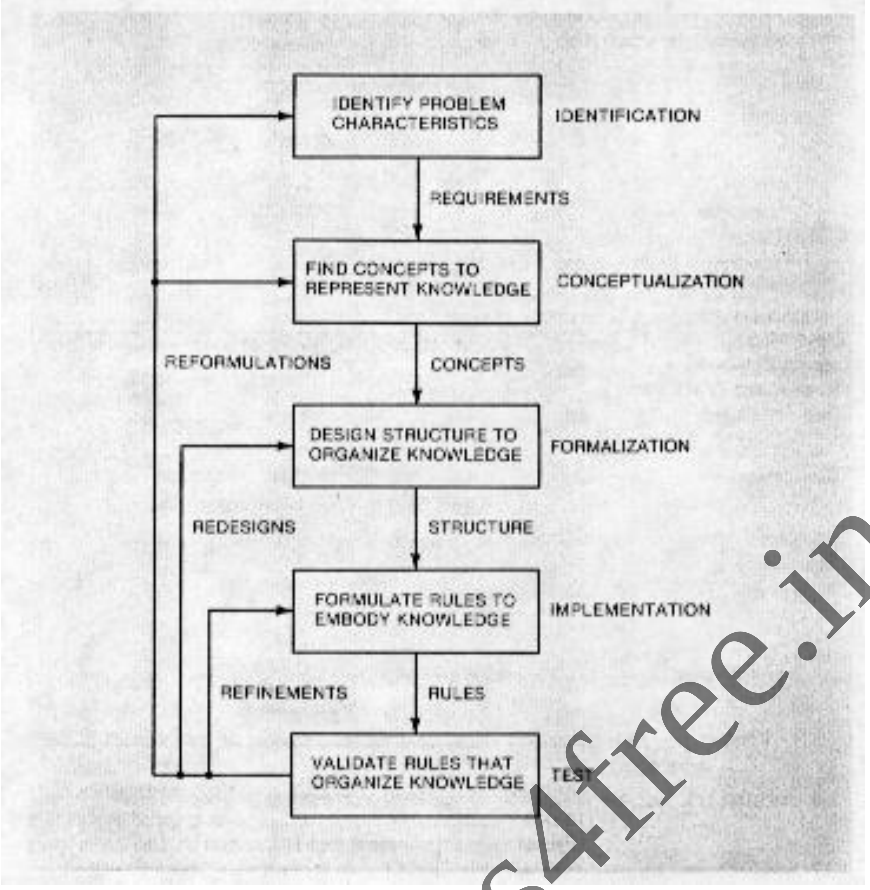


Figure: Stages of Knowledge Acquisition

Figure represents the environment in which an expert system evolves. Of course, a digital computer of sufficient capacity is required for the development work.

It is common practice to think of an expert system as having two major portions. The portion of the expert system in which the logical operations are performed is known as the *inference engine*. The various relationships and basic knowledge are known as the *knowledge base*.

The general diagnostic field to which an expert system is applicable is one in which the procedures used by the recognized experts can be expressed in a set of rules or logical relationships. The automotive diagnosis area is clearly such a field. The diagnostic charts that outline repair procedures (as outlined earlier in this chapter) represent good examples of such rules.

To clarify some of the ideas embodied in an expert system, consider the following example of the diagnosis of an automotive repair problem. This particular problem involves failure of the car engine to start. It is presumed in this example that the range of defects is very limited. Although this example is not very practical, it does illustrate some of the principles involved in an expert system.

The fundamental concept underlying this example is the idea of condition-action pairs that are in the form of IF-THEN rules. These rules embody knowledge that is presumed to have come from human experts (e.g., experienced mechanics or automotive engineers).

The expert system of this example consists of three components:
1. A rule base of IF-THEN rules
2. A database of facts
3. A controlling mechanism

Each rule of the rule base is of the form of “if condition A is true, then action B should be taken or performed.” The IF portion contains conditions that must be satisfied if the rule is to be applicable. The THEN portion states the action to be performed whenever the rule is activated (fired).

The database contains all of the facts and information that are known to be true about the problem being diagnosed. The rules from the rule base are compared with the knowledge base to ascertain which of these are applicable.

From time to time, automotive maintenance problems will occur that are outside the scope of the expertise incorporated in the expert system. In these cases, an automotive diagnostic system needs to be supplemented by direct contact of the mechanic with human experts. The GM-CAMS system, for example, has incorporated this feature into its customer support center.

Vehicle off-board diagnostic systems (whether they are expert systems or not) continue to be developed and refined as experience is gained with the various systems, as the diagnostic database expands, and as additional software is written. The evolution of such diagnostic systems is heading in the direction of fully automated, rapid, and efficient diagnoses of problems in cars equipped with modern digital control systems.

5.1.5 Occupant Protection Systems

Occupant protection during a crash has evolved dramatically since about the 1970s. Beginning with lap seat belts, and motivated partly by government regulation and partly by market demand, occupant protection has evolved to passive restraints and airbags. Airbag deployment systems can be implemented electronically, whereas other schemes are largely mechanical.

Conceptually, occupant protection by an airbag is quite straightforward. The airbag system has a means of detecting when a crash occurs that is essentially based on deceleration along the longitudinal car axis. A collision that is serious enough to injure car occupants involves deceleration in the range of tens of g's (i.e., multiples of 10 of the acceleration of gravity), whereas normal driving involves acceleration/deceleration on the order of 1 g.

Once a crash has been detected, a flexible bag is rapidly inflated with a gas that is released from a container by electrically igniting a chemical compound. Ideally, the airbag inflates in sufficient time to act as a cushion for the driver (or passenger) as he or she is thrown forward during the crash. On the other hand, practical implementation of the airbag has proven to be technically challenging. Considering the timing involved in airbag deployment it is somewhat surprising that they work as well as they do. At car speeds that can cause injury to the occupants, the time interval for a crash into a rigid barrier from the moment the front bumper contacts the barrier until the final part of the car ceases forward motion is substantially less than a second.

The Table lists required airbag deployment times for a variety of test crash conditions.

<u>Table: Airbag Deployment Times</u>

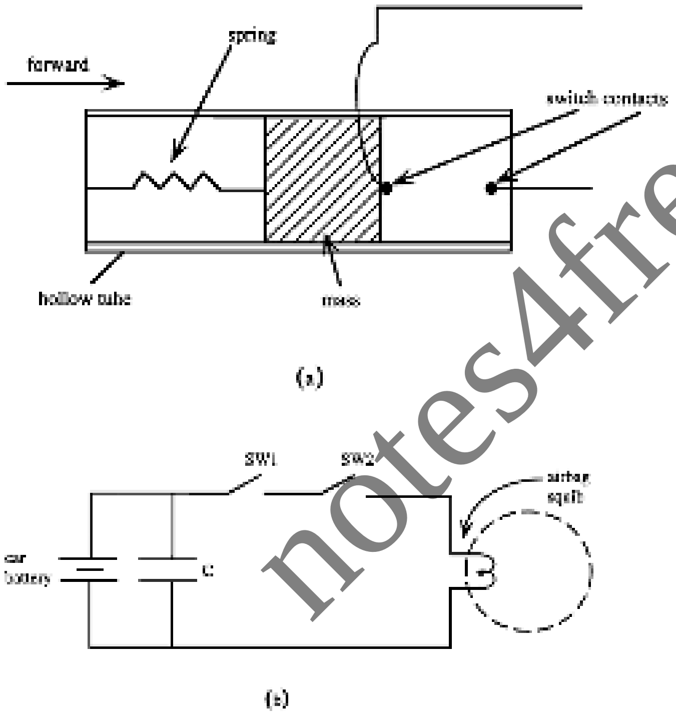
Test Library Event	**Required Deployment Time (m sec)**
9 mph frontal barrier	ND
15 mph frontal barrier	50.0
30 mph frontal barrier	24.0
35 mph frontal barrier	18.0

A typical airbag will require about 30 milliseconds to inflate, meaning that the crash must be detected within about 20 msec. With respect to the speed of modern digital electronics, a 20 msec time interval is not considered to be short. The complicating factor for crash detection is the many crash like accelerations experienced by a typical car that could be interpreted by airbag electronics as a crash, such as impact with a large pothole or driving over a curb.

The configuration for an airbag system has also evolved from electromechanical implementation using switches to electronic systems employing sophisticated signal processing. One of the early configurations employed a pair of acceleration switches SW1 and SW2 as depicted in Figure (a). Each of these switches is in the form of a mass suspended in a tube with the tube axis aligned parallel to the longitudinal car axis. Figure (b) is a circuit diagram for the airbag system. The two switches, which are normally open, must both be closed to complete the circuit for firing the squib. When this circuit is complete, a current flows through the squib ignitor that activates the charge. A gas is produced (essentially explosively) that inflates the airbag. The switches SW1 and SW2 are placed in two separate locations in the car. Typically, one is located near the front of the car and one in or near the front of the passenger compartment (some automakers locate a switch under the driver's seat on the floor pan).

Referring to the sketch in Figure (a), the operation of the acceleration-sensitive switch can be understood. Under normal driving conditions the spring holds the movable mass against a stop and the switch contacts remain open. During a crash the force of acceleration (actually deceleration of the car) acting on the mass is sufficient to overcome the spring force and move the mass. For sufficiently high car deceleration, the mass moves forward to close the switch contacts. In a real collision at sufficient speed, both switch masses will move to close the switch contacts, thereby completing the circuit and igniting the squib to inflate the airbag.

Figure (b) also shows a capacitor connected in parallel with the battery. This capacitor is typically located in the passenger compartment. It has sufficient capacity that in the event the car battery is destroyed early in the crash, it can supply enough current to ignite the squib.



(a)

(b)

Figure: Airbag Deployment System

In recent years there has been a trend to implement electronic airbag systems. In such systems the role of the acceleration-sensitive switch is played by an analog accelerometer along with electronic signal processing, threshold detection, and electronic driver circuit to fire the squib. Figure depicts a block diagram of such a system.

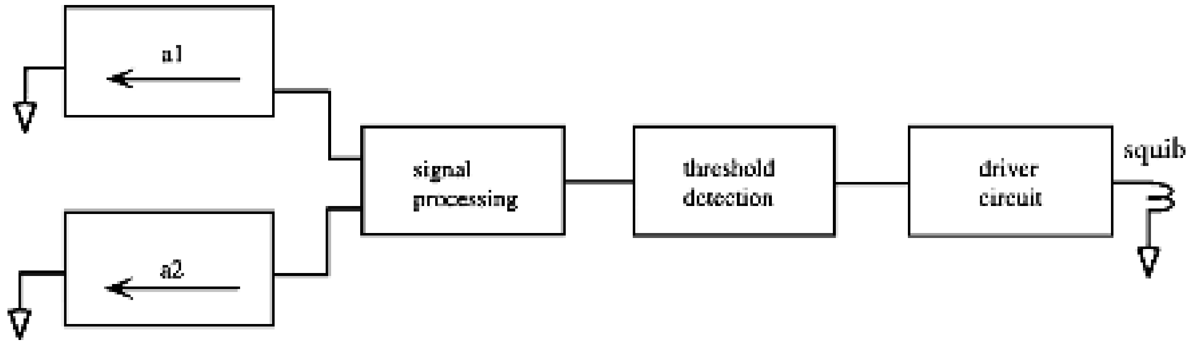


Fig: Accelerometer based Air Bag System

The accelerometers a1 and a2 are placed at locations similar to where the switches SW1 and SW2 described above are located. Each accelerometer outputs a signal that is proportional to acceleration (deceleration) along its sensitive axis.

Under normal driving conditions the acceleration at the accelerometer locations is less than 1 g. However, during a collision at a sufficiently high speed the signal increases rapidly. Signal processing can be employed to enhance the collision signature in relation to the normal driving signal. Such signal processing must be carefully designed to minimize time delay of the output relative to the collision deceleration signal.

After being processed, the deceleration signal is compared with a threshold level. As long as the processed signal is less than this threshold the driver circuit remains deactivated. However, when this signal exceeds the threshold, the driver circuit sends a current of sufficient strength to activate the squib and inflate the airbag.

Typically, the threshold is set so that airbag deployment occurs for a crash into a barrier at or above a specific speed. Depending on the system design, this speed can be anywhere between 8 and 12 mph. This speed range is chosen by the manufacturer to optimize the protection offered the car occupants while minimizing false deployment (that is, deployment when there is no crash).

There will continue to be new developments in airbag technology in order to improve performance. Complicating this task is the fact that the signature of a crash differs depending on the crash configuration. For example, there is one class of signature for a crash into a rigid barrier (i.e. a nonmoving and incompressible object) and another for a crash between a pair of cars (particularly when vehicle curb weights are different). In spite of technical difficulties in implementation, the airbag is finding broad application for occupant protection and seems destined to continue to do so.

MODULE 5 – CHAPTER 2 - FUTURE AUTOMOTIVE ELECTRONIC SYSTEMS

5.2.1 Alternative Fuel Engines

In order to reduce dependence on imported oil, there has been a considerable development effort devoted to finding alternatives to gasoline fuels. The two leading candidates are natural gas and alcohol fuels (methanol and ethanol). The latter fuel is made from grain and is a renewable fuel source. Ethanol is often mixed with gasoline, forming so-called gasohol.

Methanol is an alcohol fuel that is potentially available at relatively low cost and can replace gasoline as a motor fuel. It can be manufactured from coal, which is in abundant supply in the United States. It is routinely used as a fuel for racing cars because it has a relatively high octane rating.

Unfortunately, methanol has a number of disadvantages for passenger use. For example, it has roughly half the energy of an equivalent amount of gasoline. Thus, for a given range, the fuel tank must be roughly double the size of a fuel tank for gasoline. In addition, methanol-fueled cars do not start readily in cold weather, which is an obvious disadvantage in the northern United States. Moreover, methanol is toxic and highly corrosive. The entire fuel system must be made from stainless steel in order to cope with the severe corrosion. Yet another disadvantage of methanol is the lack of a distribution system (including gas stations equipped to sell this fuel). This latter problem can be potentially overcome with the advent of engines that can operate on either gasoline, methanol, or a mixture of the two. Vehicles that are so equipped are called *flexible fuel vehicles* (FFV).

Electronic fuel controls are vital to the success of any FFV. Fundamental to any FFV is a sensor that can measure the alcohol content of the fuel. There are two types of practical alcohol sensors available at the present time. One of these sensors measures alcohol content optically by sensing the index of refraction for the mixture, which is a unique function of the alcohol content. The other senses alcohol with a capacitive sensor. This latter sensor is based on the differences in dielectric constant of gasoline and methanol. Once the alcohol content of fuel has been measured, the electronic fuel control system can properly regulate fuel delivery to stoichiometric mixture ratio. The quantity of fuel required for a given mass air flow rate increases as the alcohol content increases. For neat methanol (100% methanol), the fuel flow rate is roughly double that for neat gasoline.

5.2.2 Electric and Hybrid Vehicles

An electric vehicle, also called an electric drive vehicle, uses one or more electric motors or traction motors for propulsion. An electric vehicle may be powered through a collector system by electricity from off-vehicle sources, or may be self-contained with a battery, solar panels or an electric generator to convert fuel to electricity.

EVs typically charge from conventional power outlets or dedicated charging stations, a process that typically takes hours, but can be done overnight and often gives a charge that is sufficient for normal everyday usage.

Most electric vehicles use lithium ion batteries. Lithium ion batteries have higher energy density, longer life span and higher power density than most other practical batteries. Complicating factors include safety, durability, thermal breakdown and cost. Li-ion batteries should be used within safe temperature and voltage ranges in order to operate safely and efficiently.

Instead of recharging EVs from electric socket, batteries could be mechanically replaced at special stations in a couple of minutes (battery swapping). Batteries with greatest energy density such as metal-air fuel cells usually cannot be recharged in purely electric way. Instead, some kind of metallurgical process is needed, such as aluminum smelting and similar. Silicon-air, aluminum-air and other metal-air fuel cells look promising candidates for *swap batteries*. Increasing the battery's lifespan decreases effective costs. One technique is to operate a subset of the battery cells at a time and switching these subsets.

There is a growing concern about the safety of EVs, given the demonstrated tendency of the Lithium-ion battery, most promising for EV use because of its high energy density, to overheat, possibly leading to fire or explosion, especially when damaged in a crash.

EVs release no tail pipe air pollutants at the place where they are operated. They also typically generate less noise pollution than an internal combustion engine vehicle, whether at rest or in motion. The energy that electric and hybrid cars consume is usually generated by means that have environmental impacts. Nevertheless, adaptation of EVs would have a significant net environmental benefit, except in a few countries that continue to rely on older coal fired power plants for the bulk of their electricity generation throughout the life of the car.

A hybrid electric vehicle combines a conventional (usually fossil fuel-powered) powertrain with some form of electric propulsion. NiMH (Nickel Metal Hydride) batteries are being used in Hybrid vehicle.

An alternative means of storing electrical energy to the car battery is the ultra high capacity capacitor (ultra-cap). This technology has very high specific power (i.e., power/unit weight), and it has very low specific energy. Ultra-cap technology is very likely to be used as a supplement to batteries for relatively short duration bursts of relatively high power. Such high power might be used to start a hybrid car engine and assist the engine in accelerating the car from a standing stop (e.g., in heavy traffic). Operational efficiency of hybrid vehicles is improved by raising the voltage level of the vehicle electrical bus. This issue is one of the motivations for changing from 14-V to 42-V vehicle electrical system.

5.2.3 Fuel Cell Powered Cars

A fuel cell vehicle (FCV) or fuel cell electric vehicle (FCEV) is a type of electric vehicle which uses a fuel cell, instead of a battery, or in combination with a battery or super capacitor, to power its on-board electric motor. Fuel cells in vehicles generate electricity to power the motor, generally using oxygen from the air and compressed hydrogen. Most fuel cell vehicles are classified as zero-emissions vehicles that emit only water and heat. As compared with internal combustion vehicles, hydrogen vehicles centralize pollutants at the site of the hydrogen production, where hydrogen is typically derived from reformed natural gas. Transporting and storing hydrogen may also create pollutants.

A fuel cell is based on a reverse reaction of water electrolysis. Hydrogen reacts with oxygen in the air to produce water. In this process, electricity and heat are generated. It is a power generation system that does not produce greenhouse gases like CO_2 in the process of power generation.

Fuel cells have been used in various kinds of vehicles including forklifts, especially in indoor applications where their clean emissions are important to air quality, and in space applications. The first commercially produced hydrogen fuel cell automobiles began to be sold by Toyota and leased on a limited basis by Hyundai in 2015, with additional manufacturers planning to enter the market. As of June 2016, the Toyota Mirai is available for retail sale in Japan, California, the UK, Denmark, Germany, Belgium, and Norway. Furthermore, fuel cells are being developed and tested in buses, boats, motorcycles and bicycles, among other kinds of vehicles.

As of 2017, there was limited hydrogen infrastructure, with 36 hydrogen fueling stations for automobiles publicly available in the U.S., but more hydrogen stations are planned, particularly in California. Some public hydrogen fueling stations exist, and new stations are being planned, in Japan, Europe and elsewhere. Critics doubt whether hydrogen will be efficient or cost-effective for automobiles, as compared with other zero emission technologies.

The environmental impact of fuel cell vehicles depends on the primary energy with which the hydrogen was produced. Fuel cell vehicles are only environmentally benign when the hydrogen was produced with renewable energy. If this is the case fuel cell cars are cleaner and more efficient than fossil fuel cars. However, they are not as efficient as battery electric vehicles which consume much less energy. Usually a fuel cell car consumes 2.4 times more energy than a battery electric car, because electrolysis and storage of hydrogen is much less efficient than using electricity to directly load a battery.

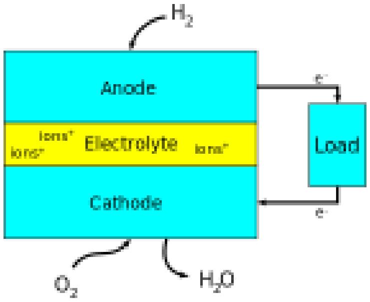


Fig: A block diagram of a fuel cell

The fuel cell structure depicted here is known as proton exchange membrane (PEM) cell. It consists of a pair of porous electrodes: an anode and a cathode separated by an electrolyte. Each electrode is coated on the electrolyte side with a platinum catalyst. The porous anode is supplied with hydrogen (H_2) which diffuses through the anode to the platinum coated junction between the anode and the electrolyte. The platinum catalyst causes each hydrogen atom to separate into a free electron and a positively charged hydrogen ion (H+) which is in fact a proton.

At the same time the porous cathode is exposed to oxygen (O_2), which passes through the cathode to the corresponding platinum catalyst. The free electrons migrate from the anode to the cathode passing through an external circuit (including an energy storage device or battery), Owing to the catalytic action, the cathode chemical reaction is:

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

i.e., the oxygen combines with free electrons and Hydrogen ions to form water. There is no other exhaust product for this ideal reaction.

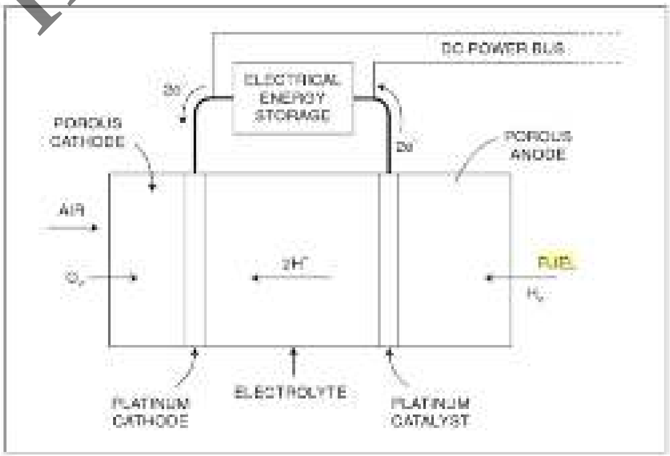


Fig: FCV System Fuel cell configuration

5.2.4 Collision avoidance radar warning system

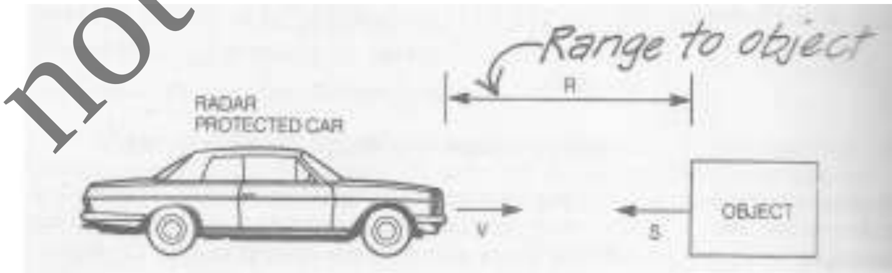
For an anti-collision warning application, the radar antenna should be mounted on the front of the car and it should project a relatively narrow beam forward. Ideally, the antenna for such system should be in a flat package as possible, and should project a beam that has a width of about 2^o to 3^o horizontally and about 4^o to 5^o vertically.

Large objects such a sign boards can reflect the radar beam, particularly on curves and trigger a false alarm. If the beam is scanned horizontally a few degrees, say 2.5^o either ride of the center, false alarms from road side objects can be reduced.

In order to test whether detected object is in the same lane as the radar equipped car travelling around a curve, the radius of the curve must be measured. This can be estimated clearly from the front wheel steering angle for an unbanked curve. Given scanning angle of the radar beam and curve radius, a computer can quickly perform the calculations to determine whether or not a reflecting object is in the same lane as the protected car.

For the collision warning system, better results can be obtained if the radar transmitter is operated in a pulsed mode rather than in a continuous wave mode. In this mode, the transmitter is switched ON for a very short time and then it is switched OFF. During the OFF time the receiver is set to receive a reflected signal. If a reflecting object is in the path of the transmitted microwave pulse, a corresponding pulse will be reflected to the receiver. The ***round trip time 't'*** from the transmitter to object and back to receiver is proportional to the range R, of the object as illustrated in figure. $t = 2R/c$, where c = speed of light (3×10^8 m/s)

Range to Object for Anticollision Warning System



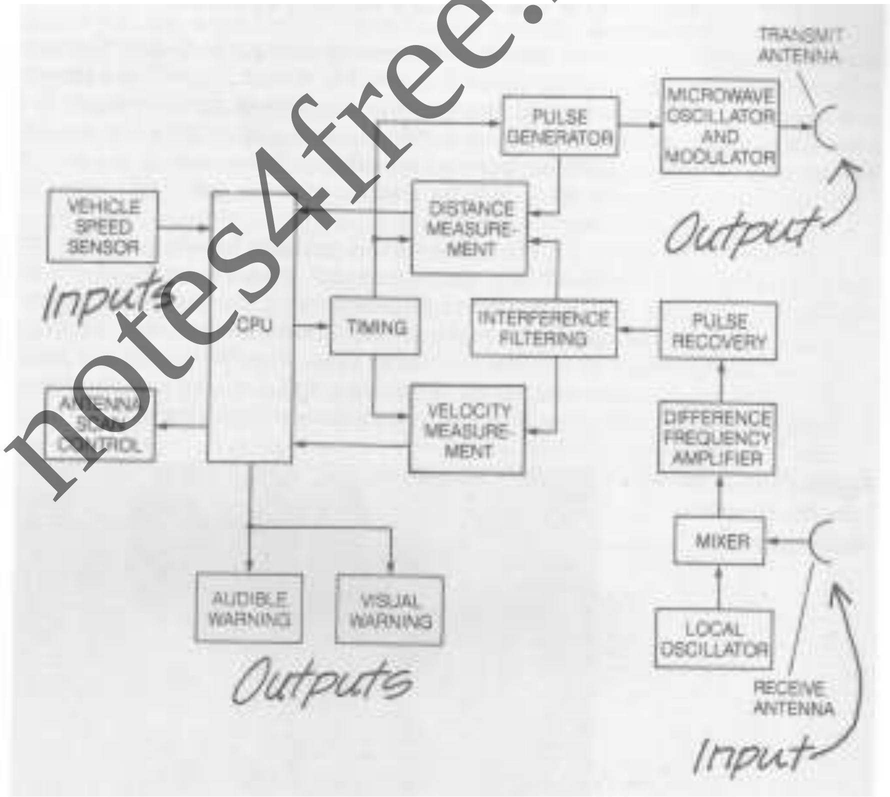
The radar system has the capability of accurately measuring this time to determine the range to the object.

It is possible to measure the vehicle speed, V, by measuring the Doppler frequency shift of the pulsed signal reflected by the ground. (The Doppler frequency shift is proportional to the speed of the moving object. The Doppler shift is what causes the pitch of the whistle of a moving train to change as it passes). This reflection can be discriminated from object reflection because the ground reflection is at a low angle and a short fixed range.

The reflection from an object will have a pulse shape which is very identical that of the transmitted pulse. A collision avoidance system compares the time needed for a micro wave signal to be reflected from an object to the time needed for a signal to be reflected from the ground. By comparing these times with vehicle speed data, the computer can calculate a "time to impact" value, and sound an alarm if necessary.

As noted, the radar system can detect this object reflection and find R to determine the distance from the vehicle to the object. In addition, the relative speed of closure between the car and object can be calculated by adding the vehicle speed, V from the ground reflected pulses and the speed of the object S, which can be determined from the change in range of the object's reflection pulses. In the system as shown in the block diagram, the range R, to the object and the closing speed V+S are measured. The computer can perform a number of calculations on this data. For example, the computer can calculate the ***time for collision, T***. Whenever this time is less than a preset value, a visual and audible warning is generated. The system could also be programmed to release the throttle and apply the brakes, if automatic control were desired.

Block Diagram of Collision Avoidance Warning System



If the object is another moving car approaching the radar equipped car head on, the closing speed is the sum of the two car speeds. In this case the ***time to closure*** or ***time for collision*** is

$$T = \frac{R}{(V+S)}$$

If the object is travelling at the same speed as the radar equipped car and in the same direction, $S = -V$.

Therefore $T = \frac{R}{(V-V)} = \frac{R}{0} = \infty$ (infinity) i.e., collision would never occur.

If the object is stationary, S = 0, and time to collision is, $T = \frac{R}{(V+0)} = \frac{R}{V}$

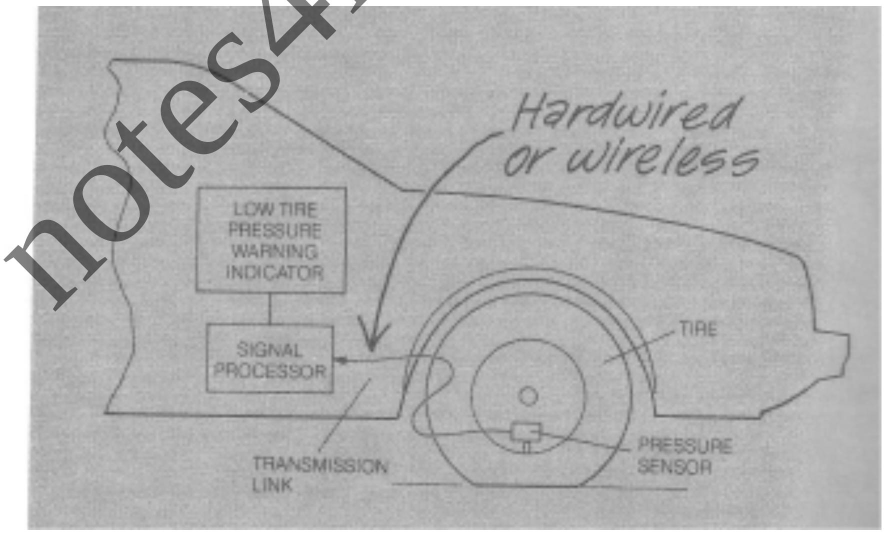
The performance of the experimental systems that have been tested is impressive. However, there are still some technical problems that must be overcome before this system is ready for production use.

5.2.5 Low tire-pressure warning system

This works while the car is in motion. A potentially dangerous situation could be avoided if the driver could be alerted to the fact that a tire has low pressure, particularly if it happens while driving. For example, if a tire develops a leak, the driver could be warned in sufficient time to stop the car before control becomes difficult.

A low tire pressure warning system utilizes a tire mounted pressure sensor. The pressure Sensor signals a loss in the pressure.

Low Tire Pressure Warning System

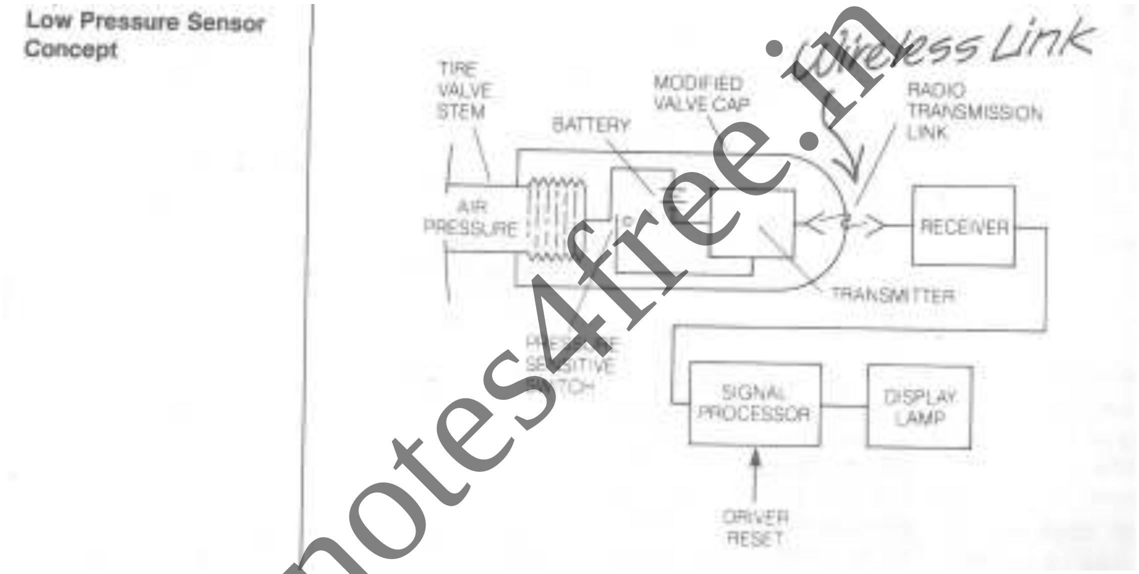


In this scheme, a tire pressure sensor continuously measures the tire pressure. The signal from the sensor mounted on the rolling tire is coupled by a link to the electronic signal processor. Whenever the pressure drops below a critical limit, a warning signal is sent to a display on the instrument panel to indicate which tire has the low pressure.

The difficult part of this system is the link from the tire pressure sensor mounted on the rotating tire to the signal processor mounted on the body. Several concepts theoretically have the potential to provide this link. For example, Slip Rings, which are similar to the brushes on a DC motor, could be used. However, this would require a major modification to the wheel axle assembly and does not appear to be an acceptable choice at the present time.

Another concept for providing this link is to use a small radio transmitter mounted on the tire by using modern solid state electronic technology, a low power transmitter could be constructed. The transmitter could be located in a modified tire valve cap and could transmit to a receiver in the wheel well. The distance from the transmitter to the receiver would be only about one foot, so only very lower power would be required.

One problem with this method is that electrical power for the transmitter would have to be provided by a self contained battery. However, the transmitter need only operate for few seconds and only when the tire pressure falls below a critical level. Therefore a tiny battery theoretically can provide enough power.


Low Pressure Sensor Concept

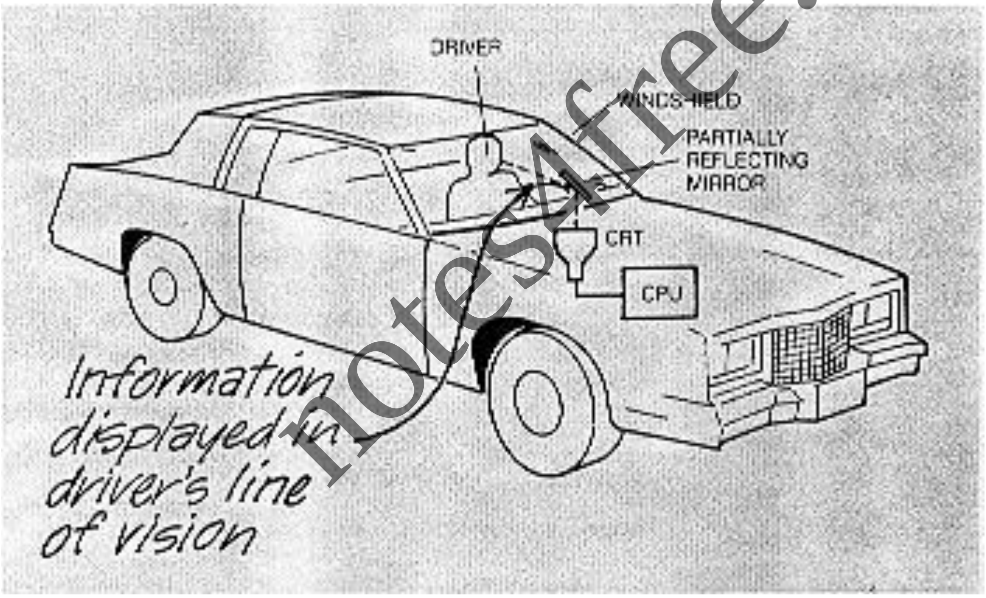
The sensor switch is usually held open by normal tire pressure on a diaphragm mechanically connected to the switch. Low tire pressure allows the spring loaded switch to close, thereby switching ON the micro-transmitter. The receiver, which is directly powered by the car battery, receives the transmitted signal and passes it to the signal processor, also directly powered by the car battery. The signal processor then activates a warning lamp for the driver, and it remains ON until the driver resets the warning system by operating a switch on the instrument panel.

One reason for using a signal processing unit is the relatively short life of the transmitter battery. The transmitter will remain ON until the low pressure condition is corrected or until the battery runs down. By using a signal processor, the low pressure status can be stored in memory so the warning will still be given even if the transmitter quits operating. The need for this feature could arise if the pressure dropped while the car was parked. By storing the status, the system would warn the driver as soon as the ignition was turned ON.

Many other concepts have been proposed for providing a low tire pressure warning system. The future of such a system will be limited largely by its cost and/or reliability.

5.2.6 Heads up Display

It is convenient to describe a HUD by presuming that the display source is a CRT, keeping in mind that many other display sources can be substituted for the CRT. Figure illustrates the concept of a HUD. In this scheme, the information that is to be displayed appears on a CRT that is mounted as shown. A partially reflecting mirror is positioned above the instrument panel in the driver’s line of sight of the road. In normal driving, the driver looks through this mirror at the road. Information to be displayed appears on the face of the CRT upside down, and the image is reflected by the partially reflecting mirror to the driver right side up. The driver can read this data from the HUD without moving his or her head from the position for viewing the road. The brightness of this display would have to be adjusted so that it is compatible with ambient light. The brightness of this data image should never be so great that it inhibits the driver’s view of the road, but it must be bright enough to be visible in all ambient lighting conditions. Fortunately, the CRT brightness can be automatically controlled by electronic circuits to accommodate a wide range of light levels.



5.2.7 Speech Synthesis

Important safety or trip-related messages could be given audibly so the driver doesn’t have to look away from the road. In addition to its normal function of generating visual display outputs, the computer generates an electrical waveform that is approximately the same as a human voice speaking the appropriate message. The voice quality of some types of speech synthesis is often quite natural and similar to human speech.

In the true speech synthesis system, relatively complex messages can be generated in response to outputs from various electronic subsystems. For example, the trip computer could give fuel status in relationship to the car's present position and known fueling stations (both of the latter being available from the navigation system). By combining information from several subsystems on board the car it is possible to inform the driver of trip status at any preprogrammed level of detail.

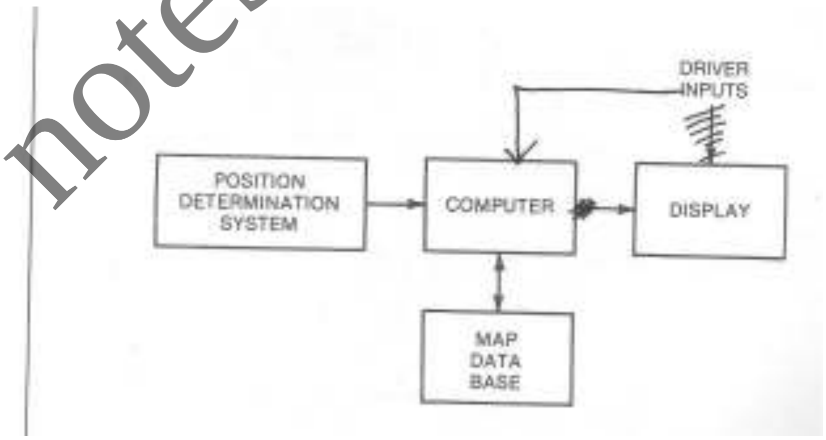
There are several major categories of speech synthesis that have been studied experimentally. Of these, phoneme synthesis is probably the most sophisticated. A *phoneme* is a basic sound that is used to build speech. By having an inventory of these sounds in computer memory and by having the capability to generate each phoneme sound, virtually any word can be constructed by the computer in a manner similar to the way the human voice does. Of course, the electrical signal produced by the computer is converted to sound by a loudspeaker. Synthesized speech is being used to automatically provide data over the phone from computer-based systems and is available on some production cars.

5.2.8 Automotive Navigation Systems

Every driver who has taken a trip to an unfamiliar location understands the problem of navigation. The driver must first obtain maps having sufficient detail to locate the destination. Along the trip the driver must be able to identify the car location in relationship to the map and make decisions at various road intersections about the route continuation.

There has been considerable research done into the development of an electronic automatic navigation system which may someday lead to the widespread commercial sale of such a system.

Generic Automotive Navigation System Block Diagram



Ideally the display device should have the capability of displaying maps with various levels of magnification. As the car approaches its destination, the map detail should increase until the driver can locate his/her position with an accuracy of about 1/2 block.

The Map data base must be capable of storing sufficient data to construct a map of an entire region. The database can either be stored in CD ROM or can be from Internet (Cloud server).

The computer portion of the generic navigation system obtains signals from position sensors and calculates the correct vehicle position in relationship to the map co-ordinates. The computer also controls the map display, accounting for magnification (called by the driver), and displaying the vehicle position super imposed on the map. The correct vehicle position might for example, be shown as a flashing bright spot or a pointer.

5.2.8.1 Navigational sensors

The most critical and costly component in the generic navigation system is the position determining system; that is the position sensor.

Among the concepts presently being considered for automotive navigation are:

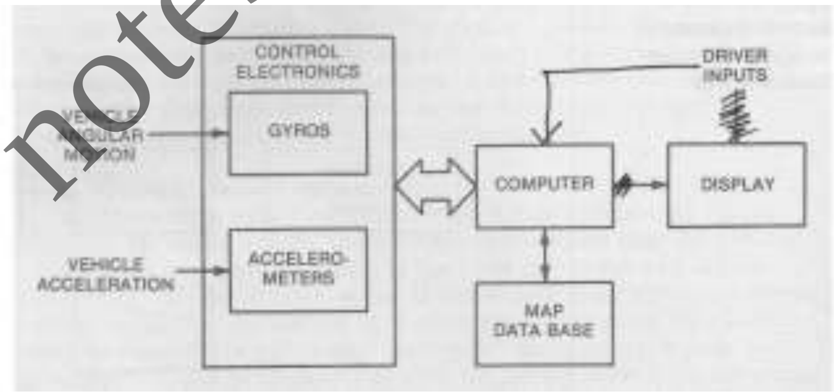
1. Inertial navigation
2. Radio navigation
3. Sign post navigation
4. Dead reckoning navigation

Each of these has relative advantages in terms of cost and performance.

5.2.8.1.1 Inertial Navigation

This has been developed for aircraft navigation, but it is relatively expensive. The aircraft inertial navigation sensor consists of three sets of gyros and accelerometers.

Block Diagram for Automotive Inertial Navigation System



An inertial navigation system locates the vehicle position relative to a known starting point by integrating acceleration twice with respect to time.

For example, along the x-direction, vehicle position at time t is x (t):

$$x(t) = x_0 + \int_0^t \int_0^r a(y)\, dy\, dt$$

Where, x_0 = initial x- position, and a = acceleration along x direction.

A similar integration is performed along the two orthogonal directions.

An inertial navigation system has position errors due to

1. Initial gyro alignment errors
2. Uncompensated gyro drift
3. Accelerometer errors.

A typical high quality commercial navigation system (e.g. Carousel IV) has a position error of about 3000 ft, for each hour of flight. Position errors generated at this rate in an automotive environment implies a trip of more than ½ hour before the error exceeds the ½ block limit. This error in combination with its relatively high cost renders the inertial navigation system unfeasible for automotive use for the foreseeable future.

5.2.8.1.2 Radio Navigation

A Radio based navigation system uses either land or satellite-based transmitters and automotive receivers for position location. The land based transmitters are primarily intended for aircraft or ship navigation and have somewhat limited coverage. The only satellite based system that is potential applicable is the Global Positioning Satellite (GPS).

The GPS, when fully operational, will have 18 orbiting satellites, of which there will be a minimum of four with in line-of-sight of any location on earth. This is sufficient for position location.

In final operational service, these will be two classes of user service available for GPS – the Precise Positioning Service (PPS), which is available only for military, and the Standard Positioning Service (SPS), which is available for automotive navigation.

Each satellite transmits clock pulses. The distance to any satellite is known by the relationship,

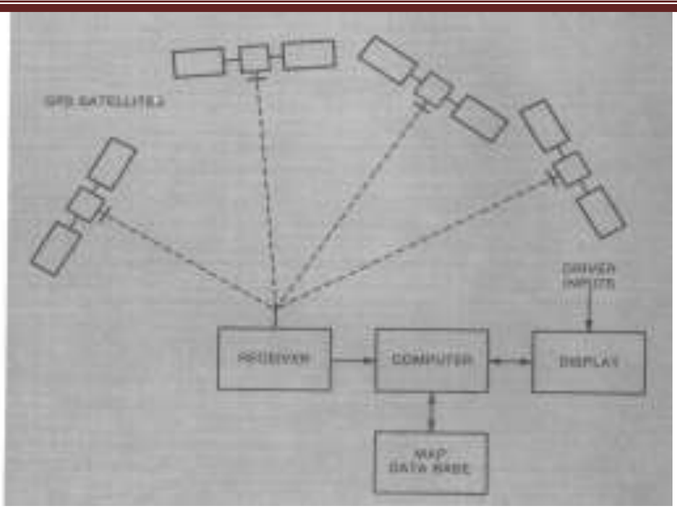
$$R_i = C\, t_i \quad \text{For } i = 1,2,3,4$$

Where, R_i = Distance to any satellite, C = Speed of light (3×10^8 m/sec) and t_i = Propagation time from satellite to car.

Position is determined (in three dimensions of time) by solving four equations involving the range to four satellites.

It is necessary to maintain a direct line of sight. This can be a problem in areas of tall buildings or in mountains terrain. Nevertheless, the GS is potentially viable for automotive navigation and has many advocates.

Automotive GPS Navigation System



5.2.8.1.3 Sign Post Navigation

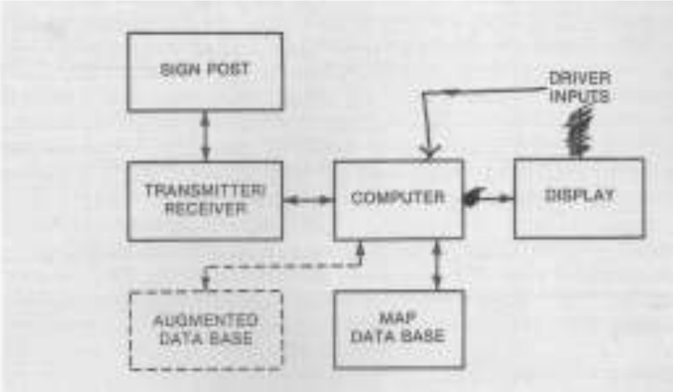
In sign post navigation, a number of information stations are located throughout the road network. In one scheme the signpost continuously transmits the data its geographic location. The onboard navigation system converts this data to map coordinates which are displayed.

This system requires an augmented data base to convert the transmitted data to map coordinates. This system has the capacity to provide position to an accuracy of a few meters. These are draw backs, however to the signpost system including,

1) Inability to determine position between sign posts
2) Inability to slow a turn until the next signpost is reached
3) The need for signpost at every intersection and
4) Requirements for large number of codes.

Thus, in spite of high accuracy of this system, it inherently requires a huge investment in transmission.

Signpost Navigation System



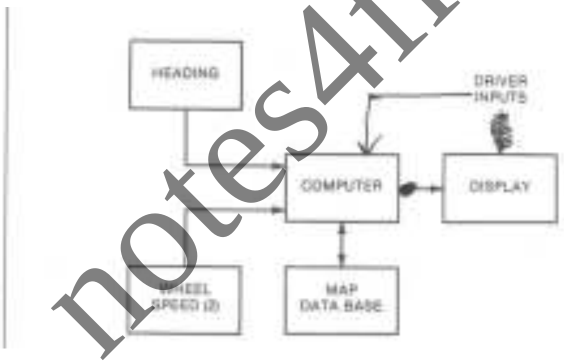
5.2.8.1.4 Dead Reckoning Navigation

Dead reckoning navigation is a method of determining present position from a known earlier position and information about vehicle motion.

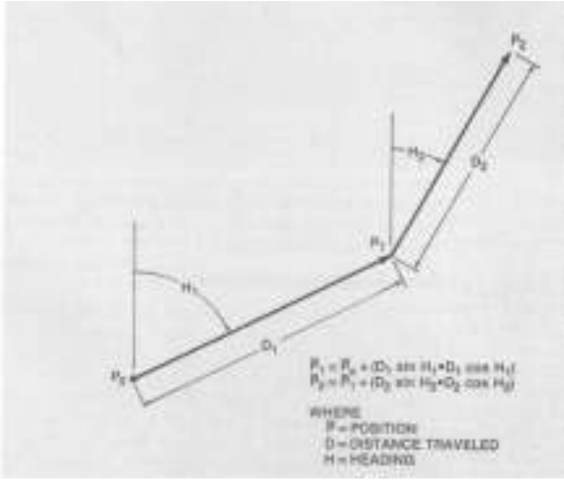
The sensor component of the system includes a ***heading sensor*** and a ***wheel speed sensor***. Experimental systems have used a form of magnetic compass, known as a flux gate, to measure heading. Although this system is conceptually simple, it suffers from poor accuracy. It is estimated that position error of about ½ blocks would accrue for trips less than 9 Kilometers.

The database can either be stored in CD ROM or can be from Internet (Cloud server). Using the stored data, the electronic map is displayed on the display identifying the present position of the car as well as its destination. Using the present position P_0 the new position P_1 is calculated. Errors occur in any dead reckoning navigation system after a time. However, in automotive navigation systems, such errors can be readily bounded. It is presumed that the car is on the road (or in a drive way or parking lot) at all times the co ordinates of the road are known as part of the navigation data base. Whenever, the estimated position Pi is off the road, the computer adjusts the car position to the nearest point on the road. This correction procedure is known as map matching and results in extremely accurate navigation.

Dead Reckoning Navigation System



Dead Reckoning Navigation Computation



5.2.9 Voice recognition cell phone dialing

As beneficial as cellular phone systems are, they do have a potential safety disadvantage. For most people, dialing a number on a cell phone requires looking at the key pad while entering the digits. If the car is moving (and particularly if it is moving in heavy traffic), the momentary distraction of dialing the phone can potentially divert the driver's attention and an accident can occur.

A scheme for dialing the phone without diverting the driver's attention from driving involves speech recognition technology. There are already cell phones available that can accept verbal dialing such that the driver simply speaks the telephone number to be dialed. When the connection is made the phone conversation can be completed without the driver having to physically hold the phone to his or her ear and mouth. However, the majority of such hands-free cell phones can recognize only one or two individual's voices. Normally such a system is trained to recognize the individual speakers. In the future it is likely that cell phone systems will be available that can recognize essentially any speaker. Using such systems, phone conversations can be completed without the driver ever having to divert his or her attention from the road.

5.2.10 Advanced Cruise Control

Advanced Cruise Control (ACC), also known as adaptive, active or intelligent cruise control, is an addition to conventional cruise control systems. ACC not only maintains the driver-set vehicle speed, but also adjusts the vehicle's speed to that of a preceding vehicle, helping to maintain a pre-selected headway time to the vehicle ahead. ACC uses a frontal radar/laser sensor to detect vehicles in front and subsequently adjusts the vehicle's speed and headway by controlling fuel flow or by slightly braking. Active braking carried out by ACC can usually reach up to maximally 30% of the vehicle's maximum deceleration. When a stronger deceleration is needed, the driver is warned by an auditory signal. Once the preceding, slower vehicle has moved out of the lane, the vehicle's speed will return to the driver-set cruise speed. The first ACC systems that were introduced to the market in the late 1990's were a rather expensive option for top-of-the line vehicle models. Today, ACC can be found on a much wider range of vehicle models. However, the equipment rate within the entire vehicle fleet is still very low. Most of the ACC systems now available function for speeds above 30 km/h, have a detection range of 120 m to 150 m, and allow for a manually set headway time between 1 and 3 seconds.

5.2.11 Stability Augmentation

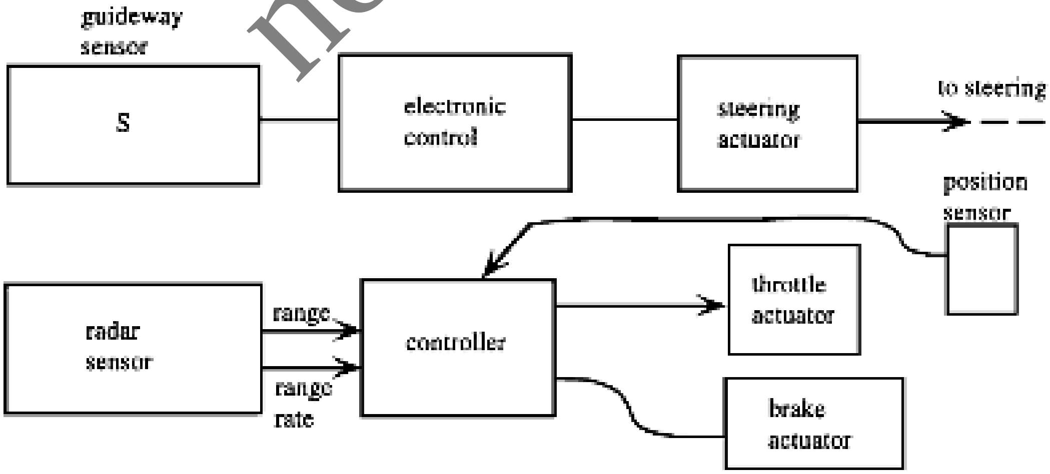
The existence of electronic controlled electric steering and electrohydraulic braking can yield improvements in vehicle stability in the future. In addition to electrohydraulic brakes, there is a possibility of pure electric brakes in which the brake pedals are moved via an electric motor (known as brake-by-wire). There have been some experimental vehicles with electric brakes, and this technology may have a future.

A stability augmentation system would incorporate vehicle roll and yaw rate sensors that provide vehicle dynamic motion measurement to a control system that regulates brakes differentially and air suspension springs and dampers to minimize vehicle roll and to achieve optimal handling during certain maneuvers.

A yaw-rate sensor is a gyroscopic device that measures a vehicle's angular velocity around its vertical axis. The angle between the vehicle's heading and vehicle actual movement direction is called slip angle, which is related to the yaw rate.

5.2.12 Automatic Driving Control

Another rather interesting (but probably pretty far in the future) technology is the vehicle guideway system. This is a purely experimental system at the time of this writing that is envisaged as an automatic driving system. The concept involves automatic steering and automatic vehicle speed control. The concept leads to a system of multiple-vehicle automatic driving called *platooning*. In a platooning system a group of cars is automatically controlled to maintain a set highway cruise speed with a fixed nominal inter-car spacing. Steering control is via a signal radiated from a wire buried in the center of the roadway. Distances between cars and vehicle speeds are maintained with the aid of measurements made by an on-board radar system.
A simplified block diagram for automatic control is shown in Figure. In this figure, a sensor (S) is located on the bottom front of the car that picks up the signal radiated by the buried wire. This sensor signal is the input to a tracking controller that outputs a control signal to a steering actuator. Steering commands guide the vehicle to maintain the sensor over the guideway wire.



Vehicle speed control is accomplished using an on-board radar sensor. This sensor is located in front of the vehicle and directs a narrow radar beam forward. The radar sensor system obtains a measurement of the range to a car in front of the given car as well as the rate of change of that range. The sensor can also measure vehicle ground speed via Doppler shift of radar signals reflected from the ground.

The control system is a multiple-input/multiple-output controller that generates control signals for a throttle actuator and a braking actuator. Normally the controller will only activate the throttle; however, if the range to the vehicle is decreasing even with a closed throttle, then braking is required. The braking actuator pressurizes the brake lines automatically to slow the vehicle as required. This action could occur if the platoon of cars were driving down a long, relatively steep mountain or slope. It could also be required if an obstacle were encountered that was stationary (as in the case of a car with a breakdown). Panic-stop braking could actually be required in extreme cases.

Whenever manual control is required (e.g., when a given vehicle exits the highway in order to reach a given destination), the driver takes control by operating a control release switch. There are many variations on the concept described above. Some will prove to be feasible; others will not. At this time the automatic vehicle guideway is an interesting experimental system with great potential for maintaining optimum traffic flow on otherwise busy or congested highways.

It should be emphasized that many of the topics included in this final chapter have an uncertain future in terms of production automobiles. Each idea discussed here has had at least an experimental confirmation of its technical feasibility. However, the final arbiter of the viability of each subsystem will be the automobile consumer, who will vote with his or her dollars on whether any given subsystem or feature is worth the incremental purchase price.

OUTCOMES

At the end of this module, the students will have a fair idea about,

1. Alternate mode of running of Automotive Engines other than gasoline and diesel.
2. The Automotive Electronic Systems that may hit the market in near future.
3. Diagnostics in case of Automotive Electronic Systems such as On-Board & Off-Board diagnostics and Expert Systems.
4. The safety systems incorporated in Automotives such as Air bags.

MODEL QUESTIONS

Module 5- Chapter 1 (Automotive Diagnostics)

1. Write notes on the following with relevant diagrams/ Flowcharts wherever applicable.
   (a) On-Board Diagnostics
   (b) Off-Board Diagnostics
   (c) Expert Systems
2. Explain the principle of functioning of Airbag with relevant diagrams.

Module 5- Chapter 2 *(*FUTURE AUTOMOTIVE ELECTRONIC SYSTEMS)

1. Explain Collision Avoidance Radar Warning System with relevant diagrams and equations.
2. Explain low tire-pressure Warning System with relevant diagrams.
3. Write notes on the following with relevant diagrams/Flow Charts and equations wherever applicable.

   (a) Alternate Fuel Engines
   (b) Electric and Hybrid Vehicles
   (c) Fuel Cell powered cars
   (d) Heads up display
   (e) Speech Synthesis
   (f) Inertial Navigation
   (g) Radio Navigation
   (h) Signpost Navigation
   (i) Dead reckoning Navigation
   (j) Voice recognition cell phone dialing
   (k) Advanced Cruise Control
   (l) Stability Augmentation
   (m) Automatic Driving Control

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