OBJECTIVE

To explain the principle of engines and vehicle electronic management system and different sensors used in the systems.

UNIT I  FUNDAMENTALS OF AUTOMOTIVE ELECTRONICS

- Microprocessor architecture, open and closed loop control strategies, PID control, Look up tables, introduction to modern control strategies like Fuzzy logic and adaptive control. Parameters to be controlled in SI and CI engines and in the other parts of the automobile.

UNIT II  SENSORS

- Inductive, Hall effect, hot wire, thermistor, piezo electric, piezoresistive, based sensors. Throttle position, air mass flow, crank shaft position, cam position, engine and wheel speed, steering position, tire pressure, brake pressure, steering torque, fuel level, crash, exhaust oxygen level (two step and linear lambda), knock, engine temperature, manifold temperature and pressure sensors.

UNIT III  SI ENGINE MANAGEMENT


UNIT IV  CI ENGINE MANAGEMENT


UNIT V  VEHICLE MANAGEMENT SYSTEMS


TOTAL : 60 PERIODS

TEXT BOOKS


Course : AU 2401 – Engine & Vehicle Management Systems
Faculty : A.J.D. Nanthakumar
REFERENCES


UNIT – I
FUNDAMENTALS OF AUTOMOTIVE ELECTRONICS

Microprocessor architecture, open and closed loop control strategies, PID control, Look up tables, introduction to modern control strategies like Fuzzy logic and adaptive control. Parameters to be controlled in SI and CI engines and in the other parts of the automobile.

Microprocessor architecture:
The term microprocessor typically refers to the central processing unit (CPU) of a microcomputer, containing the arithmetic logic unit (ALU) and the control units. It is typically implemented on a single LSI chip. This separates the "brains" of the operation from the other units of the computer. The microprocessor contains the arithmetic logic unit (ALU) and the control unit for a microcomputer. It is connected to memory and I/O by buses which carry information between the units.
Information is transferred between units of the microcomputer by collections of conductors called buses. There will be one conductor for each bit of information to be passed, e.g., 16 lines for a 16 bit address bus. There will be address, control, and data buses. All the arithmetic operations of a microprocessor take place in the arithmetic logic unit (ALU). Using a combination of gates and flip-flops, numbers can be added in less than a microsecond, even in small personal computers. The operation to be performed is specified by signals from the control unit. The data upon which operations are performed can come from memory or an external input. The data may be combined in some way with the contents of the accumulator and the results are typically placed in the accumulator. From there they may be transferred to memory or to an output unit. The accumulator is the principal register of the arithmetic logic unit of a microprocessor. Registers are sets of flip-flops which can hold data. The accumulator typically holds the first piece of data for a calculation. If a number from memory is added to that date, the sum replaces the original data in the accumulator. It is the repository for successive results of arithmetic operations, which may then be transferred to memory, to an output device, etc. The control unit of a microprocessor directs the operation of the other units by providing timing and control signals. It is the function of the microcomputer to execute programs which are stored in memory in the form of instructions and data. The control unit contains the necessary logic to interpret instructions and to generate the signals necessary for the execution of those instructions. The descriptive words "fetch" and "execute" are used to describe the actions of the control unit. It fetches an instruction by sending an address and a read command to the memory unit. The instruction at that memory address is transferred to the control unit for decoding. It then generates the necessary signals to execute the instruction.

**Memory**

Program, data and stack memories occupy the same memory space. The total addressable memory size is 64 KB.

Program memory - program can be located anywhere in memory. Jump, branch and call instructions use 16-bit addresses, i.e. they can be used to jump/branch anywhere within 64 KB. All jump/branch instructions use absolute addressing.

Data memory - the data can be placed anywhere as the 8085 processor always uses 16-bit addresses.

Stack memory is limited only by the size of memory. Stack grows downward.

First 64 bytes in a zero memory page should be reserved for vectors used by RST instructions.

**Interrupts**

The 8085 microprocessor has 5 interrupts. They are presented below in the order of their priority (from lowest to highest):

- INTR is maskable 8080A compatible interrupt. When the interrupt occurs the processor fetches from the bus one instruction, usually one of these instructions:

  > A One of the 8 RST instructions (RST0 - RST7). The processor saves current program counter into stack and branches to memory location N * 8 (where N is a 3-bit number from 0 to 7 supplied with the RST instruction).
CALL instruction (3 byte instruction). The processor calls the subroutine, address of which is specified in the second and third bytes of the instruction.

RST5.5 is a maskable interrupt. When this interrupt is received the processor saves the contents of the PC register into stack and branches to 2Ch (hexadecimal) address.

RST6.5 is a maskable interrupt. When this interrupt is received the processor saves the contents of the PC register into stack and branches to 34h (hexadecimal) address.

RST7.5 is a maskable interrupt. When this interrupt is received the processor saves the contents of the PC register into stack and branches to 3Ch (hexadecimal) address.

Trap is a non-maskable interrupt. When this interrupt is received the processor saves the contents of the PC register into stack and branches to 24h (hexadecimal) address.

All maskable interrupts can be enabled or disabled using EI and DI instructions. RST 5.5, RST6.5 and RST7.5 interrupts can be enabled or disabled individually using SIM instruction.

I/O ports

256 Input ports
256 Output ports

Registers

Accumulator or A register is an 8-bit register used for arithmetic, logic, I/O and load/store operations.

Flag is an 8-bit register containing 5 1-bit flags:

- Sign - set if the most significant bit of the result is set.
- Zero - set if the result is zero.
- Auxiliary carry - set if there was a carry out from bit 3 to bit 4 of the result.
- Parity - set if the parity (the number of set bits in the result) is even.
- Carry - set if there was a carry during addition, or borrow during subtraction/comparison.

General registers:

- 8-bit B and 8-bit C registers can be used as one 16-bit BC register pair. When used as a pair the C register contains low-order byte. Some instructions may use BC register as a data pointer.
- 8-bit D and 8-bit E registers can be used as one 16-bit DE register pair. When used as a pair the E register contains low-order byte. Some instructions may use DE register as a data pointer.
- 8-bit H and 8-bit L registers can be used as one 16-bit HL register pair. When used as a pair the L register contains low-order byte. HL register usually contains a data pointer used to reference memory addresses.

Stack pointer is a 16 bit register. This register is always incremented/decremented by 2.

Program counter is a 16-bit register.
Instruction Set

Instruction set of Intel 8085 microprocessor consists of the following instructions:

- Data moving instructions.
- Arithmetic - add, subtract, increment and decrement.
- Logic - AND, OR, XOR and rotate.
- Control transfer - conditional, unconditional, call subroutine, return from subroutine and restarts.
- Input/Output instructions.
- Other - setting/clearing flag bits, enabling/disabling interrupts, stack operations, etc.

Addressing modes

Register - references the data in a register or in a register pair.

Register indirect - instruction specifies register pair containing address, where the data is located.

Direct.

Immediate - 8 or 16-bit data.

Open-Loop Control

Theoretically, if there were no changes to the engine, the sensors, or the fuel injector, an engine control system could operate open loop at all times. In practice, owing to variations in manufactured components, as well as to factors such as wear, the open-loop control would not be able to maintain the mixture at the desired air/fuel ratio. In order to maintain the very precise air/fuel mixture ratio required for emission control over the full life of the vehicle, the engine controller is operated in closed-loop mode for as much of the time as possible.

Closed-Loop Control

The control system in closed-loop mode 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 EGO sensor generates a feedback signal for the controller input that depends on the air/fuel ratio in the intake mixture. This signal tells the controller to adjust the fuel flow rate for the required air/fuel ratio, thus completing the loop.

PID CONTROL

The PID controller is the most-used feedback control design. Among various control algorithms, traditional PID algorithm has been used successfully for many applications. The key advantages of PID control are its simplicity and practicality. Its control parameters can be tuned on line; the flexibility of its software development makes it easier to get a better control result.
LOOKUP TABLE

The engine control unit uses a formula and a large number of lookup tables to determine the pulse width for given operating conditions. The equation will be a series of many factors multiplied by each other. Many of these factors will come from lookup tables.

The basic ignition advance angle etc is obtained from a memorized cartographic map or a lookup table. These are held in a ROM chip within the ECU. The parameters for ignition advance calculations are:

- Engine rev/min – given by the flywheel sensor
- Inlet air pressure – given by the manifold absolute pressure sensor

The above two parameters (speed and load) give the basic setting but to ensure optimum advance angle the timing is corrected by:

- Coolant temperature.
- Air temperature.
- Throttle butterfly position.

FUZZY LOGIC CONTROL

FL is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded microcontrollers to large, networked, multi-channel PC or workstation-based data acquisition and control systems. FL provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. FL's approach to control problems mimics how a person would make decisions, only much faster.

ADAPTIVE CONTROL

Adaptive control is a generic term to describe the ability of a control system to react to changes in circumstances. Most of the optimum control models use some form of adaptive control to optimize the performance of a given controller architecture.

Control Parameters of an SI Engine

The major physical quantities that are outputs from the controller are:

1. Fuel metering control
2. Ignition control
3. Ignition timing
4. Exhaust gas recirculation control

Control Parameters of an CI Engine
The main aim of computer control is to ensure that the engine receives the precise amount of fuel that is required, at the correct time and under all operating conditions. There are three areas of computer control:

The three items are:

1. fuel quantity (spill control)
2. injection timing control
3. idle speed control.

UNIT – II

SENSORS

Inductive, Hall effect, hot wire, thermistor, piezo electric, piezoresistive, based sensors. Throttle position, air mass flow, crank shaft position, cam position, engine and wheel speed, steering position, tire pressure, brake pressure, steering torque, fuel level, crash, exhaust oxygen level (two step and linear lambda), knock, engine temperature, manifold temperature and pressure sensors.

VARIABLE INDUCTANCE TYPE MAP SENSOR

In this type, the iron cylinder moves in or out of the coil under the influence of the diaphragm and spring. Variations in manifold absolute pressure increase or decrease the ‘suction’ force acting on the diaphragm and the resultant changes in inductance are related to the manifold absolute pressure. The coil (inductance) forms part of an electronic circuit and this circuit is designed so that the changes in frequency of the square-wave output are accurate representations of manifold absolute pressure.

HALL EFFECT SENSOR

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

A Hall effect sensor is a transducer that varies its output voltage in response to changes in magnetic field. Hall sensors are used for proximity switching, positioning, speed detection, and current sensing applications.

In its simplest form, the sensor operates as an analogue transducer, directly returning a voltage. With a known magnetic field, its distance from the Hall plate can be determined. Using groups of sensors, the relative position of the magnet can be deduced.

Electricity carried through a conductor will produce a magnetic field that varies with current, and a Hall sensor can be used to measure the current without interrupting the circuit. Typically, the sensor is integrated with a wound core or permanent magnet that surrounds the conductor to be measured.
Frequently, a Hall sensor is combined with circuitry that allows the device to act in a digital (on/off) mode, and may be called a switch in this configuration. Commonly seen in industrial applications such as the pictured pneumatic cylinder, they are also used in consumer equipment; for example some computer printers use them to detect missing paper and open covers. When high reliability is required, they are used in keyboards.

Hall sensors are commonly used to time the speed of wheels and shafts, such as for internal combustion engine ignition timing, tachometers and anti-lock braking systems. They are used in brushless DC electric motors to detect the position of the permanent magnet. In the pictured wheel with two equally spaced magnets, the voltage from the sensor will peak twice for each revolution. This arrangement is commonly used to regulate the speed of disc drives.

**Hall probe**

A hall probe contains an indium compound crystal such as indium antimonide, mounted on an aluminum backing plate, and encapsulated in the probe head. The plane of the crystal is perpendicular to the probe handle. Connecting leads from the crystal are brought down through the handle to the circuit box.

When the Hall Probe is held so that the magnetic field lines are passing at right angles through the sensor of the probe, the meter gives a reading of the value of magnetic flux density (B). A current is passed through the crystal which, when placed in a magnetic field has a “Hall Effect” voltage developed across it. The Hall Effect is seen when a conductor is passed through a uniform magnetic field. The natural electron drift of the charge carriers causes the magnetic field to apply a Lorentz force (the force exerted on a charged particle in an electromagnetic field) to these charge carriers. The result is what is seen as a charge separation, with a build up of either positive or negative charges on the bottom or on the top of the plate. The crystal measures 5 mm square. The probe handle, being made of a non-ferrous material, has no disturbing effect on the field.

A Hall Probe is enough to measure the Earth’s magnetic field. It must be held so that the Earth’s field lines are passing directly through it. It is then rotated quickly so the field lines pass through the sensor in the opposite direction. The change in the flux density reading is double the Earth’s magnetic flux density. A hall probe must first be calibrated against a known value of magnetic field strength. For a solenoid the hall probe is placed in the center.

**Hall Effect Sensor Interface**

Hall effect sensor may require analog circuitry to be interfaced to microprocessors. These interfaces may include input diagnostics, fault protection for transient conditions, and short/open circuit detection. It may also provide and monitor the current to the hall effect sensor itself. There are precision IC products available to handle these features.

**THERMISTOR BASED SENSOR**

A typical coolant sensor consists of a thermistor mounted in a housing that is designed to be inserted in the coolant stream. This housing is typically threaded with pipe threads that seal the assembly against
coolant leakage. A thermistor is made of semiconductor material whose resistance varies inversely with temperature. The sensor output voltage varies inversely with temperature; that is, the output voltage decreases as the temperature increases. The sensor is typically connected in an electrical circuit like that shown in the figure below, in which the coolant temperature sensor resistance is denoted ‘RT’. This resistance is connected to a reference voltage through a fixed resistance R.

PIEZO ELECTRIC SENSORS

The steel washer that makes up the seismic mass the sensor has very precise dimensions. The mechanical vibrations are transmitted by the seismic mass, to the piezoelectric crystal. The ‘squeezing up’ and relaxing of the crystal in response to this action, produces a small electrical signal. The electrical signal is conducted away from the crystal by wires that are secured to suitable points on the crystal.

THROTTLE POSITION SENSOR

The throttle plate is linked mechanically to the accelerator pedal. When the driver depresses the accelerator pedal, this linkage causes the throttle plate angle to increase, allowing more air to enter the engine and thereby increasing engine power. Most throttle angle sensors are essentially potentiometers. A potentiometer consists of a resistor with a movable contact, as illustrated in the figure below. A section of resistance material is placed in an arc around the pivot axis for the movable contact. One end of the resistor is connected to ground, the other to a fixed voltage \( V_c \). The voltage \( V_p \) at the contact point of the movable contact is proportional to the angle (a) from the ground contact to the movable contact.

AIR MASS FLOW FOR ENGINE

A critically important aspect of fuel control is the requirement to measure the mass of air that is drawn into the cylinder. An engine requires the correct air–fuel ratio to suit various conditions. With electronic fuel injection the ECM controls the air–fuel ratio and in order to do this it needs a constant flow of information about the amount of air flowing to the engine. With this information, and data stored in its memory, the ECM can then send out a signal to the injectors, so that they provide the correct amount of fuel. The amount of fuel delivered can then be calculated such as to maintain the desired air/fuel ratio. There is no practically feasible way of measuring the mass of air in the cylinder directly. However, the air charge can be determined from the mass flow rate of air into the engine intake since all of this air eventually is distributed to the cylinders.

CRANK SHAFT ANGULAR POSITION

An engine speed sensor is needed to provide an input for the electronic controller for several functions. This information is used by the electronic engine controller to set ignition timing and, in most cases, to set the fuel injector pulse timing. Crank angular position can be sensed on the crankshaft directly or on the camshaft. Although the crankshaft location is potentially superior for accuracy because of torsional and gear backlash errors in the camshaft drive train, many production systems locate this sensor such that it measures camshaft position. It is desirable to measure engine angular position with a noncontacting sensor to avoid mechanical wear and corresponding changes in accuracy of the measurement. The two most common methods for noncontact coupling to a rotating shaft is to employ magnetic fields or optics.

RELUCTANCE BASED SPEED SENSOR
This sensor consists of a permanent magnet with a coil of wire wound around it. A steel disk that is mounted on the crankshaft, in front of the engine, has tabs that pass between the pole pieces of this magnet. 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, although other reference positions are also possible.

EXHAUST GAS OXYGEN SENSOR

The vehicle application for an oxygen sensor is to provide a closed loop feedback system for engine management control of the air–fuel ratio. The amount of oxygen sensed in the exhaust is directly related to the mixture strength, or air–fuel ratio. The ideal air–fuel ratio of 14.7:1 by mass is known as a lambda (λ) value of one. Exhaust gas oxygen (EGO) sensors are placed in the exhaust pipe near to the manifold to ensure adequate heating. The sensors operate reliably at temperatures between 300 °C & 850 °C. In some cases, a heating element is incorporated to ensure this temperature is reached quickly. This type of sensor is known as a heated exhaust gas oxygen sensor, or HEGO.

The amount of oxygen in the exhaust gas is used as an indirect measurement of the air/fuel ratio. As a result, one of the most significant automotive sensors in use today is the exhaust gas oxygen (EGO) sensor. This sensor is often called a lambda sensor from the Greek letter lambda (λ), which is commonly used to denote the equivalence ratio.

MANIFOLD PRESSURE

Engine load is proportional to manifold pressure in that high load conditions produce high pressure and lower load conditions [e.g., cruising] produce lower pressure. Load sensors are therefore pressure transducers. They are either mounted in the ECU or as a separate unit, and are connected to the inlet manifold with a pipe. The pipe often incorporates a sensor restriction to damp out fluctuations and a vapour trap to prevent petrol fumes reaching the sensor.

MAP sensors does not measure manifold pressure directly, but instead measure the displacement of a diaphragm that is deflected by manifold pressure.
UNIT – III

SI ENGINE MANAGEMENT


THREE-WAY CATALYTIC CONVERTER

A three-way catalytic converter system differs from the two-way catalytic converter by virtue of it promoting reactions actually among those constituents of the exhaust gases that are subject to control. In effect, the unburned hydrocarbons and carbon monoxide remove the oxygen from the oxides of nitrogen, thereby forming harmless water, carbon dioxide and nitrogen. However, a three-way catalytic converter only possesses this capability in full when the engine is being operated within a very narrow margin of its stoichiometric point, so that an extremely precise means of monitoring and adjusting the air–fuel ratio must be used. In practice, this means introducing a regulating oxygen sensor into the exhaust stream that responds electrically to changes in oxygen content of the gases or, more specifically, measures the amount of excess oxygen in the exhaust relative to that in the air. The oxygen sensor continually signals this information on the completeness of combustion to the electronic control unit of the engine management system, which then issues the appropriate commands for adjusting the mixture to either the fuel injection system or, less commonly, an electronically controlled carburettor. This provides what is sometimes referred to as a ‘closed-loop’ control system.

ENGINE OPERATION PHASES

For a typical engine there are seven different engine operating modes that affect fuel control: engine crank, engine warm-up, open-loop control, closed-loop control, hard acceleration, deceleration, and idle. The program for mode control logic determines the engine operating mode from sensor data and timers.

FUEL CONTROL MAPS

The development of any control system comes from knowledge of the plant, or system to be controlled. In the case of the automobile engine, this knowledge of the plant (the engine) comes primarily from a process called engine mapping.

For engine mapping, the engine is connected to a dynamometer and operated throughout its entire speed and load range. Measurements are made of the important engine variables while quantities, such as the air/fuel ratio and the spark control, are varied in a known and systematic manner. From this mapping, a mathematical model is developed that explains the influence of every measurable variable and parameter on engine performance.
A fuelling map, as shown below, is similar to the ignition map. The differences being that engine load is represented by throttle position and spark advance is replaced by air/fuel ratio. Each point of the surface on this map can be represented by a binary code and a range of points from a map is stored in the ROM of the ECM. The values stored in the ROM are compared with input signals from sensors in order that the computer can determine the duration of the fuel injection pulse.

![A Typical Fuelling Map](image)

**L Jetronic:**

Fuel-injection valves. The electronically controlled fuel-injection valves inject precisely metered fuel into the intake ports and onto the intake valves. Each engine cylinder has its own fuel-injection valve. The valves are solenoid-operated and are opened and closed by means of electric pulses from the electronic control unit. The fuel-injection valve consists of a valve body and the needle valve with fitted solenoid armature. The valve body contains the solenoid winding and the guide for the needle valve. When there is no current flowing in the solenoid winding, the needle valve is pressed against its seat on the valve outlet by a helical spring. When a current is passed through the solenoid winding, the needle valve is lifted by approximately 0.1mm from its seat and the fuel can be injected through the precision annular orifice. The front end of the needle valve has a specially ground pintle for atomizing the fuel (Figure 8). The pickup and release times of the valve lie in the range of 1 to 1.5 ms. To achieve good fuel distribution together with low condensation loss, it is necessary that wetting of the intake-manifold walls be avoided. The means that a particular spray angle in conjunction with a particular distance of the injection valve from the intake valve must therefore be maintained, specific to the engine concerned. The fuel-injection valves are fitted with the help of special holders and are mounted in rubber mouldings in these holders. The insulation from the heat of the engine thereby achieved prevents the formation of fuel-vapour bubbles and guarantees good hot-starting characteristics. The rubber mouldings also ensure that the fuel-injection valves are not subjected to excessive vibration.

**Operating-data sensing system:**

Sensors detect the operating mode of the engine and signal this condition electrically to the control unit. The sensors and ECU form the control system. The sensors are described in conjunction with the relevant main function or compensation function. Measured variables The measured variables characterizing the operating mode of the engine are as follows:–Main measured variables,—Measured
variables for compensation. Measured variables for precision compensation. The ECU evaluates all measured variables together so that the engine is always supplied with exactly the amount of fuel required for the instantaneous operating mode. This achieves optimum driveability. Main measured variables. The main measured variables are the engine speed and the amount of air drawn in by the engine. These determine the amount of air per stroke which then serves as a direct measure for the loading condition of the engine measured variables for compensation. For operating conditions such as cold start and warm-up and the various load conditions which deviate from normal operation, the mixture must be adapted to the modified conditions. Starting and warm-up conditions are detected by sensors which transmit the engine temperature to the control unit. For compensating various load conditions, the load range (idle, part-load, full-load) is transmitted to the control unit via the throttle-valve switch. Measured variables for precision compensation In order to achieve optimum driving behavior, further operating ranges and influences can be considered: the sensors mentioned above detect the data for transition response when accelerating, for maximum engine-speed limitation and during overrun. The sensor signals have a particular relationship to each other in these operating ranges. The control unit recognizes these relationships and influences the control signals of the injection valves accordingly. Calculating engine speed Information on engine speed and the start of injection is passed on to the L-Jetronic ECU in breaker-triggered ignition systems by the contact-breaker points in the ignition distributor, and, in breakerless ignition systems, by terminal 1 of the ignition coil (Fig. 9).

Measuring the air flow. The amount of air drawn in by the engine is a measure of its loading condition. The air-flow measurement system allows for all changes which may take place in the engine during the service life of the vehicle, e.g. wear, combustion-chamber deposits and changes to the valve settings. Since the quantity of air drawn in must first pass through the air-flow sensor before entering the engine, this means that, during acceleration, the signal leaves the sensor before the air is actually drawn into the cylinder. This permits correct mixture adaptation at any time during load changes.

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1. Fuel Tank
2. Electric fuel pump
3. Fuel filter
4. ECU
5. Fuel injector
6. Fuel rail and fuel-pressure regulator
7. Intake manifold
8. Cold start valve
9. Throttle-valve switch
10. Air-flow sensor
11. Lambda sensor
12. Thermo-time switch
13. Engine-temperature sensor
14. Ignition distributor
15. Auxiliary-air device
16. Battery
17. Ignition and starting switch

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Course : AU 2401 – Engine & Vehicle Management Systems
Faculty : A.J.D. Nanthakumar
UNIT IV:

Common Rail Diesel Injection:

Solenoid or piezoelectric valves make possible fine electronic control over the fuel injection time and quantity and the higher pressure that the common rail technology makes available provides better fuel atomisation. In order to lower engine noise, the engine’s electronic control unit can inject a small amount of diesel just before the main injection event ("pilot" injection), thus reducing its explosiveness and vibration, as well as optimising injection timing and quantity for variations in fuel quality, cold starting and so on. Some advanced common rail fuel systems perform as many as five injections per stroke.[7]

Common rail engines require very short (< 1 s) or no heating up time at all[citation needed] and produce lower engine noise and emissions than older systems.

Diesel engines have historically used various forms of fuel injection. Two common types include the unit injection system and the distributor/inline pump systems (See diesel engine and unit injector for more information). While these older systems provided accurate fuel quantity and injection timing control, they were limited by several factors:

- They were cam driven and injection pressure was proportional to engine speed. This typically meant that the highest injection pressure could only be achieved at the highest engine speed and the maximum achievable injection pressure decreased as engine speed decreased. This relationship is true with all pumps, even those used on common rail systems; with the unit or distributor systems, however, the injection pressure is tied to the instantaneous pressure of a single pumping event with no accumulator and thus the relationship is more prominent and troublesome.
- They were limited in the number and timing of injection events that could be commanded during a single combustion event. While multiple injection events are possible with these older systems, it is much more difficult and costly to achieve.
- For the typical distributor/inline system, the start of injection occurred at a pre-determined pressure (often referred to as: pop pressure) and ended at a pre-determined pressure. This characteristic resulted from “dummy” injectors in the cylinder head which opened and closed at pressures determined by the spring preload applied to the plunger in the injector. Once the pressure in the injector reached a pre-determined level, the plunger would lift and injection would start.

In common rail systems, a high pressure pump stores a reservoir of fuel at high pressure — up to and above 2,000 bars (29,000 psi). The term "common rail" refers to the fact that all of the fuel injectors are supplied by a common fuel rail which is nothing more than a pressure accumulator where the fuel is stored at high pressure. This accumulator supplies multiple fuel injectors with high pressure fuel. This simplifies the purpose of the high pressure pump in that it only has to maintain a commanded pressure at a target (either mechanically or electronically controlled). The fuel injectors are typically ECU-controlled. When the fuel injectors are electrically activated, a hydraulic valve (consisting of a nozzle and plunger) is mechanically or hydraulically opened and fuel is sprayed into the cylinders at the desired pressure. Since the fuel pressure energy is stored remotely and the injectors are electrically actuated, the injection pressure at the start and end of injection is very near the pressure in the accumulator (rail), thus producing a square injection rate. If the accumulator, pump and plumbing are sized properly, the injection pressure and rate will be the same for each of the multiple injection events.
FUEL INJECTION

Fuel injection is a system for mixing fuel with air in an internal combustion engine. It has become the primary fuel delivery system used in automotive petrol engines, having almost completely replaced carburetors in the late 1980s.

A fuel injection system is designed and calibrated specifically for the type(s) of fuel it will handle. Most fuel injection systems are for gasoline or diesel applications. With the advent of electronic fuel injection (EFI), the diesel and gasoline hardware has become similar. EFI’s programmable firmware has permitted common hardware to be used with different fuels.

Carburetors were the predominant method used to meter fuel on gasoline engines before the widespread use of fuel injection. A variety of injection systems have existed since the earliest usage of the internal combustion engine.

The primary difference between carburetors and fuel injection is that fuel injection atomizes the fuel by forcibly pumping it through a small nozzle under high pressure, while a carburetor relies on low pressure created by intake air rushing through it to add the fuel to the airstream. The fuel injector is only a nozzle and a valve: the power to inject the fuel comes from a pump or a pressure container farther back in the fuel supply. Benefits
**Engine operation**

Operational benefits to the driver of a fuel-injected car include smoother and more dependable engine response during quick throttle transitions, easier and more dependable engine starting, better operation at extremely high or low ambient temperatures, increased maintenance intervals, and increased fuel efficiency. On a more basic level, fuel injection does away with the choke which on carburetor-equipped vehicles must be operated when starting the engine from cold and then adjusted as the engine warms up.

An engine's air/fuel ratio must be precisely controlled under all operating conditions to achieve the desired engine performance, emissions, driveability, and fuel economy. Modern electronic fuel-injection systems meter fuel very accurately, and use closed loop fuel-injection quantity-control based on a variety of feedback signals from an oxygen sensor, a mass airflow (MAF) or manifold absolute pressure (MAP) sensor, a throttle position (TPS), and at least one sensor on the crankshaft and/or camshaft(s) to monitor the engine's rotational position. Fuel injection systems can react rapidly to changing inputs such as sudden throttle movements, and control the amount of fuel injected to match the engine’s dynamic needs across a wide range of operating conditions such as engine load, ambient air temperature, engine temperature, fuel octane level, and atmospheric pressure.

A multipoint fuel injection system generally delivers a more accurate and equal mass of fuel to each cylinder than can a carburetor, thus improving the cylinder-to-cylinder distribution. Exhaust emissions are cleaner because the more precise and accurate fuel metering reduces the concentration of toxic combustion byproducts leaving the engine, and because exhaust cleanup devices such as the catalytic converter can be optimized to operate more efficiently since the exhaust is of consistent and predictable composition.

Fuel injection generally increases engine fuel efficiency. With the improved cylinder-to-cylinder fuel distribution, less fuel is needed for the same power output. When cylinder-to-cylinder distribution is less than ideal, as is always the case to some degree with a carburetor or throttle body fuel injection, some cylinders receive excess fuel as a side effect of ensuring that all cylinders receive sufficient fuel. Power output is asymmetrical with respect to air/fuel ratio; burning extra fuel in the rich cylinders does not reduce power nearly as quickly as burning too little fuel in the lean cylinders. However, rich-running cylinders are undesirable from the standpoint of exhaust emissions, fuel efficiency, engine wear, and engine oil contamination. Deviations from perfect air/fuel distribution, however subtle, affect the emissions, by not letting the combustion events be at the chemically ideal (stoichiometric) air/fuel ratio. Grosser distribution problems eventually begin to reduce efficiency, and the grossest distribution issues finally affect power. Increasingly poorer air/fuel distribution affects emissions, efficiency, and power, in that order. By optimizing the homogeneity of cylinder-to-cylinder mixture distribution, all the cylinders approach their maximum power potential and the engine's overall power output improves.

A fuel-injected engine often produces more power than an equivalent carbureted engine. Fuel injection alone does not necessarily increase an engine's maximum potential output. Increased airflow is needed to burn more fuel, which in turn releases more energy and produces more power. The combustion process converts the fuel's chemical energy into heat energy, whether the fuel is supplied by fuel injectors or a carburetor. However, airflow is often improved with fuel injection, the components of which allow more design freedom to improve the air's path into the engine. In contrast, a carburetor's mounting options are limited because it is larger, it must be carefully oriented with respect to gravity, and it must be equidistant from each of the engine's cylinders to the maximum practicable degree. These design constraints generally compromise airflow into the engine. Furthermore, a carburetor relies on a
restrictive venturi to create a local air pressure difference, which forces the fuel into the air stream. The flow loss caused by the venturi, however, is small compared to other flow losses in the induction system. In a well-designed carburetor induction system, the venturi is not a significant airflow restriction.

Fuel is saved while the car is coasting because the car's movement is helping to keep the engine rotating, so less fuel is used for this purpose. Control units on modern cars react to this and reduce or stop fuel flow to the engine reducing wear on the brake.

Functioning:

The process of determining the necessary amount of fuel, and its delivery into the engine, are known as fuel metering. Early injection systems used mechanical methods to meter fuel (non electronic, or mechanical fuel injection). Modern systems are nearly all electronic, and use an electronic solenoid (the injector) to inject the fuel. An electronic engine control unit calculates the mass of fuel to inject.

Modern fuel injection schemes follow much the same setup. There is a mass airflow sensor or manifold absolute pressure sensor at the intake, typically mounted either in the air tube feeding from the air filter box to the throttle body, or mounted directly to the throttle body itself. The mass airflow sensor does exactly what its name implies; it senses the mass of the air that flows past it, giving the computer an accurate idea of how much air is entering the engine. The next component in line is the Throttle Body. The throttle body has a throttle position sensor mounted onto it, typically on the butterfly valve of the throttle body. The throttle position sensor (TPS) reports to the computer the position of the throttle butterfly valve, which the ECM uses to calculate the load upon the engine. The fuel system consists of a fuel pump (typically mounted in-tank), a fuel pressure regulator, fuel lines (composed of either high strength plastic, metal, or reinforced rubber), a fuel rail that the injectors connect to, and the fuel injector(s). There is a coolant temperature sensor that reports the engine temperature to the ECM, which the engine uses to calculate the proper fuel ratio required. In sequential fuel injection systems there is a camshaft position sensor, which the ECM uses to determine which fuel injector to fire. The last component is the oxygen sensor. After the vehicle has warmed up, it uses the signal from the oxygen sensor to perform fine tuning of the fuel trim.

The fuel injector acts as the fuel-dispensing nozzle. It injects liquid fuel directly into the engine's air stream. In almost all cases this requires an external pump. The pump and injector are only two of several components in a complete fuel injection system.

In contrast to an EFI system, a carburetor directs the induction air through a venturi, which generates a minute difference in air pressure. The minute air pressure differences both emulsify (premix fuel with air) the fuel, and then acts as the force to push the mixture from the carburetor nozzle into the induction air stream. As more air enters the engine, a greater pressure difference is generated, and more fuel is metered into the engine. A carburetor is a self-contained fuel metering system, and is cost competitive when compared to a complete EFI system.

An EFI system requires several peripheral components in addition to the injector(s), in order to duplicate all the functions of a carburetor. A point worth noting during times of fuel metering repair is that early EFI systems are prone to diagnostic ambiguity. A single carburetor replacement can accomplish what might require numerous repair attempts to identify which one of the several EFI system components is malfunctioning. Newer EFI systems since the advent of OBD II diagnostic systems, can be very easy to
diagnose due to the increased ability to monitor the realtime data streams from the individual sensors. This gives the diagnosing technician realtime feedback as to the cause of the drivability concern, and can dramatically shorten the number of diagnostic steps required to ascertain the cause of failure, something which isn't as simple to do with a carburetor. On the other hand, EFI systems require little regular maintenance; a carburetor typically requires seasonal and/or altitude adjustments.

**Typical EFI components**

- Injectors
- Fuel Pump
- Fuel Pressure Regulator
- ECM - Engine Control Module; includes a digital computer and circuitry to communicate with sensors and control outputs.
- Wiring Harness
- Various Sensors (Some of the sensors required are listed here.)
  - Crank/Cam Position: Hall effect sensor
  - Airflow: MAF sensor, sometimes this is inferred with a MAP sensor
  - Exhaust Gas Oxygen: Oxygen sensor, EGO sensor, UEGO sensor

**Functional description**

Central to an EFI system is a computer called the Engine Control Unit (ECU), which monitors engine operating parameters via various sensors. The ECU interprets these parameters in order to calculate the appropriate amount of fuel to be injected, among other tasks, and controls engine operation by manipulating fuel and/or air flow as well as other variables. The optimum amount of injected fuel depends on conditions such as engine and ambient temperatures, engine speed and workload, and exhaust gas composition.

The electronic fuel injector is normally closed, and opens to inject pressurized fuel as long as electricity is applied to the injector's solenoid coil. The duration of this operation, called the pulse width, is proportional to the amount of fuel desired. The electric pulse may be applied in closely-controlled sequence with the valve events on each individual cylinder (in a **sequential** fuel injection system), or in groups of less than the total number of injectors (in a **batch fire** system).
Since the nature of fuel injection dispenses fuel in discrete amounts, and since the nature of the 4-stroke engine has discrete induction (air-intake) events, the ECU calculates fuel in discrete amounts. In a sequential system, the injected fuel mass is tailored for each individual induction event. Every induction event, of every cylinder, of the entire engine, is a separate fuel mass calculation, and each injector receives a unique pulse width based on that cylinder's fuel requirements.

It is necessary to know the mass of air the engine "breathes" during each induction event. This is proportional to the intake manifold's air pressure/temperature, which is proportional to throttle position. The amount of air inducted in each intake event is known as "air-charge", and this can be determined using several methods. (See MAF sensor, and MAP sensor.)

The three elemental ingredients for combustion are fuel, air and ignition. However, complete combustion can only occur if the air and fuel is present in the exact stoichiometric ratio, which allows all the carbon and hydrogen from the fuel to combine with all the oxygen in the air, with no undesirable polluting leftovers. Oxygen sensors monitor the amount of oxygen in the exhaust, and the ECU uses this information to adjust the air-to-fuel ratio in real-time.

To achieve stoichiometry, the air mass flow into the engine is measured and multiplied by the stoichiometric air/fuel ratio 14.64:1 (by weight) for gasoline. The required fuel mass that must be injected into the engine is then translated to the required pulse width for the fuel injector. The stoichiometric ratio changes as a function of the fuel; diesel, gasoline, ethanol, methanol, propane, methane (natural gas), or hydrogen.

Deviations from stoichiometry are required during non-standard operating conditions such as heavy load, or cold operation, in which case, the mixture ratio can range from 10:1 to 18:1 (for gasoline). In early fuel injection systems this was accomplished with a thermostime switch.

Pulse width is inversely related to pressure difference across the injector inlet and outlet. For example, if the fuel line pressure increases (injector inlet), or the manifold pressure decreases (injector outlet), a smaller pulse width will admit the same fuel. Fuel injectors are available in various sizes and spray characteristics as well. Compensation for these and many other factors are programmed into the ECU's software.

Sample pulsewidth calculations

Note: These calculations are based on a 4-stroke-cycle, 5.0L, V-8, gasoline engine. The variables used are real data.

Calculate injector pulsewidth from airflow

First the CPU determines the air mass flow rate from the sensors - \( \text{Mass}_{\text{air}} / \text{Minute} \). (The various methods to determine airflow are beyond the scope of this topic. See MAF sensor, or MAP sensor.)

\[
\frac{\text{Mass}_{\text{air}}}{\text{Minute}} \times \frac{\text{Minutes}}{\text{Revolution}} \times \frac{\text{Revolutions}}{\text{Stroke}} = \frac{\text{Mass}_{\text{air}}}{\text{Stroke}}
\]

\( \text{Minutes} / \text{Revolution} \) is the reciprocal of engine speed (RPM).

The term \( \text{Revolutions} / \text{Stroke} = 1 / 2 \), whether it's a four stroke or a two-stroke engine.
Mass_{\text{air}} \times \frac{\text{Mass}_{\text{fuel}}}{\text{Mass}_{\text{air}}} = \text{Mass}_{\text{fuel}}

\frac{\text{Stroke}_{\text{intake}}}{\text{Mass}_{\text{air}}} \times \frac{\text{Mass}_{\text{fuel}}}{\text{Stroke}_{\text{intake}}} = \text{Mass}_{\text{fuel}}

Mass_{\text{fuel}} / Mass_{\text{air}} \text{ is the desired mixture ratio, usually stoichiometric, but often different depending on operating conditions.}

\frac{\text{Mass}_{\text{fuel}}}{\text{Stroke}_{\text{intake}}} \times \frac{1}{\text{Mass}_{\text{fuel}} / \text{Minute}} = \text{Minutes} \times \frac{\text{Stroke}_{\text{intake}}}{\text{Mass}_{\text{fuel}} / \text{Minute}} = \text{Pulsewidth}

1 / (\text{Mass}_{\text{fuel}} / \text{Minute}) \text{ is the flow capacity of the injector, or its size.}

Combining the above three terms . . .

\frac{\text{Mass}_{\text{air}}}{\text{Minute}} \times \frac{\text{Minutes}}{\text{Revolution}} \times \frac{\text{Revolutions}}{\text{Stroke}} \times \frac{\text{Mass}_{\text{fuel}}}{\text{Mass}_{\text{air}}} \times \frac{1}{\text{Mass}_{\text{fuel}} / \text{Minute}} = \text{Pulsewidth}

Substituting real variables for the 5.0 L engine at idle.

* \quad \frac{0.55}{\text{min}} \times \frac{1}{\text{min}} \times \frac{1}{\text{revolution}} \times \frac{1}{\text{2strokes}} \times \frac{1}{14.64} \times \frac{2.5}{\text{min}} = 6.7 \times 10^{-5} \text{min} = 4 \text{ms}

Substituting real variables for the 5.0 L engine at maximum power.

* \quad \frac{28}{\text{min}} \times \frac{1}{\text{min}} \times \frac{1}{\text{revolution}} \times \frac{1}{\text{2strokes}} \times \frac{1}{11.00} \times \frac{2.5}{\text{min}} = 57.9 \times 10^{-5} \text{min} = 35 \text{ms}

Injector pulsewidth typically ranges from 4 ms/engine-cycle at idle, to 35 ms per engine-cycle at wide-open throttle. The pulsewidth accuracy is approximately 0.01 ms.

Calculate fuel-flow rate from pulsewidth

- (Fuel flow rate) ≈ (pulsewidth) \times (engine speed) \times (number of fuel injectors)

Looking at it another way:

- (Fuel flow rate) ≈ (throttle position) \times (rpm) \times (cylinders)

Looking at it another way:

- (Fuel flow rate) ≈ (air-charge) \times (fuel/air) \times (rpm) \times (cylinders)

Substituting real variables for the 5.0 L engine at idle.

- (Fuel flow rate) = (2.0 \text{ ms/intake-stroke}) \times (\text{hour}/3,600,000 \text{ ms}) \times (24 \text{ lb-fuel/hour}) \times (4-\text{intake-stroke/rev}) \times (700 \text{ rev/min}) \times (60 \text{ min/h}) = (2.24 \text{ lb/h})

Substituting real variables for the 5.0L engine at maximum power.

- (Fuel flow rate) = (17.3 \text{ ms/intake-stroke}) \times (\text{hour}/3,600,000\text{-ms}) \times (24 \text{ lb-fuel/hour}) \times (4-\text{intake-stroke/rev}) \times (5500\text{-rev/min}) \times (60\text{-min/hour}) = (152 \text{ lb/h})
Single-point injection

Single-point injection, called Throttle-body injection (TBI) by General Motors and Central Fuel Injection (CFI) by Ford, was introduced in the 1940s in large aircraft engines (then called the pressure carburetor) and in the 1980s in the automotive world. The SPI system injects fuel at the throttle body (the same location where a carburetor introduced fuel). The induction mixture passes through the intake runners like a carburetor system, and is thus labelled a "wet manifold system". Fuel pressure is usually specified to be in the area of 10-15 psi. The justification for single-point injection was low cost. Many of the carburetor's supporting components could be reused such as the air cleaner, intake manifold, and fuel line routing. This postponed the redesign and tooling costs of these components. Most of these components were later redesigned for the next phase of fuel injection's evolution, which is individual port injection, commonly known as MPFI or "multi-point fuel injection". TBI was used extensively on American-made passenger cars and light trucks in the 1980-1995 timeframe and some transition-engined European cars throughout the early and mid-1990s. Mazda called their system EGI, and even introduced an electronically controlled version called the EGI-S.

Continuous injection

In a continuous injection system, fuel flows at all times from the fuel injectors, but at a variable rate. This is in contrast to most fuel injection systems, which provide fuel during short pulses of varying duration, with a constant rate of flow during each pulse. Continuous injection systems can be multi-point or single-point, but not direct.

The most common automotive continuous injection system is Bosch's K-Jetronic (K for kontinuierlich, German for "continuous" — a.k.a. CIS — Continuous Injection System), introduced in 1974. Gasoline is pumped from the fuel tank to a large control valve called a fuel distributor, which separates the single fuel supply pipe from the tank into smaller pipes, one for each injector. The fuel distributor is mounted atop a control vane through which all intake air must pass, and the system works by varying fuel volume supplied to the injectors based on the angle of the air vane, which in turn is determined by the volume flowrate of air past the vane, and by the control pressure. The control pressure is regulated with a mechanical device called the control pressure regulator (CPR) or the warm-up regulator (WUR). Depending on the model, the CPR may be used to compensate for altitude, full load, and/or a cold engine. On cars equipped with an oxygen sensor, the fuel mixture is adjusted by a device called the frequency valve. The injectors are simple spring-loaded check valves with nozzles; once fuel system pressure becomes high enough to overcome the counterspring, the injectors begin spraying. K-Jetronic was used for many years between 1974 and the mid 1990s by BMW, Lamborghini, Ferrari, Mercedes-Benz, Volkswagen, Ford, Porsche, Audi, Saab, DeLorean, and Volvo. There was also a variant of the system called KE-Jetronic with electronic instead of mechanical control of the control pressure. Some Toyotas and other Japanese cars from the 1970s to the early 1990s used an application of Bosch's multipoint L-Jetronic system manufactured under license by DENSO. Chrysler used a similar continuous fuel injection system on the 1981-1983 Imperial.

In piston aircraft engines, continuous-flow fuel injection is the most common type. In contrast to automotive fuel injection systems, aircraft continuous flow fuel injection is all mechanical, requiring no electricity to operate. Two common types exist: the Bendix RSA system, and the TCM system. The Bendix system is a direct descendant of the pressure carburetor. However, instead of having a discharge valve in the barrel, it uses a flow divider mounted on top of the engine, which controls the discharge rate and evenly distributes the fuel to stainless steel injection lines which go to the intake ports of each
cylinder. The TCM system is even more simple. It has no venturi, no pressure chambers, no diaphragms, and no discharge valve. The control unit is fed by a constant-pressure fuel pump. The control unit simply uses a butterfly valve for the air which is linked by a mechanical linkage to a rotary valve for the fuel. Inside the control unit is another restriction which is used to control the fuel mixture. The pressure drop across the restrictions in the control unit controls the amount of fuel flowing, so that fuel flow is directly proportional to the pressure at the flow divider. In fact, most aircraft using the TCM fuel injection system feature a fuel flow gauge which is actually a pressure gauge that has been calibrated in gallons per hour or pounds per hour of fuel.

Central port injection (CPI)

General Motors implemented a system called "central port injection" (CPI) or "central port fuel injection" (CPFI). It uses tubes with poppet valves from a central injector to spray fuel at each intake port rather than the central throttle-body. Pressure specifications typically mirror that of a TBI system. The two variants were CPFI from 1992 to 1995, and CSFI from 1996 and on. CPFI is a batch-fire system, in which fuel is injected to all ports simultaneously. The 1996 and later CSFI system sprays fuel sequentially.

Multi-point fuel injection

Multi-point fuel injection injects fuel into the intake ports just upstream of each cylinder's intake valve, rather than at a central point within an intake manifold. MPFI (or just MPI) systems can be sequential, in which injection is timed to coincide with each cylinder's intake stroke; batched, in which fuel is injected to the cylinders in groups, without precise synchronization to any particular cylinder's intake stroke; or simultaneous, in which fuel is injected at the same time to all the cylinders. The intake is only slightly wet, and typical fuel pressure runs between 40-60 psi.

Many modern EFI systems utilize sequential MPFI; however, in newer gasoline engines, direct injection systems are beginning to replace sequential ones.

Direct injection

Direct fuel injection costs more than indirect injection systems: the injectors are exposed to more heat and pressure, so more costly materials and higher-precision electronic management systems are required. However, the entire intake is dry, making this a very clean system. In a common rail system, the fuel from the fuel tank is supplied to the common header (called the accumulator). This fuel is then sent through tubing to the injectors which inject it into the combustion chamber. The header has a high pressure relief valve to maintain the pressure in the header and return the excess fuel to the fuel tank. The fuel is sprayed with the help of a nozzle which is opened and closed with a needle valve, operated with a solenoid. When the solenoid is not activated, the spring forces the needle valve into the nozzle passage and prevents the injection of fuel into the cylinder. The solenoid lifts the needle valve from the valve seat, and fuel under pressure is sent in the engine cylinder. Third-generation common rail diesels use piezoelectric injectors for increased precision, with fuel pressures up to 1,800 bar/26,000 psi.
UNIT V:

Modern cars will not only recover information about their internal driving state (e.g. speed or yaw rate) but will also extract information from their surroundings. Radar based advanced cruise control system, commercialized in 1999 or vision-based lane departure warning system introduced in 2000 was only the beginning for a variety of vision systems for driver information, warning and active assistance. The future cars will have their own eyes, which will deliver comparably rich information about the car’s local environment. At least two cameras will look in front of the car. Working in stereo, they will be able to recognize the current situation in 3D. They can be accompanied by other cameras looking backwards and to the side of the vehicle.

Three main reasons those promote the development of computer vision systems for cars are:

- **Safety:** The important advantage of vision-based systems is their potential to understand the current traffic situation, a prerequisite for driver warning or interventions in complex situations, in particular to avoid false alarms.
- **Convenience:** Vision-based driver assistance systems allow an unprecedented increase in driving convenience. Speed limit signs can be recognized by the computer and taken into account in an adaptive cruise control (ACC) system.
- **Efficiency:** Computer vision can be used to automate traffic on special roads or to improve the efficiency of goods transport by coupling trucks by means of an electronic tow-bar system. Another important aspect is that in the future drivers can do other jobs like administrative work, if the truck or the car is in autonomous mode.

**COLLISION WARNING SYSTEMS**

This system can be looked at in two ways. First, as an aid to reversing, which gives the driver some indication as to how much space is behind the car. Second, collision avoidance radar [Radio Detection And Ranging] can be used as a vision enhancement system. The principle of radar as a reversing aid is illustrated in the figure given below. This technique is, in effect, a range-finding system. The output can be audio or visual, the latter being perhaps most appropriate, as the driver is likely to be looking backwards. The audible signal repetition frequency of which increases as the car comes nearer to the obstruction, and becomes almost continuous as impact is imminent. Collision avoidance radar, when used as a vision enhancement system, is somewhat different.
For an anti-collision warning application, the radar antenna should be mounted on the front of the car and should project a relatively narrow beam forward. Ideally, the antenna for such a system should be in as flat a package as possible, and should project a beam that has a width of about 2° to 3° horizontally and about 4° to 5° vertically. Large objects such as signs can reflect the radar beam, particularly on curves, and trigger a false alarm. If the beam is scanned horizontally for a few degrees, say 2.5° either side of centre, false alarms from roadside objects can be reduced. The figure below shows the system as a vision enhancement system.

![Diagram of radar system](image)

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 transmitter to object and back to receiver is proportional to the range, $R$, to the object, as illustrated in the above figure and expressed in the following equation:

$$t = \frac{2R}{c}, \text{ where } c \text{ is the speed of light}$$

The reflection from an object will have a pulse shape that is very nearly identical to that of the transmitted pulse. 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 the 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. A block diagram of an experimental collision warning system is shown in the figure given below. In this system, the range, $R$, to the object and the closing speed, $V + S$, are measured.
The computer can perform a number of calculations on these data, for example the computer can calculate the time to 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.

**Child Lock**

Child safety locks are built into the rear doors of most cars to prevent rear seat passengers from opening the doors both during transit and while the vehicle is stationary. Although called a child lock it is equally effective for adult passengers. The lock is typically engaged via a small switch on the edge of the door that is only accessible when the door is open. Some cars implement the locking mechanism as a rotary device which must be turned with the vehicle key, this design prevents "sticky fingered" passengers from disabling the lock as they enter the vehicle. In both designs the lock is completely inaccessible, especially to the passenger, when the door is closed. When the child lock is engaged, the interior handle is rendered useless, usually by disconnecting the handle from the latch mechanism, or by locking the handle in place. In this state the passenger cannot open the door from the inside and is effectively "locked in", the passenger can only be released by someone lifting the outside handle. Some vehicles implement window-locking mechanisms as well.
A The door cannot be opened from the inside. [Normal operation from the outside]

B The door lock functions normally

**VISION ENHANCEMENT**

Limited visibility, whether due to darkness, obstructed views, or inclement weather, has always been one of the biggest challenges for drivers and automakers. Vision enhancement systems (VES) for night driving commonly are either night vision goggles (NVG) or in-vehicle displays. In-vehicle Vision Enhancement Systems will improve visibility for night driving, inadequate lighting, fog, drifting snow, or other inclement weather driving conditions.

Nighttime driving has always presented unique challenges for motorists. While headlights have evolved over the past century to increase their brightness and range, the basic halogen bulb has some limitations, prompting alternative solutions from manufacturers. Mercedes-Benz, for instance, has developed an "Intelligent Light System," which alters the light output and pattern depending on driving conditions. The system boosts light output as vehicle speed increases. It can also adjust the left-to-right lighting balance to compensate for weather conditions, and even allows certain elements to swivel, keeping a uniform pattern and visibility range.

The enhanced vision system is comprised of a variety of forward-looking sensors like infrared sensors, cameras, radar, and night vision equipment. That equipment records what's in front of the vehicle and relays that information to laser-generating equipment inside the vehicle. The unit analyzes the data and projects highlight lines that better define or identify those objects deemed worthy of extra driver attention. It can better define lane lines, identify obstacles in the road, road signs, point out animals at the roadside, or even highlight a destination building based on GPS route information. There are also cameras inside the vehicle to monitor the driver's position, helping to align the highlights over the corresponding objects in the real world.

Course: AU 2401 – Engine & Vehicle Management Systems
Faculty: A.J.D. Nanthakumar
Highlighting a Road Sign

By using external cameras and other sensors positioned around the vehicle, it is possible to see what is behind the car, in the blind spots or out in the front. Back-up cams have become fairly commonplace, allowing motorists to spot obstacles or people directly behind their vehicle that might otherwise be hard to see behind blind spots or below the rear windows. Side-view cameras are a feature available on some upscale vehicles. They are usually mounted on the side view mirrors and allow easier parking, but can also be used for advanced systems that help spot vehicles in the blind spots. These side sensors have also been used for lane departure warning systems that can monitor lane lines and alert a driver when he or she inadvertently crosses those lines.

Another use for external cameras and sensors is forward vision enhancement. Front prism cameras are used to detect cross-traffic at blind intersections. A system used by Rolls-Royce relays the view to the left and right of the vehicle on an in-car display screen. Other systems that use forward facing sensors include adaptive cruise control, collision avoidance braking systems, and even night vision.

One of the latest and most futuristic innovations in enhanced driver vision, unveiled by General Motors, is a new heads-up-display (HUD) that they are developing for production in a few years. The system uses data gathered from an array of vehicle sensors and cameras to project laser-generated images directly onto the windshield, just like in a proper spaceship.

AIRBAGS

An air bag slows the passenger's speed to zero with little or no damage. The constraints that it has to work within are huge. The air bag has the space between the passenger and the steering wheel or dashboard and a fraction of a second to work with. Even that tiny amount of space and time is valuable, however, if the system can slow the passenger evenly rather than forcing an abrupt halt to his or her motion.

Operation of the system

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The sequence of events in the case of a frontal impact at about 35 km/h, as shown in figure below is as follows.

1. The driver is in the normal seating position prior to impact. About 15 ms after the impact, the vehicle is strongly decelerated and the threshold for triggering the airbag is reached. The igniter ignites the fuel tablets in the inflator.

2. After about 30 ms the airbag unfolds and the driver will have moved forwards as the vehicle’s crumple zones collapse. The seat-belt will have locked or been tensioned depending on the system.

3. At 40 ms after impact the airbag will be fully inflated and the driver’s momentum will be absorbed by the airbag.

4. About 120 ms after impact the driver will be moved back into the seat and the airbag will have almost deflated through the side vents, allowing driver visibility.
There are three parts to an air bag that help to accomplish this feature.

1. The bag itself is made of a thin, nylon fabric with a coating on the inside. Prior to inflation it is folded under suitable padding, into the steering wheel or dashboard or, more recently, the seat or door. The driver’s air has a volume of about 60 litres and the passenger airbag about 160 litres.

2. The sensor is the device that tells the bag to inflate. Inflation happens when there is a collision force equal to running into a brick wall at 10 to 15 miles per hour (16 to 24 km per hour). A mechanical switch is flipped when there is a mass shift that closes an electrical contact, telling the sensors that a crash has occurred. The sensors receive information from an accelerometer built into a microchip.

3. The air bag’s inflation system (igniter and inflator) reacts sodium azide (NaN₃) with potassium nitrate (KNO₃) to produce nitrogen gas. Hot blasts of the nitrogen inflate the air bag.

4. A warning light is used as part of the system monitoring circuit. This gives an indication of a potential malfunction and is an important part of the circuit. Some manufacturers use two bulbs for added reliability.

The main components of a basic airbag system are as follows.

- Driver and passenger airbags.
- Warning light.
- Passenger seat switches.
- Pyrotechnic inflator.
- Igniter.
- Crash sensor(s).
- Electronic control unit.

The pyrotechnic inflater and the igniter can be considered together. The inflater in the case of the driver is located in the centre of the steering wheel. It contains a number of fuel tablets in a combustion chamber. The igniter consists of charged capacitors, which produce the ignition spark. The fuel tablets burn very rapidly and produce a given quantity of nitrogen gas at a given pressure.

The air bag system ignites the solid propellant, which burns extremely rapidly to create a large volume of gas to inflate the bag. The bag then literally bursts from its storage site at up to 200 mph (322 kph) -- faster than the blink of an eye! This gas is forced into the airbag through a filter and the bag inflates breaking through the padding in the wheel centre. A second later, the gas quickly dissipates through tiny holes in the bag, thus deflating the bag so you can move. After deployment, a small amount of sodium hydroxide will be present in the airbag and vehicle interior. Personal protection equipment must be used when removing the old system and cleaning the vehicle interior.

Even though the whole process happens in only one-twenty-fifth of a second, the additional time is enough to help prevent serious injury. The powdery substance released from the air bag, by the way, is
regular cornstarch or talcum powder, which is used by the air bag manufacturers to keep the bags pliable and lubricated while they're in storage.

If a failure is detected in any part of the circuit then the ECU operates a warning light.

The crash sensor can take a number of forms; these can be described as mechanical or electronic. The mechanical system, as shown in the figure, works by a spring holding a roller in a set position until an impact above a predetermined limit, provides enough force to overcome the spring and the roller moves, triggering a micro switch.

The switch is normally open with a resistor in parallel to allow the system to be monitored. Two switches similar to this may be used to ensure the bag is deployed only in the case of sufficient frontal impact. Note that the airbag is not deployed in the event of a roll over.

The other main type of crash sensor can be described as an accelerometer. This will sense deceleration, which is negative acceleration.

Airbags working on the same techniques to those described previously are being used to protect against side impacts. In some cases bags are stowed in the door pillars or the edge of the roof.
SEAT BELT

Four categories of seat belt inadequacy and the typical injuries which have been identified:

- Head and face contact with the steering wheel is almost certain to occur in collisions of about 50 km/h in which the head will arc forward and downwards with a horizontal translation of some 60 cm to 70 cm; injuries are usually AIS 1 to 3. The suggested solution is an airbag, but this has been found to cause problems for out of position drivers.
- Rear loading from unrestrained occupants can cause injuries to correctly restrained front seat occupants although this problem has greatly diminished as a result of legislation that requires rear occupants to wear seat belts.
Misuse of the seat belt is frequent with those who are overweight who tend to place the seat belt over the abdomen instead of low across the pelvis; the consequence is often severe abdominal injuries at relatively low impact speeds.

The most frequent injuries caused by the seat belt are fractures to the ribs and sternum, particularly for the elderly.

Seat belt wearers, for the most part, are well protected against all but the most severe of impacts, but there is a limit to the effectiveness of the belt and this limit may be reached typically in four ways:

- Intrusion, caused by collapse or penetration of the occupant’s compartment.
- Extension of the seat belt allowing the occupant to strike some part of the car, typically the steering wheel.
- Transmission of localized loads to the wearer through the webbing; most likely for passengers.
- High deceleration in severe impacts may be sufficient to exceed injury thresholds, particularly for the chest.

**Extend and Retract**

In a typical seatbelt system, the belt webbing is connected to a retractor mechanism. The central element in the retractor is a spool, which is attached to one end of the webbing. Inside the retractor, a spring applies a rotation force, or torque, to the spool. This works to rotate the spool so it winds up any loose webbing.

When webbing is pulled out, the spool rotates counter-clockwise, which turns the attached spring in the same direction. Effectively, the rotating spool works to untwist the spring. The spring wants to return to its original shape, so it resists this twisting motion. If you release the webbing, the spring will tighten up, rotating the spool clockwise until there is no more slack in the belt.

The retractor has a locking mechanism that stops the spool from rotating when the car is involved in a collision. There are two sorts of locking systems in common use today:
- systems triggered by the car's movement
- systems triggered by the belt's movement

The first sort of system locks the spool when the car rapidly decelerates (when it hits something, for example). The diagram below shows the simplest version of this design.

![Diagram of a system](image)

The central operating element in this mechanism is a weighted pendulum. When the car comes to a sudden stop, the inertia causes the pendulum to swing forward. The pawl on the other end of the pendulum catches hold of a toothed ratchet gear attached to the spool. With the pawl gripping one of its teeth, the gear can't rotate counter-clockwise, and neither can the connected spool. When the webbing loosens again after the crash, the gear rotates clockwise and the pawl disengages.

The second kind of system locks the spool when something jerks the belt webbing. The activating force in most designs is the speed of the spool rotation. The diagram shows a common configuration.

The central operating element in this design is a centrifugal clutch -- a weighted pivoting lever mounted to the rotating spool. When the spool spins slowly, the lever doesn't pivot at all. A spring keeps it in position. But when something yanks the webbing, spinning the spool more quickly, centrifugal force drives the weighted end of the lever outward.

The extended lever pushes a cam piece mounted to the retractor housing. The cam is connected to a pivoting pawl by a sliding pin. As the cam shifts to the left, the pin moves along a groove in the pawl. This pulls the pawl into the spinning ratchet gear attached to the spool. The pawl locks into the gear's teeth, preventing counter-clockwise rotation.

In some newer seatbelt systems, a Pre-tensioner also works to tighten the belt webbing.
SEAT BELT TIGHTENING SYSTEM [The Pre-tensioner]

Taking the ‘slack’ out of a seat-belt in the event of an impact is a good contribution to vehicle passenger safety. The decision to take this action is the same as for the airbag inflation. The two main types of tensioners are:

- Spring tension.
- Pyrotechnic.

The mechanism used by one type of seat-belt tensioner is shown in figure below. When the explosive charge is fired, the cable pulls a lever on the seat-belt reel, which in turn tightens the belt. The unit must be replaced once deployed. This feature is sometimes described as anti-submarining. The idea of a Pre-tensioner is to tighten up any slack in the belt webbing in the event of a crash. Whereas the conventional locking mechanism in a retractor keeps the belt from extending any farther, the Pre-tensioner actually pulls in on the belt. This force helps move the passenger into the optimum crash position in his or her seat. Pre-tensioners normally work together with conventional locking mechanisms, not in place of them.

There are a number of different Pre-tensioner systems on the market. Some Pre-tensioners pull the entire retractor mechanism backward and some rotate the spool itself. Generally, Pre-tensioners are wired to the same central control processor that activates the car's air bags. The processor monitors mechanical or electronic motion sensors that respond to the sudden deceleration of an impact. When an impact is detected, the processor activates the Pre-tensioner and then the air bag.

Some Pre-tensioners are built around electric motors or solenoids, but the most popular designs today use pyrotechnics to pull in the belt webbing. The diagram below shows a representative model.
The central element in this Pre-tensioner is a chamber of combustible gas. Inside the chamber, there is a smaller chamber with explosive igniter material. This smaller chamber is outfitted with two electrodes, which are wired to the central processor.

When the processor detects a collision, it immediately applies an electrical current across the electrodes. The spark from the electrodes ignites the igniter material, which combusts to ignite the gas in the chamber. The burning gas generates a great deal of outward pressure. The pressure pushes on a piston resting in the chamber, driving it upward at high speed.

A rack gear is fastened to one side of the piston. When the piston shoots up, the rack gear engages a gear connected to the retractor spool mechanism. The speeding rack rotates the spool forcefully, winding up any slack belt webbing.

**Load Limiters**

In severe crashes, when a car collides with an obstacle at extremely high speed, a seatbelt can inflict serious damage. As a passenger’s inertial speed increases, it takes a greater force to bring the passenger to a stop. In other words, the faster you’re going on impact, the harder the seatbelt will push on you.

Some seatbelt systems use load limiters to minimize belt-inflicted injury. The basic idea of a load limiter is to release a little more excess belt webbing when a great deal of force is applied to the belt. The simplest load limiter is a fold sewn into the belt webbing. The stitches holding the fold in place are designed to break when a certain amount of force is applied to the belt. When the stitches come apart, the webbing unfolds, allowing the belt to extend a little bit more.

More advanced load limiters rely on a torsion bar in the retractor mechanism. A torsion bar is just a length of metal material that will twist when enough force is applied to it. In a load limiter, the torsion bar is secured to the locking mechanism on one end and the rotating spool on the other. In a less severe accident, the torsion bar will hold its shape, and the spool will lock along with the locking mechanism. But when a great deal of force is applied to the webbing (and therefore the spool), the torsion bar will twist slightly. This allows the webbing to extend a little bit farther.

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Over the years, seatbelts have proven to be far and away the most important safety device in cars and trucks. They are by no means infallible, however, and car safety engineers see a lot of room for improvement in today's design. In the future, cars will be outfitted with better belts, better air bags and, most likely, completely new safety technology. Of course, the government will still have to address the biggest problem with safety devices -- getting people to use them.

Case Study:  *Toyota automatic seat belt tensioner*

In the event of an impact, gas is discharged from the horizontal cylinder on the right, into the chamber above the plunger, which it forces downwards. Dragging the pre-tensioner cable with it, the plunger thus pre-tensions the seat belt for the duration of the impact, after which the tension is progressively released as the gas escapes through the clearances round the cable and plunger.

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**ANTI LOCK BRAKING SYSTEM**

With conventional brake systems one of the road wheels will always tend to lock sooner than the other, due to the continuously varying tyre to road grip conditions for all the road wheels. Under braking conditions, if one or more of the vehicle wheels locks (begins to skid), there are a number of consequences:

- Braking distance increases.
- Steering control is lost.
- Abnormal tyre wear.

The obvious result is that an accident is far more likely to occur. The maximum deceleration of a vehicle is achieved when maximum energy conversion is taking place in the brake system. A good driver can pump the brakes on and off to prevent locking but electronic control can achieve even better results.
Requirements of ABS:

- In the event of the ABS system failing the conventional brakes must still operate to their full potential. In addition, a warning must be given to the driver. This is normally in the form of a simple warning light.
- Good steering and road holding must continue when the ABS system is operating.
- Even over a short distance the system must react such as to make use of the best grip on the road. The response must be appropriate whether the driver applies the brakes gently or slams them on hard.
- It should perform effectively under all operating conditions.
- The system must operate under all speed conditions down to walking pace.
- The system must be able to recognize aquaplaning and react accordingly.

Components of an ABS System

An ABS system is represented by the closed loop system block diagram shown in figure given below. The most important of the inputs are from the wheel speed sensors, and the main output is some form of brake system pressure control. The task of the control unit is to compare signals from each wheel sensor to measure the acceleration or deceleration of an individual wheel. From these data and pre-programmed look-up tables, brake pressure to one or more of the wheels can be regulated. Brake pressure can be reduced, held constant or allowed to increase. The maximum pressure is determined by the driver’s pressure on the brake pedal.
Driven and non-driven wheels on the vehicle must be treated in different ways as they behave differently when braking. A logical combination of wheel deceleration/acceleration and slip is used as the controlled variable. The actual strategy used for ABS control varies with the operating conditions.

Though there are a few variations between manufacturers involving a number of different components, there are three main components.

i. Wheel speed sensors.

Most of these devices are simple inductance sensors and work in conjunction with a toothed wheel. Some systems use ‘Hall effect’ sensors. These constantly measure wheel speeds and signal this information either electronically or, less commonly, mechanically to the anti-lock control system.

ii. Electronic control unit.

The function of the ECU is to take in information from the wheel sensors and calculate the best course of action for the hydraulic modulator. If a fault is detected, the ABS disconnects itself and operates a warning light. The ECU also has suitable input signal processing stages and output or driver stages for actuator control.

The ECU performs a self-test, which takes about 300 ms, after the ignition is switched on. A failure will result in disconnection of the system. The following list forms the self-test procedure.

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- Current supply.
- Exterior and interior interfaces.
- Transmission of data.
- Communication between the two microprocessors.
- Operation of valves and relays.
- Operation of fault memory control.
- Reading and writing functions of the internal memory.

iii. **Hydraulic modulator**

The hydraulic modulator as shown in figure given below has three operating positions.

i. Pressure build-up – brake line open to the master cylinder.
ii. Pressure reducing – brake line open to the accumulator.
iii. Pressure holding – brake line closed.

The valves are controlled by electrical solenoids, which have a low inductance so they react very quickly. The motor only runs when ABS is activated. It receives the commands from the electronic control unit and translates them, independently of driver action, into valve-based sequences that modulate either hydraulic or pneumatic pressure in the individual brake lines.

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The modulator therefore requires its own source of supply pressure, which in electro-hydraulic versions usually takes the form of an electrically driven pump capable of generating high pressure in the region of 14 to 17.5MN/m². An ABS in which hydraulic servo brakes and their modulator share a common hydraulic power supply is known as an ‘Integrated ABS’. With a hydro-mechanical anti-lock braking system, the hydraulic pump is mechanically driven from the same source that drives the flywheel wheel speed sensors. In the case of electro-pneumatic modulators for anti-lock air brakes on heavy vehicles, the continuous supply of compressed air made available by the compression and storage facilities of the braking system proper eliminates the need for an independent source of supply pressure.

Types of Anti-Lock Brake System

It is the functional differences between the various types of modulator which determine the particular operating principle of an anti-lock braking system. The principles of anti-lock braking for hydraulic systems broadly apply to the air brakes of heavy vehicles, but there is a greater multiplicity of components and basic differences in those that modulate the air pressure in the brake lines.

The modulating principles of anti-lock hydraulic braking systems may be classified as follows:

1. Plunger return

This principle of modulation was early developed to superimpose an anti-lock facility on a conventional hydraulic brake system.

A cylinder and plunger modulator is introduced into each brake line between the master cylinder and the wheel cylinders. By moving the plunger up and down within its cylinder it becomes possible to vary the volume of a particular brake line and therefore modulate the line pressure and hence braking force generated at that wheel. Except under conditions of imminent wheel locking, the plunger is maintained at its lowest position in the cylinder by fluid at high pressure directed above it from an independently driven pump and storage accumulator, while a downward projecting pin from the plunger holds open an isolating valve that allows the free passage of fluid between the master cylinder and wheel cylinder. Normal braking up to maximum pressure is therefore accomplished with the least volume of brake line, because there is always sufficient pressure acting above the plunger to restrain it from rising against master cylinder pressure acting below it.
If a wheel begins to lock the electronic control unit commands the appropriate solenoid valve in the module to shut off the fluid supplied under pressure to the plunger. As a result the plunger rises in its cylinder, the effect of which is twofold:

1. It allows the isolating valve for the master cylinder to close, so that no further increase in wheel cylinder pressure is possible no matter how much effort the driver exerts on the pedal;
2. It increases the volume and therefore relieves the pressure in the line to the wheel cylinder, which momentarily releases the braked wheel

Line pressure is of course restored to the wheel cylinder when the electronic control unit commands the solenoid valve to open, so that fluid at a higher pressure can force the plunger down its cylinder to reduce the volume of the brake line and re-establish a connection between the master cylinder and the

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wheel cylinder, via the now open isolating valve. *Lucas Girling’s* stop control system (SCS) uses a modification of this principle.

2. **Power recharge**

This has been the most widely used principle of modulation in anti-lock brake systems. Here again it is superimposed upon a conventional hydraulic brake system, but with the essential difference that a brake line has to be opened in order to reduce pressure for anti-lock control, rather than simply increasing its volume as in plunger return modulation.

In principle a solenoid-operated multifunctional hydraulic shuttle valve serves to modulate the brake pressure between the master cylinder and either a single or a pair of wheel cylinders. During normal braking up to maximum pressure the spring-retumed solenoid valve assembly is not energized, so that its upper valve remains open while the lower valve is held closed. In this position the valve assembly provides a free passage for the flow of brake fluid between the master cylinder and wheel cylinder. [See figure given below]

If a wheel begins to lock during braking, the electronic control unit initially commands the modulator to energize the appropriate solenoid with one-half maximum current, which raises the valve assembly to an intermediate position with both its upper and lower valves held closed. This has the effect of not only isolating the wheel cylinder from any further rise in master cylinder pressure, no matter how much effort the driver exerts on the pedal, but also holding constant the wheel cylinder pressure. [See figure given below]
If this action of simply preventing any further rise in wheel cylinder pressure is not sufficient to correct the imminent locking of the wheel, then the electronic control unit commands the modulator to energize the solenoid with maximum current and therefore raise the valve assembly to its fullest extent. This results in the upper valve remaining closed to isolate master cylinder pressure, but the lower valve being opened to bleed off brake fluid to the return pump via the accumulator, thereby relieving wheel cylinder pressure to free the wheel. [See figure given below]

At the same time the modulator is commanded to switch on the return pump, so that the fluid bled from the wheel cylinder line can be directed under pressure back to the master cylinder line and the inlet side of the solenoid valve assembly ready to recharge the system for the next cycle. This occurs when the modulator is commanded to switch off the pump and de-energize the solenoid, which allows the valve assembly to drop to the normal braking position. Each time a wheel cylinder line is depressurized, the
recharging pressure in the master line cases a slight raising and pulsating at the brake pedal. It should nevertheless be held firmly applied, since any sympathetic pumping of the pedal by the driver will simply increase the time taken to stop.

The power recharge principle of modulation has long been incorporated in certain versions of the Bosch ABS and has been developed to provide a high level of vehicle control under difficult braking conditions commensurate with the higher cost of this type of system.

3. **Dynamic inflow**

This principle of modulation was an essential feature of a new concept in anti-lock brake systems introduced by the German company of Alfred Teves (ATE) in the mid 1980s, wherein brake operation, servo amplification and anti-lock modulation were combined in a fully integrated system.

**ANTI THEFT SYSTEM**

Anti-theft systems are designed to raise the difficulty of theft to an infeasible (but not necessarily impossible) level. The kind of system implemented often depends on the acceptable threshold for theft. Under normal circumstances, theft is prevented simply through the application and social acceptance of property law. Ownership is often indicated by means of visual marking (license plates, name tags). When clear owner identification is not possible and when there is a lack of social observance, people may be inclined to take possession of items to their own benefit at the expense of the original owner. *Motive* and *opportunity* are two enabling factors for theft. Given that motives for theft are varied and complex and are generally speaking not within the control of the victim, most methods of theft prevention rely on reducing opportunities for theft.

Three main types of intruder alarm are used in modern passenger cars are:

- Switch operated on all entry points.
- Battery voltage sensed.
- Volumetric sensing.

Three main ways to disable the vehicle, in case of intrusion are:

- Ignition circuit cut off.
- Starter circuit cut off.
- Engine ECU code lock.

Disabling the stolen item
Items with specific functionality can often be disabled to prevent the use of the item if it should be stolen. The anti-theft system can require disabling on every use, or enabling when the item needs to be secured. Disabling the anti-theft system is usually done by requiring identification of the owner at some stage of use. Identification can occur through physical or other means (physical keys, numerical codes, complex passwords, biometric identification). A passive immobilizer makes car theft almost impossible because the vehicle cannot be started without a computer chip that is found within the ignition key.

**Movement inhibitors (immobilizer) as anti theft system:**

Movement inhibitors may be mechanical or automatic electronic system. Mechanically at least one locking member that can be inserted into at least one inhibitor to prevent at least one wheel from turning by utilizing a long steel bar that hooks and locks onto the steering wheel or by preventing inadvertent movement of a motor vehicle gear shift selector brake interlock mechanism, between a non-drive "park" or "neutral" position, and a "drive" position. Steering columns lock inhibitor for fixed and adjustable steering columns preferably without a shifting function. Shield type devices are available to adjust to fit most steering wheels, one-, two-, and three-spoke.

Passive anti-theft systems (PATS), like Ford's patented ‘SecuriLock T’ systems; protect against theft by requiring a specially coded ignition key. The vehicle starts and operates only with the key that matches the sensor in the vehicle, thwarting attempts to hot-wire the ignition. An indicator lamp shows the system is working.

**Stolen Car Tracking Devices**

Tracking devices can be built-in to an unknown part of the vehicle’s chassis. This can be activated in the event of the car being stolen, allowing the police to trace the vehicle. The ‘Tracker’ unit is a radio transponder. When the vehicle is reported stolen the police are informed and the ‘Tracker’ unit is activated. The unit then broadcasts a unique reply code, which can be detected and decoded by police tracking computers, which are fitted in police cars, helicopters and fixed land sites. The police then track the vehicle, taking appropriate action.

**Passive anti-theft system (PATS)**

This system is a vehicle immobilizer developed by Ford. It is activated directly through the ignition switch by means of an electronic code stored in a special key. Each key has a transponder that stores the code, which does not require a battery. The key code is read by the receiver (which is part of the ignition switch) when the key is turned from position 0 to 1 or 2 (usually marked as I or II). If the code matches the one stored in the module, then it allows the engine to start. These systems operate independently of the alarm.

**Electronic Keys (aka immobilizers):** Some car manufacturers have pre-installed electronic immobilizing systems that allow the vehicle to operate only with a correctly coded key. The RFID chip in the key fob contains a select set of codes designed to work with a given car. These codes are rolling
40-bit strings: With each use, the code changes slightly, creating about 1 trillion possible combinations in total. When you push the unlock button, the key-fob sends a 40-bit code, along with an instruction to unlock the car doors. If the synced-up receiver gets the 40-bit code it is expecting, the vehicle performs the instruction. If not, the car does not respond.

A second antitheft use of RFID is for remote vehicle immobilizers. These tiny chips, embedded inside the plastic head of the ignition keys, are used with more than 150 million vehicles today. Improper use prevents the car's fuel pump from operating correctly. Unless the driver has the correct key chip installed, the car will run out of fuel a few blocks from the attempted theft. (That's why valet keys don't have the chips installed; valets need to drive the car only short distances.)

- **Benefits:** These interrupt your car's ignition systems when an incorrect key or no key at all is used to start the car. Systems are easy to use and reliable.
- **Drawbacks:** Because they're invisible to thieves, inexperienced criminals will tear apart your steering column before discovering this disabling feature. Unfortunately, your steering column will need replacement and you probably won't be able to start your car.

**Electronic Tracking Devices:** An electronic transmitter hidden in the vehicle which emits a signal that is picked up by the police or a monitoring station. Alpine's Mobile Mayday, Force’s Tracker, Ford's Rescu, GM's OnStar, LoJack, BlackJax, and PageTrack2 from Motorola start at $300, plus any monthly subscription charges. There are a variety of services offered by each company, such as mapping services and vehicle-location if your car is stolen.

- **Benefits:** Very effective in helping authorities recover vehicles before they can be stripped or chopped up.
- **Drawbacks:** In addition to the high initial cost, a subscription charge ($15-$40) must be paid each month.

**Flashing LED warning lights:** Warning lights typically identify a vehicle whose alarm system has been armed. At a quick glance, the thief doesn't know that the warning light is bogus and may go on to another vehicle rather than take a risk.

- **Benefits:** An inexpensive way to bluff a car thief.
- **Drawbacks:** None

**Hood locks:** A hood lock will keep a thief from getting to your car's battery to cut the power going to the alarm.

- **Benefits:** Prevents thieves from gaining access to your vehicle's engine compartment.
- **Drawbacks:** None - Usually standard equipment on vehicles made in the past 20 years.
**Keyless entry:** Increases your personal safety by enabling you to enter and exit your vehicle without fumbling with your keys. Keyless entry enables you to lock & unlock your vehicle without using your keys, thereby increasing the chances that you will lock it. It’s also handy when you’ve got your hands full and need to open your car doors or trunk. Keyless entry comes as standard equipment on many makes and models and can be retrofitted to any vehicle that has electric door locks.

- **Benefits:** Enables you to lock & unlock your vehicle & truck without using your keys. Increases your personal safety by enabling you to enter and exit your vehicle without fumbling with your keys. Also eliminates problems caused by frozen lock cylinders.
- **Drawbacks:** None

Passive keyless entry systems mean the driver doesn’t even need to press a button to unlock the vehicle! The electronic key is simply carried in a pocket, on a belt clip or in a bag. The controllers in the doors communicate with the key using radio frequency (RF). This action determines if the correct key is present and, if it is, the doors are unlocked. This communication event is triggered by lifting the door handle, or in some cases the vehicle will even unlock as the key holder approaches it.

Figure given below shows a block diagram of a typical system incorporating a ‘smart’ ignition key which allows several functions to be controlled. Besides its primary function of door lock control, each driver could have their own personalized key that would program several vehicle functions for that person such as seat position and mirror setting. Clever car thieves who captured the transmitted key codes of upmarket vehicles using data recording equipment and then used them to gain access have been thwarted by the development of rolling code generators that allow a unique code to be generated every time the RKE system is activated. Full immobilization includes shutting off the vehicle’s fuel pump, fuel injectors, ignition, and starter while locking the transmission and steering, and causing the horn to sound and lights to flash. Additionally, the vehicle’s cell phone could broadcast its position via a Global Position Satellite receiver to police authorities.
Kill Switches: Kill switches prevent the flow of electricity or fuel to the engine until the switch is activated. Starter disablers are also growing in popularity.

- **Benefits:** It's a hidden switch that needs to be flipped on for the car to start. For their effectiveness as a security device, kill switches are for the most part inexpensive and easy to install.
- **Drawbacks:** A risk is that the driver may accidentally engage them while driving. Improperly installed switches can damage the electrical systems on new cars and have the additional drawback of voiding your new-car warranty.

Steering Column Armored Collars: Collars prevent thieves from breaking into the steering column to hot-wire the vehicle. Some are installed permanently and others must be installed manually each time the driver leaves the vehicle.

- **Benefits:** The collar provides an excellent line of defense for older vehicles, which can be easily stolen by breaking open the steering wheel column.
- **Drawbacks:** Manual collars must be removed whenever you go for a drive.

Steering Wheel Lock: A long metal bar with a lock that fits on the steering wheel and is designed to prevent the steering wheel from being turned. The locks are visible from outside the car and prevent the wheel from being turned more than a few degrees. A variation on the steering wheel lock is the J-bar or grip lock, an adjustable steel bar rod that hooks under the brake and locks to the steering wheel.

- **Benefits:** Inexpensive way to keep would-be thieves away. Especially good device to use when layering protection.
- **Drawbacks:** Only effective against amateurs and kids looking to joyride. A professional can cut through your steering wheel in a couple of seconds, making steering-wheel locks and most J-bars useless.

Theft-Deterrent Decals: Typical decals identify the vehicle is protected by either an alarm system or national theft prevention company. At a quick glance, the thief may not know that the warning sticker is bogus and may go on to another vehicle rather than take a risk.

- **Benefits:** Inexpensive way to bluff a car thief.
- **Drawbacks:** Ignored by professional thieves who recognize bogus stickers

Tire Locks: Similar to the circular steel "boots" used by many larger city police departments, tire locks make the car nearly impossible to move. The tire locks are also effective in deterring would-be thieves.

- **Benefits:** Greatly hampers thieves who are looking to make a quick getaway. Not only is the tire lock a strong visual deterrent, but it also provides a formidable challenge for would-be car thieves.
• **Drawbacks:** Bulky and time consuming to install and remove, must be installed manually each time the driver leaves the vehicle. Accumulates dirt from the tires, very inconvenient to use in bad weather.

**Window Etching:** Etching the vehicle identification number onto the window as well as other parts of the car discourages thieves from taking the vehicle and also aids in recovering the vehicle if it is stolen.

• **Benefits:** Chop-shop rings thrive on vehicles with easily removable VINs or none etched on at all. By etching the VIN on important parts of the vehicle, you make your vehicle less attractive to stolen parts resellers.

• **Drawbacks:** Unless you make the etchings extremely obvious (which will severely hurt your vehicle's resale value) it won't deter most professional thieves, as they may not have the time to check for etchings before they steal your vehicle.

**Pagers:** Pagers will let you know when your alarm has been set off. 2-way systems allow you to send commands to and get feedback from your vehicle.

• **Benefits:** Pagers let you know when your alarm has been set off.

• **Drawbacks:** Encourages confrontation with car thieves, which is not generally a good idea.

**Car Alarms:** The typical car alarm is equipped with motion sensors, impact sensors and a loud siren or series of tones in the 120-decibel range.

• **Benefits:** The best alarms arm themselves automatically when you leave the vehicle and include an automatic kill switch. The best models flash the headlights and honk the horn in addition to sounding a siren.

• **Drawbacks:** After years of false alarms, people have stopped paying attention to alarms. There is no statistical evidence that they reduce auto theft.

**Security Alarm**

A separate switch or IR transmitter can be used to set an alarm system. Often, they are set automatically when the doors are locked.

The requirements of this particular alarm system are:

• It must activate when a door is opened.
• The ignition to be disabled.
• The existing horn is used as the warning.
• Once triggered, the horn must continue even when the door is closed.
• It must reset after 15 seconds.
Simple alarm circuit

When a door is opened, the switches make an earth connection. This will be used to trigger the relay, which in turn will operate the horn. The delay must be built in using a capacitor, which will keep the relay energized even after the door closes, for a further 15 seconds. An external key switch is to be used to arm and disarm whilst isolating the ignition supply. A capacitor will discharge to about 66% of its full value in CR seconds. (If the supply voltage is 12V, the capacitor discharges to 8V in CR seconds.)

This system can be operated by remote control or using the key in a door lock. When first activated, the system checks that the doors and tailgate are closed by monitoring the appropriate switches. If all is in order, the anti-theft system is then activated after a 20-second delay. The function indicator LED flashes rapidly during this time and then slowly once the system is fully active. The alarm can be triggered in a number of ways:

- Opening a door, the tailgate or the bonnet/hood.
- Removal of the radio connector loop.
- Switching on the ignition.
- Movement inside the vehicle.
If the alarm is triggered the horn operates for 30 seconds and the hazard lights for 5 minutes. This stops if the remote key or door key is used to unlock the vehicle.

Most security alarm systems can be considered as two pieces, with a separate control unit and siren; most will have the control unit in the passenger compartment and the siren under the bonnet.

Most systems now come with two infrared remote ‘keys’ that use small button-type batteries and have an LED that shows when the signal is being sent. They operate with one vehicle only. Intrusion sensors such as car movement and volumetric sensing can be adjusted for sensitivity. shows a block diagram of a complex alarm system.

The system can be considered as a series of inputs and outputs.

**Inputs**

- Ignition supply.
- Engine crank signal.
- Volumetric sensor.
- Bonnet switch.
- Trembler switch.
- IR/RF remote (Figure 16.27).
- Doors switches.
- Control switch.

**Outputs**

- Volumetric transmitter.
- System LED.
- Horn or siren.
- Hazard lights.
- Ignition immobilizer.
- Loop circuit.

Electric windows, sun-roof and door locks.

**Central Locking System**

When the key is turned in the driver’s door lock, all the other doors on the vehicle should also lock. Motors or solenoids in each door achieve this. If the system can only be operated from the driver’s door key, then an actuator is not required in this door. If the system can be operated from either front door or by remote control, then all the doors need an actuator. Vehicles with sophisticated alarm systems often lock all the doors as the alarm is set.

The main control unit contains two change-over relays (as shown in the above figure), which are actuated by either the door lock switch or, if fitted, the remote infrared key. The motors for each door lock are simply wired in parallel and all operate at the same time. Infrared central door locking is controlled by a small hand-held transmitter and an infrared sensor receiver unit as well as a decoder in the main control unit. When the infrared key is operated by pressing a small switch, a complex code is transmitted. The number of codes used is well in excess of 50,000. The infrared sensor picks up this code and sends it in an electrical form to the main control unit. If the received code is correct, the relays are triggered and the door locks are either locked or unlocked.
If an incorrect code is received on three consecutive occasions when attempting to unlock the doors, then the infrared system will switch itself off until the door is opened by the key. This will also reset the system and allow the correct code to operate the locks again. This technique prevents a scanning type transmitter unit from being used to open the doors.

**ONBOARD DIAGNOSTIC SYSTEM [OBD]**

For the first time, OBD systems regulations were approved by the California Air Resources Board (CARB) in 1985. These regulations require that the Engine Control Module monitor critical emission related components for proper operation and illuminate a Malfunction Indicator Lamp (MIL) on the instrument panel when a malfunction is detected.

Digital electronics allow both sensors and actuators to be monitored. This is done by allocating values to all operating states of the sensors and actuators. If a deviation from these figures is detected, this is stored in the memory and can be output in the workshop to assist with fault-finding.
Bosch MOTRONIC M5 with OBD 2

Fundamentally, a contemporary microprocessor based on-board diagnostics or OBD system is intended to self-diagnose and report when the performance of the vehicle’s emissions control systems or components have degraded. This is to the extent that the tailpipe emissions have exceeded legislated levels or are likely to be exceeded in the long term. When an issue occurs the OBD system illuminates a warning lamp known as the malfunction indicator lamp (MIL) or Malfunction Indicator (MI) on the instrument cluster.

On-board diagnostic monitoring applies to systems which are most likely to cause an increase in harmful exhaust emission, namely:

- All main engine sensors
- Fuel system
- Ignition system
- Exhaust gas recirculation (EGR) system

The 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 are stored in memory using a specific fault code. At the same time, the controller generates or activates a warning signal, indicating that service is required.

The major limitation of OBD is that they cannot detect intermittent failures reliably. For the system to detect and isolate a failure, the failure must be non-reversible. 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 technician connects a scan tool that can communicate using an industry standard communications protocol. The OBD code memory is checked and data is presented in a way that also conforms to a standard. The mechanic notes the fault codes that are displayed and, using a reference manual, identifies the failed components. Whenever a defect occurs, as indicated by a fault code, the mechanic must follow a specific procedure to isolate the particular problem. These procedures are outlined for the mechanic as a sequence of steps to be followed. Once the mechanic has read all of the fault codes, he or she proceeds with the diagnosis and repair using the shop manual.

Without the aid of the onboard diagnostic capability of the electronic control system, such diagnosis would take much more time and might, in certain cases, be nearly impossible (e.g., for intermittent faults).
A typical malfunction indicator lamp

When the fault occurs the system stores a diagnostic trouble code (DTC) that can be used to trace and identify the fault. The system will also store important information that pertains to the operating conditions of the vehicle when the fault was set. A service technician is able to connect a diagnostic scan tool or a code reader that will communicate with the microprocessor and retrieve this information. This allows the technician to diagnose and rectify the fault, make a repair/replacement, reset the OBD system and restore the vehicle emissions control system to a serviceable status.

The benefits of having an OBD system are that it:

- encourages vehicle and engine manufacturers to have a responsible attitude to reducing harmful emissions from their engines via the development of reliable and durable emission control systems;
- aids diagnosis and repair of complex electronic engine and vehicle control systems;
- reduces global emissions by providing early warning
- provides ‘whole life’ emission control of the engine;

In the mid-1980s the US environmental protection agency (EPA) introduced a policy which made the use of on-board diagnostics (OBD) compulsory for vehicles in the United States. This was followed by similar requirements introduced by the California Air Resources Board (CARB). OBD2 (also OBDII) was developed, by SAE, to address the shortcomings of OBD1 and make the system more user friendly for service and repair technicians. EOBD is the European equivalent of the American OBD2 standard, which applies to petrol cars sold in Europe from 2001 (and diesel cars three years later). OBD2 works to ensure that the vehicles remain as clean as possible over their entire life. The OBD 2 system is intended to standardize the many varying, methods used by different manufacturers.

The diagnostic socket used by systems conforming to OBD 2 standards should have the following pin configuration.

1. Manufacturer’s discretion.
3. Manufacturer’s discretion.
4. Chassis ground.
5. Signal ground.
6. Manufacturer’s discretion.
8. Manufacturer’s discretion.
9. Manufacturer’s discretion.
11. Manufacturer’s discretion.
12. Manufacturer’s discretion.
13. Manufacturer’s discretion.
14. Manufacturer’s discretion.
15. L line, ISO 9141.
16. Vehicle battery positive.

The main features of OBD2 are:

- Malfunction of emission relevant components to be detected when emission threshold values are exceeded.
- Storage of failures and boundary conditions in the vehicle’s fault memory.
- Diagnostic light (MIL – Malfunction Indicator Light) to be activated in case of failures.
- Read out of failures with generic scan tool.
Course: AU 2401 – Engine & Vehicle Management Systems
Faculty: A.J.D. Nanthakumar