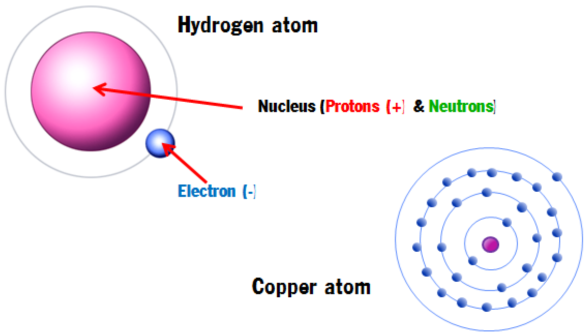
ProVQ™

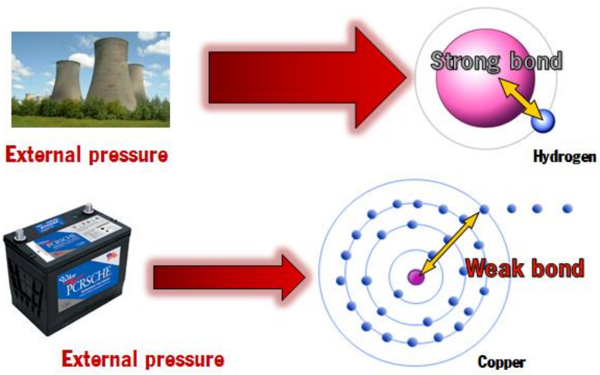
ELECTRICAL DIAGNOSIS

PHASE THREE

What is electricity?



When a given material is deconstructed, it can be seen that it consists of atoms. An atom has a nucleus that is made up of neutrons and protons. As the name would suggest, neutrons have a neutral charge and therefore play little part in the behaviour of electricity so we will disregard them. Protons have a positive charge that is often abbreviated to +VE.
Surrounding the nucleus is a number of electrons that have a negative charge (-VE). These electrons rotate around the nucleus in orbits and are kept in their orbits through their attraction to the positive charge of the nucleus (dissimilar charges attract).
Different materials have different numbers of electrons in orbit and the atoms are arranged in different ways in relation to each other. It is this that give different materials their individual properties such as texture, density etc.



The greater the number of electrons a material has in its orbits the further away from the nucleus the electrons in the outer orbits will be. The attractive force between the nucleus and these outer electrons will be relatively weak.
If we apply an external force (such as a battery) to a material constructed in this way, it will be relatively easy to make these outer electrons break free from the nucleus and move freely within the material. This movement of electrons within a material is electricity.

Conductors, semi-conductors and insulators

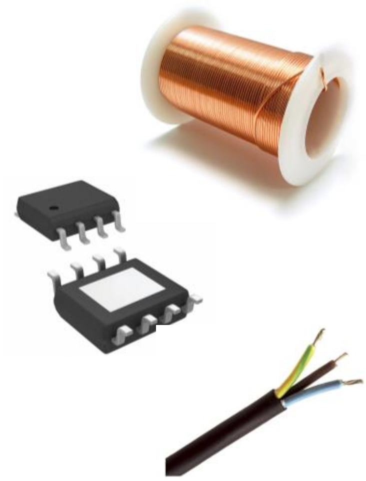
It has been seen that different materials have differing numbers of electrons in orbit within an atom. Materials with a large number of orbits will allow electricity to flow readily (due to the weak attraction) and are known as Conductors.

Materials with relatively few orbits will resist electrical current flow (due to the strong attraction) and are therefore known as insulators or sometimes resistors.

Materials that don't seem to be able to make up their mind are known as semi-conductors.
Some examples of conductors, insulators and semi-conductors are as follows:

Conductors

- copper
- Silver.



Semi-conductors

- silicon
- germanium.

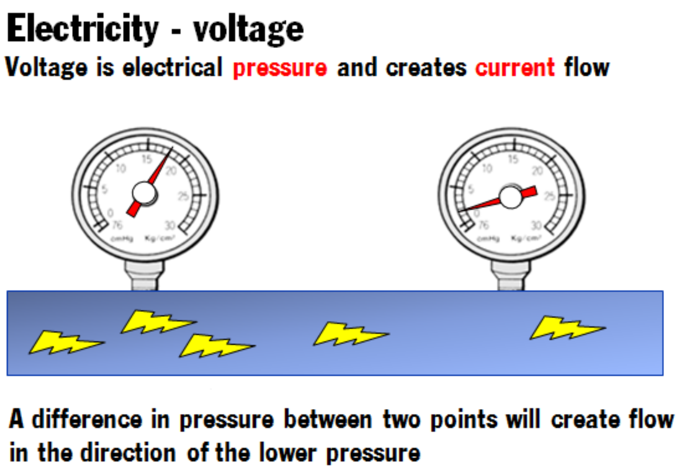
Insulators (resistors)

- bakelite
- rubber.

Units of Electricity?

Voltage

A difference in pressure between two points in a liquid will create flow in the direction of the lower pressure. Electrical current behaves in a similar way. If we create a difference in electrical pressure between two points in a conductor, current will flow in the direction of the lower electrical pressure.



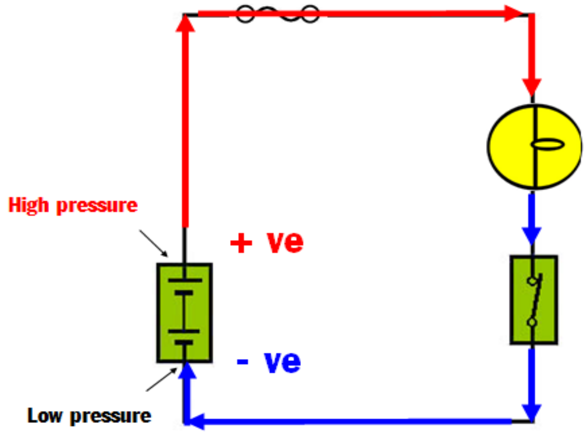
Voltage is electrical pressure and it generates current flow. A battery is a device that is capable of creating a difference in electrical pressure.

1 volt can be described in the following way:

“1 volt is said to be the amount of electrical pressure applied to a circuit, if 1 amp of current flows when that circuit has a resistance of 1 ohm”.

In the circuit, the battery has created a difference in electrical pressure in the circuit (a circuit is a combination of electrical components and wires which provide the current with a route to take).

The area of highest electrical pressure is at the positive post of the battery and the area of lowest electrical pressure is at the negative post. Current therefore flows from the positive post to the negative post, generating heat in the lamp filament as it does so. This type of current flow is known as conventional current.



In reality, current actually flows from the negative post to the positive! This is because the positive post has a positive charge and the electrons at the negative post are attracted to this and flow to it through the circuit. This is known as electron flow.

This was not discovered until sometime after the electrical rules were devised, and as it makes no significant difference to the operation of an electrical circuit (current is flowing, it doesn’t matter which way it flows, work can still be done) it is effectively ignored in vehicle applications.

Current

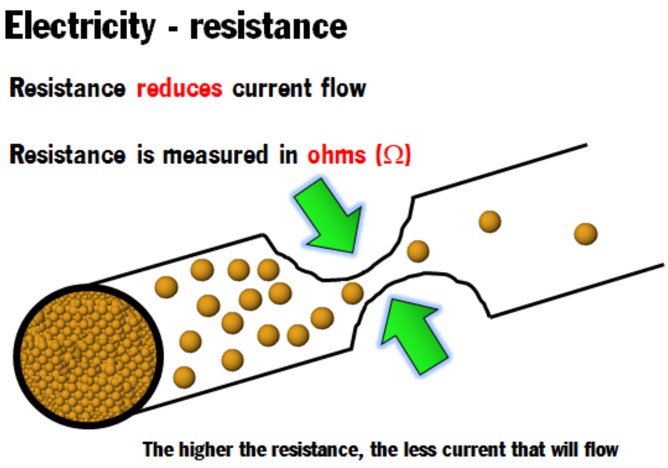
A flow of electrons is referred to as current. The unit of current is the ampere that is commonly abbreviated to the amp.
If 625,000,000,000,000,000 electrons flow past a given point in a conductor in one second, this is 1 amp of current flow.
625,000,000,000,000,000 electrons are quantified using the unit Coulomb, so 1 amp of electrical current flow could also be referred to as 1 coulomb per second.

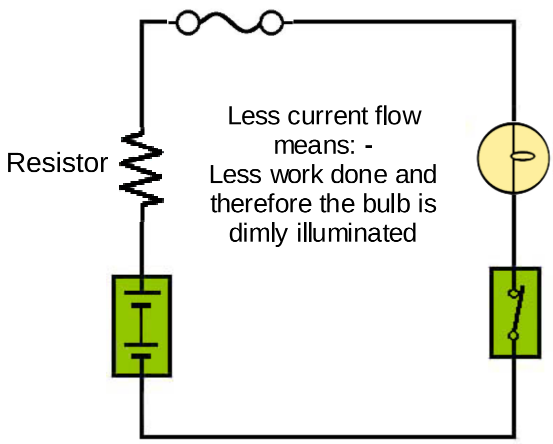
1 amp can also be described in the following way:

“1 amp is the amount of current flowing in a conductor when the conductor has a resistance of 1 ohm and 1 volt of electrical pressure has been applied to that conductor”.

Electrical resistance

If a flowing fluid experiences a resistance to flow, less fluid will flow. Electrical current flow is similar; if the flowing electrical current experiences a resistance, less electrical current will flow. As we have seen, Electrical resistance is created by the atomic structure of the material concerned rather than by a physical restriction. The unit of electrical resistance is the ohm.
This is symbolised by **Ω** (Greek letter Omega).





The ohm can be described as follows:

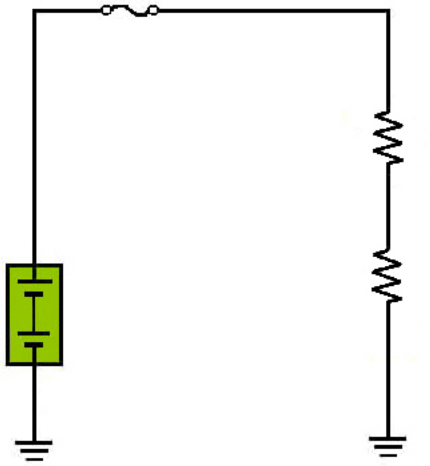
"A material is said to have a resistance of 1 ohm if 1 amp of current flows in that material when 1 volt of electrical pressure is applied".
Because resistance in a circuit reduces current flow, that current can do less work. Bright lamps will be dim; electric motors will be slow etc.

Types of circuit

The way in which components are connected in a circuit to a large extent dictates the properties of the circuit (and the performance of the component) so recognition of the different types of circuit is important.

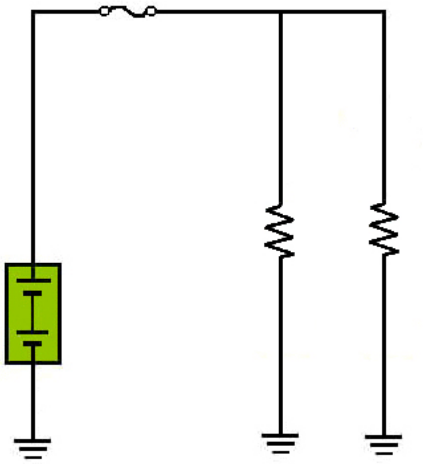
Series circuit

This is any circuit where the components in the circuit (in this instance resistors) are wired one after the other in the same wire. Coronation Street is a series – one episode after the other!



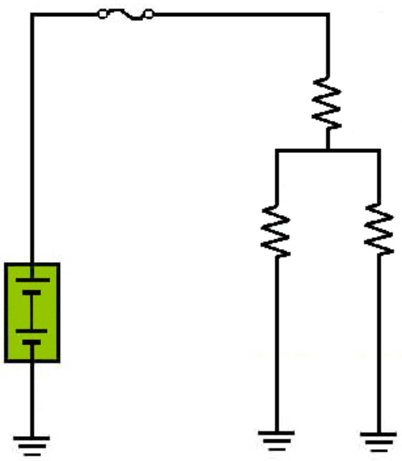
Parallel circuit

This is any circuit that has separate branches from a single power supply. As the branches pictured in a wiring diagram appear to run in parallel with each other, these circuits derive their name from this.



Series parallel circuit

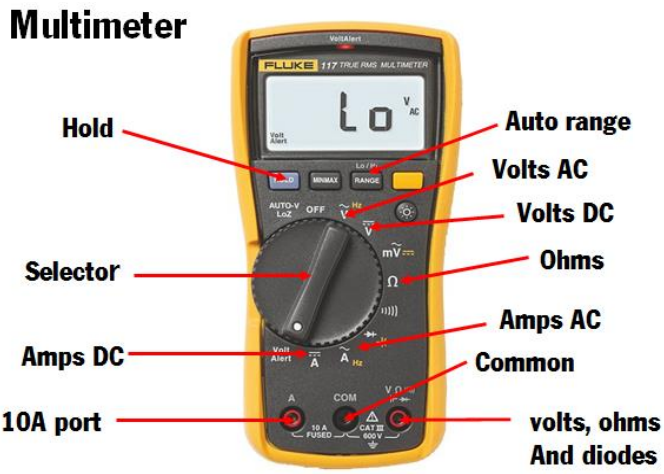
As the name (and the diagram) suggest, this circuit is a combination of the two previously discussed circuits – series and parallel.



Electrical measurement equipment

A multimeter is capable of measuring a number of electrical units / values.

The selector allows you to choose which value the meter is to measure, such as 'Volts DC' and the ports at the bottom of the meter allow for differing connections of the multimeter's leads when necessary (the red lead only has to be moved when measuring current flow normally).



Every type of multimeter normally has a button that enables the technician to choose the maximum value that he wants to measure (the range of the meter). Selecting the smallest range for the circuit that you are working on aids accuracy.
Figure 54 shows the electrical values that this multimeter can typically read. Starting form bottom left:

- amps AC
- amps DC
- volts AC
- volts DC
- 300mV DC maximum
- ohms
- diode tester.

Unit multipliers

One amp is equal to one thousand milliamps, which is written as

1 A = 1000mA

One amp is equal to one million micro amps and is written as

1A = 1,000,000 µA

One thousand amps is equal to one Kilo amp which is written as

1000A = 1KA

One million amps is equal to one Mega amp and is written as

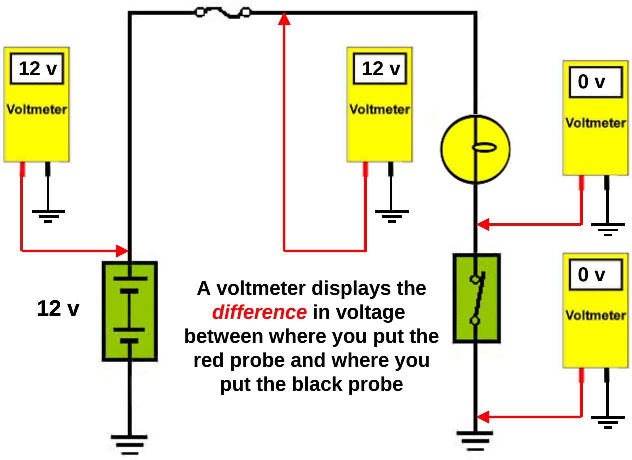
1,000,000A = 1MA

All other electrical units use the same multipliers such as, 1mΩ, 1MΩ

Multimeter use

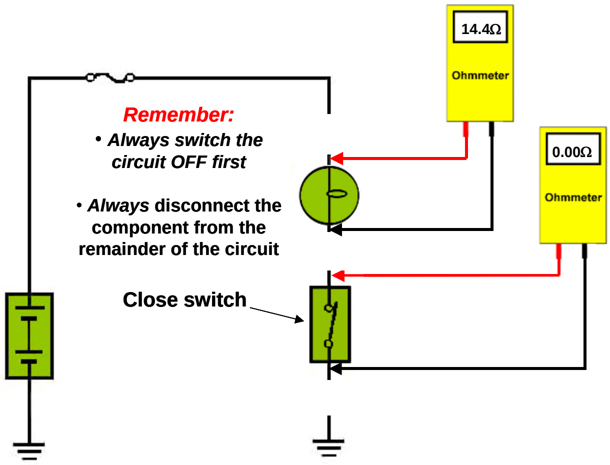
Measuring voltage

A voltmeter (a multimeter with volts selected) must always be fitted in parallel with the circuit – this means that the circuit is not broken to accommodate the meter, the meter is fitted across the circuit.



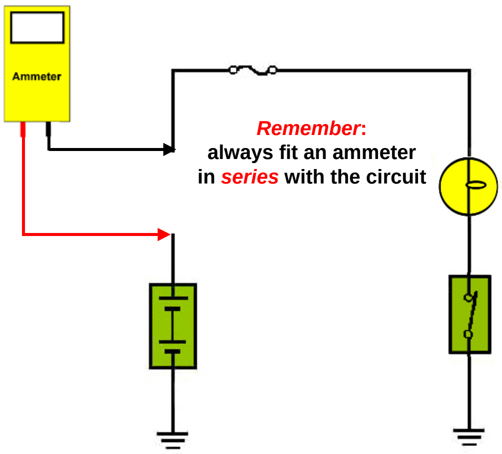
Measuring resistance

An ohmmeter (a multimeter with ohms selected) is always fitted across the component or wire that you want to test. Current must not be flowing in the part of the circuit that you are testing as this will seriously effect your readings (an ohmmeter measures circuit resistance by applying a known voltage to a circuit from a battery inside its case and measuring the resultant current flow – from these two values it can calculate the resistance using Ohm's Law in the same way that you have). If current is flowing in the circuit from a different source (i.e. the vehicle battery) this will seriously effect its calculation.



Measuring current

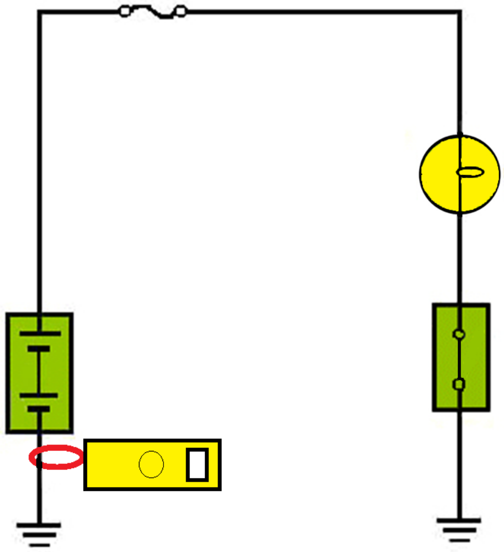
An ammeter (a multimeter with amps selected) must be fitted in series with the circuit whose current you want to measure. This means that the circuit must be broken and the ammeter must be put into the circuit. A good ammeter has an extremely small internal resistance so it is important that you take care not to short a circuit out by putting the ammeter across the only resistance in a circuit (provide the current with an easier path to take through the meter). This will at best blow a fuse in the meter and at worst set it alight!
A standard ammeter is usually limited to 10 amps which can cause problems when measuring large current circuits such as a charging circuit. An amp clamp is often used in this case as it can measure larger currents.



Never connect an ammeter across a resistance; a good ammeter has zero internal resistance

Amp clamp

This piece of equipment is an uncomplicated and safe way to measure current in a circuit. Unlike a regular meter, the clamp type does not put the meter into the circuit, but measures the field induced by a current passing through the clamp.



Ohm's law

So far we have learnt about current, voltage and resistance. We know that the following is true:

- 1 amp is said to be the current that flows when 1 volt is applied to a circuit that has a resistance of 1 ohm
- volt is said to be the amount of electrical pressure applied when 1 amp of current flows in a circuit that has a resistance of 1 ohm
- 1 ohm is said to be the amount of resistance that a circuit possesses if 1 amp of current flows when 1 volt of electrical pressure is applied.

It can be seen from this that there is most definitely a relationship between current, voltage and resistance and Ohms' Law sums up this relationship. Ohms 'Law states that the current flowing in a circuit is in proportion to the voltage applied, and inversely proportionate to the resistance. In other words, the greater the voltage the more current that will flow, the greater the resistance, the less current that will flow. This all seems fairly logical!

Ohm's Law can also be stated mathematically as can be seen below.
'I' is always used to symbolise current, strictly speaking 'A' should not be used unless we are stating a current flow figure, such as 12A.
Let's apply Ohm's Law to the above definitions of 1A and check that it works.

We will apply 1V to a circuit that has a resistance of 1Ω and in theory 1A of current should flow:

Current equals Volts divided by resistance which can be written as I=V/R. The voltage is 1V and the resistance is 1Ω therefore I=1V/1Ω and one divided by one *is one,* so 1A of current will be flowing!

Ohm's law

Ohm's law states that:

"The current flowing in a circuit is in direct proportion to the Voltage applied, and inversely proportionate to the resistance"

This can be expressed mathematically in the following way:

$$I = \frac{V}{R}$$

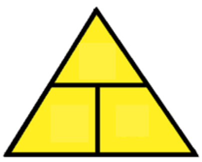
I = current - V = voltage - R = resistance

Transposing Ohm's Law

So long as we know at least two values, a third unknown value can be calculated.

Example: -

Ohm's law triangle



$$I = \frac{V}{R}$$

$$R = \frac{V}{I}$$

$$V = I * R$$

If we know voltage and resistance then we can calculate current.

If we know resistance and current then we can calculate voltage.

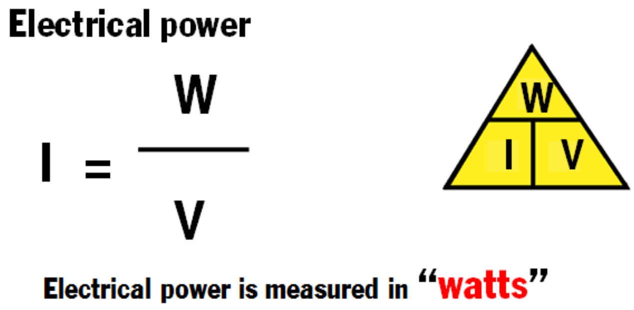
If we know voltage and current then we can calculate resistance.

Before we can do this, we have to transpose the formula (which simply means swap around) to position what we want to calculate to the left of the equals sign. The easiest way to do this is to use the Ohm's Law triangle shown above.

Simply cover up the value that you want to calculate, and then see how the remaining two values are positioned. If they are written one over the other, divide; if they are written side-by-side, multiply.

Watts

When an electrical current flow in an electrical circuit, energy is created. The electrical energy is typically converted into one of three main types:



- thermal energy -
  heat is created when electrical current flow through a resistor / heating element
- radiant energy - light is created when electrical current flows through a light bulb
- mechanical energy - movement is created when electrical current flows through an electrical motor.

The above examples represent the conversion of electrical energy into electrical power.

If voltage is applied to a circuit and current also flows through the circuit, power is created. Electrical power is measured in watts.
Therefore, a relationship exists between voltage, current flow and power.
1 Watt is the amount of power that is consumed when 1 volt is applied to a circuit with a current flow of 1 amp. So long as we know at least two values, a third unknown value can be calculated. The easiest way to do this is to use the Ohms' Law triangle shown above.

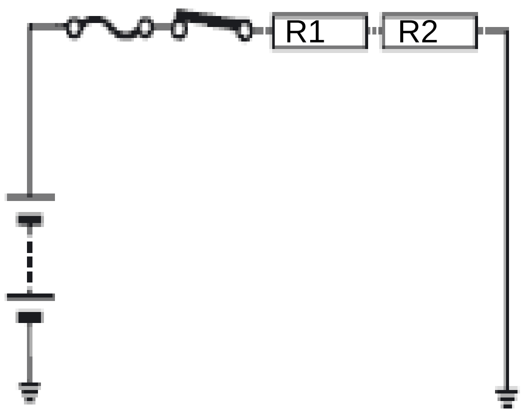
- if we know voltage and current then we can calculate power
- if we know voltage and power then we can calculate current
- if we know power and current then we can calculate voltage.

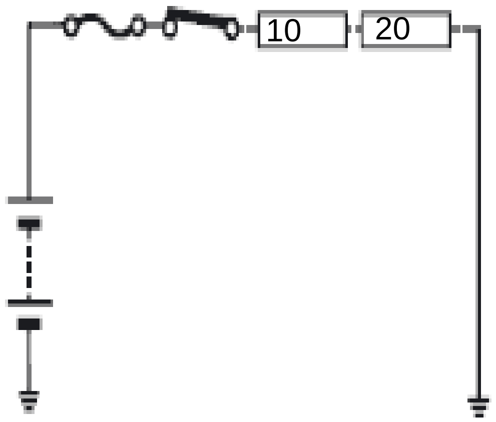
Note. 1 Horsepower is approximately equal to 746 Watts.
1 Kilowatt is approximately equal to 1.34 Horsepower

Working out of resistance in Series Circuit

The total resistance of the circuit is equal to the sum of resistors added together.

So for example:-





Total Resistance = R1 + R2

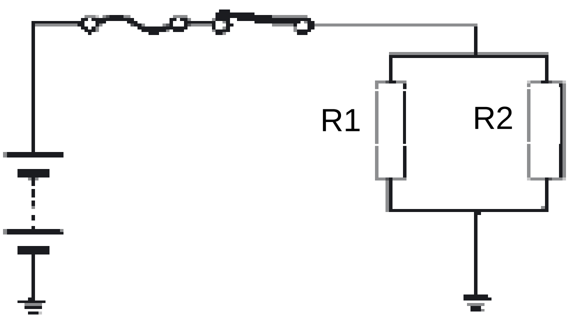
Total Resistance = R1 + R2
TR = 10 + 20
TR = 30

Working out of resistance in Parallel Circuit

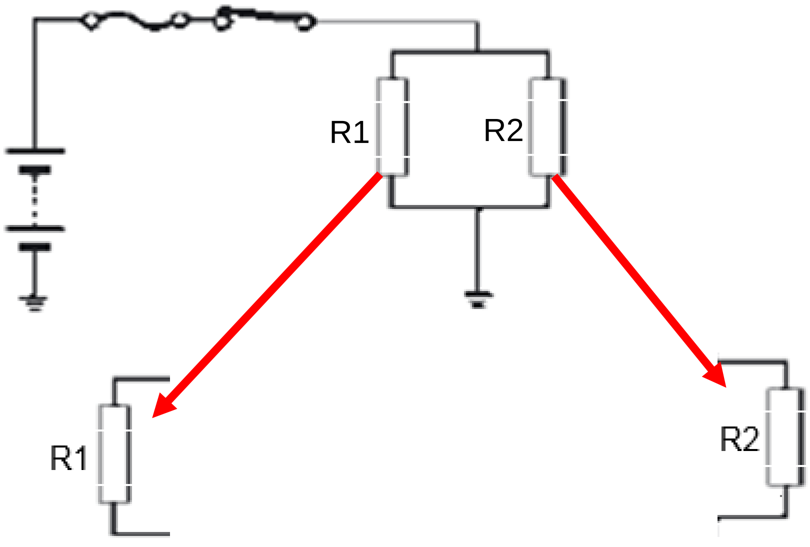
There are several ways which you can work out the total resistance of a parallel circuit.

The key is to remember that the total overall resistance of the circuit must be lower than the lowest resistive value.

The Circuit below shows a parallel circuit with two resistors labelled R1 and R2



One way of working out the resistive value is to break the circuit down into separate series circuit, for example:

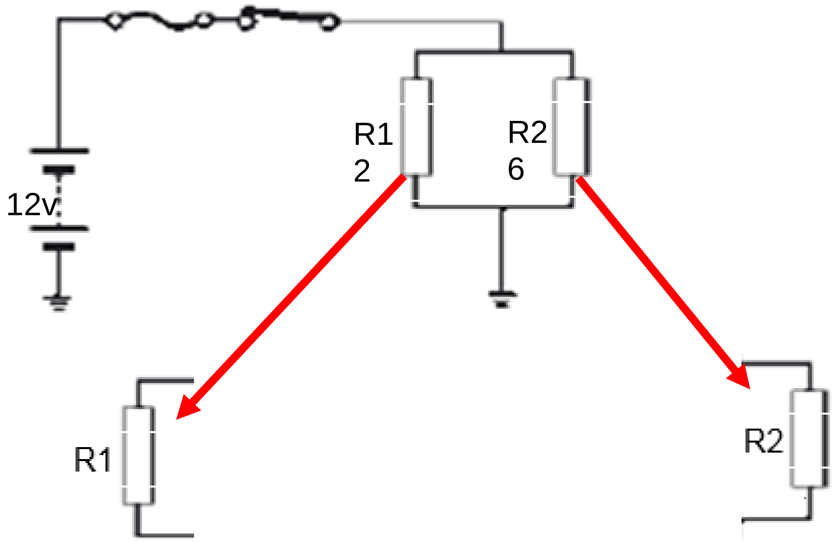


Now you have effectively two series circuits you can use ohms law to work out the current through R1 and R2, remember use the Ohms law triangle to assist.

If you add the current values together this will result in the total current of the circuit.

If you use ohms law again and use the voltage and total current this will give you the total resistance of the circuit.

This is an example



Total current through R1 = $\frac{12V}{2\Omega}$ Total current through R2 = $\frac{12V}{6\Omega}$

Total current through R1 = 6A Total current through R2 = 2A

Total current of circuit = Total current through R1 + Total current through R2

Total current of circuit = 6A + 2A

Total current of circuit = 8A

Total resistance of circuit = $\frac{\text{Voltage}}{\text{Total current of circuit}}$

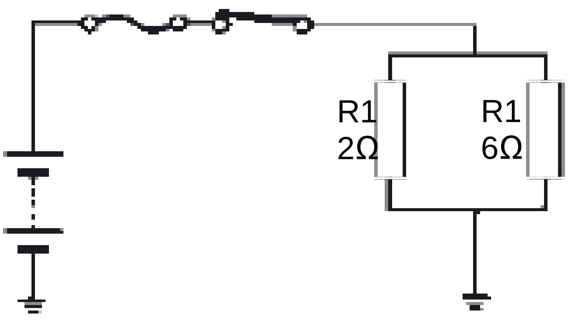
Total resistance of circuit = $\frac{12V}{8A}$

Total resistance of circuit = 1.5 Ω

Another way of working total resistance is using the following equation.

$$\frac{1}{TR} = \frac{1}{R1} + \frac{1}{R2}$$

First work out the common denominator of both resistive values (this is what both numbers can be divided into, the easiest way to work this out is to times them by themselves (R1xR2=CD) so the common denominator for this example is 12. (2x6 = 12)



$$TR = \frac{1}{2} + \frac{1}{6}$$

Now work out how many times do both resistors go into 12.
2 into 12 goes 6 times and 6 goes into 12 twice.

$$TR = \frac{6}{12} + \frac{2}{12}$$

Add the fractions together

$$TR = \frac{8}{12}$$

Flip the fraction so 12 is over 8

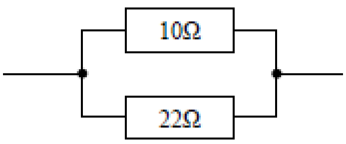
$$TR = \frac{12}{8}$$

TR = 1.5 Ω

To calculate the total overall resistance of two resistors in a parallel circuit with an unknown voltage you can use the following formula:

$$Rtotal = \frac{R1 \ x \ R2}{R1 + R2}$$

An example of this would be as follows.



$$Rtotal = \frac{R1 \times R2}{R1 + R2} = \frac{10\Omega \times 22\Omega}{10\Omega + 22\Omega} = \frac{220\Omega}{32\Omega} = \mathbf{6.87\Omega}$$

Rules of Voltage

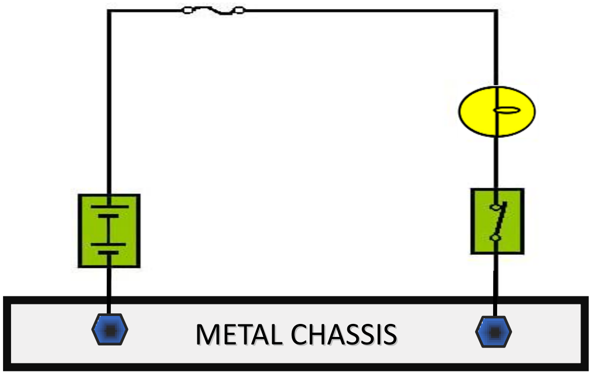
- Voltage in a circuit drops across each resistance and the amount the voltage drops by is dictated by the comparative resistance value.
- The voltage after the last resistance in a circuit will always be zero if current can flow.
- Volts drop will only occur across a resistor if current can flow.
- A voltmeter displays the difference in voltage between where you put the black probe and where you put the red probe.

EARTHING SYSTEMS

The vast majority of vehicles have a chassis formed from metal - normally steel or sometimes Aluminium alloy. As both of these materials are conductors, it allows us to use the chassis rather than wires as a means of connecting our electrical circuits to the negative post of the battery. This much simplifies the wiring of our vehicle, reducing cost and weight, the system is less problematic and diagnosis far simpler.

INSULATED RETURN SYSTEMS

Some vehicles by their very nature are not suitable for chassis return earthing systems. This could either be because their chassis construction is non-metallic/non-conductive, or in some cases it would be dangerous to have current flowing through the chassis. Vehicles that fall into the latter category would include petrol tankers (not a good idea to have a live chassis) and Main Battle Tanks where the main armament is often fired electrically.



Electrical components.

Fuses and other protective safety devices

A fuse is a short thin piece of wire that is designed to melt and break if the current exceeds the given value of the fuse rating which is usually marked on the fuse casing.

If a fuse blows it must be replaced with the correct rated fuse. Remember there is always a reason for a fuse to have blown, this could be due to an incorrect fuse fitted or a short circuit to earth.

Don't fit a fuse until the source of the problem has been known, fitting a fuse could result in melted wires and in worst case scenario a fire.

Types of fuses

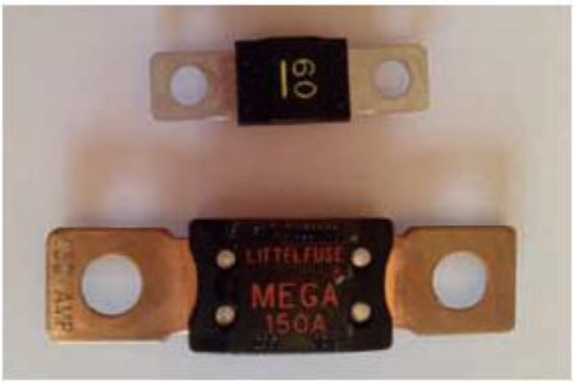
Many fuses fitted on today's vehicles are of the blade type, they are slim, easy to fit and compact, they come in three different sizes as shown in the picture below.
The smaller fuses range from 5 amps to 30 amps but the larger type Master fuse can protect circuits with a rating of 40 – 60amps.

J fuses

These type fuses are also very common, they are usually used in electrical circuits that require protection rating from 30amps to 60amps

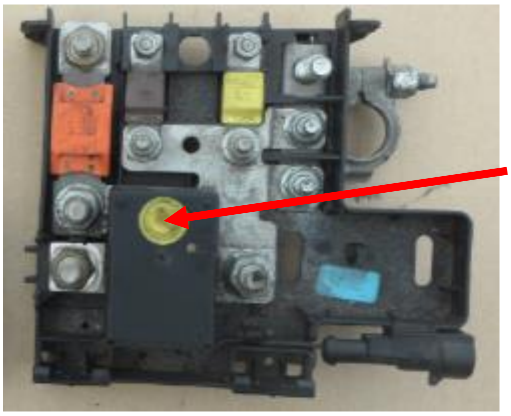
Bolted down/fusible links

As modern vehicles have become more electronically advance the current drain on the battery has become increasingly higher, this has resulted in the requirement of much larger rated fuse. Fusible links were introduced, these links can cope with current rating between 40 – 500amps.



Circuit Breakers

Circuit breakers protect system like sunroofs and electric windows. When a certain level of current has been reached, the breaker will open the circuit to stop the current from flowing, this is called ‘tripping’.
Unlike a fuse circuit breakers can be reset either manually or automatically.



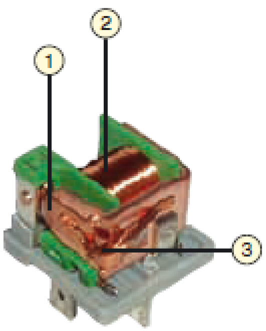
Manual Circuit Breaker

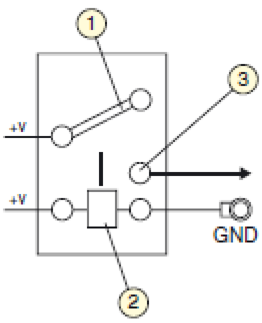
Relays

Many circuits have relays, these relays are electronic switching devices which allow a relatively small current circuit to switch a circuit that has a much larger demand on current flow.

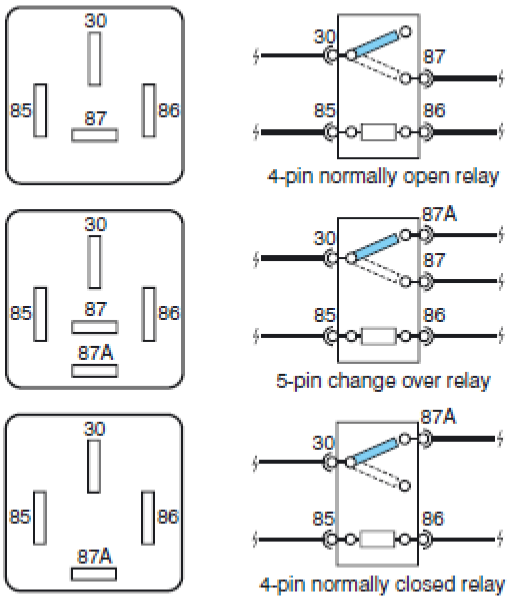
Relays are different sizes and have a variety of different current ratings, the type of relay selected would depend on circuit type.

A relay consists of a metal switching contact and coil windings, when the low current circuit is switched on, the current will flow through the coil windings in the relay and in turn generate a magnetic field around the windings, this will then draw the switch either closed or open depending on the type of relay. Current then can pass through the high current circuit to the component, or open the circuit to stop current flowing.



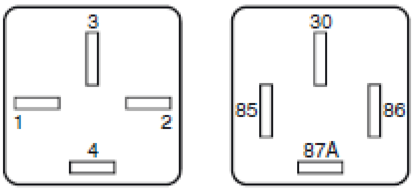


1 moving armature
2 control coil
3 switch contacts



The pin numbers on the relays are standard, the table and diagram below represent these numbers.

ISO	DIN	Designation
1	86	Switched feed
2	85	Ground
3	30	Ignition or constant feed
4	87a	Switched feed change over
5	87	Switched feed from relay to consumer



Two relay standards exist:

- DIN (Deutsches Institut für Normung)
- ISO (International Organization for Standardization)

Note: the translation for the German '*Deutsches Institut für Normung*' (DIN) is the 'German Institute for Standardization'.

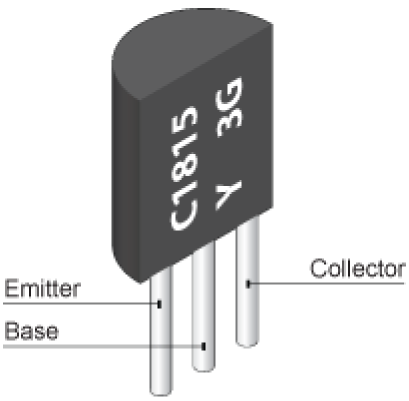
Transistors

Transistors are tiny electronic switches and amplifiers. Several thousand transistors can be put on a piece of silicon with a surface area of just $1mm^2$.

Transistors have three main uses:

- As an electronic switch within a circuit
- To switch on another part of a circuit when a change in resistance of a sensor Device is detected
- As an interface device, to receive signals from low current devices (such as ICs) and use these to turn on high current devices (such as motors)

Bipolar transistors



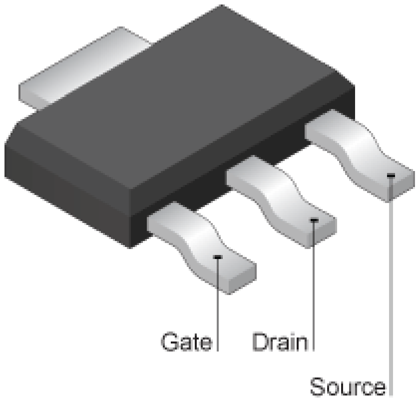
Bipolar transistors have three leads:

- **emitter**
- **collector**
- **base**

The base lead controls the transistor: once it receives a voltage of at least 0.6V, it switches the transistor on and allows (some) current to flow from the collector to the emitter.

Field-effect transistors

Field-effect transistors (FETs) are digital switches that respond to an input voltage to allow an increase in either voltage or current. They have three leads:



- **gate**
- **drain**
- **source**

When the gate leg receives a voltage of at least 2V it switches on fully, allowing electricity to flow from the source to the drain. The current continues to flow until the voltage at the gate leg falls below 2V.

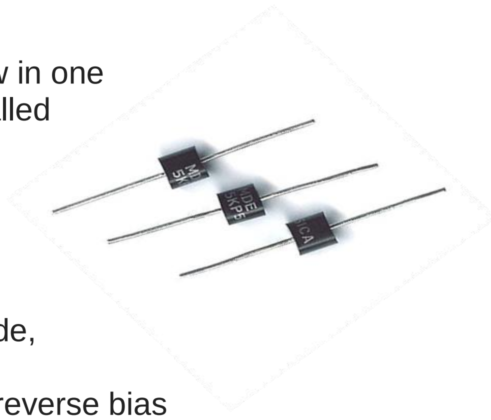
NPN and PNP

Transistors can be switch on either using a negative current or a positive current, this will only be dependent on the circuit.

NPN is positive switched and PNP is negative switched

Diodes

A diode is a very small component that allows current to flow in one direction only. It is a polarized component with two leads, called the cathode and the anode.

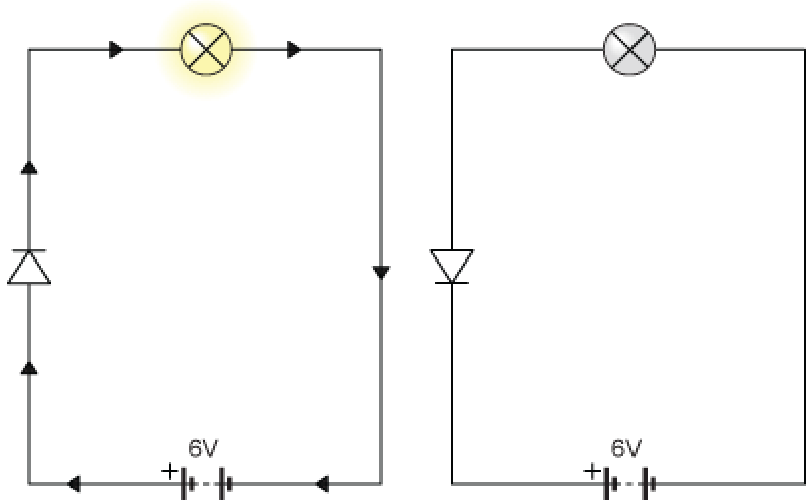


The cathode is normally marked with a silver or coloured band or a symbol.

If the anode is connected to a higher voltage than the cathode, current will be able to flow from anode to cathode. But if it's connected opposite then current will not flow. This is called reverse bias

Most diodes are made with semiconductor materials such as silicon, germanium, or selenium.

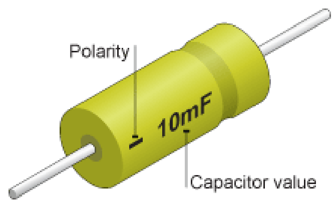
Diodes are found in many electrical circuits with in a motor vehicle, these are usually fitted to prevent damage to a circuit, if view on a wiring diagram, the symbol for a diode is shown below.



Zener diodes prevent current flow in the opposite direction but unlike a conventional diode when a threshold voltage is reached; current can then flow in the opposite direction without damaging the diode.

Capacitors

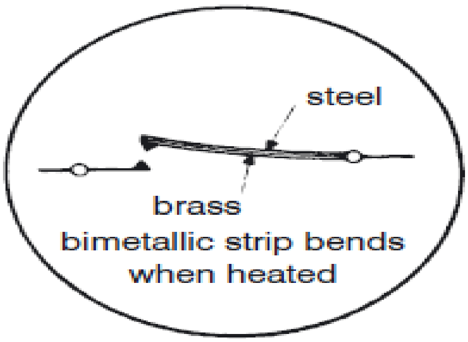
A capacitor is found in many circuit boards and come in different sizes depending on storage requirement. What makes capacitors special is their ability to store energy; they're like a fully charged electric, advantage of a capacitor is that capacitors usually lead longer lives than batteries. They're also capable of delivering energy much faster than a battery, which makes them good for applications which need a short, but high burst of power. Common applications include local energy storage, voltage spike suppression, and complex signal filtering.



Bi-Metallic Strips

The Bimetallic strip is made from two different strips of metal with different heating properties. For example, the use of Brass and Steel is common.

When bi-metallic the strip is heated when electrical current passes through it, (or around it via a coil of wire, the Brass and Steel expands at different rates, this will cause the strip to bend with the metal that expands at the greatest rate on the outside.



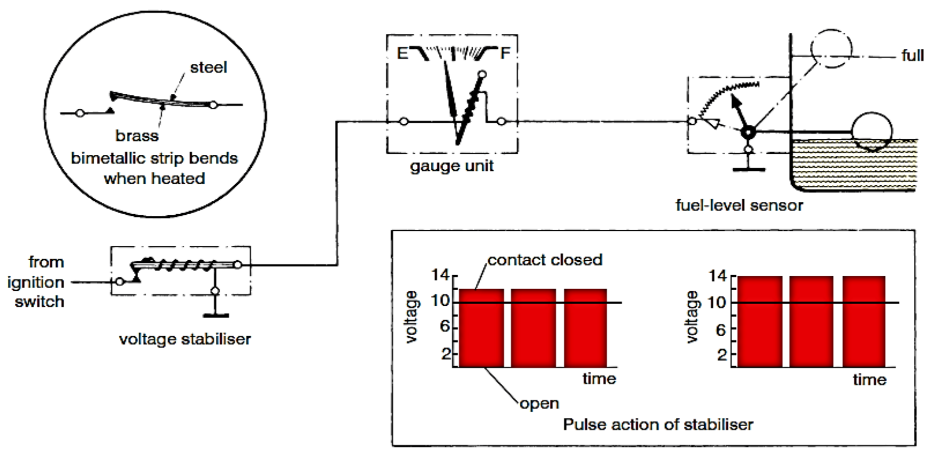
Applications such as Hazard indicators, central door locking and electric windows would most probably have Bi-metallic strips.

Voltage Stabilisers

Voltage Stabilisers can be used in numerous circuits, where there is a requirement for the Voltage to be switched on and off frequently and/or where the Voltage needs to be kept within certain parameters.

The type of Voltage regulator we will look at is the older type, commonly used in Thermal-type instrument gauges such as fuel, engine temperature etc. Bi-metallic strips were used to regulate the voltage so that there was no fluctuation in the gauge.

The diagram below represents a circuit with a voltage regulator, modern vehicles don't tend to use this type of system as its done internally of the ECUs



Sensors

Sensors on a motor vehicle have many functions, they are usually to inform the ECU of any changes in parameters, the ECU will then act upon this Information and send to the required source. For example, an ABS wheel speed sensor detects wheel speed, the ABS ECU will then receive this information, process it and pass it onto the instrument cluster.

Most common types of sensors are as follows.

Passive Sensor (Inductive)

A passive sensor is a device that detects and responds to inputs from the physical environment and generates it's own voltage.

Active sensors (Hall Effect)

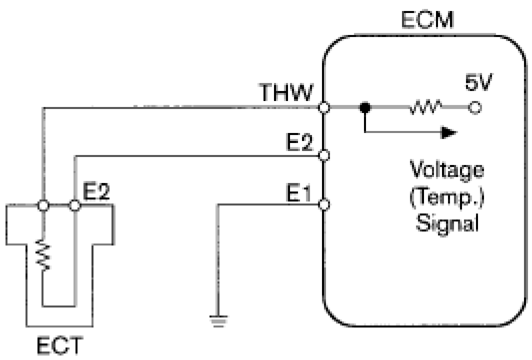
An active sensor is a sensing device that requires an external source of power to operate. This external source is usually supplied via an ECU.

Both Passive and active type sensor technologies gather data through the detection of vibrations, light, radiation, heat or other phenomena occurring in the subject's environment. These will be covered in a greater length in Year three.

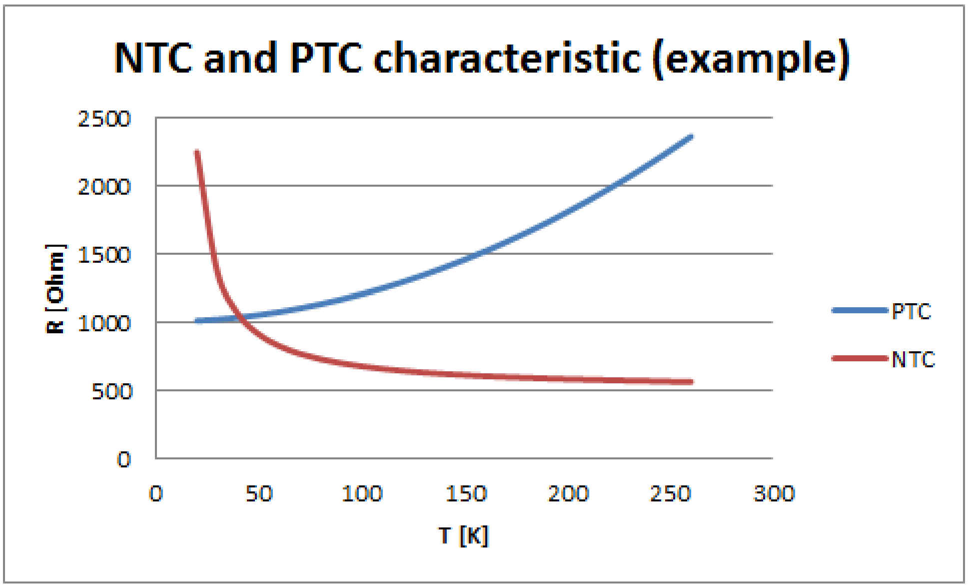
Temperature Sensors

Positive (PTC) or negative (NTC) temperature coeficient sensor pick up temperature change, these type of sensor are used throughout the car such as, Coolant, oil and ambient sensors.

An ECU sends out a regulated reference voltage (typically 5 volts) to the coolant temperature sensor. The voltage drop across the sensor will change according to the temperature because its resistance changes. The ECU is then able to calculate the temperature (ie air temperature)



On a NTC sensor as the temperature increases the resistance of the sensor deceases but on a PTC sensor as the temperature increase the resistance of the sensor increases.



Different types of electrical faults

Open circuit faults

These are breaks in a circuit which results in current unable to flow.

High resistance faults

High resistance is due to an obstruction within a circuit causing a restriction in the flow of current.

Short circuit faults

Is an electrical circuit that allows a current to travel along an unintended path with no or a very low electrical resistance.

Parasitic drain

A parasitic battery drain is when abnormal and continuous discharge of power occurs after having turned off the ignition. This is caused by a short circuit or an electrical device that remains in the "on" position or energized, such as an interior light.

Wiring

Wiring repairs are sometimes required due to damage caused by electrical faults or by physical damage. Wires may be damaged electrically by short circuits between wires or from wires to ground. Fuses or fusible links may melt from overloaded circuits. Wires may be physically damaged by scrapes or cut insulation, chemical or heat exposure, or breaks from previous testing or component repair.

Wire size

Choosing the proper size of wire when making circuit repairs is critical. While choosing wires too thick for the circuit will only make splicing them difficult and bulky, choosing wires too thin may limit current flow to unacceptable levels or even result in melted wires. Two factors must be considered:

Wiregauge

Wire gauge numbers are determined by the conductors cross-section area. The wire gauge used in Europe is based on the cross-section area in square milimeters (mm^2). these are not to be confused with AWG (American wire gauge) sizes in circular mils (0.001/ thousand of an inch).

AWG Size	Metric Size (mm^2)
20	0.5
18	0.8
16	1.0
14	2.0
12	3.0
10	5.0
8	8.0
6	13.0
4	19.0

Wire length

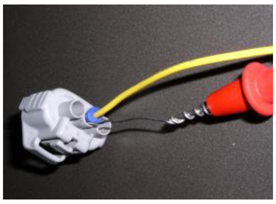
Wire length must be considered when repairing circuits because resistance increases with longer lengths. If you need to calculate the voltage drop under a given set of circumstances use the formula below:

Voltage Drop = 2 x L x I x R ÷ A

A = cross sectional area of cable in (mm^2)
L = length in metres
I = current measured in amps
R = resistance of cable (copper, steel etc.)
Resistance of copper = 0.017, Aluminium = 0.028, Steel = 0.18

Common problems

Various types of connectors, terminals and junction blocks are used on the modern vehicle. Wiring diagrams identify each type used in a curcuit. Connectors make excellent test points because the circuit can be opened without the need for wire repairs after testing. However never assume a connection is good simply because the terminals seem connected. Many electrical problems can be traced to loose, corroded, or Improper connections. These problems include a missing or bent connector pin.



Wire repairs

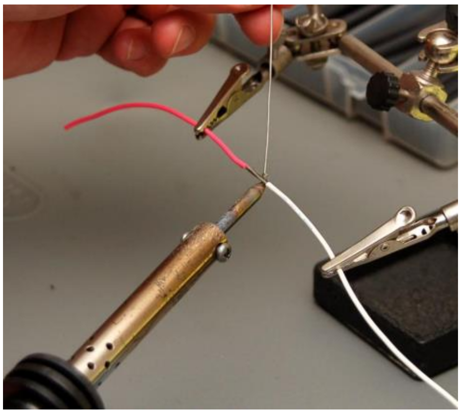
When making up wiring sections or repairing harnesses it is essential to create a strong permanent join to ensure reliability. Below are some tips to repairing wiring:

- Before commencing work on the electrical system ensure the battery is disconnected.

- If damaged wire requires replacement, make sure the same size or slightly larger is used. If available always try to use the same colour.

- If possible always use heat-shrink tubing overlapping the repair by approximately 10mm.

Soldering



Soldering joins two pieces of metal together with a lead tin alloy. The solder is a mixture of lead and tin therefore the fumes given off during soldering can be harmful to your health.

Soldering heats the wires. In doing so it accelerates oxidisation, leaving a thin film of oxide on the wire that tends to reject solder. Flux removes this oxide and prevents further oxidation during the soldering process. Rosin or resin type flux is commonly used for all automotive electrical work as it does not cause corrosion or conduct electricity.
The key to soldering is cleanliness, always remove any impurities and keep the joint neat.

The vehicle battery

The battery is the heart of any vehicle electrical system.
It produces electrical energy through the means of a chemical reaction (it converts chemical energy into electrical energy). The battery consists of a number of electrical cells – the term battery is actually a collective noun for cells in much the same way that battery is a collective noun for chickens! It should be noted therefore that referring to a single cell as a battery is technically incorrect.
Each cell can produce a maximum of 2.2 volts and a typical vehicle battery consists of six cells (13.2 volts maximum).

The cells

Each cell consists of negative plates - made from spongy lead – and positive plates – made from lead peroxide.

These dissimilar plates are suspended in an electrolyte (a solution that allows electrical current to flow within it). This electrolyte is diluted sulphuric acid. Due to the use of these materials, a vehicle battery is often referred to as a 'lead-acid battery'.

The materials from which the plates are made and the electrolyte solution in which they are suspended react in such a way that a relatively large amount of electrical current is produced.

The reaction

When a lead plate and a lead peroxide plate are suspended in dilute sulphuric acid, an electromotive force is generated between the two plates. The lead plate becomes the negative plate and the lead peroxide plate becomes the positive. Once an external circuit is connected to these plates, electrical current start to flow from the plates within the battery. The generation of electrical energy is through the chemical reaction that occurs in the battery and this reaction brings about a change in state of the materials in each cell. The following formulae represent the reaction:

Charging:

PbO_2 (lead peroxide) + $2H_2SO_4$ (Sulphuric acid)

=

Discharging:

$PbSO_4$ (lead sulphate)+ $2H_2O$ (water) + $PbSO_4$

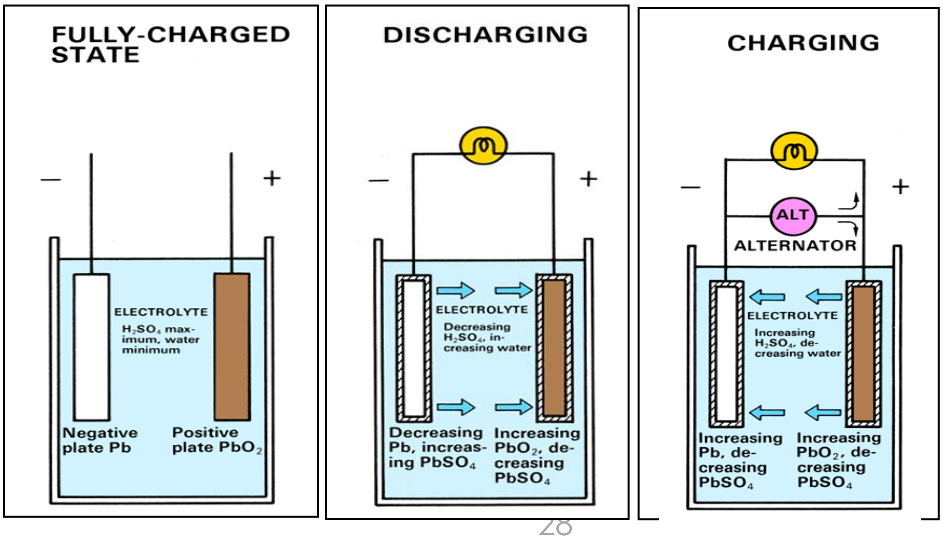
From the above equation, it can be seen that the discharging of the battery creates lead sulphate and water. Consequently, the more discharged the battery becomes the more lead sulphate is formed on the plates and the more similar they become. If the plates reach a point where they are virtually identical in their chemical makeup, no electro motive force will be generated between the two (the battery is discharged, or flat). This is often described as a ‘sulphated’ battery. However, it can also be seen from the above equation that the act of charging a battery can indeed reverse this process. This is what actually happens on a vehicle; the alternator charges the battery by supplying electrical current to it, and this has the reverse effect chemically. This happens on a continual basis ensuring that the battery remains in a fully charged state normally.

Caution

Hydrogen gas is given off when the battery is charging. Hydrogen gas is extremely flammable.
For more information:

http://www.hse.gov.uk/pubns/indg139.pdf

The reaction



Battery capacity

Battery capacity is a figure that reflects the battery's ability to discharge a given amount of current for a given amount of time. The unit that is used is 'ampere-hours 'or amp-hours. The system works as follows:

If a battery is capable of producing 1 amp continuously for 1 hour, then it is a 1 amp-hour battery. If that battery is capable of producing 60 amps continuously for a period of 1 hour, then it is a 60 amp-hour battery. The same battery would by definition be able to produce 120 amps continuously for a period of 30 minutes.
The point at which the battery is deemed to be fully discharged is when its voltage drops to 10.5 v (1.75 v per cell).

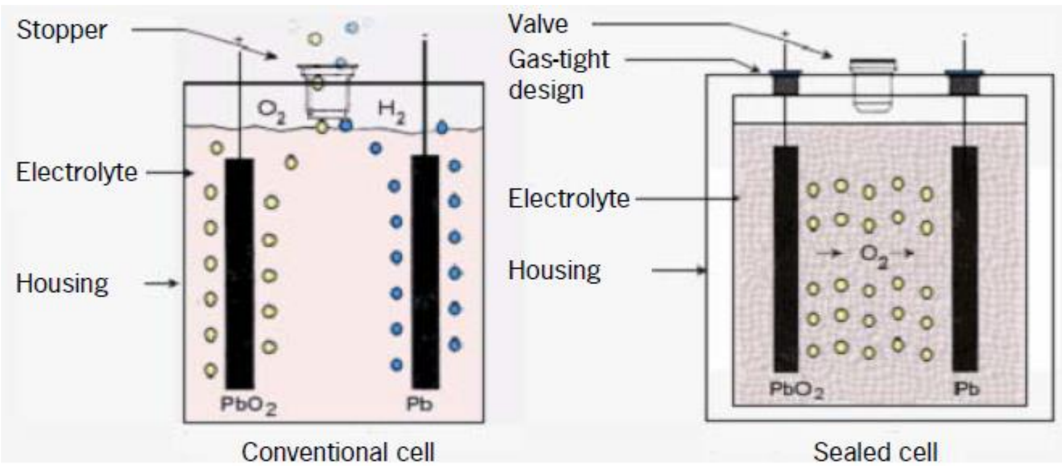
The Reserve capacity of a battery indicates the time a battery will deliver a certain current for example, (25A) at a certain temperature (25ºc) before the cell voltage reaches a certain level (1.75V)

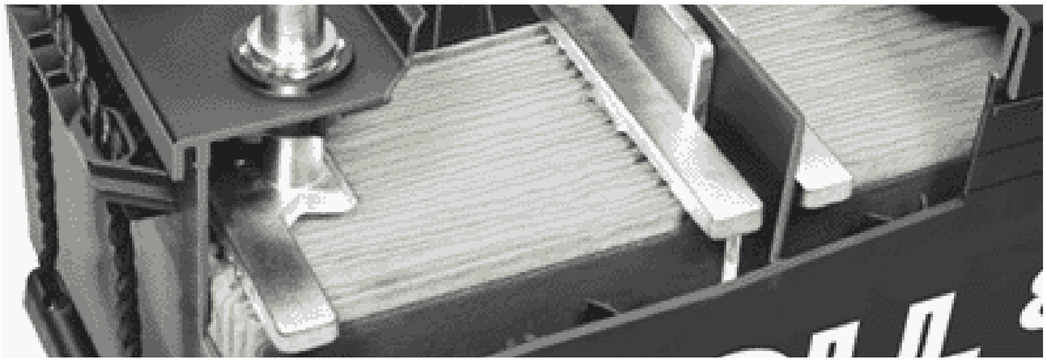
Internal resistance

A battery not only creates electromotive force (EMF) but also acts as a resistant, due to the internal resistance of its electrolyte and plates (0.02Ω). When current is flowing through the circuit, this internal resistance causes a voltage drop to occur across the battery terminals, so the actual voltage produced by the battery will be somewhat less than that which would be expected.
The internal resistance of a battery increases over time as the battery is used.

AGM (Absorbed Glass Mat)

AGM (Absorbent Glass Mat) batteries are completely maintenance-free throughout its entire service life thanks to a special separator. A valve located at the top of the unit seals the cell.
Gases that are generated inside the battery are removed electrochemically at the counter electrode. This means that very little fluid is lost and refilling with water is no longer necessary or possible.
If the battery is opened, it must be replaced.

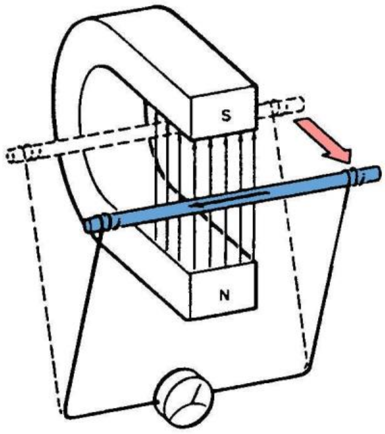




Vehicle charging systems

We have seen that in order for a vehicle's battery to maintain a good state of charge, electrical current has to flow to it in order for the chemical changes undergone during discharging can be reversed. A vehicles charging system does this and has to have a sufficient capacity to ensure that current in excess of that demanded from the battery is supplied. In this way, a high state of battery charge is maintained.

The principal of electrical generation



Electricity is generated when a magnetic field experiences a change in strength in the presence of a conductor – electricity will flow in that conductor (so long as that electrical current has a route to follow i.e. a circuit. in the diagram It can be seen that the magnetic lines of force that are being produced by the magnet a moving from the magnets north pole to the south. As the conducting bar (in blue) is moved through these magnetic lines of force (or flux) their strength is altered. This generates electrical current flow in the conductor. The circuit that is necessary in order for current to flow has been wired through an ammeter in order for the presence of current to be registered. The greater the number of magnetic lines of flux that are 'cut' per unit time, the greater the amount of current that is produced. The generator pictured in figure 5 would therefore produce very little current and it would probably take a galvanometer to register it (a very sensitive ammeter).

So how can we increase the number of lines of magnetic force that are cut per unit time in order to generate more current?

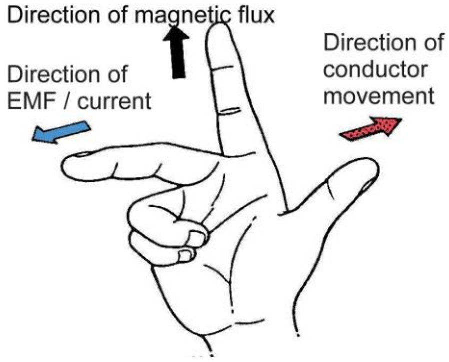
- move the conductor faster

- use a more powerful magnet
- use multiple magnets
- use multiple conductors.

An alternator generates the current required to charge a vehicles battery and it uses all of the above methods in order to increase the current generated.

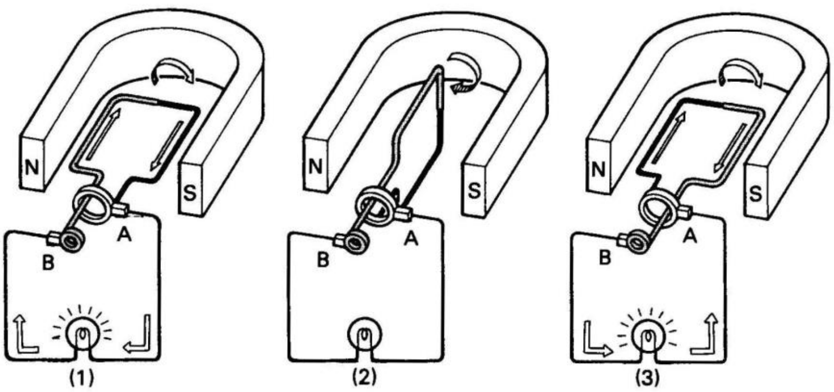
Fleming's right-hand rule

Alexander Fleming was something of a pioneer in the area of electrical discovery. He devised a rule that enables us to readily ascertain in which direction the current will flow in a conductor.
Using your right hand**,** point your index finger in the direction of the magnetic flux (north to south on the magnet). Point your thumb in the direction that you intend to move the conductor, and your third finger will now point in the direction of current flow.

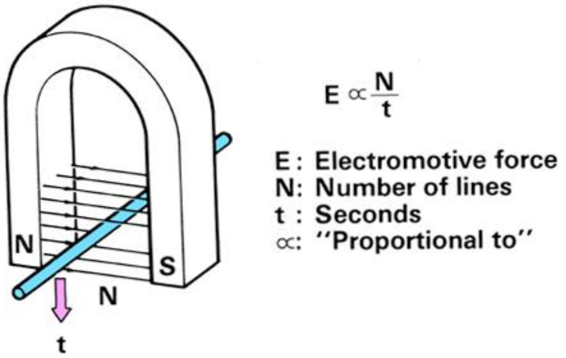


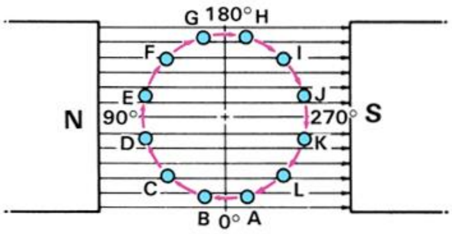
The alternator

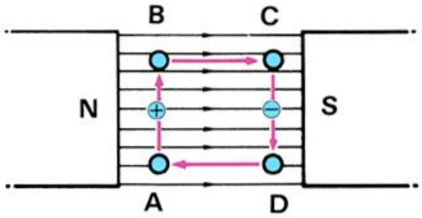
One of the easiest ways to increase the number of conductors moving in the magnetic flux; and also to enable a continuous movement to be easily achieved is to rotate a looped conductor within the flux. Apply Fleming's right hand rule to the arrangement pictured below.

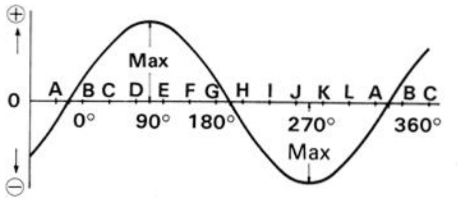


You will see that as the loop passes through the 12 / 6 o'clock position, the direction of current flow in the loop will effectively reverse – the direction of current flow alternates. Alternating current has been generated. Because the loop has to continually rotate, but the circuits on the vehicle that the current is required to flow in are static, a rotary contact is required. These are called slip rings and can be seen above. The slip rings rotate with the conducting loop and are in constant rubbing contact with the brushes. These brushes do eventually wear beyond repair, and the alternator will stop charging. Most alternators have brush packs that are easily replaced.



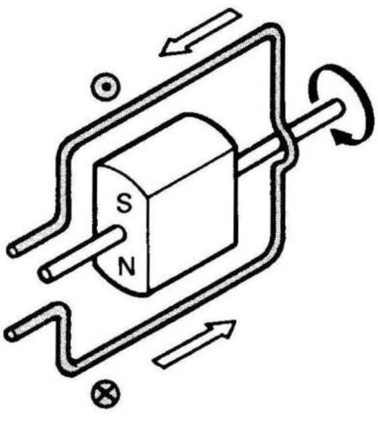




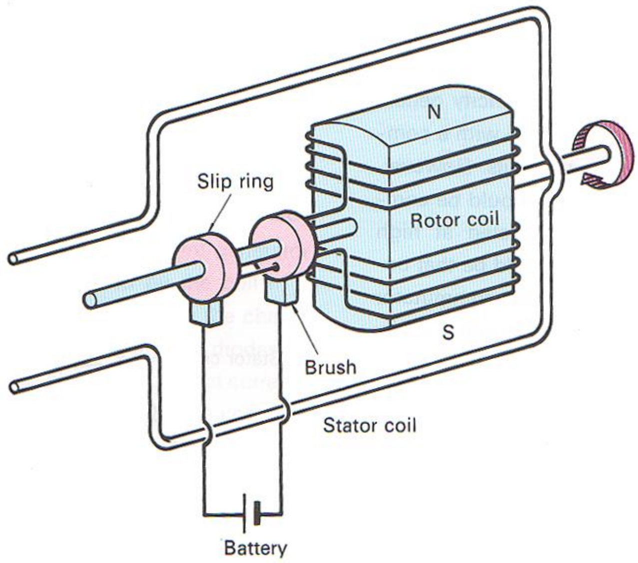


It can be seen in the diagram above that as the conductor rotates; it will either cut across the lines of flux near perpendicularly or obliquely. Remember, the more lines that are cut through per unit time, the greater the current flow generation. Therefore, as the conductor passes through the 3 / 9 o'clock position current flow will be at its highest, and conversely when the conductor passes through the 12 / 6 o'clock position current flow is minimal.

There is a major problem with the design that we have looked at so far – the conductor is rotating in the magnet. This means that the slip rings and brushes have to cope with very large amounts of current and the brushes will burn out in no time. Instead of rotating the conductor in the magnet, we rotate the magnet in the conductor. We are still cutting magnetic lines of flux we are just 'dragging' these lines over the conductor instead of the conductor over the lines. Remember, there are two ways to cut a cake – you can push the knife through the cake or you can push the cake across the knife – either way the cake gets cut!

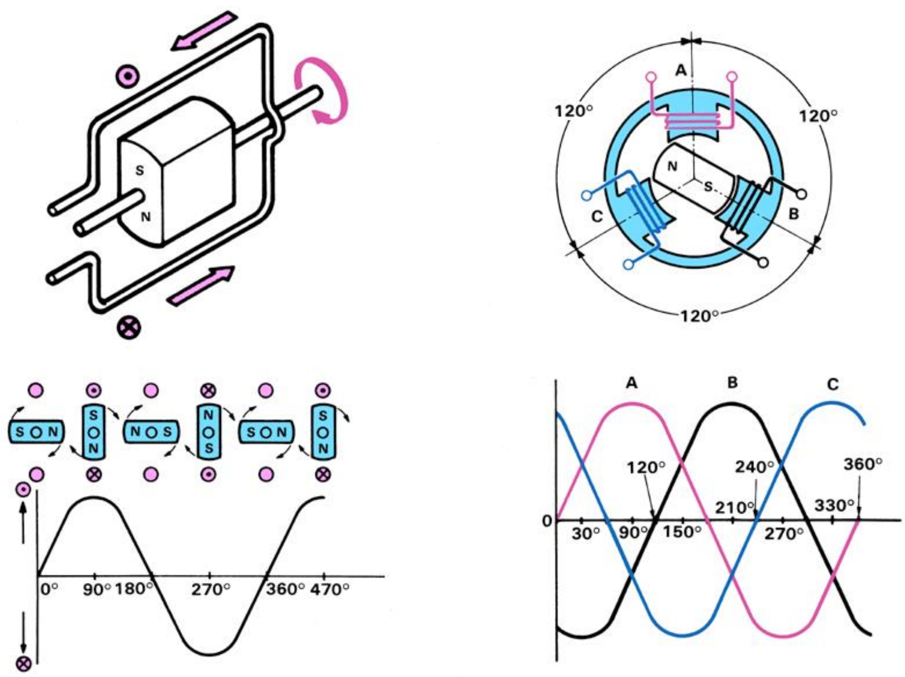


Everything that we have seen so far has used a ‘permanent’ magnet. This is an unfortunate term, as permanent magnets are far from permanent. The will over time lose their magnetism – the lines of flux become less dense and the current generated by the alternator reduces. An electro-magnet is far more powerful and consistent. The set up in this diagram shows exactly this. So what about our original desire to reduce the current flowing in the slip rings and brushes? Well, the current is still generated in the static winding (often referred to as the stator for this reason) and the electro-magnet only requires a relatively small amount of current in order to generate a sufficiently powerful magnet. The life of the slip rings and brushes can run in to hundreds of thousands of miles.



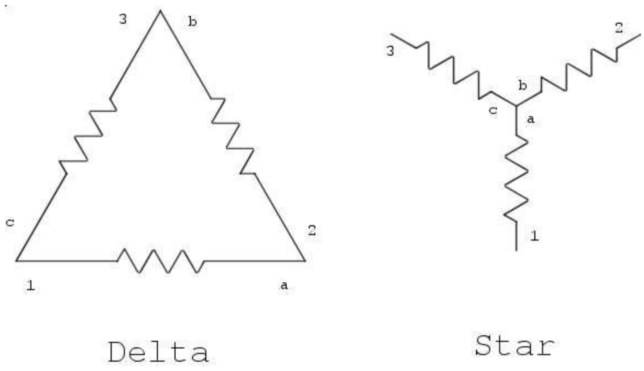
3-phase electricity

We have already seen that the more lines of flux that are cut per unit time, the more current that is generated. Therefore, if we use multiple windings this will be achieved. The resultant current is referred to as 3-phase current. Some modern luxury vehicles use 6-phase alternators to satisfy the hunger for current that such vehicles have.



Stator coil configuration

The stator coils or phases are configured in two ways as shown below.



What is the difference between Star and Delta?

The basic difference between star and delta is that star generates a high voltage at a low current, and delta generates a low voltage at a high current. The total (no load) power generated is the same.

To calculate the output AC voltage and current of a three-phase alternator wired in star or delta it is only necessary to measure the voltage and current of one of the coils. Multiply the voltage of one coil by the number of coils per phase to obtain the phase voltage. The *square root* of the number of phases (3) = 1.732 can be used to calculate the total outputs with either configuration.

For example, if you have one phase which gives 20 Volts at 12 Amps:

Star - Voltage = 20 X 1.732 = 34.6V, Current is unchanged at 12 Amps.

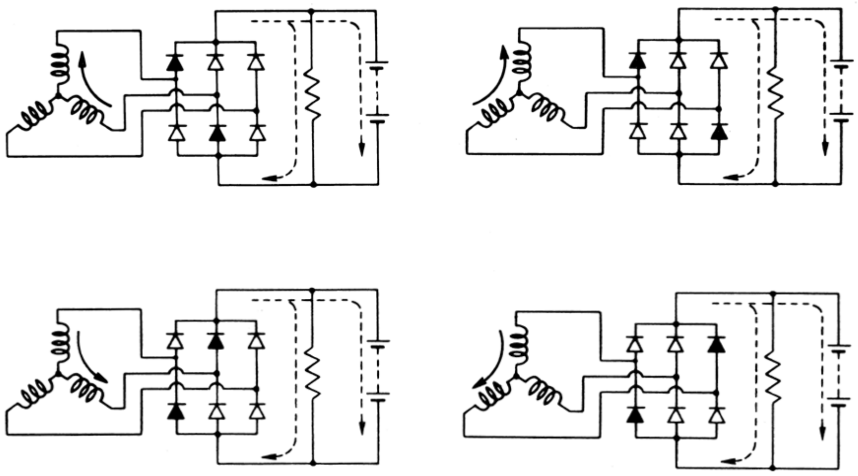
Delta - Voltage is unchanged at 20 Volts, Current = 12 X 1.732 = 20.8 Amps.

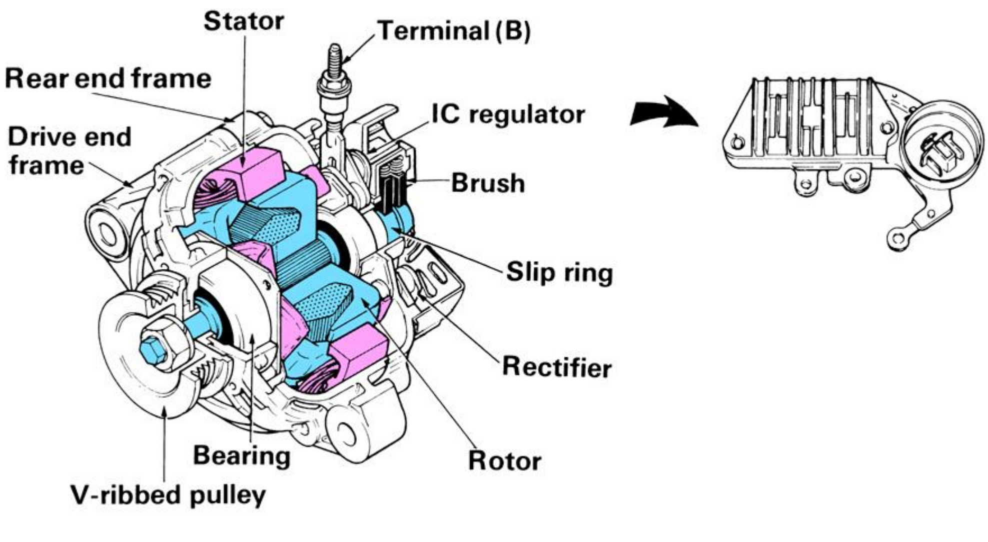
Note that since power is equal to the voltage multiplied by the current, in both cases the power is around 415 Watts in the example above

Rectification to D.C (Direct Current)

Alternating current cannot charge a battery. Its very nature is such that the negative voltage effectively cancels out the positive voltage – in other words, the current that flows into the battery in one instance is pulled immediately out in the next and we are running to stand still! Rectification is the act of converting A.C to D.C. A diode allows current to flow in one direction only; it is an electrical one-way valve. This makes it the ideal device to convert A.C to D.C current, as it will block the negative phase of the current flow. To this end, they are often referred to as 'blocking diodes'. The use of only one diode would result in 'Half-wave rectification'. This means that the negative phase would be eliminated completed rendering only half of the generated wave of use. With single-phase generation, four diodes are required constructed in a circuit known as a 'Wheatstone bridge' (after Charles Wheatstone its inventor).

3-phase generation requires six diodes wired as shown above.
It can be seen that it does not matter which phase is generating, or in what direction that current is flowing at any given time, the current will only flow in a single direction in the charging circuit.





Alternator - The real thing
The major components that make up the alternator are shown above.

Let's draw a comparison with what we have seen so far.

- **The stator –** the 3-phase windings (static, hence the name).

- **The rotor –** the electromagnet (producing the required flux). - Sometimes referred to as the field winding.

- **The slip rings and brushes –** the dynamic (moving) electrical contact

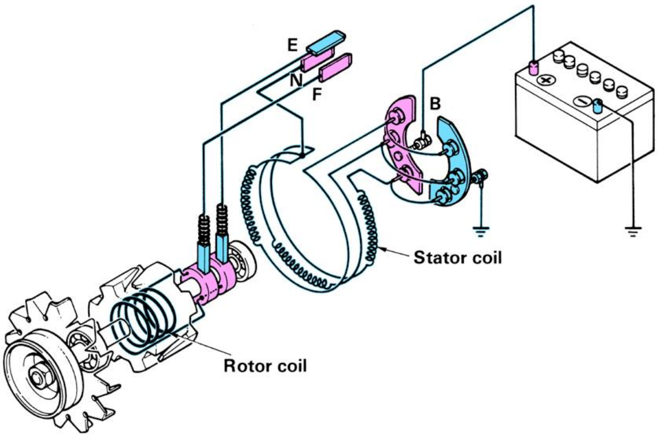
- **The rectifier –** the blocking diode pack (Wheatstone bridge).

- In addition to this we have the following:

- **Terminal B –** connected to the battery (the charging cable)

- **V-ribbed pulley –** provides drive to the rotor via a poly-vee belt and the crankshaft

- **The IC regulator –** An integrated circuit designed to regulate the
- alternators output voltage.

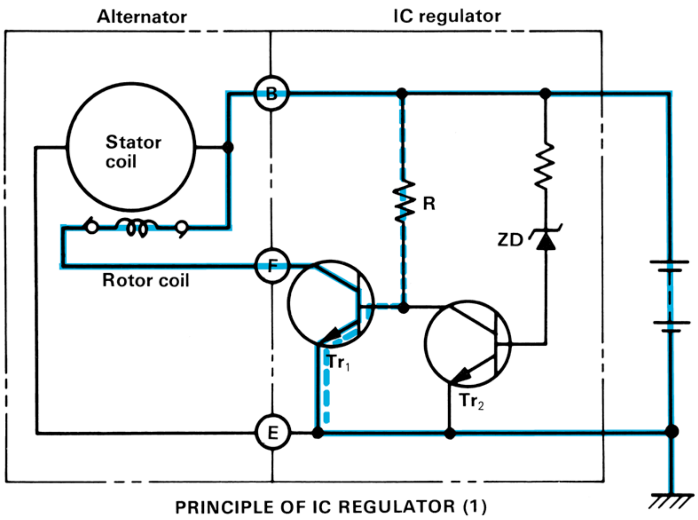


Voltage regulation

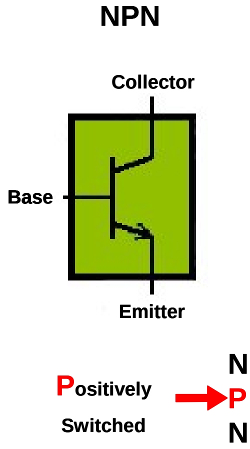
We have seen that the output of an alternator is very much dictated by the number of lines of magnetic flux that are cut per unit time. As the alternator is engine driven (belted to the crankshaft), as engine speed increases the generated voltage would also increase. If this were allowed to continue unabated, the battery would overcharge resulting in heavy gassing (and a resultant loss of electrolyte) and possibly buckled plates. If the plates buckle severely, they may short together resulting in dead cells. This reduces battery voltage by 2.2v per shorted cell with a severe loss of capacity.

The principal of voltage regulation

If we reduce the current flowing to the field winding (the rotor coil / electro-magnet), flux density will reduce and therefore the voltage output will reduce. If we increase the current flowing to the field winding, then the output voltage will increase.

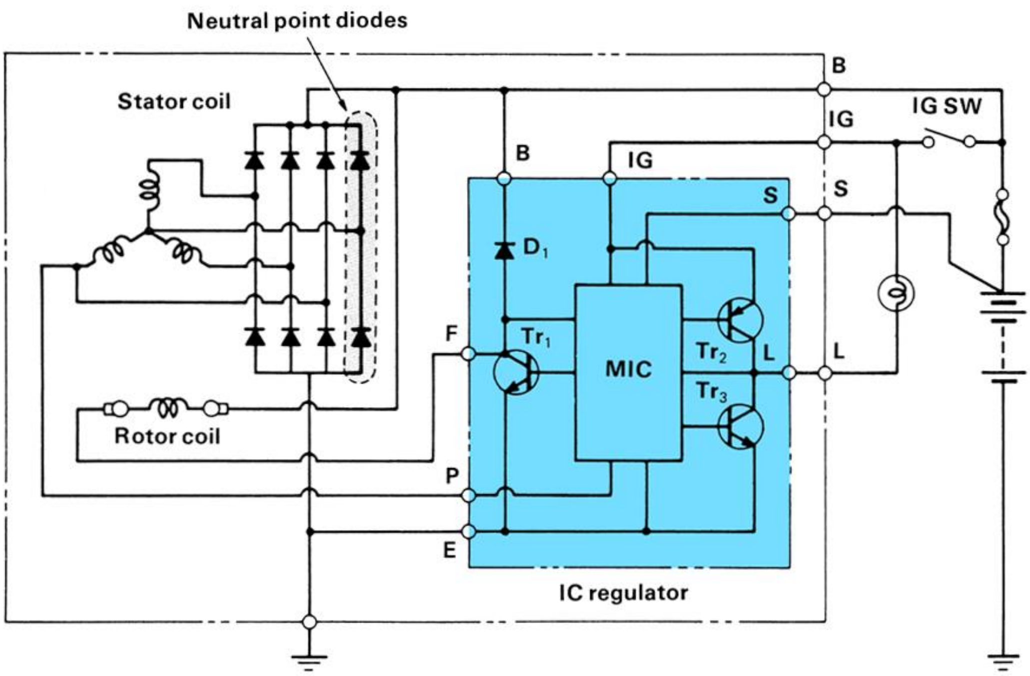


PRINCIPLE OF IC REGULATOR (1)



The diagram above shows the circuitry of a simple IC (integrated circuit) regulator. The IC regulator is solid state i.e. it has no moving parts. It consists of two NPN transistors, two resistors and a zener diode. It can be seen from the circuit that the battery positive post is connected to the rotor coil and this coil is grounded via Tr1 (which is conductive between the collector and the emitter terminals because of battery voltage being applied to the base terminal of that transistor). Therefore, battery current is able to 'excite' the coil into producing magnetic flux. When the engine starts, the rotor coil turns and current is generated in the stator coil. Once the zener diodes threshold voltage is reached, it begins to reverse conduct, applying a voltage to the base of Tr2. This switches on Tr2, diverting Tr1 base voltage to ground. Tr1 becomes open circuit depriving the rotor coil circuitry of a ground. The magnetism generated by the rotor coil reduces, the stator output reduces to the point where the zener diode no longer reverse conducts and Tr1 switches back on again. The alternator charges again. The zener threshold voltage dictates the continuing cyclic nature of this process.

Monolithic integrated circuit regulator



The diagram above shows a far more advanced version of an IC regulator and this is commonly used on modern motor vehicles. The MIC is effectively an ECM (electronic control module). All ECM's react to signals (normally voltages) and make decisions based on these received signals. These decisions result in an action of some description being carried out. It can be seen that the MIC is integrated with the alternator and the external vehicle circuits are connected to the alternator at four terminals:

B – Battery positive post

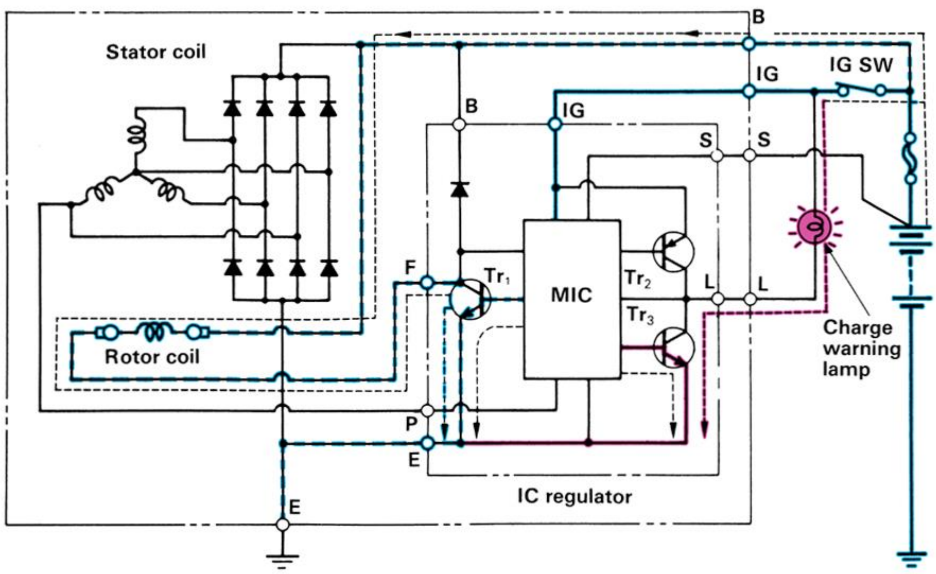
IG – Ignition Switch

S – Battery positive post (voltage Sensing)

L – Charge warning Lamp

Again, the rotor coil is connected directly to the positive post of the battery. The rotor coil ground is controlled by an NPN transistor (Tr1) providing a route to the **E** terminal (**E**arth). The MIC controls the application of base voltage to this transistor (Tr1) and is therefore able to regulate the amount of current that flows through the rotor coil (and therefore control the charging voltage) directly.

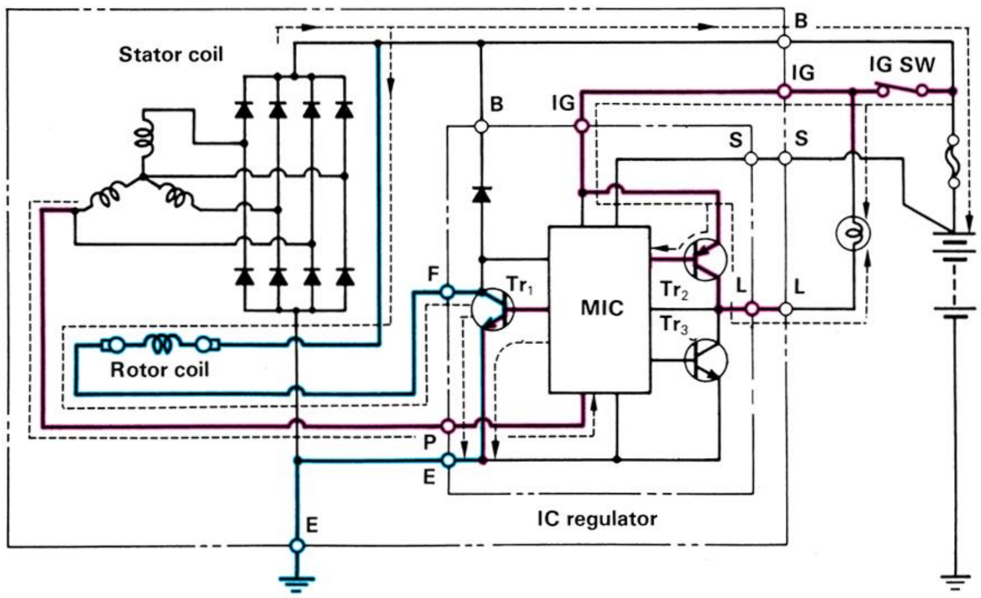
Ignition on, engine not running



In this condition, two things have to be achieved – the MIC has to ensure that controlled current is able to flow through the rotor coil in order to 'excite' the rotor (produce magnetic flux). Also, the charge-warning lamp has to be illuminated to act as a lamp check facility.

The MIC achieves these two objectives by switching voltage to the base of Tr1 (on and off very rapidly) to allow a limited amount of current to flow through the rotor coil (too much and the rotor will overheat and the battery is at risk of flattening). At the same time, it applies a base voltage to Tr3 that allows current to flow via the ignition switch and the charge-warning lamp to ground via the E terminal. The charge-warning lamp illuminates. The MIC knows that the driver has turned the ignition switch on by monitoring the voltage at the IG terminal. It also knows that the alternator is not charging through the detected voltage at the **P** terminal that is connected directly to the **p**hases. It should be noted that the method employed to regulate current flow through the rotor coil by switching Tr1 on and off rapidly is known as 'duty cycle' and is a commonly used method for creating a progressive action using digital components (on and off are the only options).

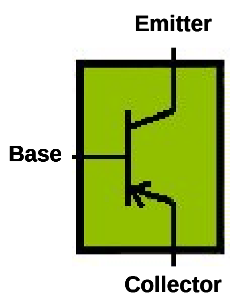
Engine running, charge voltage less than target



The diagram above shows a condition where the engine is running and the alternator is charging but producing insufficient output. It can be seen that the charge warning light has been extinguished. This has been achieved in the following way:

The voltage at the **P** terminal (**P**hases) indicates that the alternator is charging. The MIC takes the base voltage away from Tr3 and grounds the base terminal of Tr2. This transistor is a PNP transistor that becomes conductive under these circumstances. Switching Tr2 on ensures that ignition switch voltage (battery) is applied to both sides of the charge-warning lamp, and with no potential difference across the lamp, no current flows through it and it goes out.

PNP



The MIC changes the way in which it switches Tr1 (it leaves it switched on for longer than it is switched off) to ensure that there is an increase in current flow through the rotor coil. Output voltage from the alternator increases.

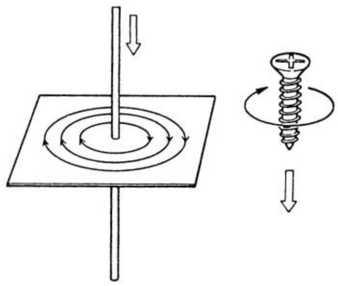
Target voltage reached

When the MIC detects that the target charging voltage has been reached (by monitoring battery positive voltage via the **S**ense terminal), it controls the switching of Tr1 to ensure that this voltage is very closely regulated regardless of any change in vehicle current demand or engine speed. It does this by continuing to monitor battery charge voltage via the **S**ense terminal.

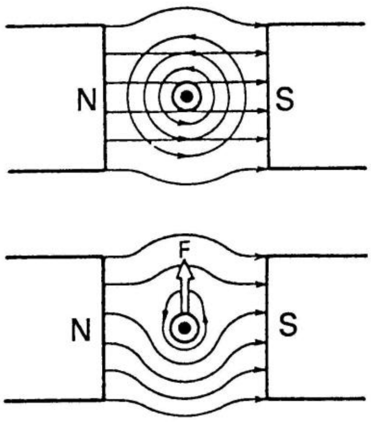
Starting systems

The purpose of the starter motor and related circuitry is to convert the electrical energy stored in the battery (put there by the alternator) into mechanical energy in order to rotate the engine to allow it to be started. An electric motor is virtually a mirror image of an alternator i.e. a conductor is suspended in a magnetic field, current is passed through this conductor and the interaction between the subsequent magnetic fields creates movement (as opposed to the mechanical movement of a conductor in the magnetic field generating current flow in the conductor).

The principal of the motor



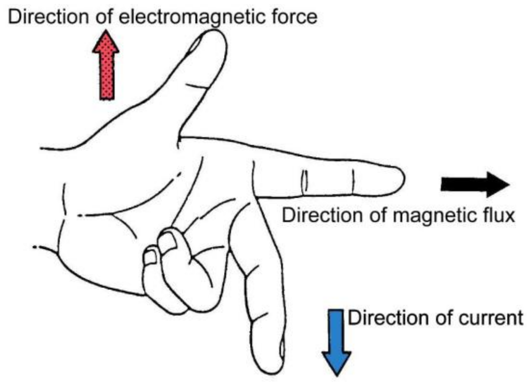
When a current flows in a conductor, a magnetic field is generated around it. This magnetic field rotates around the centreline of the conductor. Ampere's rule of right hand screw is a useful way to remember the direction in which this rotation occurs. If you imagine you are screwing a screw into a wall, you would rotate it clockwise. The screw is moving away from you (the current is moving away from you) and the screw is rotating clockwise (the magnetic flux rotates clockwise). If you now imagine that someone is screwing a screw through the wall from the other side i.e. it is coming through the wall towards you, the screw would appear to be rotating anti-clockwise to you – so if the current is flowing towards you, the magnetic flux rotates anti-clockwise. This principal is most important if an understanding of electric motors is to be achieved.



The diagram sown to the right shows such a conductor placed in a magnetic field. Look at the way in which the magnetic lines of flux generated by the magnet and those generated by the current flow in the conductor interact. Because the current is flowing towards you (point of the screw visible) the magnetic flux generated by the current flow is rotating anti clockwise. You can see that the arrows at the top of the conductor are going indifferent directions; therefore, they are acting against each other and tend to generate weaker overall field strength above the conductor. The arrows underneath the conductor are going in the same direction and therefore generate a stronger overall magnetic field beneath the conductor. Weak above, strong below, the conductor moves up.

Fleming's left hand rule

Fleming's left hand rule is a good way to calculate the direction of movement that underlies the principal of the electric motor.

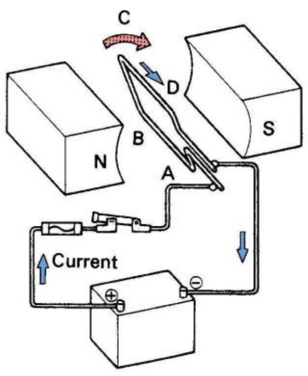


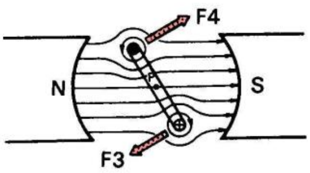
The need for a commutator

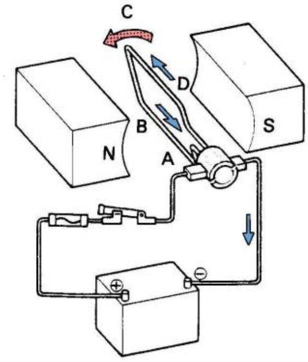
The more conductors that you have in the magnetic field, the greater the turning torque generated.

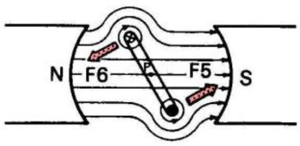
Both diagrams show a looped conductor being used. But we have a problem – as the loop passes through the 12 / 6 o'clock position the interaction between the magnetic fields effectively reverses and the loop starts to rotate the other way!

Try applying Fleming's left hand rule and prove this for yourself.

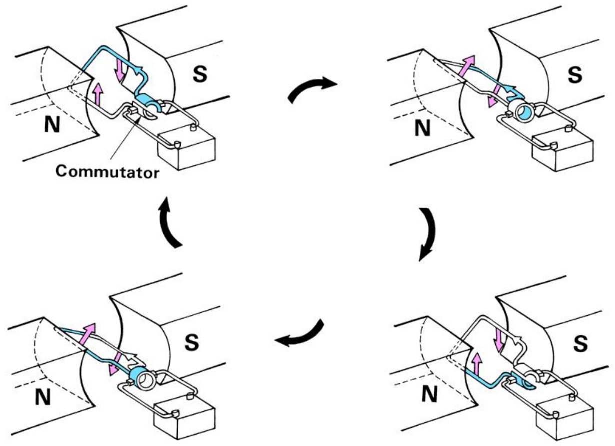






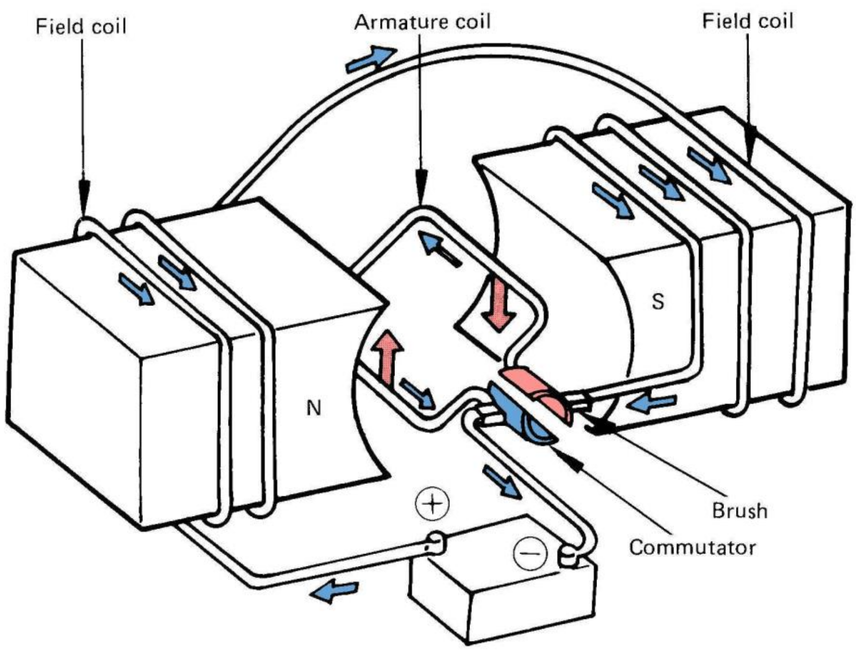


A commutator is a device that reverses the current flow through the looped conductor as it passes through the 12 / 6 o'clock position. This has the effect of continued single direction rotation (we could have reversed the poles of the magnets to achieve the same thing, but this is harder to achieve from an engineering aspect). When you think of a commutator, think of a commuter – they go to work in one direction and come home in the opposite direction – a commutator reverses the flow of current.

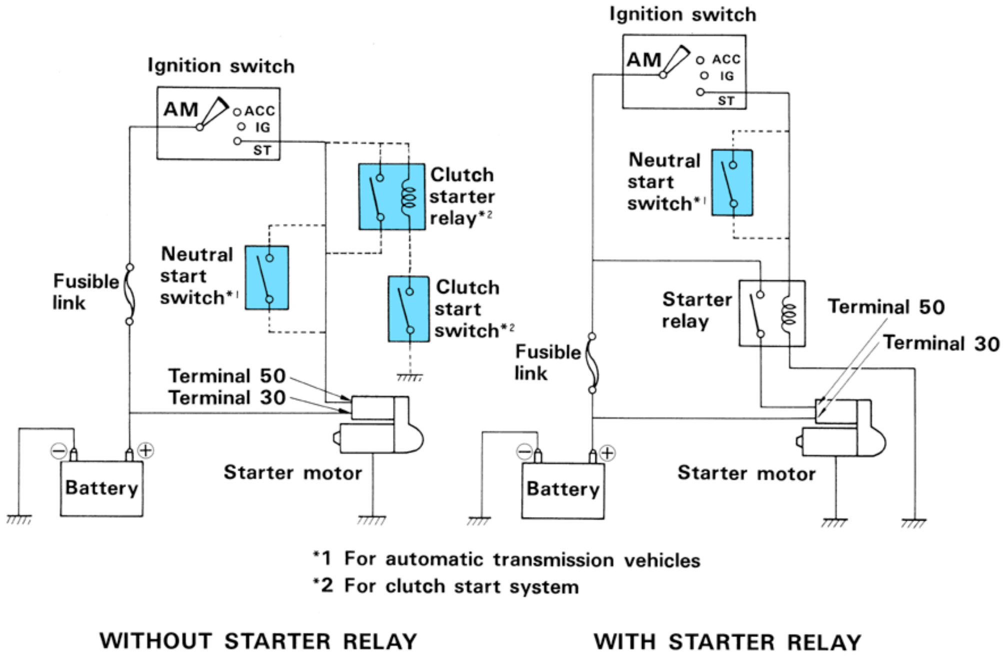


A series wound D.C motor

Like an alternator, a permanent magnet just isn't good enough – we do of course use an electro-magnet. This can be seen clearly below. If you follow the wiring through from the positive post of the battery to the negative post you will see that the field coils (the electro magnet) are wound in series with the armature coil (the rotating conductor). This arrangement generates a large amount of torque comparatively.



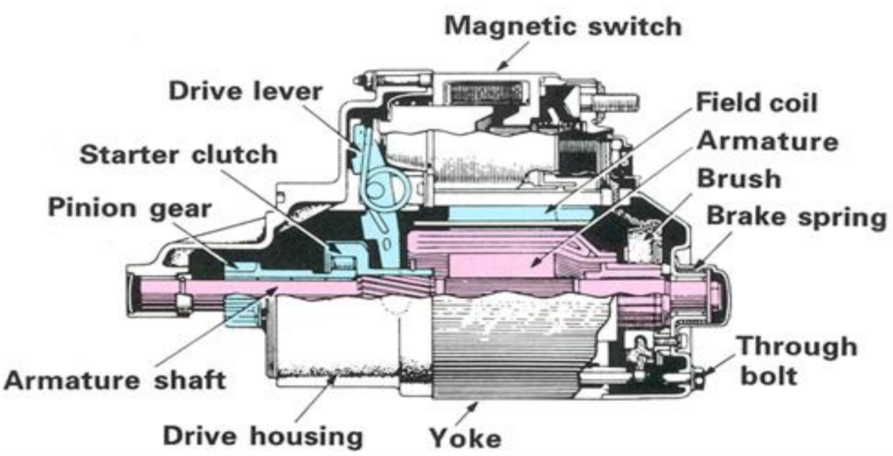
The starter circuit



Two different types of starter circuit can be seen in the diagram above.
In both instances it can be seen that terminal 30 is a permanent battery supply (the heavy duty cable). It is through this cable and terminal that the actual current flows that turns the motor to turn the engine over. This can be hundreds of amps, hence the thickness of the cable.

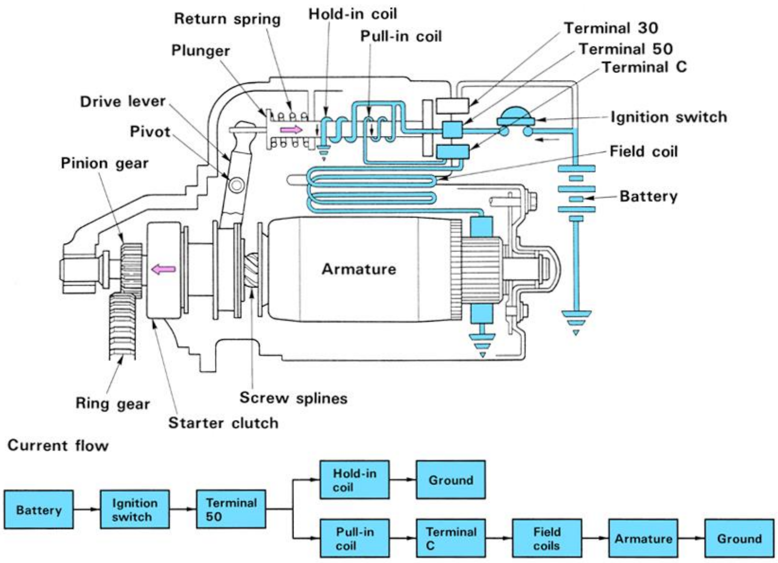
Terminal 50 in both instances is the solenoid (magnetic switch) supply. The solenoid (a device designed to create movement from electricity – normally linear) engages the pinion gear of the starter motor with the ring gear on the engine flywheel in order to turn the engine. Terminal 50 is normally supplied via a starter relay that in turn is controlled by the ignition / starter switch. The circuit on the left uses a starter relay in a similar way, but the ground of the relay winding is only available if the driver has fully depressed the clutch pedal. This is a safety feature designed to prevent the vehicle from being cranked with the vehicle in gear, clutch engaged.

Basic outline



When the driver turns the key to the crank position, current flows to the solenoid (magnetic switch) and this moves to engage the pinion with the ring gear. Once the pinion is fully engaged, a very high current can flow via the solenoid (magnetic switch) to the motor itself in order to crank the engine.

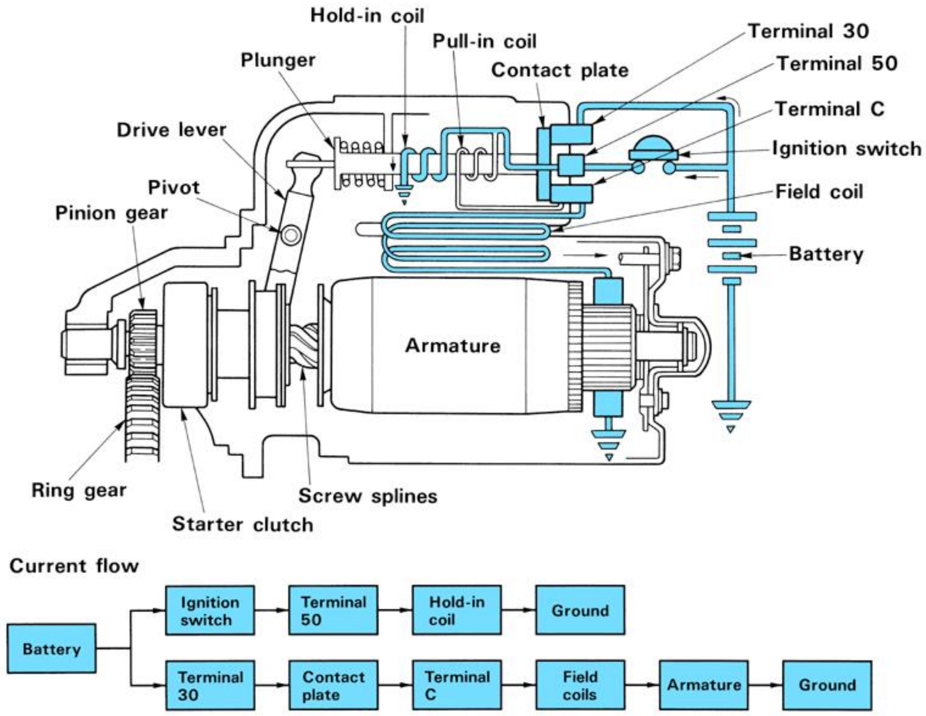
Ignition / starter switch in the crank position



Battery voltage is applied via the starter switch to terminal 50 of the starter motor. Therefore, battery voltage is applied to the pull-in coil and current flows through it to terminal C, through to the field coil and then via the commutator and brushes to the armature coil and down to ground (via the commutator and brushes again).
The hold-in coil also receives full battery voltage as it is parallel wound with the pull-in coil. The solenoid (magnetic switch) therefore generates a large amount of magnetism and the plunger of the solenoid moves to the right (as pictured) pivoting the drive lever to engage the pinion with the ring gear. Because the motor itself is receiving current it will be turning on engagement and this helps to achieve good positive meshing of the two gears (it is turning very slowly and with limited torque as it is only receiving current via the pull-in coil and this coil will cause volts drop).

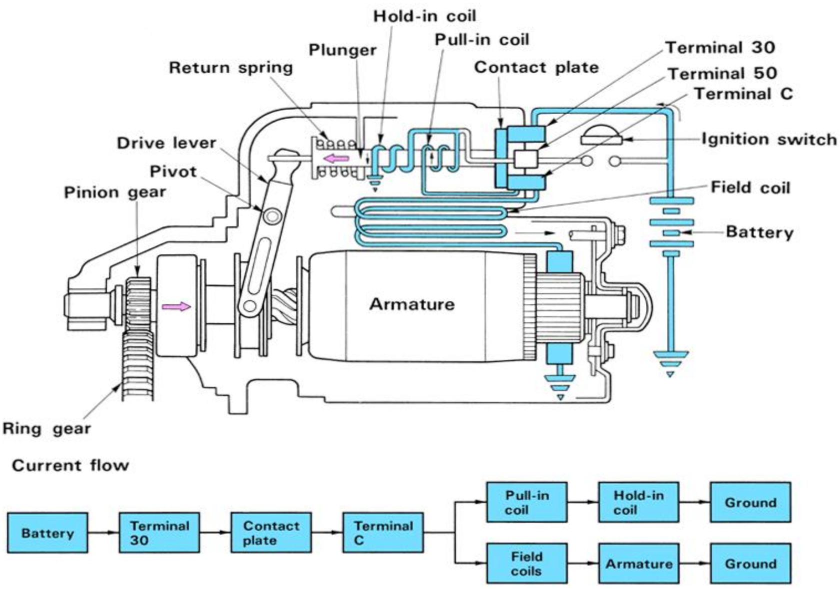
Pinion and ring gears engaged

As the plunger of the solenoid (magnetic switch) reaches a position fully to the right (as pictured) the contact plate on the plunger bridges terminal 30 and terminal C together. This allows a large amount of current to now flow from the battery via the heavy-duty cable to the field coil and armature coil (series wound) to provide sufficient torque to turn the engine. At this point, the battery is working very hard, so to help free up as much of the batteries capacity as possible for this event, the pull in coil uses no current and only the hold-in coil prevents the pinion from disengaging. This is achieved as there is no potential difference across the pull-in coil (battery voltage is applied to both ends – one end via terminal C and the other via terminal 50). Remember, it is harder to get something moving than it is to keep it there (once you have it where you want it) as moving something from a static condition requires you to overcome it's inertia and static friction – two coils to get it engaged, one coil to keep it engaged.



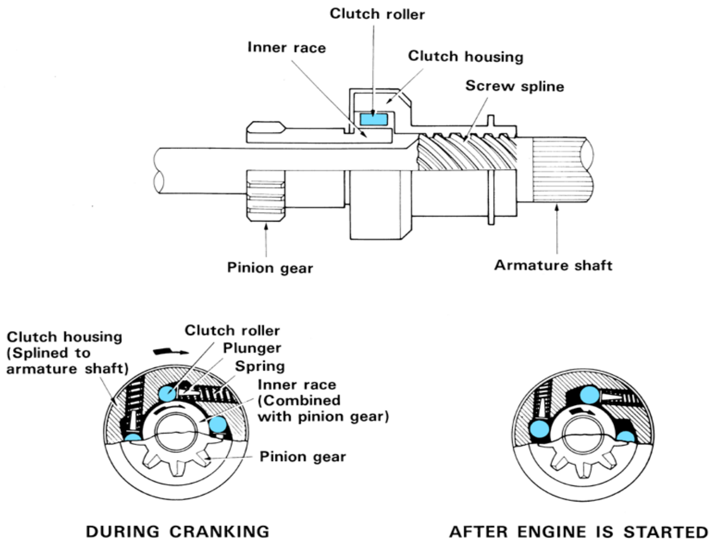
Starter switch released

When the engine starts, the driver will release the key (hopefully). When this happens, battery voltage is no longer applied to terminal 50. Current will now flow in reverse from terminal C through the pull-in coil and to ground via the hold-in coil. This reversal of current flow through the pull-in coil generates a magnetic force in the opposite direction, helping to create a fast, positive disengagement of the pinion gear. This helps to prevent serious over speeding of the armature through the engine turning the starter motor. The overdrive arrangement that this would represent would create huge armature speed even at engine idle, probably resulting in a destroyed starter motor.



Starter clutch

In the event that the driver does not release the key upon the engine firing, a unidirectional clutch is often incorporated into the armature shaft. This clutch (similar to a sprag clutch) allows the starter to drive the engine but not the engine to drive the starter. The tapered ball housings achieve this effect.



Electrical Wiring diagrams

Some technicians view wiring diagram as current flow diagrams, before understanding these diagrams it is essential that wiring colours are understood, below represents standard wiring colours.

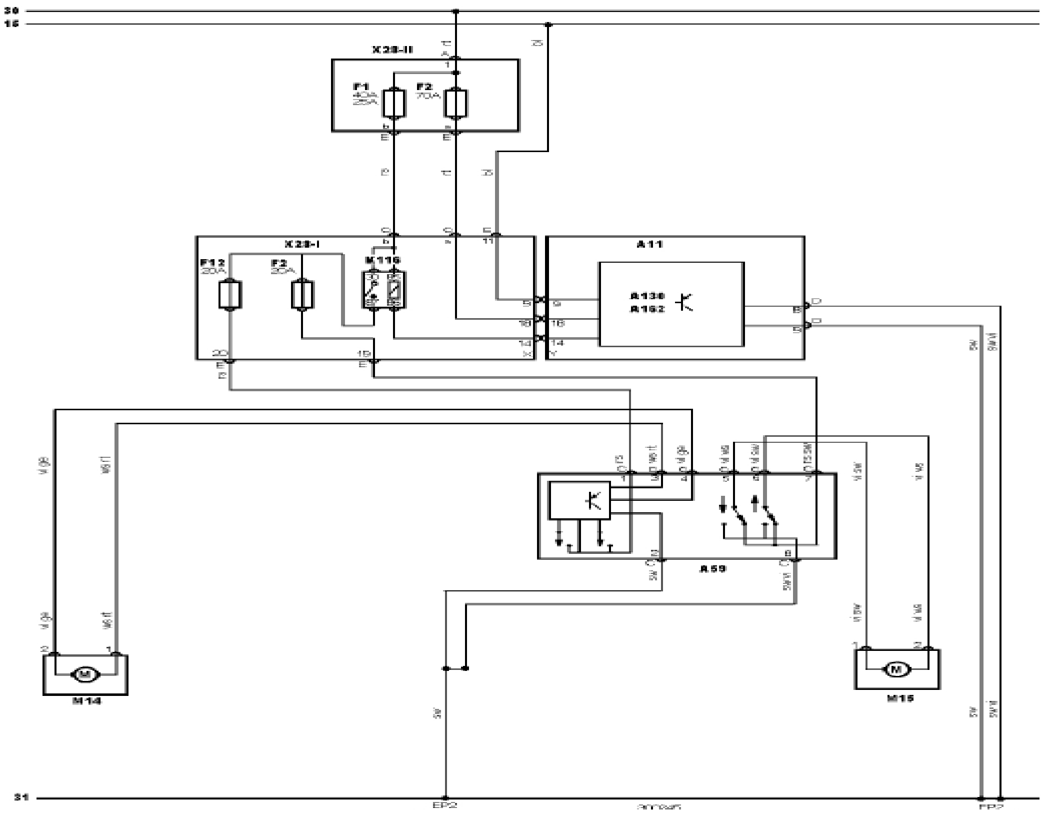
bl = blue	br = brown	el = cream	ge = yellow
gn = green	gr = grey	nf = neutral	og = orange
rs = pink	rt = red	sw = black	vi = violet
ws = white	hbl = light blue	hgn = light green	rbr = maroon
x = braided cable	y = high tension	z = non-cable connection	

In some cases, manufacturers mainly French (Peugeot, Citroen and Renault) Use numbers instead of letters, these numbers are usually located at each end of the wire by the connectors, the colour of the wires should be ignored.

The wiring diagram on the next page is an example, it is from a Fiat Punto 2004 model. All diagrams come with keys, this will help you identify components, again an example is shown on the next page.

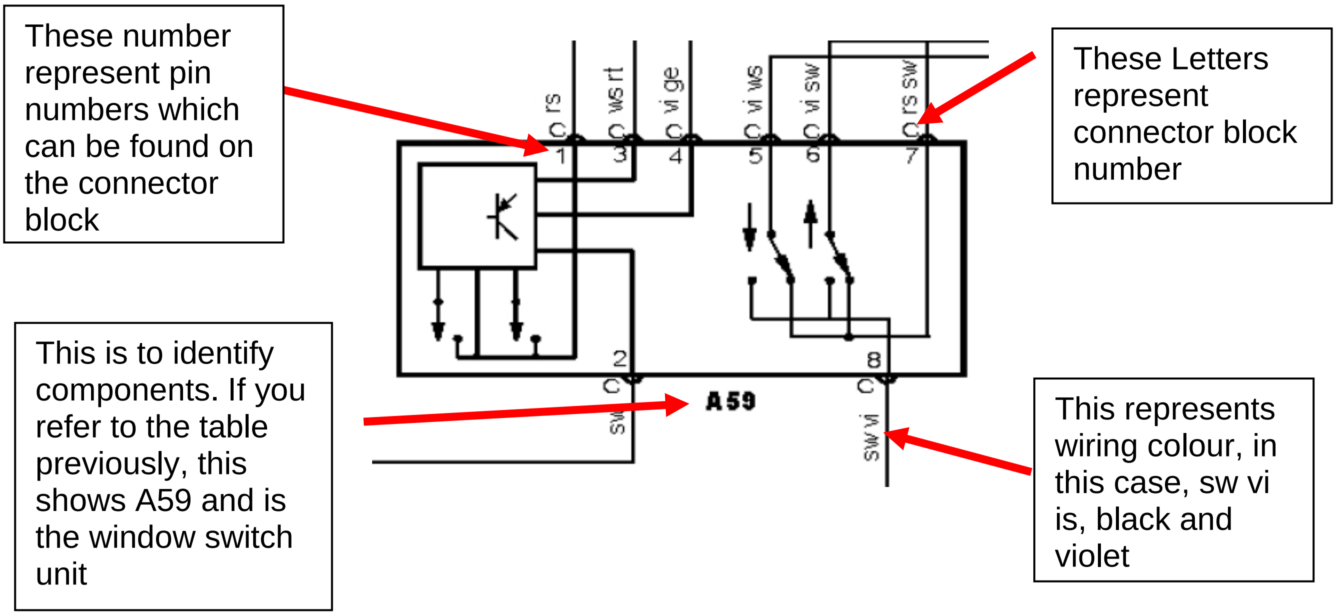
Taking time to study wiring diagrams before delving deep into full diagnosis will reduce wasting time stripping down other areas and testing.

With wiring diagrams identification of fuses, power supplies and earths can be identified



31	Battery -
30	Battery +
A130	Diagnostic module
EP2	Earth point 2
EP3	Earth point 3
K116	Electric window circuit relay
A59	Electric window console switch assembly
M14	Electric window motor, driver
M15	Electric window motor, passenger
F	Fuse
X28-II	Fuse box/relay plate - engine bay
X28-I	Fuse box/relay plate - fascia
Fs	Fuse satellite
15	Ignition switch - ignition ON
A162	Immobilizer control module
A11	Multifunction control module

The diagram below is extracted from the wiring diagram before and is labelled to help understand the numbers and letters that surrounds the components.



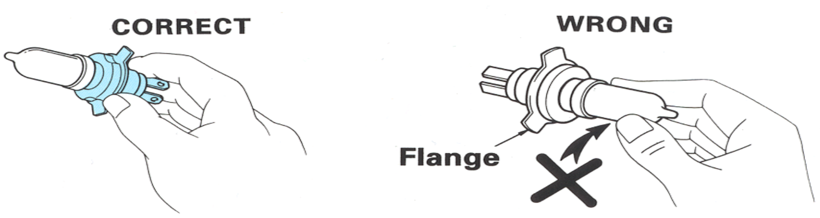
Exterior and Interior Bulbs

Bulbs Types

There are many different types of bulb in use on a modern motor vehicle. Generally, bulbs can be classified by their rating (wattage and voltage) and their fixing method i.e. how the bulb is mounted securely to the lamp assembly.
There are exceptions to this rule; certain bulbs have specialist applications such as halogen bulbs which are used exclusively for headlights.

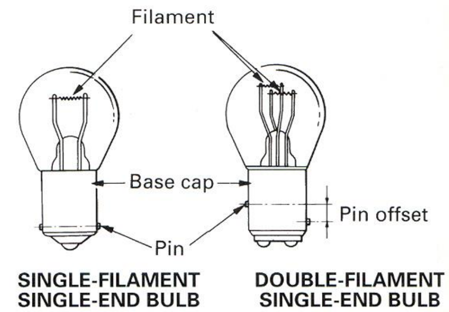
Semi-sealed type

Handling



The diagram above shows an ordinary headlight bulb and a quartz halogen type. It is most important that the glass portion of halogen bulbs is not touched, as moisture from the surface of the skin can cause localised cool areas on the glass when the bulb is operating and this can cause the bulb to break.

The diagram on the right shows a bayonet cap type design. It can be seen that the single filament bulb has bayonet pins that are on the same plane but the double filament bulb has offset pins. Offsetting the pins ensures that the internal circuitry of the bulb connects to the correct terminals of the wiring loom.

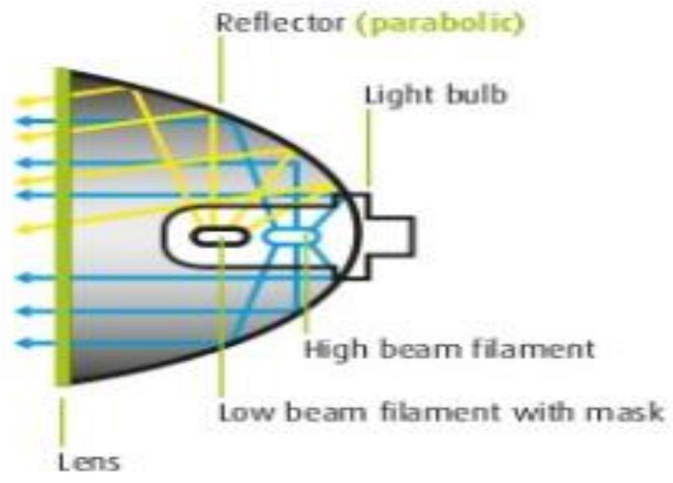


Bulbs are fitted to the socket by means of the pins located on the base cap.

Below are some variations in bulb design.

Reflective Headlamps

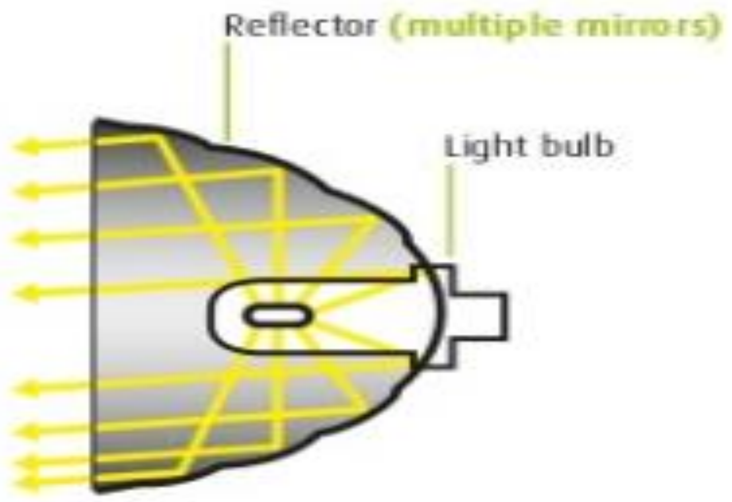
The objective of a headlamp reflector is to re-direct the beam pattern to required region in front of the vehicle. Over time there has been many modifications to the standard parabolic reflective lens demonstrated in the picture below. To avoid glare to on coming road users a shield was fitted to stop direct light rays striking the lower half of the reflector, so that the light beam reflected upwards. The light pattern that is seen on the road is achieved by patterns in the glass.



Parabolic reflectors were basically used in Europe with dual filament H4 lamps.

Complex Surface Type of reflector.

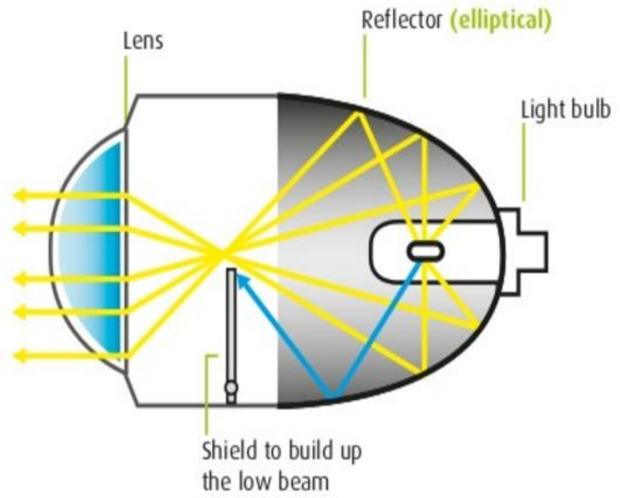
These type of reflectors, use multiple reflector technology to produce the correct pattern on the road. With this technology, any type of light source can be used such as LED They also offer a better headlight profile make them more streamline and a lot more efficient. They allowed all the light produced by the bulb to create a low beam. The technology also allows plastic lenses to be used. Low beams based on Xenon reflector-type lamps exist but must use a different type of bulb (R types) The cut of beam is achieved by using both complex surface reflectors and an opaque coating which is printed on the glass of the lamp.

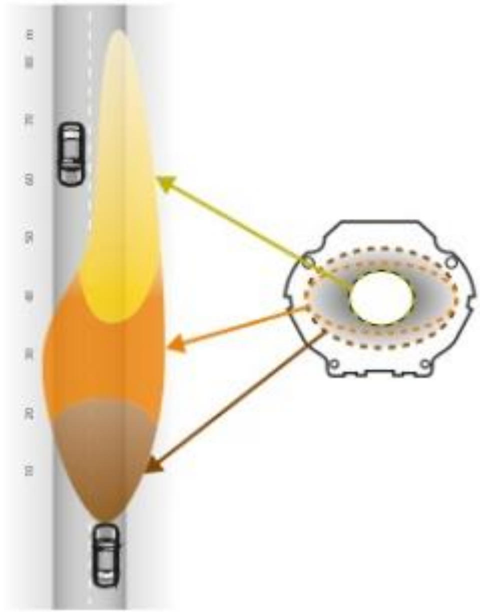


Elliptical-Type Optics

Around the light source there are several complex elliptical surfaces, the reflection of the rays in these elliptic zones gives the headlight the ability to extend the range and coverage (length and max intensity)

The parabolic zone is designed to produce the light in close range (width and near light)



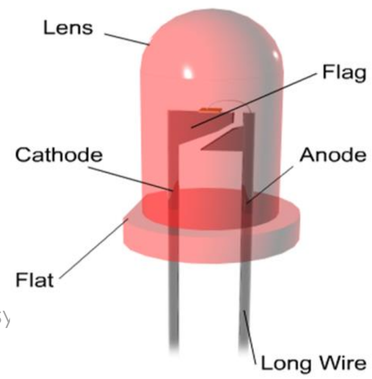


Light Emitting Diodes (LED)

A light-emitting diode (LED) is a special kind of diode that glows when electricity passes through it. Most LEDs are made from a semi-conducting material called gallium arsenide phosphide.

LEDs can be bought in a range of colours. They can also be bought in forms that will switch between two colours (bi-colour), three colours (tri-colour) or emit infra-red light.
As of a normal diode, LEDs only show light when forward Bias.
The Semiconductor material for an LED is encapsulated in a plastic case which also helps to colour the emitted light.

LEDs has two connections – anode +ve and cathode -ve.



The cathode is identified by a flat edge in the base of the LED and the connection wire for the anode is generally the longer wire.

There are many advantages of a LED and the table below demonstrates this.

	LEDs	Bulbs
Consumption	4 W	21 W
Depth (x-direction)	50 mm	150 mm
Operating temperature	50°C	100°C
Lifetime	20.000 h	1.000 h
Reliability	No service intervention requiered	15 bulb replacements necessary
Switch-on-time	1 ms	200 ms

In recent years LEDs have been become more and more noticeable in headlights and rear taillights. First applications of LED technology go back to the first half of the nineties with the development of central high mounted stop lamps with LEDs in 5 mm package for the Japanese market. In the meantime, all functions can be equipped with LEDs. These functions are tail light, fog light, turn indicator, break light and back up light.

Day Time Running Lights. (DRL)

European Union Directive 2008/89/EC made it mandatory that all new vehicles that were manufactured on or after February 2011 were fitted with DRL to improve safety and visibility on the road, first productions saw the use sidelights, then manufacturers decided that LEDs were more efficient.

Daytime running lights (DRLs) are designed to make your vehicle more visible in bright, daytime conditions. They should come on automatically when you start your engine

They should be bright enough to be seen clearly in daylight, DRLs are too bright to be used at night when they would cause dazzle.

They go off automatically when you switch your headlights on.

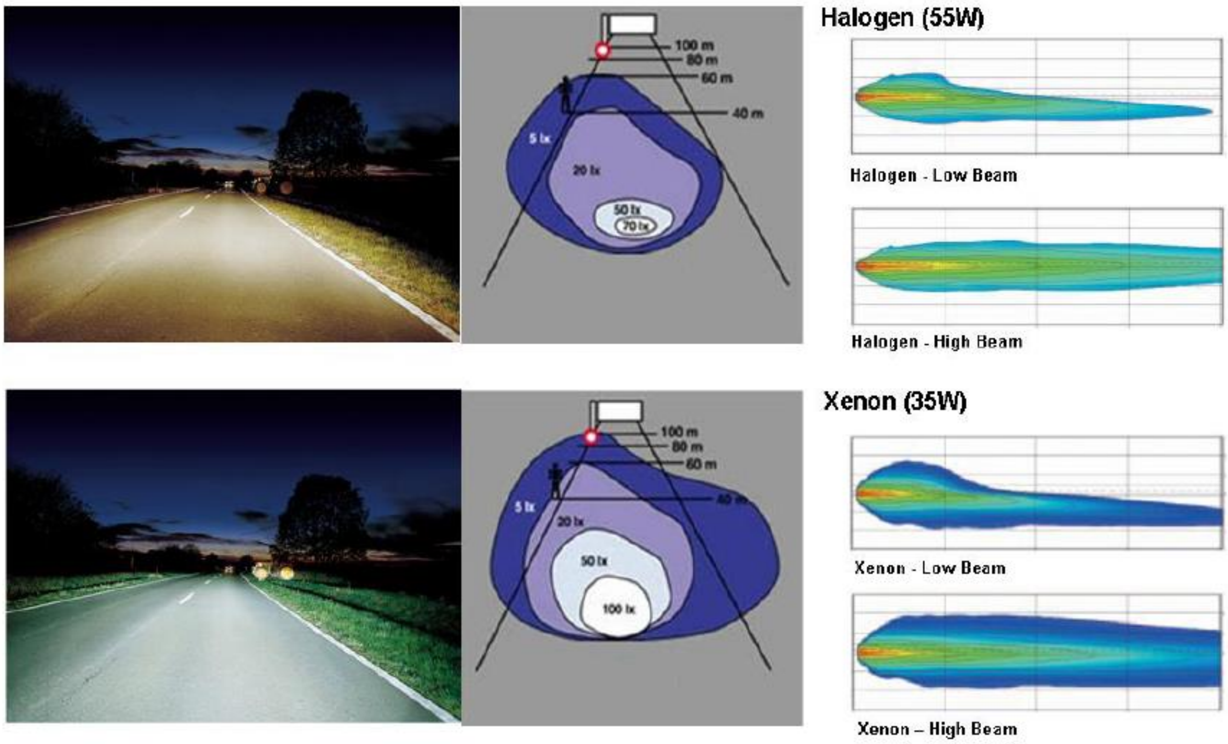
They don't have to be separate lights and are sometimes combined with the front position lamps (side lights). If this is the case, the DRLs dim when the headlights are turned on.

If your daytime running lights are very close to your indicators, the DRL will turn off while the adjacent indicator flashes

Headlights

Headlamps provide light in the traffic area in front of the vehicle. It is necessary for them to satisfy the requirements of all users. The dipped beam functions in particular are subject to legal regulations to protect oncoming traffic from being irritating glare. Xenon systems still offer the best light available in terms of quality and quantity. Optimum light distribution in all driving conditions is ensured by auxiliary systems required by law. Xenon technology is currently the most advanced development in the field of motor vehicle headlamp systems. Xenon has two decisive advantages over the light of conventional light-bulbs: A xenon light source delivers twice the light output of a modern H7 bulb while consuming only 2/3 of the energy. The improved light output makes the road brighter and illuminates a wider area, the daylight-like quality of the xenon light is welcomed by the human eye. Drivers get tired slower and driving becomes more relaxed. This means an enormous gain in safety and driving comfort. In comparison to halogen lamps, Xenon lamps offer the following advantages:

- Nearly 3 times the luminous flux (light quantity/light output)
- High light efficiency (photometric efficiency)
- Significantly lower electrical power consumption – only 35W
- Lower thermal system stress
- Significantly longer service life
- Light color almost equivalent to daylight

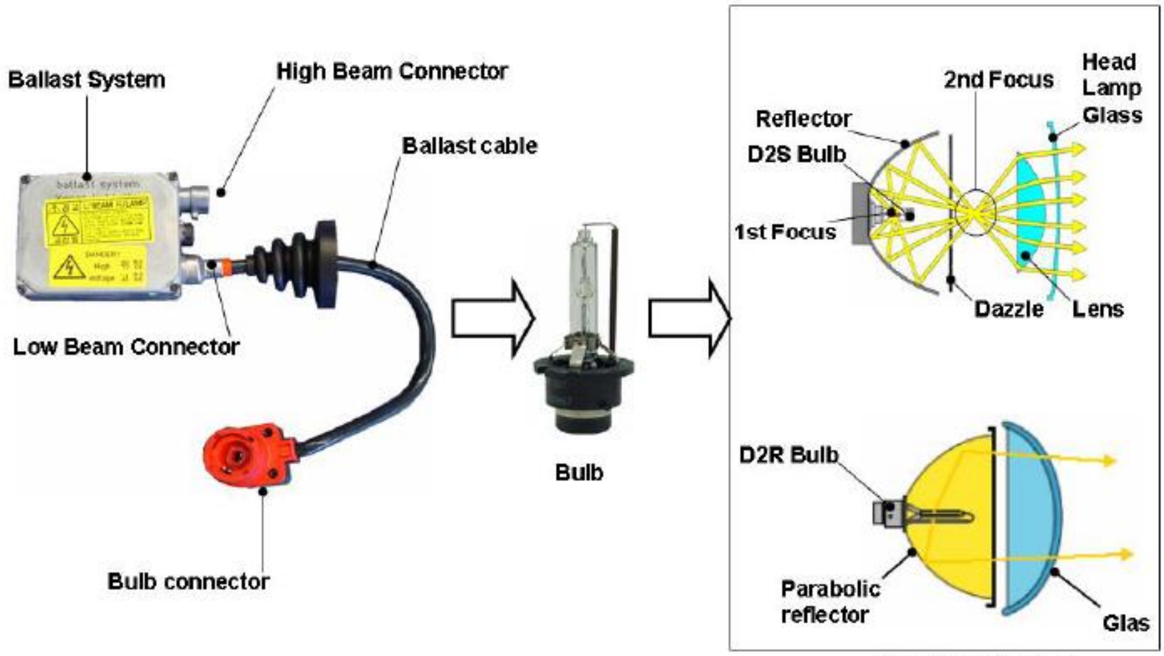


Depending on the model the Xenon technology can be applied only to the low beam. In these cases High beam is established by a H1 bulb (55W).
Depending on the country the use of an Automatic Headlamp Levelling System (AHLS) may be mandatory (example, Europe)!

Safety precautions

- D2 type bulbs operate with great pressure probably near or over 30 atmospheres
- The internal quartz arc tube temperature is typically around 800 C° (1400-1500F°)
- Bulbs should only be operated inside the headlamp housing since there is a risk of explosion
- Improper operation increases the risk of bulb explosion
- The bulb must be clean and free of dirt, grease, organic matter, ash, salt, or alkali. Contaminations will result in strains, weak spots, and maybe cracks.

System Layout



Headlamp System

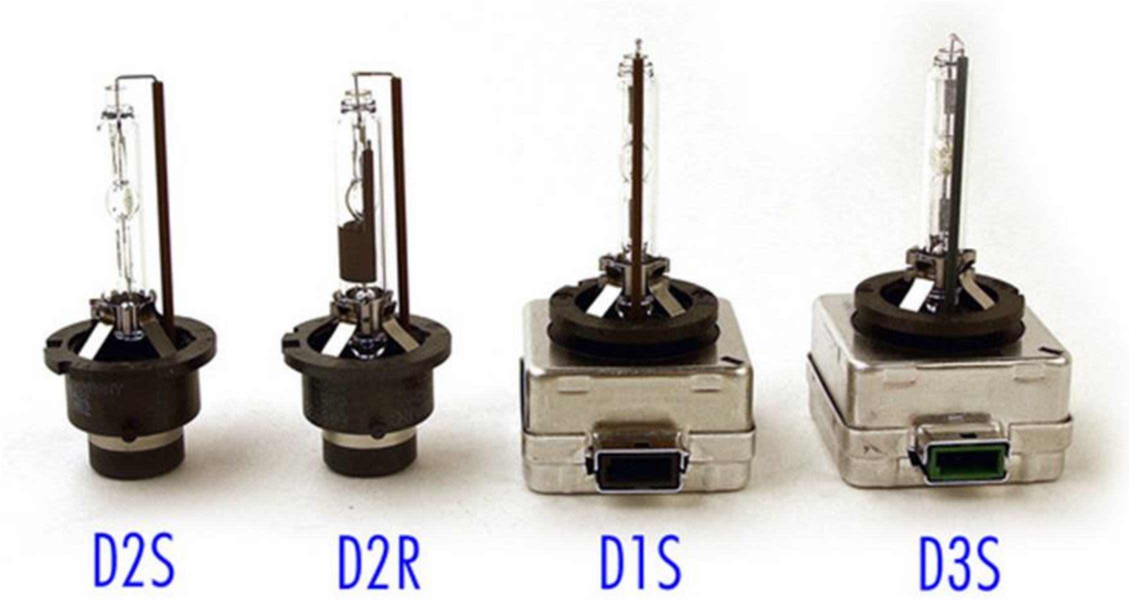
The main components of the HID System are the ballast system, the bulb (D2S or D2R) and the headlamp (projection or reflection type)

Projection type systems

In such systems, the reflector uses a free form instead of regular geometry. It collects the light produced by the light source in the vicinity of a primary focal plane. The light is projected into a secondary focal plain containing a shield. The contour of the shield is projected on to the road by a lens.

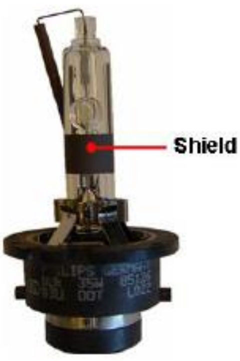
Reflection type systems

The reflector surface is designed to provide the required light output and distribution. Most reflectors are typically manufactured of heat resistant plastic materials. The reflector surface is metaled to achieve the necessary reflectivity. The bulb shield is mounted inside the reflector and prevents unwanted light (glare light) to exit the headlamp.
Both, the projection as well as the reflection type headlamps can be so called Free Form (FF) Headlamps. FF headlamps have reflector surfaces with a free spatial form. They can only be calculated and optimized with the aid of computers. Different calculations strategies are used for laying out the reflector surfaces. Nearly all modern reflection type headlamp systems for dipped beam are equipped with FF reflectors.



The four types of Xenon bulbs currently on the market are:

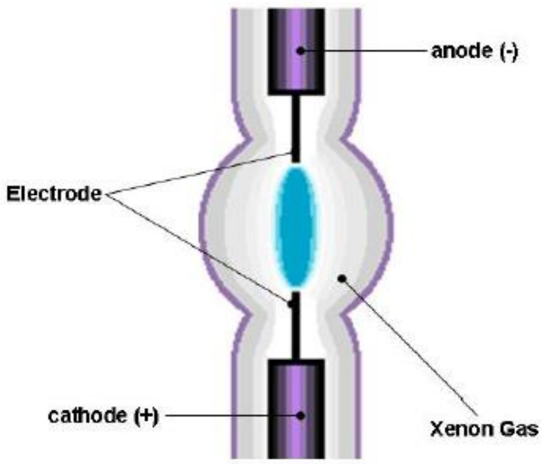
- D2S- Use in projector type systems
- D2R- Use in reflector systems (Shielding paint on glass tube)
- D1S- Use in projector type systems (Integrated ignition unit)
- D1R- Use in reflection type systems (Ignition unit integrated/shielding pain on glass tube)



D2R Bulb

D2S bulb

> ***Note:***
> The manufacturer of both left and right side should be the same for example both OSRAM or Philips.

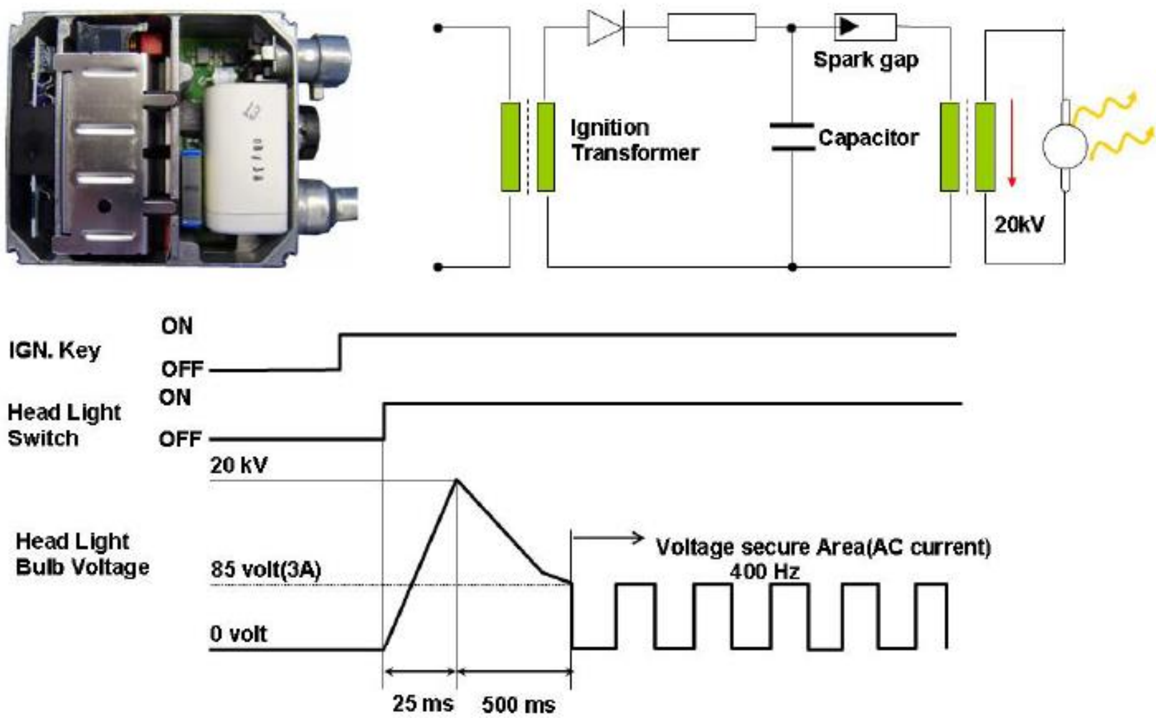


The D2R bulb is used in reflector systems only, a shielding is painted on to the bottom of the glass tube against glare. The D2S bulb is used in projection type headlamp systems only. A Xenon bulb has an operating life of approximately 2500hours and produces approximately 2800 lumens of light. The lamp consists of a tubular outer bulb approx. 10 mm (.4 inch) in diameter which contains the arc tube (inner bulb). The outer bulb is made of special quartz such as cerium-doped quartz which blocks most ultraviolet, especially the more dangerous short and medium wavelengths as well as much of the 365-366 nm long wave mercury line cluster. The arc tube or inner bulb is made of plain fused quartz and has tungsten electrodes with the distance between the tips approx. 4.2- 5millimeters (approx. or slightly under .2 inch).

Constituents of bulb gas

The arc tube has xenon gas in it at a couple of atmospheres. There is also mercury in the bulb and when it is vaporized the mercury adds at least 20 atmospheres of pressure for a total pressure of around 30 atmospheres. Metal halides - salts - are also in the arc tube.
The formulation in automotive HID lamps includes sodium and scandium halides and maybe traces of others such as lithium and thallium halides.
The high pressure xenon is used to obtain some usable light output during warm-up before the other ingredients have vaporized.

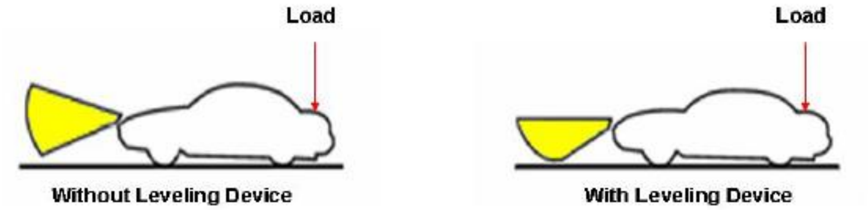
The ballast system



The Xenon lamps are gas discharge lamps which use an electric arc instead of filament as with a halogen bulb. The arc is ignited and then maintained between two exactly positioned electrodes. The electronic ballast unit is required for this process. The D2 types require a starting pulse. 7 kilovolts may on an average spark through these bulbs, but for reliability between 10 or 12 kilovolts are required. Automotive use requires ability to restart a hot bulb with the mercury vapour pressure high, and this requires even more voltage - 12 to 15 kilovolts and maybe even more for good reliability. The usual ballasts supposedly produce starting pulse voltages like 18 kilovolts minimum, 20 kilovolts typical. Once the arc is established, the ballast must supply limited current or else the arc will draw extreme current and this will be bad for the bulb and/or other parts. The voltage across the lamp is normally around 80-90 volts when it is warmed up, but will be less during warm up. The ballast must handle a lamp voltage possibly as low as 16 volts early in warm up, although this voltage usually bottoms out higher, at least in the 20's of volts. The ballast must deliver 35 watts to the lamp when the voltage across the lamp is between 70 and 110 volts. When this voltage is lower, the ballast must deliver at least 0.5 amp but generally no more than 2 amps and preferably as close to 35 watts as possible. Higher currents are preferred - a partially warmed up metal halide lamp sometimes has an unstable arc at lower current. An automotive grade ballast often delivers boosted power (above 35 watts) at some times during warm up to give near-full light output. Note that a xenon arc or a mercury vapour arc does not produce visible light as efficiently as a metal halide arc does. Automotive grade ballasts with boosted power at some points of warm up have circuitry that models the thermal characteristics of the bulb.

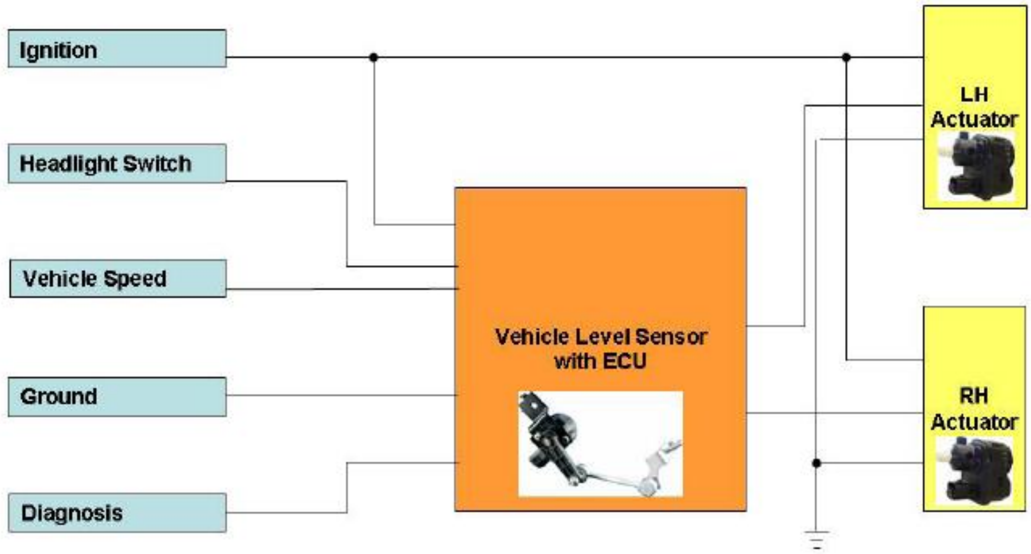
The maximum safe current for the bulb's electrodes must not be exceeded during a power boost during warm up. A voltage across the bulb higher than 110 volts only occurs in the early stage of establishing the arc or if the bulb is failing. The ballast should deliver enough power to heat up the electrode tips enough for the arc to establish - more is better and over 35 watts is OK as long as the current is not excessive. But excessive power delivered to an aging bulb can cause the bulb to explode. D2 lamps and most other metal halide lamps require AC. DC is tolerable briefly, and then preferably only if the bulb is cold. A DC electric field, hot quartz or hot glass, and salts or alkalis is not a good combination - electrolysis effects can occur which can create weak spots or cracks in the arc tube. The AC delivered to a D2 type bulb usually has a frequency of a couple hundred to a few hundred Hz. The AC current waveform in a D2 type lamp is traditionally a square wave or close to a square wave. The high-voltage pulse required to ignite the lamp is usually generated by an ignition circuit consisting of an ignition transformer, a capacitor and a switching spark gap (SSG) which is then superimposed onto the lamp's operating voltage. In view of the initial ignition value of the SSG, the open-circuit voltage of the circuit is typically selected to exceed the SSG's nominal voltage by 30 % and must be regarded as the maximum charging voltage of the capacitor. The energy of the voltage pulse must be sufficiently high to ignite the lamp at the first attempt - as far as possible - even though the properties of the lamp and SSG vary with temperature and aging. The energy of between 20 and 50 mJ stored in the capacitor is usually sufficient to ensure ignition. Both, the capacitor and the switching spark gap must be designed to handle the broad range of automotive temperatures from -40 to +125 °C (often up to +150 °C) as well as the high vibration stress.

Auto levelling functions



Safe driving in the dark is only possible with headlamps which angles of inclination are always adjusted correctly. This is the only way to ensure that the road is illuminated optimally without dazzling oncoming traffic. With the manual headlamp levelling, common in vehicles today, the driver has the possibility of adjusting the headlamp inclination to the specific loading condition with a switch on the dashboard. The automatic headlamp levelling systems adjust the angle of inclination of the headlamps to the angle of the body without the driver's assistance. The so called static headlamp levelling system corrects the inclination resulting from changes in the load and condition.
The main components of the Automatic Headlamp Levelling System (AHLS) are:

- Levelling Sensor(s)
- Auto levelling actuators located in both of the front headlamps



Inputs of the Vehicle Level Sensor are Ignition, Headlight switch, Vehicle speed and ground. There are two operating conditions for the AHLS.

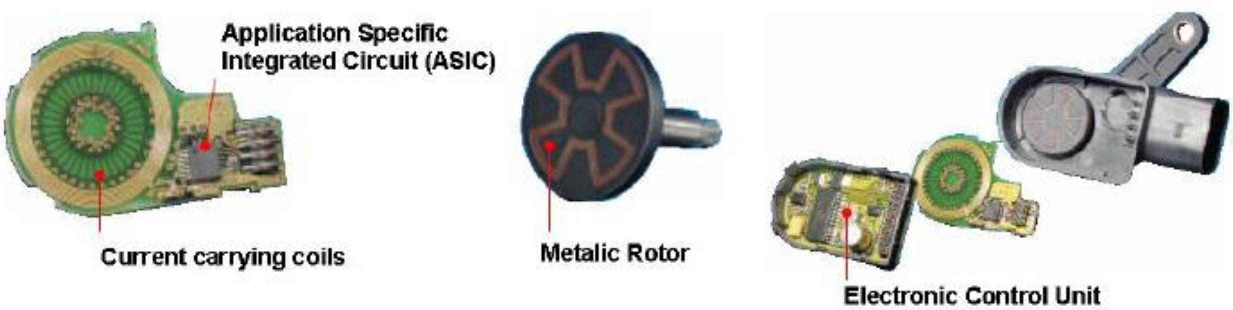
Condition 1:

Vehicle stationary, Ignition and Headlamp switch ON, AHLS adjust the Headlamps according to the load of the vehicle. If the angle changes more than 2°, adjustment of the Headlamps will be changed.

Condition 2:

While driving, Headlamp switch ON. The ECU receives a vehicle speed signal input.
If the vehicle speed is above 4km/h and the velocity change is not over 0.8-1.6km/h
Per second and loading condition is changed, then AHLS is operated. This strategy
is used to prevent headlamp adjustment under acceleration conditions.

Levelling System sensors



In the case of inductive level sensor there are several current carrying coils placed on a circuit board which produce an electro-magnetic field. A metallic rotor, connected to the sensor actuation lever, is moved above this circuit board, thereby influencing the electro-magnetic field. Other coils located on the circuit board receive a field depending on the lever position of the sensor and this field is evaluated by an Application Specific Integrated Circuit (ASIC) which has been especially developed for this purpose. The sensor allows different angle ranges to be measured. The inductive sensor provides an analogue output signal. The sensor operates fully independently of the temperature and obtains excellent accuracy.

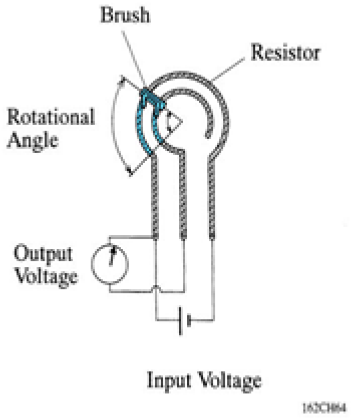
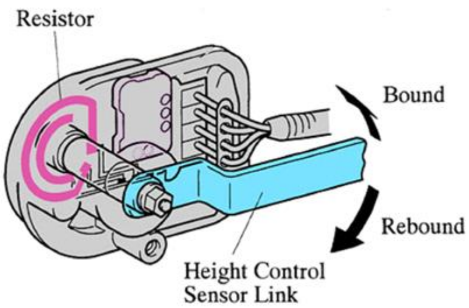
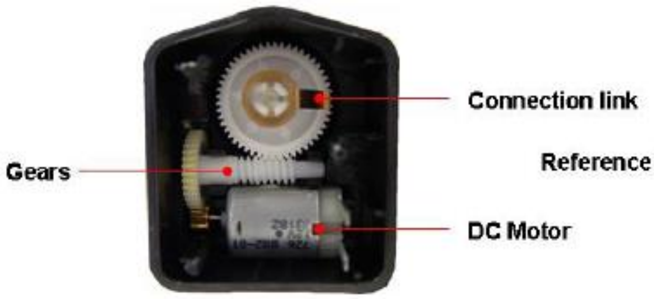


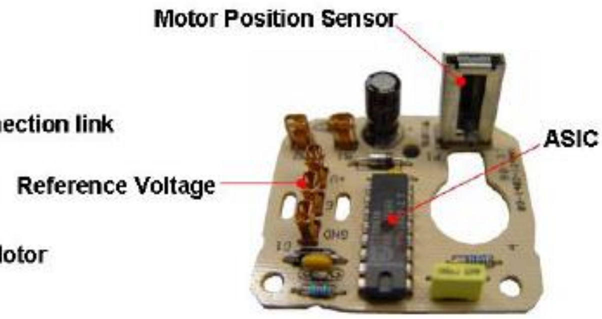
Diagram of the Principle



Front Side Height Control Sensor

Levelling system Actuators



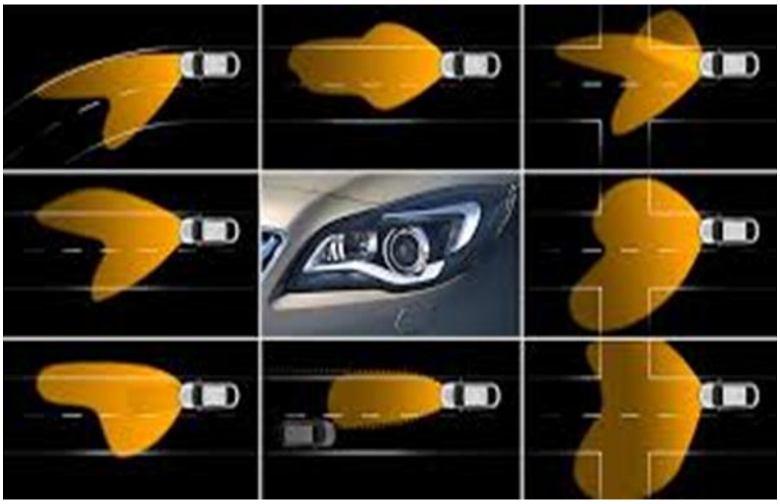


The Auto Light Levelling Actuator consists of a DC Motor, gears and a circuit board with an Application Specific Integrated Circuit. A connection link mounted on the output gear drives a position sensor, thus allowing the Auto Light Levelling Actuator to detect the actual motor position. A voltage signal is applied to reference terminal of the Auto Levelling

Actuator. This signal is send from the Inductive Level Sensor and varies depending on the vehicle load condition. Based on the reference input the Auto Levelling Actuator can adjust the headlamp position.

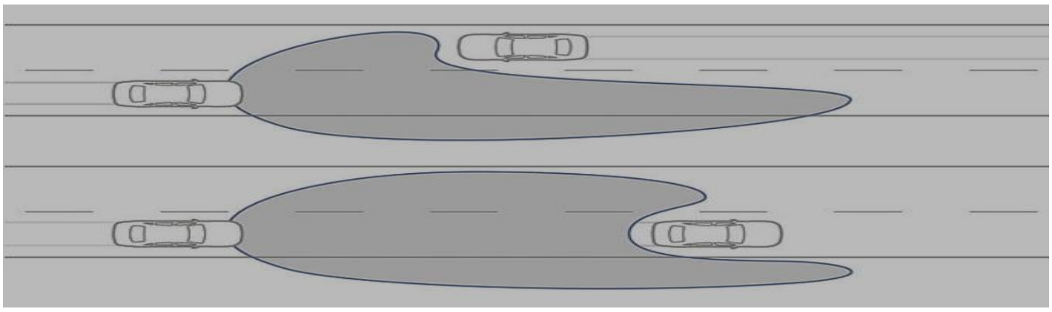
Intelligent Lighting Systems

When watching modern vehicles on the road Vehicles in recent years you would notice the front fog lights coming on, this was fitted to improve visibility when Sharpe turning, only one fog light would illuminate in the direction of turn.
Modern vehicle have an active cornering light function which provides a 90 percent improvement in road illumination, the headlamps adapt/move based on the lead angle, yaw rate and vehicle speed. At speeds of 90 km/h and above, the motorway mode switches on, increasing the driver's field of vision by up to 60 percent. The extended fog lamps improve the driver's orientation in poor visibility



A further highlight is the introduction of Adaptive High beam Assist system with LED technology, this uses a stereo camera (just like the face recognition with in your phone) to detect oncoming vehicles and vehicles ahead.

Information is used to control the headlamps in such a way that the detected vehicles are excluded from the main-beam light cone. This allows the main beams to remain on continuously without disturbing or endangering other road users.



Intelligent Rear Lighting.

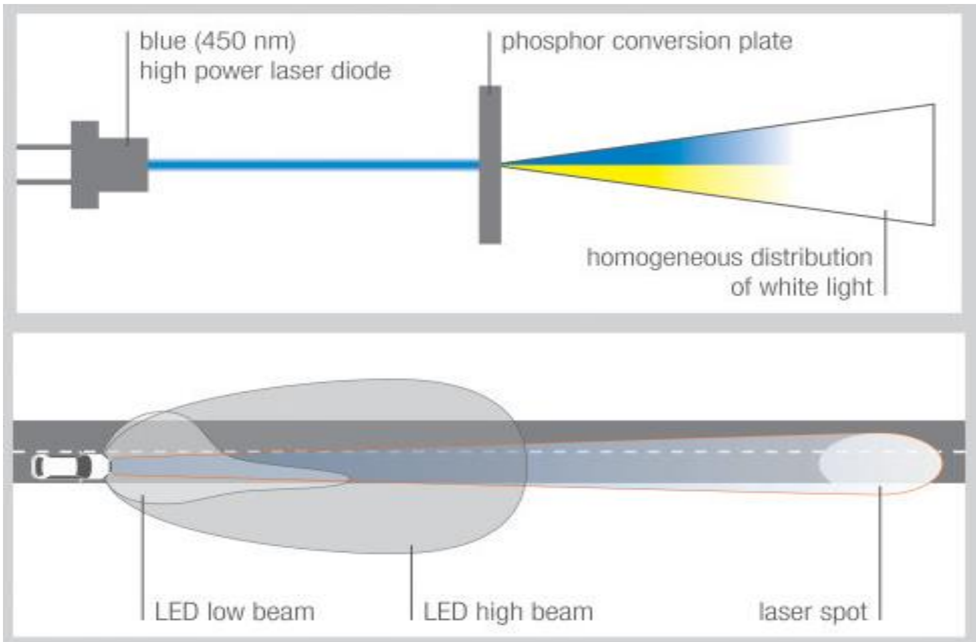
The characteristic design of the rear lamps is the first thing to catch the eye. The lights also require to be functional as well as there looks. It was noticed that in different light the rear lights shone to bright and dazzled drivers behind, this was felt a safety issue. Some modern cars overcame this by varying the light output of the rear lights.

The tail lights, indicators and brake lights varies depending on the day/night lighting conditions and speed. During daylight, it was felt that the rear tail lights would require full brightness of up to 100% but during night time driving it can be reduced to 80%. The same as the tail lights, the brake lights would be at 100% during day light and can be reduced even more of up to 60% at night. The indicators would also have this facility to reduce brightness.

Laser Headlights

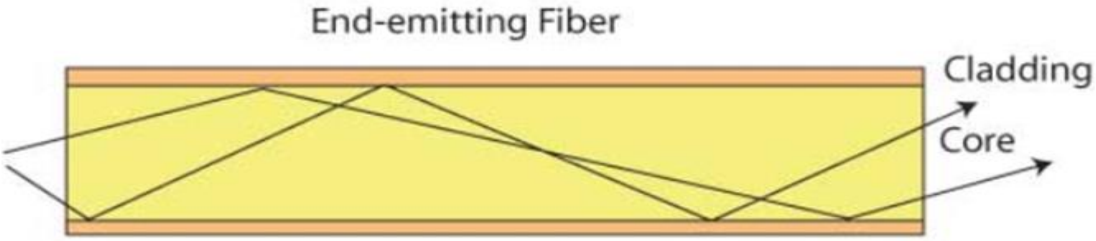
The next generation of front headlights would be the option of Laser main beam, these only start to operate over 60mph. Due to there finer dynamic resolution the brightness is already today almost four times that of an LED. This means that headlights can be made even smaller in the future – without having to compromise on light intensity. The primary benefit for drivers is that these headlights will have the longest range provided by any current headlight technology. This offers the driver improved visibility, resulting in increased road traffic safety.

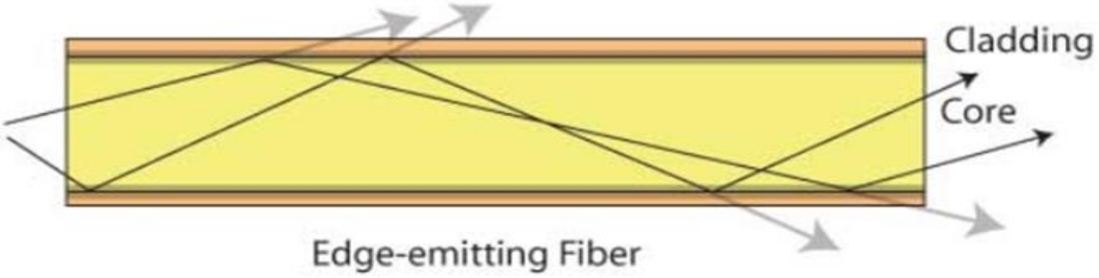
The new technology operates with a rapidly moving micro-mirror, which redirects the laser beam and changes its colour to bright light.



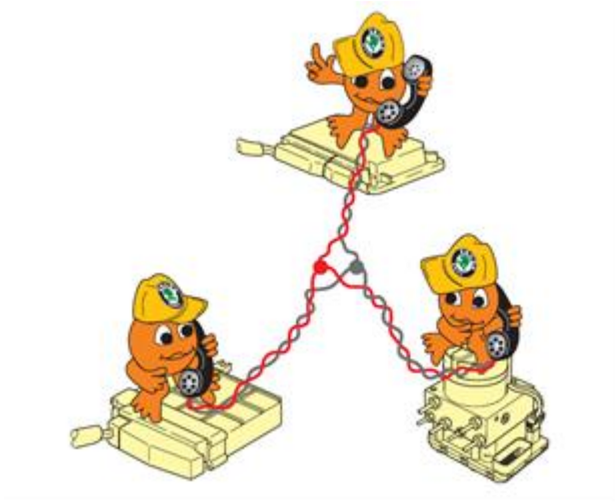
Fibre Optics

Fibre optic light technology was introduced to enhance the lighting performance of DRL and looks of the headlight. This uses conventional fibre optic wiring as used in communication systems. The light in a fiber-optic cable travels through the core (hallway) by constantly bouncing from the cladding (mirror-lined walls), a principle called total internal reflection, unlike conventional fibre optics that transfers information, this type of fibre optics has small holes across the length of the cladding so that the light can escape.





Multiplex / CAN Databus systems



The future is here and it cannot be ignored….

Motor manufacturers have used multiplexing for many years, but more recently we have seen its use reach a new level. The incorporation of such systems into a modern motor vehicle effects all that work within this industry but no more so than in the independent aftermarket. If you have little knowledge of such systems, now is the time to learn. If you work in the technical arena, your ability to continue to do your job effectively could well depend on your gaining a working knowledge of such systems. If you are in business, your future profitability will be affected by these systems, unless you understand them and appreciate the inevitable impact they will - and already are - having.

Multiplex / CAN Databus systems

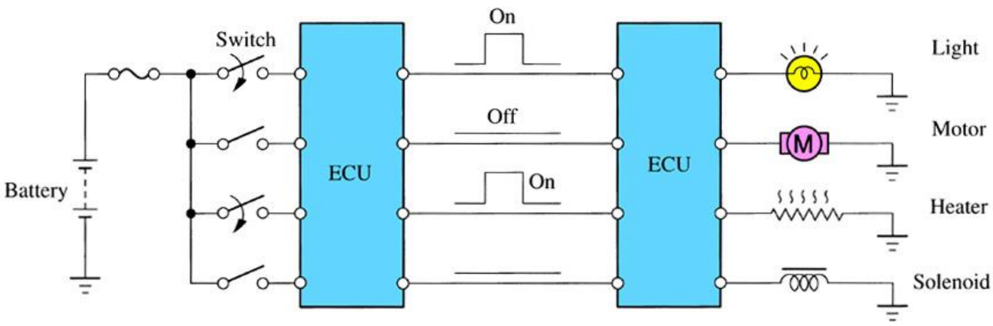
We live in the information age. Since the beginning of civilisation, methods for recording, storing and sharing what has been learnt have proved vital in the quest to cascade knowledge down through the generations. The past few decades have seen huge advances in our ability to do this through the development of cheap, powerful computers and of course the internet. Never before has it been easier to share information that we have, and access information that others have.

A single computer has a finite amount of processing power and storage space. Once the storage space is fully utilised, the computer is unable to store and therefore display any further information. Now consider that same computer connected to the Internet. The computer can now theoretically access and display any and all of the information stored on every other computer connected to the Internet (of which there are many millions). The advantages to be gained are clear.

This concept has not been lost on automotive engineers! We do of course have computers on a modern motor vehicle (ECU's or Electronic Control Units), controlling anything from systems that manage the fuelling and ignition of the engine, to emergency braking applications and power windows amongst many others.

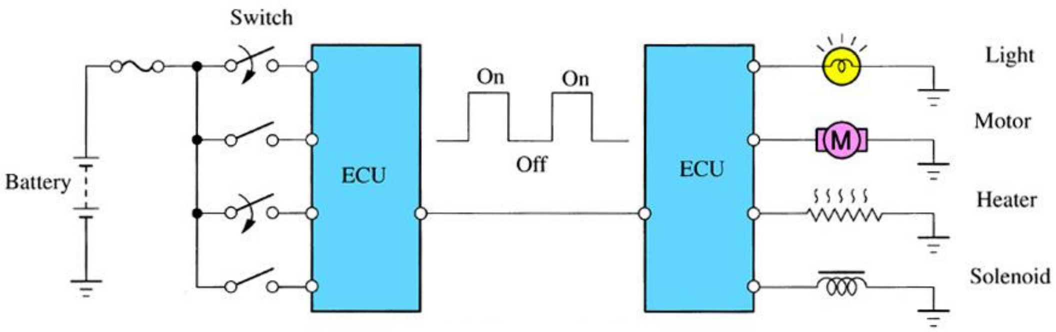
If we can enable the sharing of information between these ECU's, there are many advantages to be gained in the areas of improved functionality and cost reduction. The sharing of information is termed multiplexing.

The sharing of information



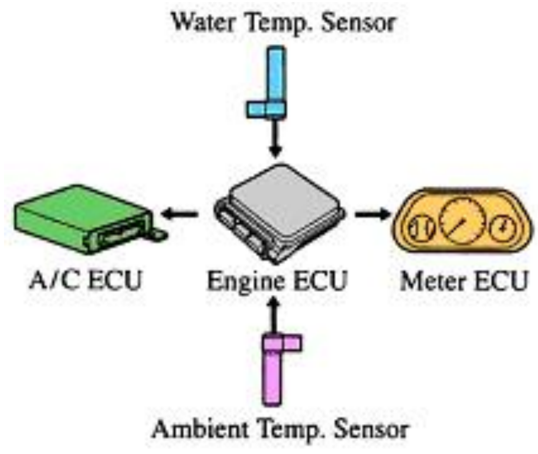
The diagram shown represents one method for the sharing of information. Each switch that the driver controls provides a signal to the ECU on the left. This ECU relays the driver's demands to the ECU on the right that has responsibility for control of the relevant actuators (light, motor, heater, solenoid) using a single dedicated wire for each switched signal. This system would certainly work effectively, and did so for a number of years – it was the motor industry's first step in the sharing of information between ECU's.
But this system has its limitations. As consumer demand for more advanced electrical / electronic systems escalated and the commercial competitiveness of the motor manufacturers came to bear, the number of wires required to enable the required functionality became unmanageable.

Think about the number of tasks that you on a daily basis are asked to perform. If a separate individual were required for each of those tasks because each person can only do one thing, how many people would your centre have to employ?



The diagram shown represents the solution. The ECU on the left now transfers the driver's demand to the actuator-controlling ECU via a single wire. Each driver demand is encoded by the transmitting ECU and each demand will have a unique code. The receiving ECU then decodes the data and acts accordingly i.e. turn on the light, motor, heater, or solenoid. Simple!
The advantages are manifold: a vast reduction in wires, a subsequent reduction in terminals with enhanced reliability through this. Less wires and terminals also mean smaller electrical connectors and ultimately smaller ECU's (it is often the size of the ECU connector that prevents the ECU being made smaller). The combined advantage represents a large cost reduction to the motor manufacturer, which will always appeal in a marginal industry.

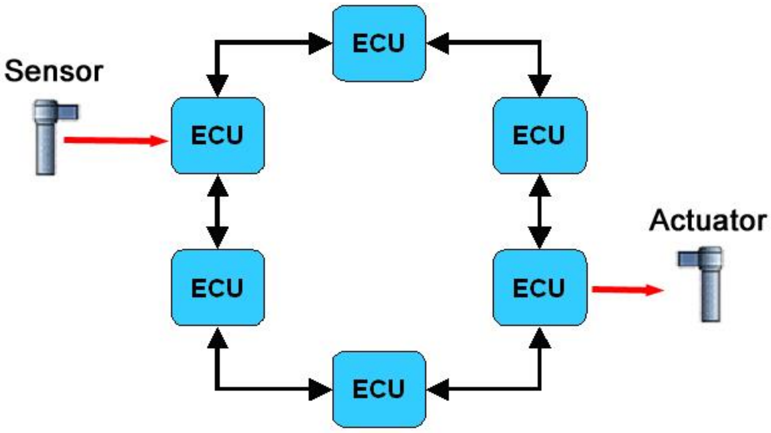
It is not only driver demand data that can be shared this way - sensor information can also be shared amongst ECU's. The diagram shows an example of this. The water temperature sensor provides the engine ECU with temperature information in the conventional way, but rather than keeping this information to its self, it encodes it and shares it with other ECU's that may need to know this. In the example shown, this is the air conditioning ECU (for control of the interior temperature through correct use of the heater matrix) and the meter ECU for correct display of the engine temperature. Where in the past multiple sensors were needed, all gathering the same information and supplying it to different ECU's, we can now use just a single sensor and all ECU's that need the information can receive it through the 'shared' approach. This represents a further considerable cost saving to the manufacturer and increased reliability.



Multiplex Communication System

Networks

A network is a group of ECU's all connected together on the vehicle for the purpose of data sharing. A vehicle-multiplexed network is often referred to as a LAN (Local Area Network) as the networked ECU's have no external link i.e. no connection outside the vehicle – the network is *local* to the vehicle only. The Internet is a WAN – Wide Area Network. *It should be noted that a number of vehicles can now communicate externally using a system referred to as telematics.*



The example shown has six ECU's and all of these will be able to 'see' the data that represents the sensor information being received by the one ECU that is actually hard wired to it. The wire (or wires, but more on this in part 2 of this article) that connects the ECU's together to form the network and act as the communication link is referred to as a communication bus. A bus in the conventional sense takes passengers from one place to the next; the communication bus does much the same with data, hence its name. Another advantage of networking is that it does not matter which ECU the sensor is actually hard wired to as all ECU's on the network receive the information regardless. Manufacturers often take advantage of this and connect the sensor to the physically nearest ECU, as this means the wires can be made shorter (weight and cost saving). This approach is referred to as 'zonal partitioning'.

Types of multiplex

There are a number of different multiplex systems used by differing manufacturers:

- CAN – DATABUS (European – Bosch)
  Controller **A**rea **N**etwork – Databus
  All relevant ECU's on the vehicle grouped logically

- BEAN (Japanese)
  Body **E**lectronics **A**rea **N**etwork
  Primarily consists of the ECU's that control the body systems

- UART (Japanese)
  Universal **A**synchronous **R**eceiver / **T**ransmitter

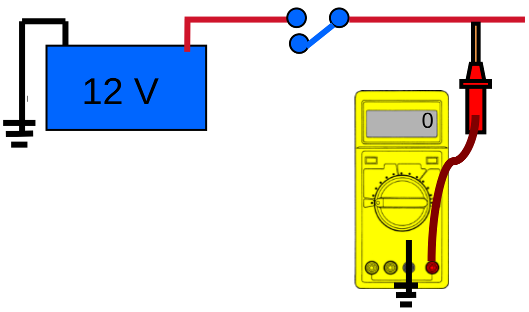
Used as a dedicated link for control systems
e.g. engine ECU and VSC

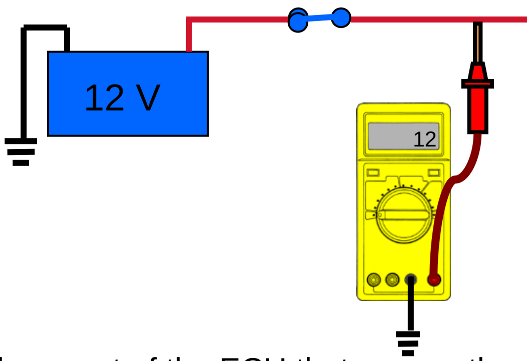
- AVC-LAN (Japanese)
  Audio **V**isual **C**ommunication – **L**ocal **A**rea **N**etwork
  Consists of the ECU's that control the audio and visual systems

- LIN (European)

Local **I**nterconnect **N**etwork
Primarily consists of the ECU's that control the body systems (1 master, upto 16 slaves)

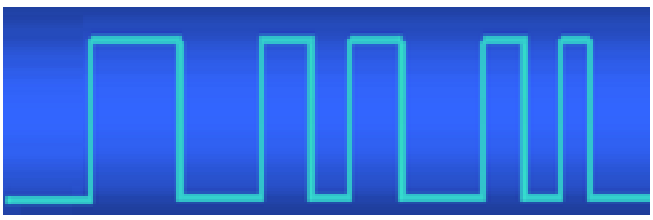
We need to advance our understanding to a point where we are able to carry out effective diagnosis of these systems.
Although similar in concept to previous vehicle electrical systems, CAN has significant operational differences and we will examine each individually.
Firstly, we need to understand the actual make up of data transfer signals.
The signals themselves are binary, in other words either a "0" or a "1" (digital) and the way these zero's and ones are produced is by switching a voltage on a wire. The wire that links all of the ECUs (sometimes referred to as *nodes)* is known as a "*databus*".





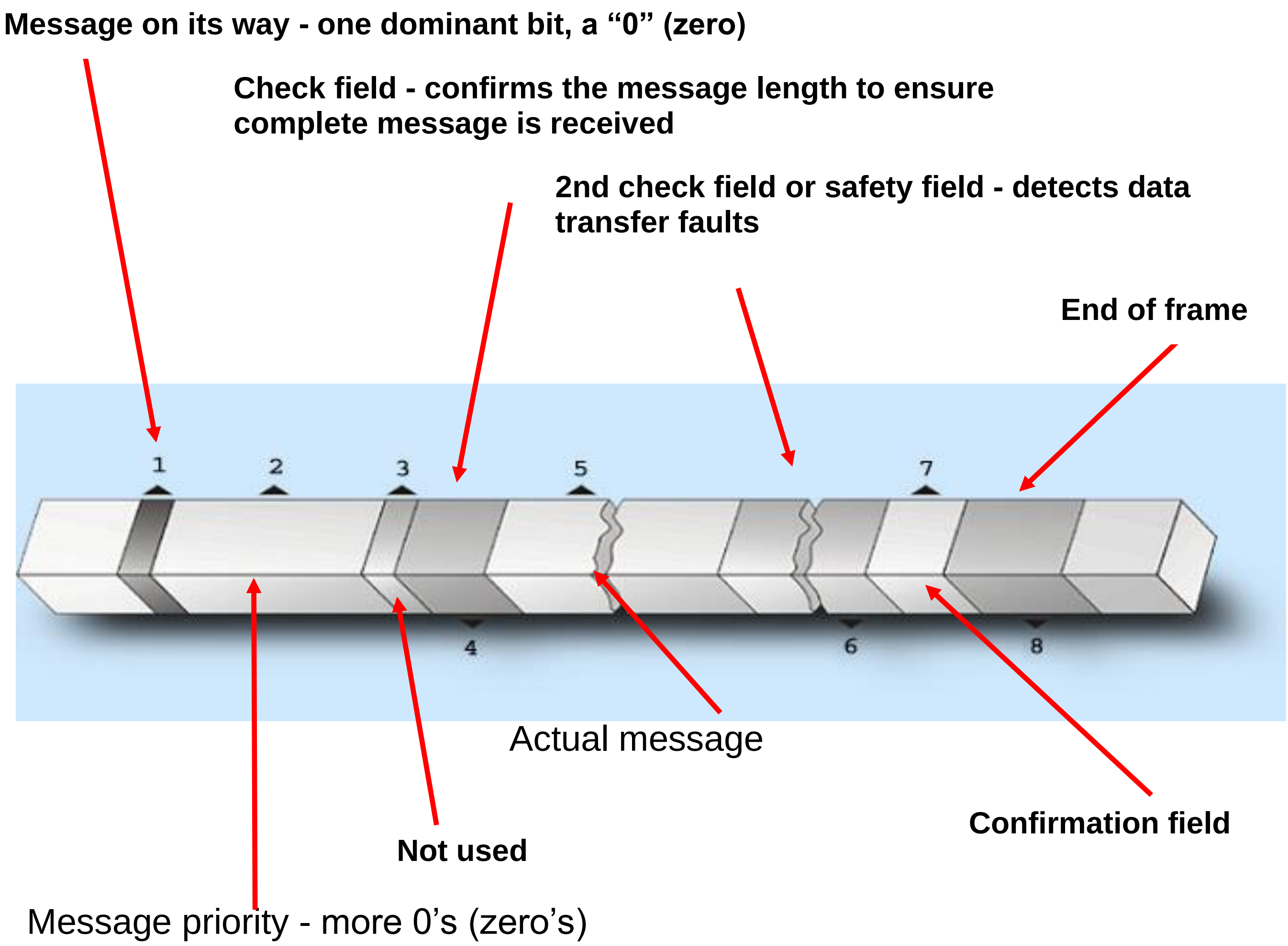
Signals on the databus are interpreted by a part of the ECU that senses the voltage changes. The example above uses a voltmeter used to illustrate this. The signals are made up of two differing voltage states - low voltage is represented by a "1" and high voltage represented by a "0".

This illustration is a representation of the signal



Messages are used to tell a component to turn on or off, stay on or off, change position, speed etc.

The actual messages are constructed into “frames” containing eight separate parts. These parts can be further divided up into bits. A bit is a change in voltage from one state to another, i.e. low to high (“1” to “0”) or high to low (“0” to “1”). The frame length varies and may contain three to four hundred bits.

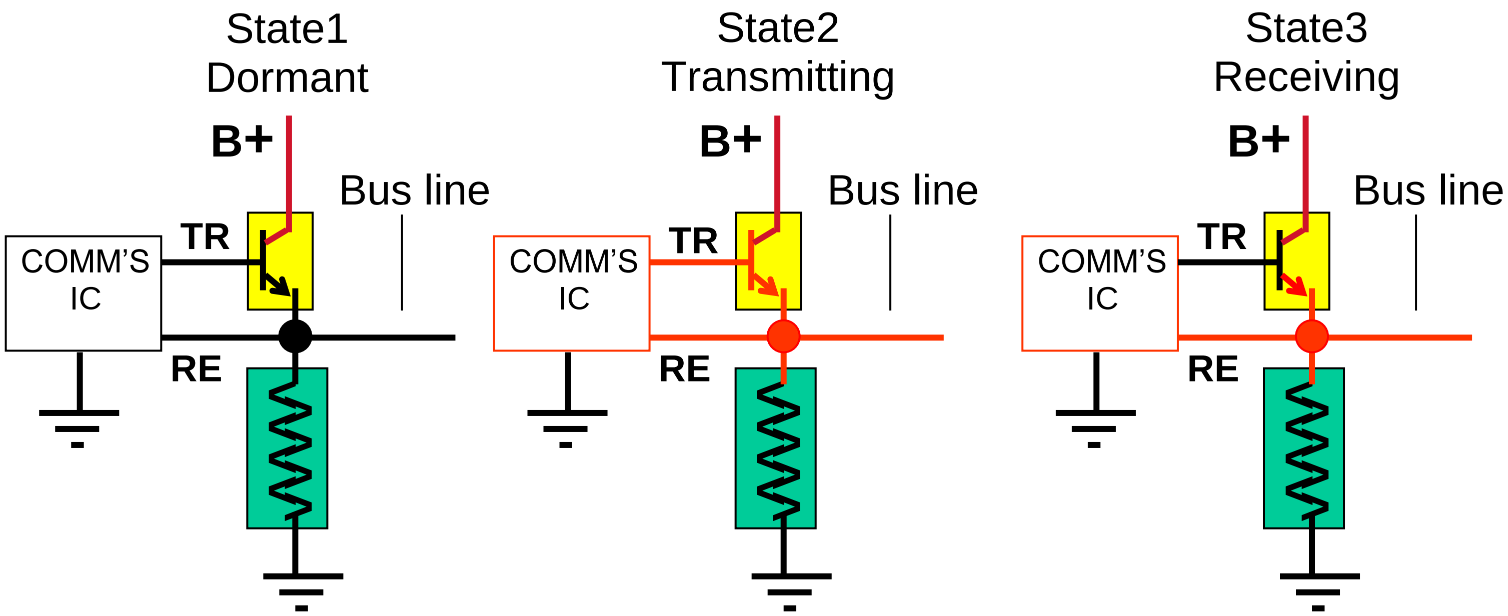


In this illustration we can see the constituent components of a frame.

Priorities. It is paramount that a system of priorities exists for the transfer of data because the databus is only one or two wires (depending upon the system), and if more than one node was to transmit data simultaneously the data would become corrupt and unusable. Therefore the node sending the most important data is given the highest priority, e.g. skid control would have a higher priority than say climate control changes.

The nodes will only try to send a message during periods when the line is silent. ECU's look for these periods to prevent a clash of signals when more than one ECU wants to transmit data simultaneously. Message priority is signified by the number of zero's (known as "Dominant" bits) at the beginning of the frame and the node with a high priority message sends more dominant bits at the beginning of its message than a lower priority signal. A dominant bit is a high voltage or high voltage difference between two voltages.

If a message starts with a lot of dominant zero's the voltage will be high for longer than in a less important message (less zero's). The ECU that outputs a high voltage signal for the longest, gains priority on the network and will continue the transmission of its message. The lower priority message transmission will be postponed until the bus goes silent again.

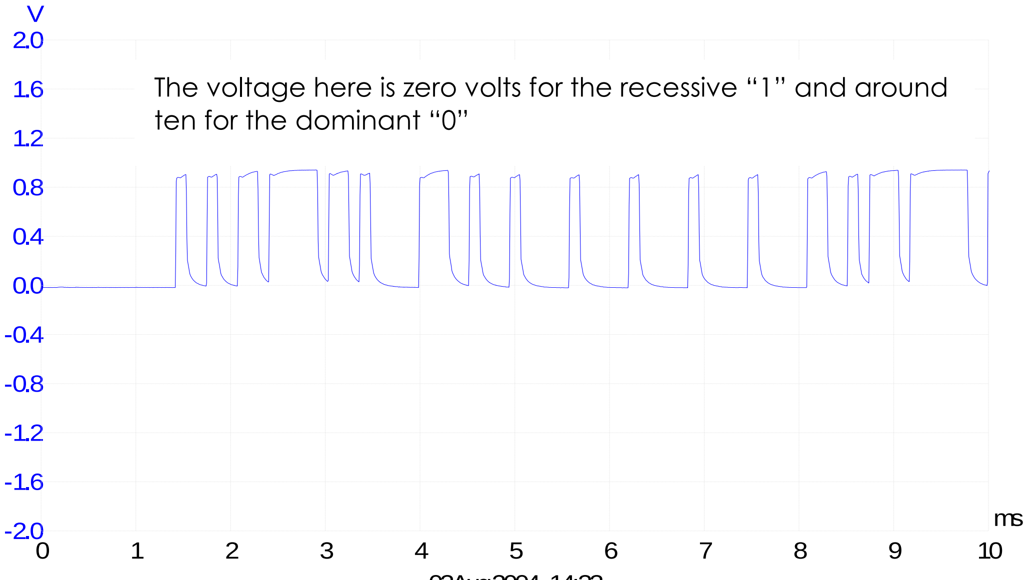


The diagram above is to show the three states of node communication. The **dormant** state is when no communication is occurring. The **transmitting** state is when the node is applying voltage to the databus. The **receiving** state is when another node is applying voltage to the databus.

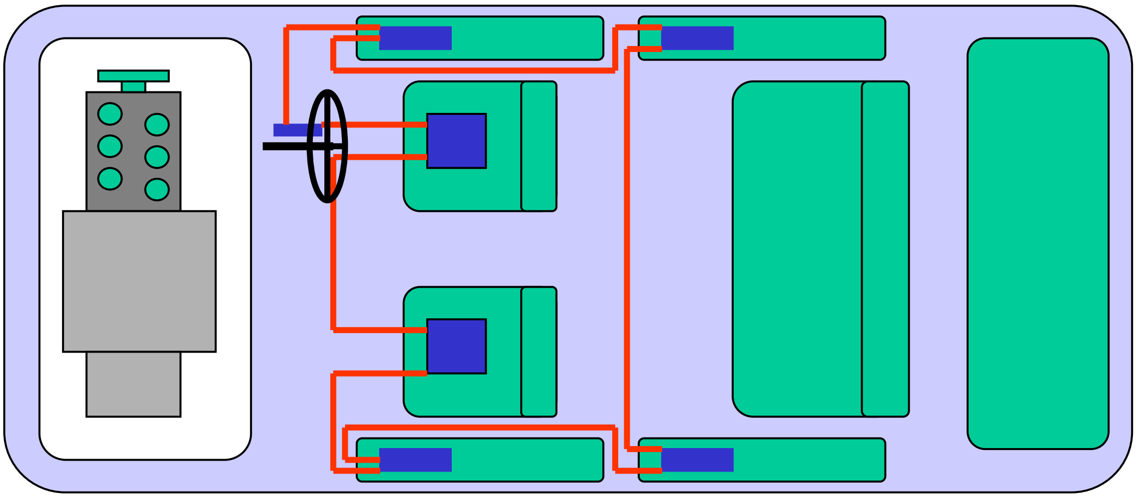
Now we have looked at the way data signals are produced it is time to look at some specific examples of multiplexing.

BEAN – **B**ody **E**lectrical **A**rea **N**etwork (Japanese versions)

The oscilloscope pattern shown below is from a BEAN network.



A typical BEAN network



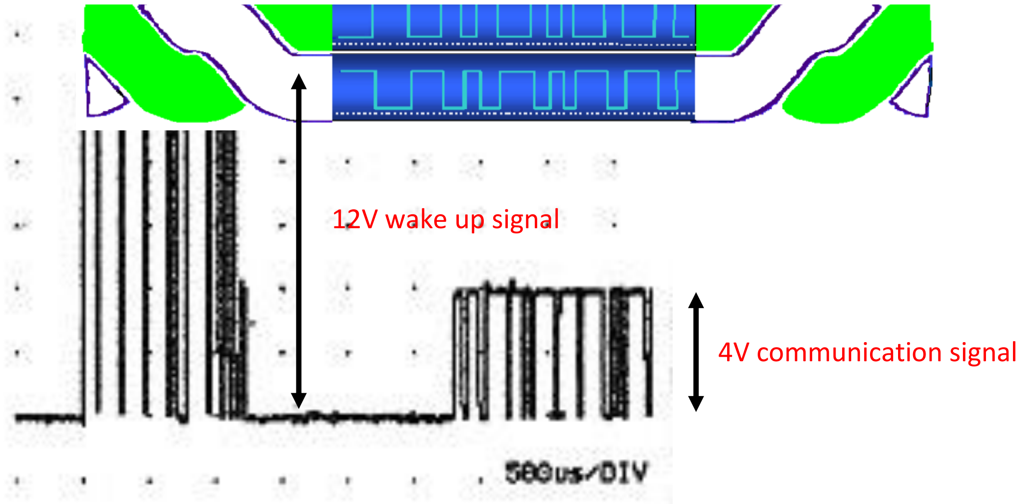
The above diagram is a typical BEAN network layout having four door nodes, two seat nodes, and a node for the steering column. This is a ring type network where the databus loops through each node.

CAN - Controller Area Network – European system

Low Speed Can

The CAN DATABUS differs from BEAN in that it has different speeds for different applications. Low Speed CAN (LSCAN) is in many ways similar to BEAN uses a single wire databus, that is usually bi-directional, but the voltage is lower, operating between 0 and 4 volts. As with BEAN it normally takes the form of a ring that has nodes connected. Another difference is that LSCAN operates when the ignition is off. During extended periods of inactivity the nodes go into a "sleep" mode and require a "wake-up" signal.

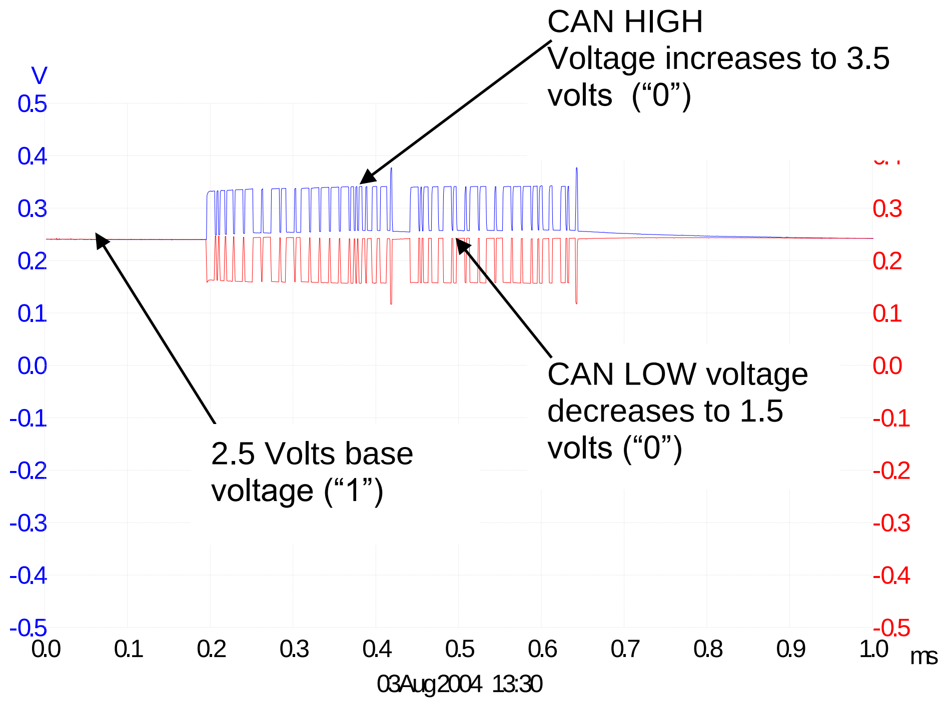
The oscilloscope pattern shown below is from a LS CAN network



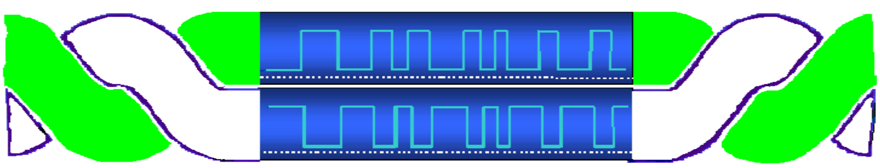
High and Medium speed CAN

The more commonly used **Medium** and **High Speed CAN,** utilise two wires for data transfer - CAN HIGH (voltage) and CAN LOW (voltage). As can be seen from the oscilloscope pattern shown, the HS CAN wires have a base voltage applied to them of 2.5 volts. Whilst the signal voltage is at 2.5 volts the "1" part of the signal is being generated, the "0" part is a 1 volt increase in the case of Can Hi and a 1 volt decrease in the case of CAN low.

CAN DATABUS

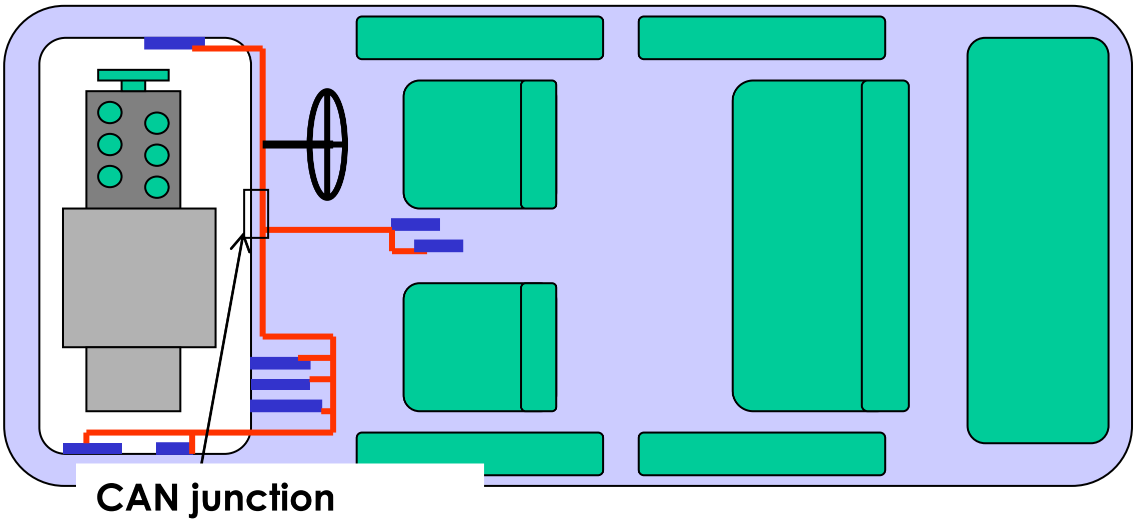


MSCAN & **HSCAN** use two wires twisted together in what is called a twisted pair which provides resistance to electrical interference. The wiring may also be shielded or screened and the data signals are mirrored to provide optimum protection against interference (electrical noise).



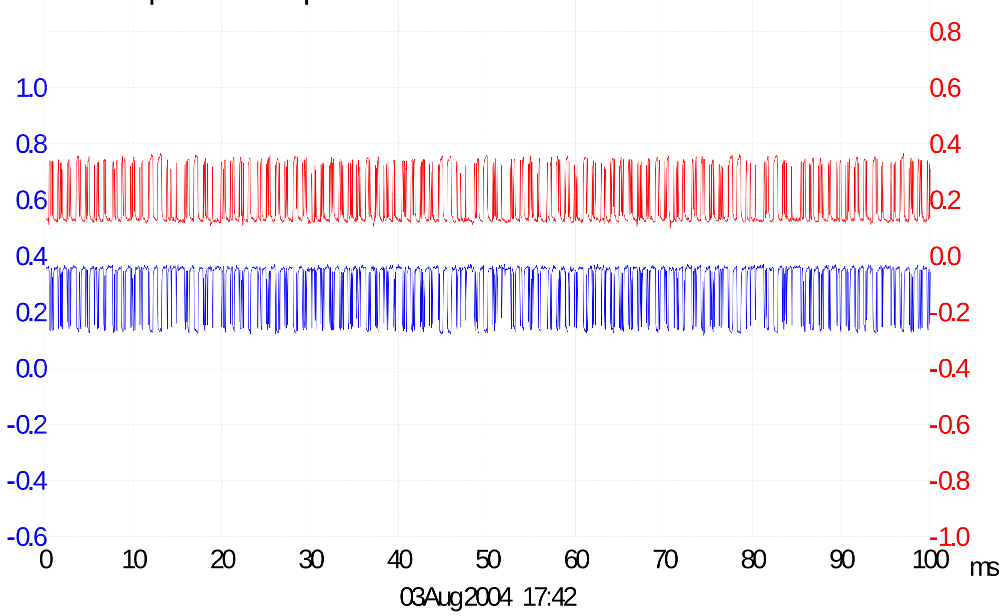
If an induced electrical spike occurred in the twisted pairs, the spike would have an equal and opposite effect on each wire so the signal would not be corrupted, this is because the voltage differential between the two wires would remain consistent to each other.

A typical high speed CAN system



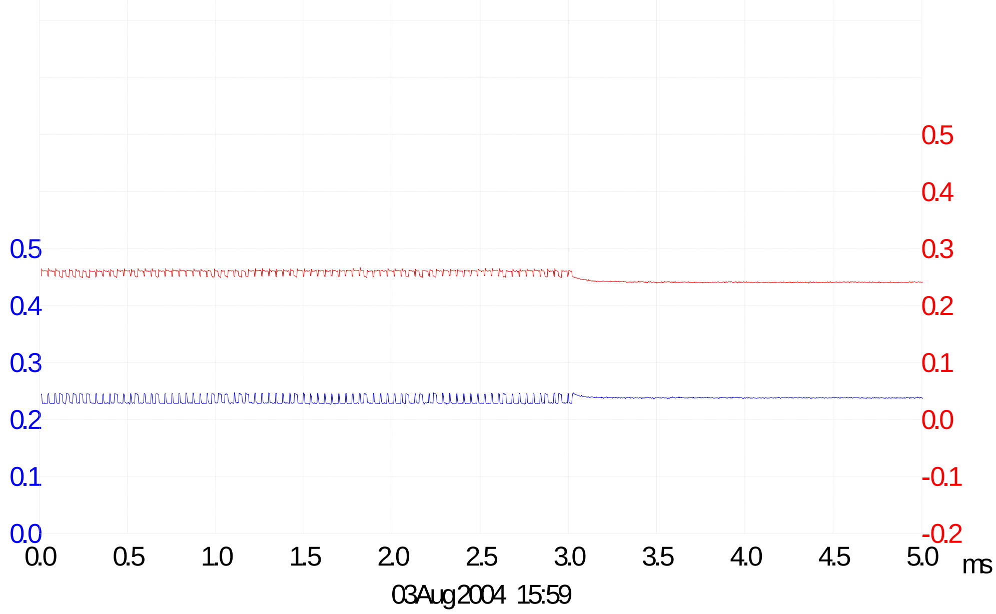
UART

UART multiplex is a system that forms a dedicated link between skid-control and engine control nodes. UART has now largely been replaced by HS CAN but it is still worth looking at the oscilloscope trace and a typical system layout as vehicles fitted with this system are very much still in use. A close inspection of this system reveals that although similar, the patterns are not mirrored as in CAN and the databus wiring has differing base voltages, data is transmitted at up to 9.6 Kbps

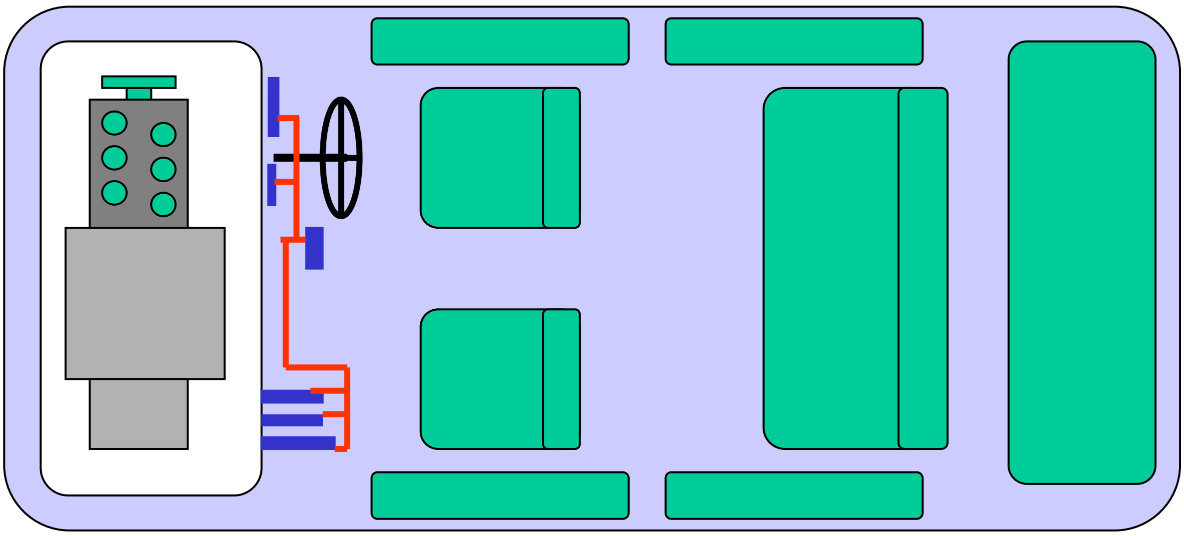


LAN Audio Visual Controller Local Area Network

AVC-LAN is a system that, as the name suggests, is based around the audio and visual systems fitted to some of today's high specification vehicles. The system is often controlled by a touch screen system for convenience giving access to features such as audio, trip computer, climate control and G.P.S. navigation. As you can see the data is communicated along a two wire databus having base voltages of 2.5. The actual data is transferred at a rate of 17Kbps and the signals themselves are comprised of voltage fluctuations of around "0.3" volts.



An AVC-LAN multiplex layout



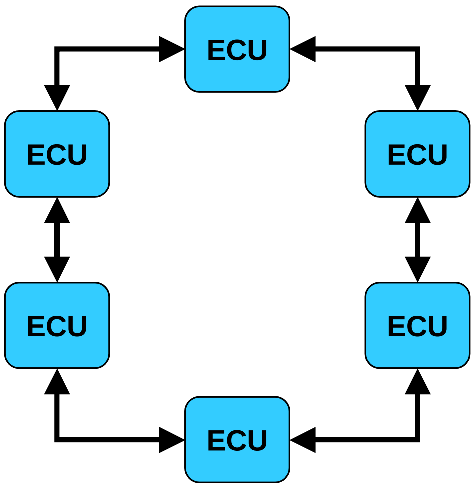
Let us now study faults that can occur with such systems and the process of diagnosing these. At this stage we will concentrate on the diagnosis of BEAN systems (Body Electronic Area Network – see previous articles for details on operation). Diagnosis of such systems is similar to many of the other systems that we have discussed. Those that differ we will discuss in the forth and final part to this article.

Multiplex – built in reliability

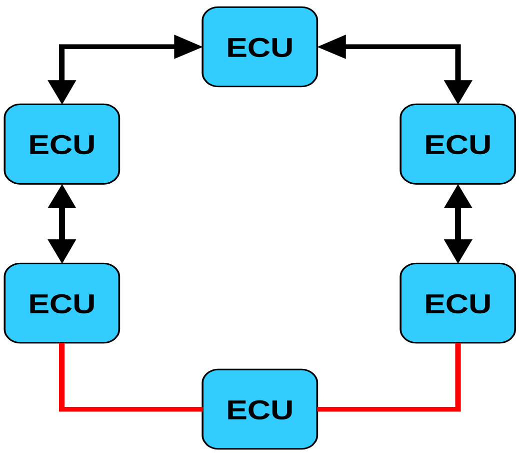
Multiplex systems are very reliable (it is one of the reasons that manufacturers use them extensively on a modern motor vehicle) however, faults do occur. Let us study the systems that manufacturers use to reduce the risk of faults producing a symptom – daisy chaining and bus cut relays.

'Daisy chaining'

This is a term used to describe the way in which communication networks are configured. The diagram to the right shows that the ECU's on the network are connected in a loop. The advantage of this approach is that a single open circuit fault in the network wire would not create a single symptom! You could actually cut the wire completely without causing any faults whatsoever. The reason?

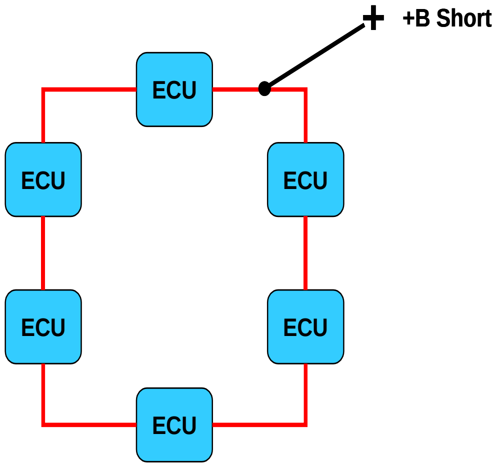


Remember that binary 0's and 1's are created on the network bus wire by switching between high and low voltages. We can still do this for the full length of the wire even if it is cut.
To clarify – if you were to connect a loop of wire to the battery positive post you would be able to measure battery voltage at any point along that loop. Open the loop up so you have a length of wire rather than a loop and you will still be able to measure battery voltage along its full length. Remember, voltage is *applied* it does not *flow*.
Current flows and does require a completed circuit, but we are not using current here we are using voltage.



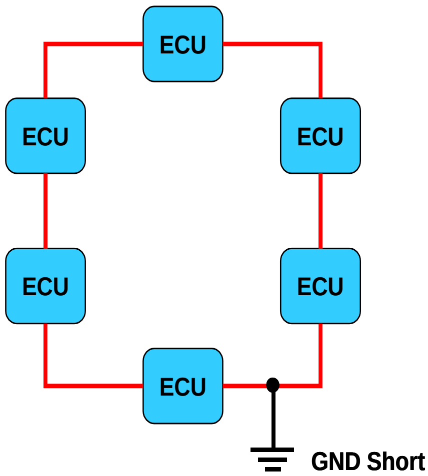
Two open circuit faults are needed on the same network in order for a fault to be experienced; and then only systems controlled by the ECU isolated through these faults will display symptoms.

Faults – short circuits
+B short



Short circuits will cause complete failure of the multiplex network.
The fault illustrated by the picture to the right is known as a +B short. An example of this would be a damaged loom that has brought a wire inside a harness at battery voltage into contact with the network bus wire.
This would result in a constant high voltage on the network, which would represent a continual stream of binary 0's. This means nothing to an ECU.

Ground short

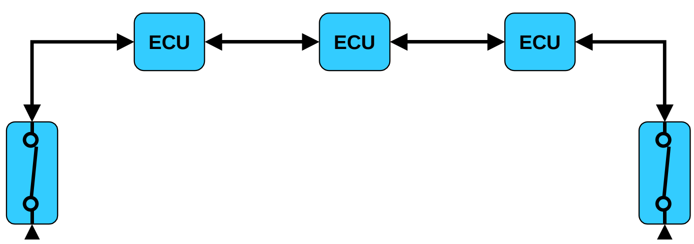


The fault illustrated by the picture to the right shows a ground short. This is where they communication bus wire has become permanently grounded (perhaps through chafing of the insulation and subsequent contact with the vehicle chassis). It is now not possible to create a high voltage on the network. A network at a constant 0 volts represents a continual stream of binary 1's to the ECU's and that makes no more sense to them than a continual stream of binary 0's.

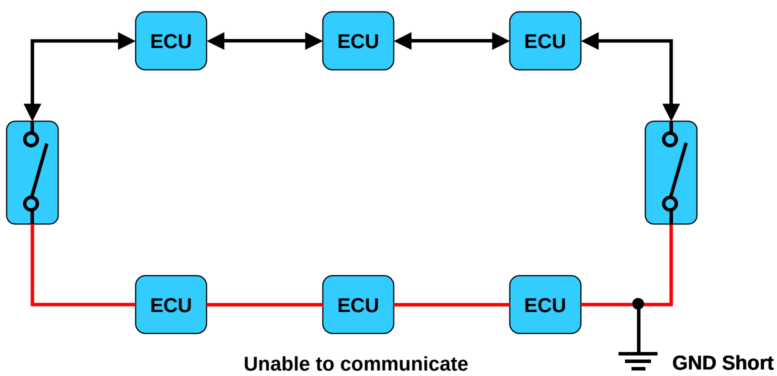
Bus cut relays

In order to enhance the reliability of multiplex systems, bus cut relays are used.

These are switching devices placed inside several ECU's on the network that can 'open' in the event of a catastrophic shut down of the network through short circuit faults. Through this action, the short circuit can be isolated from several ECU's on



Able to communicate



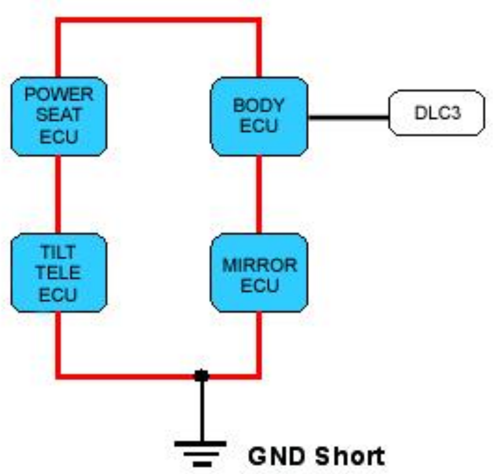
Unable to communicate

the network enabling them to communicate normally (the fault is effectively ring-fenced).

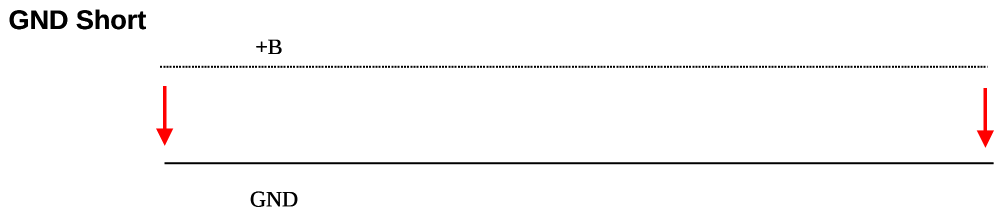
Multiplex diagnosis

Diagnosis of multiplex systems (for all their apparent complexity) is actually straight forward.

The picture below represents a typical multiplex network used to affect a memory function on the drivers seat. This circuit enables the driver to ‘store’ his or her preferences regards seat, steering wheel and mirror position. A second driver can then also store their preferences and these can be selected from a switch inside the vehicle (or even automatically set off two different ignition keys).



Let us assume that this network has suffered a ground short fault. No communication can take place on this network because high voltages (and therefore binary 0’s) cannot be generated.



Note that the individual systems on this network will still work i.e. the seat will move off its switches, the remote mirrors will work of its switch; it is only when we ask these systems to work together through communication on the network that nothing will happen.

Using suitable test equipment, extract the fault codes. For this type of fault there will always be a code.

In reality there will be multiple codes as shown in the example below:

B1201 Tilt and Telescopic steering ECU communication stop

B1202 Communication bus malfunction (short circuit)

B1203 Power seat ECU communication stop

B1204 Power mirror ECU communication stop

These codes are telling you collectively that none of the ECU's on this network can communicate with each other and that there is a short circuit fault. At this point you should run down the list of codes and ask yourself the question

Cause or affect?

Could a communication stop fault cause this problem or is this fault a reaction to another fault?

There is no way that a communication stop fault can cause a short circuit, but a short circuit can cause a communication stop problem.

Through this process of deduction you can quickly ascertain that it is a short circuit fault that you are looking for.

Working directly from the wiring diagram familiarise yourself with the location of all the key components. For the purpose of this exercise, please refer to the memory function schematic diagram.

Disconnect each of the ECU's in turn and observe the reaction of the fault code. Note that a multiplex fault code is a live code and will disappear off the code reader screen when the fault is no longer detected.

If when you disconnect the remote control mirror ECU the code disappears (the short circuit code that is), then the short lies inside that ECU and the ECU must be replaced. If the code does not disappear when the remote control mirror ECU is disconnected then it is not faulty. Reconnect that ECU and check the other ECU's in the same way. There is one ECU on the network that you cannot check in this way and it is the ECU that communicates with the tester via the diagnostic plug (the DLC3), in this example this is the body ECU.

Once you have confirmed that the checkable ECU's are serviceable, check the harnesses. Disconnect a harness between two ECU's (perhaps between the power seat ECU and the tilt and telescopic ECU). By doing this you are isolating the length of harness from the ECU that detects the fault and relays the information to the tester (the body ECU in this example). If the short circuit code disappears then the short lies in that length of harness.

Take the same approach to check all harnesses.

Once you have confirmed that it is none of the checkable ECU's and none of the harnesses then the fault must lie in the only ECU that you have been unable to check i.e. the body ECU.

With our example the ground short code will disappear from the screen of the tester when you disconnect the tilt and telescopic ECU and the mirror ECU. You have located your fault.

Remember to work easy – the ECU's and harnesses you check first should be dictated by ease of access and minimum stripping - reducing the likelihood of trim damage and making your life easier!

Fibre Optics

Traditionally, the physical medium used to carry data in a car has been shielded copper wires for both the power supply and communication. If car designers could easily rid cars of copper cables, however, they would. Copper cables are heavy, and their weight impairs fuel efficiency. At the same time, the cabling's bulky connectors can be difficult to accommodate inside the body shell, and this reduces the designer's flexibility.
Fibre optic cabling would appear to be the answer to the car designer's wish: it is light and compact, and it also offers the benefits of supporting very high data rates and of immunity from Electro-Magnetic Interference (EMI). In reality, however, the adoption of fibre optic communications in vehicles has been limited to date.

Components

Optical connector - By way of this connector, the light signals pass into the control unit or the light signals generated are conveyed to the next bus user.

Electrical connector - This connector is responsible for the power supply, ring fault diagnosis and input and output signals.

Internal power supply - The supply voltage fed into the control unit by the electrical connector is distributed to the components by the internal power supply system. This enables individual components in the control unit to be deactivated to reduce closed circuit current.

Transmitter and receiver - Fibre Optical Transmitter (FOT)
This consists of a photodiode and a light emitting diode. Incoming light signals are converted by the photodiode into a voltage signal which is relayed to the transceiver. The function of the light-emitting diode is to convert MOST transceiver voltage signals into light signals.

The light waves generated have a wavelength of 650 nm and are visible as red
light. The data are transmitted by means of light wave modulation. This modulated light is then conducted through the optical fibre to the next control unit.

Transmitter and Reciever

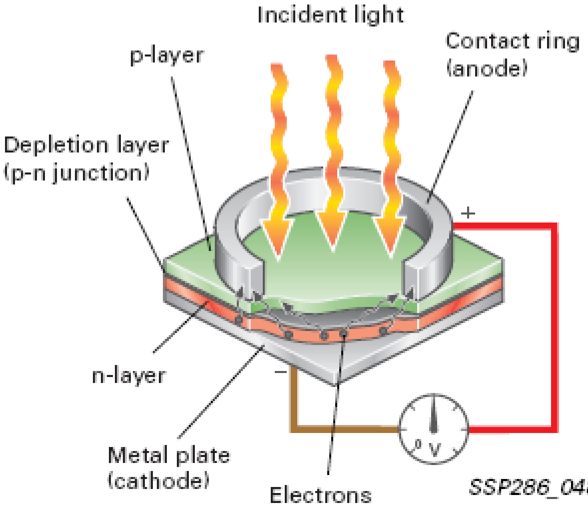
The **trans**mitter and re**ceiver**. The transmitter conveys the messages to be transmitted to the FOT in the form of a voltage signal. The receiver accepts the voltage signals from the FOT and conveys the required data to the standard microcontroller (CPU) of the control unit. Non-required messages from other control units pass through the transceiver without data being conveyed to the CPU. The messages are transmitted in unaltered form to the next control unit.

Standard microcontroller (CPU) - The standard microcontroller (CPU) is the central processing unit of the control unit. It contains a microprocessor which controls all the major functions of the control unit.

Unit-specific components - These components are responsible for the implementation of functions specific to the control unit, e.g. CD drive, radio tuner.

Photodiode

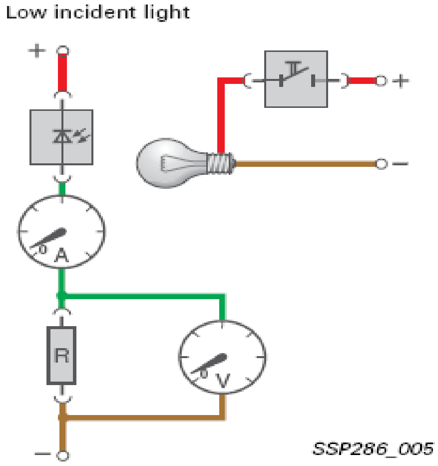
A photodiode is used to convert the light waves into voltage signals. The photodiode has a p-n junction, onto which light can be focused. On account of a heavily doped p-layer, the depletion layer extends almost exclusively into the n-layer. There is a contact (anode) at the p-layer. The n-layer is applied to the metallic base (cathode).



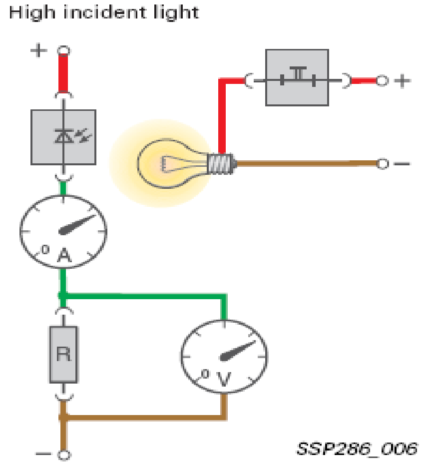
SSP286_048

The energy associated with the penetration of light or infrared rays into the p-n junction results in the formation of free electrons and holes. These give rise to a flow of current across the p-n junction. Consequently, the more light which strikes the photodiode the higher the current flowing through it. This process is referred to as the internal photoelectric effect.

In reverse direction, the photodiode is connected in series with a resistor. An increase in the current flowing through the photodiode on account of more light striking it increases the drop in voltage at the resistor. The light signal has thus been converted to a voltage signal.

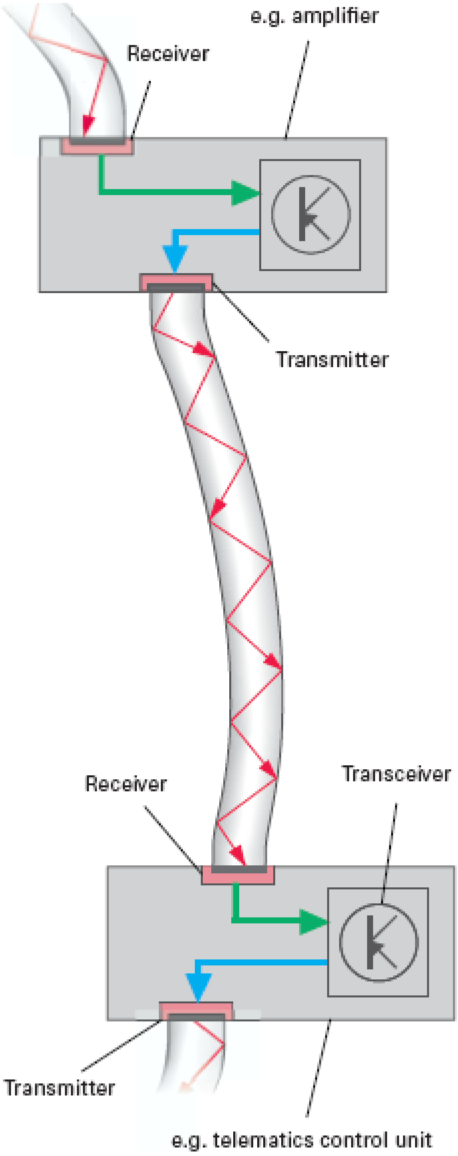


SSP286_005



SSP286_006

The optical fibre is designed to convey the light waves generated in the transmitter of one control unit to the receiver of another control unit. Development of the optical fibre was based on the following criteria:

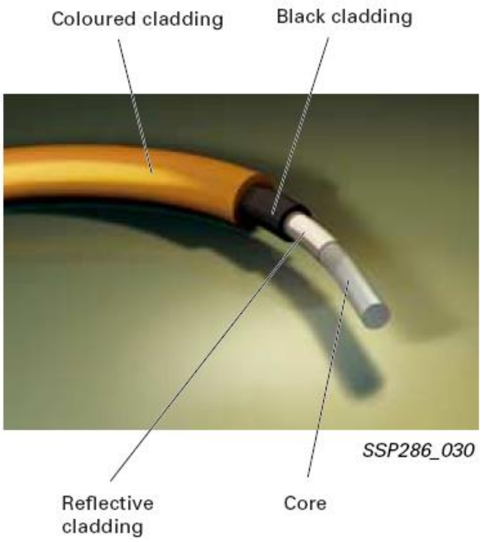


- Light waves travel in straight lines and cannot be bent. However, they have to be routed through bends in the optical fibre.
- The distance between transmitter and receiver may be several metres
- The optical fibre must not be susceptible to damage caused by mechanical impact
- (vibration, assembly work).
- The optical fibre must operate reliably despite the great temperature fluctuations
- in the vehicle.

Requirements to be met by optical fibres used for transmitting light signals:

- The optical fibre must conduct the light waves with a low level of attenuation (signal losses).
- The light waves have to be routed through bends in the optical fibre.
- The optical fibre must be flexible.
- The optical fibre must operate reliably in the temperature range between - 40 °C and 85 °C.

Fibre optic design



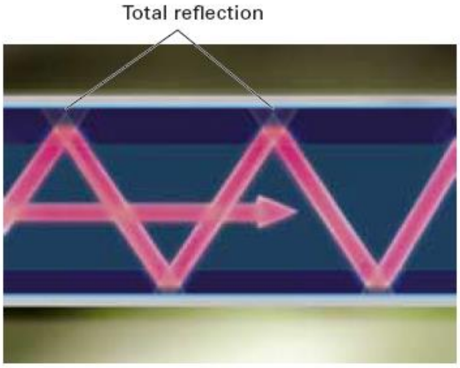
The optical fibre consists of several layers. The core forms the central part of an optical fibre. It is made of polymethyl methacrylate and represents the actual light conductor, through which the light passes with virtually no losses by way of the total reflection principle.
The optically transparent fluoropolymer cladding around the core is required for total reflection. The black polyamide cladding protects the core against external incident light.
The coloured cladding is used for identification,

protection against mechanical damage and thermal protection.

Transmission of light waves

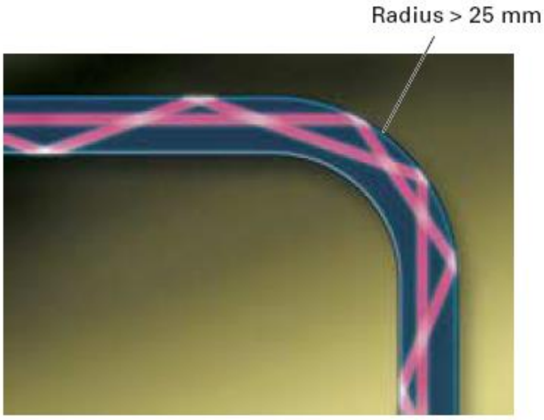
Straight optical fibre

The optical fibre conducts some of the light waves in a straight line through the core. Most of the light waves are conveyed in a zigzag pattern as a result of the total reflection occurring at the core surface.

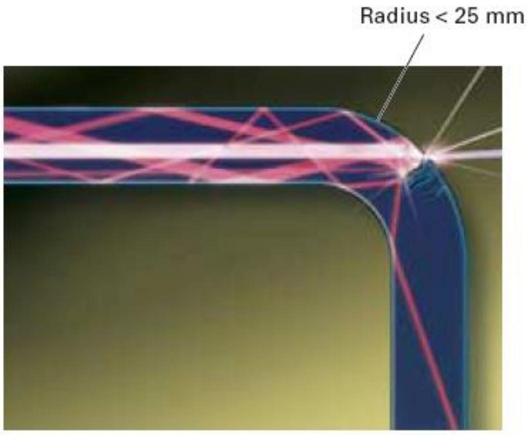


Curved optical fibre

The total reflection occurring at the core cladding boundary causes the light waves to be reflected and thus conducted through the bend.



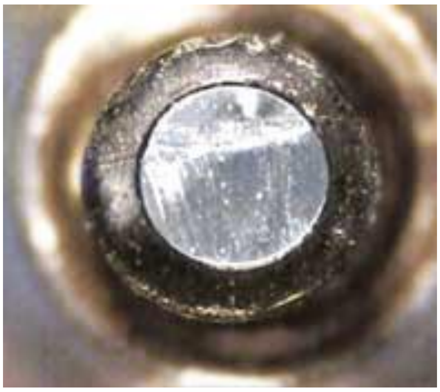
Total reflection



If a beam of light strikes a boundary layer between materials with higher and lower refractive indices at a shallow angle, the beam is fully reflected, i.e. total reflection takes place. In an optical fibre, the material of the core has a higher refractive index than that of the cladding, with the result that total reflection takes place within the core. This effect is governed by the angle of the light waves striking the boundary from inside. If this angle becomes too steep, the light waves will leave the core and high losses will occur. This situation is encountered if the optical fibre is excessively bent or kinked.

The bending radius must not be less than 25mm

Maintenance



To minimise transmission losses, the end face of the optical fibre must be:

- smooth
- perpendicular
- clean.

This can only be achieved using a special cutting tool. Dirt and scratches on the cut face cause higher losses (attenuation).

Rules for handling optical fibres and their components

- Never employ thermal working and repair methods such as soldering, hot bonding or welding
- Never employ chemical and mechanical methods such as bonding and jointing
- Never twist together two optical fibre cables or an optical fibre cable and a copper wire
- Avoid cladding damage such as perforation, cutting or crushing
- Do not stand or place objects on cladding, etc. when fitting in vehicle
- Avoid contaminating end face, e.g. with fluids, dust or other media; prescribed protective caps are only to be removed for connection or test purposes employing extreme care
- Avoid loops and knots when laying in vehicle; pay attention to correct length when replacing optical fibre

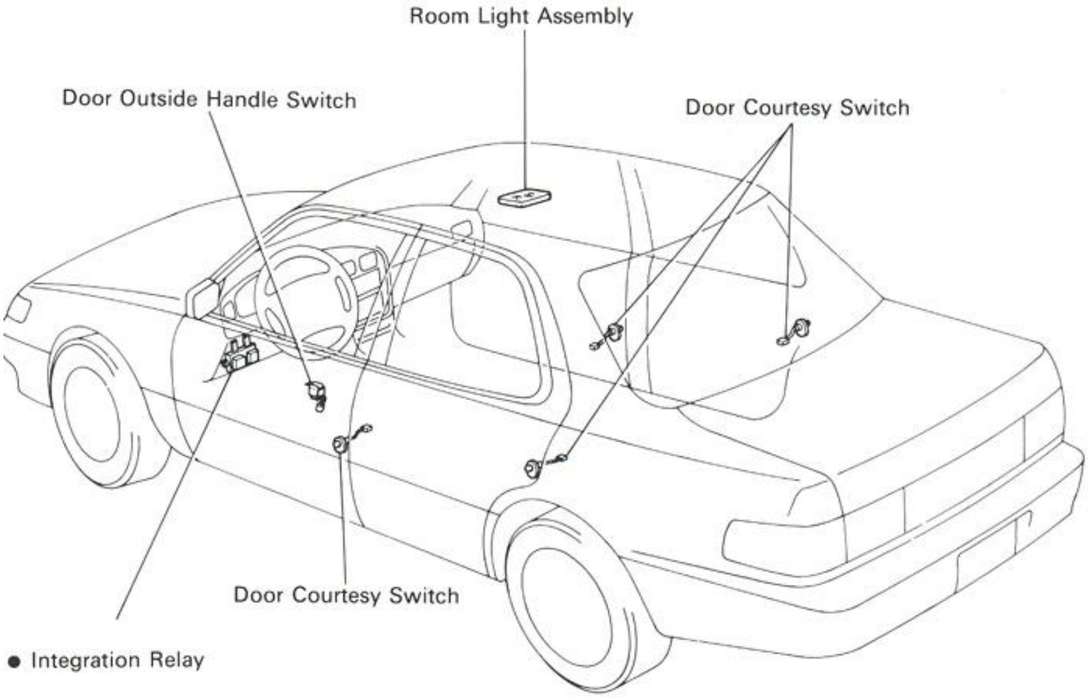
Auxiliary systems

So far we have seen how the battery stores electrical energy, how this electrical energy is replaced and supplemented and how this energy is used to start the engine. There are of course many more electrical systems on a vehicle adding to the functionality, comfort and safety of that vehicle.

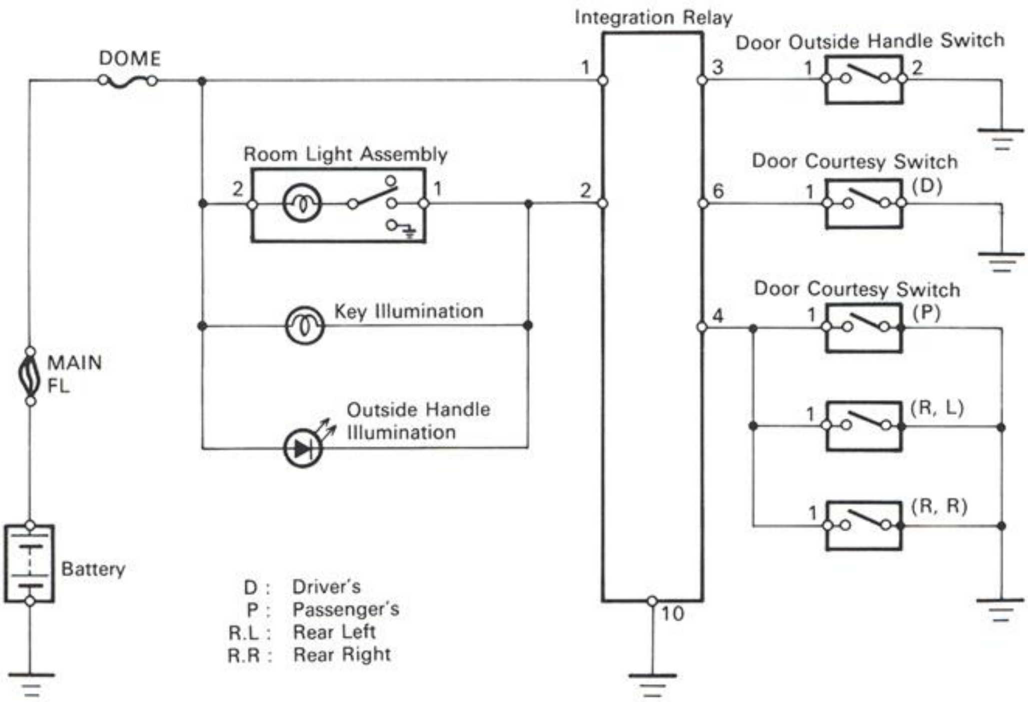
Interior light circuit

This circuit is designed to do a number of things on a modern vehicle. Yes, it certainly provides the occupants of the vehicle with a light that they can switch on and off at will, and an ‘auto-on’ function when a door is opened but it often has a delayed turn off facility now to give the driver time to engage the keys in the ignition / starter key cylinder and sometimes the light is linked in to an illuminated key cylinder both for the ignition / starter key and the drivers outside door (illuminated entry).

The diagram below shows typical locations for the key components that go to make up this system.



The interior light circuit



This circuit is electronically controlled. The integration relay is an ECM (electronic control module). As we have seen with the MIC voltage regulator on the alternator, the ECM monitors signals provided by sensors, looks at its programming and makes decisions based on this programme. These decisions control actuators in order to bring about an action of some description.

On this circuit, the following are sensors:

- door outside handle switch
- drivers door courtesy light switch
- passenger door courtesy light switch
- rear left passenger door courtesy light switch
- rear right passenger door courtesy light switch.

These sensors provide information to the ECM (integration relay) in the form of grounded circuits and the way in which the voltage in that circuit will react to the presence or absence of that ground.

The following are the actuators in the circuit (the 'doing' components):

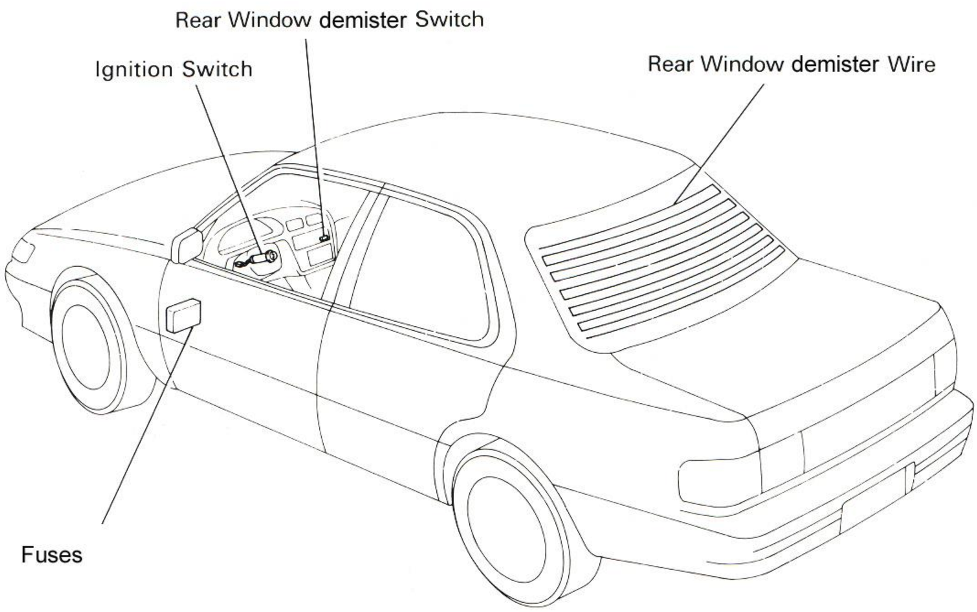
- the room light assembly (interior light)
- key illumination lamp
- outside handle illumination lamp (driver's door).

Circuit operation

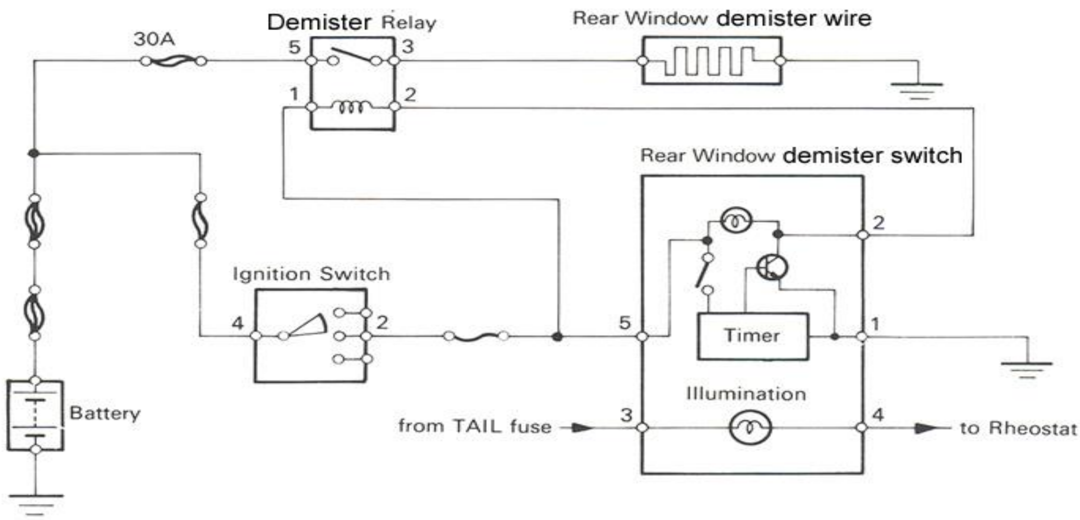
The circuit is pictured in the off position (interior light not illuminated). If the interior light switch is in position 1, then a battery positive supply is fed to the lamp assembly. It should be noted that the key illumination lamp and the outside handle illumination lamp (driver's door) receive a battery positive supply permanently. The integration relay receives a battery positive supply at terminal 1 (permanent supply). If one of the switched doors is opened, the appropriate door courtesy switch will close and the integration relay will register a change in voltage in that circuit through the presence of a ground via that closed switch. The programming that the integration relay received at manufacture contains a set of instructions that tell it to ground pin 2 under these circumstances. This provides a ground for all three lamps and they illuminate. Upon the loss of this switched ground circuit (from the operating door switch) the integration relay will keep the lamps on until it detects charge voltage at pin 1. This is its indication that the driver has started the engine and is about to pull away. At this point it extinguishes all illumination by taking the ground away from pin 2.

Rear window demister

This circuit is designed to provide a means for clearing the rear screen of frost and mist (it is referred to as a defogger by some Japanese manufacturers). The principal is quite straight forward – embedded in the rear screen is an electrical conductor that current passes through. This current generates heat and provides the means for defrosting / demisting. The diagram below shows typical locations for the major components.



The circuit
The demister switch is at the heart of this circuit. It is an ECM albeit an extremely basic one.



Circuit operation

When the ignition switch is at position 2 (engine running), batter voltage is applied to terminal 5 of the demister switch and terminal 1 of the demister relay. Voltage will not be applied to the timer inside the demister switch unless the driver presses the switch. Current at this point is unable to flow through the coil of the relay as there is no circuit to ground (The timer has not yet applied a base voltage to the NPN transistor inside the switch assembly).
When the driver presses the switch (which is a self-releasing switch to prevent the driver from forgetting to cancel the system) the timer receives battery voltage via this switch briefly. At this point, the timer applies a base voltage to the NPN transistor, which then becomes conductive between its collector and emitter terminals. This grounds the demister relay, which then energises and provides battery current to the demister wire inside the rear screen. Current is now also able to flow from terminal 5 to ground through the warning lamp mounted on the switch assembly and the NPN transistor. This tells the driver that the system has been switched on.
After a pre-determined period dictated by the programming of the timer, the base voltage is taken away from the NPN transistor and the relay will de-energise switching the system off.

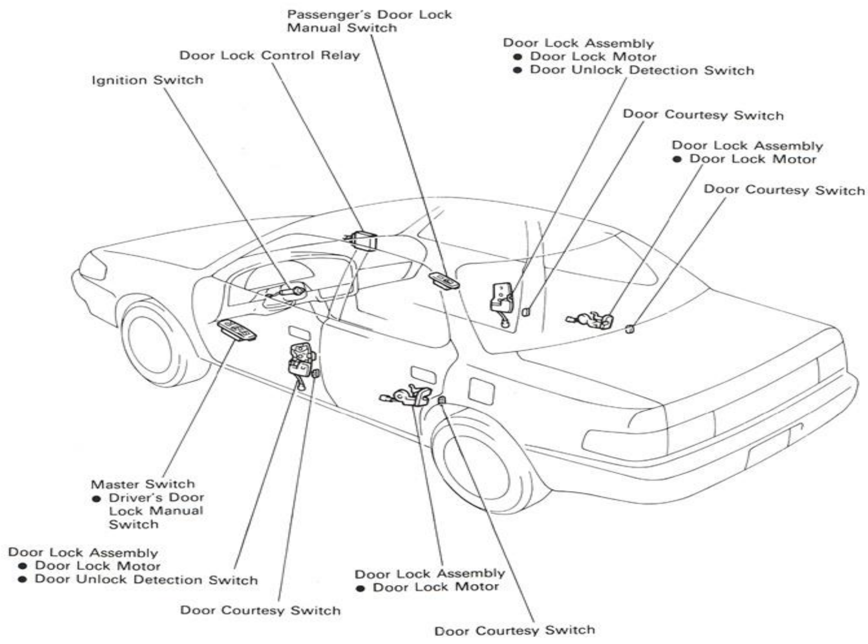
It can be seen that the switch is illuminated via a bulb that is operated directly by the taillight circuit and the brightness of this bulb can be influenced directly by the dimmer rheostat on the dashboard. The illumination simply helps the driver to locate the switch in the dark!

It should be noted that some manufacturers provide the ECM (switch assembly) with a temperature sensor, which makes for a fully automated system usually triggered at 4 degrees C.

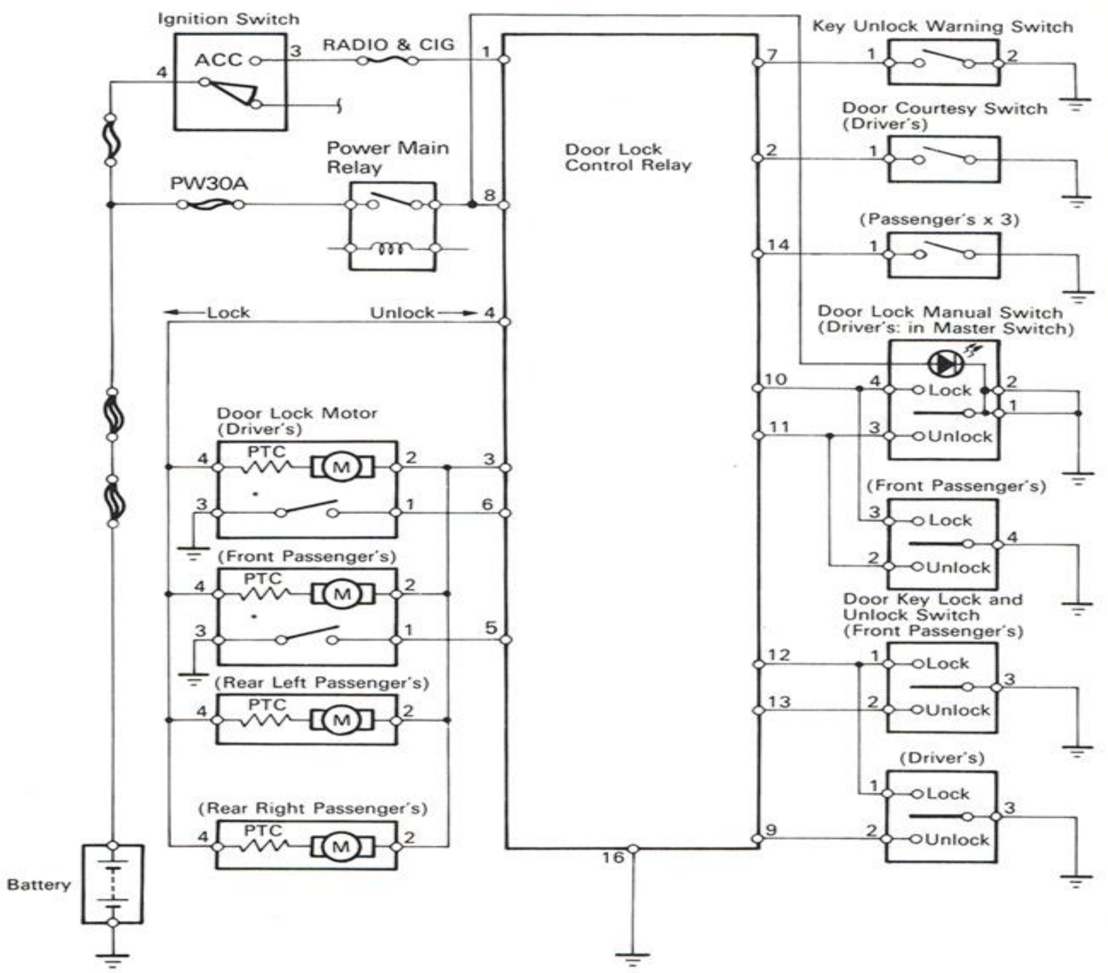
Door locking

This circuit is designed to facilitate the unlocking of all doors via a single operation at one lock assembly. Typical locations for the key components can be seen below.

The circuit



Circuit operation



Manual lock

All doors on the vehicle can be locked and unlocked simultaneously from either the driver's door or the front passenger door key cylinder or manual switch mounted to the door.
If the driver turns his key in the key cylinder, a ground is provided to terminal 12 of the ECM (door lock control relay). Upon detection of this ground, the ECM energises the power main relay and current now flows into the ECM at terminal 8 back out again at terminal 4, into each door lock motor at terminals 4, out of the motors at terminals 2, back into the ECM at terminal 3 and down to ground at terminal 16.

The current flowing through the door lock motors at this point cause all doors to lock.

Manual unlock

When the driver turns his key in the key cylinder towards the unlock position, a ground is provided to terminal 9 of the ECM. Upon receipt of this signal the ECM energises the relay and current now flows from terminal 8 to terminal 3 of the ECM, into each door lock motor at terminals 2, out of each motor at terminals 4, into the ECM at terminal 4 and down to ground at terminal 16. It can be seen from this latter action that current is now flowing through the motors in the opposite direction causing a reversal of movement i.e. the doors unlock.

This action is mirrored when the door lock / unlock switches are operated.

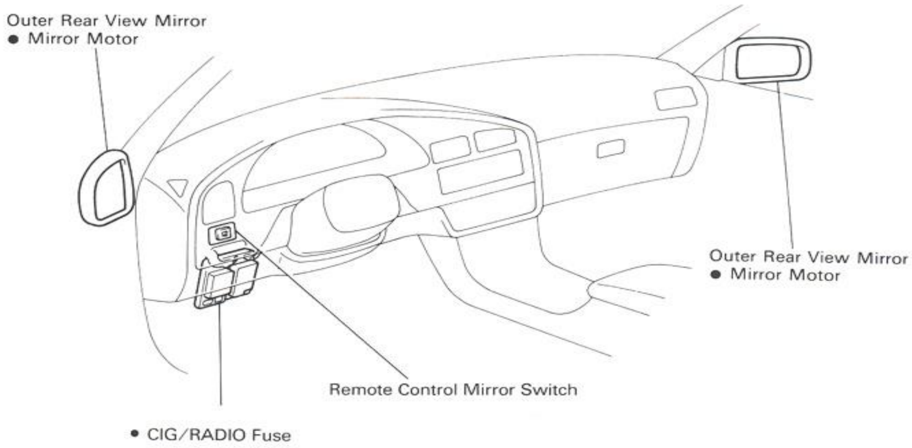
Ignition key reminder facility

The ignition key cylinder has a key unlock warning switch integrated with it. This switch closes when the key is inserted. The closing of this switch provides a ground signal to terminal 7 of the ECM. The presence of this signal ensures that any activity that could result in the keys being locked in the car will be prevented – the ECM will not allow the door lock motors to operate.

Door mirrors

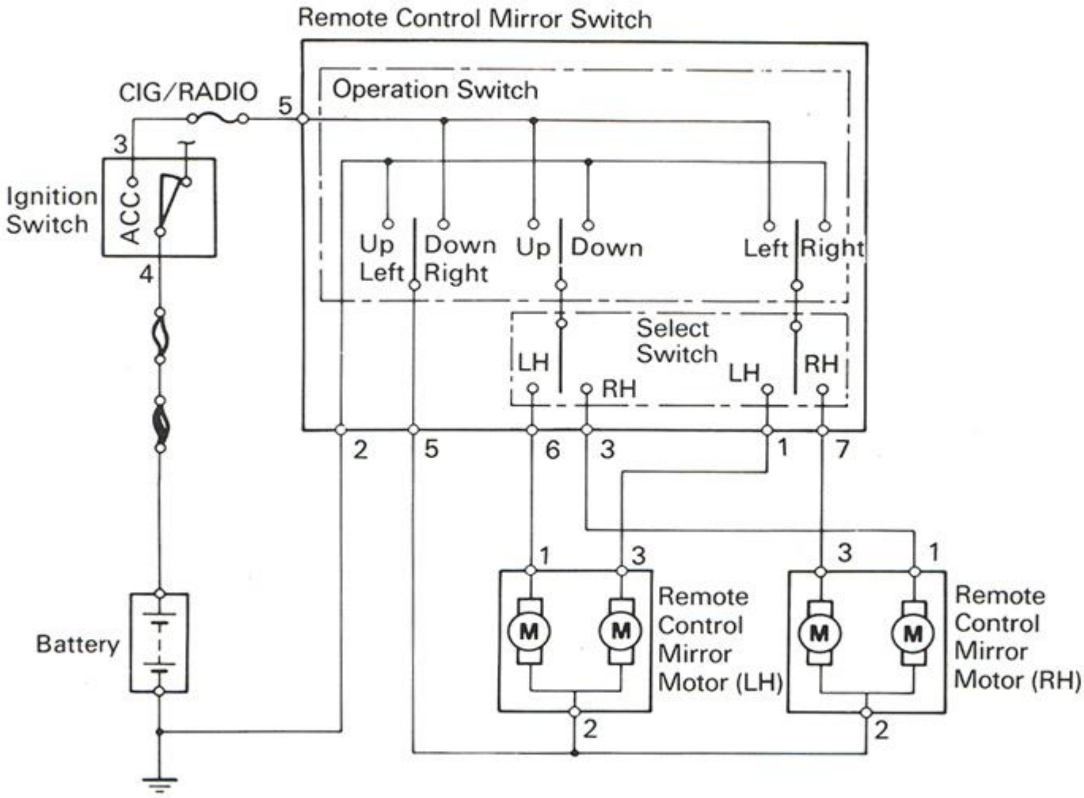
This circuit is designed to facilitate remote adjustment of both wing mirrors in two planes – up / down and left / right. Typical locations for the key components can be seen below.

The circuit



Circuit operation

Each mirror has two motors – one to control up and down movement, and one to control left and right movement. A single motor is able to move in two directions by reversing the current flow through it (reverse the polarity).
The remote control mirror switch is actually two switches in one; a selection switch that allows the driver to choose which mirror he wants to adjust, and an operation switch that dictates the direction that that mirror is to move in.
We will study the following operation in order to gain an understanding of the circuit:



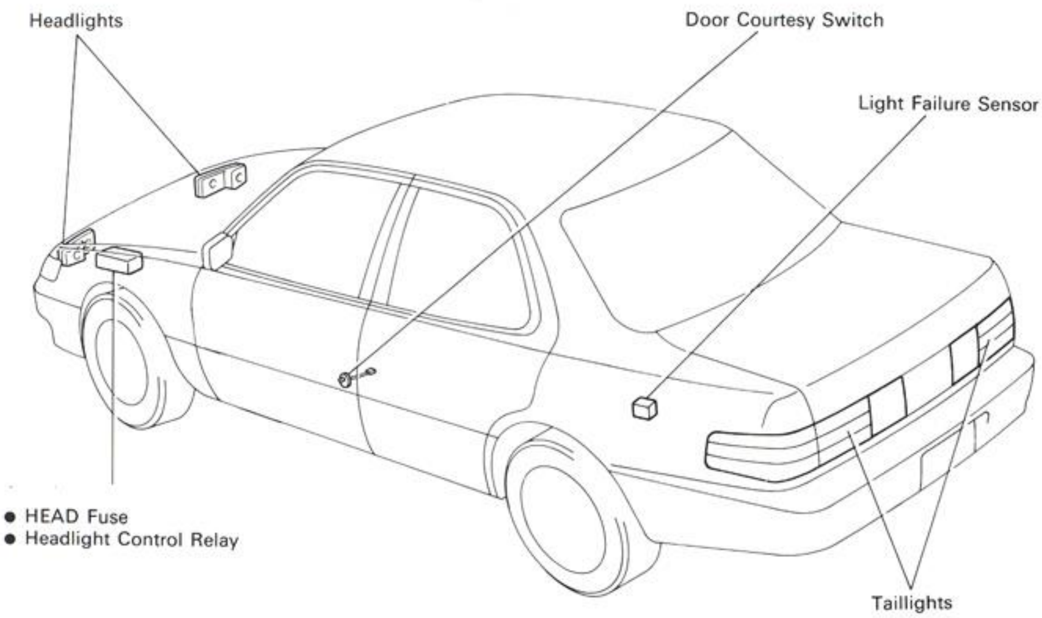
Left hand mirror tilt up

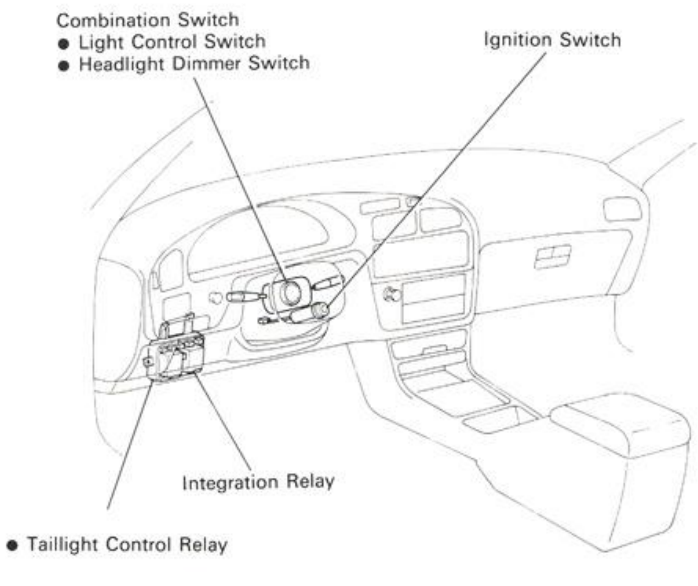
The driver selects the left hand mirror and when this is done the two contacts in the select switch adopt the LH position. The driver now moves the operation switch to the Up position. When this is done, any contacts in the operation switch that are Up applicable will move to that position (the two left most switches in the circuit diagram).

Current can now flow through the ignition switch (terminals 4 and 3) and into the switch assembly at terminal 5. This current flows across the centre switch contact (that is in the Up position) into the select switch and through the LH contact.

At this point the current flows into the left hand mirror at terminal 1, through the motor assembly, out of the mirror at terminal 2 and back into the switch assembly at terminal 5. The current then flows through the Up contact of the operation switch and down to ground via terminal 2. The left mirror tilts up.

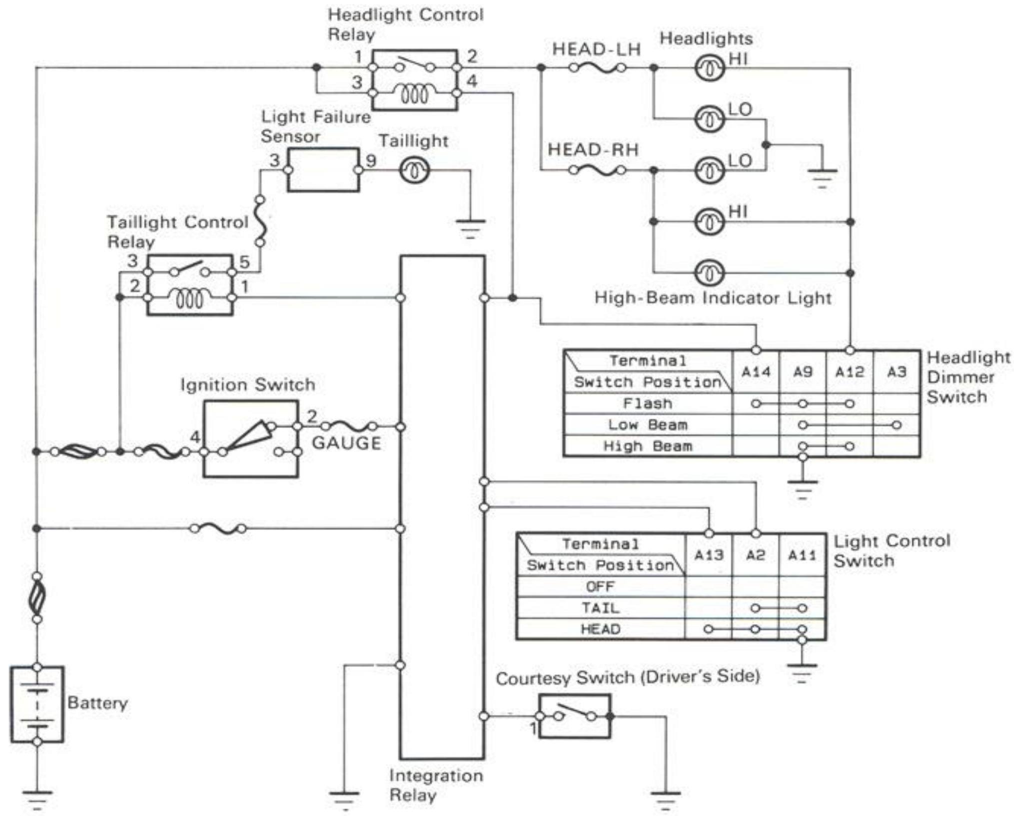
Headlights and taillights





This circuit enables the driver to turn on the taillights, the headlights (low beam and high beam) and also provides a flash facility. The major components can be seen below. The example described here also has the ability to detect a failed taillight bulb.

The circuit



Circuit operation

The headlight switch is in effect two switches in one – the light control switch that is used to control the switching of the lights to side and tail only or full lights and the headlight dimmer switch, which enables the driver to select full beam, low beam or flash.

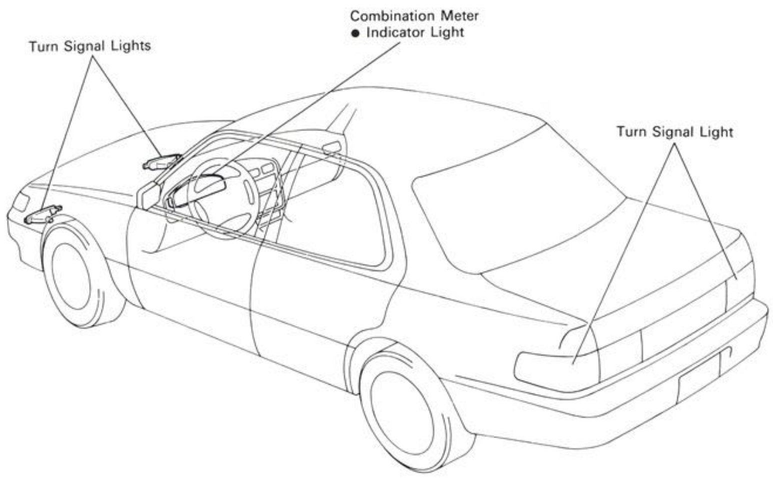
The integration relay is an ECM charged with correct control of the lighting circuit. There are two conventional relays, one for the supply of current to the taillights and the other for supply of current to the headlights.

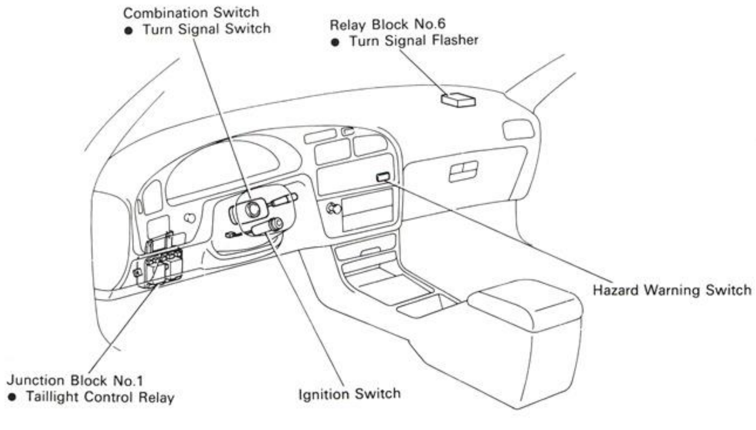
When the driver turns the light control switch to the 'Head' position all three contacts in line with the 'Head' switch position on the diagram become connected. This provides a ground to terminals A13 and A2, which the integration relay detects. Upon detection, the integration relay energises the taillight relay and the headlight relay thus providing current to both the taillights and the headlights. It can be seen from the circuit that the taillights and the low beam bulbs have their own permanent ground but the headlight main beam bulbs seek a ground via the headlight dimmer switch. This they will only receive if the driver has the switch in the high beam position (they ground via the A12 terminal).

It can be seen from the circuit that the flash function grounds the headlight control relay directly (bypassing any control from the integration relay).
The driver's courtesy light switch is connected to the integration relay to indicate to the relay that the driver has opened the door. If the lights are still on at this point, an audible warning will sound.
The light failure sensor is able to monitor the current flowing to the rear lights and will illuminate a warning lamp on the dashboard when any significant reduction in current flow can only be attributed to lamp failure.

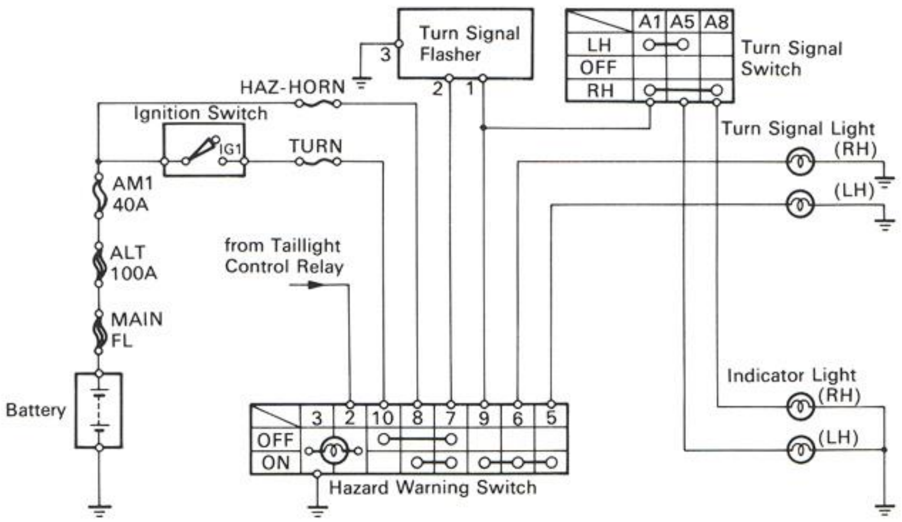
Direction indicators

This circuit enables the driver to operate the directional indicators on the vehicle. It also enables the driver to operate the hazard warning lights. Typical locations of the major components that make up this circuit can be seen below.





The circuit



Circuit operation

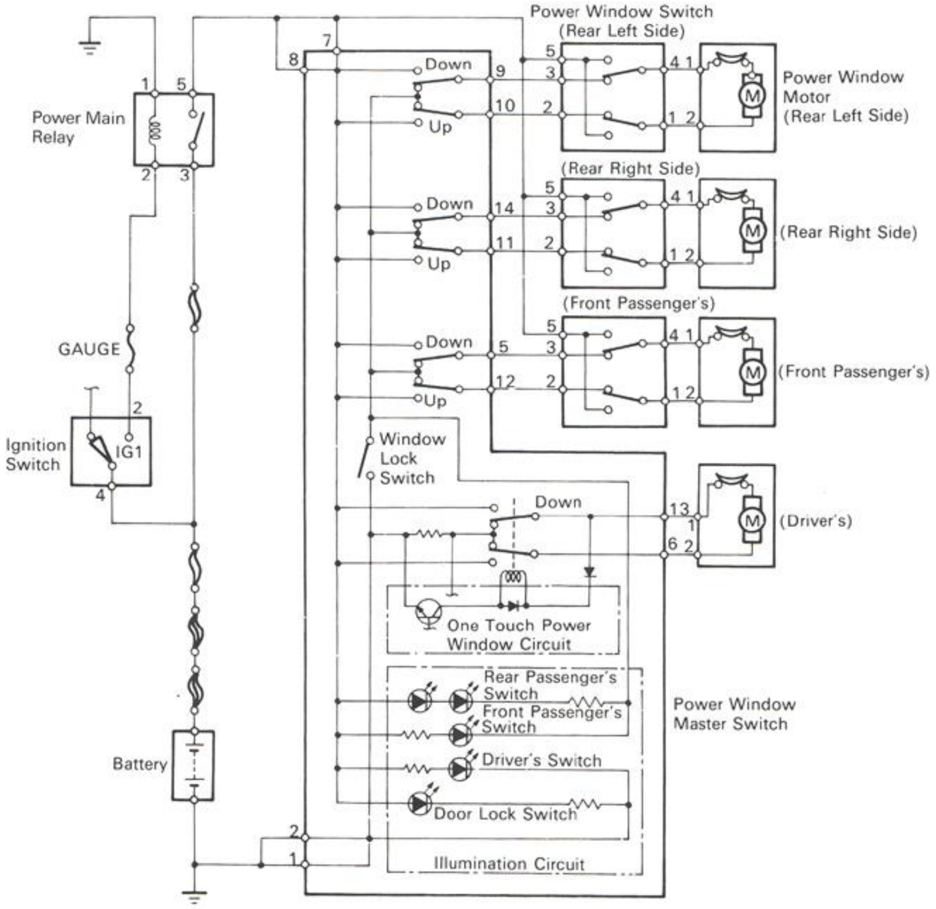
With the hazard switch in the ‘off’ position, battery voltage is applied from the ignition switch to the turn signal flasher at terminal 2 via terminals 10 and 7 of the hazard warning switch. When the driver moves the turn signal switch to the ‘left’ position, the turn signal flasher alternates the supply of current to the left indicator lamps acting on an internal timer circuit. The turn signal switch directs this control to the right indicator lamps if the driver moves the switch to this position.

If the driver turns on the hazard switch, battery voltage (not ignition controlled) is applied to terminal 2 of the turn signal flasher via terminals 8 and 7 of the hazard-warning switch. The turn signal flasher then sends its signal to terminal 9 of the hazard-warning switch. From here, the signal is sent via terminals 6 and 5 of the hazard-warning switch to all four indicator lamps.

Power windows

This circuit enables the driver to operate the windows (all four) from the driver’s master switch and the passengers to operate their personal window from their own door-mounted switch. Typical locations of the major components that make up this circuit can be seen below.

The circuit



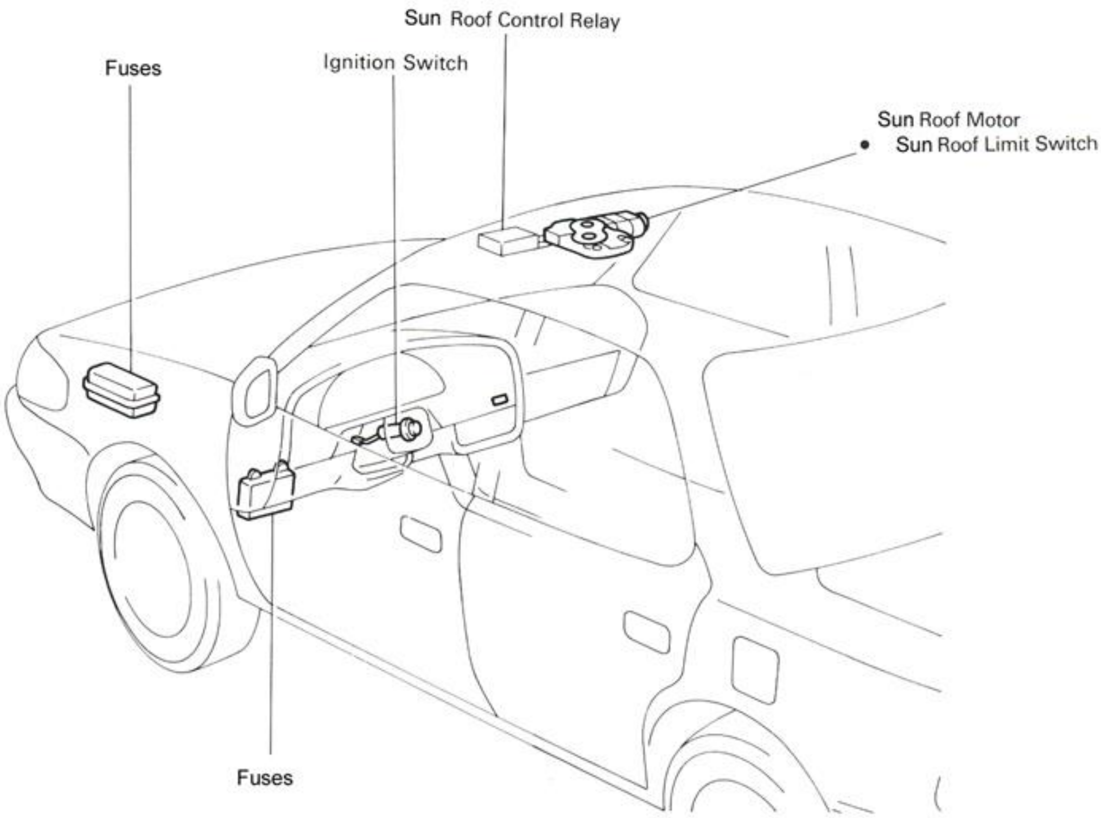
Circuit operation

To understand this circuit, we will study the operation of the front passenger window from the front passenger window switch.
When the driver turns on the ignition, the power main relay is energised. This then applies battery voltage to terminals 7 and 8 of the power window master switch (driver's door) and terminals 5 of the other window switches.
If the passenger now puts their switch in the down position, the switches position will enable current to flow from terminal 5 to terminal 4 of the passengers switch and via the loom to terminal 1 of the power window motor through the circuit breaker and motor, back out of the assembly at terminal 2 and back into the passengers switch at terminal 1. The current now flows across the contact of the switch and out from the switch assembly via terminal 2, into the power window master switch at terminal 12 across the 'Up' contact, down through the window lock switch (which will be closed unless the driver has chosen to isolate the windows) and down to ground via terminals 2 and 1 of the master switch.

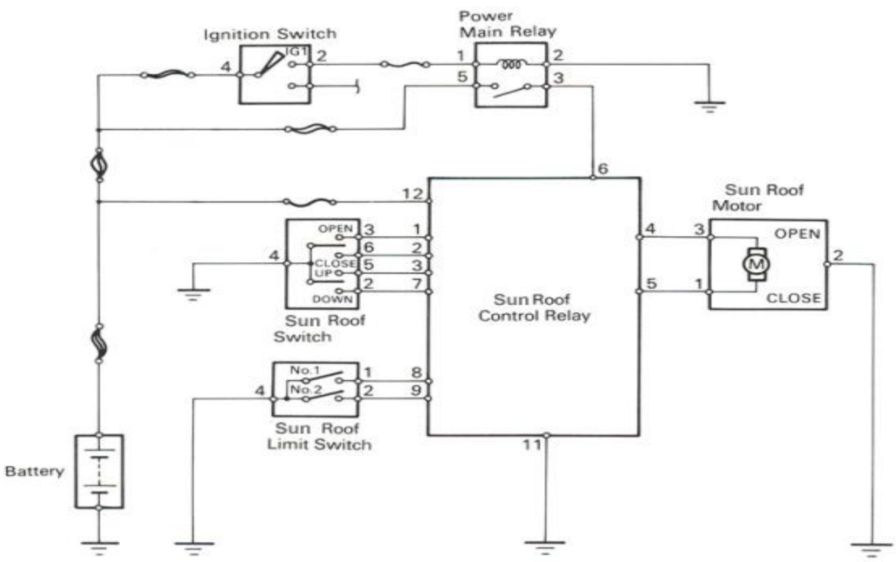
Sunroof

This circuit facilitates control of the sunroof. This assembly is able to tilt up (and back down) and can also open fully (and close fully). This type of sunroof is often referred to as a ‘slide and tilt’ sunroof.

The major components that make up this system can be seen below.



The circuit



Circuit operation

When the driver turns the ignition switch on, the power relay energises and applies battery voltage to terminal 6 of the sunroof control relay (again, a simple ECM). When the sunroof switch is moved to the open position a ground is provided to terminal 1 of the sunroof control relay via terminals 3 and 4 of the sunroof switch. Upon receipt of this ground signal, the sunroof control relay connects terminal 6 (relay supply) to terminal 4, which allows current to flow through the sunroof motor in a direction that opens the sunroof. The ground route for this current is via terminal 1 of the motor, terminals 5 and 11 of the sunroof control relay.

The sunroof limit switch assembly breaks contact relative to sunroof position i.e. fully open / fully closed and upon receipt of this signal, the motor will cut out regardless of continued operation of the sunroof switch.
The ‘Up’ and ‘Down’ contacts of the switch indicate to the sun roof control relay that the operation required is limited to tilt up and tilt down. The motor is operated accordingly.

SRS (supplementary restraint system)

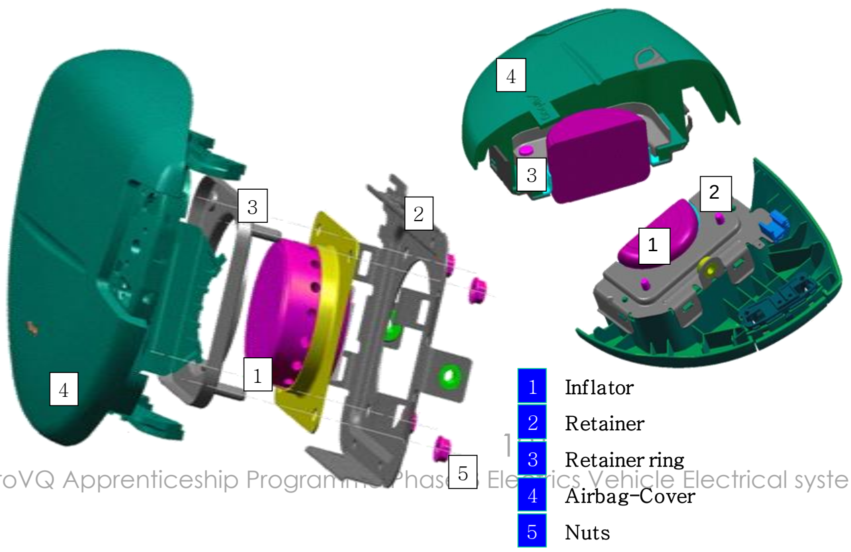
Airbags are positioned to protect the driver and passengers in the event of impact from virtually any direction with the exception of rear end shunts (where the head restraint is of primary importance). Driver’s airbags are housed within the steering wheel pad, passenger airbags within the dashboard, curtain shield airbags in the roof runner trim and side airbags in the seat back. They are fitted to protect the driver’s knees and there are also airbags that deploy across the front screen. Rollover protection airbags can now be found under roof linings on high specification vehicles.

Seat belt pre-tensioners work in conjunction with frontal protection airbags. Upon deployment of the front airbags, explosive charges will pull you back into your seat preventing you from going forwards into a deploying airbag. The importance of wearing seatbelts in a vehicle equipped with airbags cannot be over stressed. Without this restraining mechanism, airbags can indeed be lethal. Hence the term SRS – *Supplementary* Restraint System.

SRS airbag

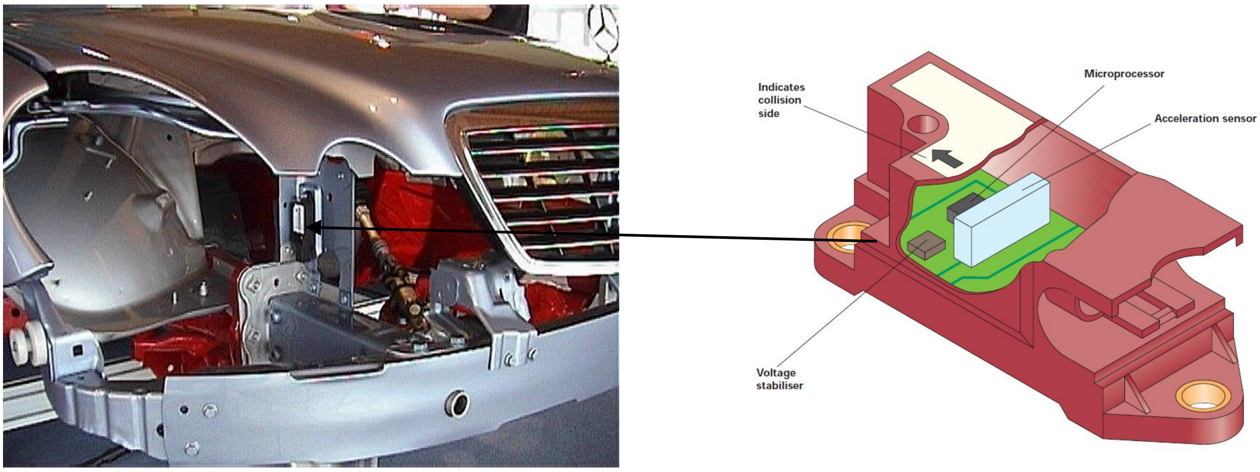
So, how do they work

Airbags are misnamed because its nitrogen gas that fills them. This comes from a chemical reaction. Sodium azide, potassium nitrate and silica react in an explosion to produce hot expanding nitrogen and silicate (glass powder) in a fraction of a second. The squib as it is often referred to, is ignited by an electrical current from the vehicles battery. You are unlikely to ever take one apart but here's whats inside .



Crash sensors

Sensors are situated in strategic places around the vehicle and are often difficult to find on an assembled vehicle. They detect large changes in velocity. Usually they are marked with an arrow to indicate the direction of the impact they are detecting.

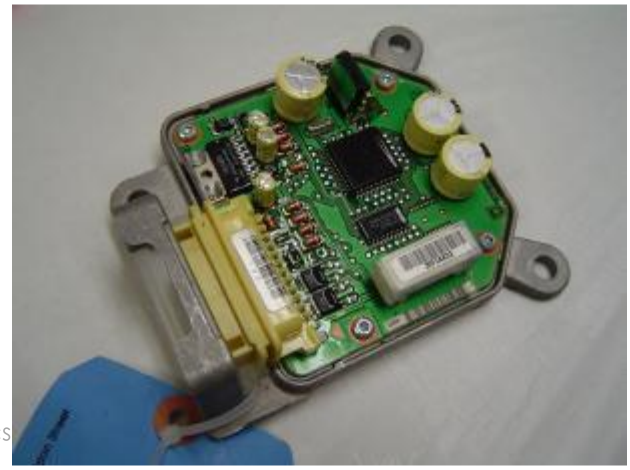


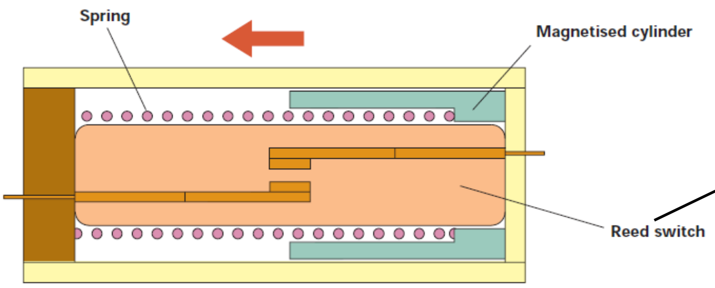
Signals from the sensors are analysed by the SRS control unit to identify the need to deploy the air bag.

Safing sensor

To avoid confusing someone kicking the front of the vehicle and a real, life threatening impact, a second sensor must confirm a serious deceleration, it is situated inside the SRS control unit.

The safing sensor does this. It is made up of a reed switch which is normally open, a magnetised cylinder and a spring. When a deceleration greater than the spring force, takes place, the cylinder moves over the reed switch and when it is just over the switch, the magnetic field closes the switch and sends a signal to the microprocessor in the control unit.





Note the three large canister type capacitors which hold enough charge to deploy the airbag should the battery become disconnected during the impact.

Spiral Cable

Unless you drive a new Citroën C4, C4 Picasso or a C5 you will notice that the driver's airbag turns with the steering wheel. This means that the electrical connection to the air bag igniter has to allow for this. This is done by the spiral cable sometimes known as the clock spring. It is a rotary coupling, is fragile and has to be carefully centralised on assembly. It can also carry multiplexed data from the controls on the pad and independently the horn signal. It is a common failure item which brings the SRS warning light up.

It is not recommended that you take one apart as in the photograph. It can be identified as a problem with a trouble code and tested with an Ohmmeter for continuity and resistance, always refer to manufacturer procedures before commencing the diagnosis. The spiral cable sits just behind the steering wheel. Its removal will be dealt with in a later article in this series.

The wiring of the SRS is identified by it's bright yellow colour. It is there as a warning. Any electrical testing should be done with great care. Removal of components should be done with the battery disconnected and a sufficient time allowed for the capacitors to discharge. Always refer to manufactures procedures when working on SRS systems as failure to do so could result in air bag deployment.

Pre tensioner

Although airbags have saved countless lives over years the real experience of the crash protection system can be traumatic. In countries where the wearing of a seatbelt is not compulsory and not worn the deploying airbag can cause injury. The problem is that the air bag is generally a "one size fits all" device. Impacts can vary in direction and speed, passengers in size and weight as a result the force of the airbag can be either excessive or insufficient. The combination of the seatbelt and the airbag reduces the chance of injury caused by the collision by restraining the occupants. When a crash occurs there is sudden change in velocity, the body's momentum means that it moves forward with a massive force. It is this force that the airbag has to cushion. If this can be shared by the seatbelt then the demands on the airbag are reduced. Here comes the problem. If the seatbelt is loose, unrestrained movement can take place before the slack in the belt is taken out. This hammer effect can cause injury to the skeleton and internal organs. The seat belt pre-tensioner takes out the slack in the belt at the point of impact.

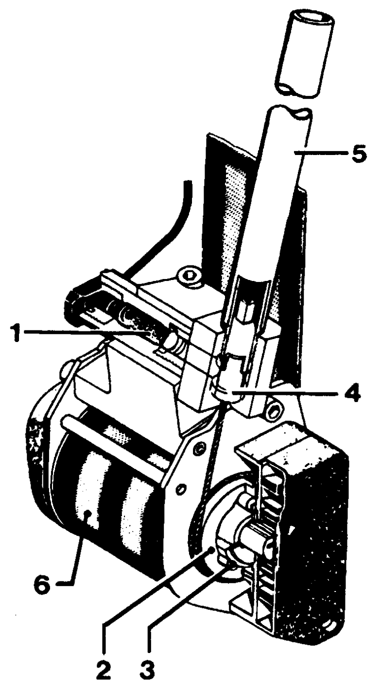
How do they work?

Like an airbag, the pre-tensioner is a pyrotechnic device (explosive).

There are two main types, piston and spool, either of which could be mechanical (old) or electronic. The mechanical type has its own integrated inertial sensor (similar to the mechanical airbag) and the electronic type is fired using current supplied by the SRS ECU. Seat belt pre-tensioners can deploy simultaneously with the front airbags only or separately dependant on the severity of the crash. This needs a more sophisticated crash sensing and logic system. Some are even deployed in the event of a rear end shunt

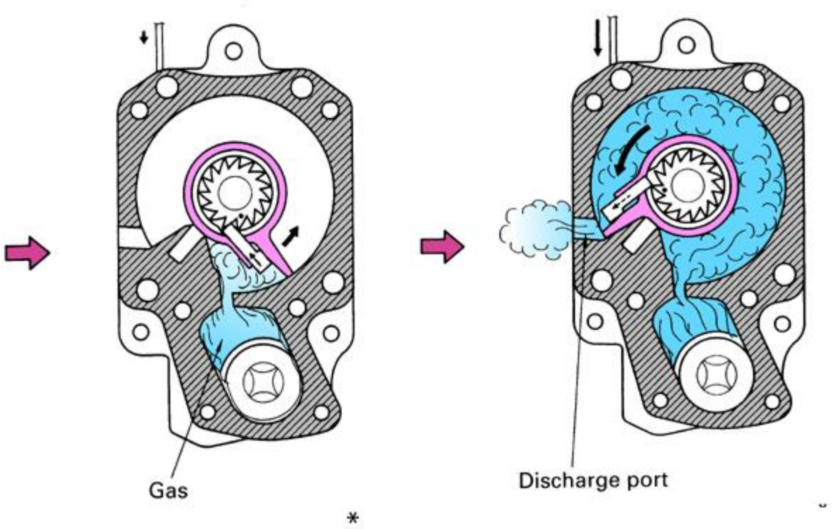
Piston type

The piston type (pictured right) is attached to the spool but can also be fitted to the buckle side. The igniting charge generates gas in the same way as a conventional airbag and the gas pressure forces the piston (4) up the cylinder. The cable attached to the piston rotates the drum (2) tightening the seatbelt or retracting the buckle.



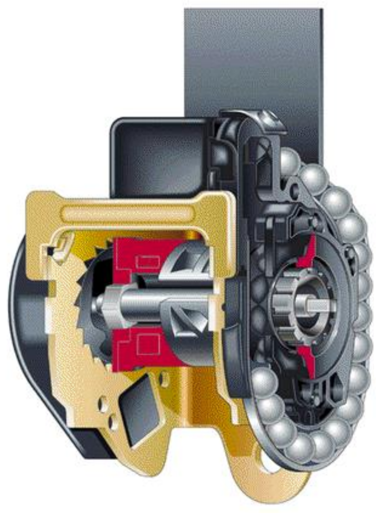
Spool type

The spool type uses a rotor to harness the gas pressure and rotate the drum.
The picture below shows the device in two stages of deployment.
This type is far more common than the piston type due to its compactness. This makes it far easier to house at the bottom of the vehicles B post.



Another type of seat belt design makes for a more compact unit. It uses steel balls (3) instead of a cable and piston. When the seat belt tensioner is triggered electrically by the SRS module, the balls accelerate through a tube due to the gas pressure created by the gas generator. The inertia of the accelerated balls is converted into a rotary action by the pinion (5) which in turn acts on the belt reel (6) to retract the belt. After the tensioning operation is complete, the balls are contained within the ball trap to stop them jamming the seat belt mechanism. The remaining balls are still located within the tube. One advantage of this design is that the inertia mechanism still functions as a seat belt after it has been deployed. It also incorporates a belt force limiter. The spool is attached to a deformable tube incorporating a torsion bar which allows the belt to unreel against a spring force.

Many manufacturers now fit belt force limiters of different designs as standard. These limiters combine with the belt pre-tensioners and airbags to reduce still further the chest and neck level crash forces acting on the driver and front passenger.



Like airbags, seatbelt pre-tensioners must be treated with respect. Remember, they are explosive devices.
Before removing pre-tensioners, they may need to be made safe through the use of an integral safety mechanism. This process varies between the manufacturers so it is essential to observe manufacturer's instructions when working on such systems.

Development

Manufacturers are using research and more sophisticated airbag technology to protect the occupants of the vehicle from impacts received from more than just the head on direction. This has resulted in the production of

Side airbags

Side curtain shield airbags

Knee airbags

Anti Slide airbags

Rear curtain airbag

All of the above airbag systems are fitted inside or behind the interior trim which means that pyrotechnic inflators are unsuitable due of their shape and the amount of heat they generate so a new generation of inflators have had to be developed.

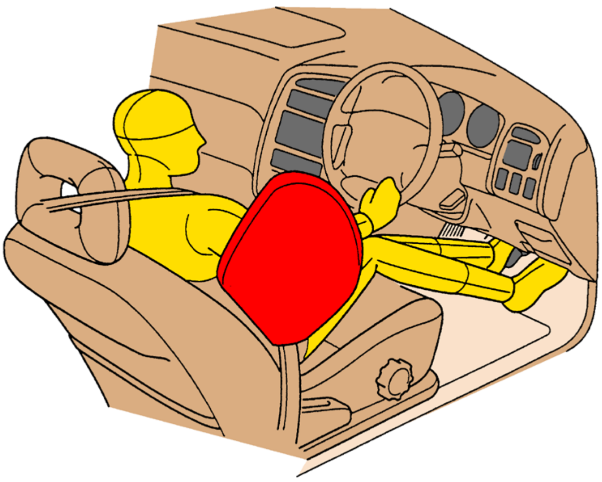
Compressed gas inflators

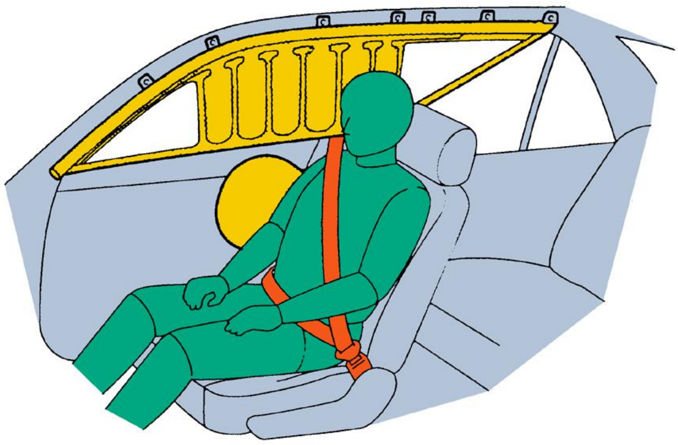
These inflators contain compressed nitrogen, argon or helium at very high pressure A compressed gas inflator is in the shape of a long cylinder which lends itself to door panels, instrument panels, seat backs, and the rails and pillars that make up the side of the vehicle. Compressed gas inflators don't generate massive amounts of heat whereas pyrotechnic inflators could ignite the trim material surrounding it.

Some compressed gas inflators use an internal pyrotechnic heating device to compensate for the cooling effect, resulting from the expansion of the compressed gas when the airbag deploys. These are potentially dangerous devices and technicians should always use proper procedures when working with them. They also create a potential hazard for fire and rescue workers cutting through a rail or pillar to rescue occupants.

Side airbags and side curtain shield airbags

Side impact accidents account for a large proportion of road casualties every year. There is less crumple zone to the side of the vehicle so not only is the risk of injury greater but the time available for deployment is reduced. Side airbags and curtain shield airbags are designed to reduce injury in this event.





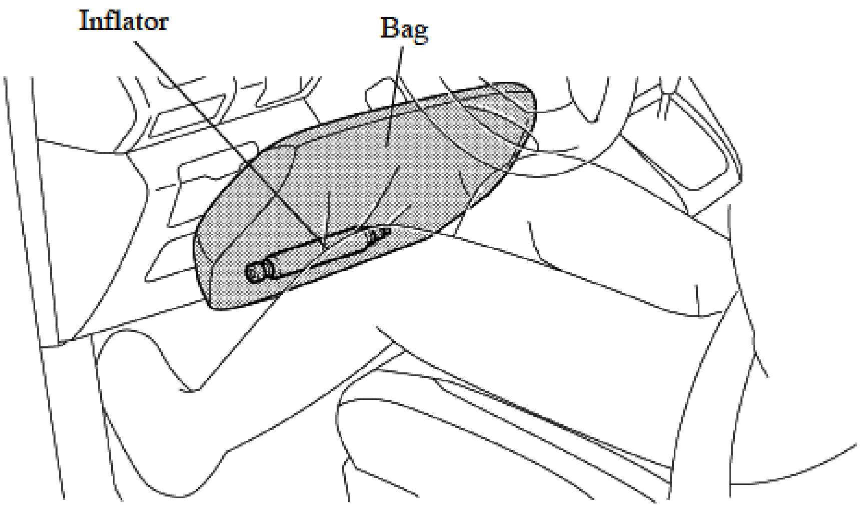
How do they work?

The operation of side and curtain shield airbags is very similar to that of driver and passenger airbags. The key difference is the provision of additional crash sensors designed to detect impact from the side. These sensors work in an identical way to those already discussed but they are normally far quicker in their ability to react. These sensors are normally mounted at the bottom of the vehicles B posts.

Anti-submarining Devices

Front airbags can only do their job if the occupants are in the right position. Seatbelts and pre-tensioners prevent forward movement of the upper body but if the driver's lower body slides under the seat belt, not only will the knees crash into the dash, but the head and face become lower in the seat. The airbag will now contact the top of hte head not properly cushioning it from the impact

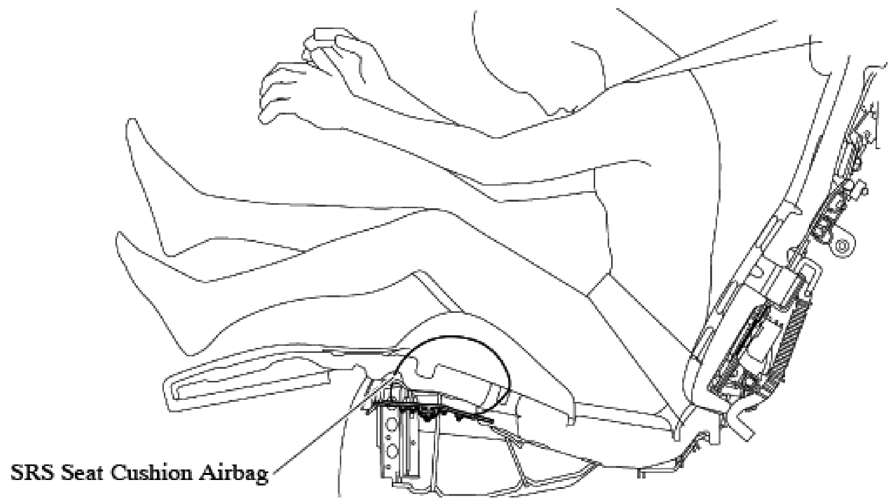
Knee bag



Knee airbags were some of the first of these devices to be developed and are still the most commonly used. These devices are actually multi purpose, they not only stop the submarining effect, holding the occupant in place but, they also protect against leg and hip injuries.

Seat cushion inflators

The device pictured is fitted to the rear passenger seats but can be fitted to front seats. It is designed to prevent the occupant from sliding down and forward under the seatbelt An air bag fitted into the lower front seat cushion becomes deployed in the event of a frontal impact.



Adaptive Supplementary Restraint Systems

Collisions vary in severity and direction and occupants vary in size and weight. What may save a large male driver suffering a high speed impact may injure a child passenger. For a system to become adaptive it must be able to recognise different types of occupants and the severity of the impact. A range of sensors have been developed to achieve this.

Modern crash sensors are not just go- no go sensors they are true decelerometers which can measure the rate of deceleration. Pressure pads in the seat can classify the weight of the occupant. Seat belt sensors or switches indicate whether a seat belt is being used or not. Seat rail sensors can indicate the position of the seat and sensors in a child seat indicate their use. Based on this information the airbag can be deployed at either a high force level, a less forceful level, or not at all.

Dual-Stage Inflator Module

Modern airbag inflator modules incorporate two squib igniters that control the amount of propellant employed. In general, a minor crash impact activates one squib ignite, resulting in slower airbag deployment with less initial force; whereas a severe impact will cause both to ignite. A further strategy is to time them to ignite a few milliseconds apart to produce a controlled inflation.

Dual stage driver's

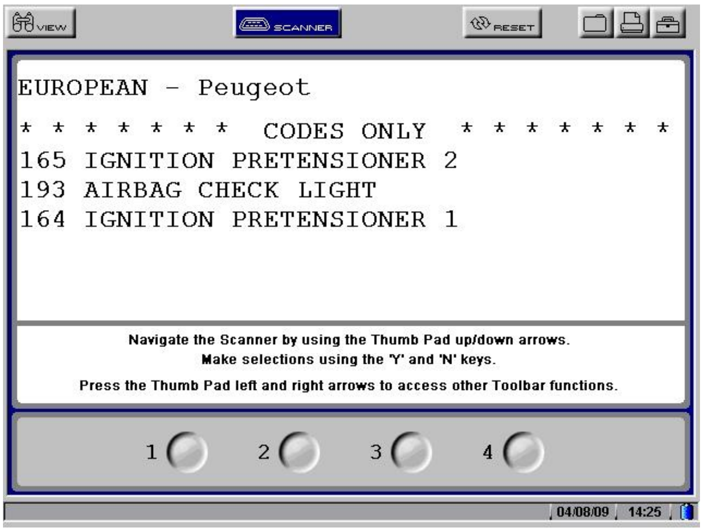
Dual stage passenger airbag. With a warning about undeployed second charges printed on the airbag itself.

What does this mean for the technician?

The dual stage airbag can be identified by the number of wires or connectors on the airbag unit, two connectors or four wires. The important thing to remember is that a deployed airbag may not be fully deployed and is therefore dangerous. If it is to be disposed of you must deploy the second stage. Also remember that if deploying an undeployed air bag for disposal to twist the pairs in parallel to ensure both squibs are ignited at the same time.

Diagnosis

When a technician is confronted with an SRS fault it will normally be because the driver of the vehicle has reported that the SRS light has indicated a fault.
SRS is a passive system; it will not produce running faults so initially you are relying almost completely on the self diagnosis capability of the system. As with any micro-processor system information is King, the more you have the easier the diagnosis will be.



Turn on the ignition and the SRS check light should illuminate for 3 to 6 seconds then go out.
If it does not illuminate it could be that the SRS fuse or bulb has blown or has been removed to disguise an SRS fault.

You will now need to access the code/s stored in the restraint SRS control unit and for this you will need either a scan tool or a method of accessing blink codes. Autodata will provide information on this. It will also provide you with procedures for disarming and rearming the system and much more.

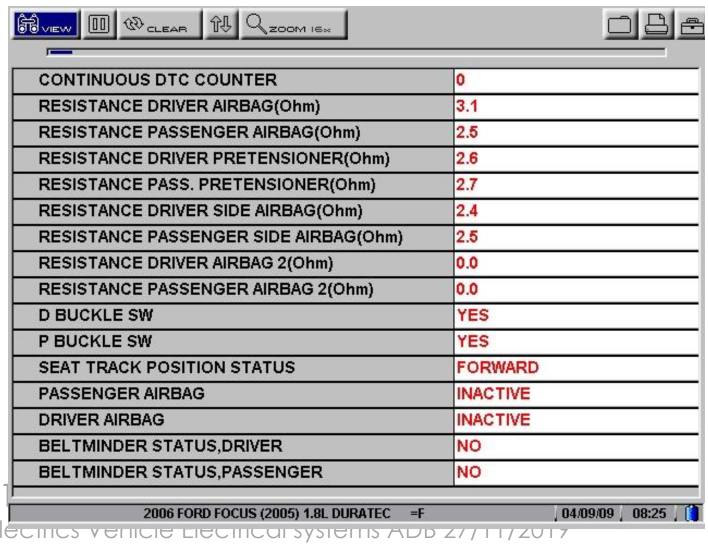
Codes can be general i.e. "Drivers airbag circuit fault" or more specific "Airbag open circuit" .OBDII B codes can be referenced at

http://www.telematica.gr/Tech/OBD/Codes/Body_en.html.

Some systems will give current data which can be very useful. You can see actual values or if the system considers the data normal or not.

Faults are manifold but generally fall into circuit faults ie

Open circuit
Short circuit
Short to ground
Short to battery



CONTINUOUS DTC COUNTER	0
RESISTANCE DRIVER AIRBAG(Ohm)	3.1
RESISTANCE PASSENGER AIRBAG(Ohm)	2.5
RESISTANCE DRIVER PRETENSIONER(Ohm)	2.6
RESISTANCE PASS. PRETENSIONER(Ohm)	2.7
RESISTANCE DRIVER SIDE AIRBAG(Ohm)	2.4
RESISTANCE PASSENGER SIDE AIRBAG(Ohm)	2.5
RESISTANCE DRIVER AIRBAG 2(Ohm)	0.0
RESISTANCE PASSENGER AIRBAG 2(Ohm)	0.0
D BUCKLE SW	YES
P BUCKLE SW	YES
SEAT TRACK POSITION STATUS	FORWARD
PASSENGER AIRBAG	INACTIVE
DRIVER AIRBAG	INACTIVE
BELTMINDER STATUS,DRIVER	NO
BELTMINDER STATUS,PASSENGER	NO

Resistance too low
Resistance too high

We will now consider the diagnosis of a DRIVER'S AIRBAG CIRCUIT.

Any SRS diagnosis should be carried out following the manufacturer's instruction the following is a general diagnostic technique

Disarming the system.

Remove the battery earth lead making sure it cannot reconnect accidentally. Also make sure there is nothing plugged into the cigar lighter socket that could provide a voltage to the system. Follow manufacturer's instructions for wait time (usually 1-2 minutes). This will allow for the capacitors in the SRS ECU to discharge before starting work.

Removing the airbag

Remove the 2 screws from the back of the steering wheel. You may have to remove the steering column cowl to get at them. Carefully remove the connector/s (look for retaining clips) and holding the airbag pad away from you when you carry it. Store it pad up in a safe place. See HSE Documents

http://www.hse.gov.uk/pubns/indg280.htm

Testing the airbag

WARNING. The airbag itself cannot be tested unless otherwise instructed DO NOT USE AN OHMMETER TO TEST THE IGNITER RESISTANCE. This could cause the squib to detonate.

Load simulators

As you can see from the captured data above each of the squib igniters has a resistance value. If you replace the airbag unit with a resistor of an equal value the

SRS ECU will not recognise the difference. Load simulators can be easily made or kits can be purchased.

Resetting the system

Now reconnect the battery and wait for a few minutes. Switch on the ignition. Clear all DTCs Turn the ignition off, then on and Check for fault codes. If the fault has gone then the airbag was faulty and should be replaced. If the same fault reappears check the spiral cable.

Testing the spiral cable

Centralise and remove the steering wheel if necessary to access the spiral cable, replace the resistor into the loom at the other side of the spiral cable. Clear any DTCs then switch the ignition off then on and check for DTCs . If the code has gone then the spiral cable is at fault. Note. Other codes may be present but are not related to this test. Alternatively the spiral cable can be tested whilst disconnected for open and short circuits using an Ohmmeter.

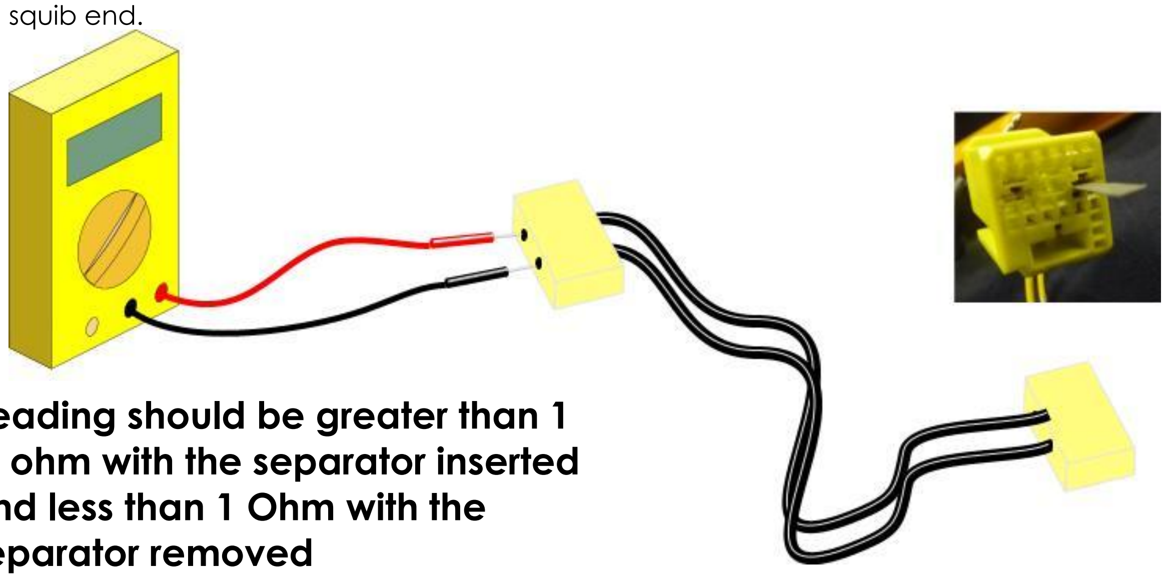
Checking the Airbag circuit for short circuit, open circuit, short to earth and short to battery

Note: Visually inspect all connectors and at all times be careful not to damage the terminals

Many modern looms have shorting pins in the female side of the connectors and at any connectors further in to the loom. When the harness is disconnected from the ECU the shorting pins connect the two igniter wires together to prevent static discharge accidentally detonating the squib.

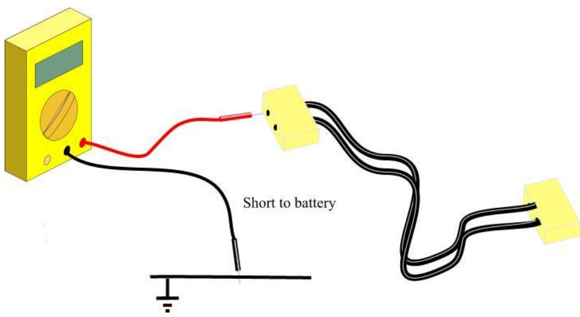
Checking for short circuit and open circuit

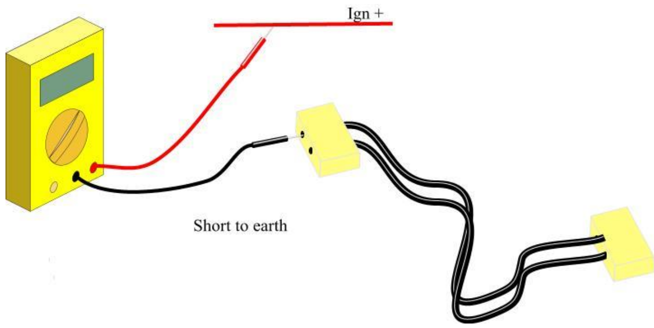
If the circuit is to be tested the system should be disarmed and the loom isolated by disconnecting the loom at both the squib and SRS ECU ends. The shorting pin should then be taken out of circuit by inserting a piece of thin plastic or card to separate the contacts. The harness can now be tested for short circuit with an ohmmeter at the squib end.



Reading should be greater than 1 M ohm with the separator inserted and less than 1 Ohm with the separator removed

Shorts to earth and shorts to battery can be checked by using a voltmeter. Disarm the system and isolate the loom by disconnecting the squib and the connector from the SRS ECU. Reconnect the battery and switch on the ignition. Using the voltmeter test both wires at the squib end connector of the loom for short to earth and to battery



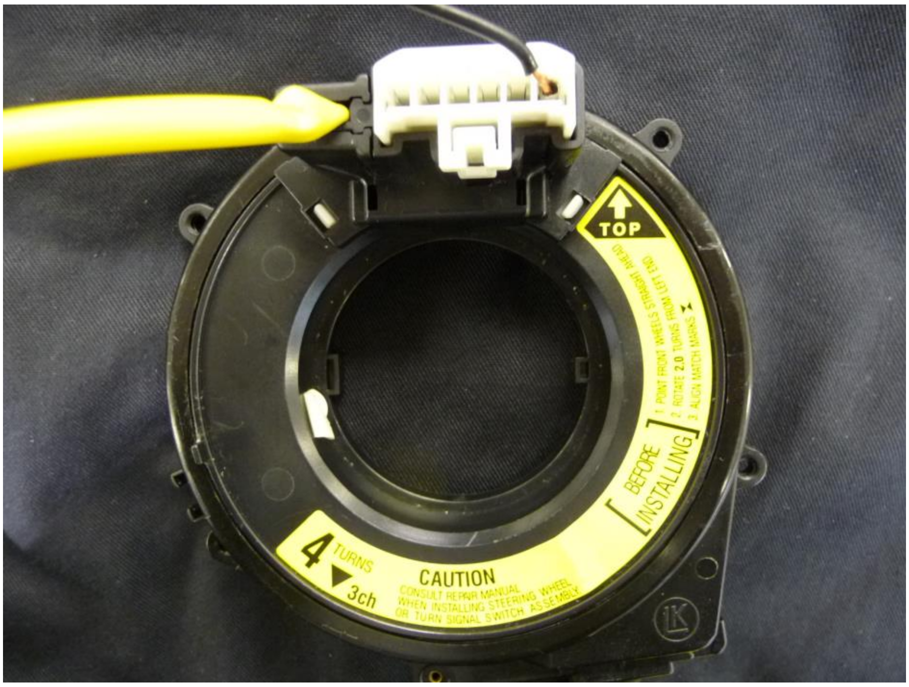


Reading should be less than 1 Volt

If the circuit is found to be serviceable and the DTC still appears one must assume the fault lies in the SRS ECU.

Realigning the Spiral cable

The spiral cable has limited movement and if it has been removed it must be centralised. Holding the unit at its centre, turn the outer part anticlockwise until resistance is felt. Now counting the number of turns rotate it clockwise until resistance is felt. Halve the number and rotate anticlockwise. There will usually be marks to align or some indication of alignment.



Satellite Navigation Systems

In years gone by navigation meant looking to the stars to plot a course or to find your bearings. In latter years it has meant struggling with a paper map.
The United States Navy was experimenting with a satellite based positioning system in the 1960's. The first in-car sat-nav appeared in the 1970's, but this was limited to an arrow pointing on a map or the position of a car on a map.
Things have moved on since then. We have sat-nav fitted as standard in many new vehicles or it is offered as an optional extra. Sat-Nav is also available in portable hand held devices etc.

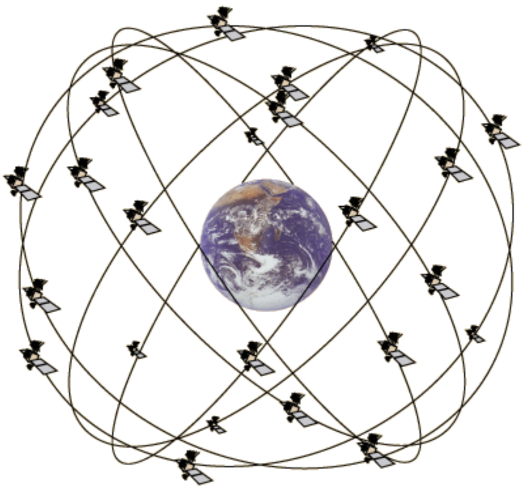
Composite navigation (also known as dead reckoning) - Uses information from additional sensors in order to establish the distance moved and direction of movement of the vehicle. From this information the current position can be predicted (although with less accuracy than with GPS information)

The Global Positioning System (GPS) we have today is owned by the United States Department of Defence. It is used for the military navigation of missiles and troop movements.

Global navigation satellites continuously transmit information as they orbit the earth in a precise formation.

The Global Positioning System is actually a constellation of 27 Earth-orbiting satellites (24 in operation and three extras in case one fails) orbiting the Earth every 12 hours at an average altitude of 12500 miles, scattered on 6 orbital planes equally spaced.
As a result, at least three satellites are always visible at anytime and from any place on earth.

The network was soon opened up to everyone else and hence the introduction of Satellite Navigation in vehicles.



Each satellite transmits radio signals to provide information about the satellite position i.e. latitude, longitude, altitude and the exact timing of the signal emission to earth (almanac data) and an accurate time signal generated by an on-board atomic clock.

Each satellite contains four atomic clocks. Therefore, nothing but a simple receiver is needed to measure the elapsed time between emission and reception of the signal. The satellite to station distance is simply deduced from this travel time.

Three different measurements taken from three different satellites give the three distances needed to determine the ***three coordinates*** of the station position : ***latitude***, ***longitude***, and ***altitude***.

The vehicle needs to receive data from the satellites to give a three dimensional fix on the current position of the vehicle.

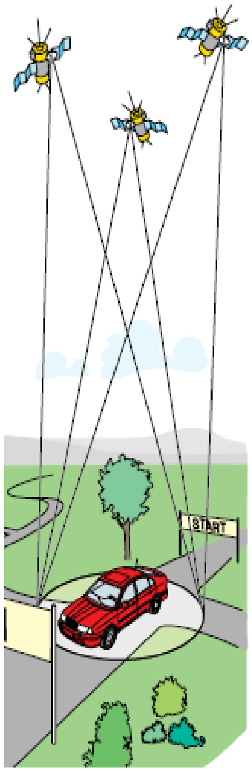
The receiver determines which satellites are 'visible' to the system and their current position and relationship to each other.

Using this information the receiver can account for positioning deviations of the satellites and compensate to enhance the accuracy of the navigation system.

The distance of the receiver from three or more satellites reveals its position on the surface of the planet.

With these distance measurements, the receiver might also calculate speed, bearing, trip time, distance to destination, altitude and more.

A GPS satellite



Measuring Distance

By comparing the time the signals were transmitted from the satellites and the time they were recorded, the receiver calculates how far away each satellite is by multiplying the signal travel time by the speed of light to determine how far the signal travelled.

Assuming the signal travelled in a straight line, this is the distance from receiver to satellite. The distance of the receiver from three or more satellites reveals its position on the surface of the planet.
In order to make this measurement, the receiver and satellite both need clocks that can be synchronized down to the nanosecond. To make a satellite positioning system using only synchronized clocks, you would need to have atomic clocks not only on all the satellites, but also in the receiver itself.

The Global Positioning System has a clever, effective solution to this problem. Every satellite contains an expensive atomic clock, but the receiver itself uses an ordinary quartz clock, which it constantly resets.

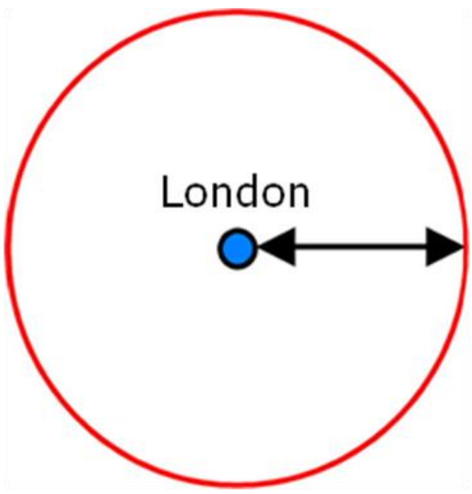
The receiver looks at incoming signals from four or more satellites and gauges its own inaccuracy. In other words, there is only one value for the "current time" that the receiver can use. The correct time value will cause all of the signals that the receiver is receiving to align at a single point in space.

That time value is the time value held by the atomic clocks in all of the satellites. So the receiver sets its clock to that time value, and it then has the same time value that all the atomic clocks in all of the satellites have.
The GPS receiver gets atomic clock accuracy "for free"

2D Trilateration

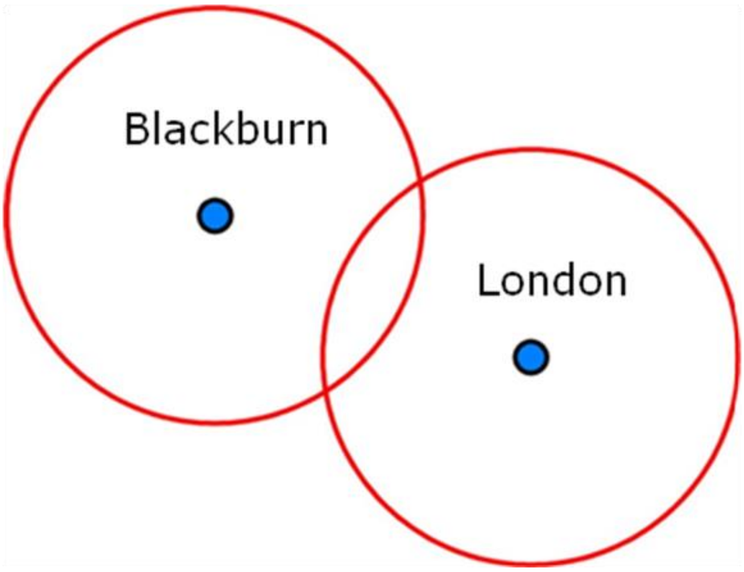
Imagine you are somewhere in the United Kingdom and you are TOTALLY lost - for whatever reason, you have absolutely no clue where you are. A local person tells you that you are, "You are 120 miles from London".

This is not particularly useful by itself. You could be anywhere on a circle around London that has a radius of 120 miles, like this:

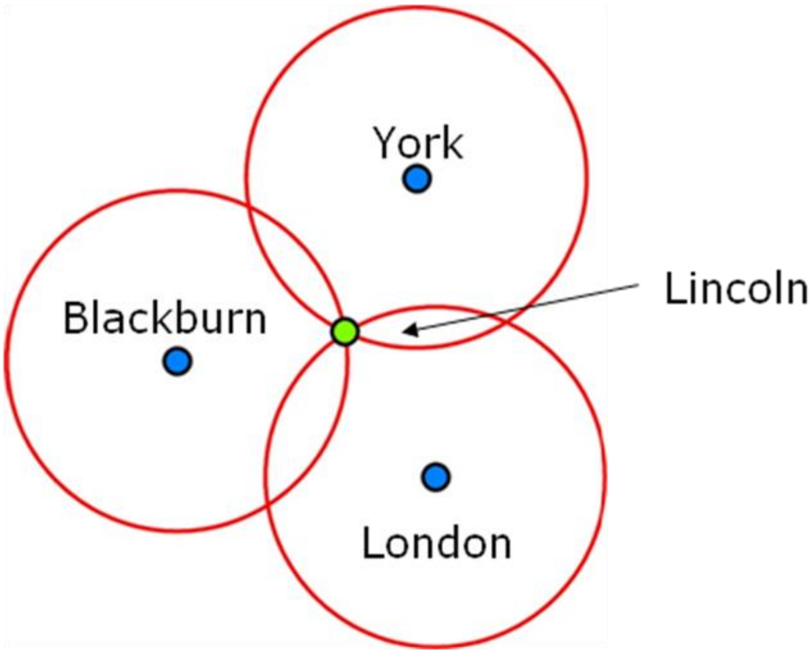


You ask somebody else where you are, and he says, "You are 135 miles from Blackburn" Now you're getting somewhere.

If you combine this information with the London information, you have two circles that intersect. You now know that you must be at one of these two intersection points, if you are 120 miles from London and 135 miles from Blackburn.



If a third person tells you that you are 60 miles from York, you can eliminate one of the possibilities, because the third circle will only intersect with one of these points. You now know exactly where you are -- *Lincoln*.



3D Trilateration

Fundamentally, 3D trilateration isn't much different from two-dimensional trilateration, but it's a little trickier to visualise. Imagine the radii from the examples in the last section going off in all directions.

So instead of a series of circles, you get a series of spheres.

Receivers

A GPS receiver picks up the transmissions of at least four satellites and combines the information in those transmissions with information in an electronic database of maps, all in order to figure out the receiver's (your) position on Earth.

The co-ordinate information is interlaced with the database of maps to display your exact position on a map. This information is updated continually when the vehicle is in motion.

Radio equipment

What is RDS ?

A Brief Introduction to RDS (Radio Data System for VHF/FM broadcasting)

The use of more and more frequencies for radio programmes in the VHF/FM range made it increasingly difficult to tune a conventional radio to a desired programme. This kind of difficulty is solved with the Radio Data System, that has been on the market since 1987, and whose spectacular evolution is still continuing.

RDS has by now conquered all receiver price classes and is nowadays a must in the standard functionality of any radio receiver.

Nowadays, almost 25 years later after that technology was created, almost all FM radios use RDS. ICs have become available that have an FM receiver and an RDS decoder on the same chip and the price for such a chip, if bought in quantities, is now extremely low, say to give the magnitude, only one to three Euro. The trend of this price is still falling and the quantity of such chips sold on the world market is still much increasing, now over 200 million units per year already.

Many applications of RDS are nowadays already within mobile phones and portable network devices. The more traditional car radios have sometimes a separate RDS decoder IC, but RDS decoding is very often an integral part of dedicated multi-purpose DSP's, necessary for the product even without RDS. In these products the RDS function price is then almost zero, as it is done in software only.

The development of RDS started some 25 years ago in the European Broadcasting Union, EBU. The developers aimed at making radio receivers very user-friendly, especially car radios when these are used where a transmitter network with a number of alternative frequencies (AF) are present. In addition listeners should be enabled to see the programme service name (PS) on an eight character alpha-numerical display and the transmitter frequency information, displayed on non-RDS radios, is then only used, in the background, by an RDS radio. All this has become possible by the using, for many years, microprocessor controlled PLL tuner technology, permitting a radio to be retuned within milliseconds. During this process the audio signal is muted which, because of the short time, is usually not detected by the ear. Thus, the radio is able to choose the transmitter frequency, among a number of alternatives that gives the best reception quality. It is also ensured that the switch-over is made to exactly the same programme service by performing a kind of identity check using the programme identity (PI) code.

Travel information with RDS is possible using the Travel Programme (TP) and Travel Announcement (TA) flags.

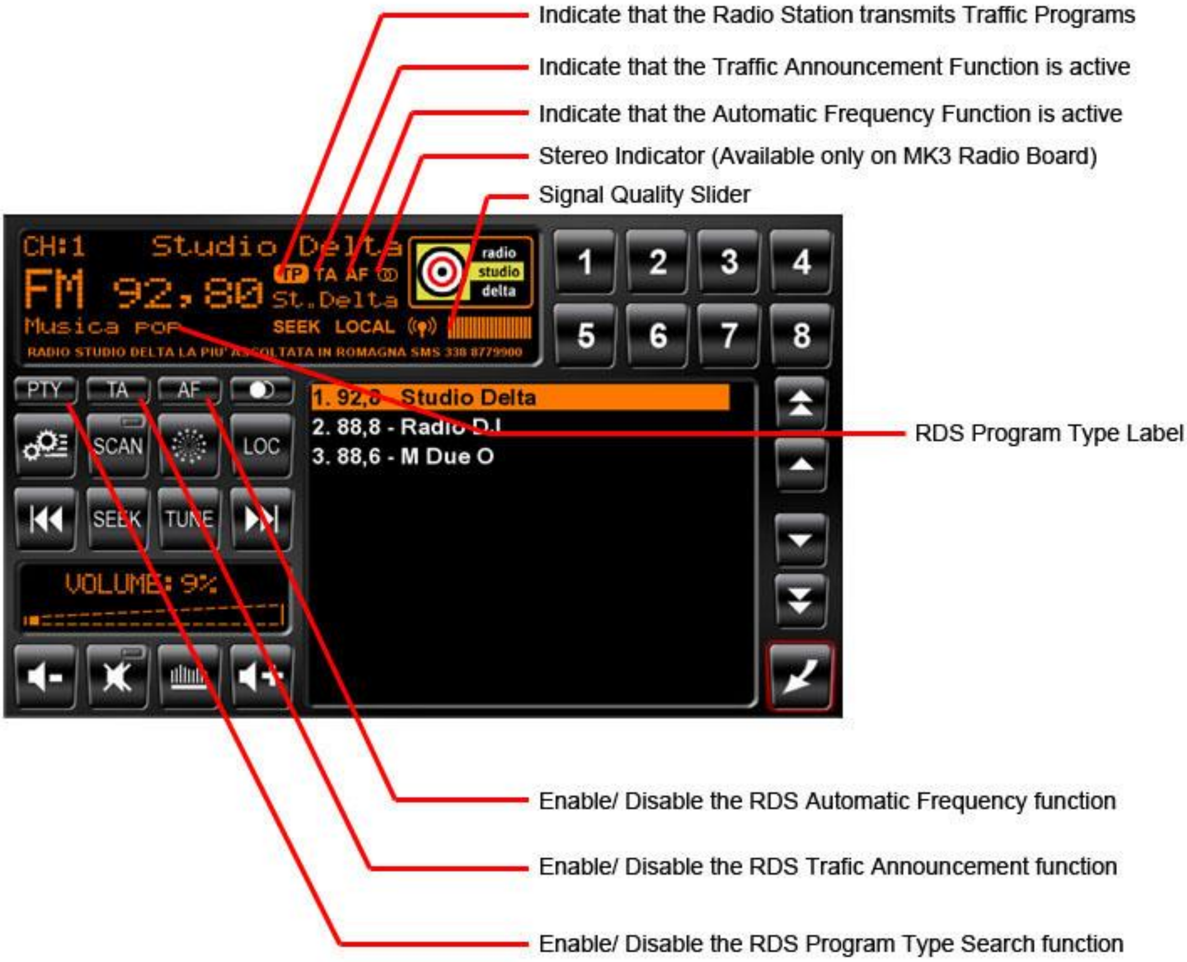
RDS is also used for the digitally coded Traffic Message Channel (TMC), which is widely introduced all over Europe within funded European Union projects. RDS-TMC is nowadays generally used by GPS navigational devices that use the TMC messages also for dynamic re-routing.

Once a radio is tuned to a programme service broadcast within a network, using the RDS feature Enhanced Other Networks (EON) additional data about other programmes from the same broadcaster will be received. This enables the listener, according to his choice, to have his radio operating in an automatic switch-mode for travel information or a preferred Programme Type (PTY, e.g. News) and this information comes from a service that, at a given time, does not necessarily contain such travel information nor broadcasts the desired programme type.

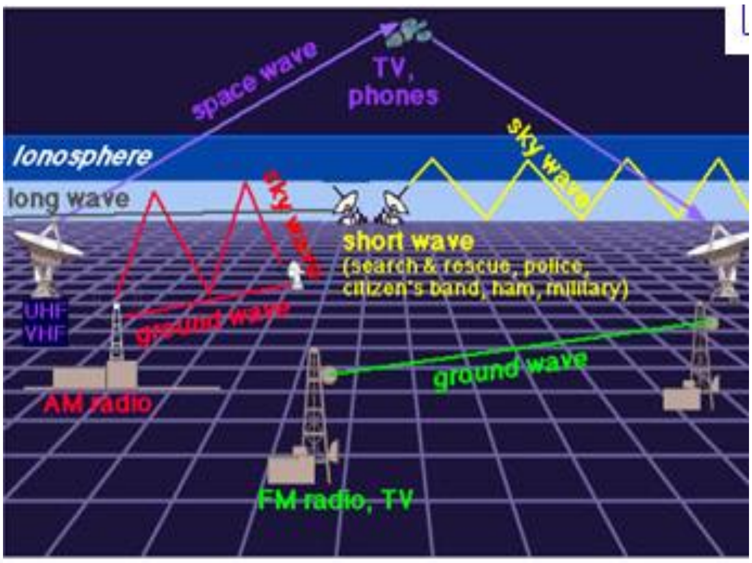
Many of the receivers, apart from the usual RDS basic features (PI, PS, TP/TA, AF), implement also some of the dynamic RDS features such as Programme Type-PTY, Radiotext-RT and Clock-Time, displaying the time/date. Since 2005 the new feature, called RadioText Plus exists and it is already implemented in some receiver models.

The recent developments of highly integrated silicon tuner solutions with embedded RDS functionality has opened up a new range of products to the market. These products, generally of the portable type such as mobile phones and hand-held devices, are now incorporating FM receivers and also short-range transmitters with RDS.

RDS is absolutely future proof and will not be replaced by DAB, at least until such time as when FM broadcasting ceases to exist and this, for sure, is not going to happen within the next 10 years, in spite of the breathtaking developments of the new era of digital broadcasting.



A **radio receiver** converts signals from a radio antenna to a usable form.
It uses electronic filters to separate a wanted radio frequency signal from all other signals, the electronic amplifier increases the level suitable for further processing, and finally recovers the desired information through demodulation and decoding. Information carried on a radio signal may represent sound, images or data.

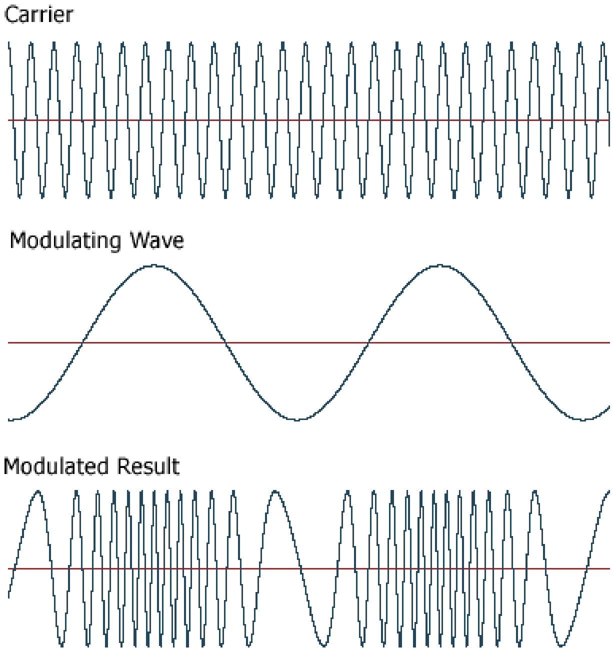


High frequency radio waves can be made to vary in amplitude and frequency during transmission and in this way, an electromagnetic wave can be used as a carrier wave for other signals at different frequencies.

Sound waves are acoustic oscillations and the frequency range of the human ear is approx 20Hz to 20kHz it is therefore possible to superimpose these sound frequencies onto a higher frequency carrier wave in order to transmit them remotely.

For **Amplitude modulation**, the amplitude of the carrier wave is modulated at the frequency of the audio signals.

For **Frequency modulation**, the frequency of the frequency carrier wave is modulated at the frequency of the audio signals.



Aerials

Aerial Amplification

Some modern vehicles are equipped with discreet aerials.
These are usually located within side or rear window glasses and appear similar to a HRW element.

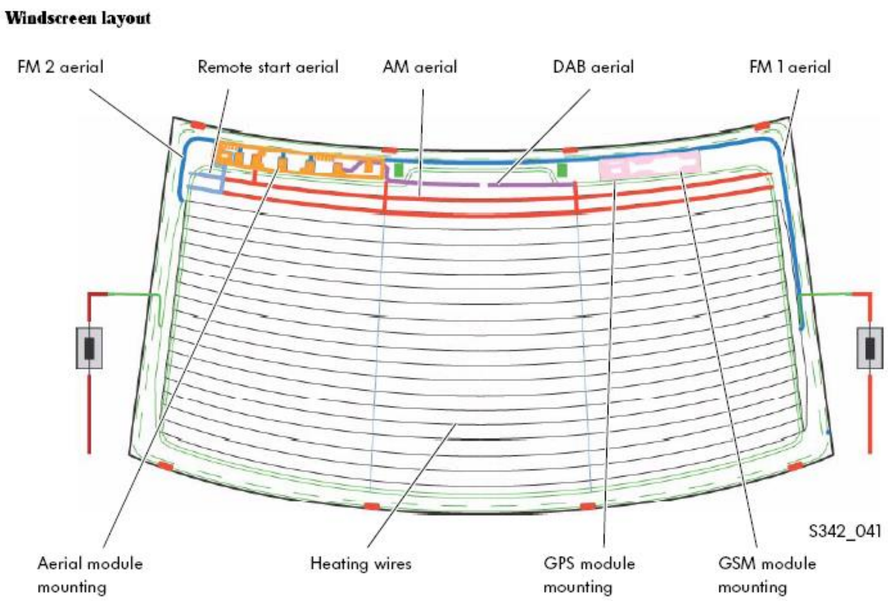
The advantages are:

Maintain body line, vandal proof,

The Disadvantages:

Expensive to replace, often require signal amplifier.

A typical aerial amplifier/booster



Vehicle Alarm Systems

A car alarm is an electronic device installed in a vehicle in an attempt to discourage theft of the vehicle itself, its contents, or both. Car alarms work by emitting high-volume sound (usually a siren, klaxon, the vehicle's own horn) when the conditions necessary for t riggering are met, as well as by flashing some of the vehicle's lights usually the indicators

Essentially an alarm system is a vehicle monitoring system. An array of sensors are positioned around the vehicle waiting for the moment that something that may trigger the sensor to activate the alarm siren.

A typical modern alarm system consists of an array of sensors and actuators including:

- Motion detection
- Tilt detection
- Shock detection
- An electronic control unit
- Pressure difference
- Door switches
- Remote control
- Central Door Docking
- Transponder ignition keys
- A siren or sounder
- Battery
- Boot release

The shock sensor is fitted so that if something or somebody moves the vehicle the sensor sends a signal to the control unit to activate the siren.

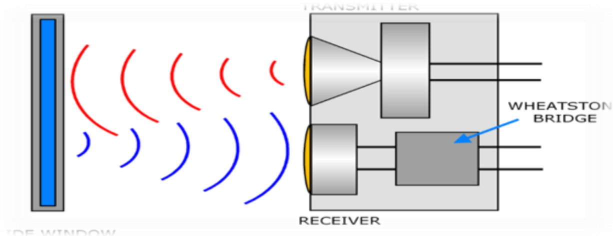
Some systems will monitor the severity of the shock. If a small shock is detected the control unit sends a signal to the siren to 'chirp' and pre-warn the person interfering with the vehicle. If larger scale shock is detected the control unit will send a signal to sound the alarm fully.

Ultrasonic Motion Sensors

These types of motion detectors use ultrasonic sound waves for detecting the motion. Motion energy detected is converted to electrical energy.
When electrical energy is produced a pulse is sent to the control unit which in turn will activate the alarm siren.

As with the shock sensor the pulse received by the control unit is analysed and if it is continuous or of a certain magnitude the control unit will activate the siren.

This Motion Detector emits short bursts of ultrasonic sound waves from the transducer. These waves fill a cone shape that are about 15° to 20°. The detector then "listens" for the echo of these ultrasonic waves.

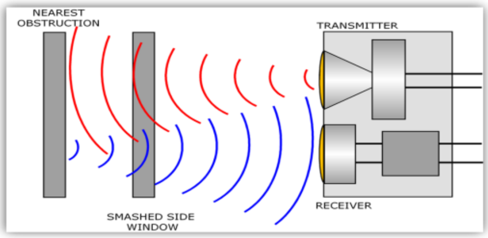


By timing how long it takes for the ultrasonic waves go from the detector to an object and back, the distance to the object can be determined based on the speed of ultrasound in air.

The motion detector will use the information collected to determine the distance to the closest object that produces a sufficiently strong echo.

When the vehicle is left alone, and the alarm is activated the ultrasound sensor sends and receives signals until the alarm is deactivated. If nothing inside the vehicle changes the signal frequency which is sent and received will be the same each time.

Only when an intruder enters the vehicle or opens the door will the signal sent and received by the sensor change. This change is translated, and a signal is sent to the control unit which will send a signal to the siren for full alarm activated.

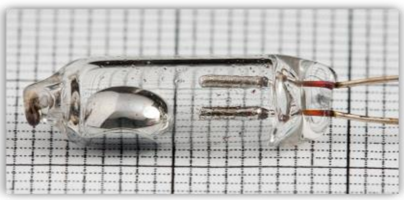


Tilt Sensors

A tilt sensor is fitted to detect if the vehicle is raised or tilted

It sensors were originally mercury switch's Their use have been discontinued since 2003 due to health and safety and environmental impact.

Mercury switch's are fairly low-tech and were prone to false alarms.



As nano-technology becomes cheaper the use of mercury switches died out quickly

Now all tilt detection is done by digital type sensors.

Vehicle alarm systems typically have a number of tilt switches positioned within the ECU.

If a thief changes the angle of the vehicle by lifting it with a recovery truck or jacking it up, the feedback from the switches will inform the ECU and the control unit will know that someone is interfering with the vehicle.

Door Switches

Door pin switches were originally fitted to activate the courtesy lights. They were then integrated into early alarm systems.

When the doors are opened the circuit is earthed activating the courtesy light. The alarm control unit will sense a current draw and activate the alarm.

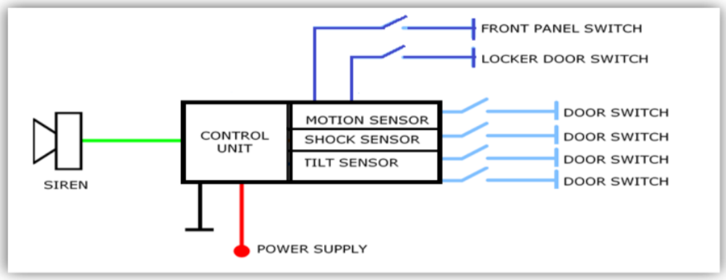
Similar switches were fitted to the bonnet and boot. And when opened the sensing wire would complete a circuit to earth. This direct earth connection is sensed by the control unit and activates the siren.

Door switches are now intergraded into the door locking unit. (Power Door Lock Latch Actuator)

Within the unit there will be several switches or sensors, to detect the position of the door catch, as well as the status of the door lock

Alarm System

In different situations, all or some of these alarm sensors discussed will cover the same ground. For example, if someone is jacking your vehicle up the tilt switches and the shock sensor will register that there is a problem.



Other systems monitored by the alarm take account of.

Battery voltage – Any change in voltage or if the battery is disconnected will trigger the alarm. (The alarm system has an internal battery back up) .

Pressure difference – This monitors the internal pressure inside the vehicle. If a door opens or a window is smashed the pressure inside will change

When the alarm is triggered the alarm, module will set off a visual and audible warning.

This is usual done by flashing the hazard lights and activating a horn or siren.
The vehicle horn and hazards can be activated vie the body computer on the can bus system. Or an independent horn/siren can be controlled by the alarm unit.
Both systems will incorporate a Battery backup so the alarm will continue to sound even if the battery is disconnected.

If an alarm is reported and has been sounding for some time, then investigations will be made by the local council to try and trace the owner.

If this fails, or the owner is not contactable, then legal action is likely to be taken. This involves serving a notice on the vehicle, and if the alarm is not silenced (normally within an hour), then the Council will arrange for the vehicle to be entered and the alarm disconnected. If this is not possible the vehicle can be towed away to a suitable place in order to silence the alarm.

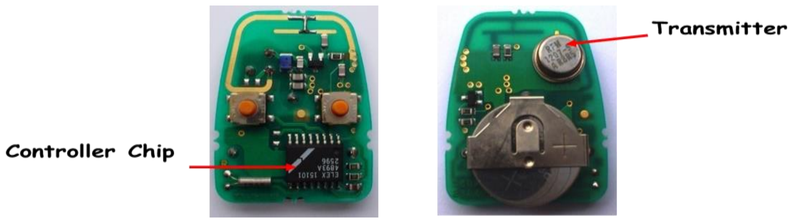
The registered owner of the vehicle will be informed of the action taken and will be charged the costs incurred. The Council has the powers to recover any costs from the owner or the keeper of the vehicle involved. The costs incurred may include having to forcibly enter the vehicle or remove it to a suitable place in order to silence the alarm.

Key Fob Transmitter

Each time one of the buttons is pressed, a radio-frequency signal is emitted. This information tells the control unit which button was pressed.

The transmitter's microchip has a memory location that holds the current 40-bit code. When you push a button on your key fob, it sends that 40-bit code along with a *function code* that tells the control unit what you want to do (lock / unlock the doors. etc.).
The receiver in the control unit also has a memory location that holds the current 40-bit code. If the receiver gets the 40-bit code it expects, then it performs the requested function. If not, it does nothing.

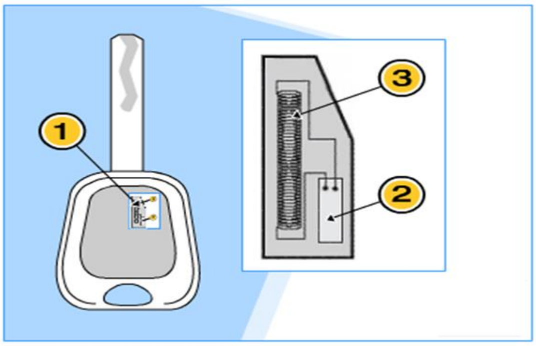
If you are away from the vehicle and accidentally push the button on the transmitter, the transmitter and receiver are no longer synchronised.
The receiver solves this problem by accepting any of the next 256 possible valid codes in the random number sequence.



If the rolling code received from the transmitter is authenticated the control unit will provide an earth path to the central locking actuator to lock or unlock the door.

Immobilisation

Immobilisers are a key feature of the vehicle security system. These alone are the devices that pose problems for thieves and in most cases the sophistication of the immobiliser deters or ensure the thief gives up with the attempted theft.



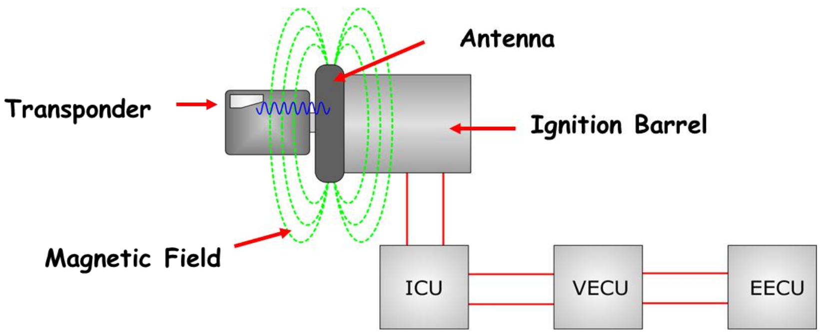
In years gone by we have seen simple circuit breakers as immobilisers usually accompanied by stickers displaying STOP, IMMOBILISER FITTED but thieves are clever and this sort of immobilisation didn't pose any problems or deter them. Immobilisers began to evolve into multi-circuit breakers, taking more of the thieves time but again the thieves caught on and simply overrode the immobilisers.

Instead of immobilisers being a stand alone fitment, manufactures now integrate them with their alarm systems to greatly strengthen the security of the vehicle. Now immobilisers cut power to the engine management, starter motor circuits etc.

Modern Immobilisers

These devices are battery-less, small enough to fit in the head of a key and contains one of a trillion possible electronic codes. Each uses a fixed, unique, read only code for the highest level of security.

When the user turns the key in the ignition lock, electromagnetic signals from the antenna coil fitted to the end of the ignition barrel are emitted to power the transponder. The transponder sends its read only code to the antenna. After the transponder is verified, the ECU sends a signal to the VECU.



Smart Keys

Also referred to as proximity keys or simply a key fobs, is an electronic access and authorization system. Smart keys have been around since the 1990s, although primarily only on high-end luxury cars. Now it is available as standard on most vehicles. Each brand has a different name for their specific systems

- **Audi:** Advanced Key
- **BMW / Mini:** Comfort Access
- **FIAT-Chrysler:** Keyless Enter-N-Go
- **Ford:** Intelligent Access with push-button start
- **General Motors:** Passive Entry Passive Start (PEPS)
- **Jaguar Cars / Toyota / Honda:** Smart Key System
- **Mazda:** Advanced Keyless Entry & Start System
- **Mercedes-Benz:** Keyless Go integrated into SmartKeys
- **Porsche:** Porsche Entry & Drive System
- **Renault:** Hands Free Keycard
- **Subaru:** Keyless Smart Entry With Push-Button Start
- **Volkswagen:** Keyless Entry & Keyless Start or KESSY

The smart key allows the driver to keep the key in their pocket when unlocking, locking and starting the vehicle.
The key is identified via one of several antennas in the car's bodywork and a radio pulse generator in the key housing. Depending on the system, the vehicle is automatically unlocked when a button or sensor on the door handle or trunk release is pressed.

Vehicles with a smart key system fitted have a mechanical backup, usually in the form of a spare key blade supplied with the vehicle. Some manufacturers hide the backup lock behind a cover for styling.

The smart key uses radio waves to "talk" to the matching vehicle containing embedded antennas that identify and confirm its presence. On some models, when the key comes within 1.5 metres of the driver's car, the door automatically locks or unlocks with a touch of the door handle. In the case of the above image, the tailgate lifts by waving a foot underneath the rear bumper.

Once inside, simply pressing the ignition button, usually located next to the steering column, starts the vehicle.
Some smart keys, can also store individual user settings so the seat, mirrors, steering wheel and even audio preferences are automatically adjusted by pressing a single button.

The operating principles, faults and testing methods of wiper and washer systems.

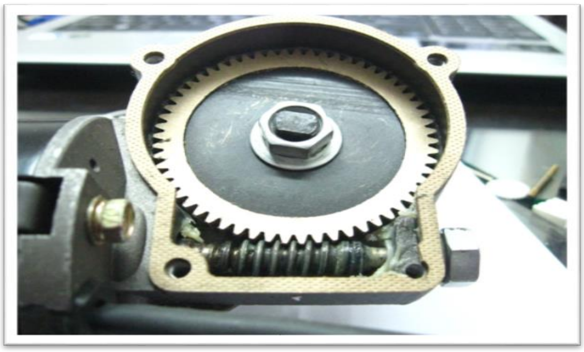
Windscreen wipers are found on car windscreens, rear screen and some car headlights
The wipers combine two mechanical technologies to perform their task:
A combination electric motor and worm gear reduction provides power to the wipers.
A linkage converts the rotational output of the motor into the back-and-forth motion of the wipers.

The key to streak-free operation is even pressure over the length of the rubber blades. Wiper blades are designed to attach in a single point in the middle, but a series of arms branch out from the middle like a tree, so the blade is actually connected in six to eight places.
Modern wiper blades us a curved sprung plastic, so has equal pressure and contact across the full length of the blade.

Motor and Gear Reduction

In order to generate the force to move the wiper blades back and forth across the windshield, a worm gear is used on the output of a small electric motor.

The worm gear reduction can multiply the torque of the motor by about 50 times, while slowing the output speed of the electric motor by 50 times as well. The output of the gear reduction operates the wiper linkage.



Inside the motor/gear assembly is an electronic circuit that senses when the wipers are in their down position. The circuit maintains power to the wipers until they are parked at the bottom of the windshield then cuts the power to the motor. This circuit also parks the wipers between wipes when they are on their intermittent setting.

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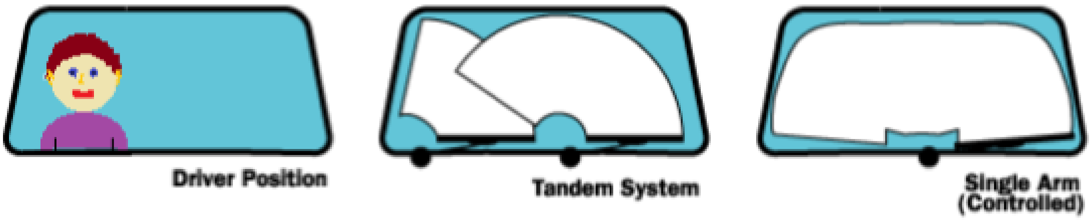
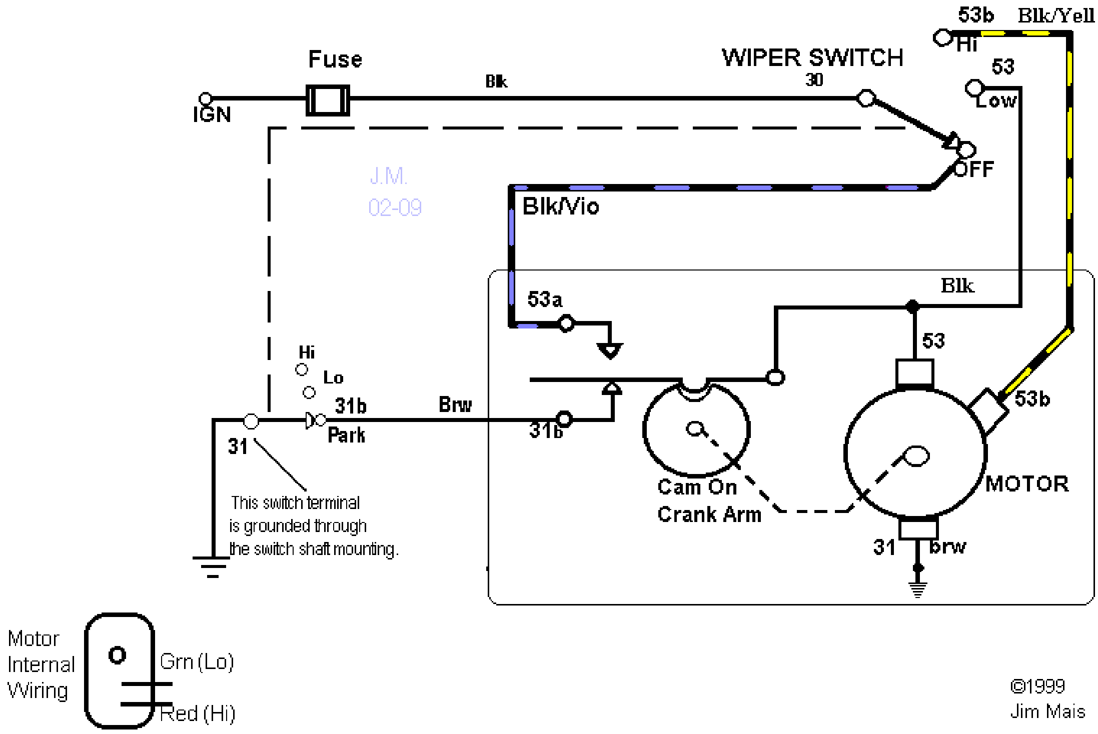
A short cam is attached to the output shaft of the gear reduction. This cam spins around as the wiper motor turns. The cam is connected to a long rod; as the cam spins, it moves the rod back and forth. The long rod is connected to a short rod that actuates the wiper blade on the driver's side. Another long rod transmits the force from the driver-side to the passenger-side wiper blade.

Most older cars have pretty much the same wiper design: Two blades move together to clean the windshield. One of the blades pivots from a point close to the side of the cars windscreen, and the other blade pivots from near the middle of the windscreen. This design clears most of the windshield that is in the driver's field of view.
There are a couple of other designs on cars. Mercedes used a single wiper arm that extends and retracts as it sweeps across the window -- Single Arm (Controlled).



Some cars use wiper blades that are mounted on opposite sides of the windscreen and move in the opposite direction, and some vehicles have a single wiper mounted in the middle.
These single blade systems don't provide as much coverage for the driver as the standard two-blade system and were only used on a few smaller vehicles.



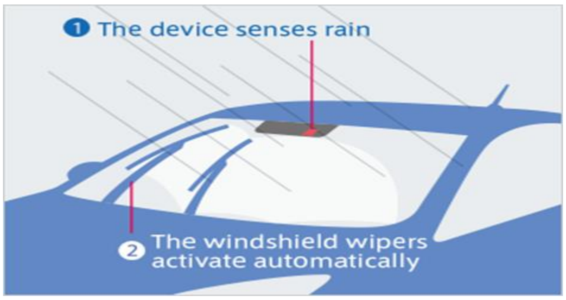
Wiper operation

Most wipers have a low and a high speed, as well as an intermittent setting. When the wipers are on low and high speed, the motor runs continuously. But in the intermittent setting, the wipers stop momentarily between each wipe. There are many different kinds of switches for wipers. Some cars have just one intermittent speed, others have numbered settings and still others have a sliding scale that can be set for almost any time interval.

Whichever kind of controls your car has, setting them just right can be tricky -- too fast and the windshield gets dry and the wipers squeak; too slow and your visibility is blocked by raindrops. Also the amount of water hitting the windscreen changes as your car speeds up and slows down.
Car manufactures tackled this problem originally with speed sensing wipers control. The body control unit would use the information from the vehicle speed sensors to speed up and slow down the wipers according to vehicle speed.

Automatic Wiper operation

Automatic Wiper operation uses a sensor, that is mounted on the inside of the windscreen, near the rear-view mirror.



The sensor projects infrared light into the windshield at a 45-degree angle. If the glass is dry, most of this light is reflected back into the sensor by the front of the windshield. If water droplets are on the glass, they reflect the light in different directions -- the wetter the glass, the less light makes it back into the sensor.

The electronics and software in the sensor turn on the wipers when the amount of light reflected onto the sensor decreases to a pre-set level. The software sets the speed of the wipers based on how fast the moisture builds up between wipes. It can operate the wipers at any speed. The system adjusts the speed as often as necessary to match with the rate of moisture accumulation.