TRADE OF VEHICLE BODY REPAIR

PHASE 2

Module 4

UNIT: 3

Protection of Electrical Systems
Produced by

SOLAS

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Introduction

Basic Electricity

When electricity was first discovered and investigated a convention was adopted that electricity flowed from positive to negative. This convention was accepted for many years and most rules of electrical theory were based on it. Eventually it was discovered that electricity was electron flow and that electrons actually pass from negative to positive. However, even now for general discussion the flow of electricity is regarded as positive to negative. From the tradition of assuming electricity flows positive to negative is quite acceptable. If we therefore assume that small particles are either positively charged or negatively charged (rather like the two poles of a magnet), then when a positively charged particle is free to move, it will be attracted to a negative charge.

The general principle can be demonstrated with two magnets. If the ‘North’ pole of one magnet is slowly moved towards the ‘South’ pole of the second magnet, the North Pole will suddenly be attracted to the South Pole.
Unit Objective:

Protection of Electrical Systems

By the end of this unit each apprentice will be able to:

- Identify the various electrical components that require surge protection
- List the equipment that can produce electrical surges that can damage vehicle electrical components
- Use surge protection devices (SPDs) to protect electrical components
- Manually disconnected electrical equipment that requires surge protection

Key Learning Points:

- Circuit protection devices, fuses, relays and circuit breakers
- Electrical surge sensitive vehicle components
- Electrical surge generating body repair equipment
- Surge protection devices
- Manual surge protection by disconnection
- Circuit arrangements, symbols and diagrams
- Air bag triggering devices
- Communication skills
1.0 Test Meters

Universal testmeters are available with ranges specially suited to automobile systems. Ranges for volts, amperes and ohms are normal, but it is rare for meters to be able to measure starter currents directly. In addition, many modern meters incorporate other functions such as dwell, point’s condition and engine speed (tachometer).
Figure 1: AC Delco ‘Freedom’ Maintenance-Free Battery

Figure 2: AC Delco ‘Freedom’ Battery Hydrometer
2.0 Secondary Batteries

The primary battery is an expendable device of the type used in torches and portable radio receivers and is of no importance in motor vehicles. The secondary battery, however, is widely used and differs from the primary type in that it is rechargeable after-use.

Nearly all vehicles use a battery of the lead-acid type, but occasionally a steel-alkaline battery is used. A lead-alkaline battery is made of a number of cells grouped together so that the battery terminal voltage is the sum of the separate cell voltages. A 12 volt battery, for example, has six 2V cells connected additively in series (Figure 3).

![Figure 3: Battery Cells in Series](image)

In practice, the actual voltage of the battery is not exactly 12 volts, but can reach as high as 14.5 volts soon after being charged, and as low as 10.8 volts in a completely discharged state.
The principle features of a lead-acid battery are as follows:

- It may be recharged after giving up its electrical energy.
- The internal resistance is low, enabling heavy starter current to be delivered without too great a terminal voltage drop.
- The liquid electrolyte is dilute sulphuric acid and being corrosive, should not be allowed to make contact with eyes, skin, clothing or car paintwork. (Apply copious amounts of cold water in case of accidents with acid.)
- During charge, the electrolyte gives off hydrogen and oxygen. This mixture is explosive and care must be taken to avoid having sparks, cigarettes or naked flames near the battery vents.
- Water is lost during discharge (except in some maintenance-free batteries) and periodic replacement with distilled or de-mineralised water is essential. NB. Tap water is not suitable.

From chemical storage and release of energy, it is necessary to have two dissimilar conducting materials in close proximity in a conducting liquid – the electrolyte. The car battery uses a lead-antimony grid of several plates per cell and the grid holes are filled with lead oxide paste. After processing these become lead peroxide for the positive plates (chocolate colour) and spongy lead for the negative plates (grey colour).

When the battery is said to be in a charged state all or most of the grid contents are lead peroxide and spongy lead, i.e. differing metallic conductors, but as discharged is approached both plates change chemically and become lead sulphate.

Chemically inert separators are used between the plates. Originally they were made of wood or porous rubber, but now use paper-based material and are constructed with non-porous ribs, but for some applications sintered PVC with or without a glass fibre retaining mat is used.

The separators must be strong, for under heavy charge and discharge the plates may swell and distort. Equally they must have a correct pore structure to allow the passage of the electrolyte. Pores which are too small represent an effective internal resistance which would lower the terminal voltage on starter load.

Battery cases were formerly made of pitch and asbestos, but modern batteries use polypropylene which is translucent, showing battery acid level readily, also having good resilience and weight.
Topping Up

Near the end of the charging period the chemical reactions give off oxygen from the positive plate and hydrogen plate. Water decomposition takes place and water is slowly lost, needing replacement. Distilled or de-ionised water is added to the electrolyte in each cell to maintain the correct level.

**Figure 4**: Maintaining the Electrolyte Level

**Figure 5**: Mixing Acid and Distilled Water
2.1 Air bag Triggering Devices Components

Vehicle Safety Features:

Driver, passenger and seat airbag, seatbelt pre-tensioners, decoupling brake pedal mechanism, energy absorbing, deformable and retracting steering column, pipe side impact beams, energy absorbing crumple zones and brake pedal retraction prevention.

SRS (Supplementary Restraint Systems)

![SRS Layout Diagram]

**Figure 6: SRS Layout**

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>055A</td>
<td>SRS ECU</td>
</tr>
<tr>
<td>103(2)</td>
<td>Electronic Seat Belt Pre-tensioners LH/RH</td>
</tr>
<tr>
<td>103(3)</td>
<td>Driver and Passenger Airbags</td>
</tr>
<tr>
<td>103(9)</td>
<td>Seat Airbags LH/RH</td>
</tr>
<tr>
<td>104A</td>
<td>Front Impact Sensor LH/RH</td>
</tr>
<tr>
<td>104B</td>
<td>Side Impact Sensor LH/RH</td>
</tr>
<tr>
<td>104C</td>
<td>Door Side Impact Sensors LH/RH</td>
</tr>
<tr>
<td>-</td>
<td>Rotary Coupler (Spiral Cable)</td>
</tr>
</tbody>
</table>
To prevent accidental firing of airbags due to physical transmission of shocks, it is necessary to deactivate or remove and store the airbags as per Health and Safety Regulations.

Testing, removing, installing and repair work should only be carried out by qualified personnel.

For SRS Health and Safety Precautions, refer to manufacturer’s recommendations and the Thatcham airbag video.
### 3.0 Electrical Components that Require Surge Protection

#### 3.1 Electrical Surge Sensitive Vehicle Components

![Figure 7: ECU Locations](image)

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Description</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>040</td>
<td>ABS ECU</td>
<td>RHF behind facia, attached to fascia support bar, in area of ‘A’ post</td>
</tr>
<tr>
<td>055</td>
<td>Engine ECU</td>
<td>LHR inner bulkhead, behind storage compartment</td>
</tr>
<tr>
<td>055A</td>
<td>SRS Airbag Sensor (ECU)</td>
<td>Front of transmission tunnel behind centre console (ash tray)</td>
</tr>
<tr>
<td>055E</td>
<td>Door Lock Control Unit</td>
<td>Behind instrument cluster accessible from underneath facia, RHF, attached to facia support</td>
</tr>
<tr>
<td>055G</td>
<td>Alarm Control Module</td>
<td>Back of transmission tunnel</td>
</tr>
<tr>
<td>055H</td>
<td>Central Electronic ECU (body)</td>
<td>RHF inner bulkhead, behind facia in area of ‘A’ post</td>
</tr>
</tbody>
</table>
3.2 Manual Surge Protection by Disconnection

Before executing repairs to the SRS system, remove key from ignition, disconnect the negative battery terminal and wait for at least 90 seconds, insulate the disconnected battery terminal.

When welding disconnect both battery terminals and alternator, remove any ECU’s in the local area.

Manufacturer’s recommendations and instructions have to be followed in relation to the disconnection/removal of electrical control units (ECU’s) and SRS components during repair.

The times for these operations, along with the removal of any other necessary parts/trims are reflected within the published met times.
Engine Control Unit

**Dynamic Headlamp Levelling**

Dynamic headlamp leveling compensates the height when there are changes in the load and chassis movement during braking and acceleration within a few milliseconds, meaning the driver always has the correct visible range.

**Figure 8: Basic Construction of an Automatic Light Levelling System**

1. Headlamp
2. Actuator
3. Front axle sensor
4. Light switch (on/off)
5. Electronic control unit
6. Rear axle sensor
7. Speed sensor
8. Load
4.0 Protection of Electrical Systems

4.1 Basic Electricity

In the example of the battery, we can assume that at the positive terminal, there are many positively charged particles. If a path is made for the particles to reach the negative terminal (negative particles), then the positively charged particles will flow along the path to the negative terminal. This path could be created by connecting a piece of wire between the positive and negative terminals, in which case this path is a complete circuit.

The greater the number of positively charged particles at the positive terminal, the greater the flow around the circuit to the negative terminal (which has no positively charged particles). Therefore we could regard the number of positively charged particles as being the amount of ‘pressure’ or voltage at the positive terminal. More positively charged particles would equal more pressure or voltage.

4.2 The Electrical Circuit

To have a continuous current flowing, there must be a complete circuit. If the circuit is broken, by opening a switch for example, the electron flow and therefore the current will stop immediately. To cause a current to flow continuously around the circuit, a driving force is required, just as a circulating pump is required to drive water around a central heating system.

The driving force is the electromotive force (abbreviated to EMF) and is the energy, which causes the current to flow in a circuit. Each time an electron passes through the source of EMF, more energy is provided to send it on its way around the circuit (Figure 10).
A circuit must have:

1. A source of supply (EMF)
2. A load (Lamp)
3. Connecting cables (Conductors)

The source of supply is always associated with energy conversion.

- Generator (converts mechanical energy to electrical energy)
- Battery (converts chemical energy to electrical energy)

The source of supply will have pressure called voltage or electromotive force, (both measured in Volts).

The international symbol for ‘supply voltage’ or ‘voltage drop’ has changed from $V$ to $U$, the symbol for the unit of voltage (the volt) remaining as $V$.

The load is any device that is placed in the electrical circuit that produces an effect when an electric current flows through it. When
an electric current flows through an incandescent lamp, the lamp gives off light from heat.

**The connecting leads** or cables from the circuit to complete it. The cable consists of the conductor to carry the current and the insulation to prevent leakage just like the water pipes must have a bore to carry the water and the pipe material (e.g. copper) to prevent leakage.

Circuits also usually contain some form of control in the form of a switch that can be used to turn on and off the load.

### 4.3 Circuit Analogy

The simplest analogy of an electric circuit is to consider a hosepipe connected to a tap. The rate of flow of water from the end of the hosepipe will depend upon the water pressure at the tap and the flow of water through the hosepipe, which will be restricted by its inner walls, particularly where, bends and kinks occur. If there are many restrictions, this will be noticeable, as the water will flow out of the hose at a reduced pressure (Figure 11).

**Figure 11: Circuit Analogy**
4.4 **A Simple Circuit**

It should be noted that water will not flow around a hydraulic circuit unless the pipe-work makes a complete path from the supply tank, around the system and back to the tank. This principle also applies to an electrical circuit. An electric current will not flow, unless a complete circuit exists. When a battery is the power source, the circuit is only complete when a path exists between the battery positive terminal and the battery negative terminal.

The action of electrical flow around the circuit is the same as a pipe bent to form a loop and filled with water. No flow of water can take place in one part of the pipe unless there is a corresponding water movement in the remainder of the loop.

A simple electrical circuit is shown in Figure 12: the circuit is formed by connecting a lamp and switch to a battery. Figure 13 shows the same circuit but it is illustrated with commonly used electrical symbols.

In figures 12 and 13 the flow of electricity is controlled by a simple on/off switch. The switch consists of a set of electrical contacts.

*Figure 12: A Simple Circuit*  
*Figure 13: With Symbols*

When the switch is in the ‘off’ position, the contacts of the switch are open: the circuit is broken (often referred to as ‘open circuit’) which prevents current from flowing in the circuit. The bulb does not light up. When the switch is moved to the ‘on’ position, the contacts close, which completes the circuit and allows current to flow. The current passes through the fine wire filament in the bulb, which causes it to glow and provides the illumination.

4.5 **Earth Return**

When a lamp is connected to a battery by two cables, one cable is called ‘supply’ and the other the ‘return’. However, nearly all vehicles use the metal body and frame of the vehicle as part of the electrical circuit.
By substituting the return cable with the body or frame of the vehicle, an ‘earth return’ system is formed (Figure 14)

![Figure 14: An Earth Return Circuit](image)

The use of an earth return circuit reduces the overall length of the cable required to create all of the electrical circuits and in so doing reduces the weight and the cost of the vehicle and simplifies the electrical wiring layout. The frame is called earth (or ground) and is connected to one of the battery terminals.

**Note:** Normally the negative terminal is connected to the frame of the vehicle. In this case the polarity of the vehicle is described as ‘negative earth’. The electrical illustrations show a negative earth circuit.

Use of the word ‘return’ is associated with the current flow in a circuit. The alternative two-wire arrangement, (called ‘insulated return’) is seldom used other than for special purpose vehicles, for example, petrol tankers and military vehicles.

**Note:** it is essential that the battery terminals are connected so as to give the correct earth polarity. Electrical and electronic components can be damaged if the battery is incorrectly connected.

### 4.6 Types of Circuits

Simple electrical circuits have only one resistance (electrical consumer) connected. However, many circuits, especially those used on modern vehicles, can have more than one resistance. Multiple resistances can be connected in a circuit using different methods.

These are referred to as:

- Series
- Parallel
4.7 Series Circuits

In the example shown in figure 15, the circuit is fitted with two bulbs.

Because one bulb follows the other in the circuit, they are referred to as being ‘in series’. For current to flow from the battery positive terminal to the battery negative terminal, the current only has one route, through both bulbs.

One disadvantage of using this circuit would be that if one bulb filament were to fail, the other bulb would also ‘go out’ as once it is broken no current can flow in the circuit.

Note that the current flow through the circuit is the same at any point in the circuit.

The total resistance \((R_T)\) of the circuit is equal to the sum (addition) of the two resistance values in the circuit i.e. \(R_1\) and \(R_2\).

\[
R_T = R_1 + R_2
\]

**Figure 15**: A Series Circuit (Shown with bulbs and with resistor symbols)

Example:

If \(R_1\) and \(R_2\) are 2\(\Omega\) and 4\(\Omega\) respectively, then

\[
R_T = 2\Omega + 4\Omega = 6\Omega
\]
The current flowing in the circuit can be calculated using Ohm’s law, but note that the calculation must use the total resistance of the circuit.

Assuming the voltage applied to the circuit is 12V, the current flow in the circuit is:

\[ I \ (\text{current}) = \frac{V}{R_T} \]

\[ = \frac{V}{R_1 + R_2} \]

\[ = \frac{12 \ \text{V}}{2 \ \Omega + 4 \ \Omega} \]

\[ = \frac{12 \ \text{V}}{6 \ \Omega} = 2 \text{A} \]

### 4.8 Parallel Circuit

In the example shown in Figure 16, the circuit is fitted with two bulbs; the bulbs are effectively arranged in two parallel circuits. Each bulb is connected to the battery positive terminal and each bulb is also connected to the negative terminal. The supply voltage to each lamp is therefore equal to battery voltage.

An advantage of using a parallel circuit is that if one bulb filament were to fail, the other bulb would still remain lit. Therefore most lighting circuits used in the motor vehicle applications are of the parallel type.

The total current flowing through the switch in figure 16 will depend on the value of each resistance in the circuit, but note that there are effectively two circuits, therefore the total current will be the current flowing through the first bulb plus the current flowing through the second bulb.

The current flowing in the circuit can be calculated by using Ohm’s law:
If $R_1$ and $R_2$ are 2Ω and 6Ω respectively then the current flow through each resistance is as follows:

For $R_1$ \[ I (\text{current}) = \frac{12 \text{ V}}{2\Omega} \]

$I$ (current) = 6A

For $R_2$ \[ I (\text{current}) = \frac{12 \text{ V}}{6\Omega} \]

$I$ (current) = 2 A

The total current flowing through the circuit

\[ = (\text{current through } R_1) + (\text{current through } R_2) \]
\[ = 6A + 2A \]
\[ = 8A \]

The total resistance of the circuit can also be calculated by Ohm’s law if the total current flow and the supply voltage are known:

\[ R_T = \frac{V}{I} \]
Note: the combined or total effective resistance value of a parallel circuit is always lower than the resistance value of the smallest resistor.

Alternatively the total resistance of a parallel circuit can be calculated by using the following formula:

\[
\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}
\]

In this case:

\[
\frac{1}{R_T} = \frac{1}{2} + \frac{1}{6}
\]

\[
\frac{1}{R_T} = \frac{3}{6} + \frac{1}{6}
\]

\[
R_T = 6 \Omega
\]
Which is the same as: \[ \quad = \quad + \quad \]

or \[ \frac{1}{R_t} = \frac{4}{6} \]

Therefore \[ \frac{R_t}{1} = \frac{6}{4} = 1.5\Omega \]

Note that, as stated earlier, the total resistance is lower than the value of the smallest resistor. Although in most cases, a vehicle technician is unlikely to require the formula for general vehicle work, there are occasions when certain diagnostic problems are encountered where an understanding of parallel resistance calculations is an advantage.

### 4.9 Voltage Drop

When current flows in a circuit, a resistance causes the voltage (potential difference) to fall as the current passes through the resistance. So the voltage available at each side of a resistance will be different; the difference in the voltage is referred to as the ‘voltage drop’.

**Note:** for a voltage drop to occur across a resistance, current must flow in the circuit.

**Volt drop across a single resistance in series**

If a single resistance exists in a circuit, (Figure 17) it effectively uses up all of the energy (or voltage) in the circuit, so the voltage drop across a single resistor in a 12-volt circuit will equal 12 volts.
Figure 17: Voltage Drop across a Single Resistance

The voltage applied to the start of the resistance is 12 volts but the resistance will use all of the available voltage and therefore the voltage at the end of the resistance will be zero volts. The voltage drop across this single resistance will be quoted as 12 volts.

Volt drop across resistances in series

If two resistances are connected in a series circuit, the total available voltage must drop across both the resistances R1 and R2. If both resistances are the same value (Figure 18), then these two resistances will share the available voltage equally, i.e. each resistance will use 6 volts. The voltage drop across both resistances would be quoted as 12 volts.

Figure 18: Voltage Drop across Two Equal Resistances in Series
However, if two resistances are connected in a series circuit and the values of the resistances are different, then the voltage drop across each resistance will be different. Note however, that the total voltage drop across the two resistances will still equal total available voltage. In a 12-volt circuit therefore, it would not matter what the values of the two series resistances were; the total voltage drop would still be 12 volts. In effect, the two resistances are sharing all the available 12 volts.

The voltage drop across each resistance can be calculated by using Ohm's law. If the resistance is known and the total current is known then the voltage can be calculated thus:

\[ V_{\text{drop}_1} = R_1 \times I \text{ (current)} \]

\[ V_{\text{drop}_2} = R_2 \times I \text{ (current)} \]

**Note:** The sum of the voltage drops across the resistances in the circuit is equal to the supply voltage. With reference to Figure 19, to calculate the voltage drop across each resistance, the current flow in the circuit must be calculated:

\[ I = \frac{V}{R_T} \]

\[ = \frac{V}{R_1 + R_2} \]

\[ = \frac{12 \text{ V}}{2\Omega + 4\Omega} \]

\[ = \frac{12 \text{ V}}{6\Omega} \]
Again referring to Figure 19, the voltage drop across each resistance can be calculated:

\[ V_1 = R_1 \times I \text{ (current)} \]

\[ = 2\Omega \times 2A \]

\[ = 4V \]

\[ V_2 = R_2 \times I \text{ (current)} \]

\[ = 4\Omega \times 2A \]

\[ = 8V \]

The sum of the voltage drop across the two resistances is equal to the supply voltage \( (V_T) \), i.e. the battery voltage.

\[ V_T = V_1 + V_2 \]

\[ = 4V + 8V \]

\[ = 12V \]

Note: if the resistance in the circuit are of the same value, the supply voltage is divided equally between the resistances, e.g. if the supply voltage is 12V and there are three resistances connected in a series circuit each having a value of 2\(\Omega\), the voltage drop across each resistance will be 4V. In fact, it does not matter what the values are of the three resistances; assuming that they are all equal the three resistances will share the voltage equally and the voltage drop will still be 4V across each resistance.

**Volt drop across resistances in parallel**

When two resistances are connected in parallel, it must be noted that each resistance is effectively independent and functions as a single resistance. This is because each resistance has the full
available voltage applied from the battery positive terminal to one end and the battery negative terminal to its other end. Therefore the voltage drop at each resistance is calculated as if it was a single resistance.

Figure 19: Voltage Drop across Two Series Resistances

5.0 Calculating Power (Watts)

When electricity flows in a circuit, energy or power is produced. The various forms of this energy or power are heat, light or creating movement (electric motors or solenoids).

Power is defined as work done in a given time and is expressed in watts (W).

The power can be calculated from the expression:

Power = voltage x current

Or

Watts = volts x amperes

If two of the values are known, the third value can be calculated. The following example indicates how the third value can be calculated if two values are known.

W = V x I

= 12V x 0.5A
5.1 Open and Short Circuits

Two types of common faults that can occur in a circuit are:

- Open Circuit
- Short Circuit

Open Circuit

The term circuit is used to describe a break in a circuit which therefore prevents current from flowing. A switch is usually connected to a circuit and provides an intentional means of making an open circuit. The switch is used to control the flow of current in the circuit.

However, an open circuit can also exist due to a fault as shown in Figure 21.

Current cannot flow and therefore the circuit will not function. In Figure 21 an ammeter (used to measure current or amps) forms part of the circuit to indicate the current in the circuit (effectively a flow rate measurement). In this case, there is an amp reading of zero because of the open circuit.
Electricity will always take the easiest route possible between the battery terminals. If the current flow has an option to either pass through a resistance, or to pass across a piece of wire which has little resistance, most of the flow will take the path of least resistance, i.e. the current will flow through the wire.

If the supply cable to an electrical component were to be accidentally connected to an earth connection (short circuit as shown in Figure 22), the current would mainly pass through the short circuit rather than taking the more difficult route through the component that acts as a resistance in the circuit.

In the diagram Figure 22, the current is mostly not passing through the resistance and the flow is therefore not so restricted. This will result in the full amperage or current flow from the battery, which is indicated by the ammeter. In such cases, the current flow will be so high that the wiring could melt and therefore some form of protection is required. A fuse would ideally be fitted to the circuit. The fuse is made with a specially selected wire that ‘blows’ or melts when the current is too high. This then protects the rest of the circuit and prevents a possible fire.

The thickness of the insulation on a cable is dictated by the voltage and current that the cable has to carry the higher the voltage and current the thicker the insulation.
6.0 Circuit Protection Devices, Fuses, Relays and Circuit Breakers

6.1 Fuses and Other Circuit Protectors

A fuse is a short length of thin wire that is fitted into a holder. The fuse is designed to melt (commonly referred to as ‘blow) and break the circuit (open the circuit) if the current exceeds the rated value (amps) marked on the fuse.

The fuse generally connected in the circuit to the supply cable, usually as near as possible to the battery positive terminal (or the supply terminal from a switch). Provided it is of the correct rating, the fuse protects the circuit to which it is fitted from excessive current and therefore overheating, reducing the risk of fire in the event of a short circuit. If the fuse ‘blows’, it must be renewed. Many fuses fitted to vehicles today are of the ‘blade’ type as shown in Figure 23. The blade fuse is slim and compact in design with the element protected by a plastic body. The various colours used for blade fuses easily identifying the fuse ratings; the fuse rating is also printed on the side of the fuse.

Figure 23: Types of Fuse
Some electrical components require a comparatively large current, so in these cases a fuse having a high amperage is specified. The protection for these high current circuits is often provided by a ‘fusible link’. The fusible link is generally larger in size to allow for the thicker fusible wire. Fusible links provide protection for circuits from 30 amps to 100 amps. If the fusible link ‘blows’ the link should be renewed and the protected circuit checked from excessive current.

Circuit Breakers
Some circuits (e.g. electric windows) are protected by circuit breakers. If the current exceeds the circuit breaker rating, it will interrupt the current (referred to as ‘tripping’), preventing the circuit from functioning. The circuit breaker can either be reset manually, or in some cases the circuit breaker resets itself automatically when the current falls to an acceptable level.

### 6.2 Switches

The flow of electricity in a conventional circuit is normally controlled by means of a switch. The switch contains a set of contacts, which can be either open or closed. When the contacts are open, the circuit is broken and the electrical current cannot flow. When the switch is operated, the contacts close and the electrical current can flow through the circuit.

Various types of switches are fitted to a motor vehicle to control different circuits; these switches can be operated by many different methods.

**Push - On/Off Switches**

These simple switches are used to control many electrical circuits throughout the motor vehicle, e.g. a heated rear window.

**Lever-Operated Switches**

Typically used to control the operation of items such as the indicators and wipers, they are often fitted to the top of the steering column for ease of use by the driver. A multi-contact switch is fitted at the base of the lever and by moving the lever up or down, different electrical circuit’s function.

**Rotary Switches**

A rotary switch is operated by rotating the knob in the desired direction to move a set of contacts at the base of the shaft. One example is an ignition switch (a key is used instead of a knob). At the base of the shaft is a multi-contact switch and depending on the position to which the key is set, different electrical circuits will function.

**Temperature/Pressure Switches**
The operation of many components on a vehicle is controlled by the use of a set of contacts fitted within a switch unit that may be affected by temperature or pressure.

**Temperature- Operated Switches**

A set of contacts is contained within the body of the switch (or sensor), which is placed in contact with a fluid. The contacts could be open when the fluid temperature is low and when a pre-determined higher temperature is reached, the contacts then close. A switch such as this can be used to operate an electric cooling fan.

**Pressure- Operated Switches**

A pressure switch is typically used for detecting the pressure of a fluid. The switch contacts are closed when the pressure of the fluid is low, but when a pre-determined higher pressure is reached, the contacts open. A pressure switch such as this can be used to operate the ‘low oil pressure’ warning light, which is situated in the instrument cluster.
6.3 Relays

The use of a relay in a circuit allows an electrical circuit with a relatively low current flow to control the operation of a circuit that has a high current flow.

Example and Advantages

As an example, Figure 24 shows a relay used to switch a headlight circuit (which would have a relatively high current demand and current flow). The relay could be located nearer to the headlights than the dashboard. Because the relay itself can be switched on using a very low current, this allows a very thin wire to be used between the headlight switch on the dashboard (or steering column switch) and the relay. The switch itself can be designed to deal with only current values. However, the wire from the relay to the headlights which carries the high current needs to be much thicker.

The driver selects headlight operation via the switch, which in turn passes a low current to the relay. The low current at the relay causes a set of contacts to close. The contacts connect the main supply (battery positive) to the headlight circuit, thus enabling high current to be passed to the headlight bulbs.

By using the relay, the light switch and the wiring to relay only carry low current, which means that less expensive wiring and switch assemblies can be used. The more expensive high current wiring is only used to connect the power supply to the relay and the relay to the headlights.

As well as a cost reduction (because using a relay reduces the length of the wiring that carries high current) this also helps overcome the build-up of resistance that can occur in a long length of wire. The resistance in a long wire carrying a high current can result in an unacceptable voltage drop across the wire and reduced current flow, which would reduce the performance of the light bulbs or other electrical consumer.

There is also a safety issue with passing high current through long lengths of wire. The wire and switch contacts can get hot due to the current flow, which can result in switch contacts failing and wiring or switches causing fires. To overcome these problems, the wiring and switches need to be constructed in such a way that the costs are unacceptable compared with using a relay.
Basic Operation of a Relay

There are many different designs of relay, depending on the task that they have to perform; however, the basic principle of most relays is the same.

A relay contains a set of contacts (two contacts that form a switch), which are typically open when the relay is active. The contacts can however be made to close when a small magnetic field is created adjacent to the contacts.

The magnetic field is created by passing a current around a coil of wire (known as a winding); this is referred to as ‘energizing’ the coil or winding. The current required to energize the coil can be relatively small, which means that it can be switched on by a relatively inexpensive switch via thin wiring. When the magnetic field is created, it attracts one part of the contact assembly, which causes the two contacts’ faces to touch (close the switch).

One of the contacts is connected to the power source (either direct to a battery positive or a main power terminal). The other contact is connected to the electrical consumer, e.g. headlights or heated rear window. When the small current causes the contacts to close, they then complete the high-current circuit from the battery to the electrical consumer.

In some cases, the reverse happens, so when the coil or winding is energized it actually causes the contacts to open which means it switches off a circuit. It is therefore also possible to use a set of contacts to pass the high current through to one of two circuits, such as the dipped headlights or the main beam headlights. When the contacts are in their natural position they complete a circuit to the dipped headlights and when the driver selects main beam, the winding energizes causing the contacts to open the dipped beam circuit, but to close the main beam circuit. The dipped circuit is now off, but the main beam circuit has been turned on.
Figure 24: A Relay as used in a Single Headlight Circuit
7.0 Cables

The various electrical components are connected to the supply by low-resistance cables (wires). Copper cables, which are usually stranded to give good flexibility, are generally used to connect components. Where several cables follow a common path they are taped together to form a ‘loom’ or wiring harness. The construction of a wiring harness reduces both the risk of chafing against the metal frame and breakage of the cable due to vibration. The harness is secured to the body of the vehicle using various securing clips, to prevent further movement and chafing.

The quoted size of a cable refers to the diameter of the wire and the number of strands. If the cable is too small for its length or for the current it has to carry, it will overheat and produce a voltage drop, which affects the performance of the component which it connects, e.g. a light will not give its full brightness or a starter motor will not rotate at the correct speed.

Cables Connecting Fuses/Relays and Switches

The current carried by a cable depends on the circuit to which it is fitted; this means that different sized cables are used throughout the motor vehicle. Most cables, other than thick starter cables, have wire diameter of approximately 0.30mm.
Note: that if a defective cable is renewed, it should be replaced with a cable of similar size. If a new circuit is to be installed, the maximum current load should be estimated in order to ascertain the cable size needed.

**Cable Covering and Coding**

Most cables are insulated with PVC or other plastics. As well as being a relatively inexpensive but good insulator, these materials have a good resistance to fuel, petrol and oil, but it should be noted that PVC gives off dangerous fumes when heated.

To aid identification, the cable coverings are coloured. The colour code used depends on the manufacturer of the vehicle; the table below gives an example of some colours that have been used for principal circuits.

In addition to the base colour, some cables have a thin ‘tracer line’ running along the cable. The colour of the tracer identifies the part of the circuit formed by this cable.

As an example, a cable shown as UW, has a blue base colour and a white tracer.

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Cable Colour</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth connections</td>
<td>Black</td>
<td>B</td>
</tr>
<tr>
<td>Ignition circuits</td>
<td>White</td>
<td>W</td>
</tr>
<tr>
<td>Main battery feed</td>
<td>Brown</td>
<td>N</td>
</tr>
<tr>
<td>Side lamps</td>
<td>Red</td>
<td>R</td>
</tr>
<tr>
<td>Auxiliaries controlled by ignition switch</td>
<td>Green</td>
<td>G</td>
</tr>
<tr>
<td>Auxiliaries not controlled by ignition switch</td>
<td>Purple</td>
<td>P</td>
</tr>
<tr>
<td>Headlamps</td>
<td>Blue</td>
<td>U</td>
</tr>
</tbody>
</table>

**7.1 Connectors**

Although connectors using traditional soldered and crimped terminals are still used to connect cables together, the need for greater terminal security and improved protection against the
ingress of salt and moisture has demanded the use of more efficient connectors.

Figure 25 shows a typical plug-and-socket harness connector, which is used to join a number of cables. At the ends of the connector, the terminals are exposed; this provides a test point for meter checks.

It should be noted that on many vehicle systems where computer control and sensors are used, the sensor circuits use very low currents. These could be greatly affected by a poor connection that offers a high resistance. Because the sensors themselves may provide information to the computer that is dependent on resistance changes in the sensor, any unwanted resistance due to poor connections could result in incorrect information to the computer and therefore incorrect system operation. For many systems therefore, terminal connections are gold plated, which provides a low resistance connection that is also relatively tolerant of moisture and other adverse elements.

**Figure 25:** Cable Connector
8.0 Circuit Arrangements, Symbols and Diagrams

8.1 Wiring Diagrams

Wiring diagrams are used to illustrate the various electrical circuits fitted to a vehicle. These wiring diagrams may show the overall electrical circuit fitted to the vehicle or due to the large number of electrical circuits fitted to a vehicle, a wiring diagram may only show a selected part of the overall wiring, e.g. a headlamp circuit.

Wiring diagrams can be used by a technician to help understand the operation of the relevant circuit and should a fault occur, the diagnosis and repair of that electrical circuit.

8.2 Electrical Symbols

Each wiring diagram is likely to show many wires and components. To simplify the wiring diagram, the electrical system is normally illustrated in a schematic (theoretical) format. The various electrical system components that make up the circuit are indicated as graphical symbols in such a schematic diagram.

Due to the large number of separate components that are used in an electrical system of a motor vehicle, a convention or standard format is needed to enable the technician to understand the various graphical symbols. Although each manufacturer uses a slightly different format in which to illustrate their wiring diagrams, many of the symbols used to represent the electrical components are similar. Familiarisation with these symbols will help the technician to understand wiring diagrams.

The British Standards Institution (BSI) recommends that the electrical symbols indicated in BS 3939-1:1986 are used in wiring diagrams. Some of the main symbols are shown in the following table. It should however be noted that European-based conventions may recommend different symbols, so reference should always be made to the relevant wiring diagram and any other references provided by the diagram supplier (such as the vehicle or part manufacturer, or publisher of the diagram).
<table>
<thead>
<tr>
<th>Description</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct current</td>
<td>![Direct Current Symbol]</td>
</tr>
<tr>
<td>Alternating current</td>
<td>![Alternating Current Symbol]</td>
</tr>
<tr>
<td>Positive polarity</td>
<td>![Positive Polarity Symbol]</td>
</tr>
<tr>
<td>Negative polarity</td>
<td>![Negative Polarity Symbol]</td>
</tr>
<tr>
<td>Current approaching</td>
<td>![Current Approaching Symbol]</td>
</tr>
<tr>
<td>Current receding</td>
<td>![Current Receding Symbol]</td>
</tr>
<tr>
<td>Battery 12V</td>
<td>![Battery Symbol]</td>
</tr>
<tr>
<td>(long line is positive)</td>
<td>![Positive Long Line]</td>
</tr>
<tr>
<td>Earth, chassis frame</td>
<td>![Earth, Chassis Frame Symbol]</td>
</tr>
<tr>
<td>Earth, general</td>
<td>![Earth, General Symbol]</td>
</tr>
<tr>
<td>Conductor (permanent)</td>
<td>![Conductor (Permanent) Symbol]</td>
</tr>
<tr>
<td>Thickness denotes importance</td>
<td>![Conductor Thickness Symbol]</td>
</tr>
<tr>
<td>Conductor (temporary)</td>
<td>![Conductor (Temporary) Symbol]</td>
</tr>
<tr>
<td>Conductor crossing without connecting</td>
<td>![Conductor Crossing Symbol]</td>
</tr>
<tr>
<td>Conductors joining</td>
<td>![Conductors Joining Symbol]</td>
</tr>
<tr>
<td>Junction, separable</td>
<td>![Junction, Separable Symbol]</td>
</tr>
<tr>
<td>Junction, inseparable</td>
<td>![Junction, Inseparable Symbol]</td>
</tr>
<tr>
<td>Plug and socket</td>
<td>![Plug and Socket Symbol]</td>
</tr>
<tr>
<td>Variability: applied to other symbols</td>
<td>![Variability Symbol]</td>
</tr>
<tr>
<td>Resistor (fixed value)</td>
<td>![Resistor (Fixed Value) Symbol]</td>
</tr>
<tr>
<td>Resistor (variable)</td>
<td>![Resistor (Variable) Symbol]</td>
</tr>
<tr>
<td>General winding (inductor, coil)</td>
<td>![General Winding Symbol]</td>
</tr>
<tr>
<td>Component Description</td>
<td>Diagram</td>
</tr>
<tr>
<td>-----------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Winding with core</td>
<td><img src="image1.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Transformer</td>
<td><img src="image2.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Diode, rectifying junction</td>
<td><img src="image3.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Light emitting diode</td>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Diode, breakdown: Zener and avalanche</td>
<td><img src="image5.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Reverse blocking triode thyristor</td>
<td><img src="image6.png" alt="Diagram" /></td>
</tr>
<tr>
<td>pnp Transformer</td>
<td><img src="image7.png" alt="Diagram" /></td>
</tr>
<tr>
<td>npn Transformer</td>
<td><img src="image8.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Lamp</td>
<td><img src="image9.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Fuse</td>
<td><img src="image10.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Switch ('make' contact, normally open)</td>
<td><img src="image11.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Switch ('break' contact, normally closed)</td>
<td><img src="image12.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Switch (manually operated)</td>
<td><img src="image13.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Switch (two way)</td>
<td><img src="image14.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Relay (single winding)</td>
<td><img src="image15.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Component</td>
<td>Symbol</td>
</tr>
<tr>
<td>----------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Relay (thermal)</td>
<td>![ Relay (thermal) ]</td>
</tr>
<tr>
<td>Spark gap</td>
<td>![ Spark gap ]</td>
</tr>
<tr>
<td>Generator ac and dc</td>
<td>![ Generator ac and dc ]</td>
</tr>
<tr>
<td>Motor dc</td>
<td>![ Motor dc ]</td>
</tr>
<tr>
<td>Meters: ammeter, voltmeter, galvanometer</td>
<td>![ Meters: ammeter, voltmeter, galvanometer ]</td>
</tr>
<tr>
<td>Capacitor, general symbol</td>
<td>![ Capacitor, general symbol ]</td>
</tr>
<tr>
<td>Capacitor, polarised</td>
<td>![ Capacitor, polarised ]</td>
</tr>
<tr>
<td>Amplifier</td>
<td>![ Amplifier ]</td>
</tr>
<tr>
<td>N-type channel</td>
<td>![ N-type channel ]</td>
</tr>
<tr>
<td>Junction f.e.t.</td>
<td>![ Junction f.e.t. ]</td>
</tr>
<tr>
<td>P-type channel</td>
<td>![ P-type channel ]</td>
</tr>
<tr>
<td>Photodiode</td>
<td>![ Photodiode ]</td>
</tr>
<tr>
<td>Thyristor</td>
<td>![ Thyristor ]</td>
</tr>
</tbody>
</table>
9.0 Equipment that can Produce Electrical Surges

- MIG welding equipment
- Resistance welding equipment
- DENT pulling equipment
- MIG Brazing/Aluminium equipment

9.1 Electrical Surge Generating Body Repair Equipment

MIG Welding Equipment

Resistance Welding Equipment

MIG Brazing/Aluminium
Health Hazard with electrical welding equipment if you have a pacemaker fitted.

10.0 Bulbs

Indicator Orange Bulb single filament single contact

Stop and tail bulb double filament double contact
11.0 Selection of wire connectors

Capless Bulb                                           Headlamp Bulb

12.0 Surge Protection Devices (SPDs) that Protect Electrical Components

12.1 Surge Protection Devices

Surge protection devices provide protection to electrical components without manual disconnection.

Care is to be taken when using Surge Protection Devices
Radio Code
Summary

All modern vehicles are fitted with an array of sensitive components that are vulnerable to electrical or shock damage, so care should be taken to protect them during the repair operation. Never take chances or let unqualified persons work on the vehicles, as it may cause serious injury or even death.

The correct procedures are as follows:

- To obtain Manufacturers Data where possible
- Thatchem Data
- Always use qualified persons
- Never take chances
- Be sure and safe if in doubt see advice
- Always store components in the recommended manner
Self Assessment

**Questions – Module 4. Unit 3**

1. What is the voltage of a standard car battery?

2. What liquid is used to top-up a battery?

3. What should be disconnected before working on SRS systems?

4. When welding how can you protect the electrical systems?

5. What is a fuse designed to do when overloaded (broken)?
6. Name two circuits found in the motor vehicle.

7. What controls the flow of electricity?

8. What is the biggest advantage of a relay?

9. What does this symbol mean? 

10. How are electrical components connected?
Answers to Questions 1-10. Module 4. Unit 3

1. 12 Volt

2. Deionised water

3. Battery negative terminal

4. Disconnect battery

5. Blow (melt)
6. Parallel/series circuits

7. Switches

8. It can be energised with a small amount of current

9. Switch

10. Cables
Suggested Exercise

1. List the electrical equipment on a motor vehicle that requires surge protection. Outline ways that this equipment can be isolated to prevent damage from electrical surges from equipment used to repair vehicle bodies.

2. State what pieces of repair equipment produce power surges that can destroy or activate vehicle electronic systems.

Safety

Disarm airbag systems before carrying out any work to avoid accidental deployment.

Only qualified personnel should dismantle SRS systems.

SRS systems should be stored in a special secure facility under health and safety.

Do not use a circuit tester to check SRS system.

Training Resources

- Classroom and workshop
- Visual aids
- Motor vehicle with electronic airbags
- Surge protection devices
- Motor vehicle wiring diagrams