Electronics for Model Railways

Chapter 7

Power supplies and cutouts

By Davy Dick

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In memory of Margaret

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Power supplies and cutouts

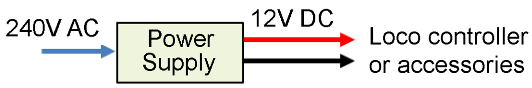
Most layouts need at least two sources of power:

- A variable voltage to run the locos.
- A fixed voltage to run lights, points, etc.

Sometimes, both power needs are built in to the one controller, with the controller providing a separate power socket for accessories.
Often, you will need a separate power supply, independent of the controller.

Most electronic devices use low-voltage DC to power their circuits. However, the mains supply is at 240V AC in the UK with other countries supplying 110V, 120V, 220V, etc.

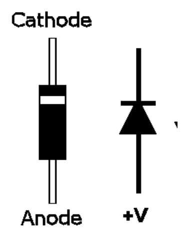
We have to convert the domestic AC mains supply into 12V DC that we can use to control locos, illuminate lights, move points, etc.



The chapter on *'Basic Electronics'* covered how a transformer can reduce the 240V AC mains supply to a more manageable low voltage AC.
So, the next stage is to convert the AC into DC. This is achieved using diodes.

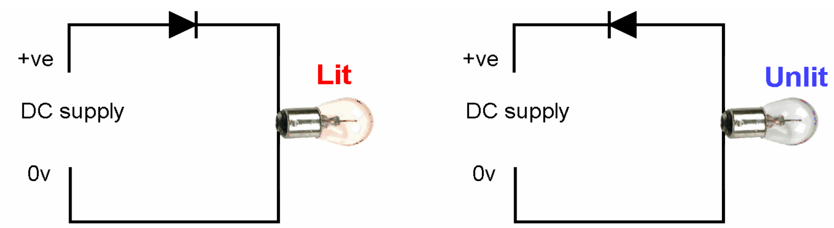
Diodes

A diode, also known as a *'rectifier'*, is a semiconductor device that allows current to pass in one direction only.
The illustration shows the shape of a common diode and its symbol.
Diodes are available in a range of sizes and shapes, depending on the maximum current they are able to handle. Other factors are operating speed and maximum operating voltages.



Diodes and DC

Consider this simple circuit of a power supply (battery or power unit) wired to a bulb via a diode. If the diode's anode is connected to the positive side of the supply, it is said to be *'forward biased'* and it allows current to flow.
Note that the electron flow is *against* the direction of the arrow. Electron current is from negative to positive, whereas 'conventional current' was thought to flow from positive to negative (in the days before electricity was fully understood).



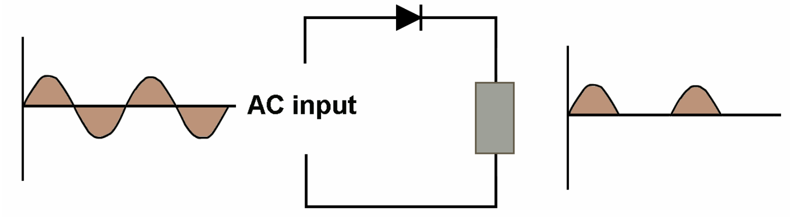
If the diode is reversed, with its cathode towards the positive supply, it is said to be *'reverse biased'* and no current will flow.
Incidentally, the bulb will not glow quite as bright as it would without the diode, as 0.65V is dropped across the diode.

Note

The end of this chapter covers the many uses for diodes in DC circuits.

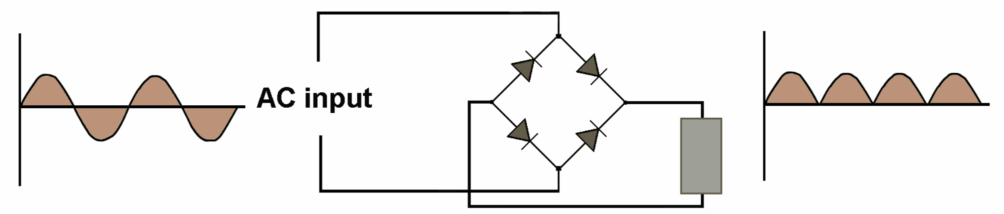
Diodes and AC

This diagram shows an AC supply being connected across a diode and a resistor.
During the first half cycle, the diode is forward biased, current flows and a voltage is developed across the resistor. During the next half cycle, the diode is reverse biased and there is no current flow, therefore no voltage across the resistor.
This process is repeated for every cycle of the AC waveform. This is known as *'half wave rectification',* as only half of the input waveform reaches the output.



The result is that the voltage across the resistor is a series of 'bumps'. It is not AC but is not a smooth DC either – it is a pulsed DC.
This is sufficient for some basic purposes but is very inefficient. The shaded areas show that only half the available power is available after rectification.

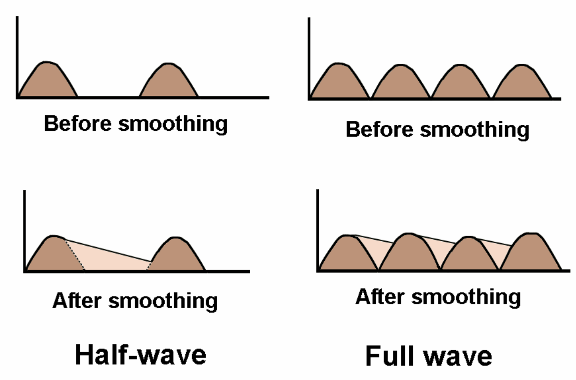
A much improved supply uses a *'bridge rectifier'* circuit as shown below.



This results in *'full wave rectification'* as both half cycles are now used in the final output.
This has greatly reduced the pulse effect and doubled the output power.
A bridge rectifier is available as a component with four connections, two for the AC input and two for the DC output.
Alternatively, a bridge circuit can be made up from four separate diodes.
Like diodes, bridge rectifiers are available in a range of sizes and shapes, depending upon the current and voltage they need to handle.

Smoothing out the ripple

The power supplies so far have very large voltage ripples on them, making them unsuitable for many circuits. The voltage level consistency can be improved with the use of *'smoothing capacitors'*. These are large energy stores that are explained later. The capacitor is fitted across the DC output and is charged (like a battery) while the voltage is high. When the voltage starts to drop, the circuit gets its current out of the capacitor. This causes the capacitor to discharge but it is then recharged during the next voltage surge.



The diagrams show the effect of the capacitors in half-wave and full-wave situations.

The darkly shaded areas are the voltage to be expected without smoothing and the lightly shaded areas show the additional voltage lift from using capacitors.
The rate at which the capacitors discharge depends on the storage ability of the capacitors and how much current is drawn from them by the circuit.

> **Note**
> The stated AC voltage from of any transformer's secondary is an RMS value. However, after rectification and smoothing, the DC level is quite different from the secondary's AC level.
> Remember, the AC peak level is 1.414 times the RMS level.
> For example, a 14V AC secondary output is really 19.796V peak.
> Since, after rectification, the smoothing capacitor maintains this level, the DC voltage across the capacitor might be thought to be 19.796V.
> However, current passes through two of the bridge diodes during any one half cycle and each diode drops 0.65V across it.
> Subtracting these two voltage losses (a total of 1.3V) from the 19.797V , the final voltage across the capacitor is 18.5V – higher than the expected voltage.

Capacitors

Capacitors are two wire components that are used in almost all electronic circuits, industrial, domestic including model railways.
They are available in a range of sizes, types and specifications. Some are built for high-frequency equipment, some are designed for high stability, some for close tolerance, some for high-voltage working and some for high storage capacity.
They are all, however, doing the same job; they store electrons for later use.

Their storage ability is measured in Farads and values range from picofarads (10^{-12}) through nanofarads (10^{-9}) and microfarads (10^{-6}) up to Farads.

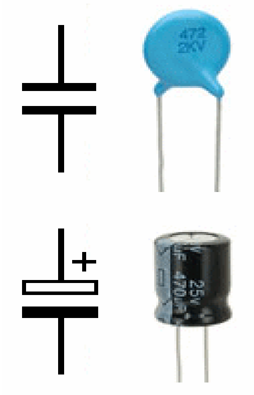
In audio and radio frequency systems, coupling capacitors are used to connect stages in the system; it passes the audio but blocks any DC component. In radio systems, they are used for tuning and filtering.

In model railways they can be found in:

- Capacitive discharge systems to move point solenoids.
- Power supply smoothing.
- Stay-alive capacitors for DCC decoders (e.g. for the Lenz Gold Mini decoder).
- Wave shaping DCC and CBUS signals.
- Timing for PWM controllers, flasher circuits, and other timers.

Capacitors are made up from two metal plates that are separated by a non-conductive material, known as the *'dielectric'*. Like a battery it can store electrons; unlike a battery, it cannot create electrons. A capacitor builds up a potential difference across its plates when a voltage is placed across it. One plate accepts electrons from the circuit, while the other plate loses electrons to the circuit.

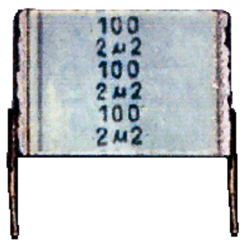
Depending on their intended use, capacitor dielectrics can be made from polystyrene, polyester polycarbonate and more, but the most used capacitors have ceramic or electrolytic dielectrics.
Ceramic capacitors have low storage capacity and are used in timing and decoupling roles. Electrolytic capacitors have much greater storage capabilities and are used for supply smoothing and capacitor discharge systems.



The upper picture shows a ceramic capacitor. These are 'non-polarised' which means they can be fitted either way round. The symbol next to it is for any non-polarised capacitor.

The lower picture is of an electrolytic capacitor, which has a chemical dielectric. It is polarised and has to be fitted the right way round or it will be destroyed. They have a strip down the side with minus signs printed on them so that you can identify the positive and negative leads. Its symbol has a white rectangle on top (the positive lead) and a filled rectangle below (the negative lead). Some diagrams will also show a positive sign next to the positive end, but not always.

Identifying values



The letter 'p' is used to represent values measured in picofarads, while 'n' represents values measured in nanofarads.
Microfarads use the Greek letter mu 'µ' to represent microfarads as shown in this image. However, it is commonly replaced by the letter 'u'. So, 2µ2 and 2u2 both represent 2.2 microfarads.
Sometimes, a value is shown without the 'F'. So 50µF, 50uF, 50µ and 50u are all the same.

Similarly, a 10 nanofarad capacitor could be found in a magazine or on a diagram as 10n or 10nF. Equally, a 15 picofarad capacitor could be identified as 15pF or just 15p.

As with resistors, the letter is used as a decimal point.
So, a 6.8pF capacitor might be marked as 6p8.

If a capacitors marking has exactly three numbers, without any letters, then the value is measured in picofarads, with the first two digits indicating the digits and the third number indicating the number of zeros that follow. If you look at the blue ceramic capacitor above, you will see that its value is 472 (i.e. 4700pF).

The capacitor on the right is marked as .01, which means that it is .01 (one hundredth) of a microfarad. Where decimal places are displayed, it describes the capacitor's value in microfarads.

Lastly, diagrams might use different ranges to describe the same capacitor value. For example, this capacitor, although marked as .01, could equally be described as 10nF. A .001 capacitor is the same as a 1nF or 1000pF capacitor.

Regulation

So far, we have been able to convert a 240V AC mains supply to a lower voltage AC, rectify it to obtain a rippled DC voltage, and smooth out the worst variations with a large value capacitor. While this is sufficient for some basic uses, a much more smooth and consistent supply is preferable (specially if it is to power electronic circuits).
In addition. The output voltage may be 11V and you actually want a 5V supply.

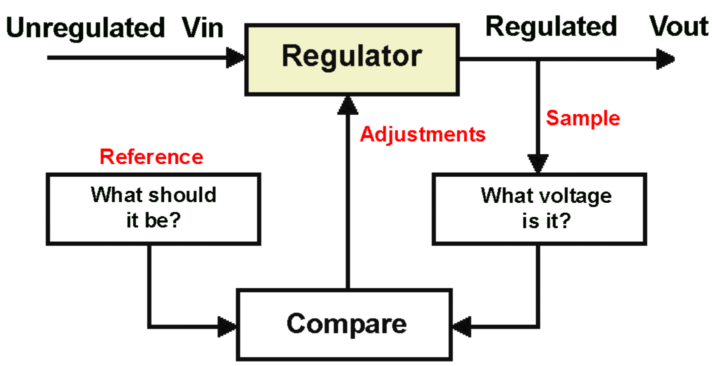
A cheap and simple solution is to use a *'voltage regulator'*

A voltage regulator is a semiconductor device that offers these benefits:

- It provides a guaranteed specific output voltage.
- It provides a constant voltage, over varying current demands.
- It eliminates almost all ripple.

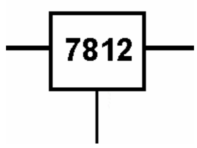
It is a three-pin device:

- A pin for the unregulated input voltage.
- A pin that is connected to 0V.
- A pin that outputs the regulated voltage.



This illustration shows how it works. The internal circuitry is always comparing the voltage at its output with what it wants it to be.
So, for example, a 5V regulator is always checking that its output is the same as its 5V reference value.
If a change of current drawn from the regulator results in a tendency to lower the output voltage, the circuity detects the change and compensates to bring the voltage back to 5V.
Any compensation changes are very fast, so the output remains very stable over a range of current demands.

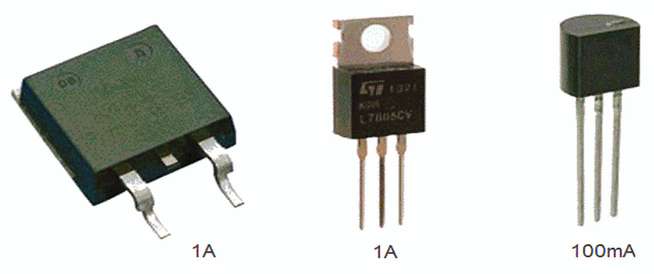
It has a very simple symbol and the output voltage can usually be understood from its markings. The most commonly used series start with a 78 or 79, followed by two other number that indicate the output voltage.



78 indicates that it produces a positive output voltage (the most commonly used type) while 79 indicates that it produces a negative output voltage (this one needs to be fed with a negative input, of course).
The voltage regulator shown in the symbol illustration is a +12V regulator.
If the first two numbers are followed by the letter 'L' it means that it is the smaller 100mA type. Some examples of regulator markings are:

7805 +5V 1A regulator
78S05 +5v 2A regulator
7806 +6V 1A regulator
78L05 +5V 100mA regulator
7912 -12V 1A regulator
LM1117T-3.3 +3.3v 800mA regulator

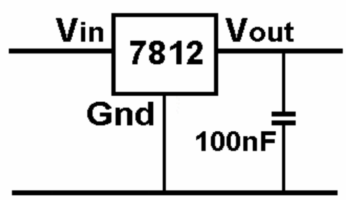
Some typical voltage regulators are shown in these images.
They are not to scale; the one on the left is a surface mount component which is smaller than a grain of rice.
The one on the right looks like a transistor and is for low current circuits as it has a maximum current handling rating of 100mA. The middle image is of a type that handles larger currents and is intended to have a heat sink (a chunk of metal with fins to dissipate unwanted heat) attached to it, or to be bolted on to a module's metal case.



The unregulated DC input is connected across the regulator's input and ground pins, with positive lead from the supply connecting to the regulator's input pin.
The input voltage should be at least 2V or 3V higher than the required output voltage. So, a 5V regulator should be fed by at least 7V and a 12V regulator should have at least 14V or 15V. Any less and the regulator cannot be guaranteed to work consistently.

Although the 78xx and 79xx range of regulators have a maximum input voltage of 35V, there should not be too high a difference between the input and output voltage. This is because any unwanted power is dissipated as heat in the regulator and if the heatsink cannot conduct it all away, the regulator will shut down.
It all depends on the current you expect the regulator to handle. Remember, power is voltage times current. A high input voltage with a small output current will produce less heat than a lower input voltage with a large output current. If in doubt, use an input voltage that is not excessive compared to the regulator's output voltage.

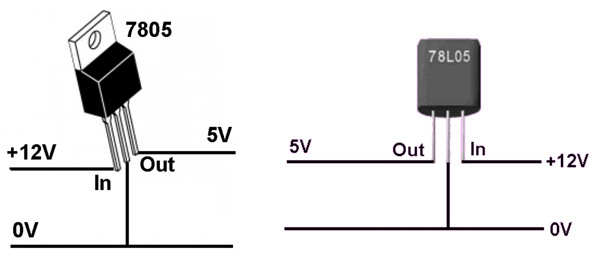
This portion of a circuit shows the voltage regulator in use, with a 100nF (0.1uF) capacitor across the output. This would be in addition to the smoothing capacitors that would be fitted.
It is fitted to shunt away any unwanted high-frequency voltage component that may have got through the regulator.



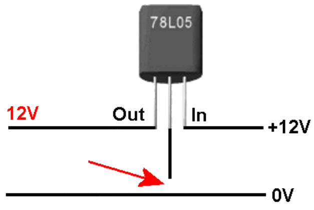
The benefits of regulators explains why MERG kits use a +12V input and convert inside the module down to 5V. Any temporary drop in the 12V supply, such as might be caused by a sudden high current (e.g. operating a solenoid or servo) would have to be very dramatic before it would affect the 5V inside the module. This ensures that the internal components of the module (e.g. logic circuits or PIC chips) are always supplied at the required operational voltage.

Connecting a regulator

Although the connections are simple, the correct orientation and proper soldering of the voltage regulator is vital to prevent a nasty accident.
If you forget to solder the third lead, or make a dry joint or intermittent connection, the output voltage will rise to the input voltage – i.e. 12V in and **12V out**.



If you mistakenly solder in the regulator the wrong way round, you also end up with 12V being applied to the rest of circuit.

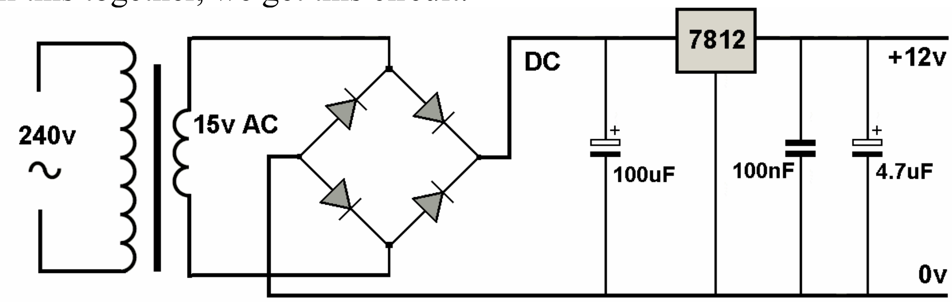


So, make sure you:

- have the regulator fitted the correct way round.
- have good soldered joints on the regulator's leads
- check the voltage coming out of the regulator before plugging in the module's chips.

The final 'linear' supply circuit

Bringing all this together, we get this circuit.



To recap, the circuit functions are:

- The 240V AC mains supply is connected to the transformer's primary winding.
- The transformer's secondary winding connects 15V AC to the bridge rectifier.
- The rectified output from the diode bridge has a ripple that is partially smoothed by the 100uF capacitor.
- This is fed to the voltage regulator, which produces a consistent +12V DC output.
- The 100nF capacitor takes care of any unwanted high-frequency components.
- The 4.7uF capacitor carries out some final smoothing.

This circuit is perfectly suitable for a range of uses on a model railway. In fact, its what you will find inside many *'wall wart'* power supplies.

Requirements for Power Supplies

What do we want from a power supply?

- A stable output voltage
- A ‘clean’ supply, with low ripple (the low frequency variation) and low noise (the high frequency variation)
- Low levels of EMI electromagnetic interference
- A set current limit
- Fast response time
- Minimum voltage, heat

A linear supply like that shown above meets many of these objectives.
It has a low component count and is found in audio equipment, signal processing, control circuits, communication, etc.

However, a linear supply has some deficiencies:

- Low efficiency (up to 80% of power can be wasted)
- Needs a large transformer, so is both large and heavy.
- Can generate a lot of heat (the regulator needs a large heatsink to be able to work at maximum current).

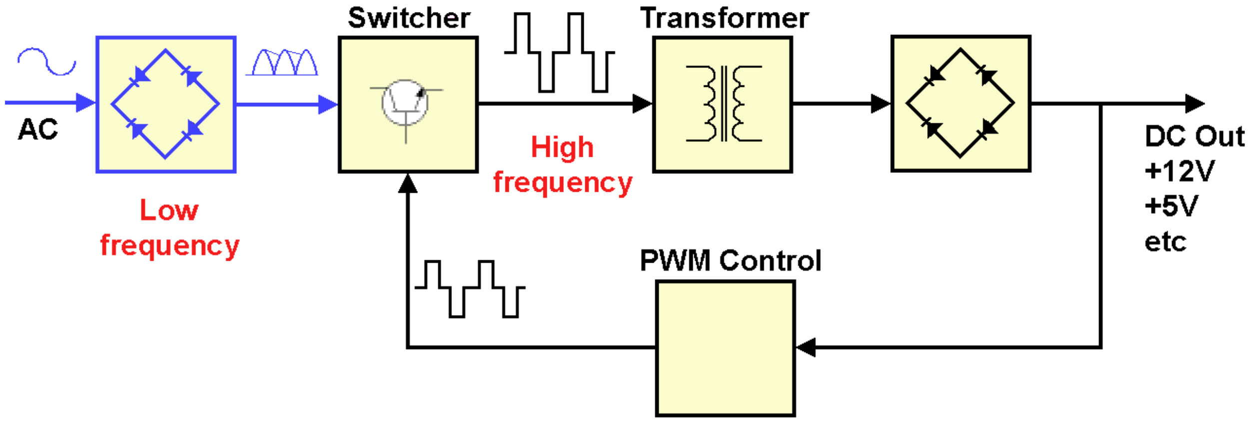
Switched Mode Power Supplies

The transformer used by a linear supply takes the voltage down from mains supply to a much lower voltage (e.g. from 240V to 12V).
The mains supply operates at a very low frequency; either 50Hz or 60Hz depending on the country.

Unfortunately, transformers operate at a very poor efficiency at low frequencies due to greater losses.
To compensate, mains transformers have to be larger.

This diagram shows the basic operation of a Switched Mode Power Supply (SMPS).
The process is:

1. The mains is full-wave rectified and smoothed – at 50Hz (or 60Hz).
2. This high voltage DC is switched on and off rapidly.
3. The current from the switcher is fed to the primary of the transformer.
4. The output of the transformer is again rectified and smoothed.
5. The feedback loop keeps the output steady.



The big benefit here is that the transformer is operating at a much higher frequency (say 100KHz - always above 20KHz so that it is out of the range of human hearing).
This raises the efficiency of SMPS units to around 95% compared to 20% or 25% for linear supplies. There is little loss through heat.
This, in turn, means that the transformer can be much smaller than that used for linear supplies. They can also use ferrite core instead of iron cores, resulting in less weight.
The same supply can usually be used with 110V or 240V mains.

SMPS units can be very small and light (think mobile phone chargers) or can be large (think PC power supplies).

Overall, SMPS units produce more power for any given size, cost or weight of linear supplies.
This property is very useful for clubs that have to transport multiple power supplies for layouts, lighting, etc.

This image shows the typical large plastic bin full of power modules and their cables that are taken to exhibitions.
After lugging the heavy crate, you have to untangle all the leads that have mysteriously tangled together.

Note

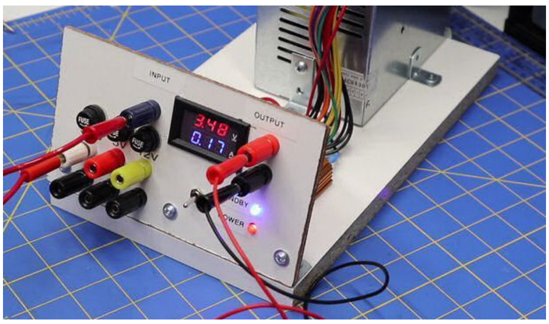
There is even a research paper called *"Spontaneous knotting of an agitated string"* for those of an inquisitive nature.
https://www.pnas.org/content/104/42/16432.full

This image shows a set of eight SMPS units mounted in a Makita case.
Of course, a metal earthed grille sits over the supplies.
The result is a much lighter system with only a single mains cable and sockets to fan out leads to each exhibit.
Each supply is rated at 3A and there is almost no heat generated even after an entire day's operation.

Using an old PC power supply

If you have an old desktop computer that is heading for the dump, you could first remove its power supply for use in electronics and in model railways.
They are usually very good quality and are not often the cause of the computer's breakdown.
Remove a few securing screws, unplug its cables and you have a supply with mutiple voltage outputs, with high ampere ratings.
Here are the outputs from a typical 300W ATX supply:

Output	Maximum current
+12V	12A
+5V	30A
+3.3V	20A
-5V	300mA
-12V	800mA



The first image shows one being converted into a single 12V supply with work carried out inside the power supply case. The second image shows a more versatile supply, using the cables that emerge from the supply.

Many web pages are devoted to demonstrating how to make the conversion.

Here is just one such website:
https://makezine.com/projects/computer-power-supply-to-bench-power-supply-adapter/

Note

A short circuit on the 12V line would produce 144Watts, the heat equivalent of ten soldering irons! Better start thinking about cutouts.

Overload and short circuit protection

You will know if something goes wrong.
With protection:

- Blown fuse
- Cutout tripped
- Module or controller shutting down

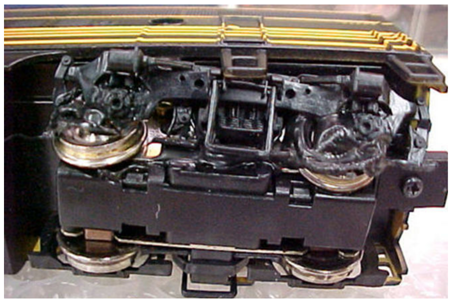
Without protection:

- Damaged modules, burnt out wiring
- Smoke
- Fire!

There are two dangers that need guarding against:

short circuit protection

Imagine buying a controller with a 10A capability. You only run a single 1A loco at the moment but are looking to the future. Now, if there is a short on the cable, there is almost zero resistance and the maximum current possible will flow. In the example, the current is not 1A but 10A. This produces 120W which will manifest itself in heat that will destroy electronic components, melt plastic and potentially causes fires. Speed controllers and power boosters have systems that detect the surge in current and switch off the supply.



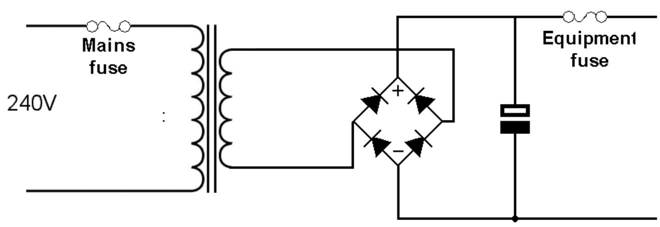
current overload protection

Short circuits produce a sudden surge in current and this is easily detected. Not all current increases need be that dramatic. Running more and more locos on a layout, switching on lighting and other devices, may incrementally increase the current demand to a level greater than that for which the supply was designed. A good controller/booster will allow the user to set the current at which the circuit will cut off the power. In the above example, a user may decide to set the 10A supply to trip at just 3A, as that is his/her current maximum usage.

Protection devices

The fuse

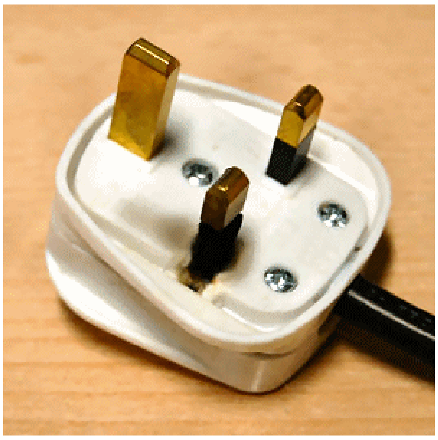
A fuse is simply a short length of wire that melts if too much current flows through it, thus breaking the circuit. The fuse is disposable and needs replacing after it blows.
The fuse may be fitted in the mains plug, or may also be fitted inside a module.



In both cases, we need to consider:

- Fuse rating
- Fuse response time

The mains plug



This image shows a mains plug that has severe burning round one of its pins.

Firstly, a 13A fuse does not blow at 13A

As BS 1362 says:

"The rated current is the current that it can safely pass whilst maintaining a low enough temperature not to overheat the plug"

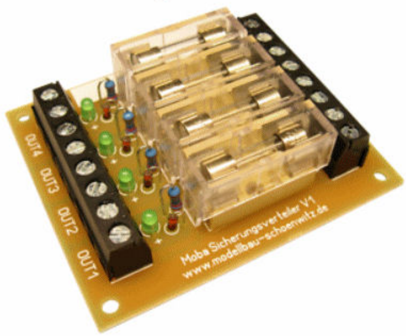
The actual blow current is 1.66 times the rated value.
For a 13A fuse this will be 21.6A.
In other words, a 13A fuse could theoretically pass 20A indefinitely.

The mains plug is not there to primarily protect your equipment. It is stop your faulty equipment interfering with the mains supply.

That is why extra protection is fitted inside equipment.

Equipment fuses

Schönwitz 01-03-19-03 4 Lamp Model Railway Fuse Distribution



The most common you will come across are 20mm glass fuses. They are available in a wide range of ratings (e.g. Rapid Electronics stock them from 32mA right up to 40A).

They also are available in different blow times.

Very Fast Acting

These fuses protect semiconductor devices such as diodes, thyristors, transistors, ICs, etc. that can be damaged with even a short period of excessive current.

Fast blow

This is the most commonly used type and protects cabling, transformers, etc.

Slow blow

Also known as *'anti-surge'* fuses. You do not always want the fuse to blow every time the current rating is exceeded for a very short period. For example, a module may have a large storage capacitor and when the module is first powered up it will draw a large current for a short time as it charges up. Thereafter, the circuit will stay under the fuse rating. Similarly, a motor will produce a surge in current on start up. To avoid the fuse blowing every time, a slow blow fuse is used. This allows short current surges without blowing but will blow if the current rating is exceeded for a more prolonged period.

Rapid Electronics stocks a wide range of fuse types and you can view the performance specifications of each type.

This image shows the markings to be found on the side of fuses.

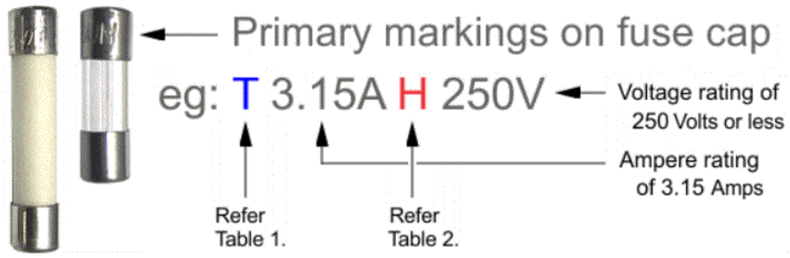


Table 1. Fuse Element Speed Markings

Marking	Fuse Element Speed
FF	Very Fast Acting (Flink Flink)
F	Fast Acting (Flink)
M	Medium Acting (Mitteltrage)
T	Slow Acting (Trage)
TT	Very Slow Acting (Trage Trage)

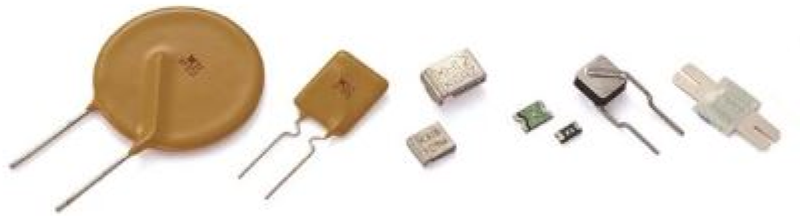
Table 2. Fuse Breaking Capacity Markings

Marking	Fuse Breaking Capacity
H	High Breaking Capacity
L	Low Breaking Capacity

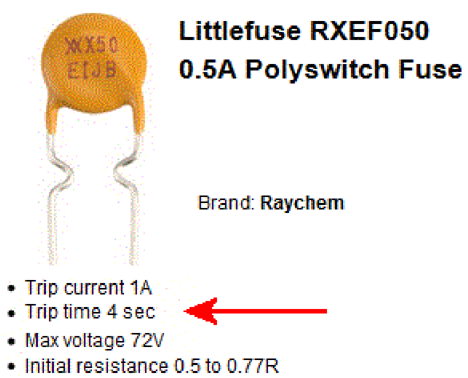
Most of it is self-explanatory apart from *'breaking capacity'*.
This describes the likelihood of the fuse case rupturing when it blows.

Resettable fuses

The above fuses are throw-away devices. Once blown, they have to be replaced.
This is not always convenient. The fuse may be inside equipment or may be sited in a hard to reach part of your layout.
This is where a self-resetting fuse is useful.

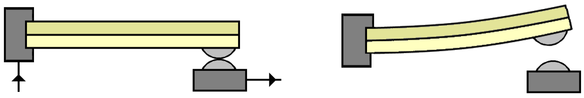


A 'polyswitch' or PTC fuse is a 'thermoplastic conductive element'. That just means that it is composed of polyethylene with graphite powder embedded in it. Normally, this fuse has a low resistance. However, when there is excessive current, the fuse heats up and expands. This results in the graphite elements being spaced further apart, which increases the resistance of the fuse to thousands of Ohms. When the cause of problem is removed, the current reduces, the fuse cools and the fuse resistance becomes low again. This example shows a fuse set to trip at 1A if this levels last for four seconds or more.

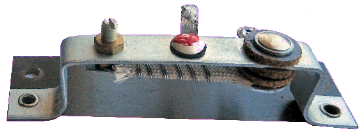


Thermal circuit breakers

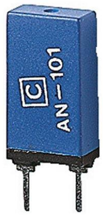
These devices also stop the flow of current when it exceeds its trip rating.



It is made from two different metal strips and these carry the current via contacts. Normally, the contacts area made and current can flow (left image). As the current increases, the heat causes the two metals to expand at different rates, resulting in them bending. Eventually, the contacts break and current flow is stopped (right image).



This type of circuit breaker has been in use for a long time. This image shows the breaker from a 1960's H&M Duette. Thermal breakers remain popular today as they do not immediately trip on short-lasting overloads. The elements take time to heat up, so they only trip with longer-lasting overloads. This means that any short duration current spikes (e.g. from a motor starting up) do not trip the breaker.

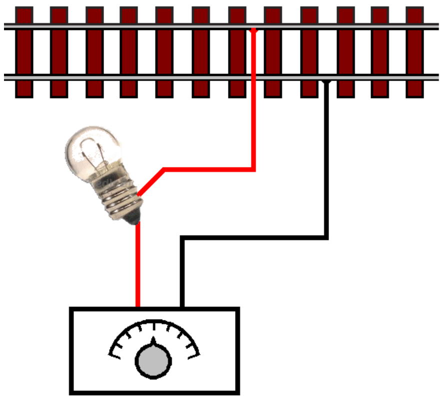


Some, like the one shown in the picture are automatically reset once the element cools down again. These are available with trip ratings of between 1A and 5A.

An alternative is a thermal circuit breaker that needs to be manually reset after it trips (like the ones in your house mains box). The picture shows a panel mounting circuit breaker, with trip ratings from 3A to 20A .
Many push to reset breakers can only be reset after a minimum time has passed (e.g. one minute). This can be a good thing, as it forces you to look at the source of the problem.

Car bulb

Perhaps one of the oldest, and most controversial, protection methods is the use of a 12V 25W car tail light bulb.



Speed controller

A car bulbs is wired in series with the supply to a track section and provides almost no resistance when unlit. The locos run happily with their full voltage. When a short occurs, the current increases rapidly, causing the bulb to light. A lit bulb has a much greater resistance than when unlit. This increased resistance then limits the amount of current flowing in the circuit, This increase occurs very rapidly, around 4mS. When the short is removed, the bulb cools down and its resistance lowers again.

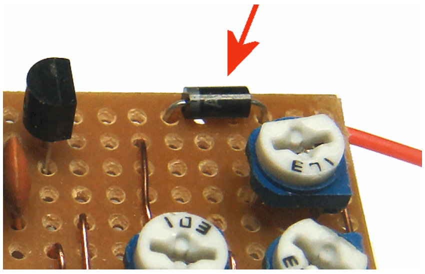
Car bulbs are cheap and you may like the idea of an immediate visual indication when a short occurs. However, it is important to remember that they are not cutouts, only current limiters. If a short occurs the current round the layout, current to the track is limited to a maximum of 2A. This still has potential for causing overheating damage.
If using car bulbs, choose their location carefully, as they are very hot when lit.

Using diodes for protection

Diodes are widely used to convert AC voltages into DC.
In electronics, they can also play a valuable role in protecting your modules and their components.

Here are a few examples.

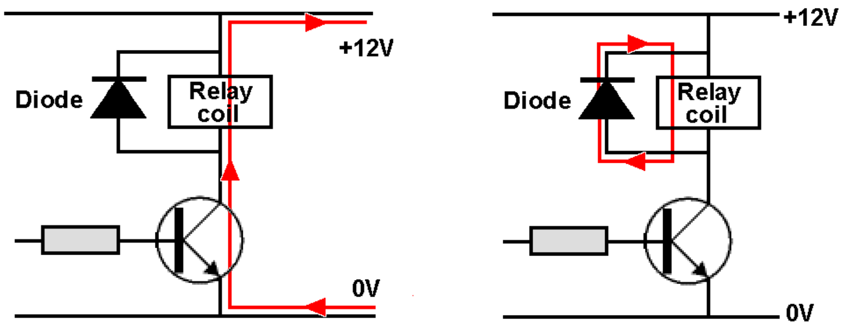
The idiot diode



It is very easy to connect the power to a module the wrong way round, often with catastrophic results for the module. If you fit a diode in series with the power to a module, current will only flow if you connect the power with the correct polarity.
No current will flow if you mistakenly connect the power in reverse. The module will not work but there will be no damage.
In this use it is call a *'reverse current protection'* diode, often referred to as an *'idiot diode'* (I wonder why?).

Relay protection diode

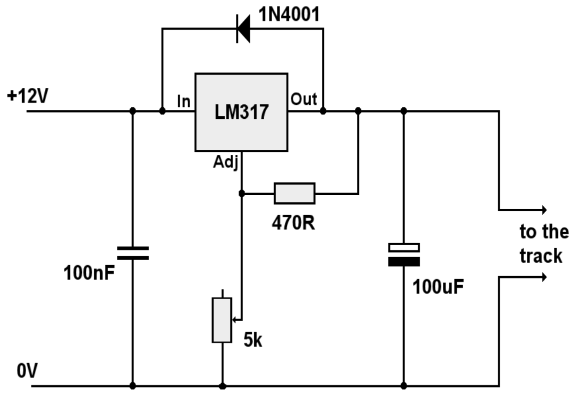
This is usually referred to as a '*flyback diode*' and is used to protect the electronics.
It is also common to see a diode placed across a relay's coil terminals, as in this portion of a diagram.



We know from the chapter on Basic Electronics that passing current through the coil results in a magnetic field being developed around it.
The illustration on the left shows the current flow when the transistor is switched on, from 0v through the transistor and the coil up to +12V. The relay creates a magnetic field to operates its switches.
When the transistor is switched off, the voltage is removed from the coil, the magnetic field collapses and this produces what is known as a *'back EMF'* – a high voltage induced in the opposite direction to the original voltage across the coil.
This, if left untackled, could lead to destructive voltages being fed back into the rest of the circuit.
The solution lies in fitting a diode across the relay. While the relay is held in, the diode is reverse biased and acts as if was not there. However, when the relay is released, it is forward biased to the back EMF, the diode conducts and the current circulates round the diode and the relay coil until dissipated. The illustration on the right shows the effect of adding the diode; it provides a safe discharge path.

Reverse bias protection

This speed controller circuit places a diode across the LM317 chip, which is an adjustable voltage regulator.

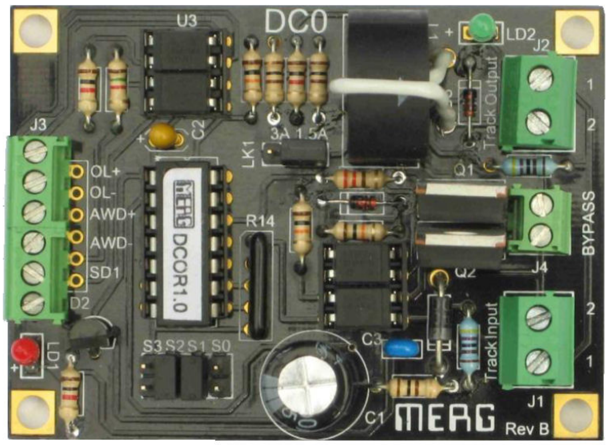


While the module is powered, the voltage on the LM317's input pin is greater than that on its output pin (i.e. the LM317 is *'forward biased'*).
If the voltage on the output pin ends up greater than that of the input pin, it is *'reverse biased'* and this could damage the regulator.
This could occur when the power to the module is switched off and the 100uF is still fully charged (the voltage on the small 100nF capacitor will dissipate much quicker than that on the 100uF capacitor)
Or the back emf from the motor might produce reverse voltages on the output pin that are greater than that on the input pin.
In these situations, the *'feedback diode'* transfers the voltage from the output to the LM317's input, preventing any damage.

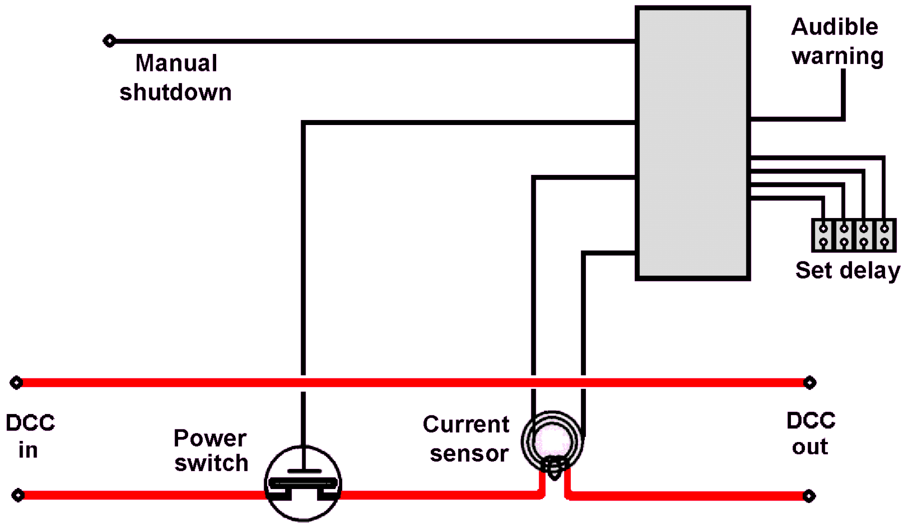
DCC protection

A DCC controller or booster has its own cutout circuitry which will cut off the power and most check periodically to see whether the short is removed before restoring the power.
If the whole layout is fed from a single controller/booster, then a short will disable the entire layout. Troubleshooting is then a problem, as the fault could be anywhere on the layout.
This is usually prevented by dividing the layout into power districts, as previously discussed.
Of course, that means that each power district would have to use a separate circuit breaker.
Now, when a short occurs, only the section affected will be cut off, with the rest of the layout working normally.
Circuit breaker modules are available as standalone devices that are wired in series with the wire from the bus to the section track. These include:

- The PSX from DCC Supplies.. Handles trip values between 4.8A and 17.8A per block, with 1 to 4 blocks on a board. Provides a choice of manual or automatic reset.
- The OnGuard! OG-CB, from DCC Specialties, rated at 4A .
- The NCE EB1 single circuit breaker. Handles trip values from 2.5A to 8A. Provides a choice of manual or automatic reset.
- The MERG DCC District Cutout Kit 57 (shown here).



The MERG NB1B DCC booster has own internal cutout with 3.3A and 5A options as standard.
This illustration shows the basic workings of a DCC cutout.



The DCC signal from the controller passes thought the cutout unit on its way to the tracks.
The power switch allows the signal to pass through.
The current sensor is constantly monitoring the current on the DCC line.
If the current level exceeds the set limit, the module turns the power transistor off and sounds an audible warning to the user.

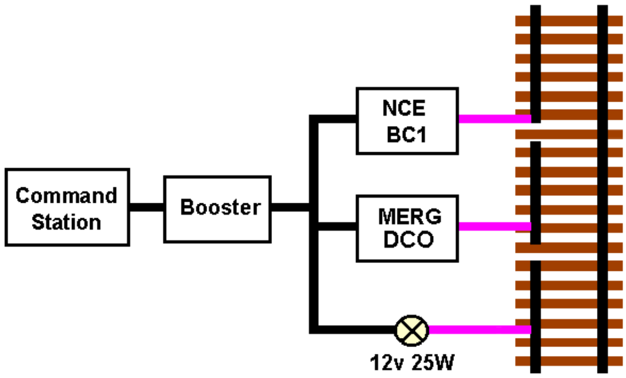
Wiring cutouts

For DC, one controller is allocated to every running loco. If a layout has many blocks, there is still only one controller powering one loco in any one block. Given that controllers have cutouts, a DC layout is already reasonably protected. If a short develops in a block, that controller's cutout will remove the power from the offending block; the rest of the blocks carry on normally, as all the block are electrically isolated from each other.
If a block is large, it may be sub-divided, with all sub-blocks still being wired to the one controller. If each sub-block was fed via a circuit breaker or car bulb, the whole block still stops working, but you can quickly identify the problem sub-block. This is an aid to troubleshooting.

For DCC, with a single command station powering the entire layout, a short anywhere on the layout cuts the power off from the entire layout. All locos stop running.
This can also be overcome by sub-dividing the layout into independent power districts, each with their own booster. A short in one power district only stops running in that power district.
Alternatively, for smaller layouts, a single command station, with or without an added booster, can feed power to power districts through a collection of DCC circuit breaker modules or other protection devices.

While circuit breaker modules are more efficient, they are also much more expensive compared to car bulbs. Since most shorts are caused by derailments at points and crossing, it makes sense to cover the blocks that contain many points with circuit breakers. Other less-frequently used blocks could be more cheaply covered with car bulbs.

In the illustration, three power districts are fed from a single command station/ booster combination. One is protected by a commercial cutout, one from a MERG district cutout, and one from a car bulb.   It is important to note that the bulb may limit the current below the level where the booster would be expected to cut out. Most modern boosters may activate before the car bulb illuminates.



In an ideal world, a DCC layout would be divided into many power districts, each supplied via its own circuit breaker module. This approach may be unsuitable for financial reasons. However, since car bulbs are substantially cheaper, they allow more sub-districts to be individually protected.
A combination of circuit breakers for point-intensive districts and bulbs for more sparse districts may be considered. Sometimes dogma has to be replaced by pragmatism. If we can't have all that we want, we can at least get what we need.

Prudent operators may wish to test that all the protection features work, before an operating session (particularly at exhibitions). This is usually achieved by placing a coin across one section of track at a time.

Commercial power supplies

These are available in a wide range of voltages, current handling capacities, current regulation and physical shapes.

The 'Wall wart'

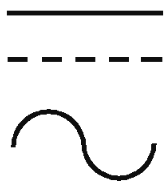
This a common name given to the power units that have an integral mains plug and are inserted straight into a mains wall socket.
You cannot always rely on the stated voltage outputs of many wall wart supplies as many do not have regulated outputs.
The cheaper ones do not match up to their performance description.   For example, a unit rated as 12V may produce 18V, dropping to only 9V when handling a load.   They are fine for general purposes but you should check before connecting to your equipment.

The 'Power brick'

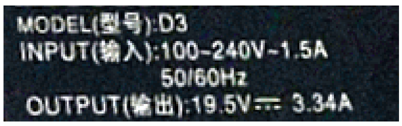
This is a common name to to the power supply adapter that has lead with a plug that inserts into the mains wall socket.
The lead is often detachable, so that they can be sold with kettle leads or 2-pin leads, etc.   You may have one left over from a now defunct laptop.
These are mostly regulated DC but some are only AC adapters.   Again, check before using.
MERG supplies tried and tested DC power supplies through its Kit Locker.

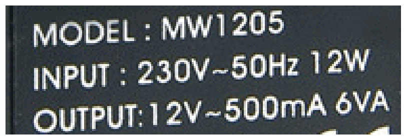
Reading labels

The supplies will have labels that will tell you about its voltage and current rating.
But how do you know if your supply has an AC or DC output?
Also, how can you be sure of the polarity of the output plug?



Some supplies will say *"12V DC"* on the label, while other may just say *"12V"*. Where the label does not say so in the text, you can tell from the symbols on the label. As this illustration show, the straight line and dotted line together indicate that the output is DC. The sine wave symbols tells you that the output is AC.
Here are labels from two power supplies. The label on the right reports that it has a DC output while the one on the right is an AC output supply.





Most power supplies have a low voltage cable that terminates in a barrel jack like that shown here:
The inner contact is known as the tip while the outer area is called the sleeve.
But how do you know whether the tip is positive or negative? As it happens, there is no agreed standard and although most have a positive tip that is by no means universal.

The label on the supply displays symbols that show the polarity of barrel jack wired to that particular supply.
The black dot in the middle represents the tip with the incomplete circle representing the sleeve.
The image on the left, therefore, shows the supply uses a positive pin and the image on the right shows a supply with negative connected to the tip.
Once again, check before you use with your modules.

Choosing a bench supply

Most power supplies for model railways require a fixed voltage, so you just connect them to your lights, modules, etc. and forget about them.

A bench supply is a different as it has to be more versatile.
Uses for a bench supply include:

- Repairing and testing kits.
- Developing new projects.
- Experimenting with kits .
- Trying out circuits from magazines or the internet.

Factors to consider

Linear or switched mode

As mentioned earlier, linear power supplies are larger and heavier that switched mode supplies. This is not important for a bench supply and switched mode supplies tend to be used when a portable supply is needed.
The linear supply has reduced output noise and reduced signal interference compared to switched supplies.

Voltage range

Wall warts and bricks are useful when you simply want to work with a fixed voltage.

There are times when you will want to work with 5V and later with 12V, and so on.
You might want to check what voltage will still rotate a 12V motor reliably.

For these, you need a power supply that has a variable output voltage.
At its simplest, you can buy a cheap variable supply like that shown here. Turning a knob alters the output voltage.

If you need more accurate voltages, you can use a power supply with a digital readout that tells you exactly what voltage is on the output terminals.
Here is a typical example, with the output voltage appearing on the top display.
Other issues affecting the supply's voltage are:

- Accuracy of the output voltage.
- Accuracy of the display.
- Stability of the output voltage, both from mains fluctuations and from changes in current drawn by the load across its terminals.
- Ripple on the output.

The supply shown above has a single knob that is turned to alter the output voltage. Since the rotation takes the output from 0V to 18.5V, a small amount of movement of the knob results in a fairly large change in voltage. It can involve a bit of twiddling back and forth to settle on the exact voltage you want.

The model shown here has two knobs for setting the voltage. The *'Coarse'* knob takes the voltage to approximately where you want to be. The *'Fine'* knob then takes the voltage to the exact value you want.

For the serious user, you can buy a supply that has dual outputs, each output being separately adjusted.

Maximum current

Both of these bench supplies have a second display that shows the current being drawn from any module attached to its voltage output terminals.
This is very useful as provides an instant indication of the health of a module.
As a rule of thumb:

- If there is no current reading, the module is faulty.
- If the current reading is what is expected, that is an initial good sign.
- If the current exceeds the expected level, there is problem with the module.

Both models above also have knobs that control the amount of current that is allowed to flow.
This known as *'current limiting'* and is very useful in our work.

Imagine connecting your newly-built piece of equipment that it is expected to work at around 30mA. You connect it to your power supply, only to find that the current leaps to 3A and your module starts to fry!
With current limiting, you can adjust the knob to the maximum current you will allow the unit to supply. If the attached load tries to draw more than the limit you have set, the current is held at your maximum allowable level.

A good supplier will allow you to read a supply's manual or read its specification sheet.
Have a read and compare models before deciding.