1   Power Supply Systems

1.1 Introduction - Electrical Safety

Most electrically powered model railways use low voltage direct current (dc) to drive the trains. This is usually drawn from the household 240v alternating current (ac) mains supply by using a transformer to reduce the voltage to that required for the model railway. The transformer feeds a rectifier to convert the ac output to dc, which is in turn fed to a speed and direction controller. In many cases these components are housed in the same casing and if properly constructed this arrangement is perfectly satisfactory.

In other cases low voltage ac or dc provided by a separate mains supplied unit is fed to one or more speed and direction controllers.

Until 1990, BS 4453 was applicable to mains voltage equipment and many transformer units marked as complying with it are in existence. In 1990 it was replaced by BS 3535 which is the British version of the International Standard EN 60742.
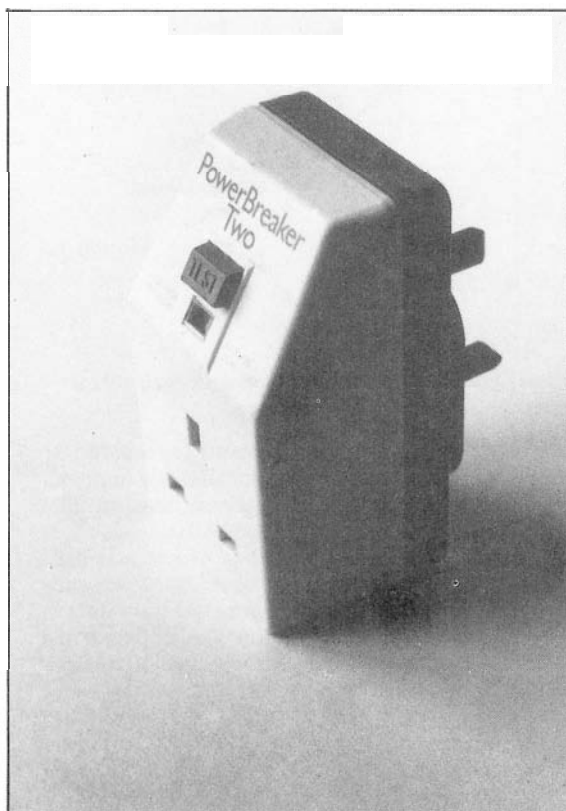

Photo 1.1 A portable RCD. A number of different makes are available for use between standard plugs and sockets.

Compiled by K. Sheale, Technical Committee
Drawn by R. Emerson, Photos T. Hughes

Mains voltage transformers not marked with any of these Standards are not necessarily unsafe, but if there is the slightest doubt regarding safety then it is advisable to seek the advice of a qualified electrician. Remember - CONTACT WITH THE HOUSEHOLD ELECTRICITY MAINS CAN PROVE FATAL.

Because of the potential danger, notes on constructing mains powered equipment are not included in this Manual. Those who know how to build it need no guidance; those that don't are strongly advised to purchase equipment from a reliable manufacturer.

With regard to mains electricity, it is recommended that the following rules be observed:-

a)   The mains supply circuit should incorporate a fuse with a rating no greater than 3 amps.

b)   It is recommended that the transformer be fed from a Residual Current Device (RCD) which measures the current flow in the live and neutral wires and in the event of a difference of only a few milliamps cuts off the power supply before there is a danger of electric shock.

Note: Modern domestic 'fuse boards' often have RCDs fitted in addition to fuses or miniature circuit breakers. Owners of installations without RCDs are strongly recommended to insert a 'plug-in' one in the supply to the transformer. (Under certain circumstances the IEE wiring regulations make the use of such a device mandatory). (Photo 1.1).

c)   Mains fed transformers should not be used outdoors unless compliance with the special requirements of BS 3535 for such use is marked on the unit. Even so it is strongly recommended that transformers feeding garden railways be located indoors, in which case the power supply to any outdoor controllers will be at a safe low voltage.

1.2 General

Most model locomotive motors are of the permanent magnet type which requires a direct current (dc) supply. Therefore the power supply system normally consists of: a transformer to provide low voltage ac: a rectifier to convert the ac to dc: and finally a speed and direction controller to supply the trains. (An explanation of rectification is given in the panel overleaf).

However, some manufacturers, notably Hornby O gauge, Maerklin and Lionel, used motors with wound field magnets connected in series with the armature in conjunction with an ac track supply. Although these motors will run on ac as well as dc, and thus eliminate the need for a rectifier, they cannot be reversed by simply changing the polarity of the supply.

Rectification

In Britain the mains frequency is 50Hz, that is the flow of electricity in a wire reverses 50 times every second. (Hertz, abbreviated Hz, is the term for 'cycles per second'; thus 50Hz simply means '50 cycles per second').

The first sketch shows the effect of placing a rectifier across the output of a transformer.
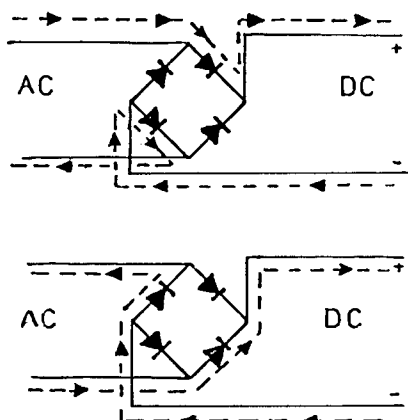

Operation of a full wave rectifier.

The two diagrams indicate the path of electric current at two instants 1/100th of a second apart. It will be seen that the rectifier output is always of the same polarity but due to the rise and fall in the ac input voltage as it reverses direction the dc voltage also rises and falls. (Because their average values are zero, alternating voltages and currents are denoted by their Root Mean Square (RMS) values as shown in the top graph of the second sketch. The theory of this is somewhat complex and is outside the scope of this publication).

Rectifiers consist of one or more diodes, which are electronic devices which pass current in only one direction. A single diode will allow forward current to pass but will block the reverse, the process being termed half wave rectification because current flows for only half of each alternating current cycle. Two diodes fed by a centre tapped transformer will allow current to pass during the whole cycle but the most common arrangement is four diodes forming what is called a bridge circuit, either arrangement providing what is known as full wave rectification.

The dc voltage output of a rectifier is not constant but follows the wave form of the ac input. With half wave rectification the voltage
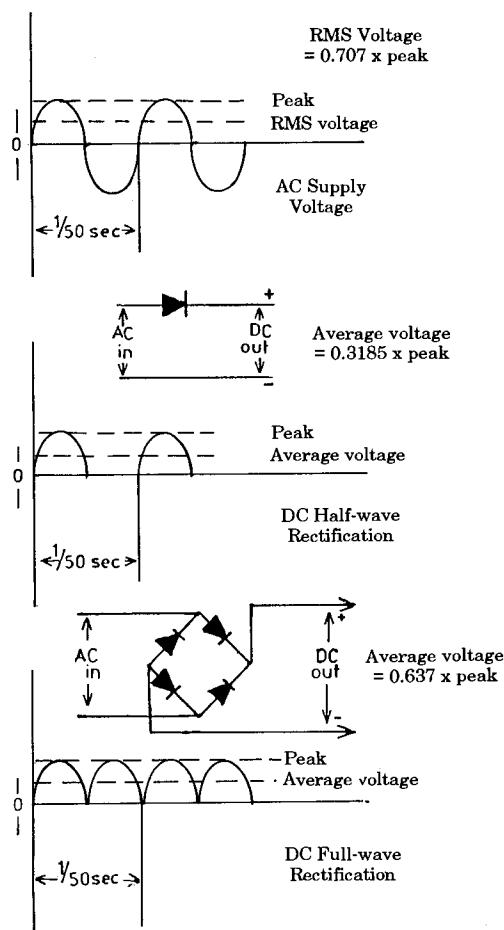
Comparison of full wave and half wave rectification.

is zero for alternate cycles and for a given ac input voltage the average dc voltage is approximately half that of full wave rectification. The graphs show the voltage for both cases.

Before the development of electronic controllers made the practice obsolete, some proprietary controllers incorporated a switch in one arm of the rectifier bridge to provide a choice of either full or half wave rectification. This was intended to improve the slow running of some types of motor which, because of their electromagnetic design, would not run smoothly at slow speed on a constant voltage. However, half wave rectification causes additional heating of the motor windings and brushgear combined with greater mechanical stresses. It should therefore be used with caution and in particular should not be employed to control coreless motors.

1.3 Definitions

Because there are a number of ways that the three elements of the supply system can be combined the following terminology is used throughout this publication:

a) Mains Fed Controller - A case containing a transformer, rectifier and speed and direction controller to convert the ac mains input to a low voltage dc output of variable voltage and polarity.

b) Low Voltage Controller - A device which converts a constant low voltage input to a dc output of variable voltage and polarity.

c) Power Supply Unit - A mains fed device providing a constant low voltage ac or dc supply to one or more separate speed and direction controllers.

Note: If either mains voltage or low voltage controllers can be used in a given application the general term 'controller' is used in the subsequent text.

particularly if older heavy-current motors are in use.

A simple terminus to fiddle yard with short trains running at low speeds can be supplied by a low power unit, but a railway with full length trains running at prototype speeds will demand considerably more power. Similarly, a small layout where only one train can run at a time will require only a single speed and direction controller, whereas a large layout will require a number of them.

The efficiency of small motors has been dramatically increased as a result of the development of more powerful permanent magnets, consequently, as examination of the motor Data Sheets will show, their starting currents, and in particular those of coreless motors, are very much less than those of earlier designs.

Finally, the need for additional supplies for point motors, signals or lighting must also be taken into account. Where a number of these features exist, a separate 'auxiliary' power supply is recommended, particularly if numerous point motors are installed. This is because a solenoid type point motor creates a brief high current demand which can result in jerky running of trains supplied from the same source.
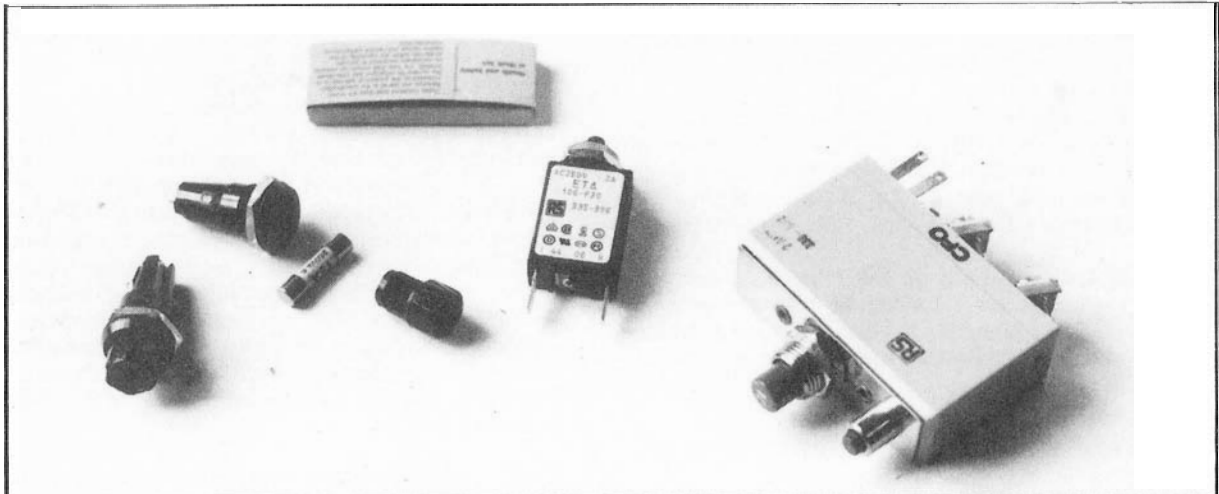

Photo 1.2 Overload protective devices. On the left are two panel mounting fuse holders, one disassembled to show the construction, with a box of spare fuses next to them. Fuse ratings can be varied to suit the controller. In the centre is a thermal trip and on the right a mechanical trip, both rated at 2 amps. They are both fitted with trip reset buttons but the mechanical unit has an additional button to provide a test or emergency trip facility. Other ratings are available.

1.4 Power Unit Requirements

The type and size of transformer/rectifier/controller combination required for a particular model railway will depend on the size and character of the railway and on the type of motors to be used. Furthermore, because the heavier and faster trains inevitably demand more power, equipment that is satisfactory for the smaller gauges may not be so for Gauge O,

1.5 Low Voltage Overload Protection

Proprietary mains fed controllers and power supply units usually have some form of protective device to prevent then being damaged by the short circuits and overloads inherent in a model railway supply system. The device is normally set to operate at about twice the stated current output of the unit. (BS 3535 requires that if such protection is not

provided the unit shall withstand a continuous short circuit without damage).

Although they are not covered by BS 3535 it is nevertheless strongly recommended that low voltage controllers should be similarly protected. The simplest device is a fuse, but a resettable overload trip, which can be either a thermal or mechanical device, is preferable. (see Photo 1.2). Where locomotives with modern can motors are used on a layout a trip unit rated at 2 amps is usually quite sufficient, but if older locomotives having open frame motors are present this should be increased to 3 amps.

Note: The trip only protects the controller or power supply unit from damage due to overload. It does NOT prevent the locomotive motor being damaged in the event of overload or seizure.

1.6   Supply voltage

While most Gauge O railways operate on a nominal 12 volts supply, the use of a higher nominal voltage (usually 24) greatly reduces the effect of unreliable contact between the wheels and the rails and reduces the need for track cleaning. It is therefore particularly suitable for large systems, especially outdoor ones. The effect of increasing the supply voltage on the choice and application of motors is covered in detail in Section 2 of Part 3, Locomotive Construction.

It should also be appreciated that some nominally 12 Volt controllers deliver a maximum of between 14 and 16 Volts in order to compensate for the voltage drop in the track feeders and loco collector system and so ensure 12 volts at the motor terminals.

Note: Not all nominally 12 Volt motors are suitable for operation on a higher voltage. In such cases a proportional voltage limiting circuit should be fitted to the locomotive, see Part 3, Section 2.7.

1.7. Single Controller Supply System

Figure 1-1 shows the power supply circuit for a small layout where only one train is required to run at a time. Normally such a system would be supplied by a mains fed controller, but a separate power supply unit and low voltage controller is equally suitable.
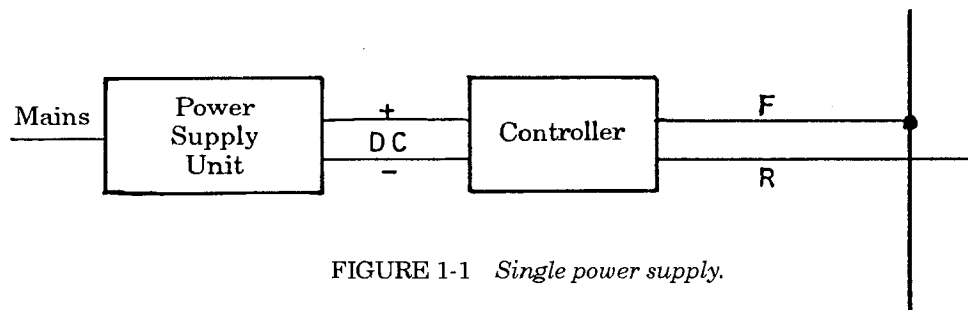
The two wires carrying power to the track from the controller are marked F (Feed) and R (Return). This convention is used because the polarities of the wires change when the locomotive direction is reversed. Switching for individual sections is dealt with in Section 4.

1.8. Multiple Controller Supply System.

If it is desired to run more than one train at a time (or if the railway is so large that single controller operation is impracticable) the additional controllers can be provided in one of the following three ways.

1.8.1   Individual mains fed controllers

This is the simplest method and has the advantage of spreading the cost of the power supply as the system is developed, but if, say, three controllers are eventually needed the cost of mains fed ones may exceed that of a single power supply unit feeding three low voltage controllers. However, this disadvantage may be outweighed by the advantage of being able to use common return wiring.   This is possible because the low voltage circuits of mains fed controllers are independent units and consequently joining one output terminal to the common return does not cause a short circuit between controllers supplying opposite polarity.

Figure 1-2 shows the common return system applied to three mains fed controllers connected to a length of track representing three control areas. One rail is designated the common return and is connected to the corresponding terminal of all three controllers. The other rail, designated the feed rail, has gaps at section breaks and between control areas, each of the three controllers being connected to the feed rail for its own area. Reversal of track polarity requires a double pole, double throw switch in the output circuit of the controller but isolation of the individual track sections requires only a single pole switch.

1.8.2   Single power supply unit feeding all controllers

This system consists of a central power supply unit feeding a number of controllers with either alternating or direct current at low voltage. In the former
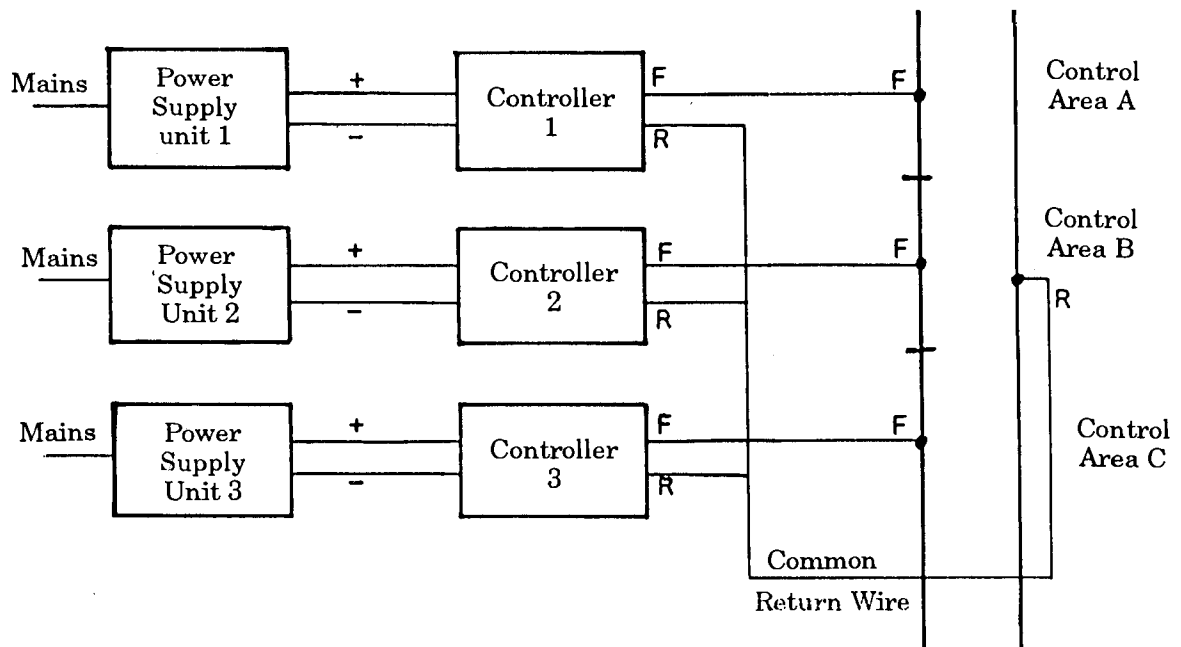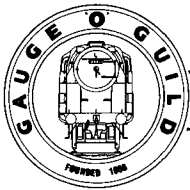

FIGURE 1-1   *Single power supply.*

FIGURE 1-2   *Common return system supplied by multiple supply units and control units.*

case conversion to direct current is by a rectifier in each controller. Reversal of track polarity is by double pole, double throw switches in the output circuit of the controllers.

A common return cannot be used with this system because breaks in both rails are necessary to allow adjacent control areas to be supplied at opposite polarity without short circuiting the low voltage supply. Briefly, the standard for two rail systems is that when facing along the track if the right hand rail is positive the locomotive will move forward.

Referring to Figure 1-3, a locomotive in Control Ar

Area A moving up the page would require the Return rail to be connected to the positive side of the supply; a locomotive in Control Area B moving down the page would require the Return rail to be connected to the negative side of the supply. Without the additional break there would be a direct short circuit via the controllers (shown by the dotted line). Isolation of sections within a control area still only requires single rail breaks and single pole switches.

When one low voltage supply unit feeds several controllers it is necessary to ensure that it can supply the maximum system load without an unac-
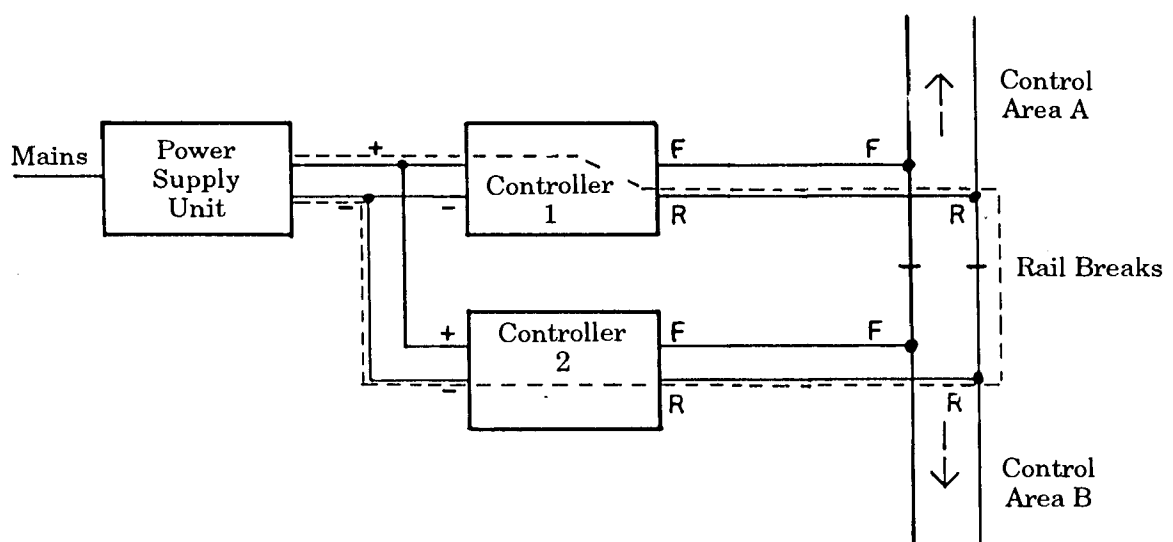
FIGURE 1-3   *Two control units supplied by a single power supply unit.*

ceptable voltage drop. This is particularly important when a battery charger is used as the low voltage source. An explanation of voltage regulation is given in the panel on page 8-1-8.

1.8.3 Split potential supply

This system allows a common return to be used with either two identical direct current power supply units or a single unit giving twice the voltage with a centre tap on the transformer secondary winding. The common return wiring is connected to either the centre tap on the transformer or to the positive terminal of one power unit and the negative of the other. Thus the supply to the controllers consists of the common return wire and a positive and negative feed wire.

Figure 1-4 shows a two unit supply and Figure 1-5 a centre tapped transformer. Note that in the latter case there is only a single rectifier and that in both cases the supply from the power unit(s) must be dc.

Polarity reversal for direction control is by single pole two way switches which connect the controllers to either the positive or negative feed wire. Figure 1-4 shows that when both controllers are fully on, a voltmeter placed across the rails of Control Area A would read 12 volts. Similarly, one placed across the

rails of Control Area B would read 12 volts but of opposite polarity. If the voltmeter is placed across the insulation gap of the feed rail between Control Areas A and B it would read 24 volts, but this does not reach the locomotives as they are only supplied from the section they occupy.

The previous comment concerning voltage regulation and power unit rating applies equally to the split potential system.

1.9 Three Rail Systems

All the above descriptions have assumed two rail electrification but many layouts use some form of three rail supply. These include centre third, outside third, stud contact and overhead supply. The circuits described above are equally applicable to these types of electrification. Figure 1-6 shows a multiple power supply common return system applied to centre third rail track.

Three rail systems have certain advantages over two rail in that sectioning is very much easier and by using insulation breaks in one running rail it is possible to provide simple track detection circuitry. Operation of return loops is greatly simplified as no special switching is required. Furthermore, the greater reliability of the sliding contact between the skate and the studs of a stud contact system and the
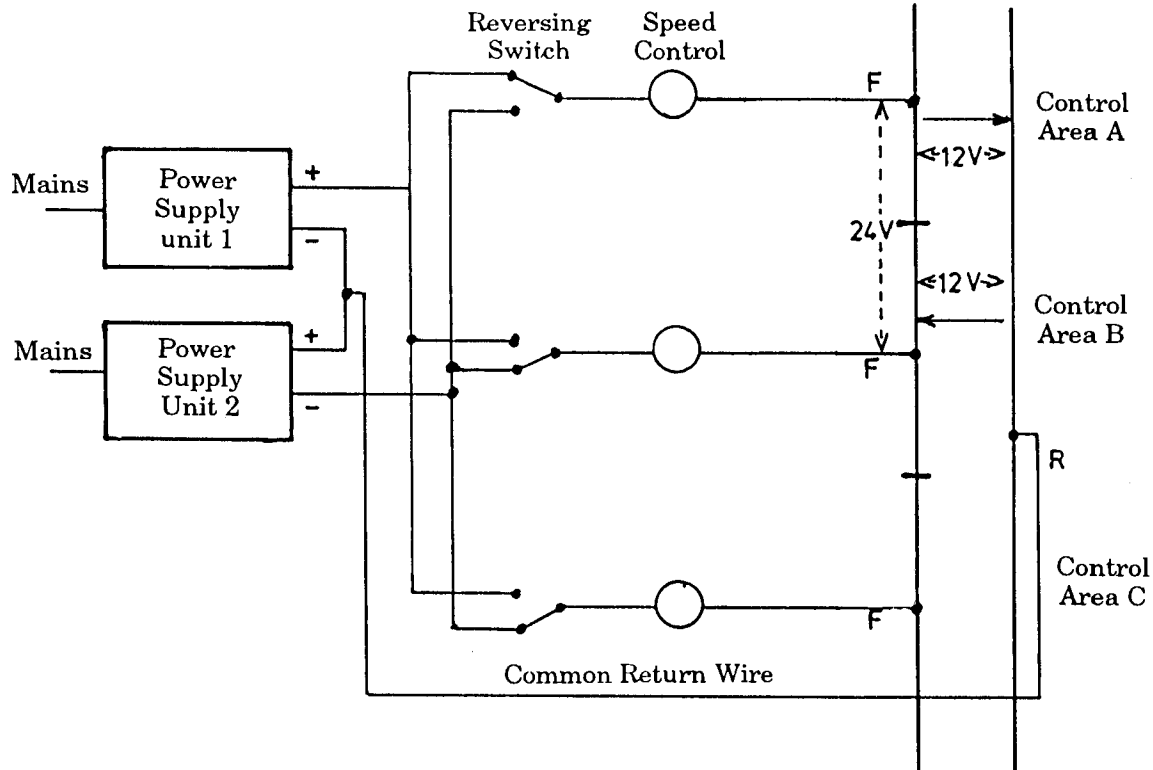

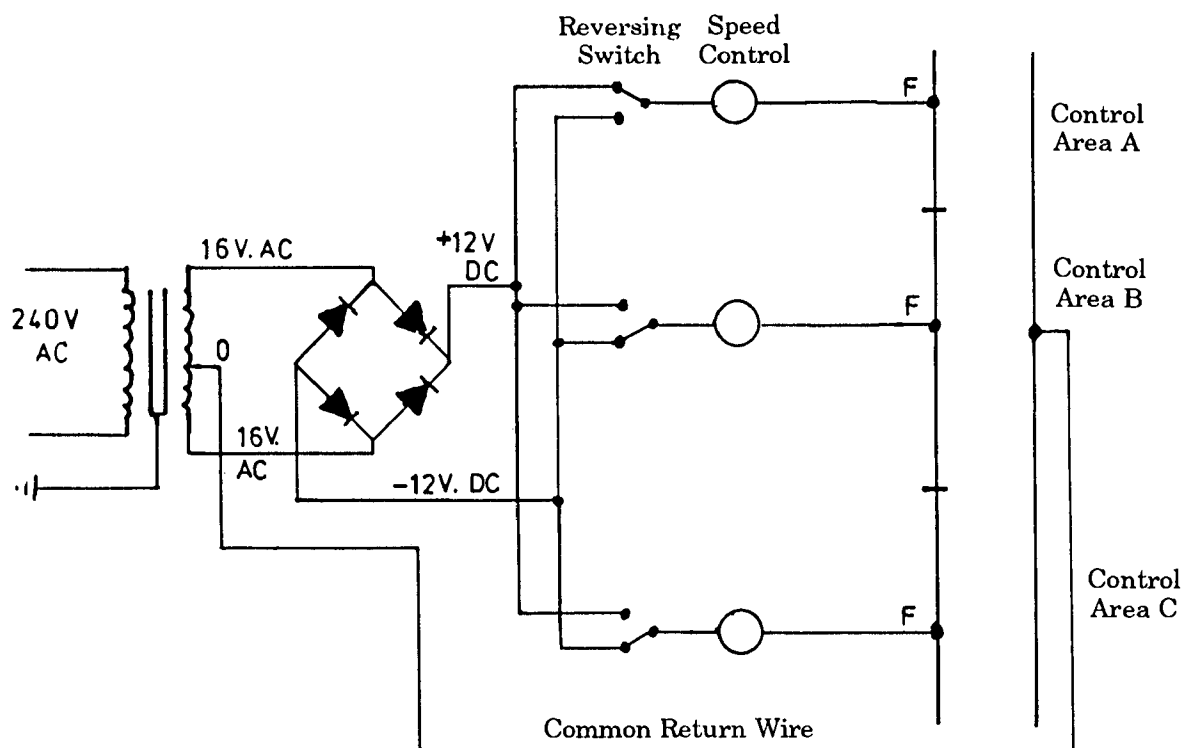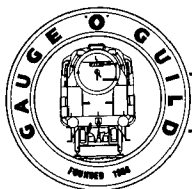FIGURE 1-4 *A split potential system having two power supply units.*

FIGURE 1-5

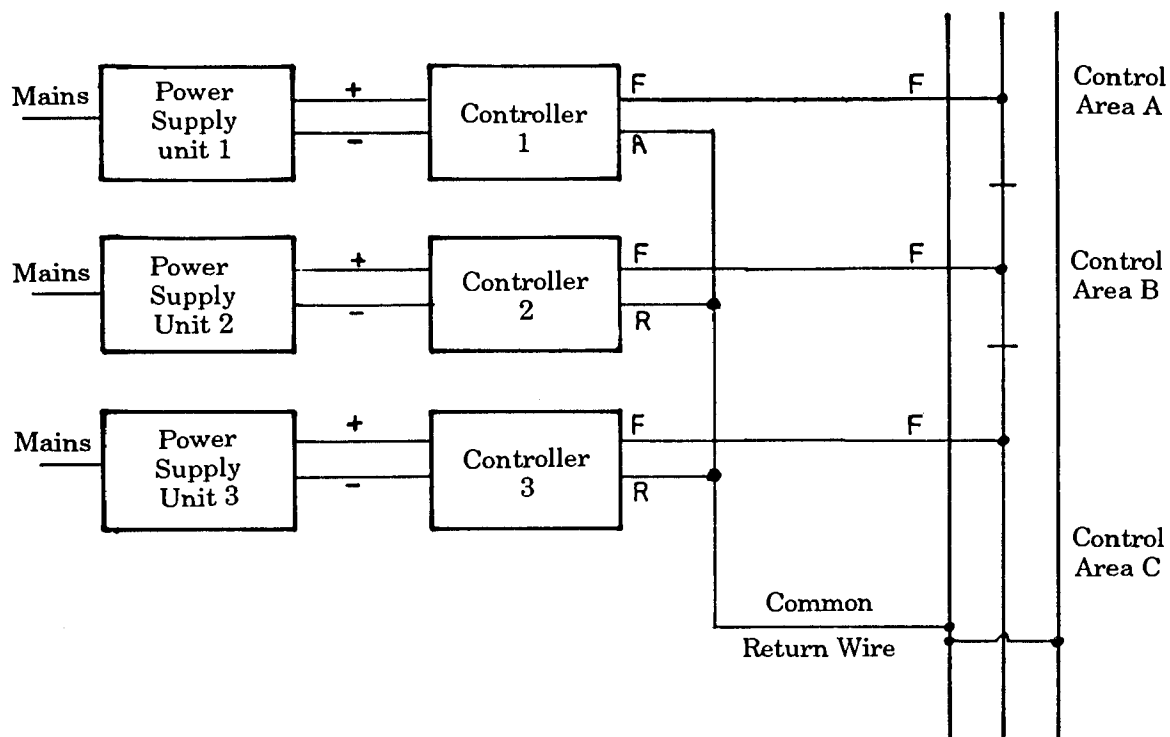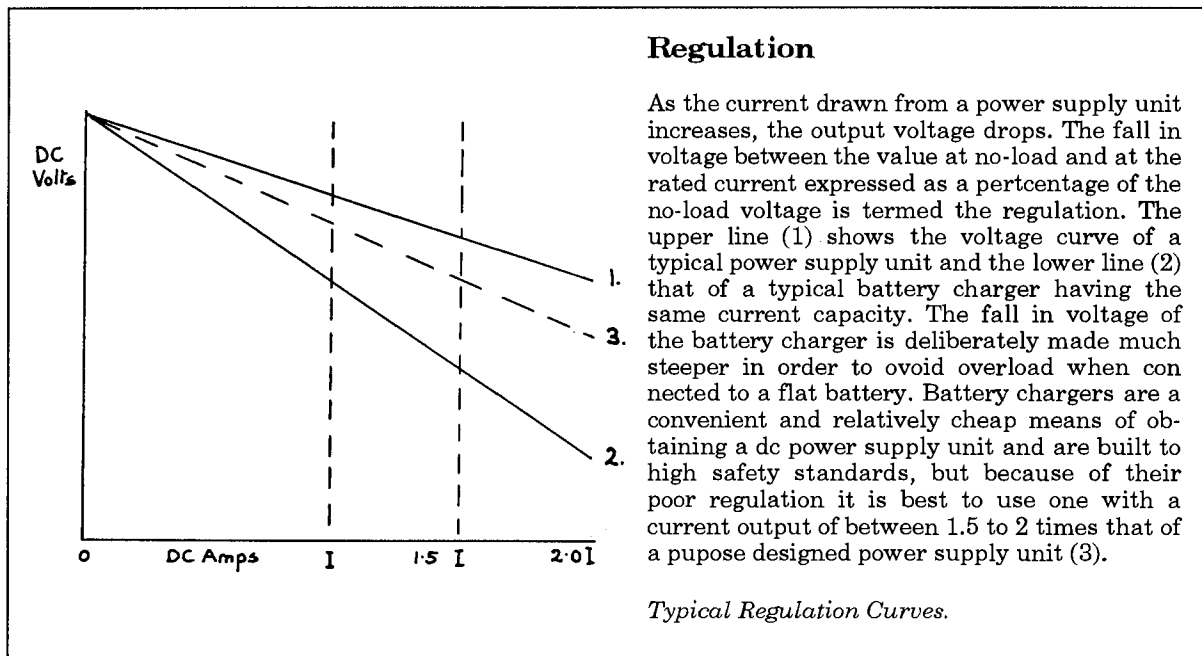*A Split potential system supplied from one heavy duty centre-tapped transformer and rectifier.*

FIGURE 1-6

Common return system with multiple power supply units applied to a three rail system.

Regulation

As the current drawn from a power supply unit increases, the output voltage drops. The fall in voltage between the value at no-load and at the rated current expressed as a pertcentage of the no-load voltage is termed the regulation. The upper line (1) shows the voltage curve of a typical power supply unit and the lower line (2) that of a typical battery charger having the same current capacity. The fall in voltage of the battery charger is deliberately made much steeper in order to ovoid overload when con nected to a flat battery. Battery chargers are a convenient and relatively cheap means of obtaining a dc power supply unit and are built to high safety standards, but because of their poor regulation it is best to use one with a current output of between 1.5 to 2 times that of a pupose designed power supply unit (3).

Typical Regulation Curves.

absence of switching at turnouts makes it particularly worthy of consideration for outdoor railways where the presence of the studs is generally less noticeable.

With three rail electrification the direction of motion for a given polarity depends on the way that the locomotive is facing, the standard being forward movement when the conductor rail or studs are positive. This is not a problem with single controller layouts, unless it is required to run two locomotives coupled together when they are facing different ways, but it creates difficulty on multiple operator systems when a driver taking over a train cannot see which way a locomotive is facing. This is particularly so with other than 'steam' locomotives. Section 2, Speed and Direction Control, explains how this difficulty can be overcome by fitting polarity switches to the locomotives.

1.10 Selection of Controller and Power Supply Unit Capacity.

When purchasing a mains fed controller or power supply unit look for an indication that it complies with either BS 4435, BS 3535 or EN60 742 Section 2. (BS 4435 has been withdrawn and replaced by the two latter standards which are technically identical with each other). Compliance with any of these standards will ensure that the unit is electrically safe, but see the earlier comments regarding the use of mains supplied equipment outdoors.

Some units will show the output as, say, 14V (volts) 28VA (voltamps). The latter figure is the power output and the corresponding current is easily calculated by dividing the voltamps by the

volts, i.e. the current corresponding to the above output is 2 amps.

When deciding on the size of controller or power unit required for a given application three factors need to be taken into account. The first is the thermal rating of the unit, which is the load it can supply for an indefinite period. The second is the voltage regulation which, explained above, governs the ability of the unit to maintain a stable voltage as the load increases, and the third is the overload trip setting which is the maximum current which can be drawn from the unit without automatic disconnection. A common trip setting is about twice the stated current output of the unit and is usually determined by the short time overload capacity of the rectifier.

These factors affect the selection of suitable equipment in the following ways:

a) The thermal rating must be sufficient to supply the average current demanded by the trains for an indefinite period without overheating. This is not usually the limiting factor.

b) The regulation must be such that the voltage when supplying the maximum steady load is not unacceptably low. This can be the most important consideration if a battery charger is used as a Power Supply Unit.

c) The overload trip setting of a speed controller, whether it is supplied by mains or low voltage, must be such that it prevents electronic devices being damaged by short-time overloads yet does not operate when accelerating a train or in the event of a momentary short circuit occurring,

for instance, when passing over a point. This is often the deciding factor.

Taking all these factors into account the following simple 'rules' should cover most cases.

For controllers used either as the sole unit on a small layout or as one unit of a multiple supply system, (Figures 1-1 and 1-2), the recommended minimum current rating is as follows:

a) For any likely load including locomotives with old high current motors or where double heading of heavy trains is a requirement: 5 amps.

b) To supply only modern high efficiency iron cored motors: At least 2 amps.

c) To supply coreless motors with high efficiency gearing: At least 1 amp.

If a battery charger is used as a direct current power supply unit the current capacity should be double the above values to compensate for the poorer regulation necessary for its normal duty. (See the side panel opposite).

As a further comment, although the current capacity stated on the nameplate of proprietary controllers takes all these factors into account, it is always advisable to use controllers and power supply units slightly more powerful than necessary as the cost of so doing is unlikely to prove excessive and the additional power may prove useful when dealing with visiting locomotives.

The determination of the capacity of a power supply unit to feed a number of controllers, (Figures 1-3 and 1-5), is more complex and it is not possible to do other than make very general recommendations. In order to do so it is necessary to consider the transformer and rectifier separately.

A transformer can withstand a considerable overload for an appreciable time without overheating. Consequently, because the average load on most railways, particularly end to end layouts, is much lower than the maximum, a transformer with a thermal rating well below the maximum load can be used providing it can maintain an acceptable system voltage. Thus the size of the transformer will most likely be determined by its voltage regulation.

On the other hand, electronic devices, including rectifiers, are quickly destroyed by overloads and consequently must have a continuous current capacity at least equal to the cut out setting. Fortunately the cost of rectifiers is now such that there is no significant economic penalty in providing ones of ample capacity.

The following formula converts the above considerations into a general recommendation, but it must again be stressed that this is only a guide and is not a firm specification for all power supply systems.

If the transformer and rectifier are obtained separately the minimum transformer rating to maintain an acceptable system voltage should be:

Nc x Iav where:

Nc is the number of controllers likely to be in use at any one time.
Iav is the assumed average load on each controller, which should be taken as:
  1.0 amp when supplying a locomotive with a high current motor.
  0.5 amp when supplying modern iron cored motors.
  0.3 amp when supplying coreless motors with high efficiency gearing.

The rectifier rating and the power unit trip setting should be the same and between 2 and 2.5 times the transformer rating.

If the power supply unit is obtained as a single proprietary unit its capacity should be at least 1.5 x Nc x Iav.

If a battery charger is used as a power supply unit its capacity should be at least 3 x Nc x Iav.

1.11 Controller Output Cable Size

The voltage available at the terminals of a control unit may not be the voltage applied to the motor terminals of the locomotive. Large layouts, particularly long garden layouts, can suffer from voltage drop if the power supply relies only on the rails to reach the locomotives. This is particularly true if the motors fitted to the locomotives are older types with fairly high current demands. As an example, consider a simple point to loop layout in a garden where the loop is some 20m (60ft) from the terminal. The total length of rail involved in the circuit is 40m (120ft) and could have a resistance of, say, 2ohms. Bringing in our old friend Ohms Law (V = IR) shows that a modern can or coreless motor drawing about 1/3rd of an amp would suffer a voltage drop of 2/3V when traversing the loop. (V = 1/3 x 2). Any slowing would be hardly noticeable. However, an old open frame motor drawing between 1.5A and 2A would suffer a voltage drop of 3V to 4V. If the operating voltage were the usual 12V supply, there would be a considerable slowing as the train traversed the loop. *(This is one of the reasons for considering the use of a 24V supply for a garden line because by doubling the voltage the current demand is halved (power W = VI) and so is the consequent voltage drop).*

By running power feed cables along the track and connecting them to the rails at about 2m (6ft) intervals the effect of voltage drop is virtually eliminated. A useful size for a power feed cable that is available from most electrical suppliers is 16/0.2mm cable with a current rating of 3A and, if the layout is to have a colour coded wiring system,

it is available in a range of colours. On a very large layout using common return wiring where several locomotives could be moving at once, the common return cable size could be increased to 32/0.2mm with a current rating of 6A. The 7/0.1mm cable that is readily available is too small and not recommended for 0 Gauge.

Table 1 Wire Resistance Table

Type	Wire Strand Diameter		Wire Resistance	
	mm	(ins)	Ohms/ Metre	Ohms/ yard
Ribbon Cable	0.127	0.005	1.30	1.19
Equipment Wire	0.15	0.006	0.93	0.85
	0.2	0.008	0.53	0.48
	0.25	0.010	0.33	0.31
	0.5	0.020	0.087	0.08
	0.6	0.024	0.055	0.05

Resistance per metre per feeder =

$$\frac{\text{ohms/metre (from table)}}{\text{No. of strands in the feeder wire}}$$

Using again the example of a garden railway with a 20m circuit but adding 16/0.2mm feeder cables to improve the power supply gives the following results:

Resistance of feeder wire with a total length of 40m = $\frac{40 \times 0.53}{16}$ = 1.325 ohms

Resistance of the rails
    (using the above estimate) = 2 ohms

Combined resistance of the rails and feeder wires in parallel = $\frac{R1 \times R2}{R1 + R2}$ = $\frac{1.325 \times 2}{1.325 + 2}$ = 0.8 ohms

Coreless motor drawing 1/3A.

Voltage drop for a 40m circuit = IR = 1/3 x 0.8 = 0.26 volts compared with the 0.66 volts shown above.

Open frame motor drawing 1.5A

Voltage drop for a 40m circuit = IR = 1.5 x 0.8 = 1.2 volts compared with 3 volts shown above.

These reduced voltage drops compared with the layout without feeders would almost eliminate any change of speed while the train traversed the loop.

1.12 Controller Output Meters

In order to keep costs down, most commercial model railway controllers do not have voltmeters and ammeters fitted as standard. Because they are helpful in monitoring locomotive performance and to locate faults, it is useful if each control unit has its own set of output meters. The easiest to fit are centre zero types as it does not matter which way round the connections are made and they can be located between the controller output and the track. (Figure 1-7) Some modern digital meters are also independent of polarity. There are two snags with these types: they are expensive and they are not readily available.
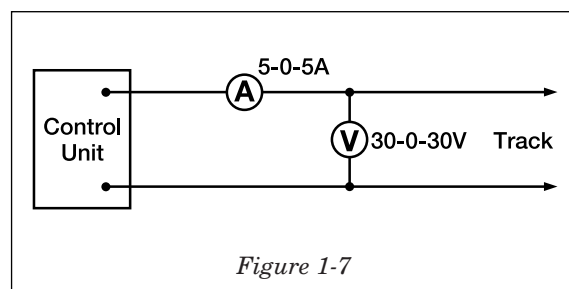

Figure 1-7

A cheaper alternative is to use polarised meters, i.e. those with their connections marked + and - . Being polarised, they can only be fitted into the control circuit before the output reversing switch. If only one meter is obtained it should be an ammeter as an indication of the voltage can be achieved using a lamp. Of the types available, the least expensive and also the most robust are the moving iron meters used for battery chargers. They are available in a number of sizes. Ammeters range from 4A to 20A and the two common sizes of voltmeters are 15V and 30V. For most applications use a 4A or 5A ammeter and, as the output of most 12V control units is actually nearer 16V, a 30V voltmeter should be adequate.

Most commercial control units are supplied as either panel mounting units or enclosed in a protective housing. Controllers enclosed in a housing normally include the power supply unit and its associated mains wiring and the internals are rendered inaccessible for this reason. If the controller is panel unit it may possible to gain access to the wiring between the speed control and the reversing switch. One wire to the reversing switch is broken and the circuit completed via the ammeter. The voltmeter is connected across the input terminals of the reversing switch. If a lamp is used for a voltage indicator, being non-polarised it could be fitted after the reversing switch. Figure 1-8 shows the connections.
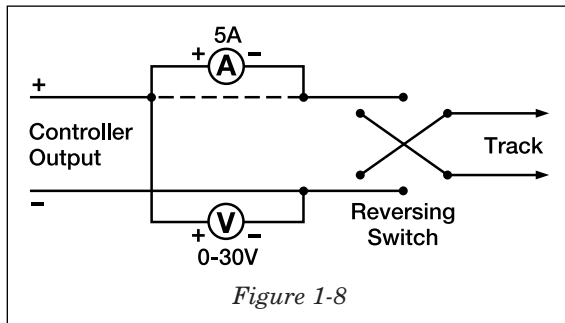
Figure 1-8

If it is not possible to get access to the wiring between the speed control and the reversing switch, then the meters can be fitted between the controller output and the track in one of two configurations. The simplest requires the use of a second reversing switch mounted on the meter panel. This is used to reverse locomotives instead of the controller switch. Figure 1-9 shows the set-up. When the meters have been connected, operate a locomotive to check that the meters respond. If they try to 'go backwards', operating the reversing switch on the controller should correct matters. Put a piece of tape over the controller reversing switch to remind yourself not to use it.
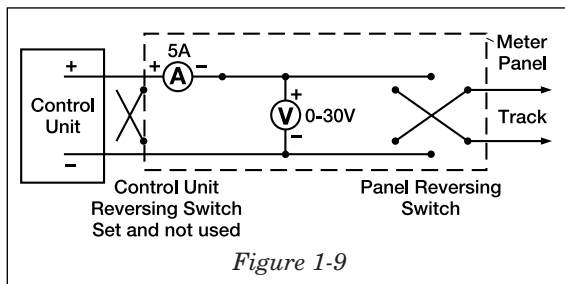
Figure 1-9

For those who feel that that a second reversing switch is a nuisance and could result in mal-operation, the alternative is to set the meters inside a diode bridge; the simplest version being a full

wave rectifier for each meter. As the Voltmeter only draws a very small current when operating, a one amp bridge is more than adequate. The ammeter however, carries the full traction current and the bridge needs to be of a higher rating to cope with this. Because solid state bridges can be quickly destroyed by a short circuit a minimum rating of 5A should be used for a low current power supply unit. For power supply units having higher ratings, use 12A, 15A or 25A bridges as these are only slightly more expensive. Figure 1-10 shows how the meters are connected to their respective bridges.
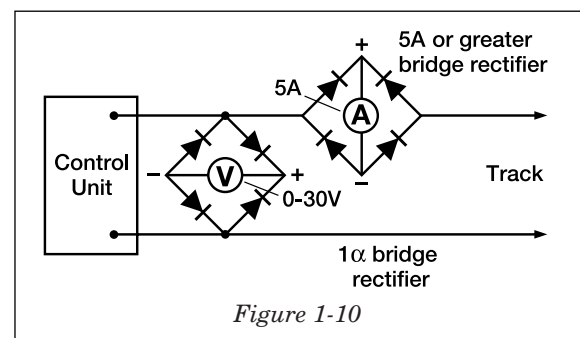
Figure 1-10

Note that a diode bridge has an internal voltage drop of about 1.2V and this would reduce the voltmeter reading by that amount. However, as the voltage drop in the voltmeter and ammeter bridges will be about the same, if the voltmeter is connected ahead of the ammeter as shown, its reading will be very close to the track voltage.

Where there are a number of control units involved, e.g. a large club layout, the cost of fitting ammeters and voltmeters to each unit may be considered too expensive, or there may not be sufficient space on the control panel, a plug in unit could be used for performance monitoring and fault finding. This could consist of a small instrument box with either centre-zero meters or meters
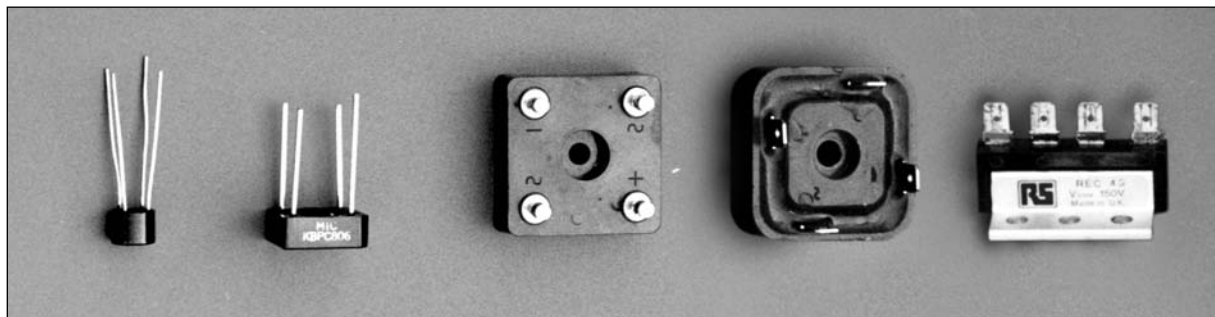

Photo 1.3
Five typical bridge or full wave rectifiers. From the left: a 1A unit, a 2A unit, an 8A unit with post terminals, an 8A unit with spade terminals, a 15A unit with spade terminals. The first two would be suitable for supplying a voltmeter. The other three can carry the full traction current required to supply an ammeter.

protected by diode bridges and fitted with a short cable terminating in a 0.25in 3-pole stereo plug. The output from each control unit reversing switch is led to a 3-pole chassis socket and from t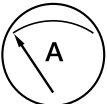here to the main control panel. Power to the track is nor- mally via a 'connector' plug but for testing or in the event of a fault occurring, the meters can be plugged in to help determine the type. Figure 1-11 shows the connections required.

Figure 1-11 Test unit plug and socket
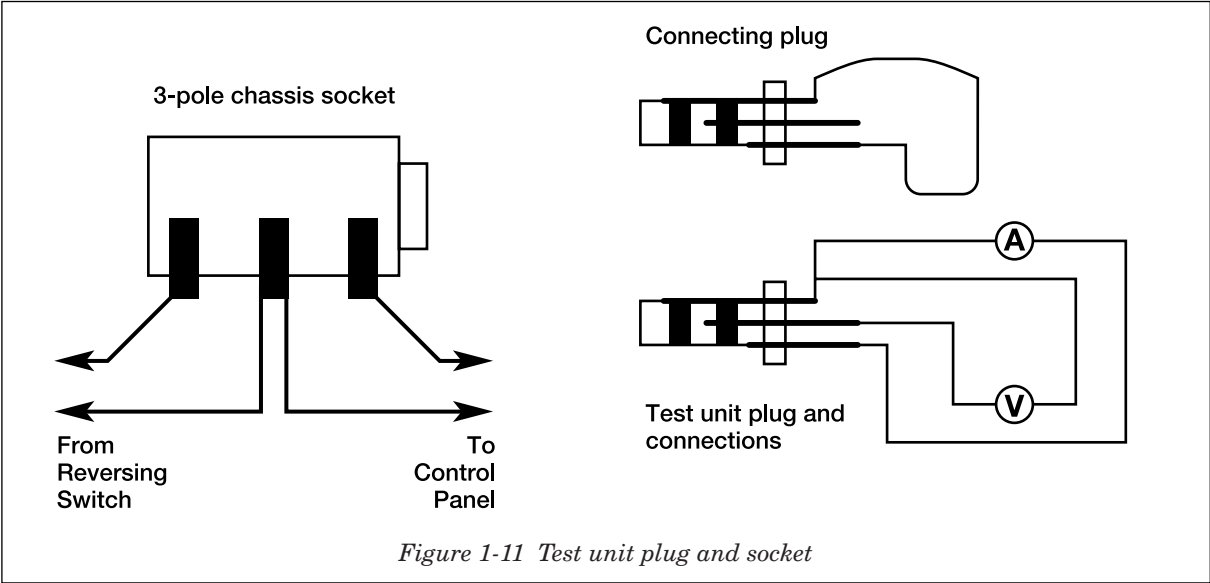
1.13 Interpreting Meter Readings

Using the figures in the motor data sheets, and with a little practice, it is possible to judge what is the normal current for a particular type of motor. For example, modern can motors only draw between 1/2 and 3/4 amp when pulling quite a rea- sonable length of train, particularly if the gearset is a high efficiency unit. Older open frame motors may need between 2 and 3 amps to perform the same duties. The following table shows some typi- cal readings and their interpretation.

Meter Readings		Controller setting	Fault
No Volts No Amps		Control knob set at an intermediate position.	Power supply failure.
High Volts No Amps		Control knob set near full speed position but locomotive does not move.	Open circuit.
Low Volts High Amps		Control knob set at an intermediate position but locomotive does not move.	Defective motor, overloaded or a short circuit.
Normal Volts Low Amps		Control set at an intermediate position. Train running poorly or stalling.	High circuit resistance.
High Volts High Amps		Control set near full speed position. Heavy train running slowly.	Caution - motor is being overloaded and could be damaged.