Electronics for Model Railways

Chapter 4

Track wiring

By Davy Dick

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In memory of Margaret

Contents

Track wiring

The previous chapter looked at running a single train on a simple loop of track with a single power feed. A place where most of us started. Later, however, you add points and extra track, to allow for more varied running.
So that chapter discussed methods of laying the track as a collection of separate isolated sections, making possible more complicated running operations. These included Cab Control systems and large DCC systems using multiple boosters to feed many power districts.

Another reason for having isolated sections, both with DC and DCC, is to allow for track detectors to detect and act upon track occupancy (knowing that a loco is sitting on that section of track, whether moving or stationary). For example, the MERG TOTI-4 and TOTI-12 kits detect tiny currents when a loco is sitting in an isolated section. How the feedback from these detectors can be used is covered in a later chapter.

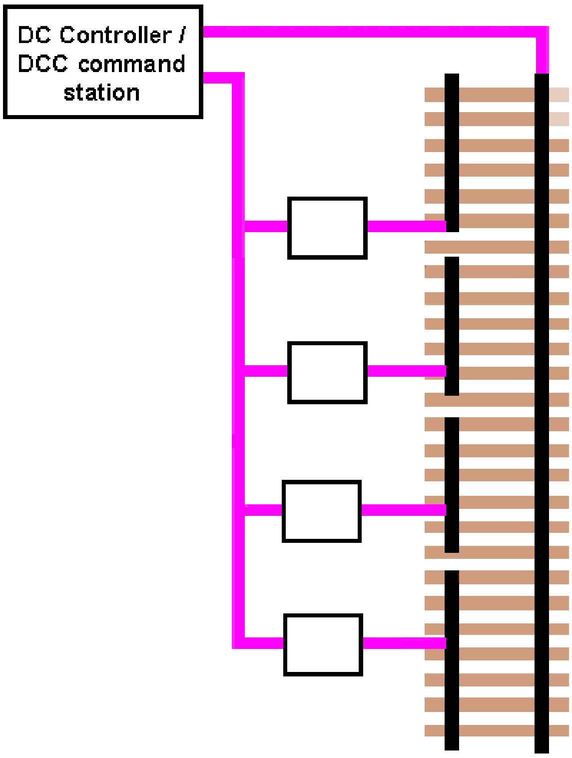
There are two approaches to wiring isolated track sections:

- Common return
- Two wire feed

If you have not yet laid your track, you may want to look at these two options and decide what is best for you.

Common returns

One wire from the controller is fed to one rail as shown in the illustration.
The other rail is cut into sections and the pieces are joined with insulated rail joiners. Each section is connected back to the controller through a device shown here as a blank box.
For a cab control system, these boxes represent switches. This means that individual sections are only powered when their corresponding switches are thrown.
Alternatively, the boxes might represent track occupancy detectors, such that the only detector triggered is the one that is passing current (through the loco's motor).



Pros:

- Simplifies wiring. Half the wiring of the twin feed approach.
- Simplifies fault-finding. If one section stops working, there is only a single wire to trace for a fault.

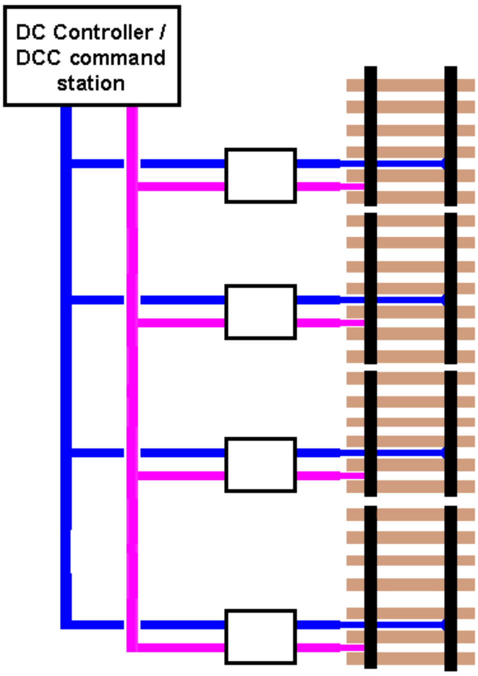
Cons:

- If using multiple boosters, the common return must have a very high amperage rating, as it has to carry the sum of all the boosters' currents. For example, if six of the sections were consuming 1A of current, the return wire has to carry 6A.

- If a single common wire is used to connect the return wire from the track, solenoids, detectors, etc., there is an increased risk of interference (e.g. a pulse from the solenoids affects the detectors resulting in false triggering).
- Reverse loops still need to have isolated sections, to avoid shorts.

An improvement could be using separate returns for different high and low current devices. So, for example, the power bus, traction bus and solenoids could share a common return. These are all high current wires but are relatively immune to interference.
Low level signal wires, such as track occupancy detectors and logic signals for motorised points could then share a common return that is unaffected by the large current pules on the other return wire.

Twin feeds



To isolate a piece of track, both rails are cut, instead of one. Every piece of track has both rails isolated from adjacent track sections and each section is is fed with two wires, one for each rail.
For block control, this means use a double-pole double throw (DPDT) switch, so that both rails are connected when the switch is thrown.

Pros:

- Reduces unwanted interactions. Since no sections share a common return wire, the chance of changes in one section affecting another section is greatly reduced.
- Easier to make future alterations, as all rails sections are already wired under the baseboard. There is no need to cut track and insert insulated joiners. You simply rewire your under board connections to what your new needs are, without touching anything above the baseboard.

Cons:

- Many more wire runs. Twice as many wires to connect.
- More scope for faults. Twice as many connections to go faulty.

Positioning track breaks

As we have seen, there are a number of circumstances when we want to introduce isolated blocks and sections:
These include:

- For DC Cab Control.
- For DCC power districts.
- For DC/DCC track occupancy detection.
- For programming the CVs of DCC decoders.

DC Cab Control

The layout's track is cut into isolated sections that meet the operational needs of the user. Sometimes a long stretch of track will be considered as a single block. If, however, you want to run several locos on that stretch at the same time, the track has to be further sub-divided. On most occasions, a single siding has to be isolated (or at both ends for a passing loop. The plan has to cover all track sections where a loco might be reasonably expected to stop, and also take into account the likely maximum length of the train on each particular isolated section.

Power to the track sections is routed through switches/relays.

DCC power districts

Power districts are introduced to spread the heavy current demand in the layout. This is usually caused by concentrated activities in distinct 'work areas' such as main line stations, goods depots, marshalling yards, fiddle yards, etc. These work areas can be isolated from each other and be fed from separate boosters, each booster taking a share of the overall current demand.

Power to the track sections is routed through DCC power boosters.

Track occupancy detectors

The isolated sections should be chosen according to the function they are to fulfil. For example, you may only want a single occupancy detector, to operate crossing gates. Another option is allocate a detector to each of a layout's hidden sidings, to indicate which are currently occupied. You might even consider having many occupancy detector sections all round a layout, to provide feedback for mimic panel updates or computer automation.

Power to the track sections is routed through the current detectors.

Programming track

DCC-equipped locos have their decoders programmed using a SPROG programmer, or the programming output from a DCC command station. The loco has to sit on a stretch of track that is dedicated for programming locos and is isolated from the rest of the layout, to prevent accidental re-programming of other locos. Some users prefer using a small piece of track on their workbench, to avoid any possible mistakes.

Power to the track comes from the SPROG programmer or a DCC command station's programming output.

Feeds and droppers

Track buses carry power all round the layout but they don't connect directly to the track rails. The track bus has to carry all the current needs of an entire layout, or an entire block or section. To minimise track resistance and connection problems, the track bus is best wired as a pair of continuous heavy current conductors that makes its way along the layout under the baseboard.

Short wires are then taken from the track bus and fed through holes in the baseboard to connect to the track rails above. These wires can be of lower current capacity, since they don't carry the total layout current.

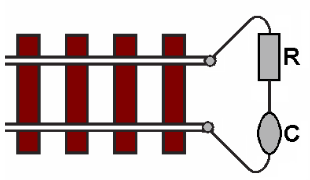
These short wires are known as droppers (because they drop through holes drilled in the baseboard) or feeders (because they feed the power from the track bus to the rails).

There are conflicting opinions on how many droppers should be used for any one section of track, with advice varying from 18" to 12'.
However, there is general agreement on:

- If a section is made up of two pieces of track, take a dropper to each piece – do not rely on getting a good contact from the rail joiners. Alternatively,some solder both rail ends to the rail joiners, although this can lead to problems when the track expands/contracts under changing temperatures.
- Droppers should be soldered to track rails, not to joiners.
- For long stretches of isolated track, use more than one dropper. This ensures continuity should one dropper fail. It also improves performance (less voltage drop, since track buses have lower resistance than most track rails).
- Use the thickest dropper wire you can manage, taking into account aesthetics and any soldering difficulties that may occur with smaller gauges.
- Droppers should be as short as possible. This prevents the introduction of a high resistance section into the current loop, which might prevent the short circuit protection system of a controller or booster from operating (the current may be sufficient to cause damage while not being high enough to trip the protection).
- Smaller gauges have track rails with much smaller mass and therefore higher resistance. It follows that a long run of z gauge track would need more droppers than the same length of O or G gauge track.

DCC bus terminators

DCC systems generally run perfectly happily, with small distortions of the DCC waveform being handled by the decoders.
However, where the bus is over 10m, or where you are experiencing decoder efficiency problems, terminators can be fitted to each end of the bus.
These devices are simple filters that prevent voltage spikes appearing on the bus and upsetting (or damaging) decoders. It is intended to improve the DCC waveform and thereby improve DCC reliability.



Terminators can be bought or can be made from two components as shown. The resistor can be around 100 to 150 ohms 1W or 2W, and the capacitor is 100nF (0.1uF) ceramic at 50V working. The two are wired in series then wired across the ends of each bus.

Wiring suggestions

These are drawn from the experiences of others and should be given due consideration.

Routing wires

The track bus should be as short as possible (to minimise voltage drop), while following the main track as closely as possible (to keep droppers as short as possible). Sometimes, you may have to run spurs off the main bus to avoid long snaking runs for the main bus.
Of course, the track bus (or buses) are not the only wires on the layout. Under the baseboard, you may have buses for accessories, lighting, point operation, track occupancy feedback, etc.

Since every piece of electrical equipment has the potential to generate magnetic fields and also to pick up these unwanted radiations, consideration has to be given to preventing mutual interference.
This means that wires from feedback devices (e.g. track occupancy detectors) should not be routed close to DCC buses or, even worse, point solenoid wires or decoupling magnets. Similarly, wires to heavy current motors should not be run close to DCC buses, to minimise motor commutation spikes from upsetting DCC signals.

Where there are multiple DCC buses (from boosters), they should be spaced apart to prevent 'crosstalk' – the signals from one booster being picked up on the neighbouring bus.
All this suggests that you should avoid running all the cable together in trunking, or bunching to pass through the same hole drilled in the baseboard frame.

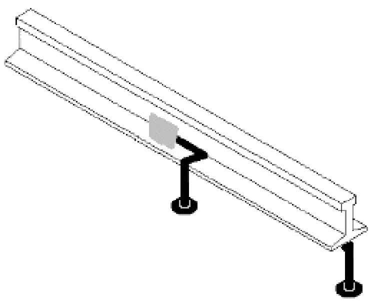
Twisting wires

DCC system rely on having clean signals that the decoders can understand. Any external interference (from loco motors, point solenoids, radio transmitters, etc.) can modify the signal and prevent reliable operations.
The longer the track bus wires, the greater is the danger of interference. While this may pose few problems for small layouts, precautions are recommended for large layouts. A bus wire acts like an aerial, picking up external interference and converting it into unwanted voltages on the wire. So, if the two bus wires are twisted together, the unwanted voltage on one wire is cancelled out by the voltage being induced in the opposite polarity in the other wire.
There is no need to buy special twisted pair wire. Just twist the two wires loosely round each other, approximately two to four twists per foot.

Connecting wires

Good, low resistance connections are essential for trouble-free operations, with reliable metal-to-metal contact. This requires making 'gas tight' connections to prevent the build up of oxides (poor conductors) between the wires and the terminals.
Soldering is the best way to ensure an air-tight connection.
Screwed connections can be successful as long as precautions are taken to ensure that the wire ends and the screw surfaces are clean, shiny and free from dirt, corrosion, rust, oils, etc. If the wire end or terminal needs cleaning, the connection should be completed as soon as possible, before surface oxidisation starts.

Fitting droppers



The illustration shows two methods of soldering droppers to the track rail. On the left, the dropper comes up through a hole in the baseboard and is bent as shown before being soldered (don't forget about cleaning the track area, tinning that area and the wire end before soldering). This method is the only option if the track is already laid.
On the right, the dropper is soldered to the underside of the rail <u>before</u> the track is laid. The other end of the wire is then inserted through the hole and soldered to the track bus. This method is used where some thought has been given to the locations of track blocks/sections prior to laying a section of track.

What current does a layout need?

The table shows typical current demands for one of each device.
These values will vary depending on different manufacturers of the same product.
The current demand can vary from as little as a few milliamps (e.g. LEDs) to 5A for a point solenoid. For locos, it can be under 100mA for a Z gauge loco and as as high as 20A for a long consist of O gauge locos.

Typical current demands

Locomotive motor: Z scale N scale TT, 00/H0 scale O scale Note : For any gauge, older motors work on higher currents	100-300mA 50-300mA 250-500mA 400mA-1A
Twin-coil turnout (point) motor e.g. Peco, SEEP	5A pulse
Motor-actuated turnout motor e.g. Tortoise, Conrad	15-20mA
R/C servo turnout motor	100mA
Memory wire actuator (turnouts and signals)	200mA
Light Emitting Diode (LED) (signals, train headlights / taillights)	5-20mA
Incandescent lamps (signals, train headlights / taillights)	40-80mA
Relay coils	20-50mA
CBUS modules	20-70mA
Track occupancy detectors	2-70mA
Signal wires (from TOTIs, to Servos, to/from CBUS modules)	2mA

Another MERG member kindly provided these test readings from his collection of N gauge locos.

	running light engine at reasonably fast speed	ditto with finger stopping it moving so wheels spin	held so wheels cannot turn
Old (Poole) Farish (open frame motor)	180mA	230mA	360mA
Dapol Brit (can motor):	105mA	145mA	205mA
Dapol Ivatt tank (can motor)	45mA	85mA	180mA
New Farish Black 5, (tender drive from can motor)	25mA	30mA	90mA
Farish 08 (can motor)	25mA	30mA	40mA
Farish WD 2-8-0 (coreless motor)	12mA	30mA	90mA

We have to ensure that the layout's wiring can meet the demands of all the locos and other devices that may need to run/operate at the same time.
Let's see what wire types are available and then decide what's best for a layout.

Wire standards

AWG	Dia (inches)	Dia (mm)
10	0.1019	2.59
11	0.0907	2.30
12	0.0808	2.05
13	0.072	1.83
14	0.0641	1.63
15	0.0571	1.45
16	0.0508	1.29
17	0.0453	1.15
18	0.0403	1.02
19	0.0359	0.91
20	0.032	0.81
21	0.0285	0.72
22	0.0254	0.65
23	0.0226	0.57
24	0.0201	0.51

As usual, why have one standard when you can have several? Why learn about them ? Because you will often find them referred to in model railway magazines and on the internet. More importantly, they are used as descriptions of wire being sold by Rapid, etc.
The American Wire Gauge (AWG) is a U.S. standard for wire gauges. Higher gauge number indicate smaller wire diameters, with thicker wires having lower gauge numbers. Although an American standard, it is often quoted in UK and European descriptions.

There is also an Imperial Standard Wire Gauge (SWG) and its values are not directly equivalent to AWG values. SWG is not often used.
Probably the most understandable is the metric measure, which describes the wire in terms of its diameter or its cross-sectional area (CSA) measured in square millimetres. Unlike AWG, higher metric measurements indicate thicker wires.

Wires are sold either as a single solid conductor, or as a multi-stranded cable.
Multi-strand cables are described in the metric system by giving the number of strands, followed by the diameter of each strand. So, for example, a wire described as 7/0.2 is made up of seven strands of wire where each strand has a diameter of 0.2mm.

AWG, on the other hand, does not make a distinction between solid and multi-strand.
So for example, an AWG value of 24 could be a single strand of 24 AWG, or it could be made up of seven strands of thinner 32 AWG wire (which together result in the same current-passing capacity as a solid 24 AWG conductor).

Current ratings of different wires

As expected, thicker wires can carry greater current than thinner wires of the same material.
This tables describes some the wires that are available from Rapid Electronics,etc.

Number of wires/ diameter of each wire	Current capability	Available colours
Kynar – 1/0.25	0.5A	11
10/0.1	0.5A	11
Ribbon cable – 7/0.127	1A	11
7/0.2	1.4A	11 (also 16 bi-colour)
Security alarm cable (7/0.2)	1.4A	4,6 and 8 core
1/0.6	1.8A	11
16/0.2	3A	11
32/0.2	6A	11
Twin and earth 1mm^2 (lighting)	15	2
Twin and earth 1.5mm^2 (lighting)	20	2
Twin and earth 2.5mm^2 (power)	24	2

Notes:

The current ratings shown are a good indication of what can be expected under normal conditions. Some manufacturers are reluctant to stipulate an exact value, as the current handling can be affected by external conditions such as the ambient temperature and problems with heat dissipation.

The picture shows a piece of 'twin and earth' cable. It has three solid conductors, two being insulated and one being bare. Normally used for house wiring, it is often stripped of its outer plastic sheath and used for carrying heavy currents round a layout.

Some cheaper wires (e.g. bell wire) may not be made from copper, instead being iron with copper plating. This increases the wire's resistance significantly (perhaps a factor of 5 times) and lowers its current carrying capacity.

Selecting wires for layouts

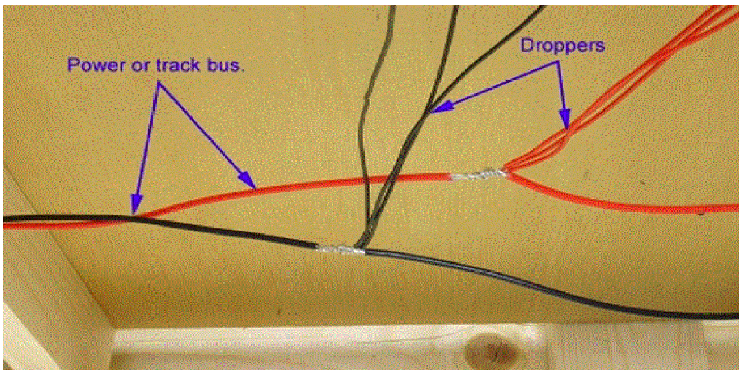
The earlier chart showed the current demands of various elements of a layout.
The wire chosen for a particular job should be able to supply the current needs of the maximum amount of devices that could be operating at the same time – plus an extra margin.

Track bus

This is likely to have the heaviest current and the one most likely to suffer from shorts (e.g. locos derailing). So, the wire should not be chosen for the maximum loco currents, but for the maximum current in the event of a short.
You cannot always rely on a controller's cutout.
Consider a 12V, 5A controller, where the bus wire's resistance is such that the circuit current can never reach 5A. In a situation where the supply can provide 5A but the short only results in 3A , the controller cutout won't trip. However, since power is calculated as I x V, the circuit (the track bus and probably part of the track) will dissipate 3 x 12 = 36W!
Clearly it is necessary to ensure the lowest possible resistance in a track bus, particularly in the larger gauges where loco currents can be many amps.
Since the track bus runs the length of the layout and is hidden under the baseboard, it pays to use the thickest twin and earth wires that you can afford.
One solution lies in sub-dividing the layout into blocks (DC) or power districts (DCC), where the current in any one section is reduced.

Droppers

The track bus carries the controller's power across the entire layout.
It does not normally appear above baseboard level.
To connect the track sections to the track bus, small connecting wires are soldered to the track, poked through holes in the baseboard and then connect to the track bus.



To prevent unsightly connections between the droppers and the track in smaller gauges, it is common to use thinner wire than that used for the track power. This is not a problem, as long as the dropper lengths are short. Although these wires are thinner and therefore have a higher resistance, the fact that they are short means that they do not much alter the overall resistance of the circuit.
The picture shows part of the insulation on the track bus being bared back to allow droppers to be soldered to them.

Points

Solenoid-operated points are designed to pass a large current for a short time and are usually used in conjunction with CDU (capacitive discharge units) modules.
I measured the coil resistance of a Peco solenoid coil at just over 5 ohms and an old H&M coil at just 2 ohms. In theory, a CDU's pulse of 20V should result in a pulse of around 4A through a Peco solenoid and a whopping 10A through an H&M solenoid. Where such small coil resistances and such large currents are in play, the presence of even a small unwanted resistance can have a major impact on performance. Wiring for solenoid power, therefore, should use either 1.5mm or 2mm wire. The same considerations apply to electromagnets used for uncouplers.
For these reasons, it is best to locate CDUs as close to the points as possible, to minimise long runs carrying high currents. After all, the signal that controls the CDUs only requires small switching currents.

Motorised switch machines, such as the Tortoise, operate with much less current (from 4mA to around 20mA) and will happily work with 7/0.2 wire or even ribbon cable – unless you have particularly long runs to the point motors.

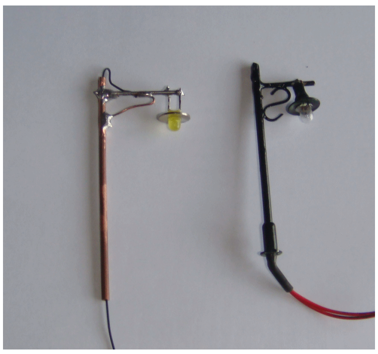
Servo operated points are becoming more popular for a variety of reasons (cost, speed, controlability). An individual servo may only demand a few hundred milliamps while operating. On the other hand,, moving multiple points (as in route switching) increases the current demand substantially during movement and that has to be taken into account when running power wires to servos.

Accessories

The connecting wires to each accessory depends on the current draw of that accessory.
In most cases, 7/0.2, alarm wire or ribbon cable is more than adequate.
If you have a large motorised accessory, you would use 16/0.2 or higher.

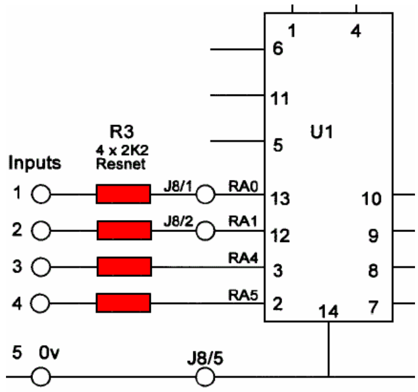
Lighting

Grain of wheat bulbs use around 80mA at 12V.
Lighting a row of buildings or a chain of street lamps soon totals a substantial current draw.
To reduce wire thickness and reduce power requirements, most modellers are turning to LED lamps for illumination
The picture shows a commercial OO lamp using a grain of wheat bulb that uses 60mA. On its left is a home-built equivalent using an LED that uses just 5mA.
Even the thinnest of wires can handle the current requirements of a chain of LEDs, particularly if they are wired as groups (where a group may consist of 3 LEDs in series).



Signal wires

Layouts may use a range of different signal wires such as feedback from occupancy detectors, signals to drive servo boards and the inputs and outputs of CANBUS modules. This diagram shows the input signals to a MERG Servo4 board. Each input has a 2k2 resistor in series. Since the voltage to any input is either +5V or 0V, the maximum current that can be drawn is 5/2k2 (a couple of milliamps). Similarly, the outputs of a CANACC8 have 10k resistors in series, limiting their current draw to half a milliamp. Consequently, 10/0.1, 7/0.2, alarm cable or ribbon cable can be used for signal wires.



Suggested wire usage

Kynar or Litz	0.5A	Anywhere where a very thin wire is needed (e.g. inside bthe brass tube of a signal or lamp standard, coach lighting, etc.).
10/0.1 or ribbon	0.5A	Colour-light signalling, individual motor-actuated switch machines (Tortoise Conrad, etc.), LED lighting, signal wires to Servo4s, from track occupancy detectors and to/from CBUS modules.
7/0.2	1A	Track feed droppers.
16/0.2	3A	DC traction feeder, DCC power Bus (booster output up to 3A), twin-coil solenoid point motors
32/0.2	6A	DCC power Bus (booster output up to 5A), DC Bus, twin-coil solenoid point motors
Twin and earth	10A , 15A, 20A	DCC power Bus (booster output up to 10A), DC Bus

Stranded v solid wire

Copper wire is available as a single solid conductor or as a set of thinner strands twisted together. To some extent, it is a matter of personal preference, although some factors have to be considered.

Stranded wire, by its construction, is much more flexible and is really essential in situations where the cable will be flexed (e.g. hand-held controls, or trailing plugs and sockets for joining multiple baseboards) or subject to excessive vibration. In these situations, solid conductors would suffer from stress fatigue and probable eventual failure. The thinner the strands used in the cable, the more flexible it is.

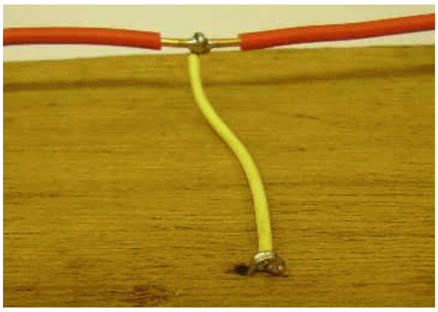
That is not to say that stranded wire may not eventually suffer from stress fatigue (I have replaced my multimeter leads three times due to broken wires inside the insulation or where the wire meets the plug). Solid wire, specially twin and earth wire, is often used for power buses under the baseboard where it is a permanent installation. Stranded wire can be used here too, although many prefer the rigid, non sagging, nature of solid conductors.

Solid wires take longer to corrode than stranded wires (less surface area) and can be useful for garden railways.

Types of connection

The layout will have many connections between wires, between wires and devices and between wires and various connectors. Users have employed and advocated a large range of connection types, with some controversy being generated as a result.
The descriptions that follow explain what connection components are available.
Users can decide which of the following methods most suits their needs.

Soldered



For many places, this is the most secure, most permanent, most trouble-free connection, if done correctly.
You can expect many years of problem-free use from soldered joints, assuming there was a good clean mechanical joint and soldering was carried out efficiently. The picture shows a dropper wire being wrapped round a power bus before being soldered.

WAGO 222

These terminal blocks are designed for handling 240v domestic lighting at 32A. They are intended for permanent installation in homes, where a robust and reliable connection is essential.
They are not straight through connectors. They are available in strips of 2, 3 or 5 lever connections, with all the sockets joined internally.
They are useful for power fanouts, with the main feed and the auxiliary feeds sharing the block.
Their use requires no special tools, just strip the wires and insert their bare ends into the holes before closing the levers. It is a very quick assembly process which is helpful when used in awkward and hard to reach locations. Wago terminal blocks can accommodate up to 2.5mm solid wires, although it also works with stranded wires.

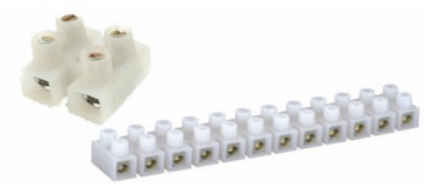
Of course, not all connections lend themselves to these two methods, since they may have to allow for devices to be plugged/unplugged or baseboards to be attached/detached on a regular basis.
There, a more flexible approach is required.

Wire nuts

These are also known as cone connectors, thimble connectors or Marrette connectors and are sometimes used as an alternative to terminal blocks. They are plastic cones with a coiled metal insert.
They are specially effective for connecting stranded wires.
They are available in five sizes and are colour coded to indicate the gauge of wire they are intended for.
To install, just bare the wires, insert them into the cone and twist the cone. The wire-to-wire and the wire-to-insert contact make a reliable connection that can be readily undone by untwisting the cone.

Screwed

The most common non-soldered connections make use of terminal blocks (also known as 'chocolate blocks').

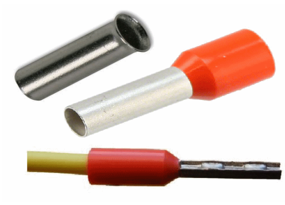


These are straight thorough connectors, with screws on either side of each connection. They are often sold as strips of ten and can be easily cut into smaller blocks with a knife.
There are holes between each connector, allowing easy screw mounting to a baseboard. They are cheap and come in different sizes, to provide 3A, 6A, 10A, 15A, 16A and 30A versions.
There are a couple of things to watch out for when using these blocks.
As MERG member Howard Watkins pointed out:

> *"Some people prefer to solder the wire, especially if several wires are to go in the same terminal block position. This should be avoided because solder is a soft metal and tends to squeeze out from between the strands. As time progresses the joint can become loose and the connection can become unreliable."*

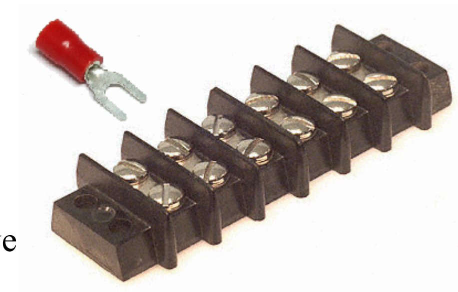
Another danger is not having every strand of wire securely held under the screw. If, for example, three strands of a 16-strand wire ended up as stray unconnected wisps, you have lost almost 20% of the connections current carrying capacity.
One way to prevent this is to use crimp ferrules.

Crimp ferrules



Where multi-strand wire is used with terminal blocks, consideration should be given to the use of crimp ferrules. These are simply metal tubes into which the bared end of a wire is inserted. The tube is then crimped to tightly grip the wire, as shown in the bottom example.
The ferrule can then be inserted into the terminal block and screwed down tightly. This provides a stronger, more resilient termination than using bare wire alone.
The illustration shows both bare and insulated versions (the bare version is also useful for chimneys on buildings or locos). The insulated version provides additional protection against stray strands of wire causing shorts or increased resistance.

Terminal blocks



These chunky connecting blocks were developed for high current connections in a range of industrial devices and power supplies.
They comprise two rows of screws and are produced in block from 3-way to 12-way.
Often referred to as *'barrier blocks'* because of the protective wall between each pair of screws.
They are available in ratings from 15A up to 45A and some have a protective cover to prevent accidental shorting, spillages, etc.
They are popular among some hobbyists due to their ease of use and their large contact surfaces. Wires can be connected by baring the ends, curling the bare ends into hooks and inserting under the screws. An alternative method, shown in the picture, is to terminate the bare wire end in a crimped spade connector.

One way to help ensure a gas tight connection is to place a star washer between the wire/spade and the head of the screw. As the screw is tightened, the star serrations bite into both the wire/spade and the screw head. This cuts through any existing layer of oxide and ensures a good contact.
This is particularly useful where the connections may be disturbed or altered, as the washer ensures a good connection each time.

PCB terminal block

These blocks provide a simple way to connect wires to a printed circuit board module and are commonly found on MERG kits and other PCBs.
Each connection uses a pin to solder to the printed circuit board and a screw terminal for connecting a wire. The bared end of a wire is inserted into the hole and the top screw is tightened.

Despite their small size, they have large current carrying capacity, with some handling as much as 57A. Even the smallest in the range can handle 6A.

They are available in different pitch widths (the distance between the pins) as the larger current carrying versions uses wider pitch widths. Pitch widths range from the commonly-used 3.5mm and 5mm up to 10.16mm. Stripboard has a 2.5mm pitch and can accommodate a 5mm pitch, although not on adjacent tracks.
The blocks are available in a range of sizes, from 2 way to 7 way and many types can be interlocked to create custom widths.

PCB terminal blocks provide for the quick and easy removal or replacement of a module, requiring only a screwdriver.
Many of these blocks use a *'rising clamp'* method of securing the wire. As the screw is tightened, the wire is gripped between two plates – one fixed to the top of the insertion hole and the other which rises as the screw is tightened. The two flat plates provide an even contact over all of the wire's strands. This results in better contact with the wire and less chance of stray wires causing problems.

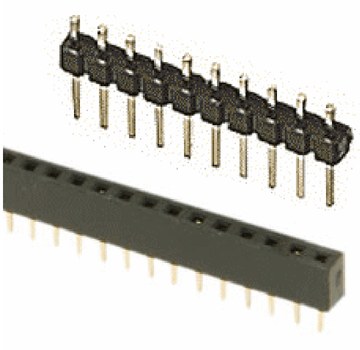
Note, however, that with some blocks, there is no physical contact between the top and bottom plates until the screw is tightened. This can sometimes lead to mistakes when taking meter readings, when the meter prod is touched the electrically unconnected screw.

Crimp connectors

The pictures shows a male and a female connector.
They have a large surface area and make a tight fit when connected. This ensures a reliable connection and they can be found in domestic (boilers, hot tubs), car audio wiring (resistant to vibration) and industrial machinery.
The bared end of a wire is inserted into the connector tube and the tube is then crimped to tightly grip the bare wire. Although pliers and wire cutters are often used, crimping is best done with a proper crimping tool. These connectors handle solid conductors and work at up to 10A.

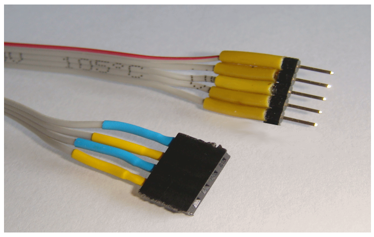
PCB interconnect

As the picture shows, these are produced as header plugs and matching PCB sockets.



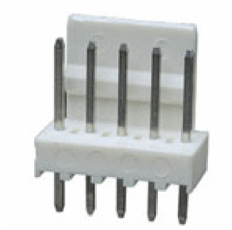
They are used on MERG kits, as jumpers on Servo4 and EzyBus modules and as ICSP connectors on CBUS kits, etc. The sockets are available in a range of sizes from 2 way to 25 way, and in single or double rows. They can be cut or sawn to create any length of strip. They have a 2.5mm pitch, making them ideal for use with home-grown projects built on stripboard.

The picture shows both types with ribbon cable soldered to them and protected by heatshrink tubing.



This provides a very neat way to achieve cable runs of multiple wires. When only three pins/sockets are used this way, it also makes a cheap alternative to commercial servo extension leads.

These connectors were designed for light duty and are only suitable for running signal wires and low current devices.



Another PCB connection is the Molex plug and socket system.

As you can see, it designed such that the plug can only be inserted into the socket one way. This polarisation prevents the accidental insertion of power leads or output leads in the wrong polarity and is commonly used for connecting power to PCBs.

DIN

DIN plugs and sockets have been around for a very long time and have been used for audio connections, MIDI connections and the old AT computer keyboard cable. They are available in 3-way, 5-way, 7-way and 8-way versions and are keyed so that the plug can only be inserted one way (no accidental polarity reversals).

They are also available as mini-DIN versions as used on the mouse and keyboard cables of older computers (known as PS/2).

Standard DIN connectors are cheap but only have a maximum rating of 2A. The socket can be mounted to the baseboard and the plugs can be wired to flying leads. An old keyboard can have its cable cut off and then you have a ready wired DIN plug and cable.

D-type

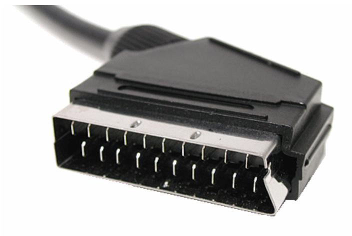
D-type plugs and sockets were designed for use with computers and data communication equipment. The various versions include the 9-pin and 25-pin (RS-232 serial ports), the 15-pin (monitor VGA ports) and the 37-pin (RS-449 high speed serial interfaces). They are rated as either 3A or 5A.

They can be found interconnecting model railway baseboards, due to their large number of contacts. Indeed, the larger versions can wire together two or more pins for a single connection – increasing the current carrying capacity and providing redundancy (if one connection fails, there is still one or more others to carry the current). However, the rear pins of the plugs and sockets can be difficult to solder wires to, particularly if the wires are thick (7/0.2 seems to be about the thickest that's usable).

The pins are bunched very close together, requiring skill/patience to avoid shorting adjacent pins (with solder blobs or stray strands of wire posing the greatest problems)
Alternatively, eBay sell a 2 metre female to female 9-pin serial cable for a couple of pounds. Simply cut it in half and you have two ready made cables. For around the same cost, buy a 25-pin male to female cable, cut it in half, and you have two trailing leads for connecting two baseboards. Make sure all the pins are wired and check for any wires crossing over.

SCART

Before HDMI emerged, most connections between DVD players, satellite boxes, TVs, etc. used SCART cables and many are still in use. SCART connectors offer 21 pin connections, although not all pins wired through in some cables.
They are low voltage low current connections and are not suitable for carrying high currents. The large pin count makes them a possibility for carrying multiple signal wires to and between baseboards (for LEDs, servos, etc.).
Like the D-type cables, a SCART cable can be hand wired or you can buy a ready-made cable and cut it in two.



Circular locking

If you want to ensure that you have a high-current connection that won't shake loose or drop out, a screwed connection is available.
As the picture shows, the socket is designed for panel mounting, although it could be mounted in a small case with a trailing lead if required.
The ends of the plug and the socket are threaded and can be screwed together for a sound mechanical joint.
The picture shows a 3-pin 5A version, which might be considered for taking power from power supply or controller to a layout.
Bulgin market 32A versions, varying from 2-pin to 10 pin.
These connectors are bulky but merit consideration for 'must work' connections.

Durability

An important issue when choosing connectors is their durability- measured in *'mating cycles'* (how many times you can plug and unplug the connection before good performance is no longer guaranteed). If you have a home layout made up from several interconnected boards, this may not be an issue, as you will only occasionally disconnect a board for maintenance/upgrading.
For a club that carries out a lot of exhibiting, it can be an important consideration.
It pays to check a particular dealer's product specification, as quality varies. D-sub connectors can have mating cycles from as low as 50 to hundreds, DIN connectors vary from 1,000 to 5,000 cycles, SCART connectors from 750 to 3,000 and Molex from 1,500 to 10,000.

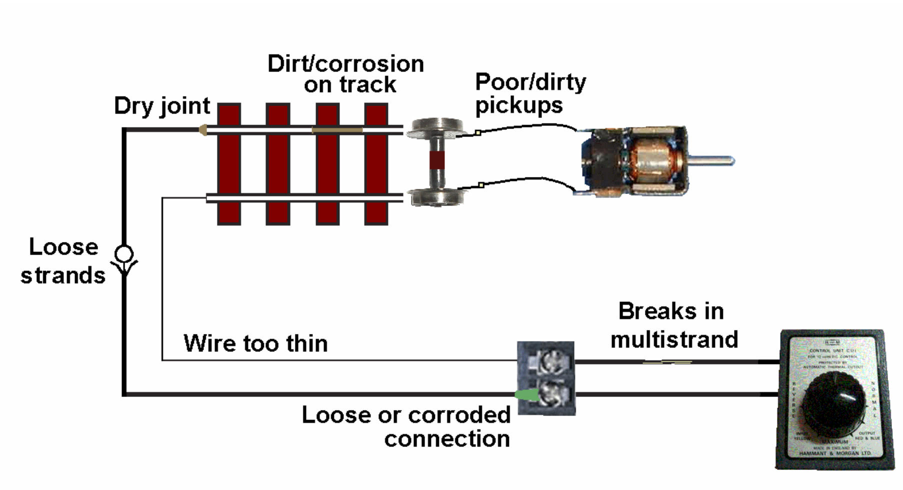
CBUS / EzyBus

Some of the connectors described above allow for huge amounts of wires to be connected together. With even the best of care, there is much scope for faults to develop.
If you find you need such large numbers of connections, you might wish to consider the merits of the 2-wire CBUS interface.

Voltage problems

In an ideal world, the only loads across your controller would be ones that you wanted, such as locos, lighting, point motors and so on.
In practice, the layout wiring, connections, plugs and sockets, switches, etc. all add unwanted additional resistance into the circuit.
Some of the power is lost in the bad connections, long wire runs, etc.
This chapter looks at what causes voltage drop problems.

This illustration shows just some likely causes of unwanted resistance in loco/track wiring.



These examples all happen and you may suffer from one or more of these problems.
- Some are the result of poor installation (poor soldering, using wires that are too thin).
- Some are the result of poor maintenance (dirty track, dirty loco pickups).
- Some just happen over time (breaks in cables, corroded or loose connections, power supplies that get overloaded with ever increasing numbers of locos being run).

If the unwanted resistance is very small compared to the wanted resistance, this causes little change to the layout performance. All layouts have some voltage loss, although mostly too small to be noticed.
However, if the unwanted resistance becomes excessive, too much of the supply voltage appears across this resistance and reduces the voltage to loco, relay, point motor or whatever. These effects are predictable and can be calculated using Ohm's Law.

Its Ohms Law time

If you don't know Ohm's Law, you really ought to get familiar with it, as it is the cornerstone of many voltage, current and resistance calculations that we will come across.

Put briefly, electric current is the flow of electrons round a circuit. The electron flow is measured in Amps (or mA – thousands of an Amp). The force that moves the electrons round the circuit is known as the voltage and is measured in Volts (or mV – thousands of a Volt). The physical properties of different materials act to resist the flow of current. This is called Resistance and is measured in Ohms (or kohms – thousands of ohms or Mohms – millions of ohms).

There is a direct relationship between the voltage, the resistance and the resulting current flow.

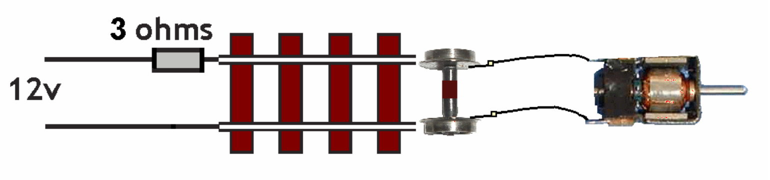
This is expressed in Ohms Law as three simple formulae:

I = V / R	- increased voltage results in increased current. - increased resistance results in reduced current.
V = I x R	- increasing current through a fixed resistance results in an increased voltage across that resistance. - increasing the value of resistance, while maintaining the same value of current through it, results in an increased voltage across that resistance.
R = I / V	- resistance is proportional to the current (i.e. increases) and inversely proportional to the voltage (i.e. decreases).

On our model railway, therefore, voltage drop occurs when current flows through our wires, our loads and any unwanted resistances. It obeys Ohm's Law, where the amount of voltage drop is equal to the resistance times the current.

Some worked examples

Consider this illustration. It shows an accumulation of 3 ohms of unwanted resistance from all the possible sources shown above. From this, we can calculate the expected voltage losses for different locos.



The best case

Let's assume we have an 'N' gauge motor which runs at 250ma (0.25A) when supplied by 12V. In an ideal world, free from unwanted resistance and other effects, the resistance of the motor must be:

R = V / I = 12/ 0.25 = 48 ohms

Working backwards, to check our formula:

V = I x R = 0.25 x 48 = 12V

Now, if there is 3 ohms of additional resistance, the total resistance has risen to 51 ohms, while the supplied voltage is still 12V.

The increased resistance results in less current:

I = V / R = 12 / 51 = 235mA (instead of 250mA)

The Voltage drop across the motor is now

V = I x R = 0.235 x 48 = 11.3V

The other 0.7V is lost across the unwanted 3 ohms of resistance.

Worse cases

The same calculations for an 'OO' gauge loco using 0.5A at 12V shows that the current drops to 440mA, the voltage across the motor is reduced to 10.7V

For an 'O' gauge loco drawing 1A, the current is reduced to 800mA and the motor voltage is reduced to only 9.6V

The worst, worst case

Now, consider a US-style consist of ten 'O' gauge locos, with a total current draw of 10A. The unwanted resistance is large in relation to the resistance of all the motors running in parallel.
The current in the circuit is reduced to a mere 2.8A and the loco motor has only 3.4V across it. The other 8.6V is dropped across the unwanted resistance.

Notes

- You won't get these exact results in practice as Ohms Law calculations are for DC and doesn't take into account effects of inductance, back emf, etc. from motors. However, it does give a fair representation of the dramatic effect of voltage drops in some circumstances.
- Voltage drop is not just an issue for loco motors. Solenoid point motors can be an even bigger problem as they have very little resistance, even lower than loco motors. The Peco solenoid measured at just over 5 ohms, while the old H & M solenoid measured just over 2 ohms. With the MERG PD3 CDU kit supplying a 20V kick, that results in current surges of 4A and 9A respectively. With such low resistances, point motor coils are even more vulnerable to unwanted resistances.

Power and heat

Power is measured in Watts and can be calculated by multiplying voltage by current. So, for example, if the N gauge loco took 0.25A when supplied by 12V, its wattage is
0.25 x 12 = 3W.
As we go up in gauge, with larger motors drawing more current, the wattage is also increased.
With motors, most of the power is used in turning the motor. With an unwanted resistance, the power will be dissipated as heat.
In the above example for an 'O' gauge loco, the voltage across the unwanted resistance was 2.4V and the current through it was 0.8A. That represents a power dissipation of
0.8 x 2.4 = 1.9W.
In the worst case example, the consist of 10 locos, the voltage across the unwanted resistance was 8.6V and the current through it was 2.8A. That represents a power dissipation of

  - x 2.8 = 24W,

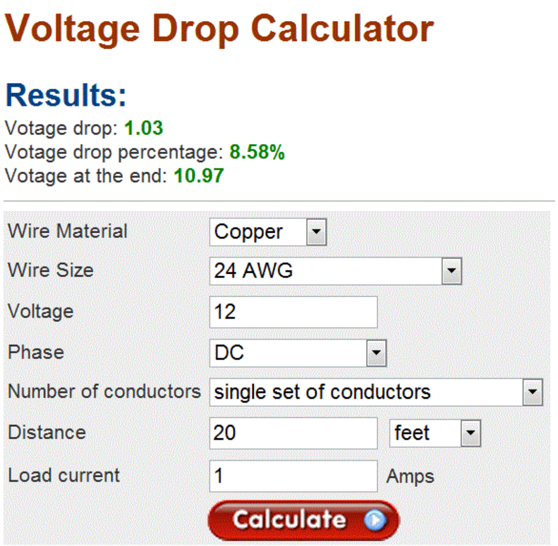
generating more heat than many soldering irons!

Wire resistance

The current carrying capacity table shown earlier does not fully tell the whole story.
Even the best conductors have some resistance and the resulting voltage drop in the cable can be calculated from its CSA (cross sectional area). The CSA can be expressed in mm^2.

The internet provides a number of calculators that let you see what voltage drop to expect from different gauges over different lengths of wire runs. Many of these the AWG sizes but you can get some conversion information at
http://www.calculator.net/voltage-drop-calculator.html

For example, 7/0.2 means 7 strands of wire each 0.2mm diameter, This results in CSA of $7x(\pi x0.2x0.2)/4 = 0.22mm^2$.
The image shows a calculation for 24AWG, the nearest equivalent to 7/0.2 stranded wire.



Remember that a circuit uses two wires, one feed and one return. So, a 10ft layout would have a 20ft run.

Some calculated results

- A 10ft layout using 7/0.2 for N gauge (250mA) locos would suffer a drop of just 0.13V.
- The same 10ft layout for OO, using 0.5A locos would suffer a 0.26V drop. If that layout was 20ft long, a drop of around half a volt would result.
- When an 'O' gauge loco at 1A is run on a 20ft layout, the voltage loss is just over 1V.
- However, if a 5 ohm solenoid coil was operated by 20V over a 10ft cable, the drop would be 4.11V. This could be reduced to 1.62V or 0.81V by using 16/02 stranded wire or 1mm solid conductors respectively.
- Our earlier example of a 10A consist running over a large 60ft layout would drop a whopping 6V using 1mm twin and earth and even 2.5mm twin and earth would result in a 2.4V loss.

Clearly, voltage drop in the layout wiring is less of an issue with smaller gauge locos, although it still pays to use as thick a wire as you can afford (specially for solenoids and other heavy current devices).
As the layouts get larger and the loco currents get larger, the problems of voltage drop become an issue that needs attention.

Note

The calculations for stranded wire assume that all strands are intact and correctly connected. It is not uncommon for stray strands of wire to fan out as wisps and fail to be connected or soldered. It is also common for wrongly-adjusted wire strippers to cut or nick some strands.

Even a nick in a strand can lead to an eventual break in that strand, if placed under stress or vibration.

Finally, note that these calculations are for voltage drop in the wire alone, while other resistances such as the bad connections, etc. mentioned earlier may have to be added to the calculations.

Rail resistance

A track bus with multiple droppers may seem excessive when we might simply rely on the nickel silver rails to carry the current. However, nickel silver is an alloy made from copper (60%), nickel and zinc. The difficulty is that the resistance of nickel silver is nineteen times greater than that of copper.

Since not all nickel silver alloys use the exact same proportions and not all rail sections have the same cross sectional area, the final resistance is not precise – although it is very significant.
That is why a length of track has a corresponding length of copper wire running underneath, with frequent connections between them. The poorer conductor (the rail) only carries current over a small section of track to the loco, while the current is mainly carried by the better-conducting copper track bus. The effect is to greatly reduce the voltage drop.

Track is sold as code 70 or code 100, etc..
The code number is the height of the rail expressed in thousands of an inch.
So, code 75 rail is 0.075" in height while code 100 is 0.1" in height.
Here are some rail types:

Code 40 – Micro Engineering N and HOn3
Code 55 - Peco N, Micro Engineering N and HO
Code 60 – Peco OO9
Code 70 - Micro Engineering N and HO, Shinohara N and HO and HOn3
Code 75 - Peco OO Finescale
Code 83 – Peco HO, Atlas, Walthers/Shinohara HO, Micro Engineering HO
Code 100 - Peco OO, Atlas, Walthers/Shinohara HO, Micro Engineering HO
Code 148 - Micro Engineering O

The rails with the smallest height and the small cross sectional area present the greatest resistance.

The DCCWiki displays a chart of measured resistance of various brands of track.

Brand	Code	Rail Resistance, Ohms/foot	Equivalent Wire (AWG)
Atlas / Shinohara	100	0.038	26
Walthers / Shinohara	83	0.052	27
Atlas / Micro Engineering	83	0.078	28
Shinohara	70	0.077	28
Micro Engineering	70	0.116	30

And adds this note:

Note the difference between two brands of Code 83 rail. One has about 50% more resistance. That can be explained by the rail profile, which has an effect on the cross sectional area of the rail. The cross section of 27AWG wire is 0.102 mm2, 28AWG is 0.08 mm2.

From this table, we could calculate that an N gauge layout with a 20ft track run would have a resistance of 40 x 0.116 = 4.64 ohms, resulting in just over 1V of voltage drop in the track.
A track bus using 1mm wire, on the other hand, would only drop 0.05V.
Now you know why lots of droppers are recommended!

You can never eliminate voltage drop entirely; you have to decide what amount of drop you can live with. You may simply prefer to increase the supply voltage to compensate, after considering whether there are any unacceptable overheating risks as a consequence.

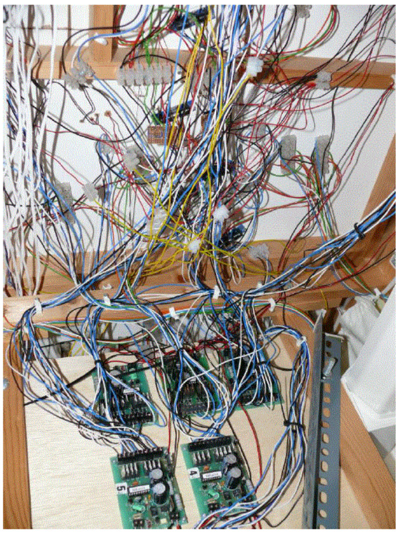
Maintenance aids

The greatest aid to maintaining a model railway layout is not a multimeter – it is knowledge. To be able to test a layouts' wiring, you have to know where wires are supposed to go and what conditions should be expected on them. As you build a layout, more and more wires are run, more components are added and configured. Unless this is approached in a methodical manner, fault-finding will be much more troublesome. Problems will start to occur long after you have forgotten what you laid where and for what purpose.

The time spent in developing and sticking to a plan for rolling out a layout is more than repaid when the layout has to be maintained.

MERG's Technical Bulletin LC01 provides details.

Colour coding



Imagine a single wire running through a rat's nest of cabling. Consider the problem of tracing it along the length of a layout. Life is much easier if you settle on a colouring scheme for wires

For example, every time you see a red wire, you know it carries +12v, an orange wire carries +5v, a yellow wire carries the output from a track occupancy detector, and so on.

There is no universally recognised 'standard' colour coding scheme, although red and black are widely used for main +ve and -ve wires.

Digitrax have their own suggested wiring scheme, see:

http://www.dccwiki.com/Wiring_color_code

for a home layout. The colour scheme is entirely up to you, as long as you record it and stick to it.

For a club layout, where many different people will be working on a layout and developing and maintaining it over a considerable period, an agreed colour code needs to be developed and recognised by all members.

Fortunately, wires are available in a range of colours.

Labelling

Unfortunately, there is not an inexhaustible range of coloured wires available, so you are liable to find many wires of the same colour running under a baseboard. Although it is useful to know what it is used for (e.g. wires to Servo4 boards), it does not tell you where the wire originated from and where it is heading. Attaching small labels to wires during installation can provide very valuable information at a later date. For example, a label that says 'ACC84/3-Ser3/2' would let you know that the wire ran from your fourth CANACC8, pin 3 to your third Sevo4 module, pin 2. Some people prefer to use a numbering scheme for their labels, with a printed table explaining what a particular wire number is used for.

Others use a lettering system for labels while some prefer adding coloured tape or short lengths of coloured shrink wrap to wires.
There is no standard for labelling; just use what makes sense to you.

Schematics

Consider a layout that has many electronic modules, connectors, etc.
By the time a fault occurs, you will have long forgotten that output 7 of this module is connected to input 5 of that other module. The only way is to manually trace it. Every time you have a fault, you have to work out what goes where all over again.
Much better to spend a little time making up a simple diagram or chart that shows how modules, connectors, etc. are interconnected. That way, when you have a fault, you know exactly where to go to make your tests.

Consider documenting a station throat as being served by number 5 Servo4 board, with points being noted as 1,2,3,4. If point 2 fails to operate due to no input signal, your chart tells you what drives that particular board input. So, for example, you can put your meter across pin 5 of a CANACC8 or across switch 7 on your control panel – or whatever. There is no need to even trace the wire initially. You can check whether the control output signal is being produced. A quick check of your schematic tells you exactly what connects to what, no matter how far apart they may be. The schematic can be further refined if the wire passes through several connecting blocks or plugs and sockets.

Documentation

Clearly, documenting your layout pays dividends in the longer term.
To be useful, the documentation must always be readily accessible - in a folder and/or wall chart.
A typical folder might contain:

- Tables, showing the colour coding and labelling of wires used on the layout.
- Schematics showing the interconnection between modules and connectors.
- Development history, detailing who added what when.
- Fault history, so that recurring faults can be identified and dealt with.
- CBUS details, listing the node numbers of each module, what events do what, etc.
- DCC details, listing the CVs of locos, accessory decoders, etc.

Important note

Documentation is a chore and most people are reluctant to keep updating it. However, it is important to recognise that documentation that has not been updated can sometimes make things worse. The key is to make the documentation easily alterable. For example, you don't want to have to redraw a diagram every time a change is made.
Those with computers have an obvious advantage, as lists, tables, etc. are more easily updated and reprinted.