Converting from Analogue to Digital in G-Scale

by Phil Spiegelhalter - Solent Area G-Scale

Digital has many advantages over Analogue

Trains by Night - Stay Alight !

Operating Accessories

Freedom of Movement - Multiple Trains on Track

Controllable Lights and Sounds

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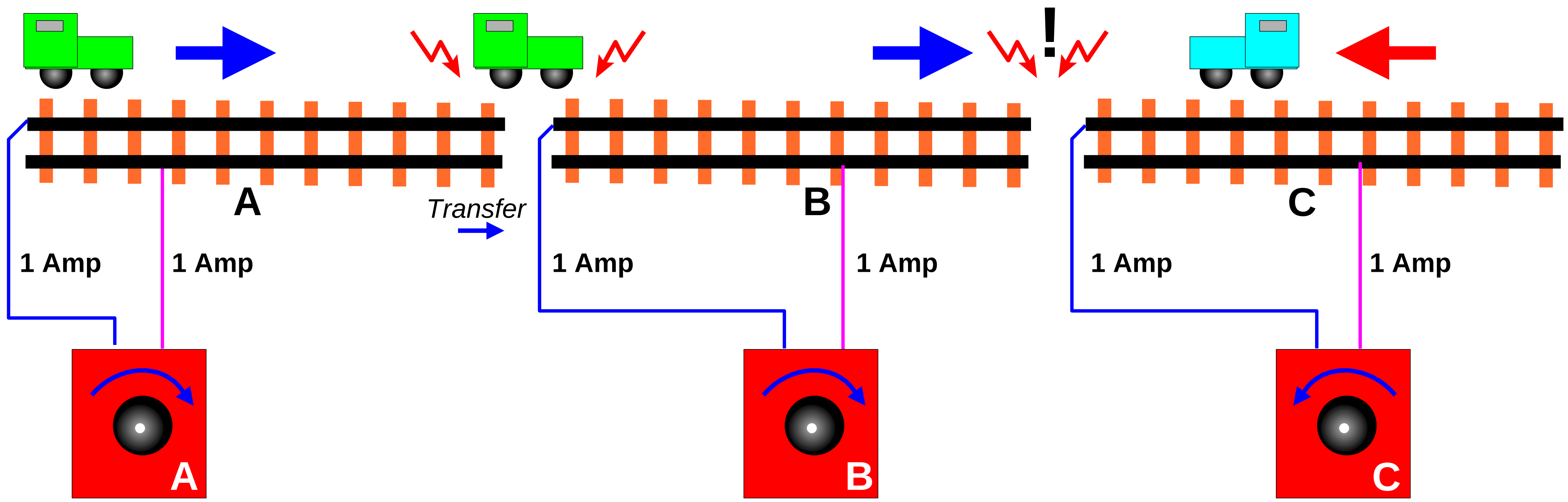
Analogue: Using Multiple Controllers - NOT RECOMMENDED ! UNLESS they are Unconnected Track Systems



ALTHOUGH often advocated to beginners for a Simple 2-Oval Layout with connecting crossover, this is NOT a good method!
DURING the transfer from 1 controller to the next, the speeds MUST be MATCHED, and the circuits become LINKED TOGETHER.
This CAN work with ancient 'basic' rheostat type controllers, but may damage electronic controllers, particularly pulse or feed back types.

Analogue Control: To have more than one loco on the layout at a time, a popular solution uses a set of *centrally-located* switches to pass a controller's output to *1 or more sections* of track. Locos may be isolated by switching both rails or just 1 with the other as a *common return*.

If 'common return' is used, then each controller must be from a totally separate secondary winding!
This excludes some 'multi-track' models from well-know suppliers - ALWAYS ASK to confirm suitability First!

The 'layout wire' used was probably suitable for up to 1 Amp at low voltage, which was adequate because only 1 loco would be running in each section, and then only occasionally. If the track-voltage dropped under load, the controller could be turned up to compensate. If a short-circuit occurred, then the wiring was capable of carrying the increased current until a low-current cutout operated.

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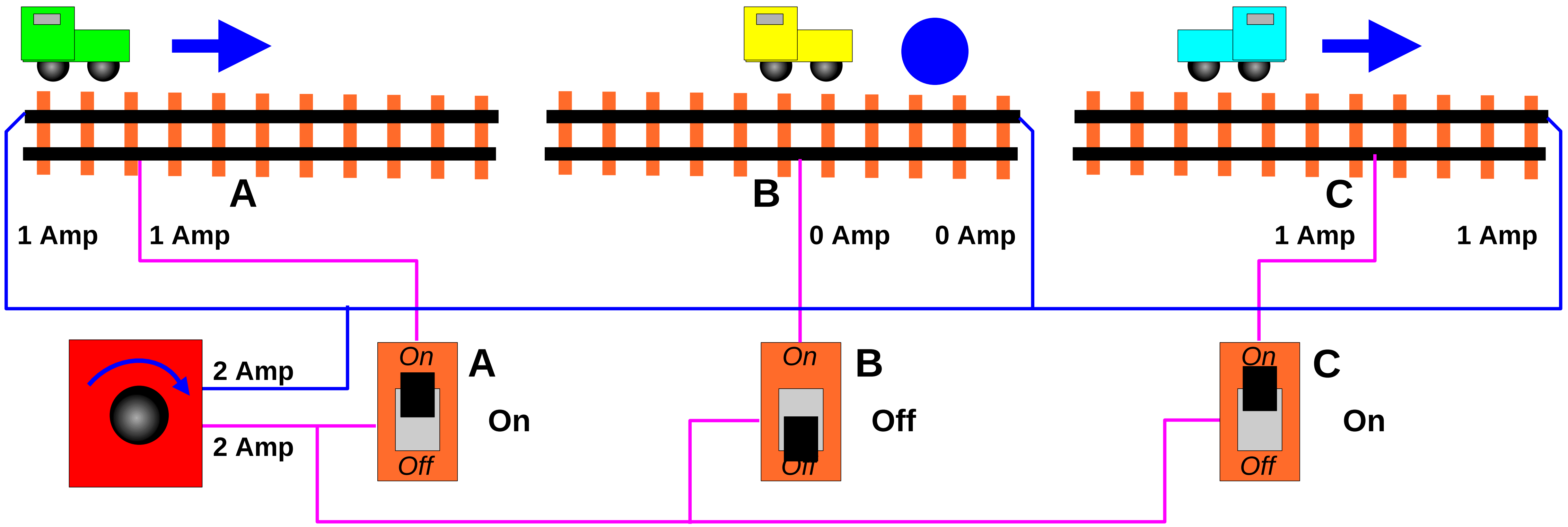
Analogue DC Control for Multiple Locomotives: ANY LOCO in Track Sections A and C will move together to the right



Note possibility of Increased current on 'common' wiring (A + B + C)

On larger layouts, with several locos running, the combined current on the common-return conductor might increase considerably (the sum), or it might average out to zero, depending on the train directions. This is often overlooked by users. Common-return wiring, can also introduce other, interference, problems.

(With '3-rail/AC' such as Marklin H0 - which is still popular - Direction, as with DCC, is related to the LOCO because it is controlled on-board the locomotive (orginally by a direction-changeover relay, now electronically) This is also why many Continental Controllers/Users favour separate direction change switches, not centre-off.)

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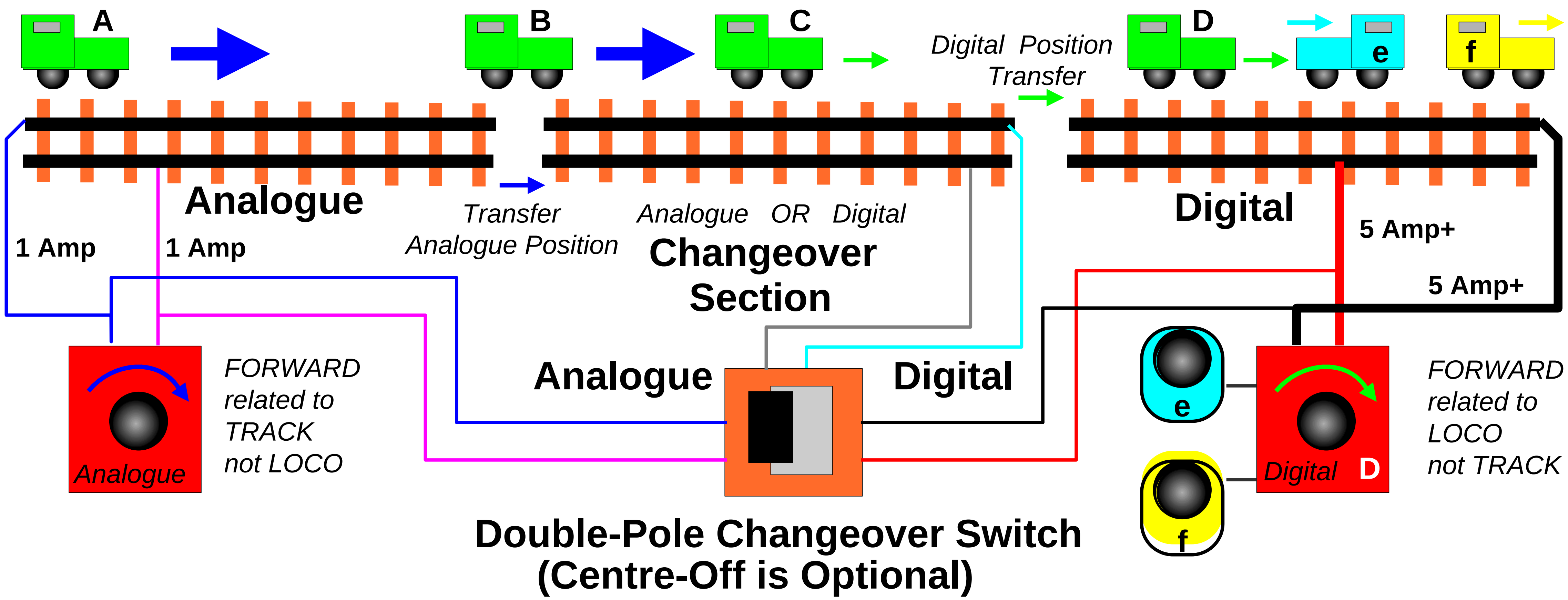
'Combining' Analogue and Digital Controlled Areas in a Layout IS Possible IF precautions are taken at the Transfer Points



If Metal-wheeled Rolling stock is used, the ENTIRE TRAIN must be able to fit inside the Changeover Section with room to spare!

When converting to Digital-on-Track, there must be NO CONNECTION between Power Supplies!
(The same can also apply when some electronic-analogue controllers are in use: Problem Avoidance!)

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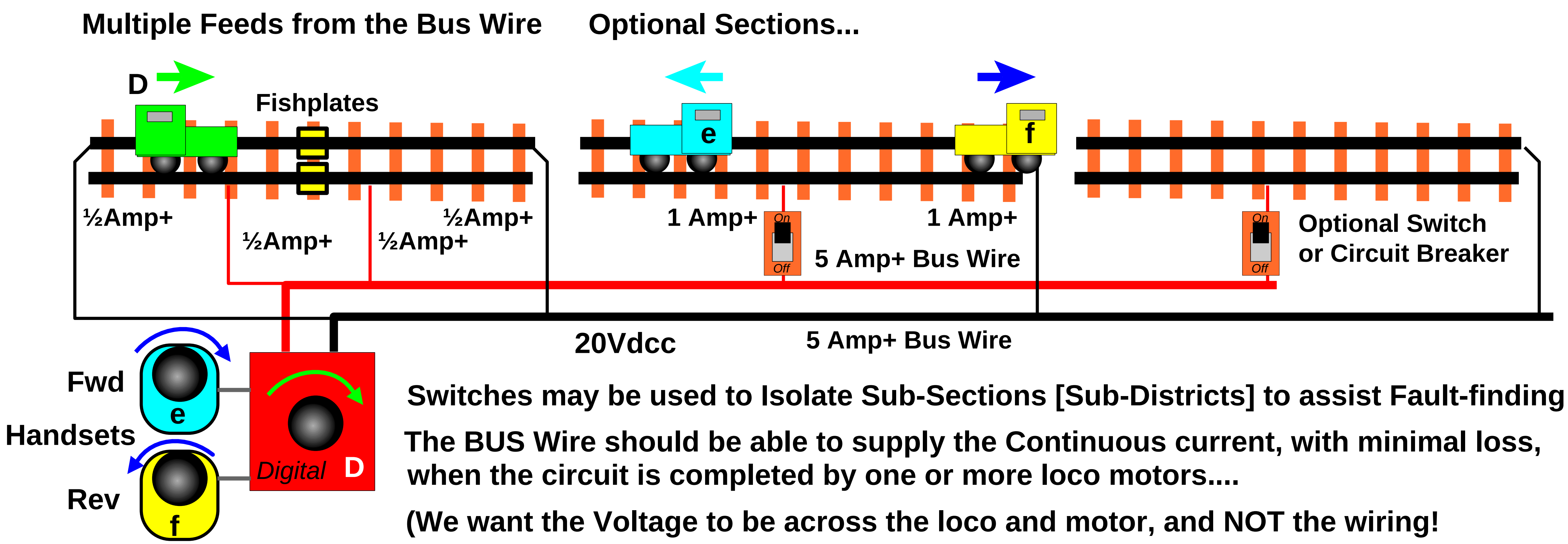
Wiring for Digital



The Central Master provides Overall Short Circuit Protection - Lower Value Breakers may be used in sub-sections

Whilst, as an early advert (from H&M) once said: “Just 2-wires”-connected to the nearest track, is all that is *needed* to run a complete digital layout; there are advantages in using a few more, and of appropriate size. Once Digital, there is more likelihood of Sound and Lighting being used - even when a train is stationary . This, as well as the increased number of locos on the track, moving or not, increases current demand.

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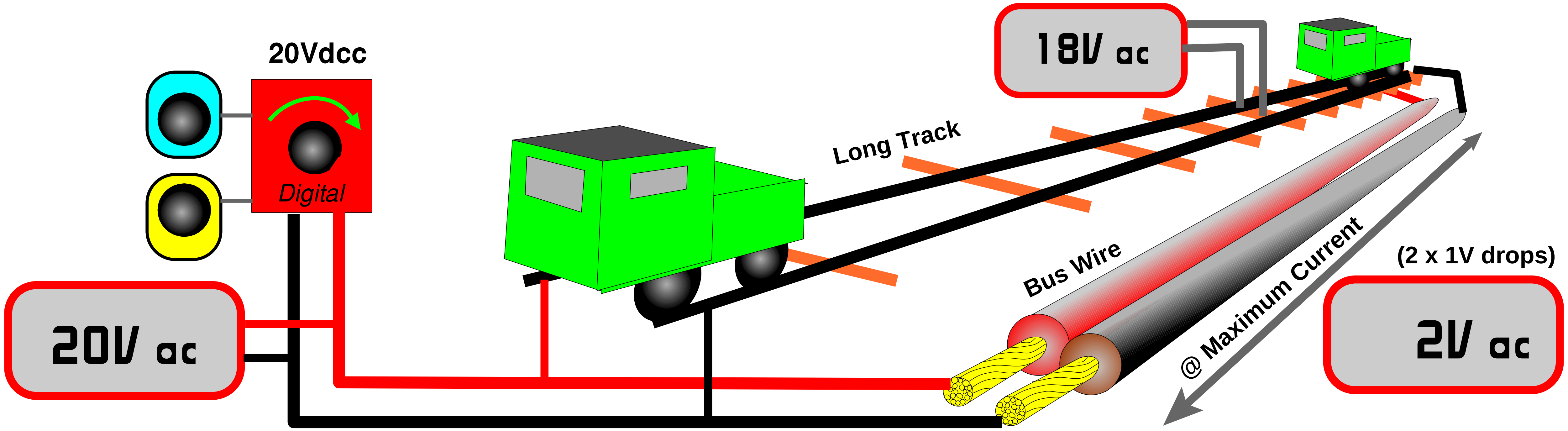
Wiring for 5Amps+:



Voltage Drop with Distance, when under load (ie a current is flowing) **at maximum continuous current**

The continuous output from the LGB MTS unit can be as high as 5A, or from Massoth and others, even higher! The track and/or wiring chosen should therefore be capable of *continuously* carrying that current, whilst still allowing the trains and accessories to operate normally. Ideally the voltage drop at the furthest part of the layout would only be about 1-2*V under load, and on 'open days' that *will* be under full load! (When no current is flowing - such as when no trains are moving - there should be no voltage drop)

***Acceptable Track Voltage Drop in Normal Use?**

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***Acceptable Track Voltage Drop in Normal Use?**

Decoders 'start working' around 5-8V - as seen when a fitted loco is used on an analogue controller, and the sound system turns on just before the loco begins to move. This is an **absolute** minimum voltage !
In smaller gauges, the dcc track voltage is usually a constant 14-16V, but for G-Scale is notionally 20-22V:*

**The current Marklin LGB controller in Starter Sets states 18V !*

1-2V drop is acceptable in OO/HO, and 2V drop is assumed here for calculation at maximum loads:

From V=IR Voltage Drop in circuit (V) = Continuous Maximum Current (I in Amps A) x Path Resistance (Ohms R or Ω)

Controller Maximum Continuous Current	Maximum Path Resistance for 2V drop		
2.5A	R =V/I	2/2.5 =	0.8 ohms
3.2A		2/3.2=	0.625 ohms
5.0A		2/5.0=	0.4 ohms
8.0A		2/8.0=	0.25 ohms
12A		2/12=	0.167 ohms

Note that if the Controller is changed to one with a higher current rating, the maximum total resistance needs lowering.

In practice, this voltage drop is difficult to measure, as many Digital Meters misread DCC's ac voltage!

However, in an earlier article, I have shown how a suitable Digital Voltage Display can be made for <£5.00

'Printing Note': Resistance, measured in ohms uses the Symbol Omega **Ω** which may not print correctly
Therefore 'R' is commonly used instead

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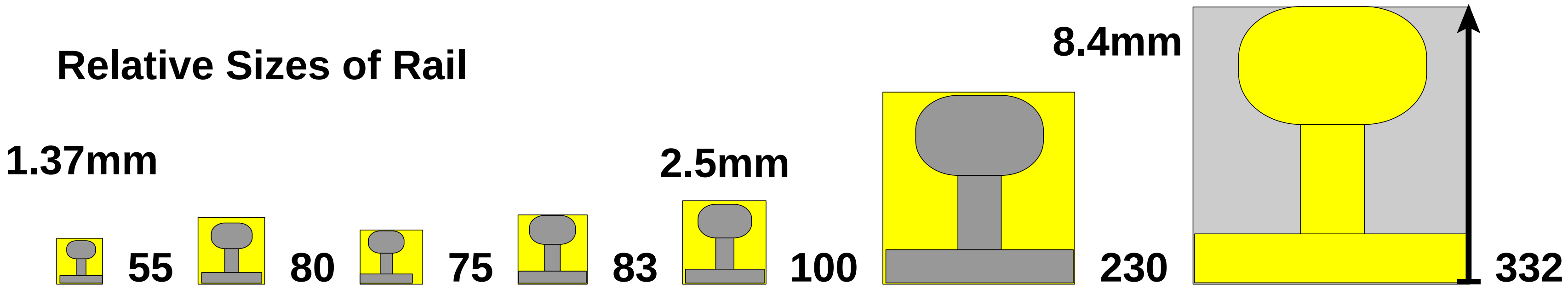
Track Type

In G-Scale the track choice is usually between Peco Nickel Silver Code* 250, or LGB Brass Code 332: Brass is a better conductor, and Code332 also has the larger cross-sectional area.
However, if Set-Track Rail is used, there may be joiners every 600mm, which will deteriorate over time. Massoth or similar clamped joiners will make firm connections which also facilitate adding connections from Bus-Wires every few metres or rail-lengths.

[*Code size is height of rail in 1/000th of an inch - i.e. Code 100 = 1/10th inch high or 2.5mm]



For comparison: In N Gauge, Code 55 or 80 rail is popular, In OO/H0, Code 75, 83 or 100 is used. Nickel Silver rail is normal. Motor currents (per loco) range from ¼ - ½Amp, with Track Voltage 12-16V*

Bus Solution

A suitable Copper-Cable-Pair placed alongside the running track, and connected to it at *frequent* intervals will help meet the requirements. There is NO single answer for the 'correct' size, as it depends on the distances involved, and the type of track used. The answer is met if *both* the *minimal-voltage-drop-under load* condition and the 'Short Circuit test', *described later*, are met. (Their calculated results are similar).

Wire Ratings

Wires may be described by their diameter, cross-section or a 'current rating' for a specified use...
Confusion is experienced with references to 'swg' (standard wire gauge) or awg (american wire gauge) for which a look-up table is needed! Diameter or Area may be measured in old Imperial units or Metric.

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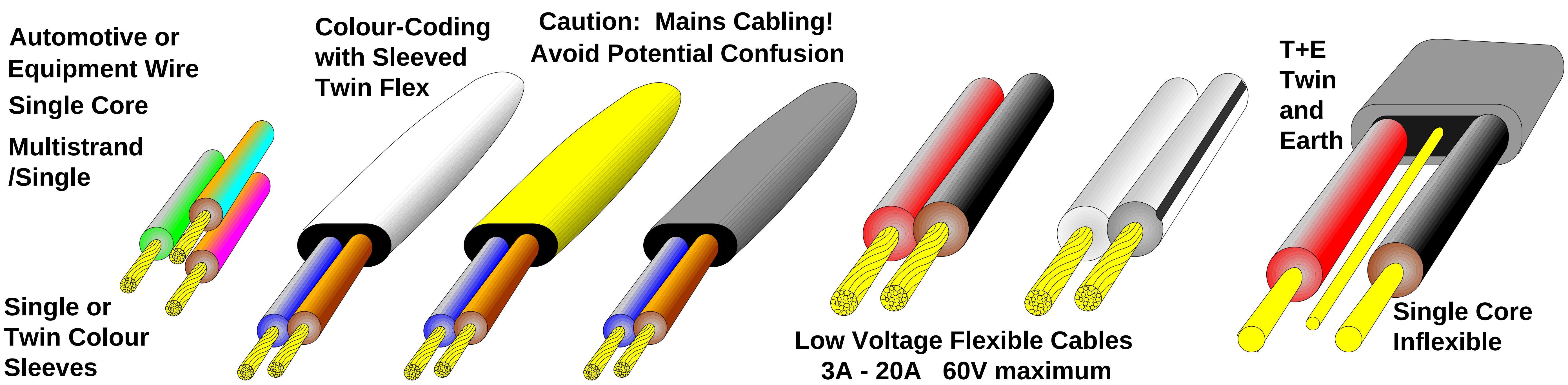
Mains Cable of ‘3A’,‘6A’,‘13A’,‘15A’ ratings are often seen, and refer to *safe-continuous-use* when buried in Plaster Walls as household wiring getting heated to 60C with the voltage drops involved...
For 230Vac use (UK/EU) 3A = 0.5mm^2, 6A = 0.75mm^2 13A= 1.25mm^2 are standard flex sizes.
CARE should be taken wherever ‘Mains’ type cables are used for ‘non-mains-voltage’ applications to AVOID POTENTIAL CONFUSION ! [i.e.: DON’T MIX - and Mains Cable *outside* should be Protected]



Automotive Low Voltage Wiring is available in Multiple Colours with high current ratings
Multistrand wire is Flexible and less likely to break under vibration or movement
ALL cables are usually 'less than half price' if bought as complete reels of 25m / 50m / 100m

Caution: Mains Cabling!
Avoid Potential Confusion

An alternative is ‘Low Voltage’ (e.g. 60Vmax) figure-of-eight twinflex in Red & Black, or White & Black such as Maplin’s ‘Power Cable’ (Red&Black) ‘6A’ 0.57mm^2, 10A 0.79mm^2, 15A 1.19mm^2 or 20A 2.12mm^2 or Black & White 15A ‘Loudspeaker Cable’ of 1.32mm^2. Search the internet for automotive-part suppliers.

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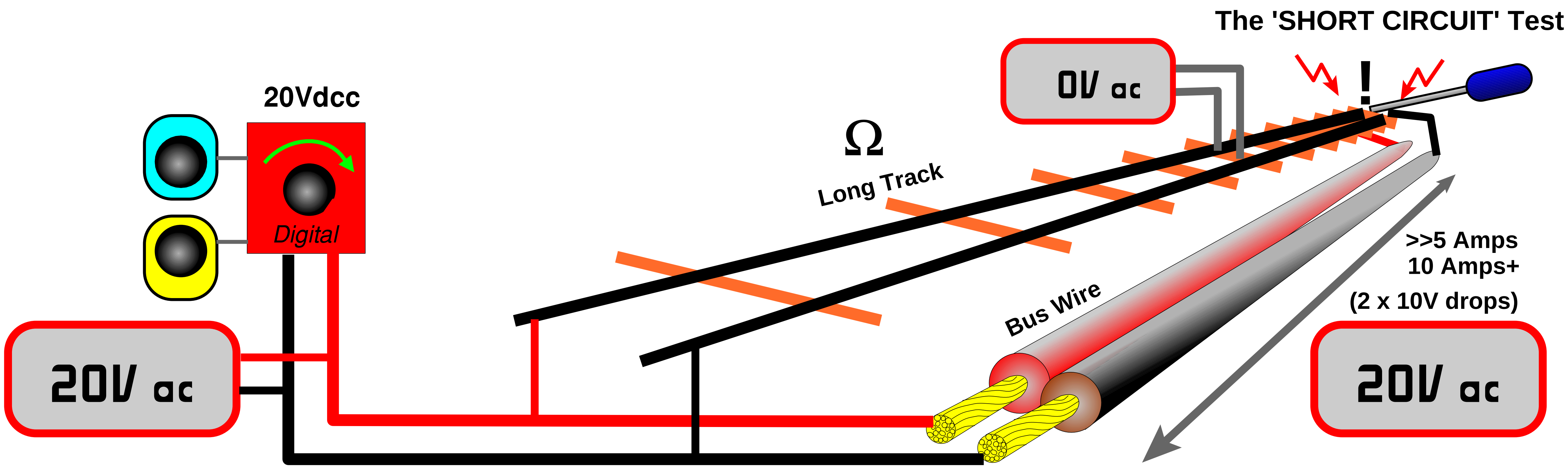
The larger the layout, and therefore lengths involved, the larger the cable needs to be, to keep the resistance down and the Short-circuit Protection OK.
Smaller flexible / single core cables may be used for the final short links to the track from the bus wires.

Parallel busses may be used to increase capacity, and there is no need to add ‘terminations’; the track itself may produce even more parallel paths for the track current, and locos add a variety of loads across the track.

The Short Circuit - Safety Test



Total Voltage drop within track and/ or wiring - Greater than Maximum Continuous Current

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If a metal object links the rails anywhere on the track, then a large current will try to flow - limited only by the power supply and layout wiring. You WANT a large current to flow! - at least enough to quickly trigger the protective cutout (in *milli*-seconds) **before** damage occurs. *Despite popular myth - it is unlikely that any of the extra short-circuit would flow* ***through*** *your locomotive (inc. decoder) unless the fault originated inside the loco - such as by faulty reassembly or decoder fitting.*

At 20 Volts (G-scale dcc) for ***more than 5 Amps*** *to flow, the total resistance* ***must be less than 4ohms****.*
For a Massoth-system set to 8 Amps, then from R=$^{V}/_{I}$*: 20/8 = <2.5 ohms, or 12 Amps: 20/12 = <* $1^{2}/_{3}$ *ohms.*
To ensure fast triggering of the *overload protection* - ensure that double the maximum continuous current can flow.

Controller Limit (A)		Full Load 2V drop Resistance		'Short Detect'	G:20Vdcc @ 2x max		OO:16V@2x max
2.5A	R =V/I	2/2.5 =	0.8 ohms	V=IR : R=$^{V}/_{I}$	= 20/I	= 4 ohms	3.2 ohms
3.2A		2/3.2 =	0.625 ohms	V=IR : R=$^{V}/_{I}$	= 20/I	= 3 ohms	2.5 ohms
5.0A		2/5.0 =	0.4 ohms	V=IR : R=$^{V}/_{I}$	= 20/I	= 2 ohms	1.6 ohms
8.0A		2/8.0 =	0.25 ohms	V=IR : R=$^{V}/_{I}$	= 20/I	= 1.25ohm	1.0 ohms
12.0A		2/12 =	0.167 ohms	V=IR : R=$^{V}/_{I}$	= 20/I	= 0.8 ohm	0.6 ohm

Note that if the Controller is changed to one with a higher current rating, the maximum total resistance needs lowering.
The short-circuit resistance ***can*** *easily be measured with any Multimeter/Ohmmeter* ***when the power is off****.*

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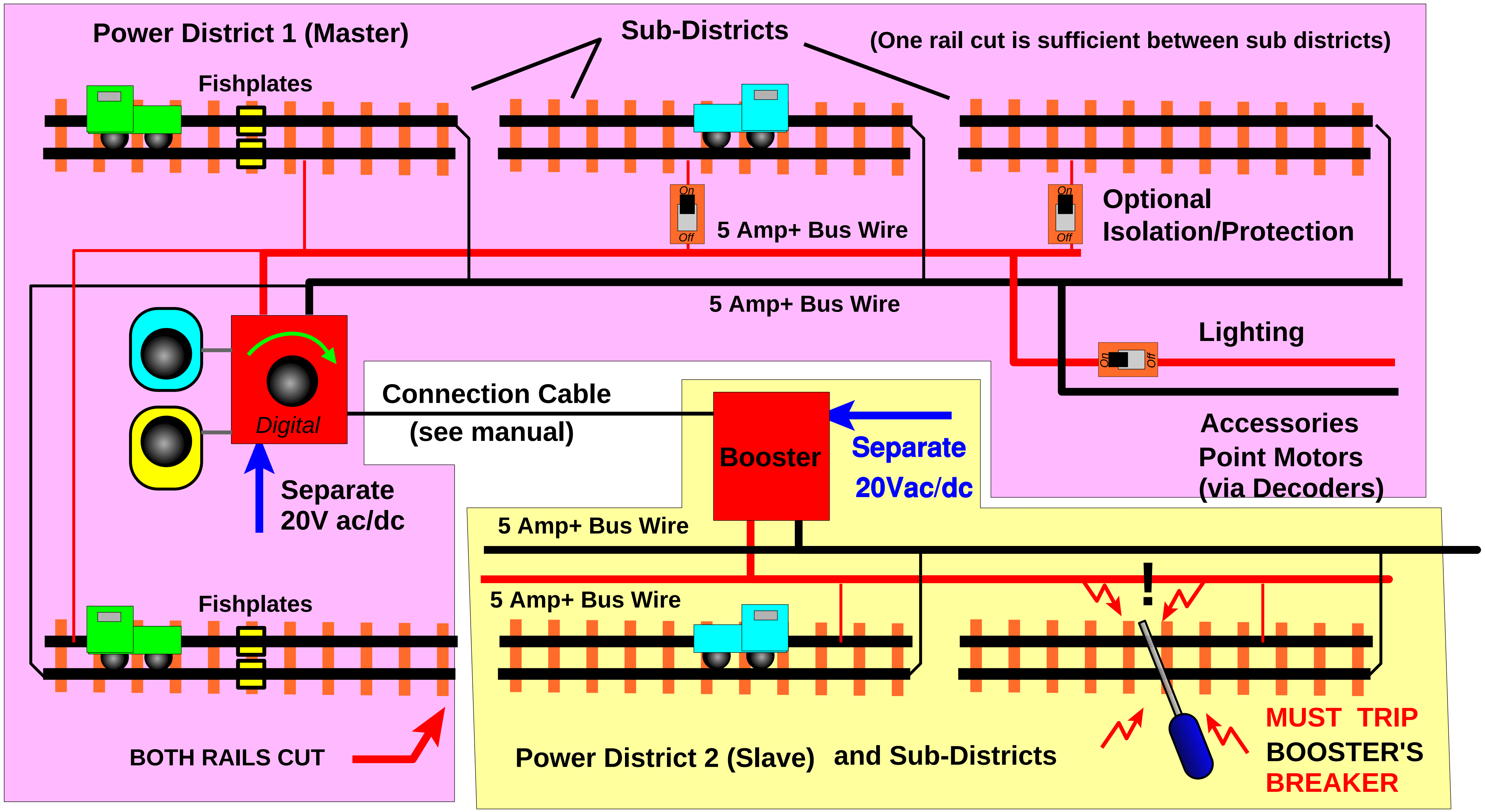
All-for One, and One-for All?

A major problem in the garden is ensuring sufficient current capability to all parts of the track, the idea of splitting it into sections, ‘as analogue’ may seem contrary to good practice. However; dividing the layout into broad geographical or other easily-separated areas of the layout, is a useful technique for providing ***more total power***, with easier fault-finding and ***lower fault/maximum currents*** in any individual section.



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The US-originated names used are a **Power District** - for the area supplied by the Central Master or a Booster and then **Sub-Districts** for further divisions. Both Power Districts and Sub-Districts may have isolating switches for easy fault-finding, and/or be protected by circuit breakers with lower individual limits. ‘Boosters’ power *additional* Power Districts, and they take their DCC signal from the Central Master Unit. **Both rails** must be cut at the boundary between **Power Districts**, and ***totally separate*** power supplies used to power ***each*** Booster and Central Master Unit, or damage will result when a metal wheel links them.

Power Supplies for Boosters Central Master Units: AC/DC

A Booster, such as Bachmann’s, can be used with *any* DCC source, and adjusted from 12 to 22V for N, OO or G scale - upto a maximum of 10A. It is delivered with its own Power Supply. EC regulations now require ‘Train Sets’ [except existing factory stocks] to be delivered with modern efficient Switched Mode Power Supplies instead of heavy and inefficient transformers. Their output is usually low-voltage DC instead of AC; but Central Units such as the LGB range accept either AC or DC inputs (refer to manuals)

Marklin / LGB have revised their controller designs in current production to operate from DC inputs... therefore allowing Energy-efficient SMPS to be used: these are also lighter and cheaper to post / deliver. Old, unused transformers contain a lot of copper which can be recycled.

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So How Long is a Piece of String? (Or How long can the Wire be?)

Copper is a good conductor (better than Nickel-Silver) which is why it is used for Electrical Wiring.
A length of Bus-wire requires the current to flow through twice its length. Copper Resistivity=1.7×10^{-8}
Resistance(ohms) of ***Twin***-Flex BusWire = ***2*** x Resistivity x (length in metres) / (cross-sectional area in m^2)

Maximum Buswire Lengths v Maximum Current

Flex Type	Area	Ohms/metre	$1\ \text{ohm}_{twin}$	*2V drop lengths* 2V@5A	2V@3.2A	*20V Short Circuit Lengths* 2x[5.0]	2x[8.0]	2x[12A]	*16Vshort* 16V2x[3.2]
'3A mains flex'	$0.50 \times 10^{-6} m^2$	= 0.068/m	7m	2.8m	4.3m	14m	8m	5m	3.4m
'6A mains flex'	$0.75 \times 10^{-6} m^2$	= 0.045/m	11m	4.4m	6.8m	22m	13m	9m	5.4m
'13A mains flex'	$1.25 \times 10^{-6} m^2$	= 0.027/m	18m	7.2m	8.8m	36m	22m	15m	11m
'10A' LV twin	$0.79 \times 10^{-6} m^2$	= 0.043/m	11m	4.4m	6.8m	22m	13m	9m	5.4m
'15A' LV twin	$1.19 \times 10^{-6} m^2$	= 0.028/m	17m	6.8m	8.0m	34m	21m	14m	10m
'20A' LV twin	$2.12 \times 10^{-6} m^2$	= 0.016/m	31m	12.4m	19m	62m	38m	25m	15m

Parallel runs of flex will increase the workable distance, as will additional parallel track connections.
5 Volt 'constant' coach lighting will not show the effect of dropping track voltage until about 8Volts.

If nearby locos show a dip in lighting when a digitally controlled point is changed, then this suggests additional bus wiring would be beneficial. In all cases, clean track will be the major criterion. Electronic Track Cleaners (which use h.f.) should NOT be used as these might interfere with the dcc signal, but *will* be in excess of the component voltage ratings, and therefore cause damage.

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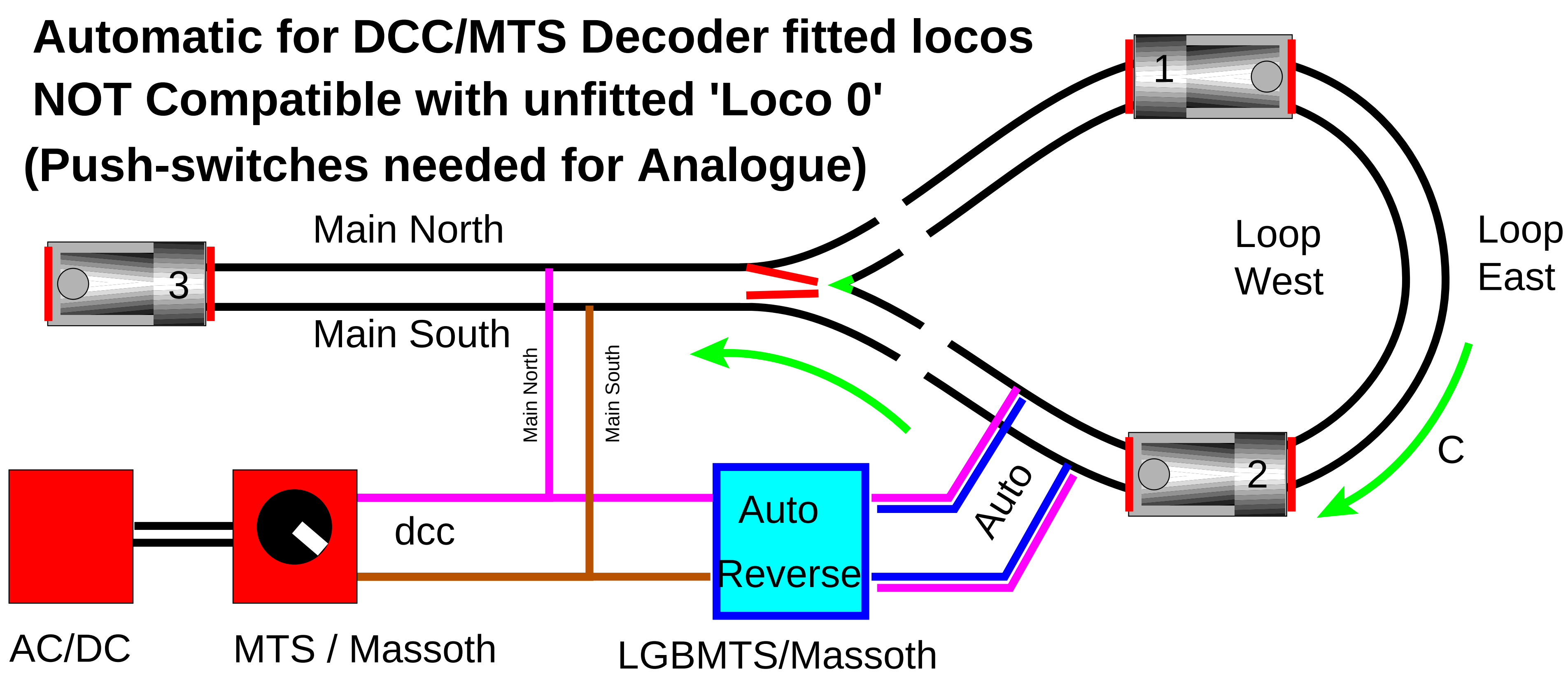
Auto-Reverse Sections and Triangle Junctions

Under Digital Control, the direction of travel is always *relative to itself* and not the track, as with analogue. Therefore the behaviour around a ‘Reverse Loop’ needs to be different. It can be simpler, but requires an Auto-Reverser Module. The module is designed to automatically switch the polarity (invert the phase) of the dcc (MTS) track signal as soon as the train enters the ‘controlled’ section, if the polarity (phase) is incorrect.

The train continues at normal speed, totally unaffected, because of the way that decoders work.



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The long-standing design of DCC/MTS Auto-Reverser shown in the previous diagram uses either relays or Electronic switches to swap the polarity if a Short-circuit is detected across any of the gaps at either end of the section: the high current momentarily flows across the metal wheel concerned (but not through or across the locomotive), and this high current immediately causes the internal circuitry to swap the connections, thus reversing the power, and removing the short-circuit ...the loco or train continues normally.
It also relies on the 3 pieces of track having a good power supply (eg from a buswire connection).
If the controller is powered up when a train is bridging either gap, it can be confused by the surge current.

'As supplied', it is incompatible with an unfitted analogue loco being driven as 'Loco 0' because these are driven by modifying the mark-space ratio of the dcc track signal to create a 'non-zero' average, to which a simple motor will respond. {Note: directional lights will be on in *both* directions due to the ac nature of the dcc signal, and the motor will audibly buzz when the 'Loco 0' is stationary because full voltage is still present}.

A momentary 'push button' [Eg sprung-to-centre, DPDT] connected across either end of the controlled-section will mimic the shorting action of the loco, and 'preset' the polarity allowing the 'Loco 0' to approach and cross the gap without a problem, stopping briefly in the middle whilst the switch is operated; otherwise, at one of the ends, the loco would try to reverse itself when the polarity changed! ... this has led to the desire of a compatible auto-reverser which also avoids the momentary short circuit current (which could be as high as 12A+ on some systems!)

The *new compatible Auto-Reversers* use a small section of detection-track (or an optical detector) to preset the polarity before the loco reaches the controlled-section, so that not even a momentary short-circuit ever occurs, and similarly when approaching the exit to the controlled section.

For both old and new types, the controlled-section must be long enough to hold all of the train if it has metal wheels - even if they are not used as pickups.

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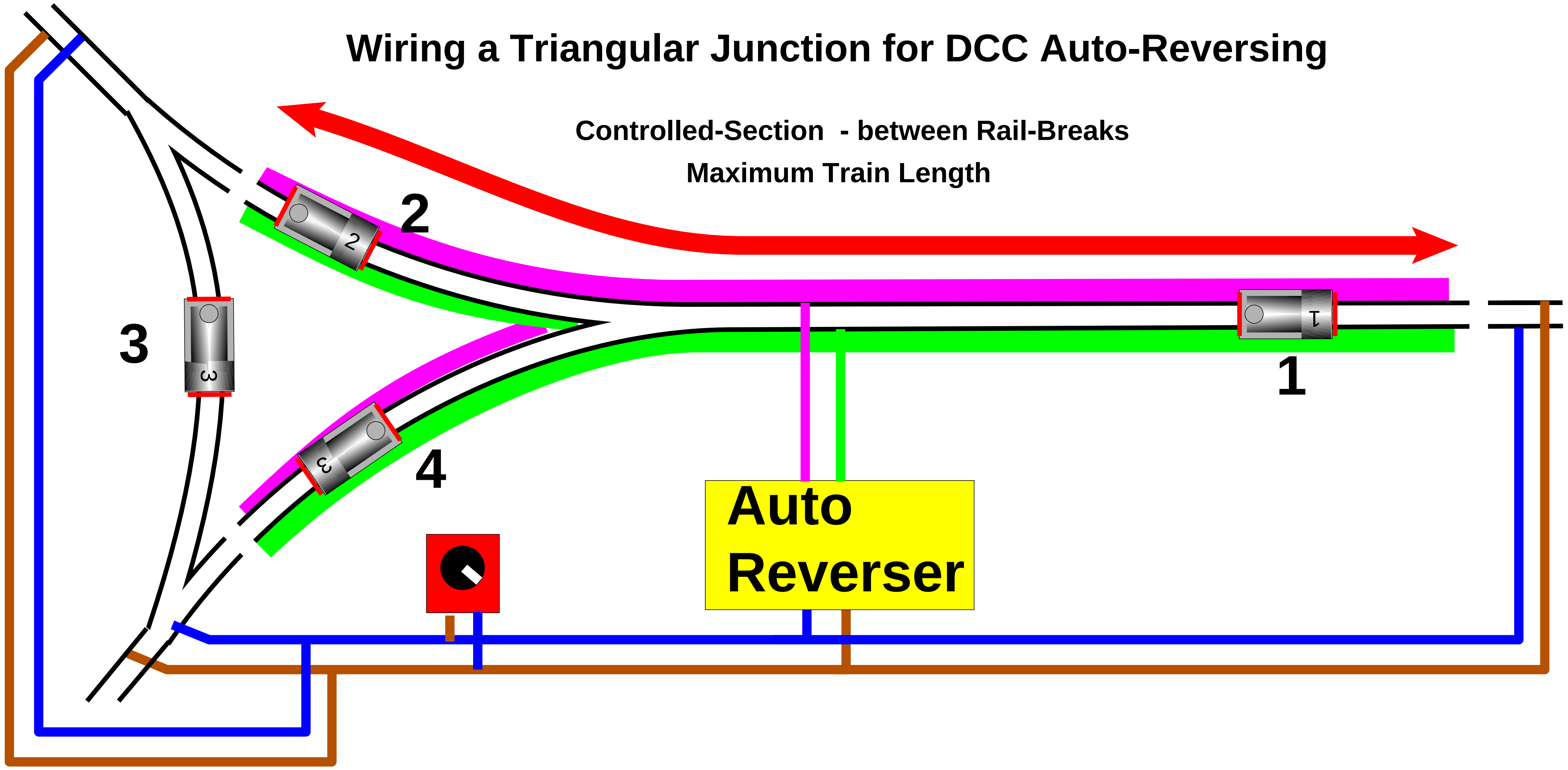

Sequence:

Train crosses gap near 1: Track Polarity becomes Green (= Blue) if it wasn't before.
Train proceeds past 2 to gap: When the left wheel bridges the left gap, Green (= Blue) will short to Brown!
Circuit *immediately* changes the Controlled-Section Polarity, so that Green = Brown, loco continues onward

Assume the points are now changed, and the loco reverses past 3 to beyond the next point ... no problems.
Change the points again, and drive the loco, over the gap, to 4. Green is still (= Brown) ..will short to Blue!
Circuit *immediately* changes the controlled-Section Polarity, to that Green = Blue, loco continues forward.
On past 1 to the last gap: Green is still (= Blue), so no problems as the loco exits, with Green (= Blue).

The additional sections used by the new, compatible design have not been included in the diagrams above.

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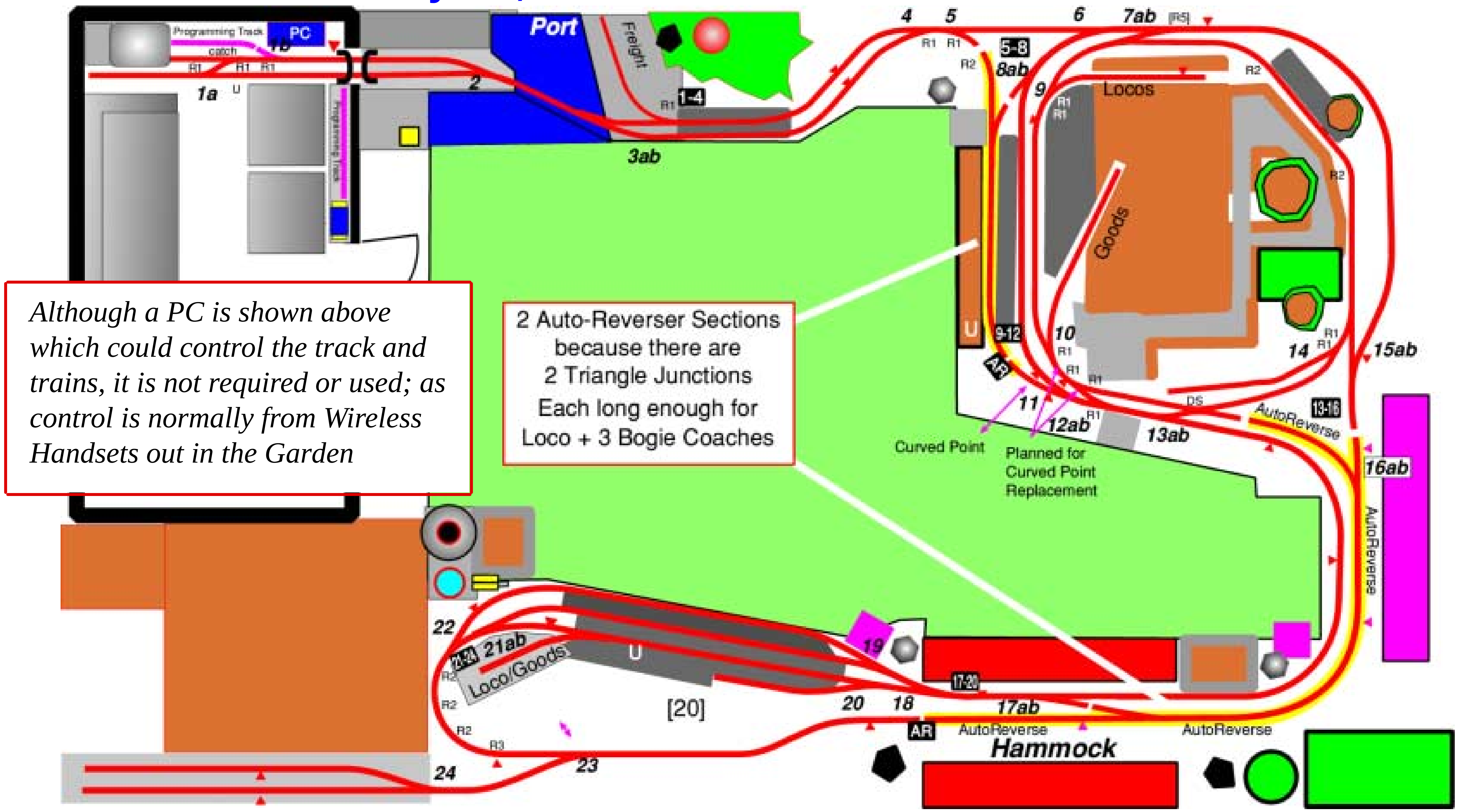
DCC Remote Point Control

Dcc Point and Signal control allows complete freedom of movement in the garden with wireless handsets.

A DCC controlled Garden Layout, with Points controlled via DCC from the same handsets.



Track shown is a single Power District with no Sub-Districts: A Short affects ALL of the track. Power Connected to track at Red ▲Triangles
All 24 Sets of Points are Controlled Digitally via Accesory Decoders powered off the Track / Bus Distribution - controlled from Handsets.

Therefore: Live Steam with Uninsulated Wheels cannot be run unless the Track Power is removed and points then changed manually.
If a separate Accessory Bus wire had been used for the Points and Signals, they could still be changed remotely with Live Steam running.

When 'Live Frog; points are used then the Digitally Controlled Points should be on a Separate Bus if possible, so that the points can still be changed after a train has overrun the point or had a derailment in the area! LGB Points are 'Dead Frog' reducing this risk but prone to stalling.

This layout could be rewired into 2 or 3 Power or Sub-Districts.with the 2 Auto-Reverse Sections at the boundaries.
Maximum observed Current with as many locos as possible running, has been about 6 Amps - the layout has a modest inline. 8A Limit.

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Using Other Controllers

LGB MTS is an early variant of the standardised NMRA dcc control system originated by Bernd Lenz. There are now many DCC Systems designed for the OO/H0 scale, as well as more specialised designs intended for 'the larger scales' with their higher current consumption.

However, as mentioned earlier, a Booster like the Bachmann model, can be be used for N to G scales with adjustable currents up to 10A, and it will work from the 'track output' of any dcc controller.

This allows low current 'starter models' to operate full-sized G-Scale Garden layouts: the original output can be used as a dedicated Power District for a separate accessory or signal bus, for example.

Massoth (LGB's electronic partner of many years) make their Dimax range of controllers, including 2-way wireless handsets with illustrations of programmed locos, as well as back-illuminated keys for night use.

The Roco Multimaus is *an example* of an 'OO/H0' handheld controller of Locos, Points and signals with graphic display and 5-character name library for 64 locos in each handset. The 3.2A 16Vdcc output, used with an SMPS 4A power supply happily powers 5 small LGB locos with sound on a level track. A Wireless version is now available, *However, as with many other 'OO/H0' controllers, it does not allow an analogue 'Loco0' as this is not recommended*. Analogue locos should not normally *remain* on powered dcc tracks.

'Console' based controllers (including Marklin's multi-protocol dcc/Mfx Central station3+) can be used, if a central control position is preferred. Z21 and other controllers work with Wi-Fi 'Smart Phones' to give illustrated loco selection and control: WiFi is now an economic wireless component in many. systems.