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1 General

1.1 Introduction and Intended Use (Informative)

This Tech Note is intended to provide information and guidance to end users for wiring your model railroad for analog DC or Digital Command Control (DCC) which will render good performance and reliable operation. Some of this document is related to both and some is specific to DCC. There exists on the internet at several websites and in various books information on wiring your model railroad. This Tech Note has been written by assembling the best practices based on experience and has been reviewed and approved by several manufacturers of DCC equipment. The user does not need to fully understand DCC to make it work. Just follow the recommendations in this Tech Note. In some places in this document we have added more information and theory for readers desiring more detail.

1.2 References

This standard should be interpreted in the context of the following NMRA Standards, Technical Notes, and Technical Information.

1.2.1 Normative

- S-9 Electrical Standards
- S-9.1 Electrical Standards for Digital Command Control, which specifies signal voltages.

1.2.2 Informative

- None

1.3 Terminology

Term	Definition
Track Bus	Pair of wires carrying DCC signal and power from the power station to the track. Hereinafter referred to as bus.
Feeder Drop	Smaller wires making a connection from the track or accessory to the bus.
Power Pack	A DC power supply and controller which varies the voltage and polarity to control DC vehicles.
Power Station	A device that amplifies the low current DCC electrical signals transmitted by a Command Station for the purpose of providing high current DCC signals with sufficient power to operate model trains and any accessory decoders that are connected to the track. The power station may be a separate device or may be combined with the command station and/or throttle. Sometimes referred to as a booster.
Decoder (mobile)	DCC receiver for controlling vehicle animation.

Term	Definition
Accessory Decoder	DCC receiver for controlling accessories.
Vehicle	Mobile model railroad device. This includes locomotives and other rolling stock.
Accessories	Fixed model railroad device. This includes turnouts, lights, signals and other devices not on the rails.
Power District	Section of track isolated from other track and powered by a separate power station (DCC).
Power Sub-district	A section of a power district protected by a separate circuit breaker.
Block	Section of track isolated from other tracks for the purpose of control (DC) or detection (DC or DCC). A block may exist in a power sub-district.
Ohms Law	**V = I x R** Where V=voltage, I=current and R=resistance (impedance)
CT Coil	Also known as a Current Transformer. A coil which magnetically couples to a wire wrapped through the hole of the coil thereby coupling and inducing a current in the coil when there is a current in the wire. Commonly used in occupancy detection circuits.

2 Electrical Properties

With DC operation the power supply usually drives one or a few locomotives on one train at any given time. The voltage on the rails will vary according to the speed setting of the DC controller (Power Pack). With DCC, many vehicles (locomotives) and accessories may be driven from one power station. Full voltage of the DCC signal is present at all times, unless switched off. The current in both cases will depend on the number of vehicles present and their speed. Although in some cases a model railroad previously wired for DC may work just fine on DCC, updating the wiring may in a few cases be necessary to obtain optimal performance. The increased power requirement may dictate updating the wiring for DCC.

DCC decoders have a minimum voltage at which they will operate reliably. In addition, a minimal voltage is required to properly drive the motor in the vehicle. Good wiring practices and following these guidelines will assure that at any point on the model railroad, sufficient voltage is present as well as a clear DCC signal.

2.1 Voltage loss

All electrical conductors have some resistance. Because rail has more resistance than the copper wire that is typically used in the bus, one should not depend on long stretches of rail to conduct power and DCC signals.

2.1.1 Bus Wire Size

The bus wire conducts the power and DCC signal from the power station to the track. Both the length of run and current draw must be considered. As the length of run increases the bus resistance increases. As the current draw increases the voltage drop increases. Ohm’s Law applies. V = I x R. Wire size and wire material will also affect voltage loss. It is recommended that copper wire be used. The wire may be stranded or solid; the wire gauge accounts for the conductive cross sectional area be it stranded or solid.

A solid wire of a given gauge will fit in a smaller terminal slot than the same gauge of stranded wire. If the bus used wire will not fit a power station or circuit breaker terminal, it is permissible to use a short section of smaller gauge stranded wire that will fit into the terminal and connect that to the larger bus wire with a secure connection such as a butt connector, terminal strip or wire nut. The added resistance of a very short section of wire is negligible. Although a solid wire of a given gauge may fit in a terminal where a stranded wire would not, care should be taken to avoid creating a stress on the terminal to avoid damage to the terminal.

The maximum voltage rating for decoders is different for each scale. Refer to S-9.1. For best performance the bus size in American Wire Gauge (AWG) shall be such that there is no more than a 5% voltage loss at the furthest point from the power station at the maximum current of the power station. The Charts 2.1 – 2.4 below gives recommended wire size for length of run and at various currents.

As a matter of safety, voltage drop is important because the booster must be able to fully drive its rated current for the overload protection to trip. Too much voltage drop (inline resistance) may limit the drive current of the booster during a short condition leading to excessive heat built up and damage to equipment. A good method to check that the circuit breaker in the power station or external circuit breaker is working properly is to place a metal object across the rails at multiple points from the power station or breaker to verify that the breaker trips. This is commonly referred to as the quarter test, as a quarter is placed across the rails to create a short. In larger scales a larger coin or other large metal object would be required to cross both rails.

The maximum current for the power station varies between scales. For N scale a power station limit of 3-5 amps is typical, for HO 5 amps, for O scale and larger power stations of 10 amps are common. However, this will vary by the size of the model railroad, amount and type of equipment (vehicles) used. The graphs below shows the voltage loss for common wire sizes at various distances. Each graph is for different currents that are common ratings for power stations.

Table 2.1 Coper Wire Resistance

Gauge	Ohms per 1000 feet	Diameter inches
#10 AWG	0.9989	0.1019
#12 AWG	1.5880	0.0808
#14 AWG	2.5250	0.0640
#16 AWG	4.0160	0.0508
#18 AWG	6.3850	0.0403
#20 AWG	10.15	0.0320
#22 AWG	16.14	0.0254
#24 AWG	25.67	0.0201

Table 2.2 Nickle Silver Rail Resistance

Rail Size	Ohms per 1000 feet
0.125”	
0.100”	17.4
0.083”	
0.070”	
0.055”	

Chart 2.1

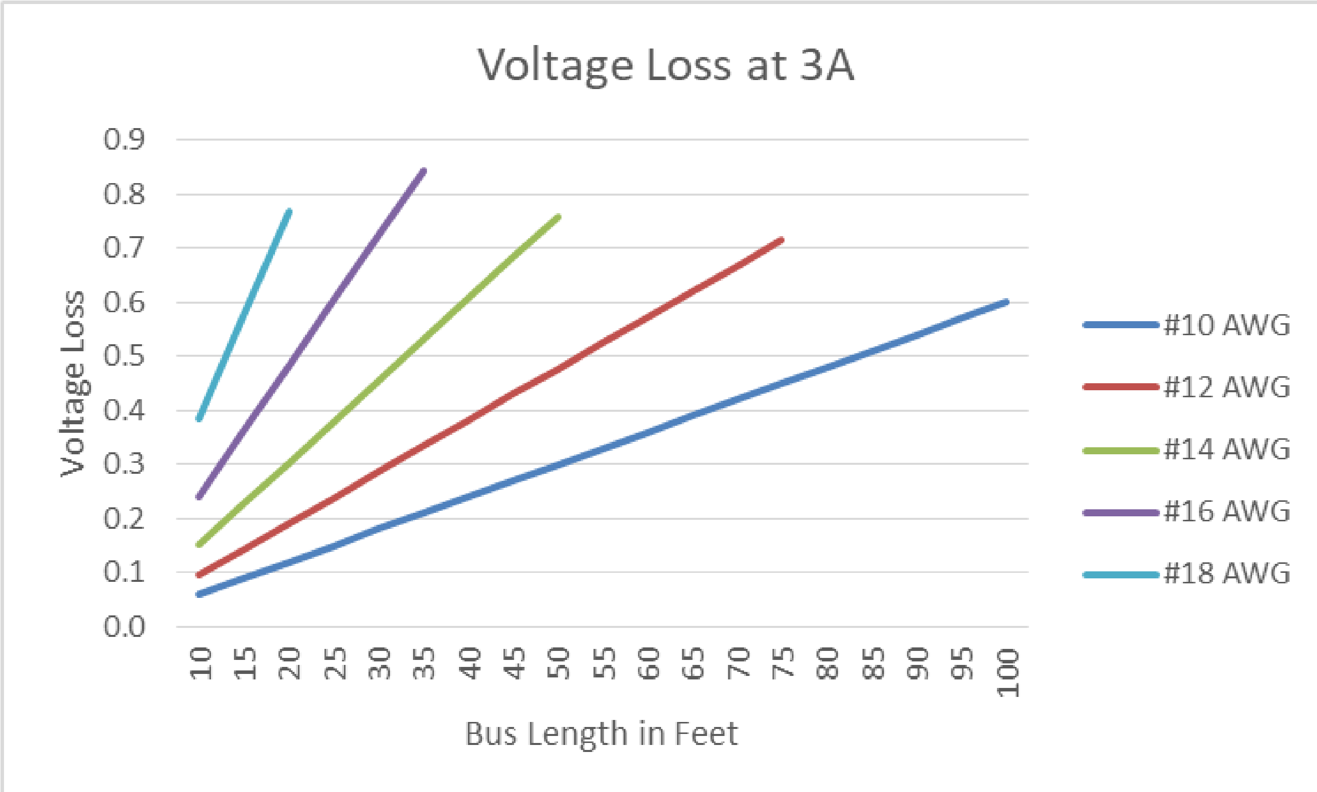

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Chart 2.2

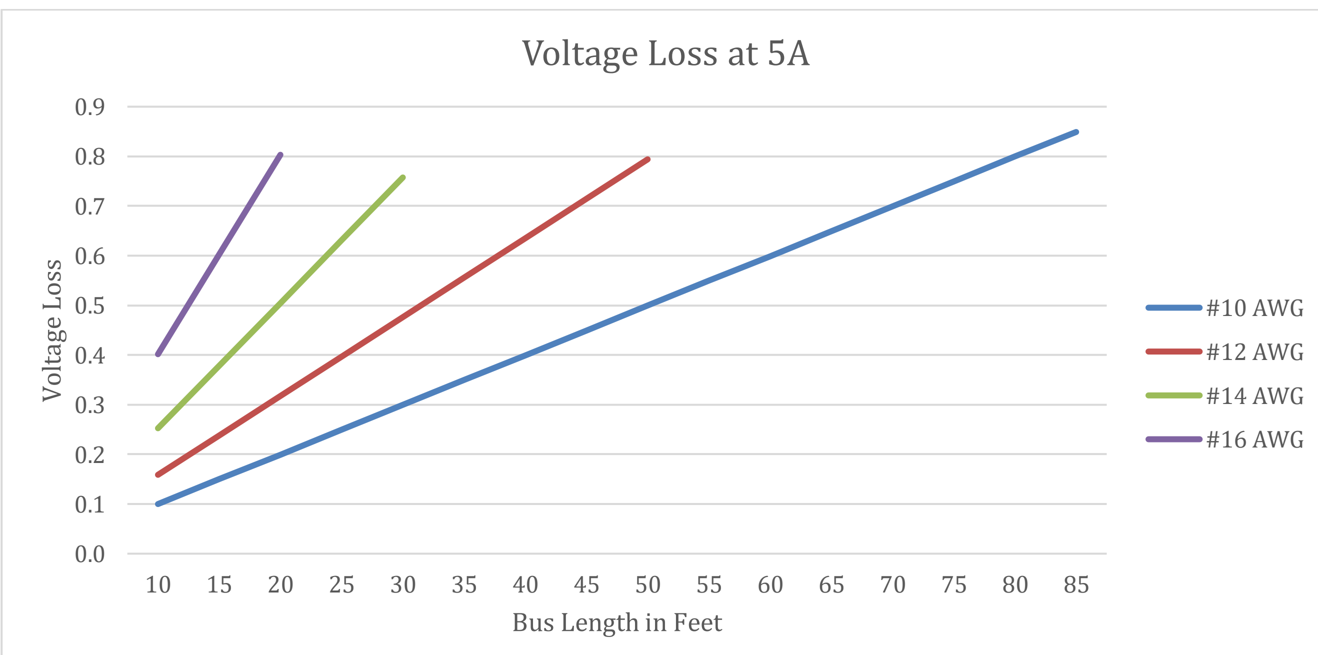


Chart 2.3

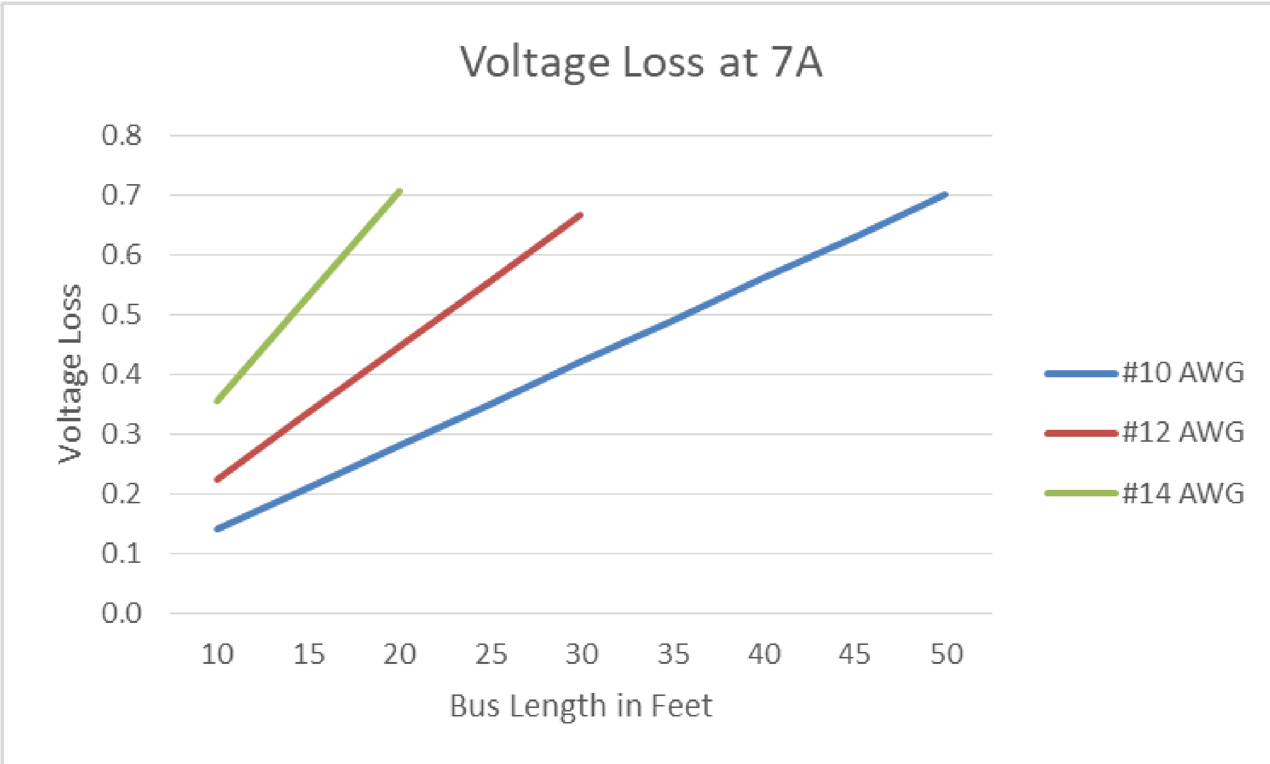
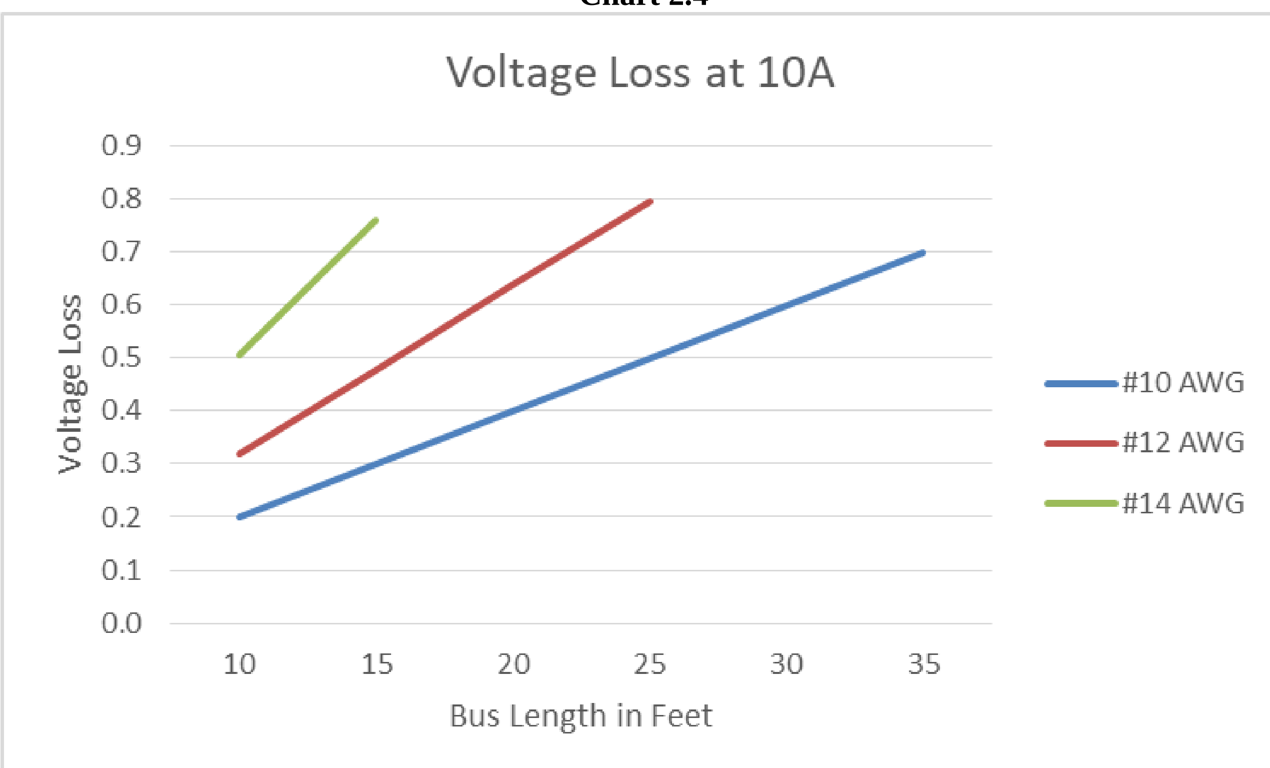


Chart 2.4



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Should sections of track exceed the length of run supported by a given wire size, the power station may need to be located closer to the track section, or the center of the section of track to feed in both directions, or break up the track into power districts and use multiple power stations one supplying each power district.

2.1.2 Feeder Drops

The feeder drop attached to each rail or accessory is typically smaller than the bus wire to accommodate connecting the feeder to the rail or accessory. The feeder drop should be securely attached to the rail. The feeder drop may be either a solid or stranded wire.

In smaller scales soldering the feeder drop to the rail is a good method for attachment. The feeder drop may be soldered to the side of the rail (field side) or to the bottom between ties. With a little practice one can solder to the bottom of track with plastic ties without melting them. Once the track is painted and ballasted the connections nearly disappear.

For large scale track (G & F) the mass of the rail makes getting enough heat to make a good solder connection difficult. For large scale track, mechanical connectors with screw terminals make a good method to connect the feeder drops to the track.

Never rely on a friction connection such as a slide on rail joiner. The connection should be by means of soldering or tight screw terminals.

Each section of rail should have a feeder drop wire attached. In no case should an unsoldered rail joiner be relied on to conduct the power and signal. Feeder drops should be spaced at no more than 3 feet or 1 meter apart. For very short sections of rail, less than 6 inches (15cm); a soldered rail joiner may be used to connect that short rail section to an adjacent rail with a feeder drop.

Each accessory should have a pair of feeders attached unless the accessory decoder takes its power directly from the rail. Some accessories such as turnouts come with an accessory decoder integrated which draw current from the rails.

Feeder drops should be sized based on the maximum current capacity of the power station or the rating of the breaker protecting that section. In a short circuit condition the full current capacity of a power station (or the max trip current of the breaker) could flow through a single feeder drop. Therefore, feeder drops should be sized for the worst condition that could be encountered.

Table 2.2 Typical Feeder Drop Size

Max Current[1]	Feeder Drop Min wire size
3A	22 AWG
5A	20 AWG
7A	18 AWG
10A	16 AWG

The feeder drop may be attached to the bus wire by various means including; stripping each wire wrapping and soldering, displacement connectors, or other suitable means for a secure connection.

[1] Max current on this section of bus. This may be the current rating of the power station. If external circuit breaker protection is use, the current in Table 2.2 would be the trip current of the protective device for this section of bus.

Bare connections should be covered by heat shrink tubing, electrical tape or other suitable means of insulation. Feeder drop wires should be kept as short as possible.

2.2 Signal Distortion

2.2.1 Twisted bus pairs

To reduce induction and high frequency interference the pair of bus wires should be as close as possible. For smaller wires a zip cord is one solution. For heavier wire they may be available only as individual wires. Twisting the wires at a rate of at least 4 turns per foot (30cm) will put them in close proximity, yet will allow enough room to attach feeder drops. Where there is a run where no feeder drops are to be attached the number of twist per unit length may be increased.

Twisting the bus reduces inductance which reduces ringing. It also increases capacitance which reduces ringing. It also reduces susceptibility to common mode noise (interference).

Be aware that this increased capacitance downstream from a current sensing occupancy detector can cause false occupancy indications. Wire downstream from the detector generally should not be twisted to avoid false occupancy indications.

2.2.2 Bus terminations

The DCC bus may be fitted with a resistor capacitor (RC) filter using a 150Ω resistor of adequate wattage in series with a 0.1µf 50V capacitor across the bus. See Table 2.3 below. Such a filter is best located near the end of the bus but additional filters may be placed at points along the bus if needed.

The purpose of such filters are to reduce ringing and to shunt any voltage spikes created when there is a short circuit created by a derailment or equipment running into a turnout set against it. Results will vary for each situation depending on the length of the bus, load on the bus and the power station. Although different power stations conform to NMRA Standards, the outputs will behave somewhat differently. If the power station output is driven hard there will be more ringing in the signal. The less load there is on the bus the more ringing will be observed. Adding an RC filter will reduce this ringing.

Such RC filters will draw a small amount of current and should not be placed down line from any current sensing occupancy detector.

Table 2.3 Termination Resistors 150Ω

Scale	Max Voltage	Wattage
Z & N	14V	1W
HO	17V	1W
S & O	19V	2W
G & F	22V	2W

2.2.3 Routing of Bus

In wiring for DCC, the bus should be laid out linearly. It should never loop back on itself, nor should there be a loop that goes out to a branch and comes back to connect to the main. The reason for this is to prevent reflection in the DCC signal timing as it reaches the decoder.

The bus should not be run parallel for long distances to other data busses such as Computer Model Railroad Interface (C/MRI) or Layout Command Control (LCC). Coupling and induction of signal is possible. Given that most railroads and models are linear it is not always possible to avoid running various wiring parallel. The DCC bus should be separated from other busses by at least 3 inches (7.6cm) for long distances.

2.3 Short Circuit Protection

2.3.1 DC Short Circuit Protection

Given that in DC, the power pack usually controls one train at a time (one or more locomotives MUed together) per output. The short circuit protection is usually built in each output by the manufacturer according to the rating of the power pack.

2.3.2 DCC Power Stations

A power station is defined as a DCC device that supplies a DCC signal with adequate power to drive a vehicle or accessory. The command station generates the DCC wave form which is imposed on the power supplied by a booster. Within any system there can be only one command station but there may be many boosters. A power station may be a combination command station and booster in one enclosure or it may be a booster with a DCC signal from a command station outside of that enclosure.

2.3.3 DCC Power Districts

Depending on the size of the model railroad, how much track, how many vehicles (locomotives), accessories and operators are in use at any given time; it may be beneficial to divide the track into multiple power districts. Should a short circuit occur in one location, the circuit breaker for that section would protect it without interrupting the power to other power districts.

Although in the past some have used 12VDC automotive tail light bulbs to protect against short circuits, today there are circuit breakers that are much faster and can be set for various trip currents and response times. It is no longer recommended to use tail light bulbs for short circuit protection.

Should the number of vehicles (locomotives) in use exceed the power capacity of the initial power station, power stations (boosters) may be added to supply additional power. Each Power Station should be in separate power district. Sub-districts may be divided, each protected by individual external circuit breakers. Power stations should never be connected in parallel to supply a power district.

2.3.4 Wiring Multiple Power Stations (Boosters)

All power stations should be tied together with a system common using a wire of adequate size to handle the current. Using a wire of the same size as the bus wire will assure it is of adequate size. This wire can be connected to the power station metal enclosure by means of a fork or ring crimp on connector attached to the wire and placed under a screw on the power station enclosure.

This common connection is very important to; prevent the potential for double voltage on common rail systems where one section is out of phase, and to allow locomotives with offset pickups to pass from one power district to another without stalling, or drawing propulsion current via the small gauge power station drive lines. This power station common should not be tied to earth or electrical system ground. Damage to equipment is possible if it is grounded and there is a power surge such as a lighting strike. It is a system common and not a ground.

Galvanic isolation of the command station is necessary if common rail wiring is in use to avoid a DCC signal on the power station common. Without the isolation DCC signal can appear on computers attached to the power station. (Dick Bronson is giving more input on this).

2.4 Common Rail Wiring

Where one rail or the bus wire for that rail is continuous through the model railroad is called common rail. Although this can be implemented in DC powered model railroads where each power pack (controller) has its own transformer. If used in DCC model railroads there is a risk, should two adjacent power district or sub districts use common rail wiring without a system common between the power stations and the adjacent districts be out of phase because one pair of bus wires was flipped; a voltage that exceeds the maximum voltage rating of the decoder could be present at the gap between these sections. Essentially this puts double the voltage of the power station at the single gap between the two districts. This can destroy a decoder.

It is recommended to have a power station common. See section 2.3.4 above or gap both rails and bus wires. Should the two sides be out of phase, the decoder will not be damaged. The locos will stop at the gap and not proceed without a system common. The issue is easily corrected by flipping one of the bus pairs.

2.5 Occupancy Detection

There exist several types of occupancy detection. We will not address external types such as magnetic reed switches or optical detectors (photo sensors or infrared, as they are external to the wiring of the track. The two common methods of current sensing detection are; a voltage drop across a diode or bridge rectifier and a current transformer (CT).

2.5.1 Voltage Drop Detection

A diode or bridge is inserted between the Power Pack or Power Station and the track. As current flows to the track the forward bias of the diode is 0.7V or 1.4V for two diodes in a bridge rectifier. A transistor base is connected to the diode(s) and used as a switch to turn on a detection circuit when a current flows to the track. This does result in a voltage loss at the track. In DC the train will run slower for any given throttle setting. In DCC the power station voltage should be increased by 1.4V to compensate for this loss.

2.5.2 Coupling Transformer Detection

A short section of wire inserted in the bus is wrapped through the hole in a current transformer hole. The more wraps of the wire, the more current is induced in the CT coil for a given current in the bus. Using a CT coil keeps the detection circuit isolated from the bus. Circuitry connected to the coil detects the current and drives an occupancy detection indication. Often such circuits are equipped with a potentiometer for sensitivity adjustment of the detection circuit. This is particularly useful in DCC applications where capacitance and inductance of the bus is affected by the external bus wiring. See more details in 2.4.4 below.

2.5.3 DC Detection

Only a voltage drop type of detection works with DC propulsion wiring. The voltage to the trains will be reduced as mentioned above. The only other advisement is to keep the different track blocks separate when wiring.

2.5.4 DCC Detection

Either method will work with DCC. See recommendations in 2.4.1 above to compensate for the reduction of voltage at the track. Because DCC is a 10 KHz signal the impedance (capacitance and inductance) of the bus comes into play. One of the common detection methods used with DCC is a current sensing CT coil. When a vehicle which draws power is present on the track a current will flow. This could be a vehicle with a decoder, a light or a resistance wheel set. This current is coupled to the detection circuit through the CT coil.

Therefore, an RC filter as mentioned in 2.2.2 should not be used downstream from the current sensing detector. The small current passing through the RC circuit may give a false occupancy indication. Likewise twisting bus wires downstream from the detector can increase the capacitance of the bus, resulting in a current flow and may create a false occupancy indication.

3 Document History

Date	Description
Jan. 25, 2021	First Release

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