AREMA

American Railway Engineering and

Maintenance-of-Way Association

Part 5

Railway Electrification Compatibility with Signal Systems

--- 2011 ---

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LIST OF FIGURES

SECTION 5.0 CHANGES FROM 1981 & 1982 EDITIONS (2011)

Part 5 has been generally updated, including a change in the title, and the order of the paragraphs revised to provide a more logical progression. In addition, two Figures have been added and the existing Figures have been redrawn and re-organized to more comprehensively reflect the required coordination between the electrification system design and signal system design, which is vital if both systems are to function correctly. The requirements applicable to dc traction power systems, which are appropriate for mass transit and light rail systems, as well as for some railroad applications, have been incorporated and the Figures revised to suit.

SECTION 5.1 SCOPE (2011)

Both ac and dc electric traction systems operating over a rail system interact directly with the track circuits used by the signal system, since both electrification systems and signal systems utilize the rails as part of their electrical circuits. Care must be taken in the design of any electric traction system to ensure that the signal system can continue to function safely as intended to control the operation of trains. The great majority of non-electrified railroads utilize dc track circuits to control the signal system. These dc circuits must be replaced with some form of alternating current circuits when the system is electrified. This section outlines the major compatibility concerns between signal systems (track circuits) and traction power return system.

Design of the traction power supply and distribution system MUST be coordinated with the signal system design.

Note that the term” railway” as used herein includes both railroad and rail transit systems.

SECTION 5.2 DISCUSSION (2011)

a. It is obvious from the characteristics noted below that the design of an electric traction system must be fully coordinated with the design of the signal system. The first conflict between the design of the signal system and the electrification system occurs because the signal circuits must be broken into relatively short blocks, while the traction return current flowing in the rails wants to flow unimpeded back to the substation. Since insulated joints are used in the rails to separate signal blocks from each other, these insulated joints would block the flow of the traction return current through the rails. To resolve this conflict, the usual approach is to use a frequency for the signal circuits which is different from that being used for the electric traction power with the introduction of an impedance bond across the insulated joints in the track. The impedance bond offers a very high impedance to the signal circuit while permitting the traction return current to pass through a lower impedance on its way back to the substation. The impedance bond is often designed so that it can be grounded and/or connected to a return conductor to supplement the running rails in the traction power return circuit.

b. Caution must be exercised in multiple track territory, when grounding or cross bonding impedance bonds on adjacent tracks, to ensure that there is no way the signal current can leak into the wrong track if one of the leads connecting to the rails becomes broken or if a rail itself breaks. The impedance bond must be sized to carry the worst case return current in each rail without overheating. The impedance bond is usually recessed between the ties at the insulated joints and between the running rails. The impedance bond should be provided with mechanical protection from equipment dragging from a train and be securely anchored to prevent theft.

c. The designers of electrification and rolling stock propulsion systems should advise the signal designer of the expected current in the traction power distribution system and the rails, as well as the level of harmonic frequencies expected to be generated by the electric motive power. This information will be used to determine the shielding required in any lineside cables, and to ensure that the signal detection circuits are immune to a false response caused by the primary current or its harmonics.

d. The use of a non-60 Hz frequency for the alternating current track circuits may require the installation of relatively small generators spaced along the railway, which may be installed at the electric traction substations and utilize local utility power distribution for their primary supply. Where the traction power distribution is an overhead catenary system, a single phase transmission line, attached to the OCS support poles, may be used to distribute this special signal power along the right of way to each of the signal sites. Alternatively, local solid state converters can be used in the relay houses to generate the track circuit frequencies without requiring space in traction power facilities for signal generators or the installation of signal power transmission lines.

e. Due to the frequent significant variations in voltage (>20 %) based on train load fluctuations, as well as frequent short circuits and outages, it was in the past typically recommended that signal and/or track circuit locations should not use traction power lines, or catenary and traction power feeders, for primary power to feed these locations. It was further recommended that the power supply for the signal system should be independent of the traction power system and, wherever possible, should be a dedicated supply without non-signal system loads. However, modern control technology can now handle significantly worse cases for voltage range, input harmonic distortion filtering, and surge and transit protection. If the option to provide signal power supply from the traction power system is adopted, the engineer needs to make certain all equipment specified is sufficiently robust and suitably for the harsh traction environment. In remote locations, the use of solar-powered batteries may be another alternative that could be considered.

SECTION 5.3 REQUIREMENTS OF THE SIGNAL AND ELECTRIFICATION SYSTEMS

5.3.1 SIGNALS (2011)

a. When track circuits are used for train detection, the signal system operates by dividing the track into many electrical blocks, which are separated from each other by insulated joints, or by distinct frequency or digital coding. The presence of a train in a block is detected when the wheels and axles electrically connect the two rails, causing loss of track signal at the receiver. Wayside logic then sets the signals to the appropriate indication. Where insulated joints are used to separate the signal blocks, impedance bonds are used to allow the traction return current to bypass the insulated joints while preventing the track circuit current from bypassing the insulated joints.

b. Where U.S. Federal Railroad Administration (FRA) regulations apply, the signal system must be able to detect broken rails on sections of track. Circuitry to detect broken rails on tracks where FRA regulations do not apply is at the option of the authority having jurisdiction.

c. In the event of a broken rail, other devices connected to the signal system must remain operational. These may include: highway-rail warning systems, hot box detectors, dragging equipment detectors, high/wide load detectors, loose wheel detectors, etc.

d. The electrical balance of the track circuit, where used, must be maintained.

5.3.2 ELECTRIC TRACTION (2011)

a. The total loop impedance from the substation to the train must be kept as low as feasible.

b. The running rails must be used as part of the return path for the electric traction current. Any Rail-to-Rail Bonds must have a rating compatible with the traction power return current that can flow through the bond. This means that they must be able to operate without damage when the current is double that which is normally carried. This will prevent damage to other bonds, so that if there is a bond failure, it will not cascade into the bonds on the other rail or to the impedance bond.

c. Grounding and bonding of all metallic structures must be compatible with the signal system, without compromising in any way the safety of Railroad Workers or the public who might be touching the metallic structures

5.3.3 ELECTRIFICATION AND SIGNAL SYSTEM INTERFACE ISSUES (2011)

The following is not an all-inclusive list of coordination issues which must be resolved by the signal and traction power system designers, but identifies some aspects that may need to be addressed.

a. The types and locations of traction power sectionalizing and section gaps must be coordinated with the locations of signals and fixed facilities, such as passenger stations, grade crossings, bridges, crossovers, etc.

b. The permissible along track distance from a traction power facility to a connected impedance bond must be identified.

c. The maximum distance between grounded or return cable connected impedance bonds should be such as to limit the rail potential within a safe value under the most adverse conditions.

d. The phase relationship between the signal power supply and an ac traction power supply needs to be locked together in order to eliminate the possibility of having two different frequencies starting to "beat" between each other. Since the signal frequency is typically "pulsed", this "beating" between two different frequencies may cause problems in the signal system.

e. Electronic "noise" is typically emitted by ac-powered electrically propelled trains (locomotives and multiple unit cars). This noise is carried in the return current via the rails and can cause interference with the audio frequency (AF) circuits. AF circuits are typically used for highway grade crossing activation on ac traction power systems. On dc traction powered systems, they are used for all track circuits except for those in interlockings, where the AF signal does not attenuate sufficiently to eliminate false signals. Electronic noise interference with AF grade crossing circuits can either cause False Clears or False Occupancies in the grade crossing track circuits, depending on the robustness of the coding or modulation used by the track circuit. A False Clear would result in grade crossing gates remaining up when a train approaches or passes the grade crossing, while a False Occupancy would result in the gates coming down even when a train is not near the crossing.

f. Special concerns concerning electric traction interference with overlay track circuits and communication-based train control systems should be carefully reviewed for compatibility.

g. The latest systems for dc propulsion use Insulated Gate Bipolar Transistor (IGBT) Technology which are producing much lower Total Harmonic Distortion than earlier systems and thus are NOT creating as many problems. Individual traction drive systems up to 400 kW per axle are currently in service. This technology will eventually be available for larger traction systems.

SECTION 5.4 ELECTRICAL EFFECTS (2011)

Operation of electric traction rolling stock subjects the signal system to a completely different environment from that present under non-electric operation. Some of the more important items are listed below.

a. Traction return current in the rails is significantly higher than the current used for the signal circuits, and the currents in the two rails may not be balanced at all times.

b. With ac electrification systems, large electromagnetic fields can be set up by the current flowing in the traction power distribution system and the return current flowing in the running rails which can induce currents in parallel conductors.

c. AC-powered, solid state equipped vehicles, using thyristor technology, produce a distorted sine wave in the currents flowing in the traction power distribution system and returning in the running rails, resulting in the traction return current having a number of harmonics of the fundamental frequency, some at relatively high currents levels, with the frequency range and amplitude varying dependent on the type of converter. AC-powered, solid state equipped vehicles, using IGBT technology in a unity power factor converter-inverter, produce less low frequency distortion in the traction power current than thyristor converters, but have higher levels of audio frequency harmonic current in clusters at even multiples of the converter pulse width modulation frequency.

d. Most older dc-powered vehicles use Chopper Drives, which also produce significant distortion, whereas even older dc-powered vehicles use cam controllers, which cause very little ripple on the dc power. The latest propulsion systems, using IGBT or similar technologies for dc-powered vehicles, produce almost no harmonics.

SECTION 5.5 USE OF IMPEDANCE BONDS IN RAILWAY ELECTRIFICATION (2011)

5.5.1 IMPEDANCE BOND DESCRIPTION (2011)

The typical impedance bond used for railway electrification systems is essentially a center tapped auto transformer arranged to provide a low impedance path for the relatively high levels of traction return current, but a high impedance for the significantly lower signal system current. The transformer winding is comprised of heavy gauge copper, fitted with a center tap and wound on an insulated iron core. When each of the rails carries equal amounts of traction current, the current from each rail passes in opposite directions through the coil from the rails to the center tap. The net flux in the iron core will, therefore, be zero and the impedance to the traction current (ac or dc) will be very low - Figure 33-5-1. Since the traction return current is relatively balanced in the two rails, a high enough impedance exists for the track circuit so that operation of the signal circuit is not impaired. The ac track circuit current, attempting to flow in through the two coils of the bond from rail to rail in the same direction, will see a higher impedance than the traction current. An important point to remember is that an auto transformer transfers most of its energy by conduction and not through a magnetic circuit. An impedance bond will thus behave in an entirely different manner if the current flows become unbalanced or part of its circuit opens up through various failure modes - see Section 5.6.2.

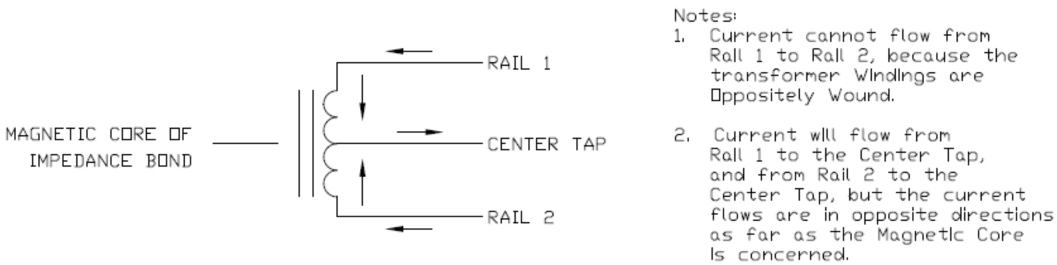

Figure 33-5-1 Current Flows at an Impedance Bond (2011)

5.5.2 IMPEDANCE BOND FUNCTIONS (2011)

Impedance bonds are normally used in pairs to permit the electric traction return current to pass the insulated joints which serve to sectionalize the signal system into signal blocks. The center taps or neutrals of the two impedance bonds are connected together to form a path for the electric traction return current around the insulated rail joints - see Figure 33-5-2. As discussed below, the center taps can be connected at selected points to either an electrical ground for ac systems or an insulated return conductor for dc systems, dependent upon the type of traction power electrification, to improve the electrical characteristics of the traction power system. Single impedance bonds are frequently used near a substation to directly drain the returning current to the substation return busbar without having to go through the nearest connected signal block point. Single impedance bonds can also be used to enhance safety at wayside facilities, such as passenger station platforms or parallel non-electrified tracks, to minimize step and touch potentials.

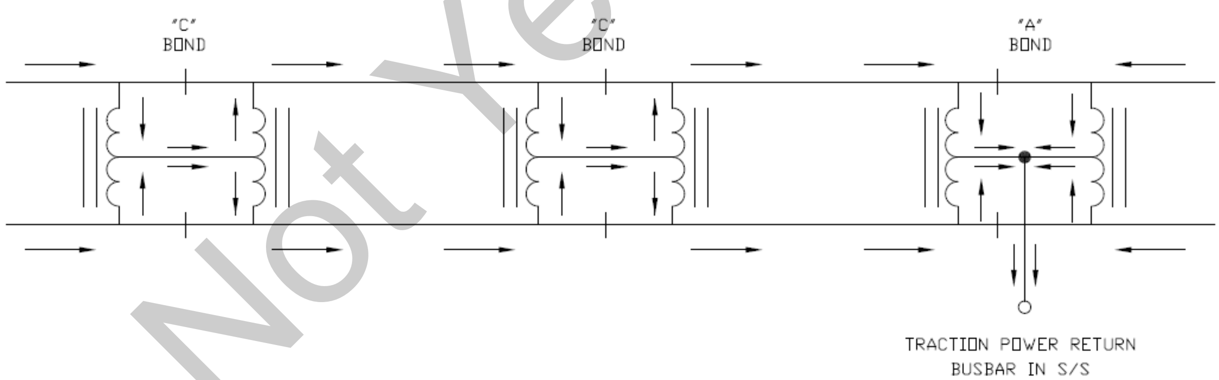

Figure 33-5-2 Traction Power Return Current Flow through 'C' Bonds and to the Substation Return Busbar at an 'A' Bond (2011)

5.5.3 SIGNAL TRACK CIRCUIT ASSUMPTIONS (2011)

It is vital that the traction power system designer fully coordinate with the signal system designer. The proposed locations and grounding and interconnections of impedance bonds must be checked and approved by qualified signal circuit designers.

5.6 IMPEDANCE BOND INSTALLATION REQUIREMENTS (2011)

5.6.1 Impedance Bond Locations (2011)

Impedance bonds are normally placed between the running rails and depressed between two ties with the connections to the rails arranged so that the insulated cables do not cross under another rail producing the possibility of shorting out the signal system. If unusual circumstances require placing the impedance bond outside the running rails, special precautions should be taken to ensure that the track connecting cables are insulated and placed in non-conducting conduit so that they cannot come in contact with any running rails. Side lead lengths should be coordinated with the signal system design.

5.6.2 Impedance Bond Connections (2011)

The grounding or interconnecting of impedance bonds indiscriminately can produce undesirable paths through which the signal current could flow. Figure 33-5-3 shows the normal and desired path for the signal current to flow from a signal power input transformer through the rails to the track relay and back. When a train enters the track circuit boundary at an insulated joint, the vehicle wheels and axles short circuit the track circuit and the relay is de-energized, giving an indication that the track circuit is occupied

Figure 33-5-3 Typical Signal Current Flow with Impedance Bonds and Properly Energized Track Circuit Relay (2011)

By comparison, Figure 33-5-4 shows that the use of grounded "A" bonds at each end of the track circuit would introduce the non-permissible grounding of the impedance bond center taps at BOTH ends of a signal track circuit. This could produce an undesired path for the signal circuit current, which would permit the current to bypass the detection of a broken rail and maintain the energized track circuit. This condition is prohibited by FRA regulations covering signal systems, since it would lead to dangerous conditions. Similar conditions can easily be produced in multiple track territory, if the interconnection of impedance bond center taps and/or grounding for ac traction power return currents, are not properly designed.

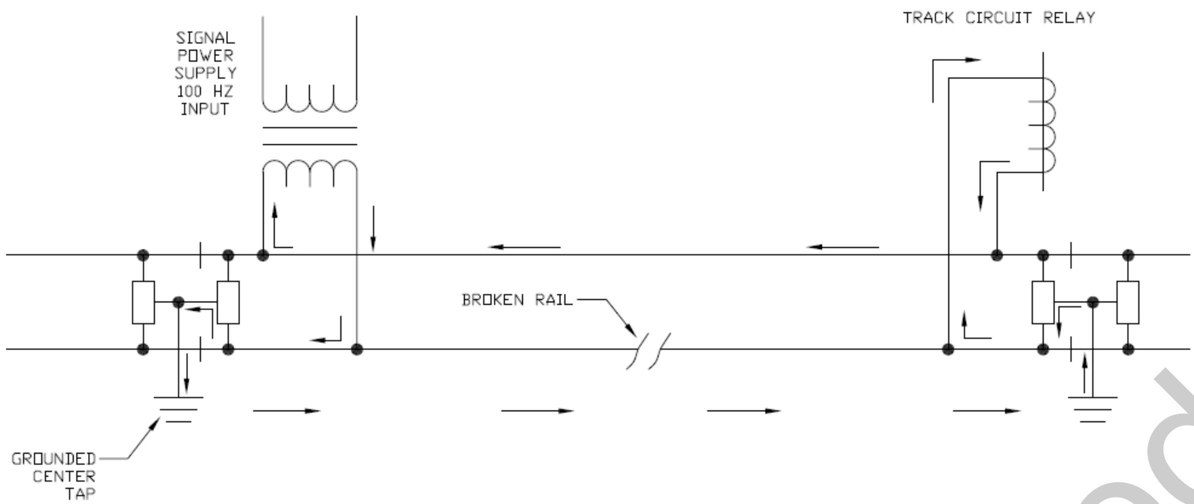

Figure 33-5-4 Unsafe Signal Current Flow through Grounded Impedance Bond Center Taps Around a Broken Rail - Falsely Energizing the Track Circuit Relay (2011)

5.6.3 Impedance Bond Windings (2011)

The windings in the impedance bond should be of sufficient size to carry normal and overload currents expected during normal traction system duty cycles, as well as the total available fault currents. The impedance bond characteristics during fault conditions must be known in order to properly set the fault clearing relays at the substation circuit breakers. Improper relay settings can result in damage if the circuit breakers are not promptly activated.

5.6.4 TYPICAL IMPEDANCE BOND CONFIGURATIONS (2011)

Where appropriate, the diagrams in this section indicate the arrangement of the impedance bond connections for ac electrified railways at the left-hand side of the diagram and for dc electrified railways at the right-hand side of the diagram.

NOTE: Diagrams for impedance bond connections on railways supporting combined operations of both ac- and dc-powered electric vehicles will developed under the next revision.

5.6.4.1 Typical Single Track Signaled Railway (2011)

Figure 33-5-5 shows the typical sequence for connecting the center taps of a set of impedance bonds on a single track signaled railway with either ac or dc electrification. To preserve the fail-safe design of the signal system, at least one set of impedance bonds shall **not** be connected to the electric traction return system between sets of impedance bonds that **are** connected to the traction return system. For convenience, the impedance bonds connected to the traction return system are designated "A" points to indicate that All bonds are connected to the return conductor. The impedance bonds which do not have their center taps connected to the return conductor are designated as "C" points to indicate that they merely provide a Continuous path for the electric traction return current.

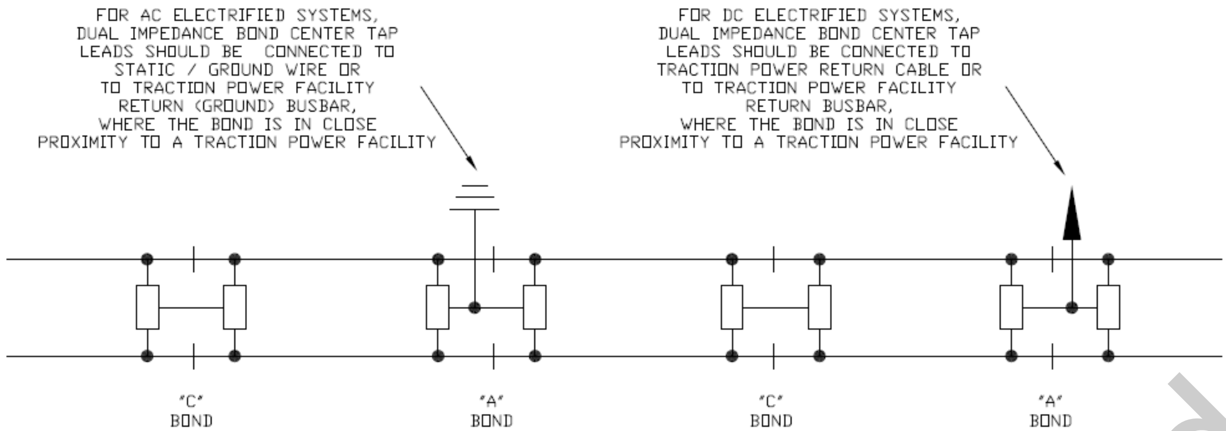

Figure 33-5-5 Single Track Signaled Railway (2011)

5.6.4.2 Typical Double Track Signaled Railway (2011)

Figure 33-5-6 shows the typical sequence of connecting the center taps of a set of impedance bonds on a double track signaled railway. The same basic technique of using "A" points and "C" points outlined above for a single track railway is used, with the addition of a "B" point to indicate that the center taps of the impedance bonds for both tracks are connected together, but not connected to the return conductor. This "B" point preserves the integrity of the signal system while improving the path for the electric traction return current by connecting the four rails of the two tracks together.

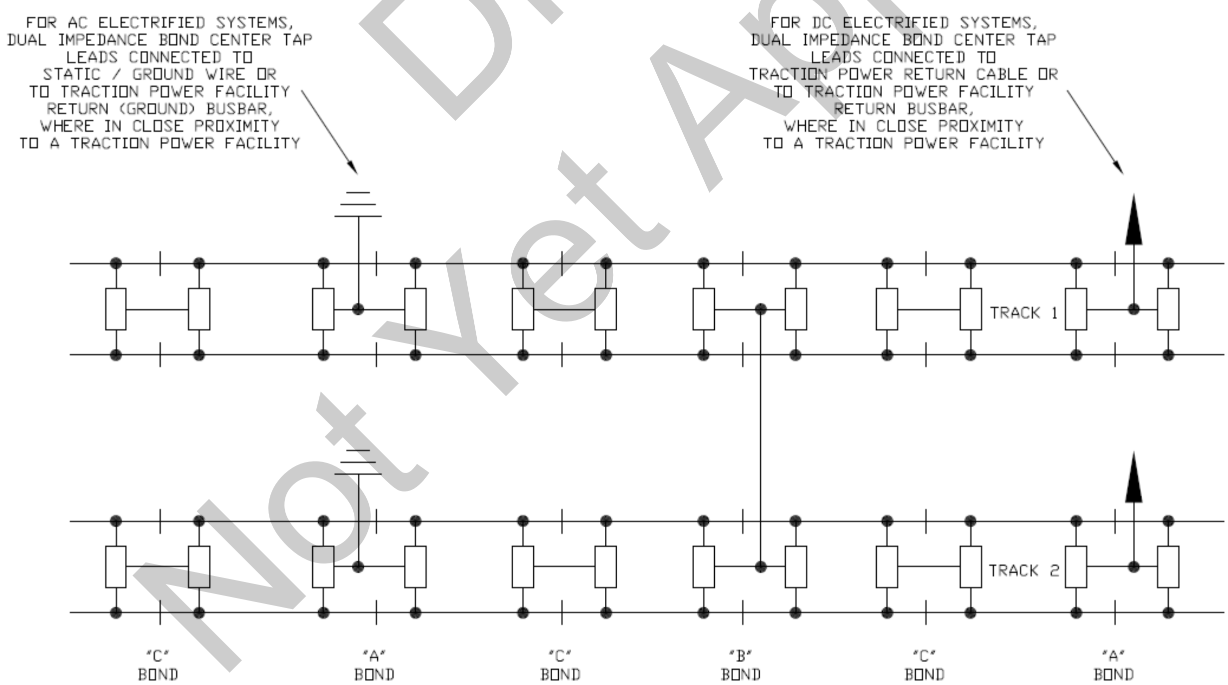

Figure 33-5-6 Double Track Signaled Railway (2011)

5.6.4.3 Typical Multi-Track Signaled Railway (2011)

Figure 33-5-7 shows the typical sequence of connecting the center taps of a set of impedance bonds on a four-track signaled railway. The four-track railway is essentially handled as two parallel double track railways. Note that the “B” points between the two double track segments are not normally interconnected.

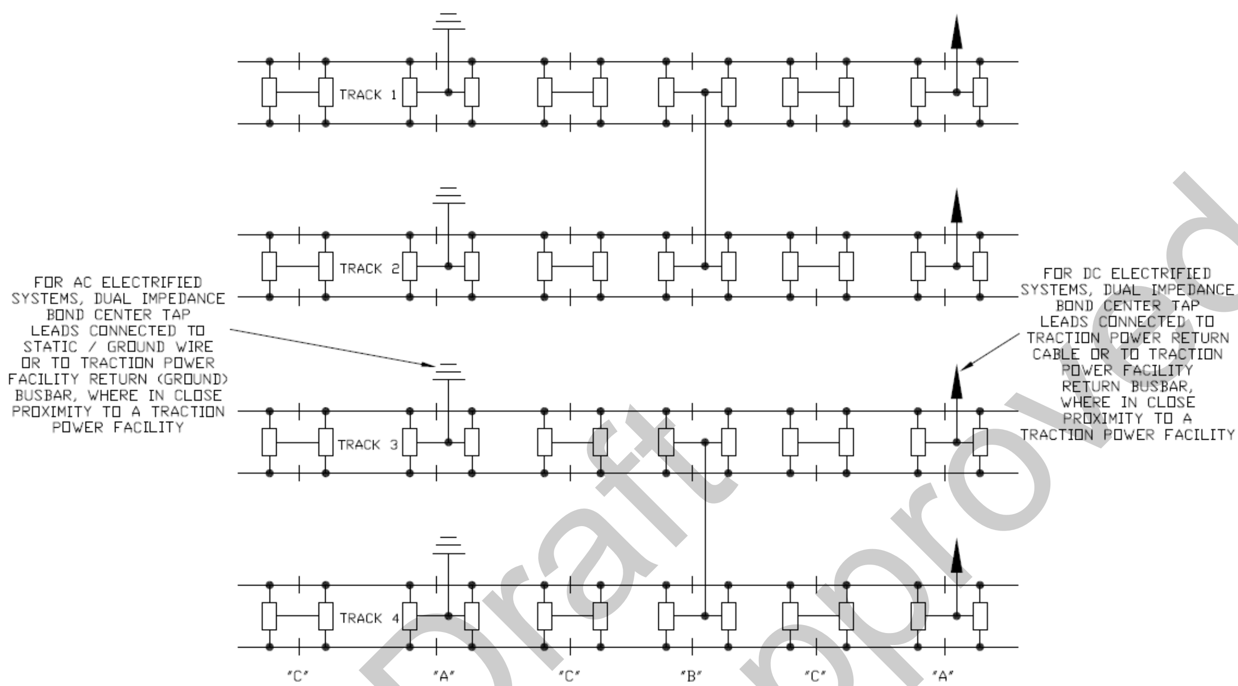

Figure 33-5-7 Multi-Track Signaled Railway
Typical 4-Track Railway shown (2011)

5.6.4.4 Typical Passing Siding (2011)

Figure 33-5-8 shows the typical sequence of connecting the center taps of the impedance bonds associated with a simple two mile long passing track in single track territory where the passing track is fully track circuited. This example shows the multiple use of "C" points where the signal circuits are relatively short, as occurs in the signal circuits associated with the two turnouts.

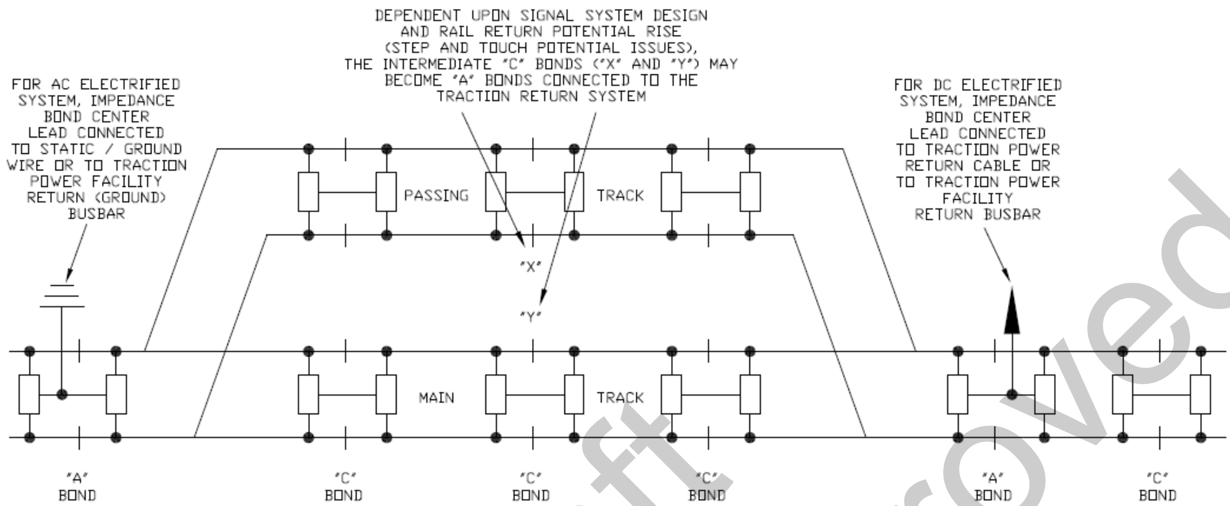

Figure 33-5-8 Single Track Signaled Railway with 2 Mile Signaled Passing Track (2011)

5.6.4.5 Electrified Tracks Without Track Circuits (2011)

Electrified tracks without track circuits are normally connected to the traction power return system at selected intervals as shown in Figure 33-5-9. The rails are bonded together and then each rail is individually connected to the return conductor. All rails of stub ended tracks must be bonded together to ensure that a broken rail condition cannot cause an unsafe voltage rise on the vehicles or running rails relative to ground. Jointed rail in non-track circuit territory must be properly bonded in order to provide the proper electrical path for the return current flow. The return conductor may or may not be grounded dependent upon the type of traction power system – ac or dc.

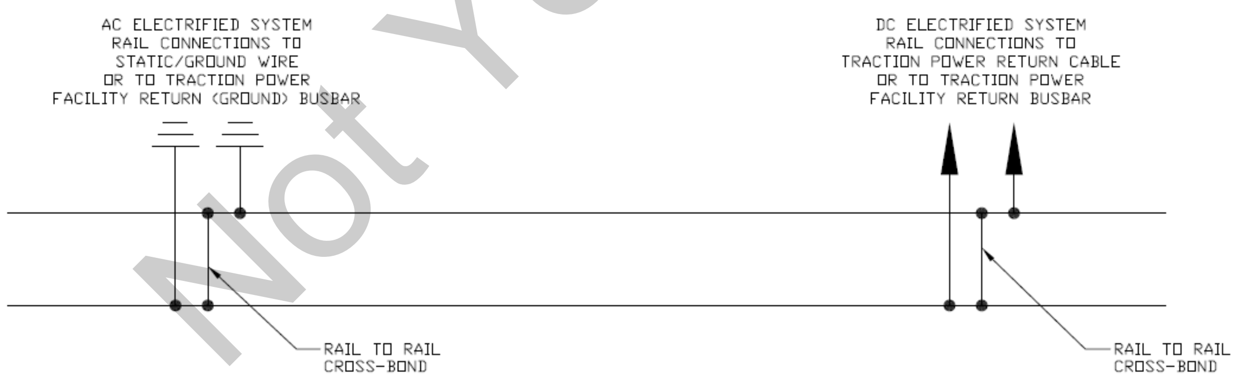

Figure 33-5-9 Rail Connections to Traction Power Return System for Non-Signaled Track (2011)

5.6.4.6 **Separation of Tracks With Track Circuits and Those Without Track Circuits** (2011)
A single impedance bond should be used at the insulated joints separating portions of track with track circuits, from those without track circuits, as shown in Figure 33-5-10, in order to permit the electric traction return current to flow around the insulated joints. The center tap on the impedance bond and the two rails should be independently bonded to each other.

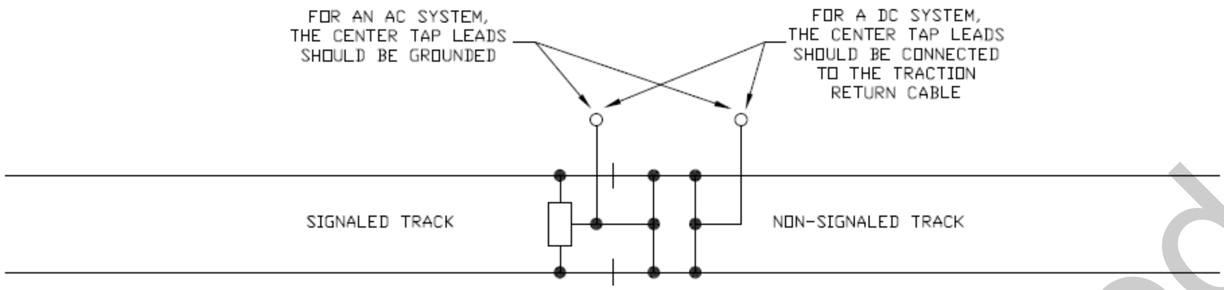

Figure 33-5-10 Impedance Bond Connections at Interface between Signaled and Non-Signaled Track (2011)

5.6.4.7 Drain Bonds (2011)
Electric traction substations may be located at some distance from a signal or from a track circuit boundary location. Where that is the case, a single impedance bond shall be located at the substation, as shown in Figure 33-5-11, with its center tap connected to the substation return system. This single impedance bond is normally referred to as a "drain bond," because its function is to drain the electric traction return current into the substation return current busbar. A drain bond may also be used to reduce touch and step potentials at wayside facilities and passenger stations, but the introduction of any such bond must be carefully coordinated with the signal system design.

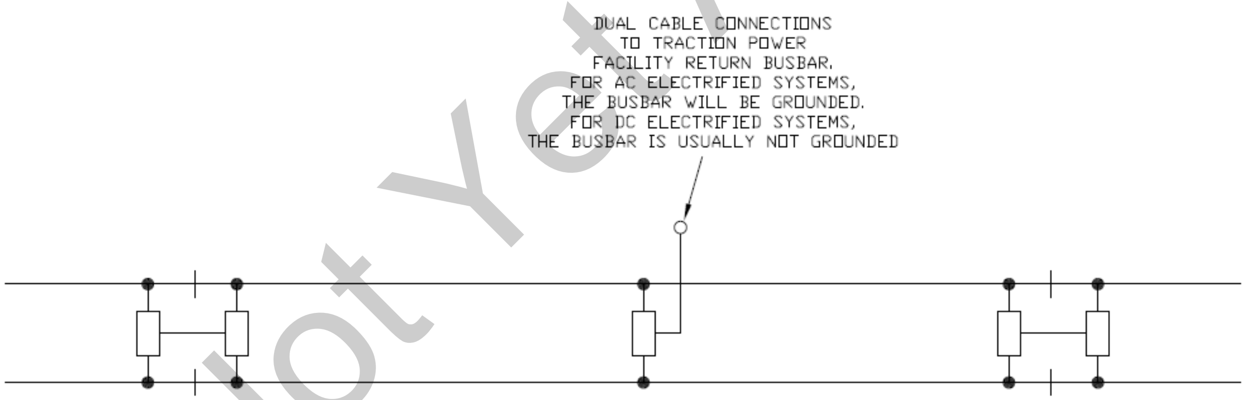

Figure 33-5-11 Substation Drain Bond on Signaled Single Track Railway (2011)

Note: The drain bond may also be used to reduce touch and step potentials at wayside facilities and passenger stations

5.6.4.8 Single Rail Track Circuits (2011)
Figure 33-5-12 shows the typical connection of impedance bonds where a full double rail signal system meets a single rail signal system. The impedance bond center tap is connected to the common electric

traction return rail, while the signal control rail is left fully insulated and unconnected to the electric traction return system.

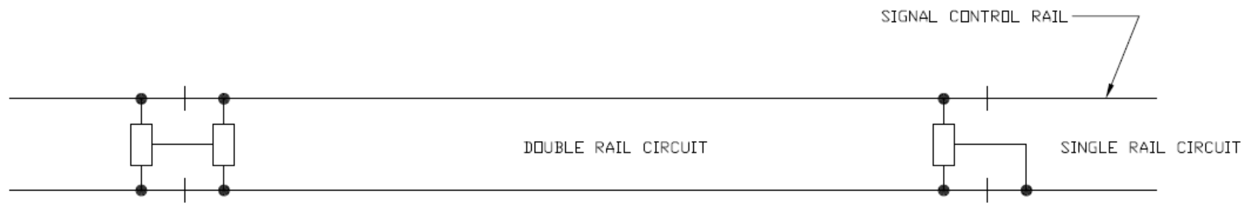

Figure 33-5-12 Double Rail Track Circuit Meeting Single Rail Track Circuit (2011)

5.6.5 NON-TYPICAL IMPEDANCE BOND CIRCUMSTANCES (2011)

It must be emphasized that track configurations and associated signal circuits are unique for each railway that is electrified. The typical configurations shown in this section are for general guidance only. It is emphasized that the proposed grounding and/or interconnection of impedance bonds must be checked and approved by qualified signal circuit designers.