



AUSTRALIAN RAIL TRACK CORPORATION LTD

Discipline: Engineering (Signalling)

Category: Standard

# Track Bonding & Signalling Infrastructure in Electrified Areas

## ESD-07-02

### Applicability

ARTC Network Wide	✓	CRIA (NSW CRN)	✓
-------------------	---	----------------	---

### Primary Source

ARTC NSW SCP 02, Vic ENG SE SPE 0001, VRIOG 12.2-2007
---

### Document Status

Version	Date Reviewed	Prepared by	Reviewed by	Endorsed	Approved
1.2	13 August 2010	Standards	Stakeholders	Chief Operating Officer	Risk & Safety Committee 06/04/2009

### Amendment Record

Version	Date Reviewed	Clause	Description of Amendment
1.0	05 Feb 09		First issue. Supersedes NSW Standard SCP 02 v1.2
1.1	07 Oct 09		Disclaimer updated as per Risk & Safety Committee 14/09/2009. References to Common Signalling Construction Standard number updated to new numbering scheme.
1.2	13 August 2010	All	Issued as final.

© Australian Rail Track Corporation Limited 2009

#### Disclaimer:

This document has been prepared by ARTC for internal use and may not be relied on by any other party without ARTC's prior written consent. Use of this document shall be subject to the terms of the relevant contract with ARTC.

ARTC and its employees shall have no liability to unauthorised users of the information for any loss, damage, cost or expense incurred or arising by reason of an unauthorised user using or relying upon the information in this document, whether caused by error, negligence, omission or misrepresentation in this document.

**This document is uncontrolled when printed.**

Authorised users of this document should visit ARTC's intranet or extranet ([www.artc.com.au](http://www.artc.com.au)) to access the latest version of this document.

# Contents

<b>1</b>	<b>General</b> .....	<b>5</b>
1.1	Electrified Areas.....	5
1.2	Infrastructure Managers Representative .....	5
1.2.1	Manager Standards .....	5
1.2.2	Signal Engineer.....	5
1.2.3	Signal Design Engineer .....	5
1.2.4	Principal Electrical Engineer .....	6
1.2.5	Traction System Engineer.....	6
1.3	Reference Standards .....	6
1.3.1	National Standards .....	6
1.3.2	ARTC Standards.....	6
1.3.3	Other Standards.....	6
1.4	Extent of works .....	6
1.4.1	Electrified Tracks.....	6
1.4.2	Electrified Area .....	7
1.4.3	Non-Electrified Area.....	7
1.4.4	Immunised Area.....	8
1.4.5	Transverse limit of Immunised Area .....	8
1.4.6	Longitudinal limit of Immunised Area .....	8
1.5	ARTC approved signalling equipment .....	10
1.5.1	New applications .....	10
1.5.2	Waivers .....	10
<b>2</b>	<b>Traction Current Provisions</b> .....	<b>10</b>
2.1	Extent of Provisions.....	10
2.1.1	Electrified Tracks.....	10
2.1.2	Adjacent to electrified tracks.....	11
2.1.3	Junctions with electrified tracks.....	11
2.1.4	Containment.....	11
<b>3</b>	<b>Electrified Track</b> .....	<b>12</b>
3.1	Traction Bonding.....	12
3.1.1	Traction System Ratings.....	12
3.1.2	Current Capacity .....	13
3.1.3	Track Circuit Bonding and Track Insulation.....	13
3.1.4	Bonding at points and crossings .....	13
3.1.5	Cross (Tie-In) Bonding .....	14

3.1.6	Traction Supply Interfaces .....	15
3.2	Train Detection Equipment .....	16
3.2.1	Axle Counters .....	16
3.2.2	50Hz AC Track Circuits.....	16
3.2.3	Audio Frequency Track Circuits.....	17
3.2.4	Impulse Track Circuits .....	18
<b>4</b>	<b>Non-Electrified Track in Electrified Area .....</b>	<b>18</b>
4.1	Traction Current .....	18
4.1.1	Isolation .....	18
4.1.2	Train Detection .....	19
4.2	Traction Fault Current.....	19
4.2.1	Fault current path in Rails.....	19
4.2.2	Other Equipment.....	21
4.3	Immunisation .....	21
4.3.1	Stray Currents (Conductive coupling) .....	21
4.3.2	Mains Harmonics (Inductive or Capacitive coupling) .....	21
4.4	Track Circuits .....	21
4.4.1	Single Rail T.C. ....	22
4.4.2	Double Rail T.C. ....	22
4.4.3	Jointless T.C. ....	22
4.4.4	Non Track Circuited Track.....	22
4.4.5	Cross Bonding.....	22
<b>5</b>	<b>Trackside .....</b>	<b>22</b>
5.1	Electrolysis bonds .....	22
5.1.1	Location.....	22
5.1.2	Connection .....	23
5.1.3	Spark Gaps .....	23
<b>6</b>	<b>Appendix 1 - Cables and Busbars .....</b>	<b>24</b>
6.1	Normal Traction Areas .....	24
6.1.1	Cables .....	24
6.1.2	Neutral Bus Bar.....	25
6.1.3	Bonding 'V' and 'K' Crossings and Mechanical Rail Joints .....	25
6.2	Heavy Traction Areas.....	25
6.2.1	Cables .....	25
6.2.2	Neutral Bus Bar.....	26
6.2.3	Bonding 'V' and 'K' Crossings and Mechanical Rail Joints .....	26
6.3	Electrolysis Bonding .....	26

---

<b>7</b>	<b>Appendix 2 - Rail Connections</b> .....	<b>27</b>
7.1	Rail Connection Methods .....	27
7.2	Connection Lugs .....	27
<b>8</b>	<b>Appendix 3 - Impedance Bonds</b> .....	<b>28</b>
8.1	Types .....	28
8.1.1	Impulse Track Circuits .....	28
8.1.2	Double Rail Track Circuits .....	28
8.2	Mounting .....	28
8.3	Connections .....	28
8.4	Side Leads .....	28
8.5	Neutral Point .....	29

# 1 General

ARTC infrastructure (owned or leased) runs between the mainland capital cities and services other areas of N.S.W., Victoria and South Australia.

Within each state tracks not managed by ARTC either abut or run adjacent to ARTC rail infrastructure; these other tracks in and around the state capitals may be used for (mainly suburban) services powered by electric traction. The traction current circuit to the powered rolling stock makes use of the rails to connect to the busbar at lineside substations.

These traction currents, and the associated infrastructure, are generally of no value to ARTC and indeed are potentially a source of dangerous interference to ARTC electrical equipment or physical injury to ARTC personnel. This specification lays out a philosophy for the design of ARTC infrastructure to isolate unwanted traction return currents and minimise the effect of any interference produced.

Where it is necessary for the electric trains to be able to run over ARTC tracks for the benefit of another infrastructure owner the traction current features will normally be implemented and maintained by ARTC using the standards of that infrastructure owner.

## 1.1 Electrified Areas

In N.S.W. the 1500V DC electrified area covers virtually all lines between Port Kembla and Dapto on the Illawarra line; Glenlee in the South; Lithgow in the West; and Newcastle in the North. In the Sydney metropolitan area the only significant line that is not electrified is the goods line to Botany and the accesses to freight yards used by the various train operating companies.

In Victoria the 1500V DC electrified area limits are Craigieburn in the North and Sunshine in the West, however only broad gauge trains use electric traction. ARTC infrastructure is generally connected to electrified lines only where grade crossings of the broad and standard gauge lines are required.

In Queensland and Western Australia 25kV AC electrified areas cover parts of the narrow gauge networks however all rail infrastructure in these states is the responsibility of the local infrastructure managers; ARTC infrastructure stops at the N.S.W or S.A. borders.

In Sydney, Melbourne and Adelaide there are also tram / light rail tracks electrified at approx. 600 V DC. These are generally on segregated rights of way and result in lower level interference than the 1500 V DC suburban train systems. They may however cross or run adjacent to ARTC infrastructure and local risks should be considered by signal designers.

## 1.2 Infrastructure Managers Representative

In this document, the following definitions of terms shall apply to the administration of the different infrastructure management organisations.

### 1.2.1 Manager Standards

The person nominated by ARTC as Approval Authority for signalling infrastructure standards and designs.

### 1.2.2 Signal Engineer

The person nominated by ARTC as responsible for the acceptance of new work and maintenance of commissioned signalling and associated traction current return bonding infrastructure.

### 1.2.3 Signal Design Engineer

The person nominated as responsible for carrying out the design of the signalling installation. Note this person will generally be a contractor however in any circumstance the Signal Design

Engineer shall be recognised as competent in accordance with ARTC specification requirements to undertake the design.

#### **1.2.4 Principal Electrical Engineer**

The person nominated by the traction current supply and distribution infrastructure manager as Approval Authority for traction supply and distribution infrastructure standards and designs.

#### **1.2.5 Traction System Engineer**

The person nominated by the organisation responsible for the installation and maintenance of the traction current supply and distribution infrastructure as its representative for the works in hand.

### **1.3 Reference Standards**

This standard makes reference to the following Standards

#### **1.3.1 National Standards**

- AS3000 Electrical Installations (SAA Wiring Rules)

#### **1.3.2 ARTC Standards**

- ESC-11-01 Construction of Cable Route and Associated Civil Works
- ESC-07-04 Installation of Equipment Racks & Termination of Cables and Wiring
- ESD-05-01 Signal Design Principles S1
- SDS 00 et seq. Signalling Design Principles
- SPS 19 Impedance Bonds
- SPS 23 Single-Phase Air-Cooled Transformers for Signalling Applications
- PDS 10 Safe Limits of DC Voltages

#### **1.3.3 Other Standards**

- VRIOG (DOT Victoria Standard) Traction Bonding

### **1.4 Extent of works**

This specification deals with areas influenced by rail traction electrification at 1500V DC from an overhead line contact wire distribution system.

Where other voltages or physical implementations occur a similar philosophy may be applied but the specific application should be designed from first principles.

Works outside the area influenced by rail traction electrification at 1500V DC from an overhead line contact wire distribution system shall be undertaken in line with the relevant ARTC standards and specifications.

#### **1.4.1 Electrified Tracks**

Tracks where electric traction units are expected to run and where provision for traction current supply is maintained.

The rails of electrified tracks shall be equipped to carry the traction return current for the electric traction units. This shall include provision for the designed normal service and peak traction return current on a continuous basis and also for the maximum potential fault currents.

## 1.4.2 Electrified Area

For the purpose of this specification the entire rail corridor under and between any electrified tracks and extending on each side to the nearer of either the rail corridor boundary or a line 15m from the centreline of the electrified track nearest to the boundary, so long as that line is outside the envelope of all traction supply equipment structures for the electrified tracks, is considered to be the electrified area.

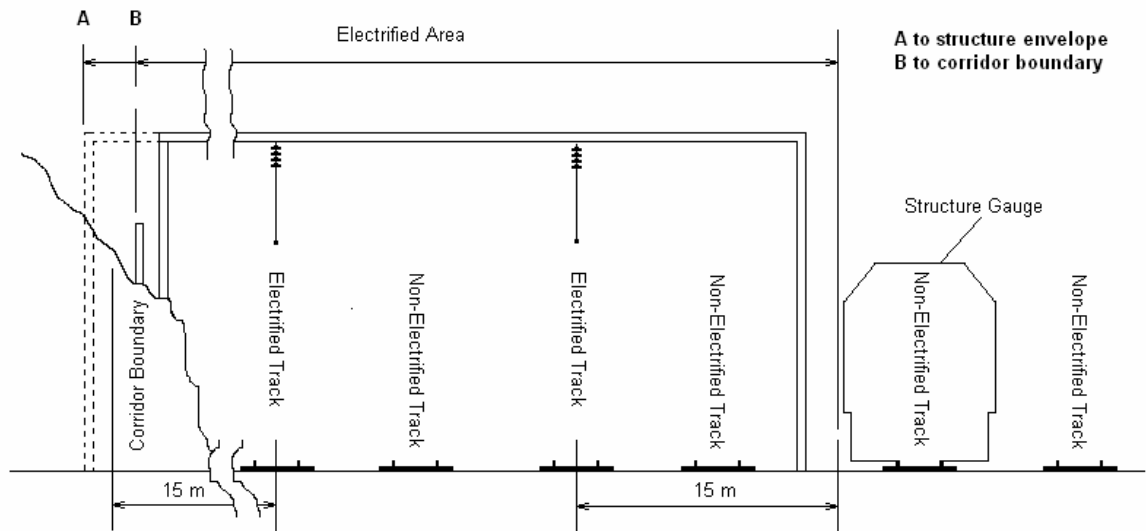


Figure 1 Transverse boundary of Electrified Area

Any ARTC track that lies within the electrified area shall be considered as potentially subject to a full traction fault at the traction supply voltage.

The distance from an electrified track that may be considered as susceptible to direct traction faults may vary under different systems of electrification and different regulation regimes.

## 1.4.3 Non-Electrified Area

Any part of the rail corridor outside the electrified area.

Where electrified tracks cross directly over or under non-electrified tracks they are considered to be on separate rail corridors. The section of rail corridor immediately above or below the electrified area is to be considered as an Electrified Area.

To differentiate which areas are to be dealt with in a particular manner it is necessary to define the point of separation between electrified and non-electrified tracks.

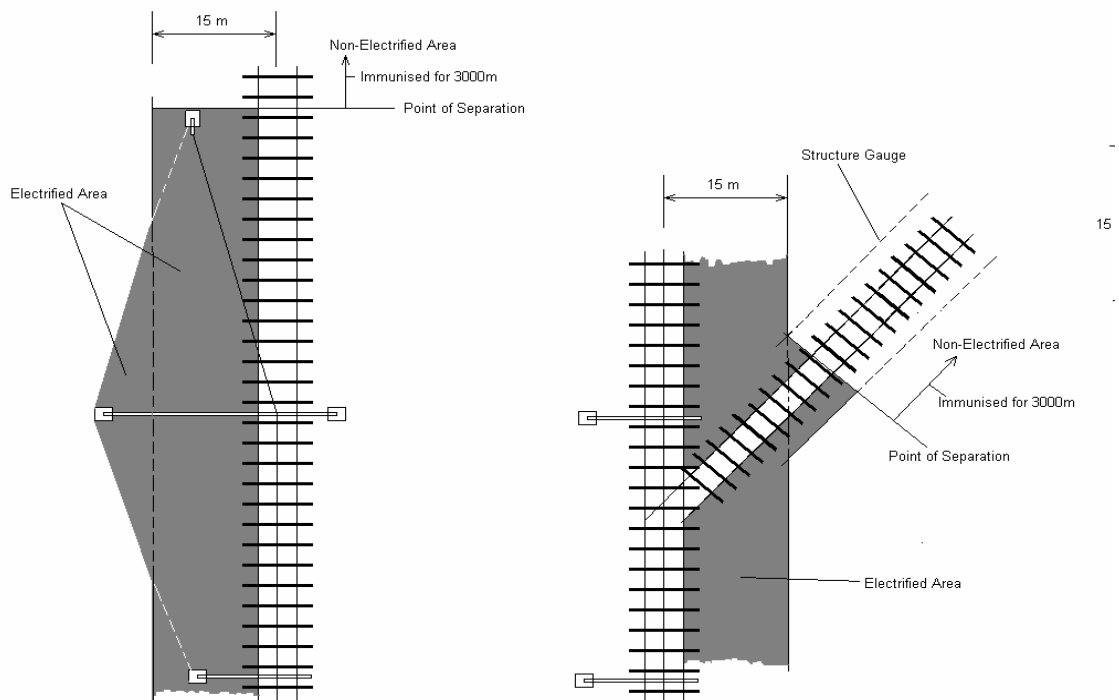


Figure 2 Point of Separation & extent of Immunisation

#### 1.4.4 Immunised Area

Once non-electrified tracks are sufficiently separated from any electrified track the chance of a fault applying full traction current to the rails (other than by conduction from the junction with the electrified area) is eliminated. The stray current effects however continue to follow the right of way for a distance beyond the actual electrification infrastructure.

Any electrical interference, which has entered the ARTC infrastructure within the electrified area, will of course flow along any metallic conductor (track, pipe work, cables, bridge structures etc.) but the actual roadbed and ballast may also provide a path for stray currents. Similarly if an electrified track is close to non-electrified ARTC track but on a separate right of way there may also be interference effects even if the two rights of way never actually join.

The signalling infrastructure installed in the vicinity an electrified area is subject to a harsher environment than that installed on the majority of the ARTC network due to both the direct conducted traction currents and the stray currents induced.

These additional factors have to be taken into consideration when designing signalling to provide additional assurances that a similar level of safety and reliability to that required anywhere on the network has been achieved. The area within which these additional precautions shall be taken is known as the Immunised Area.

Note both Electrified and Non-Electrified areas may be contained within the Immunised Area.

#### 1.4.5 Transverse limit of Immunised Area

For the purpose of this specification the entire rail corridor under and between any electrified tracks and extending on each side to the rail corridor boundary is considered to be the immunised area.

#### 1.4.6 Longitudinal limit of Immunised Area

The limit of the immunised area should be sufficiently remote from the effects of the electric traction that non-immune signalling equipment can safely be installed. The limit of the immunised area therefore comes beyond the extent of the electrification infrastructure.



- Where the non-electrified track extends directly from the end of the electrified area then a line perpendicular to all tracks at the last electrification supply structure (mast, tension anchor, substation enclosure or end of traction supply conductor) is considered the point of separation.
- Where non-electrified track diverges laterally from an electrified rail corridor the point of separation is taken as being a line at right angles to the centreline of the non-electrified track from the point where its structure gauge is clear of the boundary of the electrified area.

#### 1.4.6.1 Same Rail Corridor

Where an electrified track shares a common rail corridor with ARTC non-electrified track but the electrification terminates whilst the non-electrified track continues then all immunisation precautions should be implemented on all ARTC infrastructure within the electrified area and for a distance of at least 3000m from the point of separation.

#### 1.4.6.2 Adjacent Rail Corridors

Where an electrified track runs adjacent to a non-electrified ARTC track even where this is on a physically isolated right of way immunisation precautions should be considered whenever the centrelines of the two tracks come within 100m and should definitely be implemented if the two centrelines come within 30m.

In this instance the point of separation shall be taken as the point 15m from the centreline of the electrified track along the shortest straight line between electrified and non-electrified tracks. The remaining distance along this straight line shall count towards calculating the required extent of immunisation provision.

Where the separate rail corridors cross above / below one another the crossing is considered to be an electrified area on the non-electrified track. The points of separation shall be lines at right angles to the centreline of the non-electrified track 15m from where the centrelines of the tracks cross.

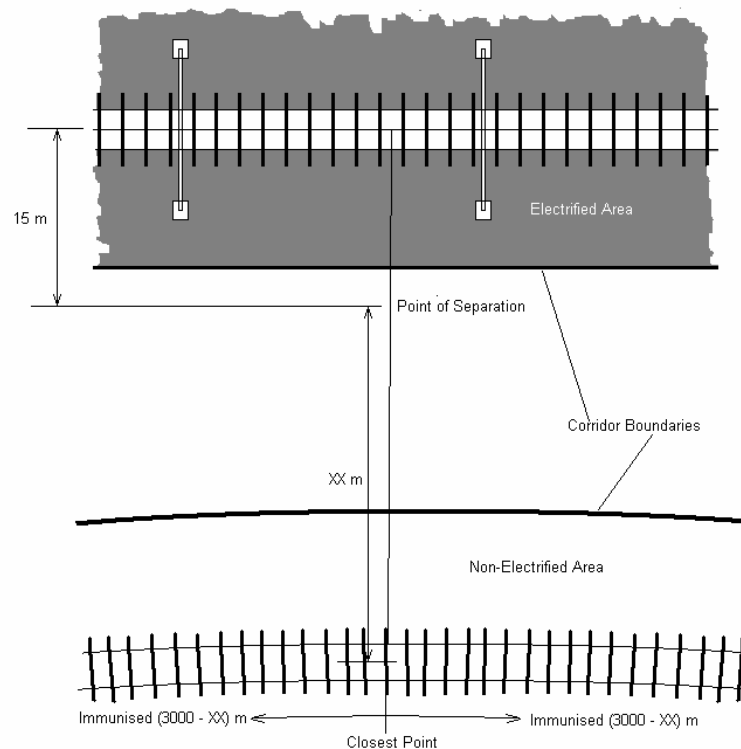


Figure 3 Immunisation of Adjacent Rail Corridor

## 1.5 ARTC approved signalling equipment

The design of the signalling infrastructure shall include only ARTC approved equipment.

### 1.5.1 New applications

Where it is proposed to utilise equipment that is not currently ARTC type approved for the application then documentation describing the equipment and its proposed use shall be submitted to the Signalling Standards Engineer with a request to issue a new type approval or amend an existing type approval.

The necessary forms for submitting a type approval request may be obtained from the ARTC intranet site.

### 1.5.2 Waivers

Where the application is unique, of short duration or rarely encountered then it may be possible to issue a Waiver to the type approval requirement for that particular instance or timeframe.

The necessary forms for submitting a waiver request may be obtained from the ARTC intranet site.

## 2 Traction Current Provisions

Where ARTC tracks run in the vicinity of electrified tracks the extent of the ARTC infrastructure provision needs to be determined. Within this area three situations exist.

- 1) **Electrified Tracks:** ARTC tracks are electrified to allow electric trains to run from the electrified area to some point on or connected to the ARTC track and must provide a return path for the electric traction current which is acceptable for the normal operation of electric trains.
- 2) **Non-Electrified Tracks in Electrified Area:** ARTC tracks are non-electrified but electric traction faults may inject fault current into the ARTC rails and a return path for the electric traction current which will avoid injury to personnel or equipment touching or connected to the ARTC rails.
- 3) **Tracks in Immunised Area outside Electrified Area:** ARTC tracks are non-electrified and subject only to the effect of stray currents coupled into the tracks or lineside circuits from the traction current circuit.

### 2.1 Extent of Provisions

Generally signalling infrastructure within an electrified area and for some distance beyond must be immunised from the effects of the electrification.

Where the ARTC rails are used by electric trains provision for normal traction current return must be made. In such cases the design of the rail bonding shall be based on making the impedance of the return path as low as practical to minimise traction supply losses, overheating of equipment and voltage build-up along the rails both from the DC and harmonic components of the return current.

Where the ARTC rails are not used by electric trains provision for normal traction current return is of no advantage to ARTC therefore it is preferable that provision for traction fault current only be made. In this case the design of the rail bonding shall be based on making the impedance of the fault current path such that voltage build-up does not reach a harmful level for either the equipment or any personnel in contact with the rails.

#### 2.1.1 Electrified Tracks

Wherever electric trains may run over ARTC tracks the infrastructure shall make full provision for traction current; including traction current bonding of the rails and immunisation of all signalling equipment against both traction return and stray currents.

Where the electric traction supply system terminates whilst the rail corridor continues the full provision for traction current shall extend at least one electric train length beyond the last point at which an electric train traction collector could make contact with the supply system.

### 2.1.2 Adjacent to electrified tracks

Where non-electrified ARTC tracks are in an electrified area they should not carry normal traction currents. The design of the rail; bonding should therefore NOT allow for traction return current to flow through the ARTC rails. Any bonding design whilst adhering to the normal signalling principles for track circuit series continuity should provide only a single path between any rail and the traction return current system.

In the event of an incident such as overhead line damage or misrouting of a train the bonding components of the non-electrified tracks could be subject to traction current return. The bonding infrastructure shall ensure that any traction fault current does not lead to an unsafe situation for personnel on the track. For fault currents the potential exposure shall be based on the time taken for the traction circuit breakers to operate.

### 2.1.3 Junctions with electrified tracks

If non-electrified ARTC track runs in an electrified area there may be situations where electrified track has either a running connection to or across the ARTC track. This connection may itself be electrified to allow electric trains to access other tracks beyond the ARTC line or to allow for electric trains to be misrouted and then recovered without damaging the electrification infrastructure.

Full traction return capability for the ARTC line shall be provided to the extent that an electric traction unit could travel whilst still drawing power from the electrified line.

### 2.1.4 Containment

Where the electric traction supply system terminates whilst the track continues efforts should be made to ensure that the return traction current is contained within the electrified area. The first provision shall be an insulated tail joint in each rail in the vicinity of the end of the electrification supply infrastructure. These joints shall be nominally 15 m from any rail of an electrified track normally coinciding with the first track circuit joint beyond the point of separation.

#### 2.1.4.1 Track-circuited track

The spread of stray traction return current using the rails should be constrained if possible therefore an additional IRJ shall be inserted in each rail of every track at a distance approximately 800m from the point of separation. This location should be chosen to coincide with both the layout of the signalling infrastructure and any physical features of the geography (e.g. watercourses, tunnels) that may act to contain or exacerbate stray currents.

#### 2.1.4.2 Non Track-circuited Track

Where electrified track abuts a non track-circuited line IRJs shall be inserted in each rail of the non track-circuited track nominally 15m from the electrified track above. The non track-circuited rails shall be bonded together and to the nearest traction return rail or impedance bond neutral point. If the non track-circuited track diverges from the electrified area then a second set of IRJs shall be installed at approximately 800m from the point of separation with the rails on the side nearer the electrified area again bonded together.

#### 2.1.4.3 Line Circuits

To contain the effects of stray current in lineside circuits it is recommended that any conductive cable route, together with the conductive (copper) cable cores should also be provided with galvanic isolation at or close to the location of the "800m" IRJs.

### 3 Electrified Track

Any traction current supply infrastructure installed on ARTC track where electric trains are intended to run shall be designed and maintained to the standards of the electrical supply infrastructure owner for the benefit of whom the equipment is installed.

The calculation of traction return resistance is the responsibility of the Traction System Engineer, however, the Signal Design Engineer should be aware that the following guidelines exist.

Number of electrified tracks	Number of rails required for traction current return
One track	2 rails at all times
Two tracks	4 rails except for short distances, within interlockings, over points where 3 may be acceptable
Multiple tracks	Maintain the ratio for dual track unless specific permission is obtained from the Principal Electrical Engineer.

**Table 1 Rails required for traction return current**

Long single-rail track circuits should not be used in electrified areas.

Where the use of single rail track circuits over long distances is unavoidable the case must be referred to the ARTC General Manager or nominated Signalling representative for specific approval, as higher traction return resistances adversely affect DC traction current Circuit Breaker (DCCB) settings.

#### 3.1 Traction Bonding

Where traction current normally flows in the rails the rail bonding and any equipment connected to the track has to be designed to take account of both the voltage and current effects. For 1500V DC traction the following are the general levels to be considered. Specific values should be obtained from the Principal Electrical Engineer.

##### 3.1.1 Traction System Ratings

- The DC resistance values of individual rails to be used to calculate traction return resistance are as follows:

Rail Section	Resistance / 1000m
45kg/m	0.0438 Ω
54kg/m	0.0368 Ω
60kg/m	0.0330 Ω

**Table 2 Resistance of standard rail sections**

- Heavy traction equipment rating of 2000A per rail continuous capacity, normal traction rating 1,000A per rail continuous capacity.
- DCCB settings 3,000A to 8,000A depending on the current loading required by train operation.
- Spacing of substations / sectioning huts 2.0 to 3.0km.
- Standardised designs consider the 6 and 10 minute rating of equipment for the typical gradients and traffic patterns within the section.

### 3.1.2 Current Capacity

All equipment attached to the rails shall be designed to withstand the currents and voltages associated with the electric traction current. For series elements the standing traction current shall be taken as the current due to the maximum number of trains within the section between adjacent substations drawing normal running current with at least one train on each track drawing maximum starting current. This figure may need to be increased if there is more than one station platform between adjacent substations.

Heat rise calculations shall include an analysis of the worst-case period of traffic throughout the day. The design must ensure that the operating temperature of the traction return equipment remains within the manufacturers specified limits given the heat rise and cool down characteristics of the equipment for the worst case segment of the timetable.

The bonding cables and cable connections are the part of the traction current return path most vulnerable to damage or vandalism. Consequently the design of all traction bonding connections shall allow for at least one parallel cable/connection to become disconnected. In this circumstance the remaining cables/connections shall still allow the normal designed return traction current to flow without causing further damage. A minimum of two cables/connectors each rated for the full normal current or three cables/connectors each rated for half the normal current shall be installed.

### 3.1.3 Track Circuit Bonding and Track Insulation

Where track circuits are installed, IRJs and bonding shall be provided as necessary to ensure that track circuits operate effectively, traction return path is maintained, train detection is maintained over all parts of the track circuit whilst broken rail protection is maintained to the extent required by Signalling Design Principles.

### 3.1.4 Bonding at points and crossings

On main lines, bonding of points shall be arranged to provide maximum broken rail detection of both rails in the main line and maximum assurance of train detection in the turnout.

On double rail track circuits this shall be achieved preferably by the use of separate receivers on each leg of the turnout. Where this is not practicable, special parallel bonding arrangements for the turnout leg of the track circuit shall be applied.

On single rail track circuits series/parallel bonding shall be used over points in preference to full parallel bonding, subject to the requirement that sufficient rails be available for traction current return.

Where the preferred methods are not practicable, for instance in crossovers between main line tracks, double rail track circuits with full parallel bonding over points may be used.

Insulation of points and crossings shall be arranged to place insulated joints in the less-used path as far as possible. Bonding shall be arranged to minimise, as far as practicable, the length of all parallel and series bonds.

Track insulation should be designed to use the minimum number of insulated joints needed to comply with all other requirements.

In complex areas track insulation should be designed using large-scale drawings of the actual point and crossing work. Even with careful design such drawings may fail to accurately reflect the relative positions of items on track; consequently complex bonding layouts which appear feasible on paper may be unmanageable in the field and should be avoided.

Designs using complex, multi-branched track circuits are not acceptable - any track circuit which branches three or more ways shall be subdivided into two or more simpler track circuits.

#### 3.1.4.1 Single Rail

The signalling rail of single rail track circuits shall be bonded to the same standards as the traction rail with exception of series bonds, which shall not be used or rated for traction return current.

Transpositions, where insulated joints and bonding are provided to swap the traction rail of a single rail track circuit between the Up and Down rails of one track circuit, or between contiguous track circuits, are not permitted except subject to prior specific individual approval by the Manager Standards or nominated Signalling representative. Where a traction transposition is installed, the number and size of cables shall be the same as are used for impedance bond neutral connections in the same area.

Series bonding of the signalling rail shall not be used for traction current return purposes. The 'series' bond connecting the turnout leg of a set of points with double receivers is for this purpose considered to be a parallel bond.

#### **3.1.4.2 Double Rail**

For the purpose of improving broken rail detection in double rail track circuits it is preferable to use additional receivers rather than full parallel bonding.

Where multiple receivers are used a minimum of three bonds shall be used to connect each rail of a turnout to its respective rail on the main line. No other parallel bonds are to be used.

Rails connected by full parallel bonding shall not exceed 50 metres in length and the track circuit parameters shall be specifically checked to conform they comply with the manufacturer's recommendations.

Where parallel bonding without multiple receivers is used in double rail track circuits over points and crossings both ends of the parallel rail shall be connected to the main line rail.

All parallel bonds shall be at least duplicated at each connection point.

### **3.1.5 Cross (Tie-In) Bonding**

Cross bonding between track circuits on adjacent tracks is used to distribute the traction return current over the maximum number of available conductors (rails) thus reducing the resistance between the train and the substation busbar. Note due to the design or switching of the feed circuits traction return current from trains on each side of a cross bond location may flow to either the nearer or the more remote substation.

In electrified areas, parallel electrified and any non-electrified tracks used for traction current return shall, subject to the restrictions imposed, be cross bonded as frequently as practicable to minimise the traction system return resistance and to ensure the availability of a traction return path. Cross bonds shall be as short as possible and tie-in points shall be as near as practicable directly opposite each other on parallel tracks.

In open track, tracks shall be tied-in at substations and sectioning huts, and between these cross bonded at intervals of between 0.8 and 1.6 kilometres. Adjacent track circuits on the same line shall always have one of the pair with no cross bonding connections. The first cross bonds on either side of a substation shall be placed as close as possible within those limits.

Cross bonding between substations and sectioning huts is normally designed to carry one third to one half of the traction return current generated on one track to the parallel track(s). In fault conditions the cross bonding may have to carry the full traction load.

The dimensions of cable, type of cable to be used and the methods of connection and installation are detailed in Appendix 1.

#### **3.1.5.1 Double Rail AC Track Circuits**

Cross bonds shall be provided at intervals of between 1 and 2 kilometres. There shall be no more than one cross bond connection in any track circuit.

Where IRJs are in use, the cross bond is made between the neutral points of the impedance bonds at the end of the track circuits. In some cases where the type of track circuit permits it, an additional impedance bond can be fitted mid track circuit for the purpose of tying-in to a parallel track.

#### **3.1.5.2 Single Rail AC Track Circuits**

Single rail track circuits provide a reduced rail cross section for the return traction current path, with consequent increased traction return resistance. Parallel traction rails shall be bonded

together by appropriately rated traction cables, to form a common traction return 'grid'. Cross bonding may also include connections to sidings or impedance bond neutral points on adjacent double-rail track circuits.

Cross bonds shall be provided at intervals of not more than 200m.

### 3.1.5.3 Single Rail Impulse Track Circuits

Single rail impulse track circuits provide a similar restriction to the traction current return path as for single rail AC track circuits.

Cross bonds shall be provided at intervals not exceeding 250m.

### 3.1.5.4 Double Rail Impulse Track Circuits

On double rail impulse track circuits the cross bonding shall be made at intervals of between 0.8 and 1.6 km with one clear track circuit between the tie-in bonds.

High voltage impulse track circuits are generally not suited to the connection of additional impedance bonds in mid-track, so that tie-in bonding may only occur between the ends of track circuits on adjacent lines.

### 3.1.5.5 Jointless Track Circuits

Cross bonds shall be provided at 0.8 - 1.6 km intervals and rated according to the traction current rating of the section. Jointless track circuits require an impedance bond to be provided approximately at the middle of the track circuit for cross bonding connections.

The actual cross bonding is connected between the neutral points of impedance bonds installed on parallel tracks. Impedance bonds used for tying-in shall be rated for the traction rating of the area where they are installed.

**The air cored inductor in the tuned loop on CSEE track circuits shall not under any circumstances be used for tying-in.**

### 3.1.5.6 Tying-in Non-Track Circuited Tracks

Where tracks are wired for electric traction but not track circuited, both rails should be bonded directly together and tied in to the traction return system at their extremities and at intermediate points, depending on the length of the track involved. Non-track circuited electrified track shall be cross bonded to track circuited electrified track at locations appropriate to the types of track circuit installed.

## 3.1.6 Traction Supply Interfaces

The traction return current rails shall be interfaced with the Traction System Engineer's negative bus bars at each substation and sectioning hut in accordance with Signalling Design Principles.

### 3.1.6.1 Substations

At each substation the connection from the negative busbar to each track used for traction current return shall be duplicated.

- Cables carrying the traction return current to the negative busbar shall be specified to carry the full rated traction load ie. 2,000A for Normal traction and 4,000A for Heavy traction.
- Where there is more than one track used for traction current return, they shall be tied together except where the traction system has provided a separate negative busbar for each track.
- Where single rail track circuited or non-track circuited track is in use the traction current return rails shall be bonded directly to the negative bus bar. It is preferable that single rail track circuits not be used for these connections unless adjacent siding or refuge tracks provide supporting parallel paths.
- Where double rail track circuits (including jointless track circuits) are in use the connection to the rails shall utilise two impedance bonds of the appropriate rating (ie. 2 x 2000A/rail impedance bonds for Heavy traction areas or 2 x 1000 A/rail impedance bonds for Normal



traction areas) with one connection to the negative busbar attached to the neutral point of each impedance bond.

- Where the connection to the substation is made at a double 50Hz track circuits the impedance bonds at substations shall be located on either side of an IRJ as the track circuit will not support two impedance bonds located mid track circuit. The adjacent bond neutral points shall be bonded together with cables or busbar in the usual manner, as well as to the substation negative busbar.
- Where jointless track circuits are in use the connection shall be made at mid track if possible but at a minimum of 50 m from any track circuit tuning unit connection. Impedance bonds in these situations may be resonated as required. Where the connection cannot be made 50 m from the junction of two jointless track circuits they be treated as conventional double rail track circuits and shall require IRJs in each rail, impedance bonds and connection to the substation negative busbar from the neutral point of the bonds.
- High voltage impulse track circuits are generally not suited to the connection of additional impedance bonds in mid-track. Connections to Substations shall be made across the junction of two track circuits specifically sited for that purpose.
- In cases where impedance bonds mounted between parallel tracks would be foul of structure gauge, they may be mounted outside the structure gauge towards the negative busbar and connected via underline crossings to a pair of low-set auxiliary busbars mounted between the tracks.

#### 3.1.6.2 Sectioning Huts

The negative bus of the sectioning hut is used to provide a reference point for DCCB operation. It may also be used for automatic earthing of the overhead conductors for maintenance and may carry high fault currents for a short period of time.

At each sectioning hut the connection from the negative busbar of the sectioning hut to each track shall be similar to that of a substation except that only one connection per track is required.

## 3.2 Train Detection Equipment

Train detection using the same rails as those carrying the traction return current requires that interference from the traction current should not allow a loss of detection. Since the current carrying rails need to provide a continuous path to the substation return busbar the usual signalling practice of using IRJs must be reconsidered.

Track circuits used in conjunction with electric traction must provide an unbroken, low-resistance path for traction current to flow from train to substation, while maintaining the sectioning of tracks to provide a means of determining the location of a train.

Axle counters do not depend on in the rail therefore no breaks in the traction current return conductor need occur indeed it is possible to bond additional conductors in parallel with the rails if necessary.

### 3.2.1 Axle Counters

Axle counter equipment has been ARTC type approved for use in DC electrified areas. With this equipment however the installation design usually requires local earthing of the trackside boxes. Care must be taken to ensure that no dangerous voltage potential can build up between the parts electrically connected to the rails and those connected to the local earth.

### 3.2.2 50Hz AC Track Circuits

It has been established that this type of track circuit is sensitive to interference by stray mains frequency currents, resulting in potentially unsafe situations. Special maintenance precautions are required to ensure safe operation of existing installations, and no new tracks of this type shall be installed except in the case of minor changes in the midst of an existing installation.



### 3.2.2.1 Double Rail

In a double rail AC track circuit impedance bonds permit the DC traction return current to flow in both rails whilst preventing the actual track circuit feed from flowing from rail to rail. Impedance bonds rely for their proper operation on traction currents remaining balanced between the rails of the track circuit. It is the responsibility of the Signal Engineer to ensure that the traction return path is properly balanced.

The impedance of these bonds on double rail AC track circuits becomes a limiting factor in setting the length of the track circuit and the maximum shunt value at which the relay will drop.

Older style bonds have an impedance of 0.3 to 0.4 ohms at 50Hz that limits the maximum shunt characteristic to 0.15-0.2 ohms. Air cooled bonds have an impedance of 0.5 ohms at 50Hz AC which limits the maximum shunt characteristic to 0.25 ohms.

A resonated bond may have an impedance approaching 2.5 ohms at 50Hz.

### 3.2.2.2 Single Rail

The design of single rail 50Hz track circuits shall include arrangements to limit the maximum level of DC traction current which may be applied to the track relay.

The design of single rail 50Hz track circuits shall include arrangements to limit the maximum level of DC traction current which may be applied to the track relay.

Track circuit length shall be limited such that the longitudinal DC voltage drop under maximum traction conditions does not exceed 20 volts. Typical maximum single rail AC track circuit lengths are; Normal traction 200m; Heavy traction 100m. However these lengths may need to be reduced in certain cases. Typical values for DC voltage drop are set out in

Table 3.

Traction Current (A)	1700	3400	5200	6800
Track Circuit Length (m)	Voltage Drop (volts) (For 60kg rail)			
50	2.81	5.61	8.58	11.22
75	4.21	8.42	12.87	16.83
150	8.42	16.83	25.74	33.66
200	11.22	22.44	34.32	44.88
250	14.03	23.05	42.90	56.10
300	16.83	33.66	51.48	67.32
Shaded values exceed permitted maximum.				

Table 3 D.C. Voltage drop across Track Relay on Single Rail Track

Similar values shall be calculated for individual track circuits and used to verify that the measures provided to protect the relay and / or feed units are sufficient.

Where the length of track circuit is excessive, the levels of DC being superimposed may result in failure of the relay-protecting fuse. The design shall provide sufficient series resistance in the relay circuit to limit DC traction current to a level that will ensure continuous operation of the track circuit equipment. A minimum DC loop resistance of 1 ohm is required in the relay circuit.

### 3.2.3 Audio Frequency Track Circuits

Jointless track circuits are normally separated by means other than mechanically IRJs. Jointless track circuits are suitable for use in Normal and Heavy traction areas as there are no traction sensitive components.

Traction current unbalances between rails are normalised at tying-in points, and by air-cored inductors in some CSEE jointless track circuits.

The maximum length of audio frequency jointless track circuits is not limited by traction current but by the net effect of shunt resistance across the track, including the effects of any impedance bonds used for tying in or connection to substations and sectioning huts.

In some circumstances, audio frequency track circuits may be installed as conventional track circuits, separated by IRJs and with impedance bonds to provide traction return continuity usually where a sharp cut off is required or when interfacing with another type of track circuit. Traction return and bonding requirements for this arrangement are the same as for conventional double rail track circuits.

### 3.2.4 Impulse Track Circuits

High voltage impulse track circuits shall be used particularly over points and crossings, and infrequently used tracks where it is most important to guarantee a safe and effective shunting of the track circuit

#### 3.2.4.1 Double Rail Impulse Track Circuits

Double rail impulse track circuits shall be used where it is necessary to maintain a two-rail traction return resistance path.

Double rail impulse track circuit impedance bonds are specialised impulse track circuit equipment and shall not be substituted with other types of impedance bonds.

#### 3.2.4.2 Single Rail Impulse Track Circuits

Single Rail Impulse Track circuits develop a higher voltage impulse than their double rail counterpart and are therefore slightly more effective in obtaining a shunt under poor conditions. The traction return rail of a single rail impulse track circuit may be connected to the neutral point of any ARTC type approved impedance bond in an adjacent track.

Single Rail Impulse Track circuits can be used in Normal and Heavy traction cases however they shall not be subject to a longitudinal DC voltage drop in excess of 30 volts. For Normal traction cases this may permit a length of up to 500m, but in Heavy traction cases the length limit may be 150-200m. Each instance shall be individually calculated based on the expected rail current.

## 4 Non-Electrified Track in Electrified Area

Even in an electrified area electric trains will not normally run over ARTC infrastructure. Except where otherwise provided by this specification normal ARTC design and maintenance standards shall generally be applied as elsewhere on the network.

The additional risks due to the presence of the electric traction infrastructure can be clearly defined as:

- 1) Electrical interference with signalling equipment due to conductive coupling from traction return current.
- 2) Electrical interference with signalling equipment due to conductive coupling from traction fault current.
- 3) Electrical interference with signalling equipment due to inductive or capacitive coupling from traction harmonics.

### 4.1 Traction Current

The first risk should be minimised by ensuring that the tracks do not provide a through path for traction current to flow from one point in the electrified network to another.

#### 4.1.1 Isolation

This isolation shall be provided by the insertion of an IRJ in each rail that abuts the rails of the electrified track as in 2.1.4 above.

Where electric trains cannot inadvertently run across these IRJs (as at a diamond crossing) then only a traction supply equipment fault should lead to the track carrying traction return current.

#### **4.1.1.1 Overruns**

Where it is possible that an electric train could be inadvertently routed onto a non-electrified track then the train itself could bridge the protecting IRJs and inject traction return current into the rails.

In such instances the non-electrified track for a distance at least the length of a normal electric train shall be provided with full traction bonding as in 3 above.

#### **4.1.1.2 Traction Run-Off**

If the traction current supply infrastructure provides for supply conductor run-offs at connections to non-electrified tracks then the tracks on which an electric train could still make contact with the supply conductor shall be considered as electrified tracks and the containment and overrun provisions outlined above shall be applied from the relevant Point of Separation as determined in 1.4.3 above.

### **4.1.2 Train Detection**

Any track subject to the provision of full traction return bonding as in 4.1.1.1 and 4.1.1.2 above shall be treated as an electrified track as far as the requirements for track circuit traction bonding, cross bonding, and immunisation of equipment is concerned.

## **4.2 Traction Fault Current**

Where non-electrified tracks run in an electrified area it is considered that a fault to the traction supply infrastructure, or to a train on the electrified tracks, could result in the full traction supply potential being connected directly to the rails.

Any signalling equipment connected to the rails shall therefore be designed to withstand possible 1500vDC traction faults. These fault currents could include stray currents with rectifier and train traction equipment harmonics as well as traction earth faults on trains. The injected current may produce both high voltages direct to the running rails and high circulating currents containing a number of harmonic frequencies.

It can be assumed that these faults will be transitory in nature (circuit breaker response time) but potentially of very high current (DCCB setting). To ensure the rapid operation of the DCCB it is necessary for the rails of the non-electrified tracks to be bonded together and, via an acceptably low impedance path, to the traction return busbar.

### **4.2.1 Fault current path in Rails**

To ensure that normal traction return current does not flow in this path the design must provide for a single ended path from each section of non-electrified track.

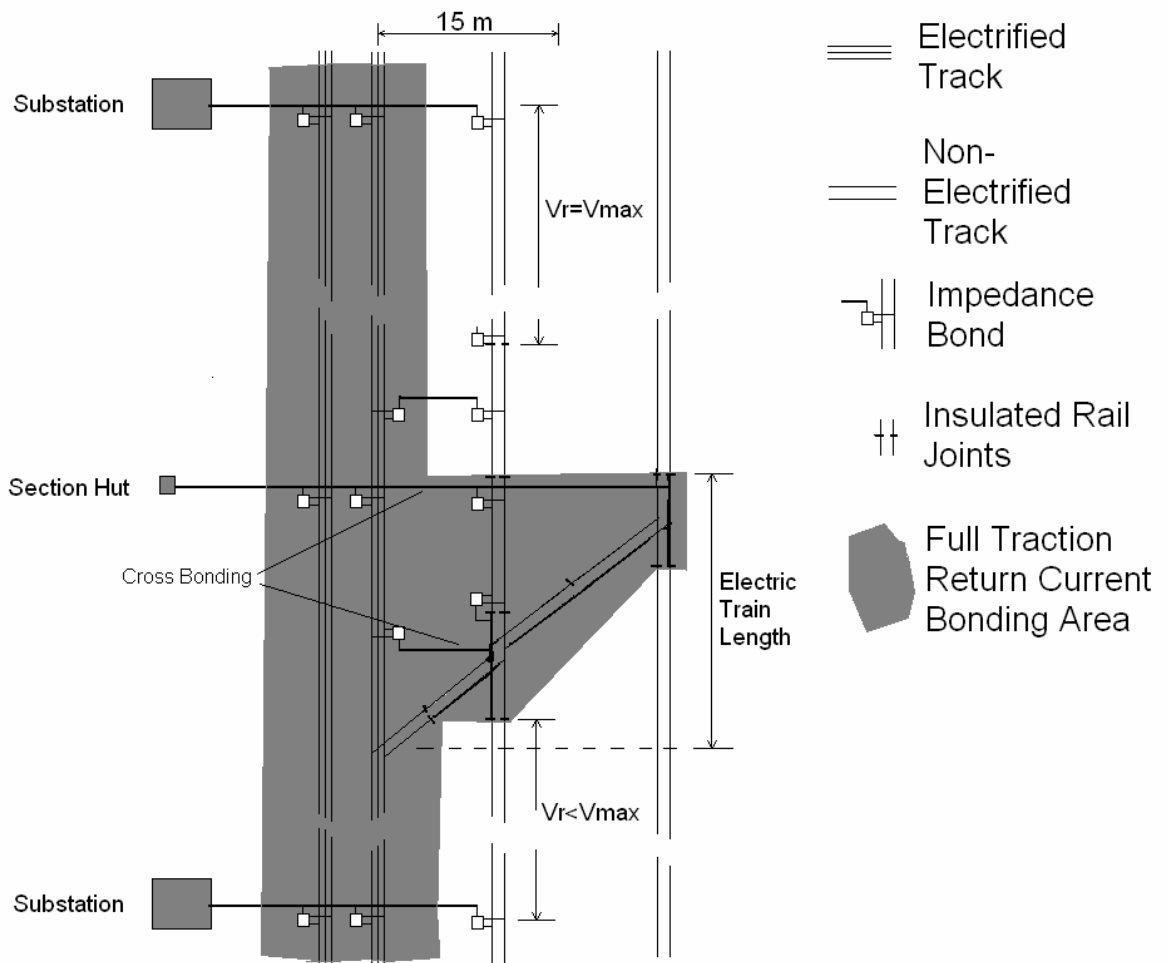


Figure 4 Bonding for Traction Current Return and Fault Protection

Because of the single ended nature of this path a traction fault at the extremity will be the worst-case design situation. Under this circumstance not only must the DCCB trip out but also the voltage rise in the rail relative to the surroundings must be constrained within an acceptable level.

#### 4.2.1.1 Acceptable Levels

The acceptable voltage level at the rail is determined by the hazard such voltage implies. For most signalling equipment suitable surge arrestors as used on the electrified tracks will cope with any expected voltage surge.

The more relevant hazard however is to personnel who may be in contact with the rails when a fault occurs. As these tracks will be considered non-electrified it is unlikely that work methods will require the rails to be specifically earthed and it may be expected that individual rails or bonding cables may be disconnected during work procedures without taking a possession of the adjacent electrification infrastructure.

Under these circumstances the bonding design should still maintain a safe voltage level **V<sub>max</sub>** the value of which may depend on the possible duration of the surge. ARTC Standard PDS 10 – ‘Safe Limits of DC Voltages’ details the factors which determine this level, the Traction System Engineer should provide details of the DCCB time to cut off the fault current.

#### 4.2.1.2 Calculation

Each section of fault current return should be calculated individually based on the DCCB settings for the location. Based on the values in 3.1.1 above with DCCB ranging from 2000 A to 8000 A and DC resistance of rail from 0.04 Ω/km to 0.033 Ω/km this gives a fault touch potential

voltage  $V_r$  of 100 volts along a single rail at a distance ranging from 312 m to 1.5 km from the negative busbar.

The spacing between substations is generally about 3 km thus any spur should be divided at the mid point giving a length of about 1.5 km and hence a maximum  $V_r$  at the end of the spur of 100 V to 500 V depending on the current setting of the DCCB.

The latter figure is above what may be considered acceptable based on Curve A of Attachment 2 in ARTC Standard PDS 10. Curve A indicates a maximum voltage for 'Long Term Threshold of Let-Go' at 160 V. By placing a rail to rail bond at the end of the spur (for double rail track circuits use an impedance bond without the neutral point connected) both rails would carry the fault current thus halving the resistance of the spur and hence  $V_r$  to 250 V. This figure may be considered acceptable for the duration of the DCCB operation.

If the calculated rail voltage  $V_r$  is still considered unacceptable then the length of the spur shall be subdivided into two or more shorter spurs by inserting IRJs as required.

#### 4.2.2 Other Equipment

Any cables to track connected equipment, including point machines and signal lamp units, should have no metallic shield or armour which could conduct fault current into the equipment housings. Any cable conductors that are terminated within the equipment housings should be provided with high capacity surge diverters to earth and series fuses at the nearest practical point to the cable entry.

### 4.3 Immunisation

All signalling equipment within an Immunised Area (see 1.4.4 above) shall be designed and constructed with a suitable level of immunity to the potentially interfering currents produced by the electric traction system.

Due to the high voltages and currents associated with electric traction supplies large circulating currents and earth return currents can be expected. These may couple to any conductive circuit within the signalling installation or may be conducted to the equipment frames via the earthing systems installed for personnel touch voltage and surge protection.

#### 4.3.1 Stray Currents (Conductive coupling)

Substations in electrified areas tend to have extensive earth grids. When traction faults occur these earth grids may be subject to considerable earth voltage rise. Where signalling equipment is installed in the vicinity of a traction substation care must be taken with the installation of any earthing electrodes to avoid the possibility of applying such earth potential rises to the internal signalling equipment circuitry.

#### 4.3.2 Mains Harmonics (Inductive or Capacitive coupling)

In DC electric traction areas it should not be assumed that the interfering currents will be only DC. Not only does multi-phase rectification of mains supply frequency introduce harmonics of the mains frequency but modern train motor control circuits use higher frequency chopping of the DC supply to manage the train speed. These chopping frequencies again generate harmonics which may be directly transmitted to the rails and via stray currents into lineside equipment and cable born circuits.

### 4.4 Track Circuits

Track circuit and Axle Counter equipment installed within the electrified area shall by definition within the Immunised Area see 1.4.4 above as far as the acceptable equipment and design is concerned.

Rail bonding within the electrified area shall be carried out to the standards of electrified tracks except that there will be no requirement for cross bonding other than for the single connection from each spur to the traction return current system.

The following additional guidelines should be considered.

#### 4.4.1 Single Rail T.C.

Keep the common rail as far as possible on the side nearest the electrified tracks.

Where only one single rail track circuit is required it may be treated as a double rail track circuit for fault current purposes. A single impedance bond may then connect both rails to the traction current return system.

#### 4.4.2 Double Rail T.C.

Since impedance bonds in series round a pair of IRJs constitute an unnecessary cost for non-electrified tracks minimise number of tracks in series on a single spur. If possible provide the single fault current bond to electrified track as close to the centre of the spur as possible.

#### 4.4.3 Jointless T.C.

Impedance bonds may only be installed in every other track circuit therefore the length of jointless track circuited spurs may easily become excessive.

IRJs shall be inserted in each rail at a minimum of one location between each pair of substations or sectioning huts to avoid providing a path for return traction current when one substation is taken out of circuit.

#### 4.4.4 Non Track Circuited Track

Non Track Circuited track should be bonded for traction current return as a spur in a similar manner to track circuited track. Both rails of non track circuited track should be bonded together with traction bonding cable at both extremities of the spur and at the cross bond tie to traction return system if that is not at an extremity.

Non track circuited track shall be treated as with jointless track circuits in the provision of IRJs between substations.

#### 4.4.5 Cross Bonding

Non-electrified lines within the electrified area should generally be connected to the cross bonds at each substation and sectioning hut to ensure the best path to trip the DCCB in the event of a traction fault.

## 5 Trackside

### 5.1 Electrolysis bonds

The traction current return system shall include the connection of electrolysis bonds as required.

The Principal Electrical Engineer in conjunction with the ARTC civil infrastructure managers shall determine the location at which electrolysis bonding facilities are required. The type of bonds to be used together with the bond conductance and expected maximum operating voltage and current shall either be calculated by the contractor and submitted for approval to or specified by the Principal Electrical Engineer.

The Signal Engineer is responsible for the connection of the electrolysis bonds to rail at the specified locations and all work shall be undertaken to his satisfaction.

#### 5.1.1 Location

Electrolysis bond connections shall be made to a convenient traction current return conductor close to the utility's electrolysis bond. The electrolysis bond should not be more than 50m from the rail connection. Suitable connection points are:

- Existing impedance bond neutral point connections,
- SI units (air-cored inductors) on CSEE track circuits,

- The traction rail of any single rail track circuit and
- Either rail of a non-track circuited track used for normal traction current return.

### 5.1.2 Connection

For double rail track circuits the SI or impedance bond shall be connected in the usual manner to rail.

Connection to a single rail track circuit shall be via bootleg riser or junction box and then to the traction rail of the track circuit.

Where suitable existing neutral points are not available a Store 54 centre tapped inductor unit may be used on double rail AC and audio frequency track circuits. The Store 54 choke is not suitable for connection to double-rail impulse track circuits. Details of the Store 54 choke are given in ARTC Specification SPS 23 Single-phase air-cooled transformers for signalling applications.

### 5.1.3 Spark Gaps

Spark gap arrestors are provided on some overhead masts, for example near stations and level crossings, and on all steel or reinforced concrete bridge structures. They are installed at locations where there is a significant probability of persons touching a metallic structure supporting the overhead traction supply, generally to protect against electric shock or electrolysis in the event of an insulator failing and rendering the structure 'live' at traction voltage.

The Traction System Engineer provides a PVC sheathed steel bonding cable from the spark gap, which shall be connected to the rail to the satisfaction of the Signal Engineer. A suitable crimp lug shall be fitted to the steel cable and connection made to the rail.

## 6 Appendix 1 - Cables and Busbars

Cables are used to connect impedance bonds and negative bus bars to rail and between neutral points of impedance bonds mounted in-track. They are also used for tie-in bonds, cross bonds, bonding of mechanical rail joints, "out of service" IRJs, and the connection of electrolysis bonds to rail.

Bus bars should be used between neutral points of adjacent impedance bonds when they are mounted externally to the track.

Crimp lugs are used to terminate bonding cables for connecting to impedance bonds, neutral busbars and rails.

The current rating of cables and busbars shall be matched to the defined traction current rating of the installation area. Specified crimp lugs are designed to carry the full traction rating.

The cables to be used in various applications are set out below. Track insulation and bonding plans may augment these minimum standards in particular circumstances.

### 6.1 Normal Traction Areas

#### 6.1.1 Cables

In Normal traction areas the standard cable size is 120mm sq. copper . This may be provided as either 608/0.5mm CSP90 hypalon or equivalent insulated copper, 925/0.5mm hypalon insulated aluminium, or 37/2.03mm PVC insulated copper when it is to be buried. Larger size copper may be used, as well as 70mm sq 'cadweld' head bonds.

Cable	120mm sq copper	185mm sq aluminium	185mm sq copper	Railhead bond 70 mm <sup>2</sup>
<b>Application</b>				
Side leads	2	2	N/A	-
Neutral leads	4	4	3	
Tie in bonds	2	2	N/A	-
Cross bonds	2	2	N/A	-
Neutral to substation neg. bus connection	6	6	4	-
Neutral to sect. hut neg. bus connection	4	4	3	-
Mechanical joint bonding	2	2	N/A	2
Bonding out IRJ	2	2	N/A	2

**Table 4 Use of Bonding Cable for Normal Traction Conditions**

Track insulation and bonding plans may augment these minimum standards in a particular installation.



### 6.1.2 Neutral Bus Bar

Where the impedance bonds are mounted on stands next to the track, the connection between adjacent impedance bond neutral points should be made using a tinned copper bus of 3500A continuous rating to AS3000 Table C.

### 6.1.3 Bonding 'V' and 'K' Crossings and Mechanical Rail Joints

Rail joint bonds may be 2 rail head bonds, 70mm sq. cadweld welded bonds welded to the outer head of the running rail, or a minimum of two (2) 1250mm lengths of copper cable as specified in Section 6.1.1.

## 6.2 Heavy Traction Areas

### 6.2.1 Cables

In Heavy traction areas the standard cable size is 185mm sq copper. This may be provided as either 962/0.5mm CSP90 hypalon or equivalent insulated copper, 1525/0.5 mm (300 mm sq) aluminium (or 3 by 925/0.5mm aluminium for each pair of copper cables), or 3 by 37/2.03mm V75 PVC insulated cables for each pair of 962/0.5mm cables, when it is to be buried. 'Cadweld' rail head bonds are 70 mm sq copper.

Cable Application	185mm sq copper	300 mm sq aluminium	120mm sq copper	185mm sq aluminium	Railhead bond 70 mm <sup>2</sup>
Side leads	2	2	3	3	-
Neutral leads	4	4	6	6	-
Tie in bonds	2	2	3	3	-
Cross bonds	2	2	3	3	-
Neutral to substation neg. bus connection	6	6	9	9	-
Neutral to sect. hut neg. bus connection	4	4	6	5	-
Mechanical joint bonding	2	2	2	2	2
Bonding out IRJ	2	2	2	2	2

**Table 5 Use of Bonding Cable for Heavy-Traction Conditions**

In certain circumstances a combination of particularly high traction currents, steep grades and frequent traffic may exceed the 2000 amp per rail continuous current rating of Heavy traction areas. Where calculations show that such circumstances may be encountered, an upgraded rating of traction cables (Heavy Class 2) shall be used. Impedance bonds rated for 2000 A/rail may be used in this application.

Cable Application	85mm sq copper	300mmsq aluminium	120mmsq copper	185mmsq alumin'm	Rail head bond 70 mm <sup>2</sup>
Side leads	4	4	4	4	-
Neutral leads	6	6	8	8	-
Tie in bonds	3	3	4	4	-
Cross bonds	2	2	3	3	-
Neutral to substation neg. bus connection	8	8	12	12	-
Mechanical joint bonding	2	2	2	2	2
Bonding out IRJ	2	2	2	2	3

Table 6 Use of Bonding Cable for Heavy-Class 2 Traction Conditions

### 6.2.2 Neutral Bus Bar

Where the impedance bonds are mounted on stands next to the track, the connection between adjacent impedance bond neutral points should be made by a tinned copper bus 3500A continuous rating to AS3000 Table C.

### 6.2.3 Bonding 'V' and 'K' Crossings and Mechanical Rail Joints

Rail joint bonds may be 3 rail head bonds, 70mm sq. cadweld welded bonds welded to the outer head of the running rail, or a minimum of two (2) 1250mm lengths of copper cable as specified above.

## 6.3 Electrolysis Bonding

Two cables shall be provided for the connection from the electrolysis bond to the traction current return conductor, SI unit or impedance bond neutral point.

- One 7/1.70 PVC/PVC/Nylon insulated cable that carries the traction current from the electrolysis bond to the neutral point connection.
- One 7/0.85 PVC/PVC/Nylon insulated cable that is connected to a voltage sensing test terminal at the electrolysis bond.

If a Store 54 unit is used it shall be connected to each rail by twin 84/0.3mm copper hypalon insulated cables. These are connected to rail by copper crimp lugs and tapered bolts or 6mm welded studs.

For connections to single rail track circuits or non-track circuited rails the electrolysis bond shall be terminated in a junction box or bootleg riser and connected to the rail by twin 84/0.3mm copper hypalon insulated cables.

## 7 Appendix 2 - Rail Connections

### 7.1 Rail Connection Methods

For bolted connection to rails, cables shall be terminated in suitable connection lugs as set out in Section 7.2 below.

Rail connections shall be by one of the following three methods

- 1) Stainless steel stud 'cadwelded' to the neutral axis of the web of the rail. Details of the welded stud arrangement are contained in Appendix B of Signalling Standard Specification - "Cable jointing, terminating and wiring of signalling systems".
- 2) Copper bush and stainless steel tapered bolt in the neutral axis of the rail. Details of the tapered bolt and copper bush and method of fitting to rail are to be found in Appendix B of Signalling Standard Specification - "Cable jointing, terminating and wiring of signalling systems".
- 3) Bifurcated 'cadwelded' connection to the outside of the head of the rail. Two cadweld headbond tails, approximately 160mm long, are joined to the 120 mm sq or 185 mm sq bonding cable by means of a suitable in-line crimp.

(This shall only be used with the specific prior agreement of the responsible track and signalling maintenance manager/s.)

### 7.2 Connection Lugs

The details of connection lugs to be used are specified in Signalling Standard Specification - "Cable lugs for railway signalling application".

## 8 Appendix 3 - Impedance Bonds

### 8.1 Types

Impedance bonds are rated for Normal (1000A/rail) or Heavy (2000A/rail) traction current areas.

#### 8.1.1 Impulse Track Circuits

In Normal traction current areas, Jeumont Schneider CTI 1400 CT1 or Westinghouse 2000P impedance bonds are suitable. In Heavy traction cases the Westinghouse 2000P impedance bond is suitable.

#### 8.1.2 Double Rail Track Circuits

In Normal traction current areas air-cooled, Westinghouse MJS, ABW/Macolo 1000 and GEC Alstom / Jeumont Schneider CIT 1400 bonds are suitable.

In Heavy traction current areas, Westinghouse 2000R and 2000P, Macolo 2000 and ABB B3 4000 bonds are suitable.

### 8.2 Mounting

New impedance bonds shall be installed on steel frames mounted outside the track and not between rails. Impedance bonds on contiguous track circuits should be mounted on a common frame.

Mounting shall be in accordance with Signalling Standard - "Construction of cable route, associated civil works and cable laying".

### 8.3 Connections

The connections of cables to impedance bonds i.e. side leads, neutral leads and tie-in bond leads shall be with crimped cable lugs specified in Appendix 2. Where the type of impedance bond does not permit direct connection of the nominated cables suitable tinned copper adapter plates shall be provided to permit correct termination of the nominated cables and lugs.

Side, neutral and tie-in lead terminations shall be accessible for examination and disconnection with the impedance bond lid or cover in place but shall not be unduly exposed to damage. Where required, cables shall be mechanically supported to reduce the load on the termination point and cable lugs.

### 8.4 Side Leads

There shall be a minimum of two side leads from the impedance bond to each rail. The track bonding plans specify the number of side leads required in particular situations.

Side lead connections to rail shall be made as close as practical to the insulated joint. Where the insulated joint has been 'Thermit' welded in place, the side leads shall be connected between the joint and the weld.

To minimise traction return system resistance, all side leads should be kept as short as possible, while maintaining a tidy and safe installation.

To avoid unreliable operation of the impedance bond due to traction current imbalance, all side leads on any individual impedance bond shall be of equal DC resistance. Generally, making all leads of equal length will satisfy this requirement. Where impedance bonds are mounted off track, the upper or farther side lead shall be connected to the near rail, and the lower or nearer side lead shall be connected to the far rail. To facilitate the use of equal side lead lengths, side lead rail connections shall be to the inside face of each rail and the upper side leads on vertical

frame-mounted impedance bonds should be terminated to the bond from above. Where welded head-bond connections are used, these shall be connected to the outside of the rail.

## 8.5 Neutral Point

The neutral connections between adjacent impedance bonds shall preferably consist of a tinned copper busbar as specified in Appendix 1. This busbar should also be used for terminating any cables for tie-in bonds or connections to substation or sectioning hut busbars.

Where the copper bus connection is not practical, such as with mid track mounted impedance bonds, there shall be a minimum of four neutral leads between the impedance bonds. The particular specification may require additional cables and specify cable cross sections. Cables between impedance bond neutral points shall be kept as short and straight as possible.

Where the impedance bond is used to change from a single rail to a double rail track circuit, the total number of neutral leads specified shall be connected to the common (traction) rail of the single rail track circuit.