Guide for the Measurement of Electrolysis Corrosion Interference

Editing, co-ordination and publishing by the Chairperson of the NSW Electrolysis Committee, c/o: The NSW Department of Climate Change, Energy, the Environment and Water (the Department), 4 Parramatta Square, 12 Darcy St, Parramatta, NSW, 2150.

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Preface

The NSW Electrolysis Committee was established in 1932 to provide guidance to the Electricity Authority of NSW on the control of stray currents and their effects on buried structures.

Under the Electricity Supply Act 1995, and the Electricity Supply (Corrosion Protection Regulation, cathodic protection systems including railway drainage bonds installed in the State of NSW must be approved by the relevant authority before they can be operated. At the time of preparation of this Guide that authority is vested in the Secretary of the Department of Climate Change, Energy, the Environment and Water.

The NSW Electrolysis Committee continues to provide technical advice, co-ordination and liaison and make recommendations for approval to the Department in respect of examining, reviewing, testing and monitoring the effects of cathodic protection and railway drainage bonds.

The publication of the Guide is an integral part of providing the Department with technical advice in this very specialised field of electrolysis corrosion engineering.

The purpose of the Guide is:

1. To provide for standardisation of interference testing procedures including methods of recording and reporting results.
2. To provide consistency of interpretation of those results thus minimising the possibility of errors and disputes arising therefrom.
3. To provide technical knowledge relevant to interference testing.
4. To provide a field guide for persons involved in interference testing.
5. To promote co-operation between all interested parties through a common understanding of the complex principles and practices associated with the mitigation of interference from stray currents.

This Guide has been prepared to assist all persons involved in the measurement of interference caused by stray current from DC Sources such as cathodic protection systems and electrified traction networks (hereafter referred to as “systems”. The Guide describes the procedures and techniques used by the Electrolysis Committee in New South Wales and does not address all alternative technology being explored by the Cathodic Protection Industry. Subsequent editions will incorporate new developments in techniques as they become available.

The Guide is not intended as a basic textbook on cathodic protection and interference testing. There are several publications concerned with the theory and practice of cathodic protection which contain background information useful for understanding interference testing, for example, “Cathodic Protection of Underground Structures” published by the Energy Authority of NSW (1985. A list of references is attached to the end of this Guide.

The nature of interference testing is such that the possibilities for error, misunderstanding and dispute are considerable. It follows therefore, that all involved parties should make a genuine effort to follow the Guide as this will provide a uniform approach to testing and assessment of interference.

NB: The Secretary of the Department has prescribed the use of this guide when carrying out interference testing in association with corrosion protection systems.

Contributors in reviewing and compiling	APA, Ausgrid, CCEng, Jemena, Freyssinet, Sydney Trains	Bilal Hamid, Jim Hickey, Gary Avery, Jim Galanos, Tony Carnovale, Lip Ung, Jack McLean, Tony Testone
External review	Worley Consulting on behalf of the Department	

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Abbreviations and Units

A	Ampere
ACA	Australasian Corrosion Association
AS	Australian Standard
CAT	Category
CP	Cathodic Protection
CPS	Corrosion Protection System
DC	Direct Current
DB	Drainage Bond
FS-E	Foreign Structure to Earth
FS-RR	Foreign Structure to Rail Return
G	Conductance (in Siemens)
Hr	Hour`
I	Current
IEC	International Electrotechnical Commission
IR	Product of Current (I) and Resistance (R) which equals Voltage (V)
kPa	Kilopascals
kV	Kilovolts
MoV	Modified Voltage
MoC	Modified Average Current
mV	Millivolts
NACE	National Association of Corrosion Engineers (USA)
NSWEC	New South Wales Electrolysis Committee
PS-E	Primary Structure to Earth
PS-RR	Primary Structure to Rail
R	Resistance
RA	Rail Authority - Transport for New South Wales (TfNSW)
RO	Rail Operator e.g. Sydney Trains, MTS or Transdev
RD	Railway Drainage Systems
SA	Standards Australia
S-E	Structure to Earth
S-RR	Structure to Rail Return
$Str_{Ano.ave}$	Anodic Average Structure Voltage

Str $\Delta_{Ano.ave}$	Anodic Average Structure Voltage Shift
Str$_{Cath.ave}$	Cathodic Average Structure Voltage
Str$_{Ref}$	Structure Reference Potential
TDB	Combined TRAD and DB system
TRAD	Transformer Rectifier Assisted Drainage System
V	Volts
XB	Cross Bond
'X' axis	Earth via Reference Cell ($Cu/CuSO_4$) to Rail or Structure to Rail
'y' axis	Structure to Earth via Reference Cell ($Cu/CuSO_4$)
+'ve' R_{ave}	Positive Average Rail Voltage
-'ve' R_{ave}	Negative Average Rail Voltage

1. INTRODUCTION

Preventing corrosion of buried or immersed metallic assets has challenged society since the beginning of the iron age. Corrosion is a wasteful process that poses an enormous cost to society, around 3 to 4% of the GDP for developed countries. The costs of corrosion in Australia are estimated to be in the order of 100 billion ASD (2022).

Electrolysis corrosion is the most aggressive form of corrosion. Whilst most corrosion reactions may have a driving voltage of hundreds of millivolts, electrolysis corrosion may have driving voltages of tens of volts. Corrosion reactions are typically 100 to 1000 times that of other forms of corrosion. For example, steel pipelines have perforated due to corrosion in Sydney, due to stray current corrosion in 6 weeks. This represents a corrosion rate of about 50 mm/year.

As an example, an accelerating train can pass 3000 amps to the rail. It only takes 0.4 milliamps over a year to put a hole in a gas pipeline at a 1 cm diameter coating defect.

Stray current flowing through the general mass of earth including water bodies and then through conductive assets back to earth is the mechanism for electrolysis corrosion. Any DC source that allows ground currents to flow can cause electrolysis corrosion of other buried or immersed conductive assets. The common DC sources that may emit stray currents are:

- Cathodic protection systems
- Electrified trains and trams
- Solar generation, Battery storage and battery charging facilities
- Electric vehicle and supporting battery charging facilities
- High Voltage Direct Current (HVDC) transmission links
- Aviation traffic control radar systems

In this version of the guide, only electrolysis corrosion (interference) from CP and electrified rail networks are covered. Future revisions of the guide will endeavour to cover the other sources of electrolysis corrosion.

Corrosion protection systems (CPS) comprise of Cathodic protection (CP) systems and Railway drainage (RD) systems. CP is a well established corrosion control system which works on the principle of applying a negative DC charge to the targeted metal structure, known as the primary structure. The negative DC charge relies on current, and ions being conducted through the ground or water, between the anodes and the primary structure. This results in shifting the voltage at the metal surface out of the corrosion zone and into the immune region when assessed on the relevant potential/pH diagram.

There are two types of cathodic protection systems discussed in this guide, the sacrificial (Galvanic) anode system and the impressed current system (ICCP). These systems are illustrated in the following modified diagrams from the Energy Authority publication “Cathodic Protection of Underground Structures” and Australian Standard 2832.1[2].

Figure 1-1 and Figure 1-2 illustrate sacrificial systems and impressed current systems. Both systems introduce direct current into the soil, a component of which can flow through nearby foreign structures and cause corrosion as shown in Figure 1-3. These systems are illustrated in the following modified diagrams from the Energy Authority publication “Cathodic Protection of Underground Structures” and Australian Standard 2832.1[2].

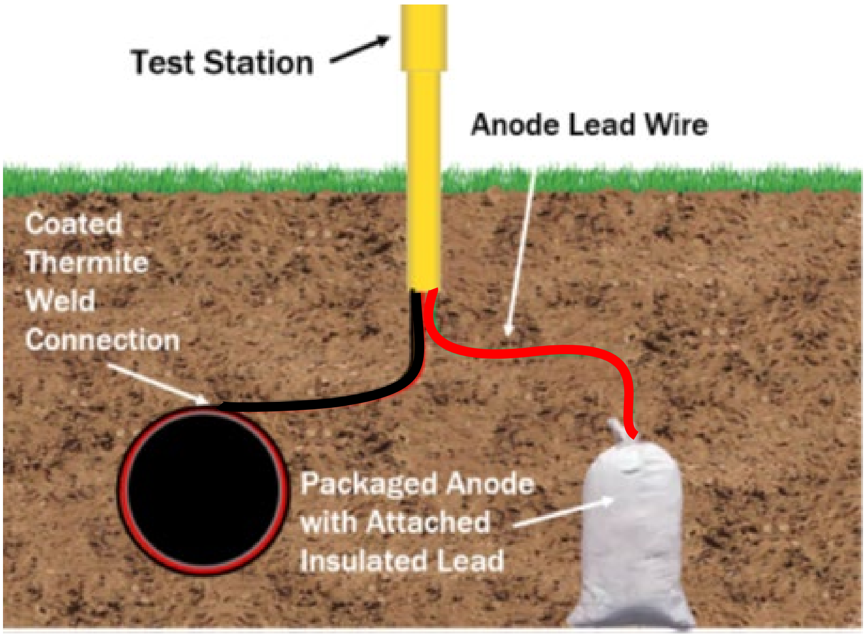


Figure 1-1: Cathodic Protection with Galvanic Anodes (Schematic) from AS 2832.1

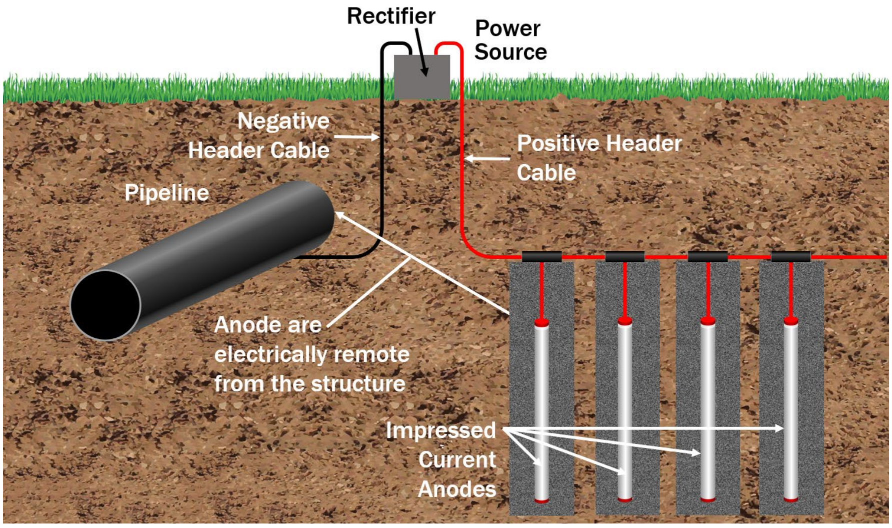


Figure 1-2: Cathodic Protection with impressed current system (schematic) from AS2832.1

When other assets, known as foreign structures, that are located near or between the CP anodes and primary structure, stray current can be conducted through these foreign structures and earth. This stray current can cause accelerated corrosion of the foreign structure, known as electrolysis corrosion. Refer to *Figure 1-3*

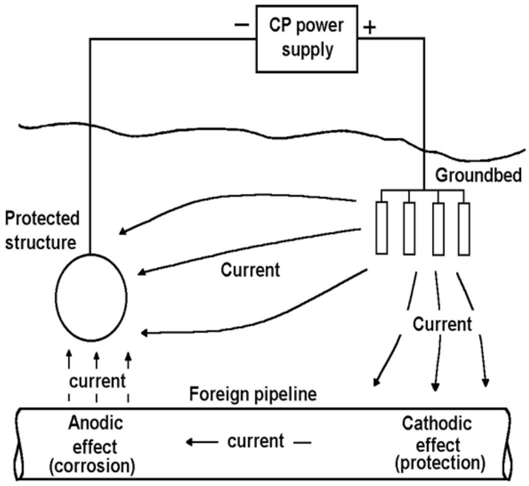


Figure 1-3: Stray Current from an impressed current Cathodic Protection system

In Australia, DC electrified trains and trams typically utilise an earth insulated network where the overhead catenary delivers the traction current to the traction vehicle, while the running rails are used as the primary return current path. Since the running rails are not perfectly insulated from earth, stray traction currents can conduct through the ground and into buried foreign structures resulting in electrolysis corrosion of the foreign structures as well as the traction rails.

Figure *1-4* illustrates how traction current can leave a railway line, enter a structure, and exits that structure at some other point causing corrosion at the exit point. A railway drainage system (RD) is a deliberate conducting path (see Figure 1-5) to return stray current to the railway line in a way that will substantially reduce corrosion.

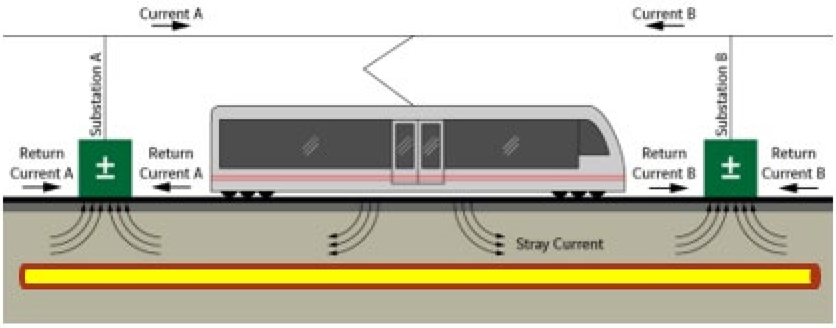


Figure 1-4: Stray Current from a Traction System

Railway Drainage (RD) systems are corrosion mitigation systems that have similar characteristics with ICCP but instead of a controlled delivery of protection current, stray traction current is directed from the structure back to the rail negative which then provides cathodic protection to that structure.

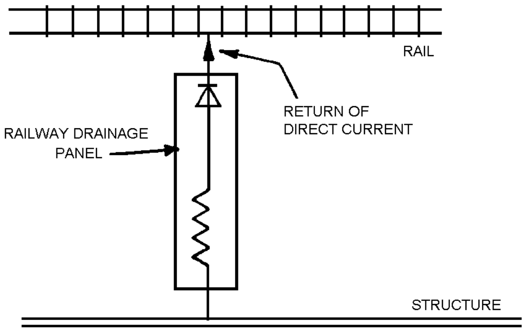


Figure 1-5: Schematic diagram of railway drainage system

Railway drainage systems (RD) can be very effective in mitigating the effects from stray traction current. They are most effective when located in areas where stray traction current discharges from a foreign structure into the ground causing the structure to become more positive (anodic). By applying an RD on the foreign structure at this location, the stray current can be redirected back to the rail negative through a low resistance conductive path rather than through the earth. This low resistance path also attracts ground stray traction currents to flow into the foreign structure and through the RD to rail which causes the structure to become more negative (cathodic). The operational principle of an RD is a semi-controlled cathodic protection system that utilises stray traction currents to protect foreign structures from electrolysis corrosion. Figure 1-7 shows the structure voltage becoming more positive and heads into the corrosion zone as the rail voltage rises positively when the RD is out of service. Conversely, when the RD is operational, the structure voltage becomes more negative and into the cathodic protection region as the rail voltage rises positively.

The TRAD incorporates a transformer rectifier (TR) with a drainage bond (DB) to provide enhanced protection where a passive DB is inadequate. Refer to *Figure 1-6*

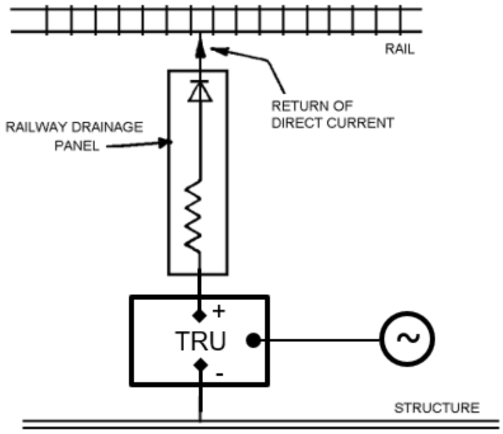


Figure 1-6: Schematic diagram of Transformer rectifier assisted drainage (TRAD) system

Figure 1-7 is known as a correlation chart and displays valuable information such as the structure and rail voltage variations, structure reference potential, nominal stray current pickup or discharge zones, electrolysis corrosion risk and levels of cathodic protection. This correlation assessment technique is especially valuable to discern interference where multiple dynamic interference sources exist such as in Sydney CBD with Sydney Light Rail, Sydney Trains and Metro Trains Sydney coexist with utility structures. The correlation testing and assessment process is detailed Section 7.3. Recent safety developments in the form of the data transfer technique have been made to move away from the need to deploy over ground leads for test purposes. The NSWEC are developing this technique further with the aim of achieving live remote correlation testing. Refer to Section 7.5 for details of the DTT method.

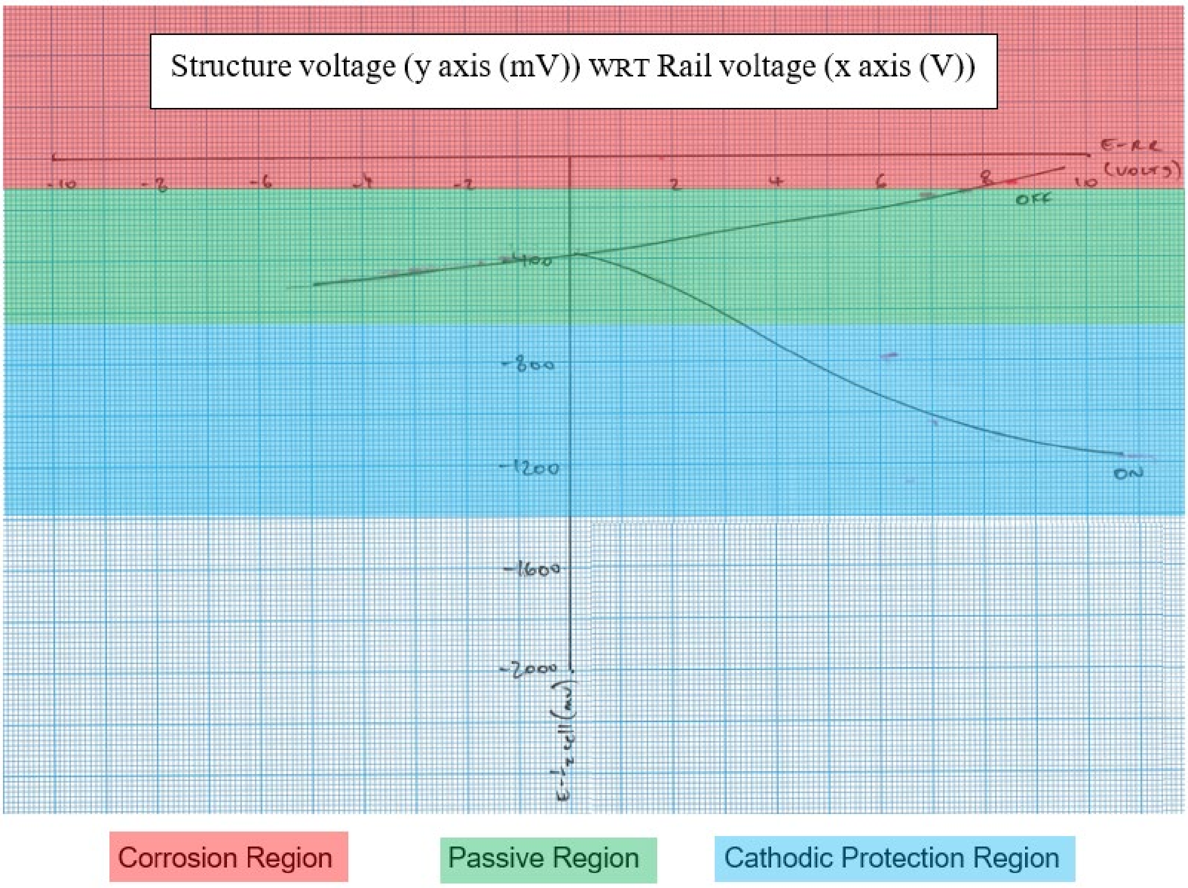


Figure 1-7: Example of RD in and out of operation

The installation of an RD on a structure may increase stray traction current flow by lowering circuit resistance which in turn may increase stray current effects (interference) on other nearby structures. Therefore, the application of the above systems, whilst they may protect the (primary) structures to which they are applied, can cause increased corrosion on other (foreign) structures. This increase in corrosion is indicated by a change of electrical potential on the foreign structure and this change is referred to as interference. When unacceptable interference is found, it is necessary to take actions to minimise it and thereby minimise corrosion.

It must be noted, however, that reference to and/or application of this procedure to any system does not indicate that the system has been proved capable of preventing corrosion of the structure to which it is applied. The determination of satisfactory corrosion mitigation performance is the responsibility of the owner of the protected structure.

The level of interference caused by an RD on a foreign structure, is determined by the modified average drain current of the system recorded over a 24hr period. This is shown in Figure 1-8 and Figure 1-9 and described in more detail in Appendix M.

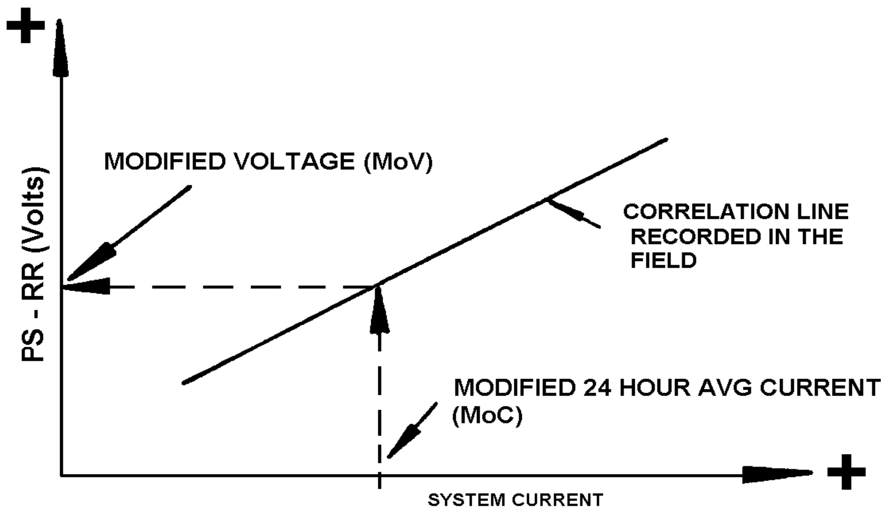


Figure 1-8: Determination of MoV (PS-RR voltage corresponding to the Modified System Current)

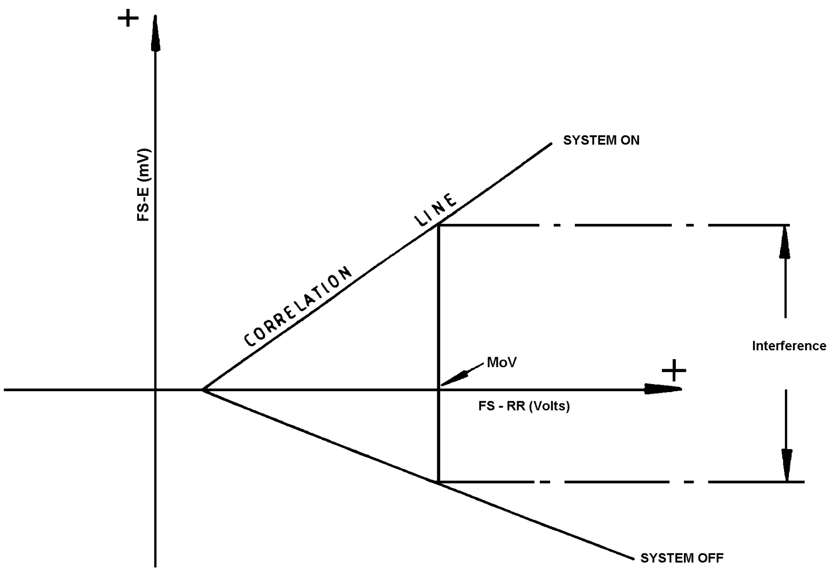


Figure 1-9: Determination of interference using the correlation chart for structures

Recent research has revealed that AC corrosion is another interference mechanism that needs to be considered by asset owners. The additional parameter associated with AC systems is induction so geometric spacing between sources and structures is important. DC circuits that are designed to provide cathodic protection can also contain induced AC waveforms that can lead to AC corrosion of the primary structure.

One of the most important parameters that can result in AC electrolysis corrosion of metallic structures, is when a structure metallic surface that is subject to AC voltages and is more negative then -1200mVdc with reference to a $Cu/CuSO_4$ reference cell. Therefore, structures with cathodic protection or structures (with or without CP) that are subject to high levels of cathodic traction interference and/or cathodic CP interference are most at risk.

With the introduction of AC traction systems in NSW, the assessment process for AC electrolysis corrosion risks is detailed in Section 10 of the guide. Further complexities in managing asset protection are introduced when AC and DC traction networks coexist with utility structures. Stray traction DC circuits can have superimposed AC interference both of which may have opposing mitigations strategies (one requires isolation while the other requires bonding).

2. DEFINITIONS

Definitions used in this Guide are the same as those contained in Australian Standard AS 2832.1 [2], except for the definitions marked with an asterisk which are additional to those used in AS2832.1 [2].

Actual potential	The measured potential of a metallic structure relative to a reference cell. It is the algebraic sum of the natural potential and the potential changes arising from stray current.
Anaerobic	Lacking molecular oxygen.
Anode (in general)	An electrode through which direct current enters an electrolyte causing oxidation reactions to take place thereon.
Corrosion cell anode	The metal surface at which metal dissolution (corrosion) takes place.
Galvanic anode	Electrode used to protect a structure by galvanic action.
Impressed current anode	The electrode connected to the positive terminal of an impressed current power supply.
Anode backfill	Material surrounding and in contact with a buried anode to maintain and/or improve its performance.
Anode screen	A safety barrier surrounding a submerged anode for the prevention of electrical shock or shorting.
Anode shield	A protective covering of insulation material applied to a coated structure in the immediate vicinity of an anode to reduce local cathodic current density.

*Anodic interference	Is the positive change of the surface potential of the foreign structure, measured relative to the surrounding electrolyte. Anodic interference is caused by the operation of a system applied to a primary structure, or by stray D.C. current otherwise generated. Note: the potential change is related to changes in current density flowing from the foreign structure to the surrounding soil or water.
*Authority	NSW Department of Climate Change, Energy, the Environment and Water.
Back e.m.f.	Instantaneous open circuit opposing voltage between anode and cathode of an operating cathodic protection system. Note: Back e.m.f. may have other definitions in other technologies.
Bond (electrical)	A metal connection between points on the same or on different structures.
Bond (coating)	Adhesion between coating materials and a substrate.
Bond (drainage)	See stray current drainage.
Cathode	The electrode through which direct current leaves an electrolyte causing reduction reactions to take place thereon
*Cathodic interference	Is the negative change of the surface potential of the foreign structure relative to the surrounding electrolyte. Cathodic interference is caused by the operation of a system applied to a primary structure, or by stray D.C. current otherwise generated. Note: the potential change is related to changes in current density flowing onto the foreign structure.
Cathodic protection	The prevention or reduction of corrosion of metal by making the metal the cathode in a galvanic or electrolytic cell.
Cell	An electrolytic system comprising an electrolyte, an anode and a cathode where current passes from the cathode to the anode by external electronic paths.
Competent Person	A person who can demonstrate competency through adequate years of relevant experience and holds the appropriate qualifications as defined in Section 3.
*Conductance	The ability of the circuit to pass current. The value is obtained by dividing the current in the circuit (in amps) by the voltage (in volts) and expressed in units of Siemens. Note: the use of conductance (Siemens) to define a drainage system was abandoned by the NSWEC in late 1996.
Copper/Copper Sulphate	($Cu/CuSO_4$) - A reference cell consisting of copper in a saturated solution of copper sulphate.
*Correlation	The relationship between the actual potential of a structure to earth (S-E) and the potential of that structure to rail (S-RR or E-RR).

	(a) **Direct Correlation** - the correlation is described as "direct" when S-E potential becomes more positive as the S-RR or E-RR potential becomes more positive. (b) **Indirect Correlation** - the correlation is described as "indirect" when the S-E potential becomes more negative as the S-RR or E-RR potential becomes more positive. (c) **Zero Correlation** - the correlation is described as "zero" (or flat) when the S-E potential remains constant as the S-RR or E-RR potential changes.
Corrosion	The deterioration of metal caused by electrochemical reaction with its environment.
Corrosion current	The current flowing in a corrosion cell, electrochemically equivalent to the anode and cathode reactions.
Cross bond	A deliberate metallic connection between the primary and foreign structures; may include a diode and/or a resistor.
Differential aeration	A condition of differing concentrations of dissolved molecular oxygen over a metal surface.
Driving voltage	The difference in electromotive force between the potentials of a structure and the operating anode.
Earth (Noun)	The conducting mass of the general body of the earth.
Earth (Verb)	The act of connecting any conductor to earth.
Electrode	An electronic conductor that allows current to flow either to or from an electrolyte with which it is in contact.
Electrode potential	The measured potential of an electrode in an electrolyte relative to the potential of a reference cell.
Electrolyte	Liquid, or the liquid component in a composite material such as soil, in which electric current may flow by the movement of ions.
Foreign (secondary)	A buried or submerged structure that may be subject to interference
Structure	arising from the cathodic protection of a primary structure.
*Fortuitous connection	An unintentional metallic connection between a primary and a foreign structure.
Galvanic Action	A spontaneous electrochemical cell reaction in which a metallic anode corrodes.
Groundbed	A group of buried anodes in a controlled backfill.

Holiday	Any flaw, discontinuity in a coating, or a thinning out of coating.
Impressed current	Direct current supplied by an external power source to cathodically protect a structure.
Insulating joint	A joint which breaks electrical continuity in a structure but does not affect the mechanical integrity.
Interference	A significant change in current density on a foreign structure caused by a cathodic protection system.
Interrupter	A timing device which permits a cyclic on/off interruption to the flow of cathodic protection current.
Loop resistance	Total circuit resistance.
Natural potential	The potential attained by a metallic structure in contact with an electrolyte after sufficient time has elapsed to allow the structure to stabilise electrochemically with its environment and not influenced by any interference.
NSWEC	New South Wales Electrolysis Committee is made up of representatives from asset owners/operators.
Polarisation	A shift in the potential of a cell from an equilibrium value resulting from current flow through its surface.
Primary structure	The structure subject to intentional cathodic protection.
Protective Potential	The potential to which a metallic structure must be reduced to achieve cathodic protection.
Protection current	The current made to flow into a metallic structure from its electrolytic environment and which cathodically protects the structure.
*Railway drainage bond	An electrical circuit for the purpose of conducting stray traction current from a structure to the railway electrical system.
Remote earth	A location sufficiently distant from the structure and anode or rail where there is no voltage gradient in the electrolyte.
**Reference electrode	Metal electrode calibrated to a reference cell.
Reference cell	A cell which has a stable potential in one or more electrolytes thus enabling it to be used in the measurement of other electrode potentials at a given temperature. Common cells used are Zn, $Cu/CuSO_4$ & Ag/AgCl.
Silver/Silver Chloride Reference Cell	(Ag/AgCl) a cell consisting of silver, coated with silver chloride
Spread Resistance	The resistance to earth through a defect in the coating of a structure.

Standard hydrogen	A cell consisting of platinum or other electrode (SHE) sufficiently noble metal in an electrolyte containing hydrogen ions at unit activity and in equilibrium with hydrogen gas at one standard atmosphere.
Stray current	Current flowing through paths other than the intended circuit.
Stray Traction Current	Stray current originating from the traction return path of a rail transport system.
Stray current drainage	An electrical means whereby stray current is removed from the structure via a conductor.
Structure	A metal surface in contact with an electrolyte.
Structure potential	The potential of a structure relative to that of a specified reference cell situated in the electrolyte immediately adjacent to the structure.
Structure potential shift	A change in measured voltage of a metallic structure caused by the application of current from an external source.
Sulphate-reducing bacteria	A group of bacteria which can reduce sulphate to sulphide in anaerobic near neutral soils and natural waters.
System	All the components that are required to change the potential of the surface of a buried or submerged structure, for the purpose of preventing or reducing corrosion. The system should include the protected structure, transformer-rectifiers, railway drainage circuits, cross bonds, anodes, cables and auxiliary components necessary for correct system operation. The extent of the protected structure should be defined by: (a) the electrical isolation of the structure, or (b) the limits of detectable change of potential (suggest 10mV) to the primary structure resulting from operation of the system.
Telluric current	The current induced by the variations in the earth's magnetic field intersecting the structure.
Test point	A nominated point of a structure for electrical contact.
Traction	Electrified Rail
Weight coating	The coating applied to a structure to provide negative buoyancy - usually concrete.

Stray Electrified Traction Definitions

Positive Average Rail Voltage (+'ve' R_{ave})	The arithmetic average of the Rail voltage data points that are more positive than zero (excluding zeros). An alternative calculation is where the modified average can be calculated as the average Rail voltage including zeros divided by the fraction of time when the current is greater than zero over the total time (24hrs). This is the same philosophy used to determine the modified average voltage (MoV) Str to Rail as detailed in this Guide.
Negative Average Rail Voltage (-'ve' R_{ave})	The arithmetic average of the Rail voltage data points more negative than zero (excluding zeros). The alternative modified averaging method can also be used for calculating the -'ve' R_{ave}. as described for +'ve' $R_{ave.}$
Anodic Average Structure Voltage ($Str_{Ano.ave}$)	During correlation testing, the anodic average structure voltage is the arithmetic average of the structure voltage data points during positive Rail to Ref Cell excursions with a direct correlation slope (excluding zeros). When there is an indirect correlation slope, average it is the average of the structure voltage data points during negative Rail to Ref Cell excursions. This calculation is applicable when a single correlation slope is obtained. When multiple correlation slopes are presented, manually derived slopes are used.
Cathodic Average Structure Voltage ($Str_{Cath.ave}$)	During correlation testing, the cathodic average structure voltage is the arithmetic average of the structure Voltage data points during negative Rail to Ref Cell excursions with a direct correlation slope (excluding zeros). When there is an indirect correlation slope, average it is the average of the structure voltage data points during positive Rail to Ref Cell excursions. This calculation is applicable when a single correlation slope is obtained. When multiple correlation slopes are presented, manually derived slopes are used.
Correlation Plot	The correlation plot is a line (can be a curve) drawn between two points, being the intersection of the positive average Rail voltage (+'ve' R_{ave}) and the anodic average structure voltage ($Str_{Ano.ave}$) to the negative average Rail voltage (-'ve' R_{ave}) and cathodic average structure voltage ($Str_{Cath.ave}$).
*Modified current (MoC)	The 24-hour system current that results from multiplication of the raw 24Hr current by the inverse of the time of operation of the system (where time of operation is expressed as a decimal).
*Modified voltage (MoV)	The voltage that results from application of the Modified Current to the system Conductance chart.
Structure Reference Potential (Str_{Ref})	The structure potential to remote earth, with reference to a $Cu/CuSO_4$ reference cell, that is free from interference from the nominated source. It can be determined from the correlation plot ("X" axis being Ref Cell to Rail and "Y" axis being Str to Ref Cell) where the correlation line intersects with the 'Y' axis (Ref Cell to Rail=0).
Anodic Average Structure Voltage Shift (Str $\Delta_{Ano.ave}$)	The voltage difference between the Structure Reference Potential (Str_{Ref}) and the Anodic Average Structure Voltage ($Str_{Ano.ave}$).

Cathodic Average Structure Voltage Shift (Str $\Delta_{Cath.ave}$)	The voltage difference between the Structure Reference Potential (Str_{Ref}) and the Cathodic Average Structure Voltage ($Str_{Cath.ave}$).
'X' axis	Earth via Reference Cell ($Cu/CuSO_4$) to Rail or Structure to Rail. When structure to Rail voltages are measured, the results can be corrected to earth to rail for interference analysis by adding the structure reference potential to structure to Rail results. Conversely, the earth to Rail measurements can be corrected to structure to Rail results by deducting the reference potential from earth to Rail measurements.
'y' axis	Structure to Earth voltage via Reference Cell ($Cu/CuSO_4$)
* NOTE:	This Guide uses the terms "structure to earth", "structure to Reference cell", "structure to electrode" and "structure to metal electrode" to describe the potential between a structure and earth. "Earth" is the general term whereas "Reference cell" and "electrode" or "metal electrode" identify how the voltmeter is electrically connected to earth, for example, a steel rod may be hammered into the soil/electrolyte adjacent to the structure and the voltmeter connected between this and the structure. Different methods are selected to suit the circumstances, for example there may be already conveniently installed permanent reference electrodes.
** NOTE:	Meaning of "Reference Electrode" deviates from the definition stated in AS2832.1[2].

3. COMPETENCY OF PERSONNEL

It is the responsibility of an organisation to utilise or engage competent personnel where required.

Personnel involved with signing off reports relating to CP interference is outlined in the competency requirements stated in AS2832 [2] and the Electricity Supply (Corrosion Protection) Regulation [1]. Greater competency is required for personnel signing off reports on traction interference due to the more complex characteristics and potentially larger stray current effects associated with a negative rail return traction system. The minimum competency requirements are:

- Competency of personnel signing off reports relating to CP interference is specified in AS2832 [2] and the Electricity Supply (Corrosion Protection) Regulation [1]

- Competency or personnel signing off reports relating to traction Interference shall be an ACA accredited Corrosion Technologist, NACE accredited CP Technologist or equivalent and have a minimum of 10 years' experience in traction interference testing and assessment. The NSWEC recommend that personnel performing traction interference testing and assessment, are to have successfully completed the ACA Authorised Testers Course.

- Independent reviewer – relevant degree qualified or ACA accredited Corrosion Technologist, NACE accredited CP Technologist or equivalent and have a minimum of 10 years' experience in cathodic protection design, installation and monitoring.

4. PREPARATION FOR INTERFERENCE TESTING

4.1. Introduction

Preparation for testing is discussed in three parts: preparation for trials consisting of temporary installations; testing of fully installed new systems and retesting of existing approved systems. Trials usually consist of a portable drainage bond or a temporary and often very "makeshift" installation where, for example, the anodes may be steel stakes and the power is provided by automotive batteries.

The NSWEC has developed a written policy covering testing of foreign structures, in particular, the involvement of foreign structure owners, refer to the NSWEC Charter[32] - Interference Testing of Non-Members' Assets.

4.2. Trial Systems

A trial system is temporarily installed for assessment of design parameters and sometimes for interference testing and is removed immediately following completion of testing. A trial system should not be operated for more than 24 hours (as per regulations), without specific approval of the Authority. Approval for a new installation may be provided based on test results obtained from trial systems - in that case the Authority may require information similar to that described in Section 4.3. A trial system may not necessarily have anodes installed in their final location and/or operate at a representative (high enough) output. As such actual interference affects may change once the permanent system is installed and energised.

4.3. New Systems

New systems that require registration can only be operated for a maximum of 24 hours without approval from the Authority, prior to interference testing being conducted for the purpose of registration.
Note: *The Electricity Supply (Corrosion Protection) Regulation [1], requires that proposed systems are approved by the Authority.*

4.3.1. Information Required

An applicant seeking approval for a new system or for substantial redesign of an existing system should present in writing, to the Authority, the following information. Refer to Appendix Q for further details:

1. A map and/or drawing showing the precise location of the transformer rectifier unit, impressed current anode bed, railway drainage system, sacrificial anode bed and the connections to the primary structure. Some systems may not require approval. See Section 5.2.2.
2. The map and/or drawing should show the extent of the system, for example, the position of insulating joints or the end of influence of the system on the primary structure and including any other structure that may be affected. The extent of the primary structure is the point where the structure to earth potential movement becomes less than 10mV.
3. Basic details of facilities for interrupting the system current. These facilities must be provided where interference testing is required.
4. Details of the primary structure including construction material, coating, type of system (whether impressed current, sacrificial anode or railway drainage system, etc.) and design current. Note that the railway authority will, in the case of railway drainage systems, require the design conductance and the 24-hour average positive structure to rail voltage to assist in design of the bond.

4.3.2. Examination of the Proposals

An Owner/Operator or their nominated agent will normally refer a proposed system to the NSW Electrolysis Committee to determine if interference testing is required. To facilitate this, copies of system information should be made available to all Committee Members at the meeting at which test dates will be determined.
The NSWEC will schedule any testing.

4.3.3. Effects on Foreign Structures

All foreign structure owners that may be affected by the operation of the proposed system must be provided with details of the system by the System Owner/Operator (as per section 4.3.1) with a minimum of 2 weeks prior to the scheduled test date. An invitation shall also be provided to all foreign structure owners to be provided the opportunity to participate and/or witness the interference testing.
Note: *The invitation can be via the NSWEC testing schedule and/or by written notification from system owner where they do not fall under the NSWEC membership.*

4.4. Retesting Existing Systems

The CPS register will notify all system Owners of any existing approved systems to be retested. The NSWEC is responsible for scheduling the retesting of systems with the system owner/operator and other interested parties. The system owner/operator will make available the information detailed in Section 4.3.1 including any cross bonds.

4.5. Administrative Procedures

4.5.1. General

The Electricity Act 1945, and the Electricity Supply (Corrosion Protection) Regulation 2020[1] require that cathodic protection, railway drainage and variations of these systems installed in the State of NSW must be approved and registered by the appropriate Authority. Registration of systems in NSW is currently delegated to the Authority.

The New South Wales Electrolysis Committee (NSWEC)) has assisted the Authority over many years in the assessment of systems and has also, through its Technical Committees, coordinated testing and resolved many issues between the parties who own the primary and foreign structures involved. The NSWEC oversee the various Sub Committees in Greater Sydney, Hunter and Illawarra regions whose members represent the owners of most primary and foreign structures in NSW.

4.5.2. Approval Procedure

When a person intends to operate a CP or RD system an application must be submitted to the Authority and the Authority's approval must be granted prior to operation. Stages in the approval process are as follows:

1. The new CPS owner requests a CPS identifier through the online CPS Register.
2. The Authority issues a CPS identifier.
3. The CPS owner or delegated Agent contacts the NSWEC to request interference testing.
4. The NSWEC will schedule the testing and if required will co-ordinate with all interested parties.
5. Modifications and additional tests may be necessary to ensure that the proposed system will not adversely affect any foreign structures.
6. The CPS owner or delegated Agent shall upload the results (Interference field testing and chart acceptance form and the current charts) and signed corrosion protection system approval sign-off form onto the online CPS Register for review by the Authority and any interested parties associated with each system.
7. Final approval to operate the system may then be granted by the Authority by online acceptance of the system through the CPS register.

Approval by the Authority to operate a system is not to be construed as providing any level of corrosion protection to the primary structure.

The NSWEC and the Authority has established a regular system of retesting of all registered systems to detect unacceptable interference that may occur due to expansion or modification of underground structures. The retesting procedures are the same as for new systems, except that re-issue of registration is not usually required. However, retesting can find interference or other problems that may require modification of the systems and issue of a new approval or cancellation of the system. The Authority has the power to retest a system at any time, however, the Technical Committees now routinely recommend nominal retest times for existing systems, typically no greater than 6 years maximum retest period. Systems that are located in non-incorporated local government areas with no nearby structures, may apply for a maximum of 10 years registration.

4.5.3. Administrative Support

The Authority provides administrative support for the provision and upkeep of the online CPS Register.

The NSWEC always strive to achieve unanimous agreement for acceptance of a system. However, a right of veto applies for any party affected by a system.

Where interference does occur, flexibility is encouraged to determine a level at which the proposed system may operate, which is an acceptable compromise to all affected parties, e.g., the recommended operating conditions may result in a lower level of protection than that originally sought by the proposer.

Further, the criteria for interference are not absolute and an affected party may present reasons for a reduced or increased level of interference in the circumstances under consideration.

The NSWEC do not determine the level of corrosion protection achieved for the protected structure. The registration issued by the Authority does not indicate whether a structure is or is not protected from electrolytic corrosion. The effectiveness of the cathodic protection system is the responsibility of the system owner.

A Technical Committee member, or any other party may seek retesting of a system if they consider conditions have changed in a way which may affect that party.

For proposed systems to be installed in New South Wales beyond the areas usually covered by the established Technical Committees, the Authority requires that the party proposing the system provides written confirmation that all other underground structure owners do not object to the proposed system. The Authority may arrange for the system operator to carry out interference testing and report to the Authority. Country systems may or may not be considered by the Technical Committees.

5. INTERFERENCE FROM CP SYSTEMS

5.1. Impressed Current Systems

5.1.1. Pre-test Condition

For a new system, the owner/operator should, with prior approval, have it operating at the maximum test current required for registration just prior to the time of testing.

For an existing approved system that is to be retested, the system owner/operator should ensure that the system is operating at the approved current for the test. For an existing approved system that is to be adjusted, such as to require reapproval, the current should be set at the new adjusted level for the retest.
CP systems should not operate above the registered output current except for testing purposes and for periods no greater than 24 hours.

5.1.2. Constant output current CP Systems

Constant current CP systems are to be tested at the maximum output current required for registration.

5.1.3. Constant output voltage CP Systems

Constant voltage CP systems will be switched to constant current mode at the maximum output current required for registration.

5.1.4. Auto Potential CP Systems

Auto Potential CP systems will be switched to constant current mode at the maximum output current required for registration.

5.1.5. Time Switch

A time switch should be provided by the system owner/operator and be placed in series with the impressed current circuit to allow interruption of the system during testing. Testing will normally be carried out in the following switching sequence (see also Sections 5.1.10 and 11.2.12):

10 seconds "**ON"** & **5** seconds "**OFF"**

This time sequence allows systems to be tested at higher levels of protection current for registration purposes than what is normally required for adequate protection.

5.1.6. Primary Structure Check

The "ON/OFF" primary structure potential and the system current should be recorded on the same chart, with at least 5 "ON" and 5 "OFF" cycles.

5.1.7. Recording of Interference

Measurement for interference is initially made using a voltmeter and reference cell. If levels of measured interference are significant, then the interference should be recorded using the method utilised in this Guide. Objections to interference can only be made based on recorded interference data. The System Owner Operator/Agent will carry out the recordings.

5.1.8. Testing of Foreign Structures

Foreign structures should be tested for interference by their owners/operators. In determining the test location, consideration should be given to the proximity of the primary and foreign structures, anode bed location, as well as electrical continuity of foreign structures.

The foreign structure potential should be simultaneously recorded on the same chart as the system current, with at least 5 switching cycles.

Notes: *(1) Reference cells are to be placed immediately adjacent to the foreign structure to reduce the soil voltage gradient error (see Appendix H). The exact position of the Reference cell should be recorded on the interference chart. Where metal reference electrodes are used, data must be standardised to copper/copper sulphate Reference cell (see Appendix I).*

(2) Metal reference electrodes are permissible when it is not practical to use reference cells (Zn, Ag/AgCl or Cu/$CuSO_4$).

(3) The measurement contains the voltage rise due to the interference current plus the soil voltage drop and the combined voltage rise is assessed against the applicable criteria in Appendix A, Appendix B, Appendix C and Appendix D. Measurements of depolarisation can be made by analysing recorded interference waveforms at the discretion of the affected foreign structure owner.

5.1.9. Testing for Systems with Overlapping Interference

In some cases, a system, or a number of systems may be installed in fairly close proximity and may produce overlapping interference with systems, or with each other, on nearby foreign structures. In these cases, the following test procedures are recommended:

(a) Single System

When interference from a single system under test overlaps with interference from other system(s), then the other system(s) should normally remain "ON" whilst the system is tested.

(b) Multiple Systems protecting a single structure

Where multiple systems are used to protect a common structure, the systems are to be treated as one system for testing purposes. Concurrent switching of the systems is required to allow the total cumulative interference to foreign structures to be measured.

5.1.10. Interim Approvals

Interim approvals may be desirable in cases where polarization of the protected structure will cause a substantial reduction in system current over time. After initial interference testing the Authority in consultation with owners/operators of foreign structures and the system owner/operator, may give interim approval for operation of a system that may be producing significant interference. Such approval shall be for a defined period to allow for current to be reduced prior to final testing. The system owner/operator should carry out regular monitoring of system current and progress with polarization and shall provide reports to the Authority as requested. Interim approvals may be terminated at any time.

Interim approvals may also be issued by the Authority to provide rapid formal, although temporary, registration for important protected structures and systems.

5.1.11. General

Procedures of general applicability are as follows:

(a) If unacceptable cathodic interference (refer Appendix C) is measured then the system owner/operator and foreign structure operators are to endeavour to find the corresponding anodic interference.
(b) It is good practice for the system proposer to assist foreign structure owners to identify likely areas of interference.
(c) Where unacceptable cathodic interference is measured on a foreign structure and it is suspected that a fortuitous connection exists, then the procedures outlined in Appendix III should be followed.
(d) All diagrams in this Guide express the S-E potential relative to a $Cu/CuSO_4$ reference cell.

Note: Measurement of interference near the ground bed of a CP system may produce a high soil gradient component in the interference measurements, producing a misleading measurement. Where possible and practical, ground beds should be located away from structures.

5.2. Registered Sacrificial Anode Systems

5.2.1. Procedures

The procedures and test methods for registered sacrificial anode systems should generally be the same as for impressed current systems.

5.2.2. Non - Registerable Systems

Refer to the Cathodic Protection Regulations[1] for details.

5.2.3. Anodic Interference

If anodic interference on the foreign structure is detected, the owners/operators of the primary and the affected foreign structure may both consider the installation of a cross bond to mitigate this interference.

5.3. Cross Bonds

A cross bond is installed to reduce the interference caused on the foreign structure by the primary structure's CP system. However, the cross bond may cause interference on other foreign structures and thus additional testing should be carried out. Should a cross bond be installed, then interference testing is required to all other foreign structures.

5.3.1. Approval

Cross-bonds will require approval and registration by the Authority.

6. INTERPRETATION OF DATA – CP INTERFERENCE

6.1. Impressed Current and Sacrificial Systems

6.1.1. Information Required

The information required for consideration by the Authority is as follows:

(a) **Primary Structure**

Simultaneous recordings of primary structure potential-time and system current-time with the system switching "ON" and "OFF". These charts are prepared by the structure Operator/Owner/Agent Figure 6-1 is an illustration showing the simultaneous plotting of system current and actual potential to earth. Information that should be included on the charts is as follows:

1. System number, where allocated
2. Owner/operator of the system
3. System test current
4. Address and GPS reference of the CP system
5. Date of test
6. Exact position of reference relative to the primary structure
7. The actual potentials of the foreign structure shall be calibrated to $Cu/CuSO_4$, with system switched both "ON" and "OFF" and noted on the chart.
8. Organisations present at the test

(b) **Foreign Structure**

Simultaneous recordings of foreign structure potential vs time and primary CP system current output with the Primary CP system switching "ON" and "OFF". These charts are prepared by the Primary the structure owner/operator/Agent. Figure 6-2 and Figure 6-3 are illustrations showing the simultaneous plotting of primary system current with foreign structure potential to earth. Information that should be included on the charts is as follows:

1. System number where allocated and description of foreign structure
2. Owner/operator of foreign structure
3. System test current
4. Address of the interference test location
5. Date of test
6. Exact position of the reference relative to the foreign structure.
7. Interference value (Note: this value to be discussed at the NSWEC Meeting).
8. The actual potentials of the foreign structure shall be calibrated to $Cu/CuSO_4$ with system switched both "ON" and "OFF" and noted on the chart.
9. Organisations present at the test.

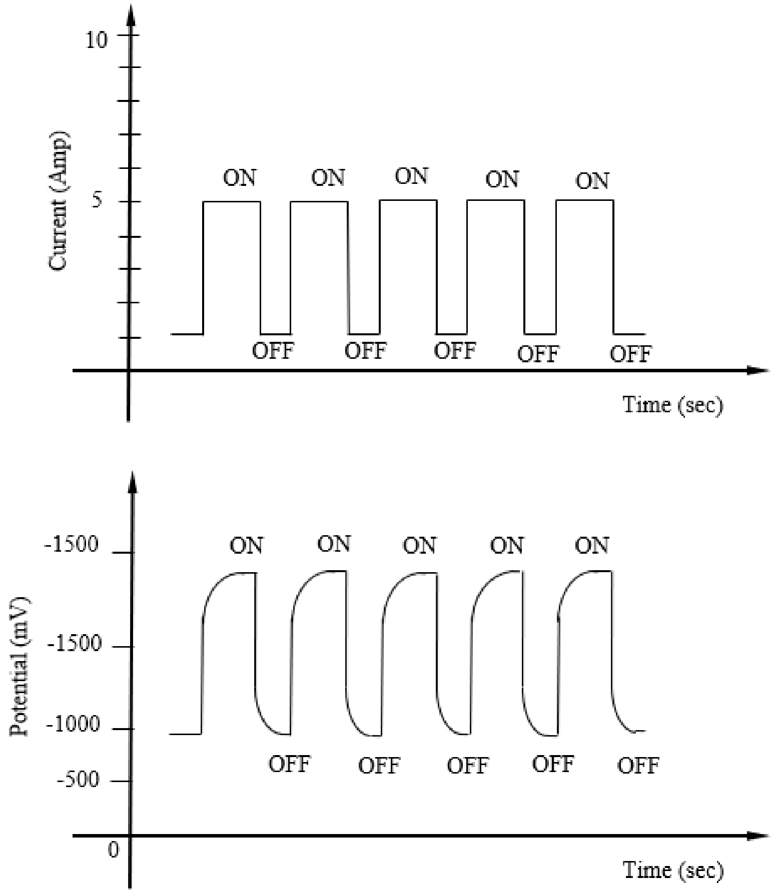


Figure 6-1: Primary Structure Current and Potential Charts

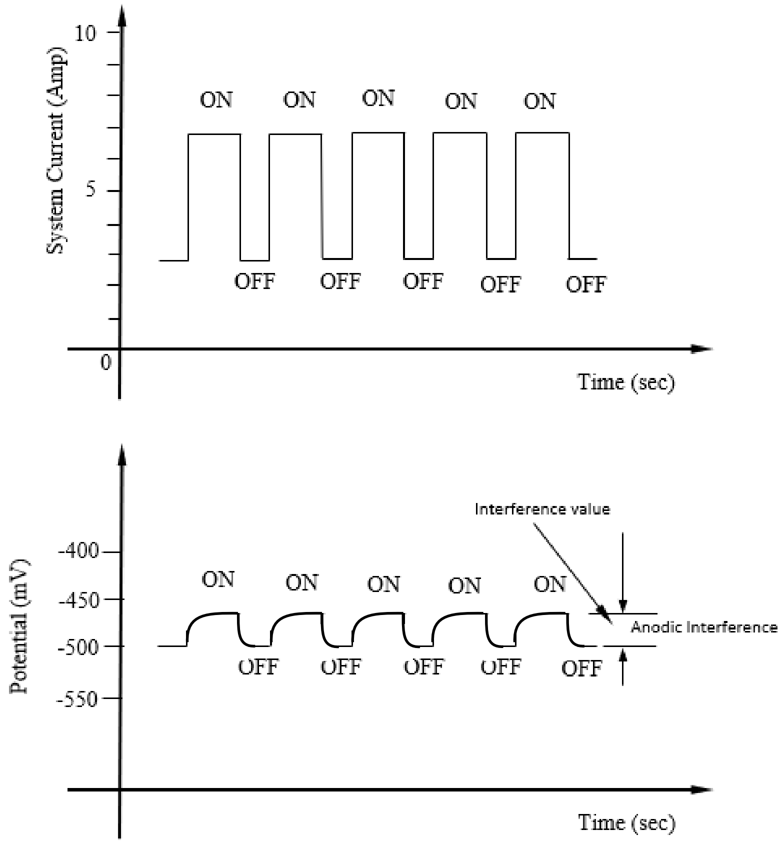


Figure 6-2: Foreign Structure - Anodic Interference Measuring Charts

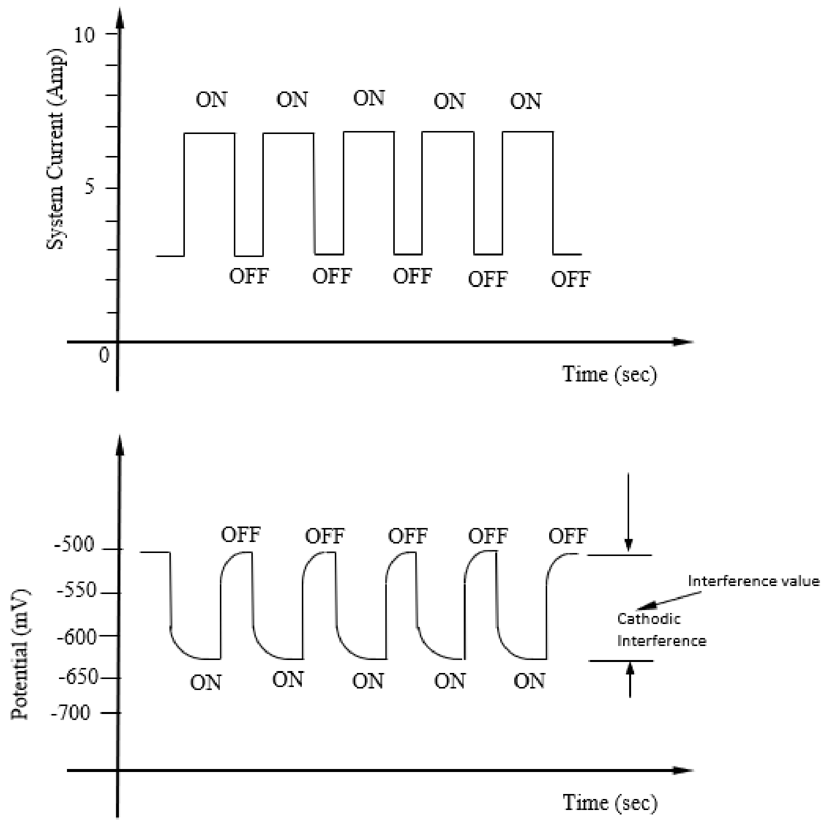


Figure 6-3: Foreign Structure - Cathodic Interference Measuring Charts

6.1.2. Interpretation of Data

Illustrations
The figures in this Guide are illustrations only and different values will be encountered in practice. The system switching points can sometimes be difficult to determine from a potential time chart alone due to rapid fluctuations caused by stray traction current. Simultaneous recording with a dual input recorder of the system current, and structure potential will help to directly illustrate the system switching points and thereby assists in pinpointing the structure potential changes corresponding to system switching.

Interference Value
The interference value is the difference in foreign structure potential, expressed in millivolts, between system "ON" and "OFF" conditions. The value is derived as illustrated in *Figure 6-2* and Figure 6-3.
Note: Some systems create current spikes, which are typically due to capacitive in-rush currents on well coated pipelines. These current spikes can be detected on foreign structures and should not be included in the interference assessment. To allow for these current spikes, the interference is calculated from the steady state magnitude after the initial spike and just prior to being switched off to the final "off" value. Refer to Figure 6-4.

Interference Criteria
The decision by foreign structure owners to object or not to object to the measured interference should be guided by the interference assessment detailed in Appendix A, Appendix B & Appendix C.

Polarisation Potential Drift
Use of low impedance measuring devices will increase the rate of drift by allowing a higher polarising current to pass. Potential drift can also be caused by Polarisation of the structure being measured: in this latter case, Polarisation is caused by CP system current flowing through the foreign structure. Refer to Figure 6-5 High input impedance instrumentation (≥10MΩ) is required for interference measurements as specified in Section 11.2.1 and AS2832.1[2].

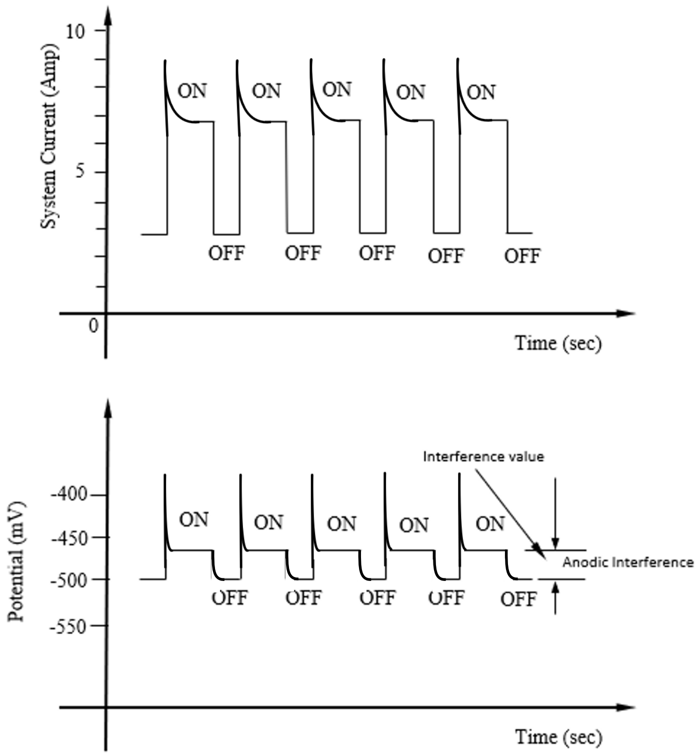


Figure 6-4: Foreign Structure - Anodic Interference with capacitive spike

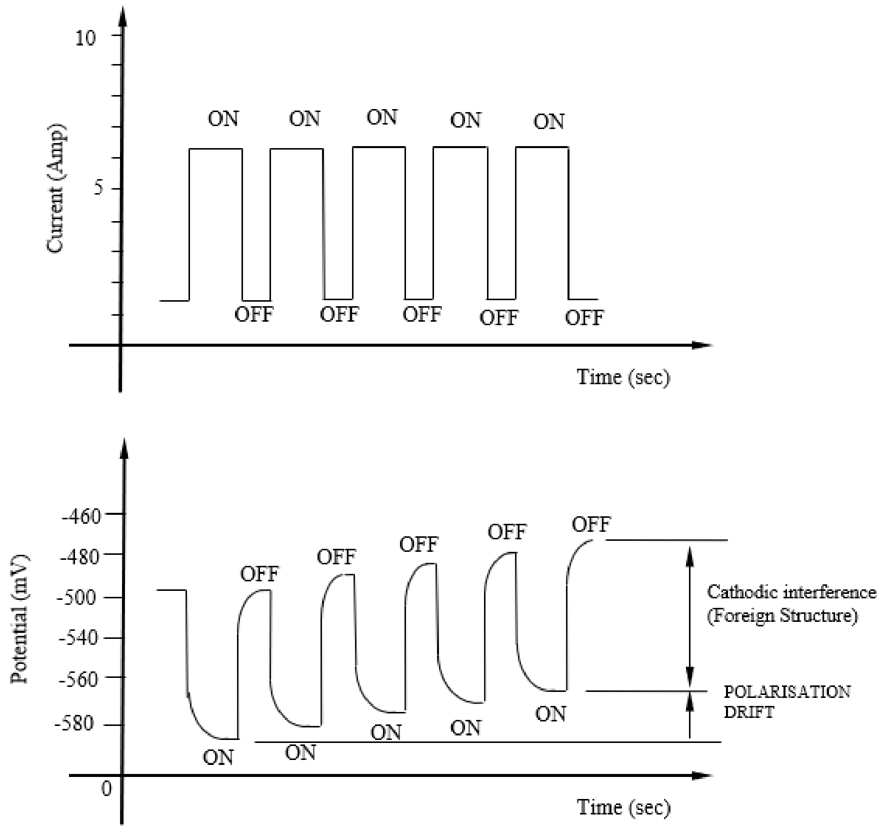


Figure 6-5: Foreign Structure Polarisation - Potential Drift

6.2. Cross-Bonds

6.2.1. Information Required

The information required for cross-bond interference testing is similar to that required for impressed and sacrificial systems, noting that the primary system and the cross-bonded asset is treated as one primary structure. Figure 6-6 is an illustration of the information required for interference testing for a cross-bond and its related primary system. Information that should be included on the chart illustrated in Figure 6-6, is as follows:

1. CP system number, where allocated
2. Owners/operators of systems
3. Primary system current
4. Cross-bond current
5. Address and GPS reference of test location
6. Date of test
7. Exact position of the reference
8. Organisations present at test
9. Interference values (Note: this value is to be confirmed at the time of CPS signoff and registration).
10. Point of connection of cross-bond to both primary and foreign structure and whether a diode is included or not.
11. Location of cross bond.

6.2.2. Cross Bonds interpretation of data

The potential change caused by the primary system, with the cross-bond operating, is the value "B" in Figure 6-6.

Where interference is detected on a foreign structure, the cross bond can be switched, and the subsequent interference data recorded on the same chart.

The first section of the plot illustrates the interference caused by the primary system only, the second section of the plot shows the combined potential change of the foreign structure with the connection of cross bond. In this illustration, the anodic interference of the primary structure system is offset by the cross bond to produce a cumulative cathodic potential change on the foreign structure. The potential change measured at "B" is evaluated in terms of the criteria in Appendix A, Appendix B & Appendix C, and both the primary system and the cross bond are accepted or rejected on the basis of interference, the value "B".

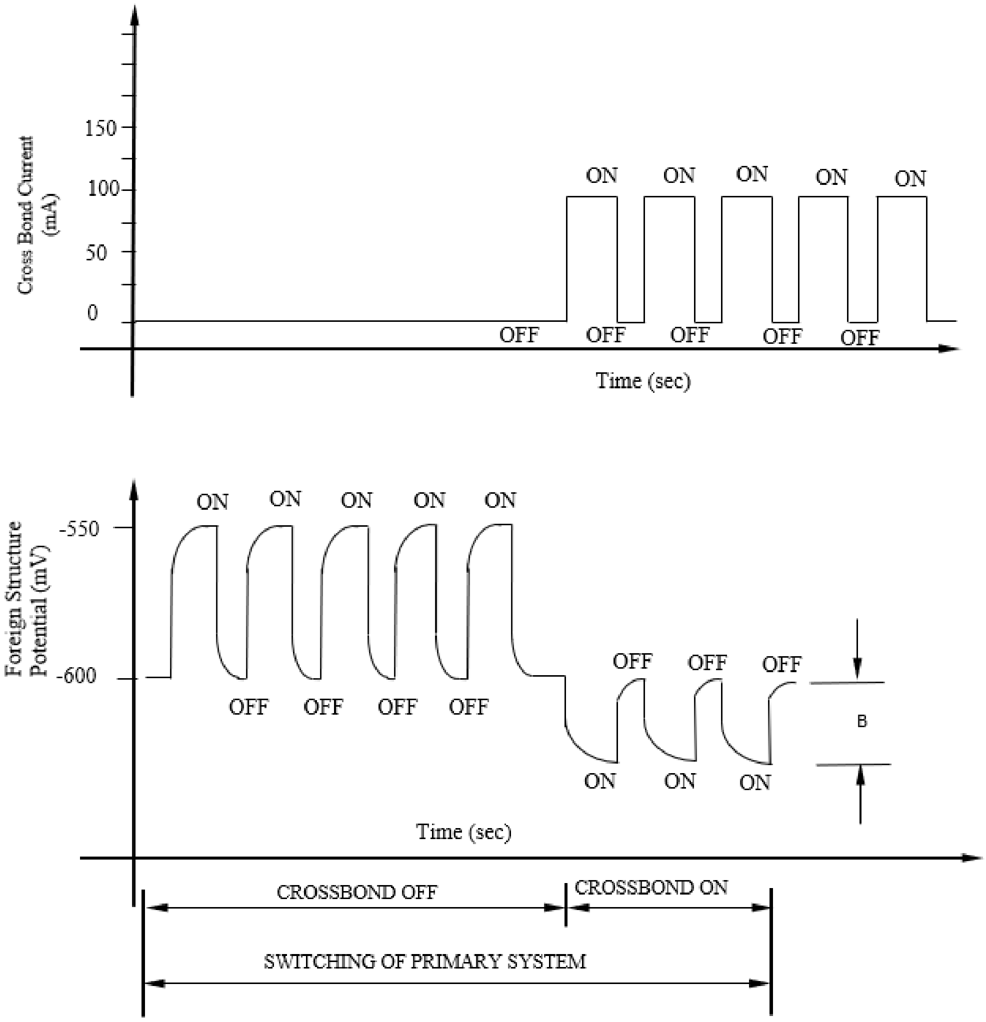


Figure 6-6: Cross Bond Interference Testing

7. STRAY DC TRACTION INTERFERENCE

7.1. Stray Traction Current

Stray traction current originates from the breakdown or by-pass of the insulation systems associated with the positive traction supply or the negative traction return circuitry. The stray traction current from the positive circuit is unidirectional, typically constant in magnitude and is generally caused by surface tracking of insulators on an overhead catenary supplied network. Stray traction current from the negative return circuit is typically from the breakdown of the rail insulation resistance to earth. The DC return current in the rails fluctuates rapidly in both magnitude and polarity due to multiple interconnected rails with varying locations of the trains in relation to the supplying substations, acceleration and braking states of the trains and arcing at contact zones which is an inherent characteristic of a moving contact system. Any current that leaks from the rails and conducts through any path, other than the dedicated negative return path (the running rails), is known as stray traction current. Where stray traction current flows through conductive assets such as pipelines, cable screens, building reinforcement and earthing systems, there is an increased risk of accelerated corrosion to both the rails and these conductive assets. Refer to Figure 7-1. – Multi rail network.

Wherever possible, measuring the actual stray traction current that enters or exits a structure will provide the most accurate assessment of the corrosion risk to the structure because this current equates to the total corrosion current. However, measurement is usually difficult if not impossible to achieve due to the physical constraints associated with buried assets e.g. insulated pipelines with coating defects with varying degrees of dielectric loss and may have numerous entry and exit paths that allow varying magnitudes of stray traction current.

Measurement of the electrolysis effects, such as the structure to earth voltage measurement via a reference cell, is generally achievable and is an accepted practise worldwide.

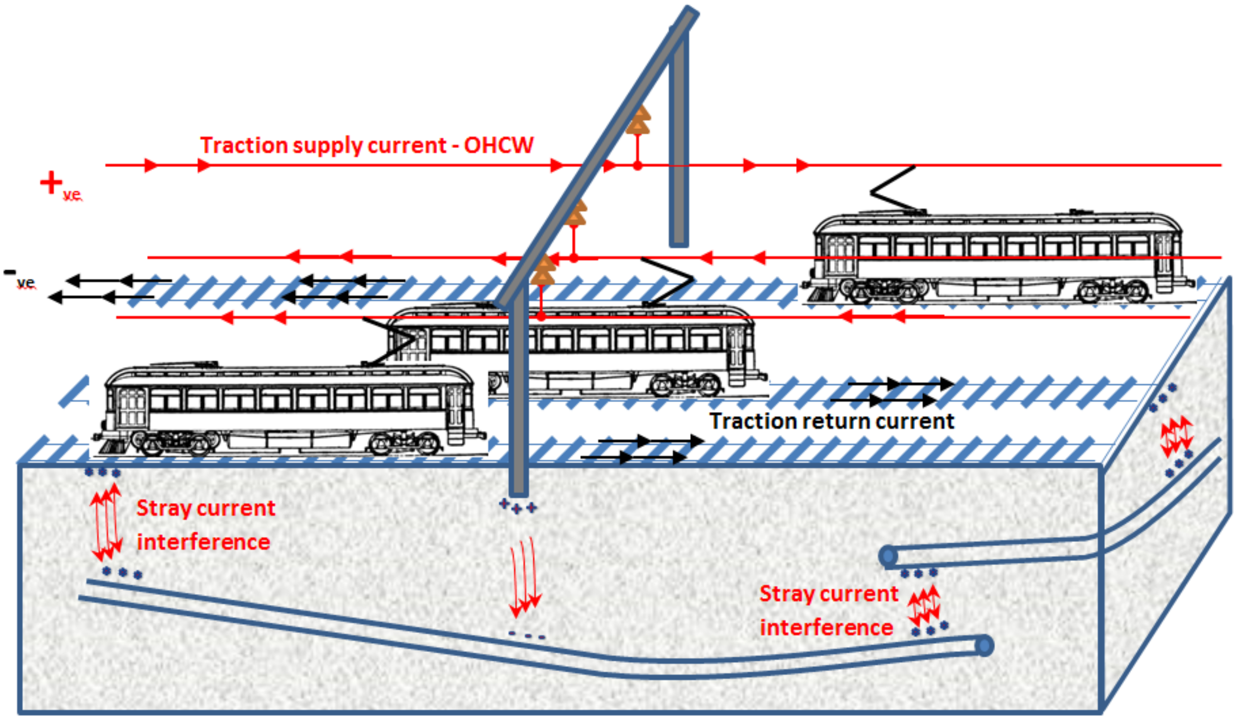


Figure 7-1: Traction Interference – Multi rail network

7.2. Structure potential or current measurement

The structure potential is measured to the surrounding electrolyte (earth), via a reference cell. These measurements are taken using a high input impedance multimeter and/or data logger for recording of results. When applying criteria based on remote earth, locating the reference cell outside the zone of influence of the primary structure/rail (remote earth from the structure and the influence from the rail) is required.

7.3. Correlation Testing

Correlation testing involves assessment of the structure to earth voltage variation compared to the structure to rail voltage or rail to earth voltage. When these two voltages are graphed on an “X Y” chart, determination of the correlation slope is made. Refer to *Figure 1-7* and *Figure 8-3*.

The correlation test process involves deploying test leads that transmit voltages to earth from the rail and from the structure to a central location, usually the test van. The relationship between the rail and the structure voltages is charted to determine the correlation slope. Refer to Section 11.1.9 for the test setup and Section 0 for interpreting the results.

7.4. Sampling rate

A minimum sampling rate of 4 samples per minute (i.e., maximum 15s sampling rate) is prescribed in AS 2832.1[2]. Some data loggers provide a recording rate that is the average of the samples taken at a fast sampling rate while other loggers simply record the value at the nominated sampling rate. When using the latter, it is recommended to select a sampling rate as fast as reasonably practicable. Anecdotal evidence has shown that data loggers that record the value at a nominated sampling rate of >3s can miss important data when the voltage rapidly changes as is the case in stray traction environments. A sampling rate of ≤10s is recommended for structure to Ref Cell recordings when recording over several days while 1s is recommended for short duration logging and correlation testing.

7.5. Data Transfer Technique (DTT)

In some cases, deploying overground leads from structures and/or rail to the test vehicle is unsafe or impractical. Our field testing environments are increasingly categorised as congested city worksites resulting in large multi-storey buildings or multi-lane roadways or multi-rail lines being located between foreign structures and targeted test sites. Previously the use of radio transmitters and receivers were used to remotely transmit voltages however, hardware availability and issues such as limited to line of sight transmission and transmission distance limitations, led to radio transmission becoming obsolete.

A new method has been developed called Data Transfer Technique (DTT) where time synced data loggers are used for remote simultaneous recordings of structure and rail voltages. Recorded data can then be downloaded and analysed using spreadsheets to produce X-Y charts. This method also allows more enhanced analysis of correlation plots such determining the structure potential (Reference Potential) at zero earth to rail voltage (E-RR = 0) while the rail under assessment is in-service. The reference potential is also known as the 'Soil Voltage' in other States where the soil voltage is the structure voltage without being affected by rail (while the rail is de-energised). The main advantage of using DTT is the distance between the structures under test is unlimited. The duration of testing can also be carried out over multiple days and only limited to the data logger recording buffer capabilities. DTT it not affected line of site obstructions nor distance between structures and the test site is unlimited.

The time synchronisation of all data loggers using the one computer or utilising the GPS clock ensures adequate synchronisation accuracy.

7.6. Characteristics and influences

It is important to note that the following characteristics typically influence the effects from stray traction current and should be considered as part of the overall risk analysis of assets susceptible to stray traction current:

- Exposure to stray traction current – magnitude of potential shifts and/or stray traction current, duration and polarity of excursions.
- Soil character – moisture content, pH level, soil resistivity.
- Structure - type of metal, length of asset and proximity to other conductive buried structures and/or separation from return circuits and supplying traction substations.
- Structure Protection – Level of protection from cathodic protection and/or concrete cover, coating effectiveness, insulation integrity, size and location of defects.

7.7. Baseline Testing

Baseline testing is undertaken to establish the background interference levels. This test should be conducted prior to the construction of a possible source of stray current, such as a new rail facility or major change to existing rail infrastructure.

Structure to earth potential recordings are referenced to a $Cu/CuSO_4$ reference cell located at remote earth from the structure being measured. The soil voltage drop is allowed for in the criteria since all measurements are taken during in-service conditions of existing sources.

Structure potentials are generally recorded over a 3 to 7 day period. A 24hr period is selected for assessment based on typical in-service conditions of the existing sources. There are no pass/fail criteria applied to the new rail facility. However, asset owners may choose to analyse the results to determine if their assets are at risk from preconstruction interference. Where excessive interference is detected, efforts should be made to locate and resolve the existing issues to then allow repeat baseline testing during normal in-service conditions.

7.8. Post Construction Pre-Energisation Testing

This testing is optional but recommended and is carried out after a large rail facility is constructed and prior to energisation to establish if the rail facility is transferring interference from other existing sources. The rail line must be in its final arrangement where all continuous rail return circuits are installed ready for service.

Correlation testing is performed between 3rd party assets and the new rail facility at locations nominated by 3rd party asset owners along the entire route of the new rail system. A zero-correlation slope (horizontal plot) indicates no transferred interference.

Structure to earth potential recordings are referenced to a $Cu/CuSO_4$ reference cell located at remote earth from the structure being measured.

7.9. Post Energisation Testing

7.9.1. Part (a) Structure to Earth potential recordings

This testing is performed while the rail facility is operating under normal in-service load conditions. Structure to earth potentials are referenced to a $Cu/CuSO_4$ reference cell. Structure potentials are generally recorded over a 3 to 7 day period. A 24hr period is selected for assessment based on normal in-service conditions. Note that structure to earth measurements include interference from all sources that affect the structure.

7.9.2. Part (b) Correlation Testing

Correlation testing is performed between 3rd party assets and the new rail facility at locations nominated by 3rd party asset owners along the entire route of the new rail system. The advantage of correlation testing over structure potential recordings is that correlation testing can discern interference from the targeted rail source. Any correlation plot that diverges from the zero-correlation slope (horizontal plot) indicates interference from the targeted source.

7.10. Railway Drainage Bond Systems

The purpose of a railway Drainage Bond (DB) system is to "drain" or conduct stray railway (traction) current from underground structures back to the rail via a metallic path. The cable connection should include a diode in series to block reverse current from the rail and a resistor (fixed or variable resistance) to control the magnitude and direction of the current passing through the bond.

Returning stray current through a metallic path to the traction negative (rail) reverses the stray current polarity from the structure into the ground to flow from the ground to the structure, resulting in a cathodic shift of the structure potential.

7.10.1. Trial Drainage Systems

The proposer/owner of a new DB system should arrange with the Rail Operator (RO) for installation of a trial drainage system and have it operating at the design current/conductance at the time of testing. Owners of existing systems should ensure that the system is operating at the approved conductance or in the case of a redesigned system, at the proposed current/conductance.

Notes:

1. *Arrangements for installation/adjustment should be made at a previous NSWEC meeting or separately with the RO.*
2. *Current carrying connections to the railway line, other than for temporary potential measurements, must be authorised by the RO. Improper connections can cause malfunction of the signalling system.*
3. *Prior permission must be obtained from the RO for access, for any purpose, within 3 metres of any rail. All person entering the rail corridor or Facility (other than stations) must hold applicable Rail Industry Worker (RIW) accreditation.*

7.10.2. Testing of Primary Structures

Primary structure correlation recordings should be made on an X-Y recorder or similar instrumentation during which the system should be switched "ON" and "OFF" at various PS-RR voltages. Recordings are to be taken over a sufficient range of PS-RR voltages to indicate system characteristics. The "ON/OFF" switching is conveniently controlled from the Test Vehicle using a DC relay in series with the drainage circuit.

7.10.3. Reference Cell

Reference cell should be copper/copper sulphate ($Cu/CuSO_4$) unless this is impractical. Data must be standardised to $Cu/CuSO_4$ in those cases where alternative reference cells are used (refer to Appendix G). Silver/silver chloride cells (Ag/AgCl) should be used in salt or brackish water or soils with chloride ion content more than 1000 ppm (parts per million).

7.10.4. Location of Reference cells

Reference cells are to be positioned at remote earth from the foreign structure and remote earth from the rail to include the soil voltage gradient in the measurement since the interference criteria includes the soil voltage rise of the structure.

Locating the rail reference cell at remote earth from the rail is preferred but not critical for assessment purposes. Locating the rail reference cell in a safe place >10m from the nearest rail or outside the rail corridor is an acceptable practice.

7.10.5. Conductance

The system conductance is recorded on the X-Y recorder and calculated from the diagram (refer to Figure 8-2).

7.10.6. Testing of Foreign Structures

Three testing methods have been developed by the NSWEC. The techniques selected depend on the "correlation shift" between the foreign structure to rail (FS-RR) and primary structure to rail (PS-RR) potentials, and on the distance between the foreign structure (FS) and primary structure (PS).
These testing methods are:

1. The correlation chart procedure. This procedure is limited to foreign structures situated such that leads can be run between the rail and the structure under test.
2. Data Transfer Technique (DTT) has replaced the radio method. The radio method was limited to line of site and had a limited range of up to 1km. Where the deployment of overground leads between the foreign structure and the rail is unsafe or impractical, then the rail and structure voltages to earth can be independently recorded using synchronised logging instrumentation. The recorded data can then be analysed using digital X-Y charting.
3. The 48-hour FS-RR potential chart. This procedure is used as an alternative to the DTT method.

7.10.7. The Correlation Chart Procedure (Assessment of Interference)

The correlation chart consists of a graph of foreign structure to earth potential plotted against foreign structure to railway potential. The change in the relationship that occurs on switching the drainage system "ON" and "OFF" is a measure of interference. If there is no change in the relationship, then there is no interference.

7.10.8. Foreign Structure Owner Responsibilities

Foreign structure owners/operators should select a suitable location where interference may be anticipated and decide the best point of connection made to the structure. Potential leads from these sites are run back to the Test Vehicle by the structure owner or the use of DTT. The correlation chart is recorded, whilst the drainage system is switched "ON" and "OFF" during the period for which the primary structure potential to rail is positive and the system is conducting. Recording should continue for as long as possible to obtain a definitive tracing for both system "ON" and system "OFF" conditions.

> *Note: The recordings will quite often include changes in the underlying correlation which will tend to mask the correlation change caused by switching of the bond. These underlying correlation changes are caused by unpredictable changes in stray current flow patterns. The testing officer must observe the recording process very closely to distinguish the switching correlation, otherwise the resulting interference data will be incorrect.*

7.10.9. Overlapping Interference

In some cases, a system, or a number of systems may be installed in fairly close proximity and may produce overlapping interference with systems, or with each other, on nearby foreign structures. In these cases, the following test procedures are recommended:

(a) Single System
When interference from a single system under test overlaps with interference from other system(s), then the other system(s) should normally remain "ON" whilst the system is tested.

(b) Multiple Systems protecting a single structure
Where multiple systems are used to protect a common structure, the systems are to be treated as one system for testing purposes. Concurrent switching of the systems is required to allow the total cumulative interference to foreign structures to be measured.

7.10.10. Switching For Correlation Charts

The foreign structure correlation charts should contain at least three "OFF" readings and three "ON" readings and, as far as is practical, the recording should capture the full rail voltage range from most negative to most positive.

7.10.11. Fortuitous Connection

Where unacceptable cathodic interference is measured on a foreign structure the tests for a fortuitous connection as outlined in Appendix E should be followed.

7.11. TRADS and Combinations of Systems

7.11.1. Purpose

The purpose of a Transformer Rectifier Assisted Drainage (TRAD) system is to drain or conduct stray railway (traction) current from underground conductive structures back to the rail. The TRAD uses a mains-powered rectifier to assist in the drainage process. TRADs are automated systems with a controlled output to maintain pre-set protection level for the primary structure and within foreign structure interference limits.

In extremely adverse conditions, where large currents are being drained, and protection levels cannot be maintained, both a TRAD and a drainage bond connected in parallel can be installed.

7.11.2. Field Procedures and Field Testing Methods

The field procedures and test methods are generally identical to those applying to railway drainage bonds - refer to Section 7.10. For TRADS the rectifier voltage is to be operated in constant current mode and adjusted to produce the nominated current required for registration. A minimum recording period of 24hr is required for the output current recording to verify that it does not exceed the registered/test current level.

8. INTERPRETATION OF DATA – DC TRACTION INTERFERENCE

8.1. Railway Drainage Systems

8.1.1. Information Required - (Primary Structure)

The following information should be supplied for a primary structure.

a) 24 Hour Current Chart (Information Required)

System current logged over a minimum of a 24-hour period. This data is processed using appropriate and recognised software to produce a 24-hour average chart and the Time of Operation of the system where the latter is expressed as a decimal fraction. Time of Operation is defined as when the system current is greater than 0.1 amps. Data used for computing the average will exclude zero current readings. The chart should include the following information:

- System number where allocated
- Owner/operator of system
- Average current and MoC
- % Operation time
- Date of test

8.1.1.1. 24 Hour Bond Current Chart (Data Logger Chart)

The 24-hour average current is determined by analysing the 24-Hour Average magnitude and the Time of Operation. Refer to Figure 8-1 and Section 8.1.1 (d). The 24-Hour Average is multiplied by the inverse of the Time of Operation to produce the Modified Average Current. Appendix M describes the method in more detail.

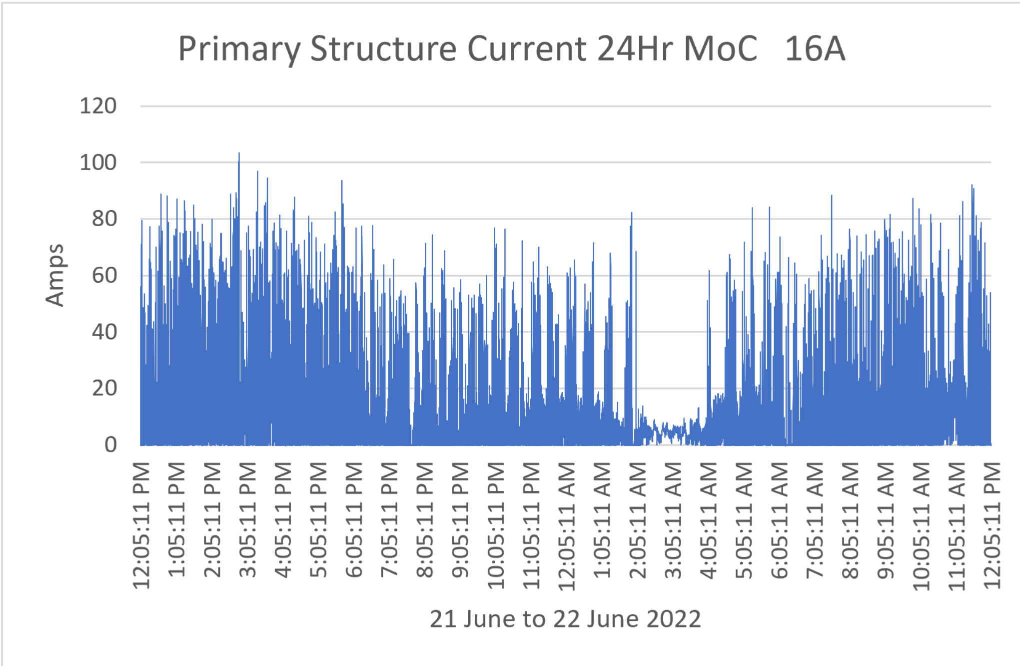


Figure 8-1: 24Hr Primary Structure Current recording – Calculated MoC

b) Conductance Chart (System Current/Voltage Chart)

System current versus structure-to-rail voltage is as illustrated in Figure 8-2. This chart is used to determine the Modified Voltage and conductance. Use of this chart is described in Appendix M. The chart should include the following information:

1. System number, where allocated
2. Owner/operator of the system
3. Address and GPS reference of the system
4. Date of test
5. Organisations present at the test

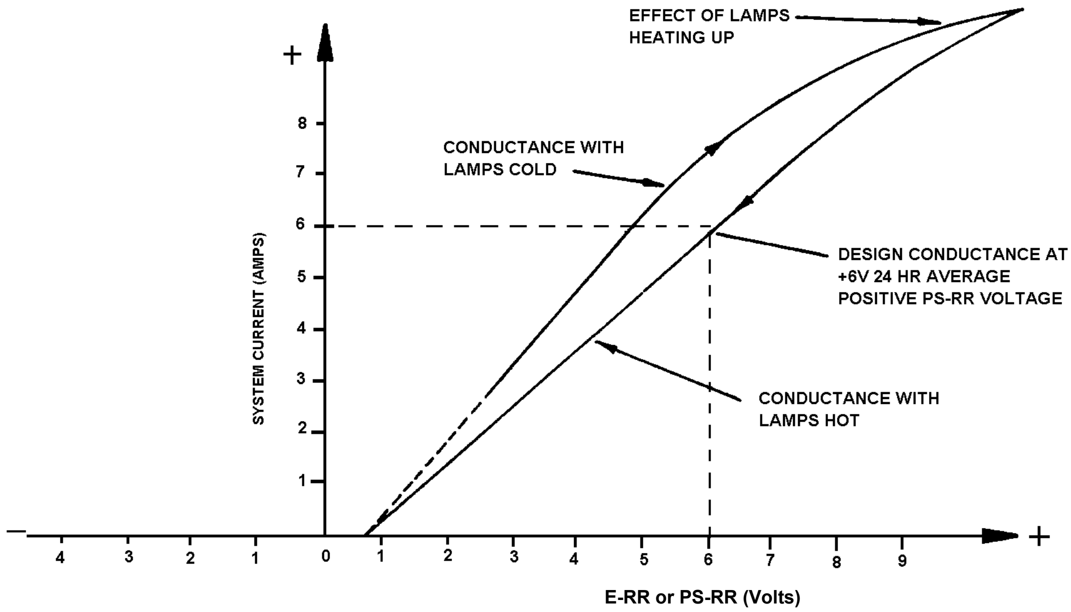


Figure 8-2: Railway Drainage System Conductance Chart

Note: If lamps are not included in the system circuit, then one conductance line should occur.

8.1.1.2. Conductance Chart (System Current/Voltage Chart)

The system Modified Average Current(MoC), determined by the procedure described in Appendix M (Section 8.1.1 also refers), is applied to the conductance chart to determine the Modified average Voltage (MoV).
In addition, these charts are used to determine the conductance of a railway drainage system and are used to design the system. Production of these charts is described in Appendix M.

8.1.1.3. Determination of system conductance

Most systems include positive temperature coefficient resistance in the form of incandescent lamps in the circuit and as the lamps heat up, the conductance lowers due to the increased resistance of the hot lamps. The initial current rise on the conductance chart occurs with the circuit lamps cold and this part of the chart is not used for determining conductance but rather the "hot lamp" line is used. In some cases, the hot and cold lines will be very similar depending on the temperature the lamp filament achieved.

The conductance of the railway drainage system is determined from equation (1).

$$G = \frac{MoC}{MoV} \quad (1)$$

Where: G is the conductance in siemens, MoC is the system modified current in amperes and MoV is the system modified voltage in volts.

In the example in Figure 8-2 a current of 6 amperes at a voltage of 6 volts results in a conductance of 1 Siemen.

Refer to Appendix F for further details on construction of charts and to Appendix M for further information on determination of interference.

8.1.1.4. Correlation Chart

A correlation chart demonstrates the change in the structure to earth potentials for a range of structure to rail or rail to reference cell voltages, that is, the change in the correlation with system both "OFF" and "ON" (see Figure 8-3). This chart demonstrates the effectiveness of the bond in protecting the primary structure. The chart should include the following information:

1. System number where allocated
2. Owner/operator of system
3. Address and GPS reference of the system
4. Date of test
5. Exact position of the reference relative to the primary structure
6. Organisations present at the test

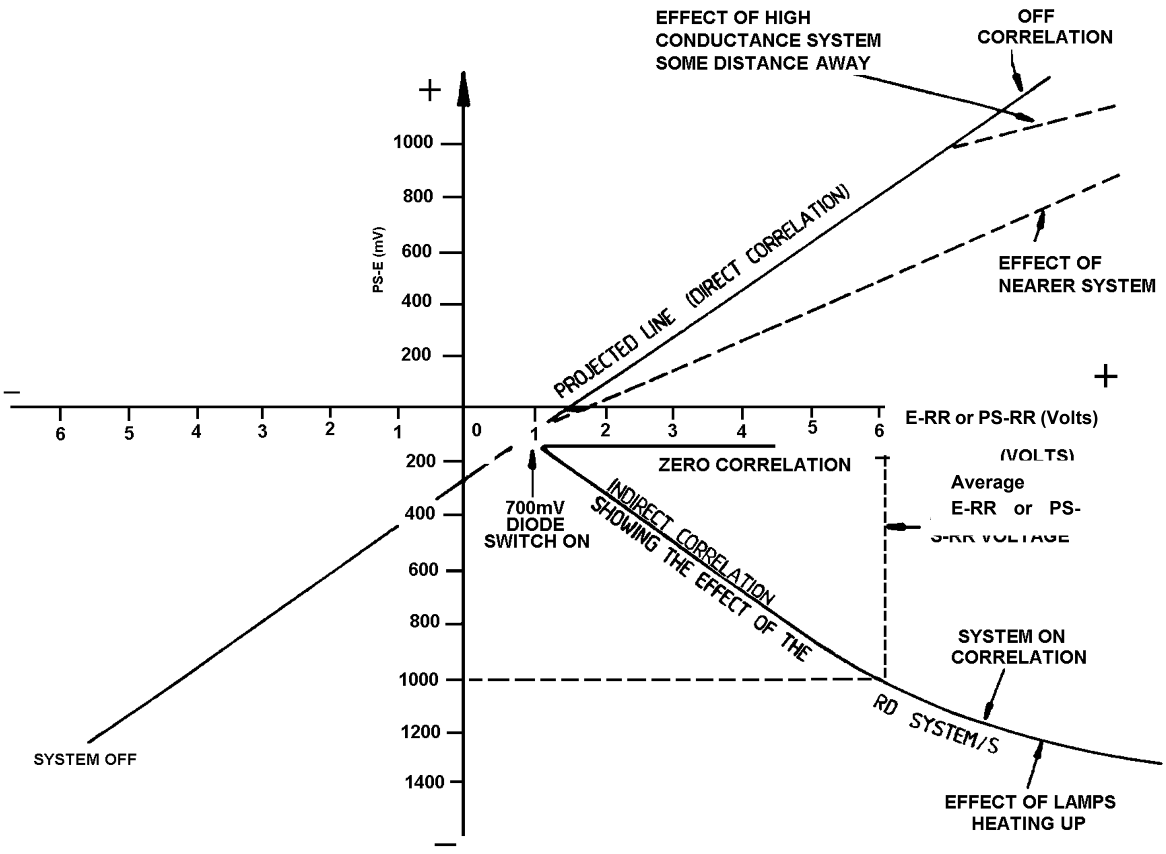


Figure 8-3: Railway Drainage System - Correlation Chart - Primary Structure

8.1.2. Correlation Charts - Primary Structure

The correlation chart expresses the relationship between the actual potential of the primary structure to earth ("Y" axis) and the potential of the same structure to rail ("X" axis). The purpose of this correlation chart is to determine the protection provided by the temporary or permanent system. This correlation chart is illustrated in Figure 8-3. This is an illustration of a correlation for a primary structure showing both the system "OFF" and the system "ON" correlation lines

(a) Neighbouring Systems

If the system is being affected by neighbouring systems, then the system "OFF" line will not be straight but will curve over as illustrated in Figure 8-3. This phenomenon is due to the voltage drop along the structure between the measurement location and the neighbouring system connection point. For a high current system that is distant from the point of measurement, the correlation line will show an effect initiated at higher structure to rail voltages.

(b) Interpretation

When the system is switched "ON" it will start to conduct when the PS-RR volts exceeds the diode forward bias voltage (typically +700mV) and the correlation will ideally enter the lower right hand quadrant as PS-RR voltage increases in the positive direction. The gradient of the curve depends on the conductance of the system. As conductance increases so does the gradient.

(c) Zero Correlation

A horizontal line is known as zero correlation.

(d) Direct Correlation

An inclined line is known as direct correlation. This line is generated when the structure voltage becomes more positive as the rail voltage (PS-RR or E-RR) increases positively.

(e) Indirect Correlation

A declined line is known as an indirect correlation. This line is generated when the structure voltage becomes more negative as the rail voltage (PS-RR or E-RR) increases positively.

(f) Effect of Lamps

Some systems contain lamps for the purpose of limiting current at high positive PS-RR voltages. As the lamps heat up, the correlation curve will flatten out as illustrated (see Figure 8-3). This is due to the positive temperature coefficient characteristic of the tungsten filament.

(g) Average Protection Levels

The system-ON correlation slope is indicative of the protection provided. The average level of protection provided is determined by projecting a vertical line from the agreed 24-hour average positive PS-RR voltage ("X" axis) onto the plotted correlation line as illustrated in Figure 8-3. From the intersection, a horizontal line is projected to determine the corresponding structure-to-earth potential of the primary structure. The adequacy of projection provided by the system can be evaluated by reference to the acceptable levels of protection listed in Appendix B. In Figure 8-3 the average protection level is 1000 mV.

Note: In this illustration the average PS-E potential is 1000 mV negative. Refer to Appendix F for further details on construction of charts and to Appendix M for further information on determination of interference.

8.1.3. Interpretation Of Data (Drainage Systems) - Primary Structures

In traction affected areas care should be taken to not confuse stray current traction effects with any possible interference from primary CP systems under test.

8.1.3.1. <u>48 Hour Structure-To-Earth Potential-Time Charts</u>

The 48-hour primary structure potential chart can assist in the correct design of the system. Figure 8-4 is an example of a 48-hour chart for primary structures and *Figure 8-5* is an analysis example.

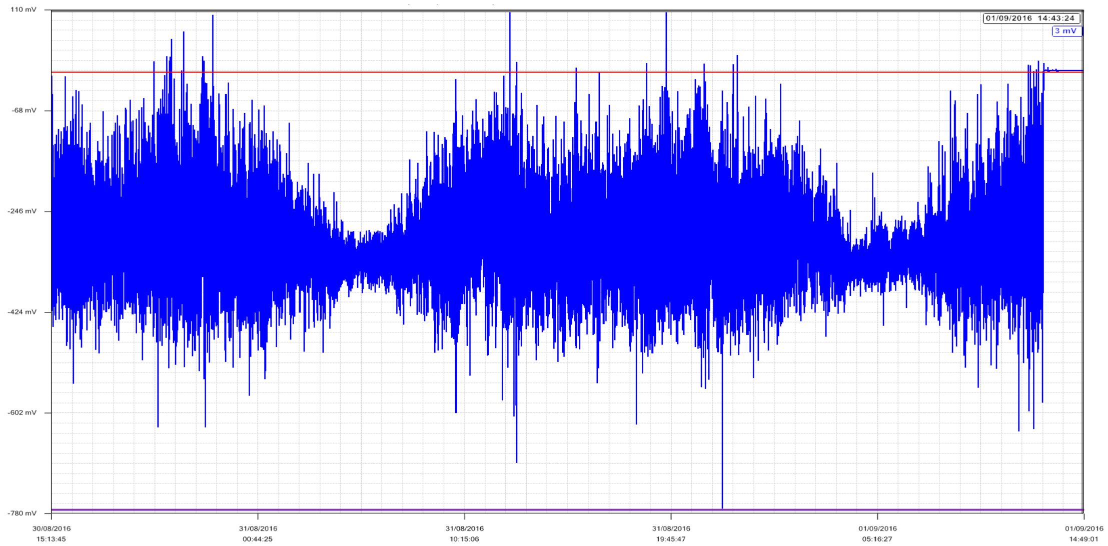


Figure 8-4: 48Hr Primary Structure Potential recording – water service

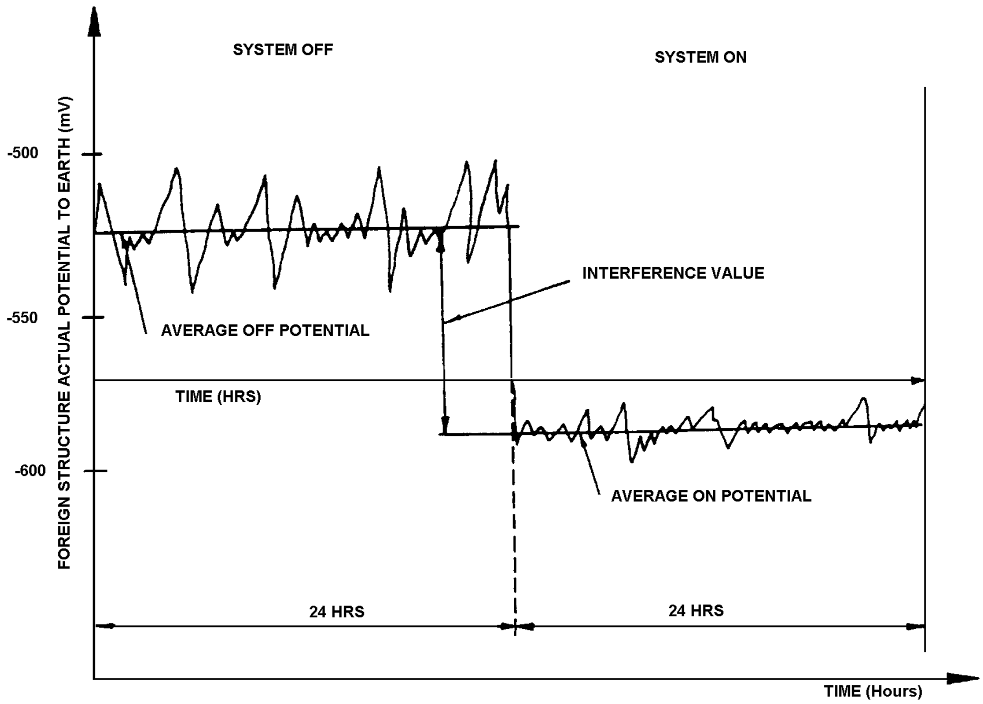


Figure 8-5: 48-hour Potential Time Chart Interference

8.1.4. Interpretation Of Data (Drainage Systems)-Foreign Structures

8.1.4.1. Correlation Charts (Determination of Interference) - Introduction

The correlation charts for foreign structures are used to determine the level of interference being caused to the foreign structure by the system applied to the primary structure. Interference is measured from the change in the correlation line when the primary structure railway drainage system is switched "ON" and "OFF". Interference is the change in actual potential to earth of the foreign structure measured at the agreed foreign structure to rail voltage that is in turn derived from the primary structure conductance chart. To determine the interference, a vertical line is drawn from the agreed PS-RR voltage (MoV) to intersect both the system ON correlation line and the system-OFF correlation line. Refer Appendix M for method of determining MoV. Two horizontal lines are drawn through the intersection points to the vertical axis to give the two potential readings, the difference being the measured interference. Figure 8-6 and Figure 8-7 are illustrations of correlation charts based on typical data for a steel structure using a copper/copper sulphate reference cell to measure potentials to earth. Figure 8-6 is an illustration of anodic interference (structure becomes more positive) and Figure 8-7 is an illustration of cathodic interference (structure becomes more negative).

The decision as to whether the measured interference is acceptable or not should be made after reference to the table of criteria in Appendix B.

***Note**: Where unacceptable cathodic interference is measured on a foreign structure the tests for a fortuitous connection, may be required.*

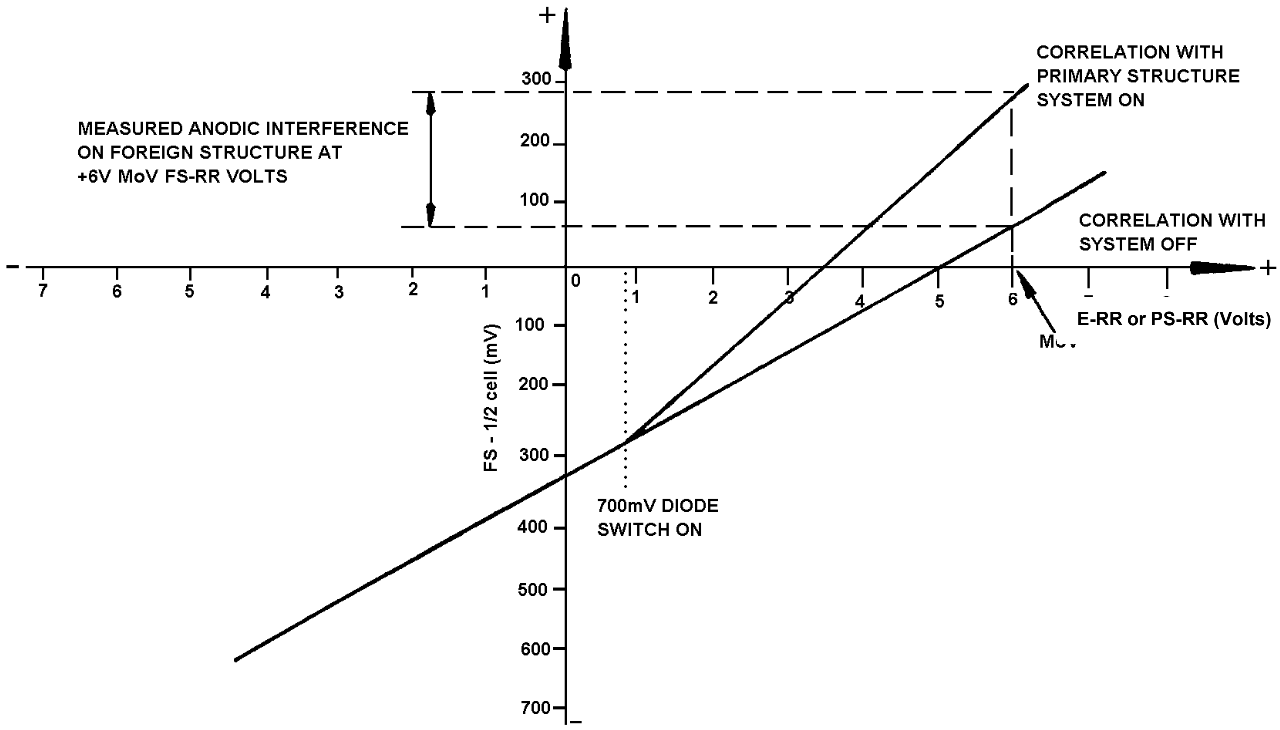


Figure 8-6: Anodic Interference - Correlation for Foreign Structure

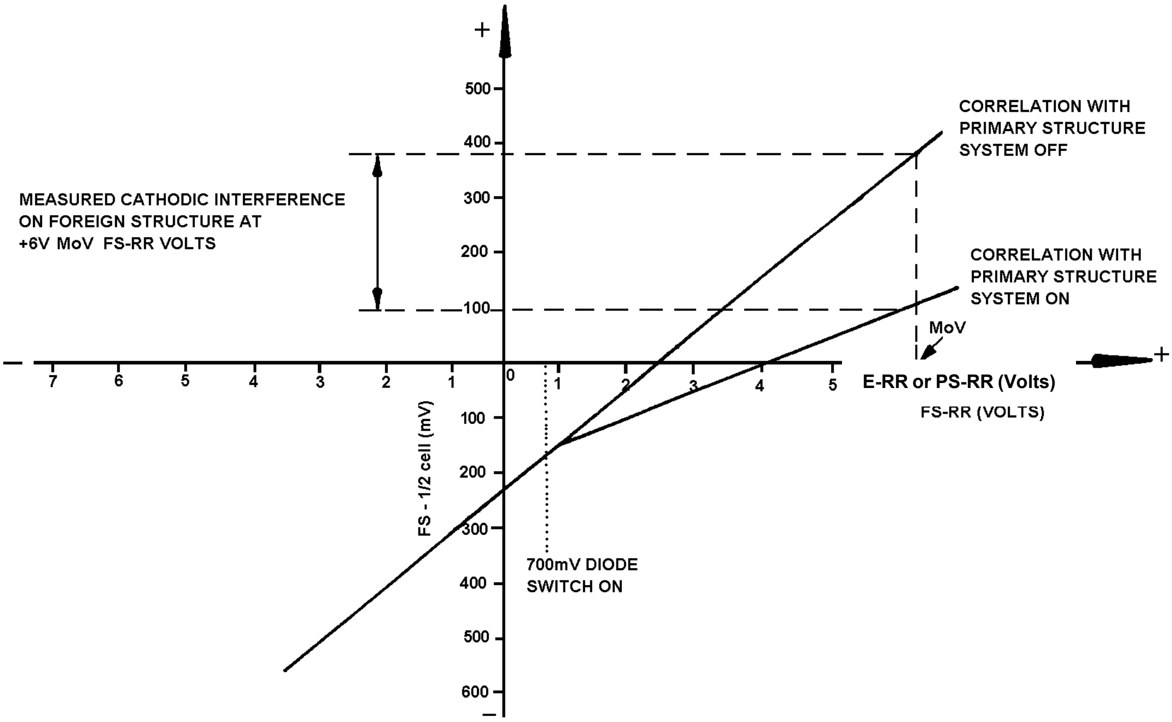


Figure 8-7: Cathodic Interference - Correlation for Foreign Structure

8.1.4.2. <u>Correlation with Collapsing Rail Volts</u>

The switching 'on' of a RD can cause the Rail voltage to drop significantly (referred to as "collapsing rail volts"), as illustrated in *Figure 8-8*. This phenomenon can occur when a system passes large drain currents which reduces the voltage rise of the localised rail return circuit. Operating a large drain current system enables increased stray currents to flow (pickup & discharge) altering both the voltage rise along the rail and the position of dominant voltage drop locations along the rail route.

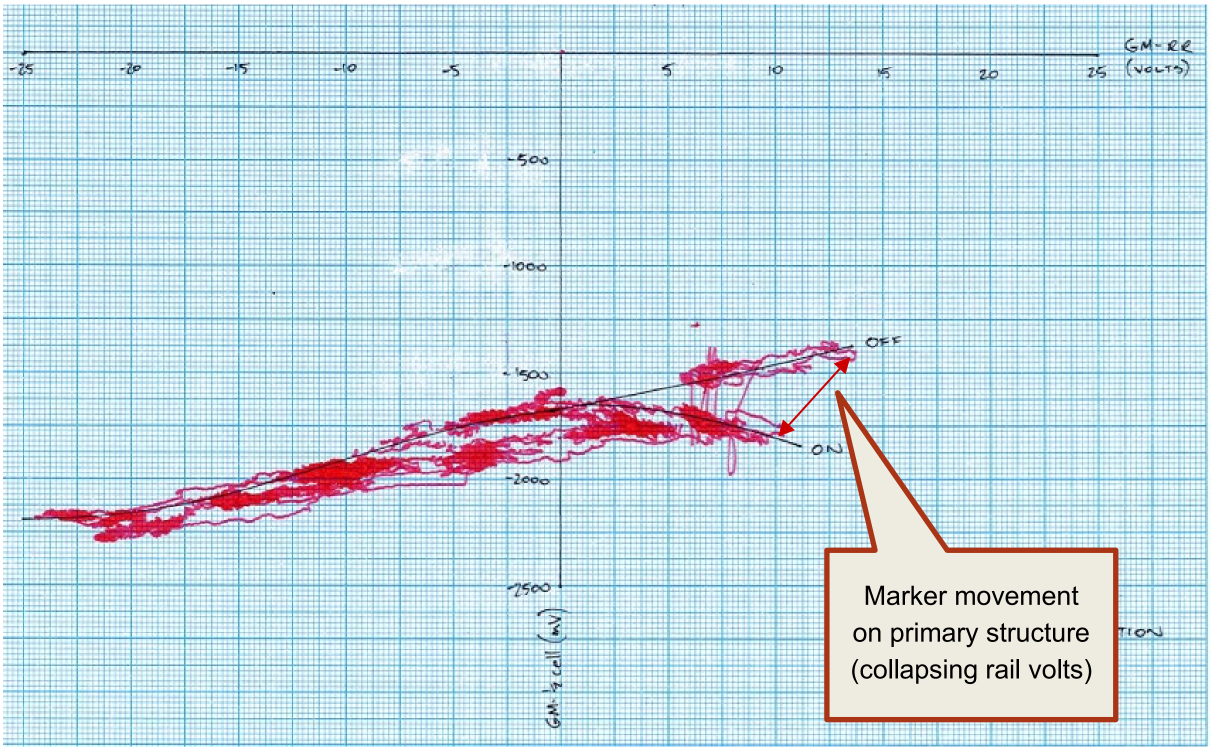


Figure 8-8: PS Correlation with collapsing rail volts

When collapsing rail volts occurs the X-Y plotter marker will be seen to take a diagonal path across the chart for the foreign structure as the DB system is switched "ON" and "OFF". Refer to *Figure 8-9*. In these cases, it is not appropriate to measure interference by projecting a vertical line from the modified average rail volts to intersect the "ON" and "OFF" lines. Instead, the two intersection points A and B are determined by projecting a vertical line from the average FS-RR volts to intersect the "OFF" correlation line at A and then projecting another line parallel to the path recorded, until it intersects the correlation line at B. The two intersection points are then projected horizontally on to the vertical axis, as previously, to obtain the interference.

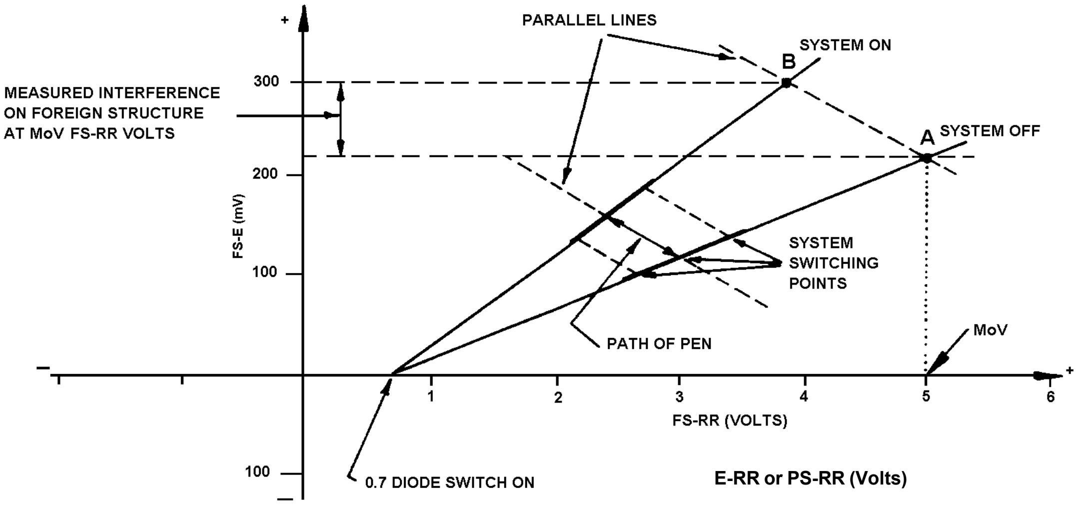


Figure 8-9: Correlation with collapsing rail volts and measurement of (anodic) interference

8.1.4.3. Multi - Correlation slopes

At times it will be observed that the correlation data points dominate along more than one line resulting in two or more correlation plots for a single structure as illustrated in Figure 8-10. The correlation trace will change between two or more arrays and is typically observed when traction vehicles are travelling (accelerating & braking) on multiple rail lines causing different effects to a common structure. This phenomenon occurs on rail networks where multiple tracks are located. Inadequate cross bonding of the rails can also contribute to different rail voltages on separate rails at the one location.

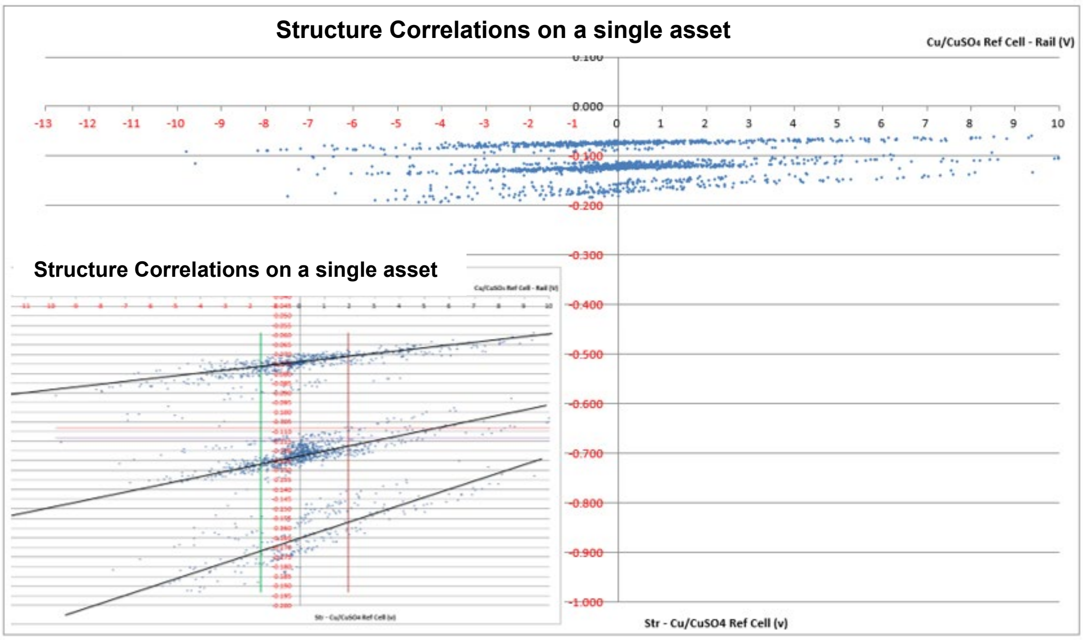


Figure 8-10: Example of changing correlation slopes

8.1.4.4. Tolerable Interference that exceeds Criteria

The owner of foreign structures that are affected by interference may consider accepting greater levels of interference than are presented in the tables of criteria shown in Appendix C and Appendix D. This approach may be taken when anodic interference is recorded on a foreign structure that already has a strongly indirect correlation or, when, cathodic interference is recorded on a structure that already has a strongly direct correlation. A structure that is already very negative with respect to earth (indirect correlation) can accept substantial anodic interference without entering the corrosion hazard zone. Similarly, a structure that is very positive with respect to earth (direct correlation) can accept substantial cathodic interference without detriment. If there is a connection between the primary and foreign structures, then an apparent cathodic interference is not interference at all but instead, the foreign structure has become part of the protected structure.

This acceptance of increased levels of interference is more appropriate for less critical Category 3 structures than for structures in Categories 1 and 2. Refer to Appendix A for structure categories.

8.2. Transformer Rectifier Assisted Drainage Systems (TRAD)

8.2.1. Information Required

The information required for TRAD systems is identical to that for Drainage Systems.

8.2.2. Interpretation

Interpretation is identical to Drainage Bonds. Note that TRADs are to be operated in constant current mode when assessing the interference levels to foreign structures.

8.3. Combination TRAD and Drainage Systems (TDB)

TDB systems consist of a TRAD and a DB connected in parallel to the same connection point on both the track and the protected structure and are thus treated as a single system for the purpose of registration.

8.3.1. Information and Interpretation

This is the same as for the DB and TRAD systems.

9. DC TRACTION INTERFERENCE CRITERIA

Acceptance criteria are noted in Appendix B and Appendix C with reference to selected structure categories shown in Appendix A.

9.1. "On" potential based criteria

When assessing the interference from traction networks, testing is carried out while the trains and trams are running to a normal timetable. Since it is impractical to de-energise an entire rail network to obtain the structure voltages free of soil voltage drop error, then the soil voltage drop needs to be included in both the testing process and criteria. Refer to Section 7.10.4 for correct location for reference cells.

AS2832.1[2] acknowledges the difficulty in determining the voltage gradients along pipelines in traction affected areas, so suggest an estimation of the electrolyte voltage gradient to determine the protection criteria. European standards such as ISO 21857[19] are using "on" potential criteria for the assessment of traction interference. For normal soils (15Ωm - 200Ωm), an allowance of 1.5 times the soil resistivity in ohmmeters is added to the criteria. To remain conservative, the NSWEC have agreed to use 1.0 times the soil resistivity in ohmmeters is added to the criteria.

9.2. Part (a) Structure to Earth potential recordings

This testing is performed while the rail facility is operating under normal load conditions. The weather and recent rainfall data should be noted if the results are used for comparison. Structure to earth potentials are referenced to a $Cu/CuSO_4$ reference cell. Structure potentials are typically recorded over a 3 to 7 day period. A minimum recording of 24hr is required to assess the levels of interference.

9.2.1. Anodic Criteria for assets with cathodic protection

For pipeline structures subject to stray DC traction effects, affected assets owners may choose one or both the following interference criteria:

(a) Criteria based on time-based voltage magnitude as detailed in AS2832.1[2]

- Refer to AS2832.1[2] with a summary detailed below.

Structures with short polarisation times (e.g: small structures or high dielectric coated pipelines)
The potential shall not be more positive than the protection criteria:

- For more than 5% of the test period
- + 50mV for more than 2% of the test period
- + 100mV for more than 1% of the test period
- + 850mV for more than 0.2% of the test period

Structures with long polarisation times (e.g: large poorly coated pipelines)
The potential shall not be more positive than the protection criteria:

- For more than 5% of the test period. The positive excursions shall be brief and have negative excursions between them.

(b) Criteria based on voltage shift

The Anodic Average Structure Voltage Shift (Str $\Delta_{Ano.ave}$) from the Protection Level shall not exceed the criteria specified in Appendix C. Refer to Appendix A for selection of asset category.

9.2.2. Cathodic Criteria for assets with cathodic protection

- Refer to AS2832.1[2] with a summary detailed below. The estimated soil voltage gradient is -1mV per Ωm of soil resistivity as allowed for in AS2832.1[2].
- The Cathodic Average Structure Voltage (Str $_{Cath.ave}$) shall not be more negative than -1200mV + -1mV/Ωm Soil.Res, e.g. a steel pipe buried in 300Ωm soil will result in Str$_{Cath.ave}$ to be more positive than -1500mV. Alternatively, the magnitude nominated by the affected asset owner.

9.2.3. Anodic Criteria for assets without cathodic protection

- The Anodic Average Structure Voltage Shift (Str $\Delta_{Ano.ave}$) from the natural potential shall not exceed the values shown in Appendix D as sourced from ACA Conference 2019 paper 13[5].

9.2.4. Cathodic Criteria for assets without cathodic protection

- The estimated soil voltage gradient is -1mV per Ωm of soil resistivity as allowed for in AS2832.1[2].
- The Cathodic Average Structure Voltage shift (Str $\Delta_{Cath.ave}$) from the natural potential shall not exceed -100mV. Alternatively, use the criteria specified in Appendix C where the structure potential is more negative then -1200mV + -1mV/Ωm Soil.Res. Refer to *Figure 9-1*.

9.3. Part (b) Correlation Testing

Correlation testing is performed between 3rd party assets and the nominated rail facility to extricate the interference levels emitted from the associated rail facility.

9.3.1. Anodic Criteria for assets with cathodic protection

- The estimated soil voltage gradient is -1mV per Ωm of soil resistivity as allowed for in AS2832.1[2].
- The Anodic Average Structure Voltage ($Str_{Ano.ave}$) shall not be more positive than
- -850mV + -1mV/Ωm Soil.Res (Steel)
- -650mV + -1mV/Ωm Soil.Res (Lead)
- -300mV + -1mV/Ωm Soil.Res (Copper)

For example, a steel pipe buried in 200Ωm soil will result in $Str_{Ano.ave}$ being not more positive than -1050mV.

Alternatively,

- The Anodic Average Structure Voltage Shift (Str $\Delta_{Ano.ave}$) from the Structure Reference Potential shall not exceed the criteria specified in Appendix C. Refer to Appendix A for selection of asset category.

9.3.2. Cathodic criteria for assets with cathodic protection

- The estimated soil voltage gradient is -1mV per Ωm of soil resistivity as allowed for in AS2832.1[2].
- The Cathodic Average Structure Voltage (Str $_{Cath.ave}$) shall not be more negative than -1200mV + -1mV/Ωm Soil.Res or the magnitude nominated by the affected asset owner.

For example, a steel pipe buried in 300Ωm soil will result in $Str_{Cath.ave}$ being not more negative than -1500mV. Refer to Figure 9-3.

Alternatively,

- The Cathodic Average Structure Voltage Shift (Str $\Delta_{Ano.ave}$) from the Structure Reference Potential shall not exceed the criteria specified in Appendix C. Refer to Appendix A for selection of asset category.

9.3.3. Anodic Criteria for assets without cathodic protection

- The Anodic Average Structure Voltage Shift (Str $\Delta_{Ano.ave}$) from the Structure Reference Potential shall not exceed the criteria specified in Appendix D. Refer to Appendix A for selection of asset category.

9.3.4. Cathodic Criteria for assets without cathodic protection

- The estimated soil voltage gradient is -1mV per Ωm of soil resistivity as allowed for in AS2832.1 [2].
- The Cathodic Average Structure Voltage shift (Str $\Delta_{Cath.ave}$) from the Structure Reference Potential shall not exceed -100mV. Alternatively, use the criteria specified in Appendix C where structure potential is more negative then -1200mV + -1mV/Ωm Soil.Res.

Refer to *Figure 9-2* & *Figure 9-3* for graphical representation of correlation interference analysis.

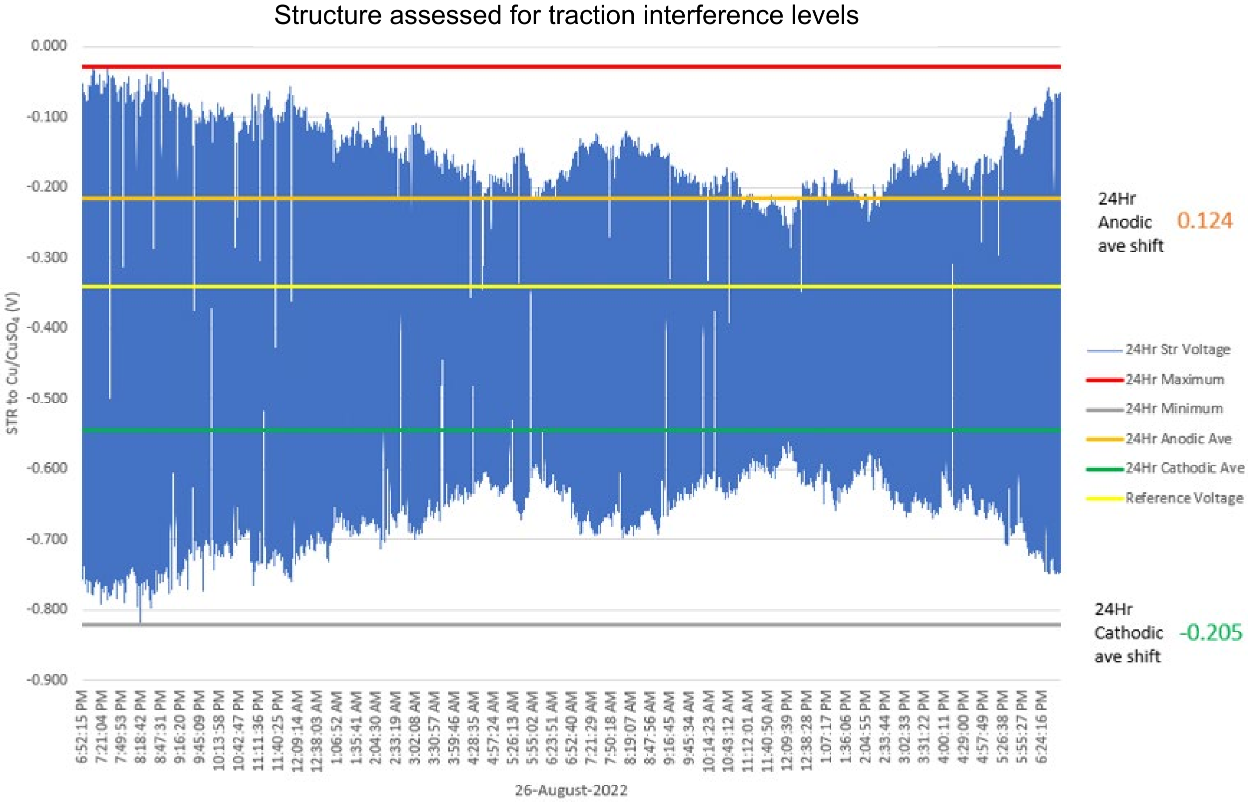


Figure 9-1: Example graphical analysis of traction interference

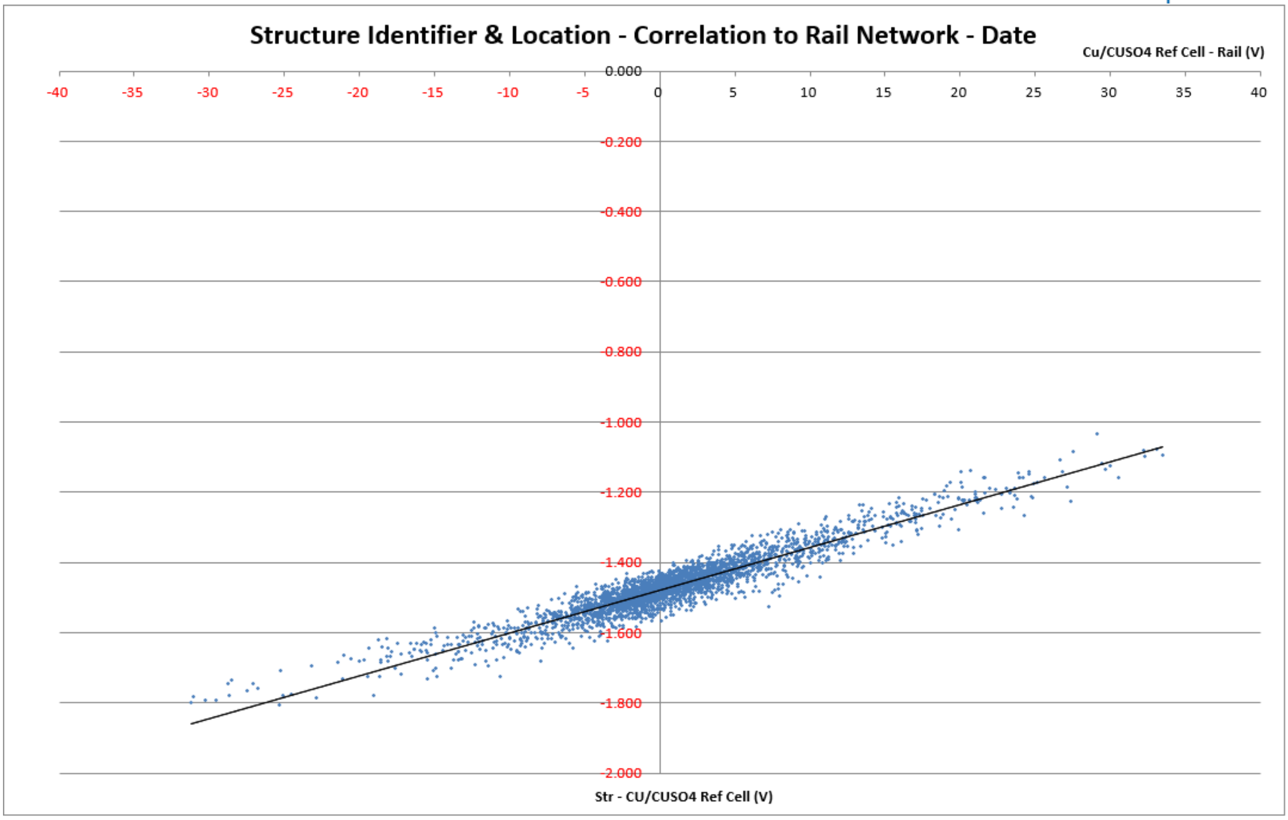


Figure 9-2: Steel Asset with a direct correlation slope

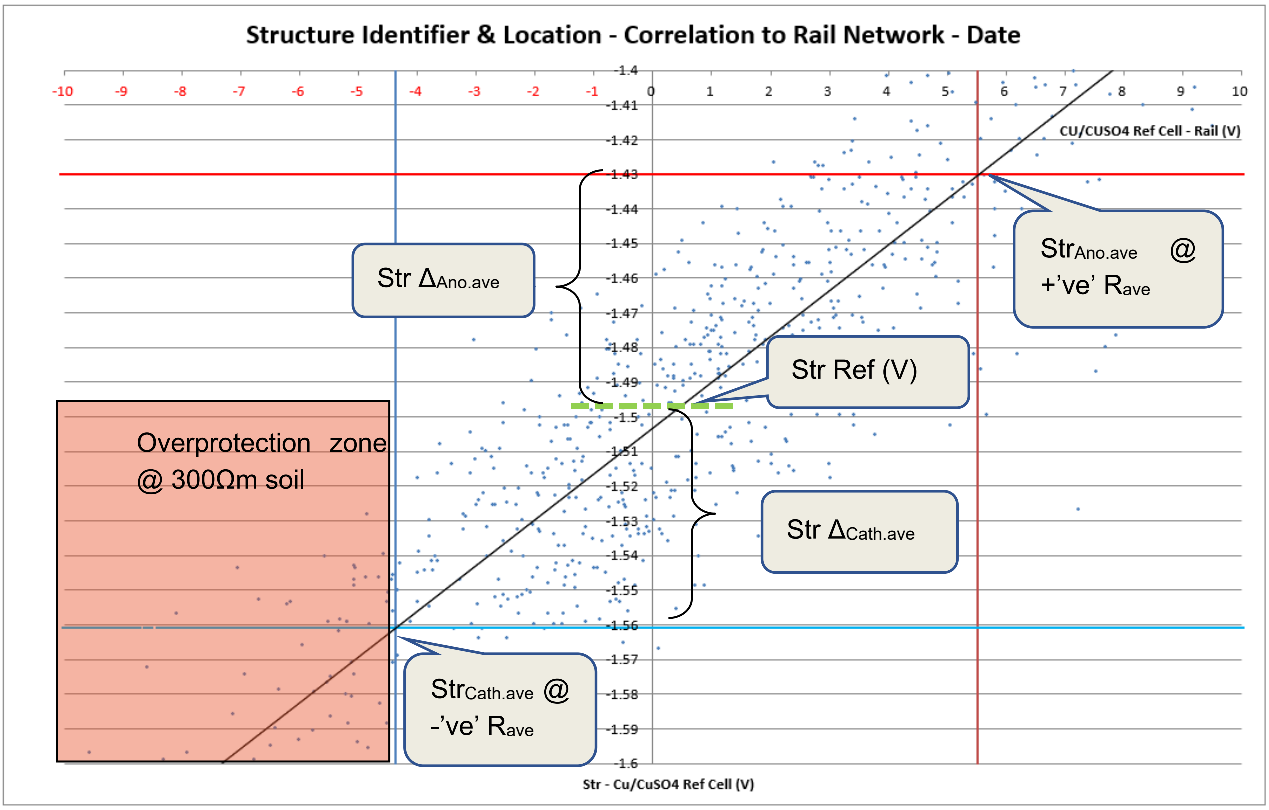


Figure 9-3: Steel Asset with direct correlation zoomed in for analysis

10. AC CORROSION – INTERFERENCE ASSESSMENT

It is important to differentiate the risks from AC corrosion voltages compared to earthing hazard voltages with respect to step, touch and transferred voltage risks. Earthing hazards are due to high magnitude AC currents for very short durations and occur during transient and earth fault events. Earthing hazard events are typically for very short durations and don't increase corrosion risks. AC corrosion voltages are lower in magnitude than earthing hazard voltages and the risks of AC corrosion are related to currents that flow continuously during normal load conditions. AC corrosion is therefore, only assessed during normal AC load conditions while transient and earth fault current events are excluded from AC corrosion assessments.

AC sources can be unintentionally applied to a structure through three different means that are not mutually exclusive:

1. Conductive coupling, where a direct low impedance connection is present between the AC source and the structure.
2. Inductive coupling, where an AC signal is magnetically induced into a structure. Cables and pipelines are most susceptible when routes are parallel with high voltage feeders.
3. Capacitive coupling, where an AC signal is electrostatically coupled into structures nearby.

It is also important to recognise that AC corrosion is more likely to be a concern from AC traction systems than from AC power systems. This is due to the unbalanced nature of the single-phase railway giving rise to elevated magnetic field influence. Single phase traction supplies have been known to cause harmonic distortion while the sliding/rolling contact traction system coupled with multiple traction vehicles simultaneously accelerating and braking on different parts of the rail network, develops asymmetrical waveshapes due to DC offset components.

There are several influences that effect the likelihood of AC corrosion occurring. The two main parameters that should be quantified on site to assess the risk of a structure's metallic surface that is in contact with an electrolyte to the effects of AC corrosion are:

1. The magnitude of AC current flowing between the metallic surface and the electrolyte and concurrently,
2. The magnitude of DC cathodic voltage at the metallic surface.

One of the most important parameters that can result in AC electrolysis corrosion of metallic structures, is when a structure metallic surface that is subject to AC voltages and is more negative then -1200mVdc with reference to a $Cu/CuSO_4$ reference cell. Therefore, structures with cathodic protection or structures (with or without CP) that are subject to high levels of cathodic traction interference and/or cathodic CP interference are most at risk. Since the levels of AC and DC vary for each situation, a single threshold value cannot be applied.

10.1. Current Density

DC current density (*Jd.c)* dictates the cathodic protection level while at the same time, the AC current density (*Ja.c)* impacts on the AC corrosion process. However, measuring and calculating the current density on a coating defect is impractical in a field environment.

The current density can be estimated using coupons installed to simulate a coating defect. Unfortunately, there are limitations when using coupons that lead to underestimations in determining current densities. Typically, the current density calculation is averaged over the entire surface of the coupon whereas the current densities are known to be larger at the coupon edges compared to the mid section. This limitation is made worse when structures are subjected to traction interference due to the increased likelihood of pitting corrosion. Another limitation is the build-up of passive films that act to decrease the coupon surface area which also can lead to underestimation of the current density. Considering these limitations, use of coupons may well be the best tool available for the assessment of AC corrosion likelihood.

Adequate DC current density results in greater cathodic protection levels and the formation of a high pH at the pipeline surface. However, the high surface pH, the decrease of the spread resistance, and the increased reduction of passive films can result in an acceleration of the corrosion rate under simultaneous AC interference. However, increased levels of DC current density can prevent anodic metal oxidation and the offset the likelihood of AC corrosion.

Elevated DC current densities alone is not guaranteed to ward off AC corrosion. Increased DC current density in the presence of high AC current density can still result in high AC corrosion rates. Hence, the ratio of AC current density to DC current density can be used to assess the AC corrosion likelihood. Provided the ratio is below 3, the AC corrosion is considered insignificant since metal oxidation in the anodic half wave is negligible. The advantage of using the AC/DC current density ratio as an indicator of corrosion likelihood is that the uncertainties regarding the condition of the metal surface (e.g., formation of a passive layer) are eliminated since the coupon surface area characteristics equally impact on both current densities.

10.2. Strategy for managing AC corrosion for CP assets

Since there are various conditions that effect the likelihood of a cathodically protected structure being exposed to AC corrosion, a multi-step approach involving reducing the AC voltage on the structure and current densities as specified below.

1) Reduce the average AC voltage on the structure to a level <15 Vac measured over a 24hr period.
2) Ensure cathodic protection levels are achieved over the entire length of the structure, and:
    a) maintaining the AC average current density to be lower than 30 A/m2 on a 1 cm2 coupon, measured over a 24hr period.; or
    b) maintaining the average cathodic current density to be lower than 1 A/m2 on a 1 cm2 coupon if the AC average current density (rms) is more than 30 A/m2; or
    c) maintaining the ratio between AC current density (($Ja.c)$ and DC current density (($Jd.c$) less than 3 measured over a 24hr period.

10.3. Measurement techniques

AC and DC voltage measurements as well as current density measurement techniques are described in ISO 18086 Corrosion of metals and alloys — Determination of AC corrosion — Protection criteria[3].

Due to the significant step change in practicality of performing corrosion assessments in a field environment, the following staged approach is adopted:

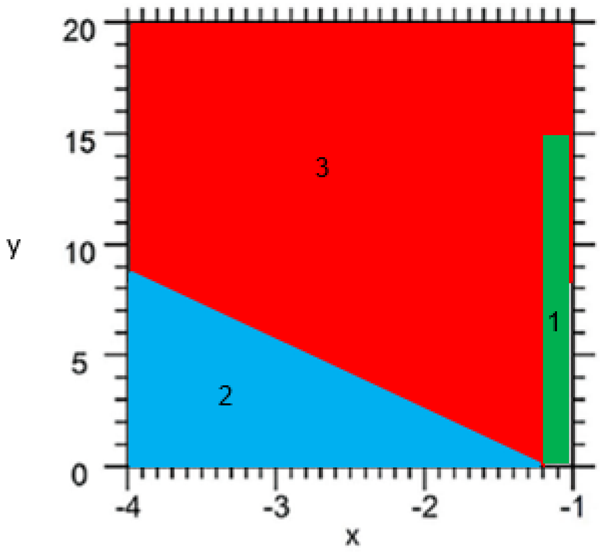
Stage 1 – Initial assessment

1. Measure the steady state induced voltage between a foreign structure and a $Cu/CuSO_4$ reference cell as described in AS 2832.1 [2] and AS 4853 [6]. Published guidance on acceptable voltage levels can be found in CIGRE TB 290 [18] and in EN 15280 [17]. The tolerable limit stated in these documents is:
   1. 4Vac for soil resistivities ≤ 25Ωm; and
   2. 10Vac for soil resistivities > 25Ωm

2. Record the average AC and DC voltage between a foreign structure and a $Cu/CuSO_4$ reference cell placed at remote earth, using a sampling rate of ≤ 1s, over a nominated 24hr period. Using the “X” axis as for the average DC voltage and the “Y” axis for the average AC voltage, apply the result to *Figure 10-1* to determine if AC corrosion is likely.

Stage 2 – Subsequent assessment if AC corrosion is likely as determined from stage 1.

3. Simultaneously record the average AC and DC current densities measured over a nominated 24hr period using a $1cm^2$ coupon placed next to the buried structure. Calculate the ratio between AC current density (Ja.c.) and DC current density (Jd.c.). Apply the result to *Figure 10-2* to determine if AC corrosion is likely.



Legend

1 less negative cathodic protection level

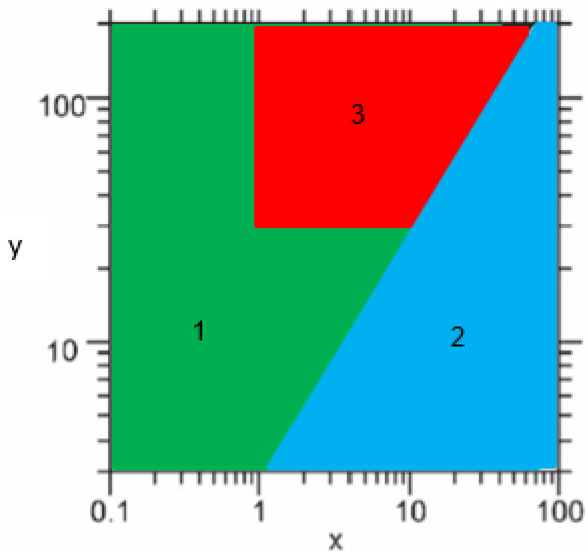
2 more negative cathodic protection level

3 AC corrosion

x Eon (V against the CSE)

y Ua.c. (V)

Figure 10-1: Relationship between DC on-potential, AC voltage and likelihood of AC corrosion



Legend

1 less negative cathodic protection level

2 more negative cathodic protection level

3 AC corrosion

x DC current density (A/m2)

y AC current density (A/m2)

Figure 10-2: Relationship between AC and DC current densities and likelihood of AC corrosion

11. STANDARDISATION AND USE OF INSTRUMENTS

11.1. Connection of Instruments

11.1.1. General

The general efficiency of field testing and the accuracy and reliability of the data obtained, and its interpretation depends to a large degree on the proper use and standardisation of instruments and associated equipment.

11.1.2. Position of Reference cells

When using interference criteria that includes the soil voltage drop such as traction interference or AC interference, the Reference cell should be positioned at remote earth from the structure being assessed. When using interference criteria that assumes minimal soil voltage error such as CP interference, then the Reference Cell should be placed as close as practical to the structure which is being measured.

Note: Large distances between the Reference cell and structure can produce a large soil potential gradient in the measuring circuit and thereby produce misleading interference measurements. For well coated structures, although the Reference cell may be very close to the pipe surface, the Reference cell may still be remote from the nearest coating defect, thus producing a large soil gradient in the measurement. When objectionable interference is measured, and where practical, the nearest coating defect should be identified, and interference measured with a Reference cell adjacent to the defect. Pipeline owners can advise the locations of their defects from historical DCVG surveys where applicable. Placement of the Reference cell adjacent to a coupon that is bonded to the structure is also effective in minimising errors from soil potential gradients.

11.1.3. Digital Voltmeters

Connect the red positive lead to the structure and the black negative lead to the Reference cell.
Note: When connected in this manner the negative sign on the meter indicates that the structure is negative with respect to the soil (Reference cell).

11.1.4. Analogue Voltmeters

Connect the red positive lead to the structure and the black negative lead to the Reference cell.

> ***Note:*** *Centre-zero meters will display negative potential readings (i.e., structure negative with respect to soil) to the left of the zero.*
> *Left-hand zero meters should be provided with a polarity-reversing switch. With the switch in the reverse-polarity position the meter then indicates that the structure is negative with respect to soil (Reference cell).*

11.1.5. Ammeters

When measuring current returning to the rail line, connect the ammeter in series with the RD system with the negative terminal to rail. When measuring current in cathodic protection circuits, connect the positive terminal of the meter to the anode-side of the circuit. Correct direction of current flow is indicated by a positive reading on the ammeter, when connected as described.

11.1.6. Recording Voltmeters and Ammeters

Recording voltmeters and ammeters are to be connected to produce a chart that conforms with Figure 11-1.

Figure 11-1: Format for Charts with Time Base

11.1.7. Connection of Recording Voltmeter

The correct method of connection for single pen recording is shown in Figure 11-2 (primary structure) and Figure 11-3 (foreign structure).

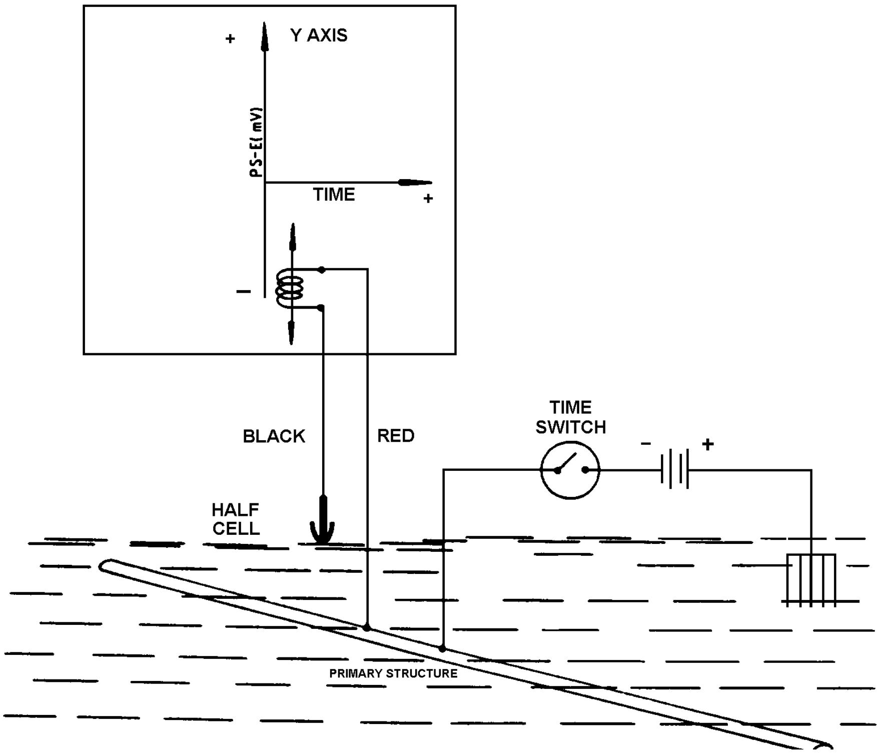


Figure 11-2: Connection of Y-T recorder-primary structure, impressed current system

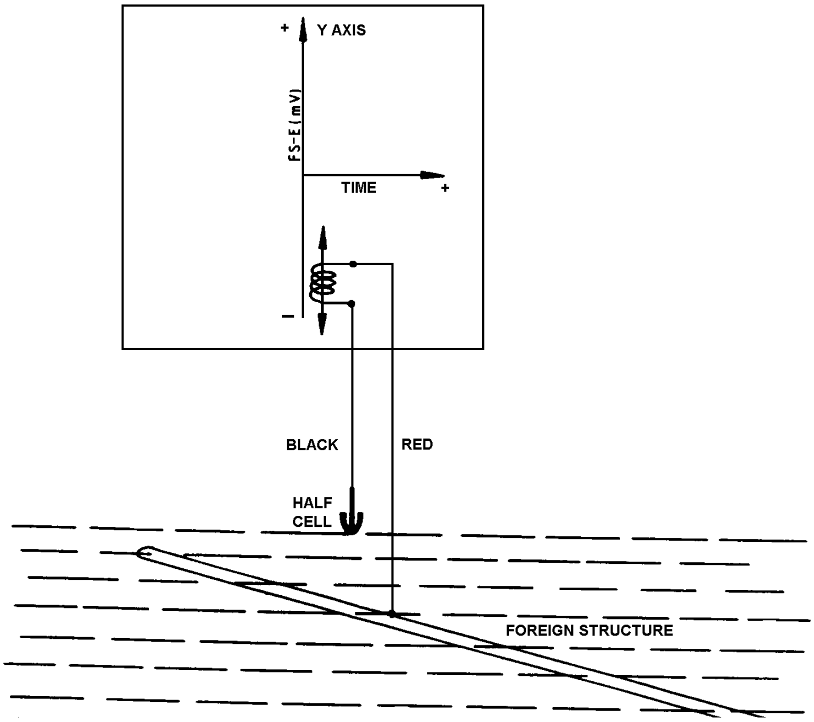


Figure 11-3: Connection of Y-T recorder-foreign structure, Impressed current system

11.1.8. Connection of Dual channel Recorders

The correct method of connection for Dual channel recording of current and potential is shown in Figure 11-4 (primary structure) and Figure 11-5 (foreign structure).

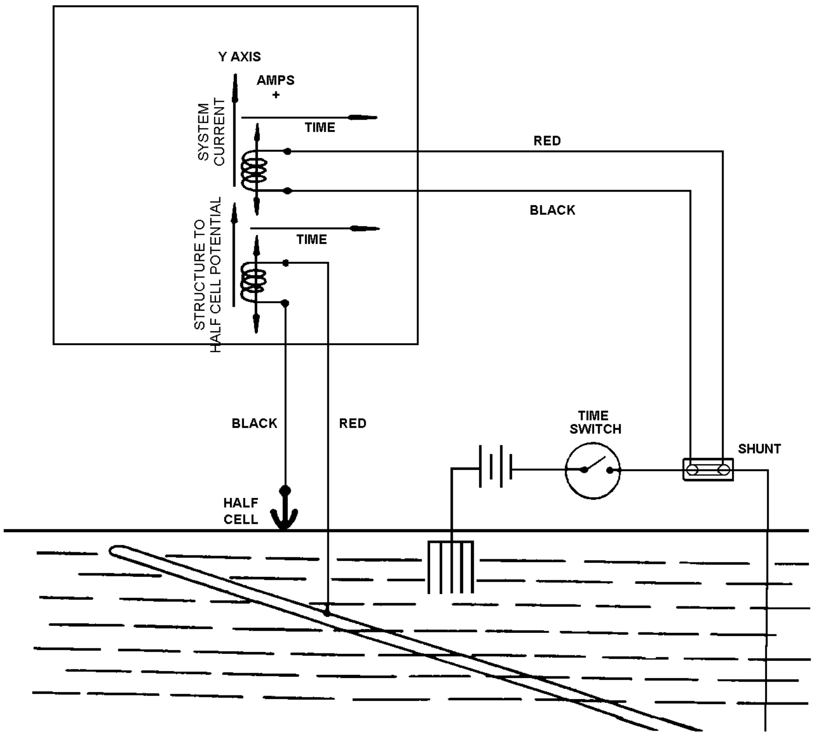


Figure 11-4: Connection to Y-T recorder for dual recording of current and potential for a primary structure

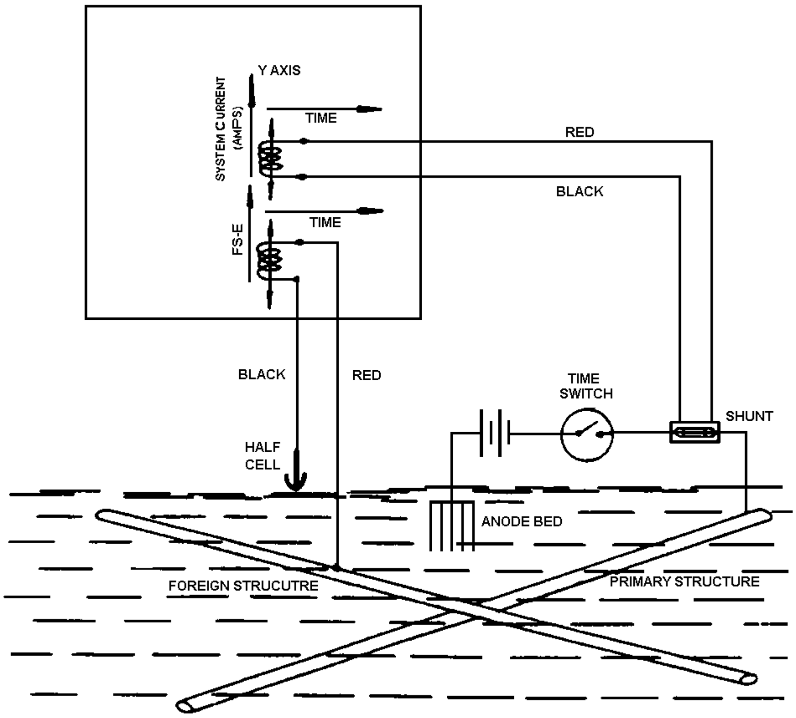


Figure 11-5: Connection of Y-T recorder for dual recording of foreign structure potential and system current

11.1.9. Connection of X-Y Recorder for Railway Drainage Systems

Connections are as follows:

a) Primary structure correlation is recorded with the potential of the structure to a Reference cell recorded on the vertical Y-axis, refer to Figure 11-6.

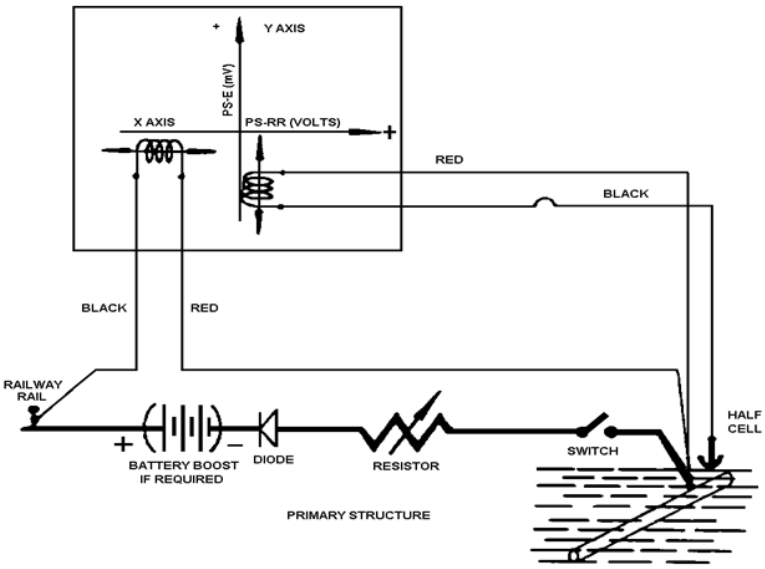


Figure 11-6: Connection of X-Y Recorder for the primary structure correlation chart

b) System conductance chart is recorded using the connections shown in *Figure 11-7*.

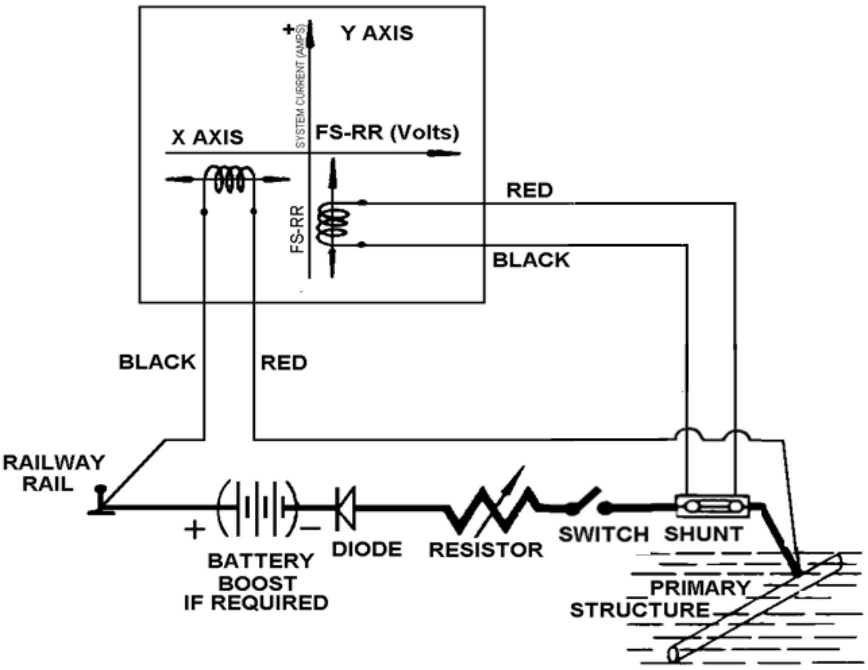


Figure 11-7: Connection of X-Y recorder for measurement of conductance

c) Foreign structure correlation is recorded with the connections shown in Figure 11-8

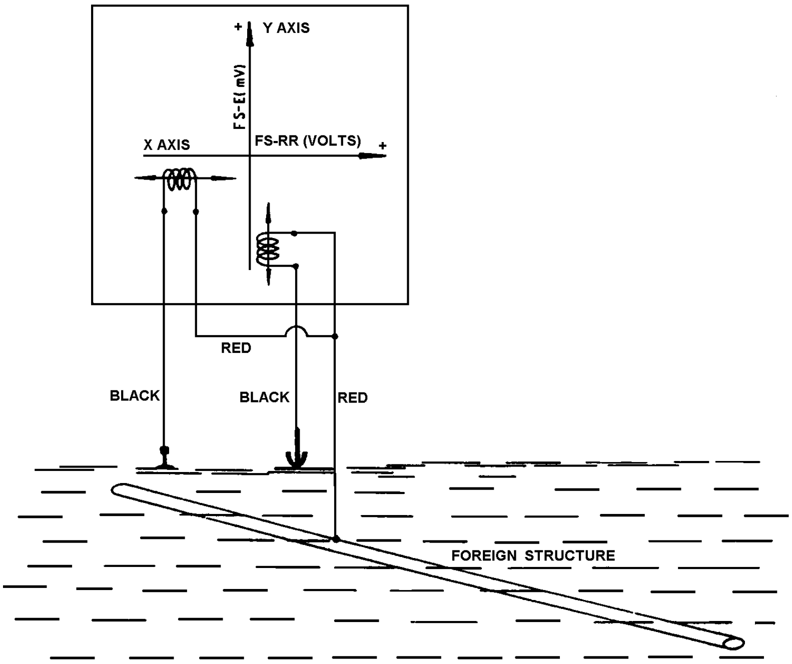


Figure 11-8: Connection of X-Y recorder for measurement of interference - foreign structure correlation

11.2. Standardised Test Equipment

The reasons for standardising equipment are:

(a) The recommended equipment is considered to be most suitable for the tasks, both in terms of accuracy of the reading obtained, and the convenience of use.

(b) The use of common equipment, combined with a standardised approach to use of the equipment, minimise the probability of misunderstanding and misinterpretation of data.

11.2.1. Portable Voltmeters (Direct Current)

(a) Internal Impedance: ≥10 MΩ.

(b) Suggested Ranges:

Analogue:	150mV, 300mV, 1.5V, 15V, 30V
Digital:	200mV, 2V, 20V, 200V

(c) Limitation on Use:
Portable meters can be difficult to read in traction-affected areas because of the constant fluctuations in voltage. Where significant traction interference exists, a recording voltmeter is recommended.

11.2.2. Portable Ammeters (Direct Current)

Ammeters are to be used with caution because of the possibility of inaccurate measurement caused by the additional resistance inserted into low resistance circuits by the ammeter. Use of low resistance shunt and voltmeter is recommended (see Section 11.2.10 for details of shunts).

11.2.3. Recording Voltmeters

(a) CAT IV Instrumentation with internal impedance: ≥10 MΩ.

(b) Desirable Ranges:
10, 20, 50, 100, 200, 500mV;
1, 2, 5, 10, 20, 50, 100V

(c) Sample rate:
e.g. 5s or 6s per cm, is suggested.

(d) The instrument should be equipped with an AC filter. A centre zero with adjustable zero offset facility is desirable.

11.2.4. Current Recording

Use a low resistance shunt and a recording voltmeter (see Section 11.2.10).

11.2.5. XY-YT Recorder

(a) CAT IV Instrumentation with internal impedance: ≥10 MΩ.

(b) Desirable ranges (both axes):
50, 100, 200, 500 millivolts and 1, 2, 5, 10, 20, 59, 100 Volts.
A convenient speed is 20s/cm.

11.2.6. Reference Cells

(a) A copper/copper sulphate ($Cu/CuSO_4$) Reference cell is recommended except for marine environments or soils with chloride ion content more than 1000 ppm (parts per million) where silver/silver chloride (Ag/AgCl) is used. Data must be standardised to copper/copper sulphate in those cases where alternative metal reference cells are used. The cell should have a minimum diameter over the porous plug of 25mm. For high resistivity soils (soils above 100 ohm-metre) larger diameter Reference cells are recommended. All Reference cells should be used with high impedance instrumentation.
Refer to Appendix I for details of cell calibration and to Australian Standard AS2832.1[2] for further information.
Diagrams in this Guide use both the copper/copper sulphate Reference cell and metal electrodes. to express the structure to earth potential.

(b) Refer to Appendix H for further details about use, calibration and maintenance of Reference cells.

11.2.7. Data Loggers

(a) Data loggers should be capable of frequent sampling over a minimum period of 48 hours. 1s to 10s sampling rates are common, however rapid sampling of 20ms may be required for assessment of Polarisation recordings, particularly on structures with fast Polarisation characteristics.
(b) IT hardware should be available (usually portable computer and printer) for production of 24-hour average data and Time of Operation
(c) The instrument should be self-contained and weather-proof and capable of connection to a printer and/or computer for production of graphical output.

11.2.8. Metal Earth Reference Electrodes

Copper/copper sulphate ($Cu/CuSO_4$) and silver/silver chloride (Ag/AgCl) reference cells should be used in preference to metal electrodes.
(a) Metal earth electrodes should be of a practical minimum diameter (e.g. 12 to 25mm diameter). Lengths as convenient to allow a minimum insertion of 150mm. Refer to Appendix I for calibration of metal reference electrodes. Data must be standardised to copper/copper sulphate in those cases where alternative metal reference electrodes are used (refer to Appendix I for details of electrode calibration).
(b) Polarisation of metal stakes may occur and produce a drift in measured potential over a time period ranging from minutes to days.

11.2.9. Interference Probes

Interference probes (which claim to minimise soil voltage drop) and coupons (which directly measure metal loss) may be used as complements to conventional Reference cells and electrodes.

11.2.10. Shunts

Shunts must be of robust construction including a substantial baseplate and heavy duty terminals. The shunt V/A should be selected for the maximum expected current. The following shunt sizes are suggested:

1A	-100mV (for use with system current up to 1A only)
10A	-100mV
50A	-100mV
100A	-100mV

With an accuracy equal to or better than $\pm$ 1%.

11.2.11. Trial Railway Drainage Panel

See Appendix K.

11.2.12. CP Unit Switching Timers

AS2832.1 suggests using 20s "on" and 10s "off" for interference testing. Experience has shown that where traction interference is present, the longer the "on" time is the more difficult it is to identify the structure "on" potential due to larger variations in magnitude. Conversely, the shorter "on" times may not be sufficient for older TRs to ramp up to the desired output current which leaves inadequate time to identify the full shift between "on" and "off" potentials. The NSWEC believe that cyclic switching using 10s "on" and 5s "off" provides the most practical timing for interference testing.

a) The timers may switch either the AC supply or the DC output of transformer - rectifier units. It may be difficult to switch heavy DC current without damaging the contacts.
b) The timing cycle should be adjustable to accommodate 10 seconds "ON" and 5 seconds "OFF".

11.2.13. Test Cables

Cable reels should have a minimum length of 100 metres of cable and consist of red and black figure eight cable. The reel should be fitted with heavy duty non-interchangeable two-pin plugs. Red coloured cable is used to connect structure and black coloured cable is used to connect Reference cell to voltmeter. Double insulated cables are recommended for use in harsh environments.

11.2.14. Potential Offset Device

The offset device to have a continuously variable range between zero and 3.0 volts. Refer to Appendix L for use of offset devices.

11.2.15. Instrument Accuracy

Instruments should conform to Australia Standards AS1042[7] and AS1024[8]. Routine calibration of instruments is needed for accuracy of results.

12. REFERENCES

[1] Electricity Supply (Corrosion Protection) Regulation

[2] AS 2832 Cathodic Protection of Metals, Parts 1 to 5

[3] ISO 18086 Corrosion of metals and alloys — Determination of AC corrosion — Protection criteria

[4] Cathodic Protection of Underground Structures, Energy Authority of NSW (1985)

[5] ACA Conference 2019 paper 13 – Stray Traction Current Interference Criteria for Assets without Cathodic Protection

[6] AS/NZS 4853 Electrical hazards on metallic pipelines

[7] AS 1024 Direct recording electrical measuring instruments and their accessories

[8] AS 1042 Direct acting indicating electrical measuring instruments and their accessories

[9] AS 3859-1991 Effects of current passing through the human body

[10] AS 2225-1994 Insulating gloves for electrical purposes

[11] AS 2210.2:1994 Occupational protective footwear Part 2: Specification

[12] AS 2210.1:1994 Occupational protective footwear Part 1: Guide to selection, care, and use

[13] AS 3527.2:1990 Hand-operated screwdrivers and screwdriver bits, Part 2: Insulated screwdrivers

[14] NACE RP-01 -77 (1983) Electrical Safety

[15] IEC 900,1987 Hand Tools For Live Work Up To 1,000 VAC and 1,500 VDC

[16] EA TP26-3,1984 Hand Held Insulated Tools For Live Working Up to 1000 Volts.

[17] EN 15280 Evaluation of AC corrosion likelihood of buried pipelines applicable to catholically protected pipelines

[18] CIGRE TB 290 AC Corrosion on metallic Pipelines due to Interference from AC Power Lines – Phenomenon, Modelling and Countermeasures

[19] ISO 21857 Petroleum. Petrochemical and natural gas industries – prevention of corrosion on pipeline systems influenced by stray currents

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[23] Dover BL, “Measurement of Interference caused by Cathodic Protection Systems”. Paper delivered to Cigre' Colloquium, Montreal, Canada, June 1987.

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[25] Martin BA, “Potential Measurement on Buried”. Paper delivered to conference on Cathodic Protection Theory and Practice - The Present Status, Coventry, England, 1982.

[26] Morgan J, “Cathodic Protection”, 2nd edition, Publication by the National Association of Corrosion Engineers, Houston, Texas, USA, 1988.

[27] Peabody A W, “Control of Pipeline Corrosion”. National Association of Corrosion Engineers, Houston, Texas, USA, 1978

[28] Robertson A G, “The Protection of Underground Water Mains from Electrolysis”. Melbourne and Metropolitan Board of Works, Melbourne, 1975.

[29] Szeliga Michael J, “Stray Current Corrosion. The Past, Present and Future of Rail Transit Systems”. National Association Of Corrosion Engineers, Houston, USA, 1994.

[30] Uhlig H H, “Corrosion and Corrosion Control”, Wiley, New York, 3rd Edition, 1985.

[31] Woodberry W K, “Cathodic Protection of Underground Structures” Energy Authority of NSW, Sydney, 1985.

[32] NSWEC Charter February 2018

Appendix A Structure Categories

The separation of underground structures into categories is considered necessary as an integral part of the selection of the interference criteria outlined in Appendix B. The underlying assumptions are that certain structures pose a greater risk to life and property and/or have greater asset value, and the cost of failure is higher and should therefore have more restrictive interference criteria than less risk-prone structures.

CATEGORY ONE (Cat 1)

a) Category one is the highest category, and these structures include the following:
b) High-pressure (> 250 kPa) gas and petroleum pipelines.
c) LPG and propane gas tanks.
d) ATC Coaxial, Trunk and Junction telecommunication cables.
e) Underground power cables of 11 kV and greater, including associated pilot cables.
f) Pipelines containing toxic materials.

CATEGORY TWO (Cat 2)

a) Category two structures include the following:
b) All steel and other metallic pipelines containing flammable materials, not included in CATEGORY ONE.
c) ATC Main telecommunication cables.
d) All steel, cast iron and ductile iron water pipelines equal to or greater than 600mm diameter.
e) Underground power distribution cables 240V and greater but less than 11kV and associated pilot cables.
f) Electrical system earthing structures.
g) Critical concrete structures such as bridges and viaducts

CATEGORY THREE (Cat 3)

a) Category three structures include the following:
b) All metallic water pipelines not already included in CATEGORY TWO.
c) ATC Subscriber's telecommunication cables.
d) All other low voltage (< 415V) cables which do not form part of the main distribution system, e.g., street lighting and other individual service cables.
e) Concrete structures such as building footings

Appendix B Guidelines for Interference Acceptance Criteria

The criteria selection is the agreed outcomes from NSWEC members contributions.

Table 12-1, Table 12-2 & Table 12-3 show values for interference acceptance/rejection criteria for assets with cathodic protection while Table 12-4 contains the criteria for assets without cathodic protection. These criteria are based on practical experience and should not be varied except by agreement between the parties concerned.

Notes:

1. Cathodic interference criteria apply only where there is no metallic connection between the protected and foreign structures.
2. Multiple Interference
3. Where a foreign structure is affected by interference from more than one source and the foreign structure owner has taken all reasonable measures to mitigate this background interference, then the owner may object to additional interference, using Appendix B as a guide. However, if any party has not taken all reasonable measures to mitigate background interference, then the party will be expected to accept greater levels of additional interference than are listed in Appendix C.
4. The actual potential is measured with the *interfering* cathodic protection system turned off.
5. All potentials are measured relative to a **$Cu/CuSO_4$** Reference cell.
6. Current Measurement

Where unacceptable interference has been measured on uncoated structures, the parties concerned may agree to consider the magnitude of the current in a cross-bond between the primary and uncoated foreign structures as an additional criterion. This approach may be acceptable because very low interference currents may be involved, indicating that interference corrosion would be insignificant even though the foreign structure potential shift exceeds the criteria. If this approach is adopted, then the following steps are taken:

a) provide a cross bond between the primary and foreign structures
b) measure the current required to offset the interference, with the system operating and decide if the apparent increase in corrosion hazard is objectionable, taking into consideration the following factors:

1. the change in potential on the foreign structure before and after applying the cross bond
2. the cross bond current
3. the Appendix A Category
4. the electrical continuity of the foreign structure.

Appendix C Interference Criteria for Assets with Cathodic Protection

Table 12-1: Stray CP Interference Criteria for CAT 1 Assets with CP

Structure Category	Protection Level Excluding Soil V.drop (mV)	Protection Level Including soil V.drop (mV)	Actual Measured Potential to $Cu/CuSO_4$ mV*	Criteria for Interference Including soil V.drop	
				Anodic shift Δ(mV)	Cathodic shift Δ(mV)
Cat 1 Steel	-850	-850 + -1mV/Ωm Soil.Res	more anodic than Protection Level	10	100
			Protection Level to -1200 + -1mV/Ωm Soil.Res	20	100
			more cathodic than -1200 + -1mV/Ωm Soil.Res	20	10
Cat 1 Lead & Aluminium	-650	-650 + -1mV/Ωm Soil.Res	more anodic than Protection Level	10	150
			Protection Level to -1200 + -1mV/Ωm Soil.Res	20	100
			more cathodic than -1200 + -1mV/Ωm Soil.Res	30	20
Cat 1 Copper	-300	-300 + -1mV/Ωm Soil.Res	more anodic than Protection Level	10	150
			Protection Level to -1200 + -1mV/Ωm Soil.Res	20	100
			more cathodic than -1200 + -1mV/Ωm Soil.Res	30	20

NB: Where MIC is present or structure operates at elevated temperatures, add -100mV to the protection level

Table 12-2: Stray CP Interference Criteria for Cat 2 Assets with CP

Structure Category	Protection Level Excluding Soil V.drop (mV)	Protection Level Including soil V.drop (mV)	Actual Measured Potential to $Cu/CuSO_4$ mV*	Criteria for Interference Including soil V.drop	
				Anodic shift Δ(mV)	Cathodic shift Δ(mV)
Cat 2 Steel	-850	-850 + -1mV/Ωm Soil.Res	more anodic than Protection Level	20	100
			Protection Level to -1200 + -1mV/Ωm Soil.Res	20	100
			more cathodic than -1200 + -1mV/Ωm Soil.Res	30	50
Cat 2 Lead & Aluminium	-650	-650 + -1mV/Ωm Soil.Res	more anodic than Protection Level	20	150
			Protection Level to -1200 + -1mV/Ωm Soil.Res	30	100
			more cathodic than -1200 + -1mV/Ωm Soil.Res	40	50
Cat 2 Copper	-300	-300 + -1mV/Ωm Soil.Res	more anodic than Protection Level	20	150
			Protection Level to -1200 + -1mV/Ωm Soil.Res	30	100
			more cathodic than -1200 + -1mV/Ωm Soil.Res	40	50

NB: Where MIC is present or structure operates at elevated temperatures, add -100mV to the protection level

Table 12-3: Stray CP Interference Criteria for Cat 3 Assets with CP

Structure Category	Protection Level Excluding Soil V.drop (mV)	Protection Level Including soil V.drop (mV)	Actual Measured Potential to Cu/CuSO4 mV*	Criteria for Interference Including soil V.drop	
				Anodic shift Δ(mV)	Cathodic shift Δ(mV)
Cat 3 Steel	-850	-850 + -1mV/Ωm Soil.Res	more anodic than Protection Level	20	100
			Protection Level to -1200 + -1mV/Ωm Soil.Res	40	100
			more cathodic than -1200 + -1mV/Ωm Soil.Res	60	50
Cat 3 Lead & Aluminium	-650	-650 + -1mV/Ωm Soil.Res	more anodic than Protection Level	20	200
			Protection Level to -1200 + -1mV/Ωm Soil.Res	40	100
			more cathodic than -1200 + -1mV/Ωm Soil.Res	60	50
Cat 3 Copper	-300	-300 + -1mV/Ωm Soil.Res	more anodic than Protection Level	20	200
			Protection Level to -1200 + -1mV/Ωm Soil.Res	40	100
			more cathodic than -1200 + -1mV/Ωm Soil.Res	60	50

Note; *Where microbial induced corrosion (MIC) is present or the structure operates at elevated temperatures, add -100mV to the protection level*

Note: *Where unacceptable levels of interference are recorded, the interested parties (source and affected assets owner) may agree to vary the acceptance criteria, particularly, if the affected structure is adequately cathodically protected. The above agreement may also include more frequent interference verification periods.*

Appendix D Interference Criteria for Assets without Cathodic Protection

Table 12-4: Interference Criteria – Single Electrode Anodic Average Current (per metre) without CP

Lead and Aluminium	Copper and Steel
110μA/m	340μA/m

Single electrode (Ø14.5mm x 1.8m) – Anodic Average potential shift including soil voltage drop

Geology	Soil Resistivity Ωm	Anodic Average Shift Pb & Al Δ(mV)	Anodic Average Shift Cu & Fe Δ(mV)
Loams, garden soils, Clay, chalk	≤10	1	3
	50	5	15
Clay, sand and gravel mixture, Peat, marsh soil and cultivated soil	100	10	30
	250	25	75
Diabase, shale, limestone and sandstone, Fresh water (lakes and rivers)	500	50	150
Sand, caribrian limestone and sandstone	1000	100	300

Table 12-5: Interference Criteria – Pipes and Cables Average Anodic potential shift including soil voltage drop without CP

Geology	Soil Resistivity (Ωm)	Pb & Al ≤ Ø100mm Δ(mV)	Cu & Fe Ø25mm Δ(mV)	Cu & Fe Ø100mm Δ(mV)	Cu & Fe Ø250mm Δ(mV)
Loams, garden soils, Clay, chalk	≤10	1	1	2	4
	50	3	3	9	19
Clay, sand and gravel mixture, Peat, marsh soil and cultivated soil	100	6	6	18	38
	250	15	15	46	94
Diabase, shale, limestone and sandstone, Fresh water	500	30	30	92	188
Sand, caribrian limestone and sandstone	1000	60	60	185	375

Appendix E Determination and Mitigation of the Effects of Fortuitous Connections

Introduction

Cathodic potential changes may be caused by three mechanisms as follows:

1. Significant stray current entering isolated foreign structures (interference),
2. A metallic (fortuitous) connection between the primary and foreign structures,
3. Location of the foreign structures in the strong potential field surrounding a ground bed.

Note: The foreign structure owner should identify which mechanism is affecting his structure, before objecting to excessive cathodic potential change. A cathodic change due to electrical connection to the primary structure is not generally a corrosion threat as the foreign structure has become part of the protected structure.

Determination of Fortuitous Connection

Temporarily connect the foreign and primary structures with a cable and note any change in potential. Negligible change in foreign structure potential indicates there is already a connection between the two structures (fortuitous connection). Conversely, if a change in potential of the foreign structure is measured, this indicates there is no fortuitous connection and therefore the measured potential change is true interference.

Mitigating Actions

Where it is demonstrated that the primary and secondary structures are fortuitously connected, the following should be considered:

a) Locating and breaking the connection thus removing the cathodic potential shift, or
b) Providing an additional and permanent connection (cross-bond) to stabilise the situation, provided the foreign structure is electrically continuous, or
c) Objecting to the primary structure system on the grounds that the cathodic potential change on the foreign structure is unacceptable.

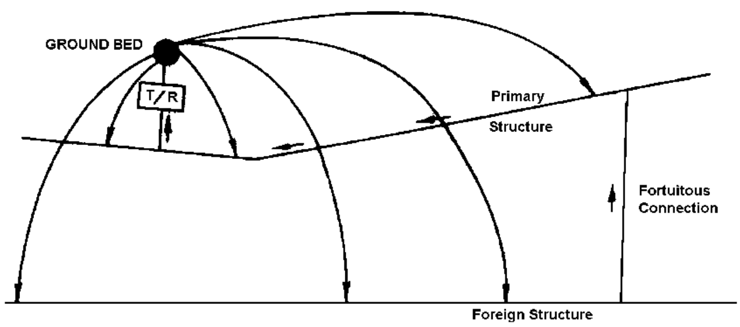

Figure 12-1: Illustration of a fortuitous connection to a foreign structure

Appendix F Production Of X-Y Recorder Charts or Plots

The correlation, conductance and potential-time charts are an important part of the interference measuring process. The techniques of construction are detailed in the sections below. Interpretation of these charts is covered in the body of the Guide.

Potential Time Charts

The chart is used for two purposes:

1. Evaluation of the protection provided by a cathodic protection system to the primary structure, and
2. Measurement of the interference caused on foreign structures by the cathodic protection system.

Production of foreign structure to earth charts on a single pen Y-T recorder or digital chart for the purpose of measuring interference, is straight forward, although it can be difficult to read the switching points on structures heavily affected by stray DC current from railways. In these cases, the system "ON" and "OFF" points will need to be identified on the chart by the Testing Officer at the moment of system switching. The following scale ranges have been found to be convenient: 20 s/cm time scale and potential scales of 500 mV to 2.0V full scale.

Generally, it is better to use a dual channel chart recorder that simultaneously records both system current and structure potential. This allows precise identification of the exact point of switching on the potential graph.

Correlation Charts (Potential-Potential)

The correlation chart is very useful for determining interference from a targeted source when multiple sources are interfering with a common foreign structure. The three main purposes are:

1. Measurement of the effect of stray traction DC current on structures,
2. Evaluation of the "protection" provided by the railway drainage system to the primary (bonded) structure, and
3. Measurement of the interference caused on foreign structures by a drainage bond applied to a primary structure.

These charts display the structure to rail (S-RR) or earth to Rail (E-RR) potential against the structure to earth (S-E) potential and two straight lines are constructed for this relationship, one line for the system "ON", and one for system "OFF". See Figure 8-3, Figure 8-6 & Figure 8-7 in the body of this Guide.

The main difficulty with production of the correlation chart is drawing a correct line through the data points. It is normal for the S-RR voltage to fluctuate rapidly at all locations and for the correlation to change at some locations. This means that careful attention must be paid to the rapidly changing data points to pick the switching points through which the lines are subsequently drawn. The chart must contain only one correlation so that the effect of system switching on this correlation is clearly seen and is not confused with changes in the correlation. It may be necessary to hand-mark the switching points whilst switching the bond with a remote-controlled DC contactor.

The following copies of actual examples illustrate the drawing of the correlation lines through the data points recorded on an analogue X-Y plotter. When using digital charting, a linear trend line can be added to the chart to automatically display the trend of the data.

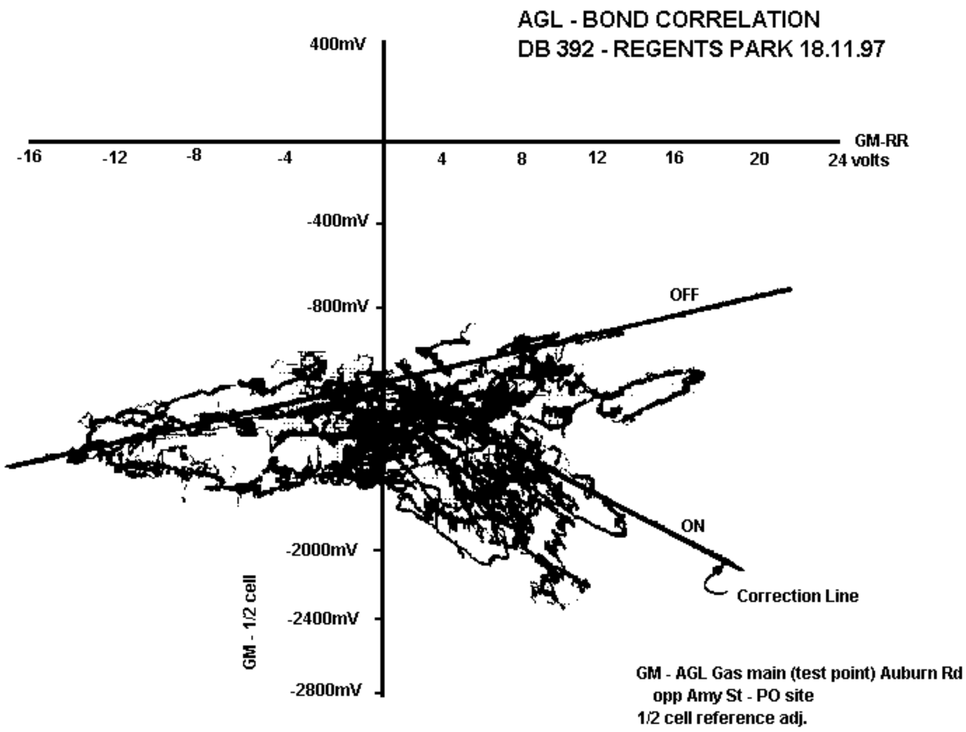

Figure 12-2: Construction of the correlation line - example one - a gas main

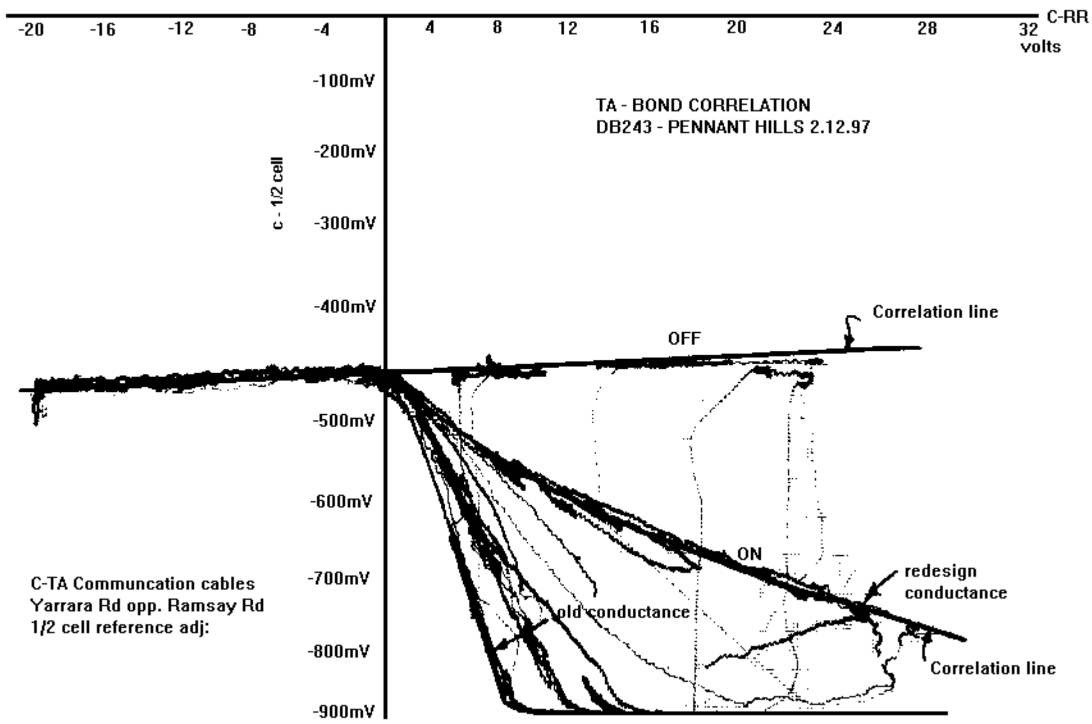

Figure 12-3: Construction of the correlation line - example two
Australian Telecommunications Corporation cable

Conductance Charts (Current-Voltage)

The conductance of a railway drainage system is defined as the system current divided by the structure to rail voltage (S-RR) or earth to rail (E-RR). The accepted conductance value is obtained by charting the system current against S-RR voltage and calculating conductance at the appropriate structure-to-rail voltage. (Refer to Figure 8-2).

Points to note when producing the conductance chart are:

1. The chart can only be produced when the system is conducting, that is when S-RR or E-RR voltage is more positive than +0.7 volts, the "switch-on" voltage for the diode normally included in the circuit.
2. The conductance line is a straight line drawn through the data points and passing through the zero amperes +0.7 volts point. Heating of lamps in the bond circuit can cause curving of this line due to the positive temperature coefficient of the lamp elements.
3. The recording needs to be taken at a time when S-RR voltage is varying sufficiently to allow drawing of a valid line, for example, over a 3 volt range.

Appendix G Boosted Systems

Temporary Boosting Of PS-RR Voltage

Where the primary structure-to-rail voltage is negative at the time of interference testing and the system is therefore not passing current, a temporary DC boost may be used to cause the bond to conduct. The boost should consist of a DC power supply inserted in the system circuit with positive terminal connected to the rail. The boost voltage should be recorded on the test data sheets. As far as is practical the boost voltage should provide the approximate average operating current of the system.

Note: The use of temporary boosting may introduce abnormal conditions of testing due to artificially raising the PS-RR voltage at one location. Therefore, testing time should be arranged as far as practical at times where boosting is not required. When temporary boosting is used, other drainage systems applied to the primary structure in the near vicinity, that are likely to cause overlapping interference on the foreign structure, should be boosted to the same voltage to allow an accurate measure of the combined interference effects on the foreign structure.

Conductance Chart-Temporarily Boosted RD Systems

In some cases, a system may need to conduct earlier then what would normally occur once the diode starts to conduct, to achieve satisfactory protection levels e.g., at a time when the PS-RR voltage is negative while the FS voltage is in the unprotected zone.

Figure 12-4 is an illustration of the method of calculating conductance for a temporarily boosted system where, for example, the 24hr average PS-RR voltage is + 6 volts. In this illustration a 4 volt temporary boost is used to cause the system to conduct at a time when the PS-RR voltage is negative. The conductance of the temporarily boosted RD systems is determined using equation (2).

$$G = \frac{I}{V} \qquad (2)$$

Where: G is the conductance in Siemens, I is the system current in Amperes and V is the 24 hour average positive PS-RR voltage measured from the boosted zero.

Correlation Chart - Permanent Boost

Figure 12-7 is an illustration of a primary structure correlation chart for a 45 volt permanent boost. The correlation chart is recorded on a suitable PS-RR voltage scale so as to give a reasonable amount of pen movement over the average PS-RR voltage. The average primary structure to earth potential is determined at V, PS-RR Voltage of 39 Volts (45 Volt permanent boost and -6 Volts 24-hour average PS-RR Voltage) measured from the boosted zero.

Boosted DB System Foreign Structure Correlation Charts

Figure 12-8 and Figure 12-9 are illustrations of foreign structure correlation charts for a temporarily boosted RD system on a steel structure and Figure 12-10 and Figure 12-11 for a permanently boosted system on a steel structure. Interference is measured at V, the modified 24-hour average positive FS-RR voltage measured from the boosted zero.

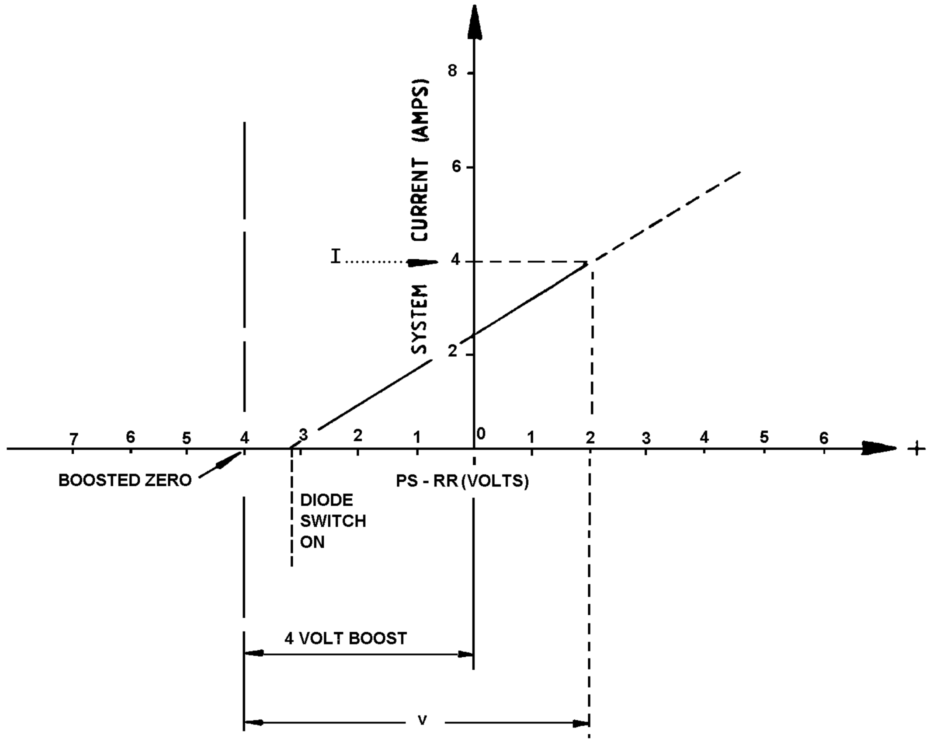

Figure 12-4: Temporarily Boosted System Conductance Chart

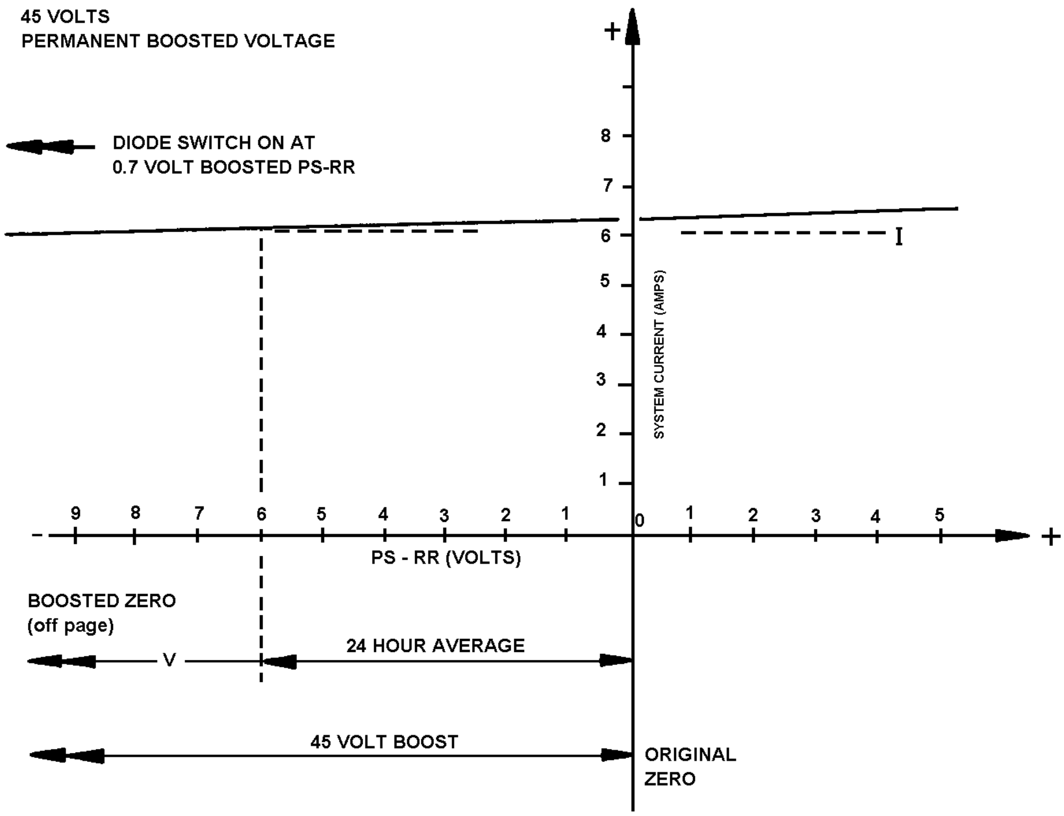

Figure 12-5: Permanently Boosted System - Conductance Chart

Correlation Chart - Temporary Boost

Figure 12-6 is an illustration of a temporarily boosted RD system correlation chart for a structure using a 4 volt boost. The average structure potential to earth of the primary structure is determined at the 24hr average of 6 volts. In this illustration the average PS-E potential is about 1280 mV negative measured from the boosted zero.

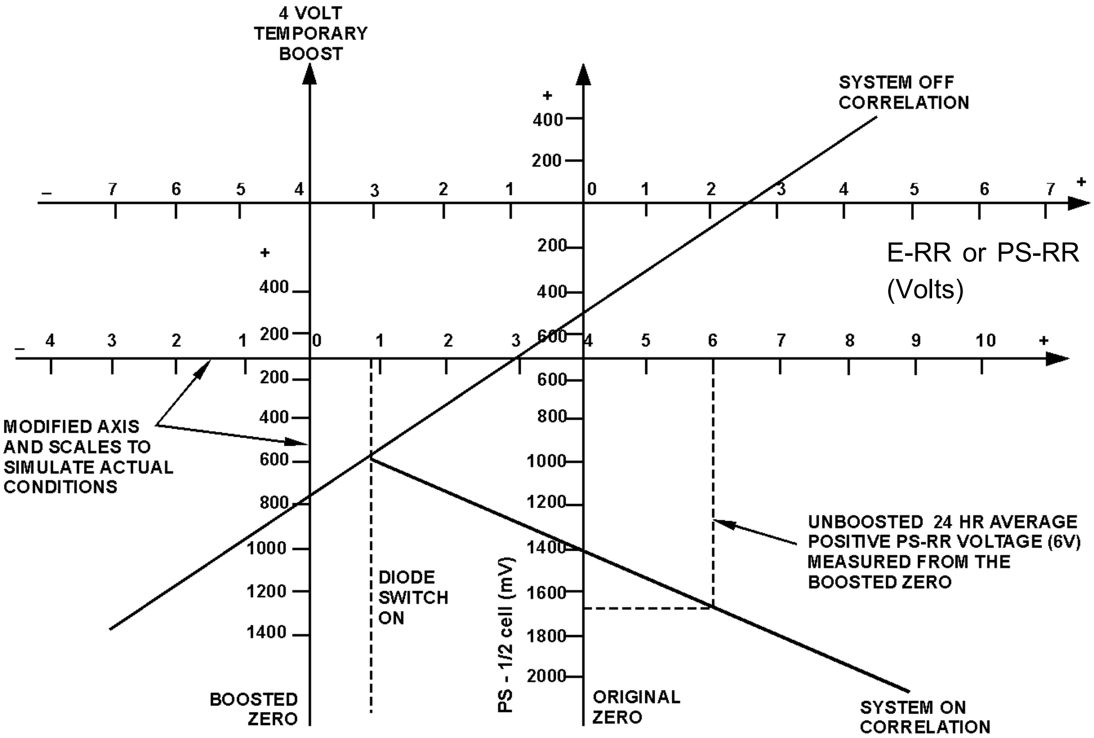

Figure 12-6: Temporarily boosted railway drainage system correlation chart - Primary Structure

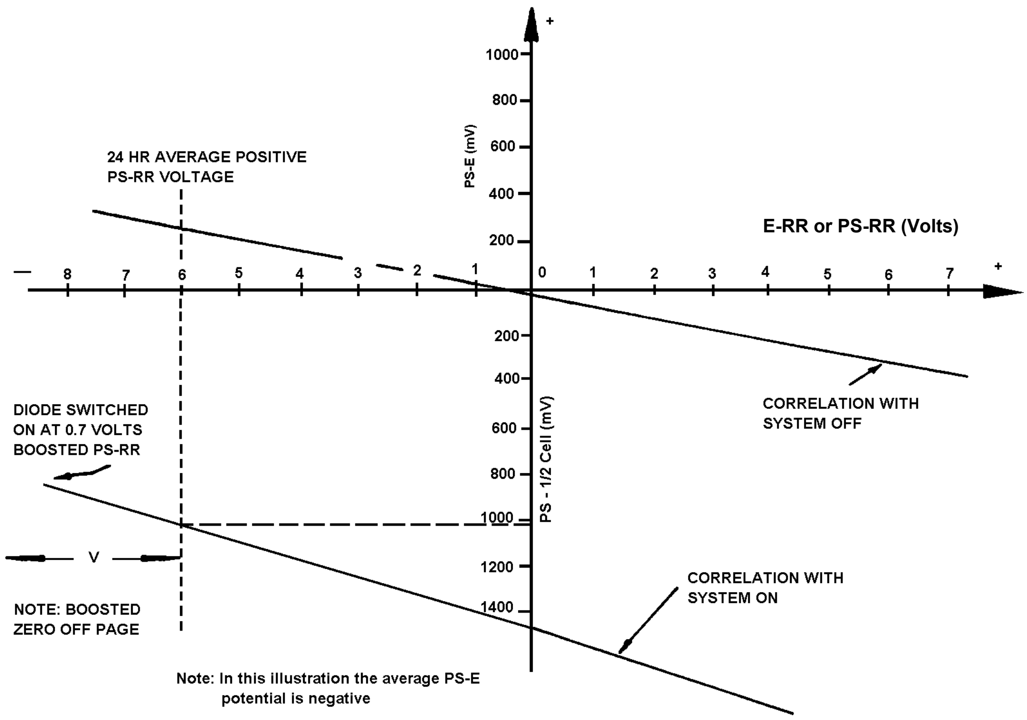

Figure 12-7: Permanently boosted railway drainage system correlation chart - Primary Structure

Conductance Chart-Permanently Boosted RD System

Permanently boosted systems are used in cases where stray traction current is adversely affecting structures in circumstances where PS-RR is mostly negative, and a conventional system will not conduct. Figure 12-5 is an illustration of the method of calculating conductance for a permanently boosted railway drainage system where, for example, the 24hr average positive PS-RR voltage is -6 volts. In this example a boost of 45 volts is used to cause the system to conduct in circumstances where the PS-RR voltage is mostly negative. The conductance chart is recorded on the normal PS-RR voltage scale to give a reasonable amount of pen movement over the average PS-RR voltage. The conductance of the permanently boosted RD system is determined by using equation (3).

$$G = \frac{I}{V} \quad (3)$$

Where: G is the conductance in Siemens

I is the system current in amps with boost

V is the sum of the average PS-RR voltage and the boost voltage, in volts, i.e., V is the average system voltage measured from the (off-page) boosted zero.

e.g., Conductance = 6.0 amps = 0.15 Siemens at 39 volts

45 + (-6) (-6V, 24hr average PS-RR volts plus 45 volts permanent boosted).

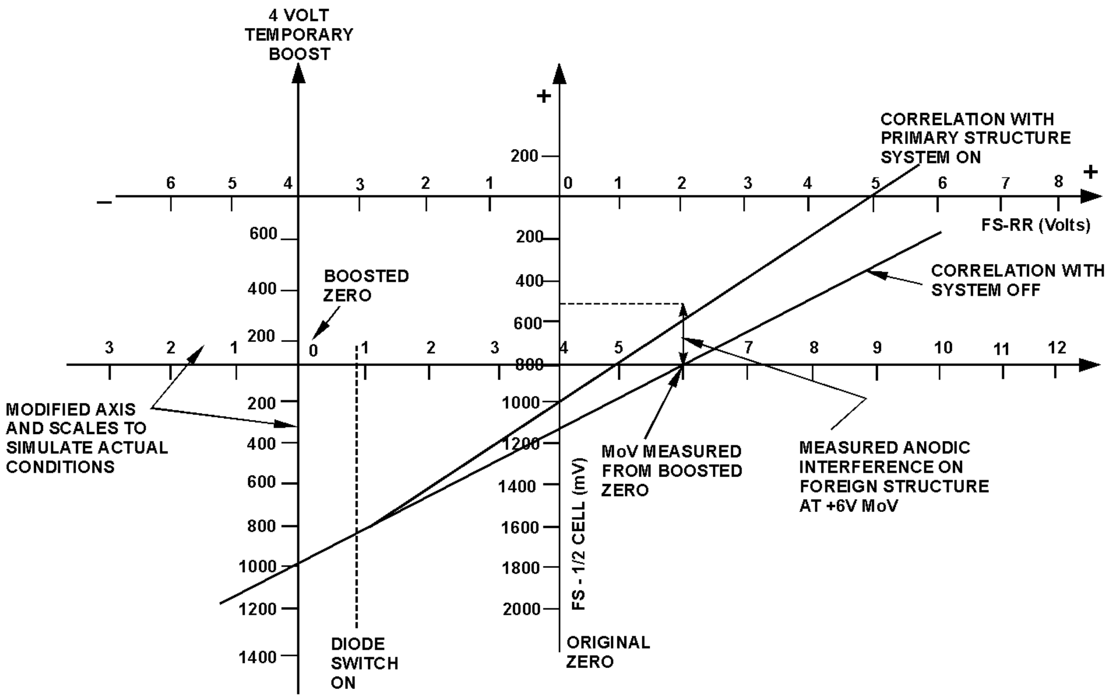

Figure 12-8: Anodic Interference - temporary boost

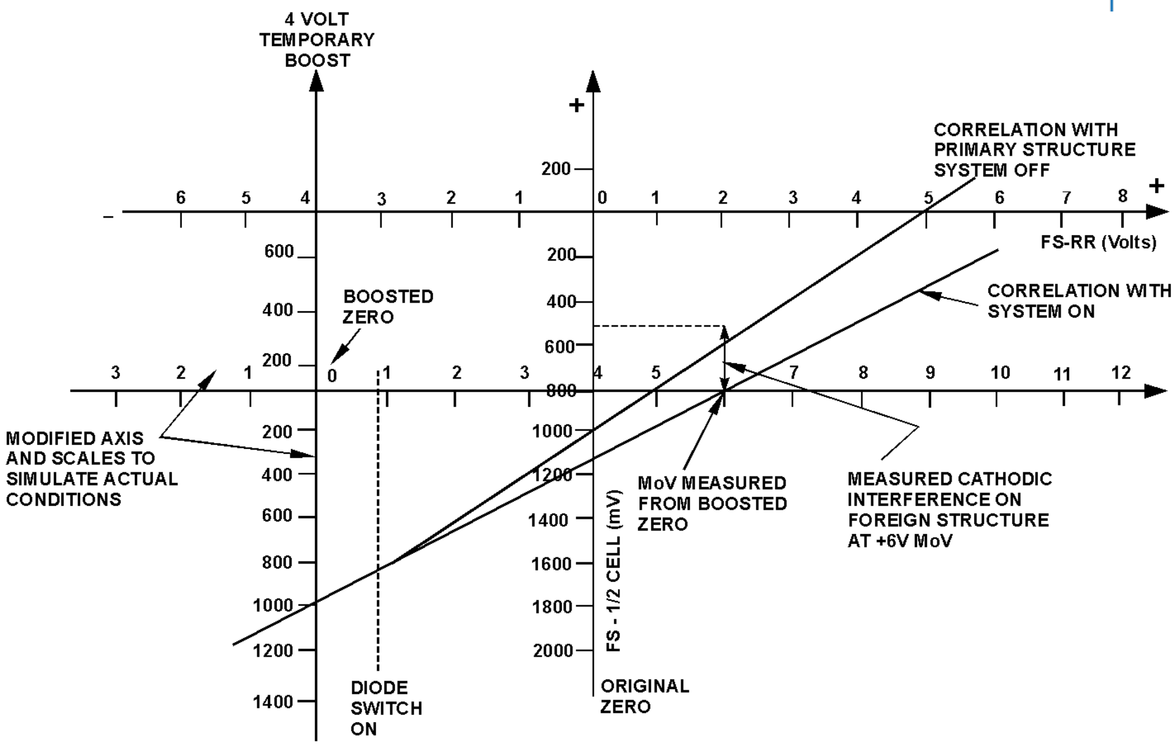

Figure 12-9: Cathodic interference - temporary boost

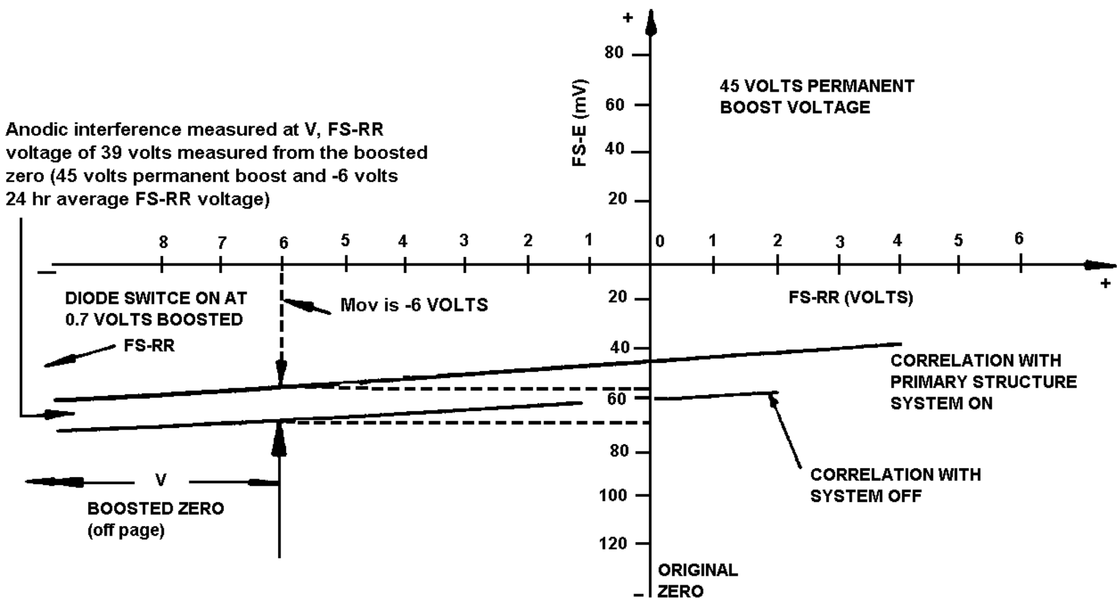

Figure 12-10: Anodic interference - permanent boost

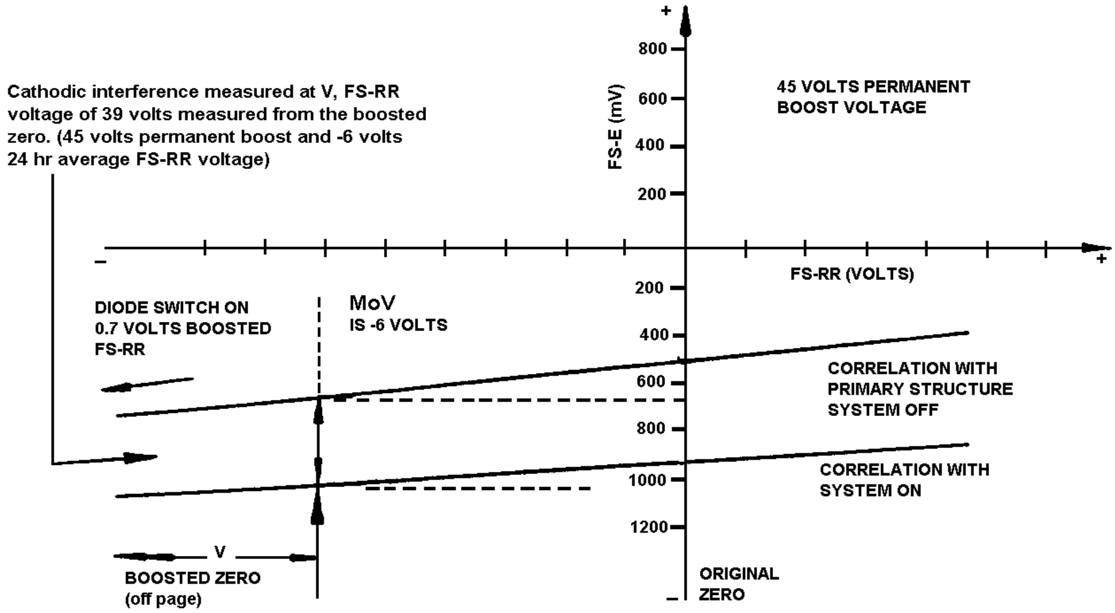

Figure 12-11: Cathodic interference - permanent boost

Appendix H Reference Cell

Potential Measurement

Potential differences between underground structures and the surrounding electrolyte are measured with the help of reference cells. The Reference cell normally used is a copper/copper sulphate reference cell which consists of a copper rod placed in a saturated solution of copper sulphate in a container having a porous plug at the base (see Figure 12-12).

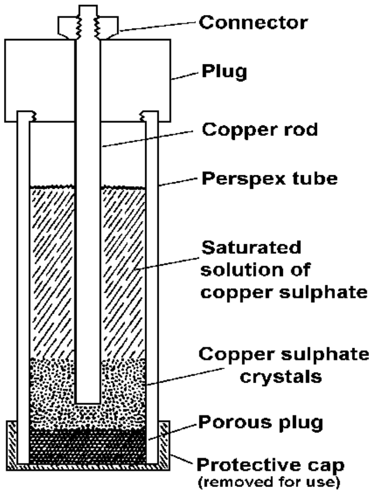

Figure 12-12: Copper Sulphate reference cell

In non-traction areas, the "actual" or "natural" potential difference between the structure and the surrounding electrolyte is generally determined by galvanic action. The potentials are generally steady or subject only to long term fluctuation. In traction affected areas the potential may fluctuate rapidly as stray current from the tracks alternately enters and leaves the structure.

When a potential measurement is being taken, the reference cell is placed on the ground as near as possible to the underground structure. The reference cell is connected to the negative terminal of a voltmeter and the positive terminal is connected to the underground structure. In the circuit shown, there are several potential differences across the various segments but some of these are very small and/or relatively constant in value. Neglecting the very small potential differences that occur across the metallic connections, the potential differences are:

E1 Potential between the copper rod and the saturated copper sulphate solution.

E2 A small potential exists between the copper sulphate solution in the porous plug and the soil due to differences in ionic concentrations. This potential is also relatively constant.

E3 This voltage drop is made up of the IR drops in the soil. It must be kept as small as possible by placing the Reference cell as near as possible to the underground structure. This is most important in locations where steep potential gradients exist in the soil.

E4 This is the metal to metal contact potential between the connecting wire and the metal of the underground structure. It is not readily measurable, but it is relatively constant and can be minimised by using connection clips made of the same metal as the metal to which contact is being made.

E5 Is the structure to electrolyte potential. This potential varies through wide limits, and it is the value of this potential that it is desired to ascertain.

E Is the potential difference measured by the voltmeter.

Potential differences E1-E4 inclusive are assumed to be small or relatively constant so that the value of E5 is predominant in the measured voltage E.

Maintenance of Cu/$CuSO_4$ Reference cells

Copper in saturated copper sulphate solution will maintain stable potentials within reasonable limits, under practical field conditions. However, with regular use in different soil conditions, copper/copper sulphate (Cu/$CuSO_4$) Reference cells may become contaminated, and the potential may deviate. Signs of contamination is a cloudy milky appearance of the copper sulphate solution. Refer to AS2832.1[2].

To maintain a stable potential the Reference cell should always be kept in good condition. This is achieved by monthly replacement of the copper sulphate solution, cleaning the copper rod with fine grade emery paper, washing of all components in distilled or demineralised water, and adding crystals of copper sulphate to ensure solution saturation. Distilled water should be used for the cell electrolyte.
Field use reference cells should be calibrated as per manufacturers procedures or as detailed in Appendix H against standard reference cells maintained to a level equivalent to “as new” condition.

Service procedure

Inspect the field use reference cell for any signs of damage and quarantine any cells found to be corroded, leaking or in any way deemed defective. Service to your reference cell as regularly as required to ensure the voltage output is constant (no drift) and within 5mV of the Standard Reference Cell (Laboratory use only cell).

1. Remove the porous tip clean with demineralised water and set aside.
2. Drain and set aside the copper sulphate solution from within the cell and dispose contents according to appropriate chemical waste procedures. Flush inside of cell using demineralised water.
3. Unscrew rod holder end and remove copper rod assembly.
4. Using a common non-metallic abrasive cleaning pad, softly buff the copper rod to remove any contaminants and oxidation residue.
5. Soak all parts in clean, demineralised water for 24 hours.
6. Re-assemble, using new copper sulphate crystals and fresh, distilled water.
7. Shake the cell vigorously to dissolve the crystals ensuring that no leaks occur. Observe either visually through the sight glass or by listening for undissolved crystals to ensure that the copper sulphate solution is saturated and is unable to absorb any more crystals. Allow 10 min for the recently serviced field use reference cell to stabilise prior to calibration.

Calibration check

To check that the field use reference cell has been effectively serviced, place the field use reference cell and the standard reference cell in the test container filled with demineralised water. Measure the voltage difference between the two reference cells as shown in. A voltage difference of ≤5mV and <1mV drift over 1 minute results in a pass. If a potential difference >5 mV is shown, then repeat the servicing procedure, as described above, or replace with a new cell.

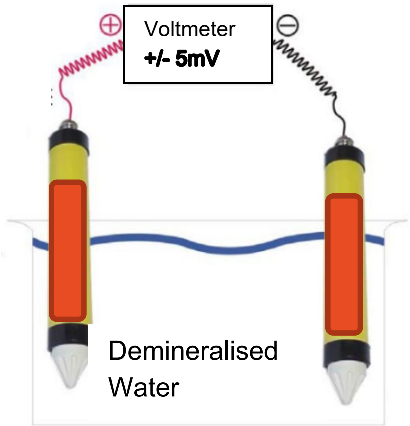

Figure 12-13: Reference Cell calibration

Reference cells compared to the Standard Hydrogen Cell

Use *Table 12-6* to convert other reference cells to a Copper/Copper Sulphate reference cell.

Table 12-6: Interference

Reference Cell	Potential v SHE @ 25°C
Saturated Calomel (SCE)	+ 242mV
Normal Calomel (NCE)	+280mV
Silver/Silver Sulphate (Ag/AgCl)	+250mV
Copper/Copper Sulphate ($Cu/CuSO_4$)	+316mV
Standard Hydrogen (SHE)	0mV
Zinc (Zn)	-800mV

Use of $Cu/CuSO_4$ Reference cells

To obtain reliable results in monitoring cathodic protection potentials there must be a conductive path between the Reference cell and the structure under test. The Reference cell must therefore be placed in intimate contact with the soil. Good results in different environments are achieved as follows:

1. Moist sand and soil - ensure intimate contact between Reference cell porous plug and sand/soil.
2. Dry soil - dig a small depression and fill with water.
3. Dry sand - pour water or $Cu/CuSO_4$ solution around the Reference cell.
4. Concrete - saturate a rag with water and place between the concrete and Reference cell.
5. Bitumen (considered an insulator) - do not use $Cu/CuSO_4$ Reference cells, use a metal earth cell driven through the bitumen to contact the underlying soil.
6. Salt and Brackish Water - use silver/silver chloride (Ag/AgCl) Reference cells. Silver/silver chloride cells (Ag/AgCl) should be used in salt or brackish water or soils with chloride ion content more than 1000 ppm (parts per million).

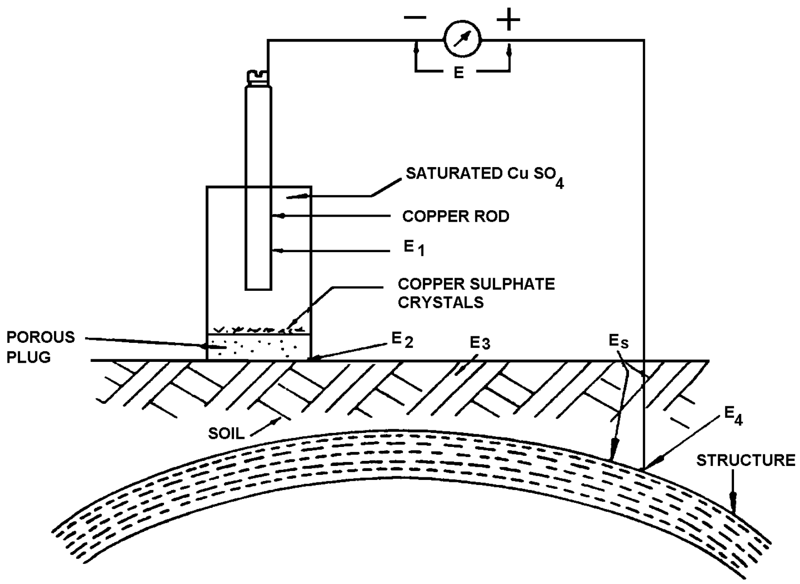

Figure 12-14: Structure to earth potential measurements with a Reference cell

Appendix I Calibration of Metal Reference Electrodes

Potential measurements are usually made between the structure and a Reference cell. In certain cases, the use of a reference electrode other than a Reference cell is required. Examples of such cases are:
Where a temporary reference is required (say for a 24-hour test) in a - public area where a Reference cell may be interfered with or vandalised.

1. Where a reference electrode is required to be installed near a deeply buried structure.
2. Where a structure is buried under hard cover or is not easily accessible e.g., bitumen surfaces.

Long term installation of Reference cells is not satisfactory due to the need for maintenance.
Note: the cables to permanently installed earth plates or other reference electrodes must be secure, with durable soldering or welding being preferred. In addition, if different metals or alloys are used, the connections must also be completely insulated to prevent the occurrence of galvanic corrosion and consequent loss of connection.

It is desirable to have the reference electrode made of a metal with a similar potential to that of the structure. This means that the potential developed between the structure and the reference is minimised and a lower instrument full-scale range can be used and therefore small potential changes are more easily measured.

Calibration

Calibration of a metal reference electrode means determining its potential and polarity with respect to a Reference cell (usually copper/copper sulphate).
When the potential V1, is added algebraically to V2, the measured potential of the metal electrode to structure, to give a resultant potential V3, which is the equivalent to that which would be read if the structure was measured directly to a Reference cell (see Figure 12-15).
The method to be used for calibration is as follows:

1. Measure the potential of the metal electrode to Reference cell (V1) with the negative terminal of the voltmeter connected to the Reference cell.
2. Measure the potential of structure being tested to the metal electrode (V2), this time with the negative terminal of the voltmeter connected to the metal electrode.
3. The potential of the structure with respect to the Reference cell is the algebraic sum of the two potentials measured above.

Notes:

1. *In traction-affected areas it is necessary to take voltage measurements V1 and V2 simultaneously, due to the rapid traction-induced fluctuations in the values. Care should be exercised in interpretation of these results due to fluctuating potential gradients.*
2. *If either the metal electrode or the Reference cell is moved before calibration is completed, then re-calibration is necessary.*
3. *The potential of a metal electrode may vary after insertion as it polarizes. Therefore, it is advisable to insert temporary electrodes for several hours before measurement. In high resistivity soils, Polarisation takes place more slowly and, therefore, the final Polarisation will take longer to achieve.*

   The error introduced into the measurement by Polarisation can be minimised by using a high impedance voltmeter (10 M-ohm).

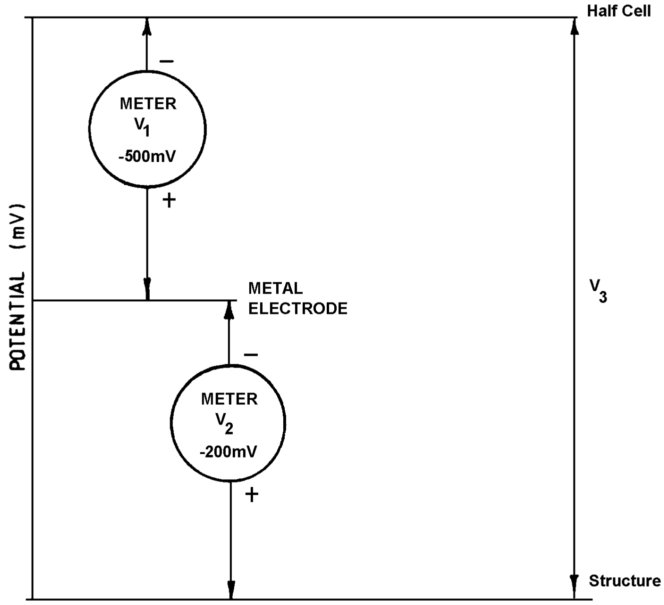

Figure 12-15: Calibration of metal electrodes

V3 = V1 + V2
= -500 + (-200)mV
= -700mV
= The potential of the structure relative to the Reference cell.

Note: *Two separate measurements must be made. In this practical case a metal electrode has been used to measure the potential to earth (-200mV) but this value has been corrected to -700mV relative to a Reference cell.*

Two separate measurements must be made.

Appendix J Test Points

Test points are installed to provide conveniently accessible connections to buried structures or to buried reference cells (refer to Figure 12-16, Figure 12-17 & Figure 12-18). Test points are used to give information about the level of interference or the effectiveness of protection from a cathodic protection system. They may also be used to facilitate a cross bond between the structures or connection of RD or CP systems.
Cables from the structure and reference cell are terminated in a robust housing, which can be a buried cast iron box with hinged lid at ground level, or a vertical column provided with either fixed exposed terminals or a terminal box.
NB: Open circuiting energised cable screens is not permitted due to safety implications of interfering with in-service earthing conductors. Only personnel authorised by the responsible Electrical Authority can conduct testing on electrical cables. Advice should be sought from the responsible Electricity Authority before any measurements are conducted.

Structure Connections

Two separate cables should be provided between the test point and the structure. The two cables are separately connected to the structure. The reason for two cables is that in the event of the test point being converted for use as a current carrying cable connection for a cathodic protection or railway drainage system, or as a cross bond, one cable remains for measuring potentials. Two cables also provide for continuity testing. In the case of intersecting structures, it is recommended that two cables be provided on both structures.

Earth Plates

A reference electrode may be in the form of an earth plate. The earth plates may be connected with two cables to provide a circuit for verification of the integrity of the cable connections to the earth plate.

Location of Test Points

Test points are installed at critical areas of a structure where problems are likely to be encountered or where extra precautions are required, or structure potentials need to be known. Further details are contained in Australian Standard Series 2832. Examples of typical installation points are:

At likely areas of stray current pick-up, discharge, and
Near to foreign structures.
Test points should be sited where they will be accessible but unlikely to be damaged after installation. They should be so located as to minimise hindrance to site usage and be sited to avoid attracting vandalism.

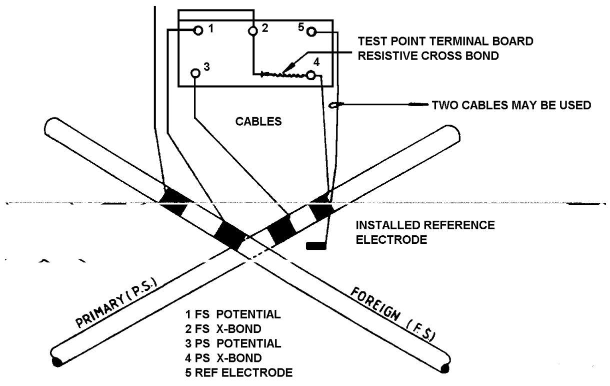

Figure 12-16: Test points for intersecting structures

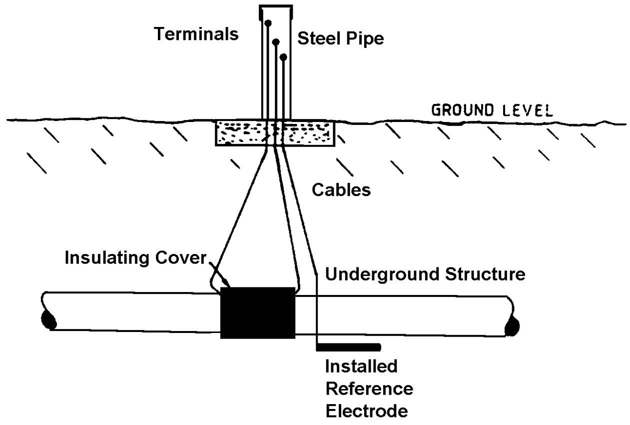

Figure 12-17: Test points - above ground stand pipe

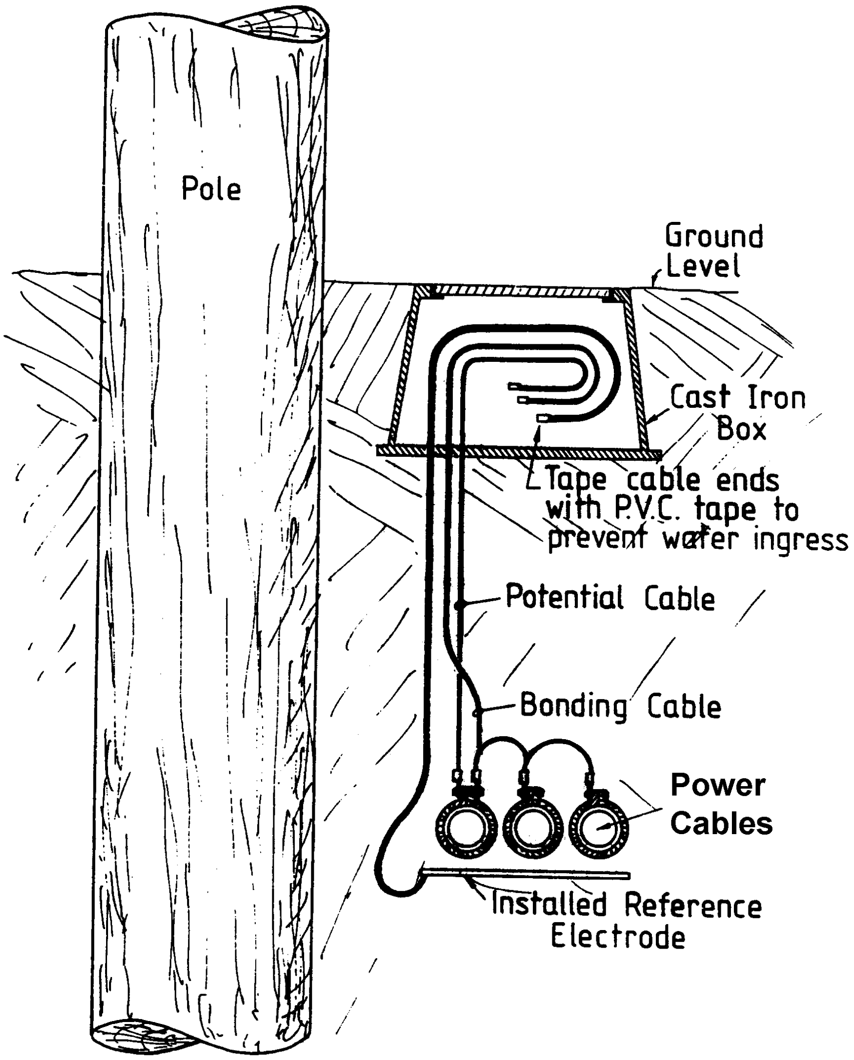

Figure 12-18: Test points - details for inground box

Appendix K Trial Railway Drainage Panel

For those cases where a railway drainage system is required to offset the effect of strong traction current, it is advisable to temporarily set up a trial drainage bond so that interference effects can be measured.

Therefore, all parties who require systems should equip themselves with a suitable drainage panel. The circuit diagram shown at Figure 12-19 is a suitable panel that will provide a wide range of conductance characteristics and will facilitate accurate measurement of system conductance.

Resistor Switch	
Position 1 (s/c)	0Ω
Position 2	0.10Ω
Position 3	0.25Ω
Position 4	0.50Ω
Position 5	0.75Ω
Position 6	1.00Ω
Position 7	2.00Ω

DESIGN DATA

C1	100uF ELECTROLYTIC CAPACITOR 350 VOLTS
D1 & D2	48A SILICON DIODE TYPE BYX 52
D3	STC SAFE T STAC TYPE H 930 6
F1	30A HRC FUSE
R1 TO R6	RESISTORS 100 WATT
SH1 TO SH4	SHUNTS 100 MILLI VOLT
SW1	20A SINGLE POLE
SW2	7 POSITION HEAVY DUTY ROTARY SWITCH

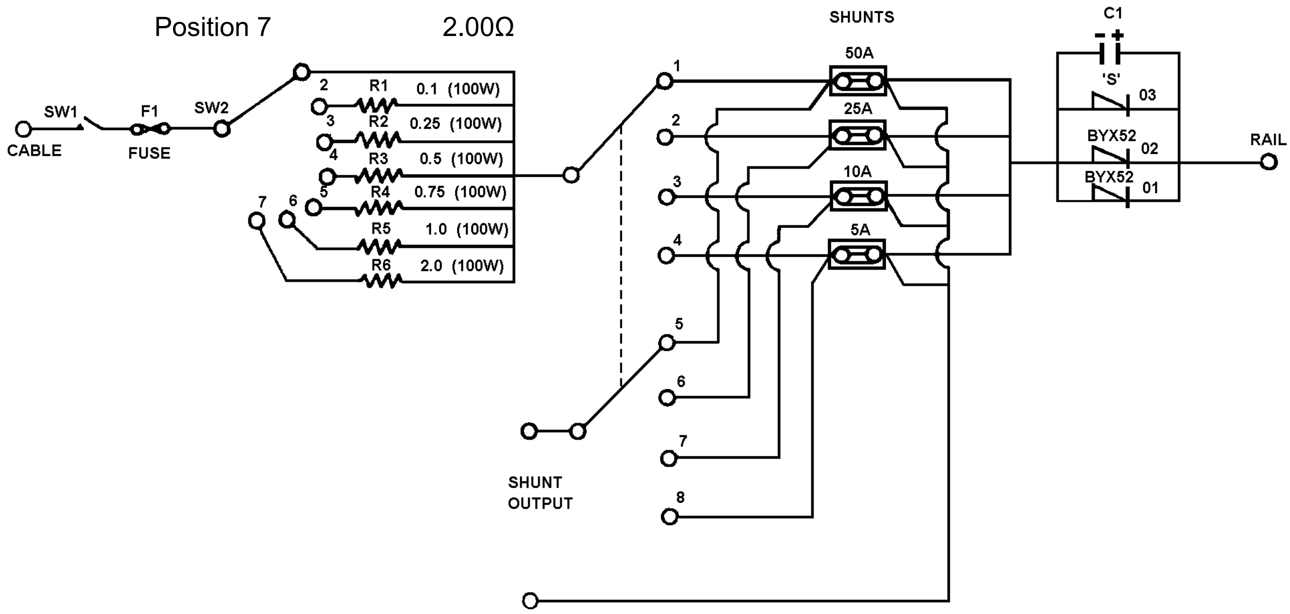

Figure 12-19: Example of a Railway drainage system design panel

Appendix L Potential Offset Device

Where, because of interference or, for any other reason, it is desired to measure the change in potential of a structure with respect to a Reference cell (or metal reference) and the structure potential is large in magnitude in comparison to the value of the change in potential, then a potential offset device may be used to obtain more accurate measurements. For example, where the potential of a structure with respect to a Reference cell is 1500 mV the most likely full-scale range used to make such a measurement would be 3.0 V or 5.0V, depending on the scales available. If it is desired to measure a change in this potential of, say, 15mV then an accurate reading is impossible to obtain. To accurately measure 15 millivolts, an instrument with a full-scale range of 50, 100 or 300 mV would need to be used. To overcome this difficulty, a multi-range instrument and a potential offset device should be used to clearly show the 15mV change and to prevent the instrument going off-scale.

A potential offset device consists of a DC voltage supply of 3.0 volts and a voltage divider wired such that an output voltage of from zero to 3.0 volts is provided. Alternatively, some recorders contain an in-built offset device.

The procedure to be adopted for an offset box is as follows (refer to Figure 12-20):

1. Measure structure to Reference cell potential on a suitable voltmeter range.
2. With the instrument on the same range insert the potential offset device in series with the measuring circuit, with the polarity of the offset device opposite to that of the voltmeter.
3. Adjust the potential offset device output so that the overall voltage of the circuit (i.e., the algebraic sum of the potentials of the structure to Reference cell and the offset device) is approximately zero.
4. Alter the instrument range to that appropriate for measuring the change in potential and record the potentials.

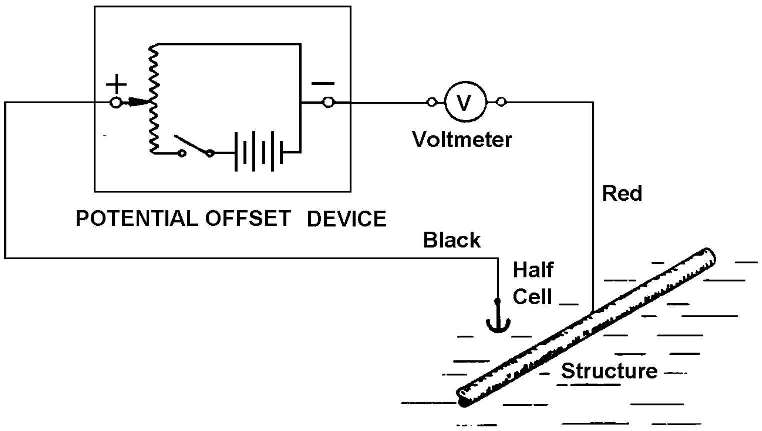

Figure 12-20: Connection of a potential offset device

Appendix M Determination of Interference from A Railway Drainage System

(Also applies to transformer rectifier assisted drainage systems)
This appendix describes the procedures for determining an interference value for a railway drainage system and the TRAD system or combinations of these systems.

Previous to late 1996, drainage bonds were registered in terms of Siemens but since that time they have been registered in terms of 24-hr average current. This has resulted in changes in the methods described in this revision of the Guide.

The latest Data Transfer Technique which provides an alternative to radiotelemetry of data has allowed much greater use of correlation charts where previously these were restricted to structures situated very close together. Nevertheless, the 48-hr recording method (refer 8.1.3.1) remains a valid alternative for application as a matter of individual preference or where the radio-telemetry system fails due to poor transmission.

Step One – Record System Current and Det. Mod. Current

The permanent drainage system or a temporary drainage panel must be installed to allow operation of the system over 24 hours whilst the current is recorded. This is done using a suitable weather-proof data logger that is loaded with appropriate software. The 24-hour data is recorded including the zero current values. Data is downloaded to a computer and analysed to produce the modified 24-hour average current (MoC). A Time of Operation is calculated and expressed as a fraction of the 24 hours that current exceeds 0.1 amps. The raw 24-hour average is then multiplied by the inverse of the operating time to produce the modified 24-hour average current.

Example: If the raw 24 Hr average is 10 amps and the actual current exceeds 0.1 amps for half the 24-hour period then the modified 24 hour current is calculated as follows using equation (4).

$$MoC = \frac{Anodic\ Ave\ amps}{\left(\frac{time\ of\ operation}{24hr}\right)}$$

$$20A = \frac{10A}{0.5} \qquad (4)$$

Step Two – Determine Modified Voltage

A conductance chart showing system current plotted against primary structure to rail voltage is produced, see Figure 12-21. The modified 24 hr average current is entered onto the current axis (x-axis) of the conductance chart. A line is then projected vertically to the hot lamp conductance curve. At this intersection, a line is projected across to the PS-RR axis (y-axis). This produces the modified voltage (MoV) for application to the correlation chart. The principle remains the same when the current and voltage axes are swapped around.

Step Three

Use of the Correlation Chart to Determine a Value of Interference

The degree of interference is represented by the change in slope of the correlation line; however, it is necessary to determine a single measure of interference for comparison with the criteria and when deciding to object or accept a proposed drainage system. This single measure of interference is the change in FS-E potential measured at the modified voltage (MoV) as shown in Figure 8-9. A vertical line is drawn from the modified voltage to intersect the two correlation lines and interference is the interval marked "Interference" in Figure 12-22.

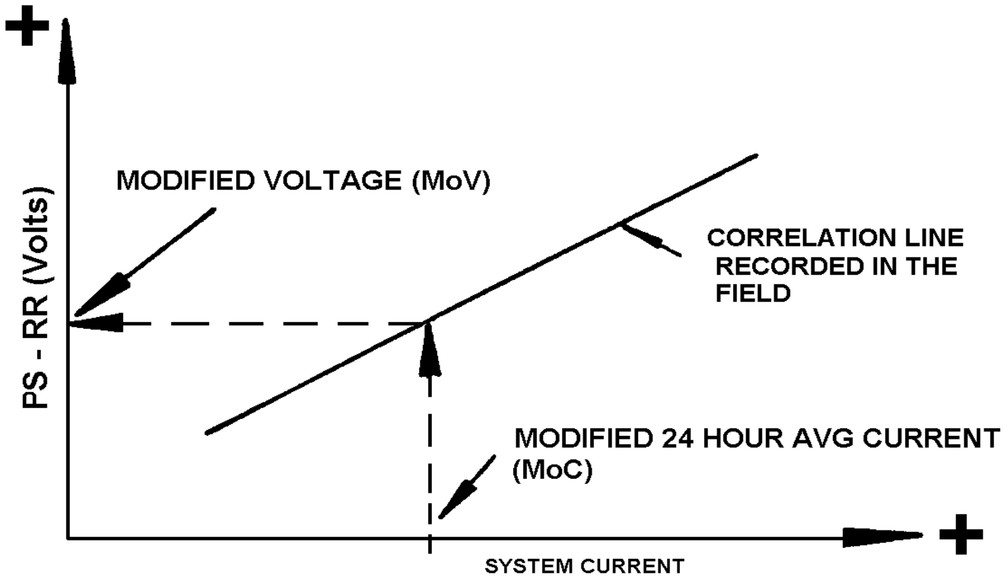

Figure 12-21: Determination of MoV (PS-RR voltage corresponding to the Modified System Current)

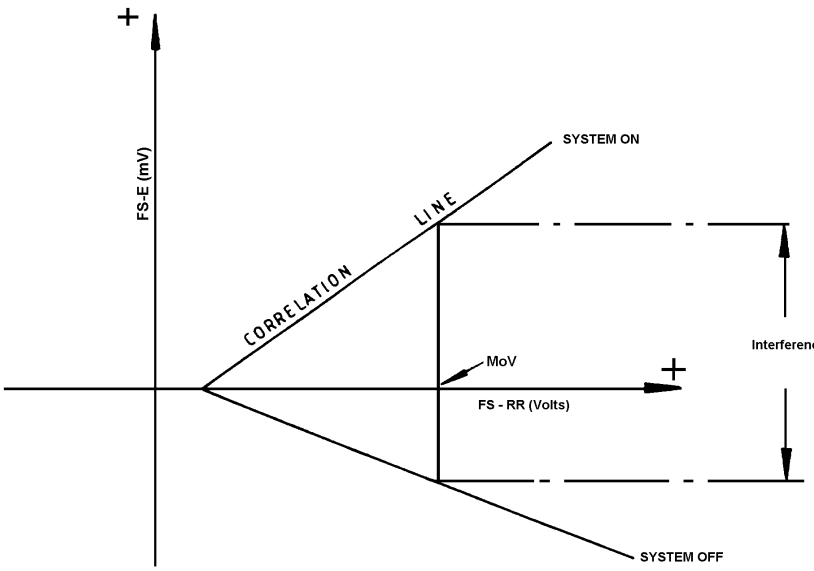

Figure 12-22: Determination of interference using the correlation chart for structures

Appendix N Personal Safety

PART 1: GENERAL

Worker Safety legislation in NSW covers safety in the workplace and all members are encouraged to familiarised themselves with their responsibilities under legislation to ensure a safe workplace. Refer to Appendix O for a typical work site risk assessment.

Safety matters that are of particular concern to the members of the New South Wales Electrolysis Committee include the following:

1. Access to rail tracks.
2. Traffic hazards when working directly adjacent to busy roads.
3. Hazards to pedestrians from open manholes.
4. Electrical hazards that we usually associated with electrical equipment. Part 2 of this appendix details safety precautions associated with traction interference testing; and
5. Underground safety.

Access to rail tracks
Access to rail tracks, other than railway stations, is strictly prohibited by the railway authorities, unless there is a clear need to gain access and the persons are properly clothed including prescribed safety vests and they have been duly trained and authorised by the Rail Access Corporation. Great care must be always exercised to avoid being struck by a passing train. Electrolysis personnel should avoid the tracks unless they have a clear need to be there.

Traffic Hazard
Points of access to cables and pipes is frequently in footpaths or otherwise adjacent to busy roads. Therefore, there is a constant danger of accident, and all staff must remain alert and work with great care and caution. Wearing of bright coloured safety vests is very strongly recommended.
Where it is necessary to convey an electrical signal across a busy road, use of the radio data telemetry equipment, normally carried by the Electrolysis Testing Officer, is recommended. Laying wires across roads is hazardous although the risk is tolerable in light traffic secondary roads.

Pedestrian Hazard
Access to pipes and cables is often via manholes in footpaths and adjacent areas. Where a manhole is opened then orange coloured safety cones must be placed on all sides of the hole.
Cables laid along and across footpaths are also a hazard and care must be always exercised to minimise the risk to pedestrians by choosing the least-risk path to lay the cables and using orange safety cones where appropriate.

Underground Safety
Access to pipe cables is often via manholes and hazards that exist include explosive gas mixtures, poisonous gas mixtures, deep water and insects. Personnel must always enter manholes with care and follow the procedures prescribed under safety legislation and organisation safety policy. Testing for explosive gas mixtures is compulsory in most organisations and there must always be a second person on standby in case of difficulties.

PART 2: RAILWAY TRACTION DRAINAGE SYSTEMS

GUIDE TO ELECTRICAL SAFETY
(for use by members of the NSW Electrolysis Committee)

PURPOSE

This document will provide guidance to electrolysis field staff with respect to safe electrical work practices to be followed when they are employed on maintaining or testing railway stray traction current drainage systems (including panels and bond boxes of conventional and Transformer Rectifier Assisted Drainage systems (TRADS)).

SCOPE

This document will cover the required personal and other protective equipment plus relevant testing procedures, if any, as well as the practices to be followed when working or testing near or within railway drainage systems.

SUMMARY

The safe working practices and procedures contained in this document will generate a safe and healthy environment for electrolysis staff to work in when testing and maintaining railway traction drainage systems.

PRECIS OF THE PROBLEM

Over voltage

Over a period electrolysis field staff have detected large increases in electrical potential measured between the underground metallic structures of Utility's plant and the Railway D.C. traction systems. In some areas a negative 270 volts D.C. has been recorded. Not only can this voltage appear on the utility structures, but it can also appear on drainage panels, and, under certain fault conditions, it may also appear on bond cabinets. This increase in voltage has been brought about by a need of the NSW State Rail Authority to increase the number of electric locomotives attached to the freight hauling trains on certain lines, increased power of urban trains and improved track isolation.

Because of the very low source impedance (the track) of this voltage, it can generate dangerously high currents through the body of any person who may accidentally make contact with it and earth at the same time. These high currents represent a hazardous situation to the staff working on these systems, and as such there are mandatory practices that must be followed to eliminate any possible dangerous occurrences.

NOTE: The recommended limit for DC hazardous voltage is 60 volts. For information on the effects of current passing through the human body see Ref. No. 1
Faults in the electrical system can produce voltages up to 1500 VDC for very short periods. The probability of this occurring is remote but still represents a risk that should be accounted for in safety procedures.

Personal Safety Equipment to be used

To mitigate the effect of the above high voltages the following protective equipment must be used. The safe working procedures to be observed at the same time are set out in Appendix O of this document.

Rubber Gloves (Reference No. 2)

Safety eye protection is recommended when using insulated rubber gloves.

(i) Type

There are two recommended types of rubber gloves that can be used for electrical protection, and they are medium and light weight.

The preferred type for this work is the **lightweight** gloves because they give the user greater control of the tools, etc. but with the same degree of electrical protection. These gloves are a gauntlet style that are dipped, and proof tested to 5,000 Vrms for a working voltage of 650 (See Ref No. 2).

(ii) Testing

For this type of glove, the only tests required are visual as the voltage test is only to be applied when new (see (a) below). The necessary tests to be carried out on these gloves are:

(a) Expiry Date Check

Once the gloves have been in use longer than 12 months from the date of manufacture, as shown on the cuff of the gloves, the gloves must then be disposed of and a new pair requested. **These gloves are not to be retested for electrical integrity.**

(b) Field Examination

The supervisor should ensure that every glove is visually examined to determine whether it is satisfactory to use before being placed in service. Briefly the important defects to look for are:

- Surface cracks, cuts or nicks
- Signs of perished rubber or softening
- Abrasive wear
- Moisture.

Once the gloves pass the above test then they are inflated with air to test for small holes in the rubber.

Safety Footwear (Ref No. 3)

Type

Safety shoes type 1, in accordance with AS 2210.2 and other relevant company documents, must always be worn. However, from an electrical safety point of view, these shoes must not be relied upon as the only means of preventing an electrical incident. Safety will depend primarily on the use of insulating gloves and insulated tools.

Testing

There are no specific tests for safety shoes, however As 2211 [11], [12] sets out the recommended practices for the care of protective footwear.

Clothing

Hi Vis safety clothing is considered normal attire for field workers.

Safety helmets

Safety helmets are required to be worn when entering a rail corridor, most construction sites and for any work involving working aloft or in confined spaces. Safety helmets are to be inspected prior to use and every 6 months and are to be replaced after 2 years of service regardless of their condition.

Safety Equipment

Insulated Hand Tools (Ref 5, 7 and 8)

All hand tools such as spanners, adjustable spanners, pliers, screwdrivers, etc. used in work on the railway traction drainage systems should be electrically insulated to withstand 1,000 VAC or 1,500 VDC and marked accordingly. However, the rating only applies to new tools and subsequent use, or misuse may affect the insulating properties. Tools may need to be tested for insulation integrity every 6 months.

NOTE: Insulated tools must be replaced if any damage or noticeable deterioration occurs.

The only Australian reference for insulated tools is AS 3527.2 [13]and this reference only covers screwdrivers (See Ref. 5).

However, tools are available in Australia that are manufactured to comply with International Electrotechnical Commission Standard 900 (1987) (up to 1000 VAC and 1500 VDC) [15] and with Electricity Association (Great Britain) Technical Specification 26.3 1984 (1000 VAC)[20].

Instrumentation

All meters and instrumentation should be CAT IV rated.

WORK PRACTICES

Due to the intermittent and unpredictable nature of the voltages that occur on the rail tracks and drainage systems, it is dangerous to rely on the voltage measurement taken at the time to indicate as to whether the voltage is safe or not. Lethal voltages could occur at any moment in time. Always assume that dangerous voltages do exist and therefore before any testing or maintenance work is carried out observe the following practices:

(a) Always wear the safety equipment (helmets, gloves, protective eyewear and boots) mentioned above and wear Hi-Vis safety clothing that is suitable for rail corridor work.

(b) Use only insulated tools and gloves to perform the necessary work.

(c) Once the work had been completed the safety equipment is to be stored in the correct manner as set out in the relevant references.

Note: 1. All safety equipment must be always worn until the work is completed.

2. Use similar procedures when working at locations remote from the Bond Cabinet where electrical connection to the rail track do exist.

Appendix O Risk Assessment

WHS risk assessment title	Regulatory requirement (Legislation, Codes of Practice, Australian Standards)
Working on pipelines and cables that are subject to an impressed current cathodic protection system.	NSW WHS Regulation, AS/NZS 3000 AS/NZS 3100, AS 2832.1

Location of hazard (Identify location of the hazard, ie, building/depot/workstation/room number)	Additional information (Explain any further information regarding the risks identified and background information about the assessment, insert picture if available)
Pipelines and cables located throughout NSW.	
Description of issue (Briefly outline/describe the risk)	
Working on pipelines & cables and associated equipment that are subject to an impressed current cathodic protection system.	
Risk likelihood (Briefly outline the frequency of exposure, periods of exposure etc)	
Workers and the public can frequently come into contact with pipelines & cables and associated equipment such as test points, valves and corrosion protection equipment such as Transformer Rectifier Units (TDUs), that are located in public spaces.	
Potential risk consequence (Briefly outline the potential outcomes, ie, injury, illness, damage to property, environment)	
Muscle sensation through to fatality caused by electric shock.	

Tasks assessed in this risk assessment			
Structure Potential Surveys	Live work on ELV side of TRUs	Operating Valves, Pipe Repairs & Maintenance	Testing Railway Drainage Systems
AC/DC Voltage Gradient	Live work on LV side of TRUs	Testing bonds & Insulating Joints	Cable Jointing
Pipeline Current Mapping	Isolate & Test LV to allow de-energised work on ELV	Testing at designated test points	Cable Testing & Fault Locating
Adjusting ELV controls on TRUs	Coating defect repairs	Soil Resistivity Testing	Cable Identification & Tracing

Risk Matrix	Hierarchy of Controls

LIKELIHOOD	CONSEQUENCE	Insignificant	Minor	Moderate	Major	Severe
	Almost Certain	11	16	20	23	25
	Likely	7	12	17	21	24
	Possible	4	8	13	18	22
	Unlikely	2	5	9	14	19
	Rare	1	3	6	10	15

Likelihood		Consequence	
Almost Certain	Probability of event occurring – more than five times in one year	Severe	One or more fatalities. Significant permanent injuries/work related illnesses to one or more persons
Likely	Probability of event occurring – more than once in one year but no more than five times in one year	Major	Permanent injuries/work related illnesses to one or more persons
Possible	Probability of event occurring – more than once in ten years but no more than once in one year	Moderate	Significant non-permanent injuries/work related illnesses requiring emergency surgery or hospitalisation for more than seven days
Unlikely	Probability of event occurring – more than once in 25 years but no more than once in ten years	Minor	Non-permanent injuries/work related illnesses requiring medical treatment
Rare	Probability of event occurring – less than once every 25 years	Insignificant	Low level injury/symptom requiring first aid only

Hierarchy of Hazards

The hierarchy of hazard controls is a guideline for solutions from the best to the last resort – change process item to a less risky one

1. **Elimination** – remove the hazard.
2. **Substitution** – change process item to an item of less risk, eg, substances.
3. **Isolation** – use preventative mechanism, eg, guarding
4. **Engineering** – use machines rather than manual labour.
5. **Administrative** – develop and implement safe work procedures, conduct training, implement a checklist.
6. **Personal Protective Equipment** – use personal protective

				equipment, eg, hard hats, respirators, hearing protection, insulating gloves, safety protective footwear.

HAZARD	POTENTIAL RISK	RISK RANKING	CONTROL 1. Elimination 2. Substitution 3. Isolation 4. Engineering 5. Administrative 6. PPE	RESIDUAL RISK RANKING
Structure Potential Surveys ELV electric shock from contacting pipeline or Test Points	Muscle sensation	**Consequence** Minor **Likelihood** Possible **Risk** 8	3. Isolation Class III equipment - AS/NZS 3100 3. Isolation Extra Low voltage to minimise electrical hazards - AS 2832.1 3. Isolation Insulation of live parts - AS/NZS 3000 & AS/NZS 3100 4. Engineering Design and construction of (TRU) to meet AS/NZS 3000 & AS/NZS 3100 for Basic and fault protection by use of extra low voltage and/or Safety extra low voltage 4. Engineering Earthing facilities - AS/NZS 3000 & AS/NZS 3100 4. Engineering Use of protective earthing and functional earthing - AS/NZS 3000 5. Administration CP Technician Training & Qualifications to AS 2832.1 needed for live work on ELV side of TRU. 5. Administration Safe work procedures 6. PPE PPE where required	**Consequence** Minor **Likelihood** Rare **Risk** 3

HAZARD	POTENTIAL RISK	RISK RANKING	CONTROL 1. Elimination 2. Substitution 3. Isolation 4. Engineering 5. Administrative 6. PPE	RESIDUAL RISK RANKING
AC/DC Voltage Gradient Testing ELV electric shock from contacting pipeline or Test Points	Muscle sensation	Consequence Minor Likelihood Possible Risk 8	3. Isolation Class III equipment - AS/NZS 3100 3. Isolation Extra Low voltage to minimise electrical hazards - AS 2832.1 3. Isolation Insulation of live parts - AS/NZS 3000 & AS/NZS 3100 4. Engineering Design and construction of (TRU) to meet AS/NZS 3000 & AS/NZS 3100 for Basic and fault protection by use of extra low voltage and/or Safety extra low voltage. 4. Engineering Earthing facilities - AS/NZS 3000 & AS/NZS 3100 4. Engineering Use of protective earthing and functional earthing - AS/NZS 3000 5. Administration CP Technician Training & Qualifications to AS 2832.1 5. Administration Safe work procedures 6. PPE PPE where required	Consequence Minor Likelihood Rare Risk 3
AC/DC Voltage Gradient Testing LV electric shock from contacting Test Equipment	Muscle sensation, Burns, Heart Failure	Consequence Major Likelihood Possible Risk 18	3. Isolation Class III equipment - AS/NZS 3100 3. Isolation Guarding of live parts - AS/NZS 3000 & AS/NZS 3100 3. Isolation Insulation of live parts - AS/NZS 3000 & AS/NZS 3100 4. Engineering Use RCD protected supply for test equipment 5. Administration CP Technician Training & Qualifications to AS 2832.1 5. Administration Safe work procedures 6. PPE Use PPE where required	Consequence Minor Likelihood Rare Risk 3

HAZARD	POTENTIAL RISK	RISK RANKING	CONTROL 1. Elimination 2. Substitution 3. Isolation 4. Engineering 5. Administrative 6. PPE	RESIDUAL RISK RANKING
Pipeline Current Mapping ELV electric shock from contacting pipeline or Test Points	Muscle sensation	Consequence Minor Likelihood Possible Risk 8	3. Isolation Class III equipment - AS/NZS 3100 3. Isolation Extra Low voltage to minimise electrical hazards - AS 2832.1 3. Isolation Guarding of live parts - AS/NZS 3000 & AS/NZS 3100 3. Isolation Insulation of live parts - AS/NZS 3000 & AS/NZS 3100 4. Engineering Earthing facilities - AS/NZS 3000 & AS/NZS 3100 4. Engineering Use of protective earthing and functional earthing - AS/NZS 3000 5. Administration CP Technician Training & Qualifications to AS 2832.1 5. Administration Safe work procedures 6. PPE Use PPE where required	Consequence Minor Likelihood Rare Risk 3
Accessing designated Test Points ELV electric shock from contacting pipeline or Test Points	Muscle sensation	Consequence Minor Likelihood Possible Risk 8	3. Isolation Class III equipment - AS/NZS 3100 3. Isolation Extra Low voltage to minimise electrical hazards - AS 2832.1 3. Isolation Insulation of live parts - AS/NZS 3000 & AS/NZS 3100 4. Engineering Earthing facilities - AS/NZS 3000 & AS/NZS 3100 4. Engineering Use of protective earthing and functional earthing - AS/NZS 3000 5. Administration CP Technician Training & Qualifications to AS 2832.1 5. Administration Safe work procedures 6. PPE Use PPE where required	Consequence Minor Likelihood Rare Risk 3

HAZARD	POTENTIAL RISK	RISK RANKING	CONTROL 1. Elimination 2. Substitution 3. Isolation 4. Engineering 5. Administrative 6. PPE	RESIDUAL RISK RANKING
Adjusting ELV Controls ELV electric shock from contacting TRU control panel	Muscle sensation	Consequence Minor Likelihood Possible Risk 8	3. Isolation Class III equipment - AS/NZS 3100 3. Isolation Extra Low voltage to minimise electrical hazards - AS 2832.1 3. Isolation Guarding of live parts - AS/NZS 3000 & AS/NZS 3100 3. Isolation Insulation of live parts - AS/NZS 3000 & AS/NZS 3100 4. Engineering Design and construction of (TRU) to meet AS/NZS 3000 & AS/NZS 3100 for Basic and fault protection by use of extra low voltage and/or Safety extra low voltage 4. Engineering Earthing facilities - AS/NZS 3000 & AS/NZS 3100 4. Engineering Use of protective earthing and functional earthing - AS/NZS 3000 5. Administration CP Technician Training & Qualifications to AS 2832.1 5. Administration Safe work procedures 6. PPE Use PPE where required	Consequence Minor Likelihood Rare Risk 3

HAZARD	POTENTIAL RISK	RISK RANKING	CONTROL 1. Elimination 2. Substitution 3. Isolation 4. Engineering 5. Administrative 6. PPE	RESIDUAL RISK RANKING
Live work on exposed ELV side of TRUs ELV electric shock from contacting ELV side of TRU.	Muscle sensation, Muscle soreness, Burns	Consequence Minor Likelihood Possible Risk 8	3. Isolation Class III equipment - AS/NZS 3100 3. Isolation Extra Low voltage to minimise electrical hazards - AS 2832.1 3. Isolation Guarding of live parts - AS/NZS 3000 & AS/NZS 3100 3. Isolation Insulation of live parts - AS/NZS 3000 & AS/NZS 3100 4. Engineering Design and construction of (TRU) to meet AS/NZS 3000 & AS/NZS 3100 for Basic and fault protection by use of extra low voltage and/or Safety extra low voltage 4. Engineering Earthing facilities - AS/NZS 3000 & AS/NZS 3100 4. Engineering Use of protective earthing and functional earthing - AS/NZS 3000 5. Administration CP Technician Training & Qualifications to AS 2832.1 5. Administration Safe work procedures 6. PPE Use PPE where required	Consequence Minor Likelihood Rare Risk 3

HAZARD	POTENTIAL RISK	RISK RANKING	CONTROL 1. Elimination 2. Substitution 3. Isolation 4. Engineering 5. Administrative 6. PPE	RESIDUAL RISK RANKING
Live work on exposed LV side of TRUs LV electric shock from contacting Transformer Rectifier Units (TRUs) and associated cabling.	Muscle soreness, Burns, Heart failure, Fatality	Consequence Severe Likelihood Possible Risk 22	3. Isolation Unplug portable TRU from LV supply point or de-energise ELV on hard wired TRUs – test and prove de-energised. 4. Engineering Design and construction of (TRU) enclosure to meet AS/NZS 3000 for protection against electric shock. Basic protection and Fault protection. Protective earth used on all metallic housings. 4. Engineering Design and construction of (TRU) to meet AS/NZS 3000 for control and Isolation. 5. Administration Electrical Supervisor Qualifications needed for live work on LV side of TRU 5. Administration CP Technician Training & Qualifications to AS 2832.1 needed for live work on ELV side of TRU. 5. Administration Safe work procedures 6. PPE Use PPE where required	Consequence Severe Likelihood Rare Risk 15

HAZARD	POTENTIAL RISK	RISK RANKING	CONTROL 1. Elimination 2. Substitution 3. Isolation 4. Engineering 5. Administrative 6. PPE	RESIDUAL RISK RANKING
Live work on exposed LV side of TRUs LV electric shock while Isolating & proving de-energised.	Muscle soreness, Burns, Heart failure, Fatality	Consequence Severe Likelihood Possible Risk 22	3. Isolation Unplug portable TRU from LV supply point or de-energise ELV on hard wired TRUs – test and tag. 4. Engineering Design and construction of (TRU) enclosure to meet AS/NZS 3000 for protection against electric shock. Basic protection and Fault protection. Protective earth used on all metallic housings. 4. Engineering Design and construction of (TRU) to meet AS/NZS 3000 for control and Isolation. 5. Administration Electrical Supervisor Qualifications or Restricted Electrical Qualifications needed for operating & proving de-energised on permanently wired TRUs. 5. Administration Safe work procedures 6. PPE Use PPE where required	Consequence Severe Likelihood Rare Risk 15
Coating defect repairs ELV electric shock from contacting pipeline	Muscle sensation	Consequence Minor Likelihood Possible Risk 8	4. Engineering Design and construction of (TRU) to meet AS/NZS 3000 & AS/NZS 3100 for Basic and fault protection by use of extra low voltage and/or Safety extra low voltage 4. Engineering Earthing facilities - AS/NZS 3000 & AS/NZS 3100 4. Engineering Use of protective earthing and functional earthing - AS/NZS 3000 5. Administration Safe work procedures 6. PPE Use PPE where required	Consequence Minor Likelihood Rare Risk 3

HAZARD	POTENTIAL RISK	RISK RANKING	CONTROL 1. Elimination 2. Substitution 3. Isolation 4. Engineering 5. Administrative 6. PPE	RESIDUAL RISK RANKING
Operating Valves ELV electric shock from contacting pipeline	Muscle sensation	Consequence Minor Likelihood Possible Risk 8	4. Engineering Design and construction of (TRU) to meet AS/NZS 3000 & AS/NZS 3100 for Basic and fault protection by use of extra low voltage and/or Safety extra low voltage 4. Engineering Earthing facilities - AS/NZS 3000 & AS/NZS 3100 4. Engineering Use of protective earthing and functional earthing - AS/NZS 3000 5. Administration Safe work procedures 6. PPE Use PPE where required	Consequence Minor Likelihood Rare Risk 3
Testing bonds & Isolating Joints ELV electric shock from contacting pipeline	Muscle sensation	Consequence Minor Likelihood Possible Risk 8	4. Engineering Design and construction of (TRU) to meet AS/NZS 3000 & AS/NZS 3100 for Basic and fault protection by use of extra low voltage and/or Safety extra low voltage 4. Engineering Earthing facilities - AS/NZS 3000 & AS/NZS 3100 4. Engineering Use of protective earthing and functional earthing - AS/NZS 3000 5. Administration Safe work procedures 6. PPE Use PPE where required	Consequence Minor Likelihood Rare Risk 3

HAZARD	POTENTIAL RISK	RISK RANKING	CONTROL 1. Elimination 2. Substitution 3. Isolation 4. Engineering 5. Administrative 6. PPE	RESIDUAL RISK RANKING
Testing at designated Test Points ELV electric shock from contacting pipeline or Test Points	Muscle sensation	Consequence Minor Likelihood Possible Risk 8	3. Isolation Class III equipment - AS/NZS 3100 3. Isolation Extra Low voltage to minimise electrical hazards - AS 2832.1 3. Isolation Guarding of live parts - AS/NZS 3000 & AS/NZS 3100 3. Isolation Insulation of live parts - AS/NZS 3000 & AS/NZS 3100 4. Engineering Design and construction of (TRU) to meet AS/NZS 3000 & AS/NZS 3100 for Basic and fault protection by use of extra low voltage and/or Safety extra low voltage 4. Engineering Earthing facilities - AS/NZS 3000 & AS/NZS 3100 4. Engineering Use of protective earthing and functional earthing - AS/NZS 3000 5. Administration CP Technician Training & Qualifications to AS 2832.1 5. Administration Safe work procedures 6. PPE Use PPE where required	Consequence Minor Likelihood Rare Risk 3
Pipe Repairs & Maintenance ELV electric shock from contacting pipeline	Muscle sensation	Consequence Minor Likelihood Possible Risk 8	4. Engineering Design and construction of (TRU) to meet AS/NZS 3000 & AS/NZS 3100 for Basic and fault protection by use of extra low voltage and/or Safety extra low voltage 4. Engineering Earthing facilities - AS/NZS 3000 & AS/NZS 3100 4. Engineering Use of protective earthing and functional earthing - AS/NZS 3000 5. Administration Safe work procedures 6. PPE Use PPE where required	Consequence Minor Likelihood Rare Risk 3

HAZARD	POTENTIAL RISK	RISK RANKING	CONTROL 1. Elimination 2. Substitution 3. Isolation 4. Engineering 5. Administrative 6. PPE	RESIDUAL RISK RANKING
Soil Resistivity Testing Electric shock from soil voltage gradients	Muscle sensation	Consequence Minor Likelihood Unlikely Risk 5	5. Administration Safe work procedures 6. PPE Use PPE where required	Consequence Insignificant Likelihood Rare Risk 1
Railway Drainage System Testing Electric shock from uncontrolled ELV or LV rail voltages	Muscle sensation, Muscle soreness, Burns, Heart failure	Consequence Major Likelihood Possible Risk 18	3. Isolation Isolate rail voltage prior to contact. 3. Isolation Class IV equipment - AS/NZS 3100 4. Engineering Design and construction of drainage board enclosure to meet AS/NZS 3000 for protection against electric shock. Basic protection and Fault protection. 4. Engineering Design and construction of drainage board to meet AS/NZS 3000 for control and Isolation. 5. Administration Restricted Electrical Qualifications needed for live work e.g. testing and fault finding. 5. Administration CP Technician Training & Qualifications to AS 2832.1 needed for de-energised work. 5. Administration Safe work procedures and PPE where required 6. PPE Use PPE where required	Consequence Moderate Likelihood Rare Risk 6

HAZARD	POTENTIAL RISK	RISK RANKING	CONTROL 1. Elimination 2. Substitution 3. Isolation 4. Engineering 5. Administrative 6. PPE	RESIDUAL RISK RANKING
Cable Jointing Electric shock from contacting cable screens	Muscle sensation, Muscle soreness, Burns, Heart failure	Consequence Major Likelihood Possible Risk 18	3. Isolation Isolate & prove de-energised prior to contact 3. Isolation Class IV equipment - AS/NZS 3100 3. Isolation Guarding of live parts - AS/NZS 3000 & AS/NZS 3100 3. Isolation Insulation of live parts - AS/NZS 3000 & AS/NZS 3100 4. Engineering Equipotential work environment when cable jointing 5. Administration Electrical Cable Jointing qualifications required – cables rated above ELV only 5. Administration Safe work procedures - equipotential bonding or earthed work zone. 6. PPE Use PPE where required	Consequence Major Likelihood Rare Risk 10
Cable Fault Location, Identification & Tracing Electric shock from contacting cable screens	Muscle sensation, Muscle soreness, Burns, Heart failure	Consequence Major Likelihood Possible Risk 18	3. Isolation Isolate & prove de-energised 3. Isolation Class IV equipment - AS/NZS 3100 3. Isolation Guarding of live parts - AS/NZS 3000 & AS/NZS 3100 3. Isolation Insulation of live parts - AS/NZS 3000 & AS/NZS 3100 5. Administration Electrical Supervisor Qualifications required 5. Administration Safe work procedures and PPE where required. 6. PPE Use PPE where required	Consequence Major Likelihood Rare Risk 10

HAZARD	POTENTIAL RISK	RISK RANKING	CONTROL 1. Elimination 2. Substitution 3. Isolation 4. Engineering 5. Administrative 6. PPE	RESIDUAL RISK RANKING
Cable Fault Location, Identification & Tracing Electric shock from contacting LV	Muscle sensation, Muscle soreness, Burns, Heart failure, Fatality	Consequence Severe Likelihood Possible Risk 22	3. Isolation Isolate & prove de-energised 3. Isolation Class IV equipment - AS/NZS 3100 3. Isolation Guarding of live parts - AS/NZS 3000 & AS/NZS 3100 3. Isolation Insulation of live parts - AS/NZS 3000 & AS/NZS 3100 5. Administration Electrical Supervisor Qualifications required 5. Administration Safe work procedures and PPE where required. 6. PPE Use PPE where required	Consequence Severe Likelihood Rare Risk 15

Appendix P Rail Access Corporation (RAC)- Railway Drainage Bond Procedures

The procedure for installation of a new Electrolysis bond (Railway Drainage Bond) on a new site is as detailed below.

1. NSW Electrolysis Committee (NSWEC) member requests a trial of a new Drainage Bond (DB) at a committee meeting.
2. Trial of the new DB is programmed by the committee scheduler.
3. NSWEC member provides Rail Services Authority (RO) Electrolysis Engineer with a drawing showing the proposed trial DB location including railway tracks and the nearest stanchion number, etc.
4. RO Electrolysis Engineer arranges a temporary rail connection.
5. Trial of a new DB on site by NSWEC members.
6. Approval of installation of permanent DB or cancellation of trial DB or retrial of trial DB are decided during a meeting following DB trial.
7. Requested DB given an identification DB number by Authority and placed on list of DB's to be made permanent.
8. RO Electrolysis Engineer notifies local Signals Engineer.
9. Site meeting with the Electrolysis Engineer, NSWEC member and local Signals Engineer to verify suitability of the proposed DB location with respect to the rail connection requirements.
10. Signals Engineer draws a plan showing track insulation and rail connection details and sends it to Signals Design Section.
11. NSWC member provides RO Electrolysis Engineer with any outstanding design information required, eg. 24 hour voltage and current charts showing peaks and averages.
12. RO Electrolysis Engineer designs the new DB.
13. Signals Design Section completes the signal track circuit design and returns it to the Signals Engineer for the installation of the new DB rail connection.
14. A search for services must be carried out before any excavation is commenced on Railway property.
15. Installation of support, enclosure, and DB panel.
16. RO Electrolysis Engineer advises NSWEC members their cables can be installed.
17. Local Signals Engineer advises the Electrolysis Engineer that a new Electrolysis Bond rail connection has been installed.
18. New DB ready to be connected by Electrolysis Engineer or Assistant.
19. Testing of new DB by NSWEC members.

20 Final approval, regarding interference criteria, by NSWEC members.

Appendix Q Railway Drainage bond Flowchart

Signals Engineer draws a plan showing track insulation and rail connection details and sends it to *Signals Design Section*

NSW Electrolysis Committee *(NSWEC) member* requests a trial of a new Drainage Bond (DB) at a *committee meeting*

NSWEC member provides *RO Electrolysis Engineer* with any outstanding design *information* required e.g., 24-hour voltage and current charts showing peaks and averages

Trial of the new DB is programmed by *DoE Testing Officer*

RO Electrolysis Engineer designs the new DB

NSWEC member provides *RO Electrolysis Engineer* with a drawing showing the proposed trial DB location including railway tracks and the nearest stanchion number, etc.

Signals Design Engineer completes the signal track circuit design and returns it to the *Signal Engineer* for the installation of the new DB rail connection

RO Electrolysis Engineer arranges a temporary rail connection

Trial of a new (DB) on site by *DoE* and *NSWEC members*

A search for services must be carried out before any excavation is commenced on Railway property.

Installation of post, box, and DB panel.

Approval of installation of permanent DB or cancellation of trial DB or retrial of trial DB decided at next *NSWEC meeting* following DB trial. *NSWEC members* to review correlation charts and required 24 hour charts before decision for approval may be given by *RO Electrolysis Engineer*.

RO Electrolysis Engineer advised *NSWEC member* their cables can be installed

Requested DB given an identification DB number *by Authority* and placed on list of DB's to be made permanent.

Local Signals Engineer advises the *RO Electrolysis Engineer* that a new Electrolysis Bond rail connection has been installed.

New DB ready to be connected by *RO Electrolysis Engineer* or *Assistant*

RO Electrolysis Engineer notifies local Signals Engineer.

Testing of the new DB by DoE and *NSWEC members*

Site meeting with the *RO Electrolysis Engineer*, *NSWEC member* and the local *Signals Engineer* to verify suitability of the proposed DB location with respect to the rail connection requirements.

Final approval, with regard to interference criteria, by members at NSWEC meeting

Appendix R – Registering a CPS

The ***Electricity Supply (Corrosion Protection) Regulation 2020*** requires approval for a CPS with a current of 250mA or greater. Registration and management of corrosion protection systems occurs via the NSW CPS Register: ***https://cpsregister.nsw.gov.au***. Please visit this site for further information.