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Level 2

Methodology for the Demonstration Of Electrical Compatibility with Train Detection Systems in Use on Non-electrified Lines

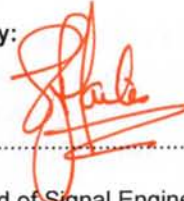
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Issue record

Issue	Date	Comments
1	Oct 2007	New Specification
2	August 2008	Updated to reflect Phase 2A / Engineering reorganisation responsibility change, no technical changes.

Compliance

This Network Rail standard is mandatory and shall be complied with by Network Rail and its contractors if applicable from 26 August 2008.

When this standard is implemented, it is permissible for all projects that have formally completed GRIP Stage 4 to continue to comply with the Issue of any relevant Network Rail Standards current when GRIP Stage 4 was reached and not to comply with requirements contained herein, unless the designated Standard Owner has stipulated otherwise in the accompanying Briefing Note.

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1 Purpose

This Level 2 document provides a methodology to demonstrate electromagnetic compatibility (EMC) with train detection systems on the non-electrified lines of Network Rail Controlled Infrastructure. This is achieved by:

- Identifying the train detection systems in use on non-electrified lines;
- identifying the potential, credible electromagnetic interference mechanisms presented by rolling stock;
- providing a methodology for the analysis of these mechanisms;
- providing a set of standard voltage limits for axle to axle interference, where there is available information to determine these;
- providing a methodology to establish compatibility arguments.

This methodology together with the standard limits shall be used for the demonstration of compatibility between train detection systems on non-electrified lines, and rolling stock, as part of a Route Acceptance Safety Case.

2 Scope

The scope of this Level 2 document is limited to the demonstration of electromagnetic compatibility of rolling stock with train detection systems installed on the non-electrified lines of Network Rail Controlled Infrastructure, which are not covered by other specifications in the ...SIG/500XX series.

The methodology described, considers both intact and faulty infrastructure. Axle to axle voltage limits, and a method for determining associated train circuit current limits for both continuous welded rail (CWR) and jointed rail (JR) track types, are established where there is available information to determine these.

The limits derived, include an appropriate apportionment factor, which takes into account other potential interference contributions, component tolerances and a safety margin for errors and unknowns in the derivation.

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3 Reference documentation

3.1 RSSB Group Standards

GE/RT8270	Route Acceptance of Rail Vehicles including changes in Operation or Infrastructure
GK/RT0011	Train Detection
GK/GN0611	Train Detection
GM/RT2477	TCA Configuration for Rail Vehicles
GM/RT2304	Equipotential Bonding of Rail Vehicles to Running Rail Potential
GM/RC2514	Recommendations for Equipotential Bonding of Rail Vehicles to Running Rail Potential

3.2 Network Rail Company Standards

NR/L2/SIG/11752	Train Detection
NR/L2/TRK/102	Track Construction Standards
NR/L2/SIG/11755	DC Track Circuits
NR/L2/SIG/11757	AC Phase Sensitive Track Circuits
NR/L2/SIG/11762	Track Circuit Assister Interference Detectors
NR/L2/SIG/11763	Reed Type RT Track Circuits
NR/GN/SIG/50002	Methodology for the Demonstration of Electrical Compatibility with Single Rail Reed Track Circuits on the AC Railway
NR/L2/SIG/50004	Methodology for the Demonstration of Electrical Compatibility with DC (AC immune) Track Circuits
NR/GN/SIG/50005	Methodology for the Demonstration of Electrical Compatibility with 50Hz Single Rail Track Circuits
NR/L2/SIG/50006	Methodology for the Demonstration of Electrical Compatibility with 50Hz Double Rail Track Circuits
NR/GN/SIG/50007	Methodology for the Demonstration of Electrical Compatibility with HVI Track Circuits
NR/GN/SIG/50008	Methodology for the Demonstration of Electrical Compatibility with TI21 Track Circuits
NR/GN/ELP/27010	Compatibility between Electric Trains and Electrification Systems

3.3 Other Standards

BS EN 50121-3-1: 2000	Electromagnetic compatibility. Rolling stock. Train and complete vehicle
BS EN 50121-3-2: 2000	Electromagnetic compatibility. Rolling stock. Apparatus
BS EN 50238: 2003	Compatibility between Rolling Stock and Train Detection Systems
BS 452: 1932	Specification for tractive armature d.c. neutral track relays
BS 1659: 1950	Specification for tractive armature direct current neutral track

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BR930	and line relays for railway signalling Specification for miniature tractive armature DC neutral line relay, plug-in type for railway signalling purposes, September 1971
BR933A	Specification for miniature tractive armature AC immune DC slow pick-up neutral line relay, plug-in type for railway signalling purposes, September 1971
BR938A	Specification for miniature tractive armature DC neutral track relay plug-in type for railway signalling purposes, September 1971
BR939A	Specification for miniature tractive armature AC immune DC neutral track relay, plug-in type for railway signalling purposes, September 1971
BR966	Specification for miniature tractive armature relays, plug-in type for railway signalling purposes, August 1981
BR968	Specification for miniature tractive armature DC neutral track relay plug-in type for railway signalling purposes, September 1971
TRS/T09/83	BR WR Quick Release Track Circuit Feed Unit, May 1983.
TRS/T10/83	BR WR Quick Release Track Circuit Relay End Unit, January 1983.
TRS/T11/83	BR WR Quick Release Track Circuit Relay End Unit for use with BR938 Relay, January 1983.

3.4 Other Documents

TIR 90019	British Rail Technical Investigation report: Compatibility Tests for the Operation of the Inductive Shunt Assister (ISA) with Track Circuits, July 1990
TIR 03804	Atkins Rail Investigative Services report: Methodology for the Demonstration of Compatibility with Non-AC Immune Track Circuits, Phase 1 Works, February 2004
TIR 04537	Atkins Rail Investigative Services report: Characterisation of DC Track Circuit Relays, April 2004
TIR 04547	Atkins Rail Investigative Services report: Laboratory Testing of Style UR1 and SF15 Track Circuit Receivers, May 2004
TIR 04568	Atkins Rail Investigative Services report: Aster U / SF15 PSpice Model Validation Tests, September 2004
TIR 04802	Atkins Rail Investigative Services report: Track Circuit Assister Interference Detector (TCAID): Maloperation from Trainborne Interference, April 2005
TIR 05802	Atkins Rail Investigative Services report: Diode Track Circuit: Maloperation from Trainborne Interference, April 2005
TIR 04803	Atkins Rail Investigative Services report:

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	Reed Jointless Track Circuit: Maloperation from Trainborne Interference, April 2005
TIR 04805	Atkins Rail Investigative Services report: 32 kHz Overlay Rail Circuit: Maloperation from Trainborne Interference, April 2005
TIR 04806	Atkins Rail Investigative Services report: DC Coded Track Circuit: Maloperation from Trainborne Interference, April 2005
TIR 04530	Atkins Rail Investigative Services report: Characterisation of Western Region Quick Release Relay End Units, March 2004
TIR 04563	Atkins Rail Investigative Services report: Characterisation of a Lucas Track Circuit Receiver, August 2004
TIR 04564	Atkins Rail Investigative Services report: Characterisation of TCAID-N and TCAID-MC Equipment, August 2004
5030877-L-TR-001	Atkins Rail modelling report: Axle to Axle Voltage Limits for Aster Track Circuits, 29/11/04
C2180-1	Atkins Rail Investigative Services report: Characterisation of DC Track Relays (Report 98097) – Normalisation of Frequency Response Results, 14/9/98
LR ES 009	British Rail Research report: AC Immune d.c. Track Relay Tests, December 1993
STG-D-RFD(092)- RP-8, Issue 1	British Rail Research report: DC Track Circuit Relays, Static Tests, August 1995
STG-D-RFD(092)- RP-8, Issue 1	British Rail Research report: DC Track Circuit Relays, Static Tests, August 1995

Where required by Route Acceptance related projects, all listed references are available from Network Rail Acceptance Services.

4 Definitions & abbreviations

AC-immune

A system or equipment that is inherently immune to the electromagnetic environment associated with the AC-electrified lines of Network Rail Controlled Infrastructure (25 kV, 50 Hz), including all normal and fault currents associated with passive loads.

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ALARP

As Low As is Reasonably Practicable: the reduction of likelihood and/or consequences of an occurrence to a level below which the costs and/or constraints of further mitigation outweigh their benefit.

Apportionment factor

The ratio between the derived susceptibility level for a train detection receiver and the applicable limit for an individual train, which takes into account other potential interference contributions, component tolerances and a safety margin for errors and unknowns in the derivation. For example, an apportionment factor of 1.25 means that a susceptibility level of 100 mV would be reduced by a factor of 1.25 resulting in a train limit of 80 mV (i.e. a reduction by 20%).

Ballast resistance

The effective resistance value between the two rails forming a track circuit or rail circuit, comprising the leakage to earth of each rail, due to casual connection through the rail fixings, bearers, ballast and track support, in series. May be expressed either as a value in Ohms for an individual track circuit, or as a value in Ohm.km for particular conditions.

Broken rail

A running rail or a series bond between running rail sections which has broken, causing an open circuit failure.

CWR

Continuous Welded Rail

DC-immune

A system or equipment that is inherently immune to the electromagnetic environment associated with the DC-electrified lines of Network Rail Controlled Infrastructure (750 V), including all normal and fault currents associated with passive loads.

Double rail track circuit

Configurations of track circuits where adjacent track sections are separated by IRJs in each running rail.

ELLIPSE

The Network Rail work and management system, which contains information on the location of all assets, including train detection systems.

EMC

Electromagnetic Compatibility: compatibility of systems, in respect of emission and immunity levels, so that operation of one system is not adversely affected by emissions from another system. For the purposes of this specification, EMC assessment shall include consideration of conductive, inductive, capacitive and radiated effects at all frequencies from d.c.

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EMI

Electromagnetic interference: emissions of electromagnetic energy which have the potential to threaten electromagnetic compatibility.

F&G

Field & Grant: a signalling equipment manufacturer. This term is used to identify a generic design of signalling relay, although these relay designs have also been manufactured or relabelled under other company names (e.g. Tyer's, Zone Controls and STS).

FSK

Frequency Shift Keying: modulation of a carrier frequency by fixed shifts in frequency.

GEC

General Electric Company: a signalling equipment manufacturer. This term is used to identify a generic design of signalling relay, although these relay designs have also been manufactured or relabelled under other company names (e.g. AEI, MV, SGE, GRS, GASL, Alstom and Unipart Rail).

HVI

High Voltage Impulse: a type of track circuit manufactured by GEC and derived from the earlier Jeumont Schneider track circuit. Susceptibility levels are identified in NR/GN/SIG/50007.

Immunity

The ability of a system or equipment to operate without failure or malfunction in the presence of electromagnetic interference.

IRJ

Insulated Rail Joint: a method of joining rail ends together whilst maintaining electrical insulation between them.

JR

Jointed Rail

JTC

Jointless Track Circuit: a track circuit whose extremities are not defined by use of IRJs (e.g. by a tuned zone).

Rail circuit

Train detection equipment using the rails in an electric circuit, which detects the presence of a train (as opposed to its absence).

RAR

Railtrack Asset Register: a Network Rail database, which contained information on the location of all assets, including train detection systems. The data has now been incorporated into the ELLIPSE work and management system.

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Risk assessment

The integrated analysis of safety risks inherent to a product, system or project and their significance in an appropriate context.

Route Acceptance

Defined in GE/RT8270 as the process leading to acceptance by Network Rail (formalised by the issue of a Certificate of Authority to Operate), that all safety issues associated with the physical and operational characteristics of specified vehicles and their compatibility with the infrastructure on defined routes have been examined, and that the associated risks have been reduced to a level which is ALARP.

Route Acceptance Safety Case

The documentation which demonstrates the conditions under which vehicles can be operated safely on the defined routes and which forms the basis of an application for a Certificate of Authority to Operate.

Single rail track circuit

Configurations of track circuits where adjacent track sections are separated by IRJs in one running rail only, the other (common) rail being electrically continuous.

Steady state

A level of energisation that exists for a period longer than the time taken by the train detection receiver to operate.

Susceptibility

Sensitivity of equipment to electromagnetic emissions.

TCA

Track Circuit Assister: a device fitted to a vehicle which causes a nominal 165 kHz signal to pass between the wheels of the vehicle and assists in the breakdown of the insulation at the wheel to rail interface due to leaf-fall, rust etc.

TCAID

Track Circuit Assister Interference Detector: a device fitted to the track which when it detects the presence of a nominal 165 kHz signal in the rail, causes the track circuit to show occupied.

TPR

Track repeat relay: normally having a slow to operate (pick) characteristic (e.g. relay to specification BR 933A). The TPR provides an interface between the track circuit and the rest of the signalling system.

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TR

Track relay: generally a neutral relay with a low coil resistance and low power consumption that acts as part of a track circuit. It is either connected directly to the rails or via a capacitor or tuning unit.

Track circuit

Train detection equipment using the rails in an electric circuit, which detects the absence of trains on a defined section of line.

Track section

A portion of railway track having fixed boundaries and for which the train detection system provides information on its state of occupancy.

Train

For the purposes of this specification, a train is any permitted combination of rail vehicles.

Train detection system

Equipment and systems forming part of or providing input to the signalling systems to detect:

- The presence or absence of vehicles within the limits of a track section; or
- That a train has reached, is passing or has passed a specific position.

Transient

Short duration and/or changing levels of energisation, when compared to the dynamic response of the train detection receiver.

WRSL

Westinghouse Rail Systems Ltd.: a signalling equipment manufacturer. This term is used to identify a generic design of signalling relay, although these relay designs have also been manufactured or relabelled under other company names (e.g. Westinghouse Signals and Westinghouse Brake and Signal Company (WB&SCo.)).

5 Train detection systems in use on non-electrified lines

These are train detection systems that are typically not immunised against the effects of electric traction supplies.

The types of train detection systems specifically considered in this Business Process Specification, are as follows:

- DC track circuits (non AC-immune);
- Aster track circuits (U / SF15 types);
- Aster track circuits (1 Watt type);
- Western Region quick release track circuits;
- Track circuit assister interference detectors (TCAID);

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- Lucas track circuits;
- Reed track circuits (jointless configuration);
- Overlay rail circuits (32 kHz type);
- Diode track circuits;
- Coded DC track circuits ("tick-tock");
- 50Hz track circuits.

These represent the majority of train detection types found on non-electrified lines.

Other types of train detection systems which are either a.c. immune, d.c. immune or dual immune, can be fitted on non-electrified lines, where there is some expected influence from stray traction currents, there are residual voltage problems (see [NR/L2/SIG/11752](#)), or for consistency in a given area. These train detection systems are covered by other specifications in the ...SIG/500XX series, and the guidance in these documents should be followed with regard to applicable interference mechanisms (e.g. axle to axle voltage).

Where other signalling equipment, not covered by the specifications in the ...SIG/500XX series, is identified on the routes or boundaries of interest, then the advice of the Network Rail EMC National Specialists team shall be sought.

5.1 General methodology

Appendix A considers the credible electromagnetic interference mechanisms with train detection systems on non-electrified lines:

- radiated;
- induced;
- conducted;

concluding that the only significant potential interaction between (non electric traction) rolling stock and train detection systems is conductive, and that detailed analysis will normally be limited specifically to axle to axle (longitudinal) voltage scenarios which are described in Appendix B.

Sections 6 to 16 of this specification, provide a brief description of each of the train detection systems covered, together with a derivation of the applicable axle to axle voltage interference limits.

Whilst recognising that there are a large number of possible configurations for the electrical systems on-board trains, a general method for the analysis of electrical systems, with respect to axle to axle voltage interference, is given in Appendix C on, such that the maximum axle to axle voltages can be calculated, together with their respective probabilities.

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Where the maximum calculated axle to axle voltage is less than the given limit appropriate to the particular equipment in question, no further demonstration of compatibility is necessary as far as that equipment is concerned.

Where this cannot be shown, it will be necessary for a risk assessment to be undertaken, taking into account both the likelihood of the exceedance of axle to axle voltage limits, and the probability of any necessary infrastructure conditions for the application of that limit (e.g. failures), being coincident within the exposure period. The infrastructure failure rates used for the assessment, shall be based on the latest available data from Network Rail.

The results of such a risk assessment shall form part of the Route Acceptance Safety Case for the vehicles, and where the total exceedance rate cannot be shown to be ALARP in the context of the safety requirements of the project, can result in route restrictions.

6 DC track circuits (non AC-immune)

6.1 Track circuit description

DC track circuits are the predominant track circuit type installed throughout the UK rail network and there are several variants.

DC track circuits provide a simple and reliable track circuit for use on non d.c. electrified lines. In their basic form, a feedset applies power to the rails at one end of the section and is transmitted via the rails to the d.c. track relay at the other end.

Non a.c. immune d.c. track circuits are those d.c. track circuits that are not specifically immunised against the effects of the 50 Hz a.c. traction supply. It should be noted however that many d.c. track circuits installed on non electrified lines, may well use a.c. immune feedsets and/or relays due to standardisation and other advantages such as better lightweight vehicle detection and no requirement for adjustment.

Two principal installation configurations are employed – “double rail”, where both rails are fitted with IRJs (Insulated Rail Joints) at each end of the section to keep adjacent track circuits electrically separate, and “single rail”, where only one of the rails is fitted with IRJs at either end of the section, and the other rail is thus electrically common with the adjacent track circuit.

The d.c. power supply is obtained from a transformer/rectifier or a battery, and is connected through a feed resistor to the rails. This resistor limits the current drawn from the power supply when the track circuit is shunted by the train, and permits the track circuit sensitivity to be adjusted. The performance of d.c. track circuits is determined by:

- the shunt resistance presented by the train;

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- the drop away rail voltage (to tolerate d.c. interference and rail contamination);
- the minimum ballast resistance at which the track circuit remains functional;
- d.c. interference from other track circuits and external sources – e.g. battery effects;
- the need, or otherwise, for a.c. immunity.

Detailed descriptions of d.c. track circuits and their operation and installation are given in Network Rail Product Specification [NR/L2/SIG/11755](#).

6.2 Applicable axle to axle voltage scenarios

All three of the general scenario types described in Appendix B, are applicable to d.c. track circuits, where the rail resistance is very low compared to the track relay resistance.

Therefore, the absolute worst case is for the entire axle to axle interference voltage to be presented directly across the track relay. Therefore the 'standard' axle to axle voltage limit is simply the drop away voltage of the relay in question, with an appropriate apportionment factor applied to account for interference which may be present from other sources.

For axle to axle voltages, an apportionment factor of 2 (50%) is appropriate, as the worst case scenario, where the whole of the axle to axle voltage is presented across a track relay, will only occur under infrastructure failure conditions. Therefore, the maximum permissible axle to axle voltage is considered to be 50% of the specified minimum drop away voltage of the track relay.

The factor of 2 (50%) for axle to axle voltage, is in line with the factors applied in [NR/L2/SIG/50004](#) and other ...SIG/500XX series documents, where the interference mechanism is partially reliant upon infrastructure failures, but there is potential for other interference sources to be present.

6.3 DC track circuit relay susceptibility

6.3.1 Steady state levels

Seven different d.c. track relay types, which account for the majority of non a.c. immune types in use (together with the three most common a.c. immune types, which are used in non-electrified areas due to standardisation), have been considered. These include all types recognised in Network Rail Product Specification [NR/L2/SIG/11755](#). Table 1 summarises key data for these relay types. Specified values are

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given based on the parameters given in the relay specifications. These are consistent with measured values (TIR 04537).

Relay Spec	Contacts	Nominal Relay Coil Res. (Ohms)	Drop Away Voltage (mV)	Permissible Axle to Axle Voltage (mV)
BR939A	2F	20	1100	550
BR966 F2	2F	9	730	365
BR966 F9	2F	60	1900	950
BR938	2F	4	252	126
BS1659	4F 2F/B	9	276	138
BS1659	2F 2F/B	9	226	113
BS1659	2F/B	9	215	107
BS1659	4F 2F/B	2.25	138	69
BS1659	2F 2F/B	2.25	114	57
BS1659	2F/B	2.25	107	53

Table 1 – DC Track Relay Characteristics

It should be noted that BS1659 and BR938 are examples of relay specification numbers. In addition to these numbers, manufacturers often also have their own unique part number.

This can cause confusion where route surveys derived from Network Rail's assets register include a variety of different relay numbers which can be referring to the same type of relay. For example, relays are often listed in the assets register by specification type e.g. BR938 and sometimes by manufacturers' type number e.g. QT2 (which is a Westinghouse part number for a relay built to BR938 specification). Refer to Table 2 for details.

Relay Spec	Contacts	Coil Res. (Ohms)	Manufacturer		
			WRSL	GEC	F&G
BR939A	2F	20	QTA2	ZA 0051 ZA 0005 12M01	G4/TA
BR966 F2	2F	9	QTA2	ZA 0151 ZA15/2	G4/TA
BR966 F9	2F	60	QTA2	ZA 0061	TY 153-4
BR938	2F	4	QT2		
BS1659	4F 2F/B	9 / 2.25	NT1 D5 D6	SN6	G3
BS1659	2F 2F/B	9 / 2.25	NT1	SN4	G3

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Relay Spec	Contacts	Coil Res. (Ohms)	Manufacturer		
			WRSL	GEC	F&G
			D5 D6		
BS1659	2F/B	9 / 2.25	NT1 D5 D6	SN2	G3

Table 2 – DC Track Relays: Manufacturers' Type Numbers

WRSL - Westinghouse Rail Systems Ltd.

GEC - General Electric Company

F&G - Field & Grant, incorporating Tyler's and Zone Controls designs

Network Rail Product specification [NR/L2/SIG/11755](#) (section 2.2.1), specifies that only a.c. immune, d.c. track relays (to BR939 or BR966) are preferred for new work. As can be seen in the table above, these relays have a relatively high susceptibility level, compared to BR938 and BS1659 relay types, which although they presently exist in large numbers throughout the network, may not be "installed on new work, except where relatively minor alterations are involved and more extensive replacement would not be economically justified" (section 4.3.1 of [NR/L2/SIG/11755](#)). Therefore, it can be assumed that the d.c. susceptibility applicable to a particular route, will not be worsened by any design changes, as low voltage relays are effectively prohibited from proliferation.

In particular, [NR/L2/SIG/11755](#) (section 4.3.3.3) states that 2.25 Ohm relays, which define the worst case susceptibility levels, are not to be installed.

Whilst other more obscure relay types may exist (e.g. to BS452: 1932, which was superseded by BS1659 in 1961), their whereabouts is not easily determined, and it has been generally accepted that the most sensitive known d.c. track relay installed on non-electrified lines is a 2.25 Ohm relay with 2F/B contact configuration to BS 1659. This has a specified minimum pick-up current of 74 mA, which taking into account a specified minimum release of 68%, and a specified coil resistance tolerance of 5%, can be expressed as a minimum drop away voltage of 107 mV ($74 \times 2.25 \times 0.68 \times 0.95$).

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The proposed network wide limit is based on the most sensitive known DC track circuit relay installed on non-electrified lines (2.25 Ohm 2F/B contact configuration to specification BS1659) and is therefore very pessimistic alone. These relays are well known for their low drop shunt values and prohibited from proliferation; see NR/L2/SIG/11755.

Some track circuits are fitted with additional feed end relays, to enhance the integrity of the track circuit under degraded conditions (broken bond, etc.) and cope with the battery effect where identified (NR/L2/SIG/11755). Track circuits which have feed end relays are not susceptible to longitudinal voltage interference, and therefore there is no maximum permissible axle to axle voltage applicable for these track circuits.

In practice, when considering the complete set of required routes for a particular train, the most susceptible d.c. track circuit on those routes shall be taken in account to define the applicable train limit

6.3.2 Relay response to low frequency AC

Most rolling stock will have some d.c. electrical systems, so the susceptibility of d.c. track circuits to a.c. axle to axle voltages is also considered. As the most significant likely sources of a.c. axle to axle voltages will be 50Hz systems, then frequencies up to this value have been considered. DC track relays are considered to be effectively immune to frequencies above 50Hz.

Whilst non-immune d.c. track relays are not immunised against the effect of a.c. voltages on their input, there are three mechanisms by which their sensitivity to a.c. voltages is effectively reduced:

- at very low frequencies (< 20 Hz), the relay will follow an a.c. signal, intermittently energising and de-energising, therefore the pick-up value is relevant to frequencies below 20Hz;
- coil impedance increases with frequency (at 10 kHz > x 20 @ 50Hz);
- operate current increases with frequency (> x 3 @ 50Hz).

The response to a.c. depends on the relay type. The susceptibility curves in Figure 1, are derived from the test results recorded in reference TIR 04537, which included a representative collection of relays of different manufacture. The BS1659 / BR938 curves are a combination of the widest frequency response, normalised to the minimum operate value. In conjunction with the apportionment factor of 2 (50%), the approach is considered to be reasonably pessimistic.

**Susceptibility of D.C. Track Relays to Low Frequency (< 50Hz)
Including x2 (50%) Apportionment Factor**

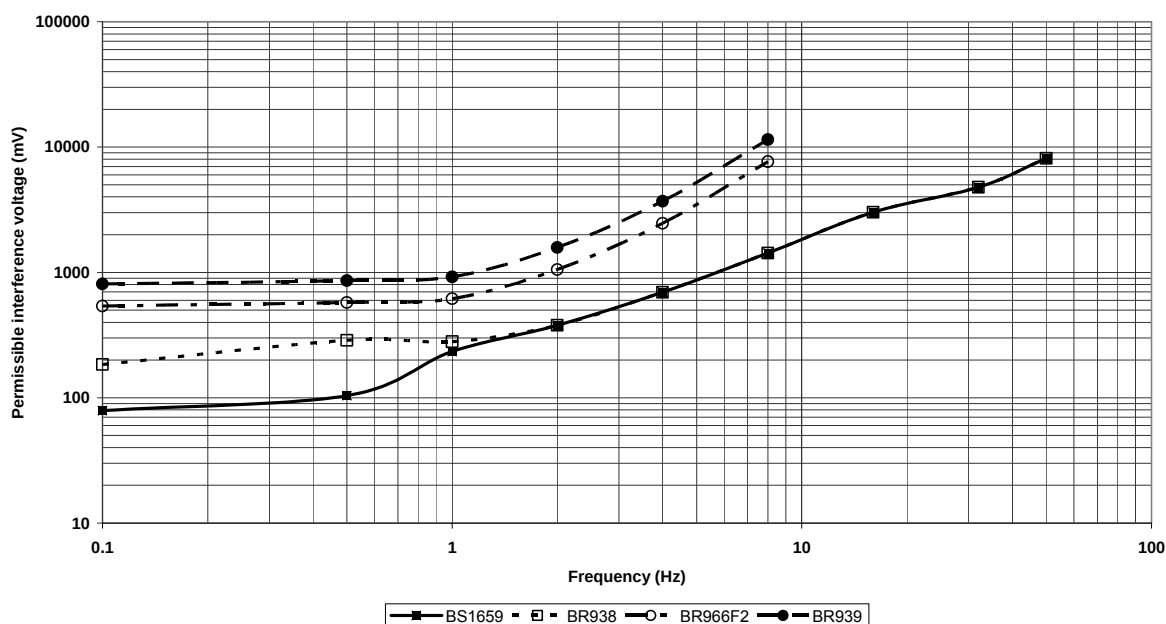


Figure 1:
Susceptibility of DC Track Relay to Low Frequency (< 50Hz)
Including x2 (50%) Apportionment Factor

Whilst below 2Hz, separate characteristics are given for the shelf type relays to BS1659 and the BR930 series plug-in relays to BR938, above 2 Hz a single characteristic is given. For comparison, the equivalent susceptibility characteristics for the most common a.c. immune d.c. track relay types (BR939 and BR966-F2) are also shown.

Given the common use of on-board 50Hz electrical systems, of particular significance is the effective 50Hz axle to axle voltage limit of 8.14V. It shall be noted that this is far higher than the 50Hz voltage limit applicable to 50Hz or Western Region Quick release Track Circuits, described in other sections of this Business Process Specification.

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When applying the factors in the above characteristic to frequencies below 20Hz, it should be recognised that exceedance of the adjusted interference voltage limit indicates that there is a risk of intermittent false operation of the track relay. The significance of such intermittent operation will depend upon the use of the track relay within the signalling system. Where, in accordance with current best practice, slow to pick repeat relays or TPRs (e.g. to specification BR933A), are fitted, or equivalent interlocking delay applied (NR/L2/SIG/11755, section 2.2.2), the track relay would need to be energised for sufficient time for a change of track circuit state to be registered, before there was any possibility of interference with the signalling system.

However, in producing the composite characteristic, no allowance has been made for slow to pick TPRs, since they are not universally applied on the older installations where the most susceptible relays tend to be used.

The mechanism being considered is conducted interference to the TR from the running rails. The TPR is effectively isolated from this interference current and no change in response is to be expected, or has been observed in tests.

6.3.3 Relay Response to short term DC and criteria for compatibility

Where a higher axle to axle voltage can be present for a short duration, for example during earth fault clearance, there is the potential for a momentary false operation of a track relay. In order to assess this risk, the maximum expected axle to axle voltage time integral (V.s) should be determined, for comparison against the track relay susceptibility.

The most sensitive d.c. track relays to BS1659 or BR938, may be operated by a single pulse of value 100 mV.s (Ref. TIR 04537). Given the very short time at risk involved, then it is considered appropriate to only reduce this by an apportionment factor of 1.25 (20%), resulting in a limit of 80 mV.s.

The contribution of feed through from rectified a.c. present on the track is considered to be readily encompassed within this apportionment factor.

AC-immune DC track relays such as those to specifications BR939 and BR966 are inherently less sensitive to short pulses. Detailed characteristics of these relays can be found in specification [NR/L2/SIG/50004](#).

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7 Aster track circuits (U / SF15 types)

7.1 Track circuit description

The “Aster U” track circuit dates back to the 1960’s and is a jointless track circuit which is a derivative of the older “Aster 1 Watt” variant (see Section 8). More recently manufactured Aster track circuit equipment may be identified as being of type SF15 (introduced 1979). Whilst the internal components of transmitter and receiver differ from the original U type, the operating mechanism is the same, and they are considered to be ‘like for like’ replacements. Therefore the term “Aster U”, will be used to describe either U type or SF15 type, but as the equipment modules are interchangeable, the worst case has been considered in determining the susceptibility level.

The Aster U track circuit is installed in a double rail configuration and operates at audio frequencies similar to those used by TI21 track circuits. Specifically there are four different Aster U track circuit operating frequencies: 1700 Hz, 2000 Hz, 2300 Hz and 2600 Hz. Unlike TI21 track circuits the Aster track circuits are simple single frequency devices: there is no FSK (frequency shift keying), or other coding of the transmitted signal.

Similar to TI21 track circuits, when Aster U track circuits are required adjacent to one another they are installed in pairs. The frequencies 1700 Hz and 2300 Hz are paired as are the frequencies 2000 Hz and 2600 Hz. In areas track circuited with Aster track circuits it is usual for one pair of frequencies to be used on the Up line and the other on the Down line.

The track circuit essentially consists of a transmitter, a receiver and a pair of track transformers, which provide the means by which the track circuit signal is coupled into and out of the rails. The nominal length of the track circuit is the distance between the rail connections and the track transformer at each end. The maximum permitted length for a single track circuit is 1000 m.

Normally, where Aster U track circuits are required adjacent to one another, the limits of each track circuit are defined by a ‘Tuned Zone’, termination, comprising two series tuned circuits, each of which acts as a short circuit to only one of the two frequencies. These are formed by the combination of a tuning unit and 13m of rail between the track transformer and the respective tuning unit.

Figure 2 shows the normal layout of tuning units and track transformers between successive Aster track circuits.

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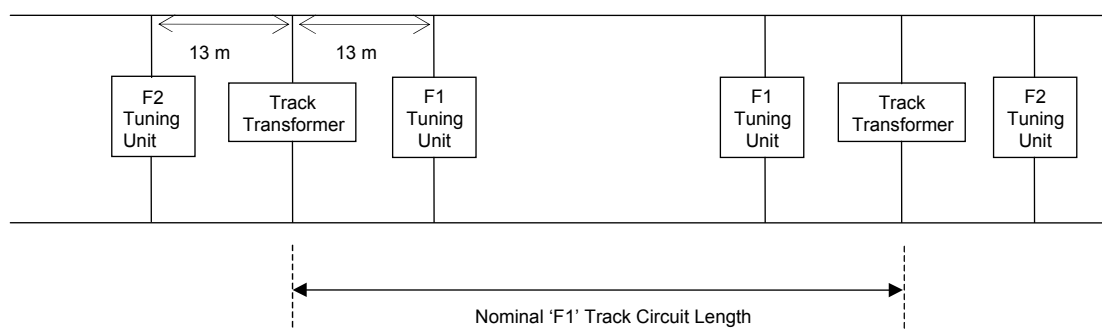


Figure 2: Aster U Track Circuit Layout (Tuned Zone termination)

When the Aster U track circuit is required to abut another type of track circuit, a pair of insulated rail joints (IRJs) shall be installed, in which case the relevant tuning unit is connected directly to the track transformer, just short of the pair of IRJs, as per Figure 3.

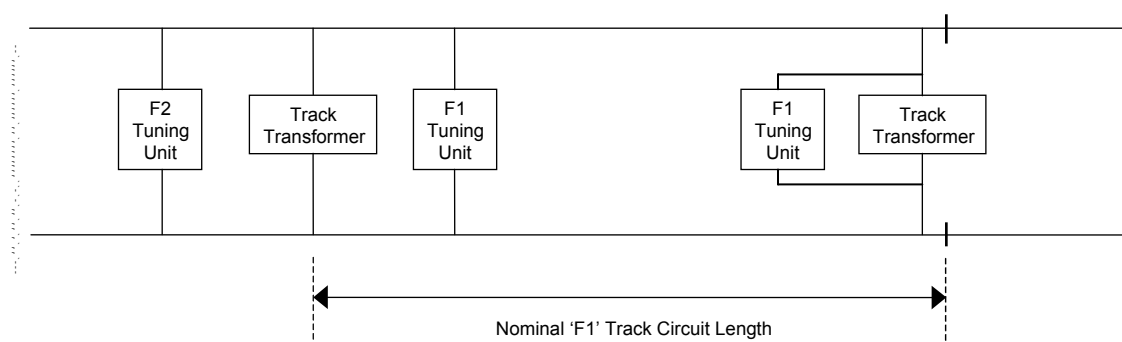


Figure 3: Aster U Track Circuit Layout (IRJ termination)

The track circuits can also be centre fed, the two halves functioning independently. As for the normal layout the maximum length of either side shall not exceed 1000 m.

They can also be installed at points and crossings subject to certain limitations, none of which are significant in respect of the maximum permissible levels of interference current in the rails.

There are four different transmitters (one for each track circuit operating frequency). In the same manner there are four different receivers and four different tuning units. There is only one track transformer which is an air cored transformer used for track circuits of all frequencies.

The transmitter is a simple arrangement consisting of an oscillator, a power amplifier and output regulation and protection circuits as shown in Figure 4.

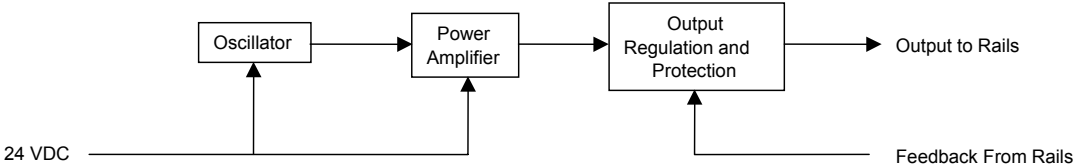


Figure 4: Aster U Track Circuit Transmitter

The receiver consists of a 2 stage amplifier fed from a narrow band pass filter as shown in Figure 5.

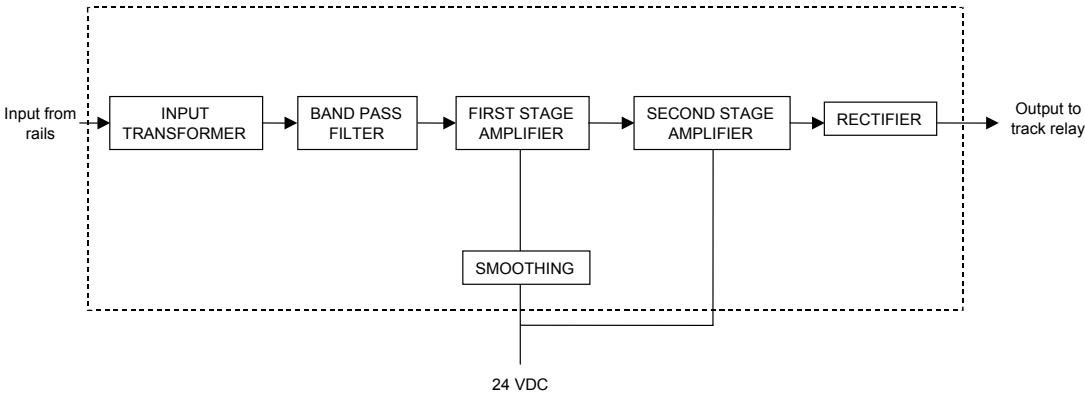


Figure 5: Aster U Track Circuit Receiver

The transmitter is connected to one of the secondary windings of the track transformer (either terminals 1 & 2, 4 & 5, or 5 & 6), with the primary (terminals T1 & T2) connected to the rails (see Figure 6).

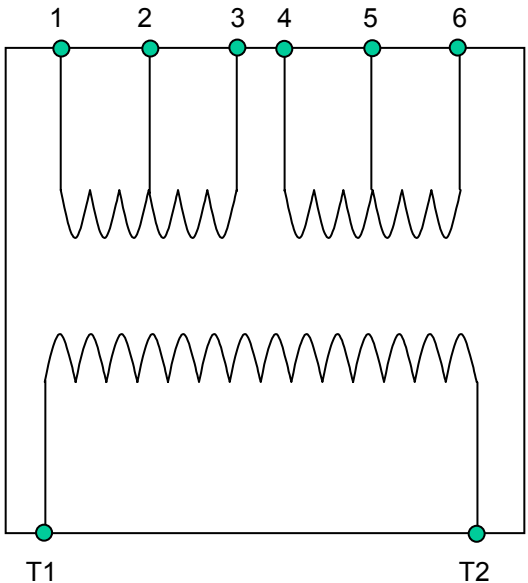


Figure 6: Track Transformer windings

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At the other end of the track circuit, the receiver input is connected to the secondary windings (either terminals 1 & 3 or 4 & 6), which provides a step-up ratio from the track voltage of 14:47, although in practice, with the receiver loading, the effective voltage step-up is below x3 (ref. TIR 04568).

The receiver input transformer has five secondary windings to provide a means of adjusting the overall gain of the receiver and by selecting taps the gain may be adjusted in 49 steps each equal to 1/49 of the maximum gain. This is necessary because the voltage received will vary according to the track circuit length whilst the relay can tolerate a much smaller variation.

The received signal is passed through a band pass filter which is tuned to reject frequencies other than the transmitted signal, two stages of amplification followed by rectification to provide a d.c. output to a d.c. relay, to specification BR 968, which provides an interface between the track circuit and the rest of the signalling system.

The selectivity of the receiver is not adequate to guarantee immunity from false operation of the track circuits by harmonics of the 50 Hz traction supply, particularly when the effects of the permissible drift on the supply frequency are considered. Therefore Aster track circuits are not installed on a.c. electrified lines, or within their boundary areas.

7.2 Applicable axle to axle voltage scenarios

Of the three general scenario types described in Appendix B, only the internal scenario (Appendix B.1), where circulating current flows along the rails upon which the train is standing, is considered to be applicable to Aster track circuits, where the rail impedance is high compared to the effective receiver input impedance.

As Aster U track circuits are installed in double rail configuration (for either Tune Zone or IRJ terminations), in normal circumstances they are electrically balanced. Consequently, in the absence of any imbalance between the rails there is no possibility of any stray axle to axle currents from a train being coupled into the receiver since there will be no net voltage developed across the track transformer and hence no interference current flowing through it.

However, significant imbalance can be introduced due to:

- a broken rail (or series bonding);
- a tuning unit disconnection;
- unequal earthing of each rail through the ballast;
- the presence of check rails;
- earthing of either rail;

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- track curvature.

A broken rail or disconnected tuning unit, will give rise to the maximum imbalance, but can reasonably be expected to cause a right side failure of the track circuit. The other causes of imbalance will be less significant although the precise degree of imbalance is difficult to predict. In order to determine the worst case susceptibility limit, a broken rail has been assumed. If the broken rail is placed between the axles of the train then the rail currents will be unbalanced forcing current into the resonant circuits of the tuned zone which will impact upon the receiver voltage.

Rudimentary modelling can be conducted on the basis that the axle to axle voltage source is considered to drive a fault current governed by the impedance between the two relevant train axles: the track transformer voltage being determined by potential division, considering all the components in the current path.

On this basis, it was considered appropriate to conduct more accurate modelling on the scenarios where there is a rail break under the train, for both the tuned zone and IRJ terminations (Ref. 5030877-L-TR-001), as it was surmised that the track transformer voltage may exhibit resonant characteristics for certain positions of the axles, whereby the value of the track transformer voltage can exceed that of the applied axle to axle voltage.

The modelling considered different lengths of wheelbase (subject to remaining within the limits for a valid wheelbase (2.5 m to 17.51m – see [GK/GN0611](#)) and different wheel set positions. All four operating frequencies ($f_1 = 1700, 2000, 2300, 2600$ Hz) were considered, but only the SF15 receiver type was modelled, it having been established by laboratory tests (ref. TIR 04547), to be more sensitive than the alternative U type. Sensitivity analysis was conducted to determine the effect of changing the wheel set positions and adjusting the assumed component values, in order to determine the highest value of receiver voltage for a given axle to axle voltage.

The worst case arrangement for the tuned zone termination, was determined to be for a 2000/2600 Hz tuned zone, fitted with a 2600 Hz (SF15 type) receiver, when a 1.0 Volts axle to axle voltage at 2600 Hz could result in a maximum track transformer voltage of 1.4 Volts.

A similar analysis approach was used to determine the worst case arrangement for the IRJ termination. This was determined to be for a 1700 Hz (SF15 type) receiver, when a 1.0 Volts axle to axle voltage at 1700 Hz could result in a maximum track transformer voltage of 1.5 Volts.

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Considering that the validation testing suggests that the modelling is up to 35% pessimistic, and that the worst case arrangement derived, is very specific, then adding an additional 25% to allow for feed through from the transmitter of the track circuit around an imperfect train shunt, which was not represented in the model, is considered to be a sufficient apportionment factor, resulting in a worst case track transformer voltage of twice the axle to axle voltage.

7.3 Aster track receiver susceptibility

7.3.1 Steady state levels

In the absence of published data, practical test results on the sinusoidal response of Aster U and SF15 receivers (ref. TIR 04547), indicates minimum receiver sensitivities (at maximum gain) of 97mV to operate (Pick-up) and 86mV to release (Drop-away), for the SF15 type 2600Hz receiver.

As the worst case scenario examined, depends upon either a broken rail or disconnected tuning unit, which can reasonably be expected to cause a right side failure of the track circuit, then only the minimum operate value of 97mV is relevant.

As the receiver input is connected to a secondary winding of the track transformer, the effective voltage step-up ratio from the track voltage of x3 (ref. TIR 04547), is taken into account.

Therefore, the worst case axle to axle voltage limit is given by the following formula:

$$V = v / (R_1 \cdot R_2)$$

Where:

- V Axle to axle Voltage limit (V)
- v Minimum receiver operate Voltage (V)
- R₁ Effective track transformer step-up ratio (x3)
- R₂ Worst case ratio of axle to axle voltage to track transformer voltage, including apportionment factor (x2)

Giving a figure of 16 mV, across the frequency range described in section 7.3.2, which is applicable for both tuned zone and IRJ terminations, which would both normally be present in any given route.

7.3.2 Bandwidth

In order to determine the effective bandwidth, with respect to axle to axle voltages, both the sinusoidal response of the receivers themselves (ref.

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TIR 04547), and the response of the track termination (ref. 5030877-L-TR-001), is considered.

The worst case bandwidth is defined by the IRJ termination, with a half-power bandwidth of +/- 35Hz. This is considered to be pessimistic, but avoids odd 50Hz harmonics:

1665 – 1735 Hz

1965 – 2035 Hz

2265 – 2335 Hz

2565 – 2635 Hz

7.3.3 Transient / short term response

Unlike TI21 track circuits, which are not susceptible to transient interference, no significant pick-up time delay is present in the Aster track circuit receiver (defined as Operating Category B “Medium to Pick-Up, Medium to Drop-Away” in specification [NR/L2/SIG/11752](#)) and therefore it is susceptible to short duration transients.

Whilst therefore any transient that exceeded the steady state limit at the receiver would have to be assumed to be capable of causing its wrong side failure, the acceptability of transients shall be assessed on a probabilistic basis, taking into account, the infrastructure conditions required, the rolling stock conditions required and the possible consequence scenarios.

8 Aster track circuits (1 Watt type)

Although, the signalling equipment on the routes or boundaries of interest to a Route Acceptance related project shall always be underwritten by the Signal & Telecoms Maintenance Engineer in the relevant Delivery Maintenance Unit, the ELLIPSE database (taking account additional information in TIR 03804) indicates that there are only a limited number of Aster 1 Watt track circuits remaining in use:

- Warwick – Tylesley South Jcn (DCL: 107-125 miles)
- Hebden Bridge (MVN2: 23-24 miles)
- Water Orton – Walsall (CBR: 40-41 miles)
- Whitacre Jcn – Nuneaton (NWO: 3-5 miles)

8.1 Track circuit description

The Aster 1 Watt type of track circuit pre-dates the more common ‘U’ or SF15 types considered in section 7. It is similar in terms of its basic operating