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Methodology for the demonstration of compatibility with FS2600 track circuits on the DC Railway. (formerly RT/E/C/50009)

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METHODOLOGY FOR THE DEMONSTRATION OF COMPATIBILITY WITH FS2600 TRACK CIRCUITS ON THE D.C. RAILWAY

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IMPLEMENTATION

The provisions of this code of practice may be used from the date of issue.

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1.0 Objectives

1.1 Purpose

The purpose of this document is to provide a methodology to demonstrate compatibility with FS2600 track circuits on Railtrack 750V d.c. electrified railway.

1.2 Scope

This document covers FS2600 track circuits installed in double rail configuration on d.c. electrified Railtrack controlled infrastructure.

Methodology is based on level alone for simplicity of demonstration. This is achieved by:

- Providing a characterisation of the track circuit components.
- Providing a characterisation of the infrastructure.
- Providing a methodology to define the susceptibility for worst case scenarios.

Combining these elements will allow an analytical investigation to find the maximum permissible interference for trains in d.c. electrified areas, with double rail FS2600 circuits applicable to Railtrack infrastructure. The minimum levels found from the susceptibility analysis are taken as the maximum permissible interference levels. Methods are included to analyse intact and faulty infrastructure for single and double track configurations.

The FS2600 track circuit has been designed to be 'traction immune', so that it cannot be energised by any single interference frequency or transient. This is achieved by using Digital Signal Processing (DSP) to monitor the signal it receives from the track. The use of DSP enables the validity of the signal to be checked in terms of its frequency content and amplitude at the same time. This overcomes the traditional problem encountered with separate level and code checking systems which can be erroneously activated by small genuine signals with a higher general noise signal overlaid. Energisation of the receiver requires a train to produce a modulated current which gives an FFT signature similar to that of the FS2600 transmitter. This is unlikely to occur in practice. Hence the results of this analysis are highly pessimistic.

1.3 Scenarios covered by this Document

A FS2600 track circuit will continue to operate in the presence of interference currents flowing in the traction return system of any single track circuit up to the levels indicated in Table 1 [12]. The system will also withstand up to 60Vrms across the rails at the receiver end of the track circuit without failure.

Frequency (Hz)	Maximum Current in Traction Return Rails (A)
DC	8,000
1 to 152	400
152 to 312	100
312 to 576	3
576 to 3,000	100

Table 1: FS2600 Traction Interference Reliability Levels

The tolerated interference current level for the FS2600 frequency band for RSF are higher than those allowed for wrong side failure (WSF) [12], hence this documents stresses on failure modes causing WSF even if the probability of these happening is considered incredible.

- Failure Mode 1**

Wrong side failure caused by interference current with all rails intact
- Failure Mode 2**

Wrong side failure caused by interference currents, with a broken traction return rail or impedance bond connection

- **Axle to Axle Voltage** Wrong side failure caused by a train on an adjacent track producing axle to axle voltage

The analysis was carried out for single and two track areas only. The results produced are valid for areas with any number of tracks, as the effect of interference is reduced by the increasing number of parallel return paths.

Only two interference mechanisms (return current through track circuit and axle-to-axle voltage) are analysed. Other mechanisms, such as induction directly into the impedance bond or receiver tail cables are not covered by this report, since very high interference-field levels would be required to have a significant effect.

2.0 SOURCE DOCUMENTS

2.1 Group and Line Standards

1. Electrified Lines Traction Bonding, GL/RT1254, Issue 1, April 2000.
2. Railtrack Company Product Specification - Westinghouse Signals FS2600 Track Circuits, RT/E/PS/11760, Issue 1, December 2000.
3. Railtrack Company Product Specification - Compatibility between Electric Trains and Electrification Systems, RT/E/C/27010, Issue 1, June 1999.
4. Railtrack Company Product Specification - Design and Installation of Negative Bonding and Associated Equipment on D.C. Electrified Lines, RT/E/C/27022, issue 1, March 1998.
5. Railtrack Company Specification MRS - Index of Railtrack Documents Relating to Electrical Distribution & Electro-Mechanical Plant Engineering Activities, RT/E/S/20000, Issue 9, April 2001.

2.2 Previous Safety Case documentation

6. 'Class 92 Locomotive EMC Safety Assessment - Volume 6 - FS2600 Track Circuits', AEAT Rail (former TCI) Ref. 120-dr0344, Version b0, September 1997.
7. Class 365/5 Networker Express EE&CS EMC Safety Assessment for D.C. Operation, AEAT Rail (former TCI) Ref. TCS120-dr0148, September 1997.
8. 'Juniper Project - FS2600 Track Circuit Interference Limits - DC Routes', AEAT Rail Ref. PRJ-SCSE(JUN)-RP-6, Issue 2, October 1998.

2.3 Other Standards

9. prEN 50238 'Railway Applications: Compatibility between Rolling Stock and Train Detection Systems' Final draft 1998
10. Specification for the Design and Installation of Negative Bonding and Associated Equipment on the High Current D.C. Electrified Lines of Network South East, EHQ/SP/C/501, Issue 1, November 1994.

2.4 Other Documentation

11. FS2600 System Design Specification, Westinghouse Signals Limited XI306/35/A00006, issue 2, I J Lewis, 15 March 1994.
12. FS2600 Traction Compatibility Explanatory Information, Westinghouse Signals Ref. XI306/35/A00056.
13. FS2600 Track Circuit, Transfer Function for Interference Currents, British Rail Research STS-D-CTP(FST)-RP-2, issue 1, N B Rambukwella, 31 January 1994.
14. FS2600 Track Circuit Handbook, Westinghouse Signals Limited XI306/35/TCH M, issue 2, R Wood, 31 March 1994, AEA Technology Rail Ref: STS-D-CTP(FST)-ID-21, issue 4.
15. British Railway Track, Design, Construction and Maintenance, Permanent Way Institute, 5th Edition, 1979.

3.0 INFRASTRUCTURE ASSUMPTIONS

The infrastructure assumed during the analysis is as described below, further assumptions are listed in Appendix B:

- 1 The track circuits and cross-bonding is assumed to be set up in accordance with the FS2600 Track Circuit Handbook [14].
- 2 The interference source is a train capable of producing an FSK signal identical to that of the track circuit signal.
- 3 Ballast resistance is assumed to be infinite.
- 4 A balanced train shunt of $10 \mu\Omega$ per wheel was used for double rail track circuits.

- 5 100% imbalance is assumed, for faulty infrastructure cases, this is pessimistic compared to the nominal imbalance values of 70%/30% in the case of 750 V d.c. power supplies [8].
- 6 The traction bonding arrangements are compliant with [1] and [4].
- 7 The running rails are assumed to be type BSI 13A, normal grade. Check rails are excluded. The sleepers are conventional concrete or wooden type. The track is assumed to be of standard gauge.
- 8 Impedance bonds' saturation effect is not considered.
- 9 The permissible interference current level is lower for operation at Channel-10 carrier frequency of 508.8 Hz [13]. The results presented reflect Channel-10 operation but are being applied across FS2600 band.
- 10 Impedance bonds are type 3 - WH3 (Westinghouse).
- 11 The infrastructure fault is always positioned to achieve the maximum effect on the track circuit receiver.

4.0 Abbreviations used

I_{TB}	Transmitter Breakthrough Current
I_{int}	Traction Interference Current
I_{int_max}	Maximum Permissible Interference Current
I_{RX}	Receiver Current
$I_{RX\ max}$	Maximum Permissible Receiver Current, Track Circuit Occupied
I_{da}	Receiver Drop-away Current
V_{RX}	Receiver Voltage
V_T	Transmitter Voltage
V_{aa}	Axle-to-axle Voltage
I_{aa}	Current at the Receiver Caused by Axle-to-axle Voltage

V_{aa_max} Maximum Permissible Axle-to-axle Voltage

I_{aa_max} Maximum Permissible Receiver Current, Track Circuit Occupied and Axle-to-axle Voltage

5.0 FS2600 Track circuit operation

The system architecture of the double rail track circuits is shown in Figure I. The FS2600 has only been approved in double rail configuration.

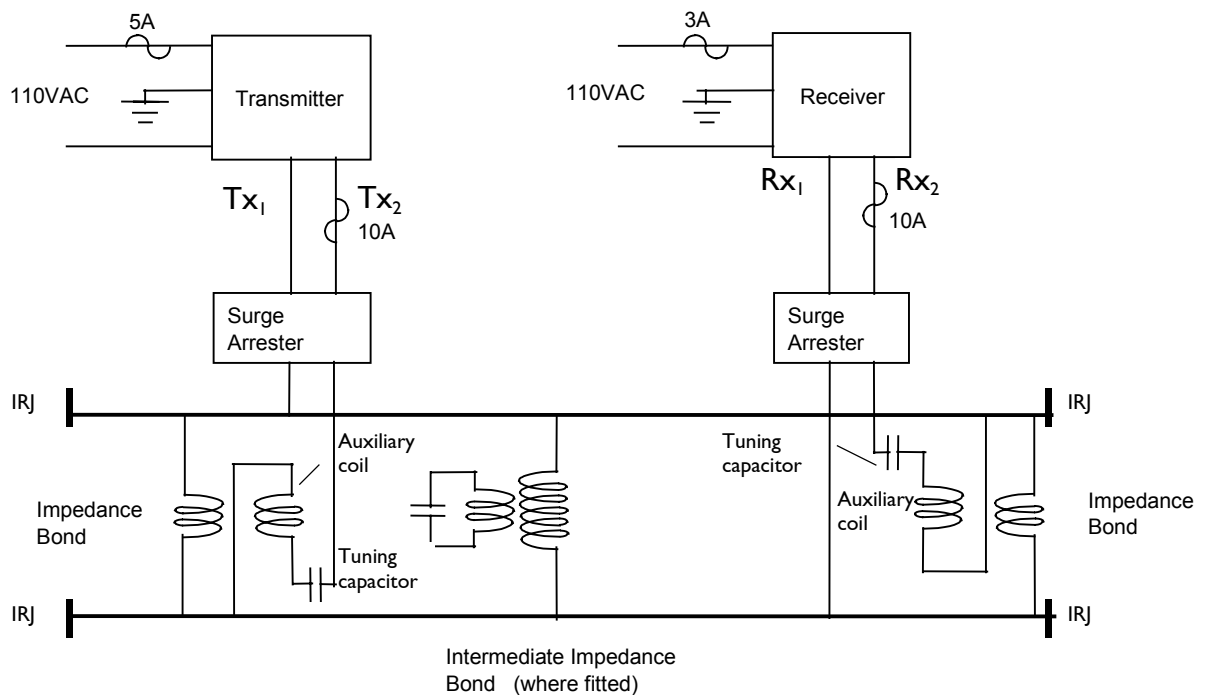


Figure I: FS2600 track circuit in double rail configuration

The traction current by-passes Insulated Rail Joints (IRJs) via impedance bonds while the track circuit current is contained within the limits of the track circuit the extend of which is defined by the IRJs. The track circuit signal from the transmitter is passed to the rails via an auxiliary coil on the impedance bond. A fixed value tuning capacitor in the impedance bond is used to tune the auxiliary coil of the impedance bond to the operating frequency of the track circuit, i.e. the carrier frequency.

The signal in the rails flows via the impedance bond at the receiver end. This current results in a voltage being induced in the auxiliary winding which is connected to the receiver. A tuning capacitor is used to tune the bond to the operating frequency of the track circuit. In the double rail configuration FS2600 track circuits may be

installed between 50m and 1200 m in length.

Protection against EMI is provided by the FSK nature of the transmitted signal which must be present for a minimum of 944 milliseconds for the receiver to recognise it as a valid transmitted signal.

The transmitter generates a FSK signal which is fed to the rails at one end of the track circuit. The transmitter output is derived from three crystal oscillators. One provides a low frequency modulation signal, the other two providing an upper and lower shift frequency. The modulation frequency is used to switch the output between the upper and lower shift frequencies. Thus the FSK waveform consists of the upper shift frequency (upper side band) alternating with the lower shift frequency (lower side band) at a rate determined by the modulation frequency. If such an FSK signal is observed in the frequency domain for periods of time much less than the period of the modulation frequency then alternate "bursts" of upper and lower shift frequency will be seen (F_{upper} and F_{lower}). Ten pairs of frequencies are used in the range of 371.8 - 525.8 Hz, as shown in Table 2 below:

Channel	F_{lower}	F_{upper}	Lower Side Band (Hz)	Carrier (Hz)	Upper Side Band (Hz)
1	371.8	405.8	373.2	388.8	404.4
2	386.2	420.2	387.6	403.2	418.8
3	400.6	434.6	402.0	417.6	433.2
4	415.0	449.0	416.4	432.0	447.6
5	424.6	458.6	426.0	441.6	457.2
6	439.0	473.0	440.4	456.0	471.6
7	453.4	487.4	454.8	470.4	486.0
8	467.8	501.8	469.2	484.8	500.4
9	477.4	511.4	478.8	494.4	510.0
10	491.8	525.8	493.2	508.8	524.4

Table 2: FS2600 Track Circuit Signal Frequencies

The important features in respect of the track circuits immunity to interference are as follows:

1. The FS2600 track circuits operate by the transmission of two separate frequencies termed F_{lower} and F_{upper} , which are modulated (i.e. switching between the two frequencies F_{lower} and F_{upper}) at a rate of 15.6 Hz.
2. The receiver contains a Digital Signal Processor (DSP) to analyse the received signal. The nature of this signal processing is such that the carrier frequency of the FSK signal must be an integer multiple of 4.8 Hz. The receiver will reject signals as they approach ± 2.4 Hz from their nominal value. Since all signals are crystal controlled they will be within 400 parts per million of their nominal value.
3. The receiver performs sampling and analysis of the input signal in parallel. The sampling process lasts for 208.3 ms and the analysis takes 236 ms. Figure 2 depicts the relationship between these two tasks:

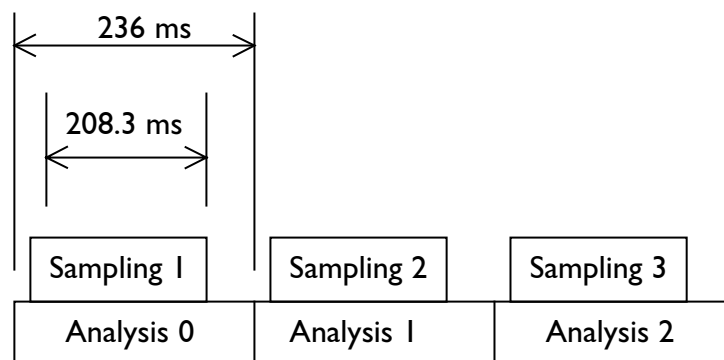


Figure 2: Cycle of Operation

The sampling frequency used is 614.4 Hz, so 128 samples of the input signal are obtained per sampling period. The input signal is heterodyned and filtered prior to being sampled. The sequence of operations performed by the receiver is detailed in [12].

The analysis conducted by the receiver on the transmitted FSK signal consists of a total of six tests for each 208.3 ms sample of the input signal. The six tests carried out are as follows:

- a check to ensure that the power level of the carrier frequency is greater than that of both side bands,
- a check that the power level of the carrier frequency is above the 'upper hysteresis' level in which case it is passed. If the power level of the carrier frequency is below the 'lower hysteresis' level the test is failed. If the power level of the carrier frequency is between the upper and lower hysteresis levels then the track circuit will not change state,
- a check that the power level of the upper sideband remains between the upper and lower limits (corresponding to the 'on' and 'off' conditions),
- a check that the power level of the lower sideband remains between the upper and lower limits (corresponding to the 'on' and 'off' conditions),
- a check of the power levels of the two sidebands to ensure that the largest is less than four times as great as that of the smallest,
- a check that the relative phase of the resultant of the two main sidebands with respect to the carrier is $90^\circ \pm 45^\circ$.

If all of the above six tests pass on four consecutive cycles of the receiver analysis (i.e. the signal is recognised as a valid transmitted signal) then the receiver output is energised. If any of these tests fail on any two consecutive cycles then the receiver output is de-energised.

In order for the receiver to recognise a signal as 'valid' a total of 24 tests must be carried out and passed (six tests on four consecutive sampled signals). Since it takes 236 ms for one set of tests (incl. sampling and analysis) this means that the signal must be present for a minimum of 944 ms for the track circuit to energise.

There is further time delay, implemented by the output relay within the receiver. The transmitter FSK signal must exist for a minimum of 1.29 seconds before the receiver will show the track clear (receiver pick-up time), see [7].

For double rail configuration impedance bonds are used. The methodology provided accommodates for type 3 - WH3 (Westinghouse). The use of type 3 impedance bonds rated at 4,500 A at all substations and track paralleling huts is mandated by [5] and [10]. The use of Howells type 3 impedance bonds has no impact on the analysis as the different parameters are compensated by different value tuning capacitors [2] to achieve the same effect.

6.0 Susceptibility Analysis

Sections 6.1, 6.2 and 6.3 show how the various components, which were used in the