PD CLC/TS 50238-2:2015

BSI Standards Publication

Railway applications — Compatibility between rolling stock and train detection systems

Part 2: Compatibility with track circuits

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National foreword

This Published Document is the UK implementation of CLC/TS 50238-2:2015. It supersedes DD CLC/TS 50238-2:2010 which is withdrawn.

The UK participation in its preparation was entrusted by Technical Committee GEL/9, Railway Electrotechnical Applications, to Subcommittee GEL/9/1, Railway Electrotechnical Applications - Signalling and communications.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Published by BSI Standards Limited 2015

ISBN 978 0 580 84433 1
ICS 29.280; 45.060.10

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 June 2015.

Amendments/corrigenda issued since publication

Date	Text affected

TECHNICAL SPECIFICATION
SPÉCIFICATION TECHNIQUE
TECHNISCHE SPEZIFIKATION

CLC/TS 50238-2

May 2015

ICS 29.280; 45.060.10

Supersedes CLC/TS 50238-2:2010

English Version

Railway applications - Compatibility between rolling stock and train detection systems - Part 2: Compatibility with track circuits

Applications ferroviaires - Compatibilité entre le matériel roulant et les systèmes de détection des trains - Partie 2 - Compatibilité avec les circuits de voie

Bahnanwendungen - Kompatibilität zwischen Fahrzeugen und Gleisfreimeldesystemen - Teil 2: Kompatibilität mit Gleisstromkreisen

This Technical Specification was approved by CENELEC on 2015-04-20.

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Comité Européen de Normalisation Electrotechnique
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Foreword

This document (CLC/TS 50238-2:2015) has been prepared by CLC/SC 9XA "Communication, signalling and processing systems" of Technical Committee CLC/TC 9X, "Electrical and electronic applications for railways".

This document supersedes CLC/TS 50238-2:2010.

CLC/TS 50238-2:2015 includes the following significant technical changes with respect to CLC/TS 50238-2:2010:

– The interference current limits for RST have been updated in the normative Annex A.

– The measurement and evaluation methods for verifying conformity of rolling stock to the limits for interference current emissions have been moved to the new normative Annex B.

This Technical Specification is intended to become Part 2 of the EN 50238 series published under the title *Railway applications — Compatibility between rolling stock and train detection systems*. The series consists of:

– *Part 1: General* [1]:

– *Part 2: Compatibility with track circuits* [this document];

– *Part 3: Compatibility with axle counters*.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

1) The existing EN 50238:2003 was renumbered EN 50238-1 when the voting procedure on Parts 2 and 3 was closed.

Introduction

This Technical Specification is being developed to permit compliance with the Interoperability Directives (High Speed and Conventional).

This Part 2 of the series defines:

- a set of interference current limits for rolling stock based on defined track circuits,
- measurement and evaluation methods to verify rolling stock interference current emissions and demonstrate compatibility with the track circuits;
- traceability of compatibility requirements (types of track circuit and associated limits).

1 Scope

This Technical Specification defines, for the purpose of ensuring compatibility between rolling stock and track circuits, the limits for interference current emissions from rolling stock. The measurement and evaluation methods for verifying conformity of rolling stock to these limits are presented in a dedicated annex.

The interference limits are only applicable to interoperable rolling stock which is intended to run on lines exclusively equipped with preferred track circuits listed in this Technical Specification. National Notified Technical Rules are still to be used in all cases, where the line over which the rolling stock is intended to run is equipped with any type of older version or non-preferred track circuits that are not listed in this Technical Specification. However, the rolling stock test methodology (infrastructure conditions, test configurations, operational conditions, etc.) presented in this Technical Specification is also applicable to establish compatibility with non-preferred track circuits.

This Technical Specification gives guidance on the derivation of interference current limits specified for rolling stock and defines measurement methods and evaluation criteria in a dedicated annex.

This Technical Specification defines:

a) a set of interference current limits for RST (Rolling Stock) applicable for each of the following types of traction system:
    1) DC (750 V, 1,5 kV and 3 kV);
    2) 16,7 Hz AC;
    3) 50 Hz AC;
b) methodology for the demonstration of compatibility between rolling stock and track circuits;
c) measurement method to verify interference current limits and evaluation criteria.

NOTE 1 The basic parameters of track circuits associated with the interference current limits for RST are not in the scope of this Technical Specification.

NOTE 2 Any phenomena linked to traction power supply and associated protection (over voltage, short-circuit current, under- and over-voltage if regenerative brakes are used) is part of the track circuit design and outside the scope of this Technical Specification.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 50126 (all parts), *Railway applications — The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)*

EN 50128, *Railway applications — Communication, signalling and processing systems — Software for railway control and protection systems*

EN 50129, *Railway applications — Communication, signalling and processing systems — Safety related electronic systems for signalling*

EN 50238-1:2003, *Railway applications — Compatibility between rolling stock and train detection systems — Part 1: General*

CLC/TS 50238-3:2013, *Railway applications — Compatibility between rolling stock and train detection systems — Part 3: Compatibility with axle counters*

EN 50388, *Railway Applications — Power supply and rolling stock — Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability*

CLC/TR 50507, *Railway applications — Interference limits of existing track circuits used on European railways*

UIC 550, *Power supply installations for passenger stock*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 50238-1:2003 and CLC/TS 50238-3:2013 and the following apply.

3.1.1
coupled vehicles
part of the influencing unit which may be considered as an individual source of interference, different to the Traction Subsystem

Note 1 to entry: See Figure 1 for examples.

Note 2 to entry: Since one influencing unit may consist of multiple sources of influence, it is normally ensured that the resulting interference current emitted by the influencing unit into the power supply network does not exceed the interference current limits for RST value.

3.1.2
influencing unit
rolling stock influencing the train detection system

Note 1 to entry: One influencing unit comprises all coupled/connected vehicles, e.g. complete train with single or multiple traction, single vehicle, multiple connected/coupled vehicles and wagons, e.g. one complete passenger train, consisting of one or more TUs and up to 16 coaches.

3.1.3
integration time
window size over which the output of the bandpass filter is calculated using RMS

3.1.4
interference source
equivalent to traction unit which is fed from its own power supply interface point (pantograph or shoe gear)

3.1.5
propulsion system
electrical/mechanical system that produces mechanical force to push the train forward

3.1.6
sources
interference sources which can generate harmonics independently

3.1.7
train detection system
system which comprises of equipment to detect the presence of a train

3.1.8
traction power unit
unit on the train housing, the converter/inverter equipment and its associated control to drive the propulsion system

Note 1 to entry: It is also known as the motor car.

3.1.9
traction subsystem
subset of the Traction Unit which produces traction force or electric brake force

3.1.10
train under test
influencing unit used for the test measurements

3.1.11
traction unit
subset of influencing unit, which comprises all Traction Subsystems including auxiliary supplies and other power supplies, which can be collectively switched off by one collector/pantograph

Note 1 to entry: See CLC/TR 50507.

Note 2 to entry: The influencing unit may consist of several "traction units" (TU). Each TU is fed from one pantograph. One TU may be:

- one locomotive;
- one electric multiple unit, with one or several propulsion systems or traction power units (motor cars);
- one complete passenger train, consisting of individual passenger coaches.

Note 3 to entry: The number of TUs that form one IU depends on the type of rolling stock and its application. Therefore, the definition of such numbers is out of the scope of this Technical Specification. The following figure shows some examples for various types and compositions of traction units, forming one influencing unit in each case:

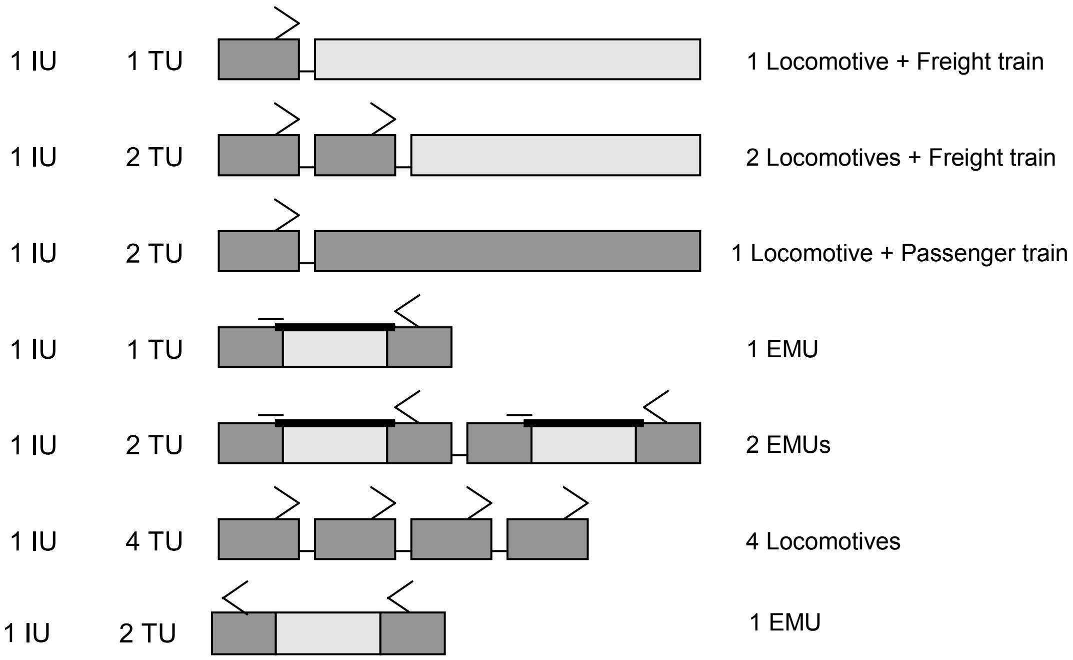


Figure 1 — Examples of IUs

3.1.12
transmitter breakthrough
background interference which can be present at the track circuit receiver from rolling stock on adjacent tracks or substation harmonics due to shared cross bonds and/or electrical imbalance of the track circuit

3.2 Abbreviations

For the purposes of this document, the abbreviations given in CLC/TS 50238-3:2013 and the following apply.

AC Alternating Current

A/D Analogue to Digital

DC Direct Current

EMU Electrical Multiple Unit

FFT Fast Fourier Transforms

FSK Frequency Shift Keying

HVI High Voltage Impulse

IU Influencing Unit

PC Personal Computer

PWM Pulse Width Modulation

RMS Root Mean Square

RSF Right Side Failure

RST Rolling stock

TC Track Circuit

TDS Train Detection System

TS Traction Subsystem

TU Traction Unit

WSF Wrong Side Failure

4 General aspects of interference current limits for RST

4.1 Derivation of interference current limits for RST

The interference limits are defined for a set of preferred types of existing track circuits which are also defined by Railway Infrastructure companies for use on future new signalling projects on interoperable lines[2)]. If it is found that the line over which the rolling stock is intended to run is equipped with an older version or with non-preferred track circuit then National Notified Technical Rules shall be used. It is not the intention of this Technical Specification to mandate any particular type of train detection but it is expected that because the list of preferred types and their limits for compatibility are drawn on the basis of established performance criteria, the trend will be that upgraded interoperable lines are fitted with types which meet the compatibility limits published in this Technical Specification. The complete set of compatibility requirements for existing preferred and future types of track circuits to be installed on interoperable lines is outside the scope of this Technical Specification.

In principle, the preferred types of track circuits from CLC/TR 50507 have been considered in defining the interference current limits for RST. Where new upgrades of track circuits are available, their improved susceptibility limits have been taken into account in this Technical Specification.

Annex A defines the interference current limits for compatibility with track circuits. The interference current limits for RST are defined up to and including the highest frequency range occupied by existing track circuits.

The limits I_0 are defined under worst case credible failure conditions of the track circuit such as unbalance or broken bonds or rails as defined by national authorities.

The transfer function between the interference current limit I_0 and the susceptibility of the track circuit can be different for different infrastructure conditions. In the worst case, if the transfer function ratio is one, the total interference current limit is defined by the susceptibility of the track circuit, taking into account any contribution from the power supply.

2) The interference current limits and the measurement specification defined in this standard apply to rolling stock intended to run over interoperable lines equipped with preferred types of track circuits as defined by national infrastructure authorities.

4.2 Application of Interference current limits to RST design

The interference current limits for RST apply to one influencing unit.

By definition, the interference current limits for RST are based on the maximum steady state interference signal to which the track circuit may be exposed.

The rolling stock interference current limits incorporate the established margins for the relevant track circuits which take into account the interference current generated by other vehicles on adjacent or the same tracks. Specific traction supply harmonics circulated through the impedance of the influencing unit are dealt with as part of the evaluation methods presented in Annex B.

In the case of testing of single traction units on the operational railway the interference current limits for RST will have to be applied to the influencing unit by using applicable summation rules, as explained in Annex B.

The interference current limits for RST are defined at absolute frequencies and therefore not dependent on mains frequency variations. The measured RST interference current is dependant on the mains frequency variations.

A vehicle is required to conform only to the interference current limits for RST for the traction system(s) (DC, 16,7 Hz, 50 Hz) on which it is intended to operate.

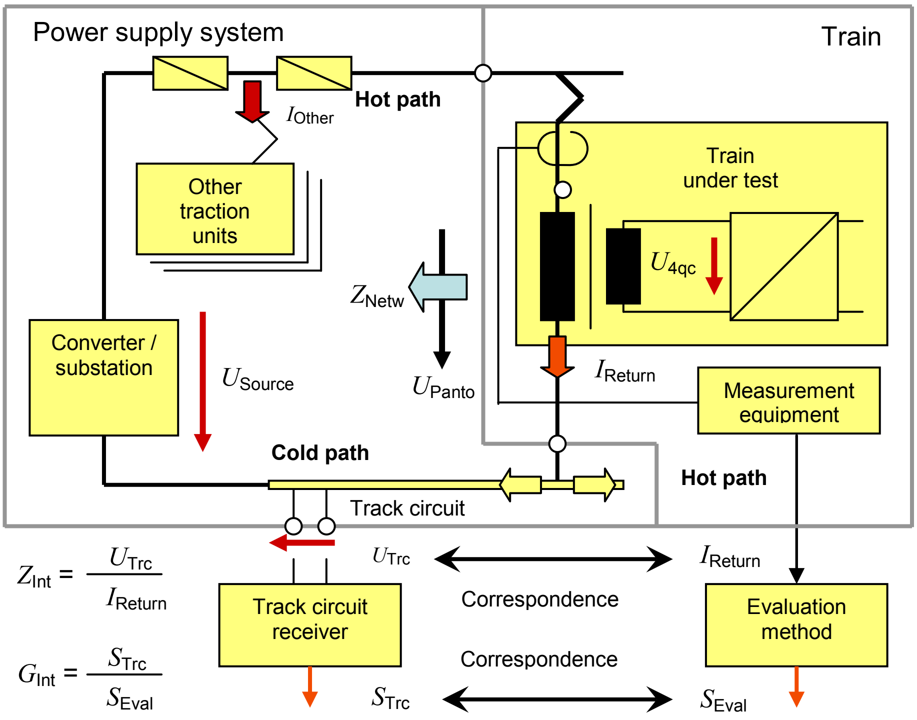
4.3 System definition

4.3.1 Structure

The overall system to be considered is shown in Figure 2 [3]. It consists of four main parts that are defined in the following subclauses.

Example characterization of parts of the system based on a recent measurement campaign in different railway networks can be found in Annex C.

3) If the configuration is applied to DC, normally DC transducers are placed in the ‘Hot path'.



Key

	Return current path between the traction unit and the energy source via rails
G_{In}	Ratio of signal at the track circuit receiver and measured interference signal
Hot path	Path between the energy source and the traction unit for drawing current
I_{Other}	Current measured in the pantograph of other trains
I_{Return}	Current measured in the pantograph of the train under test
S_{Eval}	Interference signal processed using established evaluation criteria
S_{Trc}	Actual interference signal at the track circuit receiver produced by the train under test while over the TC
U_{Panto}	Voltage measured at the pantograph of the train
U_{Source}	Voltage measured at the substation(s) or converter(s). Some railway systems have multiple side feeding arrangements
U_{Trc}	Voltage measured at the track circuit receiver while occupied by the train
U_{4qc}	Voltage developed at the four quadrant converter of the train
Z_{Int}	Railway impedance as seen by the train; it defines the transfer function (coupling factor) between interference signal produced by RST and the track circuit
Z_{Netw}	Railway line impedance as seen by the train

Figure 2 — System configuration considered for interference

4.3.2 Train under test

In the context of this Technical Specification, the ‘train under test’ is the source of interference for which the respective interference current limits apply. It can be a part of or the whole influencing unit. By operation of its traction and auxiliary converters and other interaction it produces interference currents which are conducted into the infrastructure.

A train may contain one or several traction units (not necessarily all of the same type) plus auxiliaries (in both traction units and individual wagons).

The interface between train and infrastructure is at the point of drawing current (pantograph or shoe gear) and wheel-rail. All requirements towards the train are formulated for this interface.

4.3.3 Power supply system

The power supply system comprises all live parts of the electrical system, such as power generators and transmission lines or substations and catenary lines. Other trains interference can also be circulated via the power supply and thus have an influence on the measured current values of the train under test. For interference current evaluations this part is called the “hot path“.

4.3.4 Return current path (I_{return})

In the evaluated system, the rails are an important part of the return current path. The same rails form part of the track circuit train detection system known as track circuit and therefore it is important to maintain the integrity of the track circuit to ensure it is not compromised by return currents.

For interference current evaluations this part is called the “cold path“.

The “transfer function“ is the relationship which links the return current of the train to the input voltage of the track circuit receiver.

4.3.5 Track circuit receiver

The track circuit receiver detects whether a track is clear. For reliable and safe operation it shall not be disturbed by interference currents which are injected into the system by trains and power supply.

The track circuit receiver reacts to the voltage between rails. The receiver itself can be characterized without taking into account the power systems.

4.3.6 Measurement and evaluation method

The measurement and evaluation method is applied to the total line (or return) current of one influencing unit and has to show whether the measured emissions generated by the train under test exceeds the respective interference current limits for RST or not.

The method shall be chosen such that it reflects the behaviour of the track circuit.

Annex A
(normative)

Interference current limits for RST

A.1 Definitions

f_0 [Hz]	Centre filter frequency for evaluation
Δf [Hz]	Frequency Shift of FSK
Δf_0 [Hz]	Tolerance of f_0
I_0 RMS [A]	Allowed RST interference current per influencing unit at f_0, measured at the pantograph
Δf_{3dB} [Hz]	Difference between the upper and lower frequencies of 3 dB points of the filter curve
Δf_{20dB} [Hz]	Difference between the upper and lower frequencies of 20 dB points of the filter curve
2*N [-]	Filter order outside the 20 dB bandwidth: providing the attenuation factor N in 6 dB/oct. If not provided, the closest standard order shall be chosen in the evaluation method to match the 3 dB and 20 dB roll-out points.
T [s]	Maximum time during which interference currents may exceed the defined limit, It is defined by the reaction time of the track circuit receiver.
Ti [s]	See definition of "integration time " in 3.1
Tp [s]	Minimum time between two permitted exceedances of limit's value
dB	$20 \log_{10}$ (factor), this means 20 dB is factor 10
Overlap [%]	Parameter associated with the use of true RMS routines for evaluation of the output signal from band pass filter. It defines the part of the data sample which is processed by adjacent routines.

T [s] and Ti [s] may differ in some cases as defined in the tables below. If Ti [s] is not defined, the values are identical.

The RST line current, analyzed by a filter as defined by f_0 and Δf 20 dB points in the tables below, shall remain below the indicated value I_0. This applies to all frequency ranges as defined by the tables. It is considered that the 3 dB and 20 dB points (20 dB can be substituted by the filter order) are sufficient, in most cases, to replicate the performance of the track circuit by the measurement specification.

If Δf is defined, two separate filters shall be defined per centre filter frequency, for evaluation of interference. In case Δf_0 is defined, this indicates the working range of the track circuit.

The RST line current which is measured is the total current that flows from the catenary via the pantograph(s) through the train to the traction return circuit.

The measurement method defined in this Technical Specification is subject to further validation to confirm that measurements taken with one RST in one country are reproducible in another country. This shall be taken into account if compatibility with these limits is used for the purposes of cross-acceptance.

A.2 Preferred track circuits for DC traction

List of currently defined preferred track circuits that meet the requirements of 4.1:

- Italy – coded track circuit (BACC, CDB 83,3 Hz), ATIS (CBDAC), Digicode DTC24-2, CORTO

- Netherlands – Jade 1 & 2, FTGS 46, FTGS 917, HVI, GRS 75 Hz ATP coded TC

- UK – EBI Track 200 (TI21), EBI Track 400, HVI

- Czech Republic – EVKO 75 Hz, EVKO 275 Hz, KOA 75 Hz, KOA 275 Hz, ASE, ASAR, Specific types of 75 Hz and 275 Hz TCs with EFCP track circuit receiver

- Belgium – Jade 1 & 2, HVI
- Germany - FTGS 46, FTGS 917, TCM100
- France – UM71 C*, UM71 CB*, UM71 CTVM*, HVI, UM 2000, UC 9500 (Universelle Court)

  * Equipped with RENUM receptor.
- Poland – EOC-1, EOC-3,SOT-1, SOT-2, EON-1, EON-3, EON-6
- Spain – FS3000, FS2000/2500/2550/5000

A.3 Preferred track circuits for RST for 16,7 Hz traction

List of currently defined preferred track circuits that meet the requirements of 4.1:

- Austria – S50108914 106,7 Hz; S1722-8 100 Hz
- Germany – FTGS 46, FTGS 917, TCM100
- Netherlands – FTGS 46, FTGS 917, HVI
- Norway – FTGS 46, FTGS 917, TI21, 95 Hz, 105 Hz
- Sweden – JRK10470
- Switzerland – UGSK 95, UGSK 3, FTGS 46, FTGS 917

It should be noted that the only even harmonic presently used for track circuits operation is the sixth harmonic of 16,7 Hz for 100 Hz track circuits.

NOTE The audio frequency track circuit types used in Austria, Germany and Switzerland are mainly of the same technology as in the rest of interoperable Europe using 50 Hz traction and similar limits apply at operational frequencies of track circuits.

The limits for interoperable track circuits for 16,7 Hz traction are defined in Annex A.

A.4 Preferred track circuits for RST for 50 Hz traction

List of currently defined preferred track circuits that meet the requirements of 4.1:

- Belgium – Jade 2, HVI
- Czech Republic – EVKO 75 Hz, EVKO 275 Hz, KOA 75 Hz, KOA 275 Hz, ASE, ASAR, Specific types of 75 Hz and 275 Hz TCs with EFCP track circuit receiver
- Denmark – DC TC, 77 Hz, FTGS 46, FTGS 917
- France – UM71 C*, UM71 CB*, UM71 CTVM*, UM 2000, HVI, UC 9500 (Universelle Court)

  * Equipped with RENUM receptor.
- Italy – coded track circuit (CDB 83,3 Hz). ATIS (CBDAC), Digicode DTC24-2, CORTO
- Poland – SOT-1, SOT-2, EON-1, EON-3, EON-6
- Netherlands – Jade 1-28, Jade 1-31, Jade 1-49, Jade 1-67, Jade 2, HVI
- UK – EBI Track 200 (TI21), EBI Track 400, DC AC immune various, HVI

- Spain – FS3000, FS2000/2500/2550/5000

NOTE There are no limits defined in this annex for HVI track circuits. National rules apply if defined.

A.5 UGSK3

Table A.1 — UGSK3

Type	f_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [–]	Ti [s]	Tp [s]	Remark
UGSK 3	208,75	4	6,5	14	6	0,5		
UGSK 3	222,45	4	6,5	14	6	0,5		
UGSK 3	242,15	4	6,5	14	6	0,5		

A.6 UGSK95

Table A.2 — UGSK95

Type	f_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [–]	Ti [s]	Tp [s]	Remark
UGSK 95	134	4	19	39	6	0,5		f_{Op} = 137 Hz
UGSK 95	169,5	4	19	39	6	0,5		f_{Op} = 175 Hz
UGSK 95	230	4	19	39	6	0,5		f_{Op} = 225 Hz

Values in column f_0 correspond to the centre frequency of required bandpass filters. Operating frequencies f_{0p} mentioned under remarks are slightly different; they are not relevant for compatibility check between rolling stock and UGSK 95 track circuits.

A.7 FTGS 46 / FTGS 917/TCM100

Table A.3 — FTGS/TCM100

Type	f_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [–]	T [s]	Tp [s]	Remark
FTGS 46	4 750	1	200	560		0,04	0,12	
FTGS 46	5 250	1	206	570		0,04	0,12	
FTGS 46	5 750	1	214	580		0,04	0,12	
FTGS 46	6 250	1	220	590		0,04	0,12	
FTGS 917	9 500	0,33	360	900		0,04	0,12	
FTGS 917	10 500	0,33	380	920		0,04	0,12	
FTGS 917	11 500	0,33	400	950		0,04	0,12	
FTGS 917	12 500	0,33	425	1 015		0,04	0,12	
FTGS 917	13 500	0,33	445	1 100		0,04	0,12	
FTGS 917	14 500	0,33	470	1 160		0,04	0,12	
FTGS 917	15 500	0,33	490	1 195		0,04	0,12	
FTGS 917	16 500	0,33	510	1 230		0,04	0,12	

A.8 GRS

GRS is an ATP coded track circuit.

Measurements shall not be performed on lines which can be influenced by 25 kV 50 Hz interference currents.

Table A.4 — GRS

System / Type	f_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T [s]	Tp [s]	Remark
GRS (ATBEG)	75	0,5	20	40	6	0,2	1,7	

In the case of DC-traction we have to consider harmonic frequencies as a result of the rectifying process. Generally these are characteristic harmonics of the 50 Hz multiplied by 6, 12, 18, etc. so harmonics at 300 Hz, 600 Hz, etc. shall be considered as part of the evaluation. In addition, other order harmonics of the main supply frequency can also be present, e.g. 50 Hz and multiples of 100 Hz.

In the case when the DC substation supply is under weak load condition, the rectifier diodes will operate as a modulator. Hence, if a train produces a current with a frequency of 225 Hz for example, this can result in a 75 Hz current due to the modulating process with the main supply harmonics.

This phenomenon leads to requirements for interference currents with frequency bands around 225 Hz, 375 Hz, 525 Hz and 675 Hz. The applicable interference current limits for rolling stock are provided in Table A.4.

Table A.5 — GRS - limits due to rectifying traction supply

System / Type	f_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T [s]	Tp [s]	Remark
GRS (ATBEG)	225	1	20	40	6	0,2	1,7	
GRS (ATBEG)	375	1	20	40	6	0,2	1,7	
GRS (ATBEG)	525	1	20	40	6	0,2	1,7	
GRS (ATBEG)	675	1	20	40	6	0,2	1,7	

A.9 Jade

- **Interference current limits for 25 kV, 50 Hz lines:**

Table A.6 — Jade 25 kV, 50 Hz lines

System / Type	f_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T [s]	Tp [s]	Remark
Jade 2 / 16	1 575	0,87	50	500	-	0,04	0,68	
Jade 2 / 19	1 874	0,72	60	500	-	0,04	0,68	
Jade 1 & 2 / 22	2 186	0,62	50	400	-	0,04	0,68	
Jade 1 & 2 / 25	2 480	0,54	60	500	-	0,04	0,68	
Jade 1 (HS) / 28	2 821	0,56	60	350	-	0,04	0,68	
Jade 1 (HS) / 31	3 137	0,47	80	400	-	0,04	0,68	
Jade 1 (HS) / 49	49 082	0,20	8k	10.10^3	-	0,04	0,68	
Jade 1 (HS) / 67	67 232	0,14	8k	10.10^3	-	0,04	0,68	

- **Interference current limit, DC lines:**

Table A.7 — Jade DC lines

System / Type	f_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T [s]	Tp [s]	Remark
Jade 1 & 2 / 16	1 575	0,54	35	400	-	0,04	0,68	
Jade 1 & 2 / 19	1 874	0,45	35	400	-	0,04	0,68	
Jade 1 & 2 / 22	2 186	0,39	35	400	-	0,04	0,68	
Jade 1 & 2 / 25	2 480	0,34	35	400	-	0,04	0,68	

A.10 Coded track circuits for DC traction

Table A.8 — Limits for BACC and CDB 83,3 Hz

System / Type	f_0 [Hz]	Δf_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T [s]	Remark
BACC	50	46 65	0,4	-7 +16	-19 +16		1	
CDB 83,3	84	84 85	2.0	-2 +2	-5 +5		1	

A.11 Digicode

Tchebyshev filter 0,01 dB order 10 .

Table A.9 — Digicode

System / Type	f_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T [s]	Remark
DTC24-2	2 100	2,2	400	440	10	1	
DTC24-2	2 500	2,2	400	440	10	1	
DTC24-2	2 900	1.5	400	440	10	1	
DTC24-2	3 300	1.5	400	440	10	1	
DTC24-2	3 700	1,5	400	440	10	1	
DTC24-2	4 100	1,5	400	440	10	1	
DTC24-2	4 500	1,5	400	440	10	1	
DTC24-2	4 900	1,5	400	440	10	1	

A.12 CoRTo

Table A.10 — CoRTo

System / Type	f_0 [Hz]	Δf [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T [s]	Remark
CoRTo	30 000	5 000	0,12	8 000	20 000	4	2.5	Δf [Hz] – Bandwidth of FSK

A.13 CBDAC

Tchebyshev filter 0,01 dB order 10 .

Table A.11 — CBDAC

System / Type	f_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T [s]	Remark
CBDAC	3 750	1,5	± 300	± 500	10	1	
CBDAC	4 250	1,5	± 300	± 500	10	1	
CBDAC	4 750	1,5	± 300	± 500	10	1	
CBDAC	5 250	1,5	± 300	± 500	10	1	
CBDAC	5 750	1,5	± 300	± 500	10	1	
CBDAC	6 250	1,5	± 300	± 500	10	1	
CBDAC	6 750	1,5	± 300	± 500	10	1	
CBDAC	7 250	1,5	± 300	± 500	10	1	
CBDAC	9 500	0,5	± 300	± 500	10	1	
CBDAC	10 500	0,5	± 300	± 500	10	1	
CBDAC	11 500	0,5	± 300	± 500	10	1	
CBDAC	12 500	0,5	± 300	± 500	10	1	
CBDAC	13 500	0,5	± 300	± 500	10	1	
CBDAC	14 500	0,5	± 300	± 500	10	1	
CBDAC	15 500	0,5	± 300	± 500	10	1	
CBDAC	16 500	0,5	± 300	± 500	10	1	

A.14 Preferred track circuit in Czech Republic

KOA and EFCP is an ATP coded track circuit.

Table A.12 — 50 Hz AC and DC Traction

System / Type	f_o [Hz]	Δf_0 [Hz]	I_o RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T [s]	T_p [s]	Remark
KOA	75	2	1,9	4	26	-	2	1	FFT
KOA	275	2	1,9	4	26	-	2	1	FFT
EVKO	75	10	1,42	-15 +5	-68 +105	-	1	2	
EVKO	275	10	1,42	-15 +5	-68 +105	-	1	2	
Specific types of TCs with EFCP	75	2	1	5	44	-	0,2 2 *)	1	*)
Specific types of TCs with EFCP	275	2	0,5	5	44	-	0,2 2 *)	1	*)
ASE, ASAR	50 000	-	0,053	6 000	20 000	-	1	2	

Remark FFT:
Analysis technique FFT at frequencies 73 Hz – 77 Hz and 273 Hz – 277 Hz (with step 1 Hz), with 1 Hz resolution, 50% overlap and Hanning window. Time domain analysis is also possible, according to parameters in the table.
Remark *):
Relates to TCs equipped with an external fail-safe delay circuit. A delay of a transition to an unoccupied state of TC can be realized even in a follow-up interlocking system.

A.15 All kind of UM71 equipped with RENUM receptor and UC 9500

UM71CTVM is a coded track circuit for high speed line.

FFT is the applicable evaluation method. Defined parameters:

- Hanning window of 1 s;
- 80 % minimum overlaps;
- minimum sampling frequency of 16 kHz.
- Additional 3 A limit applies at frequencies out of defined operational bandwidths from 1 500 Hz to 3 000 Hz.

Table A.13 — UM71 C, UM71 CB, UM71C TVM and UC9500

System / Type	f_0 [Hz]	Δf [Hz]	I_0 RMS [A]	T [s]	Remark
All kind of UM71 equipped with RENUM receptor	1 700	90	0,3	0,3	
All kind of UM71 equipped with RENUM receptor	2 000	90	0,3	0,3	
All kind of UM71 equipped with RENUM receptor	2 300	90	0,3	0,3	
All kind of UM71 equipped with RENUM receptor	2 600	90	0,3	0,3	
UC 9500	9 500	100	0,3	0,3	

A.16 DC track circuits in UK

Table A.14 — DC track circuits in UK

System / Type	f_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T_i [s]	Tp [s]	Remark
AC Immune	0	1,56	0,5	4,14		0,318	1,5	Transformer inrush current is excluded.

A.17 EBI Track 200 (TI21)

Table A.15 — EBI Track 200 (TI-21) Double Rail Limit for in-band frequencies — AC traction only

System / Type	f_0 [Hz]	Δf [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T_i [s]	Tp [s]	Remark
E	1 549	±17	0,806	12	60		0,04		Analysis technique: digital filter
A	1 699	±17	0,731	12	60		0,04		
G	1 848	±17	0,753	12	60		0,04		
C	1 996	±17	0,696	12	60		0,04		
F	2 146	±17	0,498	12	60		0,04		
B	2 296	±17	0,492	12	60		0,04		
H	2 445	±17	0,440	12	60		0.04		
D	2 593	±17	0,416	12	60		0.04		

Table A.16 — EBI Track 200 (TI-21) Double Rail Limit for in-band frequencies — DC traction or non-electrified lines

System / Type	f_0 [Hz]	Δf [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T_i [s]	Tp [s]	Remark
E	1 549	±17	0,134	12	60		0,04		Analysis technique: digital filter
A	1 699	±17	0,101	12	60		0,04		
G	1 848	±17	0,142	12	60		0,04		
C	1 996	±17	0,091	12	60		0,04		
F	2 146	±17	0,148	12	60		0,04		
B	2 296	±17	0,132	12	60		0,04		
H	2 445	±17	0,143	12	60		0,04		
D	2 593	±17	0,167	12	60		0,04		

A.18 EBI Track 400

Table A.17 — EBI Track 400 Open Line Frequency Double Rail Track Circuit Limit for in-band frequencies

Frequency Channel	In- band range, Hz	In-band 50Hz harmonic, Hz	Limit per train within the range, A	Remark
E	1 549 ± 5	1 550	0,953	Analysis technique: FFT with 1 Hz resolution, 50 % overlap and Hanning window
A	1 699 ± 5	1 700	0,936	
G	1 848 ± 5	1 850	0,810	
C	1 996 ± 5	2 000	0,778	
F	2 146 ± 5	2 150	0,663	
B	2 296 ± 5	2 300	0,628	
H	2 445 ± 5	2 450	0,545	
D	2 593 ± 5	-	0,547	

Table A.18 — EBI Track 400 Open Line Frequency Double Rail Track Circuit Limit for out of band frequencies

Frequency range 1, Hz	Frequency range 2, Hz	Adjacent channel	Limit per train within the range, A	Remark
1 506-1 543	1 554-1 594	E	2,383	Analysis technique: FFT with 1 Hz resolution, 50 % overlap and Hanning window
1 656-1 693	1 705-1 744	A	2,340	
1 806-1 842	1 854-1 894	G	2,025	
1 956-1 990	2 002-2 044	C	1,945	
2 106-2 140	2 152-2 194	F	1,658	
2 246-2 290	2 302-2 344	B	1,570	
2 406-2 439	2 451-2 494	H	1,363	
2 546-2 587	2 599-2 644	D	1,368	

Table A.19 — EBI Track 400 Station Area Frequency Double Rail Track Circuit Limit

Frequency Channel	In- band range, Hz	In-band 50Hz harmonic, Hz	Limit per train within the range, A	Remark
F5	5 700 ± 35	5 700	1,081	Analysis technique: FFT with 1 Hz resolution, 50 % overlap and Hanning window
F1	6 100 ± 35	6 100	1,073	
F7	6 500 ± 35	6 500	1,052	
F3	6 900 ± 35	6 900	1,062	
F6	7 300 ± 35	7 300	1,046	
F2	7 700 ± 35	7 700	1,058	
F8	8 100 ± 35	8 100	1,053	
F4	8 500 ± 35	8 500	1,149	

A.19 FS3000

FS3000 is a digitally coded track circuit using phase modulation.

- **Interference current limits for 3 kV, DC lines:**

Table A.20 — FS3000 3 kV, DC lines

Type	f_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T [s]	Tp [s]	Remark
FS3000	4 080	0,66	124	222	-	0,016	0,514	$\Delta f_{40\ dB}$ = 320 Hz
FS3000	4 320	0,59	124	222	-	0,016	0,514	
FS3000	4 560	0,52	124	222	-	0,016	0,514	
FS3000	5 040	0,66	124	222	-	0,016	0,514	
FS3000	5 280	0,34	124	222	-	0,016	0,514	
FS3000	5 520	0,32	124	222	-	0,016	0,514	
FS3000	6 000	0,31	124	222	-	0,016	0,514	
FS3000	6 480	0,28	124	222	-	0,016	0,514	
FS3000	6 720	0,27	124	222	-	0,016	0,514	
FS3000	7 200	0,26	124	222	-	0,016	0,514	

- **Interference current limits for 25 kV, 50 Hz lines:**

Table A.21 — FS3000 25 kV, 50 Hz lines

Type	f_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T [s]	Tp [s]	Remark
FS3000	4 080	0,52	124	222	-	0,016	0,514	$\Delta f_{40\ dB}$ = 320 Hz
FS3000	4 320	0,45	124	222	-	0,016	0,514	
FS3000	4 560	0,39	124	222	-	0,016	0,514	
FS3000	5 040	0,66	124	222	-	0,016	0,514	
FS3000	5 280	0,27	124	222	-	0,016	0,514	
FS3000	5 520	0,27	124	222	-	0,016	0,514	
FS3000	6 000	0,26	124	222	-	0,016	0,514	
FS3000	6 480	0,25	124	222	-	0,016	0,514	
FS3000	6 720	0,24	124	222	-	0,016	0,514	
FS3000	7 200	0,24	124	222	-	0,016	0,514	

A.20 FS2000 / FS 2500 / FS 2550 / FS 5000

This is a family of FSK modulated track circuits.

- **Interference current limits for 3 kV, DC lines:**

Table A.22 — FS2000 / FS 2500 / FS 2550 / FS 5000 3 kV, DC lines

Type	f_0 [Hz]	Δf [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T [s]	Ti [s]	Tp [s]	Remark
FS2000 FS2500 FS2550	1 699	±17	3,7	50		-		0,21		For 1 % traction current unbalance between rails. $\Delta f_{35\ dB}$ = 600 Hz
	2 001	±17	3,2	50		-		0,21		
	2 299	±17	3,3	50		-		0,21		
	2 601	±17	2,8	50		-		0,21		
FS2500 FS2550 FS5000	4 080	±40	0,5	160	480	-	0,04	0,4	0,88	$\Delta f_{35\ dB}$ = 960 Hz
	4 320	±40	0,5	160	480	-	0,04	0,4	0,88	
	4 560	±40	0,5	160	480	-	0,04	0,4	0,88	
	5 040	±40	0,5	160	480	-	0,04	0,4	0,88	
	5 280	±40	0,5	160	480	-	0,04	0,4	0,88	
	5 520	±40	0,5	160	480	-	0,04	0,4	0,88	
	6 000	±40	0,5	160	480	-	0,04	0,4	0,88	

A.21 Track circuits of 95 Hz and 105 Hz in Norway

Table A.23 — Track circuits of 95 Hz and 105 Hz in Norway

System / Type	f_0 [Hz]	I_0 RMS [A]	Δf_{3dB} [Hz]	Δf_{20dB} [Hz]	2*N [-]	T [s]	Ti [s]	Remark
95 Hz	95	1,00	6,00			1,00		
105 Hz	105	1,00	6,00			1,00		

A.22 JRK 10470

Table A.24 — JRK 10470

Type	f_0 [Hz]	Limits [A]	Δf_{3dB} [Hz]	T [s]	Remark
JRK 10470	DC	25,0	2		Normal operation
		45,0		1,5	The inrush current shall be tested at a location where the short circuit current is greater than or equal to 20 kA on a single track line.
		25,0		2,5	

Annex B
(normative)

Rolling Stock Interference Evaluation methods

B.1 General

Track circuits use narrow band frequency signals sent via rails to detect the presence of trains. Therefore the applicable mechanism of interference is conducted. Outside of this band they are largely immune to conducted interference. The frequency or amplitude content of the signal within the band varies with respect to time depending on whether the track circuit is occupied or not (on/off), see Figure B.1 as an example of the time domain method.

B.2 Selected evaluation method

The unique set of track circuit parameters for verifying rolling stock emissions are: centre frequencies, of operation, interference current limit at the centre frequency which also encompasses currents at all influencing frequencies within channel bandwidth using RMS values, reaction time of track circuit receiver.

Depending on the selected evaluation method as defined in the individual tables for preferred track circuits in Annex A, additional parameters are specified.

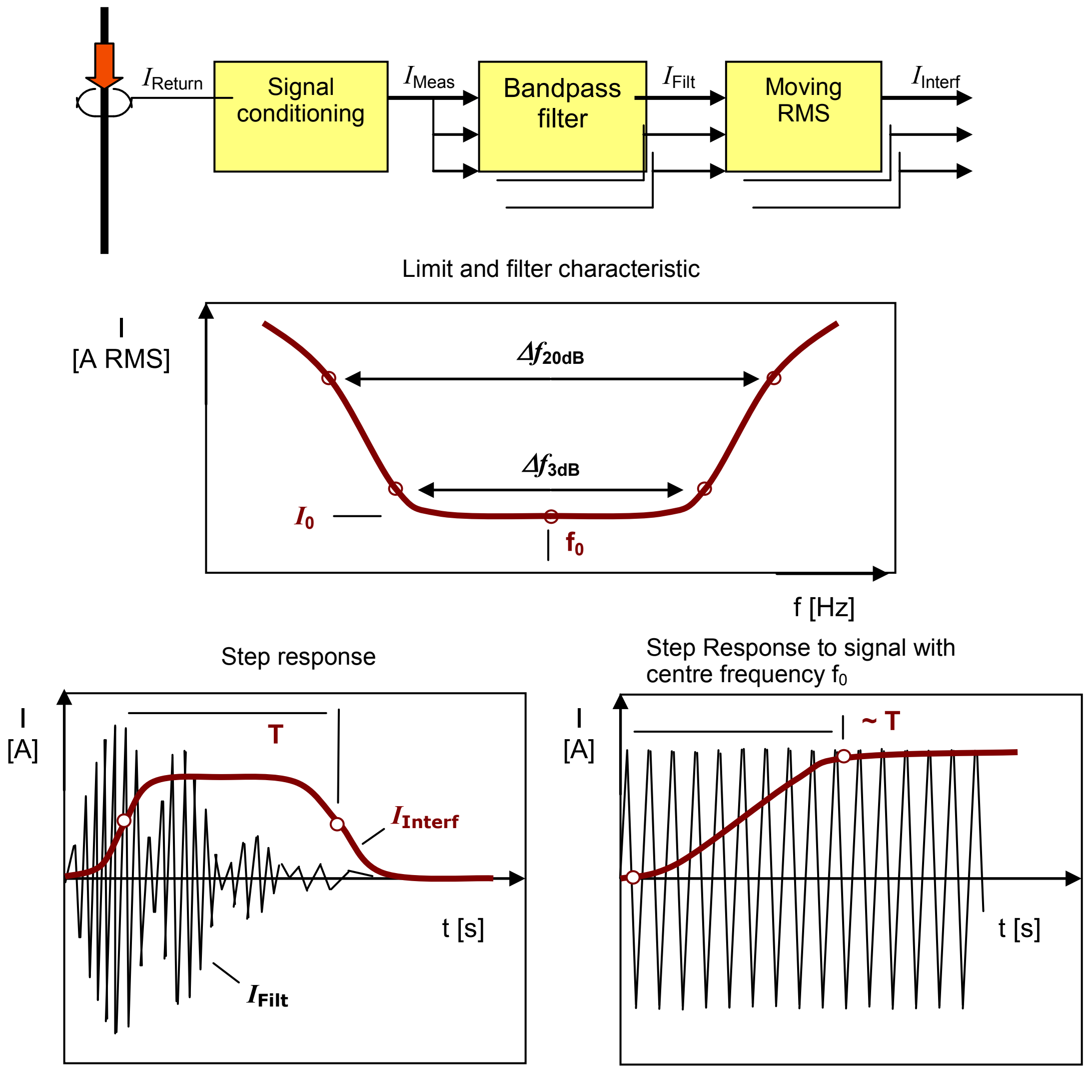


Figure B.1 — Time domain method

NOTE 1 Moving RMS is the true RMS calculation over a moving time window of a constant length defined by Ti.

NOTE 2 Step response is the reaction (response) time of the evaluation method to an instantaneous change of the measured current from 0 A to 1 A.

B.3 Derivation of the interference current limits for RST

The interference current limits for RST in Annex A of this Technical Specification are based on track circuit susceptibility limits and apply to one influencing unit.

Track circuit susceptibility limits are defined under worst case credible failure conditions such as unbalance and broken bonds or rails. WSF and RSF analyses are conducted for a realistic set of conditions that provide the most frequent causes of failure.

NOTE The track circuit interference current limits published in Annex A are derived from the track circuit susceptibility limits following the process for assigning any margin as explained in EN 50617-1.

B.4 Criteria for compatibility

B.4.1 Location

The measurement chain shall, if possible, be positioned such that it can measure the total return current from the influencing unit. In cases when the measurement of the total current of the influencing units is not possible or practicable, individual traction unit shall be measured and respective summation rules used according to B.8.

B.4.2 Criteria

The interference current shall not exceed the limits as defined in B.5. This limit shall be met for each track circuit channel as listed in the normative Annex A.

Single non-repetitive exceedances of the limits can be tolerated if they can be proved to result from transient events and that they do not affect the designed behaviour of the track circuit as defined in the corresponding table in Annex A. Examples of transient phenomena are current bouncing, gapping, circuit breaker operation and inrush.

B.4.3 Safety and availability

Demonstration of compatibility shall be a pass/fail criterion under worst case operating conditions (nominal and degraded) for the train against declared interference current limits.

The interference current limits for RST are defined under credible track circuit degraded conditions. Numerical targets may be available and assigned to these types of TDS degraded conditions but cannot be verified by testing. Therefore the trains shall meet the interference current limits for RST defined in this Technical Specification under all train operating conditions (nominal and degraded). Any exceedances of the defined interference current limits in the rolling stock shall be managed in accordance with specific rules if declared. Tests shall be conducted under controlled conditions and the fundamental traction supply frequency at the time of the test obtained through measurements. For DC network, the infrastructure manager shall provide the qualification of the frequency stability of the network at the time of conducting the test. For 16,7 Hz network only, the tests' results shall be evaluated taking into account the frequency variations in accordance with C.1.

B.5 Defined interference current limits for RST: for use under interoperability regulation

Interference current limits for RST as defined for individual track circuit types shall be used for demonstrating compatibility in the respective country of operation. Compatibility results can be used for cross-acceptance against the same track circuits in another country if it is confirmed the cross-acceptance applies to the same influencing unit, this includes any software configuration that existed at the time of testing. The interference current limits for RST are provided in the tables in Annex A for all preferred types of track circuits in their frequency range.

B.6 Test specifications for RST interference measurements

B.6.1 General

The complete methodology for demonstration of compatibility with track circuits on interoperable lines shall be in accordance with EN 50238-1.

The measurement and evaluation method of emissions from interoperable rolling stock shall be able to distinguish between steady state interference and interference due to transient behaviour. Exceedances of a limit that can undisputedly be attributed to perturbations from the power supply shall be discussed with the infrastructure manager in the evaluation of the interference behaviour of the train. In all other cases, a more detailed study is required and additional information shall be sought from the design authority if not provided in Annex A.

Tests are type tests and shall be performed before the first unit is put into regular service.

The test method for traction units is specified in detail below.

B.6.2 Purpose of compatibility tests

B.6.2.1 General

The purpose of the compatibility tests is to verify conformity to the interference current limits for all train configurations listed below.

B.6.2.2 Configurations of the train under test during measurements

The following configurations shall be applied to the train under test:

a) completely switched off (reference measurement);

b) auxiliaries only;

c) traction in normal configuration (including auxiliaries);

d) all credible degraded modes (e.g. one or more converter out of operation) which might occur during operation;

e) faults inside the train under test and corresponding effects are not considered during the test;

f) if interlacing between traction units is required to fulfill the compatibility requirements then the train consist to be tested shall have the multiple traction units required to achieve compatibility.

NOTE For locomotives, when forming the train under test, the heating line for wagons is treated as auxiliaries. Passenger coaches are excluded from this specification at this stage unless treated as part of IU.

B.6.2.3 Operating conditions for the measurements tests

The following operating conditions shall be applied for the measurement tests:

a) start-up and switching off of vehicle at standstill (only informative test, no pass-fail criterion). The results of this test shall be documented;

b) running through neutral sections (AC) or gaps (DC). Neutral section’s effects can be simulated by opening and closing of the main circuit breaker without a neutral section being present;

c) acceleration up to V_{max} and braking at 100 % and 50 % of available tractive effort/power limitation; conditions with worst case interference generation shall be included in these test cycles and the test runs shall be performed in a way to achieve this;

d) this can be realized by an appropriate load or by help of a braking unit incl. coasting, to allow measurement of interference current under different conditions and identify the relationship; it is recommended that at least three points are defined according to the worst case interference current that can be experienced;

e) abrupt changes of tractive/braking effort, both operated manually and by automatic speed control (if applicable);

f) acceleration and braking (100 %) under poor adhesion:

1) measurements shall include instances of slip/slide operation of the rolling stock control system. The following conditions are recommended to be used as comparable conditions if natural slip/slide operation cannot be reproduced at the time of testing. If it is not practicable

to subject the whole influencing unit to slip-slide conditions, the interference currents shall be measured for only part of it which shall constitute the train under the test and evaluated using respective summation rules according to B.8.1;

2) the fluid used to reduce adhesion shall be a water based solution of a detergent with a fatty acid or ten carbon non-cyclic fatty acid (sum of active constituents) in a concentration between 10 % and 15 % and without mineral fillers. The detergent shall be biodegradable, mix readily with water and be safe to disposal on the track;

3) dilution of the agent shall enable the simulation of a required ratio of adhesion τa between 0,05 and 0,08 during the initial braking period, not taking into account a possible first peak of the adhesion coefficient. The nominal composition of the mixture shall include 1 % active constituents. It is permitted to vary the concentration as a function of available adhesion without, however, exceeding the bottom limit of 0,1 % active constituents. The solution shall be released in front of each wheel of the first wheelset under a pressure of 0,1 bar to 0,2 bar through 8 mm diameter nozzles located along the longitudinal axis of the rail, a few centimeters from both the rail and the wheel.

g) the rolling stock operational conditions from above which are found to contribute to the highest interference currents relevant to the track circuits being assessed shall be clearly identified.

Each cycle shall be carried out a number of times under the same set of infrastructure conditions to give confidence that the test results are reproducible.

B.6.2.4 Infrastructure requirements for measurements

B.6.2.4.1 General

As long as the requirements below are fulfilled, measurements can be done on either normal operational railway networks (interconnected or isolated) or on test tracks (isolated). Isolated networks and test tracks normally offer only fixed resonance conditions, which might not fulfil the requirements. However, it is acceptable to modify the resonance conditions of a test track, e.g. by switching/reconfiguring additional high voltage cables in order to meet the requirements.

B.6.2.4.2 Infrastructure conditions for AC power supply networks (15 kV 16,7 Hz and 25 kV 50 Hz)

The following infrastructure conditions shall be met for the interference measurements:

- measurements shall be conducted both close to a substation and far from substations (at least 20 km);
- measurements shall be conducted on open line and in an area with larger concentrated electrical capacitances (e.g. large railway stations, or tunnels with cables);
- the lowest power supply resonance frequency for the network f_{Res} shall be calculated according to C.4 and shall be equal to or lower than 80 % of the lowest centre frequency of the audio frequency track circuit on the network f_{TC}:

$$f_{\mathrm{Re}s} \leq 0{,}8 * f_{TC}$$

- the test runs shall comprise different sections of a network with different numerical values for the resonances. This can be reached by passing at least three substations in a 16,7 Hz network, or running through three phase sections of different length in a 50 Hz network;
- other vehicles in the same network may be present or not, since their influence is negligible in most cases;
- isolated networks shall not be fed from a static frequency converter (although without significance in most cases, this would mix requirements for rolling stock and static converters and complicate the interpretation of results);
- for rolling stock with capacitive input impedance (e.g. caused by long power cables on the roof) additional requirements shall be defined in accordance with the section below ‘Special conditions for AC trains with a capacitor directly at the input’.

B.6.2.4.3 Infrastructure conditions for DC power supply networks (750 V, 1 500 V and 3 000 V)

The following infrastructure conditions shall be covered by the interference measurements:

- measurements both close to a substation and far from substations (at least 3,5 km for 750 V systems, 7 km for 1 500 V systems, 15 km for 3 000 V systems);
- measurements both on open line and in an area with larger concentrated electrical capacitances (e.g. large railway stations, or tunnels with cables);
- no resonance conditions exist;
- the network shall comprise at least three different feeding sections with separators in between, leading to steps in line voltage when passed under applied traction power;
- feeding from a substation with a 6-pulse rectifier without any output filter shall be included;
- other vehicles may be present in the same network or not (no requirements).

B.6.2.5 Special conditions for AC trains with a capacitor directly at the input

This subclause defines additional requirements for rolling stock with direct capacitive input impedance (e.g. caused by long power cables on the roof). If the capacitive input impedance is effectively damped, the train no longer falls under the category ‘with direct capacitive input impedance’.

Capacitances directly at the input of the train (as seen from the power supply) can form a resonant circuit together with the line inductance. In this case, high harmonic currents can circulate in this circuit and, therefore, through the interface overhead line pantograph and wheels/rail. The resonance conditions are also influenced by the line capacitance and the capacitances of other vehicles.

Such resonance effects occur locally in the network, with a frequency depending on the precise combination of infrastructure and rolling stock parameters. It is not possible to define infrastructure conditions for tests in such a general way that worst case credible cases for interference generation can be guaranteed for all trains. Two methods can be applied to prove compatibility between rolling stock and track circuits in this case:

- either full compatibility study (theoretical analysis and measurements) according to EN 50238-1 (signalling compatibility) and EN 50388 (influence of power supply system),
- or simplified assessment, with division of the allowed interference current I0 from the tables in Annex A by a reduction factor k_{res} according to the following table:

Table B.1 — Reduction factors for capacitive input impedance

Distance from nearest substation	< 2 km	> 2 km
k_{res}	$1 + (C_{in} / 50\ nF) * (f_0 / 16\ kHz)$	1

NOTE C_{in} is input capacitance of the influencing unit seen from the power supply. C_{in} can be taken from the technical data of the train by multiplying the specific unit capacitance of the cable by the actual cable length. f_0 is the centre frequency for the corresponding interference current limit for RST. The reduction is necessary only for audio frequency track circuits (f_0 > 1 000 Hz) and for input capacitances larger than 10 nF.

This means that the influencing unit has to comply with reduced limit I_0 / k_{res} in the vicinity of substations, where no sharp resonances can be expected. In this case the train can be expected not to exceed the allowed limit I_0 under all resonance conditions which may occur during operation in various networks, but not during the compatibility tests. Clause C.5 provides the background to this simplified approach.

B.7 Test equipment requirements (hardware)

The test equipment shall meet the following requirements:

a) each common feeding point (e.g. pantograph) of one influencing unit shall be equipped with a separate current sensor. The correct phase addition of individual current measurements shall be considered according to B.8.1 for the relevant frequency range;

b) anti-aliasing filter;

c) the measurement data shall be recorded in such way that extraction of selected parts of a test run and the conversion to digital data files in a widely used format (e.g. ASCII or Matlab) shall be possible;

d) the accuracy of the whole chain (with respect to individual limits) shall be 10 % or better with a coverage factor k = 2 [ENV 13005]. The following requirements shall be met:

   1) the resolution of A/D conversion shall be at least 16 bit, with the target of 24 bit (depending on the ratio of interference limit to fundamental current value);

   2) the frequency bandwidth of the recorded signal shall be at least 20 kHz, which requires a sampling rate higher than 48 kHz for the current channel. Higher frequencies may be required to be recorded in some countries depending on the susceptibility bandwidth of track circuits;

e) additional recording of vehicle status (speed, traction effort, line voltage fundamental) and location etc., with an adequate (potentially lower) resolution than required for the current signal. Reference to current signal shall be established during measurement, for post processing and evaluation;

f) verification of the measurement chain in the train under test required prior to the measurements for any background emissions which can potentially affect the accuracy of results (stray fields, etc.).

B.8 Train interference analysis and evaluation methods

B.8.1 Evaluation method

There are two principal methods for evaluation of the measurements. The chosen method and the parameters shall be clearly identified from the relevant track circuit table in Annex A:

- frequency domain analysis: e.g. FFT, Hanning window (or other), window length (defined by T_i), overlap of 75 % or 80 % as indicated in the individual tables in Annex A, for a broad band spectrum of the line current. The sampling rate shall be chosen such that the highest operational frequency of the track circuit is captured in the current spectrum;

- time domain analysis: true RMS measurement using one band-pass filter per track circuit channel with type, order and other characteristics as defined in Annex A, e.g. Butterworth 2 x 3^{d} order. For analogue filtering, the correction/smoothing factor of the band pass output after diode rectification shall be 1,111 or an alternative true RMS conditioning shall be used.

The application of these methods is two-fold:

- visualization of the spectrum during the test for quick verification of correct function of the train under test and on-line comparison with interference current limits for RST;

- detailed evaluation of compatibility with each track circuit channel.

Compatibility is reached if the limit is never exceeded for longer time than specified for the corresponding track circuit.

In case of non-compatibility: the time spans where the limit is exceeded will be analysed using the spectrum (FFT), which shall show the nature of the exceedance and indicate possible causes. Analyses using only band pass filters do not normally give sufficient information about the reason for exceedances. It shall be demonstrated that I_{interf} (see Figure B.1) which can be attributed to single transient events (gapping, pantograph bouncing, etc.) does not affect the operation of the track circuit over time.

All evaluation shall be done digitally.

The evaluation method is the same for transients and steady state conditions if possible. Integration and reaction times, as defined for each type of track circuit, shall be applied. The final compatibility argument shall demonstrate the overall reliability and safety of the system are not affected.

Complete information on the relevant track circuits used in the analysis shall be available at the design stage of any new RST to enable the use of a common set of parameters in any analysis and allow comparisons between simulation and measurements with the same methods or even the same evaluation tools.

B.8.2 Summation rules

A train may consist of several identical or different interference sources that can draw power from one or more supply points (pantographs or shoe gear). This creates difficulty for the measurement of the total interference current of a train because a true-phase addition of signals from several current sensors is required.

Sometimes power limitations of the substation do not permit more than a certain number of trains on the same section so the limits to be applied for multiple influencing units can be different. Agreement with the infrastructure owner or customer shall be obtained beforehand such cases.

The following rules are recommended to simplify the evaluation process.

The interference current of only one TU is measured, and multiplied with a factor K to derive the total interference current produced by N traction units. Different factor K shall be applied, depending on the types of harmonics in the evaluated frequency band. Table 2 defines three categories of trainborne harmonics. The values of the factor K for each of the three categories of harmonics are defined in Table B 2.

The harmonic category shall be defined for each frequency band of evaluation. The decision shall be based on the general design of the traction unit and the dominating interference mechanism for this frequency band. It is not possible to give an upper frequency limit above which non-synchronization is applicable because this depends on the technology of inverters, other components and their control and will continue to change in future. NOTE 1 and NOTE 2 provide further clarification of the summation factors K.

Table B.2 — Summation categories

Synchronized to common reference	**Synchronized to independent clocks**	**Completely uncorrelated**
K_S = N (red line in Figure B.2)	K_I = f(N) (purple line in Figure B.2)	$K_U = \sqrt{N}$ (blue line in Figure B.2)
Synchronization to: • common internal clock, or • AC line voltage	Synchronization to: • independent clocks • motor angular position	No synchronization at all
EXAMPLES: • Harmonics from substation • Steps in line voltage • Non-interlaced PWM harmonics synchronous to AC line voltage	EXAMPLES: • Harmonics from fixed frequency PWM • Motor inverter harmonics with phase depending on the motor angular position only	EXAMPLES: • High order harmonics, depending on converter parameters • Interference from pantograph bounces, neutral sections, gaps

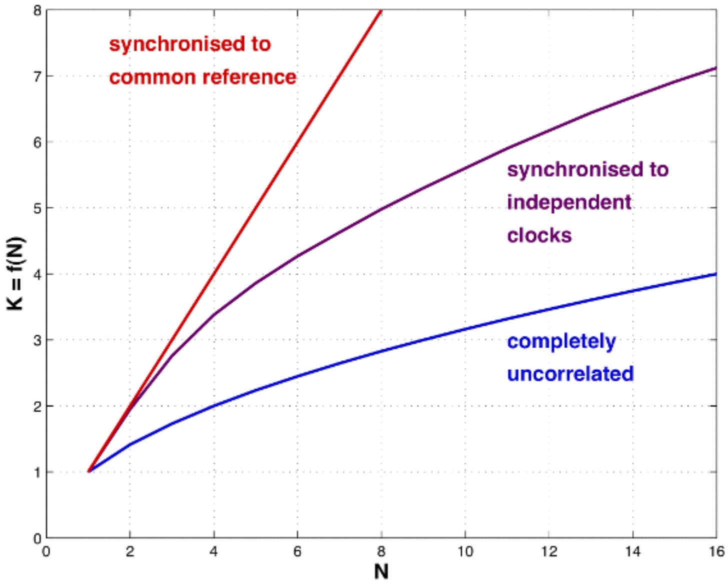


Figure B.2 — Superposition factors

Table B.3 — K factor values

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
K_S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
K_I	1,0	1,95	2,76	3,38	3,86	4,27	4,63	4,98	5,30	5,60	5,90	6,17	6,44	6,68	6,91	7,12
K_U	1,0	1,41	1,73	2,00	2,23	2,45	2,65	2,82	3,00	3,16	3,32	3,46	3,61	3,74	3,87	4,00

Partial or full elimination of some harmonics can be reached for multiple units consisting of two or more TUs with systematic interlacing between PWM patterns (referenced to the AC line voltage or a common clock). Such cases shall be handled separately, however *K* can never be smaller than 1. If partial or full elimination of harmonics is part of the design, the correct functioning of the interlacing shall be demonstrated by measurements. Special attention shall be given to degraded modes of operation when the reduction of harmonic interference might be incomplete due to one or more TUs being switched off. If in band interference current of a specific TC frequency band contains shares from all categorized harmonics which cannot be separated, the train manufacturer shall advise on the summation rule to be applied for the particular frequency, depending on the technique used and according to the definitions presented in Table 2, for normal and degraded conditions.

Superposition rules for harmonics generated by diode and phase angle controlled converters are dealt with according to UIC 550.

NOTE 1 Values K_U for completely uncorrelated harmonics are equal to the square root of number of units N. Numerically, these values correspond to the 95 % confidence level that the sum of N phase vectors with random length between 0 and 1 and random phase (i.e. the absolute value of the sum of N such phase vectors) is below or equal to K_U = f (N). This is equivalent to route sum square (RSS) addition which is widely used in the railway industry with 99 % confidence level. Therefore the recommended summation rule is pessimistic.

NOTE 2 Values K_I for harmonics synchronized to independent clocks are computed in the same way using Monte Carlo simulation, but with N phase vectors of length 1 and random phase. This reflects the fact that harmonics synchronized to independent clocks may have equal amplitude, but nearly never sum up linearly with increasing number N. The values are chosen with a confidence level of 96 %, which is the probability that the resulting vector is below K_U = f (N). Therefore the recommended summation rule is pessimistic.

B.9 Requirements for on-train interference monitoring and control

If in known fault and specified degraded operational conditions of the rolling stock compatibility with the interference current limit cannot be achieved, interference current monitors shall be deployed on board the train to protect the safe operation of the track circuit.

Proof of safety shall be performed in accordance with the EN 50126 series, EN 50128 and EN 50129.

The design shall provide the integrity level commensurable with the legal national/international availability/safety requirements applicable at the time of introduction into service.

B.10 Documentation

The following documentation shall be compiled to ascertain evidence of compatibility between RST and track circuits:

a) the measured data shall be stored in an easily accessible digital format;

b) the characterization of the train under test shall be documented in the context of influencing unit so that the respective summation rules can be defined. The following points shall be covered:

   1) overall schematics diagram (traction and auxiliaries) which allows identifying the number of converters, whether the vehicle has passive filters, etc.;

   2) switching frequencies of the traction and auxiliary line converters;

   3) description of the modelling and behaviour of the interference sources; for example harmonics as a first order approximation, dependency of speed and/or power;

c) the measurements shall be documented in a report, which contains:

   1) description of the test equipment used and its accuracy;

   2) definition of infrastructure on which the tests were performed;

   3) description of test conditions (load, travelling direction, weather, etc.);

   4) one typical steady state spectrum for each configuration with indication of the corresponding operation point;

   5) peak hold spectrum per test cycle (excluding major transients). Make time domain analyses to identify transients and perform peak hold spectrum analyses over periods of interference with no transient event recorded;

   6) speed, tractive effort and line voltage as well as time domain results for each track circuit channel (output of evaluation method as defined above) versus time for each test cycle.

Annex C
(informative)

Infrastructure data

C.1 Supply frequency

Supply frequencies are defined in EN 50163. For both 50 Hz and 16,7 Hz networks, variations as defined are relatively large. In practice, the variation of supply frequency is much smaller. In order to avoid over dimensioned systems, the following values for supply frequency variations can be applied to check compatibility between track circuits and rolling stock:

Table C.1 — Supply frequency

System / nominal frequency	Limits of variation	Remark
16,7 Hz	16,7 Hz (± 1,2 %)	
50 Hz	50 Hz (± 0,1 %)	Applies also to DC traction systems where the supply voltage is provided from the national 50 Hz grid.

These practical values are recommended for consideration in the compatibility assessment.

Variations may be included in the interference current limits already. Enquiries to confirm this should be addressed to the relevant IM.

C.2 Infrastructure characterization

The equivalent diagram in the following figure is the highest possible abstraction of the considered system. However, this simplification is possible for each frequency in case the system is sufficiently linear, which is the case for small signals like harmonic interference currents generated by trains.

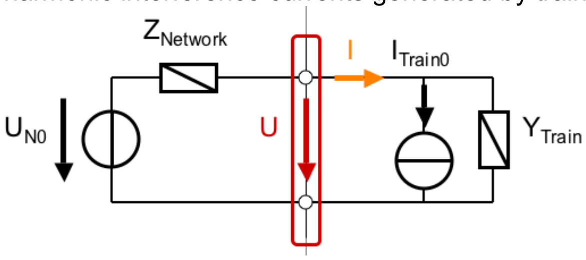


Figure C.1 — Infrastructure characterization

In order to characterize the infrastructure (left part of the figure), both the source voltage U_{N0} and the impedance $Z_{Network}$ have to be known. For the purpose of this Technical Specification, this is done in the following way:

- voltage: the source voltage U_{N0} is not directly accessible, and is a synthetic value not present physically in most of the systems. The voltage U at the interface is taken instead. This voltage can be measured during normal railway operation. Results from the EU project which were taken as an input to this Technical Specification are shown in C.3. For interference current measurements with traction units, there are no explicit requirements for this voltage;

- power supply impedance/resonances: seen from the interface this is a complex characterization, influenced by many parameters of the system. Precise measurements are very demanding. Therefore, a guideline on how to calculate the lowest resonance frequency of a railway network with sufficient accuracy for the purpose of this Technical Specification is given below, together with the results from measurements from one specific line.

C.3 Power supply impedance

The impedance of railway power supply systems is resistive-inductive at fundamental frequency (16,7 Hz or 50 Hz). For higher frequencies, distributed capacitances in the catenaries and transmission lines form resonances together with inductances in lines and transformers.

The detailed frequency response of the impedance of a network depends on the structure of the network and a large number of parameters. The Figure below shows some examples. It originates from dedicated measurements in the 2 x 25 kV, 50 Hz system of Betuweroute in the Netherlands. A test train was used to inject a single frequency test current, which was varied over time and the voltage response was measured. Results for various train positions along the route, and for normal and several degraded feeding configurations are overlaid. No other train was present in the system:

- up to a certain frequency, the power supply is resistive-inductive only;
- minor signs of a well damped resonance at 150 Hz originate from the 150 kV public grid; they have no significance on the railway side in 50 Hz networks;
- the lowest resonance frequency is characteristic for each feeding configuration. In the example, the lowest value is 500 Hz (degraded mode). It can be as high as 2 kHz for strong feeding and short line sections;
- above the lowest resonance for each configuration, resonances have to be expected at any frequency. Values vary with the position of the train. White areas in the figure are caused by limitations of the measurement technique (converter switching frequency of the test train).

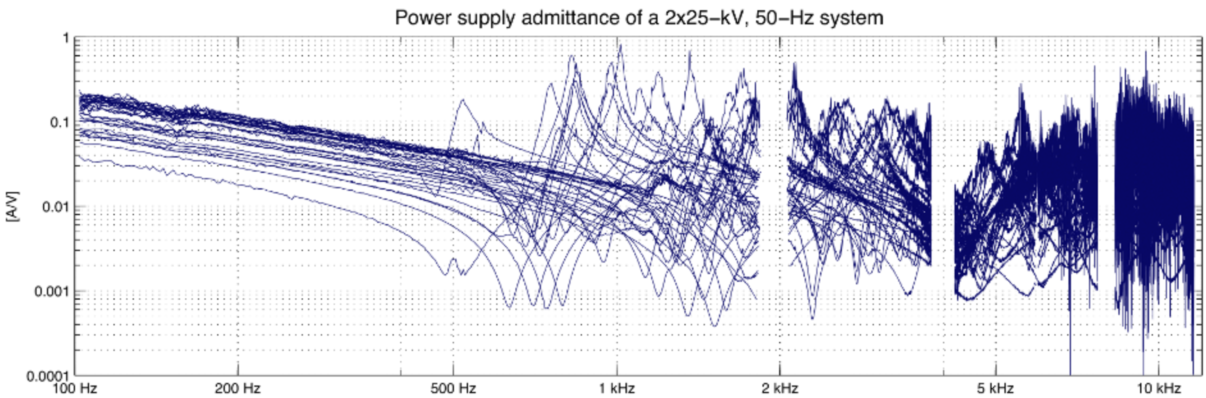


Figure C.2 — Power supply admittance

For DC railways, resonance effects do not have the same importance as for AC railways.

C.4 Approximate calculation of the lowest power supply resonance frequency

In AC railway systems (16,7 Hz and 50 Hz), an approximate value for the lowest resonance frequency of the electrical network shall be calculated from the following data:

- total length l_{Lines} of electrified tracks, including side tracks;
- total length l_{Cables} of power supply cables;
- specific capacitance c_{Line} of electrified tracks, with the following typical values or lines without any cables.

Table C.2 — Capacitance parameters for electrified lines

	c_{Line}	
c_{Line}	1 x 15 kVor 1 x 25 kV	2 x 15 or 2 x 25 kV (AT systems)
Single-track line	10 nF/km to 12 nF/km	12 nF/km to 18 nF/km (positive phase) 10 nF/km to 15 nF/km (negative phase)
Double-track line	17 nF/km to 20 nF/km	20 nF/km to 24 nF/km (positive phase) 15 nF/km to 18 nF/km (negative phase)

- specific capacitance C_{Cable} of power supply cables, with the following typical values:

$$C_{Cable} = 150 \text{ nF/km to } 240 \text{ nF/km (to } 330 \text{ nF/km)}$$

- no-load feeding voltage U_0, typically:

Table C.3 — No-load supply voltage levels

f_N	16,7 Hz	50 Hz
$U_{nominal}$	15 kV	25 kV
U_0	16,5 kV	27,5 kV

- total short circuit current I_{Shc} (i.e. sum of short circuit currents of all connected transformers in all substations of the considered test run). These values are available from the substation transformer data.

The lowest resonance is then calculated as follows:

$$f_{Res} = 1/2\pi * 1/\sqrt{(L_{Shc} * C_{Tot})}$$

where

L_{Shc} is the combined short circuit inductance of all substations:

$$L_{Shc} = U_0 / I_{Shc} / (2\,\pi\,f_N)\text{; and}$$

C_{Tot} is the total capacitance of all lines and cables of the considered region:

$$C_{Tot} = c_{Lines} * l_{Lines} + c_{Cable} * l_{Cables}$$

Note that for a first order approximation, short circuit currents and capacitances of the positive and negative phase part in an AT system can be summed up linearly in order to get I_{Shc} and C_{Tot}.

C.5 Simplified method to handle resonance effects with roof cables

As mentioned already, generation of worst case harmonics for AC vehicles with capacitive input impedance occurs only under a precise combination of infrastructure and rolling stock parameters and can not easily be tested with sufficient probability to reach the maximum interference current. The following Figure C.3 shows the compact results from corresponding theoretical investigations provided by the EC sponsored project "RAILCOM".

The model calculations have been done for a double-track railway line in a 16,7 Hz system, 20 km length, and a substation at each end. Validated models for railway lines and substations have been used.

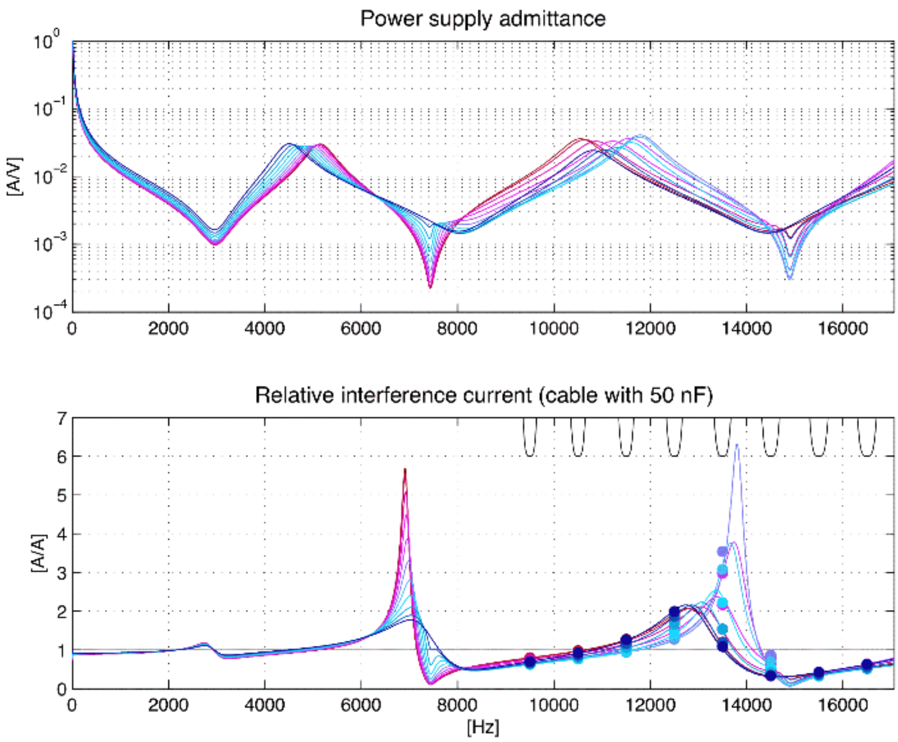


Figure C.3 — Resonance effects for various RST positions

The upper half figure shows:

- the power supply admittance versus frequency, seen from different positions along the line, without any other train;
- resonances occur at all positions. Much sharper resonances only occur in some distance from the substations, whereas the resonances close to the substations are damped much better (dark lines).

The lower figure shows:

- the relative interference current, normalized to the current at a very strong, non-resonant network;
- the amplification of individual harmonics under the conditions of the model network (solid lines). Dark lines are valid for locations close to the substations, and show a moderate amplification, whereas the amplification far from the substation is much higher and much sharper (smaller bandwidth);
- interference currents in eight frequency bands (corresponding to FTGS 917 in this case), shown as dots for each band and location in the network. Results have been calculated in the frequency domain and are valid for steady state conditions. Filter characteristics as defined in Annex A have been used;
- for reference: filter curves for the eight bands at the upper edge of the figure. Numerical values in the y axis are without significance for these curves.

The following observations lead to the approach for the compatibility assessment defined here:

- it depends on the combination of infrastructure and rolling stock parameters whether a strong amplification of harmonics falls into the frequency band of a track circuit or between them. This results in a high sensitivity of the results (interference currents) with respect to parameters, and to the conclusion that worst case conditions can not be planned in reality;
- there is a deterministic ratio between amplification of harmonics close to a substation and far from a substation. This ratio depends on the input capacitance of the influencing unit (parameter study not shown in the figure above). Larger capacitances and higher frequencies lead to a higher ratio.

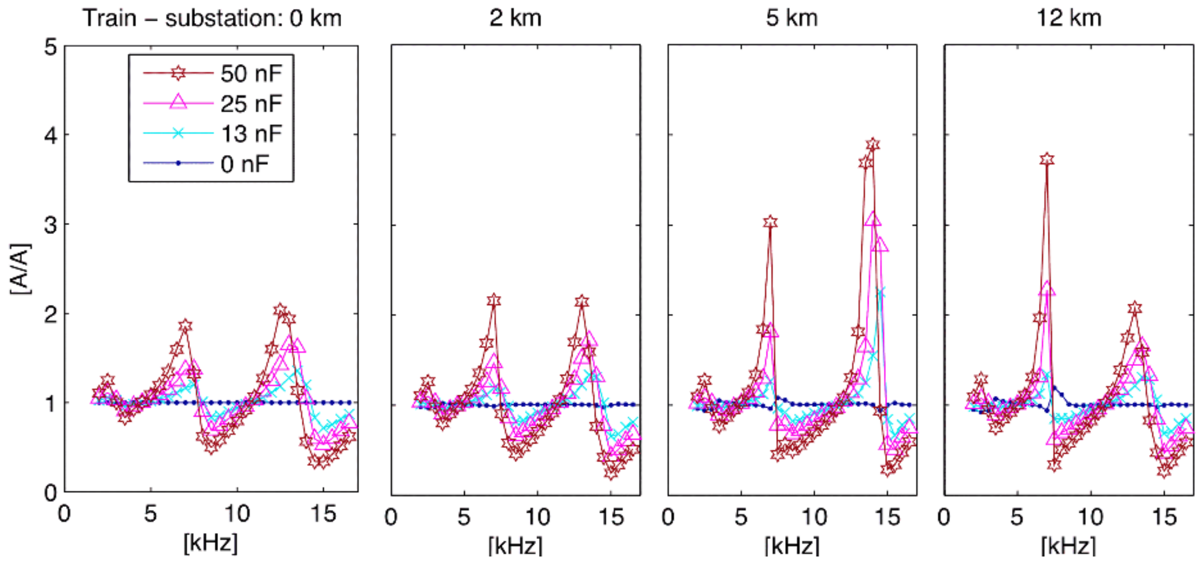


Figure C.4 — Resonance effects for various RST input capacitance

Since conditions close to a substation can be reproduced more easily and have lower sensitivity to parameters, values measured there serve as reference. The formula defined in 'Special conditions for AC trains with a capacitor directly at the input' is a simplification from the theoretical investigations, and can be handled easily. The situation has been principally verified by comparison with measurements on a train with two pantographs and a cable between them in the context of the "RAILCOM" project.

C.6 Return current transfer function

No information about the return current transfer function is given, as this is a product specific issue and not directly one for interoperability.

Values depend on the centre frequency of the track circuit, on the return current arrangement and corresponding geometrical parameters as well as parameters like ground resistivity, etc.

Annex D
(informative)

Typical voltage resonance graphs

D.1 General

The graphs shown originate from EU research project "RAILCOM" (2006 – 2009), from specialized measurement campaigns for the characterization of the electrical interface between infrastructure and trains. They are provided for information only on typical conditions in the different power supply systems, and for preliminary validation of the infrastructure conditions formulated in the main part of the Technical Specification.

D.2 Interface voltage/current measurement

All results shown in the following Figures have been computed by the same method, i.e. the application of bandpass filters plus integration time with the following parameters:

Table D.1 — Measurement parameters

Filter type	Butterworth
Order	2 * 3
Center frequency	According to table below
20 dB bandwidth	5 % of center frequency
Integration time	0,5 s

Table D.2 — Measurement frequencies

From [Hz]	To [Hz]	Resolution [Hz]
50	200	3,333
200	300	4,166
300	500	5,555
500	1 000	8,333
1 000	2 000	33,33
2 000	3 000	41,66
3 000	5 000	55,55
5 000	10 000	83,33
10 000	12 000	333,3

D.3 Voltage resonance graphs for 15 kV 16,7 Hz network

The measurements were taken on one locomotive Re 460 on the network of SBB. The following characteristics can be extracted from Figure D.1:

- low order odd harmonics of the fundamental frequency;
- no influence of single harmonics above 1 kHz, due to permanent variation of the line frequency;
- resonance effects around 200 Hz (high voltage network), above about 800 Hz (15 kV network; but dominated by influences from other vehicles);

- influence from other vehicles in many areas (600 Hz to 1 000 Hz, 1,2 Hz to 2 kHz, and strongly on 4,8 Hz and 12 kHz).

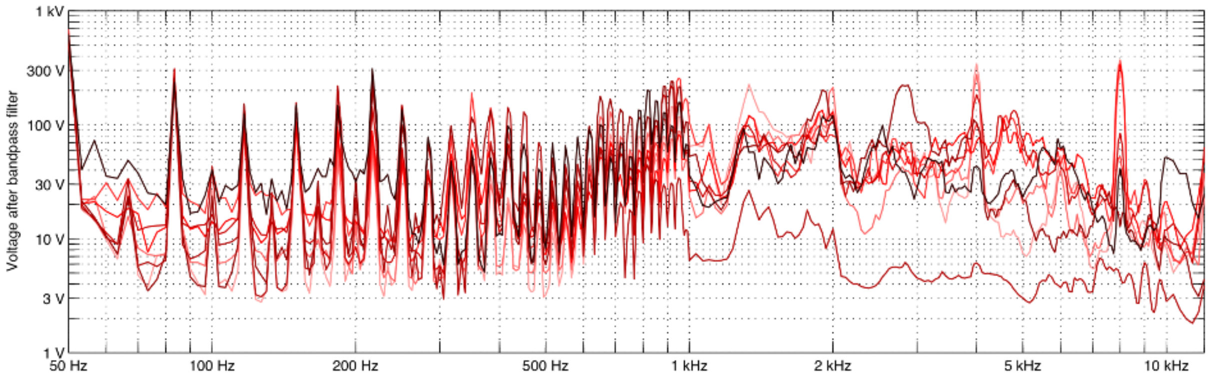


Figure D.1 — Voltage resonance graph for 15 kV 16,7 Hz network

D.4 Voltage resonance graphs for 25 kV, 50 Hz network

The measurements were taken on one locomotive TGV DASYE running on the SNCF network. The following characteristics can be extracted from Figure D.2:

- odd harmonics of fundamental frequency can be distinguished up to more than 2 kHz;
- lowest resonance frequency between 700 Hz and 1 000 Hz (classical lines) or 1,2 Hz and 2 kHz (high speed lines);
- resonance effects become dominating for frequencies higher than 2 Hz to 3 kHz.

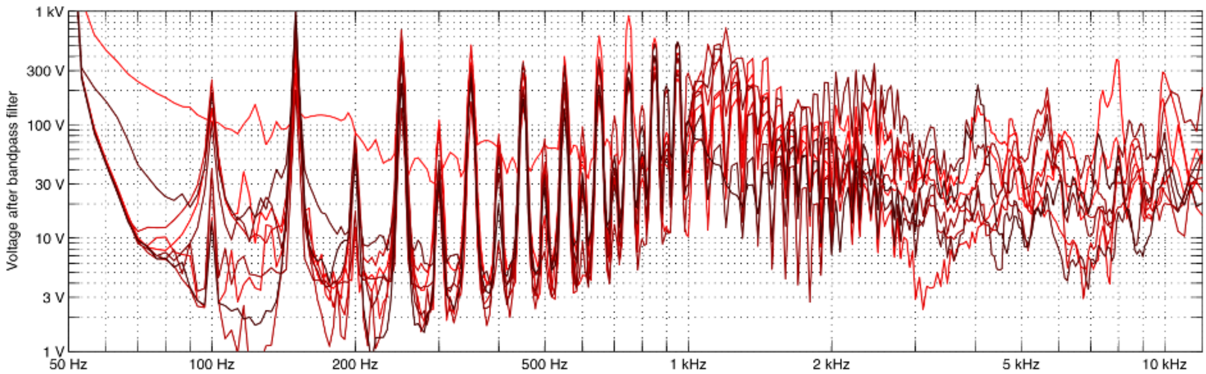


Figure D.2 — Voltage resonance graphs for 25 kV 50 Hz network

D.5 Voltage resonance graphs for 1 500 V DC network

The measurements were taken on one locomotive TGV DASYE running on the SNCF network. The following characteristics can be extracted from Figure D.3:

- N*6th harmonics of the power supply frequency (i.e. multiples of 300 Hz) are absolutely dominating (characteristic harmonics of 6-pulse diode rectifiers);
- N*2nd harmonics are visible, but much smaller (asymmetries in the public 50 Hz utility);
- single frequencies (like 220 Hz in the example) can originate from other equipment being present in the network. Such frequencies are out of the frequency bands of track circuits and are, therefore, not of relevance;
- no effects from other trains are visible;
- no resonance effects for frequencies up to about 1,5 Hz to 2 kHz.

- resonance effects, if any, are not dominant, and at frequencies of 4 kHz or more.

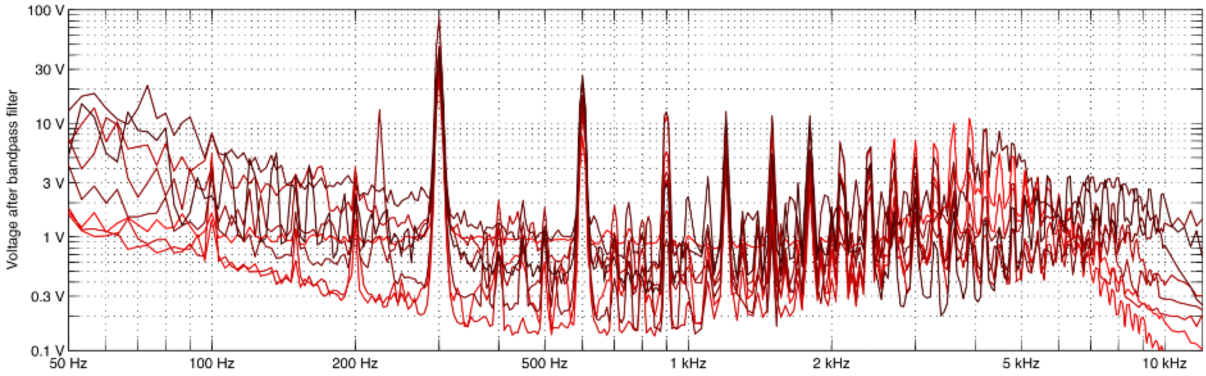


Figure D.3 — Voltage resonance graphs for 1 500 V DC network

D.6 Voltage resonance graphs for 3 000 V DC network

The measurements were taken on one locomotive running on the of CD and PKP networks. The following characteristics can be extracted from Figure D.4:

- the situation is comparable to the 1 500 V network;
- breakthrough of track circuit frequencies (e.g. 83 Hz) can be seen for single cases (see Annex B for a description of this phenomenon).

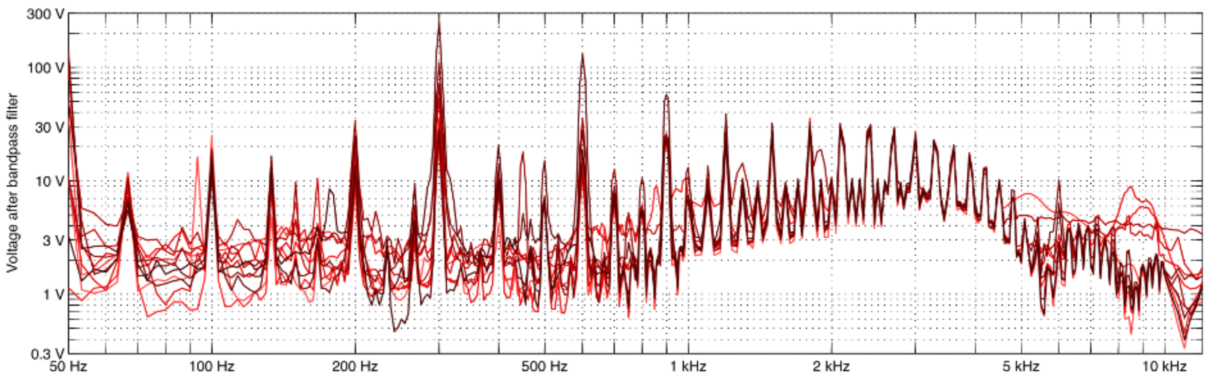


Figure D.4 — Impedance graphs for 3 000 V DC network

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[2] EN 50163, *Railway applications — Supply voltages of traction systems (IEC 60850)*

[3] EN 50617-1, *Railways applications — Basic parameters of train detection systems — Part 1: Track circuits*

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