BS EN 50728:2024



BSI Standards Publication

Railway applications — Rolling stock — Testing for electromagnetic compatibility with track circuits

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The UK participation in its preparation was entrusted to Technical Committee GEL/9/2, Railway Electrotechnical Applications - Rolling stock.

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

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Bahnanwendungen - Fahrzeuge - Prüfung der elektromagnetischen Verträglichkeit mit Gleisstromkreisen

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Contents

Page

European foreword 6
Introduction 7
1 Scope 8
2 Normative references 8
3 Terms, definitions and abbreviations 8
3.1 Terms and definitions 8
3.2 Abbreviations 14
4 Test specification 14
4.1 Preparation 14
4.1.1 General 14
4.1.2 Vehicle data 14
4.1.3 Applicable requirements 15
4.1.4 Pre-analysis 16
4.2 Test specification 17
4.3 Test setup 18
4.3.1 Sensor location 18
4.3.2 Current or voltage measurement 18
4.3.3 Apparatus 19
4.3.4 Other signals and information 19
4.4 Test conditions 19
4.4.1 Vehicles 19
4.4.2 Infrastructure 19
4.4.3 Environment 22
4.5 Test procedure for vehicles 23
4.5.1 General 23
4.5.2 Pre-test of the measurement chain on the vehicle 23
4.5.3 Static tests 23
4.5.4 Dynamic tests 23
4.5.5 Long term tests 25
4.6 Test conditions for separate auxiliary converters 25
4.6.1 General 25
4.6.2 Definition of requirements 25
4.6.3 Test procedure 25
4.7 Check of input impedance 26
4.7.1 Passive inductive impedance 26
4.7.2 Passive capacitive impedance 26
4.7.3 Controller influence 27
5 Measurement analysis 27

Documents
Document Sharing Hub
Full document details: BS EN 50728:2024

5.1 Summation - General 27
5.2 Summation - DC rolling stock 28
5.2.1 Synchronisation 28
5.2.2 Point of measurement 28
5.2.3 Scaling 28
5.2.4 Current sharing 28
5.3 Summation - AC rolling stock 29
5.3.1 Synchronisation 29
5.3.2 Point of measurement 29
5.4 Resonances 30
5.5 Phenomena to be discarded 30
5.5.1 Variation of line voltage 30
5.5.2 Variation of supply frequency 30
5.5.3 Asymmetry in the public supply network and substation load 30
5.5.4 Evaluation of short duration exceedances 31
5.5.5 Other rolling stock 32
5.5.6 Electric traction power supply system resonances 32
5.6 Test report 33
5.7 Pass / fail criteria 33
5.8 Impact analysis of changes 34
Annex A (normative) Measurement equipment 35
A.1 General 35
A.2 Whole measurement chain 35
A.3 Voltage sensors 36
A.4 Current sensors 36
Annex B (normative) Resonances 37
B.1 Amplification factors 37
B.2 Measurement setups 39
B.3 Comparison with limits 41
Annex C (informative) Identification of transients 43
C.1 General 43
C.2 Recommendations 43
C.3 Examples 43
Annex D (informative) Substation, traction and auxiliary system structures 47
D.1 General 47
D.2 Overall system 47
D.3 AC substations 48
D.4 DC substations 48
D.5 AC rolling stock 49
D.6 DC rolling stock 50

Documents
Document Sharing Hub
Full document details: BS EN 50728:2024

Annex E (normative) Summation rules 53
E.1 DC Rolling Stock: Scaling of independent IISs to the IU 53
E.2 DC rolling stock: Scaling from the sum of Q independent IISs to a single IIS 56
E.3 AC rolling stock 63
Annex F (informative) Resonances 64
F.1 General 64
F.2 System definition 64
F.3 Resonance amplification 65
F.4 Relevance in railway systems 67
F.5 Identification of resonances from measurements 68
F.6 Examples 71
Annex G (informative) Converters with small input filters 75
G.1 Introduction 75
G.2 Problems with such converters 75
G.3 Analysis 75
G.4 Tests 76
Annex H (informative) Superposition of interference from electric traction power supply system and rolling stock 77
H.1 General 77
H.2 Equivalent circuit diagram 77
H.3 AC systems 77
H.4 DC systems 78
Annex I (informative) Voltage versus current measurement in DC vehicles 80
I.1 Traction system 80
I.2 Goal 80
I.3 Influence of a magnetic core 80
I.4 Characteristics of an air cored inductor 81
I.5 Resonances in the filter inductor 82
Annex J (informative) Automatic data processing 83
J.1 General 83
J.2 Identification of interference source(s) 83
J.3 Characterization of identified interference sources 84
J.4 Justification of completeness 85
J.5 Transients 85
J.6 Quantify the maximum value(s) of the respective interference source(s) 85
Annex K (informative) Summation- background 86
K.1 Scope 86
K.2 Theoretical background 86
K.3 Continuous approximation 88
K.4 Measuring a group of Q independent IISs 89

Documents
Document Sharing Hub
Full document details: BS EN 50728:2024

Annex ZZ (informative) Relationship between this European Standard and the Essential Requirements of EU Directive (EU) 2016/797 aimed to be covered 97

Bibliography 98

Documents
Document Sharing Hub

Full document details: BS EN 50728:2024

European foreword

This document (EN 50728:2024) has been prepared by CLC/SC 9XB “Electromechanical material on board rolling stock” of CLC/TC 9X “Electrical and electronic applications for railways”.

The following dates are fixed:

• latest date by which this document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2025-12-31
• latest date by which the national standards conflicting with this document have to be withdrawn	(dow)	2027-12-31

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This document has been prepared under a standardization request addressed to CENELEC by the European Commission. The Standing Committee of the EFTA States subsequently approves these requests for its Member States.

For the relationship with EU Legislation, see informative Annex ZZ, which is an integral part of this document.

Any feedback and questions on this document should be directed to the users’ national committee. A complete listing of these bodies can be found on the CENELEC website.

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Introduction

This document defines the testing, measurement and evaluation methods for rolling stock interference current emissions to demonstrate compatibility with track circuits. The evaluation is done at the interface between rolling stock and infrastructure (the total interference current of the IU), and not at the receiver of a track circuit.

In the context of European interoperability, interference current limits for rolling stock are defined in the TSI Interface document ERA/ERTMS/033281.

Outside European interoperability, individual limits and summation rules are defined in other documents such as NNTRs and PD CLC/TS 50238-2. In specific application cases outside the scope of Interoperability Regulations, limit values can be notified by the track circuit manufacturer, according to the process defined in EN 50617-1.

Proof of compliance of rolling stock with the interference current limits is done in three main steps. First, a test specification is defined, based on the specific characteristics of rolling stock to be tested (see Clause 4). This ensures that the final results give sufficient confidence in the level of compliance. Then the tests are performed according to the specification. Finally, the results are processed under a defined set of rules, in order to demonstrate compliance with the given limits (see Clause 5).

Tests for the demonstration of vehicle compatibility are type tests and are performed before the first unit is put into regular service. When completed in accordance with this document, it is the goal to perform measurements only once per electric traction power supply system voltage and frequency.

As far as possible, common requirements are defined for both AC and DC systems. However, these differ in several aspects. In AC systems, the impedance of the electric traction power supply system is small compared with the impedance of the vehicle, but resonance effects need to be considered. The main source of interference is the rolling stock. In DC systems, the impedance and, therefore, the distance from substations, is important, but resonance effects are largely neglectable. Rectifier substations have a significant contribution to the total interference current in DC systems, and also the traction and auxiliary systems of DC rolling stock are normally different from those of AC. Where necessary or appropriate, this document differentiates between AC and DC systems. If requirements are not clearly indicated as relevant to AC or DC systems then they are relevant to both AC and DC.

In order to limit the influence from static converters (AC) and substations (DC) on track circuits, a minimum rolling stock impedance is required. This document defines how to prove conformity with such requirements as well.

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1 Scope

This document defines the measurement and evaluation methods of rolling stock interference current emissions to demonstrate compatibility with track circuits. This includes rolling stock with or without traction equipment. The established limits for compatibility are defined in ERA/ERTMS/033281, PD CLC/TS 50238-2 or NNTRs as current flowing between the vehicle and the electric traction power supply system that can disturb the track circuit receiver, as part of the track circuit system. Additionally, the referred documents can define a minimum rolling stock impedance in order to guarantee compatibility between the electric traction power supply system and track circuits.

This document is relevant to the interference current limits defined in the “frequency management” for track circuits as defined in ERA/ERTMS/033281. It is also applicable to the demonstration of compatibility with all other types of track circuits which have established compatibility according to EN 50617-1. Finally, the methodology defined in this document can also be applied to other track circuit types, including those for which the only requirements are defined in NNTRs.

NOTE 1 Interface parameters between rolling stock and track circuits other than interference currents and impedance are out of the scope of this document.

NOTE 2 For track circuits prone to wrong side failures additional precautions might be needed to mitigate safety risks. The necessary precautions and safety considerations are outside the scope of this document, but can be found in NNTRs.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 50388-1:2022, *Railway Applications - Fixed installations and rolling stock - Technical criteria for the coordination between electric traction power supply systems and rolling stock to achieve interoperability - Part 1: General*

EN 50163:2004,[1] *Railway applications. Supply voltages of traction systems*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— IEC Electropedia: available at https://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1.1
beating
interference pattern between two or more slightly different frequencies, perceived as a periodic variation in amplitude with a rate dependent on the differences in frequencies

[1] As impacted by EN 50163:2004/A1:2007, EN 50163:2004/corrigendum May 2010, EN 50163:2004/AC:2013, EN 50163:2004/A2:2020, EN 50163:2004/A3:2022.

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Full document details: BS EN 50728:2024

3.1.2
controlled impedance
increase of impedance by appropriate control of a connected converter

Note 1 to entry: The resulting controlled impedance is equal to the frequency response of the small signal ratio voltage divided by current.

Note 2 to entry: The increased impedance can be a result of controlling other quantities, e.g. active interference current suppression.

3.1.3
degraded mode
mode of operation of rolling stock with a reduced number of ES or IIS, which has been anticipated in the design

Note 1 to entry: Degraded modes (failure modes) are operating modes which can be activated in order to isolate a defect and continue the operation of the rolling stock. When operating in a degraded mode the system performance might be reduced. Examples of degraded modes are deactivated traction motors or traction converters that have an impact on the remaining ones, such as increasing power and / or traction, changing the interlacing strategy or switching frequency.

[SOURCE: IEC 60050-811:2017, 811-01-52, modified – The term “degraded modes” has been replaced with “degraded mode” and “have been” with “has been”; “in the presence of faults” has been replaced with “of rolling stock with a reduced number of ES or IIS,”; “of the signalling system or the rolling stock” has been deleted; the Note 1 to entry has been added.]

3.1.4
electric traction power supply system
railway electric distribution network used to provide energy for rolling stock

Note 1 to entry: The system includes

— contact line systems,

— return circuit of electric traction systems,

— running rails of non-electric traction systems, which are in the vicinity of, and conductively connected to the running rails of an electric traction system,

— electric installations, which are supplied from contact lines either directly or via a transformer,

— electric installations in power plants and substations, which are utilized solely for generation and distribution of power directly to the contact line,

— electric installations of switching stations.

[SOURCE: IEC 60050-821:2017, 821-36-21, modified – “power supply” has been added in the term]

3.1.5
electrical subsystem
ES
smallest unit which is practicably accessible for interference current measurements

Note 1 to entry: See Figure 1 and Figure 2.

Note 2 to entry: An ES is fed from the line voltage via distribution lines inside a TU. Internally, an ES can consist of one or several interference sources (such as traction and / or auxiliary converters) which cannot practicably be evaluated individually.

Note 3 to entry: An ES can be an IIS, however it can also consist of multiple IISs.

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3.1.6
individual interference source
IIS
smallest subset of an electrical subsystem that can be identified and characterised as an interference current source

Note 1 to entry: The individual interference source is the basis for evaluation, in DC systems, of the total interference current produced by an influencing unit, but it might not always be practicable to measure at IIS level.

Note 2 to entry: Individual interference sources can be various types of components and their control.

3.1.7
influencing unit
IU
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 coaches.

Note 2 to entry: The influencing unit can consist of several “Traction Units“ (TU).

See Figure 1 and Figure 2 for clarification.

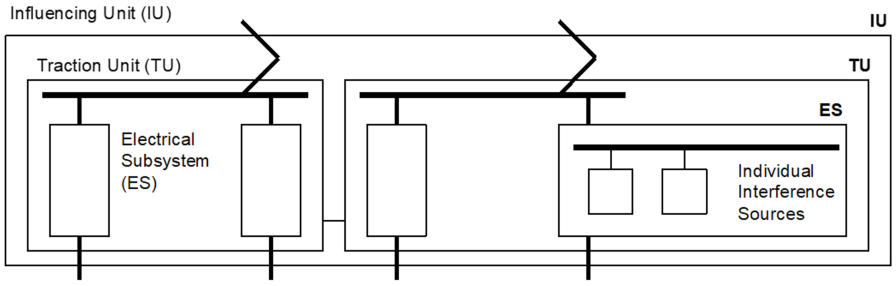


Figure 1 — Definition of IU, TU and Electrical Subsystem (ES)

[SOURCE: CLC/TS 50238-2:2020, 3.1.2, modified – The Note 1 to entry and Note 2 to entry have been modified. The note 3 to entry has been omitted. The Figure 1 has been replaced.]

3.1.8
infrastructure
all fixed railway installations

Note 1 to entry: In the given context it includes the electric traction power supply system and train detection systems.

3.1.9
integration time
window size over which the root mean square (RMS) of the output of the bandpass filter is calculated

[SOURCE: CLC/TS 50238-2:2020, 3.1.3]

3.1.10
interference current
undesired frequency content in the line current, which is in the operating frequency range of the track circuits

3.1.11
interference current budget
part of the interference current limit, based on the summation rules, which can be used by an IU, TU, ES or IIS

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3.1.12
interference current limit
maximum interference current which an influencing unit is allowed to produce at a given frequency to remain compatible with a track circuit

Note 1 to entry: Interference current limits are defined in ERA/ERTMS/033281, NNTRs or PD CLC/TS 50238-2.

Note 2 to entry: Interference current limits are defined by a number of evaluation parameters, such as FFT parameters, or bandpass filter centre frequency and bandwidth and integration time.

3.1.13
interference current monitor
system or function that monitors the interference current production of an influencing unit, traction unit or electrical subsystem

Note 1 to entry: The interference current monitor is not part of the test specification as given in this document. It might, however, be one of the safety measures required.

Note 2 to entry: In case interference currents can result in a wrong side failure, an interference current monitor which is able to switch off an interference current source is a possible mitigation measure.

3.1.14
line current
current that flows from the contact line via the pantograph(s) (or current collectors) through the IU, TU or ES to the return circuit

Note 1 to entry: In this document, line current is used in a more general sense and not only to the pantograph current to one TU.

3.1.15
normal operating mode
mode of operation of rolling stock with all electrical subsystems in fault-free working configuration

3.1.16
number of tests
number of times that a condition defined in the test specification is met

Note 1 to entry: This is not necessarily equal to the number of test runs.

3.1.17
right side failure
RSF
mode of failure which does not directly compromise the safe operation of trains but can reduce availability

3.1.18
small input filter
low pass passive input filter for DC supplied vehicle with a cut-off frequency which is higher than 1/3 of the centre frequency f_0 of the considered track circuit

Note 1 to entry: 1/3 is set so that the filter cut-off frequency is well below the lowest track circuit centre frequency.

Note 2 to entry: For an LC filter the cut-off frequency is $\frac{1}{2\pi\sqrt{LC}}$

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3.1.19
steady state
operating condition of a system in which the system state variables can be considered to be constant compared to time interval of interest

Note 1 to entry: For example, a varying speed should be considered as potentially constant if a train can stay at a certain speed for a longer time than the time interval of interest.

[SOURCE: IEC 60050-603:1986, 603-02-06, modified – “conditions” has been replaced with “condition”. “network” has been replaced with “system”. “are” has been replaced with “can be”. “sensibly constant” has been replaced with “constant compared to time interval of interest”. The Note 1 to entry has been added.]

3.1.20
substation
<in electric traction> installation which supplies a contact line

Note 1 to entry: The voltage of a primary supply system, and in certain cases the frequency, is converted by the substation to the voltage and frequency of the contact line.

3.1.21
summation rule
calculation method to scale a set of measurements on traction unit or electrical subsystem level to the maximum interference current for an IU with a specified confidence level

3.1.22
traction unit
TU
locomotive, motor coach or train-unit

Note 1 to entry: Each TU is fed from one pantograph or collector (or UIC busbar in case of coaches / wagons). A TU contains at least one ES. One TU can be:

— one locomotive;

— one electric multiple unit, with one or several Electrical Subsystems (ES) in one or several cars;

Note 2 to entry: A TU does not have to have traction equipment.

See Figure 2 for examples. This Figure is not exhaustive.

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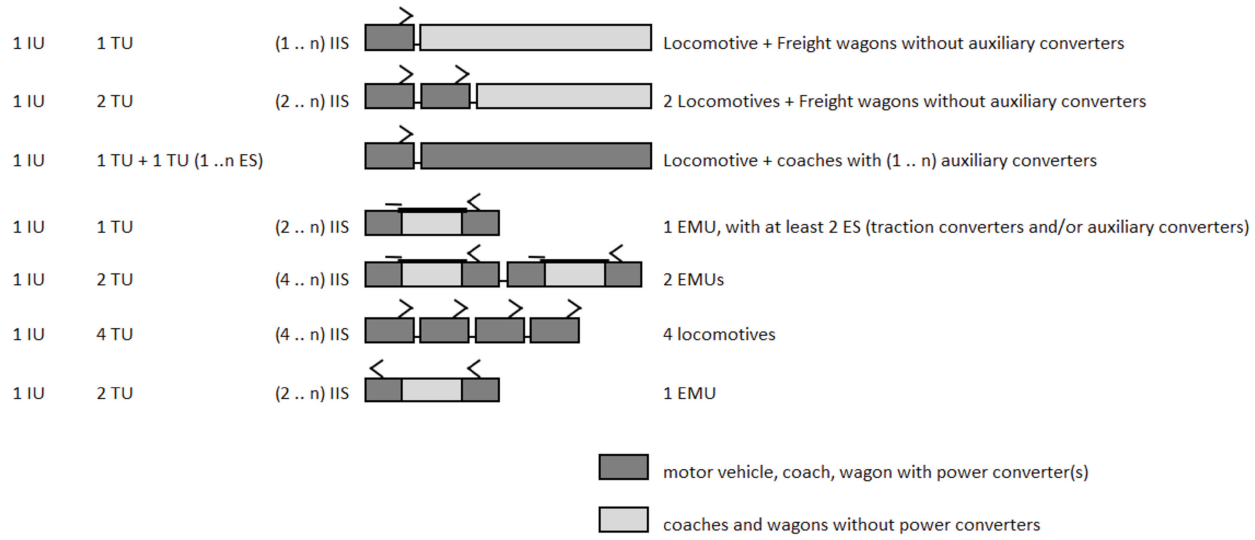


Figure 2 — Term clarification for Traction unit (TU) and Influencing Unit (IU)

[SOURCE: IEC 60050-811:2017, 811-02-04, modified – The Notes 1 and 2 to entry have been added. Figure 2 has been added.]

3.1.23
transient
<adjective> pertaining to a phenomenon or quantity which passes from one steady state to another consecutive steady state during a time interval short compared to the timescale of interest

Note 1 to entry: The term “transient” is also used as a noun to mean a transient phenomenon or quantity.

[SOURCE: IEC 60050-103:2009, 103-05-02, modified – “during a time interval short compared to the timescale of interest” has been added.]

3.1.24
transient
<noun> phenomenon or quantity which varies between two consecutive steady states during a time interval short compared to the timescale of interest

[SOURCE: IEC 60050-702:2019, 702-07-781]

3.1.25
UIC busbar
single-pole line for the supply of auxiliaries through a whole train

Note 1 to entry: The return current flows through the rails.

Note 2 to entry: For additional information see UIC 550:2005-04.

3.1.26
vehicle impedance
impedance of an influencing unit seen between pantograph(s) and wheels

Note 1 to entry: The minimum impedance is defined in ERA/ERTMS/033281 or NNTRs.

Note 2 to entry: The minimum impedance can be defined in terms of inductance and capacitance.

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3.1.27
wrong side failure
WSF
mode of failure which can compromise the safe operation of trains

3.2 Abbreviations

For the purposes of this document, the following abbreviations apply.

AC	Alternating Current
DC	Direct Current
EC	European Commission
EU	European Union
EMU	Electric Multiple Unit or Battery Electric Multiple Unit when connected to the electric traction power supply system
ERTMS	European Rail Traffic Management System
FFT	Fast Fourier Transform
GPS	Global Positioning System
LC	Inductor-Capacitor
NNTR	National Notified Technical Rules
PWM	Pulse Width Modulation
RMS	Root Mean Square
TSI	Technical Specification for Interoperability
UIC	International Union of Railways

4 Test specification

4.1 Preparation

4.1.1 General

Rolling stock and their traction and auxiliary system configurations as well as control systems and parameters can be very diverse. It is, therefore, necessary to prepare for interference current measurements by a pre-analysis for the specific rolling stock. The compiled data serve as input to the test specification and will guarantee an efficient performance and evaluation of the measurements.

The following subclauses specify this data collection and its analysis.

4.1.2 Vehicle data

4.1.2.1 General

The vehicle manufacturer shall document the following data characterizing the vehicle to be tested:

a) Rolling stock configuration (locomotive, or EMU);

b) Electric traction power supply system(s) under which the rolling stock is intended to operate;

c) Main circuit diagram (traction and auxiliaries);

d) Main data: maximum speed, tractive and brake effort and power at wheel;

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e) Dynamic braking systems (regenerative, rheostatic, mixed);

f) Operational configurations (double or multiple traction, traction battery if applicable);

g) Whether a UIC busbar is fitted and maximum number of coaches

h) Whether the UIC busbar is fed from a converter, instead of directly from the catenary or via a transformer winding

i) Degraded modes of operation (e.g. traction or auxiliary converters isolated);

j) Maximum currents of IU, TU, traction and auxiliary converters, and voltage dependency of these maxima.

Based on this information, one Influencing Unit (IU) shall be defined. Traction units (TU) and Electrical Subsystems (ES) shall be identified according to 3.1.7, 3.1.22 and 3.1.5. This will be part of the documentation of the pre-analysis (see 4.1.4).

4.1.2.2 Converter control data

The following information about converter control is essential to perform the pre-analysis:

a) Switching method and frequency and how it varies with operating point;

b) Interlacing scheme;

c) Information about the effect of converter or control failures on switching parameters (e.g. frequency, pulse pattern) and interlacing of remaining converters;

d) Use of controlled impedance;

e) Cut-off frequency of the input filter (see 3.1.18);

f) Limitations which can have an influence on interference current generation.

This information is not part of the documentation for interference current measurements. It can be shared with the other involved parties. It is essential to perform the pre-analysis (see 4.1.4).

4.1.3 Applicable requirements

4.1.3.1 General

The vehicle manufacturer shall compile the following for the IU, apportioned to the analysed formation:

a) Interference current limits (including all relevant parameters);

b) Minimum IU input impedance (inductive, capacitive).

for both interoperable (TSI) and national operation, depending on the intended use of the vehicle.

The split of limits (both interference current and impedance) between locomotives and coaches “intended to be used in general operation” (as specified in Commission Regulation (EU) No 1302/2014, 7.1.1.5.2) is defined in other documents.

4.1.3.2 DC Systems- Interference current budget for rolling stock and power supply

For track circuits used on DC systems at frequencies where the substation contributes significantly to interference currents, the limit shall be budgeted to allow for the substation contribution. See informative Annex H for more explanation.

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For the DC system interference current limits defined in the TSI Interface document ERA/ERTMS/033281 at N x 100 Hz, where N is an integer, the budget for IU generated currents shall be 60 % of the limit, if the IU has exactly the minimum required input impedance.

For higher input impedances the IU interference current budget is higher, since the influence from the substation will be lower. For example for 2 p.u. input impedance: the substation contribution is only 40 %, and the IU budget is $\sqrt{(1 - 0{,}4^2)} = 91{,}7$ %.

For limits in PD CLC/TS 50238-2, NNTRs or other documents other budgets may apply. Informative Annex H may be used as a guide.

4.1.4 Pre-analysis

4.1.4.1 General

The vehicle manufacturer shall identify the expected interference currents, covering all relevant operating conditions and expected worst case operational configurations, including degraded modes. This is an input to the test specification.

This can be done by

a) Simulation in the time domain (this may include the consideration of step and/or impulse response of the complete system including controllers);

b) Calculation in the frequency domain;

c) Comparison with measurements from previous projects in case relevant parameters are sufficiently similar;

d) Laboratory test of part of the Influencing Unit.

For frequencies within the bandwidth of control, normally time domain simulation is needed. For effects which are difficult to predict by simulation (e.g. sensor inaccuracies and delays), measurements from previous projects can help to simplify the analysis.

An assignment of a budget of the limits both for interference currents and impedance shall be made. The interference current budget shall consider expected summation rules (see normative Annex E), whereas admittances (the inverse of impedances) always sum up linearly.

4.1.4.2 Results

The following results shall be documented:

a) Vehicle data as specified in 4.1.2;

b) Expected line current spectrum for each relevant configuration;

c) Operation points (for example: speed, tractive / braking effort, line voltage, auxiliary load) where highest interference currents occur (only for configurations where the currents have a small margin to limits) including the whole range of permitted wheel diameters from new to fully worn;

NOTE 1 The margin to the limit depends on the method and accuracy of calculation.

d) Which speeds will be tested and which can be extrapolated from test results;

e) For speed related harmonics the effect of different possible acceleration rates;

NOTE 2 This is to avoid a speed related interference current (which could be a steady-state effect at a low acceleration rate) being seen only as a transient during tests;

f) The budget of limits both for interference currents and impedance;

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Full document details: BS EN 50728:2024

g) Effects of interlacing and corresponding power imbalances (e.g. caused by wheelslip, unequal auxiliary loads);

Exact modelling of the effect of wheelslip is not necessary; the intent is only to check the effect of the maximum power unbalance caused by wheelslip.

h) Which configurations (including degraded modes) have to be tested, and which do not have to be tested because results can be derived from other tests;

i) A justification whether wheelslip tests are necessary or not, considering the effects mentioned in 4.4.3.2;

j) If tests are not to be performed with a 6 pulse rectifier, a justification considering the intermodulation effect mentioned in 4.4.2.3.

k) Sensor location in the main circuit diagram (based on requirement in 4.3.1 and 4.3.2);

l) Assumption of summation rules during pre-analysis for the relevant phenomena for each frequency band (see normative Annex E);

m) Required number of tests (see normative Annex E);

n) Minimum IU impedance (inductive, capacitive, see also 4.7);

o) Subsystems with a small input filter which need additional analysis, see 4.6.3.3 and informative Annex G;

p) Additional control or power change over points dependant on e.g. line voltage.

q) If the UIC busbar is fed from a converter, instead of directly from the catenary or via a transformer winding, specific analysis and if necessary tests shall be specified to quantify any interference currents it can produce.

r) A justification whether laboratory test results can be used as replacement for on train tests for a part of the test programme.

4.1.4.3 Infrastructure parameters

For simulation and calculation, the following parameters shall be used for the infrastructure.

— AC networks: an ideal voltage source (fundamental frequency only) and zero-line impedance~~;~~

— DC networks: an ideal DC voltage source plus an inductive line impedance for DC networks (0,5 mH for 1 500 V, 1,25 mH for 3 000 V, corresponding to a typical substation plus 200 m track with 1,3 mH/km). This applies for Frequency Management track circuits only, these values may be used for calculation of the Current Sharing Factor – see 5.2.4.

NOTE For DC, the worst-case interference current will occur with zero line impedance.

4.2 Test specification

Prior to the tests, a test specification shall be written. It consists of a detailed definition of the interference current measurements:

a) based on the results of the pre-analysis, see 4.1.3 and 4.1.4;

b) taking into account all requirements from 4.3, 4.4 and 4.5.

It contains also all project-specific information which are necessary to perform the tests, including any special equipment required.

Documents
Document Sharing Hub
Full document details: BS EN 50728:2024

The test specification may be split among several documents if required.

4.3 Test setup

4.3.1 Sensor location

Sensors (current, voltage) shall be placed on an IU, TU or ES according to the results of the pre-analysis. For DC systems it is recommended to place the sensors in a unit of the lowest accessible level, i.e. in an ES and not in the TU, see 5.2. Scaling rules for Q out of N sources shall be applied for DC systems (see normative Annex E) if sensors are not placed at IIS level. For AC systems see 5.3.

Current sensors shall measure the line current of the respective unit (IU, TU or ES).

The return (cold side) current may be used for low frequency measurements. This shall be justified for the specific application.

Voltage sensors, if used as described in 4.3.2, shall be connected between line voltage and rail potential (directly after the pantograph / shoe gear, before cables) in AC systems, or across the input filter capacitor in DC systems. An additional voltage sensor connected between line voltage and rail potential can help for additional analyses in DC systems, e.g. for identification of the instantaneous supply frequency or contribution of external sources.

Sensors for interference current and voltage measurements shall be independent from sensors used for vehicle control unless it can be shown that the measurement system does not affect the vehicle system and vice versa.

If analogue or digital summation of the output of more than one sensor is used, the correct summation shall be proven by a test. For example, a test signal at given frequencies (minimum and maximum frequency of interest) can be applied on all sensors at the same time and the result verified based on the summation of each individual sensor output.

For interlaced systems, refer to 5.3.

4.3.2 Current or voltage measurement

The line current of the tested IU, TU or ES shall be measured, as defined by the pre-analysis.

Voltage measurement(s) are applicable in the following cases:

a) In AC networks: if required for the evaluation of resonance effects (see 5.4 and Annex B).

b) In DC networks: if the evaluation is based on the filter voltage instead of line current (see also Annex I and Clause D.6). The line current is then used for information only. This may be applied as follows:

    1) If the converter has a low pass LC input filter (other passive filter structures are not excluded);

    2) Saturation of the input filter inductor shall be compensated during evaluation.

    3) For a low pass LC input filter, the line current can then be calculated as the measured filter voltage divided by the impedance of the filter inductor at the corresponding track circuit centre frequency.

    4) Other filter structures can have different requirements - in all cases the transfer function linking the filter voltage to the line current shall be used.

If the filter voltage is measured in DC, tests do not have to be made close to the substation (see 4.4.2).

NOTE 1 The filter voltage method allows the worst-case interference to be evaluated independent of the distance from the substation. It does not cover power limitation effects far from a substation, see 4.4.2.

NOTE 2 This method is most readily used when the inductance is approximately constant over the band of interest and the filter has a cut-off frequency well below the centre frequency f_0 of the considered track circuit.

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Document Sharing Hub
Full document details: BS EN 50728:2024

4.3.3 Apparatus

Requirements for sensors and recorders are specified in normative Annex A.

4.3.4 Other signals and information

Additional information which is necessary to evaluate and document the measurements shall be recorded. This may use signals which are read out and recorded from the vehicle or converter control units. For example: speed, location, tractive effort, line voltage (fundamental, RMS or DC), the state of energy storage systems and their instantaneous power, vehicle status.

Recording the signals of additional sensors can also help to identify the cause in case of exceedances of the limits.

All signals shall be recorded in such a way that the measurement system does not affect the vehicle system and vice versa.

Any other information needed to evaluate the tests, such as status of infrastructure, other trains, timetable information or events on the test train can be recorded by any appropriate means (handwritten or computer notes, GPS signals, video).

4.4 Test conditions

4.4.1 Vehicles

The vehicle to be tested shall be:

a) in full working order with regards to traction/brake equipment, auxiliary converters, auxiliary loads and the pantograph/ contact shoes;

b) in known software configuration for all controllers which can have an influence on interference current generation (vehicle, traction converters, auxiliaries).

It is a prerequisite that all traction and auxiliary controllers are stable for all operating points (however, testing and proving stability is out of the scope of this document).

During the tests, all auxiliaries shall be capable of providing the load conditions defined in the test specification. The UIC busbar, if existing, shall be switched off. Converters connected to the UIC busbar shall be tested separately (see 4.6).

The status of these items shall be documented.

NOTE 1 Instability can create harmonic frequencies which do not occur in stable operation and which are not foreseen in the design of the vehicle.

NOTE 2 Stability phenomena and the corresponding requirement for the input impedance to be passive (damping for resonances) above a specified limit frequency are not part of the present document. They are part of the interface between rolling stock and energy supply system.

4.4.2 Infrastructure

4.4.2.1 General

Interference current measurements shall be performed either on normal railway lines (with or without other traffic), or on isolated test tracks. Test conditions and evaluation methods are specified in a way to minimize corresponding influences.

Requirements for infrastructure are defined in 4.4.2.2, 4.4.2.3 and 4.4.2.4.

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Full document details: BS EN 50728:2024

4.4.2.2 AC electric traction power supply systems

a) Supply via transformer substations from public networks (50 Hz) or from a railway high voltage network (16,7 Hz): no special requirements because the substation voltage spectrum is not significantly influenced by the load;

b) No-load feeding voltage should be between about 100 % and 110 % of nominal voltage according to EN 50163:2004 - higher values are allowed but can lead to exceedances which would not be seen with the correct values;

NOTE 1 This range of no-load feeding voltage corresponds to the normal situation in AC railway networks and can be checked if necessary to explain the results.

c) Other voltages may be required to fully test e.g. hybrid rolling stock;

d) Direct supply from static converters into the contact line is allowed, but recommended only if the rolling stock is expected not to use more than 70 % of the interference current limits (see informative Annex H for the background). There is no such limitation for static converters feeding a high-voltage distribution system;

e) Railway lines fed from static converters which feed first into a high voltage network count as transformer-fed railway lines;

f) Substation load: no requirement;

g) There shall be minimum one power supply station within the test track. The length of the test track shall either be:

1) at least 15 km;

2) or if under 15 km, at least one of the following four variations to the configuration of the electric traction power supply system shall be used:

— single and double end feeding;

— single and double track;

— side tracks connected and not connected;

— feeding by converter and transformer.

NOTE 2 The limited distance criterion for AC to produce the typical variation of line voltage in practice is based on the experience that 4 Quadrant converter harmonics do not vary significantly with line voltage. The specified distances give a reasonable range of operating conditions.

h) Resonances: no specific requirements. See 5.4 for measurement and evaluation;

i) Autotransformers: no specific requirements.

4.4.2.3 DC electric traction power supply systems

a) The supplying substation shall be in accordance with Table 1. For interoperable (TSI) lines, operation fed by a 6-pulse rectifier can occur.

NOTE 1 Operation fed by a 6-pulse rectifier is worst case for voltage harmonics at low frequencies, possibly giving rise to intermodulation products.

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Document Sharing Hub
Full document details: BS EN 50728:2024

Table 1 — Possible substation types for supply of DC rolling stock during interference current measurements

		Operation substation type			
		6-pulse	12-pulse	with filter	Static converter
Measurement substation type	6-pulse	X	X	X	X
	12-pulse	-	X	X	X
	with filter	-	-	X	X
	Static converter	-	-	-	X
X means “If interference current measurements are performed with the measurement substation type, then the test results may be used to demonstrate compatibility with track circuits when operating with substations of the operation substation type(s)”					
- means “‘If tests are performed with the Measurement substation type, then the test results cannot be used to demonstrate compatibility with track circuits when operating with substations of the Operation substation type(s)”					

b) Refer to 4.1.3.2 and informative Annex H for consideration of substation harmonics and vehicle impedance.

c) No rolling stock specific tests with supply from static converter (reversible) substations (e.g. with PWM converters) are required.

NOTE 2 Compatibility between the emissions of static converter substations and track circuits are guaranteed via the required minimum vehicle impedance.

d) No-load feeding voltage at the substation should be between about 110 % and 125 % of nominal voltage according to EN 50163:2004 - higher values are allowed but can lead to exceedances which would not be seen with the correct values.

NOTE 3 This range of no-load feeding voltage corresponds to the normal situation in DC railway networks and can be checked if necessary to explain the results.

e) Substation load should be below a current which leads to an overlap angle of 40 ° in the diode rectifier. See 5.5.3, informative Annex D and informative Annex H. For non-interoperable lines, the infrastructure manager may define lower values. There is no need to reach this overlap angle in the substation during the tests.

NOTE 4 40 ° corresponds to the normal situation in DC railway networks (see also Figure D.4 in Clause D.4).

f) The infrastructure shall be capable of providing both receptive (e.g. by means of other trains/ loads or regenerative substations) and non-receptive network conditions for power regenerated by the rolling stock under test;

g) Asymmetry of public supply network (50 Hz 3-phase network) should be below 2 % negative sequence (see Figure D.5). A higher asymmetry during tests is allowed, but there is no need for rolling stock to comply with the limits under such conditions as long as it complies with the impedance requirements (see also 4.1.3.2, 5.5.3 and Clause H.4);

h) Distance from substation: Tests shall be performed in two areas:

1) Close to the substation- within 1 km (See 4.3.2 - not necessary if filter voltage is measured);

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2) Far from the substation- tests shall be performed in a way that the vehicle reaches power limitation due to low and high line voltage for maximum load. The distance from the substation shall reach D, where for distances > 0,9 x D, the pantograph voltage during the test is below a x U_N according to EN 50388-1:2022, 7.3. If no power limitation is reached, the distance from substation shall be increased and if necessary the substation voltage lowered for this test. Alternatively this condition may be tested by means of a real code simulator which has been verified against test data in a similar application and shown to give an acceptable accuracy;

NOTE 5 This test is to check for high interference current caused by controller action during power limitation.

i) Resonances: no specific requirements. See 5.4 (and 5.5.6 for cases to be discarded).

4.4.2.4 Both AC and DC electric traction power supply systems

a) Supply frequency (public 50 Hz network, or railway 16,7 Hz network): Measurement results are valid if the supply frequency is between ± 0,4 % (50 Hz AC networks, DC networks) or ± 1,2 % (16,7 Hz AC networks). A higher frequency deviation during tests is allowed, but there is no need for rolling stock to comply with the limits under such conditions. The responsibility for preventing a safety issue is then on the infrastructure side;

NOTE For networks fed from 50 Hz, ± 0,4 % frequency deviation is equal to ± 200 mHz which is the “maximum steady-state frequency deviation” for Continental Europe in Table 1 of Commision Regulation (EU) 2017/1485 of 2 August 2017 “establishing a guideline on electricity transmission system operation”.

b) Passing power supply interruptions such as neutral sections (AC) and gaps (DC) shall be included, e.g. to check interlacing or triggering of active control effects. Exceedances with no amplification, oscillation or instability when passing such locations will be treated as transients (see 5.5.4);

c) It is not necessary for the test line to be equipped with track circuits or other train detection. If it is, safety and availability of the test track during the tests should be ensured- this assurance is out of the scope of this document;

d) There are no restrictions on operation of other rolling stock during the tests.

e) The test line or lines shall allow the tests to be performed in terms of all other aspects- for example train length, maximum speed and available power.

4.4.3 Environment

4.4.3.1 General

The environmental conditions when performing the tests shall be as follows:

a) Temperature, humidity, wind: no requirements;

b) Adhesion conditions between wheels and rails shall allow at least 80 % of the maximum tractive effort to be applied by the vehicle under test;

c) No tests under iced contact line are required.

4.4.3.2 Low adhesion tests

Tests with intentionally bad adhesion are required only if a relevant influence of adhesion control is expected:

a) Mechanical oscillation (especially torsional oscillations within the wheelsets) can be transferred to corresponding frequencies in the line current spectrum. Low adhesion tests shall check for this condition

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Full document details: BS EN 50728:2024

unless shown to be unnecessary by pre-analysis which demonstrates that mechanical eigenfrequencies do not fall within the bandwidths of track circuit limits;

b) For interference current limits which have significantly higher values (e.g. 10 × higher) compared with rolling stock emissions or where only high frequency (e.g. audio frequency) track circuits are used, tests under bad adhesion may be ruled out in the pre-analysis without further investigation;

c) However, it shall be considered that power imbalances (resulting from bad adhesion at only some of the electrical subsystems) can have an influence in all frequency areas (e.g. making interlacing ineffective);

If tests under bad adhesion are performed, the precise conditions shall be defined in the test plan. The tests may be at the same time as tests to validate traction and braking performance in low adhesion conditions, in accordance with EN IEC 61133. Interference current measurements shall be performed as follows:

d) If no interference current monitor is fitted, measurements shall be performed during the bad adhesion tests in accordance with this document.

e) If an interference current monitor is fitted, the absence of tripping the monitor may be used instead of interference current measurement.

4.5 Test procedure for vehicles

4.5.1 General

The following procedures describe the basic test parameters. More detailed inputs for specific test scenarios shall be addressed/given by the pre-analysis.

All tests shall be done for all configurations according to the test specification (normal operating mode, degraded modes) and include special tests which may have been identified as necessary in the pre-analysis.

4.5.2 Pre-test of the measurement chain on the vehicle

Before starting the measurement, a pre-test of the measurement chain shall be carried out with the main circuit breaker switched off. This allows the measurement chain to be checked in view of background noise and absence of interference from on-board sources like the auxiliary supply from batteries.

4.5.3 Static tests

Static tests shall be done with the rolling stock at standstill, and comprise for example:

a) Main circuit breaker switched on;

b) Only auxiliary converters active with maximum possible load;

c) Switching auxiliary loads on and off while auxiliary converter only running;

d) Operating the traction converter as far as possible while stationary.

4.5.4 Dynamic tests

Dynamic tests are done with the rolling stock running with its own traction and braking systems. They are not required for passenger coaches or other auxiliary loads at the UIC busbar. Tests comprise:

a) Running from standstill to the maximum permitted speed defined by the pre-analysis and then braking down to standstill using the brake mode defined by the pre-analysis;

b) Close to and far from the substation:

1) For AC: To achieve the variation defined in 4.4.2.2;

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Document Sharing Hub
Full document details: BS EN 50728:2024

2) For DC: Passing by the trackside feeding point at different operation points (see 4.3.2 and 4.4.2.3);

3) For DC: Reaching the distance where power limitation is reached as defined in 4.4.2.3.

c) With 80 % to 100 % of the maximum traction and dynamic braking force (based on the diagram traction power over speed); other values shall be selected in addition if concluded from the pre-analysis, e.g. in case of change of pulsing frequency or control methods (according to the test plan). If the required tractive effort cannot be reached with the rolling stock under test, additional wagons as a load shall be added (for locomotives) or the maximum allowed acceleration shall be increased (for multiple units).

1) For locomotives, a braking locomotive or several coaches can be needed. It is also possible to change the maximum acceleration from typically 1 m/s^2 to another allowed value to achieve the maximum traction force (see 5.5.5 for guidance on distinguishing emissions of the braking locomotive from the vehicle under test)

2) For some passenger rolling stock the tractive effort is load-weighed. In this case the rolling stock should be loaded, or the full loading could be simulated by change of the relevant software parameter

d) The effect of different possible acceleration rates shall be tested as defined by the pre-analysis, so as to avoid a speed related interference current (which could be a steady-state effect at a low acceleration rate) being seen only as a transient during tests, see also E.2.1;

e) Inclusion of abrupt changes of power or torque (for example, driver selects > 80 % of full torque then removes demand instantaneously);

f) Operating points with worst-case interference currents (according to the pre-analysis) shall be included;

g) In DC, rolling stock has to be tested both in rheostatic braking and regenerative braking (limited to the maximum regenerated power required by the test specification);

h) If interlacing is employed and if identified as necessary by the pre-analysis, tests of varying load between interlaced systems shall be performed;

i) Passing neutral sections (for AC only); if the test track has no neutral sections this can be simulated by e.g. manual opening/closing of the main circuit breaker;

j) Passing gaps (for DC only).

This full set of dynamic tests shall be done for normal operating mode:

— performed at least three times;

— if more testing time is needed to give a sufficient confidence level in terms of summation rules (see normative Annex E): repeated only for relevant operation points, based on the pre-analysis and dynamic test results. For example, several runs in a small speed range with a DC vehicle where only several IISs can be measured together.

Three repetitions are necessary to show consistency of the results. The summation rules (see normative Annex E) can require more tests.

It is allowed to define a reduced test set of degraded modes, based on the pre-analysis and defined in the test plan.

If it can be shown (based on evidence from both pre-analysis and dynamic tests for normal operating mode) that degraded modes do not need a full performance of all tests again, reduced numbers or cycles in degraded modes are possible. This case shall be identified already in the test plan.

EXAMPLE If it can be shown that interference currents of an AC vehicle depend only on the power, but not on speed, it is not necessary to perform tests in degraded modes up to the maximum speed three times.

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Full document details: BS EN 50728:2024

4.5.5 Long term tests

After successful performance of the tests as specified in this document, the vehicle is ready for operation (in terms of compatibility with track circuits). No long-term tests are required.

Degradation of components in service (e.g. partial short circuits in inductors, failure of capacitors, motors or sensors) can lead to an exceedance of limits and incompatibility with track circuits. Special attention shall be paid in case track circuits can show wrong side failures as a result of exceedance of the limits. There are different methods to handle such cases. This is out of the scope of this document.

4.6 Test conditions for separate auxiliary converters

4.6.1 General

Auxiliary converters which are connected to the line directly, via passive filters or transformers (e.g. via the UIC busbar) have a contribution to the total interference current of an Influencing Unit (IU).

Converters which are tested as part of a complete vehicle test (either locomotive or EMU) do not have to be tested separately. Examples are:

a) Converters which are connected to vehicle-internal 2- or 3-phase networks;

b) Converters necessary to operate the traction equipment.

4.6.2 Definition of requirements

Requirements for one auxiliary converter are derived from those for one IU in terms of

a) interference current limits I_{Lim};

b) impedance Z

taking into account the “budgets” defined in the pre-analysis (see 4.1.4). For the variety of products (power rating, technology, filter, PWM and control parameters) it is not possible to specify general requirements for all applications.

4.6.3 Test procedure

4.6.3.1 Test location

Interference current tests for auxiliary converters may be done as follows:

Either:

a) In a test laboratory. The following test conditions shall in this case be met:

   1) Line voltage (steady-state): U_{min2}, U_n and U_{max2} according to EN 50163:2004;

   2) Line voltage step: between 5 % and 10 % of nominal voltage;

   3) The source impedance of the laboratory set up shall not reduce harmonics by more than 10 % of the limit value. If this requirement is not met, a correction factor may be applied.

   NOTE This can be checked with a calculation using the output impedance of the power supply and the input impedance of the auxiliary converter.

Or:

b) On board of rolling stock. Test cycles and test conditions shall be identical to those for complete vehicles. Test for separate auxiliary converters may be combined with those for a complete vehicle, additionally measuring and evaluating the line current or filter voltage of the auxiliary converter.

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Document Sharing Hub
Full document details: BS EN 50728:2024

4.6.3.2 Test specification

The check of input impedance shall be done according to 4.7.

The following operating points of the auxiliary converter and impact of the load shall be included:

a) Variation of output load (zero to representative power for maximum harmonic emissions) for both three-phase and (if applicable) single-phase loads;

b) Variable or constant output frequencies / speed of loads (like pumps, compressors) which can create harmonics in the input current due to special frequencies on the output side (e.g. compressor piston frequency);

c) The fastest steps in load (up, down) which occur in normal operating mode;

d) Operation at the limitation of power as a function of line voltage if relevant.

4.6.3.3 Small input filters

For auxiliary converters with small input filters, additional effects shall be checked (see also informative Annex G for the background and additional analysis).

NOTE For track circuits prone to wrong side failures, defects of components or undetected instabilities can lead to safety problems and appropriate actions can be necessary. This is outside the scope of this document.

4.7 Check of input impedance

4.7.1 Passive inductive impedance

The inductive input impedance of a vehicle influences compatibility between electric traction power supply system, rolling stock and low frequency and lower audio frequency track circuits. Proof of conformity is done as follows:

For the inductance of passive components only (transformers, filter inductors) by copying the values from the type test report of the components; no measurement is necessary. The values shall be:

a) For AC operation- at fundamental line frequency (50 Hz, 16,7 Hz);

b) For DC operation:

   1) For 50 Hz if only track circuits below 300 Hz are considered;

   2) For the frequency bands where impedance requirements exist when track circuits above 300Hz are considered;

c) For the lowest value in case of saturation as a function of current that occurs in designed operation modes;

d) For the worst-case configurations of an IU (where the impedance is lowest).

The line current and voltage at substation harmonics recorded during interference current tests may also be used to validate the input impedance.

If the effects described in Clause I.4 are relevant, measurements of the component or on board the vehicle can be necessary.

4.7.2 Passive capacitive impedance

The capacitive input impedance of a vehicle is relevant for higher frequencies, and influences compatibility between electric traction power supply system, rolling stock and audio frequency track circuits. It has a significant influence on resonance effects in AC network. Proof of conformity is done as follows, for all relevant configurations of an IU:

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Document Sharing Hub
Full document details: BS EN 50728:2024

a) For high voltage cables only (e.g. cables connecting pantographs, main circuit breakers, transformers or input filters)- from the drawings of the rolling stock (total length of cables) and the cable data sheet (nominal specific capacitance). No measurement is necessary;

b) Parasitic capacitances of transformers and filter inductors may be disregarded as long as the cable capacitance does not exceed 50 % of the maximum allowed capacitance;

c) If the cable capacitance exceeds 50 % of the maximum allowed capacitance - the transformer/ inductor capacitance shall be measured;

d) The capacitance value influences the resonance factor, therefore not only the worst case (largest) capacitance is of importance.

4.7.3 Controller influence

If the impedance of components is not sufficient to meet the impedance requirements, the vehicle (or auxiliary converter) input impedance may be obtained with a controlled impedance. In this case, the verification for concerned frequencies shall be done as follows:

a) by evaluation of:

   1) line voltage and line current measurements (on the rolling stock or in a combined test);

   2) or by means of a real code simulator which has been verified against test data in a similar application and shown to give an acceptable accuracy.

b) with an external interference current source (real or simulated) with a terminal voltage V of at least $V = 0{,}5 \times Z \times I_{Lim}$ for the corresponding unit (IU, TU, ES, auxiliary converter). Where Z = required input impedance and I_{Lim} = interference current limit for the corresponding unit.

c) for a representative set of combinations of line voltage and input power;

d) If a laboratory test with the specified voltage cannot be achieved, then a lower voltage may be used with justification that the result is still correct.

In case a steady-state evaluation of impedance (division of spectral lines for voltage and current) is not possible or not practicable (e.g. for nonlinear behaviour, intermittent operation with short cycles, or broad band noise in the line current), an evaluation of the line current shall be done for a constant (or piece-wise constant) external source voltage. All evaluation rules for the line current then apply, including discarding or not-discarding of transients.

5 Measurement analysis

5.1 Summation - General

Limits and evaluation parameters for interference current measurements always apply to the interference current at the interface with the infrastructure, equivalent to the total current leaving the Influencing Unit (IU). In train design however, the emissions are often assessed for the individual converter. Similarly for testing, it is often appropriate to measure a small group of IIS rather than the whole IU. In both cases, scaling to the IU is necessary. This mainly depends on the synchronisation between the sources i.e. their phase angle relation, for example:

a) Independent: All sources are independent and not intentionally synchronised; their frequencies are close but not exactly identical.

   EXAMPLE unsynchronised converter clocking and motor harmonics in DC mode.

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Document Sharing Hub
Full document details: BS EN 50728:2024

b) Passively synchronised to the line voltage.

EXAMPLE Diode rectifiers in AC mode.

c) Actively synchronised, often to the line voltage.

EXAMPLE Four Quadrant converters (4QC) synchronised to the AC line frequency, possibly interlaced to achieve mutual cancellation.

The summation rules described in 5.2 and 5.3 do not apply to events which are separated in time.

Informative Annex J describes a proposal on automation of the evaluation of the interference current. Informative Annex K provides some theoretical background on summation.

NOTE The summation rules in this document have been derived from physical principles and can differ from those defined in previous standards.

5.2 Summation - DC rolling stock

5.2.1 Synchronisation

On DC mode trains the individual converters are usually independent, their switching not synchronised. Mutual synchronisation is the exception and not explicitly covered here; AC rules can apply in such cases. Traction motors on different axles are considered independent and not synchronised.

5.2.2 Point of measurement

The contributions of independent IIS can add up or cancel each other, depending on their momentary phase relationship. When measuring the total current of the IU, it is difficult to determine the correct amplitude. For DC mode, it is therefore recommended to measure the smallest possible unit and to scale the results to the IU.

5.2.3 Scaling

The scaling from one IIS to the IU physically depends on the phase relation between the IIS and its dynamics. In general, the probability of several IIS to add up constructively decreases strongly with the number of IIS; the duration of such periods depends on the frequency stability. These factors need to be weighed in relation to the track circuit response time. See Clause E.1 for instructions.

In case several IIS are measured together, they need to be scaled “down” to a single IIS before scaling up to the IU. The statistical nature of the summation makes it necessary to repeat tests or to run tests over a longer time to obtain reliable results. See Clause E.2 for guidance.

5.2.4 Current sharing

When measuring a smaller unit than the IU, it can be worth considering that part of the current can be sunk by other parallel IISs within an ES/TU or other TUs within the IU. Only the remaining part reaches the track circuit receiver. This can provide an additional reduction of the IU interference current. This is dependent on the substation impedance, the length of the track circuit setting the limit, the line impedance, the composition of the rolling stock and impedance of the IU.

This scaling may optionally be applied if all necessary information is specified together with the limits.

The principle is illustrated in Figure 3.

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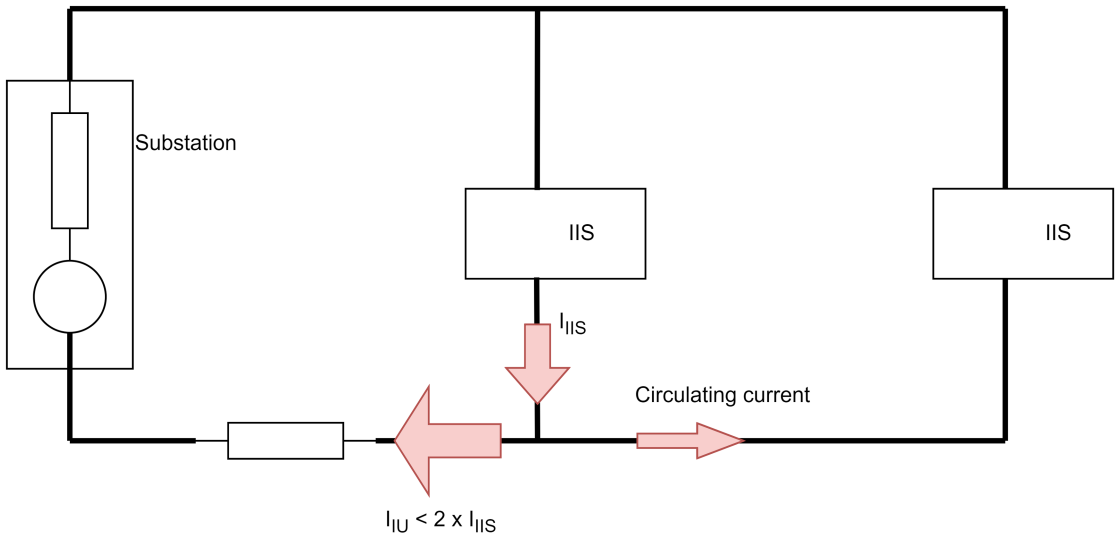


Figure 3 — Principle of Current Sharing

NOTE 1 This mechanism is most relevant for DC and provides no benefit for AC as long as the IU impedance is significantly larger than the substation impedance.

NOTE 2 The higher the number of parallel IISs, the greater the benefit of this approach.

5.3 Summation - AC rolling stock

5.3.1 Synchronisation

AC mode trains usually employ four quadrant converters (4QCs) for power conversion, and the line current is dominated by the 4QC harmonics. Switching is synchronised to the frequency and phase of a common signal (usually the line voltage), phase angles can be set to reduce specific harmonics (interlaced), or to arbitrary random values. They can also be readjusted in case of individual 4QC failures. With identical frequencies and controlled phase relations, 4QC harmonics will scale very differently than for independent sources. Motor or motor inverter harmonics can often be neglected because they are reduced in magnitude by the DC link capacitance.

Auxiliary converters can be fed from the 4QC output (the DC link), in which case their emissions at the pantograph are small, similar to motor or motor inverter harmonics. Alternatively, they can directly be fed from the transformer, using passive input rectifiers within the auxiliary converter (passive synchronisation), or choppers switching at high frequency, possibly crystal controlled without necessarily synchronising to the line frequency, i.e. independent.

5.3.2 Point of measurement

The synchronisation including phase angles and their static and dynamic variations dominate the addition of individual IIS currents. It is hardly possible to assess this on IIS level, and the recommendation is to measure the whole IU. In case this is not possible, scaling factors expressing the effect of the designed phase angles may be used, but these do not necessarily apply correctly to transient events or dynamic state changes, e.g. load changes.

For specific cases such as independent auxiliary choppers, measurement at IIS level can be adequate. Whether a separate consideration of such contributions is necessary should be decided on the basis of expected levels and their frequencies.

If interlacing is applied only within a TU the line current shall be measured at TU level.

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