IEC 60512-28-100

Edition 2.0 2019-11
REDLINE VERSION

INTERNATIONAL STANDARD

colour inside

Connectors for electrical and electronic equipment – Tests and measurements – Part 28-100: Signal integrity tests up to ~~1 000 MHz on IEC 60603-7 and IEC 61076-3 series connectors~~ 2 000 MHz – Tests 28a to 28g

IEC 60512-28-100:2019-11 RLV(en)

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CONNECTORS FOR ELECTRICAL AND ELECTRONIC EQUIPMENT – TESTS AND MEASUREMENTS –

Part 28-100: Signal integrity tests up to ~~1 000 MHz on IEC 60603-7 and IEC 61076-3 series connectors~~ 2 000 MHz – Tests 28a to 28g

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International Standard IEC 60512-28-100 has been prepared by subcommittee 48B: Electrical connectors, of IEC technical committee 48: Electrical connectors and mechanical structures for electrical and electronic equipment.

This second edition cancels and replaces the first edition, issued in 2013, and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- The title is revised from 1 000 MHz to 2 000 MHz to reflect the range of frequencies which may be tested.
- All tables and requirements have been revised up to 2 000 MHz.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
48B/2756/FDIS	48B/2766/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

A list of all parts of IEC 60512 series, under the general title *Connectors for electrical and electronic equipment – Tests and measurements* can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
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CONNECTORS FOR ELECTRICAL AND ELECTRONIC EQUIPMENT – TESTS AND MEASUREMENTS –

Part 28-100: Signal integrity tests up to ~~1 000 MHz on IEC 60603-7 and IEC 61076-3 series connectors~~ 2 000 MHz – Tests 28a to 28g

1 Scope

This part of IEC 60512 specifies the test methods for signal integrity and transmission performance for connectors specified in respective parts of IEC 60603-7, IEC 61076-1, IEC 61076-2, and IEC 61076-3 ~~series connectors up to 1 000 MHz~~ standards for connecting hardware applications up to 2 000 MHz. It is also suitable for testing lower frequency connectors, however, the test methodology specified in the detail~~ed~~ specification for any given connector remains the reference conformance test for that connector. The above list of connector series of standards does not preclude referencing this document in other connector manufacturer's specifications or published standards.

~~The test methods~~ Test procedures provided herein are:

– insertion loss, test 28a;

– return loss, test 28b;

– near-end crosstalk (NEXT) test 28c;

– far-end crosstalk (FEXT), test 28d;

– transverse conversion loss (TCL), test 28f;

– transverse conversion transfer loss (TCTL), test 28g.

Other test procedures referenced herein are:

– transfer impedance (Z_T), see IEC 60512-26-100, test 26e.

– for coupling attenuation (a_C), see IEC 62153-4-12.

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.

IEC 60050-581, *International Electrotechnical Vocabulary (IEV) – Part 581: Electromechanical components for electronic equipment*

IEC 60169-15, *Radio-frequency connectors – Part 15: R.F. coaxial connectors with inner diameter of outer conductor 4,13 mm (0.163 in) with screw coupling – Characteristic impedance 50 ohms (Type SMA)*

IEC 60512-1, *Connectors for electronic equipment – Tests and measurements – Part 1: ~~General~~ Generic specification*

IEC 60512-26-100~~:2008~~, *Connectors for electronic equipment – Tests and measurements – Part 26-100: Measurement setup, test and reference arrangement and measurements for connectors according to IEC 60603-7 – Tests 26a to 26g*

IEC 60512-27-100, *Connectors for electronic equipment – Tests and measurements – Part 27-100: Signal integrity tests up to 500 MHz on 60603-7 series connectors – Tests 27a to 27g*

IEC PAS 60512-27-200, *Connecteurs for electrical and electronic equipment – Tests and measurements – Part 27-200: Additional specifications for signal integrity tests up to 2 000 MHz on IEC 60603-7 series connectors – Tests 27a to 27g*

IEC 60512-29-100, *Connectors for electronic equipment – Tests and measurements – Part 29-100: Signal integrity tests up to 500 MHz on M12 style connectors – Tests 29a to 29g*

IEC 60603-7, *Connectors for electronic equipment – Part 7: Detail specification for 8-way, unshielded, free and fixed connectors*

IEC 60603-7-1, *Connectors for electronic equipment – Part 7-1: Detail specification for 8-way, shielded, free and fixed connectors*

IEC 60603-7-2, *Connectors for electronic equipment – Part 7-2: Detail specification for 8-way, unshielded, free and fixed connectors, for data transmissions with frequencies up to 100 MHz*

IEC 60603-7-3, *Connectors for electronic equipment – Part 7-3: Detail specification for 8-way, shielded, free and fixed connectors, for data transmission with frequencies up to 100 MHz*

IEC 60603-7-4, *Connectors for electronic equipment – Part 7-4: Detail specification for 8-way, unshielded, free and fixed connectors, for data transmissions with frequencies up to 250 MHz*

IEC 60603-7-5, *Connectors for electronic equipment – Part 7-5: Detail specification for 8-way, shielded, free and fixed connectors, for data transmissions with frequencies up to 250 MHz*

IEC 60603-7-7, *Connectors for electronic equipment – Part 7-7: Detail specification for 8-way, shielded, free and fixed connectors for data transmission with frequencies up to 600 MHz*

IEC 60603-7-41, *Connectors for electronic equipment – Part 7-41: Detail specification for 8-way, unshielded, free and fixed connectors, for data transmissions with frequencies up to 500 MHz*

IEC 60603-7-51, *Connectors for electronic equipment – Part 7-51: Detail specification for 8-way, shielded, free and fixed connectors, for data transmissions with frequencies up to 500 MHz*

IEC 60603-7-71, *Connectors for electronic equipment – Part 7-71: Detail specification for 8-way, shielded, free and fixed connectors, for data transmission with frequencies up to 1 000 MHz*

IEC 60603-7-81, *Connectors for electronic equipment – Part 7-81: Detail specification for 8-way, shielded, free and fixed connectors, for data transmissions with frequencies up to 2 000 MHz*

IEC 60603-7-82, *Connectors for electronic equipment – Part 7-82: Detail specification for 8-way, 12 contacts, shielded, free and fixed connectors, for data transmission with frequencies up to 2 000 MHz*

IEC 61076-1, *Connectors for electronic equipment – Product requirements – Part 1: Generic specification*

IEC 61076-2, *Connectors for electronic equipment – Product requirements – Part 2: Sectional specification for circular connectors*

IEC 61076-2-109, *Connectors for electronic equipment – Product requirements – Part 2-109: Circular connectors – Detail specification for connectors with M 12 x 1 screw-locking, for data transmission frequencies up to 500 MHz*

IEC 61076-3, *Connectors for electronic equipment – Product requirements – Part 3: Rectangular connectors – Sectional specification*

IEC 61076-3-104, *Connectors for electronic equipment – Product requirements – Part 3-104: Detail specification for 8-way, shielded free and fixed connectors for data transmissions with frequencies up to ~~1 000~~ 2 000 MHz*

IEC 61076-3-110, *Connectors for electronic equipment – Product requirements – Part 3-110: Detail specification for ~~shielded,~~ free and fixed connectors for data transmission with frequencies up to ~~1 000~~ 3 000 MHz*

~~IEC 61156 (all parts), *Multicore and symmetrical pair/quad cables for digital communications*~~

IEC 61156-1, *Multicore and symmetrical pair/quad cables for digital communications – Part 1: Generic specification*

~~IEC 61156-6, *Multicore and symmetrical pair/quad cables for digital communications – Part 6: Symmetrical pair/quad cables with transmission characteristics up to 1 000 MHz – Work area wiring – Sectional specification*~~

IEC 61156-9, *Multicore and symmetrical pair/quad cables for digital communications – Part 9: Cables for channels with transmission characteristics up to 2 GHz – Sectional specification*

IEC 61156-10:2016, *Multicore and symmetrical pair/quad cables for digital communications – Part 10: Cables for cords with transmission characteristics up to 2 GHz – Sectional specification*

IEC 61169-16, *Radio-frequency connectors – Part 16: RF coaxial connectors with inner diameter of outer conductor 7 mm (0,276 in) with screw coupling – Characteristic impedance 50 ohms (75 ohms) (Type N)*

IEC 62153-4-12, *Metallic communication cable test methods – Part 4-12: Electromagnetic compatibility (EMC) – Coupling attenuation or screening attenuation of connecting hardware – Absorbing clamp method*

ISO/IEC 11801-1:2017, *Information technology – Generic cabling for customer premises – Part 1: General requirements*

3 Terms, definitions and ~~acronyms~~ abbreviated terms

For the purposes of this document, the terms and definitions given in IEC 60050-581, IEC 61076-1, IEC 60512-1, IEC 60603-7, IEC 61076-3-104 and IEC 61076-3-110, and the following apply.

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1
intermodal <parameter or measurement>
parameter or measurement that either sources on the common mode and measures on the differential mode, or sources on the differential mode and measures on the common mode

3.1.2
mixed mode <parameter or measurement>
parameters or measurements containing differential mode, common mode, and intermodal S-matrices

3.2 ~~Acronyms~~ Abbreviated terms

a_C	coupling attenuation
CM	common mode
DM	differential mode
DUT	device under test
FEXT	far-end crosstalk loss
~~IEC~~	~~International Electrotechnical Commission~~
LCL	longitudinal conversion loss
LCTL	longitudinal conversion transfer loss
NA	network analyzer
NEXT	near-end crosstalk loss
TCL	transverse conversion loss
TCTL	transverse conversion transfer loss
SE	single ended
Z_T	transfer impedance

4 Overall test arrangement

4.1 General

This document specifies test methods and procedures for connectors.

The test methods and procedures for signal integrity and transmission performance specified herein are referenced by connector standards, specified in IEC 60603-7, IEC 60603-7-1, IEC 61076-2, 61076-3 and other standards for connecting hardware and their sectional specifications, with signal integrity specifications up to 2 000 MHz; such connector standards include IEC 60603-7-81, IEC 60603-7-82, IEC 61076-3-110, IEC 61076-3-104, and IEC 61076-2-109, which are used with twisted-pair cables having 100 Ω nominal differential characteristic impedance.

The test methods and procedures specified herein are referenced by connector standards for connecting hardware typically used with twisted-pair cables having 100 Ω nominal differential characteristic impedance, which are specified in accordance with IEC 61156-1 cable standards and its sectional specifications up to 2 000 MHz, e.g. IEC 61156-9 and IEC 61156-10.

4.2 Test instrumentation

4.2.1 General

All test instrumentation shall be capable of performing measurements over the frequency range of 1 MHz to ~~1 000~~ 2 000 MHz.

4.2.2 Vector network analyser

The test procedures hereby described require the use of a vector network analyzer. The analyzer ~~should~~ shall have the capability of full 2-port calibrations. The analyzer shall cover the frequency range of 1 MHz to ~~1 000~~ 2 000 MHz at least.

Measurements are to be taken using a mixed mode test set-up, which is often referred to as an unbalanced, modal decomposition or balun-less setup. This allows measurements of balanced devices without use of an RF balun in the signal path.

Such a configuration also allows testing with either a common or differential mode stimulus ~~and~~ or responses, ensuring that intermodal parameters can be measured without reconnection.

A 16-port network analyzer ~~is required~~ shall be used to measure all combinations of a 4-pair device without external switching, however the network analyzer shall have a minimum of 2-ports (including one bi-directional port) to enable the data to be collated and calculated.

It should be noted that the use of a 2-port analyzer will involve successive repositioning of the measurement port in order to measure any given parameter.

A 4-port network analyzer is recommended as a practical minimum number of ports, as this will allow the measurement of the full 16 term mixed mode S-parameter matrix on a given pair combination without switching or reconnection in one direction.

4.2.3 RF switching unit

In order to minimise the reconnection of the DUT for each pair combination the use of a RF switching unit is also recommended.

Each conductor of the pair or pair combination under test shall be connected to a separate port of the network analyzer, and results are processed either by internal analysis within the network analyzer or by an external application.

4.2.4 Reference loads and termination loads

Reference loads and through connections ~~are needed~~ shall be utilised for the calibration of the set-up. Requirements for the reference loads ~~are~~ shall be as given in 4.9. Termination loads ~~are needed~~ shall be utilised for termination of pairs, used and unused, which are not terminated by the network analyzer. Requirements for the termination loads ~~are~~ shall be as given in ~~4.7 and 4.10~~ 4.11.

Loads used for calibration shall be paired as explained in Annex E to ensure good symmetry at the calibration plane.

4.3 Measurement precautions

To ensure a high degree of reliability for transmission measurements, the following precautions are required.

- Consistent and stable resistor loads shall be used throughout the test sequence.
- Cable and adapter discontinuities, as introduced by physical flexing, sharp bends and restraints shall be avoided before, during and after the tests.
- Consistent test methodology and termination resistors shall be used at all stages of transmission performance qualifications.
- The relative spacing of conductors in the pairs shall be preserved throughout the tests to the greatest extent possible.

- The balance of the cables shall be maintained to the greatest extent possible by consistent conductor lengths and pair twisting to the point of load.
- The sensitivity to set-up variations for these measurements at high frequencies demands attention to details for both the measurement equipment and the procedures.
- The test setup has to be grounded appropriately.

4.4 Mixed mode S-parameter nomenclature

The test methods specified in this document are based on a balunless test setup in which all terminals of a device under test are measured and characterised as single ended (SE) ports, i.e. signals (RF voltages and currents) ~~are~~ shall be defined relative to a common earth (ground). For a device with 4 terminals, a diagram is given in Figure 1.

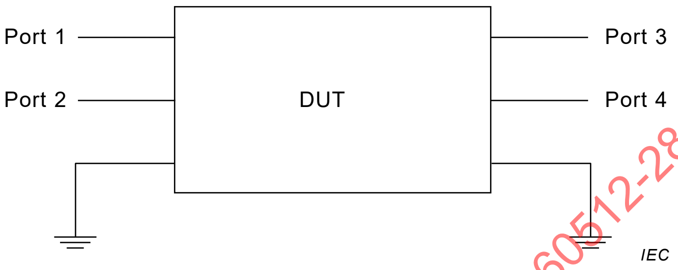


Figure 1 – Diagram of a single ended 4-port device

The 4-port device in Figure 1 ~~is~~ shall be characterised by the 16-term SE S-matrix given in Formula 1, in which the S-parameter S_{ba} expresses the relation between a single ended response on port “b” resulting from a single ended stimulus on port “a”.

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \quad (1)$$

For a balanced device, each port ~~is~~ shall be considered to consist of a pair of terminals (= a balanced port) as opposed to the SE ports defined above, see Figure 2.

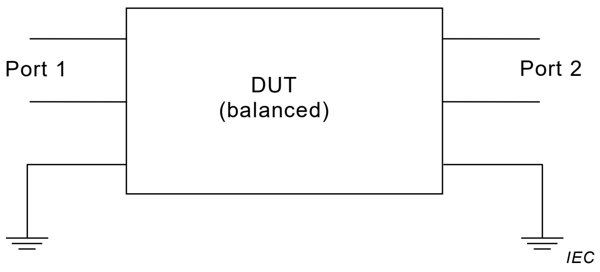


Figure 2 – Diagram of a balanced 2-port device

~~In order to characterize the balanced device, both the differential mode and the common mode signals on each balanced port shall be considered.~~ The device ~~can be~~ is characterised by a mixed mode S-matrix that includes all combinations of modes and ports, e.g. the mixed mode S-parameter S_{DC21} that expresses the relation between a differential mode response on port 2 resulting from a common mode stimulus on port 1. Using this nomenclature, the full set of mixed mode S-parameters for a 2-port ~~can be presented as~~ are given in Table 1.

Table 1 – Mixed mode S-parameter nomenclature

		Differential mode stimulus		Common mode stimulus	
		Port 1	**Port 2**	**Port 1**	**Port 2**
Differential mode response	Port 1	S_{DD11}	S_{DD12}	S_{DC11}	S_{DC12}
	Port 2	S_{DD21}	S_{DD22}	S_{DC21}	S_{DC22}
Common mode response	Port 1	S_{CD11}	S_{CD12}	S_{CC11}	S_{CC12}
	Port 2	S_{CD21}	S_{CD22}	S_{CC21}	S_{CC22}

A 4-terminal device can be represented both as a 4-port SE device as in Figure 1 characterised by a single ended S-matrix (Formula 1) and as a 2-port balanced device as in Figure 2 characterised by a mixed mode S-matrix (Table 1). As applying a SE signal to a port is mathematically equivalent to applying ~~superposed~~ superimposed differential and common mode signals, the SE and the mixed mode characterisations of the device are interrelated. The conversion from SE to mixed mode S-parameters is given in Annex A. Making use of this conversion, the mixed mode S-parameters may be derived from the measured SE S-matrix.

4.5 Coaxial cables and interconnect for network analyzers

Assuming that the characteristic impedance of the network analyzer is 50 Ω, coaxial cables used to interconnect the network analyzer, switching matrix and the test fixture shall be of 50 Ω characteristic impedance and of low transfer impedance (double screen or more).

These coaxial cables should be as short as possible. ~~(It is recommended that they do not exceed 1 000 mm each.)~~ Max 1 000 mm (on each port).

The screens of each cable shall be electrically bonded to a common earth (ground) plane.

To optimize dynamic range, the total interconnecting cable insertion loss should be less than ~~3 dB at 1 000 MHz~~ 7 dB at 2 000 MHz per metre.

4.6 ~~Requirements~~ Characteristic for switching matrices

Switches (if used) ~~shall~~ may be of a minimum of 2x4 configuration at all ports, although a switch with a higher number of ports (e.g. 2x8, 1x16, 4x16) is recommended as this can allow more complete or even total measurement of the DUT without reconnection or moving the DUT. When such switching is used, it shall be constructed such that each port ~~be~~ is configurable as ~~either~~ input, output or 50 Ω termination. All inactive ports of the switch shall be terminated with a 50 Ω impedance load.

~~The switch shall be capable of swapping the ports of the network analyser in a paired fashion to correctly connect to each conductor of the DUT transmission pair.~~

~~The switch should be constructed to minimise the different path lengths for each signal path of the pair.~~

The switch ~~shall~~ may comply ~~to~~ with the minimum switch performance recommendations given by Table 2.

Table 2 – Switch performance recommendations requirements

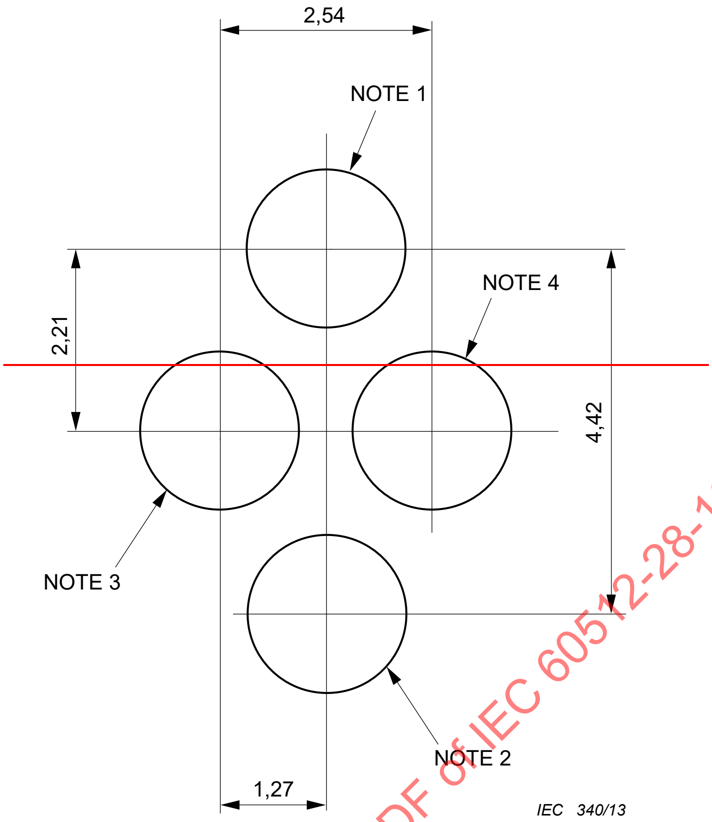
Parameter	Frequency MHz	Requirement up to 1 000 MHz
Insertion loss (dB)	1 ≤ f ≤ 1 000)	≤ 0,5 dB
Return loss (dB)		≥68-20log(*f*) dB 40 dB max 24 dB min
Crosstalk (dB)		≥ 95 dB

Parameter dB	Requirement 1 MHz to 1 000 MHz	Requirement 1 000 MHz to 2 000 MHz
Insertion loss	0,5 dB max.	2,0 dB max.
Return loss	68-20log(*f*) dB min. 40 dB max. 24 dB min.	18 dB min.
Crosstalk loss	105 dB min.	102 dB min.

4.7 Test fixture requirements

For ease of interfacing to test fixtures, a pin and fixed connector interface with dimensions as shown in Figure 3 is recommended. Information concerning examples of fixed connectors that may be used for this interface is given in Annex B.

Dimensions in millimeters



NOTE 1 Ground

NOTE 2 Ground

NOTE 3 First conductor in a pair

NOTE 4 Second conductor in a pair

Figure 3 – Test interface pattern

Test fixtures shall meet the requirements of Table 3 when tested using appropriate resistor terminations at the DUT interface fixed connectors of the fixture after the network analyser has been calibrated at the end of the coaxial cables intended to interface to the fixture.

Table 3 – Test fixture requirements

Parameter	Frequency MHz	Requirement up to 1 000 MHz
SE Port (50 Ω) return loss (dB)	$1 \leq f \leq 1\,000$	≥72-20log(*f*) dB 40 dB max
DM port (100 Ω) return loss (dB)		≥78-20log(*f*) dB 40 dB max
CM port (100 Ω) return loss (dB)		≥68-20log(*f*) dB 35 dB max
SE (50 Ω) Port to Port Isolation NEXT and FEXT		≥114-20log(*f*) dB 75 dB max
DM (100 Ω) Port to Port Isolation NEXT and FEXT pair to pair		≥130-20log(*f*) dB 94 dB max
DM (100 Ω) insertion loss		< 0,5 dB
TCL LCL		≥100-20log(*f*) dB

		~~70 dB max~~
~~TCTL LCTL~~		~~≥90-20log(*f*) dB~~ ~~50 dB max~~

4.7.1 Test fixture types

Test fixtures are covered in three types, corresponding to three groups of connectors:

a) **Indirect-reference** test fixtures, for connector types utilizing a reference connector for measurement of transmission parameters, with additional specifications, e.g. crosstalk (NEXT) vector for crosstalk compensation parameters; e.g. IEC 60603-7 series (8-pole types), IEC 60603-7-2, IEC 60603-7-3, IEC 60603-7-4, IEC 60603-7-5, IEC 60603-7-41, IEC 60603-7-51, and IEC 60603-7-81.

b) **Direct-probe** test fixtures, for connector types utilizing single ended direct-probe measurement of transmission parameters, e.g. IEC 60603-7 series (12-pole types), IEC 60603-7-7, IEC 60603-7-71, IEC 60603-7-82, and IEC 61076-3-110.

c) **Specialized** test fixtures, for connector types utilizing a combination of direct-probe and indirect-reference measurement of transmission parameters, e.g. IEC 61076-3-104, and IEC 61076-2-109.

For the test fixture types a), b), and c) detail specifications, see Annex C, Annex B, and Annex C respectively.

4.8 Requirements for termination performance at calibration plane

Termination performance at the calibration plane shall meet the requirements of Table 3.

Table 3 – Requirements for terminations at calibration plane

~~**Parameter**~~	~~**Frequency** MHz~~	~~**Requirement up to 1 000 MHz**~~
~~SE Port (50 Ω) return loss (dB)~~	~~1 ≤ f ≤ 1 000~~	~~≥74-20log(*f*) dB~~ ~~40 dB max~~
~~DM port (100 Ω) return loss (dB)~~		~~≥74-20log(*f*) dB~~ ~~40 dB max~~
~~DM Port to Port residual NEXT~~		~~≥130-20log(*f*) dB~~ ~~94 dB max~~

Parameter	**Requirement** 1 MHz to 1 000 MHz	**Requirement** 1 000 MHz to 2 000 MHz
SE Port (50 Ω) return loss (dB)	≥72-20log(f) dB 40 dB max. 12 dB min.	12 dB min.
DM port (100 Ω) return loss (dB)	≥78-20log(f) dB 40 dB max. 20 dB min.	20 dB min.
DM Port to Port residual NEXT	≥130-20log(f) dB 94 dB max.	70 dB max.

4.9 Reference loads for calibration

To perform a 1-port or 2-port calibration of the test equipment, a short circuit, an open circuit and a reference load are required. These devices shall be used to obtain a calibration.

The reference load shall be calibrated against a calibration reference, which shall be a 50 Ω load, traceable to an international reference standard. One 50 Ω reference load shall be calibrated against the calibration reference. The reference load for calibration shall be placed in an N-type connector according to IEC 61169-16, or in an SMA-type connector according to IEC 60169-15, types ~~meant~~ suitable for panel mounting, which ~~is~~ are machined flat on the back side, see Figure 3.

The option to use SMA-type connectors, according to IEC 60169-15 is preferred.

The load shall be fixed to the flat side of the connector. A network analyzer shall be calibrated, 1-port full calibration, with the calibration reference. Thereafter, the return loss of the reference load for calibration shall be measured. The verified return loss shall be >46 dB at frequencies up to 100 MHz and >40 dB at frequencies above 100 MHz and up to the limit for which the measurements are to be carried out.

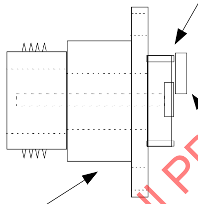


Figure 3 – Calibration of reference loads

4.10 Calibration

4.10.1 General

Isolation measurements shall be used as part of the calibration if the requirements of Table 3 are not met.

The calibration shall be equivalent to a minimum of a full 2-port SE calibration for measurements where the response and stimulus ports are the same (S_{xx11} and S_{xx22}), and a minimum of a full 4-port SE calibration for measurements where the response and stimulus ports are different (S_{xx12} and S_{xx21}).

An individual calibration shall be performed for each signal path used for the measurements.

If a complete switching matrix and 4-port network analyzer test setup is used, a full set of measurements for a 4-pair device (i.e. 16 single-ended ports), will require 28 separate 4-port calibrations, although many of the measurements within each calibration are in common with other calibrations.

A software or hardware package may be used to minimise the number of calibration measurements required.

~~The calibration shall be applied such that the calibration plane shall be at the ends of the fixed connectors of the test fixture.~~

The calibration may be performed at the test interface using appropriate calibration artefacts, or at the ends of the coaxial test cable using coaxial ~~terminations~~ standards and de-embedding data representing the test fixture.

4.10.2 Calibration test interface

Where calibration is performed at the test interface, open, short and load measurements shall be taken on each SE port concerned, and through and isolation measurements shall be taken on every pair combination of those ports.

4.10.3 Calibration at end of coaxial test cables

Where calibration is performed at the end of the coaxial test cables, open, short and load measurements shall be taken on each port concerned, and through and isolation measurements shall be taken on every pair combination of those ports. In addition, the test fixture shall then be de-embedded from the measurements. The de-embedding techniques shall incorporate a fully populated 16 port S-matrix. It is not acceptable to perform a de-embedded calibration using only reflection terms (S_{11}, S_{22}, S_{33}, S_{44}) or only near end terms (S_{11},S_{21},S_{12}, S_{22}).

De-embedding using reduced term S-matrices may be used for post-processing of results.

4.11 Termination loads for termination of conductor pairs

4.11.1 General

~~50 Ω wire to ground terminations shall be used on all active pairs under test. 50 Ω differential mode to ground terminations shall be used on all inactive pairs and on the opposite ends of active pairs for NEXT and FEXT testing. Inactive pairs for return loss testing shall be terminated with 50 Ω differential mode to ground terminations.~~

50 Ω loads to earth (ground) shall be used on all active wires under test for termination. 50 Ω loads to earth (ground) shall be used on all inactive wires and on the opposite ends of active wires for NEXT and FEXT testing for termination. Inactive wires for return loss testing shall be terminated with 50 Ω loads to earth (ground). See Figure 4.

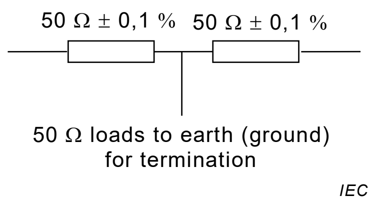


Figure 4 – Resistor termination networks

Small geometry chip resistors shall be used for the construction of resistor terminations. The two 50 Ω ~~DM~~ SE terminating resistors shall be matched to within 0,1 % at DC, and 2 % at ~~1 000~~ 2 000 MHz (corresponding to a 40 dB return loss requirement at ~~1 000~~ 2 000 MHz). ~~The length of connections to impedance terminating resistors shall be minimized. Use of soldered connections without leads is recommended.~~

4.11.2 ~~Verification of termination loads~~ Impedance matching resistor termination networks

The performance of impedance matching resistor termination networks shall be verified by measuring the return loss of the termination and the residual NEXT between any two resistor termination networks at the calibration plane.

For the return loss measurement, a 2-port SE calibration ~~is required~~ shall be done using a reference load verified according to 4.9.

After calibration, connect the resistor termination network and perform a full 2-port SE S-matrix measurement. The measured SE S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameters S_{DD11} and S_{CC11} from which the differential mode return loss RL_{DM} and the common mode return loss RL_{CM} are determined. The return loss of the resistor termination network shall meet the requirements of Table 3.

For the residual NEXT measurement, a 4-port SE calibration is required. After calibration, connect the resistor termination networks and perform a full 4-port SE S-matrix measurement. The measured S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{DD21} from which the residual NEXT of the terminations, $NEXT_{residual\_term}$, is determined. The residual NEXT shall meet the requirements of Table 3.

4.12 Termination of screens

~~If~~ As the connector under test is normally screened, screened measurement cables shall be applied. The screen or screens of these cables shall be fixed to the earth (ground) plane as close as possible to the calibration plane.

4.13 Test specimen and reference planes

4.13.1 General

The test specimen is a mated pair of relevant connectors. The connector reference plane for the test specimen is the point at which the cable sheath enters the connector (the back end of the connector) or the point at which the internal geometry of the cable is no longer maintained, whichever is farther from the connector, see Figure 5. This definition applies to both ends of the test specimen. The ~~fixed connector~~ DUT shall be terminated in accordance with the manufacturer's instructions and shall be compatible with the measurement test set up and fixtures.

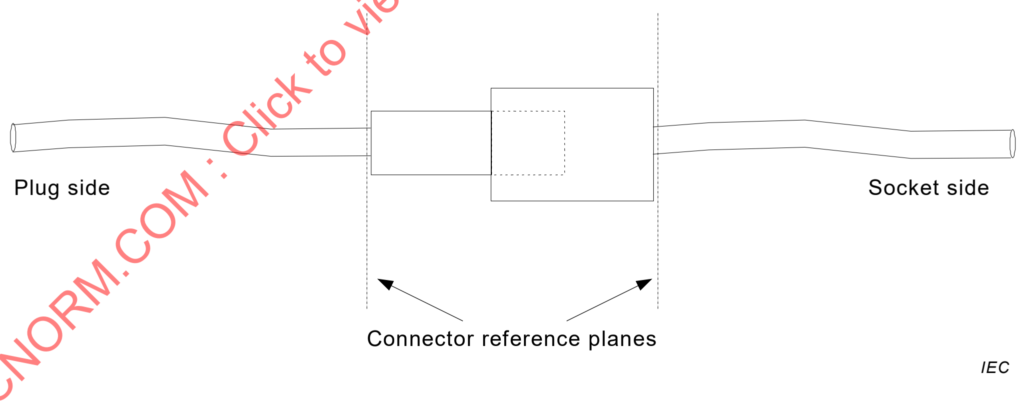


Figure 5 – Definition of reference planes

4.13.2 Interconnections between device under test (DUT) and the calibration plane

4.13.2.1 General

Twisted-pair ~~interconnect~~, coax, printed circuits or other qualified interconnections ~~are~~ shall be used between the connector reference plane of the DUT and the calibration plane. It is ~~necessary~~ required to control the characteristics of these interconnections to the best extent possible as they are beyond the calibration plane. These interconnections ~~should~~ shall be as short as practical and their CM and DM impedances shall be managed to minimize their effects on measurement. ~~Refer to Annex B for additional information about test pins which may be used to facilitate impedance management.~~

The DM return loss performance of the interconnections shall meet the requirements of Table 4. The insertion loss performance of the interconnections is assumed to be less than ~~0,1~~ 0,2 dB over the frequency range from 1 MHz to ~~1 000~~ 2 000 MHz.

~~It is recommended that all DUTs, including test free connectors, have fixed connectors with 2,54 mm spacing applied to the ends of their interconnect to facilitate a consistent interfacing with the test fixture.~~

4.13.2.2 Twisted-pair interconnect

4.13.2.2.1 General

When used, twisted-pair interconnect shall have 100 Ω nominal differential characteristic impedance. The twisted pairs should not exhibit gaps between the conductor insulation. The twisted-pair interconnect may be obtained as an individual twisted-pair interconnect, or it may be part of a cable.

Refer to Annex B for additional information about interconnections between device under test (DUT) and the calibration plane, for connector types typically utilizing twisted-pair interconnect with indirect-reference test fixtures.

Refer to Annex B for additional information about interconnections between device under test (DUT) and the calibration plane, wherein it is recommended that all DUTs, including reference test free connectors, have fixed connectors with 2,54 mm spacing applied to the ends of their interconnect to facilitate a consistent interfacing with the test fixture.

Refer to Annex B for additional information about test pins which may be used to facilitate impedance management.

The interconnect shall comply with the return loss requirements of ~~4.12.1.2~~ Table 4.

DM to earth (ground) terminations ~~are required~~ shall be used and the interconnect ~~should~~ shall be placed in an impedance managing system. The maximum length of the twisted-pair leads at each end of the DUT shall be 51 mm, however ~~it is recommended to~~ they shall be kept as short as possible.

4.13.2.2.2 Individual twisted-pair interconnect

Individual twisted-pair interconnect may be obtained from discrete twisted-pair stock or removed from sheathed cable.

Prior to attachment to the DUT, the return loss of the pair shall be tested. For this test, a 100 mm length of individual twisted-pair shall be used. The twisted-pair shall be terminated with a 50 Ω differential mode to earth (ground) resistor termination network as described in 4.11. The resistor termination network shall be attached directly to the conductors of the pair in such a way as to minimize the disturbance of the pair. Potential disturbances include gaps between the conductor insulation in the pair, melting insulation, and excess solder.

Return loss shall be tested according to ~~4.12.1.2~~ Table 4.

The twisted-pair leads are then trimmed for attachment to the DUT and the test fixture.

4.13.2.2.3 Interconnect as part of cables

Interconnect may also be obtained from a section of twisted-pair cables where the four twisted-pair interconnects are maintained in the cable sheath. This method will most often be used with free connectors cut from the ends of assembled balanced cords, but can also be used with fixed connectors.

Prior to attachment to the DUT, the return loss of each of the cable pairs within the cable shall be tested. For this test, a 100 mm length of cable shall be used. Each pair of the cable shall be terminated as described for the individual twisted-pair interconnect in 4.11. For the inactive pairs, i.e. pairs not under test, the termination shall be applied to both ends.

Return loss shall be tested according to ~~4.12.1.2~~ Table 4.

The cable shall then be terminated to the DUT per manufacturer's instructions and trimmed for attachment to the test fixture.

When this method is used with free connectors cut from assembled cords, it shall be sufficient if the return loss of the cord cable is compliant to the category ~~7_A~~ 8.1 and category 8.2 requirements of ~~IEC 61156-6~~ IEC 61156-10:2016, or if the return loss of the assembled cord is compliant to the balanced cord category ~~7_A~~ 8.2 requirements of ISO/IEC 11801-1:2017.

4.13.2.3 Direct probe single ended interconnect

When used, direct probe single ended interconnect shall have 50 Ω nominal single ended (coaxial) characteristic impedance. Coaxial cables and printed circuit transmission lines within the test fixture, connected to the DUT connector contacts, should be sufficiently matched to conform to the interconnection DM return loss requirements of 4.13.2.4.

Refer to Annex C for additional information about Interconnections between device under test (DUT) and the calibration plane, for connectors utilizing Direct-probe test fixtures.

The interconnect shall comply with the return loss requirements of Table 4.

4.13.2.4 Interconnection DM return loss requirements

The return loss of the interconnection shall be tested using the mixed mode approach as described in 4.11.2 for the verification of resistor termination networks. The interconnection shall be tested for differential mode return loss only and shall meet the requirements in Table 4.

Table 4 – Interconnection DM return loss requirements

~~**Frequency**~~ ~~MHz~~	~~**DM return loss**~~ ~~dB~~
~~$1 \le f < 80$~~ ~~$80 \le f \le 1\ 000$~~	~~40 dB~~ ~~78 – 20log(f) dB~~ ~~20 dB min~~

Frequency MHz	**DM return loss** dB
$1 \le f < 100$ $100 \le f \le 2\ 000$	40 80 – 20log(f) dB 20 dB min.

Twisted-pair interconnects shall be prepared for test as described in ~~4.12.1.1.1 and 4.12.1.1.2.~~ 4.13.2.2. When testing other interconnections, equivalent differential mode to earth (ground) terminations shall be applied.

4.14 Overall test setup requirements

The requirements of the overall test setup shall meet the requirements of Table 5 when tested using terminations according to 4.11.

Table 5 – Overall test setup requirements

~~**Parameter**~~	~~**Frequency**~~ ~~MHz~~	~~**Requirement**~~ ~~**up to** 1 000 MHz~~
~~SE port (50 Ω) return loss, (dB)~~	~~1<f<1 000~~	~~> 65 – 20log(f)~~ ~~40 dB max~~ ~~10 dB min~~
~~DM port (100 Ω) return loss, (dB)~~		~~> 68 – 20log(f)~~ ~~40 dB max~~ ~~10 dB min~~
~~CM port (100 Ω) return loss, (dB)~~		~~> 60 – 20log(f)~~ ~~35 dB max~~ ~~10 dB min~~
~~SE (50 Ω) port-to-port (pair-to-pair) isolation:~~ ~~NEXT and FEXT~~		~~113 – 20log(f)~~ ~~75 dB max.~~
~~SE (50 Ω) port-to-port (within a pair) isolation:~~ ~~NEXT and FEXT~~		~~> 74 – 20log(f)~~ ~~75 dB max.~~
~~DM (100 Ω) port-to-port isolation: NEXT and FEXT~~		~~130 – 20log(f)~~ ~~94 dB max~~
~~DM (100 Ω) insertion loss~~		~~< 1 dB~~
~~TCL, LCL~~		~~100 – 20log(f)~~ ~~70 dB max~~
~~TCTL, LCTL~~		~~> 90 – 20log(f)~~ ~~50 dB max~~

Parameter	**Requirement** 1 MHz to 1 000 MHz	**Requirement** 1 000 MHz to 2 000 MHz
SE port (50 Ω) return loss, (dB)	> 68 – 20log(f) 20 dB max. 12 dB min.	12 dB min.
DM port (100 Ω) return loss, (dB)	> 68 – 20log(f) 20 dB max. 12 dB min.	12 dB min.
CM port (50 Ω) return loss, (dB) [1]	> 68 – 20log(f) 20 dB max. 12 dB min.	12 dB min.
SE (50 Ω) port-to-port (pair-to-pair) isolation: NEXT and FEXT	> 125 – 20log(f) 80 dB max.	65 dB min.

Parameter	Requirement 1 MHz to 1 000 MHz	Requirement 1 000 MHz to 2 000 MHz
SE (50 Ω) port-to-port (within a pair) isolation: NEXT and FEXT	> 100 – 20log(f) 70 dB max.	40 dB min.
DM (100 Ω) port-to-port isolation: NEXT and FEXT	> 140 – 20log(f) 94 dB max.	80 dB min.
DM (100 Ω) port-to-port isolation: near-end-to-far-end[2]	> 140 – 20log(f) 94 dB max.	80 dB min.
DM (100 Ω) insertion loss	< 12 dB	< 12 dB
TCL, LCL	> 90 – 20log(f) 50 dB max.	30 dB min.
TCTL, LCTL	> 90 – 20log(f) 50 dB max.	30 dB min.

[1] DUT common mode impedance is usually specified as 50 Ω, therefore for measurements, a transformation is required as specified in Annex A. For the case of balunless measurements the common mode impedance measurement and thus return loss is derived as specified in Annex A.

[2] The requirement can be met either though separation or shielding applied between fixtures.

5 Connector measurements up to ~~1 000~~ 2 000 MHz

5.1 General

~~The measurements made in this clause are of a mated free connector and fixed connector. Compliance to this standard for a particular interface does not ensure interoperability with other interfaces qualified to this standard e.g. IEC 61076-3-104 is not interoperable with IEC 61076-3-110.~~

~~It is assumed that the performance variation of all free connectors of a given interface can be ignored. Consequently, it is not necessary to qualify the free connectors used for the connecting hardware performance measurements.~~

The measurements made in this clause are on a free connector mated with a fixed connector.

5.2 Insertion loss, test 28a

5.2.1 Object

The object of this test is to measure the insertion loss of a connecting hardware pair. Insertion loss is defined here as the additional attenuation that is caused by a connecting hardware pair inserted in a communication cable.

5.2.2 Connecting hardware insertion loss

Connecting hardware shall be tested for insertion loss in one direction using at least one free connector.

5.2.3 Test method

Insertion loss is evaluated from the mixed mode parameter S_{DD21} for each conductor pair. The mixed mode S-parameters are derived by transformation of the SE S-matrix.

5.2.4 Test set-up

The test set-up consists of a network analyzer and two test fixtures as described in Clause 4. An illustration of the test set-up, which also shows the termination principles, is shown in Figure 6. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs. Interconnects (if used) shall be prepared and controlled per 4.13.2.

5.2.5 Procedure

5.2.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.9.

5.2.5.2 Measurement

The DUT shall be arranged in a test set-up according to 5.2.4 and Figure 6, including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured SE S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{DD21} from which insertion loss is determined.

Test all conductor pairs and record the results.

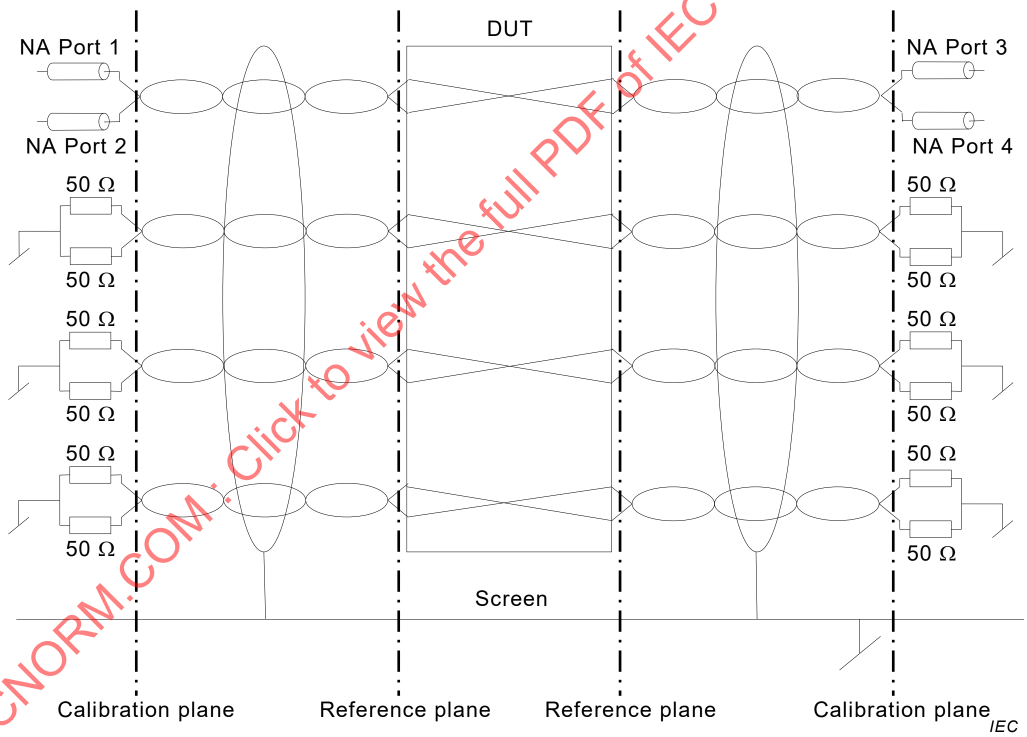


Figure 6 – Insertion loss and TCTL measurement

5.2.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.2.7 Accuracy

Mate the two interfaces of the test equipment at the calibration plane and perform an IL measurement.

~~The accuracy shall be within ±0,05 dB.~~ The accuracy shall be better than ±1 dB at the specification limit.

5.3 Return loss, test 28b

5.3.1 Object

The object of this test is to measure the return loss of a connecting hardware pair at the two reference planes.

5.3.2 Connecting hardware return loss

Connecting hardware shall be tested for return loss in both directions using at least one free connector.

5.3.3 Test method

Return loss is evaluated from the mixed mode parameters S_{DD11} and S_{DD22} for all conductor pairs. The mixed mode S-parameters are derived by transformation of the measured SE S-matrix.

~~NOTE As a connector is a low-loss device, the return loss of the two sides is nearly equal.~~

5.3.4 Test set-up

The test set-up consists of a network analyzer and two test fixtures as described in Clause 4. An illustration of the test set-up, which also shows the termination principles, is shown in Figure 9. Resistor termination networks in accordance with 4.11 shall be applied for all active and inactive pairs. Interconnects (if used) shall be prepared and controlled per 4.13.2.

Return loss may be measured in a test set-up using only one fixture and a 2-port SE calibration and measurement. In this case, the return loss is measured in only one direction at a time.

5.3.5 Procedure

5.3.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.3.5.2 Measurement

The DUT shall be arranged in a test set-up according to 5.3.4 and Figure 9, including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured SE S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameters S_{DD11} and S_{DD22} from which the return loss is determined.

Test all conductor pairs in both adirections and record the results.

5.3.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.3.7 Accuracy

The return loss of the load for calibration is verified to be greater than 46 dB up to 100 MHz and greater than 40 dB at higher frequencies. The uncertainty of the connection between the connector under test and the test fixture is expected to deteriorate the return loss of the set-up (effectively the directional bridge implemented by the test set-up) by 6 dB. The accuracy of the return loss measurements is then equivalent to measurements performed by a directional bridge with a directivity of 40 dB and 34 dB.

5.4 Near-end crosstalk (NEXT), test 28c

5.4.1 Object

The object of this test procedure is to measure the magnitude of the electric and magnetic coupling between the near ends of a disturbing and disturbed pair of a connecting hardware pair combination.

5.4.2 Connecting hardware NEXT

Connecting hardware shall be tested for NEXT in both directions using at least one free connector.

5.4.3 Test method

NEXT is evaluated from the mixed mode parameter S_{DD21} for all conductor pair combinations. The mixed mode S-parameters are derived by transformation of the measured SE S-matrix.

5.4.4 Test set-up

The test set-up consists of a network analyzer and a test fixture as described in Clause 4. An illustration of the test set-up, which also shows the termination principles, is shown in Figure 7. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs and for the ends of active pairs not being connected to the network analyzer ports. Interconnects (if used) shall be prepared and controlled per 4.13.2.

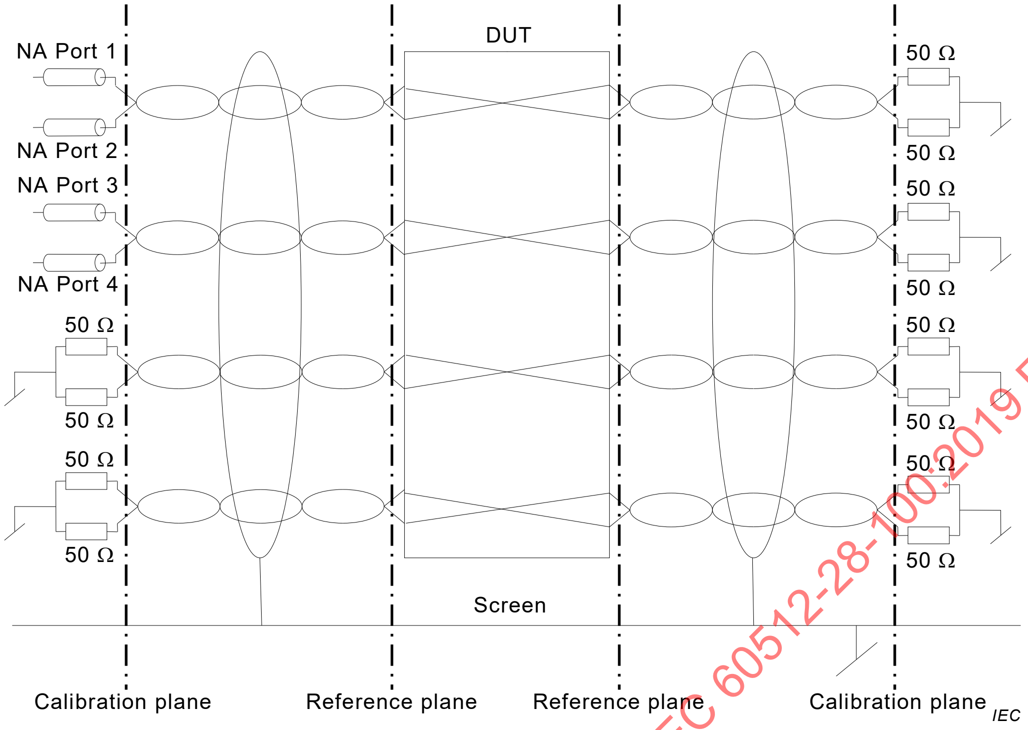


Figure 7 – NEXT measurement

5.4.5 Procedure

5.4.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.4.5.2 Establishment of noise floor

The noise floor of the set-up shall be measured. The level of the noise floor is determined by white noise, which may be reduced by increasing the test power and by reducing the bandwidth of the network analyzer, and by residual crosstalk within the test fixture.

The noise floor shall be measured by terminating the test ports of the test fixture with resistor termination networks and performing a full SE S-matrix measurement. The measured SE S-matrix is transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{DD21} from which the noise floor is established. The noise floor shall be established for all possible conductor pair combinations.

The noise floor shall be 20 dB lower than any specified limit for the crosstalk. If the measured value is closer to the noise floor than 20 dB, this shall be reported.

For high crosstalk values, it may be necessary to screen the terminating resistors.

5.4.5.3 Measurement

The DUT shall be arranged in a test set-up according to 5.4.4 and Figure 7, including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured SE S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{DD21} from which NEXT is determined.

The test has to be performed from both ends of the connecting hardware. Test all conductor pair combinations and record the results.

5.4.5.4 Determining pass and fail

The NEXT of the connecting hardware shall satisfy the requirements of the relevant detail specification for all pair combinations and in both directions.

5.4.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.4.7 Accuracy

The accuracy shall be better than ±1 dB at measurements up to 60 dB and ±2 dB at measurements up to 85 dB.

5.5 Far-end crosstalk (FEXT), test 28d

5.5.1 Object

The object of this test procedure is to measure the magnitude of the electric and magnetic coupling between the near end of a disturbing pair and the far end of disturbed pair of a connecting hardware pair combination.

5.5.2 Connecting hardware FEXT

Connecting hardware shall be tested for FEXT in both directions using at least one free connector.

5.5.3 Test method

FEXT is evaluated from the mixed mode parameter S_{DD21} for all conductor pair combinations. The mixed mode S-parameters are derived by transformation of the measured SE S-matrix.

5.5.4 Test set-up

The test set-up consists of a network analyzer and two test fixtures as described in Clause 4. An illustration of the test set-up, which also shows the termination principles, is shown in Figure 8. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs and for the ends of active pairs not being connected to the network analyzer ports. Interconnects (if used) shall be prepared and controlled per 4.13.2.

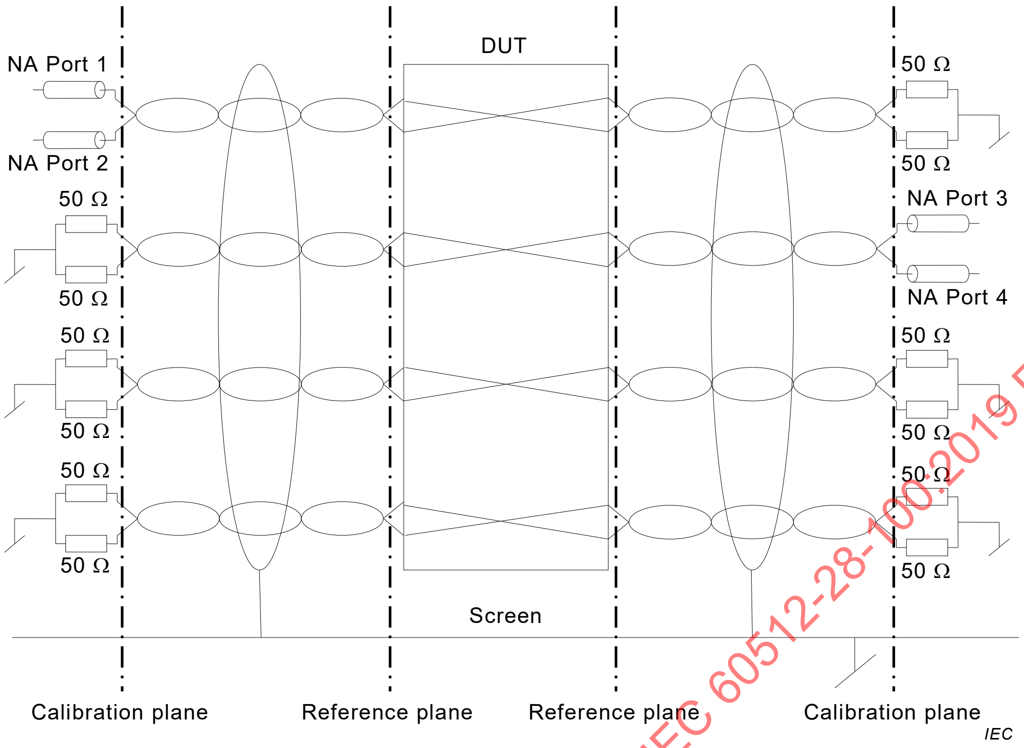


Figure 8 – FEXT measurement

5.5.5 Procedure

5.5.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.5.5.2 Establishment of noise floor

The noise floor of the set-up is established as outlined in 5.4.5.2.

5.5.5.3 Measurement

The DUT shall be arranged in a test set-up according to 5.5.4 and Figure 8, including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured SE S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{DD21} from which FEXT is determined.

Test all conductor pair combinations and record the results.

5.5.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pair combinations shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.5.7 Accuracy

The accuracy shall be better than ±1 dB at measurements up to 60 dB and ±2 dB at measurements up to 85 dB.

~~5.6 Transfer impedance (Z_T), Test 28e~~

~~Refer to test 26e of IEC 60512-26-100.~~

5.6 Transverse conversion loss (TCL), test 28f

5.6.1 Object

The object of this test is to measure the mode conversion (differential to common mode) of a signal in the conductor pairs of the DUT. This is also called unbalance attenuation or Transverse Conversion Loss, TCL.

5.6.2 Connecting hardware TCL

Connecting hardware shall be tested for TCL from both directions using at least one free connector.

5.6.3 Test method

TCL is evaluated from the mixed mode parameter S_{CD11} for all conductor pairs. The mixed mode S-parameters are derived by transformation of the measured SE S-matrix.

5.6.4 Test set-up

The test set-up consists of a network analyzer and a test fixture as described in Clause 4. An illustration of the test set-up, which also shows the termination principles, is shown in Figure 9. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs and for the ends of active pairs not being connected to the network analyzer ports. Interconnects (if used) shall be prepared and controlled per 4.13.2.

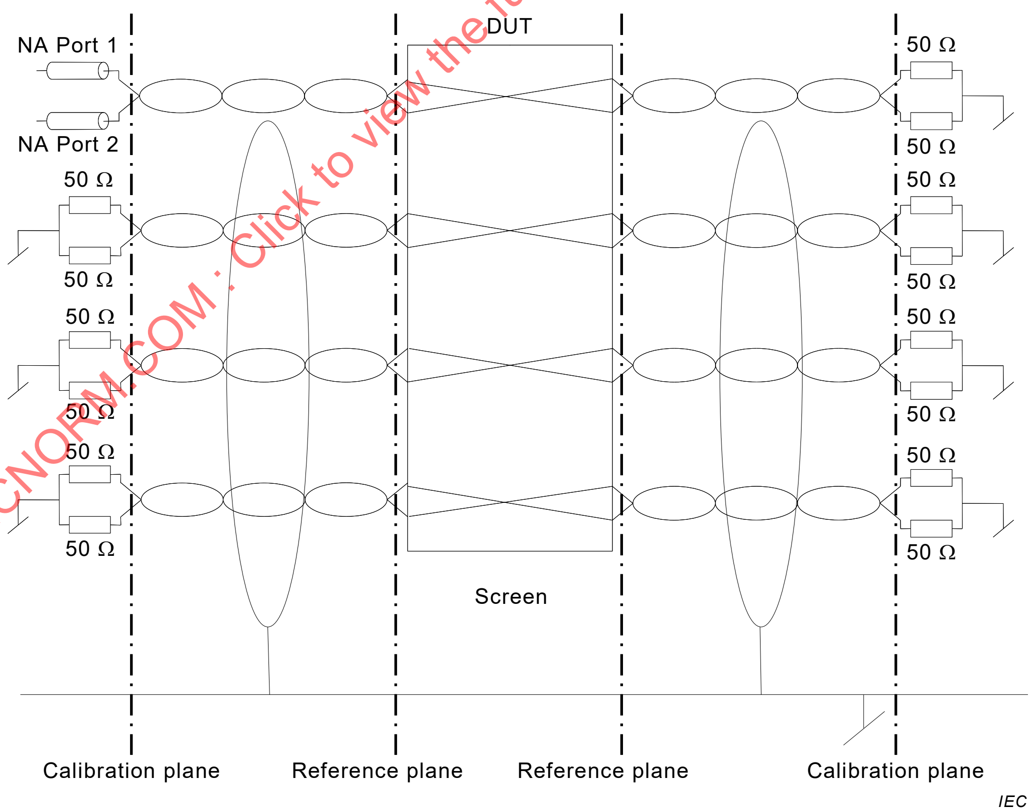


Figure 9 – Return loss and TCL measurement

5.6.5 Procedure

5.6.5.1 Calibration

A full 2-port SE calibration shall be performed at the calibration plane in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.6.5.2 Noise floor

The noise floor of the set-up shall be measured. The level of the noise floor is determined by white noise, which may be reduced by increasing the test power and by reducing the bandwidth of the network analyzer, and by residual intermodal crosstalk within the test fixture.

The noise floor, a_{noise}, shall be measured by terminating the test ports of the test fixture with resistor termination networks and performing a full SE S-matrix measurement. The measured SE S-matrix is transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{CD11} from which the noise floor is calculated as:

$$a_{\text{noise}} = -20\log\left|S_{\text{CD11}}\right| \quad (2)$$

The noise floor shall be established for all conductor pairs.

The noise floor shall be 20 dB lower than any specified limit for balance. If the measured value is closer to the noise floor than ~~10~~ 20 dB, this shall be reported.

5.6.5.3 Measurement

The DUT shall be arranged in a test set-up according to 5.6.4 and Figure 9, including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured SE S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{CD11} from which TCL is calculated as:

$$TCL = -20\log\left|S_{\text{CD11}}\right| \quad (3)$$

The test ~~has to~~ shall be performed from ~~the free connector end of~~ both directions on the connecting hardware. Test all conductor pairs and record the results.

5.6.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.6.7 Accuracy

The accuracy shall be better than ±1 dB at the specification limit.

5.7 Transverse conversion transfer loss (TCTL), test 28g

5.7.1 Object

The object of this test is to measure the mode conversion (differential to common mode) of a signal in the conductor pairs of the DUT at the far end. This is also called far end unbalance attenuation or Transverse Conversion Transfer Loss, TCTL.

5.7.2 Connecting hardware TCTL

Connecting hardware shall be tested for TCTL from both directions using at least one free connector.

5.7.3 Test method

TCTL is evaluated from the mixed mode parameter S_{CD21} for all conductor pairs. The mixed mode S-parameters are derived by transformation of the measured SE S-matrix.

5.7.4 Test set-up

The test set-up consists of a network analyzer and two test fixtures as described in Clause 4. An illustration of the test set-up, which also shows the termination principles, is shown in Figure 6. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs. Interconnects (if used) shall be prepared and controlled per 4.13.2.

5.7.5 Procedure

5.7.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.7.5.2 Noise floor

The noise floor of the test set-up shall be measured using the same approach as outlined in 5.7.5.2 adapted to the 4-port test set-up used for TCTL.

The noise floor a_{noise} is calculated from S_{CD21} as:

$$a_{noise} = -20\log\left|S_{CD21}\right| \tag{4}$$

The same requirements as described in 5.6.5.2 adapted to TCTL as in the four--ort test set-up used for TCL ~~measurements apply~~.

5.7.5.3 Measurement

The DUT shall be arranged in a test set-up according to 5.7.4 and Figure 6, including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured (4-port) SE S-matrix shall be transformed into the associated (2-port) mixed mode S-matrix to obtain the S-parameter S_{CD21} from which TCTL is calculated as:

$$\text{TCTL} = -20\log\left|S_{CD21}\right| \tag{5}$$

~~The test has to be performed from the free connector end of the connecting hardware. Test all conductor pairs and record the results.~~

The test shall be performed from both directions on the connecting hardware. Test all conductor pairs and record the results.

5.7.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.7.7 Accuracy

The accuracy shall be better than ±1 dB at the specification limit.

5.8 Shield transfer impedance (Z_T), test 26e

5.8.1 Object

The object of this test is to measure the shield transfer impedance of a common-mode signal transferred through the shield of the DUT. This is specifically required for screened connectors and not applicable for unshielded connectors.

For further information on applicability, see IEC 60512-26-100, refer to test 26e.

5.8.2 Connecting hardware Ttansfer impedance (Z_T)

Connecting hardware Transfer impedance (Z_T) shall be tested in accordance with IEC 62153-4-12 up to 100 MHz.

5.8.3 Test method

The transfer impedance (Z_T) test method for connectors utilizes the triaxial-tube-in-tube or the line injection apparatus.

5.8.4 Test set-up

The test set-up consists of a network analyzer and test fixtures as described in IEC 62153-4-12. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs. Interconnects (if used) shall be prepared and controlled per 4.13.2.

Transfer impedance measurement data may be derived from a common measurement set-up described in IEC 62153-4-12.

5.8.5 Procedure

5.8.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.8.5.2 Noise floor

The noise floor of the test set-up shall be measured using the same approach as outlined in 5.6.5.2 adapted to the 4-port test set-up used for TCTL.

The noise floor a_{noise} is calculated from S_{CD21} as:

$$a_{noise} = -20\log\left|S_{CD21}\right| \tag{6}$$

5.8.5.3 Measurement

The DUT shall be arranged in a test set-up according to the test fixtures as described in IEC 62153-4-12.

The test should be performed from the free connector end of the connecting hardware. Test all conductor pairs and record the results.

5.8.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.8.7 Accuracy

The accuracy shall be better than ±3 dB at the specification limit.

5.9 Coupling attenuation (a_C)

~~Coupling attenuation measurements, when required by the detail specification, apply only to shielded connectors.~~

~~Coupling attenuation shall be performed per IEC 62153-4-12, over the frequency range of 30 MHz to 1 000 MHz.~~

5.9.1 Object

The object of this test is to measure the mode conversion ratio through the shield (common-mode to differential-mode) of a signal in the conductor pairs of the DUT. This is specifically required for screened connectors and optional for unshielded connectors.

5.9.2 Connecting hardware coupling attenuation (a_C)

Connecting hardware coupling attenuation shall be tested in accordance with IEC 62153-4-12 over the frequency range of 30 MHz to 2 000 MHz.

5.9.3 Test method

The coupling attenuation (a_C) test method for connectors is based on coupling attenuation (a_C) measurement methods, which utilize triaxial-tube-in-tube or absorbing-clamp apparatus.

5.9.4 Test set-up

The test set-up consists of a network analyzer and test fixtures as described in IEC 62153-4-12. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs. Interconnects (if used) shall be prepared and controlled per 4.13.2.

5.9.5 Procedure

5.9.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.9.5.2 Noise floor

The noise floor of the test set-up shall be measured using the same approach as outlined in 5.6.5.2 adapted to the 4-port test set-up used for TCTL.

The noise floor a_{noise} is calculated from S_{CD21} as:

$$a_{noise} = -20\log\left|S_{CD21}\right| \tag{7}$$

5.9.5.3 Measurement

The DUT shall be arranged in a test set-up according to the test fixtures as described in IEC 62153-4-12 including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured (three-port) SE S-matrix shall be transformed into the associated (two-port) mixed mode S-matrix to obtain the S-parameter S_{SD21} from which coupling attenuation is calculated as.

$$A_C = -20\log\left|S_{CD21}\right| \tag{8}$$

The test should be performed from the free connector end of the connecting hardware. Test all conductor pairs and record the results.

5.9.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.9.7 Accuracy

The accuracy shall be better than ±3 dB at the specification limit.

Annex A
(informative)

~~Example~~ Derivation of mixed mode parameters using the modal decomposition technique

A.1 General

It is not a requirement of this document to require that a full derivation is produced, and any method of extracting the required S-parameters is acceptable. This may be achieved by the use of network analyzer hardware functions, specific mathematical software, or by circuit simulation tools.

This informative annex presents a summary of how to derive mixed mode parameters from 4-port measurements of S-parameters.

An impedance matrix (Z) of the DUT can be calculated based on Formula A.1.

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & Z_{13} & Z_{14} \\ Z_{21} & Z_{22} & Z_{23} & Z_{24} \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} \\ Z_{41} & Z_{42} & Z_{43} & Z_{44} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} \quad (A.1)$$

Where V is the voltage and I is the current, see Figure A.1:

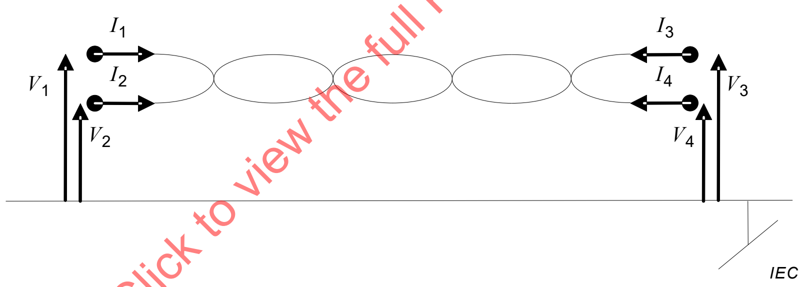


Figure A.1 – Voltage and current on balanced DUT

A.2 Example of a calculation

The modal domain impedance matrix [Z^m] is then calculated from Formula A.2 below, using the conversion matrices given in Formula A.3 and Formula A.4.

$$Z^m = P_e^{-1} Z Q_e \quad (A.2)$$

$$P_e^{-1} = \begin{bmatrix} P^{-1} & 0 \\ 0 & P^{-1} \end{bmatrix} \quad (A.3)$$

$$Q_e = \begin{bmatrix} Q & 0 \\ 0 & Q \end{bmatrix} \quad (A.4)$$

In the case of a 1 pair DUT, the size of the conversion matrices becomes 4x4 with the values given in Formula A.5 and Formula A.6

$$P = \begin{bmatrix} \frac{1}{2} & 1 \\ -\frac{1}{2} & 1 \end{bmatrix} \quad \text{(A.5)}$$

$$Q = \begin{bmatrix} 1 & \frac{1}{2} \\ -1 & \frac{1}{2} \end{bmatrix} \quad \text{(A.6)}$$

The conversion matrices replace the balun transformers and are referred to as mathematical baluns, producing Formula A.7 and Formula A.8.

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = P_e \begin{bmatrix} V_{D1} \\ V_{C1} \\ V_{D2} \\ V_{C2} \end{bmatrix} \quad \text{(A.7)}$$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = Q_e \begin{bmatrix} I_{D1} \\ I_{C1} \\ I_{D2} \\ I_{C2} \end{bmatrix} \quad \text{(A.8)}$$

Substituting Formula A.7 and Formula A.8 into Formula A.1 Formula A.9 is obtained, which is equivalent to a set of hybrid transformers attached at each end of the cable pair as described in Figure A.2.

$$\begin{bmatrix} \mathbf{V_{D1}} \\ \mathbf{V_{C1}} \\ \mathbf{V_{D2}} \\ \mathbf{V_{C2}} \end{bmatrix} = \begin{bmatrix} \mathbf{Z^m_{11}} & \mathbf{Z^m_{12}} & \mathbf{Z^m_{13}} & \mathbf{Z^m_{14}} \\ \mathbf{Z^m_{21}} & \mathbf{Z^m_{22}} & \mathbf{Z^m_{23}} & \mathbf{Z^m_{24}} \\ \mathbf{Z^m_{31}} & \mathbf{Z^m_{32}} & \mathbf{Z^m_{33}} & \mathbf{Z^m_{34}} \\ \mathbf{Z^m_{41}} & \mathbf{Z^m_{42}} & \mathbf{Z^m_{43}} & \mathbf{Z^m_{44}} \end{bmatrix} \begin{bmatrix} \mathbf{I_{D1}} \\ \mathbf{I_{C1}} \\ \mathbf{I_{D2}} \\ \mathbf{I_{C2}} \end{bmatrix} \quad \text{(A.9)}$$

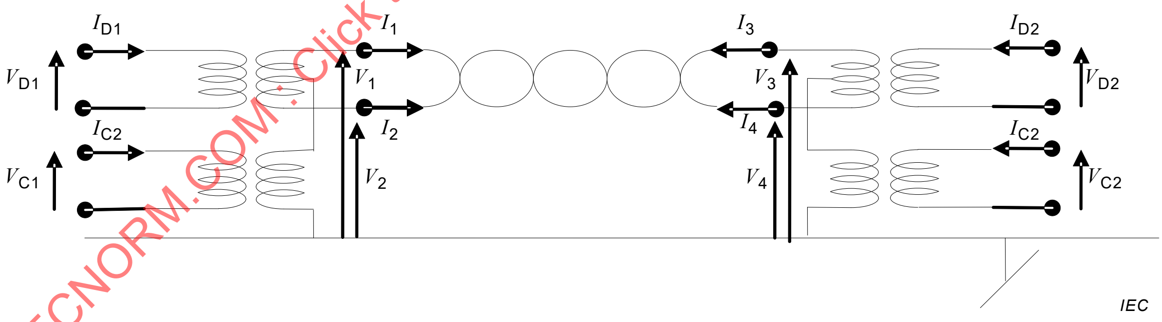


Figure A.2 – Voltage and current on unbalanced DUT

For the measurements concerned in this standard, S-parameters are measured and converted into Z-Parameters. The Z-parameter matrix of a 2n-port circuit~~s~~ can be derived using Formula A.10.

$$Z = R^{\frac{1}{2}}[E + S][E - S]^{-1}R^{\frac{1}{2}} \quad \text{(A.10)}$$

Where E is a 2n x 2n unit matrix and $R^{\frac{1}{2}}$ is given by Formula A.11.

$$R^{\frac{1}{2}} = \begin{bmatrix} \sqrt{r_1} & 0 & \dots & 0 \\ 0 & \sqrt{r_2} & 0 & \vdots \\ \vdots & 0 & \ddots & 0 \\ 0 & \dots & 0 & \sqrt{r_{2n}} \end{bmatrix} \quad (A.11)$$

Where r_x is the impedance of the measurement port, typically 50 Ω, giving Formula A.12

$$R^{\frac{1}{2}} = \begin{bmatrix} \sqrt{50} & 0 & \dots & 0 \\ 0 & \sqrt{50} & 0 & \vdots \\ \vdots & 0 & \ddots & 0 \\ 0 & \dots & 0 & \sqrt{50} \end{bmatrix} \quad (A.12)$$

The S-parameters in the modal domain are then calculated using Formula A.13, giving Formula A.14.

$$S^m = R_m^{-\frac{1}{2}}[Z^m - R_m][Z^m + R_m]^{-1}R_m^{\frac{1}{2}} \quad (A.13)$$

$$R_m^{\frac{1}{2}} = \begin{bmatrix} \sqrt{r_{m1}} & 0 & \dots & 0 \\ 0 & \sqrt{r_{m2}} & 0 & \vdots \\ \vdots & 0 & \ddots & 0 \\ 0 & \dots & 0 & \sqrt{r_{m2n}} \end{bmatrix} \quad (A.14)$$

By this method it is possible to convert unbalance network analyzer measurements into mixed mode S-matrices which contain both balanced and unbalanced parameters, as in Formula A.15.

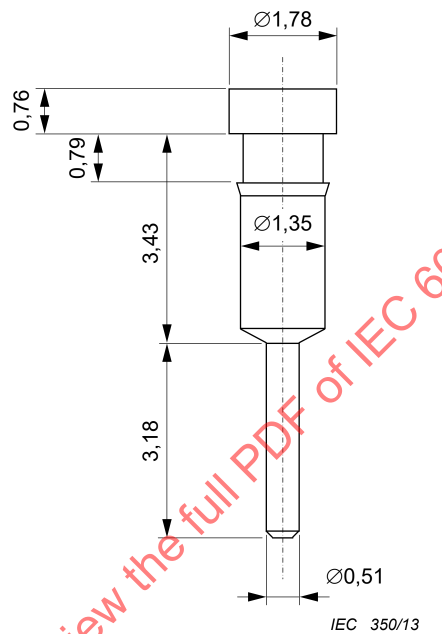
$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \Rightarrow \begin{bmatrix} S_{DD11} & S_{DC11} & S_{DD12} & S_{DC12} \\ S_{CD11} & S_{CC11} & S_{CD12} & S_{CC12} \\ S_{DD21} & S_{DC21} & S_{DD22} & S_{DC22} \\ S_{CD21} & S_{CC21} & S_{CD22} & S_{CC22} \end{bmatrix} \quad (A.15)$$

Annex B
(informative)

Test pins – Dimensions and references

This annex contains dimensions and references of commonly used test interface pins (see Figure B.1). Use of such items is not required by this standard but may allow increased compatibility of sample prepared for test with other test laboratories.

Dimension in millimeters



Key

General tolerance:

Linear = 0,127 mm

Diameter = 0,05 mm

Angular = 2°

Figure B.1 – Example of pin and fixed connector dimensions

Example of fixed connector description:

Mill-Max 1001-0-15-15-30-27-04-0

Material: Brass alloy

Contact: 30 = Standard 4 finger contact

Contact material: Beryllium copper

Shell plating: 15 = 8,5 µm (10 µ") gold over nickel

Contact plating: 27 = 25,4 µm (30 µ") gold over nickel

Press-in 1,45 mm (0,057 in) mounting hole

Annex B
(normative)

Indirect-reference test fixtures

B.1 General

Indirect-reference test fixtures are used for measurement of transmission parameters for connector types e.g. IEC 60603-7 series (8-pole types), IEC 60603-7-2, IEC 60603-7-3, IEC 60603-7-4, IEC 60603-7-5, IEC 60603-7-41, IEC 60603-7-51, IEC 60603-7-81.

The indirect-reference test fixtures and associated test procedures used for measuring IEC 60603-7 series 8-pole connector types transmission parameters shall conform to their respective detail specification test procedures requirements and to the requirements in this annex. In the case that a conflict arises between the requirements in the respective detail specification test procedures and this standard, the respective detail specification test procedures shall take precedence.

The IEC 60603-7 series, 8-pole connector types detail specifications and respective detail test procedures standards for connector transmission parameters measurements are given in Table B.1.

Table B.1 – IEC 60603-7 series, 8-pole connector types detail specifications and respective detail connector test procedures standards

Connector specification	Frequency MHz	Test procedure	Frequency MHz
IEC 60603-7-2 IEC 60603-7-3	100	IEC 60512-26-100	100
IEC 60603-7-4 IEC 60603-7-5	250	IEC 60512-26-100	250
IEC 60603-7-41 IEC 60603-7-51	500	IEC 60512-27-100	500
IEC 60603-7-81	2 000	IEC PAS 60512-27-200	2 000

B.2 Requirements

B.2.1 General requirements

Indirect-reference test fixtures shall meet the overall test fixtures minimum signal integrity requirements listed in 4.14.

NOTE The overall test fixtures minimum signal integrity requirements are additional requirements, applicable to all test fixture types.

B.2.2 Specific requirements

Reference test fixtures shall conform to the test fixtures requirements given in the respective connector standard test procedure standard, given in Table B.1.

The 2 000 MHz reference connector crosstalk (NEXT) vector for testing crosstalk compensation circuits shall conform to the limits or fall within the boundary value ranges described in Table B.2.

The reference test fixtures shall be modified for 2 000 MHz according to the requirements given in the supplemental 2 000 MHz connector standard test procedure, IEC PAS 60512-27-200.

Table B.2 – Reference connector crosstalk (NEXT) vector

Case #	Pair combination	Limit	Limit free connector NEXT loss magnitude dB	Limit free connector NEXT loss phase (degrees)[1), 2)]
Case 1	3,6-4,5	Low	78,1-20log(*f*)	Measured TFC phase
Case 2	3,6-4,5	Central	78,6-20log(*f*)	Measured TFC phase
Case 3	3,6-4,5	Central	79,0-20log(*f*)	Measured TFC phase
Case 4	3,6-4,5	High	79,5-20log(*f*)	Measured TFC phase
Case 5	1,2-3,6	Low	86,5-20log(*f*)	Measured TFC phase
Case 6	1,2-3,6	High	89,5-20log(*f*)	Measured TFC phase
Case 7	3,6-7,8	Low	86,5-20log(*f*)	Measured TFC phase
Case 8	3,6-7,8	High	89,5-20log(*f*)	Measured TFC phase
Case 9	1,2-4,5	Low	97-20log(*f*)	+90
Case 10	1,2-4,5	High	110-20log(*f*)	-90
Case 11	4,5-7,8	Low	97-20log(*f*)	+90
Case 12	4,5-7,8	High	110-20log(*f*)	-90
Case 13	1,2-7,8	Low	106-20log(*f*)	Measured TFC phase
Case 14	1,2-7,8	High	106-20log(*f*)	Measured TFC phase minus 180°

1) TFC NEXT loss phase is determined by following the procedure in IEC PAS 60512-27-200.

2) The reference plane for measuring TFC NEXT loss phase and mated NEXT loss shall be the interface plane as described in IEC PAS 60512-27-200.

Annex C
(normative)

Direct-probe test fixtures

C.1 General

Direct-probe test fixtures are for connector types utilizing single ended direct-probe measurement of transmission parameters, e.g. IEC 60603-7 series (12-pole types), IEC 60603-7-7, IEC 60603-7-71, IEC 60603-7-82, and IEC 61076-3-110.

The direct-probe test fixtures and associated test procedures used for measuring IEC 60603-7 series 12-pole connector types transmission parameters shall conform to their respective detail specification test procedures requirements and to the requirements in this annex. In the case that a conflict arises between the requirements in the respective detail specification test procedures and this standard, the respective detail specification test procedures shall take precedence.

C.2 Requirements

C.2.1 General requirements

Direct-probe test fixtures shall meet the overall test fixtures minimum signal integrity requirements listed in 4.14.

NOTE The overall test fixtures minimum signal integrity requirements are additional requirements, applicable to all test fixture types.

C.2.2 Specific requirements

Direct-probe connector's signal integrity test fixtures should meet the minimum signal integrity requirements listed in Table C.1.

Table C.1 – Direct-probe test fixture requirements

Parameter	**Requirement** 1 MHz to 1 000 MHz	**Requirement** 1 000 MHz to 2 000 MHz
SE port (50 Ω) return loss, (dB)	> 78 – 20log(f) 30 dB max. 18 dB min.	18 dB min.
DM port (100 Ω) return loss, (dB)	> 78 – 20log(f) 30 dB max. 18 dB min.	18 dB min.
CM port (50 Ω) return loss, (dB)	> 78 – 20log(f) 30 dB max. 18 dB min.	18 dB min.
SE (50 Ω) port-to-port (pair-to-pair) isolation: NEXT and FEXT	> 135 – 20log(f) 85 dB max.	75 dB min.
SE (50 Ω) port-to-port (within a pair) isolation: NEXT and FEXT	> 110 – 20log(f) 80 dB max.	50 dB min.
DM (100 Ω) port-to-port isolation: NEXT and FEXT	> 140 – 20log(f) 94 dB max.	80 dB min.
DM (100 Ω) port-to-port isolation: near-end-to-far-end	> 140 – 20log(f) 94 dB max.	80 dB min.
DM (100 Ω) insertion loss	< 6 dB	< 6 dB
TCL, LCL	> 90 – 20log(f) 50 dB max.	30 dB min.
TCTL, LCTL	> 90 – 20log(f) 50 dB max.	30 dB min.

DUT common mode impedance is usually specified as 50 Ω, therefore for measurements, a transformation is required as specified in Annex A. For the case of balunless measurements the common mode impedance measurement and thus return loss is derived as specified in Annex A.

The requirement can be met either though separation or shielding applied between fixtures.

Annex D
(normative)

Specialized test fixtures

D.1 General

Specialized test fixtures are for connector types utilizing a combination of direct-probe and indirect-reference measurement of transmission parameters, e.g. IEC 61076-3-104, and IEC 61076-2-109.

The specialized test fixtures, for connector types utilizing a combination of direct-probe and indirect-reference test fixtures, and the associated test procedures used for measuring their transmission parameters, shall conform to their respective detail specification test procedures requirements and to the requirements in this annex. In the case that a conflict arises between the requirements in the respective detail specification test procedures and this standard, the respective detail specification test procedures shall take precedence.

D.2 Requirements

D.2.1 General requirements

Specialized test fixtures shall meet the overall test fixtures minimum signal integrity requirements listed in 4.14.

NOTE The overall test fixtures minimum signal integrity requirements are additional requirements, applicable to all test fixture types.

Specialized test fixtures should meet the direct-probe test fixtures minimum isolation requirements listed in Table C.1.

D.2.2 Specific requirements

Specialized test fixtures shall conform to the requirements given in the respective connector standard test procedure, e.g. IEC 60512-29-100.

Annex E
(informative)

Symmetry verification of resistors used for calibration

To ensure correct evaluation of symmetry of test fixtures the resistors used as termination have to be verified. This will avoid wrong calibration and wrong test results afterwards if a real DUT is connected to the test interface. If we consider the TCL formula from above and add the single ended S-parameters in the formula we find:

$$TCL = -20\log\left|S_{\mathrm{CD11}}\right| = -20\log\left|S_{11}+S_{13}-S_{31}-S_{33}\right| \qquad \text{(E.1)}$$

We can expect that the crosstalk from wire ‘a’ to wire ‘b’ is the same as from wire ‘b’ to wire ‘a’.

$$S_{13} = S_{31} \qquad \text{(E.2)}$$

In this case we have to compare the two return loss measurements S_{11} and S_{33}. The conclusion therefore is, that only if both measurements are similar high TCL values can be achieved for termination networks.

As a first step a reference termination has to be chosen. This will be used to find similar terminations which can be achieved after to achieve best TCL values on the calibration plane. This reference termination has to be used to do a full 1-port calibration using the reference termination as load. To see differences between loads it is recommended to use a polar plot as shown in Figure E.1.

As the DUT reaches highest TCL values at low frequencies this part of the frequency range has to be used to define which terminations have to be paired.

As shown in Figure E.1 also 50 Ω SMA termination will differ one from another. TCL is most critical at low frequencies and therefore only this range is given above.

One has to choose two loads which show the same deviations to the reference load.

As an example Figure E.2 shows the same cable tested, once using paired termination and once using terminations with the same magnitude but opposite phases. As explained above the effect can be seen at the lowest frequencies, for 100 m cables up to 10 MHz. If other DUTs are used like mated connectors, this can cover the whole frequency range, as the attenuation of the DUT is very low.

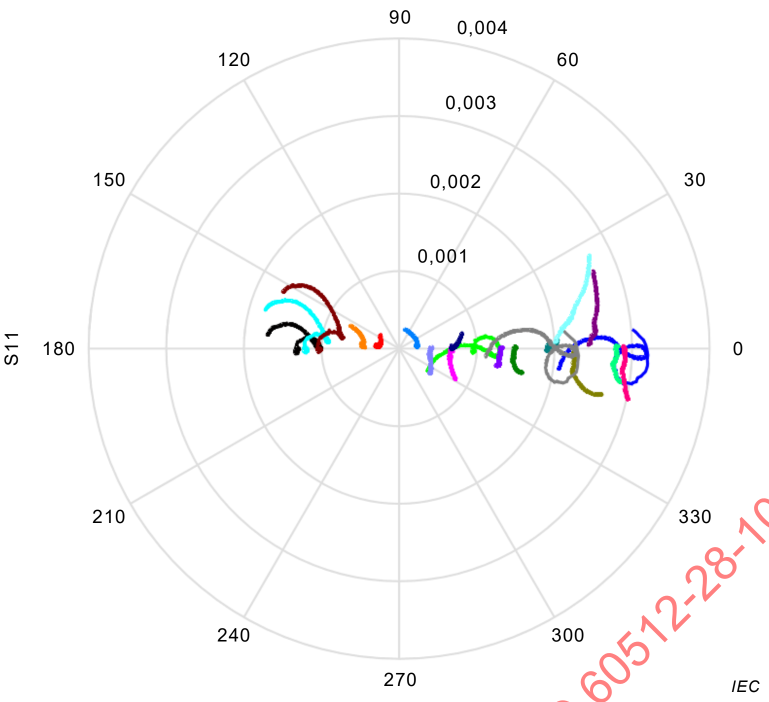


Figure E.1 – Example of 50 Ω SMA termination comparison (1 MHz – 100 MHz)

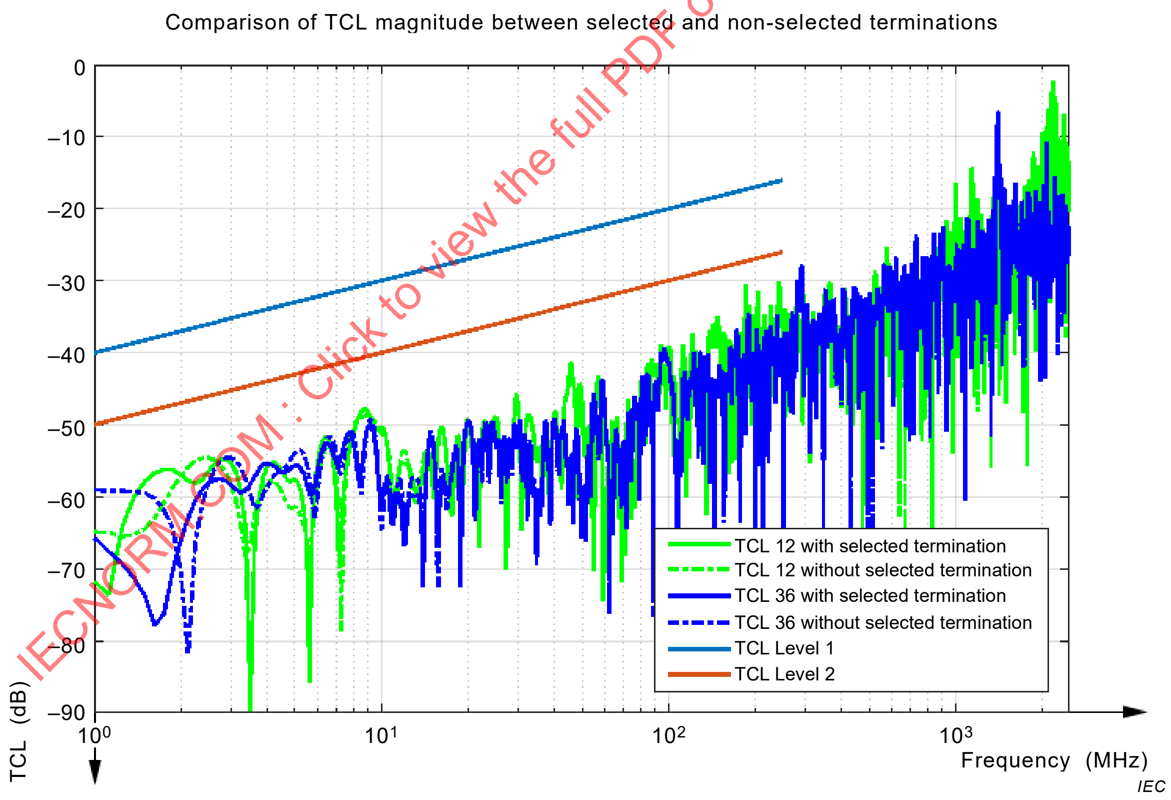


Figure E.2 – Comparison of phase selected and only magnitude selected terminations

At these levels also the transmission and reflection measurement uncertainty of the VNA cannot be neglected. This leads to a residual TCL level. By using paired termination at least the influence of the termination can be reduced.

Even though terminations' return loss might be exactly the same (in practice they do not), transmission uncertainty is not, and thus there will always be a finite residual symmetry value.

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IEC 60512-28-100

Edition 2.0 2019-11

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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Connectors for electrical and electronic equipment – Tests and measurements – Part 28-100: Signal integrity tests up to 2 000 MHz – Tests 28a to 28g

Connecteurs pour équipements électriques et électroniques – Essais et mesures – Partie 28-100: Essais d'intégrité des signaux jusqu'à 2 000 MHz – Essais 28a à 28g

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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CONNECTORS FOR ELECTRICAL AND ELECTRONIC EQUIPMENT – TESTS AND MEASUREMENTS –

Part 28-100: Signal integrity tests up to 2 000 MHz – Tests 28a to 28g

FOREWORD

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International Standard IEC 60512-28-100 has been prepared by subcommittee 48B: Electrical connectors, of IEC technical committee 48: Electrical connectors and mechanical structures for electrical and electronic equipment.

This second edition cancels and replaces the first edition, issued in 2013, and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- The title is revised from 1 000 MHz to 2 000 MHz to reflect the range of frequencies which may be tested.
- All tables and requirements have been revised up to 2 000 MHz.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
48B/2756/FDIS	48B/2766/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

A list of all parts of IEC 60512 series, under the general title *Connectors for electrical and electronic equipment – Tests and measurements* can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

CONNECTORS FOR ELECTRICAL AND ELECTRONIC EQUIPMENT – TESTS AND MEASUREMENTS –

Part 28-100: Signal integrity tests up to 2 000 MHz – Tests 28a to 28g

1 Scope

This part of IEC 60512 specifies the test methods for signal integrity and transmission performance for connectors specified in respective parts of IEC 60603-7, IEC 61076-1, IEC 61076-2, and IEC 61076-3 standards for connecting hardware applications up to 2 000 MHz. It is also suitable for testing lower frequency connectors, however, the test methodology specified in the detail specification for any given connector remains the reference conformance test for that connector. The above list of connector series of standards does not preclude referencing this document in other connector manufacturer's specifications or published standards.

Test procedures provided herein are:

– insertion loss, test 28a;

– return loss, test 28b;

– near-end crosstalk (NEXT) test 28c;

– far-end crosstalk (FEXT), test 28d;

– transverse conversion loss (TCL), test 28f;

– transverse conversion transfer loss (TCTL), test 28g.

Other test procedures referenced herein are:

– transfer impedance (Z_T), see IEC 60512-26-100, test 26e.

– for coupling attenuation (a_C), see IEC 62153-4-12.

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.

IEC 60050-581, *International Electrotechnical Vocabulary (IEV) – Part 581: Electromechanical components for electronic equipment*

IEC 60169-15, *Radio-frequency connectors – Part 15: R.F. coaxial connectors with inner diameter of outer conductor 4,13 mm (0.163 in) with screw coupling – Characteristic impedance 50 ohms (Type SMA)*

IEC 60512-1, *Connectors for electronic equipment – Tests and measurements – Part 1: Generic specification*

IEC 60512-26-100, *Connectors for electronic equipment – Tests and measurements – Part 26-100: Measurement setup, test and reference arrangement and measurements for connectors according to IEC 60603-7 – Tests 26a to 26g*

IEC 60512-27-100, *Connectors for electronic equipment – Tests and measurements – Part 27-100: Signal integrity tests up to 500 MHz on 60603-7 series connectors – Tests 27a to 27g*

IEC PAS 60512-27-200, *Connecteurs for electrical and electronic equipment – Tests and measurements – Part 27-200: Additional specifications for signal integrity tests up to 2 000 MHz on IEC 60603-7 series connectors – Tests 27a to 27g*

IEC 60512-29-100, *Connectors for electronic equipment – Tests and measurements – Part 29-100: Signal integrity tests up to 500 MHz on M12 style connectors – Tests 29a to 29g*

IEC 60603-7, *Connectors for electronic equipment – Part 7: Detail specification for 8-way, unshielded, free and fixed connectors*

IEC 60603-7-1, *Connectors for electronic equipment – Part 7-1: Detail specification for 8-way, shielded, free and fixed connectors*

IEC 60603-7-2, *Connectors for electronic equipment – Part 7-2: Detail specification for 8-way, unshielded, free and fixed connectors, for data transmissions with frequencies up to 100 MHz*

IEC 60603-7-3, *Connectors for electronic equipment – Part 7-3: Detail specification for 8-way, shielded, free and fixed connectors, for data transmission with frequencies up to 100 MHz*

IEC 60603-7-4, *Connectors for electronic equipment – Part 7-4: Detail specification for 8-way, unshielded, free and fixed connectors, for data transmissions with frequencies up to 250 MHz*

IEC 60603-7-5, *Connectors for electronic equipment – Part 7-5: Detail specification for 8-way, shielded, free and fixed connectors, for data transmissions with frequencies up to 250 MHz*

IEC 60603-7-7, *Connectors for electronic equipment – Part 7-7: Detail specification for 8-way, shielded, free and fixed connectors for data transmission with frequencies up to 600 MHz*

IEC 60603-7-41, *Connectors for electronic equipment – Part 7-41: Detail specification for 8-way, unshielded, free and fixed connectors, for data transmissions with frequencies up to 500 MHz*

IEC 60603-7-51, *Connectors for electronic equipment – Part 7-51: Detail specification for 8-way, shielded, free and fixed connectors, for data transmissions with frequencies up to 500 MHz*

IEC 60603-7-71, *Connectors for electronic equipment – Part 7-71: Detail specification for 8-way, shielded, free and fixed connectors, for data transmission with frequencies up to 1 000 MHz*

IEC 60603-7-81, *Connectors for electronic equipment – Part 7-81: Detail specification for 8-way, shielded, free and fixed connectors, for data transmissions with frequencies up to 2 000 MHz*

IEC 60603-7-82, *Connectors for electronic equipment – Part 7-82: Detail specification for 8-way, 12 contacts, shielded, free and fixed connectors, for data transmission with frequencies up to 2 000 MHz*

IEC 61076-1, *Connectors for electronic equipment – Product requirements – Part 1: Generic specification*

IEC 61076-2, *Connectors for electronic equipment – Product requirements – Part 2: Sectional specification for circular connectors*

IEC 61076-2-109, *Connectors for electronic equipment – Product requirements – Part 2-109: Circular connectors – Detail specification for connectors with M 12 x 1 screw-locking, for data transmission frequencies up to 500 MHz*

IEC 61076-3, *Connectors for electronic equipment – Product requirements – Part 3: Rectangular connectors – Sectional specification*

IEC 61076-3-104, *Connectors for electronic equipment – Product requirements – Part 3-104: Detail specification for 8-way, shielded free and fixed connectors for data transmissions with frequencies up to 2 000 MHz*

IEC 61076-3-110, *Connectors for electronic equipment – Product requirements – Part 3-110: Detail specification for free and fixed connectors for data transmission with frequencies up to 3 000 MHz*

IEC 61156-1, *Multicore and symmetrical pair/quad cables for digital communications – Part 1: Generic specification*

IEC 61156-9, *Multicore and symmetrical pair/quad cables for digital communications – Part 9: Cables for channels with transmission characteristics up to 2 GHz – Sectional specification*

IEC 61156-10:2016, *Multicore and symmetrical pair/quad cables for digital communications – Part 10: Cables for cords with transmission characteristics up to 2 GHz – Sectional specification*

IEC 61169-16, *Radio-frequency connectors – Part 16: RF coaxial connectors with inner diameter of outer conductor 7 mm (0,276 in) with screw coupling – Characteristic impedance 50 ohms (75 ohms) (Type N)*

IEC 62153-4-12, *Metallic communication cable test methods – Part 4-12: Electromagnetic compatibility (EMC) – Coupling attenuation or screening attenuation of connecting hardware – Absorbing clamp method*

ISO/IEC 11801-1:2017, *Information technology – Generic cabling for customer premises – Part 1: General requirements*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the terms and definitions given in IEC 60050-581, IEC 61076-1, IEC 60512-1, IEC 60603-7, IEC 61076-3-104 and IEC 61076-3-110, and the following apply.

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1
intermodal <parameter or measurement>
parameter or measurement that either sources on the common mode and measures on the differential mode, or sources on the differential mode and measures on the common mode

3.1.2
mixed mode <parameter or measurement>
parameters or measurements containing differential mode, common mode, and intermodal S-matrices

3.2 Abbreviated terms

a_C	coupling attenuation
CM	common mode
DM	differential mode
DUT	device under test
FEXT	far-end crosstalk loss
LCL	longitudinal conversion loss
LCTL	longitudinal conversion transfer loss
NA	network analyzer
NEXT	near-end crosstalk loss
TCL	transverse conversion loss
TCTL	transverse conversion transfer loss
SE	single ended
Z_T	transfer impedance

4 Overall test arrangement

4.1 General

This document specifies test methods and procedures for connectors.

The test methods and procedures for signal integrity and transmission performance specified herein are referenced by connector standards, specified in IEC 60603-7, IEC 60603-7-1, IEC 61076-2, 61076-3 and other standards for connecting hardware and their sectional specifications, with signal integrity specifications up to 2 000 MHz; such connector standards include IEC 60603-7-81, IEC 60603-7-82, IEC 61076-3-110, IEC 61076-3-104, and IEC 61076-2-109, which are used with twisted-pair cables having 100 Ω nominal differential characteristic impedance.

The test methods and procedures specified herein are referenced by connector standards for connecting hardware typically used with twisted-pair cables having 100 Ω nominal differential characteristic impedance, which are specified in accordance with IEC 61156-1 cable standards and its sectional specifications up to 2 000 MHz, e.g. IEC 61156-9 and IEC 61156-10.

4.2 Test instrumentation

4.2.1 General

All test instrumentation shall be capable of performing measurements over the frequency range of 1 MHz to 2 000 MHz.

4.2.2 Vector network analyser

The test procedures hereby described require the use of a vector network analyzer. The analyzer shall have the capability of full 2-port calibrations. The analyzer shall cover the frequency range of 1 MHz to 2 000 MHz at least.

Measurements are to be taken using a mixed mode test set-up, which is often referred to as an unbalanced, modal decomposition or balun-less setup. This allows measurements of balanced devices without use of an RF balun in the signal path.

Such a configuration also allows testing with either a common or differential mode stimulus or responses, ensuring that intermodal parameters can be measured without reconnection.

A 16-port network analyzer shall be used to measure all combinations of a 4-pair device without external switching, however the network analyzer shall have a minimum of 2-ports (including one bi-directional port) to enable the data to be collated and calculated.

It should be noted that the use of a 2-port analyzer will involve successive repositioning of the measurement port in order to measure any given parameter.

A 4-port network analyzer is recommended as a practical minimum number of ports, as this will allow the measurement of the full 16 term mixed mode S-parameter matrix on a given pair combination without switching or reconnection in one direction.

4.2.3 RF switching unit

In order to minimise the reconnection of the DUT for each pair combination the use of a RF switching unit is also recommended.

Each conductor of the pair or pair combination under test shall be connected to a separate port of the network analyzer, and results are processed either by internal analysis within the network analyzer or by an external application.

4.2.4 Reference loads and termination loads

Reference loads and through connections shall be utilised for the calibration of the set-up. Requirements for the reference loads shall be as given in 4.9. Termination loads shall be utilised for termination of pairs, used and unused, which are not terminated by the network analyzer. Requirements for the termination loads shall be as given in 4.11.

Loads used for calibration shall be paired as explained in Annex E to ensure good symmetry at the calibration plane.

4.3 Measurement precautions

To ensure a high degree of reliability for transmission measurements, the following precautions are required.

- Consistent and stable resistor loads shall be used throughout the test sequence.
- Cable and adapter discontinuities, as introduced by physical flexing, sharp bends and restraints shall be avoided before, during and after the tests.
- Consistent test methodology and termination resistors shall be used at all stages of transmission performance qualifications.
- The relative spacing of conductors in the pairs shall be preserved throughout the tests to the greatest extent possible.
- The balance of the cables shall be maintained to the greatest extent possible by consistent conductor lengths and pair twisting to the point of load.
- The sensitivity to set-up variations for these measurements at high frequencies demands attention to details for both the measurement equipment and the procedures.
- The test setup has to be grounded appropriately.

4.4 Mixed mode S-parameter nomenclature

The test methods specified in this document are based on a balunless test setup in which all terminals of a device under test are measured and characterised as single ended (SE) ports, i.e. signals (RF voltages and currents) shall be defined relative to a common earth (ground). For a device with 4 terminals, a diagram is given in Figure 1.

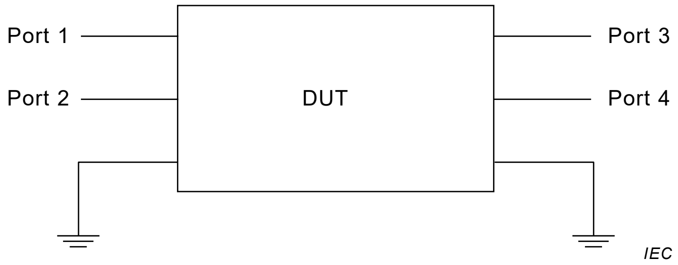

Figure 1 – Diagram of a single ended 4-port device

The 4-port device in Figure 1 shall be characterised by the 16-term SE S-matrix given in Formula 1, in which the S-parameter S_{ba} expresses the relation between a single ended response on port "b" resulting from a single ended stimulus on port "a".

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \quad (1)$$

For a balanced device, each port shall be considered to consist of a pair of terminals (= a balanced port) as opposed to the SE ports defined above, see Figure 2.

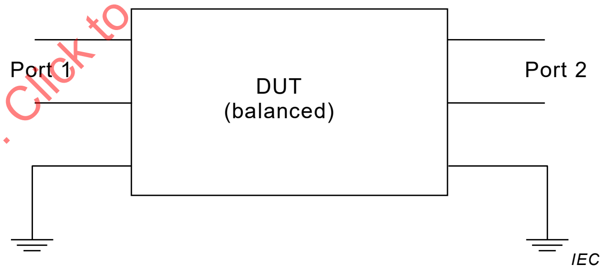

Figure 2 – Diagram of a balanced 2-port device

The device is be characterised by a mixed mode S-matrix that includes all combinations of modes and ports, e.g. the mixed mode S-parameter S_{DC21} that expresses the relation between a differential mode response on port 2 resulting from a common mode stimulus on port 1. Using this nomenclature, the full set of mixed mode S-parameters for a 2-port are given in Table 1.

Table 1 – Mixed mode S-parameter nomenclature

		Differential mode stimulus		Common mode stimulus	
		Port 1	Port 2	Port 1	Port 2
Differential mode response	Port 1	S_{DD11}	S_{DD12}	S_{DC11}	S_{DC12}
	Port 2	S_{DD21}	S_{DD22}	S_{DC21}	S_{DC22}
Common mode response	Port 1	S_{CD11}	S_{CD12}	S_{CC11}	S_{CC12}
	Port 2	S_{CD21}	S_{CD22}	S_{CC21}	S_{CC22}

A 4-terminal device can be represented both as a 4-port SE device as in Figure 1 characterised by a single ended S-matrix (Formula 1) and as a 2-port balanced device as in Figure 2 characterised by a mixed mode S-matrix (Table 1). As applying a SE signal to a port is mathematically equivalent to applying superimposed differential and common mode signals, the SE and the mixed mode characterisations of the device are interrelated. The conversion from SE to mixed mode S-parameters is given in Annex A. Making use of this conversion, the mixed mode S-parameters may be derived from the measured SE S-matrix.

4.5 Coaxial cables and interconnect for network analyzers

Assuming that the characteristic impedance of the network analyzer is 50 Ω, coaxial cables used to interconnect the network analyzer, switching matrix and the test fixture shall be of 50 Ω characteristic impedance and of low transfer impedance (double screen or more).

These coaxial cables should be as short as possible. Max 1 000 mm (on each port).

The screens of each cable shall be electrically bonded to a common earth (ground) plane.

To optimize dynamic range, the total interconnecting cable insertion loss should be less than 7 dB at 2 000 MHz per metre.

4.6 Characteristic for switching matrices

Switches (if used) may be of a minimum of 2x4 configuration at all ports, although a switch with a higher number of ports (e.g. 2x8, 1x16, 4x16) is recommended as this can allow more complete or even total measurement of the DUT without reconnection or moving the DUT. When such switching is used, it shall be constructed such that each port is configurable as input, output or 50 Ω termination. All inactive ports of the switch shall be terminated with a 50 Ω impedance load.

The switch may comply with the minimum switch performance recommendations given by Table 2.

Table 2 – Switch performance requirements

Parameter dB	Requirement 1 MHz to 1 000 MHz	Requirement 1 000 MHz to 2 000 MHz
Insertion loss	0,5 dB max.	2,0 dB max.
Return loss	68-20log(f) dB min. 40 dB max. 24 dB min.	18 dB min.
Crosstalk loss	105 dB min.	102 dB min.

4.7 Test fixture requirements

4.7.1 Test fixture types

Test fixtures are covered in three types, corresponding to three groups of connectors:

a) **Indirect-reference** test fixtures, for connector types utilizing a reference connector for measurement of transmission parameters, with additional specifications, e.g. crosstalk (NEXT) vector for crosstalk compensation parameters; e.g. IEC 60603-7 series (8-pole types), IEC 60603-7-2, IEC 60603-7-3, IEC 60603-7-4, IEC 60603-7-5, IEC 60603-7-41, IEC 60603-7-51, and IEC 60603-7-81.

b) **Direct-probe** test fixtures, for connector types utilizing single ended direct-probe measurement of transmission parameters, e.g. IEC 60603-7 series (12-pole types), IEC 60603-7-7, IEC 60603-7-71, IEC 60603-7-82, and IEC 61076-3-110.

c) **Specialized** test fixtures, for connector types utilizing a combination of direct-probe and indirect-reference measurement of transmission parameters, e.g. IEC 61076-3-104, and IEC 61076-2-109.

For the test fixture types a), b), and c) detail specifications, see Annex C, Annex B, and Annex C respectively.

4.8 Requirements for termination performance at calibration plane

Termination performance at the calibration plane shall meet the requirements of Table 3.

Table 3 – Requirements for terminations at calibration plane

Parameter	Requirement 1 MHz to 1 000 MHz	Requirement 1 000 MHz to 2 000 MHz
SE Port (50 Ω) return loss (dB)	≥72-20log(f) dB 40 dB max. 12 dB min.	12 dB min.
DM port (100 Ω) return loss (dB)	≥78-20log(f) dB 40 dB max. 20 dB min.	20 dB min.
DM Port to Port residual NEXT	≥130-20log(f) dB 94 dB max.	70 dB max.

4.9 Reference loads for calibration

To perform a 1-port or 2-port calibration of the test equipment, a short circuit, an open circuit and a reference load are required. These devices shall be used to obtain a calibration.

The reference load shall be calibrated against a calibration reference, which shall be a 50 Ω load, traceable to an international reference standard. One 50 Ω reference load shall be calibrated against the calibration reference. The reference load for calibration shall be placed in an N-type connector according to IEC 61169-16, or in an SMA-type connector according to IEC 60169-15, types suitable for panel mounting, which are machined flat on the back side, see Figure 3.

The option to use SMA-type connectors, according to IEC 60169-15 is preferred.

The load shall be fixed to the flat side of the connector. A network analyzer shall be calibrated, 1-port full calibration, with the calibration reference. Thereafter, the return loss of the reference load for calibration shall be measured. The verified return loss shall be >46 dB at frequencies up to 100 MHz and >40 dB at frequencies above 100 MHz and up to the limit for which the measurements are to be carried out.

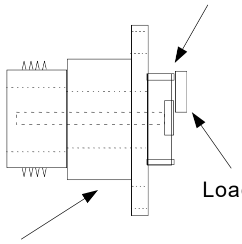

Figure 3 – Calibration of reference loads

4.10 Calibration

4.10.1 General

Isolation measurements shall be used as part of the calibration if the requirements of Table 3 are not met.

The calibration shall be equivalent to a minimum of a full 2-port SE calibration for measurements where the response and stimulus ports are the same (S_{xx11} and S_{xx22}), and a minimum of a full 4-port SE calibration for measurements where the response and stimulus ports are different (S_{xx12} and S_{xx21}).

An individual calibration shall be performed for each signal path used for the measurements.

If a complete switching matrix and 4-port network analyzer test setup is used, a full set of measurements for a 4-pair device (i.e. 16 single-ended ports), will require 28 separate 4-port calibrations, although many of the measurements within each calibration are in common with other calibrations.

A software or hardware package may be used to minimise the number of calibration measurements required.

The calibration may be performed at the test interface using appropriate calibration artefacts, or at the ends of the coaxial test cable using coaxial standards and de-embedding data representing the test fixture.

4.10.2 Calibration test interface

Where calibration is performed at the test interface, open, short and load measurements shall be taken on each SE port concerned, and through and isolation measurements shall be taken on every pair combination of those ports.

4.10.3 Calibration at end of coaxial test cables

Where calibration is performed at the end of the coaxial test cables, open, short and load measurements shall be taken on each port concerned, and through and isolation measurements shall be taken on every pair combination of those ports. In addition, the test fixture shall then be de-embedded from the measurements. The de-embedding techniques shall incorporate a fully populated 16 port S-matrix. It is not acceptable to perform a de-embedded calibration using only reflection terms (S_{11}, S_{22}, S_{33}, S_{44}) or only near end terms (S_{11},S_{21},S_{12}, S_{22}).

De-embedding using reduced term S-matrices may be used for post-processing of results.

4.11 Termination loads for termination of conductor pairs

4.11.1 General

50 Ω loads to earth (ground) shall be used on all active wires under test for termination. 50 Ω loads to earth (ground) shall be used on all inactive wires and on the opposite ends of active wires for NEXT and FEXT testing for termination. Inactive wires for return loss testing shall be terminated with 50 Ω loads to earth (ground). See Figure 4.

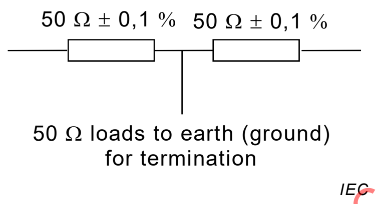

Figure 4 – Resistor termination networks

Small geometry chip resistors shall be used for the construction of resistor terminations. The two 50 Ω SE terminating resistors shall be matched to within 0,1 % at DC, and 2 % at 2 000 MHz (corresponding to a 40 dB return loss requirement at 2 000 MHz).

4.11.2 Impedance matching resistor termination networks

The performance of impedance matching resistor termination networks shall be verified by measuring the return loss of the termination and the residual NEXT between any two resistor termination networks at the calibration plane.

For the return loss measurement, a 2-port SE calibration shall be done using a reference load verified according to 4.9.

After calibration, connect the resistor termination network and perform a full 2-port SE S-matrix measurement. The measured SE S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameters S_{DD11} and S_{CC11} from which the differential mode return loss RL_{DM} and the common mode return loss RL_{CM} are determined. The return loss of the resistor termination network shall meet the requirements of Table 3.

For the residual NEXT measurement, a 4-port SE calibration is required. After calibration, connect the resistor termination networks and perform a full 4-port SE S-matrix measurement. The measured S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{DD21} from which the residual NEXT of the terminations, $NEXT_{residual\_term}$, is determined. The residual NEXT shall meet the requirements of Table 3.

4.12 Termination of screens

As the connector under test is normally screened, screened measurement cables shall be applied. The screen or screens of these cables shall be fixed to the earth (ground) plane as close as possible to the calibration plane.

4.13 Test specimen and reference planes

4.13.1 General

The test specimen is a mated pair of relevant connectors. The connector reference plane for the test specimen is the point at which the cable sheath enters the connector (the back end of the connector) or the point at which the internal geometry of the cable is no longer maintained, whichever is farther from the connector, see Figure 5. This definition applies to both ends of the test specimen. The DUT shall be terminated in accordance with the manufacturer's instructions and shall be compatible with the measurement test set up and fixtures.

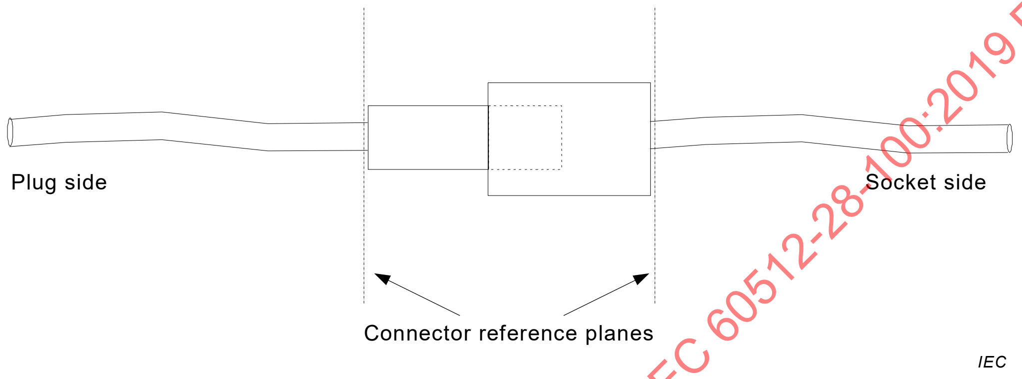

Figure 5 – Definition of reference planes

4.13.2 Interconnections between device under test (DUT) and the calibration plane

4.13.2.1 General

Twisted-pair, coax, printed circuits or other qualified interconnections shall be used between the connector reference plane of the DUT and the calibration plane. It is required to control the characteristics of these interconnections to the best extent possible as they are beyond the calibration plane. These interconnections shall be as short as practical and their CM and DM impedances shall be managed to minimize their effects on measurement.

The DM return loss performance of the interconnections shall meet the requirements of Table 4. The insertion loss performance of the interconnections is assumed to be less than 0,2 dB over the frequency range from 1 MHz to 2 000 MHz.

4.13.2.2 Twisted-pair interconnect

4.13.2.2.1 General

When used, twisted-pair interconnect shall have 100 Ω nominal differential characteristic impedance. The twisted pairs should not exhibit gaps between the conductor insulation. The twisted-pair interconnect may be obtained as an individual twisted-pair interconnect, or it may be part of a cable.

Refer to Annex B for additional information about interconnections between device under test (DUT) and the calibration plane, for connector types typically utilizing twisted-pair interconnect with indirect-reference test fixtures.

Refer to Annex B for additional information about interconnections between device under test (DUT) and the calibration plane, wherein it is recommended that all DUTs, including reference test free connectors, have fixed connectors with 2,54 mm spacing applied to the ends of their interconnect to facilitate a consistent interfacing with the test fixture.

Refer to Annex B for additional information about test pins which may be used to facilitate impedance management.

The interconnect shall comply with the return loss requirements of Table 4.

DM to earth (ground) terminations shall be used and the interconnect shall be placed in an impedance managing system. The maximum length of the twisted-pair leads at each end of the DUT shall be 51 mm, however they shall be kept as short as possible.

4.13.2.2.2 Individual twisted-pair interconnect

Individual twisted-pair interconnect may be obtained from discrete twisted-pair stock or removed from sheathed cable.

Prior to attachment to the DUT, the return loss of the pair shall be tested. For this test, a 100 mm length of individual twisted-pair shall be used. The twisted-pair shall be terminated with a 50 Ω differential mode to earth (ground) resistor termination network as described in 4.11. The resistor termination network shall be attached directly to the conductors of the pair in such a way as to minimize the disturbance of the pair. Potential disturbances include gaps between the conductor insulation in the pair, melting insulation, and excess solder.

Return loss shall be tested according to Table 4.

The twisted-pair leads are then trimmed for attachment to the DUT and the test fixture.

4.13.2.2.3 Interconnect as part of cables

Interconnect may also be obtained from a section of twisted-pair cables where the four twisted-pair interconnects are maintained in the cable sheath. This method will most often be used with free connectors cut from the ends of assembled balanced cords, but can also be used with fixed connectors.

Prior to attachment to the DUT, the return loss of each of the cable pairs within the cable shall be tested. For this test, a 100 mm length of cable shall be used. Each pair of the cable shall be terminated as described for the individual twisted-pair interconnect in 4.11. For the inactive pairs, i.e. pairs not under test, the termination shall be applied to both ends.

Return loss shall be tested according to Table 4.

The cable shall then be terminated to the DUT per manufacturer's instructions and trimmed for attachment to the test fixture.

When this method is used with free connectors cut from assembled cords, it shall be sufficient if the return loss of the cord cable is compliant to the category 8.1 and category 8.2 requirements of IEC 61156-10:2016, or if the return loss of the assembled cord is compliant to the balanced cord category 8.2 requirements of ISO/IEC 11801-1:2017.

4.13.2.3 Direct probe single ended interconnect

When used, direct probe single ended interconnect shall have 50 Ω nominal single ended (coaxial) characteristic impedance. Coaxial cables and printed circuit transmission lines within the test fixture, connected to the DUT connector contacts, should be sufficiently matched to conform to the interconnection DM return loss requirements of 4.13.2.4.

Refer to Annex C for additional information about Interconnections between device under test (DUT) and the calibration plane, for connectors utilizing Direct-probe test fixtures.

The interconnect shall comply with the return loss requirements of Table 4.

4.13.2.4 Interconnection DM return loss requirements

The return loss of the interconnection shall be tested using the mixed mode approach as described in 4.11.2 for the verification of resistor termination networks. The interconnection shall be tested for differential mode return loss only and shall meet the requirements in Table 4.

Table 4 – Interconnection DM return loss requirements

Frequency MHz	DM return loss dB
$1 \leq f < 100$	40
$100 \leq f \leq 2\ 000$	80 – 20log(f) dB 20 dB min.

Twisted-pair interconnects shall be prepared for test as described in 4.13.2.2. When testing other interconnections, equivalent differential mode to earth (ground) terminations shall be applied.

4.14 Overall test setup requirements

The requirements of the overall test setup shall meet the requirements of Table 5 when tested using terminations according to 4.11.

Table 5 – Overall test setup requirements

Parameter	Requirement 1 MHz to 1 000 MHz	Requirement 1 000 MHz to 2 000 MHz
SE port (50 Ω) return loss, (dB)	> 68 – 20log(f) 20 dB max. 12 dB min.	12 dB min.
DM port (100 Ω) return loss, (dB)	> 68 – 20log(f) 20 dB max. 12 dB min.	12 dB min.
CM port (50 Ω) return loss, (dB) [1]	> 68 – 20log(f) 20 dB max. 12 dB min.	12 dB min.
SE (50 Ω) port-to-port (pair-to-pair) isolation: NEXT and FEXT	> 125 – 20log(f) 80 dB max.	65 dB min.
SE (50 Ω) port-to-port (within a pair) isolation: NEXT and FEXT	> 100 – 20log(f) 70 dB max.	40 dB min.
DM (100 Ω) port-to-port isolation: NEXT and FEXT	> 140 – 20log(f) 94 dB max.	80 dB min.
DM (100 Ω) port-to-port isolation: near-end-to-far-end[2]	> 140 – 20log(f) 94 dB max.	80 dB min.
DM (100 Ω) insertion loss	< 12 dB	< 12 dB
TCL, LCL	> 90 – 20log(f) 50 dB max.	30 dB min.

Parameter	Requirement 1 MHz to 1 000 MHz	Requirement 1 000 MHz to 2 000 MHz
TCTL, LCTL	> 90 – 20log(*f*) 50 dB max.	30 dB min.

[1] DUT common mode impedance is usually specified as 50 Ω, therefore for measurements, a transformation is required as specified in Annex A. For the case of balunless measurements the common mode impedance measurement and thus return loss is derived as specified in Annex A.

[2] The requirement can be met either though separation or shielding applied between fixtures.

5 Connector measurements up to 2 000 MHz

5.1 General

The measurements made in this clause are on a free connector mated with a fixed connector.

5.2 Insertion loss, test 28a

5.2.1 Object

The object of this test is to measure the insertion loss of a connecting hardware pair. Insertion loss is defined here as the additional attenuation that is caused by a connecting hardware pair inserted in a communication cable.

5.2.2 Connecting hardware insertion loss

Connecting hardware shall be tested for insertion loss in one direction using at least one free connector.

5.2.3 Test method

Insertion loss is evaluated from the mixed mode parameter S_{DD21} for each conductor pair. The mixed mode S-parameters are derived by transformation of the SE S-matrix.

5.2.4 Test set-up

The test set-up consists of a network analyzer and two test fixtures as described in Clause 4. An illustration of the test set-up, which also shows the termination principles, is shown in Figure 6. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs. Interconnects (if used) shall be prepared and controlled per 4.13.2.

5.2.5 Procedure

5.2.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.9.

5.2.5.2 Measurement

The DUT shall be arranged in a test set-up according to 5.2.4 and Figure 6, including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured SE S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{DD21} from which insertion loss is determined.

Test all conductor pairs and record the results.

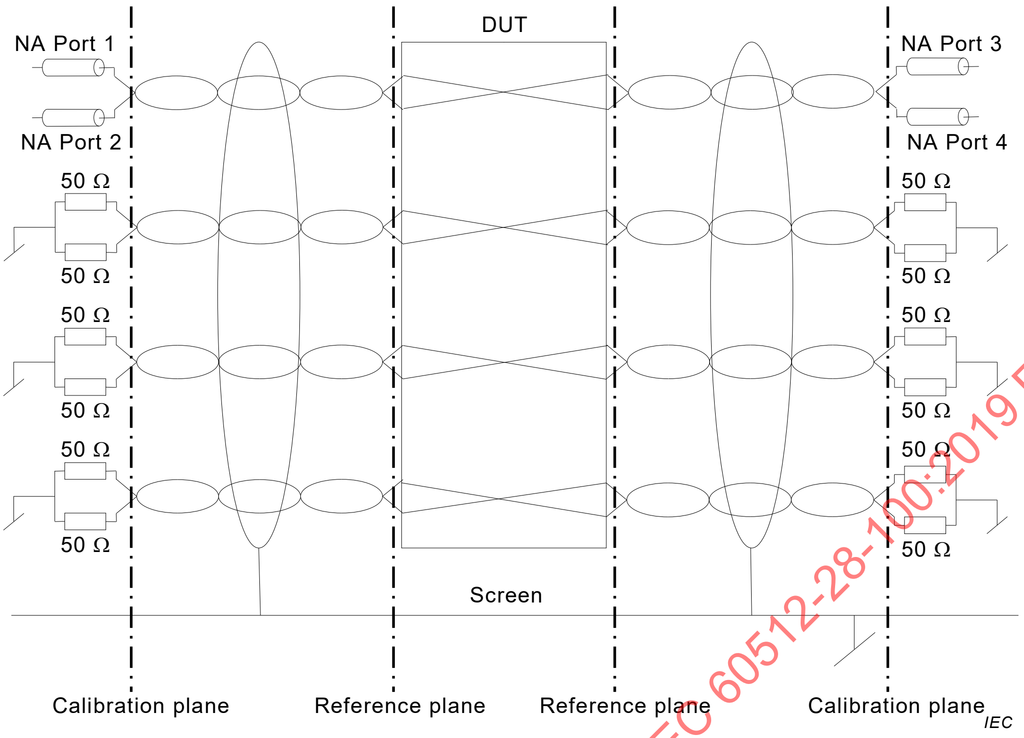

Figure 6 – Insertion loss and TCTL measurement

5.2.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.2.7 Accuracy

Mate the two interfaces of the test equipment at the calibration plane and perform an IL measurement.

The accuracy shall be better than ±1 dB at the specification limit.

5.3 Return loss, test 28b

5.3.1 Object

The object of this test is to measure the return loss of a connecting hardware pair at the two reference planes.

5.3.2 Connecting hardware return loss

Connecting hardware shall be tested for return loss in both directions using at least one free connector.

5.3.3 Test method

Return loss is evaluated from the mixed mode parameters S_{DD11} and S_{DD22} for all conductor pairs. The mixed mode S-parameters are derived by transformation of the measured SE S-matrix.

5.3.4 Test set-up

The test set-up consists of a network analyzer and two test fixtures as described in Clause 4. An illustration of the test set-up, which also shows the termination principles, is shown in Figure 9. Resistor termination networks in accordance with 4.11 shall be applied for all active and inactive pairs. Interconnects (if used) shall be prepared and controlled per 4.13.2.

Return loss may be measured in a test set-up using only one fixture and a 2-port SE calibration and measurement. In this case, the return loss is measured in only one direction at a time.

5.3.5 Procedure

5.3.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.3.5.2 Measurement

The DUT shall be arranged in a test set-up according to 5.3.4 and Figure 9, including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured SE S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameters S_{DD11} and S_{DD22} from which the return loss is determined.

Test all conductor pairs in both directions and record the results.

5.3.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.3.7 Accuracy

The return loss of the load for calibration is verified to be greater than 46 dB up to 100 MHz and greater than 40 dB at higher frequencies. The uncertainty of the connection between the connector under test and the test fixture is expected to deteriorate the return loss of the set-up (effectively the directional bridge implemented by the test set-up) by 6 dB. The accuracy of the return loss measurements is then equivalent to measurements performed by a directional bridge with a directivity of 40 dB and 34 dB.

5.4 Near-end crosstalk (NEXT), test 28c

5.4.1 Object

The object of this test procedure is to measure the magnitude of the electric and magnetic coupling between the near ends of a disturbing and disturbed pair of a connecting hardware pair combination.

5.4.2 Connecting hardware NEXT

Connecting hardware shall be tested for NEXT in both directions using at least one free connector.

5.4.3 Test method

NEXT is evaluated from the mixed mode parameter S_{DD21} for all conductor pair combinations. The mixed mode S-parameters are derived by transformation of the measured SE S-matrix.

5.4.4 Test set-up

The test set-up consists of a network analyzer and a test fixture as described in Clause 4. An illustration of the test set-up, which also shows the termination principles, is shown in Figure 7. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs and for the ends of active pairs not being connected to the network analyzer ports. Interconnects (if used) shall be prepared and controlled per 4.13.2.

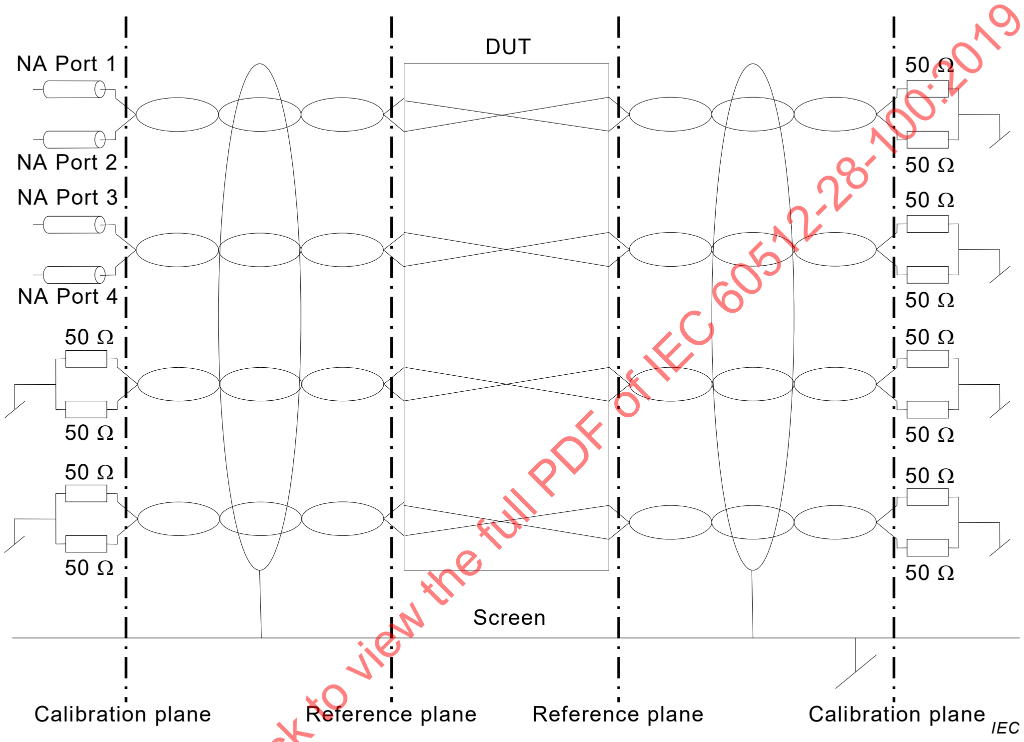

Figure 7 – NEXT measurement

5.4.5 Procedure

5.4.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.4.5.2 Establishment of noise floor

The noise floor of the set-up shall be measured. The level of the noise floor is determined by white noise, which may be reduced by increasing the test power and by reducing the bandwidth of the network analyzer, and by residual crosstalk within the test fixture.

The noise floor shall be measured by terminating the test ports of the test fixture with resistor termination networks and performing a full SE S-matrix measurement. The measured SE S-matrix is transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{DD21} from which the noise floor is established. The noise floor shall be established for all possible conductor pair combinations.

The noise floor shall be 20 dB lower than any specified limit for the crosstalk. If the measured value is closer to the noise floor than 20 dB, this shall be reported.

For high crosstalk values, it may be necessary to screen the terminating resistors.

5.4.5.3 Measurement

The DUT shall be arranged in a test set-up according to 5.4.4 and Figure 7, including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured SE S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{DD21} from which NEXT is determined.

The test has to be performed from both ends of the connecting hardware. Test all conductor pair combinations and record the results.

5.4.5.4 Determining pass and fail

The NEXT of the connecting hardware shall satisfy the requirements of the relevant detail specification for all pair combinations and in both directions.

5.4.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.4.7 Accuracy

The accuracy shall be better than ±1 dB at measurements up to 60 dB and ±2 dB at measurements up to 85 dB.

5.5 Far-end crosstalk (FEXT), test 28d

5.5.1 Object

The object of this test procedure is to measure the magnitude of the electric and magnetic coupling between the near end of a disturbing pair and the far end of disturbed pair of a connecting hardware pair combination.

5.5.2 Connecting hardware FEXT

Connecting hardware shall be tested for FEXT in both directions using at least one free connector.

5.5.3 Test method

FEXT is evaluated from the mixed mode parameter S_{DD21} for all conductor pair combinations. The mixed mode S-parameters are derived by transformation of the measured SE S-matrix.

5.5.4 Test set-up

The test set-up consists of a network analyzer and two test fixtures as described in Clause 4. An illustration of the test set-up, which also shows the termination principles, is shown in Figure 8. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs and for the ends of active pairs not being connected to the network analyzer ports. Interconnects (if used) shall be prepared and controlled per 4.13.2.

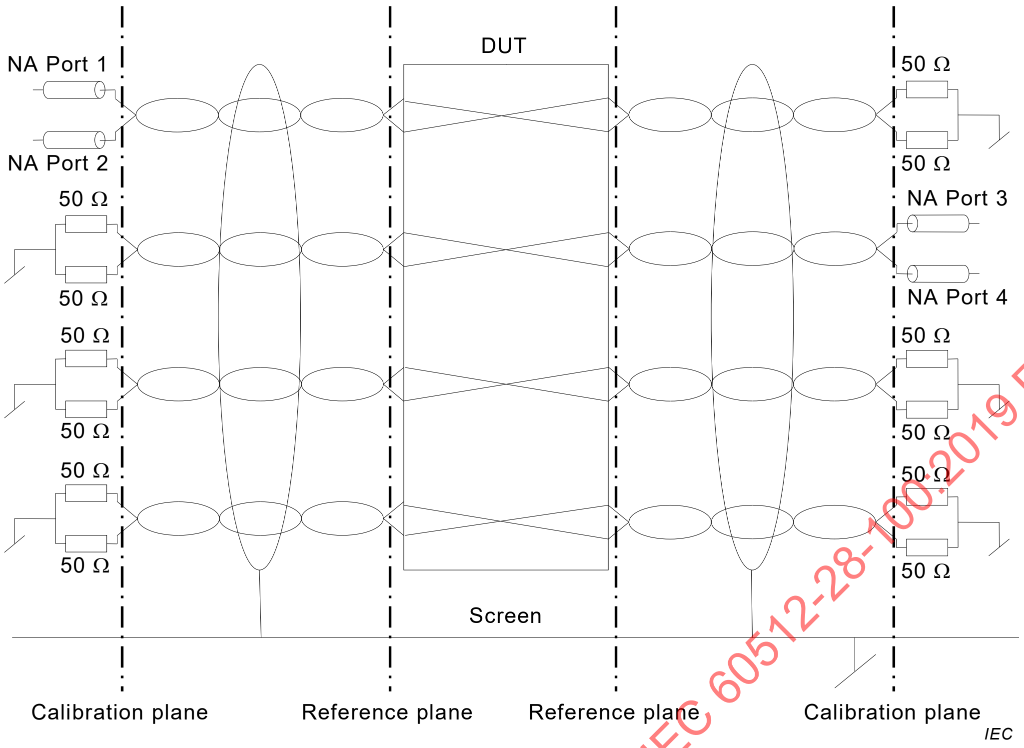

Figure 8 – FEXT measurement

5.5.5 Procedure

5.5.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.5.5.2 Establishment of noise floor

The noise floor of the set-up is established as outlined in 5.4.5.2.

5.5.5.3 Measurement

The DUT shall be arranged in a test set-up according to 5.5.4 and Figure 8, including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured SE S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{DD21} from which FEXT is determined.

Test all conductor pair combinations and record the results.

5.5.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pair combinations shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.5.7 Accuracy

The accuracy shall be better than ±1 dB at measurements up to 60 dB and ±2 dB at measurements up to 85 dB.

5.6 Transverse conversion loss (TCL), test 28f

5.6.1 Object

The object of this test is to measure the mode conversion (differential to common mode) of a signal in the conductor pairs of the DUT. This is also called unbalance attenuation or Transverse Conversion Loss, TCL.

5.6.2 Connecting hardware TCL

Connecting hardware shall be tested for TCL from both directions using at least one free connector.

5.6.3 Test method

TCL is evaluated from the mixed mode parameter S_{CD11} for all conductor pairs. The mixed mode S-parameters are derived by transformation of the measured SE S-matrix.

5.6.4 Test set-up

The test set-up consists of a network analyzer and a test fixture as described in Clause 4. An illustration of the test set-up, which also shows the termination principles, is shown in Figure 9. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs and for the ends of active pairs not being connected to the network analyzer ports. Interconnects (if used) shall be prepared and controlled per 4.13.2.

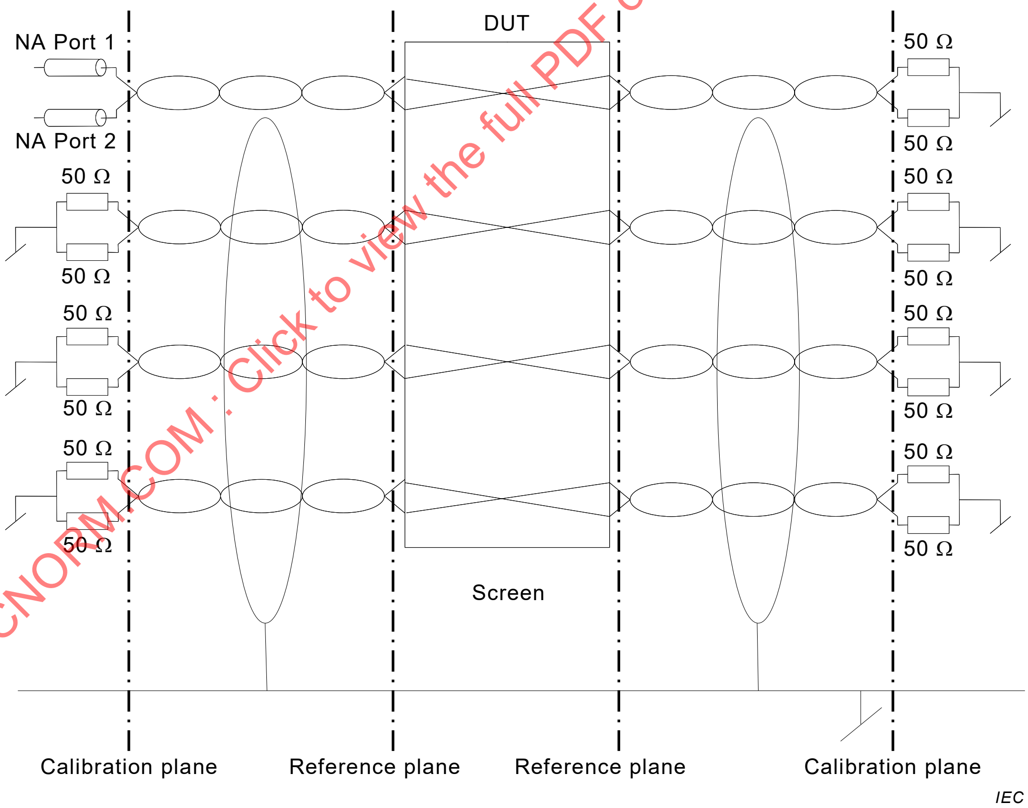

Figure 9 – Return loss and TCL measurement

5.6.5 Procedure

5.6.5.1 Calibration

A full 2-port SE calibration shall be performed at the calibration plane in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.6.5.2 Noise floor

The noise floor of the set-up shall be measured. The level of the noise floor is determined by white noise, which may be reduced by increasing the test power and by reducing the bandwidth of the network analyzer, and by residual intermodal crosstalk within the test fixture.

The noise floor, a_{noise}, shall be measured by terminating the test ports of the test fixture with resistor termination networks and performing a full SE S-matrix measurement. The measured SE S-matrix is transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{CD11} from which the noise floor is calculated as:

$$a_{\text{noise}} = -20\log\left|S_{\text{CD11}}\right| \tag{2}$$

The noise floor shall be established for all conductor pairs.

The noise floor shall be 20 dB lower than any specified limit for balance. If the measured value is closer to the noise floor than 20 dB, this shall be reported.

5.6.5.3 Measurement

The DUT shall be arranged in a test set-up according to 5.6.4 and Figure 9, including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured SE S-matrix shall be transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{CD11} from which TCL is calculated as:

$$TCL = -20\log\left|S_{\text{CD11}}\right| \tag{3}$$

The test shall be performed from both directions on the connecting hardware. Test all conductor pairs and record the results.

5.6.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.6.7 Accuracy

The accuracy shall be better than ±1 dB at the specification limit.

5.7 Transverse conversion transfer loss (TCTL), test 28g

5.7.1 Object

The object of this test is to measure the mode conversion (differential to common mode) of a signal in the conductor pairs of the DUT at the far end. This is also called far end unbalance attenuation or Transverse Conversion Transfer Loss, TCTL.

5.7.2 Connecting hardware TCTL

Connecting hardware shall be tested for TCTL from both directions using at least one free connector.

5.7.3 Test method

TCTL is evaluated from the mixed mode parameter S_{CD21} for all conductor pairs. The mixed mode S-parameters are derived by transformation of the measured SE S-matrix.

5.7.4 Test set-up

The test set-up consists of a network analyzer and two test fixtures as described in Clause 4. An illustration of the test set-up, which also shows the termination principles, is shown in Figure 6. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs. Interconnects (if used) shall be prepared and controlled per 4.13.2.

5.7.5 Procedure

5.7.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.7.5.2 Noise floor

The noise floor of the test set-up shall be measured using the same approach as outlined in 5.7.5.2 adapted to the 4-port test set-up used for TCTL.

The noise floor a_{noise} is calculated from S_{CD21} as:

$$a_{noise} = -20\log|S_{CD21}| \tag{4}$$

The same requirements as described in 5.6.5.2 adapted to TCTL as in the four--ort test set-up used for TCL.

5.7.5.3 Measurement

The DUT shall be arranged in a test set-up according to 5.7.4 and Figure 6, including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured (4-port) SE S-matrix shall be transformed into the associated (2-port) mixed mode S-matrix to obtain the S-parameter S_{CD21} from which TCTL is calculated as:

$$\text{TCTL} = -20\log|S_{CD21}| \tag{5}$$

The test shall be performed from both directions on the connecting hardware. Test all conductor pairs and record the results.

5.7.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.7.7 Accuracy

The accuracy shall be better than ±1 dB at the specification limit.

5.8 Shield transfer impedance (Z_T), test 26e

5.8.1 Object

The object of this test is to measure the shield transfer impedance of a common-mode signal transferred through the shield of the DUT. This is specifically required for screened connectors and not applicable for unshielded connectors.

For further information on applicability, see IEC 60512-26-100, refer to test 26e.

5.8.2 Connecting hardware Ttansfer impedance (Z_T)

Connecting hardware Transfer impedance (Z_T) shall be tested in accordance with IEC 62153-4-12 up to 100 MHz.

5.8.3 Test method

The transfer impedance (Z_T) test method for connectors utilizes the triaxial-tube-in-tube or the line injection apparatus.

5.8.4 Test set-up

The test set-up consists of a network analyzer and test fixtures as described in IEC 62153-4-12. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs. Interconnects (if used) shall be prepared and controlled per 4.13.2.

Transfer impedance measurement data may be derived from a common measurement set-up described in IEC 62153-4-12.

5.8.5 Procedure

5.8.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.8.5.2 Noise floor

The noise floor of the test set-up shall be measured using the same approach as outlined in 5.6.5.2 adapted to the 4-port test set-up used for TCTL.

The noise floor a_{noise} is calculated from S_{CD21} as:

$$a_{noise} = -20\log\left|S_{CD21}\right| \tag{6}$$

5.8.5.3 Measurement

The DUT shall be arranged in a test set-up according to the test fixtures as described in IEC 62153-4-12.

The test should be performed from the free connector end of the connecting hardware. Test all conductor pairs and record the results.

5.8.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.8.7 Accuracy

The accuracy shall be better than ±3 dB at the specification limit.

5.9 Coupling attenuation (a_C)

5.9.1 Object

The object of this test is to measure the mode conversion ratio through the shield (common-mode to differential-mode) of a signal in the conductor pairs of the DUT. This is specifically required for screened connectors and optional for unshielded connectors.

5.9.2 Connecting hardware coupling attenuation (a_C)

Connecting hardware coupling attenuation shall be tested in accordance with IEC 62153-4-12 over the frequency range of 30 MHz to 2 000 MHz.

5.9.3 Test method

The coupling attenuation (a_C) test method for connectors is based on coupling attenuation (a_C) measurement methods, which utilize triaxial-tube-in-tube or absorbing-clamp apparatus.

5.9.4 Test set-up

The test set-up consists of a network analyzer and test fixtures as described in IEC 62153-4-12. Resistor termination networks in accordance with 4.11 shall be applied for all inactive pairs. Interconnects (if used) shall be prepared and controlled per 4.13.2.

5.9.5 Procedure

5.9.5.1 Calibration

A full 4-port SE calibration shall be performed at the calibration planes in accordance with 4.10. Reference loads used for calibration shall be in accordance with 4.11.

5.9.5.2 Noise floor

The noise floor of the test set-up shall be measured using the same approach as outlined in 5.6.5.2 adapted to the 4-port test set-up used for TCTL.

The noise floor a_{noise} is calculated from S_{CD21} as:

$$a_{noise} = -20\log\left|S_{CD21}\right| \tag{7}$$

5.9.5.3 Measurement

The DUT shall be arranged in a test set-up according to the test fixtures as described in IEC 62153-4-12 including proper termination of the active and inactive pairs. A full SE S-matrix measurement shall be performed. The measured (three-port) SE S-matrix shall be transformed into the associated (two-port) mixed mode S-matrix to obtain the S-parameter S_{SD21} from which coupling attenuation is calculated as.

$$\mathrm{A_C} = -20\log\left|S_{\mathrm{CD21}}\right| \quad (8)$$

The test should be performed from the free connector end of the connecting hardware. Test all conductor pairs and record the results.

5.9.6 Test report

The test results shall be reported in graphical or table format with the specification limits shown on the graphs or in the table at the same frequencies as specified in the relevant detail specification. Results for all pairs shall be reported. It shall be explicitly noted if the test results exceed the test limits.

5.9.7 Accuracy

The accuracy shall be better than ±3 dB at the specification limit.

Annex A
(informative)

Derivation of mixed mode parameters using the modal decomposition technique

A.1 General

It is not a requirement of this document to require that a full derivation is produced, and any method of extracting the required S-parameters is acceptable. This may be achieved by the use of network analyzer hardware functions, specific mathematical software, or by circuit simulation tools.

This informative annex presents a summary of how to derive mixed mode parameters from 4-port measurements of S-parameters.

An impedance matrix (Z) of the DUT can be calculated based on Formula A.1.

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & Z_{13} & Z_{14} \\ Z_{21} & Z_{22} & Z_{23} & Z_{24} \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} \\ Z_{41} & Z_{42} & Z_{43} & Z_{44} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} \quad \text{(A.1)}$$

Where V is the voltage and I is the current, see Figure A.1:

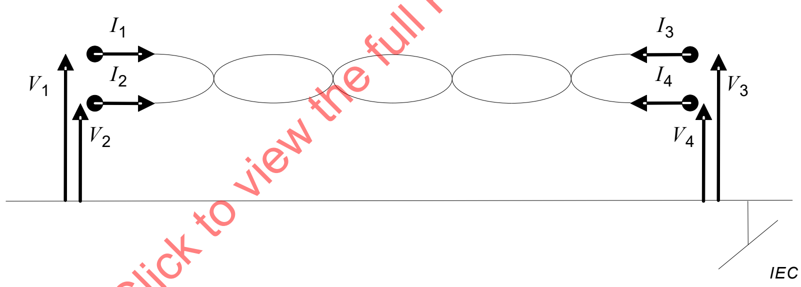

Figure A.1 – Voltage and current on balanced DUT

A.2 Example of a calculation

The modal domain impedance matrix [Z^m] is then calculated from Formula A.2 below, using the conversion matrices given in Formula A.3 and Formula A.4.

$$Z^m = P_e^{-1} Z Q_e \quad \text{(A.2)}$$

$$P_e^{-1} = \begin{bmatrix} P^{-1} & 0 \\ 0 & P^{-1} \end{bmatrix} \quad \text{(A.3)}$$

$$Q_e = \begin{bmatrix} Q & 0 \\ 0 & Q \end{bmatrix} \quad \text{(A.4)}$$

In the case of a 1 pair DUT, the size of the conversion matrices becomes 4x4 with the values given in Formula A.5 and Formula A.6

$$P = \begin{bmatrix} \frac{1}{2} & 1 \\ -\frac{1}{2} & 1 \end{bmatrix} \quad \text{(A.5)}$$

$$Q = \begin{bmatrix} 1 & \frac{1}{2} \\ -1 & \frac{1}{2} \end{bmatrix} \quad \text{(A.6)}$$

The conversion matrices replace the balun transformers and are referred to as mathematical baluns, producing Formula A.7 and Formula A.8.

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = P_e \begin{bmatrix} V_{D1} \\ V_{C1} \\ V_{D2} \\ V_{C2} \end{bmatrix} \quad \text{(A.7)}$$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = Q_e \begin{bmatrix} I_{D1} \\ I_{C1} \\ I_{D2} \\ I_{C2} \end{bmatrix} \quad \text{(A.8)}$$

Substituting Formula A.7 and Formula A.8 into Formula A.1 Formula A.9 is obtained, which is equivalent to a set of hybrid transformers attached at each end of the cable pair as described in Figure A.2.

$$\begin{bmatrix} \mathbf{V_{D1}} \\ \mathbf{V_{C1}} \\ \mathbf{V_{D2}} \\ \mathbf{V_{C2}} \end{bmatrix} = \begin{bmatrix} \mathbf{Z^m_{11}} & \mathbf{Z^m_{12}} & \mathbf{Z^m_{13}} & \mathbf{Z^m_{14}} \\ \mathbf{Z^m_{21}} & \mathbf{Z^m_{22}} & \mathbf{Z^m_{23}} & \mathbf{Z^m_{24}} \\ \mathbf{Z^m_{31}} & \mathbf{Z^m_{32}} & \mathbf{Z^m_{33}} & \mathbf{Z^m_{34}} \\ \mathbf{Z^m_{41}} & \mathbf{Z^m_{42}} & \mathbf{Z^m_{43}} & \mathbf{Z^m_{44}} \end{bmatrix} \begin{bmatrix} \mathbf{I_{D1}} \\ \mathbf{I_{C1}} \\ \mathbf{I_{D2}} \\ \mathbf{I_{C2}} \end{bmatrix} \quad \text{(A.9)}$$

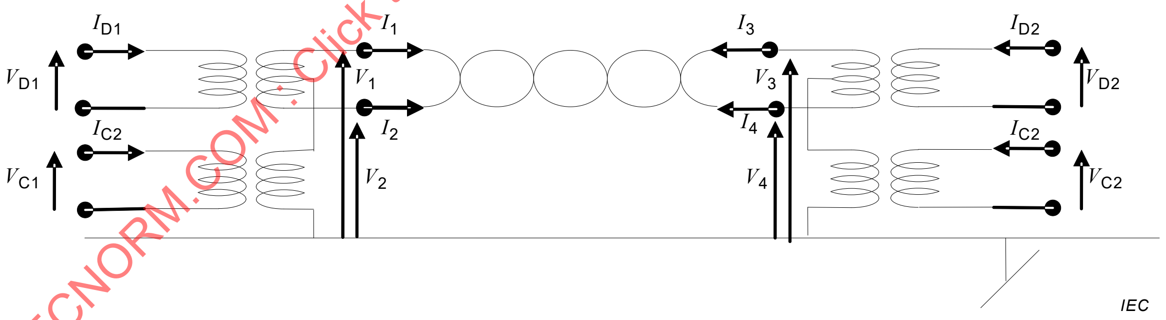

Figure A.2 – Voltage and current on unbalanced DUT

For the measurements concerned in this standard, S-parameters are measured and converted into Z-Parameters. The Z-parameter matrix of a 2n-port circuit can be derived using Formula A.10.

$$Z = R^{\frac{1}{2}}[E + S][E - S]^{-1}R^{\frac{1}{2}} \quad \text{(A.10)}$$

Where E is a 2n x 2n unit matrix and $R^{\frac{1}{2}}$ is given by Formula A.11.

$$R^{\frac{1}{2}} = \begin{bmatrix} \sqrt{r_1} & 0 & \dots & 0 \\ 0 & \sqrt{r_2} & 0 & \vdots \\ \vdots & 0 & \ddots & 0 \\ 0 & \dots & 0 & \sqrt{r_{2n}} \end{bmatrix} \quad \text{(A.11)}$$

Where r_x is the impedance of the measurement port, typically 50 Ω, giving Formula A.12

$$R^{\frac{1}{2}} = \begin{bmatrix} \sqrt{50} & 0 & \dots & 0 \\ 0 & \sqrt{50} & 0 & \vdots \\ \vdots & 0 & \ddots & 0 \\ 0 & \dots & 0 & \sqrt{50} \end{bmatrix} \quad \text{(A.12)}$$

The S-parameters in the modal domain are then calculated using Formula A.13, giving Formula A.14.

$$S^m = R_m^{-\frac{1}{2}}[Z^m - R_m][Z^m + R_m]^{-1}R_m^{\frac{1}{2}} \quad \text{(A.13)}$$

$$R_m^{\frac{1}{2}} = \begin{bmatrix} \sqrt{r_{m1}} & 0 & \dots & 0 \\ 0 & \sqrt{r_{m2}} & 0 & \vdots \\ \vdots & 0 & \ddots & 0 \\ 0 & \dots & 0 & \sqrt{r_{m2n}} \end{bmatrix} \quad \text{(A.14)}$$

By this method it is possible to convert unbalance network analyzer measurements into mixed mode S-matrices which contain both balanced and unbalanced parameters, as in Formula A.15.

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \Rightarrow \begin{bmatrix} S_{DD11} & S_{DC11} & S_{DD12} & S_{DC12} \\ S_{CD11} & S_{CC11} & S_{CD12} & S_{CC12} \\ S_{DD21} & S_{DC21} & S_{DD22} & S_{DC22} \\ S_{CD21} & S_{CC21} & S_{CD22} & S_{CC22} \end{bmatrix} \quad \text{(A.15)}$$

Annex B
(normative)

Indirect-reference test fixtures

B.1 General

Indirect-reference test fixtures are used for measurement of transmission parameters for connector types e.g. IEC 60603-7 series (8-pole types), IEC 60603-7-2, IEC 60603-7-3, IEC 60603-7-4, IEC 60603-7-5, IEC 60603-7-41, IEC 60603-7-51, IEC 60603-7-81.

The indirect-reference test fixtures and associated test procedures used for measuring IEC 60603-7 series 8-pole connector types transmission parameters shall conform to their respective detail specification test procedures requirements and to the requirements in this annex. In the case that a conflict arises between the requirements in the respective detail specification test procedures and this standard, the respective detail specification test procedures shall take precedence.

The IEC 60603-7 series, 8-pole connector types detail specifications and respective detail test procedures standards for connector transmission parameters measurements are given in Table B.1.

Table B.1 – IEC 60603-7 series, 8-pole connector types detail specifications and respective detail connector test procedures standards

Connector specification	Frequency MHz	Test procedure	Frequency MHz
IEC 60603-7-2 IEC 60603-7-3	100	IEC 60512-26-100	100
IEC 60603-7-4 IEC 60603-7-5	250	IEC 60512-26-100	250
IEC 60603-7-41 IEC 60603-7-51	500	IEC 60512-27-100	500
IEC 60603-7-81	2 000	IEC PAS 60512-27-200	2 000

B.2 Requirements

B.2.1 General requirements

Indirect-reference test fixtures shall meet the overall test fixtures minimum signal integrity requirements listed in 4.14.

NOTE The overall test fixtures minimum signal integrity requirements are additional requirements, applicable to all test fixture types.

B.2.2 Specific requirements

Reference test fixtures shall conform to the test fixtures requirements given in the respective connector standard test procedure standard, given in Table B.1.

The 2 000 MHz reference connector crosstalk (NEXT) vector for testing crosstalk compensation circuits shall conform to the limits or fall within the boundary value ranges described in Table B.2.

The reference test fixtures shall be modified for 2 000 MHz according to the requirements given in the supplemental 2 000 MHz connector standard test procedure, IEC PAS 60512-27-200.

Table B.2 – Reference connector crosstalk (NEXT) vector

Case #	Pair combination	Limit	Limit free connector NEXT loss magnitude dB	Limit free connector NEXT loss phase (degrees)[1), 2)]
Case 1	3,6-4,5	Low	78,1-20log(*f*)	Measured TFC phase
Case 2	3,6-4,5	Central	78,6-20log(*f*)	Measured TFC phase
Case 3	3,6-4,5	Central	79,0-20log(*f*)	Measured TFC phase
Case 4	3,6-4,5	High	79,5-20log(*f*)	Measured TFC phase
Case 5	1,2-3,6	Low	86,5-20log(*f*)	Measured TFC phase
Case 6	1,2-3,6	High	89,5-20log(*f*)	Measured TFC phase
Case 7	3,6-7,8	Low	86,5-20log(*f*)	Measured TFC phase
Case 8	3,6-7,8	High	89,5-20log(*f*)	Measured TFC phase
Case 9	1,2-4,5	Low	97-20log(*f*)	+90
Case 10	1,2-4,5	High	110-20log(*f*)	-90
Case 11	4,5-7,8	Low	97-20log(*f*)	+90
Case 12	4,5-7,8	High	110-20log(*f*)	-90
Case 13	1,2-7,8	Low	106-20log(*f*)	Measured TFC phase
Case 14	1,2-7,8	High	106-20log(*f*)	Measured TFC phase minus 180°

1) TFC NEXT loss phase is determined by following the procedure in IEC PAS 60512-27-200.

2) The reference plane for measuring TFC NEXT loss phase and mated NEXT loss shall be the interface plane as described in IEC PAS 60512-27-200.

Annex C
(normative)

Direct-probe test fixtures

C.1 General

Direct-probe test fixtures are for connector types utilizing single ended direct-probe measurement of transmission parameters, e.g. IEC 60603-7 series (12-pole types), IEC 60603-7-7, IEC 60603-7-71, IEC 60603-7-82, and IEC 61076-3-110.

The direct-probe test fixtures and associated test procedures used for measuring IEC 60603-7 series 12-pole connector types transmission parameters shall conform to their respective detail specification test procedures requirements and to the requirements in this annex. In the case that a conflict arises between the requirements in the respective detail specification test procedures and this standard, the respective detail specification test procedures shall take precedence.

C.2 Requirements

C.2.1 General requirements

Direct-probe test fixtures shall meet the overall test fixtures minimum signal integrity requirements listed in 4.14.

NOTE The overall test fixtures minimum signal integrity requirements are additional requirements, applicable to all test fixture types.

C.2.2 Specific requirements

Direct-probe connector's signal integrity test fixtures should meet the minimum signal integrity requirements listed in Table C.1.

Table C.1 – Direct-probe test fixture requirements

Parameter	**Requirement** 1 MHz to 1 000 MHz	**Requirement** 1 000 MHz to 2 000 MHz
SE port (50 Ω) return loss, (dB)	> 78 – 20log(f) 30 dB max. 18 dB min.	18 dB min.
DM port (100 Ω) return loss, (dB)	> 78 – 20log(f) 30 dB max. 18 dB min.	18 dB min.
CM port (50 Ω) return loss, (dB)	> 78 – 20log(f) 30 dB max. 18 dB min.	18 dB min.
SE (50 Ω) port-to-port (pair-to-pair) isolation: NEXT and FEXT	> 135 – 20log(f) 85 dB max.	75 dB min.
SE (50 Ω) port-to-port (within a pair) isolation: NEXT and FEXT	> 110 – 20log(f) 80 dB max.	50 dB min.
DM (100 Ω) port-to-port isolation: NEXT and FEXT	> 140 – 20log(f)	80 dB min.

Parameter	Requirement 1 MHz to 1 000 MHz	Requirement 1 000 MHz to 2 000 MHz
	94 dB max.	
DM (100 Ω) port-to-port isolation: near-end-to-far-end	> 140 – 20log(*f*) 94 dB max.	80 dB min.
DM (100 Ω) insertion loss	< 6 dB	< 6 dB
TCL, LCL	> 90 – 20log(*f*) 50 dB max.	30 dB min.
TCTL, LCTL	> 90 – 20log(*f*) 50 dB max.	30 dB min.

DUT common mode impedance is usually specified as 50 Ω, therefore for measurements, a transformation is required as specified in Annex A. For the case of balunless measurements the common mode impedance measurement and thus return loss is derived as specified in Annex A.

The requirement can be met either though separation or shielding applied between fixtures.

Annex D
(normative)

Specialized test fixtures

D.1 General

Specialized test fixtures are for connector types utilizing a combination of direct-probe and indirect-reference measurement of transmission parameters, e.g. IEC 61076-3-104, and IEC 61076-2-109.

The specialized test fixtures, for connector types utilizing a combination of direct-probe and indirect-reference test fixtures, and the associated test procedures used for measuring their transmission parameters, shall conform to their respective detail specification test procedures requirements and to the requirements in this annex. In the case that a conflict arises between the requirements in the respective detail specification test procedures and this standard, the respective detail specification test procedures shall take precedence.

D.2 Requirements

D.2.1 General requirements

Specialized test fixtures shall meet the overall test fixtures minimum signal integrity requirements listed in 4.14.

NOTE The overall test fixtures minimum signal integrity requirements are additional requirements, applicable to all test fixture types.

Specialized test fixtures should meet the direct-probe test fixtures minimum isolation requirements listed in Table C.1.

D.2.2 Specific requirements

Specialized test fixtures shall conform to the requirements given in the respective connector standard test procedure, e.g. IEC 60512-29-100.

Annex E
(informative)

Symmetry verification of resistors used for calibration

To ensure correct evaluation of symmetry of test fixtures the resistors used as termination have to be verified. This will avoid wrong calibration and wrong test results afterwards if a real DUT is connected to the test interface. If we consider the TCL formula from above and add the single ended S-parameters in the formula we find:

$$TCL = -20\log\left|S_{\text{CD11}}\right| = -20\log\left|S_{11}+S_{13}-S_{31}-S_{33}\right| \quad \text{(E.1)}$$

We can expect that the crosstalk from wire ‘a’ to wire ‘b’ is the same as from wire ‘b’ to wire ‘a’.

$$S_{13} = S_{31} \quad \text{(E.2)}$$

In this case we have to compare the two return loss measurements S_{11} and S_{33}. The conclusion therefore is, that only if both measurements are similar high TCL values can be achieved for termination networks.

As a first step a reference termination has to be chosen. This will be used to find similar terminations which can be achieved after to achieve best TCL values on the calibration plane. This reference termination has to be used to do a full 1-port calibration using the reference termination as load. To see differences between loads it is recommended to use a polar plot as shown in Figure E.1.

As the DUT reaches highest TCL values at low frequencies this part of the frequency range has to be used to define which terminations have to be paired.

As shown in Figure E.1 also 50 Ω SMA termination will differ one from another. TCL is most critical at low frequencies and therefore only this range is given above.

One has to choose two loads which show the same deviations to the reference load.

As an example Figure E.2 shows the same cable tested, once using paired termination and once using terminations with the same magnitude but opposite phases. As explained above the effect can be seen at the lowest frequencies, for 100 m cables up to 10 MHz. If other DUTs are used like mated connectors, this can cover the whole frequency range, as the attenuation of the DUT is very low.

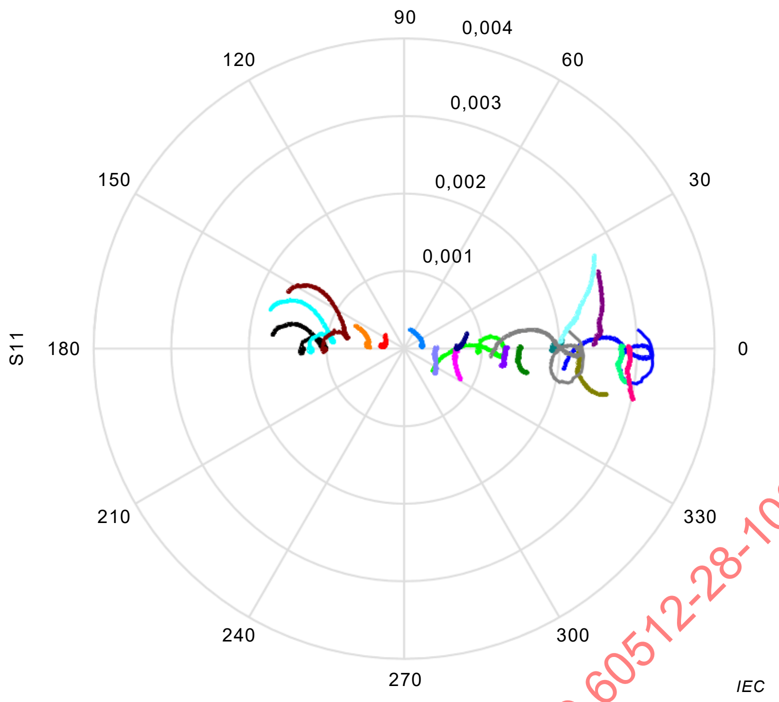

Figure E.1 – Example of 50 Ω SMA termination comparison (1 MHz – 100 MHz)

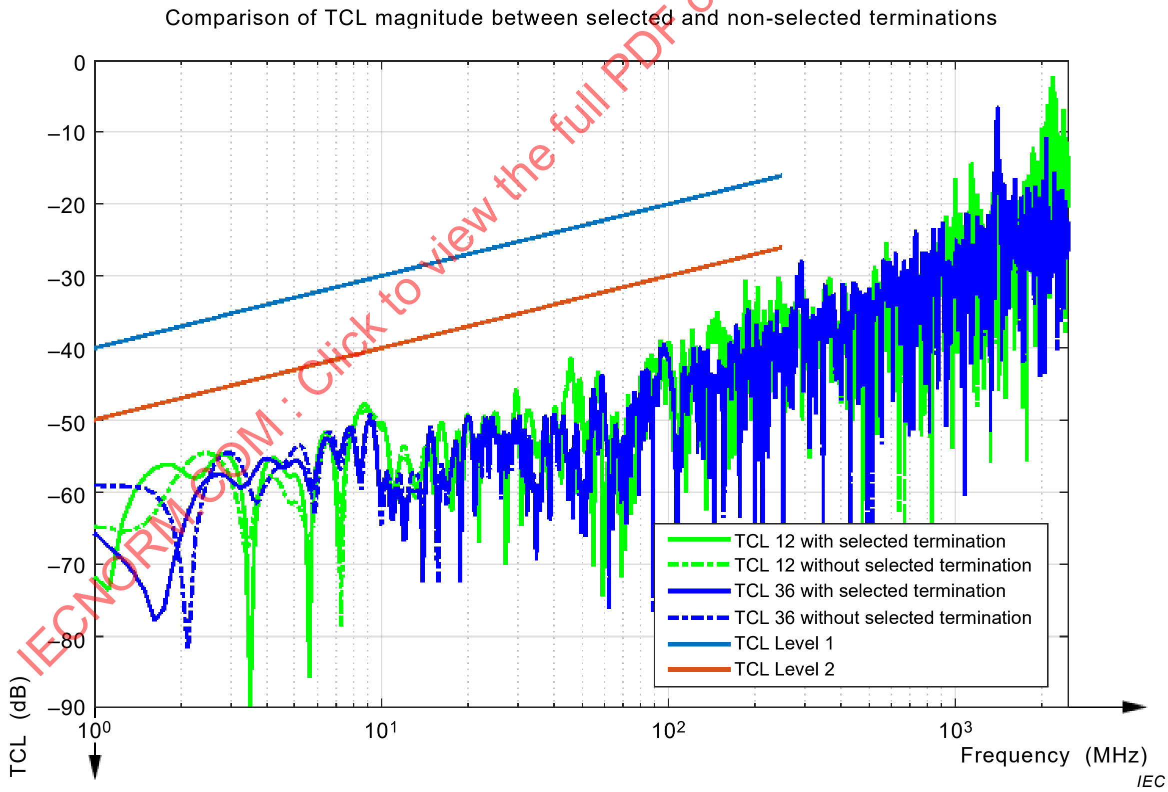

Figure E.2 – Comparison of phase selected and only magnitude selected terminations

At these levels also the transmission and reflection measurement uncertainty of the VNA cannot be neglected. This leads to a residual TCL level. By using paired termination at least the influence of the termination can be reduced.

Even though terminations' return loss might be exactly the same (in practice they do not), transmission uncertainty is not, and thus there will always be a finite residual symmetry value.

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ITU-T Recommendation O.9, *Measuring arrangements to assess the degree of unbalance about earth*

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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CONNECTEURS POUR ÉQUIPEMENTS ÉLECTRIQUES ET ÉLECTRONIQUES – ESSAIS ET MESURES –

Partie 28-100: Essais d'intégrité des signaux jusqu'à 2 000 MHz – Essais 28a à 28g

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La Norme internationale IEC 60512-28-100 a été établie par le sous-comité 48B: Connecteurs électriques, du comité d'études 48 de l'IEC: Connecteurs électriques et structures mécaniques pour les équipements électriques et électroniques.

Cette deuxième édition annule et remplace la première édition parue en 2013 et constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

- Le titre a été modifié, 1 000 MHz a été remplacé par 2 000 MHz afin de refléter la plage des fréquences qui peuvent être soumises à des essais.

- Tous les tableaux et toutes les exigences ont été révisés jusqu'à 2 000 MHz.

Le texte de cette Norme internationale est issu des documents suivants:

FDIS	Rapport de vote
48B/2756/FDIS	48B/2766/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette norme.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

Les futures normes de cette série porteront dorénavant le nouveau titre général cité ci-dessus. Le titre des normes existant déjà dans cette série sera mis à jour lors de la prochaine édition.

Une liste de toutes les parties de la série IEC 60512, sous le titre général *Connecteurs pour équipements électriques et électroniques – Essais et mesures* peut être consultée sur le site web de l'IEC.

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CONNECTEURS POUR ÉQUIPEMENTS ÉLECTRIQUES ET ÉLECTRONIQUES – ESSAIS ET MESURES –

Partie 28-100: Essais d'intégrité des signaux jusqu'à 2 000 MHz – Essais 28a à 28g

1 Domaine d'application

La présente partie de l'IEC 60512 spécifie les méthodes d'essai d'intégrité des signaux et de qualité de transmission pour des connecteurs spécifiés dans les parties respectives des normes IEC 60603-7, IEC 61076-1, IEC 61076-2 et IEC 61076-3 pour des applications de matériel de connexion jusqu'à 2 000 MHz. Elle s'applique également aux essais de connecteurs de fréquences inférieures, mais la méthodologie d'essai stipulée dans la spécification particulière pour tout connecteur donné reste l'essai de conformité de référence pour le connecteur en question. La liste ci-dessus de séries de normes concernant les connecteurs n'exclut pas le fait de faire référence au présent document dans d'autres normes publiées ou spécifications des fabricants de connecteurs.

Les procédures spécifiées ici sont:

– perte d'insertion, essai 28a;
– affaiblissement de réflexion, essai 28b;
– paradiaphonie (NEXT), essai 28c;
– télédiaphonie (FEXT), essai 28d;
– perte de conversion transverse (TCL), essai 28f;
– perte de transfert de conversion transverse (TCTL), essai 28g.

Les autres procédures citées ici en référence sont:

– impédance de transfert (Z_T), voir l'IEC 60512-26-100, essai 26e;
– pour l'affaiblissement de couplage (a_C), voir l'IEC 62153-4-12.

2 Références normatives

Les documents suivants cités dans le texte constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60050-581, *Vocabulaire Électrotechnique International (IEV) – Partie 581: Composants électromécaniques pour équipements électroniques*

IEC 60169-15, *Connecteurs pour fréquences radioélectriques – Partie 15: Connecteurs coaxiaux pour fréquences radioélectriques avec diamètre intérieur du conducteur extérieur de 4,13 mm (0,163 in) à verrouillage à vis – Impédance caractéristique 50 ohms (type SMA)*

IEC 60512-1, *Connecteurs pour équipements électriques et électroniques – Essais et mesures – Partie 1: Spécification générique*

IEC 60512-26-100, *Connecteurs pour équipements électroniques – Essais et mesures – Partie 26-100: Montage de mesure, dispositifs d'essai et de référence et mesures pour les connecteurs conformes à l'IEC 60603-7 – Essais 26a à 26g*

IEC 60512-27-100, *Connecteurs pour équipements électroniques – Essais et mesures – Partie 27-100: Essais d'intégrité des signaux jusqu'à 500 MHz sur les connecteurs de la série IEC 60603-7 – Essais 27a à 27g*

IEC PAS 60512-27-200, *Connecteurs for electrical and electronic equipment – Tests and measurements – Part 27-200: Additional specifications for signal integrity tests up to 2 000 MHz on IEC 60603-7 series connectors – Tests 27a to 27g* (disponible en anglais seulement)

IEC 60512-29-100, *Connecteurs pour équipements électroniques – Essais et mesures – Partie 29-100: Essais d'intégrité des signaux jusqu'à 500 MHz sur les connecteurs de type M12 – Essais 29a à 29g*

IEC 60603-7, *Connecteurs pour équipements électroniques – Partie 7: Spécification particulière pour les fiches et les embases non écrantées à 8 voies*

IEC 60603-7-1, *Connecteurs pour équipements électroniques – Partie 7-1: Spécification particulière pour les fiches et les embases écrantées à 8 voies*

IEC 60603-7-2, *Connecteurs pour équipements électroniques – Partie 7-2: Spécification particulière pour les fiches et les embases non blindées à 8 voies pour la transmission de données à des fréquences jusqu'à 100 MHz*

IEC 60603-7-3, *Connecteurs pour équipements électroniques – Partie 7-3: Spécification particulière pour les fiches et les embases blindées à 8 voies pour la transmission de données à des fréquences jusqu'à 100 MHz*

IEC 60603-7-4, *Connecteurs pour équipements électroniques – Partie 7-4: Spécification particulière pour les fiches et les embases non blindées à 8 voies pour la transmission de données à des fréquences jusqu'à 250 MHz*

IEC 60603-7-5, *Connecteurs pour équipements électroniques – Partie 7-5: Spécification particulière pour les fiches et les embases blindées à 8 voies pour la transmission de données à des fréquences jusqu'à 250 MHz*

IEC 60603-7-7, *Connecteurs pour équipements électroniques – Partie 7-7: Spécification particulière pour les fiches et les embases blindées à 8 voies pour la transmission de données à des fréquences jusqu'à 600 MHz*

IEC 60603-7-41, *Connecteurs pour équipements électroniques – Partie 7-41: Spécification particulière pour les fiches et les embases non blindées à 8 voies pour la transmission de données à des fréquences jusqu'à 500 MHz*

IEC 60603-7-51, *Connecteurs pour équipements électroniques – Partie 7-51: Spécification particulière pour les fiches et les embases blindées à 8 voies pour la transmission de données à des fréquences jusqu'à 500 MHz*

IEC 60603-7-71, *Connecteurs pour équipements électroniques – Partie 7-71: Spécification particulière pour les fiches et les embases blindées à 8 voies pour la transmission de données à des fréquences jusqu'à 1 000 MHz*

IEC 60603-7-81, *Connecteurs pour équipements électroniques – Partie 7-81: Spécification particulière pour les fiches et les embases blindées à 8 voies pour la transmission de données à des fréquences jusqu'à 2 000 MHz*

IEC 60603-7-82, *Connecteurs pour équipements électroniques – Partie 7-82: Spécification particulière pour les fiches et les embases écrantées à 8 voies et 12 contacts pour la transmission de données à des fréquences jusqu'à 2 000 MHz*

IEC 61076-1, *Connecteurs pour équipements électroniques – Exigences de produit – Partie 1: Spécification générique*

IEC 61076-2, *Connecteurs pour équipements électroniques – Exigences de produit – Partie 2: Spécification intermédiaire pour les connecteurs circulaires*

IEC 61076-2-109, *Connecteurs pour équipements électroniques – Exigences de produit – Partie 2-109: Connecteurs circulaires – Spécification particulière relative aux connecteurs avec verrouillage à vis M 12 x 1, pour les transmissions de données à des fréquences jusqu'à 500 MHz*

IEC 61076-3, *Connecteurs pour équipements électroniques – Exigences de produit – Partie 3: Connecteurs rectangulaires – Spécification intermédiaire*

IEC 61076-3-104, *Connectors for electronic equipment – Product requirements – Part 3-104: Detail specification for 8-way, shielded free and fixed connectors for data transmissions with frequencies up to 2 000 MHz* (disponible en anglais seulement)

IEC 61076-3-110, *Connecteurs pour équipements électroniques – Exigences de produit – Partie 3-110: Spécification particulière pour les fiches et les embases pour la transmission de données à des fréquences jusqu'à 3 000 MHz*

IEC 61156-1, *Câbles multiconducteurs à paires symétriques et quartes pour transmissions numériques – Partie 1: Spécification générique*

IEC 61156-9, *Multicore and symmetrical pair/quad cables for digital communications – Part 9: Cables for channels with transmission characteristics up to 2 GHz – Sectional specification* (disponible en anglais seulement)

IEC 61156-10:2016, *Multicore and symmetrical pair/quad cables for digital communications – Part 10: Cables for cords with transmission characteristics up to 2 GHz – Sectional specification* (disponible en anglais seulement)

IEC 61169-16, *Connecteurs pour fréquences radioélectriques – Partie 16: Spécification intermédiaire – Connecteurs coaxiaux pour fréquences radioélectriques avec diamètre intérieur du conducteur extérieur de 7 mm (0,276 in) à verrouillage à vis – Impédance caractéristique 50 ohms (75 ohms) (type N)*

IEC 62153-4-12, *Metallic communication cable test methods – Part 4-12: Electromagnetic compatibility (EMC) – Coupling attenuation or screening attenuation of connecting hardware – Absorbing clamp method* (disponible en anglais seulement)

ISO/IEC 11801-1:2017, *Information technology – Generic cabling for customer premises – Part 1: General requirements*(disponible en anglais seulement)

3 Termes, définitions et termes abrégés

Pour les besoins du présent document, les termes et définitions donnés dans l'IEC 60050-581, l'IEC 61076-1, l'IEC 60512-1, l'IEC 60603-7, l'IEC 61076-3-104 et l'IEC 61076-3-110, ainsi que les suivants, s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

3.1 Termes et définitions

3.1.1
intermodal <paramètre ou mesure>
paramètre ou mesure dont la source est sur le mode commun et la mesure se fait sur le mode différentiel ou dont la source est sur le mode différentiel et la mesure se fait sur le mode commun

3.1.2
mode mixte <paramètre ou mesure>
paramètres ou mesures contenant un mode différentiel, un mode commun et des matrices S intermodales

3.2 Termes abrégés

a_C	affaiblissement de Couplage
CM	Common Mode (mode commun)
DM	Differential Mode (mode différentiel)
DUT	Device Under Test (dispositif en essai)
FEXT	far-end crosstalk loss (télédiaphonie)
LCL	Longitudinal Conversion Loss (perte de conversion longitudinale)
LCTL	Longitudinal Conversion Transfer Loss (perte de transfert de conversion longitudinale)
NA	Network Analyzer (analyseur de réseau)
NEXT	near-end crosstalk loss (paradiaphonie)
TCL	Transversal Conversion Loss (perte de conversion transverse)
TCTL	Transversal Conversion Transfer Loss (perte de transfert de conversion transverse)
SE	Single Ended (asymétrique)
Z_T	transfer impedance (impédance de transfert)

4 Dispositif d'essai global

4.1 Généralités

Le présent document spécifie des méthodes et des procédures d'essai pour des connecteurs.

Les méthodes et les procédures d'essai d'intégrité des signaux et de qualité de transmission spécifiées dans le présent document sont référencées par normes de connecteurs, spécifiées dans l'IEC 60603-7, l'IEC 60603-7-1, l'IEC 61076-2, l'IEC 61076-3 et d'autres normes relatives au matériel de connexion et leurs spécifications intermédiaires, avec des spécifications d'intégrité des signaux jusqu'à 2 000 MHz; de telles normes de connecteurs incluent l'IEC 60603-7-81, l'IEC 60603-7-82, l'IEC 61076-3-110, l'IEC 61076-3-104 et l'IEC 61076-2-109, qui sont utilisées avec des câbles à paire torsadée ayant une impédance caractéristique différentielle nominale de 100 Ω.

Les méthodes et les procédures d'essai spécifiées dans le présent document sont référencées par normes de connecteurs pour le matériel de connexion typiquement utilisé avec des câbles à paire torsadée ayant une impédance caractéristique différentielle nominale de 100 Ω, qui sont spécifiés conformément à la norme de câbles IEC 61156-1 et ses spécifications intermédiaires jusqu'à 2 000 MHz, par exemple l'IEC 61156-9 et l'IEC 61156-10.

4.2 Instrumentation d'essai

4.2.1 Généralités

Tous les instruments d'essai doivent être capables d'effectuer les mesures sur la plage de fréquences comprises entre 1 MHz et 2 000 MHz.

4.2.2 Analyseur vectoriel de réseau

Les procédures d'essais décrites exigent l'utilisation d'un analyseur vectoriel de réseau. L'analyseur doit présenter une capacité d'étalonnage complet sur 2 accès. L'analyseur doit au minimum couvrir la plage de fréquences comprises entre 1 MHz et 2 000 MHz.

Les mesures doivent être effectuées à l'aide d'un montage d'essai en mode mixte, souvent appelé montage sans symétriseur, à décomposition modale ou déséquilibré. Ceci permet de mesurer des dispositifs équilibrés sans placer de symétriseur RF sur le chemin du signal.

Une telle configuration permet également d'effectuer les essais avec un stimulus ou des réponses en mode commun ou différentiel, garantissant ainsi que les paramètres intermodaux peuvent être mesurés sans reconnexion.

Un analyseur de réseau à 16 accès doit être utilisé pour mesurer toutes les combinaisons d'un dispositif à 4 paires sans commutation externe. Toutefois, l'analyseur de réseau doit avoir au minimum 2 accès (y compris un accès bidirectionnel) pour permettre aux données d'être assemblées et calculées.

Il convient de noter que l'utilisation d'un analyseur à 2 accès implique le repositionnement successif de l'accès de mesure afin de mesurer n'importe quel paramètre donné.

Il est recommandé d'utiliser un analyseur de réseau à 4 accès car il offre un nombre minimal pratique d'accès. Ce nombre permet en effet de mesurer les 16 termes de la matrice des paramètres S en mode mixte sur une combinaison de paires donnée, sans commutation ni reconnexion dans une direction.

4.2.3 Unité de commutation RF

Afin de réduire le plus possible la reconnexion du DUT pour chaque combinaison de paires, il est également recommandé d'utiliser une unité de commutation RF.

Chaque conducteur de la paire ou de la combinaison de paires en essai doit être connecté à un accès distinct de l'analyseur de réseau, et les résultats sont traités par une analyse interne dans l'analyseur de réseau ou par une application externe.

4.2.4 Charges de référence et charges de sortie

Des connexions traversantes et des charges de référence doivent être utilisées pour l'étalonnage du montage d'essai. Les exigences concernant les charges de référence doivent être celles indiquées en 4.9. Des charges de sortie doivent être utilisées pour la terminaison des paires, utilisées et non utilisées, qui ne sont pas raccordées à l'analyseur de réseau. Les exigences concernant les charges de sortie doivent être celles indiquées en 4.11.

Les charges utilisées pour l'étalonnage doivent être accouplées suivant les explications de l'Annexe E afin de garantir une bonne symétrie au niveau du plan d'étalonnage.

4.3 Précautions de mesure

Pour assurer un haut degré de fiabilité pour les mesures de transmission, les précautions suivantes sont exigées.

- Des charges résistives stables et cohérentes doivent être utilisées tout au long de la série d'essais.
- Avant, pendant et après les essais, les discontinuités dans les câbles et les adaptateurs, qui peuvent être causées par des flexions physiques, des coudes en équerre et des forces de contrainte, doivent être évitées.
- Une méthodologie d'essai et des résistances de sortie cohérentes doivent être utilisées à toutes les étapes des qualifications de la qualité de transmission.
- L'espacement relatif entre conducteurs dans les paires doit être préservé tout au long des essais au maximum de ce qui est possible.
- La symétrie des câbles doit être maintenue autant que possible par des longueurs de conducteurs cohérentes et un torsadage des paires jusqu'au point de charge.
- La sensibilité aux variations de montage pour ces mesures à hautes fréquences nécessite de prêter attention aux détails tant en ce qui concerne l'équipement de mesure que les procédures.
- Le montage d'essai doit être correctement mis à la terre.

4.4 Nomenclature des paramètres S en mode mixte

Les méthodes d'essai spécifiées dans le présent document sont basées sur un montage d'essai sans symétriseur dans lequel toutes les bornes d'un dispositif en essai sont mesurées et caractérisées comme des accès asymétriques (SE), c'est-à-dire que les signaux (tensions et courants RF) doivent être définis par rapport à une terre (masse) commune. Le schéma de la Figure 1 représente un dispositif équipé de 4 bornes.

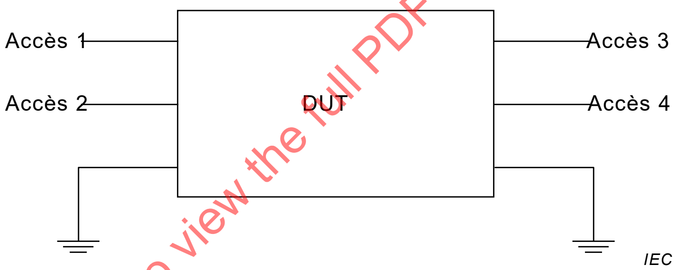

Figure 1 – Schéma d'un dispositif à 4 accès asymétriques

Le dispositif à 4 accès de la Figure 1 doit être caractérisé par les 16 termes de la matrice S asymétrique donnée dans la Formule 1, dans laquelle le paramètre S, S_{ba}, représente la relation entre une réponse asymétrique sur l'accès “b” résultant d'un stimulus asymétrique sur l'accès “a”.

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \quad (1)$$

Pour un dispositif équilibré, chaque accès doit être considéré comme étant constitué d'une paire de bornes (= un accès équilibré) par opposition aux accès asymétriques définis ci-dessus (voir Figure 2).

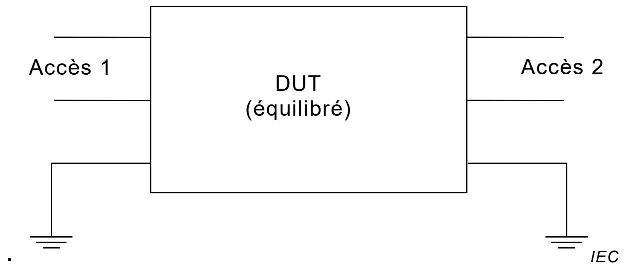

Figure 2 – Schéma d'un dispositif à 2 accès équilibrés

Le dispositif doit être caractérisé par une matrice S en mode mixte qui inclut toutes les combinaisons de modes et d'accès, par exemple le paramètre S, S_{DC21}, en mode mixte qui exprime la relation entre une réponse en mode différentiel sur l'accès 2 résultant d'un stimulus en mode commun sur l'accès 1. En utilisant cette nomenclature, l'ensemble complet des paramètres S en mode mixte pour 2 accès est indiqué dans le Tableau 1.

Tableau 1 – Nomenclature des paramètres S en mode mixte

		Stimulus en mode différentiel		Stimulus en mode commun	
		Accès 1	**Accès 2**	**Accès 1**	**Accès 2**
Réponse en mode différentiel	Accès 1	S_{DD11}	S_{DD12}	S_{DC11}	S_{DC12}
	Accès 2	S_{DD21}	S_{DD22}	S_{DC21}	S_{DC22}
Réponse en mode commun	Accès 1	S_{CD11}	S_{CD12}	S_{CC11}	S_{CC12}
	Accès 2	S_{CD21}	S_{CD22}	S_{CC21}	S_{CC22}

Un dispositif à 4 bornes peut être représenté à la fois comme un dispositif asymétrique à 4 accès comme sur la Figure 1, caractérisé par une matrice S asymétrique (Formule 1), et comme un dispositif équilibré à 2 accès comme sur la Figure 2, caractérisé par une matrice S en mode mixte (Tableau 1). Comme l'application d'un signal asymétrique à un accès revient mathématiquement à appliquer des signaux en mode différentiel et en mode commun superposés, les caractérisations en modes mixte et asymétrique du dispositif sont liées. La conversion des paramètres S asymétriques en paramètres S en mode mixte est présentée en Annexe A. En utilisant cette conversion, les paramètres S en mode mixte peuvent être obtenus à partir de la matrice S asymétrique mesurée.

4.5 Câbles coaxiaux et interconnexion pour analyseurs de réseau

En supposant que l'impédance caractéristique de l'analyseur de réseau soit 50 Ω, les câbles coaxiaux utilisés pour interconnecter l'analyseur de réseau, la matrice de commutation et le dispositif d'essai doivent présenter une impédance caractéristique de 50 Ω et une basse impédance de transfert (double écrantage ou plus).

Il convient que ces câbles coaxiaux soient les plus courts possible. 1 000 mm max. (sur chaque accès).

Les écrans de chaque câble doivent être reliés électriquement à un plan de terre (masse) commun.

Pour optimiser la dynamique, il convient que la perte d'insertion totale des câbles d'interconnexion soit inférieure à 7 dB à 2 000 MHz par mètre.

4.6 Caractéristiques pour les matrices de commutation

Les commutateurs (le cas échéant) peuvent présenter une configuration minimale de 2x4 au niveau tous les accès, bien qu'un commutateur présentant un plus grand nombre d'accès (par exemple 2x8, 1x16, 4x16) soit recommandé pour permettre une mesure plus complète, voire totale, du DUT sans reconnexion ni déplacement du DUT. Lorsqu'une telle commutation est utilisée, elle doit être construite de telle sorte que chaque accès puisse être configuré en entrée, en sortie ou en charge de 50 Ω. Tous les accès inactifs du commutateur doivent être raccordés à une charge de 50 Ω.

Le commutateur peut satisfaire aux recommandations de performances minimales de commutation données dans le Tableau 2.

Tableau 2 – Exigences de performances de commutation

Paramètre dB	Exigence 1 MHz à 1 000 MHz	Exigence 1 000 MHz à 2 000 MHz
Perte d'insertion	0,5 dB max.	2,0 dB max.
Affaiblissement de réflexion	68-20log(f) dB min. 40 dB max. 24 dB min.	18 dB min.
Diaphonie	105 dB min.	102 dB min.

4.7 Exigences du dispositif d'essai

4.7.1 Types de dispositifs d'essai

Les dispositifs d'essai sont classés en trois types, correspondant à trois groupes de connecteurs:

a) Les dispositifs d'essai à **référence indirecte**, pour les types de connecteurs utilisant un connecteur de référence pour la mesure des paramètres de transmission, avec des spécifications supplémentaires, par exemple un vecteur de diaphonie (NEXT) pour les paramètres de compensation de diaphonie; par exemple de la série IEC 60603-7 (types à 8 voies), IEC 60603-7-2, IEC 60603-7-3, IEC 60603-7-4, IEC 60603-7-5, IEC 60603-7-41, IEC 60603-7-51 et IEC 60603-7-81.

b) Les dispositifs d'essai à **sonde directe**, pour les types de connecteurs utilisant la mesure à sonde directe asymétrique des paramètres de transmission, par exemple de la série IEC 60603-7 (types à 12 voies), IEC 60603-7-7, IEC 60603-7-71, IEC 60603-7-82, IEC 61076-3-110.

c) Les dispositifs d'essai **spéciaux**, pour les types de connecteurs utilisant une combinaison de mesure à sonde directe et à référence indirecte des paramètres de transmission, par exemple l'IEC 61076-3-104 et l'IEC 61076-2-109.

Pour la spécification particulière des dispositifs d'essai de types a), b) et c), voir respectivement l'Annexe C, l'Annexe B et l'Annexe C.

4.8 Exigences relatives aux performances des terminaisons sur le plan d'étalonnage

Les performances des terminaisons sur le plan d'étalonnage doivent satisfaire aux exigences du Tableau 3.

Tableau 3 – Exigences relatives aux terminaisons sur le plan d'étalonnage

Paramètre	Exigence 1 MHz à 1 000 MHz	Exigence 1 000 MHz à 2 000 MHz
Affaiblissement de réflexion de l'accès SE (50 Ω), (dB)	≥ 72-20log(f) dB 40 dB max. 12 dB min.	12 dB min.
Affaiblissement de réflexion de l'accès DM (100 Ω), (dB)	≥ 78-20log(f) dB 40 dB max. 20 dB min.	20 dB min.
NEXT résiduelle entre accès DM	≥ 130-20log(f) dB 94 dB max.	70 dB max.

4.9 Charges de référence pour l'étalonnage

Pour réaliser un étalonnage sur 1 ou 2 accès de l'équipement d'essai, un court-circuit, un circuit ouvert et une charge de référence sont exigés. Ces dispositifs doivent être utilisés pour obtenir un étalonnage.

La charge de référence doit être étalonnée par rapport à une référence d'étalonnage, qui doit être une charge de 50 Ω, pouvant être raccordée à une Norme internationale de référence. Une charge de référence de 50 Ω doit être étalonnée par rapport à la référence d'étalonnage. La charge de référence pour l'étalonnage doit être placée dans un connecteur de type N conforme à l'IEC 61169-16, ou dans un connecteur de type SMA conforme à l'IEC 60169-15, les types étant adaptés au montage sur panneau, qui est usiné plat sur son côté arrière (voir Figure 3).

L'option concernant l'utilisation de connecteurs de type SMA, conformes à l'IEC 60169-15, est privilégiée.

La charge doit être fixée sur le côté plat du connecteur. Un analyseur de réseau doit être étalonné par étalonnage complet sur un accès avec la référence d'étalonnage. Ensuite, l'affaiblissement de réflexion de la charge de référence destinée à l'étalonnage doit être mesuré. L'affaiblissement de réflexion ainsi vérifié doit être > 46 dB pour les fréquences inférieures ou égales à 100 MHz et > 40 dB pour les fréquences supérieures à 100 MHz, et jusqu'à la limite pour laquelle les mesures doivent être réalisées.

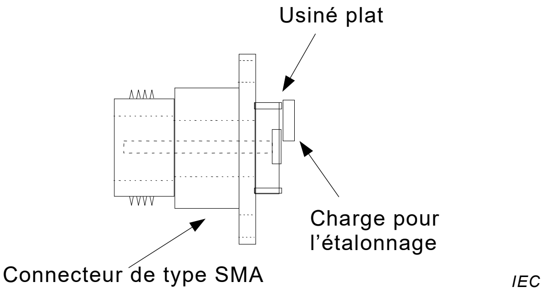

Figure 3 – Etalonnage des charges de référence

4.10 Etalonnage

4.10.1 Généralités

Des mesures d'isolation doivent être utilisées dans le cadre de l'étalonnage si les exigences du Tableau 3 ne sont pas satisfaites.

L'étalonnage doit être équivalent à un minimum d'un étalonnage asymétrique complet à 2 accès pour des mesures où les accès de réponse et de stimulus sont identiques (S_{xx11} et S_{xx22}), et à un minimum d'un étalonnage asymétrique complet à 4 accès pour des mesures où les accès de réponse et de stimulus sont différents (S_{xx12} et S_{xx21}).

Un étalonnage individuel doit être effectué pour chaque chemin de signal utilisé pour les mesures.

Si un montage d'essai à matrice de commutation complète et à analyseur de réseau à 4 accès est utilisé, un ensemble complet de mesures pour un dispositif à 4 paires (c'est-à-dire 16 accès asymétriques), nécessite 28 étalonnages distincts à 4 accès, bien que plusieurs des mesures dans chaque étalonnage soient communes à d'autres étalonnages.

Un outil logiciel ou matériel peut être utilisé pour réduire le plus possible le nombre de mesures d'étalonnage exigées.

L'étalonnage peut être effectué au niveau de l'interface d'essai en utilisant des artefacts d'étalonnage appropriés, ou aux extrémités du câble d'essai coaxial en utilisant des étalons coaxiaux et les données de découplage.

4.10.2 Interface d'essai pour l'étalonnage

Lorsque l'étalonnage est effectué au niveau de l'interface d'essai, des mesures de circuit ouvert, de court-circuit et de charge doivent être réalisées sur chaque accès asymétrique concerné. Des mesures d'isolation traversantes doivent être effectuées sur chaque combinaison de paires de ces accès.

4.10.3 Etalonnage à l'extrémité des câbles d'essai coaxiaux

Lorsque l'étalonnage est effectué au niveau de l'extrémité des câbles d'essai coaxiaux, des mesures de circuit ouvert, de court-circuit et de charge doivent être réalisées sur chaque accès concerné. Des mesures d'isolation traversantes doivent être effectuées sur chaque combinaison de paires de ces accès. En outre, le dispositif d'essai doit alors être découplé des mesures. Les techniques de découplage doivent intégrer une matrice S à 16 accès entièrement peuplée. Il n'est pas acceptable d'effectuer un étalonnage découplé en utilisant seulement des termes de réflexion (S_{11}, S_{22}, S_{33}, S_{44}) ou seulement des termes d'extrémité proche (S_{11},S_{21},S_{12}, S_{22}).

Un découplage utilisant des matrices S à termes réduits peut être utilisé pour le post-traitement des résultats.

4.11 Charges de sortie pour la terminaison des paires de conducteurs

4.11.1 Généralités

Des charges de 50 Ω mises à la terre (masse) doivent être utilisées sur tous les fils actifs en essai de terminaison. Des charges de 50 Ω mises à la terre (masse) doivent être utilisées sur tous les fils inactifs et sur les extrémités opposées des fils actifs pour les essais NEXT et FEXT de terminaison. Les fils inactifs pour l'essai d'affaiblissement de réflexion doivent être connectés à des charges de 50 Ω mises à la terre (masse). Voir la Figure 4.

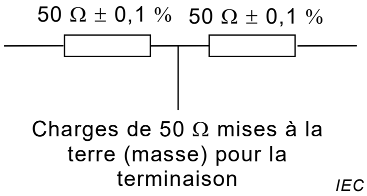

Figure 4 – Réseaux de charges résistives

Des résistances pastilles de petite géométrie doivent être utilisées pour la construction des charges résistives. Les deux résistances de charge SE de 50 Ω doivent être adaptées sur DC à 0,1 % près et à 2 % près à 2 000 MHz (correspondant au 40 dB de l'exigence d'affaiblissement de réflexion à 2 000 MHz).

4.11.2 Réseaux de charges résistives d'adaptation d'impédance

Les performances des réseaux de charges résistives d'adaptation d'impédance doivent être vérifiées en mesurant l'affaiblissement de réflexion de la charge de sortie et la paradiaphonie résiduelle entre deux réseaux quelconques de charges résistives au niveau du plan d'étalonnage.

Pour la mesure de l'affaiblissement de réflexion, un étalonnage asymétrique à 2 accès doit être effectué en utilisant une charge de référence vérifiée selon 4.9.

Après l'étalonnage, connecter le réseau de charges résistives et effectuer une mesure de la matrice S asymétrique complète à 2 accès. La matrice S asymétrique mesurée doit être transformée en la matrice S en mode mixte associée pour obtenir les paramètres S, S_{DD11} et S_{CC11}, à partir desquels l'affaiblissement de réflexion en mode différentiel RL_{DM} et l'affaiblissement de réflexion en mode commun RL_{CM} sont déterminés. L'affaiblissement de réflexion du réseau de charges résistives doit satisfaire aux exigences du Tableau 3.

Pour la mesure de la paradiaphonie résiduelle, un étalonnage asymétrique à 4 accès est exigé. Après l'étalonnage, connecter les réseaux de charges résistives et effectuer une mesure de la matrice S asymétrique complète à 4 accès. La matrice S mesurée doit être transformée en la matrice S en mode mixte associée pour obtenir le paramètre S, S_{DD21}, à partir duquel la paradiaphonie résiduelle des terminaisons, $NEXT_{residual\_term}$, est déterminée. La paradiaphonie résiduelle doit satisfaire aux exigences du Tableau 3.

4.12 Sortie des écrans

Lorsque le connecteur en essai est écranté normalement, des câbles de mesure écrantés doivent être utilisés. L'écran (ou les écrans) de ces câbles doit (doivent) être fixé(s) au plan de terre (masse), aussi près que possible du plan d'étalonnage.

4.13 Eprouvette et plans de référence

4.13.1 Généralités

L'éprouvette est une paire accouplée de connecteurs adaptés. Le plan de référence d'un connecteur pour l'éprouvette est soit le point auquel la gaine de câble entre dans le connecteur (extrémité arrière du connecteur), soit le point à partir duquel la géométrie interne du câble n'est plus maintenue, selon ce qui est le plus éloigné du connecteur (voir Figure 5). Cette définition s'applique aux deux extrémités de l'éprouvette. Le DUT doit être terminé selon les instructions du fabricant et doit être compatible avec les dispositifs et les montages d'essai de mesure.

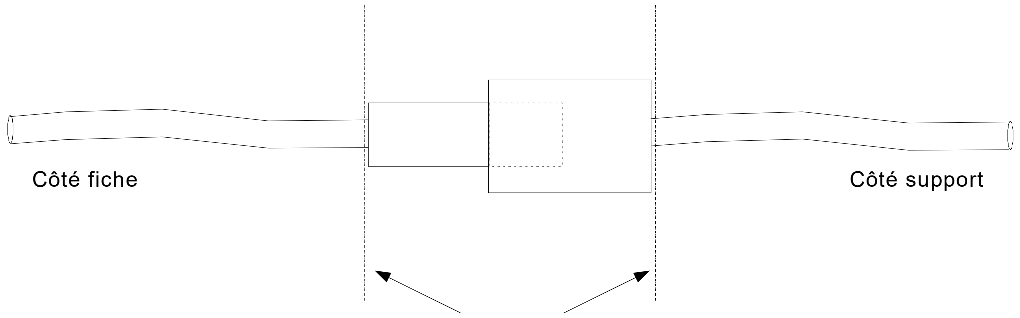

Figure 5 – Définition des plans de référence

4.13.2 Interconnexions entre le dispositif en essai (DUT) et le plan d'étalonnage

4.13.2.1 Généralités

Des interconnexions torsadées, coaxiales, de circuits imprimés ou d'autres interconnexions qualifiées doivent être utilisées entre le plan de référence du connecteur du DUT et le plan d'étalonnage. Il est exigé de contrôler les caractéristiques de ces interconnexions le mieux possible car elles dépassent le plan d'étalonnage. Ces interconnexions doivent être aussi courtes que possible et leurs impédances CM et DM doivent être gérées pour réduire le plus possible leurs effets sur la mesure.

Les performances de l'affaiblissement DM de réflexion des interconnexions doivent satisfaire aux exigences du Tableau 4. Par hypothèse, les performances en ce qui concerne les pertes d'insertion des interconnexions sont considérées comme étant inférieures à 0,2 dB sur la plage de fréquences comprises entre 1 MHz et 2 000 MHz.

4.13.2.2 Interconnexion torsadée

4.13.2.2.1 Généralités

Lorsque des interconnexions torsadées sont utilisées, elles doivent présenter une impédance caractéristique différentielle nominale de 100 Ω. Il convient qu'il n'y ait pas d'espace entre les paires torsadées et l'enveloppe isolante. L'interconnexion torsadée peut être obtenue comme une interconnexion torsadée individuelle, ou elle peut faire partie d'un câble.

Se référer à l'Annexe B pour plus d'informations sur les interconnexions entre le dispositif en essai (DUT) et le plan d'étalonnage, pour les types de connecteurs utilisant typiquement une interconnexion torsadée avec des dispositifs d'essai à référence indirecte.

Se référer à l'Annexe B pour plus d'informations sur les interconnexions entre le dispositif en essai (DUT) et le plan d'étalonnage, pour lesquelles il est recommandé que tous les DUT, y compris les fiches d'essai de référence, soient équipés d'embases avec un espacement de 2,54 mm appliqué aux extrémités de leur interconnexion afin de faciliter un raccordement cohérent au dispositif d'essai.

Se référer à l'Annexe B pour plus informations sur les broches d'essai qui peuvent être utilisées pour faciliter la gestion de l'impédance.

L'interconnexion doit satisfaire aux exigences d'affaiblissement de réflexion du Tableau 4.

Des charges entre terre (masse) et DM doivent être utilisées et l'interconnexion doit être placée dans un système de gestion de l'impédance. La longueur maximale des fils torsadés à chaque extrémité du DUT doit être 51 mm. Elle doit toutefois être maintenue aussi petite que possible.