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Edition 1.0 2018-10

PUBLICLY AVAILABLE SPECIFICATION

PRE-STANDARD

colour inside

Connectors 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

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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CONNECTORS 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

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IEC PAS 60512-27-200 has been processed by subcommittee 48B: Electrical connectors, of IEC technical committee 48: Electrical connectors and mechanical structures for electrical and electronic equipment.

The text of this PAS is based on the following document:	This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document
Draft PAS	**Report on voting**
48B/2652/DPAS	48B/2673/RVDPAS

Following publication of this PAS, which is a pre-standard publication, the technical committee or subcommittee concerned may transform it into an International Standard.

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.

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.

This PAS shall remain valid for an initial maximum period of 3 years starting from the publication date. The validity may be extended for a single period up to a maximum of 3 years, at the end of which it shall be published as another type of normative document, or shall be withdrawn.

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**CONNECTORS 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

1 Scope

This part of IEC 60512 covers additional, supplemental specifications for signal integrity and transmission performance test methods of IEC 60512-27-100, for connectors using de-embedded crosstalk measurements, which are specified in respective parts of IEC 60603-7 standards for connecting hardware applications up to 2 000 MHz.

These additional specifications are also applicable for testing the related lower frequency connectors. However, the test methodology specified in the detail specification for any given connector remains the reference conformance test for that connector.

Test procedures of IEC 60512-27-100 affected by these supplemental methods and procedures are:

- insertion loss, test 27a;
- return loss, test 27b;
- near-end crosstalk (NEXT) test 27c;
- far-end crosstalk (FEXT), test 27d;
- transverse conversion loss (TCL), test 27f;
- transverse conversion transfer loss (TCTL), test 27g.

Other test procedures referenced here are:

- transfer impedance (Z_T), see test procedures in IEC 62153-4-6 or IEC 62153-4-7.
- for coupling attenuation (a_C), see test procedures in IEC 62153-4-7 or 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 60512-1, *Connectors for electronic equipment – Tests and measurements – Part 1: General*

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 60512-28-100, *Connectors for electronic equipment – Tests and measurements – Part 28-100: Signal integrity tests up to 2 000 MHz on IEC 60603-7 and IEC 61076-3 series connectors – Tests 28a to 28g*

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 60603-7-41, *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 60603-7-81, *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 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, *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: Sectional specification – RF coaxial connectors with inner diameter of outer conductor 7 mm (0,276 in) with screw coupling – Characteristics impedance 50 ohms (75 ohms) (type N)*

IEC 61935-1, *Specification for the testing of balanced and coaxial information technology cabling – Part 1: Installed balanced cabling as specified in ISO/IEC 11801 and related standards*

IEC 61935-2, *Specification for the testing of balanced and coaxial information technology cabling – Part 2: Cords as specified in ISO/IEC 11801 and related standards*

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

ITU-T Recommendation G.117, *Transmission aspects of unbalance about earth*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-581, IEC 60512-1 and IEC 60603-7 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

4 Overall test arrangement

4.1 General

This document specifies test methods and procedures for connectors.

The test fixtures and reference connectors specified in this document are referenced by IEC 60512-28-100.

The test methods and procedures for signal integrity and transmission performance, specified in IEC 60512-28-100, covering the frequency range up to 2 000 MHz, are referenced by connector standards, specified in IEC 60603-7 and IEC 60603-7-1, with signal integrity specifications up to 2 000 MHz; e.g., IEC 60603-7-81.

This document extends the frequency range, up to 2 000 MHz, for IEC 60512-27-100, which has a frequency range up to 500 MHz.

The test methods and procedures for signal integrity and transmission performance specified herein are for connectors using de-embedded crosstalk specifications and measurements up to 2 000 MHz; e.g. IEC 60603-7-81.

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

4.2 Indirect-reference test fixtures

Indirect-reference test fixtures are for connector types utilizing indirect reference to re-embedded crosstalk vectors for measurement of transmission parameters, e.g. IEC 60603-7 series (8-way 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.

The detail tests and measurement specifications for the measurement of the respective transmission parameters required by the detail product specifications of the IEC 60603-7 series 8-way connector types are given in Annex A.

The indirect-reference test fixtures and associated test procedures used for measuring IEC 60603-7 series 8-way connector types transmission parameters, up to 2 000 MHz, shall conform to their respective detail tests and measurements specifications requirements, given in Annex A, and to the additional requirements in this standard, which are given in Annex B, Annex C, Annex D, and Annex E.

Annex A
(normative)

Indirect-reference test fixtures

A.1 General

Indirect-reference test fixtures are for connector types utilizing indirect reference to re-embedded crosstalk vectors for measurement of transmission parameters, e.g. IEC 60603-7 series (8-way 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-way connector types transmission parameters shall conform to their respective detail specification test procedures requirements and to the requirements in this annex.

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

Table A.1 – IEC 60603-7 series, 8-way 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 60512-25-x series	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

A.2 Requirements

Indirect reference test fixtures for 2 000 MHz shall also meet the overall test fixtures minimum signal integrity requirements for 2 000 MHz listed in IEC 60512-28-100.

Annex B
(normative)

Measurement requirements (general)

B.1 General test configuration

This annex describes general measurement requirements for 4-pair 100 Ω components and cabling systems from 1 MHz to the highest referenced frequency using laboratory equipment.

The transmission tests described in this document typically require the use of a network analyzer or equivalent, coaxial cables, baluns, UTP test leads, and impedance matching terminations. Network analyzers provide capability to correct for source and load port inaccuracies and measurement errors due to output port gain errors and measurement port sensitivity. In addition, signal leakage from the output port to measurement port can be compensated. Each component of the test setup shall be qualified over the frequency range specified for the category to which the DUT is being evaluated. Equivalent test setups may be used. For the case of balunless measurements, the general requirements for wire termination, test setup, configurations, and performance are detailed in IEC 60512-28-100 from 1 MHz to 2 000 MHz.

The transmission tests described in this annex may be performed using a network analyzer or equivalent, coaxial cables, baluns, test leads, and impedance matching terminations. Each setup component shall be qualified to a measurement bandwidth of at least 1 MHz to the highest frequency of measurement for each category. Test equipment design, calibration and fixturing should be such as to ensure a measurement floor of 20 dB below the required measurement limit.

This document discusses in detail:

- Network analyzer requirements
- Test fixture requirements
- Impedance matching termination requirements
- Calibration artefacts and calibration procedures
- Port identification and nomenclature
- Other requirements

All of the requirements of this annex apply up to the maximum frequency of the DUT category.

B.2 Termination of a cable DUT to test system

B.2.1 General

The DUT connection point is to a cable pair. To minimize length of the termination and disturbance of the cable pairs, the cable pair should be connected to the reference plane with less than 5 mm (0,2”) of wire or pair unjacketed or untwisted. Shield terminations including individual pair shield terminations should be within 5 mm (0,2”) of the reference plane. Pair twist and spacing should be maintained to the reference plane as much as possible. Shield terminations should provide a 360° contact with the overall cable shield as close to the end of the screen as is possible. Example cable and shield terminations are shown in Figure B.1 and Figure B 2.

B.2.2 Interconnections between the device under test (DUT) and the calibration plane

When testing DUT's that do not present naturally a cable pair to the test interface, test leads may be constructed to provide that connection.

Twisted-pair test leads, printed circuits or other interconnections may be used between the DUT and the calibration plane. It is necessary to control the characteristics of these interconnections to the best extent possible as they are beyond the calibration plane. These interconnections should be as short as practical and their CM and DM impedances shall be managed to minimize their effects on measurements. The return loss performance of the interconnections shall meet the requirements of Clause B.2. The insertion loss performance of the interconnections is assumed to be less than 0,1 dB over the frequency range from 1 MHz to 500 MHz and less than 0,2 dB for the frequency range from 500 MHz to 2,0 GHz.

When used, twisted-pair test leads shall have 100 Ω nominal characteristic impedance. The twisted-pairs should not exhibit gaps between the conductors insulation. The maximum length of the test leads extending from each end of the device shall be 51 mm (2 in).

Prior to attachment to the DUT, the return loss of each twisted-pair shall be tested. For this test, 100 mm (4 in) lengths of twisted-pair shall be used. The test leads shall be DM terminated across each pair at the far end with a precision 0,1 % 0603 or similar chip resistor as described in Clause B.4. The resistor shall be attached directly to the conductors of the pair in such a way as to minimize the disturbance of the twisted-pair. Potential disturbances include gaps between the conductor insulation in the twisted-pair, melted insulation, and excess solder. When tested, the test lead shall be attached to the balun or DM test port using the same fixtures as when testing the device. The test leads are then trimmed for attachment to the DUT and the test fixtures. See Annex E for an appropriate test fixture. It is recommended to use the same load for both calibration and termination of the test lead during measurement.

B.2.3 Test lead return loss requirements

For connecting hardware return loss measurements, the interconnection shall meet the requirements in B.2.2 and Table B.1 relative to the specified calibration resistor termination. These requirements apply up to the maximum frequency of the category of the DUT.

Table B.1 – Interconnection return loss

Frequency MHz	Return loss dB
$1 \le f < 80$	40
$80 \le f \le 2\,000$	$38 - 20 \log (f/100)$

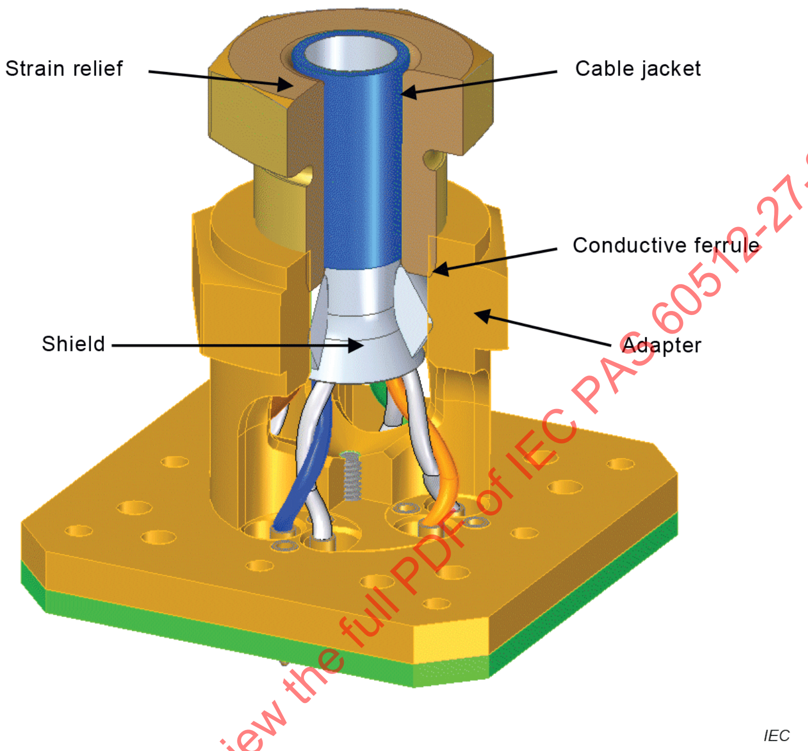


Figure B.1 – Example 360° shielded cable termination

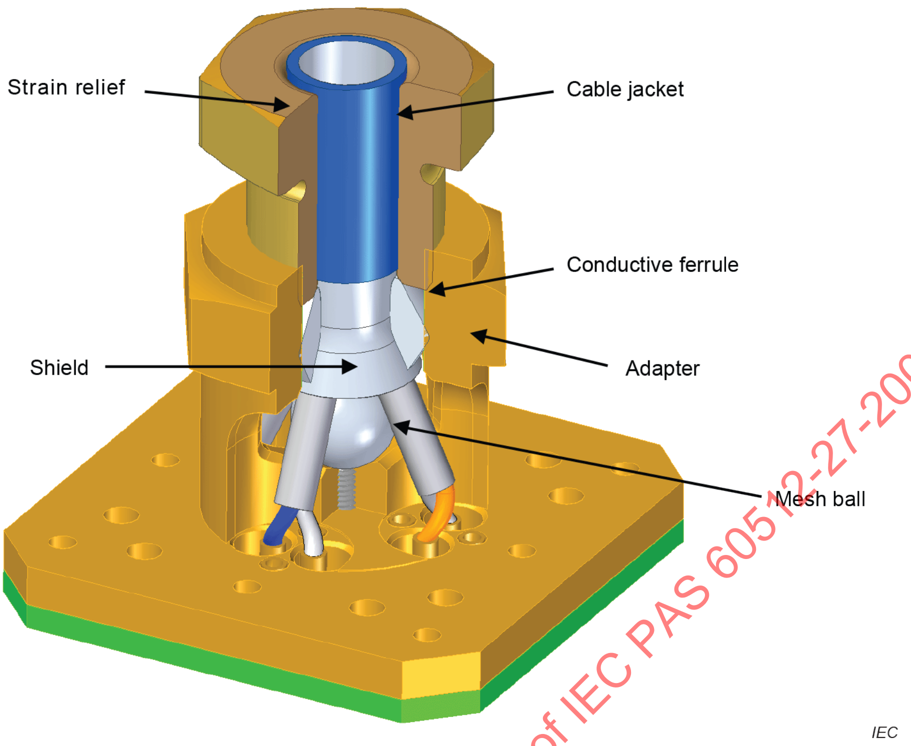


Figure B 2 – Example individually shielded pair cable termination

For ease of interfacing to test fixtures, the balun or balunless test interface should present a pin and socket interface with dimensions as shown in Figure B.3. Sockets should be gold plated contact material and should be compatible with an example socket as shown in Figure B.4.

Dimensions in millimetres (inches)

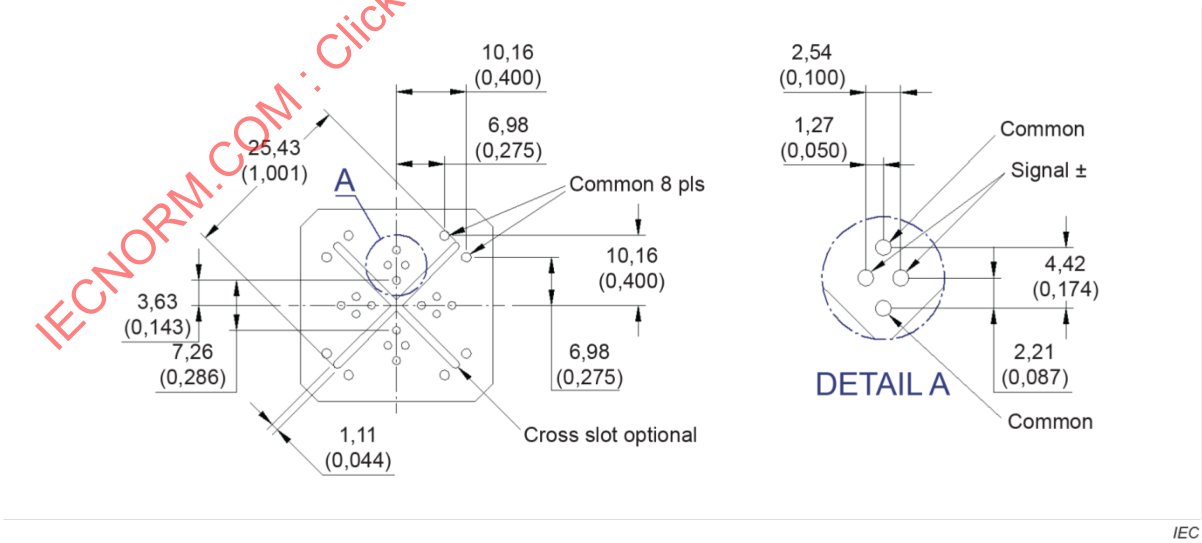
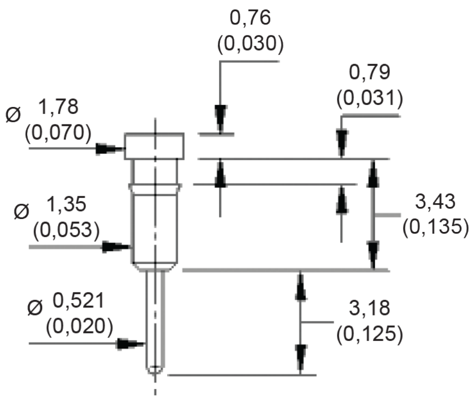


Figure B.3 – Test fixture interface pattern

Dimensions in millimetres (inches)



Example socket 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 = 10 µ" gold over nickel

Contact plating: 27 = 30 µ" gold over nickel

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

Figure B.4 – Example pin and socket dimension

B.2.4 Ground plane requirements

The balun or balunless test fixture common mode nodes shall be bonded to a ground plane. The common mode nodes of passive terminations shall also be bonded to the ground plane.

B.2.5 Network analyzer requirements

The network analyzer shall provide a sinusoidal reference signal source and receiver in one unit and shall provide the ability to measure amplitude and phase response over a specified frequency range for cabling or cabling components under test. In addition, the performance of the network analyzer shall be specified over the frequency range of interest and the network analyzer shall include functionality to perform two-port and one-port calibrations.

B.3 Measurement points and spacing

Unless otherwise specified, the minimum number of measurement points within a specified frequency range shall meet the requirements of Table B.2.

Table B.2 – Minimum number of measurement points

DUT length (L) m	Minimum number of measurement points per decade of specified frequency range
L ≤ 10	100
10 < L ≤ 20	200
L > 20	300

B.4 Impedance matching terminations

B.4.1 General

Either balun terminations, direct network analyzer terminations, or resistive terminations may be used for the termination of far-end ports of active pairs under test and for the termination of inactive pair near-end and far-end ports. Resistor terminations are recommended for termination unless the port is included in the current active measurement calibration. Improving the return loss of port terminations will improve measurement accuracy. In all cases, the type of termination shall be consistent between all pairs at each end and consistent with the common mode termination value of the test system. (i.e. DMCM terminations are not mixed with DM terminations for the near-end of the DUT or the far-end of the DUT). Annex C provides diagrams for terminations for balun systems and Annex D provides diagrams of terminations for balunless systems.

B.4.2 Resistor terminations

Resistors shall be 0603 or smaller wideband chip resistors. 0,01 % tolerance chip resistors should be used for calibration references and also for all DUT resistor terminations.

Resistor DM terminations shall exhibit impedance of 100 Ω ± 0,1 % (two times 50 Ω ± 0,1 %) as shown in Figure B.5. The resistors used for common mode (CM) terminations shall include the addition of a common mode 25 Ω ± 1 % or better resistor as shown in Figure B.6. In this case, the common mode impedance formed by the 25 Ω resistor in series with the two 50 Ω resistors in parallel provides a common mode impedance of 50 Ω.

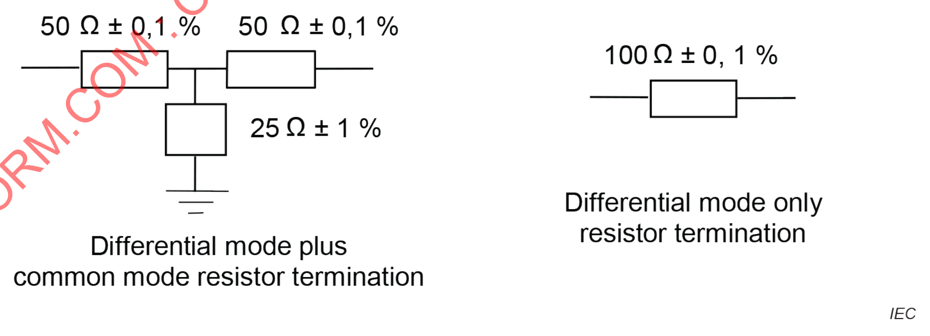


Figure B.5 – Resistor termination networks for balun testing

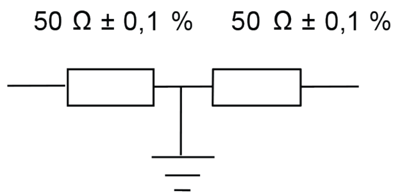


Figure B.6 – Balunless resistor termination network

B.4.3 Termination return loss performance at the calibration plane

The performance of impedance matching resistor termination networks shall be verified by measuring the return loss of the termination at the calibration plane. For this measurement, a one port calibration is required using a traceable reference load per IEC 60603 series. The DM return loss of the load termination shall meet or exceed 20 – 20 log (f /500). Calculations that result in DM return loss limit values greater than 40 dB shall revert to a requirement of 40 dB minimum. The CM return loss shall exceed 15 dB. The residual NEXT loss between any two impedance termination networks shall exceed the requirements of formula (B.1). Calculations that result in residual NEXT loss limit values greater than 84 dB shall revert to a requirement of 84 dB minimum.

$$NEXT_{residual\_term} \geq 74 - 20 \log (f/100) \text{ dB} \tag{B.1}$$

The DM return loss requirement above results in better performance at frequencies below the upper frequency limit for resistor terminations versus balun terminations. It is for this reason that resistor terminations are recommended, even though the performance requirements (as specified here) are essentially the same.

B.4.4 Termination TCL performance at the calibration plane

The resistor terminations should be verified by testing TCL up to the highest frequency of testing for each category or 2 GHz and should meet the requirements of formula (B.2).

$$TCL_{Rterm} >= 56 - 20*\log (f/100) \text{ or } 50 \text{ dB min} \tag{B.2}$$

B.4.5 Calibration methods

One-port and two-port calibrations are acceptable for return loss measurements. Two-port calibration and measurement methods, which include compensation for the balun response, shall be used for insertion loss, NEXT loss and FEXT loss measurements. See Annexes C and D for more information on calibration methods and types.

There are two commonly used calibration methods:

a) Two-port calibration used for through measurements that involve an output port and a measurement port (insertion loss, NEXT loss, and FEXT loss).

b) One-port calibration used when making one-port (return loss) measurements. In this case, the remote end of the device under test is terminated using a resistive circuit. It is possible to use a two-port calibration for one-port measurements. In this case, one port provides the balun termination at the remote end and its return losses are calibrated out of the measurement.

Both one-port and two-port calibrations require reflection calibration that corrects for imperfect source and load impedance of the measurement system, including the near- and far-end measurement ports of the network analyzer, baluns and interconnections up to the location of the reference plane. Reflection calibration typically involves connecting open, short, and load calibration devices at the location of the reference plane. Absolute measurement accuracy is determined by the accuracy of the calibration load.

In addition to the reflection calibration, transmission and isolation calibrations are also required for two-port calibrations. Transmission calibration requires interconnecting the near- and far-end measurement ports at the location of the reference plane with a known reference. The reference may be a short piece of twisted-pair conductors. Isolation calibration is only required if there is significant crosstalk between the near- and far-end measurement ports at the location of the reference plane. If the level of uncompensated crosstalk at this location is near the noise floor of the network analyzer, then the isolation calibration may be omitted. If used, during isolation calibration, the near- and far-end measurement ports should be terminated into 100 Ω at the location of the reference plane.

B.4.6 Two-port calibration of the test system

A two-port calibration utilizing load, open, and short and through calibration references shall be specified. Transmission through calibration requires interconnecting the near-end and far-end measurement ports at the location of the reference plane with a known reference through calibration artefact. Isolation calibration is required if there is significant crosstalk between measurement ports. If the level of residual crosstalk is compliant to test system performance requirements, then isolation calibration may be omitted.

B.4.7 One-port calibration of the test system

If a one-port calibration is used, then load, open, and short calibration references shall be used.

B.5 General calibration plane

B.5.1 General

For all measurement configurations, the calibration plane represents the location where calibration devices are connected to the test setup as shown in Figure B.7. The calibration plane is defined at the test interface and is the point of connection between the device under test and the test fixture.

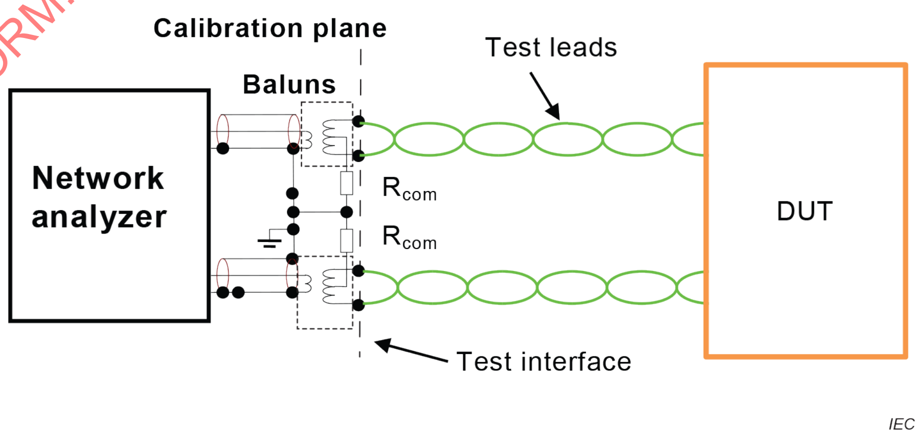


Figure B.7 – Calibration plane

The calibration plane location can be established based on:

Formal definitions of calibration planes for cabling (e.g., reference plane for the channel or permanent link).

These measurement considerations should be taken into account:

a) Proximity to the cabling or cabling component under test to avoid introduction of measurement errors (i.e. from the network analyzer, baluns and interconnect wiring).
b) Convenience of connecting devices to be tested.
c) Minimizing disruption of the transmission performance at the location where devices are connected, particularly to avoid reflections and parasitic crosstalk effects.

B.5.2 Calibration references

Internal test calibration standards reference values within the network analyzer shall be selected to reflect the characteristics of the actual standards used for calibration as specified by the instrument manufacturer. Typical parameters for a network analyzer using open-short-load-through calibration standards are open circuit capacitance, short circuit inductance, through offset delay and offset impedance Z0. Test facilities should maintain appropriate documentation detailing the calibration procedures and calibration standard values used and the expected accuracy.

B.5.3 50 Ω and 100 Ω calibration reference load requirements

Calibration reference load impedance terminations can be compared against a 50 Ω coaxial load, which is traceable to an international reference standard using the following procedure. The calibration reference load shall be equal to the nominal differential impedance of twisted-pair cabling defined in this document, which is 100 Ω. This may be achieved by using a single 100 Ω resistor or with the network shown in Figure B.5.

The following procedure can be used for reference load verification.

The reference load(s) for calibration are placed in an N-type connector according to IEC 60169-16 (i.e. designed for panel mounting and machined flat on the back side). The load(s) shall be fixed to the flat side of the connector and distributed evenly around the centre conductor. One port full calibrations shall utilize the 50 Ω coaxial calibration reference.

The reference load may be compared directly to the 50 Ω calibration reference. In this case, an additional source of uncertainty is introduced by the network analyzer. Refer to the test equipment manufacturer's guidelines for additional information on calibration device and network analyzer measurement uncertainty. Another method is to place two 100 Ω reference loads in parallel. In this case, the uncertainty introduced by the network analyzer is negligible and the accuracy of the two 100 Ω reference loads in parallel is determined by the accuracy of the 50 Ω calibration reference. It may be assumed that either method will result in approximately the same uncertainty for a single, 100 Ω reference load.

Care shall be used to maintain symmetrical calibration load positioning with reference to the ground connection.

B.5.4 Calibration reference load return loss requirement

The verified return loss of the calibration reference load shall meet the requirements of Table B.3 from 1 MHz to the highest referenced frequency of measurement for the cabling category.

Table B.3 – Calibration reference load return loss requirement

Frequency MHz	**Return loss** dB
$1 \leq f < 1\,000$	≥ 40
$1\,000 \leq f \leq 2\,000$	$\geq 40 - 20 \log (f/1\,000)$

B.5.5 Typical test equipment performance parameters

See IEC 60512-28-100 for typical test equipment performance parameters.

Annex C
(normative)

Cabling and component test procedures using baluns

C.1 Measurement test setup and apparatus

C.1.1 General

The measurement requirements in this Annex, apply to categories 3, 5e, 6, 6A, and 8 up to the upper frequencies of those categories. In some cases, there are specific requirements for specific categories, and those are so noted.

C.1.2 Balun terminations

Baluns used for termination shall comply with the requirements of C.1.3. The common mode termination resistor applied to the common mode port of the balun shall be 50 Ω ± 1 %.

C.1.3 Balun requirements

Balun transformers are used to convert the unbalanced measurement capability of the network analyzer to the balanced terminals of the cabling interface. Baluns shall be RFI shielded and shall comply with the specifications listed in Table C.1 up to the highest referenced frequency for the category of component or cabling system under test.

Table C.1 – Test balun performance characteristics

Parameter	Frequency MHz	Value
Impedance, primary [1)]	$1 \leq f \leq 2\,000$	50 Ω unbalanced
Impedance, secondary	$1 \leq f \leq 2\,000$	100 Ω balanced
Insertion loss	$1 \leq f \leq 1\,000$ $1\,000 < f \leq 2\,000$	2,0 dB maximum 3,0 dB maximum
Return loss, bi-directional [2)]	$1 \leq f < 15$ $15 \leq f \leq 1\,000$ $15 < f \leq 2\,000$	12 dB minimum 20 dB minimum 15 dB minimum
Return loss, common mode [2)]	$1 \leq f < 15$ $15 \leq f < 400$ $400 \leq f \leq 2\,000$	15 dB minimum 20 dB minimum 15 dB minimum
Power rating	$1 \leq f \leq 2\,000$	0,1 watt minimum
Longitudinal balance [2)]	$1 \leq f < 100$ $100 \leq f \leq 500$ $500 < f \leq 1\,000$ $1\,000 < f \leq 2\,000$	60 dB minimum 50 dB minimum 42 dB minimum 40 dB minimum
Output signal balance [2)]	$1 \leq f \leq 1\,000$ 1 000 s $< f \leq 2\,000$	50 dB minimum 40 dB minimum
Common mode rejection [2)]	$1 \leq f \leq 1\,000$ $1\,000 < f \leq 2\,000$	50 dB minimum 40 dB minimum

1) Primary impedance may differ, if necessary, to accommodate analyzer outputs other than 50 Ω.

2) Measured per ITU-T (formerly CCITT) Recommendation G.117 with the network analyzer calibrated using a 50 Ω load.

Figure C.1 depicts the proper test configurations for qualifying test baluns to the requirements of this standard.

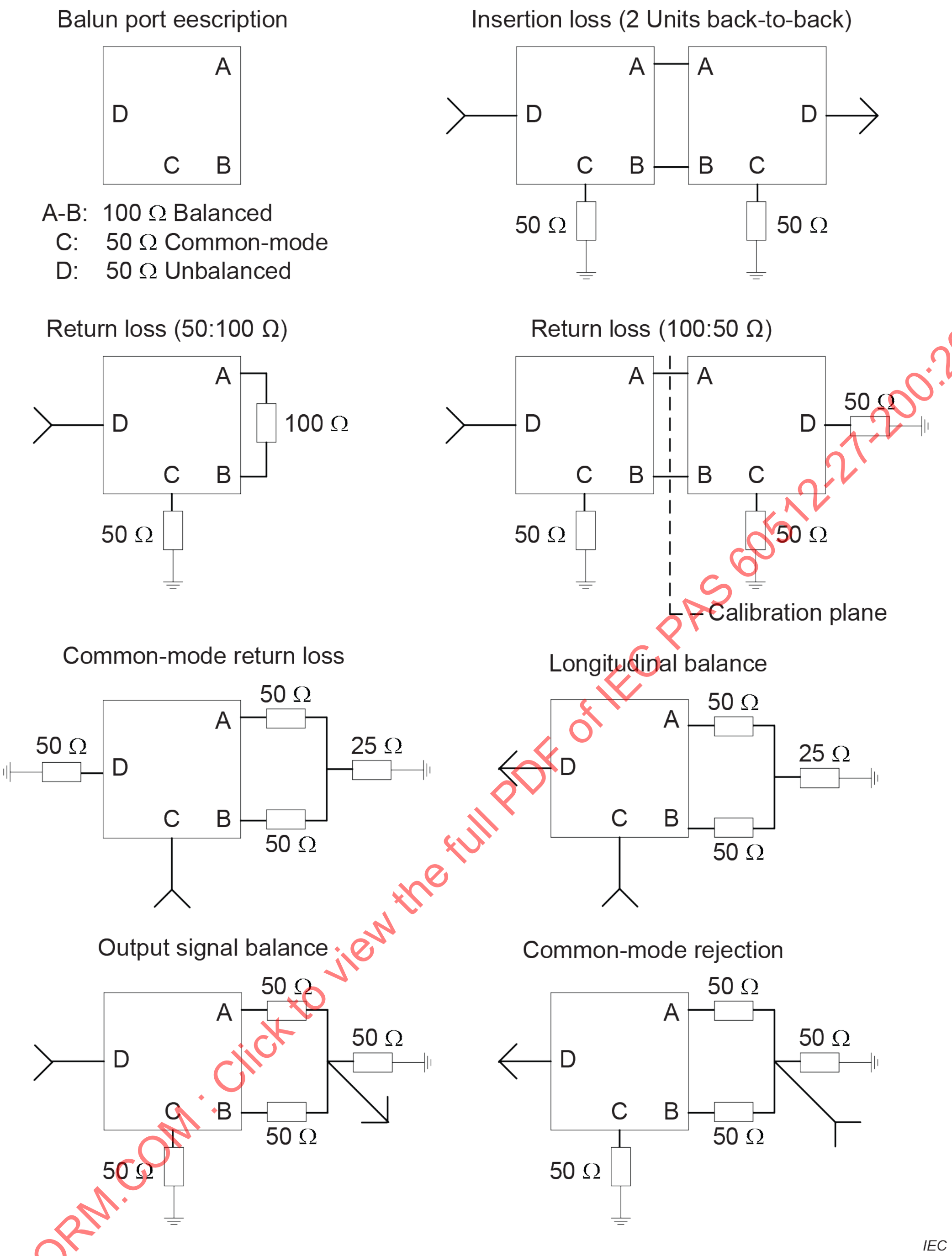


Figure C.1 – Measurement configurations for test balun qualification

C.2 Testing of cabling

C.2.1 Cabling DC resistance

DC resistance shall be measured in accordance with IEC 61935-1.

C.2.2 Return loss testing of cables and channels

C.2.2.1 Test configuration of cable and channel return loss

Figure C.3 depicts the typical schematic diagram for testing return loss. Resistor terminations are generally preferred for unused pairs at the far-end because of better return loss performance. See Clause B.4 for information on resistor terminations. DMCM terminations are recommended for return loss measurements although DM terminations are acceptable. The detailed schematic diagram of the balun is shown in Figure C.2 The connection labelled "C" represents the connection to the common mode port, the connection labelled "D" represents the connection to the 50 Ω unbalanced port, and ports labelled "A and B" represent a connection to the 100 Ω differential mode port of the DUT.

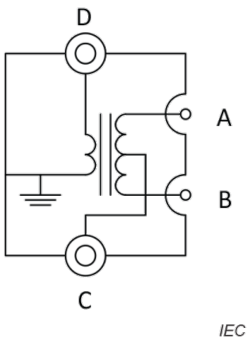


Figure C.2 – Balun schematic diagram

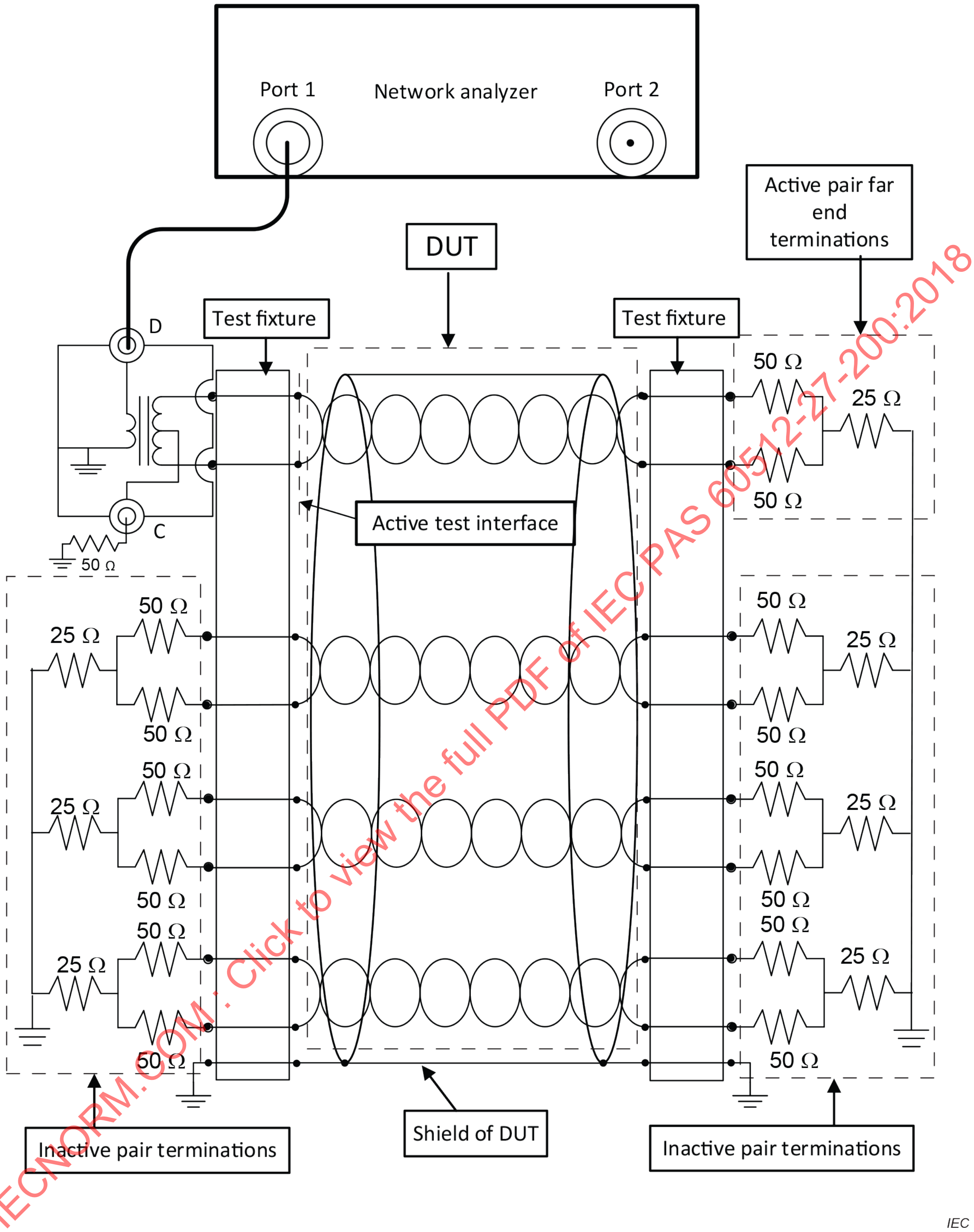


Figure C.3 – Laboratory test configuration for return loss

C.2.2.2 Measurement of cable and channel return loss

Calibrate in accordance with B.4.5. Measure the S11 parameter with the network analyzer connected to each pair on the near-end. Return loss shall be tested in both directions.

C.2.3 Insertion loss of cables and channels

C.2.3.1 Test configuration of cable and channel insertion loss

Figure C.4 depicts the typical schematic diagram for testing insertion loss, FEXT loss, ACRF, and propagation delay.

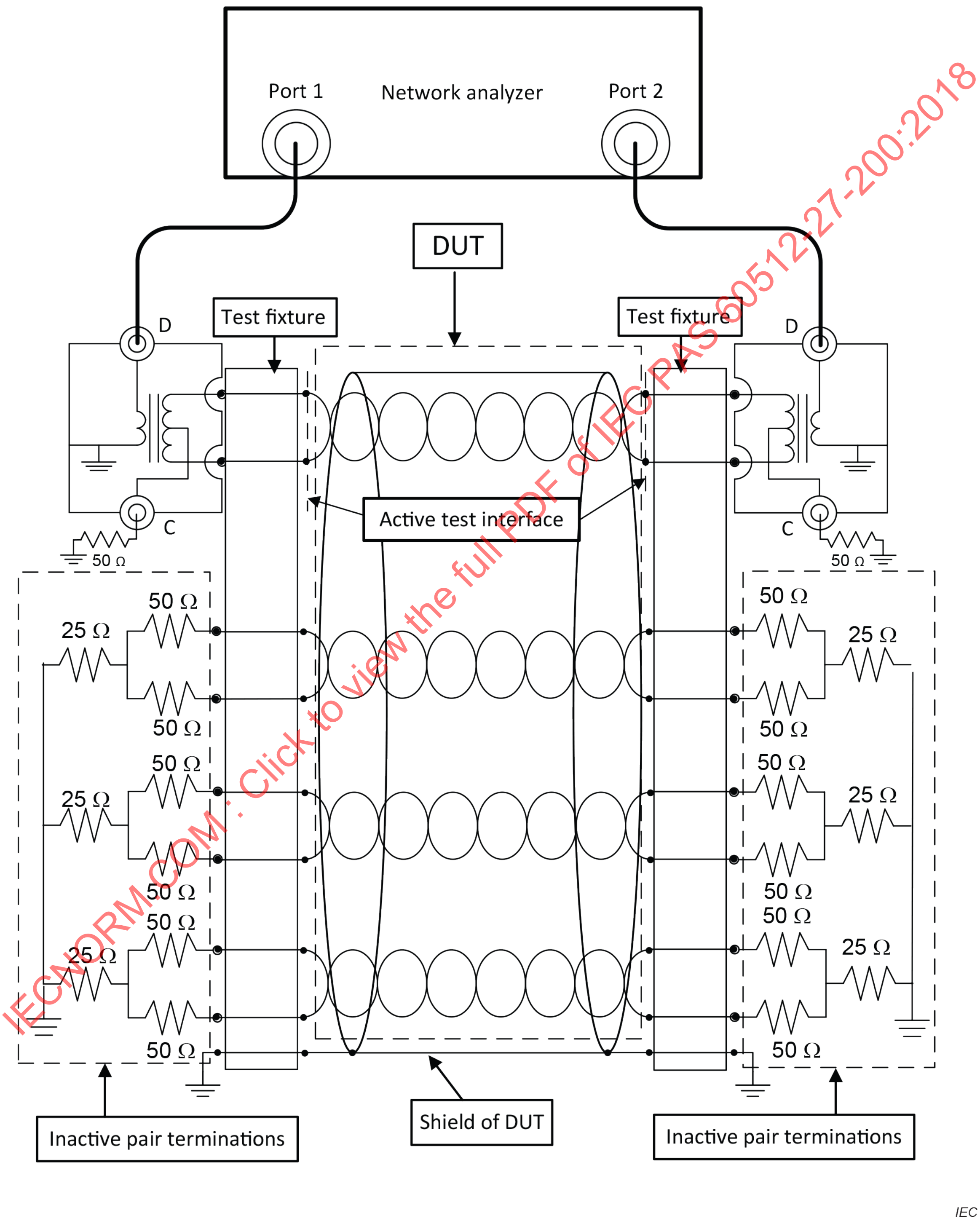


Figure C.4 – Laboratory test configuration for insertion loss and propagation delay measurements

Shields and screens, if any, should be bonded (low inductance connections) to the measurement ground.

The test interfaces shall provide a high quality interface to the calibration reference devices used during two-port and one-port calibration of the network analyzer, as well as provide a convenient connection to the cabling or cabling component under test.

C.2.3.2 Calibration of cable and channel insertion loss

The calibration for cable and channel insertion loss shall comply with B.4.5.

C.2.3.3 Measurement of cable and channel insertion loss

Measure the S21 parameter with the pair under test connected to the network analyzer at both the near-end and the far-end. It is not necessary to measure cable insertion loss from both ends due to reciprocity.

C.2.4 NEXT loss of cables and channels

C.2.4.1 Test configuration of cable and channel NEXT loss

Figure C.5 depicts the typical schematic diagram for testing NEXT loss. Resistor terminations are generally preferred for unused pairs at the far-end because of better return loss performance. See Clause B.4 for information on resistor terminations. DMCM terminations shall be used for NEXT loss measurements.

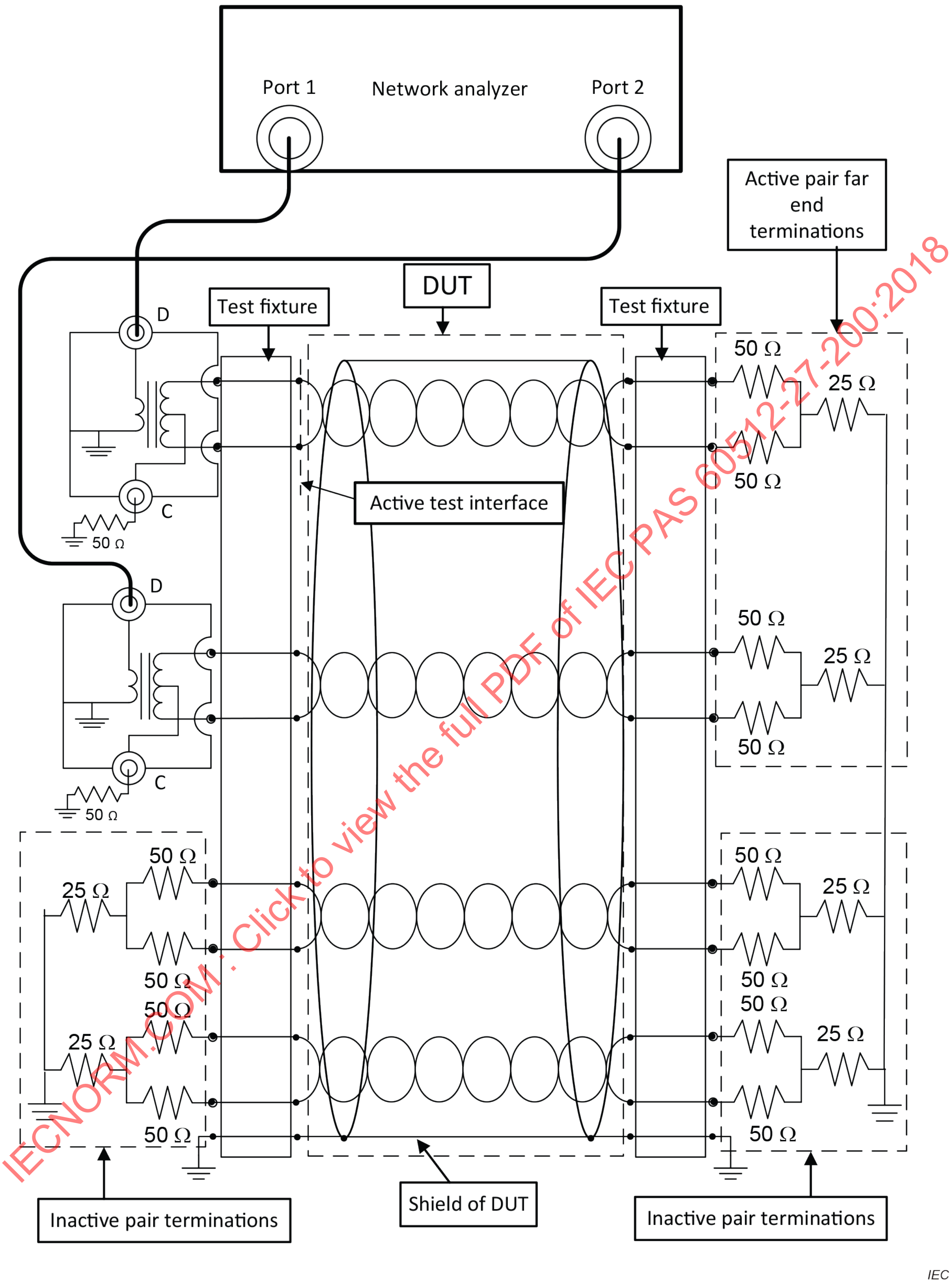


Figure C.5 – Laboratory test configuration for cable and channel NEXT loss

C.2.4.2 Calibration of cable and channel NEXT loss

The calibration for cable and channel NEXT loss shall comply with Clause B.5.

C.2.4.3 Measurement of cable and channel NEXT loss

Measure the S21 parameter with the network analyzer connected to each of the 6 pair combinations of the four pairs. NEXT loss shall be tested in both directions.

C.2.5 FEXT loss of cables and channels

C.2.5.1 Test configuration of cable and channel FEXT loss

Figure C.6 shows the test configuration of cable and channel FEXT loss. DMCM terminations shall be used for all inactive pairs and active pairs.

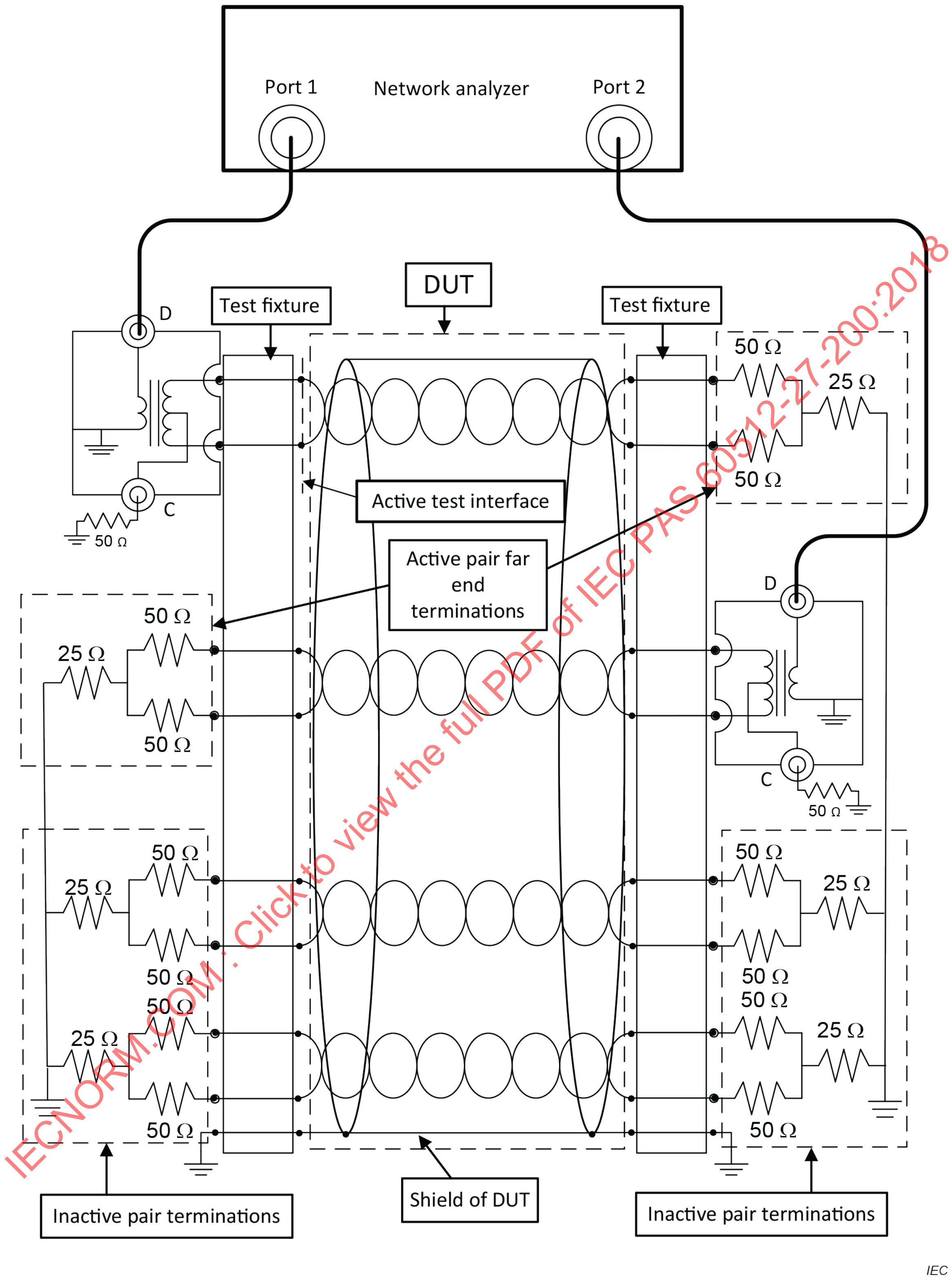


Figure C.6 – Laboratory test configuration for FEXT loss

C.2.5.2 Calibration of cable and channel FEXT loss

The calibration for cable and channel FEXT loss shall comply with Clause B.5.

C.2.5.3 Measurement of cable and channel FEXT loss

Measure the S21 parameter with the network analyzer connected to each of the 12 pair combinations of the four pairs in one direction.

C.2.6 Cable and channel propagation delay

C.2.6.1 Test configuration of cable and channel propagation delay

The propagation delay measurement configuration shall comply with the requirements of C.2.3.1

C.2.6.2 Calibration of cable and channel propagation delay

A one or two-port calibration, as described in Clause B.4, may be used to calibrate propagation delay.

C.2.6.3 Measurement of cable and channel propagation delay

Measure all 4 pairs for cable propagation delay. It is not necessary to measure cable propagation delay from both ends due to reciprocity.

C.2.7 TCL of cables and channels

C.2.7.1 General

Balunless techniques are recommended for measurement of TCL, however balun techniques may be used.

C.2.7.2 Test configuration of cable and channel TCL

Figure C.7 depicts the typical schematic diagram for testing TCL. The cabling or DUT pair under test shall be connected to the differential mode balun output terminals. All unused near-end pairs shall be terminated with DMCM resistor terminations (see Clause B.4) or baluns shall be bonded together and connected to ground as shown in Figure C.7.

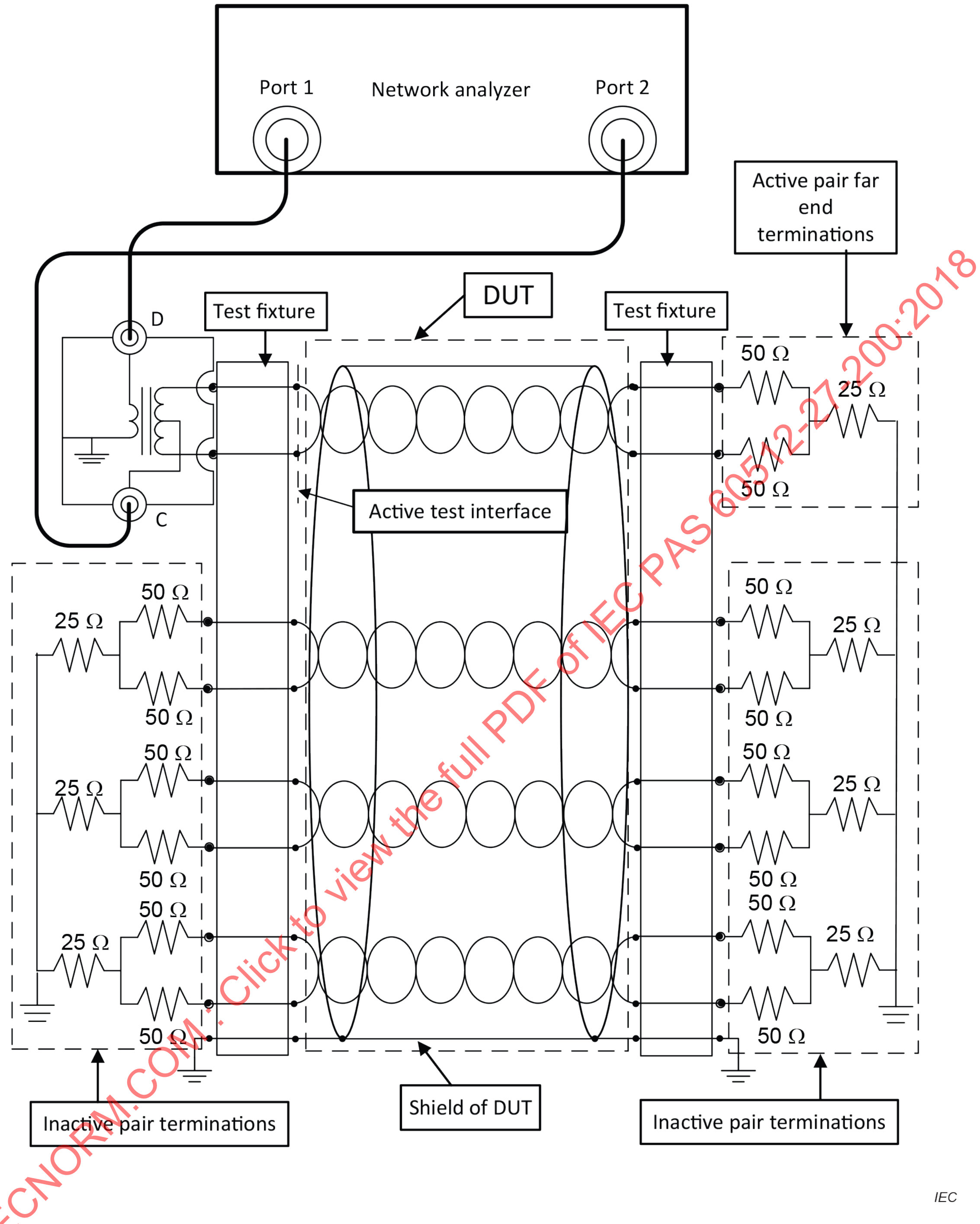


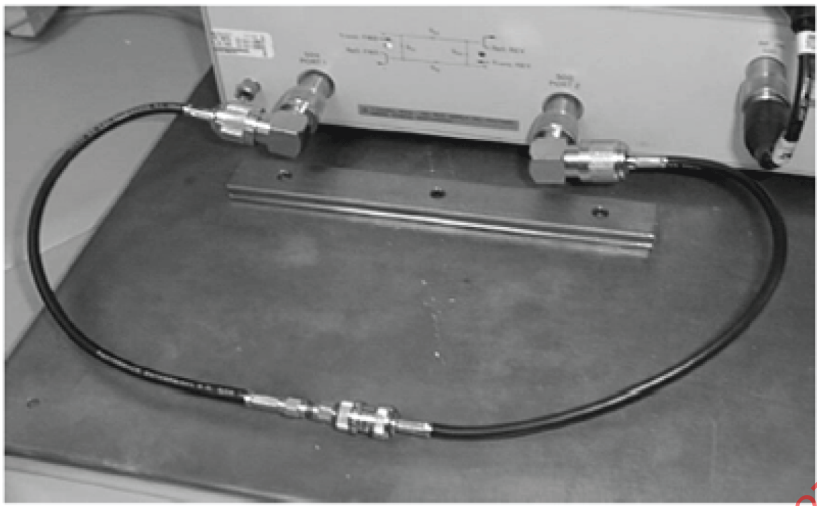
Figure C.7 – Laboratory test configuration for TCL

For cable TCL measurements, the far-end common mode termination should be connected to ground.

C.2.7.3 Calibration of channel TCL

TCL calibration is performed in three steps.

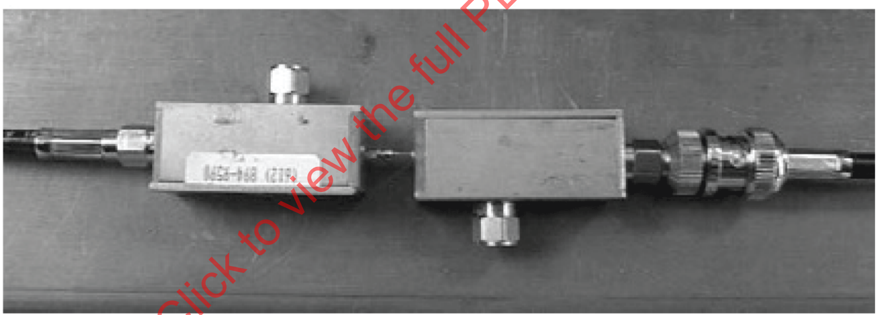
STEP 1: The coaxial test leads attached to the network analyzer are calibrated out by performing short, open, load, and through measurements at the point of termination to the balun. An example of the test lead through connection is shown in Figure C.8.



IEC

Figure C.8 – Coaxial lead through calibration

STEP 2: The attenuation of the differential signals of the balun is measured by connecting two identical baluns back-to-back with minimal lead length as shown in Figure C.9. Notice that the baluns are positioned so as to maintain polarity and they are bonded (firmly attached, e.g. clamped) to a ground plane. The measured insertion loss is divided by 2 to approximate the insertion loss of one balun for a differential signal. The calculated insertion loss is recorded as $IL_{bal,DM}$.



IEC

Figure C.9 – Back-to-back balun insertion loss measurement

STEP 3: The insertion loss of the common mode signals of the test balun is measured by connecting the common mode port terminals to the differential output terminals of the balun as shown in Figure C.10. Notice that the output terminals of the balun are short-circuited and connected to the inner conductor of the coaxial test lead. The outer shield of the coaxial test lead shall be bonded to the ground plane. An example ground bonding is shown in Figure C.11 The measured insertion loss is recorded as $IL_{bal,CM}$.

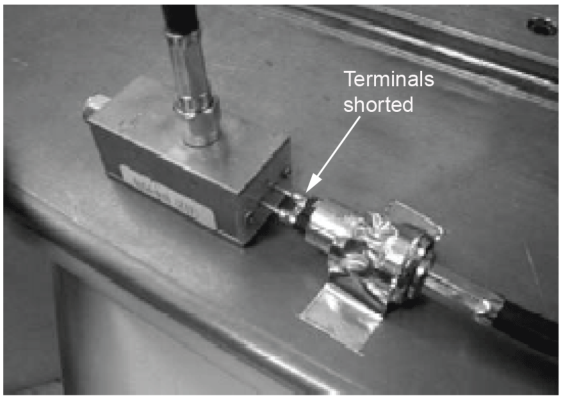


Figure C.10 – Output terminal connection

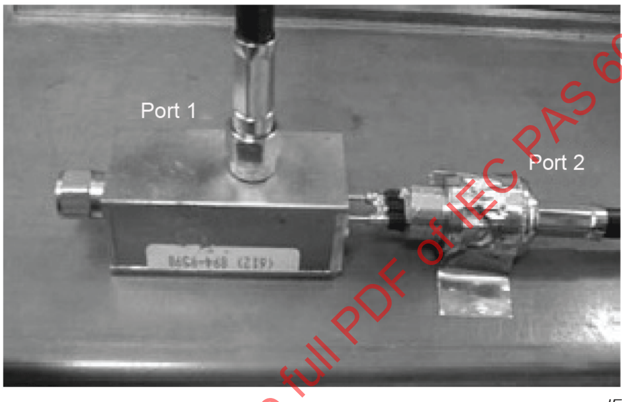


Figure C.11 – Outer shield grounding position

C.2.7.4 Measurement of cable and channel TCL

An S21 measurement between the differential and common mode ports of the balun is performed. To maintain consistency, port 1 of the network analyzer shall be connected to the 50 Ω input of the balun, while port 2 of the network analyzer shall be connected to the common mode terminal of the balun. The measured raw balance data is recorded as IL_{meas}.

TCL, corrected to remove the insertion loss of the test setup and to allow for the impedance ratio of the balun, is determined using formula (C.1).

$$TCL = (IL_{meas} - IL_{bal,DM} - IL_{bal,CM})\ \text{dB} \tag{C.1}$$

NOTE The proximity of the cable under test to ground planes may have an impact upon cable balance measurements.

TCL shall be tested in both directions.

C.2.8 TCTL of cables and channels

C.2.8.1 General

Balunless techniques are recommended for measurement of TCTL, however balun techniques may be used.

C.2.8.2 Test configuration of channel TCTL

Figure C.12 depicts the typical schematic diagram for testing TCTL. Two ends of the same cabling or DUT pair shall be connected to the differential outputs of the test baluns. For consistency, the output port of the network analyzer will be referred to as port 1 and the input port will be designated as port 2. Port 1 shall be connected to the differential input of the balun connected to the input end of the pair under test, while port 2 shall be connected to the common mode terminal of the balun connected to the output end of the pair under test. All unused pairs on both ends shall be terminated with DMCM resistor terminations as shown in Figure B.5. There shall be a common ground at each end. The grounds of the two ends shall be connected securely to the same ground plane.

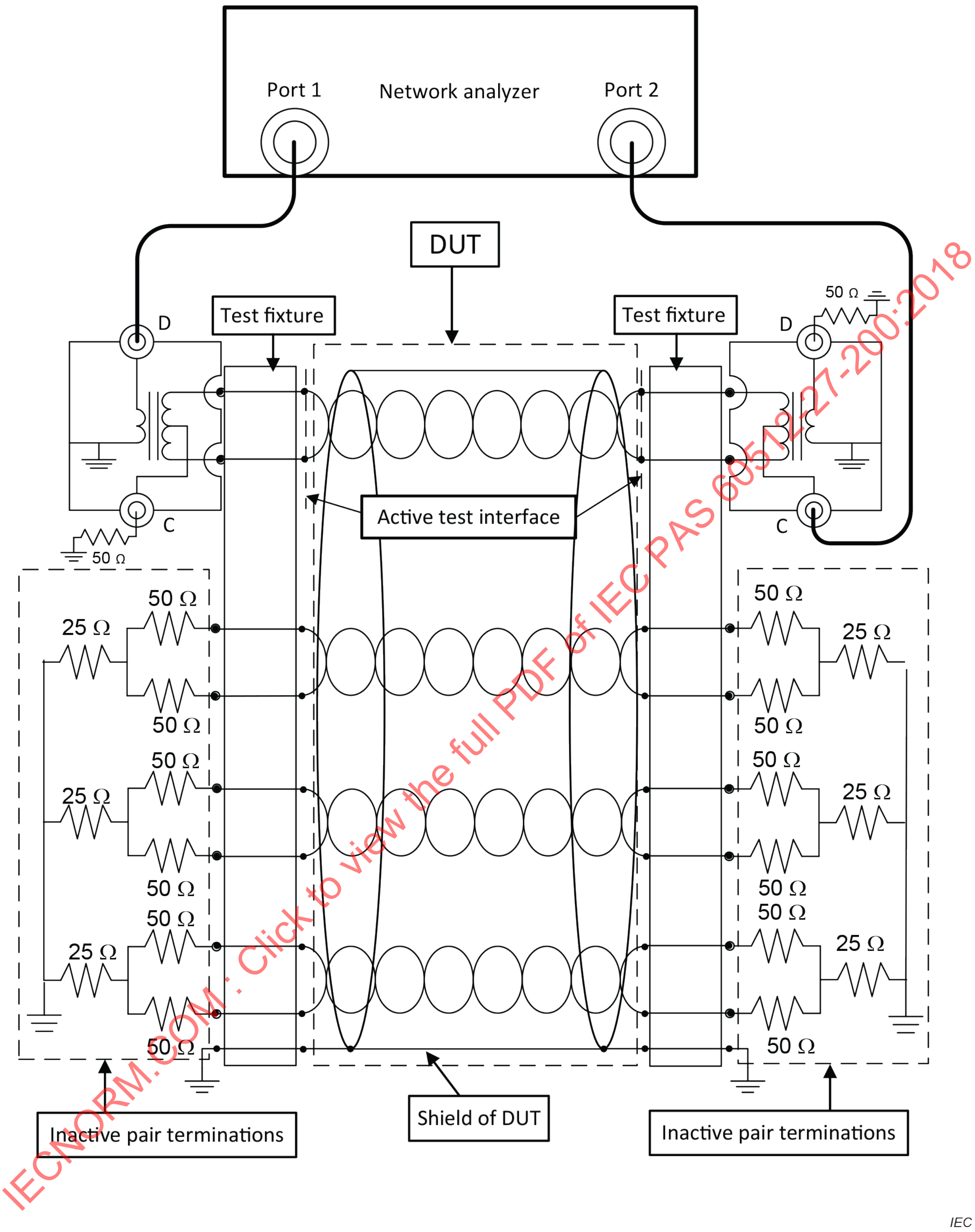


Figure C.12 – Laboratory test configuration for TCTL

C.2.8.3 Calibration of cable and channel TCTL

The calibration of the test hardware for TCTL measurements shall follow the procedure outlined in C.6.5.8 for both baluns being used in the measurement and the calibration values should be recorded as $IL_{bal,DM.1}$, $IL_{bal,DM.2}$, $IL_{bal,CM.1}$, and $IL_{bal,CM.2}$.

C.2.8.4 Measurement of cable and channel TCTL

The S12 measurement is performed and the result is recorded as Il_{meas2}.

TCTL, corrected to remove the insertion loss of the test setup and corrected for the transformer impedance ratio, is calculated using formula (C.2).

$$TCTL = (IL_{meas2} - IL_{bal,DM,1} - IL_{bal,CM,2})\ \mathrm{dB} \qquad \text{(C.2)}$$

TCTL shall be tested in both directions.

NOTE The proximity of a cable under test to ground planes may have an impact upon cable balance measurements.

C.2.9 Cable and channel measurement precautions

Mutual capacitance, capacitance unbalance, characteristic impedance, return loss, insertion loss, SRL, NEXT loss, ACRF, TCL, and TCTL measurements and calculations shall be performed on cable samples of 100 m (328 ft) (or 30m for category 8) removed from the reel or packaging. The test sample shall be laid out along a non-conducting surface, loosely coiled, or supported in aerial spans, and all pairs shall be terminated according to the specific requirements of this annex. Other test configurations are acceptable if correlation to the reference method has been verified. In case of conflict, the reference method (100 m or 30 m, off-reel, resistor terminated) shall be used to determine conformance to the minimum requirements of this standard.

It may be desirable to perform measurements on lengths of cable greater than 100 m (328 ft) or 30 m (98 ft) in order to improve measurement accuracy at frequencies at or below 1 MHz. For example, when measuring insertion loss, it is recommended that the sample length exhibit no less than 3 dB of insertion loss at the lowest frequency tested. More than one length may be required to test a full range of frequencies. Cables tested for insertion loss at elevated temperatures shall be placed inside an air-circulating oven until the cable has stabilized at the reference temperature. No more than 3 m (10 ft) of each cable end should exit the oven for connection to the measurement equipment.

C.2.10 Screened or shielded cable and channel measurement configurations

For all laboratory and field transmission measurements of screened cables, the cable shield shall be grounded at both ends. Attention should be given to providing low impedance connections from the shield to ground and between grounding points of the two cable ends.

C.3 Permanent link test procedures

C.3.1 General

This clause describes test and calibration procedures for permanent links.

C.3.2 Permanent link measurement configurations

The following requirements apply to the test configurations for permanent link measurements and for other components, assemblies, and test parameters as indicated by reference.

For all laboratory and field transmission measurements of screened cables, the cable shield shall be grounded at both ends. Attention should be given to providing low impedance connections from the shield to ground and between grounding points of the two cable ends.

Testing shall be carried out using a modular test plug compliant with clause C.6.6 inserted between the test interface and the permanent link under test. The crosstalk, insertion loss and return loss of the modular test plug shall not be calibrated out.

C.3.3 Calibration of permanent link test configurations.

The permanent link test configuration shall be calibrated by applying appropriate open, short, load and through calibration artefacts to the test interface between the test system and the modular test plug.

C.3.4 Return loss of permanent links

C.3.4.1 Test configuration of permanent link return loss

The permanent link return loss measurement configuration shall comply with the requirements of Figure C.13.

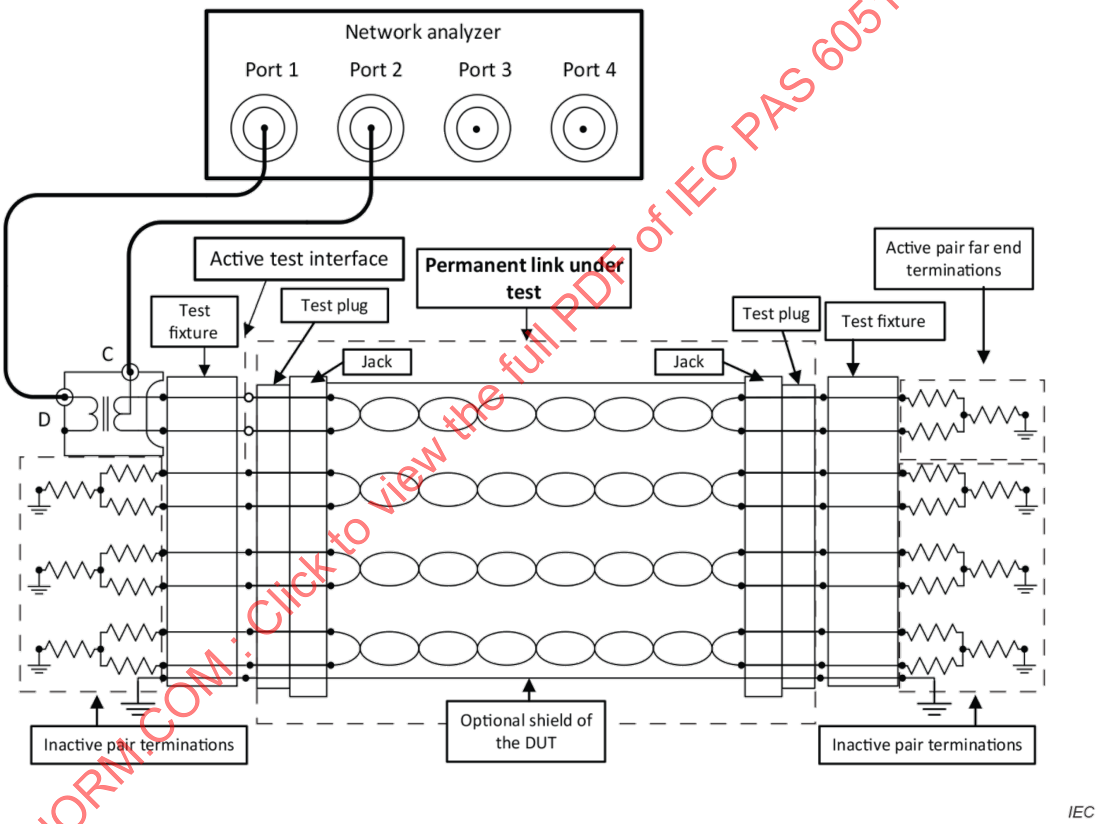


Figure C.13 – Laboratory test configuration for permanent link return loss and TCL measurements

C.3.4.2 Calibration of permanent link return loss

The calibration for permanent link return loss shall comply with Clause B.4.

C.3.4.3 Measurement of permanent link return loss

Measure the Sdd11 parameter with the network analyzer connected to each pair on each end; permanent link return loss shall be tested in both directions.

C.3.5 Insertion loss of permanent link

C.3.5.1 Test configuration for permanent link insertion loss, (also used for FEXT loss, ACRF, and propagation delay)

The permanent link insertion loss measurement configuration shall comply with the requirements of Figure C.14.

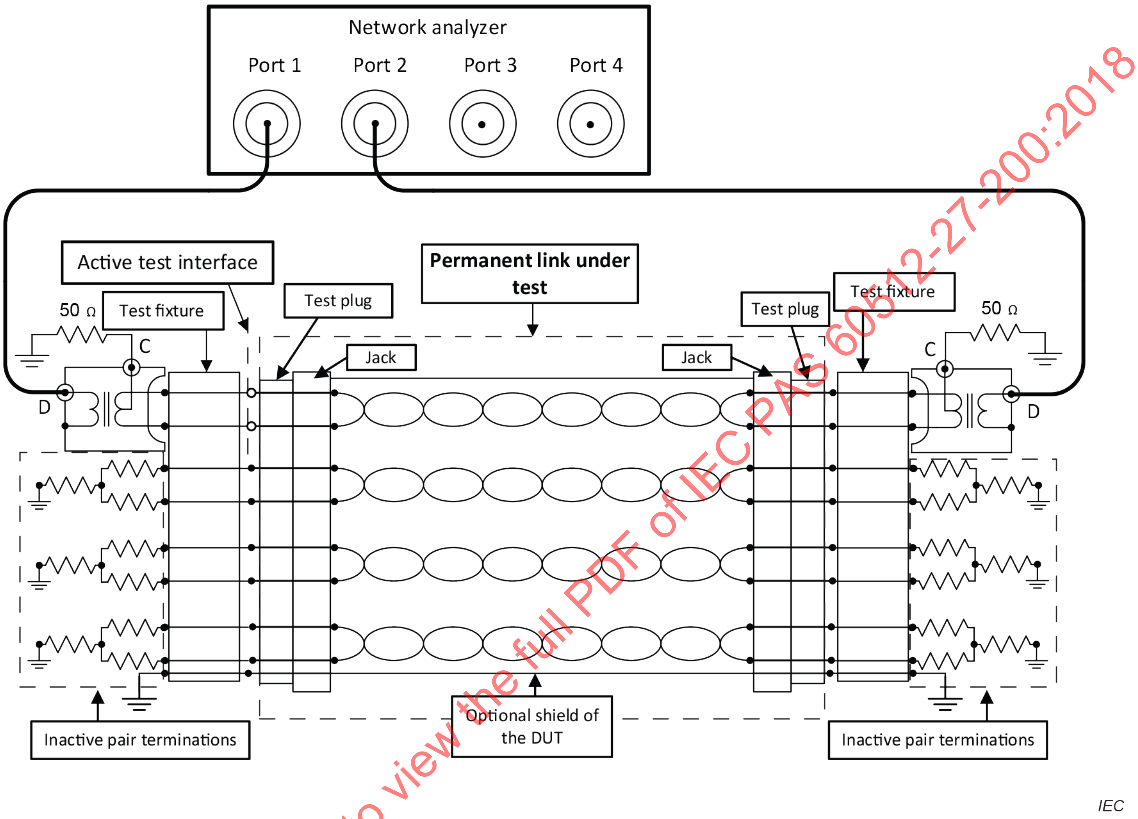


Figure C.14 – Laboratory test configuration for permanent link insertion loss and propagation delay measurements

C.3.5.2 Calibration of permanent link insertion loss

The calibration for permanent link return loss shall comply with Clause B.4.

C.3.5.3 Measurement of permanent link insertion loss

Measure the Sdd21 parameter with the pair under test connected to the network analyzer at both the near-end and the far-end. Permanent link insertion loss shall be tested in both directions.

C.3.6 NEXT loss of permanent link

C.3.6.1 Test configuration for permanent link NEXT loss

The permanent link NEXT loss measurement configuration shall comply with the requirements of Figure C.15.

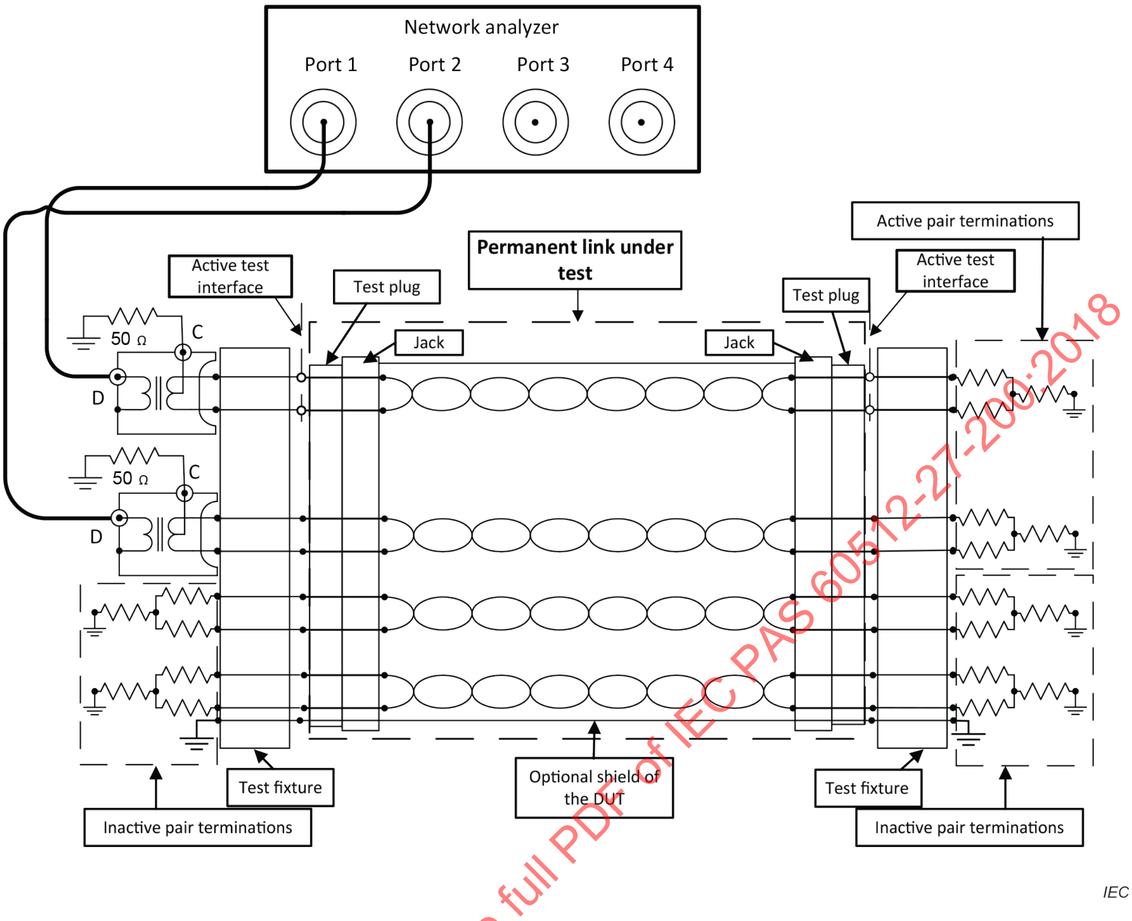


Figure C.15 – Laboratory test configuration for permanent link NEXT loss measurements

C.3.6.2 Calibration of permanent link NEXT loss

The calibration for permanent link NEXT loss shall comply with Clause B.4.

C.3.6.3 Measurement of permanent link NEXT loss

Measure the Sdd21 parameter with the network analyzer connected to each of the 6 pair combinations in a four pair permanent link. Permanent link NEXT loss shall be tested in both directions.

C.3.7 FEXT loss of permanent link

C.3.7.1 Test configuration of permanent link FEXT loss

The permanent link FEXT loss measurement configuration shall comply with the requirements of Figure C.16.

C.3.7.2 Calibration of permanent link FEXT loss

The calibration of permanent link FEXT loss shall comply with B.4.5.

C.3.7.3 Measurement of permanent link FEXT loss

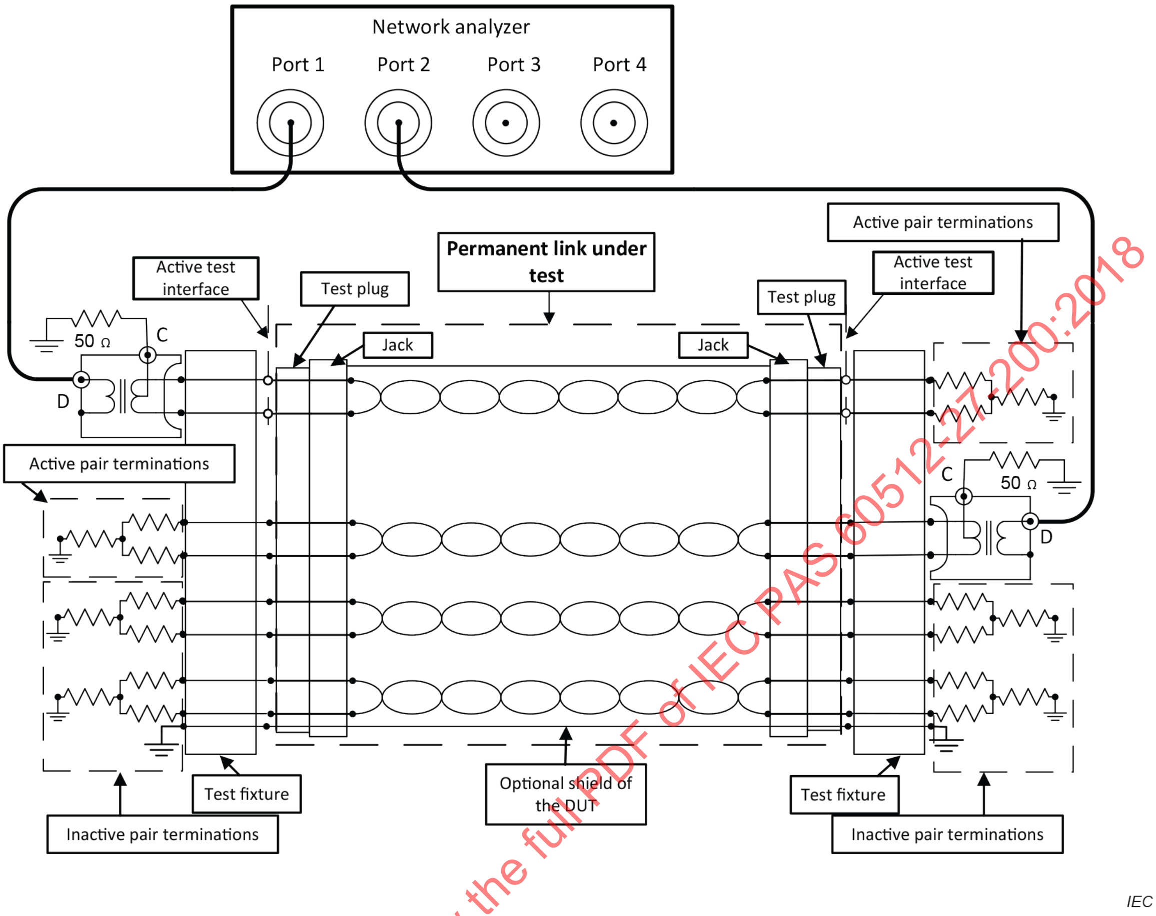


Figure C.16 – Laboratory test configuration for permanent link FEXT loss (ACRF)

Measure Sdd21 for all of the 12 pair combinations for permanent link FEXT loss, launching from one end only. It is not necessary to measure permanent link FEXT loss from both ends due to reciprocity.

C.3.8 TCL of permanent link

C.3.8.1 Test configuration of permanent link TCL

The permanent link TCL measurement configuration is shown in Figure C.17.

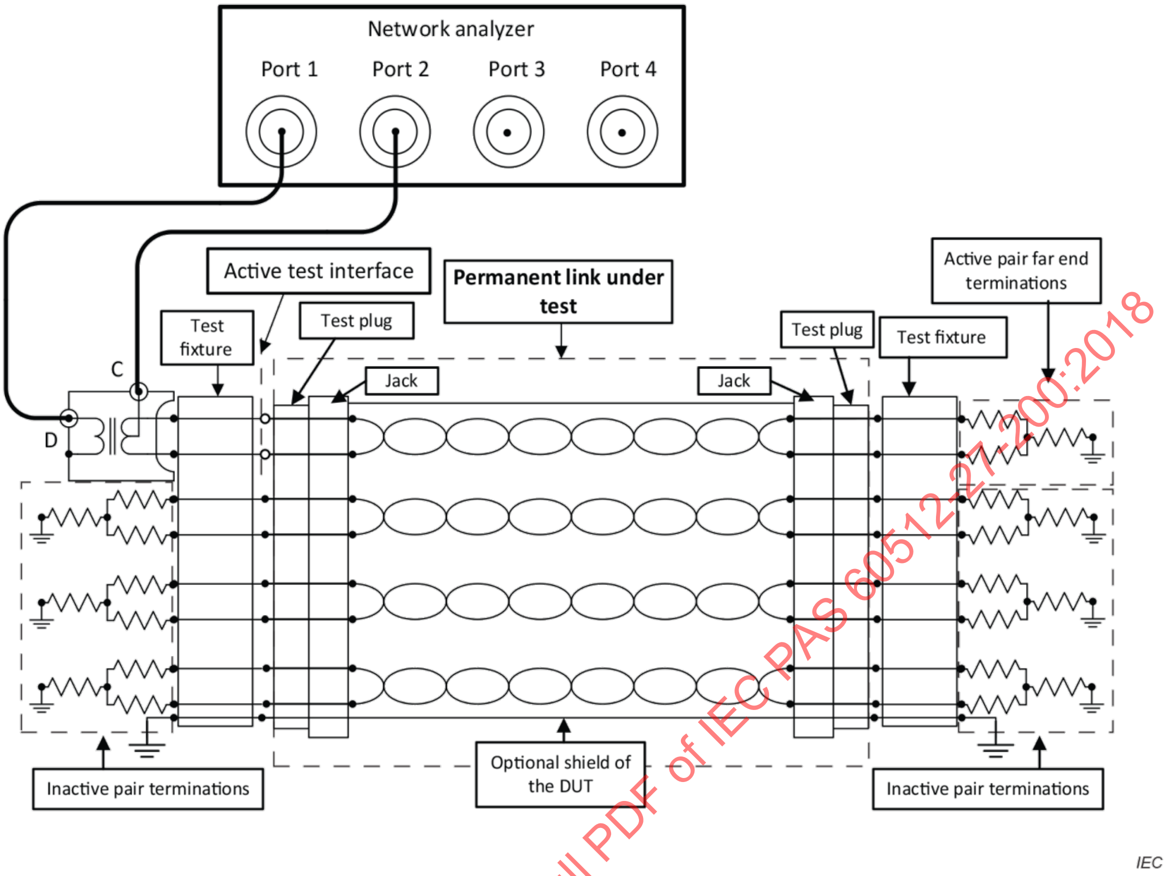


Figure C.17 – Laboratory test configuration for permanent link TCL measurements

C.3.8.2 Calibration of permanent link TCL

The calibration of permanent link TCL shall comply with C.2.7.3.

C.3.8.3 Measurement of permanent link TCL

Measure permanent link TCL on each pair in both directions.

C.3.9 TCTL of permanent link

C.3.9.1 Test configuration of permanent link TCTL

The permanent link TCTL measurement configuration is shown in Figure C.18.

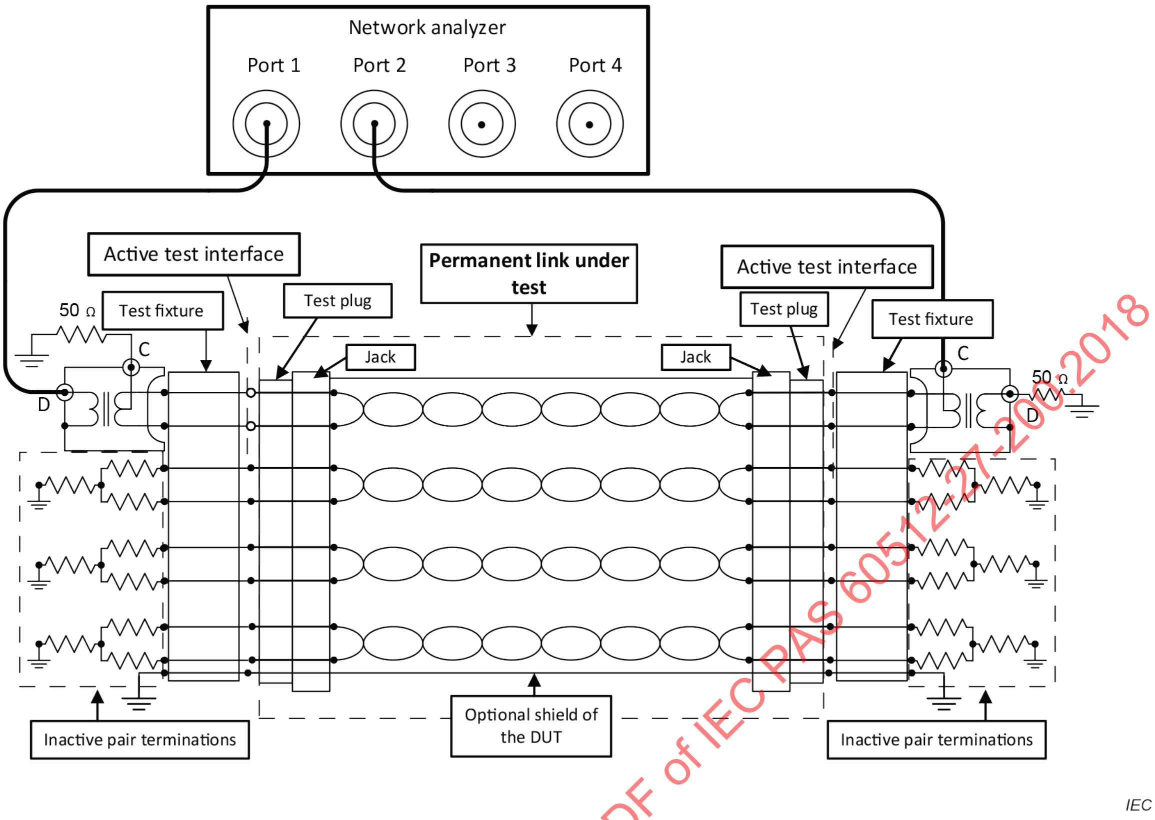


Figure C.18 – Laboratory test configuration for permanent link TCTL

C.3.9.2 Calibration of permanent link TCTL

The calibration of permanent link TCTL shall comply with C.2.8.3.

C.3.9.3 Measurement of permanent link TCTL

Measure permanent link TCTL on each pair in both directions.

C.3.10 Propagation delay of permanent link

C.3.10.1 Test configuration of permanent link propagation delay

The permanent link propagation delay measurement configuration shall comply with the requirements of Figure C.14.

C.3.10.2 Calibration of permanent link propagation delay

The calibration of permanent link propagation delay shall comply with B.4.5.

C.3.10.3 Measurement of permanent link propagation delay

Measure all 4 pairs for permanent link propagation delay. It is not necessary to measure permanent link propagation delay from both ends due to reciprocity.

C.4 Direct attach measurement procedures

C.4.1 Direct attach test configurations

In Figures 19 to 24, the far end termination is shown combined with the test fixture. It is acceptable to configure the far end terminations within the test fixture, or attached to the test fixture. Switching may be used and that switching may configured within the test fixture. See IEC 60512-28-100 for a more detailed discussion of wire termination test fixture configurations. The test jacks shall be compliant to the category patch cord test head requirements in Clause C.7.

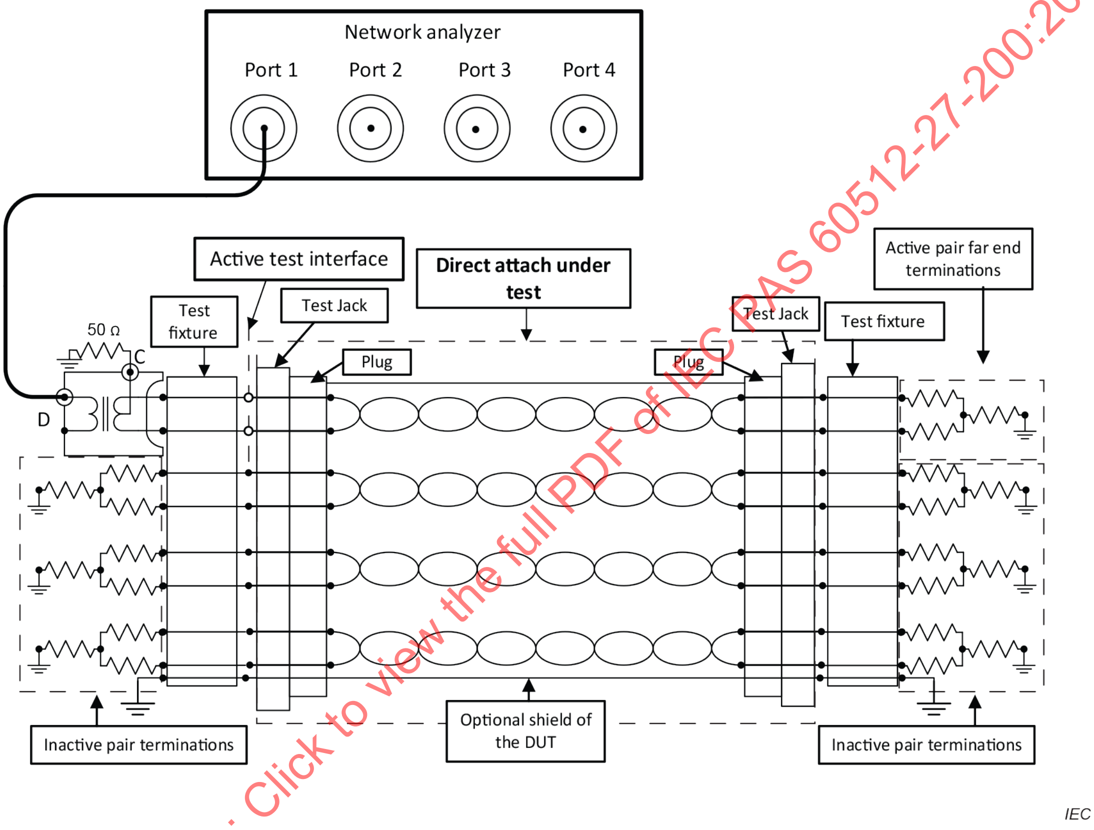


Figure C.19 – Direct attach return loss test configuration

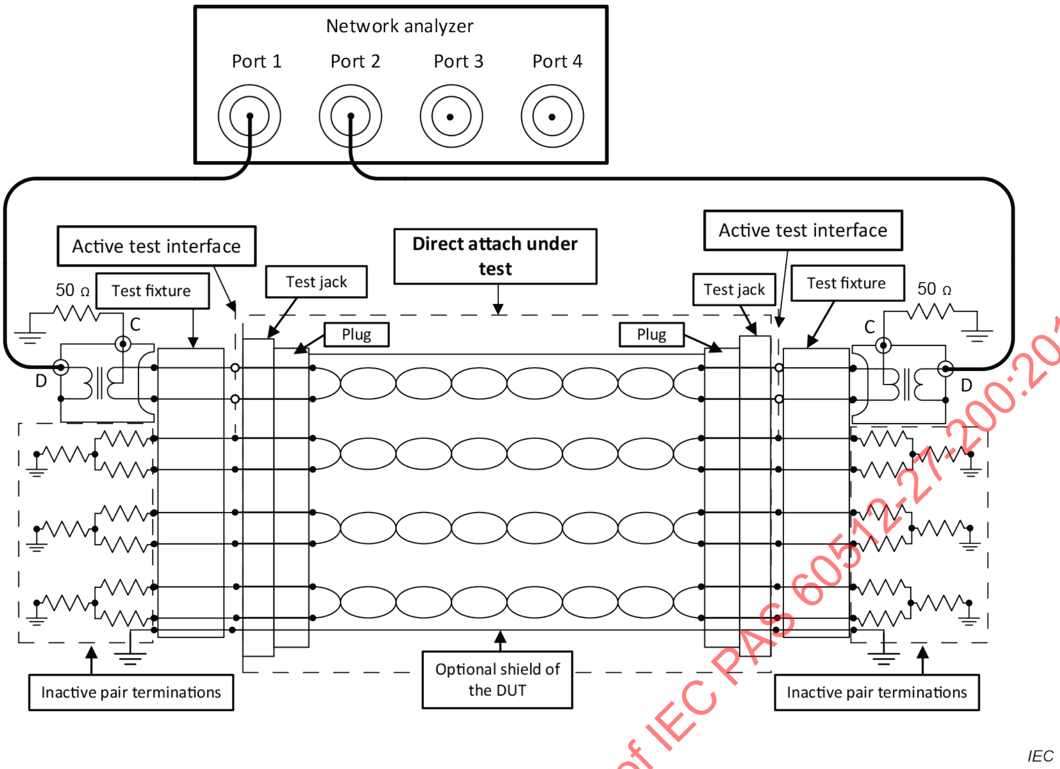


Figure C.20 – Direct attach cord insertion loss test configuration

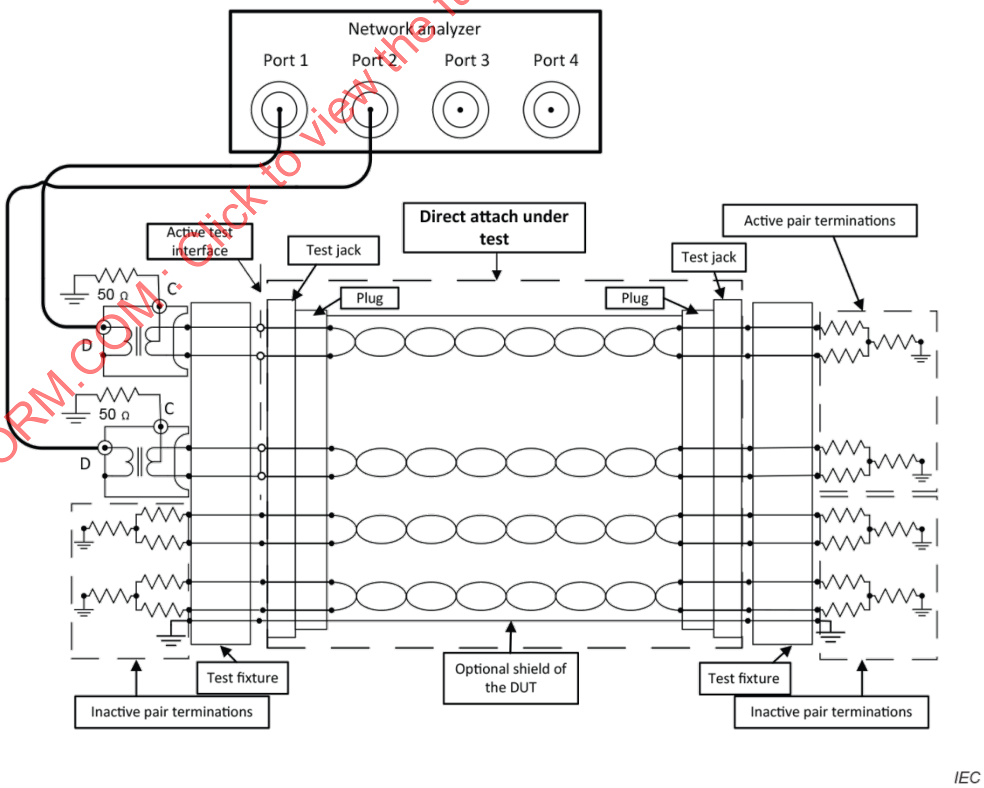


Figure C.21 – Direct attach cord NEXT loss test configuration

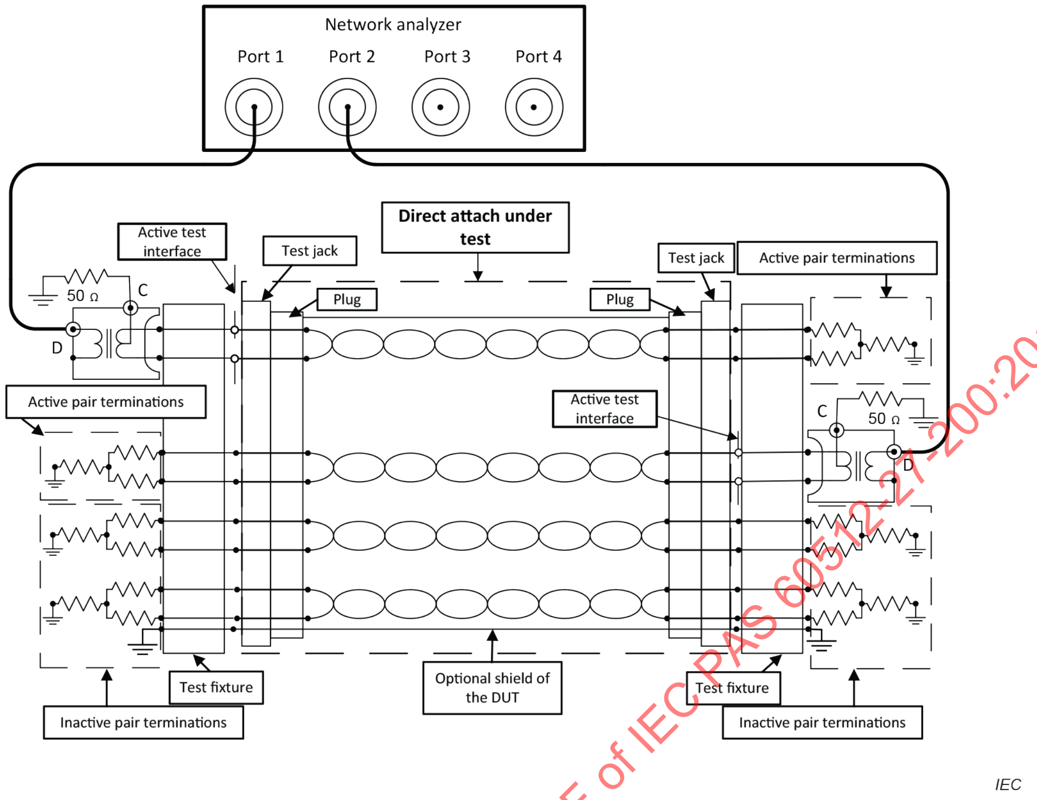


Figure C.22 – Direct attach cord FEXT loss, (ACRF) test configuration

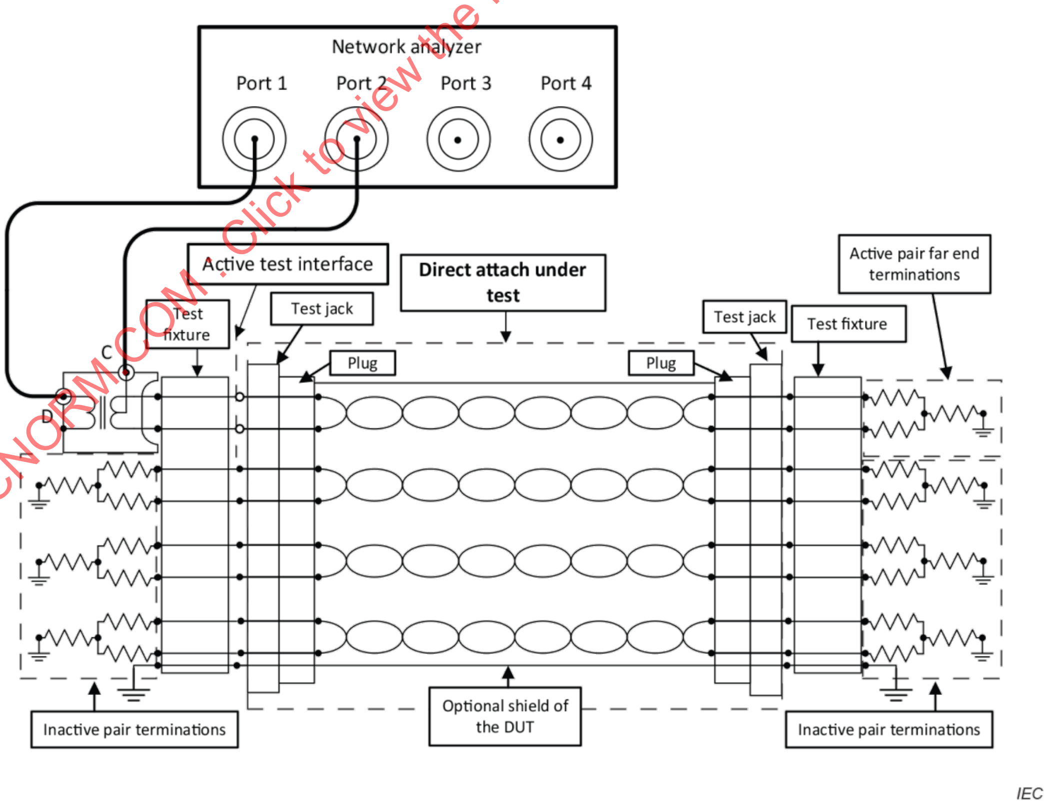


Figure C.23 – Direct attach cord TCL test configuration

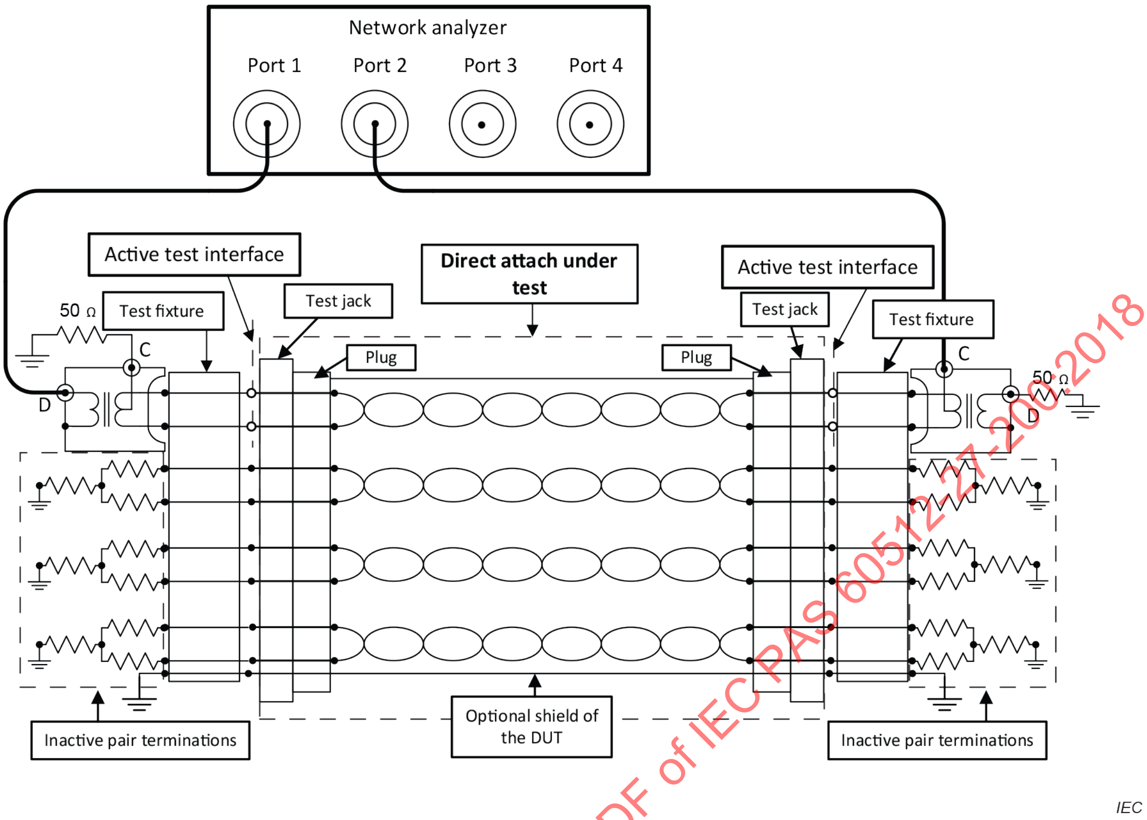


Figure C.24 – Direct attach cord TCTL test configuration

C.5 Modular cord test procedures

C.5.1 Network analyzer test configuration

The network analyzer configuration for modular cord testing is depicted in Figure C.25, Figure C.26, and Figure C.27 which show balun configurations for the three required tests.

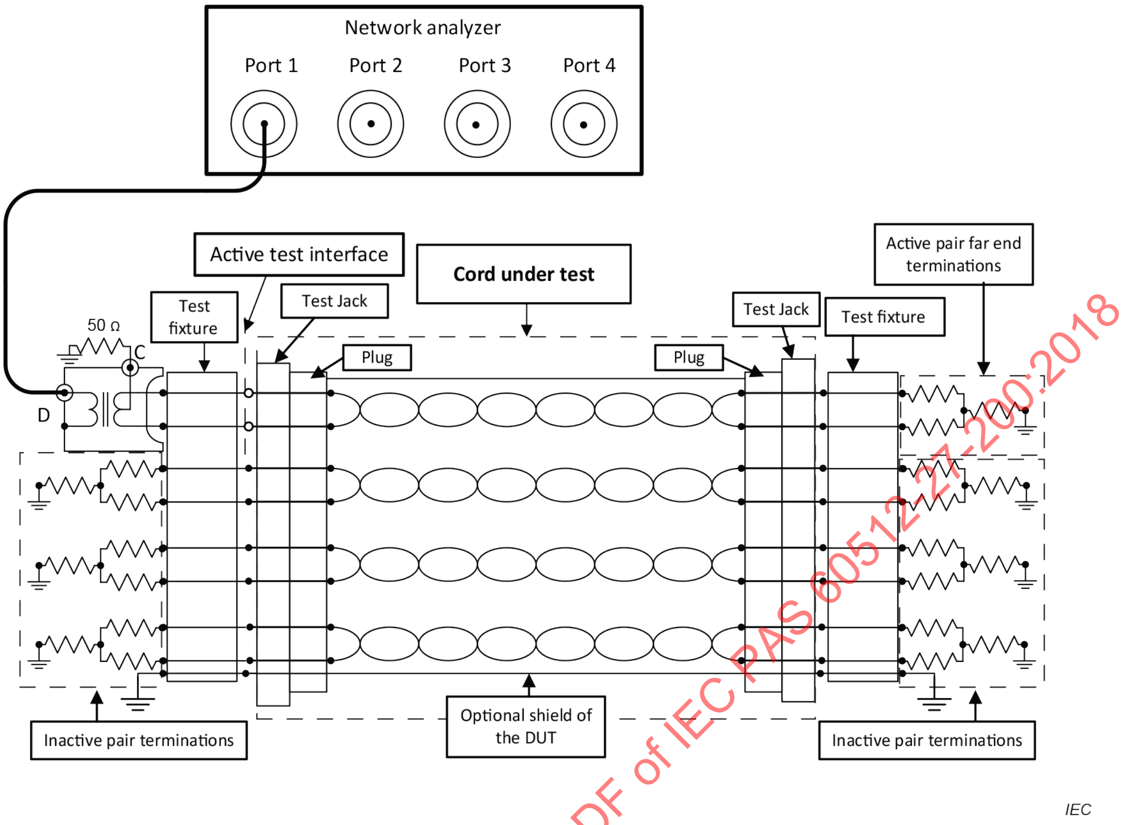


Figure C.25 – Modular cord return loss test configuration

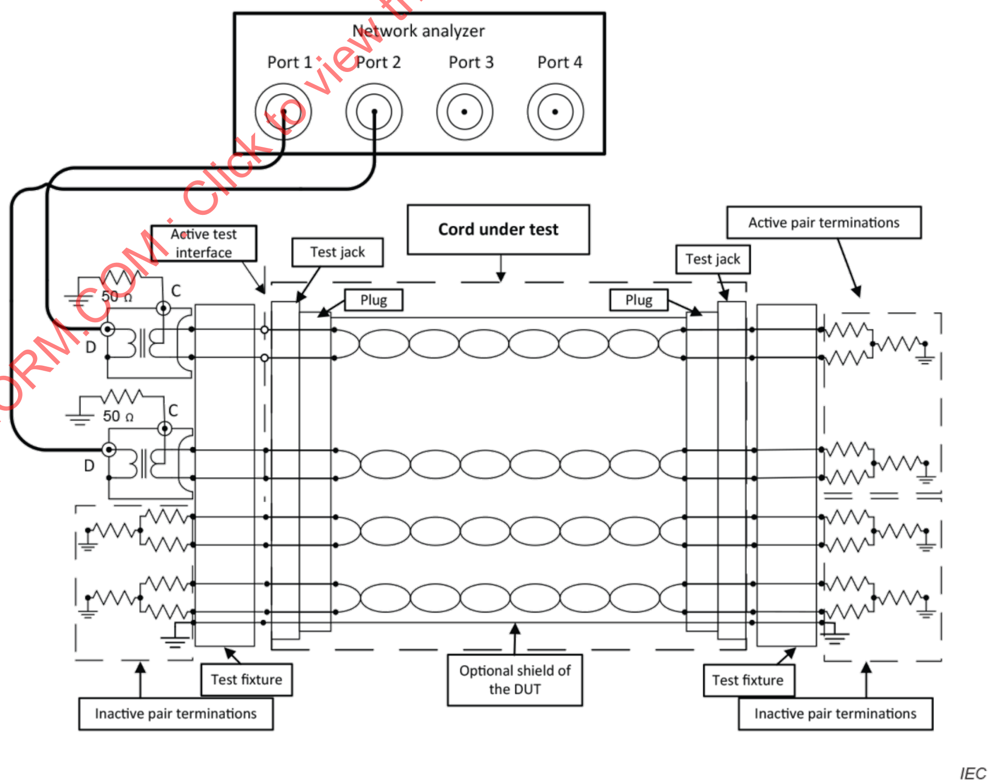


Figure C.26 – Modular cord NEXT loss test configuration

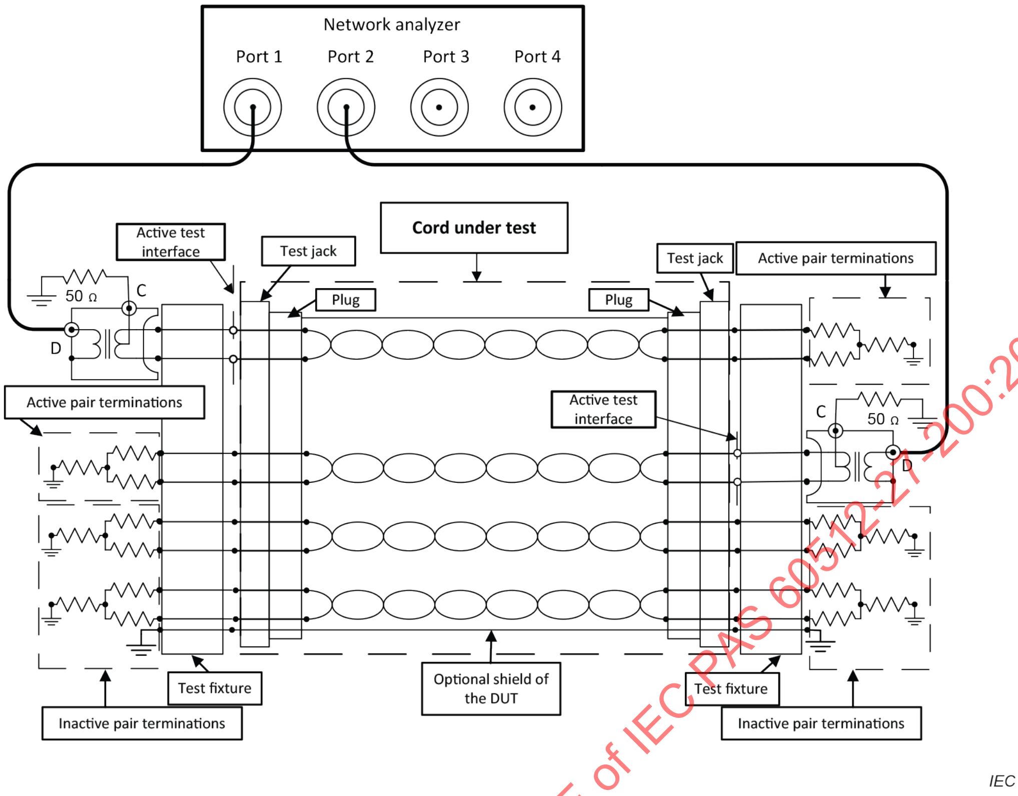


Figure C.27 – Modular cord FEXT loss, (ACRF) test configuration

C.5.2 Test fixturing for modular cords

Modular cord test head NEXT loss, FEXT loss, and return loss requirements are specified in Clause C.7. For the purpose of testing modular cord NEXT loss, the modular cord test head shall meet all of the requirements of this clause. For the purpose of measuring modular cord return loss, it is sufficient for the test head to meet only the requirements of C.7.4. The test head used at each end of the test configuration shall be of the same design.

C.5.3 Modular cord measurements.

NEXT loss and return loss are required for modular cords.

NEXT loss and return loss requirements are given in respective modular cords specifications.

NOTE For category 6A and category 8 modular cord pair combination 3,6 – 4,5 NEXT measurements, the respective determined modular cord limits are calculated using the connector contributions in Table C.4 to account for modular plug pair combination 3,6 – 4,5 NEXT range and measurement repeatability.

C.6 Connecting hardware testing

C.6.1 General

This clause describes test and calibration procedures for connecting hardware.

C.6.2 Connecting hardware measurement configurations

The following requirements apply to the test configurations for connecting hardware measurements and for other components, assemblies, and test parameters as indicated by reference. The test methods and setup requirements described herein apply to one (1) or more pairs of twisted-pair conductors. The nature of these tests is such that, when conducted properly, worst case transmission performance may be determined for a specific connector, regardless of the number of pairs that it is capable of terminating. Connecting hardware transmission testing shall be conducted upon products terminated per manufacturer's guidelines and recommended installation methods unless otherwise specified. For connecting hardware with modular interface components (i.e. plug and jack connectors), transmission tests shall be performed in a mated state. Test plug requirements are specified in C.6.6.

DM only and DMCM resistor terminations are shown in Figure B.5 and Figure B.6. DMCM terminations shall be used on all active pairs under test except when measuring return loss, where DM only resistor terminations are recommended. DMCM resistor terminations shall be used on all inactive pairs and on the opposite ends of active pairs for NEXT loss and FEXT loss testing. DMCM terminations shall be used on inactive pairs for insertion loss testing. Inactive pairs for return loss testing may be terminated with DM or DMCM resistor terminations, or left unterminated. Balun terminations may be used on the far-end of all pairs and the near-end of all inactive pairs provided that their differential mode and common mode return loss performance characteristics meet the minimum performance of the specified resistor networks.

Interconnection (including test lead) requirements are specified in Clause B.2.

For the purpose of testing connecting hardware mated performance, the test plug phase reference plane and calibration planes shall be as defined in C.6.6.14. Connecting hardware shall be defined as a mated plug and jack, with cable terminated to both. The connector is considered to begin at the point where the sheath of the cable is cut or the point inside the sheath where the cable conductor geometry is no longer maintained. The portion of the cable [typically 12 mm (0,5 in) or less] that is disturbed by the termination shall be considered to be part of the connector under test. Unless otherwise specified for a specific test, the performance of the entire mated connector shall be assessed.

For testing screened connecting hardware, a balun ground plane shall be provided as part of the test setup and apparatus, and the shield of the connecting hardware shall be bonded to the ground plane during the testing of transmission characteristics.

C.6.3 Return loss measurements

Connecting hardware shall be tested in both directions for return loss. Connecting hardware return loss is determined by measuring connecting hardware when mated to a test plug qualified per C.6.6. When possible, it is recommended to use the same resistor terminations at the far-end as were used for instrument calibration.

C.6.4 Insertion loss measurements

Connecting hardware insertion loss shall be measured in accordance with the requirements of C.6.4. Measure connecting hardware insertion loss with interconnections prepared and controlled in accordance with Clause B.2. Connecting hardware shall be measured with at least one test plug in at least one direction. There are no insertion loss requirements for test plugs and the insertion loss contribution of the interconnections at each end of the mated connection is assumed to be negligible. For improved accuracy, the insertion loss of the interconnections at each end of the mated connection may be subtracted from the measurement of the DUT.

Balanced attenuation pads, meeting the requirements of Clause B.4 with the exception of insertion loss, may be used in line with the DUT on both ends provided that they are calibrated out of the measurement. The insertion loss of the balanced attenuation pads should be 2 dB to 10 dB over the applicable frequency range.

C.6.5 NEXT loss measurements

C.6.5.1 General

The measurement set up shall comply with Clause B.1 and with C.2.10. A two-port calibration is required per Clause B.4. For category 3 testing, any plug may be used. For categories 5e, 6, and 6A, qualified test plugs are required and a "re-embedding" process is used to assure compliance with a range of plugs, as described below.

Connecting hardware shall be tested in both directions for NEXT loss using at least one test plug. In addition, connecting hardware NEXT loss on all pair combinations shall be qualified with the full set of 14 test plug limit vectors specified in Table C.2 for category 6 or 6A or Table C.3 for category 5e when mated to a qualified test plug specified in C.6.6.4.

C.6.5.2 Connecting hardware NEXT loss measurement and calculation of plug limit vector responses in the forward direction

a) Measure the NEXT loss vector (magnitude and phase) for the jack mated to the test plug, in the forward direction (launch signal into the test plug).
b) Correct the phase to the test plug phase reference plane using the delay procedures in C.6.6.14.
c) Subtract the corrected test plug NEXT loss forward vectors obtained using C.6.6.6 from the corrected mated NEXT loss vectors obtained in steps 1 and 2. This will yield de-embedded jack vectors.
d) Add the plug NEXT loss limit vectors in Table C.2 to the de-embedded jack vectors obtained in step 3. This yields 14 "re-embedded" mated connecting hardware NEXT loss responses.
e) Pass-fail qualification is determined by comparing the results in step 4 to the corresponding mated connecting hardware requirements.

C.6.5.3 Connecting hardware NEXT loss measurement and calculation of plug limit vector responses in the reverse direction

a) Determine the delay of the jack by measuring the test plug delay, mating the test plug to the jack, and measuring the delay of the assembly. Subtract the test plug delay from the delay of the assembly to get the jack delay.
b) Measure the NEXT loss vector (magnitude and phase) for the jack mated to the test plug, in the reverse direction (launch signal into the jack).
c) Correct the phase to the test plug phase reference plane using the results obtained in step 1.
d) Subtract the corrected test plug NEXT loss reverse vectors obtained using Table C.2 from the corrected mated NEXT loss vectors obtained in steps 2 and 3. This will yield de-embedded jack vectors.
e) Add the plug NEXT loss limit vectors in Table C.2 to the de-embedded jack vectors obtained in step 4. This yields 14 "re-embedded" mated connecting hardware NEXT loss responses.
f) Pass-fail qualification is determined by comparing the results in step 5 to the corresponding mated connecting hardware requirements.

C.6.5.4 Determining the plug NEXT loss limit vectors

The plug NEXT loss limit vectors for each case are determined by combining the magnitude values and phase values as shown in Table C.2 for categories 6, 6A, and 8, and Table C.3 for category 5e.

Table C.2 – Category 6, 6A and 8 test plug NEXT loss limit vectors

Case #	Pair combination	Limit	Plug NEXT loss limit magnitude dB	Plug NEXT loss limit phase degrees[1), 2)]
Case 1	3,6 – 4,5	Low	38,1 – 20 log (f/100)	Test plug NEXT loss phase
Case 2	3,6 – 4,5	Central	38,6 – 20 log (f/100)	Test plug NEXT loss phase
Case 3	3,6 – 4,5	Central	39,0 – 20 log (f/100)	Test plug NEXT loss phase
Case 4	3,6 – 4,5	High	39,5 – 20 log (f/100)	Test plug NEXT loss phase
Case 5	1,2 – 3,6	Low	46,5 – 20 log (f/100)	Test plug NEXT loss phase
Case 6	1,2 – 3,6	High	49,5 – 20 log (f/100)	Test plug NEXT loss phase
Case 7	3,6 – 7,8	Low	46,5 – 20 log (f/100)	Test plug NEXT loss phase
Case 8	3,6 – 7,8	High	49,5 – 20 log (f/100)	Test plug NEXT loss phase
Case 9	1,2 – 4,5	Low	57 – 20 log (f/100)	+90
Case 10	1,2 – 4,5	High	70 – 20 log (f/100)	–90
Case 11	4,5 – 7,8	Low	57 – 20 log (f/100)	+90
Case 12	4,5 – 7,8	High	70 – 20 log (f/100)	–90
Case 13	1,2 – 7,8	Low	66 – 20 log (f/100)	Test plug NEXT loss phase
Case 14	1,2 – 7,8	High	66 – 20 log (f/100)	Test plug NEXT loss phase minus 180°

1) Test plug NEXT loss phase is determined by following the procedure in C.6.5.2.

2) The reference plane for measuring test plug NEXT loss phase and mated NEXT loss shall be the test plug phase reference plane as described in C.6.6.14.

Table C.3 – Category 5e test plug NEXT loss limit vectors

Case #	Pair combination	Limit	Plug NEXT loss limit magnitude dB	Plug NEXT loss limit phase degrees[1), 2)]
Case 1	3,6 – 4,5	Low	35,8 – 20 log (f/100)	Test plug NEXT loss phase
Case 2	3,6 – 4,5	Central	n/a	n/a
Case 3	3,6 – 4,5	Central	n/a	n/a
Case 4	3,6 – 4,5	High	39,5 – 20 log (f/100)	Test plug NEXT loss phase
Case 5	1,2 – 3,6	Low	42 – 20 log (f/100)	Test plug NEXT loss phase
Case 6	1,2 – 3,6	High	50 – 20 log (f/100)	Test plug NEXT loss phase
Case 7	3,6 – 7,8	Low	42 – 20 log (f/100)	Test plug NEXT loss phase
Case 8	3,6 – 7,8	High	50 – 20 log (f/100)	Test plug NEXT loss phase
Case 9	1,2 – 4,5	Low	50 – 20 log (f/100)	90° or –90°
Case 10	1,2 – 4,5	High	n/a	n/a
Case 11	4,5 – 7,8	Low	50 – 20 log (f/100)	90° or –90°
Case 12	4,5 – 7,8	High	n/a	n/a
Case 13	1,2 – 7,8	Low	60 – 20 log (f/100)	90° or –90°
Case 14	1,2 – 7,8	High	n/a	n/a

1) Test plug NEXT loss phase is determined by following the procedure in C.6.5.2.

2) The reference plane for measuring test plug NEXT loss phase and mated NEXT loss shall be the test plug phase reference plane as described in C.6.6.14.

C.6.5.5 Connecting hardware NEXT loss requirements

The re-embedded response for case 2, case 3, and cases 5 – 14, as specified in Table C.3, shall meet the respective connecting hardware NEXT loss requirements. For categories 6, 6A, and 8, the re-embedded response for pair combination 3,6 – 4,5 case 1 and case 4, as specified in Table C.2, shall meet the requirements of Table C.4.

Table C.4 – Category 6, 6A and 8 connecting hardware NEXT loss requirements for case 1 and case 4

	Frequency MHz	**NEXT loss** dB
Category 6 and 6A	$1 \leq f \leq 250$ $250 < f \leq 500$	52,5 – 20 log (f /100) 44,54 – 40 log (f /250)
Category 8	$1 \leq f \leq 250$ $250 < f \leq 500$ $500 < f \leq 2\ 000$	52,5 – 20 log (f /100) 44,54 – 30 log (f /250) 35,51 – 40 log (f /500)

C.6.5.6 FEXT loss measurements

Test leads shall be connected to both ends of the test sample. The measurement set up shall comply with Clause B.1 and with C.2.3. A two-port calibration is required per Clause B.4. Connecting hardware FEXT loss is determined by measuring connecting hardware when mated to a test plug qualified per C.6.6.4. Test all 12 pair combinations in at least one direction.

C.6.5.7 TCL measurements

Test set up, calibration, and measurement shall be done per C.2.7 except for differences specified in this clause.

Test plugs used in connecting hardware TCL testing should comply with the test plug requirements given in C.6.6.

For connecting hardware TCL measurements, the near end and far-end common mode ground terminations should ensure a low impedance connection over the frequency range of test.

C.6.5.8 TCTL measurements

Test set up, calibration, and measurement shall be done per Clause B.1. In addition, test plugs used in connecting hardware TCTL testing should comply with the test plug requirements given in C.6.6.

C.6.6 Test plug characterization

C.6.6.1 General

This subclause describes the construction, qualification, and requirements for test plugs for verifying category 5e, 6, 6A and 8 connecting hardware performance.

C.6.6.2 Test plug measurement

Due to variations that are inherent in terminating cables to modular plugs, the test plug used to qualify connecting hardware performance shall be carefully controlled. To measure connecting hardware NEXT loss, test plugs need only be qualified in the near-end test direction, with the cable end of the plug designated as the near-end. Test plugs thus qualified are used to characterize mated connecting hardware performance for both the near-end and far-end measurement orientations.

C.6.6.3 Test plug construction

Testing low loss devices to RF frequencies requires the use of stable and predictable connectors and interconnecting leads between the device under test, the test fixtures and equipment. A reasonably stable interface is a printed circuit board designed to mate to device connections and fixture connections. The characteristic impedance, both differential and common mode, of the circuit board traces can be controlled, and multiple copies can be produced which will have similar performance. Figure C.28 and Figure C.29 describe dimensions for a connector interface to mate a circuit board test artefact to a test fixture. This connector design has excellent crosstalk and outstanding return loss performance and is rugged enough for repeated mating cycles without loss of performance.

Figure C.28 shows the female connector interface, including pin-pair number designations which are based upon standard modular connector pin-pair designations. This is an example pin-out, and other pin-outs are also allowed. Figure C.30 describes the mating dimensions of a PCB layout (paddle card) that mates to the connector. The dimensions shown are nominal dimensions that are suggested for the interface and suitable mating tolerances are the responsibility of the user to determine. These tolerances will necessarily depend on the manufacturing capabilities of the PCB supplier and the connector vendor selected. The connector is based upon a specific connector interface however it is assumed there are multiple suppliers of similar products.

Connector total number of contacts: 20 in two rows of 10.

Connector nominal contact spacing: 0,8 mm.

Connector nominal PCB mating board thickness: 1,6 mm.

Ground connections are placed between active circuit connections for guarding purposes. The mating PCB also includes ground planes between the two rows of connections for impedance control and guarding purposes.

This connector interface is useful especially for modular test plug artefacts and for paddle card interfaces to IDC connecting points on modular connecting hardware.

The connector shown is for vertical surface mounting to a printed circuit board that interfaces to a test fixture. Locating pins are included on the connector housing for physical stability and orientation. Other types of connector PCB mounting are possible, such as a horizontal orientation or an edge card orientation. See also Figure C.31.

Dimensions in millimetres (inches)

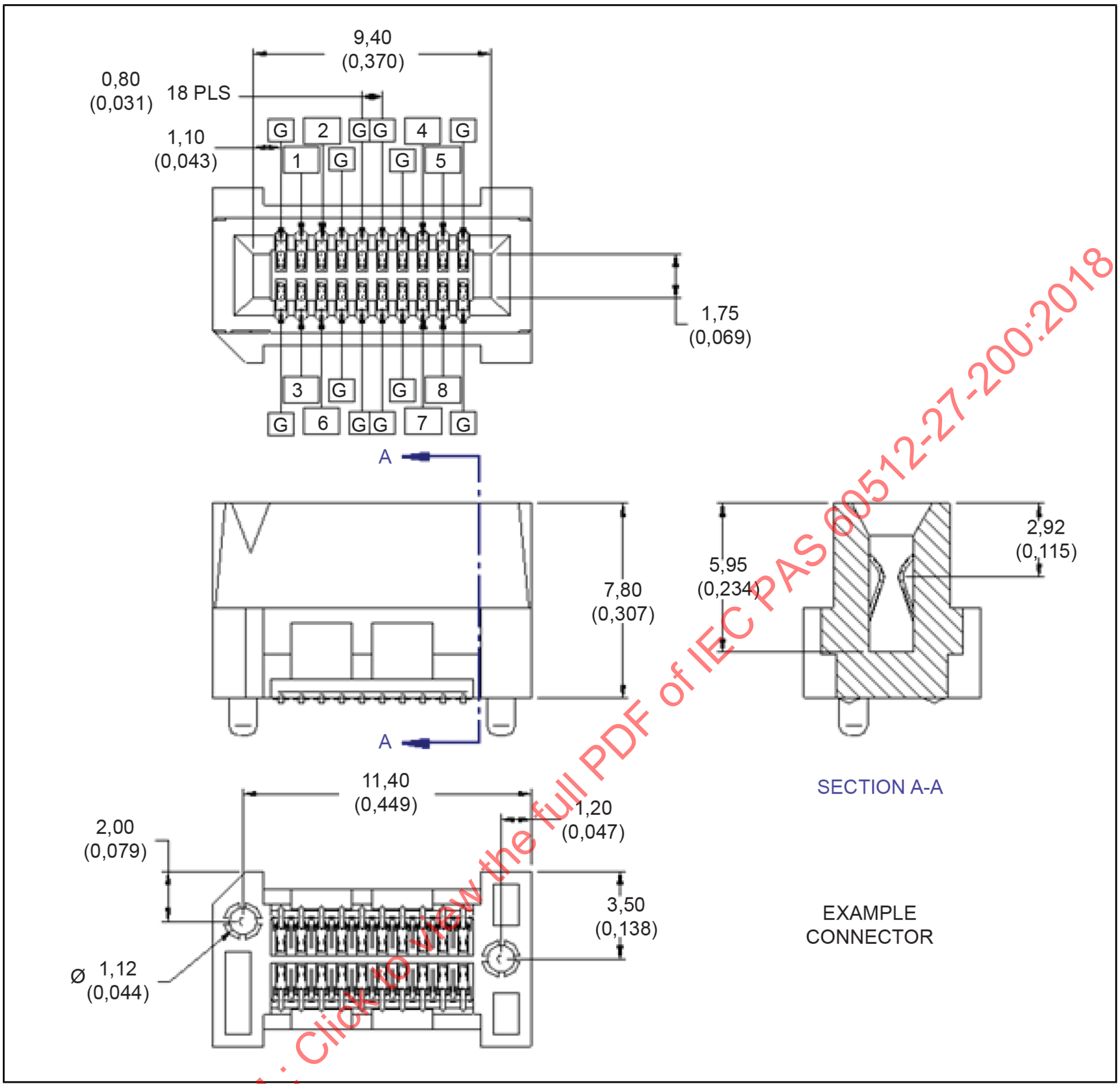


Figure C.28 – Female test connector interface mating dimensions (1)

Dimensions in millimetres (inches)

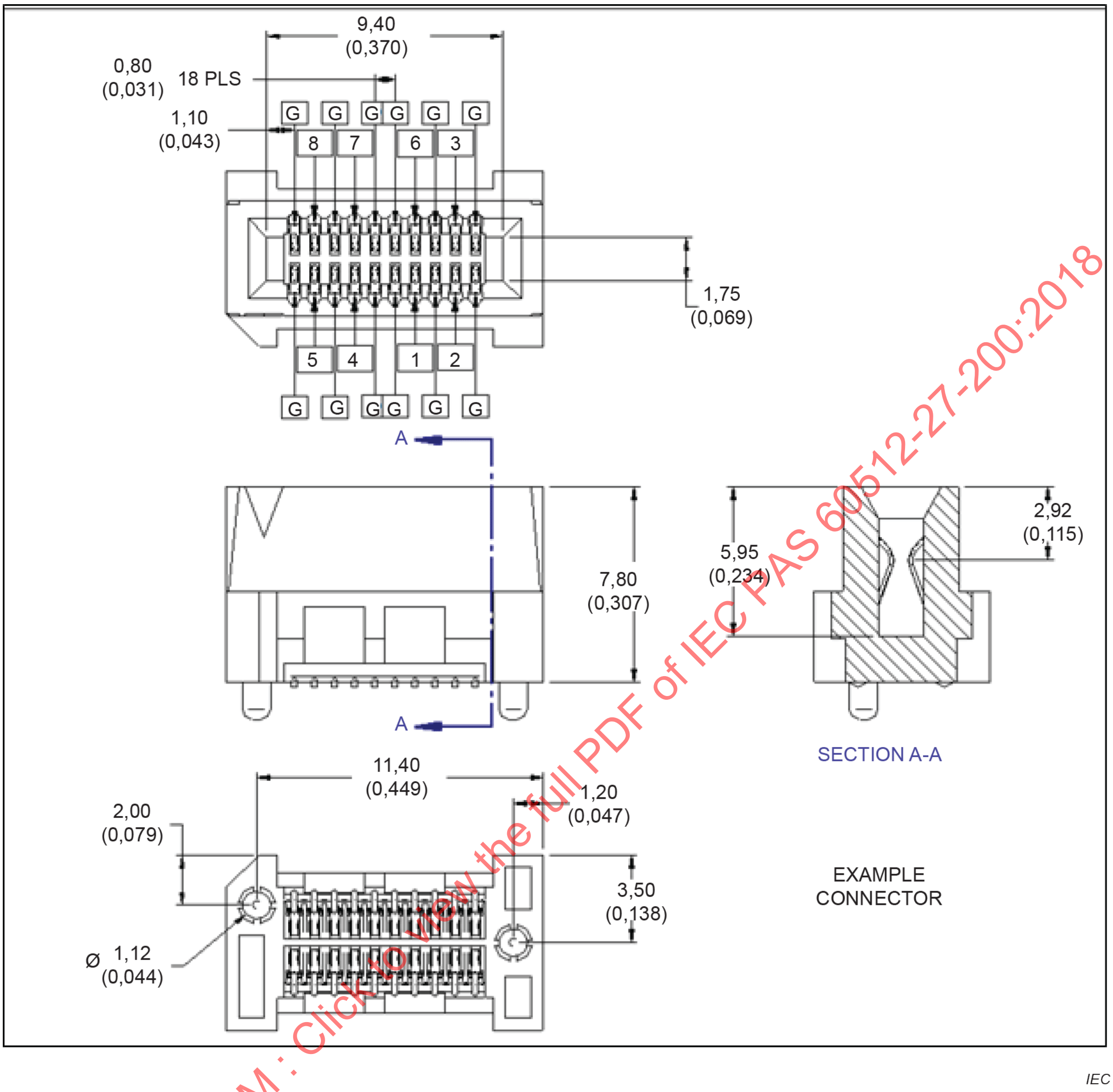


Figure C.29 – Female test connector interface mating dimensions (2)

Refer to connector specifications for pin numbers in this diagram.

Dimensions in millimetres (inches)

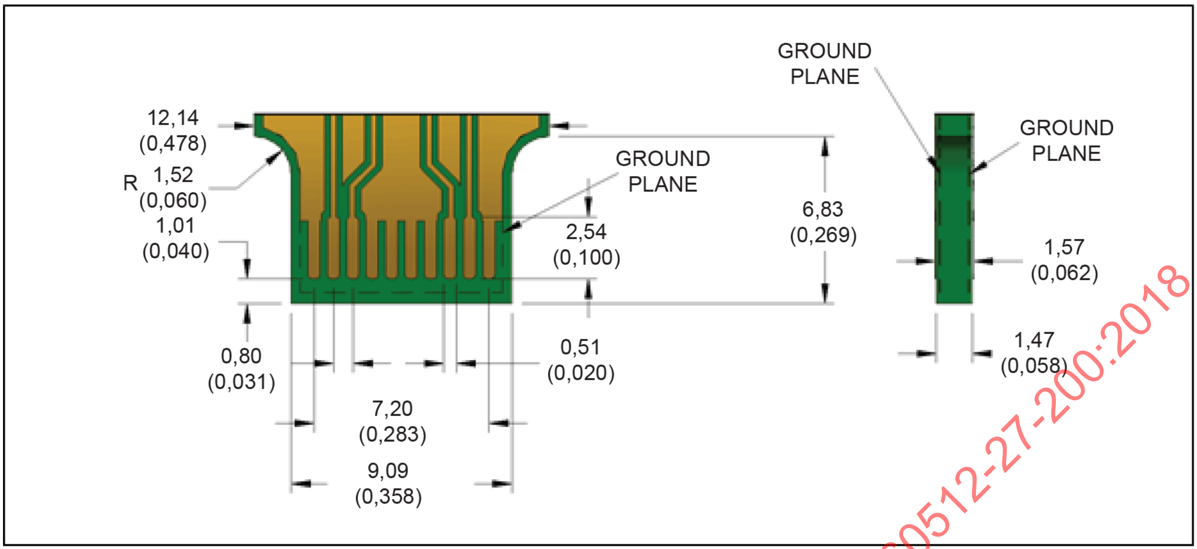


Figure C.30 – Balun fixture PCB paddle card interface mating dimensions

Dimensions in millimetres (inches)

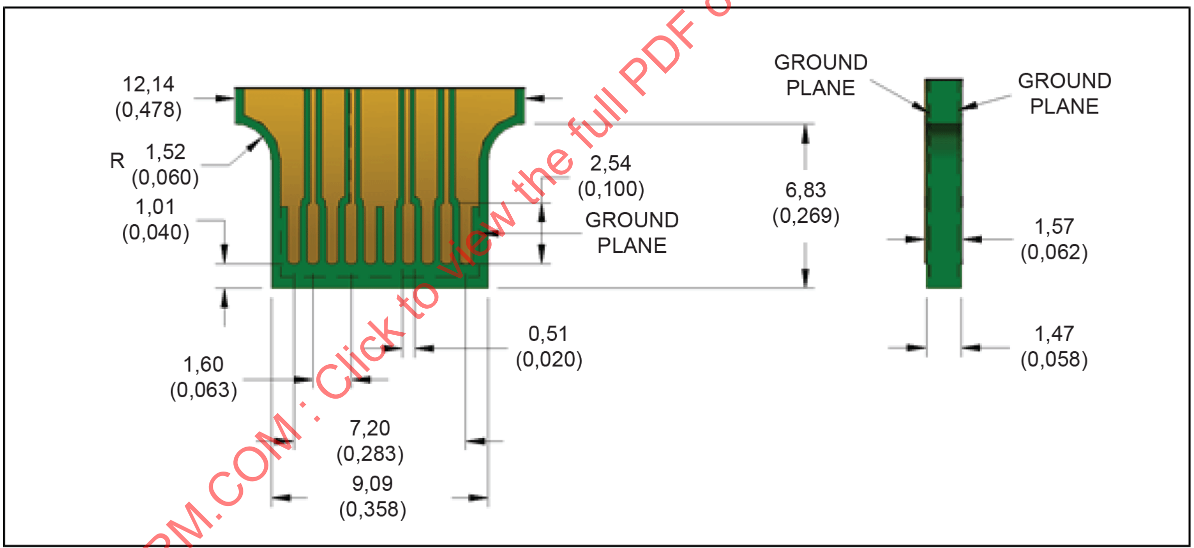


Figure C.31 – Balunless fixture PCB paddle card interface mating dimensions

NOTE The design goal for printed circuit board signal conductors is 50 Ω nominal impedance (single-ended), and 100 Ω (differential) impedance.

Hard gold plating of paddle card contact pads is recommended for durability.

Other methods of interface between the PWB of the test-plug and the PWB interface between DUT and the test equipment are also allowed.

NOTE 2 The direct plug measurement fixture, as specified in C.6.6.12, is compatible with plugs having a contact area ≥ 2,60 mm (0,102 in) as defined by dimension H2 of IEC 60603-7.

The reproducibility of connecting hardware NEXT loss measurements can be optimized by:

a) Use of modular plugs with centred NEXT loss and FEXT loss performance.

b) Use of a PCB based modular test plug.

c) Use of test fixtures having terminations that provide improved isolation and return loss.

d) Minimizing the electrical length of the test plug interconnections as described in Clause C.6.

e) Improvement of the wire management in the test fixture of any test leads used as part of plug construction and mounting.

PCB fixtures shall conform to the requirements of Annex D (overall test setup performance after calibration).

Where a cable is used to terminate a plug, test fixtures described in IEC 60512-28-100 are designed to provide suitable interface and termination.

Example test fixtures and devices described in Annex E are designed to provide suitable interface and termination.

C.6.6.4 Test plug qualification

Test plugs shall be qualified for all requirements of C.6.6.5 (NEXT loss), C.6.6.7 (FEXT loss) and C.6.6.9 (return loss) up to the maximum specified frequency for the category.

NEXT loss and FEXT loss, of test plugs shall be measured using the direct fixture or equivalent described in C.6.6.12.

C.6.6.5 Test plug NEXT loss requirements

The corrected NEXT loss vectors (magnitude and phase) of the test plug in the forward direction shall be within the test plug NEXT loss ranges of Table C.5. Test plug NEXT loss requirements apply in the forward direction only. Test plug NEXT loss in the reverse direction shall also be measured so that the data can be used in the reverse direction connecting hardware NEXT loss qualification procedure as described in C.6.5.5. See also Table C.6.

Table C.5 – Category 5e, 6, and 6A test plug NEXT loss ranges

Pair combination	NEXT loss magnitude range dB [1]	NEXT loss phase range degrees[2]
3,6 – 4,5	10 – 300 MHz: 38,1 – 20 log (f/100) ≤ NEXT loss ≤ 39,5 – 20 log (f/100) [5] 300 – 500 MHz: 38,1 – 20 log (f/100) ≤ NEXT loss ≤ 39,5 – 20 log (f/100) + 0,5 (f – 300)/200	50 – 100 MHz: (–90 + 1,5· f/100) ± 1 100 – 500 MHz: (–90 + 1,5· f/100) ± f/100
1,2 – 3,6	46,5 – 20 log (f/100) ≤ NEXT loss ≤ 49,5 – 20 log (f/100)	(–90 +1,5 f/100) ± 3· f/100
3,6 – 7,8	46,5 – 20 log (f/100) ≤ NEXT loss ≤ 49,5 – 20 log (f/100)	(–90 +1,5· f/100) ± 3· f/100
1,2 – 4,5	NEXT loss ≥ 57 – 20 log (f/100) [4]	90 ± (30· f/100) [3]
4,5 – 7,8	NEXT loss ≥ 57 – 20 log (f/100) [4]	90 ± (30· f/100) [3]
1,2 – 7,8	NEXT loss ≥ 66 – 20 log (f/100) [4]	Any phase

[1] Magnitude limits apply over the frequency range from 10 MHz to 500 MHz.

[2] Phase limits apply over the frequency range from 50 MHz to 500 MHz.

[3] When the measured test plug NEXT loss magnitude is greater than 70 – 20 log (f/100) or 70 dB, the phase limit does not apply.

[4] When the NEXT loss magnitude limit calculation results in a value greater than 70 dB, the limit shall revert to 70 dB.

[5] When the fixture described in C.6.6.12 or an equivalent is used, the magnitude high limit for pair combination 36 – 45, 39,5 – 20 log (f/100), shall be 39,5 – 20 log (f/100) + 0,5(f – 300)/200 for the frequency range from 300 MHz to 500 MHz.

An alternative procedure for qualification of test plug NEXT loss may be used if equivalent results and equivalent or better accuracy can be demonstrated.

Table C.6 – Category 8 test plug NEXT loss ranges

Pair combination	NEXT loss magnitude range dB [1]	NEXT loss phase range degrees[2]
3,6 – 4,5	10 – 300 MHz: 38,1 – 20 log (f /100) ≤ NEXT loss ≤ 39,5 – 20 log (f /100) 300 – 2 000 MHz: 38,1 – 20 log (f /100) ≤ NEXT loss ≤ 39,5 – 20 log (f /100) + 0,5(f – 300)/200	50 – 100 MHz: (–90 + 1,5· f /100) ± 1 100 – 500 MHz: (–90 + 1,5· f /100) ± f /100
1,2 – 3,6	10 – 300 MHz: 46,5 – 20 log (f /100) ≤ NEXT loss ≤ 49,5 – 20 log (f /100) 300 – 2 000 MHz: 46,5 – 20 log (f /100) ≤ NEXT loss ≤ 49,5 – 20 log (f /100) + 0,5(f – 300)/200	(–90 +1,5 f /100) ± 3· f /100
3,6 – 7,8	10 – 300 MHz: 46,5 – 20 log (f /100) ≤ NEXT loss ≤ 49,5 – 20 log (f /100) 300 – 2 000 MHz: 46,5 – 20 log (f /100) ≤ NEXT loss ≤ 49,5 – 20 log (f /100) + 0,5(f – 300)/200	(–90 +1,5· f /100) ± 3· f /100
1,2 – 4,5	NEXT loss ≥ 57 – 20 log (f /100) [4]	90 ± (30· f /100) [3]
4,5 – 7,8	NEXT loss ≥ 57 – 20 log (f /100) [4]	90 ± (30· f /100) [3]
1,2 – 7,8	NEXT loss ≥ 66 – 20 log (f /100) [4]	Any phase

[1] Magnitude limits apply over the frequency range from 10 MHz to 2 000 MHz.

[2] Phase limits apply over the frequency range from 50 MHz to 2 000 MHz.

[3] When the measured test plug NEXT loss magnitude is greater than 70 – 20 log (f /100) or 70 dB, the phase limit does not apply.

[4] When the NEXT loss magnitude limit calculation results in a value greater than 70 dB, the limit shall revert to 70 dB.

C.6.6.6 Test plug NEXT loss measurement

Measure the test plug NEXT loss vectors for all pair combinations in both directions. Use the direct fixture specified in C.6.6.12 or equivalent. Correct the phase of all NEXT loss measurements to the test plug phase reference plane, as shown in Figure C.39, using the procedures in C.6.6.14. An example of a measurement setup for test plug NEXT loss is shown in Figure C.32.

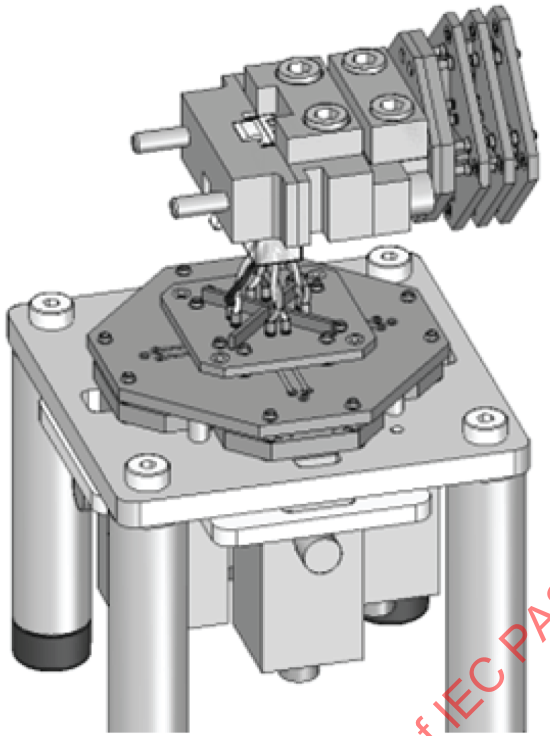


Figure C.32 – Example of a measurement setup for test plug NEXT loss

C.6.6.7 Test plug FEXT loss requirements

The corrected FEXT loss vectors (magnitude and phase) of all 12 pair combinations of the test plug shall be within the test plug FEXT loss ranges of Table C.7. Test plug requirements apply over the frequency ranges from 10 MHz to the upper frequency of the category.

Table C.7 – Test plug FEXT loss ranges

Pair combination	**Frequency range** MHz	**FEXT loss magnitude range** dB	**Phase** degrees
3,6 – 4,5	10 – 2 000	46 – 20 log (f /100) ≤ FEXT loss ≤ 56 – 20 log (f /100) [3]	–90 ± (30· f /100) [1), 2)]
1,2 – 3,6	10 – 2 000	46 – 20 log (f /100) ≤ FEXT loss ≤ 56 – 20 log (f /100) [3]	–90 ± (30· f /100) [1), 2)]
3,6 – 7,8	10 – 2 000	46 – 20 log (f /100) ≤ FEXT loss ≤ 56 – 20 log (f /100) [3]	–90 ± (30· f /100) [1), 2)]
1,2 – 4,5	10 – 2 000	FEXT loss ≥ 55 – 20 log (f /100) [4]	any phase
4,5 – 7,8	10 – 2 000	FEXT loss ≥ 55 – 20 log (f /100) [4]	any phase
1,2 – 7,8	10 – 2 000	FEXT loss ≥ 55 – 20 log (f /100) [4]	any phase

1) When the measured test plug FEXT loss is greater than 70 dB, the phase requirement does not apply.

2) Phase limits apply over the frequency range from 100 MHz to 2 000 MHz.

3) When upper limit FEXT loss calculations result in values greater than 70 dB, there shall be no upper limit for FEXT loss.

4) When lower limit FEXT loss calculations result in values greater than 70 dB, the lower limit FEXT shall revert to a limit of 70 dB.

C.6.6.8 Test plug FEXT loss measurement

Measure the test plug FEXT loss vectors for all pair combinations. Use the direct fixture specified in C.6.6.12 or equivalent. Correct the phase of all FEXT loss measurements to the test plug phase reference plane, as shown in Figure C.39, using the procedures specified in C.6.6.14. An example of a measurement setup for test plug FEXT loss is shown in Figure C.33.

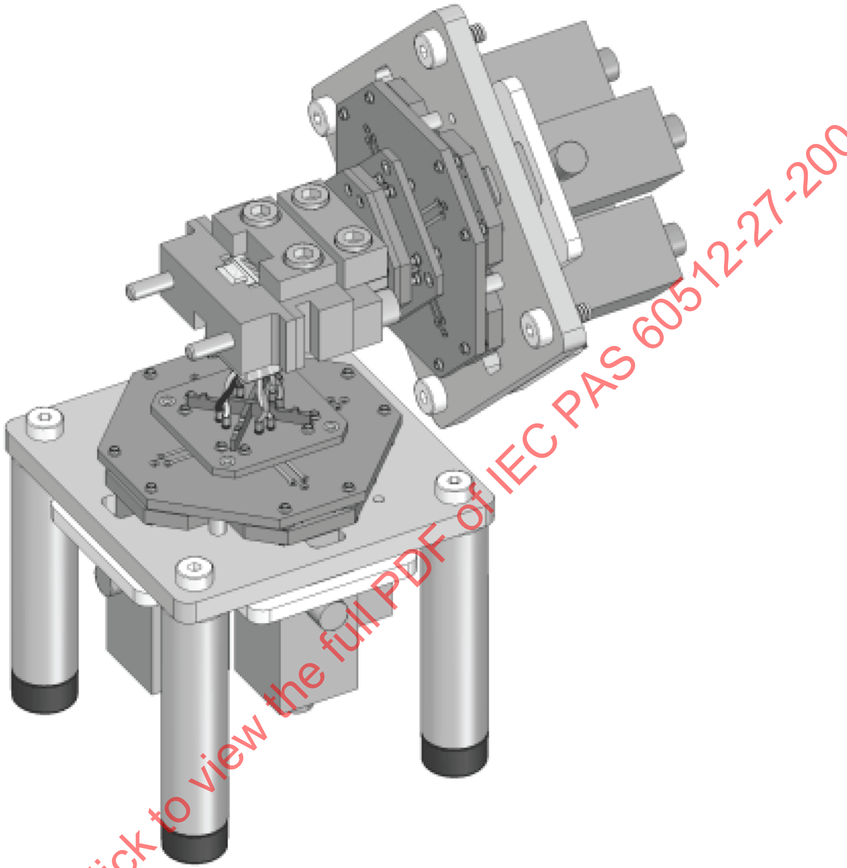


Figure C.33 – Example of a measurement setup for test plug FEXT loss

C.6.6.9 Test plug return loss requirements

The return loss, magnitude and phase, of the test plug shall meet the values specified in Table C.8 or Table C.9.

Test plug return loss requirements apply over the frequency ranges from 10 MHz to the upper frequency of the category.

Table C.8 – Category 5e, 6 and 6A test plug return loss requirements

Pair	Frequency range MHz	Return loss magnitude dB [2)]	Return loss Phase degrees [1)]
1,2	10 – 500	≥ 33,5 – 20 log (*f* /100)	negative phase
3,6	10 – 500	≥ 33,5 – 20 log (*f* /100) [3)]	positive phase
4,5	10 – 500	≥ 33,5 – 20 log (*f* /100)	negative phase
7,8	10 – 500	≥ 33,5 – 20 log (*f* /100)	negative phase

1) The phase requirement does not apply when the measured magnitude is greater than 35 – 20 log (*f* /100).

2) Calculations that result in return loss requirements greater than 40 dB shall revert to a requirement of 40 dB minimum.

3) For category 5e test plugs, the return loss magnitude shall be ≥ 30 – 20 log (*f* /100).

Table C.9 – Category 8 test plug return loss requirements

Pair	Frequency range MHz	Return loss magnitude (dB) [1)]
1,2	10 – 2 000	≥ 35 – 20 log (*f* /100) min 14
3,6	10 – 2 000	≥ 35 – 20 log (*f* /100) min 14
4,5	10 – 2 000	≥ 35 – 20 log (*f* /100) min 14
7,8	10 – 2 000	≥ 35 – 20 log (*f* /100) min 14

1) Calculations that result in return loss requirements greater than 40 dB shall revert to a requirement of 40 dB minimum.

It is impractical to verify return loss properties of plugs while they are attached to cords. The transmission properties of modular cords are included in the requirements of IEC 61935-2 describing cord and jumper cord return loss.

C.6.6.10 Test plug return loss measurement

This clause describes procedures for test plug return loss testing. At least one test plug shall be qualified for connecting hardware return loss testing. Test plug return loss shall be qualified in the reverse direction

C.6.6.11 Test plug return loss interconnections and termination

The interconnections used to construct the test plug shall be qualified, in the reverse direction, using the procedure in Clause B.2. The direct fixture shall be connected to the measurement equipment. The test plug shall be mounted in the direct fixture. The far-end of the plug should be terminated with the calibration reference load resistor terminations. The impedance effects of the direct plug measurement fixture shall be removed.

The impedance effects of the direct plug measurement fixture shall be removed by calibration. For balunless measurements, a minimum of a full 2-port calibration shall be performed for each pair under test. For measurements using baluns, a minimum of a 1-port calibration shall be performed for each pair under test. Clause B.4 describes calibration methods.

The extensions of the coaxial probes shall be controlled during calibration, to match their positions during the measurement of a plug. To achieve this, the calibration standards should be constructed in such a way so that once the calibration has been completed; the calibration reference plane is at the tips of the probes when extended to 0,66 mm (0,026 in) as shown in Figure C.39.

The direct fixture is used during test plug NEXT loss and FEXT loss measurements and may also be used for test plug return loss measurements. Refer to Annex D for additional information about the direct fixture and other test fixtures used to facilitate impedance control of interconnections for measurement of connecting hardware performance parameters. Impedance controlled measurement fixtures may be used when the use of unjacketed pair leads is necessary between the connecting hardware under test and the calibration plane.

C.6.6.12 Direct fixture

A direct fixture is specified for measurement of test plug performance. The direct fixture provides for electrical connection of the test plug to measurement equipment with minimal residual effect on the measurement properties of the test plug. The direct fixture is a precision device with properties controlled by design and manufacture. The direct fixture shall conform to the dimensional requirements of Figure C.34, Figure C.35, and Figure C.36. It is recommended to use the direct fixture as shown in Figure C.36, Figure C.37, and Figure C.38. The direct fixture residual NEXT loss, FEXT loss, and return loss shall comply with the requirements of Table C.10.

Dimensions in millimetres (inches)

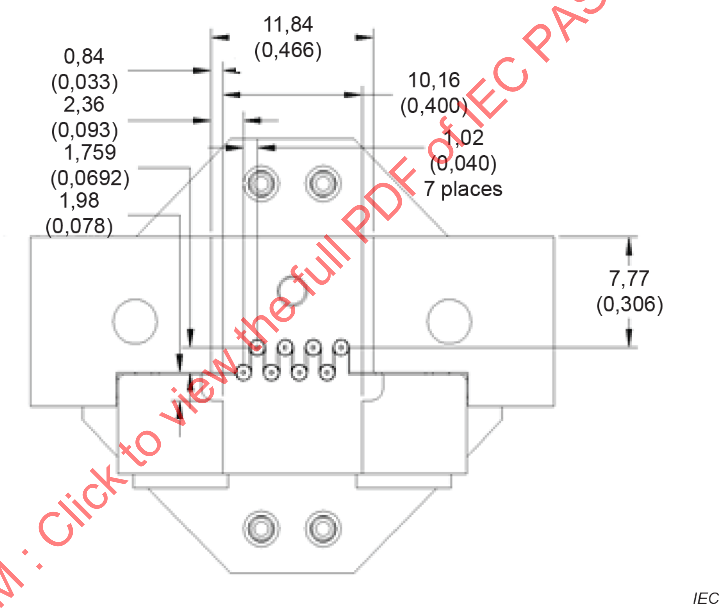


Figure C.34 – Direct fixture mating dimensions, top view

Dimensions in millimetres (inches)

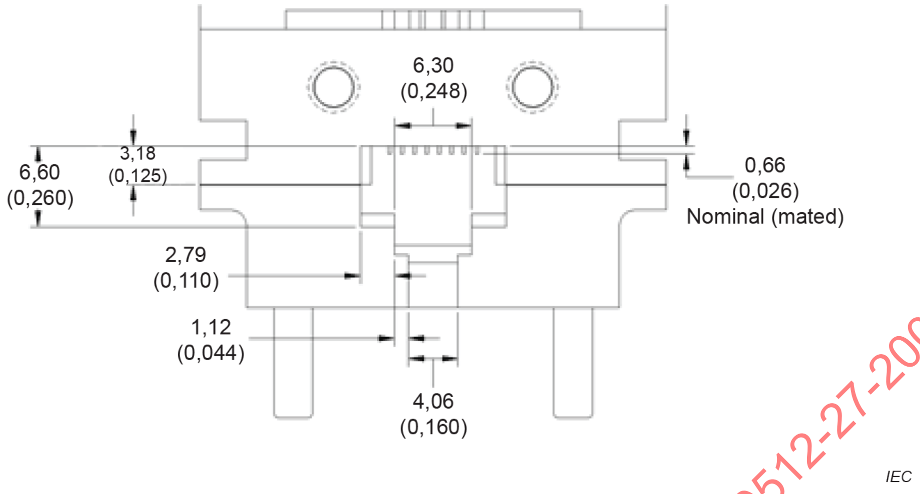


Figure C.35 – Direct fixture mating dimensions, front view

Dimensions in millimetres (inches)

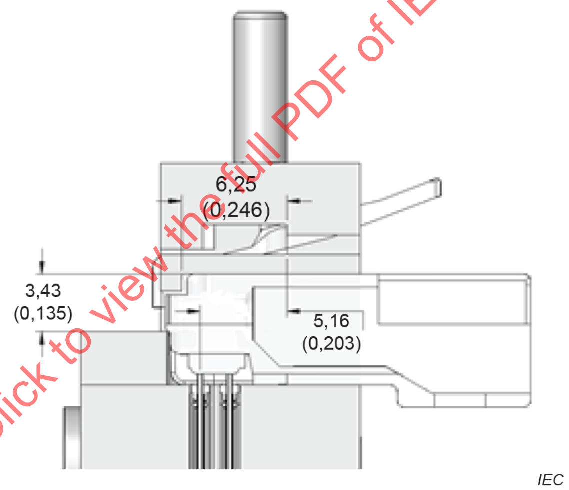


Figure C.36 – Direct fixture mating dimensions, side view

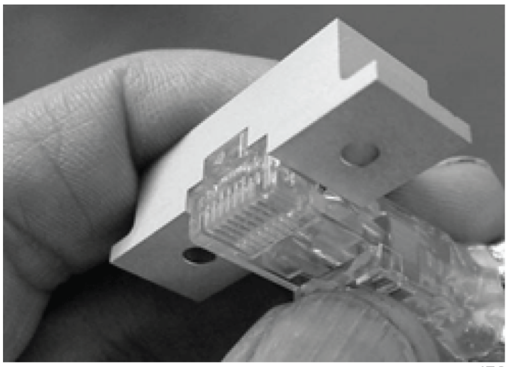
Dimension tolerances for Figure C.34, Figure C.35, and Figure C.36 are ± 0,025 mm (0,001 in).

Table C.10 – Direct fixture performance

Direct fixture performance parameter	Value dB
Pair-to-pair residual NEXT loss and FEXT loss	≥ 74 – 20 log (*f* /100), 75 dB max.
Return loss	≥ 34 – 20 log (*f* /100), 40 dB max.

C.6.6.13 Procedure for mating a test plug to the direct fixture

a) Place the test plug into the plug clamp as shown in Figure C.37.



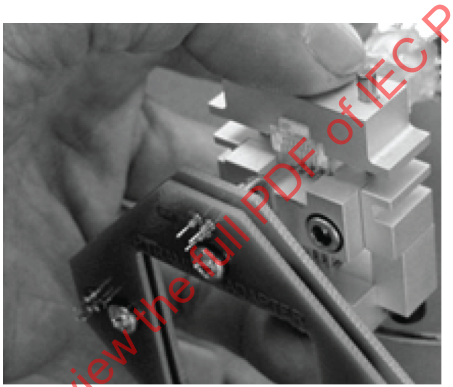
IEC

Figure C.37 – Modular plug placed into the plug clamp

NOTE Photos are for illustrative purposes only and do not constitute an endorsement by IEC.

b) Holding the test plug in place, slide the plug clamp onto the clamp block guide pins as shown in Figure C.38.

NOTE 1 The spring-loaded pin in the clamp block pushes against the test plug and holds it in position against the plug clamp.



IEC

Figure C.38 – Guiding the plug into position

NOTE 2 Photos are for illustrative purposes only and do not constitute an endorsement by IEC.

c) Guide the test plug into position against the coaxial probes making certain that the test plug does not rock in the plug clamp and that it slides vertically onto the coaxial probes. Avoid any side loading on the coaxial probes as they may break if pushed sideways.

d) Secure the plug clamp and the clamp block together using suitable spring clips as shown in Figure C.37.

C.6.6.14 Test plug phase reference plane and calibration planes

For categories 5e, 6, 6A and 8 connecting hardware measurements of return loss, insertion loss, NEXT loss, and FEXT loss are conducted by mating connecting hardware with a test plug that complies with Clause C.6. Certain plug parameters include phase requirements, and certain connecting hardware requirements are based on calculations that involve both test plug and connecting hardware phase data. There are no test plug requirements for category 3 connecting hardware. To maintain a consistent phase reference, a "test plug phase reference plane" shall be used, as explained below.

The test plug phase reference plane shall be at the tip of the plug where it connects to the jack contacts. This is accomplished with a calibration at the calibration plane plus port extension. The calibration planes should be as close as possible to the test plug phase reference plane as shown in Figure C.39. Refer to Clause B.2 for requirements of the interconnections between each appropriate calibration plane and the DUT. Alternatively, the direct fixture (see C.6.6.12) can be calibrated at the tips of the coaxial probes (see Figure C.34, Figure C.35, and Figure C.36) using suitable calibration artefacts. Examples are shown in Figure C.40.

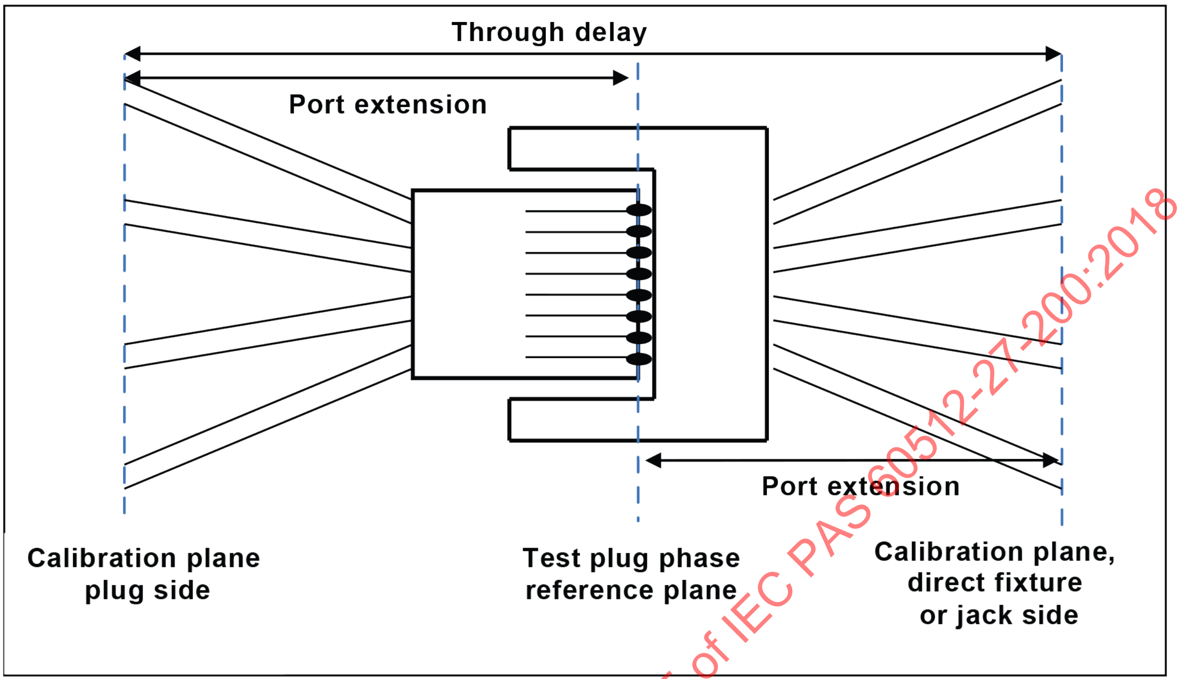


Figure C.39 – Calibration planes, test plug phase reference plane, and port extensions

C.6.6.15 Device delay measurements

Use these measurement procedures for all test plug measurements, and for jack and direct fixture measurements to be used in de-embedding calculations.

The port extension values calculated according to formula (C.4) are applied to each port (for each pair) to align measurement reference planes to the location where contact is made with the jack contacts.

For all measurements subsequently used in vector or matrix calculations and/or where phase requirements are specified, the appropriate port extensions shall be applied after calibration to adjust the measurement to the test plug phase reference plane. This may be done by applying the calculated port extensions directly to the network analyzer or by adjusting the phase after measurement using formula (C.3).

$$phase_{(testplugphase\_ref\_plane)}\ (\text{deg}) = phase_{(calibration\_plane)}\ (\text{deg})\ldots$$

$$\ldots + 360 \cdot frequency\ (\text{Hz}) \cdot delay\ (\text{sec}) \qquad (C.3)$$

C.6.6.16 Network analyzer settings for delay measurement

The settings of the network analyzer shall be sufficient to achieve a maximum of +/-5 ps of random variation. Recommended settings are as follows:

a) Measurement function is S11 delay
b) Averaging 4x or higher
c) Intermediate frequency bandwidth (IFBW) 300 Hz or less

d) Output power level in the range of –5 dBm to 0 dBm for phase critical measurements

C.6.6.17 Test plug delay and port extension

The procedure for measuring the delay of the test plug is as follows:

a) With the test plug connected to the test baluns, measure the S11 delay for each pair determined with an open circuit at the test plug phase reference plane.
b) Place a short on the test plug. This short shall connect the contacts of the pair under test at the test plug phase reference plane and be no further than 3 mm (0,12 in) from the point of contact with the jack. Measure the S11 delay for each pair shorted in this manner.
c) The delay value for each pair is calculated by averaging the open and short delay measurements over the frequency range of 100 MHz to 500 MHz using linear spacing and a minimum of 100 frequency points. These delay measurements represent round-trip delays. The one-way delay is half of the round-trip S11 delay.

C.6.6.18 Calculation of port extension

The one-way measured delays (open and short) shall be used to calculate the port extension for each pair as determined by formula (C.4). It is recognized that there is an inherent error in the delay measurements due to the finite length of the short. To correct this error, a correction factor $Td_{shortingjack}$ described in formula (C.5) shall be applied for each port extension.

$$PortExtension = average(\frac{TD_{open} + TD_{short} - TD_{shortingjack}}{4}) \quad (C.4)$$

C.6.6.19 Plug delay correction

A recommended procedure for establishing a suitable short delay correction is as follows:

a) Select a plug that can be used for this procedure and is then discarded. Three or more plugs are recommended.
b) Mount the plug rigidly onto a pyramid or other suitable impedance management fixture.
c) Measure the S11 round-trip delay of the plug mated to the shorting jack (see IEC 60512-27-100 for a description of the shorting jack) on all pairs and record these value as Delay round-trip plug jack.
d) Without removing the plug from the pyramid, trim the plastic ribs separating the contacts, and solder a wire across all 8 contacts where they make contact with a mating jack.
e) Measure the S11 round-trip delay of the plug on each pair and record these values as Delay round-trip plug .
f) Subtract 14 ps for pair 3,6 and 5 ps for the other three pairs (1,2 and 4,5 and 7,8) from Delay round-trip plug to account for the delay of the short spanning the plug contacts. Record these values as Delay adjusted round-trip plug.
g) Determine the difference in round-trip delay for each pair of the shorting jack as follows:

$$TD_{shortingjack} = Delay_{roundtripplugjack} - Delay_{adjustedroundtripplug} \quad (C.5)$$

The delay measurements are dependent on the proximity to ground planes. The positioning of the interconnections (e.g. twisted-pairs) should remain fixed during all measurements.

NOTE The measurement accuracy of this method is approximately 20 ps in a round-trip measurement, corresponding to a one-way distance of approximately 2 mm (0,08 in).

C.6.6.20 Direct fixture delay and port extension

The procedure for measuring the delay of the direct fixture is as follows:

a) Insert a short artefact into the direct fixture and measure the S11 delay for each pair of the direct fixture.

b) Subtract 14 ps for pair 3,6 and 5 ps for the other three pairs (1,2 and 4,5 and 7,8) from the measured short delay to account for the delay of the short spanning the coaxial probes.

c) Remove the short artefact, insert an open artefact into the direct fixture and measure the S11 delay for each pair of the direct fixture.

d) The delay value for each pair is calculated by averaging the open and short delay measurements over the frequency range of 100 MHz to 500 MHz using linear spacing and a minimum of 100 frequency points. These delay measurements represent round-trip delays. The one-way delay is half of the round-trip S11 delay.

Ensure that the extended length of the coaxial probes during the measurement using the open and short artefacts is consistent with the extended length when mated to a test plug.

Short and open artefacts shall be compatible with the dimensional requirements of the direct fixture as shown in Figure C.34, Figure C.35 and Figure C.36. The mating surface of these artefacts to the coaxial probes of the direct fixture shall be the same as the terminated modular plug contact height specified in IEC 60603-7 series (i.e. 5,89 – 6,17 mm). Examples of these are shown in Figure C.40. Artefacts can also be created from modular plugs as long as they meet these requirements.

For calculating port extension, only the open and the short artefacts are necessary. The remaining artefacts can be used for other calibrations.

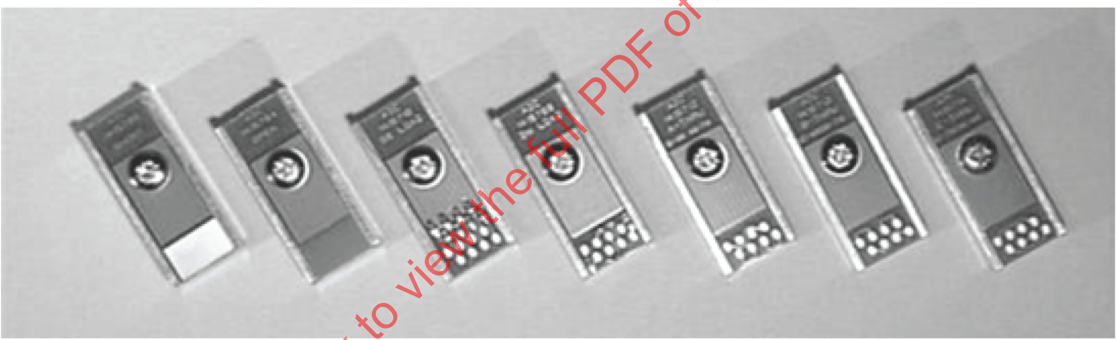


Figure C.40 – Examples of direct fixture short, open, load, and through artefacts

NOTE 1 The direct fixture artefacts shown in Figure C.40 may be obtained from industry sources.

NOTE 2 Photos are for illustrative purposes only and do not constitute an endorsement by IEC.

C.6.6.21 Alternative delay procedure for a test plug

For each pair, the delay of the test plug may also be determined by measuring the direct fixture delay, mating the test plug to the direct fixture, and then measuring the delay of the assembly (test plug plus direct fixture). Subtract the direct fixture delay from the delay of the assembly to get the test plug delay.

C.6.7 Category 6A measurement reproducibility

C.6.7.1 General

The content of this subclause is provided for information only. Measurement reproducibility is provided for test plugs and mated connecting hardware. Measurement reproducibility for mated connecting hardware is dependent on the performance of test plugs.

C.6.7.2 NEXT loss measurement reproducibility between laboratories

The measurement reproducibility of category 6A connecting hardware NEXT loss is primarily limited by the measurement reproducibility and variability of the test plugs. Controlled experiments have demonstrated that the test plug measurement process is reproducible within the noise floor levels indicated in informative Table C 11. The variability of test plugs is controlled by the test plug requirements of Table C.6, Table C.7, and Table C.9.

Table C 11 – Category 6A NEXT loss measurement reproducibility between laboratories

Pair combination	Frequency range MHz	Measurement noise floor dB	Maximum error at the limit		
			Test plug requirement at 100 MHz dB	Test plug Reproducibility dB	Reproducibility for mated NEXT loss at the test limit dB
3,6 – 4,5	10 – 500	66 – 20 log (f /100)	(38,77) nominal	0,2	3,0
1,2 – 3,6	10 – 500	66 – 20 log (f /100)	(47,87) nominal	0,5	1,5
3,6 – 7,8	10 – 500	66 – 20 log (f /100)	(47,87) nominal	0,5	1,5
1,2 – 4,5	10 – 500	68 – 20 log (f /100)	(57,00) minimum	2,0	1,5
4,5 – 7,8	10 – 500	68 – 20 log (f /100)	(57,00) minimum	2,0	1,5
1,2 – 7,8	10 – 500	72 – 20 log (f /100)	(66,00) minimum	3,0	1,5

C.6.7.3 FEXT loss test plug measurement reproducibility between laboratories

The measurement reproducibility of category 6A connecting hardware FEXT loss is primarily limited by the measurement reproducibility and variability of the test plugs. Controlled experiments have demonstrated that the test plug measurement process is reproducible within the noise floor levels indicated in Table C.12.

Table C.12 – Category 6A FEXT loss measurement reproducibility between laboratories

Pair combination	Frequency range MHz	Measurement noise floor dB	Maximum error at the limit	
			Test plug requirement at 100 MHz dB	Test plug Reproducibility dB
3,6 – 4,5	10 – 500	66 – 20 log (f /100)	(49,6) nominal	1,0
1,2 – 3,6	10 – 500	66 – 20 log (f /100)	(49,6) nominal	1,0
3,6 – 7,8	10 – 500	66 – 20 log (f /100)	(49,6) nominal	1,0
1,2 – 4,5	10 – 500	68 – 20 log (f /100)	n/a	-
4,5 – 7,8	10 – 500	68 – 20 log (f /100)	n/a	-
1,2 – 7,8	10 – 500	72 – 20 log (f /100)	n/a	-

C.6.7.4 Return loss measurement reproducibility between laboratories

Laboratory-to-laboratory measurement accuracy is highly affected by the accuracy of the reference load. The variability as a function of frequency that may be expected in the results at the pass/fail limit for category 6A connecting hardware return loss is in shown in Figure C.41.

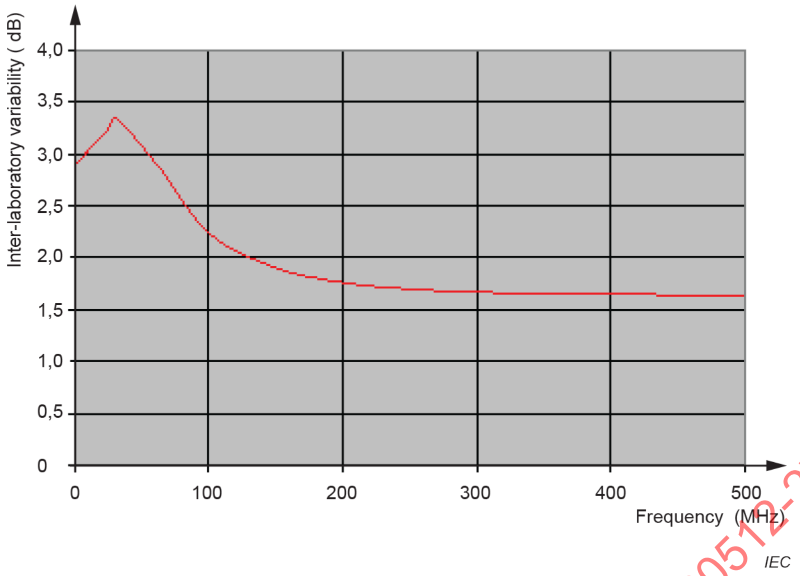


Figure C.41 – Inter-laboratory return loss variability for testing category 6A connecting hardware

C.7 Modular cord test head requirements

C.7.1 General

Refer to Clause C.5 for modular cord test procedures.

C.7.2 Modular cord test head NEXT loss

Mated modular cord test head NEXT loss shall be measured for all pair combinations in accordance with C.6.5 for all frequencies from 10 MHz to the upper frequency of the category. Modular test head NEXT loss performance shall meet the connecting hardware NEXT loss requirements specified for categories 6, 6A and 8 and shall exceed 47 – 20 log (f/100) from 10 to 100 MHz for category 5e. In addition, the best case NEXT loss performance of the mated modular cord test head shall be centred for pair combinations 3,6 – 4,5, 1,2 – 3,6, and 3,6 – 7,8 as verified by the following procedure.

a) Measure the mated NEXT loss throughout the frequency range from 10 to the upper frequency of the category for the low and high limit-value virtual test plugs per the procedures in clause C.6.

b) Determine the minimum margin (dB) to the category 6, 6A or 8 connecting hardware NEXT loss requirements as specified in Table C.4 for pair combination 3,6 – 4,5 and clause C.6 for pair combinations 1,2 – 3,6 and 3,6 – 7,8 from 10 MHz to the upper frequency of the category for both the low and high test plug limit vectors. Use the correct table for category 6, 6A, 8, or category 5e.

c) The difference between these minimum margins for the high and low limit-value test plugs shall be less than 2 dB for the pair combination terminated on pins 3,6 4,5 and 4 dB for the pair combinations terminated on pins 1,2 – 3,6 and 3,6 – 7,8.

There are no centring requirements for pair combinations 1,2 – 4,5, 4,5 – 7,8, or 1,2 – 7,8.

C.7.3 Modular cord test head FEXT loss

Mated modular cord test head FEXT loss shall be measured for all pair combinations in accordance with C.6.5.6. For all frequencies from 10 MHz to the upper frequency of the category, modular test head FEXT loss performance shall exceed the values determined using formula (C.6).

$$FEXT_{Test\_Head} \geq 48.1 - 20\log(f/100)\ dB \quad \text{(C.6)}$$

C.7.4 Modular cord test head return loss

Mated modular cord test head return loss shall be measured for all pair combinations in accordance with C.6.3. For all frequencies from 10 MHz to the upper frequency of the category, modular test head return loss performance shall meet the values determined using Table C.13. See also Table C.14.

Table C.13 – Category 5e, 6, and 6A modular cord test head return loss

Frequency MHz	Return loss dB
$10 \leq f < 50$	≥ 35
$50 \leq f \leq 500$	$\geq 29 - 20 \log (f/100)$

Table C.14 – Category 8 modular cord test head return loss

Frequency MHz	Return loss dB
$10 \leq f < 70$	≥ 35
$70 \leq f < 1\,000$	$\geq 32 - 20 \log (f/100)$
$1\,000 \leq f \leq 2\,000$	≥ 12

C.8 Alien crosstalk measurements

C.8.1 Cabling ANEXT loss and AFEXT loss laboratory measurement procedures

C.8.1.1 General

Cabling test configuration for ANEXT and AFEXT loss.

C.8.1.2 Termination of pairs

During all testing, the unused pairs, and the opposite end of the used pairs, of the disturbed and disturbers, of the channels under test, shall be terminated with DMCM terminations at both ends.

C.8.1.3 Calibration of cabling ANEXT loss or AFEXT loss

Calibrate according to the methods outlined in Clause B.4.

C.8.1.4 Calculation of cabling PSANEXT loss or PSAFEXT loss

C.8.1.4.1 General

For each port, the power sum alien crosstalk shall be calculated using the 6 worst disturber channels.

C.8.1.4.2 PSANEXT calculation procedure

Using measured ANEXT data from disturber channels to disturbed channel:

a) Calculate single disturbing channel PSANEXT from each disturbing channel to the disturbed channel at each frequency.

b) At each frequency point, identify the 6 channels with highest PSANEXT to the disturbed channel.

c) For each frequency point, power sum the PSANEXT from the worst 6 channels identified in step 2 into the disturber and calculate the margin.

d) Identify the frequency point with the lowest PSANEXT margin. When the lowest margin occurs at more than one frequency, select the highest frequency point.

e) Utilize the six channels corresponding to that frequency point and calculate 6-to-1 PSANEXT into the disturbed channel at all frequency points. Report these PSANEXT values as the PSANEXT performance of that disturbed port.

C.8.1.4.3 PSAACRF calculation procedure

AFEXT loss is the coupling of crosstalk at the far-end from external DUT pairs into a disturbed pair of the 4-pair DUT under test. PSAACRF is the calculated power sum from all external pairs into the disturbed pair. PSAACRF for a DUT is determined using formula C.7 for the case of a 4-pair DUT.

$$PSAACRF_k = PSAFEXT_k - IL_k \text{ dB} \tag{C.7}$$

For channels and permanent links, the calculations in formulas C.8 through C.10 shall be used to determine PSAFEXT loss when the disturbed pair has greater insertion loss than the disturbing pair.

If $IL_k > IL_{ij}$, then:

$$AFEXTnorm_{k,i,j} = AFEXT_{k,i,j} + (IL_k - IL_{i,j}) - 10\log\left(\frac{IL_k}{IL_{i,j}}\right) \text{ dB} \tag{C.8}$$

If $IL_k \le IL_{ij}$, then:

$$AFEXTnorm_{k,i,j} = AFEXT_{k,i,j} \text{ dB} \tag{C.9}$$

where:

$$PSAFEXT_k = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{n} 10^{-\frac{AFEXTnorm_{k,i,j}}{10}}\right) \text{ dB} \tag{C.10}$$

$PSAACRF_k$ is the PSAACRF of disturbed pair *k*.

$AFEXTnorm$ is AFEXT loss, in dB, normalized to the coupled length (the minimum length of the disturbed and disturbing pair) relative to the length of the disturbed pair.

IL_k is the insertion loss of disturbed pair *k*.

$IL_{i,j}$ is the insertion loss of pair i of disturbing DUT *j*.

N is the total number of disturbing devices under test (DUT).

n is the number of pairs in disturbing devices under test *j* (usually 4).

$AFEXT_{k,i,j}$ is the measured AFEXT loss, in dB, to pair *k* of the disturbed DUT from pair *i* in disturbing DUT *j*.

k is the number of the disturbed pair in a disturbed DUT.

i is the number of a disturbing pair in a disturbing DUT.

j is the number of a disturbing DUT.

ACRF shall be measured for all DUT pair combinations and PSAACRF shall be calculated for all DUT pairs. ACRF shall be measured in accordance with Clause B.1.

Using AFEXT data from disturber channels to disturbed channel and measured IL:

a) Using formulas 1-11 from IEC 60512-27-100, normalize the AFEXT for insertion loss.

b) Using the normalized AFEXT, calculate single disturbing channel PSAFEXT from each disturbing channel to the disturbed channel at each frequency.

c) Convert this to PSAACRF from the single disturbing channel, using formula 9 from IEC 60512-27-100, to subtract the IL.

d) At each frequency point, identify the 6 channels with the worst PSAACRF to the disturbed channel.

e) Identify the frequency point with the lowest PSAACRF margin. When the lowest margin occurs at more than one frequency, select the highest frequency point.

f) Utilize the 6 channels with the worst PSAACRF that were identified in step 4 at that frequency point to calculate 6-to-1 PSAACRF into the disturbed channel at all frequency points. Use the channel PSAACRF values from step 3 which were calculated using the normalized AFEXT values from step 1. Report these PSAACRF values as the PSAACRF performance of that disturbed port.

C.8.2 ANEXT loss and AFEXT loss of cable

C.8.2.1 General

This subclause describes requirements for measuring ANEXT loss and AFEXT loss between pairs of adjacent cables in a 7-cable assembly consisting of cables of the same design. The frequency range is 1 MHz to the upper frequency of the category.

The cable ANEXT loss and AFEXT loss measurement configuration shall comply with the requirements of this clause. Prepare the cables to be tested in the form of an assembly consisting of seven cables. The seven cables shall be maintained in a 6-around-1 parallel configuration throughout the length to be tested as shown in Figure C.42. Non-metallic bindings shall be longitudinally spaced no more than 200 mm (8 in) apart for the entire length of cable except for the last 1,0 m (3,3 ft) from each end of the cable bundle. The 6 cables shall not be deformed by the non-metallic bindings. The assembly shall be arranged such that a minimum separation of 100 mm (3,9 in) is maintained between sections of the assembly. The pairs at each end of the assembly shall be terminated with DMCM resistors as described in Clause B.4.

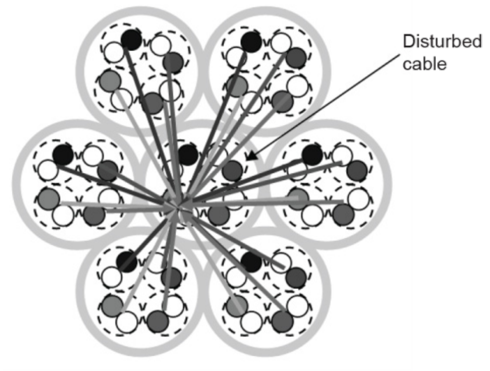


Figure C.42 – 6-around-1 cable test configuration

C.8.2.2 Test configuration for cable ANEXT loss and AFEXT loss

During all testing, the unused pairs, and the opposite end of the used pairs, of the disturbed and disturber cables, of the channels under test, shall be terminated with DMCM terminations at both ends.

C.8.2.3 Calibration of cable ANEXT and AFEXT loss

The calibration for ANEXT and AFEXT loss shall comply with B.4.5. A calibration is required between all ports under test.

C.8.2.4 Measurement of cable ANEXT and AFEXT loss

Measure the Sdd21 parameter with the network analyzer connected to each pair of the disturbed cable and each pair of every disturbing cable. This will result in 96 measurements each for ANEXT loss and AFEXT loss.

C.8.2.5 Cable PSAFEXT loss and PSAACRF calculation

To calculate PSAFEXT loss from the measured data, power sum the appropriate 24 measurements for each disturbed pair. PSAACRF is calculated in accordance with formula C.11.

$$PSAACRF_k = PSAFEXT_k - IL_k \text{ dB} \tag{C.11}$$

where k is the disturbed pair.

C.8.2.6 Optional category 8 cable alien crosstalk testing method using two cables

This subclause describes an optional category 8 cable alien crosstalk test method using two cables. Controlled experiments have demonstrated that these cables provides an alien crosstalk performance that is free of statistical contribution and near the measurement floor. Therefore, the power sum of a 6-around-1 bundle can be accurately predicted using two cables bundled together.

The two cables shall be attached together at every 200 mm (8 in) and one cable shall be designated to act as the disturbed cable. The ANEXT and AFEXT loss shall be determined per C.8.2.3 and will result in 16 measurements per direction for each ANEXT and AFEXT loss. The cable PSANEXT and PSAACRF shall then be calculated using four combinations for each disturbed pair and then adjusted by an offset of 10 log (6) to predict the 6-around-1 performance.

$$PSANEXT_{PREDICTED_k} = PSANEXT_{1CABLE_k} - 10\ \log(6)\, dB$$

Where: $PSANEXT_{1CABLE_k}$ $is\ the\ PSANEXT\ loss\ of\ a\ pair\ calculated\ in\ accordance\ with\ formula\ (6)$

And: $PSAFEXT_{PREDICTED_k} = PSAFEXT_{1CABLE_k} - 10\ \log(6)\ dB$

And: $PSAFEXT_{1CABLE_k}$ $is\ the\ PSAFEXT\ loss\ of\ a\ pair\ calculated\ in\ accordance\ with\ formula\ (8)$

If the margin of PSANEXT(predicted(k)) to formula (PSANEXT Limit) obtained with this method is less than 10 dB, then the cable PSANEXT and PSAACRF performance shall be determined using the complete 6-around-1 test configuration.

This optional method only applies to Category 8 cables and does not apply to Category 8 channels or permanent links to take into account connector contributions and installation factors.

C.8.3 Connecting Hardware ANEXT loss and AFEXT loss measurements

C.8.3.1 General

This subclause describes the reference test procedure for measuring ANEXT loss and AFEXT loss between pairs of separate connecting hardware, or different ports of the same multi-port connector assembly.

C.8.3.2 Measurement outline

a) Network analyzer setup and calibration
b) Measurement floor (including fixturing) determination and measurement
c) Terminate DUTs
d) Measure ANEXT loss
e) Calculate PSANEXT loss
f) Measure AFEXT loss
g) Calculate PSAFEXT loss

C.8.3.3 Network analyzer settings

Maximum IF bandwidth should be 100 Hz.

C.8.3.4 Measurement floor

The measurement floor includes the effects of the fixturing that is used and the random noise floor of the network analyzer. The measurement floor for the test fixture should be measured with the terminating cables and resistor terminations in place. The fixture/measurement setup, including network analyzer settings, should be designed and positioned such that the desired measurement floor is achieved. Due to the improved alien crosstalk requirement of category 8 connecting hardware the recommended measurement floor is 20 dB better than the connecting hardware PSANEXT loss or PSAFEXT loss requirement, as appropriate.

C.8.3.5 DUT setup for ANEXT loss and AFEXT loss measurement

The ANEXT loss measurement is performed between two DUTs as shown in Figure C.43. The AFEXT loss measurement is performed between two DUTs as shown in Figure C.44. Each DUT consists of a mated modular plug and socket combination and shall be mounted in its specified mounting arrangement (e.g. patch panel, TO) according to the manufacturer’s instructions. Each modular test plug should be of a design known to meet the test plug requirements detailed in C.6.6. Cables between the baluns and the DUT should be less than 300 mm (12 in). If interconnecting cables need to be longer than 300 mm (12 in) (e.g. testing large multi-port panels), their insertion loss shall be accounted for.

For ANEXT loss measurements, it is recommended that the far-end of each modular plug and socket mated combination be terminated with a minimum of 40 m (131 ft) of cable. For AFEXT loss measurement, it is recommended that the far-end of the disturbing modular plug and socket and near-end of the disturbed modular plug and socket are terminated with a minimum of 40 m (131 ft) of cable. The use of minimum category 6A-rated S/FTP cable (as defined by ISO/IEC 11801-1) is recommended.

However, it is possible to use F/UTP, UTP or other cable types if the recommended measurement floor can be demonstrated.

The other end of each of the terminating cables should be DMCM terminated, with the CM terminations of the four pairs in each cable connected to ground.

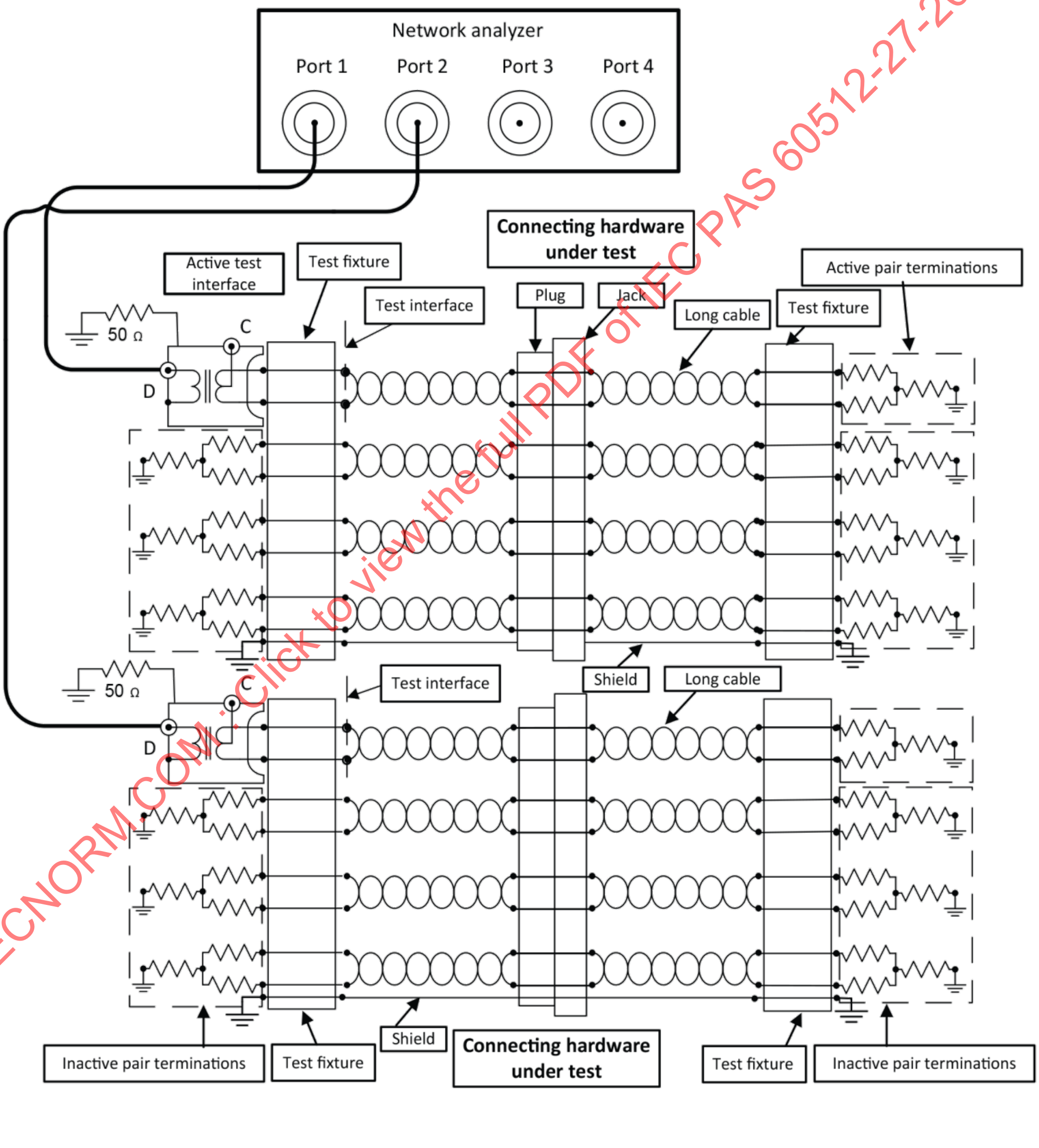


Figure C.43 – Connecting hardware ANEXT loss measurement setup

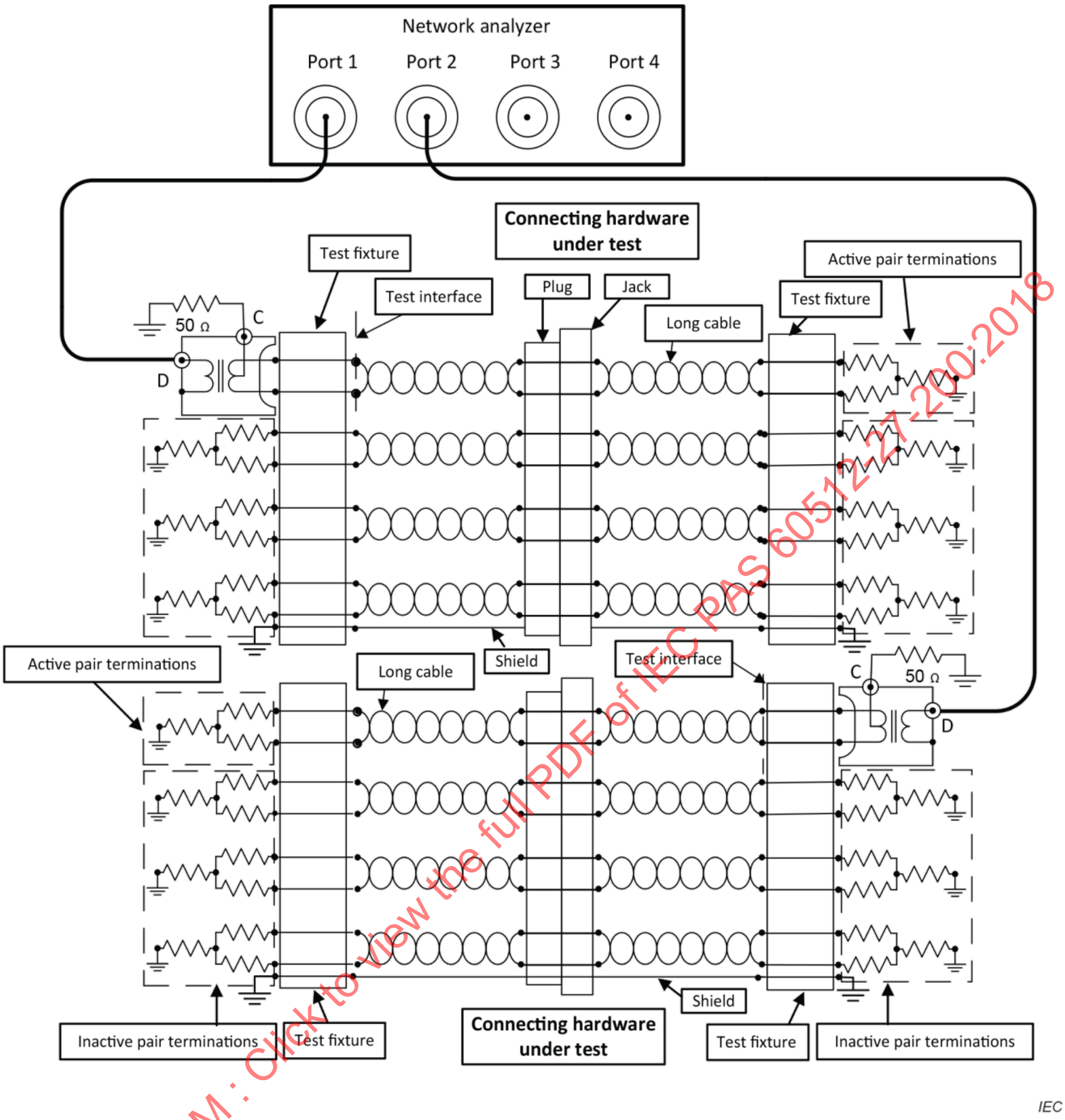


Figure C.44 – Connecting hardware AFEXT loss measurement setup

C.8.3.6 Disturbing connectors included

A port is included if it is one of the adjacent connectors, either above, below, left, or right, or one of four diagonally adjacent connectors, if present, as shown in Figure C.45 or a port that is part of the same multi-port connector assembly.

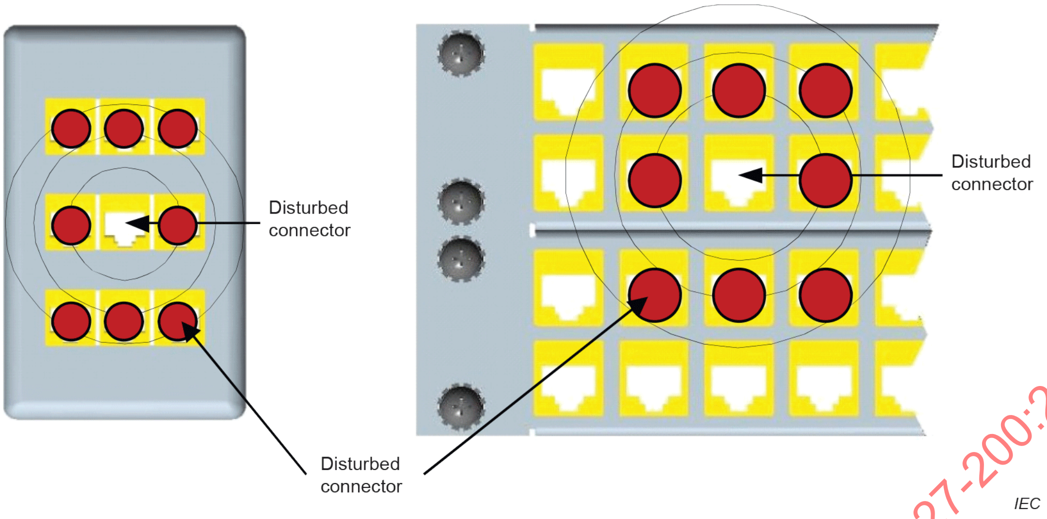


Figure C.45 – Example connector configurations for alien crosstalk

C.8.3.7 PSANEXT loss and PSAFEXT loss calculation

From the ANEXT or AFEXT loss contribution of all disturbing pairs, calculate the respective PSANEXT or PSAFEXT loss of the disturbed port (DUT).

Annex D
(normative)

Cabling and component balunless test procedures

D.1 Balunless measurement requirements

When performing measurements using balunless methods, the procedures and wire termination fixturing shall be in accordance with IEC 60512-28-100.

The measurement requirements in this annex, can be applied to any category of cabling. Refer to Annex B as well as IEC 60512-28-100 for wire termination fixturing, and general setup requirements. The requirements of this clause focus on specific test interfaces unique to this test method.

It is acceptable to configure the far end terminations within the test fixture, or attached to the test fixture. Switching may be used and that switching may configured within the test fixture. See IEC 60512-28-100 for a more detailed discussion of wire termination test fixture configurations.

Each setup component shall be qualified to a measurement bandwidth of at least 1 MHz to the upper frequency of the category.

Measurements of cabling performance parameters to 2 000 MHz for category 8 are facilitated by use of four port network analyzers. In addition, four port network analyzers can directly measure balance (TCL, TCTL), common mode, and cross-modal coupling parameters. General measurement methods using four port network analyzers are described in IEC 60512-28-100.

These standards include test fixture performance requirements, calibration methods, port nomenclature, and general procedures and precautions.

Other measurements methods that are demonstrated to show equivalence to the methods in this annex are allowed.

Balunless measurement results shall be converted to a termination impedance of 100 Ω differential mode, 50 Ω common mode. The terminations given below for balunless measurements result in a 25 Ω common mode impedance. Instructions are given in IEC 60512-28-100.

D.2 Resistor terminations used with balunless measurement systems

Resistors used for terminations shall exhibit impedance of 50 Ω ± 0,1 % or better as shown in Figure D.1. Each single wire, 50 Ω port is terminated to ground. The differential impedance between two single wire, 50 Ω ports is 100 Ω. SMA terminations shall meet the requirements of IEC 60512-28-100.

Terminations of inactive conductors and far end ports of active conductors shall provide the equivalent of 50 Ω at the interface to the cable under test. See IEC 60512-28-100 for performance requirements of test fixtures and systems.

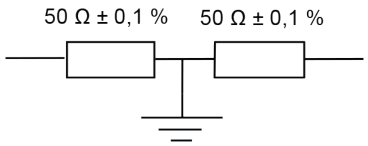


Figure D.1 – Balunless resistor termination network

Additionally,

a) Small geometry chip resistors shall be used for the construction of resistor terminations.

b) The two 50 Ω DM terminating resistors shall be matched to within 0,1 % at DC.

c) The length of connections to impedance terminating resistors shall be minimized.

D.3 Calibration methods

When using balunless measurement methods, a two-port or four port calibration is the minimum requirement. For insertion loss, NEXT loss, and FEXT loss measurements, a four-port calibration is the minimum requirement when using balunless test methods. Multi-port n-port calibration is considered an extension of two-port calibration. See IEC 60512-28-100 for more information on balunless measurement calibration methods.

D.4 Testing of cables and cabling

D.4.1 Cabling and cable measurement procedures

Mutual capacitance, capacitance unbalance, return loss, insertion loss, NEXT loss, ACRF, TCL, and TCTL measurements and calculations shall be performed on cable samples of 100 m (328 ft) for Categories up through 6A, or 30 m (98,4 ft) for category 8 removed from the reel or packaging. The test sample shall be laid out along a non-conducting surface, loosely coiled, supported in aerial spans, or wound around a non-conducting drum with 13 mm minimum separation between cables. All pairs shall be terminated according to the specific requirements of this annex. Other test configurations are acceptable if correlation to the reference method has been verified. In case of conflict, the reference method (30 m, off-reel, resistor termination of inactive ports) shall be used to determine conformance to the minimum requirements of this document.

It may be desirable to perform measurements on lengths of cable greater than 100 m (328 ft) for Categories up through 6A, or 30 m (98,4 ft) for category 8 in order to improve measurement accuracy at lower frequencies. For example, when measuring insertion loss, it is recommended that the sample length exhibit no less than 1 dB of insertion loss at the lowest frequency tested. More than one length may be required to test a full range of frequencies. Cables tested for insertion loss at elevated temperatures shall be placed inside an air-circulating oven until the cable has stabilized at the reference temperature. No more than 3 m (9 ft) of each cable end should exit the oven for connection to the measurement equipment.

Shields and screens should be bonded (low inductance connections) to the measurement grounds at both ends.

The test interfaces shall provide a high quality interface to the calibration reference devices used during calibration of the network analyzer, as well as provide a convenient connection to the cabling or cabling component under test.

The measurement result shall be mathematically transformed to convert the measured values in the native common mode impedance of 25 Ω to the resultant values which are referenced to the common mode impedance of 50 Ω which are required by this standard. Instructions are given in IEC 60512-28-100.

The figures in this clause illustrate a single wire test method using a 4-port network analyzer.

D.4.2 Cabling and cable DC resistance

DC resistance shall be measured in accordance with IEC 61935-1.

D.4.3 Cabling and cable return loss

D.4.3.1 Test configuration of cabling and cable return loss

The test configuration is as shown in Figure D.2.

Each wire shall be terminated with 50 Ω to ground per IEC 60512-28-100. Maximum length of cable jacket removal shall be 13 mm (0,5"), unless the un-jacketed cable pair impedance is maintained by other means such as fixturing. The length of pair untwist shall be minimized.

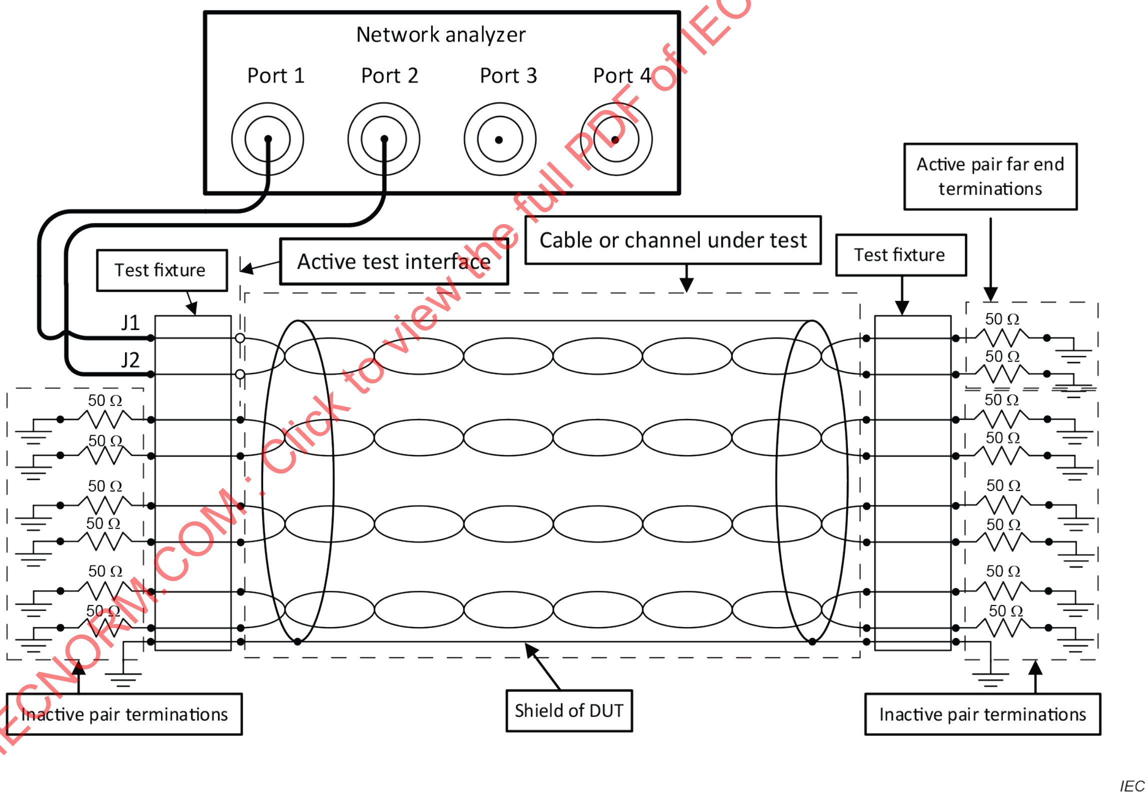


Figure D.2 – Laboratory test configuration for cabling and cable return loss and TCL measurements

D.4.3.2 Calibration of cabling and cable return loss

The calibration for cabling and cable return loss shall comply with Clause D.3.

D.4.3.3 Measurement of cabling and cable return loss

Terminate cable ends in accordance with B.2. Measure the Sdd11 parameter with the network analyzer connected to each pair on the near-end. Return loss shall be tested in both directions. Transform the measurement result common mode impedance from the native 25 Ω to 50 Ω. Instructions are given in IEC 60512-28-100.

D.4.4 Insertion loss of cables and channels

D.4.4.1 Test configuration of cabling and cable insertion loss

Figure D.3 depicts the typical schematic diagram of a balunless test interface for testing insertion loss, TCTL, and propagation delay.

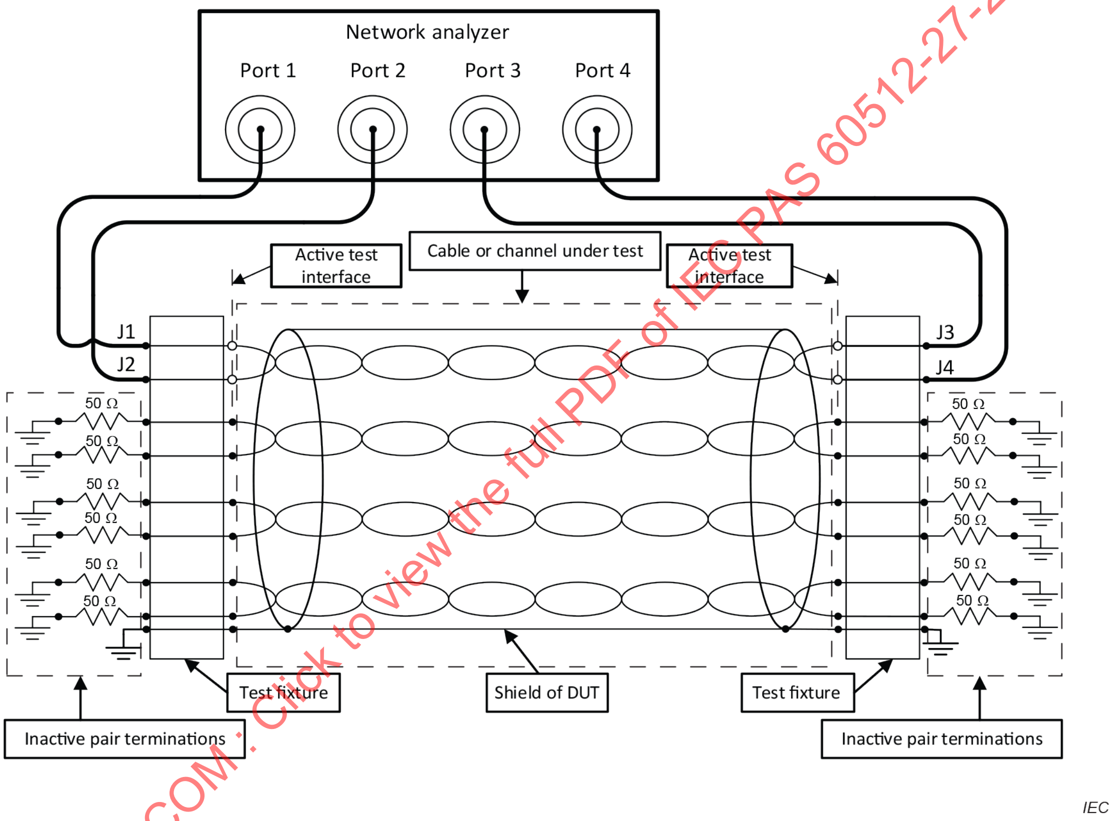


Figure D.3 – Laboratory test configuration for cabling and cable insertion loss, TCTL, and propagation delay measurements – Alternate test configuration for return loss and TCL.

D.4.4.2 Calibration of cabling and cable insertion loss

The calibration for cabling and cable insertion loss shall comply with Clause D.3.

D.4.4.3 Measurement of cabling and cable insertion loss

Terminate cable ends in accordance with Clause B.2. Measure the Sdd21 parameter with the pair under test connected to the network analyzer at both the near-end and the far-end. It is not necessary to measure cable insertion loss from both ends due to reciprocity.

D.4.5 NEXT loss of cables and channels

D.4.5.1 Test configuration of cabling and cable NEXT loss

Figure D.4 depicts the typical schematic diagram for testing NEXT loss. Resistor terminations are preferred for unused pairs at the far-end.

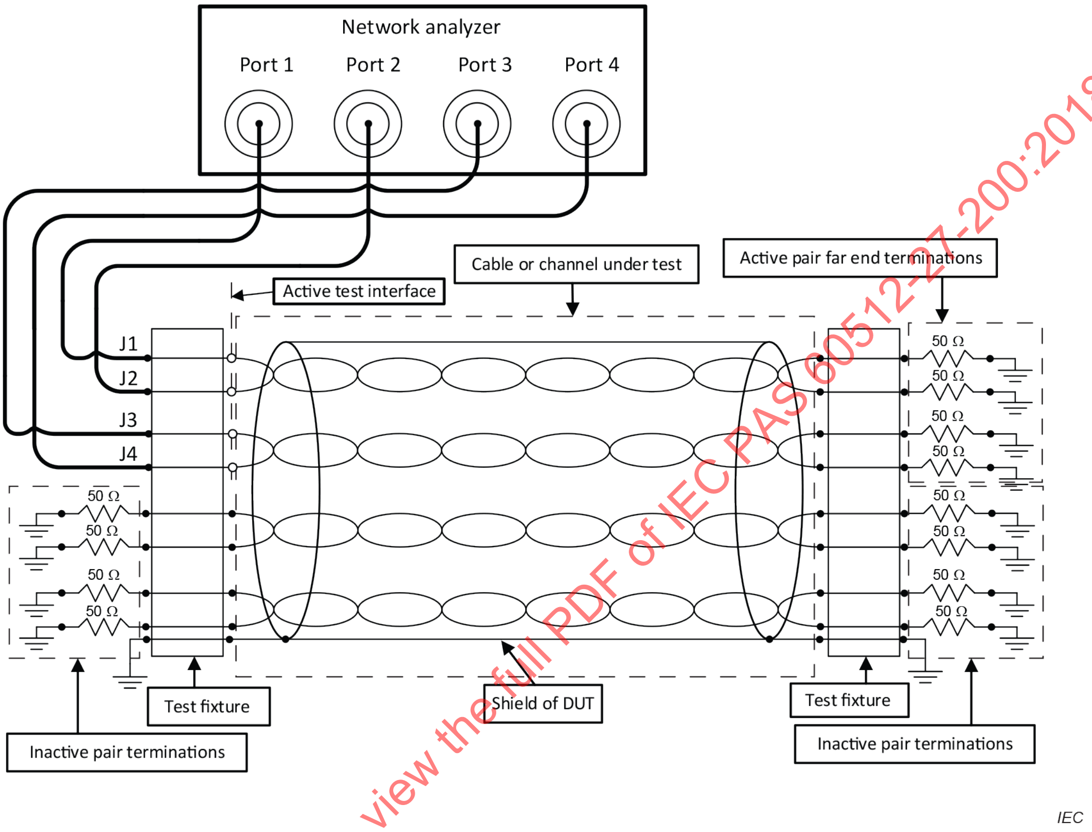


Figure D.4 – Laboratory test configuration for cabling and cable NEXT loss

D.4.5.2 Calibration of cabling and cable NEXT loss

The calibration for cabling and cable NEXT loss shall comply with Clause D.3.

D.4.5.3 Measurement of cabling and cable NEXT loss

Measure the Sdd21 parameter with the network analyzer connected to each of the 6 pair combinations of the four pairs. NEXT loss shall be tested in both directions.

D.4.6 FEXT loss of cables and channels

D.4.6.1 Test configuration of cabling and cable FEXT loss

Figure D.5 depicts the typical schematic diagram for testing FEXT loss of cables and channels.

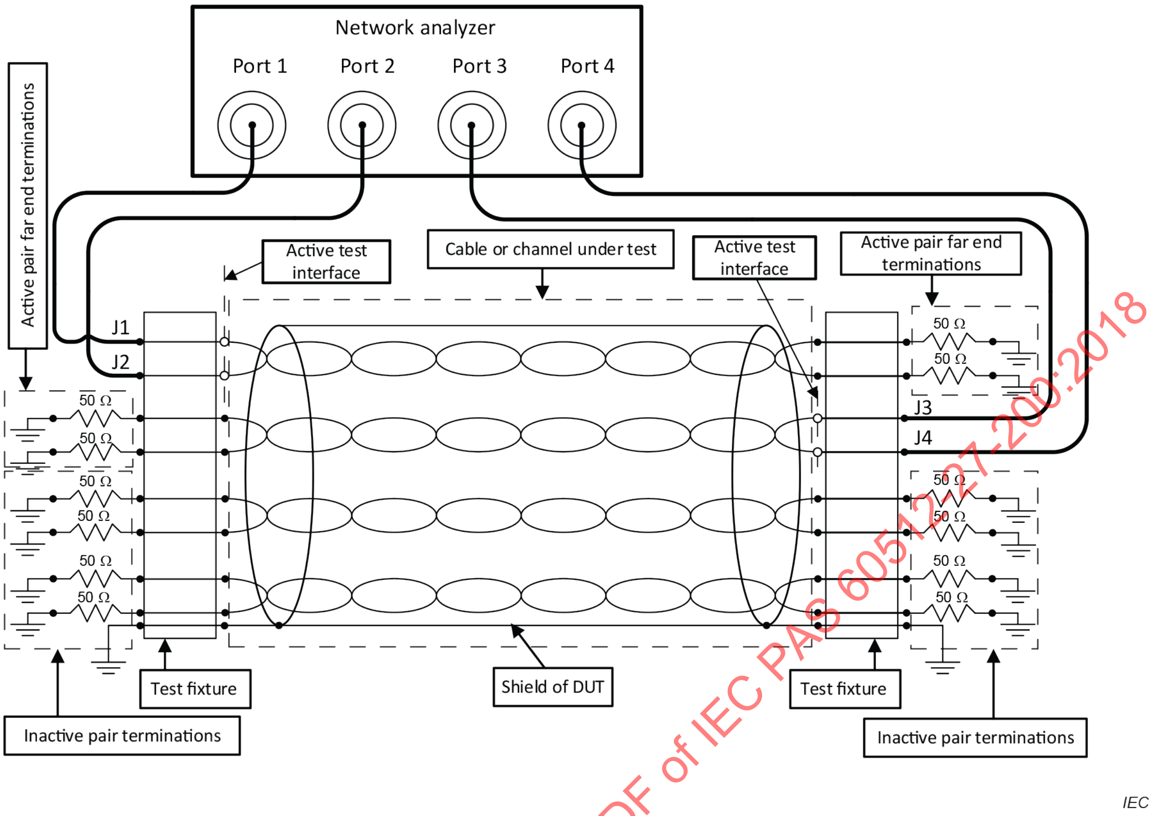


Figure D.5 – Laboratory test configuration for cabling and cable FEXT loss (ACRF)

D.4.6.2 Calibration of cabling and cable FEXT loss

The calibration for cabling and cable FEXT loss shall comply with Clause D.3.

D.4.6.3 Measurement of cabling and cable FEXT loss

Measure Sdd21 for all of the 12 pair combinations for FEXT loss, launching from one end only. It is not necessary to measure FEXT loss from both ends due to reciprocity.

D.4.7 TCL of cabling and cables

D.4.7.1 Test configuration of cabling and cable TCL

Figure D.2 depicts the typical schematic diagram for measurement of TCL. The near-end terminating resistor networks shall be bonded and connected to the measurement ground plane. The far-end resistor networks shall be bonded together. Alternatively, the test configuration of Figure D.2 may be used for TCL measurements.

D.4.7.2 Calibration for measurement of cabling and cable TCL

The calibration for cabling and cable TCL shall comply with Clause D.3.

D.4.8 TCTL of cabling and cables

D.4.8.1 Test configuration of cabling and cable TCTL

Figure D.3 depicts the typical schematic diagram for testing TCTL.

D.4.8.2 Calibration of cabling and cable TCTL

The calibration of the test hardware for TCTL measurements shall follow the procedures outlined in Clause D.3.

D.4.8.3 Measurement of cabling and cable TCTL

TCTL shall be tested in both directions.

D.4.9 Propagation delay of cabling and cable

D.4.9.1 Test configuration of cabling and cable propagation delay

The cabling and cable propagation delay measurement configuration shall comply with the requirements of D.4.4.

D.4.9.2 Calibration of cabling and cable propagation delay

The calibration of cabling and cable propagation delay shall comply with Clause D.3.

D.4.9.3 Measurement of cabling and cable propagation delay

Measure all 4 pairs for cabling and cable propagation delay. It is not necessary to measure cabling and cable propagation delay from both ends due to reciprocity.

D.5 Permanent link test procedures

D.5.1 General

This clause describes test and calibration procedures for permanent links.

D.5.2 Permanent link measurement configurations

The following requirements apply to the test configurations for permanent link measurements and for other components, assemblies, and test parameters as indicated by reference.

For all laboratory and field transmission measurements of screened permanent links, the shield shall be grounded at both ends. Attention should be given to providing low impedance connections from the shield to ground and between grounding points of the two cable ends.

Testing shall be carried out using a modular test plug compliant with C.6.6 inserted between the test interface and the permanent link under test. The crosstalk, insertion loss and return loss of the modular test plug shall not be calibrated out.

D.5.3 Calibration of permanent link test configurations.

The permanent link test configuration shall be calibrated by applying appropriate open, short, load and through calibration artefacts to the test interface between the test system and the modular test plug.

D.5.4 Return loss of permanent links

D.5.4.1 Test configuration of permanent link return loss

The permanent link return loss measurement configuration shall comply with the requirements of Clause D.3.

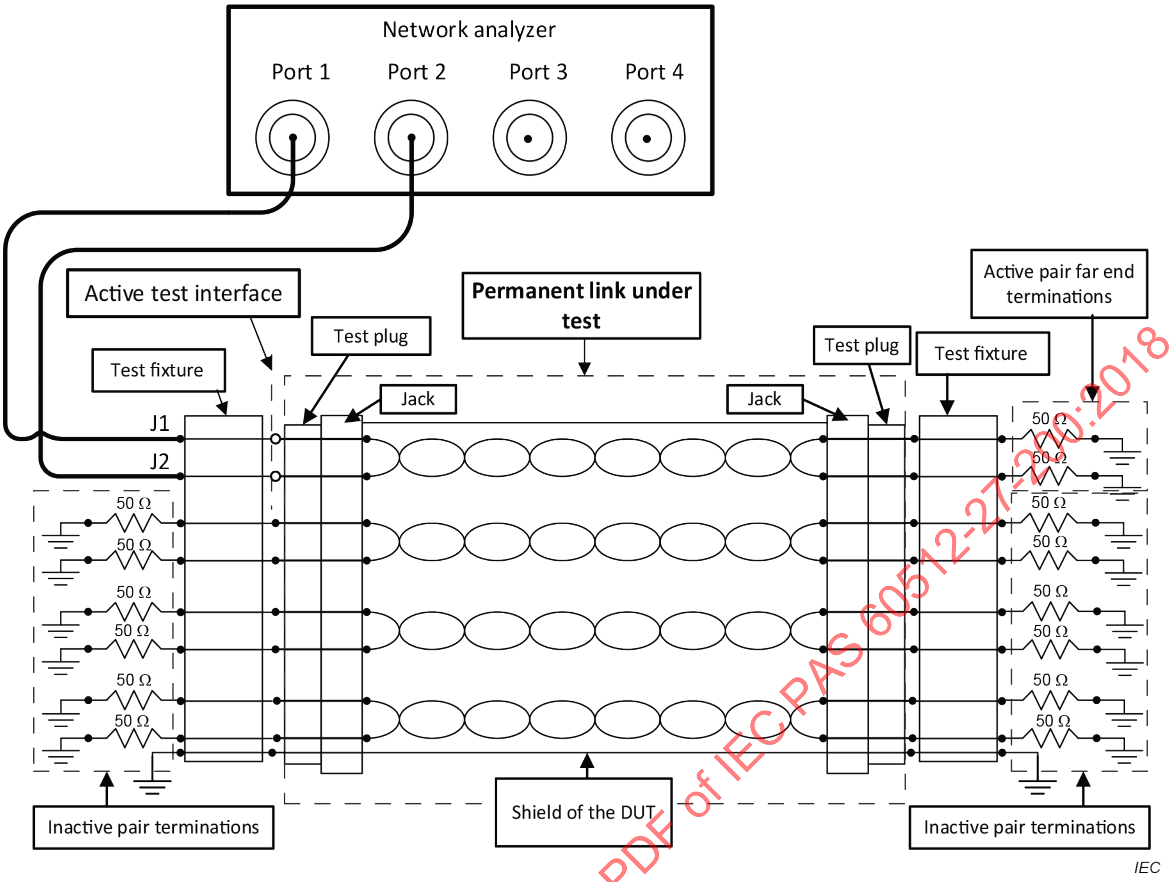


Figure D.6 – Laboratory test configuration for permanent link return loss and TCL measurements

D.5.4.2 Calibration of permanent link return loss

The calibration for permanent link return loss shall comply with Clause D.3.

D.5.4.3 Measurement of permanent link return loss

Measure the Sdd11 parameter with the network analyzer connected to each pair on each end; permanent link return loss shall be tested in both directions.

D.5.5 Insertion loss of permanent link

D.5.5.1 Test configuration for permanent link insertion loss, (also used for FEXT loss, ACRF, and propagation delay)

The permanent link insertion loss measurement configuration shall comply with Figure D.7.

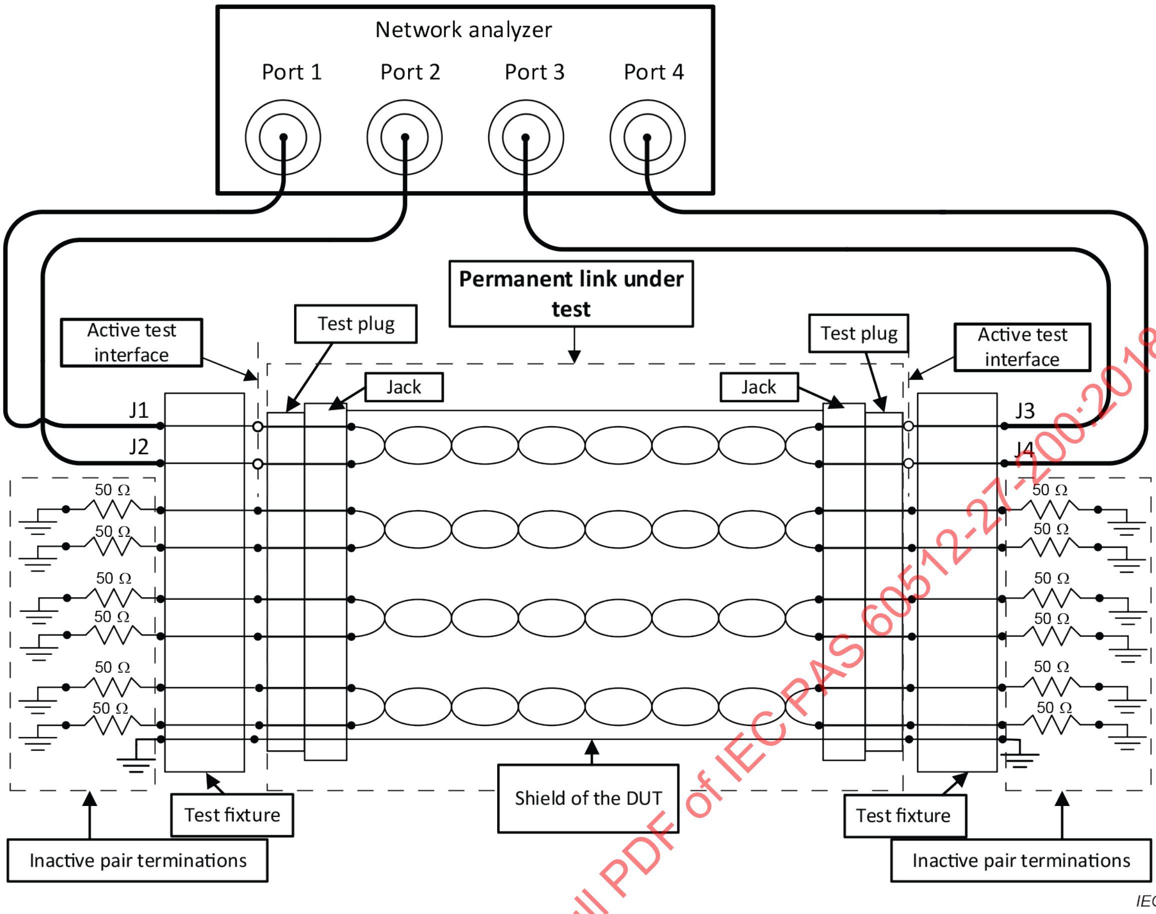


Figure D.7 – Laboratory test configuration for permanent link insertion loss, TCTL, and propagation delay measurements – Alternate test configuration for return loss and TCL

D.5.5.2 Calibration of permanent link insertion loss

The calibration for permanent link return loss shall comply with Clause D.3.

D.5.5.3 Measurement of permanent link insertion loss

Measure the Sdd21 parameter with the pair under test connected to the network analyzer at both the near-end and the far-end. Permanent link insertion loss shall be tested in both directions.

D.5.6 NEXT loss of permanent link

D.5.6.1 Test configuration for permanent link NEXT loss

The permanent link NEXT loss measurement configuration shall comply with Figure D.8.

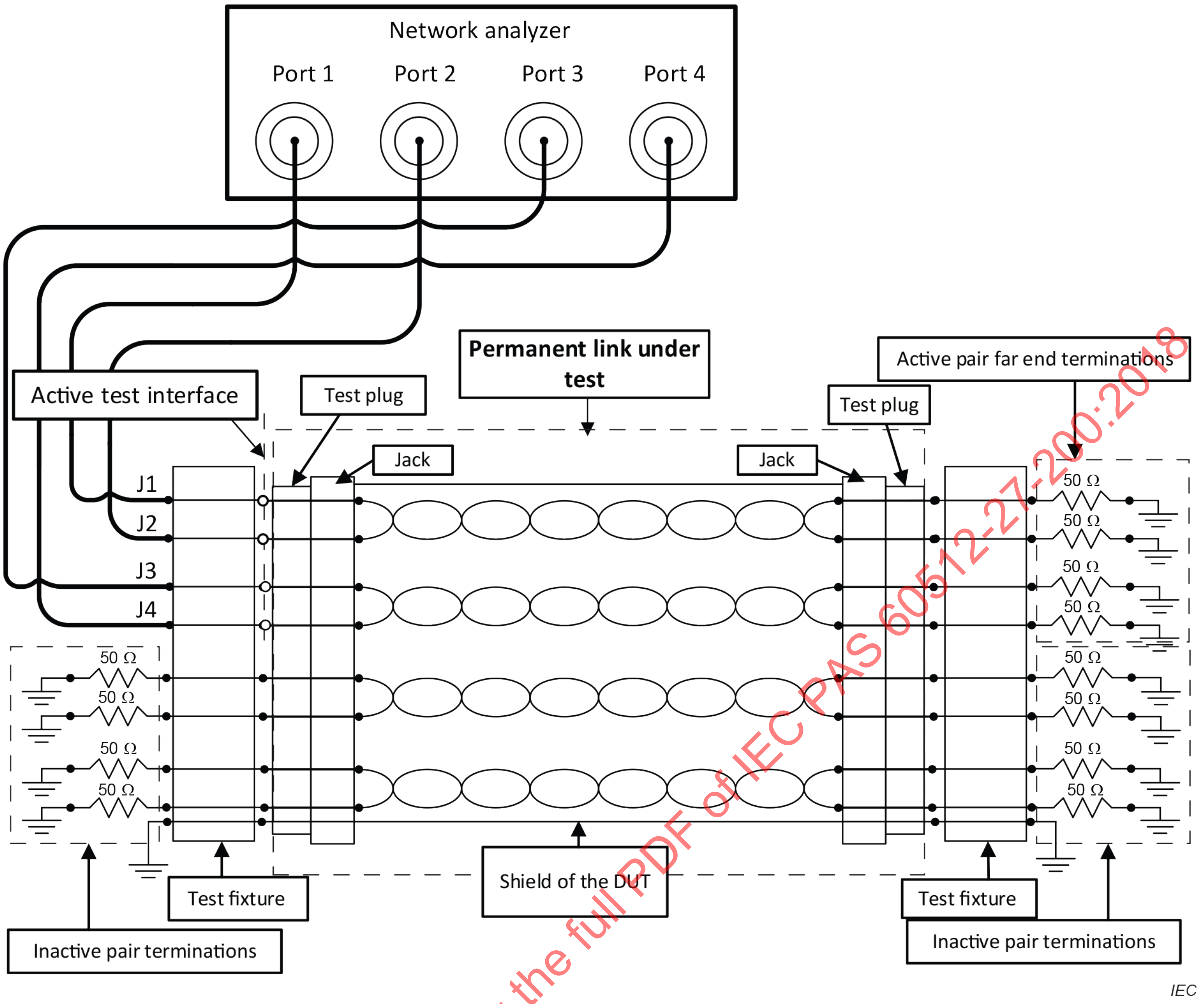


Figure D.8 – Laboratory test configuration for permanent link NEXT loss measurements

D.5.6.2 Calibration of permanent link NEXT loss

The calibration for permanent link NEXT loss shall comply with Clause D.3.

D.5.6.3 Measurement of permanent link NEXT loss

Measure the Sdd21 parameter with the network analyzer connected to each of the 6 pair combinations in a four pair permanent link. Permanent link NEXT loss shall be tested in both directions.

D.5.7 FEXT loss of permanent link

D.5.7.1 Test configuration of permanent link FEXT loss

The permanent link FEXT loss measurement configuration shall comply with Figure D.9.

D.5.7.2 Calibration of permanent link FEXT loss

The calibration of permanent link FEXT loss shall comply with Clause D.3.