IEC 61935-1

Edition 5.0 2019-09

INTERNATIONAL STANDARD

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

Spécification relative aux essais des câblages symétriques et coaxiaux des technologies de l'information –
Partie 1: Câblages symétriques installés selon les spécifications de l'ISO/IEC 11801-1 et des normes connexes

IEC 61935-1:2019-09(en-fr)

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SPECIFICATION FOR THE TESTING OF BALANCED AND COAXIAL INFORMATION TECHNOLOGY CABLING –

Part 1: Installed balanced cabling as specified in ISO/IEC 11801-1 and related standards

FOREWORD

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International Standard IEC 61935-1 has been prepared by IEC technical committee 46: Cables, wires, waveguides, RF connectors, RF and microwave passive components and accessories.

This fifth edition cancels and replaces the fourth edition, published in 2015. This edition constitutes a technical revision.

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

a) the upper frequency goes up to 2 000 MHz;
b) it introduces a new level of field tester (level VI to 2 000 MHz);
c) error models and requirements for level VI testers are improved and updated.

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

FDIS	Report on voting
46/725/FDIS	46/730/RVD

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

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

A list of all parts in the IEC 61935 series, published under the general title *Specification for the testing of balanced and coaxial information technology cabling*, can be found on the IEC website.

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INTRODUCTION

Telecommunication cabling, once specified uniquely by each telecommunications application, has evolved into a generic cabling system. Telecommunications applications now use the ISO/IEC 11801-1 cabling standard to meet their cabling requirements. Formerly, connectivity tests and visual inspection were deemed sufficient to verify a cabling installation. Now users need more comprehensive testing in order to ensure that the link will support telecommunications applications that are designed to operate on the generic cabling system. This part of IEC 61935 addresses reference laboratory and field test methods and provides a comparison of these methods.

Transmission performance depends on cable characteristics, connecting hardware, patch cords and cross-connect cabling, the total number of connections and the care with which they are installed and maintained. IEC 61935 (all parts) provides test methods for installed cabling and pre-fabricated cable assemblies. These test methods, where appropriate, are based on those used for components of the cable assembly.

This Part 1 contains the test methods required for installed cabling. Part 1-1 provides requirements for the optional testing of TCL and ELTCTL. Part 1-2 provides requirements for the optional testing of resistance unbalance. Part 2 contains the test methods required for patch cords and work area cords.

SPECIFICATION FOR THE TESTING OF BALANCED AND COAXIAL INFORMATION TECHNOLOGY CABLING –

Part 1: Installed balanced cabling as specified in ISO/IEC 11801-1 and related standards

1 Scope

This part of IEC 61935 specifies reference measurement procedures for cabling parameters and the requirements for field tester accuracy to measure cabling parameters identified in ISO/IEC 11801-1.

This document applies when the cable assemblies are constructed of cables complying with IEC 61156 (all parts), and connecting hardware as specified in IEC 60603-7 (all parts) or IEC 61076-3-104, IEC 61076-3-110, IEC 61076-2-101 and IEC 61076-2-109. Where cables and/or connectors do not comply with these standards, then additional tests may be required.

This document is organized as follows:

- reference laboratory measurement procedures on cabling topologies are specified in Clause 4. In some cases, these procedures may be used in the field (see IEC TR 61156-1-2:2009/AMD1:2014);
- descriptions and requirements for measurements in the field are specified in Clause 5;
- performance requirements for field testers and procedures to verify performance are specified in Clause 6.

NOTE 1 This document does not include tests that are normally performed on the cables and connectors separately. These tests are described in IEC 61156-1 and IEC 60603-7 or IEC 61076-3-104, IEC 61076-3-110, IEC 61076-2-101 and IEC 61076-2-109, respectively.

NOTE 2 Wherever possible, cables and connectors used in cable assemblies, even if they are not described in IEC 61156 or IEC 60603-7, IEC 61076-3-104, IEC 61076-3-110, IEC 61076-2-101 and IEC 61076-2-109, are tested separately according to the tests given in the relevant generic specification. In this case, most of the environmental and mechanical tests described in this standard can be omitted.

This document relates to performance with respect to 100 Ω cabling. For 120 Ω or 150 Ω cabling, the same principles apply but the measurement system should correspond to the nominal impedance level.

Field tester types include certification, qualification and verification. Certification testing is performed for the rigorous needs of commercial/industrial buildings to this document. Qualification testing is described in IEC 61935-3. Qualification testing determines whether the cabling will support certain network technologies (e.g. 1000BASE-T, 100BASE-TX, 10G Base-T). Qualification testers do not have traceable accuracy to national standards and only provide confidence that specific applications will work. Verification testers only verify connectivity.

Throughout this document, 4-pair cabling is assumed. The test procedures described in this document may also be used to evaluate one or two pair balanced cabling. However, 2-pair cabling links that share the same sheath with other links are tested as 4-pair cabling.

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 60169-15, *Radio-frequency connectors – Part 15: R.F. coaxial connectors with inner diameter of outer conductor 4.13 mm (0.163 in) with screw coupling – Characteristic impedance 50 ohms (Type SMA)*

IEC 60169-22, *Radio-frequency connectors – Part 22: R.F. two-pole bayonet coupled connectors for use with shielded balanced cables having twin inner conductors (Type BNO)*

IEC 60512-25-9, *Connectors for electronic equipment – Tests and measurements – Part 25-9: Signal integrity tests – Test 25i: Alien crosstalk*

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

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

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

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

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

IEC 61076-2-101, *Connectors for electronic equipment – Product requirements – Part 2-101: Circular connectors – Detail specification for M12 connectors witch screw-locking*

IEC 61076-2-109, *Connectors for electronic equipment – Product requirements – Part 2-109: Circular connectors – Detail specification for connectors M12 × 1 witch screw-locking, for data transmission frequencies up to 500 MHz*

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

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

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

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

IEC TR 61156-1-2:2009, *Multicore and symmetrical pair/quad cables for digital communications – Part 1-2: Electrical transmission characteristics and test method of* symmetrical pair/quad cables
IEC TR 61156-1-2:2009/AMD1:2014

IEC 61156-5, *Multicore and symmetrical pair/quad cables for digital communications – Part 5: Symmetrical pair/quad cables with transmission characteristics up to 1 000 MHz – Horizontal floor wiring – Sectional specification*

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

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

IEC 61156-10, *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 – Sectional specification – RF coaxial connectors with inner diameter of outer conductor 7 mm (0,276 in) with screw coupling – Characteristics impedance 50 Ω (75 Ω) (type N)*

IEC 61935-1-1, *Specification for the testing of balanced communication cabling in accordance with ISO/IEC 11801 and coaxial information technology cabling – Part 1-1: Additional requirements for the measurement of transverse conversion loss and equal level transverse conversion transfer loss*

IEC 61935-1-2, *Specification for the testing of balanced and coaxial information technology cabling – Part 1-2: Installed balanced cabling as specified in ISO/IEC 11801 – Additional requirements for measurement of resistance unbalance with field test instrumentation*

IEC 62153-4-9, *Metallic communication cable test methods – Part 4-9: Electromagnetic compatibility (EMC) – Coupling attenuation of screened balanced cables, triaxial method*

IEC 62153-4-11, *Metallic communication cable test methods – Part 4-11: Electromagnetic compatibility (EMC) – Coupling attenuation or screening attenuation of patch cords, coaxial cable assemblies, pre-connectorised cables – Absorbing clamp method*

IEC 62153-4-14, *Metallic communication cable test methods – Part 4-14: Electromagnetic compatibility (EMC) – Coupling attenuation of cable assemblies (Field conditions) absorbing clamp method*

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

ISO/IEC 14763-1[1], *Information technology – Implementation and operation of customer premises cabling – Part 1: Administration*

ISO/IEC 14763-2, *Information technology – Implementation and operation of customer premises cabling – Part 2: Planning and installation*

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1 Withdrawn.

ITU-T Recommendation G.117:1996, *Transmission aspects of unbalance about earth*

ITU-T Recommendation O.9:1999, *Measuring arrangements to assess the degree of unbalance about earth*

3 Terms, definitions and abbreviations

For the purposes of this document, the terms and definitions given in ISO/IEC 11801-1 apply.

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

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

3.1 Terms and definitions

3.1.1
cable assembly
combination of cable(s) and connector(s) with specified performance, used as a single unit intended to be a part of a cabling link as defined in ISO/IEC 11801-1 (or equivalent)

Note 1 to entry: Examples are: patch cord, work area cord, link.

3.1.2
certification
measurements of installed cabling specified in ISO/IEC 11801-1 (e.g. Class D, Class E, Class E_A, Class F, Class F_A, Class I and Class II)

Note 1 to entry: This requires field testers with traceable accuracy to national standards.

3.1.3
comparative test
test that is performed to check the deviation between the results obtained with the reference test method and those obtained with another test set-up (i.e. field test equipment)

3.1.4
coupling attenuation
a ratio, in dB, of the differential power in the signal pairs to the power generated by the excited common mode currents

3.1.5
DC resistance
measure of the sum total of the DC resistance of the wires of a pair (refer to loop DC resistance)

3.1.6
delay skew
worst case value of the phase delay difference between any pair in the same cable assembly

3.1.7
electrical length
equivalent free-space length of the cable assembly

3.1.8
far-end cross-talk
FEXT
decrease in magnitude of power of a signal that propagates between disturbing and disturbed pairs contained within the same link measured at the far end

Note 1 to entry: When the power decrease is referenced to the near end of the disturbing pair, the characteristic is named input output crosstalk (IO FEXT).

Note 2 to entry: When the power decrease is referenced to the far end of the disturbing pair, the characteristic is named equal level far end crosstalk (ELFEXT).

Note 3 to entry: When the power decrease is referenced to the far end of the disturbed pair, the characteristic is named attenuation-to-crosstalk ratio, far end (ACR-F).

Note 4 to entry: FEXT is expressed in dB.

Note 5 to entry: ISO/IEC 11801-1 series documents replace the term ELFEXT with term ACR-F.

Note 6 to entry: This note applies to the French language only.

3.1.9
near-end cross-talk
NEXT
near end measurement of square root of signal power coupling from one circuit to another within a cable assembly when a square root of signal power is fed and measured at the same end

Note 1 to entry: Near-end cross-talk is expressed in dB relative to the incident square root of signal power.

Note 2 to entry: This note applies to the French language only.

3.1.10
nominal impedance
impedance for which the system is designed, the nominal impedance being purely resistive

3.1.11
output signal balance
OSB
ratio of the output common mode voltage to the output differential voltage generated by a source port

Note 1 to entry: This note applies to the French language only.

3.1.12
power sum NEXT
combined NEXT on a receiving pair from all disturbing links operating simultaneously

3.1.13
power sum ACR-F
combined ACR-F on a receiving pair from all disturbing links operating simultaneously

3.1.14
power sum ELFEXT
combined ELFEXT on a receiving pair from all disturbing links operating simultaneously

3.1.15
propagation delay
phase delay at each frequency in the frequency range of interest for the propagation of a transverse electromagnetic mode (TEM) wave between the reference planes of the cable assembly, expressed in nanoseconds per metre (ns/m)

3.1.16
qualification
measurements of installed cabling for specific network technologies

Note 1 to entry: An example would be 100BASE-T, IEEE802.3, 1000BASE-T, 10 GBASE-T, IEEE 1394b.

3.1.17
reference plane
reference position of the cabling under test or necessary mating connector at which the performance requirements are specified

3.1.18
reflection coefficient
Γ
ratio of the complex square root of wave amplitude of the reflected wave to the complex square root of wave amplitude of the incident wave at a port or transverse cross section of a cable assembly when the cable assembly is terminated with its application or nominal impedances, Z_{nom}

$$\Gamma = \left(\frac{|Z_{\text{in}} - Z_{\text{nom}}|}{|Z_{\text{in}} + Z_{\text{nom}}|} \right) \tag{1}$$

3.1.19
return loss
RL
ratio of the power delivered to a cable assembly terminated at the far end with its nominal characteristic impedance, to the reflected power at the input port of the cable assembly

$$RL = 20 \log \left(\frac{u_{\text{i}}}{u_{\text{r}}} \right) \quad \text{or} \quad RL = -20 \lg \left(\frac{|Z_{\text{in}} - Z_{\text{nom}}|}{|Z_{\text{in}} + Z_{\text{nom}}|} \right) \tag{2}$$

where

u_{i} is the incident voltage;

u_{r} is the reflection voltage.

Note 1 to entry: This note applies to the French language only.

3.1.20
unbalance attenuation
ratio of the common mode square root of signal power to the differential mode square root of signal power in a pair due to unbalanced properties of the given pair

3.1.21
verification
measurements of installed cable or cabling for continuity

Note 1 to entry: No other transmission performance parameters other than connectivity are measured.

3.2 Acronyms

AACR-F Attenuation to alien crosstalk ratio at the far-end

ACR	Attenuation to crosstalk ratio
ACR-F	Attenuation to crosstalk ratio at the far-end
ACR-N	Attenuation to crosstalk ratio at the near-end
AFEXT	Alien far-end crosstalk (loss)
ANEXT	Alien near-end crosstalk (loss)
CP	Consolidation point
DC/d.c.	Direct current
EI	Equipment interface
ELTCTL	Equal level TCTL
ELFEXT	Equal level FEXT
EMC	Electromagnetic compatibility
ELTCTL	Equal level TCTL
FEXT	Far end crosstalk attenuation (loss)
LCL	Longitudinal to differential conversion loss
LCTL	Longitudinal to differential conversion transfer loss
NEXT	Near end crosstalk attenuation (loss)
NVP	Nominal velocity of propagation
PS AACR-F	Power sum attenuation to alien crosstalk ratio at the far-end
PS AACR-F_{avg}	Average power sum attenuation to alien crosstalk ratio at the far-end
PS ACR	Power sum ACR
PS ACR-N	Power sum attenuation to crosstalk ratio at the near-end
PS ACR-F	Power sum attenuation to crosstalk ratio at the far-end
PS $AFEXT_{norm}$	Normalized power sum alien far-end crosstalk (loss)
PS AFEXT	Power sum alien far-end crosstalk (loss)
PS ANEXT	Power sum alien near-end crosstalk (loss)
PS $AFEXT_{norm}$	Normalized power sum alien far-end crosstalk (loss)
PS $ANEXT_{avg}$	Average power sum alien near-end crosstalk (loss)
PS FEXT	Power sum FEXT (loss)
PS NEXT	Power sum NEXT (loss)
RL	Return loss
RFI	Radio frequency interference

4 Reference measurement procedures for electrical properties

4.1 General

Clause 4 describes reference measurement procedures for electrical parameters. The measurement procedures are intended to be used in a laboratory environment using laboratory equipment. In some cases, a measurement procedure may also be applicable for field testing. If this is the case, the procedure shall be specifically identified as being suitable for installed cabling testing and appropriate precautions shall be described.

Users of this document are advised to consult with applications standards, equipment manufacturers and system integrators to determine the suitability of these requirements for specific networking applications.

4.2 Common measurement considerations

4.2.1 Test equipment consideration

The reference measurement procedures that are described in this document require the use of a network analyser, RF transformers (baluns), twisted pair (TP) test leads and impedance matching terminations. Separate generator/receiver test instrumentation may also be used for some of the measurements. Other measurement procedures, which can be shown to yield equivalent results, may be used.

4.2.2 Network analyser test requirements

Usually the input and output terminals of a network analyser are unbalanced. RF transformers with balanced outputs (baluns) can be used with unbalanced signal connections to the network analyser. For balunless test adapters, refer to IEC TR 61156-1-2:2009/AMD1:2014. Balunless test adapters are particularly suitable for mixed mode measurements.

4.2.3 Test set-up

The test set-up shall be calibrated at the specified reference plane for the cabling under test before testing. Full one-port calibrations shall be used when making one-port (e.g. return loss) measurements, Full two-port calibration shall be used when making two-port measurements (e.g. insertion loss) measurements.

4.2.4 Termination of conductor pairs

During measurement, all conductor pairs of the cabling under test shall be terminated at both ends with impedance matching loads. For pairs under test, this is provided by the test instrumentation at one or both ends. For pairs not under test or not connected to test instrumentation, resistor loads or terminated baluns shall be applied.

Unless otherwise specified, the nominal differential mode impedance of the termination shall be 100 Ω for 100 Ω and 120 Ω cabling, and 150 Ω for 150 Ω cabling. The nominal common mode impedance shall be 50 Ω ± 25 Ω, unless otherwise specified in the measurement procedure.

Resistor loads shall use resistors specified for ±0,1 % accuracy at DC and have a return loss of 46 dB up to 100 MHz and 40 dB up to maximum frequency. For pairs connected to a balun, common mode load is implemented by applying a load at the centre tap of the balun. The impedance of the load is equal to the common mode impedance. For pairs connected to other kinds of balancing devices (180° power splitters), common mode load is implemented by use of an attenuator at each of the balanced terminals of the balancing device. This method is also used if the centre tap is not available at the balun used. The attenuation provided by the attenuators shall be ≥ 6 dB (see Figure 3). The common mode impedance is approximately one fourth of the differential mode impedance for this implementation. For pairs connected to resistor loads, common mode load is implemented by the Y configuration shown in Figure 1.

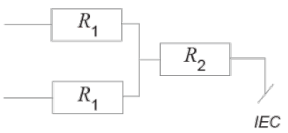


Figure 1 – Resistor load

where

$$R_1 = \frac{R_{dif}}{2} \quad (3)$$

$$R_1 = 50\ \Omega \pm 0{,}1\ \%$$

and

$$R_2 = R_{com} - \frac{R_{dif}}{4} \tag{4}$$

$$R_2 = 25\ \Omega \pm 1\ \%$$

where

R_{dif} is the differential mode resistance (Ω);

R_{com} is the common mode resistance (Ω).

For unscreened cabling, the common mode termination points for all pairs are connected together at either end of the cabling. For screened cabling, the common mode termination points are connected to the cable screen or screens at each end of the cabling.

NOTE Accuracy is dependent on the uses of equivalent calibration techniques.

4.2.5 Reference loads for calibration

To perform a one or two-port calibration of the test equipment, a short-circuit, an open circuit and an impedance matching termination are required. These devices shall be used to obtain a calibration at the reference plane.

The impedance matching termination shall be calibrated against a calibration reference, which shall be a 50 Ω load, traceable to a national reference standard. If the value of the reference load for calibration is 100 Ω, two loads in parallel shall be calibrated against the calibration reference. If the value of the reference load for calibration is 150 Ω, three loads in parallel shall be calibrated against the calibration reference. The reference loads for calibration shall be placed in an N type connector according to IEC 61169-16 or SMA type according to IEC 60169-15, meant for panel mounting, which is machined flat on the back side. The loads shall be fixed to the flat side of the connector, distributed evenly around the center conductor. A network analyser shall be calibrated, one port full calibration, with the calibration reference. Thereafter, the return loss of the reference loads for calibration shall be measured. The verified return loss shall be 46 dB up to 100 MHz and 40 dB up to maximum frequency.

4.2.6 Test configurations

The cabling configurations that are tested in the field are as follows (see Figure 2):

– Channel. The channel test configuration is intended to be used by system designers and users of data communication systems to verify the performance of the overall channel. The channel as defined in ISO/IEC 11801-1 (or equivalent), includes up to 90 m of horizontal cable, a work area equipment cord, a telecommunications outlet/connector, an optional consolidation point connection close to the work area and two cross-connect connections in the floor distributor. The total length of work area, patch cords and jumpers shall not exceed 10 m. The connections to the equipment at each end of the channel are not included in the channel definition. The end-user patch cord shall be used to test channel performance.

– Permanent link. The permanent link test configuration is intended to be used by installers and users of data communication systems to verify the performance of permanently installed cabling. The permanent link distributor as defined in ISO/IEC 11801-1 (or equivalent) consists of up to 90 m of horizontal cabling and one connection at each end. The permanent link excludes both the cable portion of the test cord of the test equipment and the connection to the test equipment, but may include the optional consolidation point.

– CP link. The CP link test configuration is intended to be used by installers and users of data communication systems to verify the portion of a permanent link between the floor distributor and consolidation point.

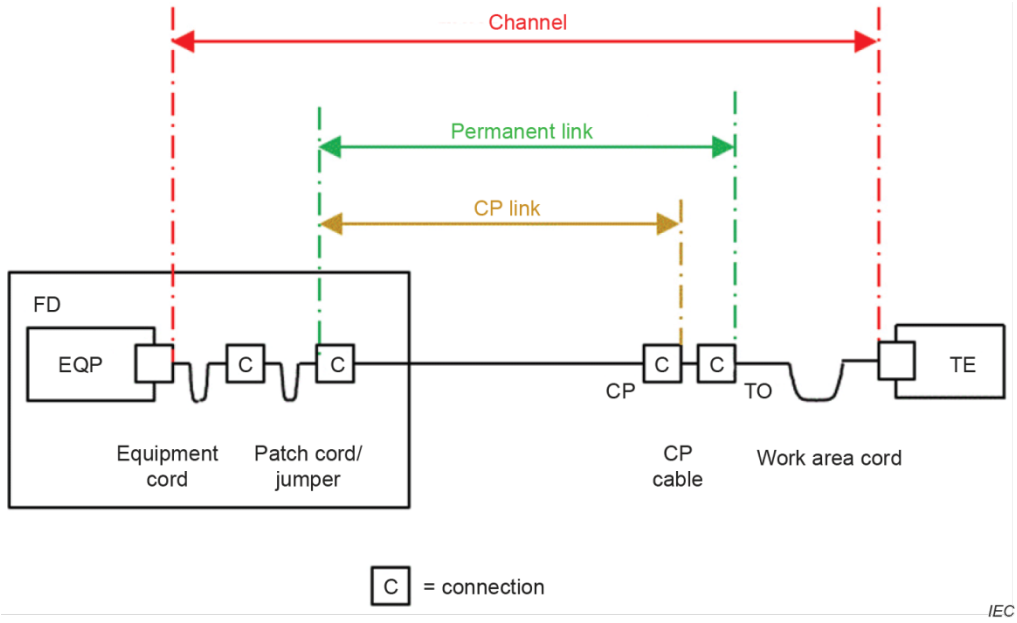


Figure 2 – Reference planes for permanent link, CP link and channel

The test configuration reference planes of a permanent link are at the end of the permanent link test cords where the cable enters the body of the plug attached to the test cords at the local end, and where the cable exits the body of the plug attached to the test cord at the remote end, which each mate with the permanent link under test. Practically, the reference plane of measurement should be within 5 mm from the reference plane definition when making measurements on a permanent link. The test configuration reference plane of a channel are at the end of the user patch cords where the cable enters the body of the plug attached to the user patch cord at the local end, and where the cable exits the body of the plug attached to the user patch cord at the remote end, which each mate with the channel adapter. Practically, the reference plane of measurement should be within 5 mm of the reference plane definition when making measurements on a channel.

4.2.7 Coaxial cables and test leads for network analysers

Coaxial cable assemblies between the network analyser and any test fixture should be as short as possible. (It is recommended that they do not exceed 600 mm each). The coaxial cables shall be double screened. The baluns (when used) shall be attached to a common ground plane.

4.2.8 Balanced test leads

Balanced test leads and associated connecting hardware to connect between the test equipment and the cable assembly under test shall be taken from components that meet or exceed the requirements for the category of the cable assembly under test. Balanced test leads shall be limited to a length of 50 mm between any test fixtures and the reference plane of the cabling under test. Pairs shall remain twisted between any test fixtures to where connections are made to the DUT to where connections are made, and unscreened balanced test leads shall be separated by 5 mm from any ground plane.

For balunless test adapters, refer to IEC TR 61156-1-2:2009/AMD1:2014.

The S-parameters of a mixed mode measurement consist of 16 terms for a single measurement path, providing the full matrix of common and differential parameters. The nomenclature is given by Table 1.

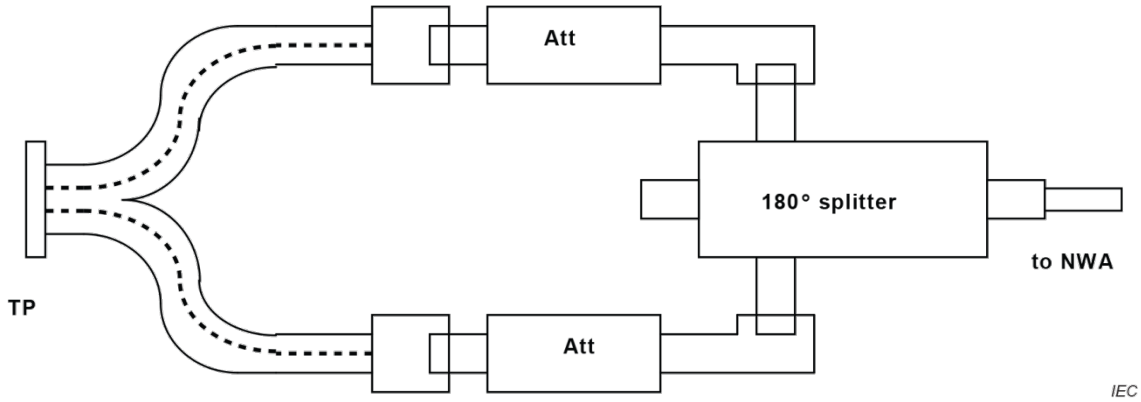
Table 1 – Mixed mode S-parameter nomenclature

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

4.2.9 Balun requirements

Depending on the test set-up, baluns are an optional element that may be required for measurements. In case baluns are used, the following applies:

The baluns may be balun transformers or 180° hybrids with attenuators to improve matching if needed (see Figure 3).



Key

Att	attenuator
180° splitter	180 degrees phase splitter
to NWA	connection to network analyser
TP	connections at test port

Figure 3 – 180° hybrid used as a balun

A balun is designated class A in the frequency range for which the class A requirements are met. A balun is designated class B in the frequency range for which the class B requirements are met. A balun may be class A in one frequency range and class B in another extended frequency range.

Class A baluns are preferred for verification of performance characteristics of all classes of cabling.

Class B baluns (see Annex D) may be used to verify performance of all classes of cabling, provided that the lower performance of the balun is taken into account in the measurement error calculation.Baluns shall be RFI shielded and shall comply with the requirements given in Table 2.

Table 2 – Test balun performance characteristics

Parameter	Class A 250 1 to 250 MHz	Class A 500 1 to 500 MHz	Class A 1000 1 to 1000 MHz	Class A 2000 1 to 2000 MHz
Impedance, primary[a]	50 Ω unbalanced	50 Ω unbalanced	50 Ω unbalanced	50 Ω unbalanced
Impedance, secondary	Matched balanced [d]	Matched balanced [d]	Matched balanced [d]	Matched balanced [d]
Insertion loss[e]	3 dB maximum	2 dB maximum	3 dB maximum	3 dB, 1 MHz to 3 MHz 2 dB, 3 MHz to 15 MHz 2 dB, 15 MHz to 1 000 MHz 3 dB, 1 000 MHz to 2 000 MHz
Return loss secondary, minimum	20 dB	12 dB, 1 MHz to 15 MHz 20 dB, 15 MHz to500 MHz	12 dB, 4 MHz to 15 MHz 20 dB, 15 MHz to 550 MHz 17,5 dB, 550 MHz to 600 MHz 10 dB, 600 MHz to 1 000 MHz	8 dB, 1 MHz to 3 MHz 12 dB, 3 MHz to 15 MHz 20 dB, 15 MHz to 1 000 MHz 18 dB, 1 000 MHz to 2 000 MHz
Return loss, common mode[b], **minimum**	10 dB	15 dB, 1 MHz to 15 MHz 20 dB, 15 MHz to 400 MHz 15 dB, 400 MHz to 500 MHz	15 dB, 4 MHz to 15 MHz 20 dB, 15 MHz to 400 MHz 15 dB, 400 MHz to 600 MHz 10 dB, 600 MHz to 1 000 MHz	6 dB, 1 MHz to 3 MHz 10 dB, 3 MHz to 500 MHz ffs., 500 MHz to 2 000 MHz
Power rating	0,1 Watt minimum	0,1 Watt minimum	0,1 Watt minimum	0,1 Watt minimum
Longitudinal balance[c], **minimum**	60 dB	60 dB, 1 MHz to 100 MHz 50 dB, 100 MHz to 500 MHz	60 dB, 4 MHz to 350 MHz 50 dB, 350 MHz to 600 MHz 40 dB, 600 MHz to 1 000 MHz	60 dB, 1 MHz to 100 MHz 50 dB, 100 MHz to 500 MHz 42 dB, 500 MHz to 1 000 MHz 34 dB, 1 000 MHz to 2 000 MHz
Output signal balance[c], **minimum**	50 dB	50 dB	60 dB, 4 MHz to 350 MHz 50 dB, 350 MHz to 600 MHz 40 dB, 600 MHz to 1 000 MHz	ffs.
Common mode rejection[c], **minimum**	50 dB	50 dB	50 dB, 4 MHz to 600 MHz 40 dB, 600 MHz to 1 000 MHz	50 dB, 1 MHz to 500 MHz 42 dB, 500 MHz to 1 000 MHz 34 dB, 1 000 MHz to 2 000 MHz

[a] Primary impedance may differ, if necessary, to accommodate analyser outputs other than 50 Ω.

[b] Measured either by connecting the balanced output terminals together and measuring the return loss. The unbalanced balun input terminal shall be terminated by a 50 Ω load. Or measured at the common-mode port – if available – while terminating the balanced port for differential and common mode.

[c] Measured per ITU-T Recommendations G.117 and O.9.

[d] For 120 Ω cables, 120 Ω baluns will be used only in cases where it is requested by the user. Usually 100 Ω baluns will be used.

[e] In case separate attenuators are used, they shall be excluded from the insertion loss measurement.

NOTE Proper test for configurations for qualifying tests baluns to the requirements are given in Annex D.

Baluns according to Annex D may also be used where legacy compatibility is required.

4.2.10 Balunless

Where balunless techniques are used for measurement, the requirements are provided by IEC TR 61156-1-2:2009/AMD1:2014.

4.2.11 Network analyser measurement precautions

To assure a high degree of reliability for transmission measurements, the following precautions are required:

a) the reference plane of the calibration shall coincide with the measurement reference plane; in case of differences, the magnitude of errors shall be determined;

b) consistent and stable baluns (when used) and resistor loads shall be used for each pair throughout the test sequence (see 4.2.4);

c) cable and adapter discontinuities, as introduced by physical flexing, sharp bends and restraints shall be avoided before, during and after the tests;

d) the relative spacing of conductor pairs shall be preserved throughout the tests to the greatest extent possible;

e) unscreened balanced cable test leads and interconnects shall remain separated from metallic surfaces, such as ground planes, and isolated from sources of electromagnetic interference (EMI);

f) the balance of the cables is maintained to the greatest extent possible by consistent conductor lengths and pair twisting to the point of load;

g) coaxial, balanced lead and printed line lengths shall be kept as short as possible so that resonance and parasitic effects are minimised;

h) connections to the baluns (when used) and pins from IC socket interfaces shall be made in such a way that conductor movement resulting from connection of different pairs to the network analyser or test fixture shall produce minimal variability for repeated measurements on the same reference cable (±0,25 dB or less is acceptable). Where practical, a rigid test fixture is recommended;

i) overload conditions of the network analyser shall be avoided;

j) the sensitivity to set-up variations for these measurements at high frequencies demands attention to detail for both the measurement equipment and the procedures. Data interpretation and application of the requirements is appropriate only if a satisfactory measurement repeatability of ±1 dB or better is achieved;

k) the accuracy of a network analyser is not negligible for measurements or correlations to field testers. This should be considered;

l) shielded cables should be grounded by a low impedance connection to ground as close as possible to the ground plane.

4.2.12 Data reporting and accuracy

The measurement uncertainty shall be determined for each test. This shall be calculated by determining the uncertainty from each error source expressed as the resulting spread in the result. The values of the different error sources are based on instrumentation specifications, calculated errors from imperfect calibration loads and measurement experience. The overall estimated measurement uncertainty is calculated as two times the resulting spread coming from the different error sources. The resulting spread is calculated as:

$$\sigma_{\text{res}} = \sqrt{\sigma_1^2 + \sigma_2^2 + ...\sigma_n^2} \tag{5}$$

where σ_1 to σ_n is the spread of the different error sources.

The overall measurement uncertainty is defined as $2\,\sigma_{\text{res}}$ which is approximately equivalent to a 95 % confidence level. A measurement uncertainty band is determined on both sides of the specified limit.

For Class FA and below, test results that are outside the uncertainty band are reported as either 'pass' or 'fail'. Test results that are inside the uncertainty band are reported as either '*pass' or '*fail' as appropriate. To which extent '*' results shall determine approval or disapproval of the cabling under test shall be defined in the relevant detail specification, or agreed on as a part of a contractual specification.

4.2.13 Frequency step size

Unless otherwise specified, if the test instrument measures at discrete frequencies, the frequency steps shall be no greater than:

- 150 kHz up to 31,25 MHz;
- 250 kHz from 31,25 MHz up to 100 MHz;
- 500 kHz from 100 MHz up to 250 MHz;
- 1 MHz from 250 MHz up to 6 00 MHz;
- 2 MHz from 600 MHz up to 2 000 MHz.

4.3 DC loop resistance

4.3.1 Objective

The objective of this test is to ensure the DC and low frequency continuity of the conductors.

This test is applicable to laboratory and installed cabling testing.

4.3.2 Test method

Measurement of loop resistance shall be carried out on each pair at the near end after applying a short circuit between each wire of that pair at the far end.

4.3.3 Test equipment and set-up

A four terminal ohmmeter (see 4.4.2) suitable for low resistance measurements shall be used. The pairs at the far end of the cabling under test shall be short-circuited at the reference plane. The test set-up is shown in Figure 4.

4.3.4 Procedure

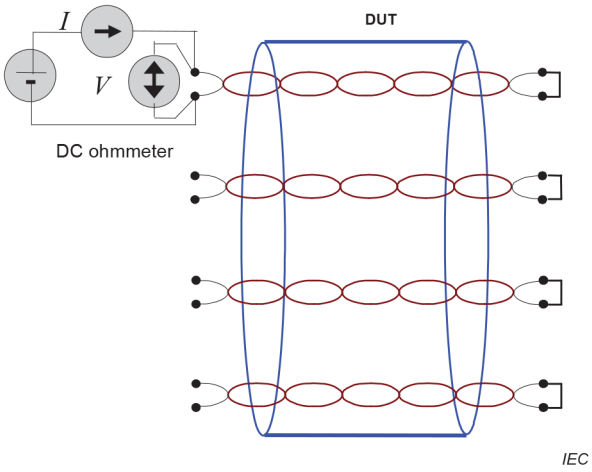
4.3.4.1 Calibration

The ohmmeter shall be calibrated for 0 Ω at the ends of the test leads. After calibration, the test leads shall be connected to the cabling at the measurement reference plane.

The calibration shall be done for 0,00 Ω to be able to measure 0,1 Ω.

4.3.4.2 Measurement

The loop resistance for all four pairs shall be measured.



Key

DUT device under test

V voltage applied to device under test

I current applied to device under test

Figure 4 – Loop resistance measurement

4.3.5 Test report

The measured value shall be reported for the pair with the highest resistance and this pair shall be identified. The highest resistance shall be compared to the requirement specification limits.

4.3.6 Uncertainty

The uncertainty of reference DC resistance measurements shall be less than 0,1 Ω in the range from 0 Ω to 50 Ω.

4.3.7 DC loop resistance recalculation

Measured value of the loop resistance should be recalculated at 20 °C by the following formula:

$$R_{20} = \frac{R_t}{1+\alpha_R (t-20)} \quad (6)$$

where

R_{20} is the loop resistance at 20 °C, in °C;

R_t is the loop resistance, measured at t, in °C;

α_R is the temperature coefficient of resistance;

t is the temperature, at which the measurement was carried out, in °C.

4.4 Direct current (DC) resistance unbalance

4.4.1 Objective

The objective of this test is to ensure the DC resistance unbalance meets the requirements.

This test is applicable for laboratory testing. For installed cabling testing of resistance unbalance, see IEC 61935-1-2.

4.4.2 Test method

The test method is shown in Figure 5. The test configuration for one wire is shown. Measurement of resistance unbalance shall be carried out on each pair.

Each wire is measured and the DC resistance unbalance is the ratio of the difference of the DC resistance of each wire within a pair related to the sum of the DC resistance of each wire.

$$\Delta R = \frac{R_{\text{max}} - R_{\text{min}}}{R_{\text{max}} + R_{\text{min}}} \times 100 \quad (7)$$

where

ΔR is the resistance unbalance expressed in %.

4.4.3 Test equipment and set-up

A four terminal ohmmeter (see 4.4.2) suitable for low resistance measurements shall be used.

4.4.4 Procedure

4.4.4.1 Calibration

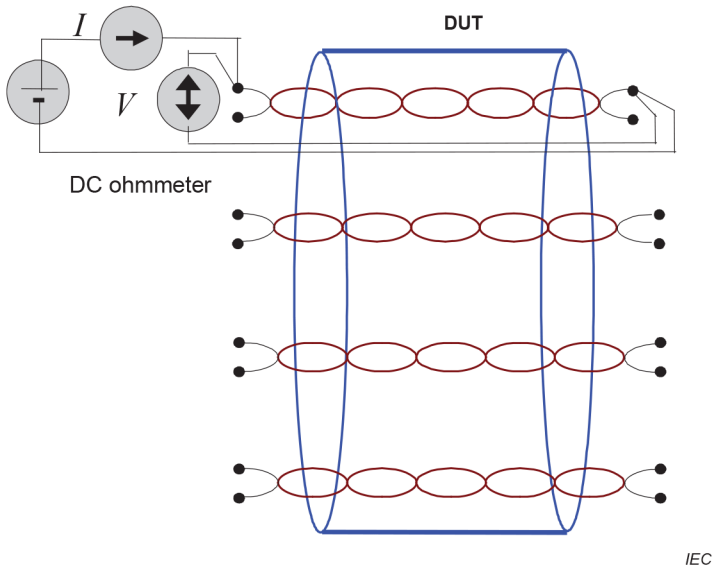
The ohmmeter shall be calibrated for 0 Ω at the ends of the test leads. After calibration, the test leads shall be connected to the cabling at the measurement reference plane.

The calibration shall be done for 0,000 Ω to be able to measure 0,01 Ω.

4.4.4.2 Measurement

Measure the DC resistance of each wire of a pair. Then calculate the DC resistance unbalance per Equation (7).

The DC resistance unbalance for all four pairs shall be measured.



Key

DUT device under test

V voltage applied to wire under test

I current applied to wire under test

Figure 5 – DC resistance unbalance measurement

4.4.5 Test report

The measured value shall be reported for the pair with the highest resistance unbalance and this pair shall be identified. The highest resistance unbalance shall be compared to requirement specification limits.

4.4.6 Uncertainty

The uncertainty of DC resistance unbalance measurements shall be less than 0,3 % + 0,025 Ω in the range from 0 Ω to 50 Ω.

4.5 Direct current (DC) resistance unbalance between pairs

4.5.1 Objective

The objective of this test is to ensure the DC resistance unbalance between pairs meets the requirements.

This test is applicable to laboratory and installed cabling testing. For installed cabling testing of resistance unbalance between pairs, see IEC 61935-1-2.

4.5.2 Test method

The test method is shown in Figure 5. The test configuration for one wire is shown. Measurement of resistance unbalance shall be carried out on each pair combination.

Each wire is measured for DC resistance and the DC resistance unbalance between pairs is the ratio of the difference of the parallel DC resistance of each pair related to parallel DC resistance of each other pair

$$\Delta R_{\text{Between pairs}} = \frac{\left| \left(\frac{(R_{1A} \cdot R_{1B})}{(R_{1A} + R_{1B})} \right) - \left(\frac{(R_{2A} \cdot R_{2B})}{(R_{2A} + R_{2B})} \right) \right|}{\left(\frac{(R_{1A} \cdot R_{1B})}{(R_{1A} + R_{1B})} \right) + \left(\frac{(R_{2A} \cdot R_{2B})}{(R_{2A} + R_{2B})} \right)} 100\ \% \quad (8)$$

where

R_{1A} is the resistance of the first wire of pair 1 in Ω;

R_{1B} is the resistance of the second wire of pair 1 in Ω;

R_{2A} is the resistance of the first wire of pair 2 in Ω;

R_{2B} is the resistance of the second wire of pair 2 in Ω;

$\Delta R_{\text{Between pairs}}$ is the resistance unbalance between pairs expressed in %.

4.5.3 Test equipment and set-up

A four terminal ohmmeter (see 4.4.2) suitable for low resistance measurements shall be used.

4.5.4 Procedure

4.5.4.1 Calibration

The ohmmeter shall be calibrated for 0 Ω at the ends of the test leads. After calibration, the test leads shall be connected to the cabling at the measurement reference plane.

The calibration shall be done for 0,000 Ω to be able to measure 0,01 Ω.

4.5.4.2 Measurement

Measure the DC resistance of each wire of a pair. Then calculate the DC resistance unbalance between pairs.

The DC resistance unbalance between pairs for all six combinations of pairs shall be measured.

4.5.5 Test report

The measured value shall be reported for the pair combination with the highest resistance unbalance and this pair combination shall be identified. The highest resistance unbalance shall be compared to requirement specification limits.

4.5.6 Uncertainty

The uncertainty of DC resistance unbalance measurements shall be less than 0,7 % + 0,035 Ω in the range from 0 Ω to 50 Ω.

NOTE The accuracy shown is a minimal requirement to support the limits provided by system committees (and is not based on the worst case acceptable accuracy for DC loop resistance).

4.6 Insertion loss

4.6.1 Objective

The objective of this test is to measure the insertion loss of the cabling being tested.

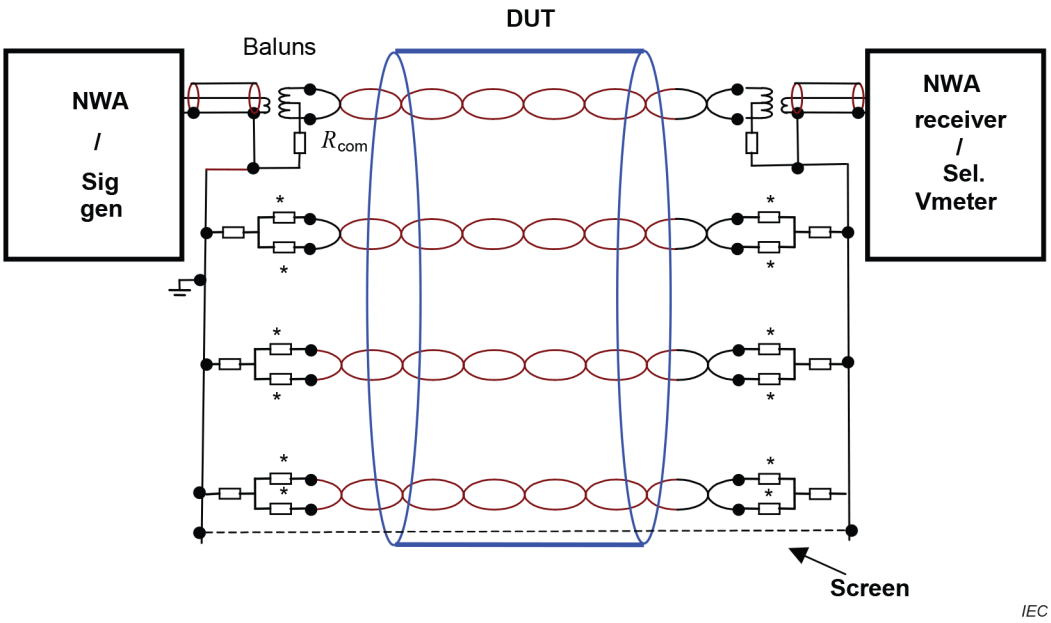
The test method is applicable to cabling in a laboratory environment. If insertion loss has to be measured for installed cabling using laboratory equipment, then a separate generator and receiver is required.

4.6.2 Test method

Insertion loss is measured by determining the signal loss of the device under test, referenced to the signal loss of a short connection between the test ports of the measuring instrument.

4.6.3 Test equipment and set-up

The general instrumentation requirements apply (see 4.2). The test configuration is shown in Figure 6 and the device under test shall be measured at the reference planes defined in Figure 2.



Key

DUT	device under test
NWA/Sig gen	signal generator of network analyser or signal generator
NWA receiver/Sel. Vmeter	receiver of network analyser or selective voltmeter
*	matched resistors (in pairs)
Screen	screen (if present)
R_{com}	common mode impedance (optional in insertion loss test)
Baluns	baluns to interface laboratory equipment and balanced cabling

Figure 6 – Insertion loss test configuration

4.6.4 Procedure

4.6.4.1 Calibration

A transmission (S_{21}) 2-port calibration shall be performed at the reference plane. This is carried out by applying a calibration cable between the terminals of the baluns and carrying out the appropriate calibration procedure.

4.6.4.2 Measurement

Calibrated insertion loss measurements of the cabling shall be performed. Each pair shall be measured. Pairs shall be terminated with loads according to 4.2.4 when not under test. The loads according to 4.2.4 shall be applied at the test cable pairs. Common mode loads are not needed for pairs not under test. Measurements shall be performed in the specified frequency range. The frequency step size shall be according to 4.2.13.

4.6.4.3 Test report

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

4.6.5 Temperature correction

Insertion loss measurements should be conducted at the expected highest operating temperature of the cabling, which may be affected by DC power that is supplied over the cabling system.

If it is not possible to conduct the measurements at the expected highest operating temperature of the cabling, adjustments for insertion loss should be made based on the estimated difference of the expected highest operating temperature of the installation and the actual temperature at the time of measurement. This may be a critical issue when link lengths are near the maximum value.

The temperature coefficient for screened cabling is 0,2 %/°C. For unscreened cabling, the temperature coefficient is specified to be maximum 0,4 %/°C below between 20 °C and 40 °C and 0,6 %/°C between 40 °C and 60 °C, see IEC 61156-5 , IEC 61156-6, IEC 61156-9 and IEC 61156-10.

4.6.6 Uncertainty

The uncertainty of reference insertion loss measurements for cabling shall be less than 0,5 dB.

4.7 Propagation delay and delay skew

4.7.1 Objective

The objective of this test is to measure propagation delay and delay skew of the cabling being tested.

The test method is applicable to cabling in a laboratory environment only. The reference test method cannot be used for installed cabling.

4.7.2 Test method

Propagation delay is measured by determining the phase delay of a signal transmitted through the cabling using Equation (9).

$$\delta = \frac{\varphi}{2\pi f} \tag{9}$$

where

δ is the phase delay in seconds;

φ is the phase in radians;

f is the frequency in Hertz.

Delay skew is calculated as the worst case difference of propagation delay for the pairs in the cabling.

4.7.3 Test equipment and set-up

The set-up is the same as for insertion loss measurements (see 4.6.3). Insertion loss and delay can be measured in the same test with one sweep if the network analyser can measure the complex scattering parameter, S_{21}.

4.7.4 Procedure

4.7.4.1 Calibration

See 4.6.4.1.

4.7.4.2 Measurement

See 4.6.4.2, but note that for this measurement a linear frequency sweep shall be applied. The frequency steps shall be made small enough to ensure that the phase shift from one measurement frequency to the next measurement frequency is less than 2π. In order to assure an adequate margin, the frequency steps shall be no greater than 1 MHz.

4.7.4.3 Calculation

Some network analysers give a readout of the continuous phase trace of the tested item. This readout can be directly inserted in Equation (10). It is usual for the network analyser to measure the phase in an interval of $\pm\pi$. As the ratio of phase versus frequency is a continuously decreasing function, 2π shall be subtracted from the measured phase every time there is a positive step in the measured phase versus frequency trace, therefore:

$$\varphi_f = \varphi_{\mathrm{m}} - 2n\pi \tag{10}$$

where

φ_f is the accumulated phase in degrees;

φ_{m} is the measured phase in degrees;

n is the number of times the measured phase has passed $-\pi$ during the measurement from the lowest frequency to the actual frequency f.

The propagation delay is calculated by applying Equation (9).

Delay skew is calculated as the difference between the measured propagation delays of the individual pairs.

4.7.5 Test report

Propagation delay and delay skew is reported at 10 MHz. Results at other frequencies shall be reported, if required in the relevant sectional specification.

4.7.6 Uncertainty

Uncertainty of reference propagation delay measurements shall be less than 2,5 ns in the range of 0 ns to 60 ns.

Uncertainty of reference delay skew measurements shall be less than 5 ns in the range of 0 ns to 600 ns.

4.8 Near-end cross-talk (NEXT) and power sum NEXT

4.8.1 Objective

The objective of this test is to determine the coupling between a signal applied at the near end of one pair to the signal received at the near end of a different pair.

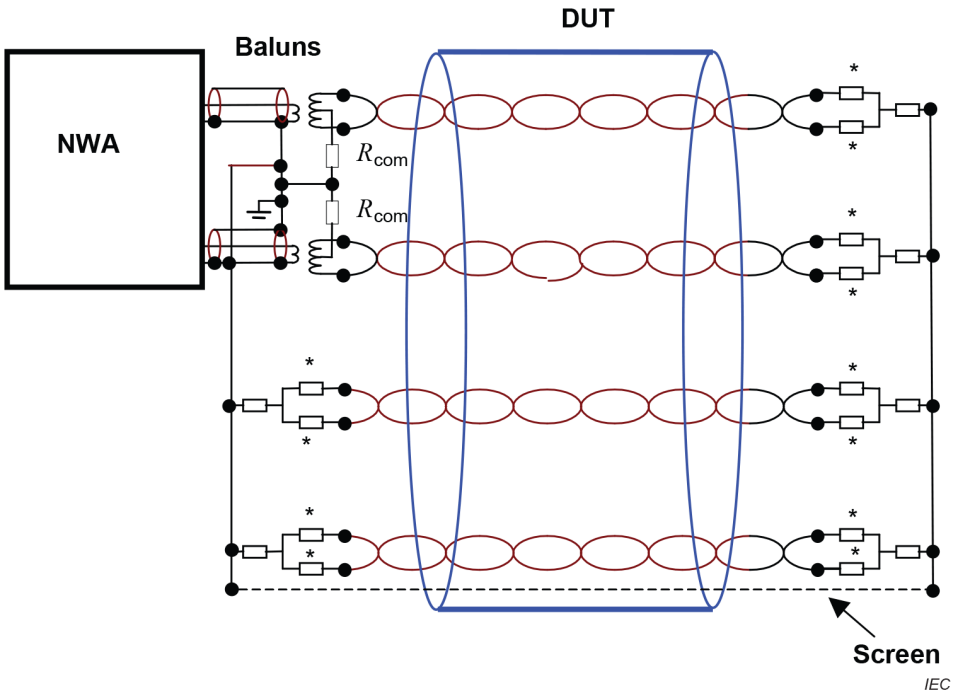
The test method is applicable to laboratory and installed cabling testing.

4.8.2 Test method

NEXT is measured by applying the signal at the near end of one pair and measuring the coupled signal at the near end of a different pair.

4.8.3 Test equipment and set-up

The general instrumentation requirements apply (see 4.2). The test configuration is shown in Figure 7 and the device under test shall be measured at the reference planes shown in Figure 2.



Key

DUT	device under test
NWA	network analyser
*	matched resistors (in pairs)
Screen	screen (if present)
R_{com}	common mode impedance
Baluns	baluns to interface laboratory equipment and balanced cabling

Figure 7 – NEXT test configuration

4.8.4 Procedure

4.8.4.1 Calibration

A transmission (S_{21}) calibration shall be performed at the reference plane.

Residual NEXT shall be determined by measuring the insertion loss between the test ports when the baluns are terminated with resistor loads according to 4.2.4. If the residual NEXT is closer than 30 dB to the measured NEXT, then isolation calibration shall be applied. The noise floor shall be measured in the same way. If the noise floor is closer than 30 dB from the measured NEXT, then the dynamic range shall be increased by increasing the test power and decreasing the measurement bandwidth, as appropriate. For cabling with high NEXT, this is not always possible, in which case the actual value of residual NEXT and noise floor shall be estimated in the calculation for uncertainty.

4.8.4.2 Measurement

Calibrated NEXT measurements of the cabling shall be performed. Each pair combination shall be measured from the near end and far end of the device under test. For four pair cabling, this is six measurements from each end, providing a total of twelve measurements. Pairs shall be terminated with loads in accordance with 4.2.4 when not under test. The loads shall comply with the requirements given in 4.2.4. The device under test shall be terminated with a connector at the far end with loads at each pair. Pairs that are not used in the measurement shall have terminations at the near end. Loads at both ends shall provide differential and common mode terminations (see Figure 7). At each end, the screens shall be connected to the common mode ground port. Measurements shall be performed in the specified frequency range. The frequency step size shall be according to 4.2.13.

4.8.4.3 Calculation

NEXT is calculated from:

$$NEXT = NEXT_{i,k} = -20\log\left|S_{21i,k}\right| \tag{11}$$

where

$NEXT_{i,k}$ is the NEXT between the disturbing pair i and the disturbed pair k in dB.

Power sum NEXT shall be calculated based on the measured NEXT values.

The power sum NEXT to disturbed pair k $PSNEXT_k$ shall be calculated over the specified frequency range from:

$$PS\,NEXT_k = -10\log\left(\sum_{i=1, i\neq k}^{n} 10^{\frac{-NEXT_{i,k}}{10}}\right) \tag{12}$$

where

$PS\ NEXT_k$ is the power sum of near-end cross-talk at the disturbed pair k in dB;

n is the number of pairs.

4.8.5 Test report

The measured results shall be reported in table or graphical format with the specification limits shown on the graphs. Results from all pair combinations shall be reported for reference measurements. It shall be explicitly noted if the measured results exceed the requirements.

4.8.6 Uncertainty

The uncertainty of reference NEXT measurements is defined to be valid at the pass/fail limit. The measurement accuracy shall be better than 1 dB at 100 MHz, 1,2 dB at 250 MHz, 2 dB at 1 000 MHz and 3 dB at 2 000 MHz. These accuracies are valid for both NEXT and power sum NEXT measurements.

NOTE If requirements for residual NEXT and noise floor cannot be achieved, the actual uncertainty can be calculated and reported (see 4.2.12).

4.9 Attenuation to crosstalk ratio, near end (ACR-N) and power sum ACR-N

4.9.1 Objective

The objective of this test is to determine the contribution to the signal-to-noise ratio from NEXT and insertion loss.

This test is applicable to laboratory and installed cabling testing.

4.9.2 Test method

NEXT and insertion loss are measured and the ACR-N is computed from the NEXT and insertion loss measurements.

4.9.3 Test equipment and set-up

Refer to 4.6 and 4.8.

4.9.4 Procedure and calculation

Refer to 4.6 and 4.8.

The ACR-N of disturbed pair k to disturbing pair i is calculated from Equation (13):

$$ACRN_{i,k} = NEXT_{i,k} - IL_k \tag{13}$$

where

$ACRN_{i,k}$ is the ACR-N for disturbing pair i and disturbed pair k;

$NEXT_{i,k}$ is the NEXT for disturbing pair i and disturbed pair k;

IL_k is the insertion loss of disturbed pair k.

Power sum ACR-N shall be calculated based on the measured power sum NEXT values.

4.9.5 Test report

The measured results shall be reported in table or graphical format with the specification limits shown on the graphs. Results from all pair combinations shall be reported for reference measurements. It shall be explicitly noted if the measured results exceed the requirements.

4.9.6 Uncertainty

The uncertainty of ACR-N measurements is the calculated summed uncertainties of insertion loss and NEXT measurements and shall be calculated as shown in 4.2.11.

4.10 Far-end cross-talk (FEXT) and power sum FEXT

4.10.1 Objective

The objective of this test is to determine the coupling between a signal applied at the near end of one pair to the signal received at the far end on a different pair.

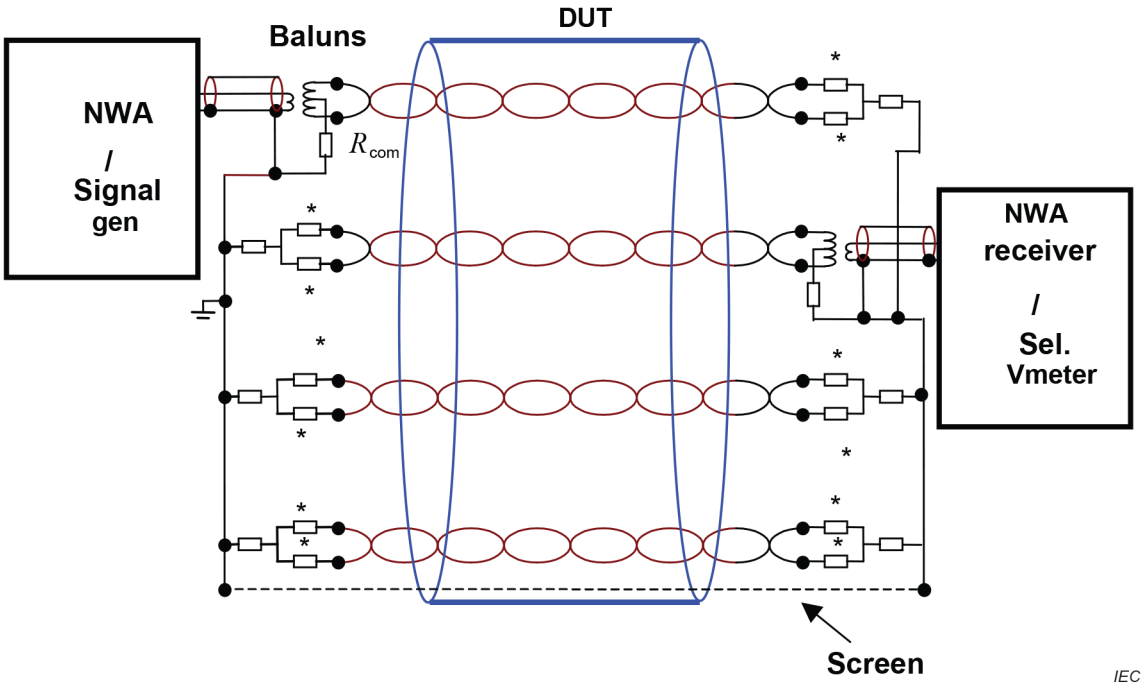
This test is applicable for cabling in a laboratory environment. If far end crosstalk has to be measured for installed cabling using laboratory equipment, then a separate generator and receiver shall be required.

4.10.2 Test method

FEXT is measured by applying the signal to the near end of one pair and measuring the coupled signal at the far end of a different pair.

4.10.3 Test equipment and set-up

The general instrumentation requirements apply (see 4.2). The test configuration is shown in Figure 8 and the device under test shall be measured at the reference planes shown in Figure 2.



Key

DUT	device under test
NWA / Signal gen	signal generator of network analyser or signal generator
NWA receiver / Sel Vmeter	receiver of network analyser or selective voltmeter
*	matched resistors (in pairs)
Screen	screen (if present)
R_{com}	common mode impedance
Baluns	baluns to interface laboratory equipment and balanced cabling

NOTE A network analyser can be used after determining that a ground connection that exists inside the network analyser between source and load does not affect the result.

Figure 8 – FEXT test configuration

4.10.4 Procedure

4.10.4.1 Calibration

The method of calibration is the same as for NEXT (see 4.8.4.1).

4.10.4.2 Measurement

FEXT measurements of the cabling shall be performed and each pair combination shall be measured. The generator shall be connected to one end of the cabling while the receiver shall be connected to the other end. It is not necessary to interchange generator and receiver as $S_{21} = S_{12}$. For four pair cabling, a total of 12 measurements are needed. Pairs shall be terminated as defined for NEXT measurements. Requirements for maximum frequency step size are also as for NEXT (see 4.2.13).

4.10.4.3 Calculation

The FEXT from disturbing pair i to disturbed pair k is calculated from:

$$FEXT_{i,k} = -20\log\left|S_{21i,k}\right| \tag{14}$$

where

$FEXT_{i,k}$ is the far-end cross-talk loss between the disturbing pair i and the disturbed pair k in dB.

Power sum FEXT shall be calculated based on the measured FEXT values.

The power sum to disturbed pair k shall be calculated over the specified frequency range.

$$PS\ FEXT_k = -10\ \log\left(\sum_{i=1, i\neq k}^{n} 10^{\frac{-FEXT_{i,k}}{10}}\right) \tag{15}$$

where

$PS\ FEXT_k$ is the power sum of far end crosstalk at the disturbed pair k in dB;

n is the number of pairs.

4.10.5 Test report

The measured results shall be reported in table or graphical format with the specification limits shown on the graphs. Results from all pair combinations shall be reported. It shall be explicitly noted if the measured results exceed the requirements.

4.10.6 Uncertainty of FEXT measurements

The uncertainty of FEXT measurements is assumed to be approximately the same as for NEXT measurements.

4.11 Attenuation to crosstalk ratio, far end (ACR-F)

4.11.1 Objective

The objective of this test is to determine ELFEXT or ACR-F by calculation from the measured insertion loss and far-end cross-talk.

This test is applicable to laboratory and installed cabling testing.

NOTE In Edition 3:2009 of IEC 61935-1, this parameter was described as: Equal level far end crosstalk (ELFEXT).

4.11.2 Calculation

ACR-F between disturbing pair i and disturbed pair k is calculated from the expressions:

$$ACR\text{-}F_{i,k} = FEXT_{i,k} - IL_k \tag{16}$$

where

$ACR\text{-}F_{i,k}$ is the computed ACR-F between disturbing pair i and disturbed pair k in dB;

$FEXT_{i,k}$ is the measured far-end cross-talk loss between disturbing pair i and disturbed pair k in dB;

IL_k is the measured insertion loss of disturbed pair k in dB.

For four pair cabling, there are 12 ACR-F results.

Power sum ACR-F to disturbed pair k is calculated from the expression:

$$PS\ ACR\text{-}F_k = PS\ FEXT_k - IL_k \tag{17}$$

where

$PS\ ACR\text{-}F_k$ is the calculated power sum ACR-F to pair k in dB;

$PS\ FEXT_k$ is power sum FEXT in dB from disturbed pair k (measured and calculated) in dB;

IL_k is the measured insertion loss in dB of the disturbed pair k.

4.11.3 Test report

See 4.9.5.

4.11.4 Uncertainty

The uncertainty ACR-F measurements are the calculated summed uncertainties of insertion loss and FEXT measurements and shall be calculated as shown in 4.2.11.

4.12 Return loss

4.12.1 Objective

The objective of this test is to measure the return loss of the cable assembly.

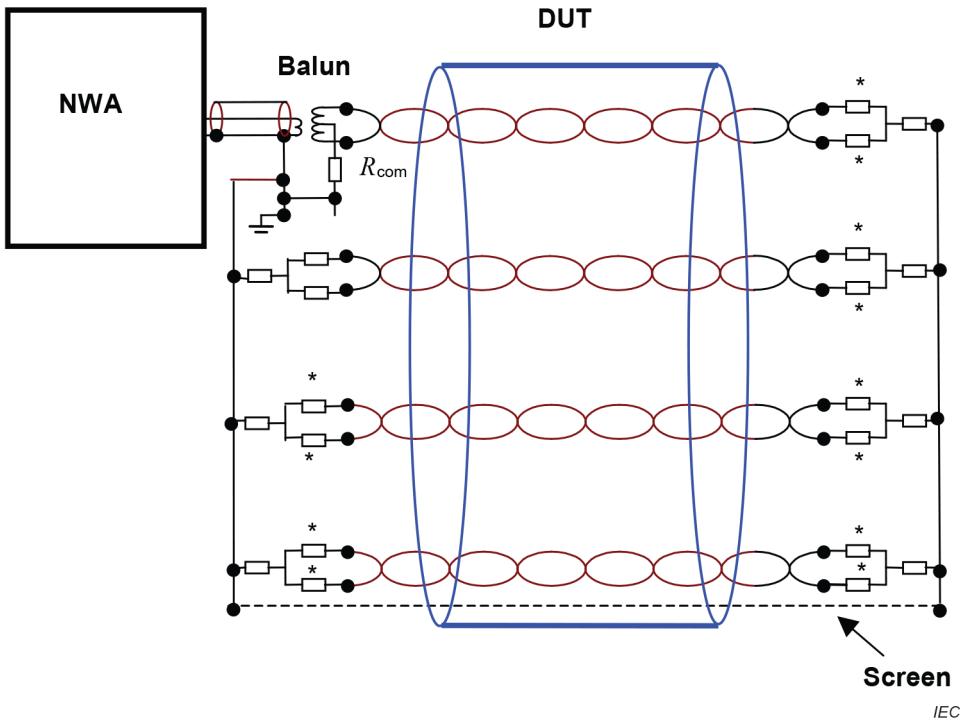
This test is applicable to cabling in a laboratory environment and for installed cabling.

4.12.2 Test method

Return loss is calculated by measuring the input impedance of the cabling, which is terminated in the far end by a load of the specified nominal impedance according to 4.2.4.

4.12.3 Test equipment and set-up

The general instrumentation requirements apply (see 4.2). The test configuration is shown in Figure 9. The device under test shall be measured at the reference planes shown in Figure 2.



Key

DUT	device under test
NWA	network analyser with S-parameter test set
*	matched resistors (in pairs)
Screen	screen (if present)
R_{com}	common mode impedance (optional in return loss tests)
Balun	balun to interface laboratory equipment and balanced cabling

Figure 9 – Return loss test configuration

4.12.4 Procedure

4.12.4.1 Calibration

A full one port (S_{11}) calibration shall be performed at the reference plane.

4.12.4.2 Measurement

Each pair shall be measured. The far end of the cabling shall be terminated with loads according to 4.2.4, which are integrated into a connector, which mates with the far end connector of the cabling. The loads shall comply with the requirements given in 4.2.4. The frequency step size shall be according to 4.2.13. Return loss for both ends of the cabling shall be measured.

4.12.5 Test report

The measured results shall be reported in tabular or graphical format with the specification limits shown on the graphs. Results from all pairs shall be reported.

4.12.6 Uncertainty

The uncertainty is specified at the performance limit (the pass/fail limit).

The uncertainty of return loss measurements shall be better than 1 dB up to 250 MHz, 2 dB up to 1 000 MHz and 3 dB up to 2 000 MHz.

NOTE The accuracy of the reference load used for calibration is the dominant error source.

4.13 PS alien near end crosstalk (PS ANEXT – Exogenous crosstalk)

4.13.1 Objective

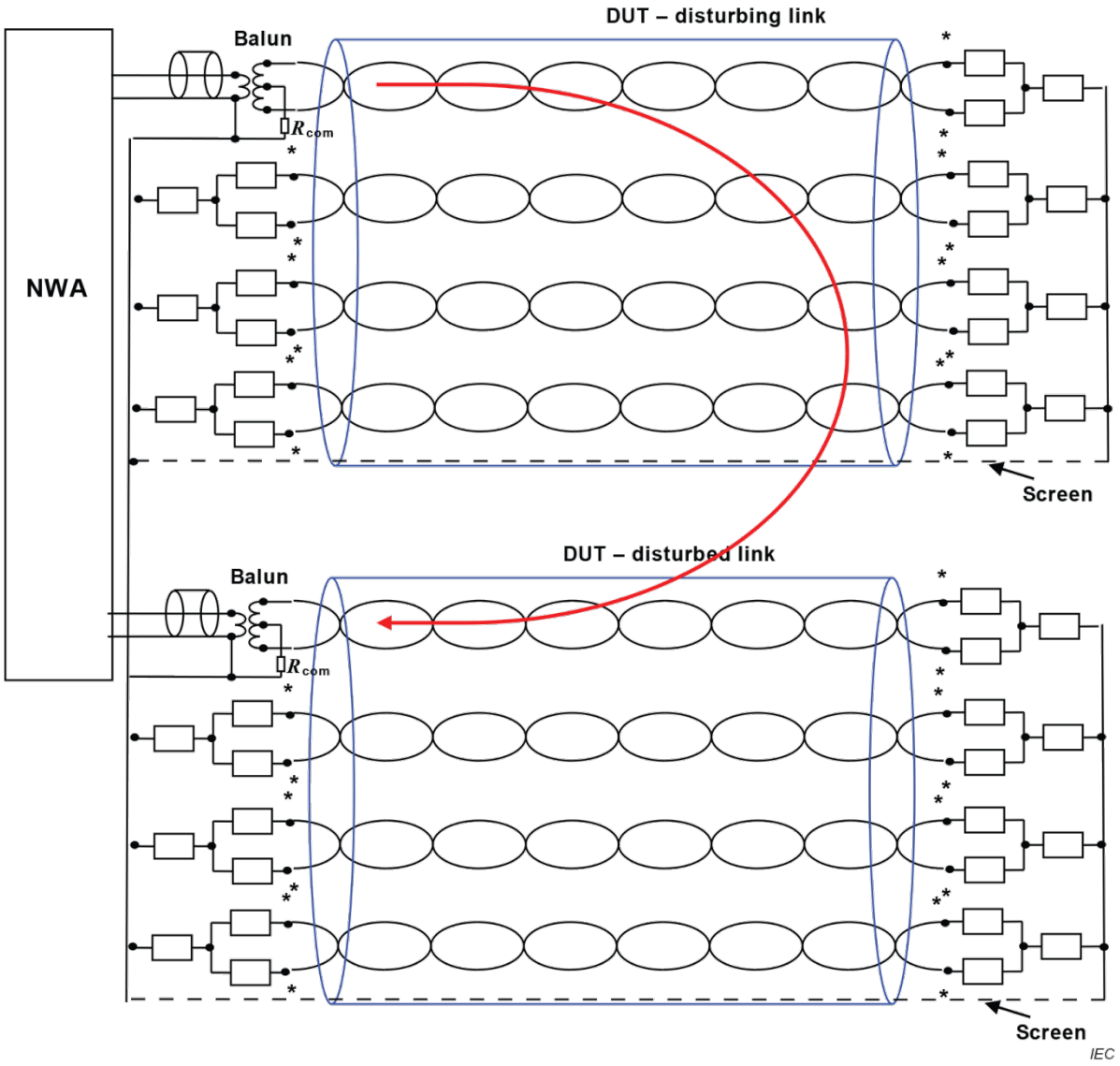
The objective of this test is to determine the PS ANEXT of the cabling. This test is applicable to cabling in a laboratory environment and for installed cabling. A sample laboratory reference measurement assembly is described in Annex B.

4.13.2 Test method

ANEXT contributions to an overall PS ANEXT are measured by applying the signal at the near end to one pair to a disturbing link and measuring the coupled signal at the near end of a pair in a disturbed link. This process is repeated for every pair in a disturbing link and for all other links in close proximity. The PS ANEXT for each pair in a disturbed link is obtained by power summing the ANEXT results to that pair from all pairs in disturbing links in close proximity.

4.13.3 Test equipment and set-up

The test configuration for an alien near end crosstalk measurement is shown in Figure 10. The cabling under test shall be measured at the reference planes shown in Figure 2.



Key

DUT – disturbing link	device under test – disturbing link
DUT – disturbed link	device under test – disturbed link
NWA	network analyser
*	matched resistors (in pairs)
Screen	screen (if present)
R_{com}	common mode impedance
Balun	balun to interface laboratory equipment and balanced cabling

Figure 10 – ANEXT measurement

4.13.4 Procedure

4.13.4.1 Calibration

A transmission (S_{21}) calibration shall be performed at the reference plane.

The noise floor of the measurement can affect the results substantially. If the noise floor is closer than 30 dB from the measured ANEXT, then the dynamic range should be increased by increasing the test power and decreasing the measurement bandwidth, as appropriate. For

cabling with high ANEXT this is not always possible, in which case the actual value of noise floor shall be estimated in the calculation of a corrected results or measurement uncertainty, see E.2.6.6.

4.13.4.2 Measurement

Calibrated ANEXT measurements of the cabling shall be performed. For each pair, the ANEXT from every pair of a disturbing link in close proximity shall be measured. For each disturbing to disturbed link there are 16 pair combinations (4 pairs of a disturbing link are coupled to each 4 pairs of the disturbed link). Therefore the number of alien crosstalk measurements to be made is 16x the number of disturbing links. Each pair combination shall be measured from the near end and far end of the cabling under test.

For the reference laboratory test configuration described in Annex B, there are a minimum of 6 disturbing channels around a single disturbed channel. A full characterization therefore consists of a minimum of two 96 pair combination alien NEXT measurements. For sampling test strategies of installed cabling, refer to E.2.7.

Baluns provide the interface to the cabling under test. All pairs of the disturbed and disturbing link not directly connected to the baluns shall be terminated with loads according to 4.2.4. The loads shall comply with the requirements given in 4.2.4. Loads at both ends shall provide differential and common mode terminations; see Figure 10. At each end, the common mode resistors of the terminations and the screens, if applicable, shall be connected to the common mode ground port. Measurements shall be performed in the specified frequency range. The frequency step size shall be according to 4.2.13.

4.13.4.3 Calculation

The PS ANEXT frequency response of pair k of a disturbed channel is computed per Equation (18).

$$PS\ ANEXT_k(f) = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{n} 10^{\frac{-\left(ANEXT_{k,i,j}(f)\right)}{10}}\right) \quad (18)$$

where

$PS\ ANEXT_k(f)$ is the computed PS ANEXT to pair k as a function of frequency f in dB;

f is the frequency;

k is the number of the disturbed pair (in a disturbed channel);

i is the number of a disturbing pair (in a disturbing channel);

j is the number of a disturbing channel;

N is the total number of disturbing channels;

n is the total number of disturbing pairs (4) in each of N disturbing channels;

$ANEXT_{k,i,j}(f)$ is the frequency response of the ANEXT coupled from pair i of disturbing channel j into pair k of the disturbed channel in dB.

NOTE Pairs external to the disturbed channel are all those pairs surrounding the channel that belong to other disturbing channels in close proximity that could disturb the disturbed channel.

The average PS ANEXT frequency response in dB of all pairs is computed by averaging the values of each pair expressed in dB as in Equation (19).

$$PS\ ANEXT_{\text{avg}}(f) = \frac{1}{4}\sum_{k=1}^{4} PS\ ANEXT_k(f) \quad (19)$$

4.13.4.4 Test report

The measured results shall be reported in table or graphical format with the specification limits shown on the graphs. Results from all pair combinations shall be reported for reference measurements. It shall be explicitly noted if the measured results exceed the requirements.

4.13.4.5 Uncertainty

The uncertainty of reference PS ANEXT measurements is defined to be valid at the pass/fail limit. The error equations as in 6.11 are applicable, except that the random noise error contribution degrades 3 dB for every doubling of the number of ANEXT measurements that are included in the overall power sum result.

4.14 PS attenuation to alien crosstalk ratio, far end crosstalk (PS AACR-F – Exogenous crosstalk)

4.14.1 Objective

The objective of this test is to measure the power sum attenuation to alien crosstalk ratio, far end of the cable assembly. This test is applicable to cabling in a laboratory environment and installed cabling. If far end crosstalk has to be measured for installed cabling using laboratory equipment then a separate generator and receiver shall be required.

A sample laboratory reference measurement assembly is described in Annex B.

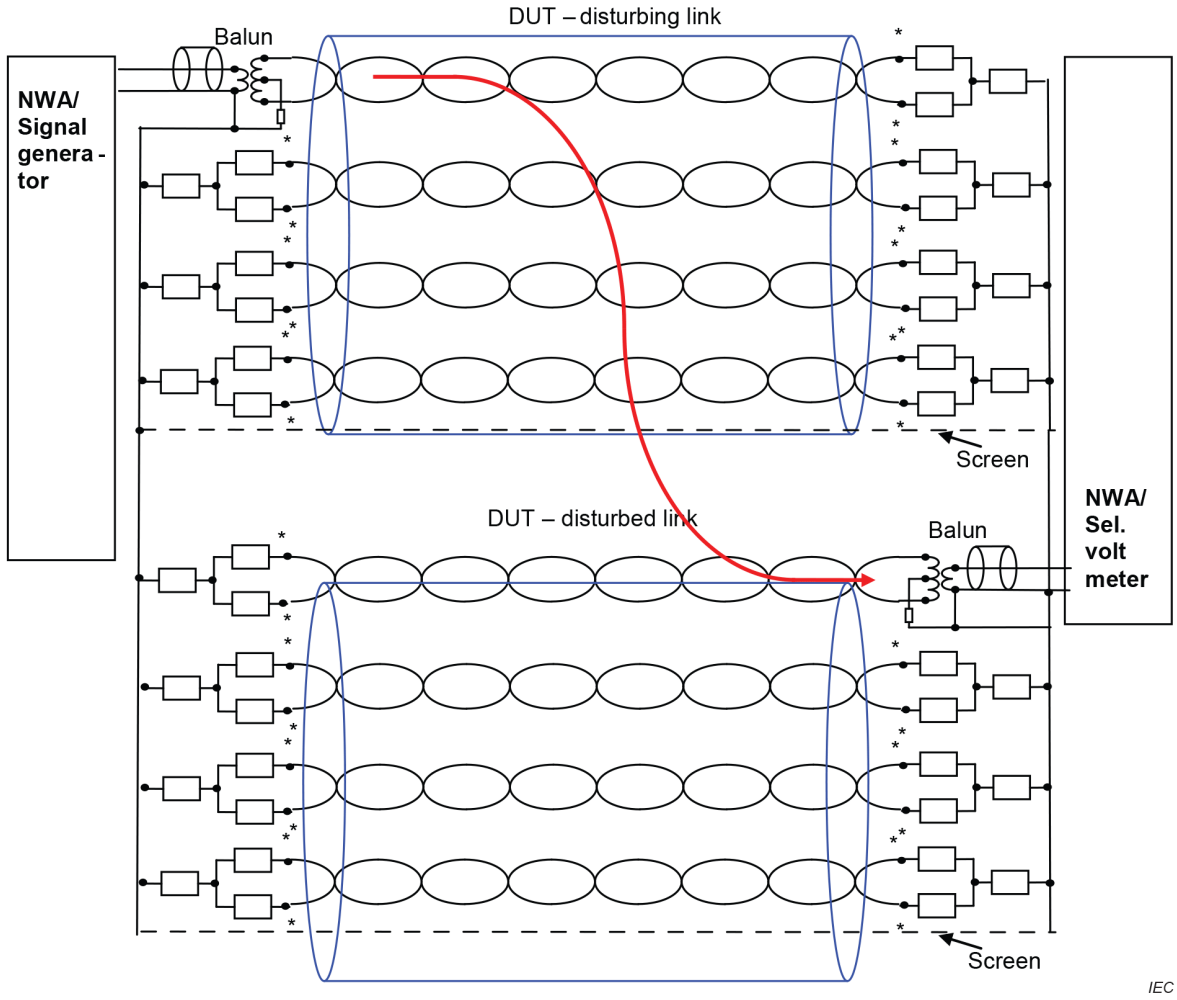
4.14.2 Test method

Far end alien crosstalk contributions to an overall PS AFEXT are measured by applying the signal at the near end to one pair to a disturbing channel or link and measuring the coupled signal at the far end of a pair in a disturbed channel or link. This process is repeated for every pair in a disturbing link and for all links in close proximity.

A normalization, which is dependent on the relative length of disturbing and disturbed links is applied to each AFEXT measurement. Then the PS AFEXT for each pair in a disturbed channel or link is obtained by power summing the normalized far end alien crosstalk results to that pair from all pairs in disturbing links in close proximity.

4.14.3 Test equipment and set-up

The test configuration for an alien far end crosstalk measurement is shown in Figure 11. The cabling under test shall be measured at the reference planes shown in Figure 2.



Key

DUT – disturbing link	device under test – disturbing link
DUT – disturbed link	device under test – disturbed link
NWA/Signal generator	signal generator of network analyser or signal generator
NWA/Sel. voltmeter	receiver of network analyser or selective voltmeter
*	matched resistors (in pairs)
Screen	screen (if present)
R_{com}	common mode impedance
Balun	balun to interface laboratory equipment and balanced cabling

Figure 11 – Alien far end crosstalk measurement

A network analyser may be used after determining that a ground connection that exists inside the network analyser between source and load does not affect the result.

4.14.4 Procedure

4.14.4.1 Calibration

A transmission (S_{21}) calibration shall be performed at the reference plane.

The noise floor of the measurement can affect the results substantially. If the noise floor is closer than 30 dB from the measured AFEXT, then the dynamic range should be increased by increasing the test power and decreasing the measurement bandwidth, as appropriate. For cabling with high AFEXT this is not always possible, in which case the actual value of noise

floor shall be estimated in the calculation of a corrected results or measurement uncertainty; see E.2.6.6.

4.14.4.2 Measurement

Calibrated AFEXT measurements of the cabling shall be performed and each pair combination shall be measured. The generator shall be connected to one end of the cabling while the receiver shall be connected to the other end. It is not necessary to interchange generator and receiver as $S_{21} = S_{12}$. For four pair cabling, a total of 12 measurements are needed. Pairs shall be terminated as defined for NEXT measurements. Requirements for maximum frequency step size are also as for NEXT (see 4.8.4.2).

For each pair, the AFEXT from every pair of a disturbing link in close proximity shall be measured. For each disturbing to disturbed link there are 16 pair combinations (4 pairs of a disturbing link couple to each 4 pairs of the disturbed link). Therefore the number of alien crosstalk measurements to be made is 16x the number of disturbing links. Each pair combination shall be measured from the near end and far end of the cabling under test.

For the reference laboratory test configuration described in Annex B, there are a minimum of 6 disturbing channels around a single disturbed channel. A full characterization therefore consists of a minimum of 2 × 96 pair combination AFEXT measurements. For sampling test strategies of installed cabling, refer to 5.4.8.

Baluns provide the interface to the cabling under test. All pairs of the disturbed and disturbing link not directly connected to the baluns shall be terminated with loads according to 4.2.4. The loads shall comply with the requirements given in 4.2.4. Loads at both ends shall provide differential and common mode terminations, see Figure 11. At each end, the common mode resistors of the terminations and the screens, if applicable, shall be connected to the common mode ground port. Measurements shall be performed in the specified frequency range. The frequency step size shall be according to 4.2.13.

4.14.4.3 Calculation of PS AACR-F from AFEXT and insertion loss measurements

The measured alien FEXT values of a pair k in a disturbed link from the disturbing link j shall be normalized by the difference of the insertion losses of disturbing and disturbed links and a length scaling term as in Equations (20) and (21).

If $IL_k(f) - IL_{i,j}(f) > 0$ then:

$$AFEXT_{\text{norm}k,i,j}(f) = AFEXT_{k,i,j}(f) + IL_k(f) - IL_{i,j}(f) - 10\log\left(\frac{IL_k(f)}{IL_{i,j}(f)}\right) \quad (20)$$

Otherwise

$$AFEXT_{\text{norm}k,i,j}(f) = AFEXT_{k,i,j}(f) \quad (21)$$

where

f is the frequency;

k is the number of the disturbed pair in a disturbed link;

i is the number of a disturbing pair in a disturbing link;

j is the number of a disturbing link;

$AFEXT_{k,i,j}(f)$ is frequency response of the measured AFEXT in dB to pair k of the disturbed link from pair i in disturbing link j.

$IL_k(f)$ is the measured frequency response of the insertion loss in dB of pair k of the disturbed link. Practically, the average response in dB of all pairs may be used. In the ratio to $IL_{i,j}(f)$, the average insertion loss at 250 MHz may be used.

$IL_{i,j}(f)$ is the measured frequency response of the insertion loss in dB of pair i of disturbing link j. Practically, the average response in dB of all pairs may be used. In the ratio relative to $IL_k(f)$, the average insertion loss at 250 MHz may be used.

For screened cabling meeting coupling attenuation requirements in ISO/IEC 11801-1, the result of Equation (25) shall be used in all cases.

The frequency response of the power sum alien FEXT of pair k $\mathrm{PSAFEXT}_k(f)$ of a disturbed channel is computed per Equation (22).

$$PS\ AFEXT_k(f) = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{n} 10^{\frac{-\left(AFEXT_{\mathrm{norm}k,i,j}(f)\right)}{10}}\right) \quad (22)$$

where

n is the number of pairs in disturbing channel j;

N is the total number if disturbing channels.

The PS AACR-F frequency response to disturbed pair k in dB of pair k of a disturbed link is computed per Equation (23).

$$PS\ AACRF_k(f) = PS\ AFEXT_k(f) - IL_{\mathrm{avg}}(f) \quad (23)$$

where

$PS\ AACRF_k(f)$ is the computed PS AACR-F to pair k in dB;

f is the frequency;

k is the number of the disturbed pair;

$IL_{\mathrm{avg}}(f)$ is the frequency response of the average insertion loss of all pairs expressed in dB.

When required, it shall be measured according to 4.6.

The frequency response of the average insertion loss is computed per Equation (24).

$$IL_{\mathrm{avg}}(f) = \frac{1}{4}\sum_{n=1}^{4} IL_n(f) \quad (24)$$

NOTE Pairs external to the disturbed channel are all those pairs surrounding the channel that belong to other disturbing channels in close proximity that could disturb the disturbed channel.

The frequency response of the average PS AFEXT of all pairs is computed by averaging the values of each pair expressed in dB as in Equation (25).

$$PS\ AFEXT_{\text{avg}}(f) = \frac{1}{4} \sum_{k=1}^{4} PS\ AFEXT_k(f) \tag{25}$$

The frequency response of the average PS AACR-F in dB is computed per Equation (26):

$$PS\ AACRF_{\text{avg}}(f) = PS\ AFEXT_{\text{avg}}(f) - IL_{\text{avg}}(f) \tag{26}$$

where

$PS\ AACRF_{\text{avg}}(f)$ is the computed average PS AACR-F in dB.

4.14.4.4 Test report

The measured results shall be reported in table or graphical format with the specification limits shown on the graphs. Results from all pair combinations shall be reported for reference measurements. It shall be explicitly noted if the measured results exceed the requirements.

4.14.4.5 Uncertainty

The uncertainty of reference PS AACR-F measurements is defined to be valid at the pass/fail limit. The error equations, as in 6.11.7, are applicable, except that the random noise error contribution degrades 3 dB for every doubling of the number of alien FEXT measurements that are included in the overall power sum result.

4.15 Unbalance attenuation, near end

4.15.1 Objective

The objective of this test is to measure the unbalance attenuation, near end of the cable assembly. This parameter is the same as the transfer conversion loss (TCL) and longitudinal conversion loss (LCL).

This test is applicable to cabling in a laboratory environment. For installed cabling testing of unbalance attenuation, see IEC 61935-1-1

4.15.2 Test method

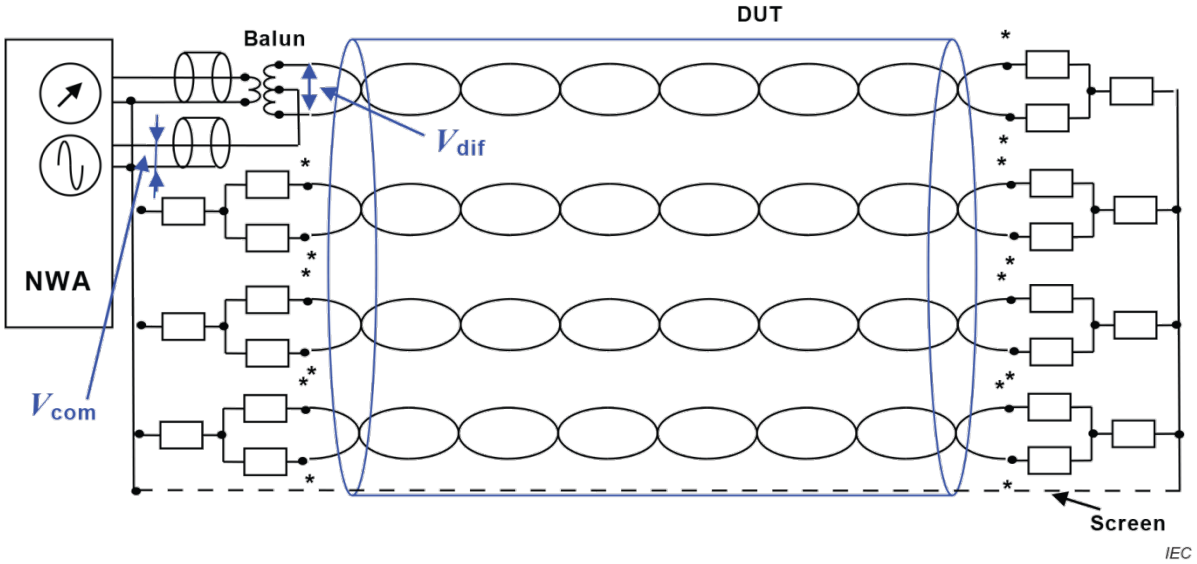
Unbalance attenuation, near end or TCL is measured by calculating the ratio of differential mode power to common mode power on a pair within a cabling system, which is exited with differential mode power only.

The differential mode voltage V_{dif} and common mode voltage V_{com} are shown in Figure 12.

4.15.3 Test equipment and set-up

The test configuration using baluns in the measurement is described in detail. Multi-port network analysers can provide measurements of node voltages that are all referenced to the measurement ground. This avoids the use of baluns and may provide higher unbalance attenuation measurement accuracies at high frequencies.

The general instrumentation requirements apply; see 4.2. The test configuration is shown in Figure 12. The cabling under test shall be measured at the reference planes shown in 4.2.6.



Key

DUT	device under test
NWA	network analyser with S-parameter test set
*	matched resistors (in pairs)
Screen	screen (if present)
Balun	balun to interface laboratory equipment and balanced cabling
V_{dif}	differential mode voltage
V_{com}	common mode voltage

Figure 12 – Unbalance attenuation, near end test configuration

4.15.4 Procedure

4.15.4.1 Calibration

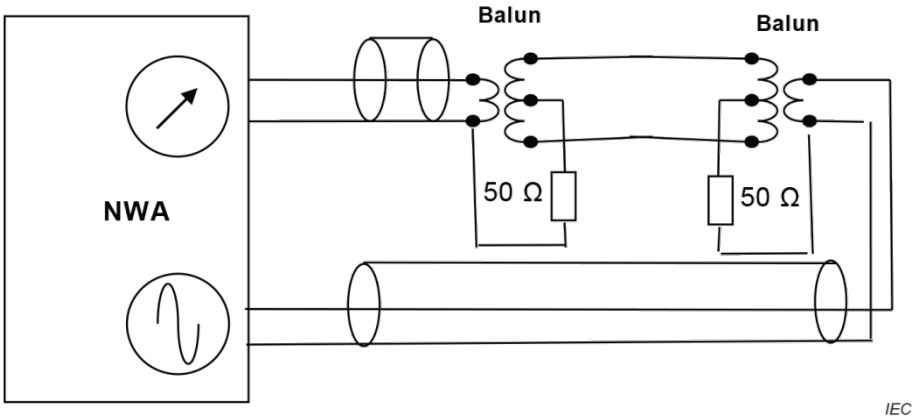
When using a balun based reference tests setup, TCL calibration is performed in four steps, as follows:

Step 1.

The coaxial test leads attached to the network analyser are calibrated out by performing through measurements at the point of termination to the balun.

Step 2.

The insertion loss 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 13. 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 coaxial sockets for the common mode signals are terminated with 50 Ω. The measured insertion loss between the coaxial sockets for the differential signals is divided by 2 to approximate the insertion loss of one balun for a differential mode signal. The calculated differential mode insertion loss is recorded as $IL_{bal,DM}$.



Key

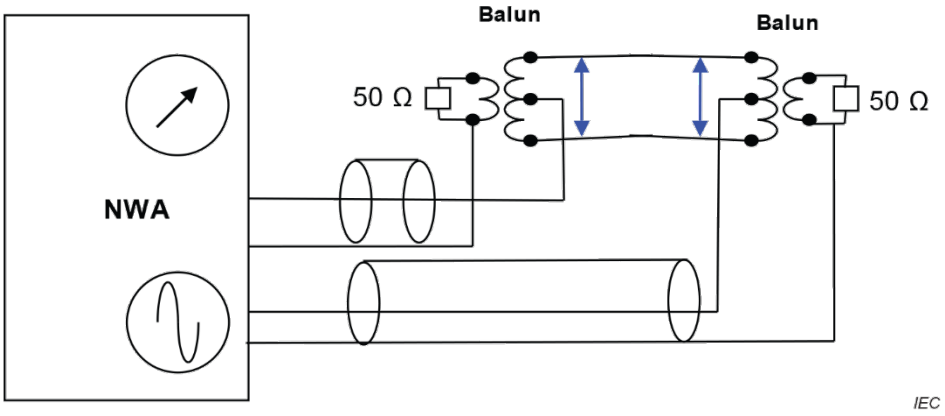
NWA network analyser with S-parameter test set

Balun balun to interface laboratory equipment and balanced cabling

Figure 13 – Back-to-back balun differential mode insertion loss measurement

Step 3.

The insertion loss of the common mode signals of the test balun is measured as shown in Figure 14. The coaxial sockets for the differential signals are terminated with 50 Ω. The measured insertion loss between the coaxial sockets for common mode signals is divided by 2 to approximate the insertion loss of one balun for a common mode signal. The calculated common mode insertion loss is recorded as $IL_{\text{bal,CM}}$.



Key

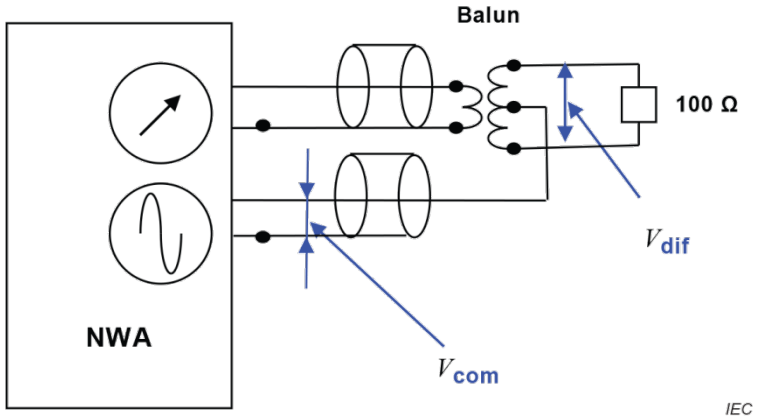
NWA network analyser with S-parameter test set

Balun balun to interface laboratory equipment and balanced cabling

Figure 14 – Back-to-back balun common mode insertion loss measurement

Step 4.

A TCL measurement performance step shall be performed on the measurement balun by itself by terminating the differential port of the balun with a 100 Ω RF chip resistor. See Figure 15. If the internal unbalance attenuation is within 6 dB of the pass/fail limit of the unbalance test, then the TCL measurement performance is inadequate and higher performing measurement equipment shall be used. The method to compute the TCL is shown in 4.15.4.2.



Key

NWA	network analyser with S-parameter test set
Balun	balun to interface laboratory equipment and balanced cabling
V_{dif}	differential mode voltage
V_{com}	common mode voltage

Figure 15 – Unbalance performance test of the measurement balun

When using other types of test equipment e.g. balunless, other calibration techniques should be applied.

4.15.4.2 Balun measurement

Each pair shall be measured from each end of the DUT. The far end of the cabling shall be terminated with loads according to 4.2.4, which are integrated into a connector, which mates with the far end connector of the cabling. The near end pairs not under test shall be terminated either with resistor loads according to 4.2.4 or with balun terminations (the unbalanced and common mode connectors on the balun shall be terminated with 50 Ω coaxial loads). The termination of the pairs not under test provides return path for the common mode signal for unscreened systems. For screened systems, the screen provides this path as well.

Unbalance attenuation near end (or TCL) is calculated using Equation (27):

$$TCL = IL_{\text{meas},TCL} - IL_{\text{bal,DM}} - IL_{\text{bal,CM}} \quad (27)$$

where

TCL	is the computed unbalance attenuation near end in dB;
$IL_{\text{meas},TCL}$	is the measured loss (S_{21}) in dB;
$IL_{\text{bal,DM}}$	is the insertion loss of balun for differential mode signals in dB;
$IL_{\text{bal,CM}}$	is the insertion loss of balun for common mode signals in dB.

4.15.4.3 Balunless measurement

For balunless measurements, refer to IEC TR 61156-1-2:2009/AMD1:2014.

4.15.5 Test report

The measured results shall be reported in tabular or graphical format with the specification limits shown on the graphs. Results from all pairs shall be reported.

4.15.6 Uncertainty

The uncertainty is dependent upon the difference of the measured result and the internal unbalance attenuation of the balun (other contributions to the uncertainty are disregarded). See Table 3.

Table 3 – Estimated uncertainty of unbalance, near end measurement

Difference between measured unbalance attenuation and unbalance attenuation of balun by itself	Estimated uncertainty
30 dB	0,3 dB
20 dB	0,8 dB
10 dB	2,4 dB
6 dB	3,5 dB

4.16 Unbalance attenuation, far end

4.16.1 Objective

The objective of this test is to measure the unbalance attenuation, far end of the cable assembly. This measured parameter is used to compute the equal level transverse conversion transfer loss (ELTCTL) from the measured unbalance attenuation, far end and the insertion loss of the pair under test. Requirements for ELTCTL are specified in cabling standards.

This test is applicable to cabling in a laboratory environment. For installed cabling testing of unbalance attenuation, see IEC 61935-1-1.

4.16.2 Test method

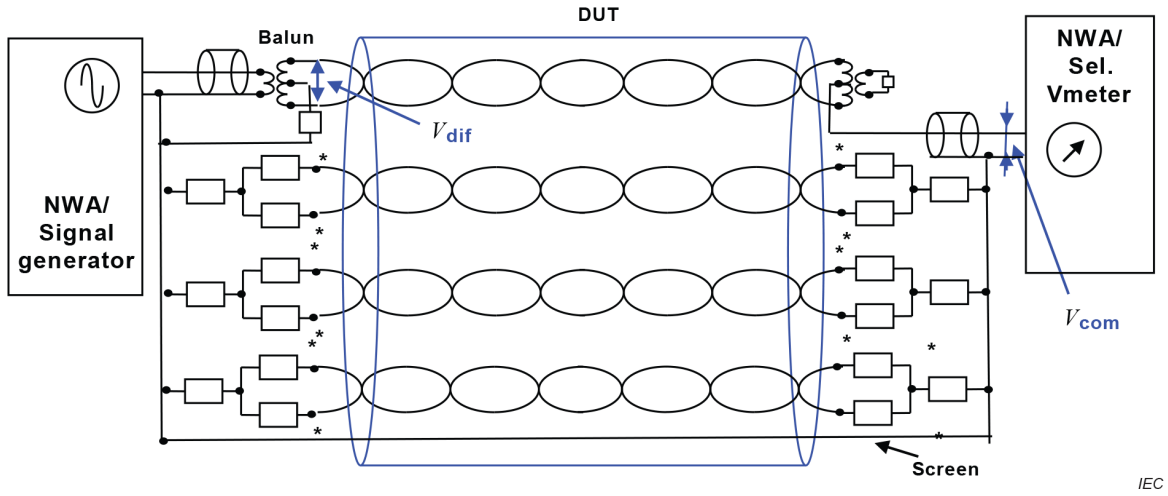
Unbalance attenuation, far end or ELTCTL is measured by calculating the ratio of differential mode power to common mode power in a cabling system, which is exited with differential mode power only. This value is the TCTL. The ELTCTL is obtained by subtracting the insertion loss of the DUT from TCTL. The calculation is based on measured ratio between differential and common mode voltage.

4.16.3 Test equipment and set-up

If both ends of the DUT are in close proximity, a network analyser can be used for the TCTL measurement. If the ends of the DUT are not in close proximity, which is common for installed cabling, a signal generator and selective RF voltmeter is used.

The test configuration using baluns in the measurement is described in detail. Multi-port network analysers can provide measurements of node voltages that are all referenced to the measurement ground. This avoids the use of baluns and may provide higher unbalance attenuation measurement accuracies at high frequencies.

The general instrumentation requirements apply; see 4.2. The test configuration is shown in Figure 16. The cabling under test shall be measured at the reference planes shown in 4.2.6.



Key

DUT	device under test
NWA/Signal generator	network analyser with S-parameter test set, signal port or a signal generator
NWA/Selective voltmeter	network analyser with S-parameter test set, load port or a selective RF voltmeter
*	matched resistors (in pairs)
Screen	screen (if present)
Balun	balun to interface laboratory equipment and balanced cabling
V_{dif}	differential mode voltage
V_{com}	common mode voltage

Figure 16 – Unbalance attenuation far end test configuration

4.16.4 Procedure

4.16.4.1 Calibration

The calibration for TCTL measurements shall follow the procedure outlined in 4.15.4.1 for both baluns being used in the measurement and the calibration values should be recorded as $IL_{\text{bal,DM1}}$, $IL_{\text{bal,DM2}}$, $IL_{\text{bal,CM1}}$, and $IL_{\text{bal,CM2}}$.

4.16.4.2 Measurement

Each pair shall be measured from both ends of the cabling. Two ends of the same DUT pair shall be connected to the differential terminals of the test baluns as shown in Figure 16. The test signal shall be applied to the unbalanced input of the balun connected to the input end of the pair under test. The common mode port of the balanced output terminals at the input end shall be terminated with 50 Ω coaxial load. The signal to be measured is at the common mode terminal of the balun which is connected to the output end of the pair under test. The unbalanced output terminal of the balun at the far end shall be terminated with a 50 Ω coaxial load resistor. All unused pairs on both ends of the DUT shall be terminated with 100 Ω differential and 50 Ω common mode resistor terminations according to 4.2.4. There shall be a common ground at each end. If a network analyser is used, the grounds of the two ends of the DUT shall be connected securely to the same ground plane. The termination of the pairs not under test provides return path for the common mode signal for unscreened systems. For screened systems, the screen provides this path as well.

Unbalance attenuation far end (or TCTL) is calculated using Equation (28).

$$TCTL = IL_{\text{meas},TCTL} - IL_{\text{bal,DM1}} - IL_{\text{bal,CM2}} \quad (28)$$

where

$TCTL$ is the computed TCTL in dB;

$IL_{\text{meas},TCTL}$ is the measured loss (S_{21}) in dB;

$IL_{\text{bal,DM1}}$ is the insertion loss of the input balun for differential mode signals in dB;

$IL_{\text{bal,CM2}}$ is the insertion loss of the output balun for common mode signals in dB.

The ELTCTL is computed as in Equation (29).

$$ELTCTL = TCTL - IL_{\text{DUT}} \tag{29}$$

where

$ELTCTL$ is the computed ELTCTL in dB;

IL_{DUT} is the measured insertion loss of the device under test.

4.16.5 Test report

The measured results shall be reported in tabular or graphical format with the specification limits shown on the graphs. Results from all pairs shall be reported.

4.16.6 Uncertainty

The uncertainty is dependent upon the difference of the measured result and the internal unbalance attenuation of the baluns (other contributions to the uncertainty are disregarded); see Table 4.

Table 4 – Estimated uncertainty of unbalance, far end measurement

Difference between measured unbalance attenuation and unbalance attenuation of balun	Estimated uncertainty
30 dB	0,3 dB
20 dB	0,8 dB
10 dB	2,4 dB
6 dB	3,5 dB

4.17 Coupling attenuation

Coupling attenuation measurements shall be conducted as per IEC 62153-4-9 or IEC 62153-4-11 in the laboratory environment and IEC 62153-4-14 in the field environment.

5 Field test measurement requirements for electrical properties

5.1 Introductory remark

Clause 5 applies to field test specifications for post-installation performance measurements of installed cabling designed in accordance with ISO/IEC 11801-1 (or equivalent).

The information contained in clause 5 uses the links and channels defined in ISO/IEC 11801-1 (or equivalent), and specifies parameters for field testers, test methods and interpretations of test results, leading to a practical solution to the issues related to field testing. Classes of twisted pair cabling links referred to herein correspond with those described in ISO/IEC 11801-1 (or equivalent).

Field test equipment is classified by performance level. Currently, levels I, II, IIE, III, IIIE, IV, V, and VI are used in the industry. Clause 5 specifies requirements for field test equipment used to certify class D, E, E_A, F, F_A, I and II cabling as defined in ISO/IEC 11801-1.

– Level IIE test equipment or better is required to test class D cabling.
– Level III test equipment or better is required to test class E cabling.
– Level IIIE test equipment or better is required to test class E_A cabling.
– Level IV test equipment or better is required to test class F cabling.
– Level V test equipment or better is required to test class F_A cabling.
– Level VI test equipment or better is required to test Class I and II cabling.

Clause 5 specifies in detail the electrical characteristics of field test equipment and test methods. Field test equipment characteristics needed for swept/stepped frequency measurements are described to ensure consistent and accurate measurements. Other methods using frequency domain or time domain measurement techniques that demonstrate equivalence to the requirements in Clause 5 are acceptable. Methods to compare results reported by field test equipment with those obtained using laboratory methods are also described.

Users of this document are advised to consult with applications standards, equipment manufacturers and system integrators to determine the suitability of these requirements for specific networking applications.

5.2 Cabling configurations tested

The cabling test configurations are described in 4.2.6.

5.3 Field test parameters

5.3.1 General

The following field test measurement parameters and measurement requirements are specified in this document:

– inspection of workmanship and connectivity testing;
– propagation delay;
– delay skew;
– length (not a pass/fail requirement parameter per ISO/IEC 11801-1);
– insertion loss;
– near-end crosstalk (NEXT) loss;
– NEXT, power sum;
– attenuation-to-crosstalk ratio, near end (ACR-N);
– ACR-N, power sum (PS ACR-N);
– attenuation-to-crosstalk ratio, far end (ACR-F);
– attenuation-to-crosstalk ratio, far end (PS ACR-F), power sum;
– return loss;
– DC loop resistance;

– power sum alien NEXT (PS ANEXT);

– power sum attenuation-to-alien crosstalk ratio, far end (PS AACR-F).

Other parameters may be tested in the field as specified by the installation agreement (such as ISO/IEC 14763-1), however are not covered by this document.

Refer to Annex C for general information on power sum alien crosstalk performance of installations.

5.3.2 Optional field test parameters

The following field test measurement parameters are specified as optional by ISO/IEC 11801-1 and requirements for field test of their measurement are specified according to Table 5.

Table 5 – Optional field test parameter measurement requirements

Measurement parameter	Requirement provided by
TCL ELTCTL	IEC 61935-1-1
Resistance unbalance Resistance unbalance between pairs	IEC 61935-1-2
Coupling attenuation	IEC 62153-4-14

5.3.3 Inspection of workmanship and connectivity testing

5.3.3.1 Visual inspection

Visual inspection of installed cabling is performed by observing that

– the condition, workmanship and finish are satisfactory;

– the marking is legible;

– mechanical damage is absent and there is no undesired movement or displacement of parts;

– flaking of materials or finishes is absent.

Examination may generally be carried out without any magnification.

5.3.3.2 Wire map

A conductor map test is intended to verify correct pin termination at each end and to check for installation connectivity errors. For each of the conductors in the cable, and the screen(s), if any, the conductor map indicates

– continuity to the remote end;

– shorts between any two or more conductors/screen(s);

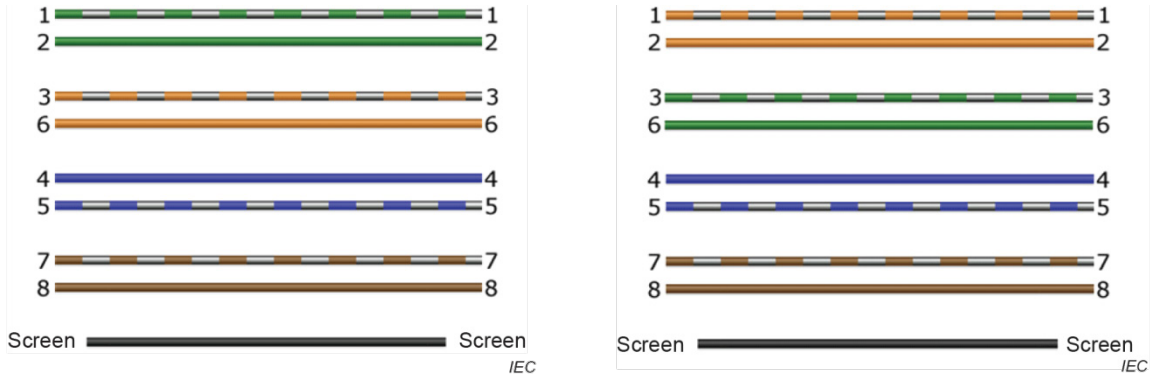
– transposed pairs;

– reversed pairs;

– split pairs;

– any other connection errors.

Correct connectivity of telecommunications outlet/connectors is defined in ISO/IEC 11801-1 (or equivalent), and is illustrated in Figure 17 (for four pair cables).



a) TIA568A **b) TIA568B**

Figure 17 – Correct pairing

A reversed pair occurs when the polarity of one pair is reversed at one end of the link (also called a Tip/Ring reversal). See Figure 18a for an illustration of a reversed pair.

A transposed pair occurs when the two conductors in a pair are connected to the position for a different pair at the remote connection. See Figure 18b for an illustration of transposed pairs.

NOTE Transposed pairs are sometimes referred to as crossed pairs.

Split pairs occur when pin to pin continuity is maintained but physical pairs are separated. See Figure 18c for an illustration of split pairs.

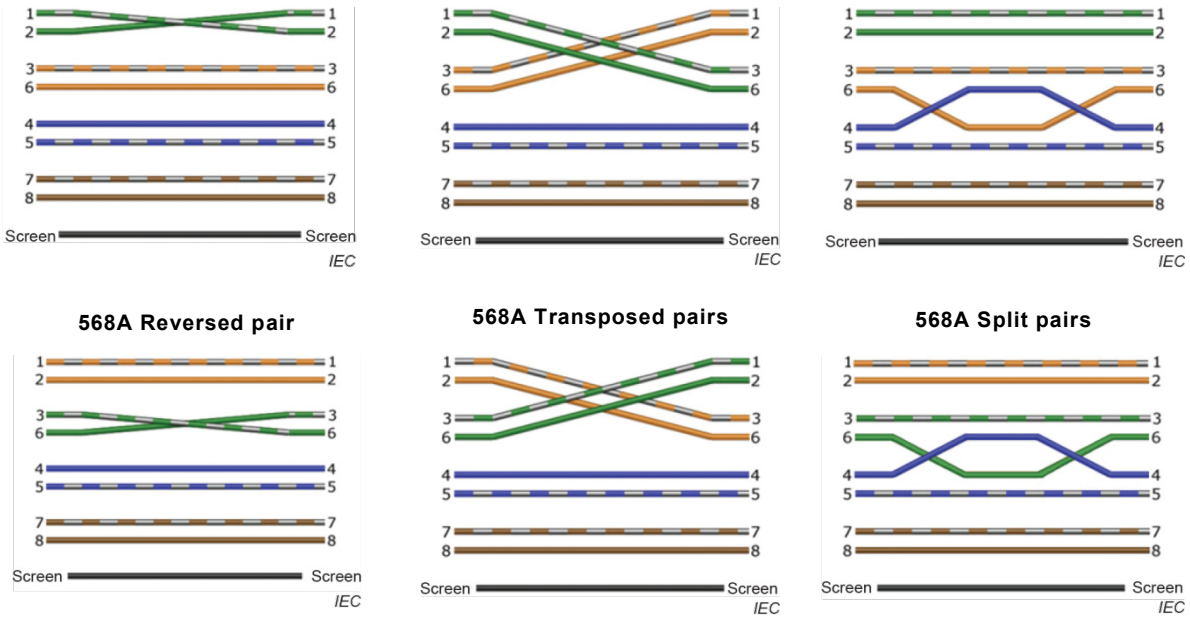


Figure 18 – Incorrect pairing

For level VI testers, it is understood that the screen continuity is measured along the path of the cabling.

Wire map tests shall report "Pass" if cabling is determined to be correct.

5.3.4 Propagation delay and delay skew

Propagation delay and delay skew may be determined from phase angle measurements and is frequency dependent. For field testing purposes, the propagation delay at 10 MHz shall be reported. The field test equipment shall be capable of measuring the propagation delay on each pair. Test limits for the channel and link configurations shall be as specified in ISO/IEC 11801-1 (or equivalent).

5.3.5 Length

The length is not a pass/fail requirement per ISO/IEC 11801-1.

The physical length of the channel and link is defined as the sum total of the physical length of the cabling between the defined reference planes. The physical length may be determined by measuring the lengths of the components that make up the cabling. The length of cable segments may be determined from the length markings on the cables, when present, however the accuracy of the length marking should be considered.

The lengths can also be estimated from an electrical length measurement. The electrical length is derived from the propagation delay of signals and depends on the twist helix and dielectric material.

Calibration of nominal velocity of propagation (NVP) is critical to the accuracy of length measurements when estimating length from either frequency or time domain methods. NVP refers to the velocity of propagation of the signal in the pair. It is typically expressed as a fraction of the speed of light in vacuum, for example 0,67 c. An incorrectly set NVP is the

most common cause of inaccurate length measurements when using field test equipment. The NVP for any given cable is a function of its design.

The NVP can vary widely between different cable designs and is also frequency dependent. At 1 MHz, the NVP can be up to 5 % less than the NVP at 100 MHz.

It is the responsibility of the user to ensure the NVP of the cable matches the setting of the field testers. Field test equipment shall provide functional capability for “NVP calibration”. The NVP in a cable sample is determined as follows:

a) physically measure the length of the cable sample, using a sample that should be at least 30 m. Greater accuracy in NVP determination will be obtained using longer lengths. For example, if the resolution of the measurement is 1 m, the best NVP accuracy that can be expected for a 25 m cable is 1/25 or 4 %;

b) set the field test equipment to its “NVP calibration” mode. Enter the measured distance into the tester. NVP as a fraction of the speed of light is calculated as follows using appropriate length units:

$$NVP = \frac{Physical\ \ length}{Measured\ \ propagation\ \ delay \times Velocity\ \ of\ \ light\ \ in\ \ vacuum} \tag{30}$$

where the velocity of light in vacuum = 3×10^{8} m/s.

Use this NVP when making subsequent length measurements on cable from the same spool.

The NVP is calibrated to the pair with the longest twist length. This is the pair with the shortest electrical delay. There can be up to 5 % variation in the NVP per pair between different pairs in the same sheath. This, together with varying twist ratios, explains why different pairs in the same sheath appear to have different lengths.

For length evaluation, the field tester shall use the measured length of the same pair for which the NVP was calibrated.

5.3.6 Insertion loss

Insertion loss can be derived from swept/stepped frequency voltage measurements. A balanced input differential signal is applied to a pair at the near end of the link while the differential signal on the same pair is measured at the far end.

Insertion loss test limits for the channel and link configuration shall be as specified in ISO/IEC 11801-1 (or equivalent). Insertion loss increases with temperature.

The measurements shall be conducted at the same temperature throughout the test so that the effect of the change of temperature is negligible. Refer to 4.6.5 for further information.

5.3.7 NEXT, power sum NEXT

NEXT can be derived from swept/stepped frequency voltage measurements. A balanced input signal is applied to a disturbing pair at the near end of the link while the induced differential signal on the disturbed pair is measured at the near-end.

Power sum NEXT is computed from the NEXT to a certain pair. For example, the power sum NEXT of the 1,2 pair is given by Equation (12):

NEXT and power sum NEXT test limits are as specified in ISO/IEC 11801-1 (or equivalent).

5.3.8 ACR-N and power sum ACR-N

5.3.8.1 ACR-N

The ACR-N of each pair combination of a channel shall meet the difference of the NEXT requirement and the insertion loss (IL) requirement. The ACR-N requirements shall be met at both ends of the cabling.

The ACR-N from disturbing pair i to disturbed pair k is computed by Equation (13).

5.3.8.2 ACR-N, power sum

The PS ACR-N requirements shall be met at both ends of the cabling.

The PS ACR-N shall be calculated according to 4.9.4.

5.3.9 ACR-F, power sum ACR-F

ELFEXT and ACR-F are computed from far-end cross-talk (FEXT) and insertion loss measurements.

FEXT can be derived from swept/stepped frequency voltage measurements. A balanced input signal is applied to a disturbing pair at the near end of the link while the induced differential signal on the disturbed pair is measured at the far end.

The ACRF is given by Equation (14), and the PS ACR-F is given by Equation (15).

All ACR-F and PS ACR-F quantities are assumed to be expressed in positive units of dB.

ACR-F and power sum ACR-F test limits are as specified in ISO/IEC 11801-1 (or equivalent). ELFEXT and PS ELFEXT limits are assumed to be identical to those for ACR-F and PS ACR-F respectively.

5.3.10 Return loss

Return loss is a measure of the reflected energy caused by impedance mismatches in the cabling system. Return loss is especially important for applications that use simultaneous bi-directional transmission.

Return loss test limits are specified in ISO/IEC 11801-1 (or equivalent).

5.3.11 Direct current (DC) loop resistance

The DC loop resistance is the sum total of all DC resistances in the loop of a pair, including the connectivity. Direct current (DC) loop resistance test limits are as specified in ISO/IEC 11801-1 (or equivalent).

5.3.12 Direct current (DC) resistance unbalance between pairs

The DC resistance unbalance between pairs is the parallel resistance unbalance between two pairs, including the connectivity. Direct current (DC) resistance unbalance between pair test limits are as specified in ISO/IEC 11801-1 (or equivalent).

5.3.13 Alien crosstalk parameters

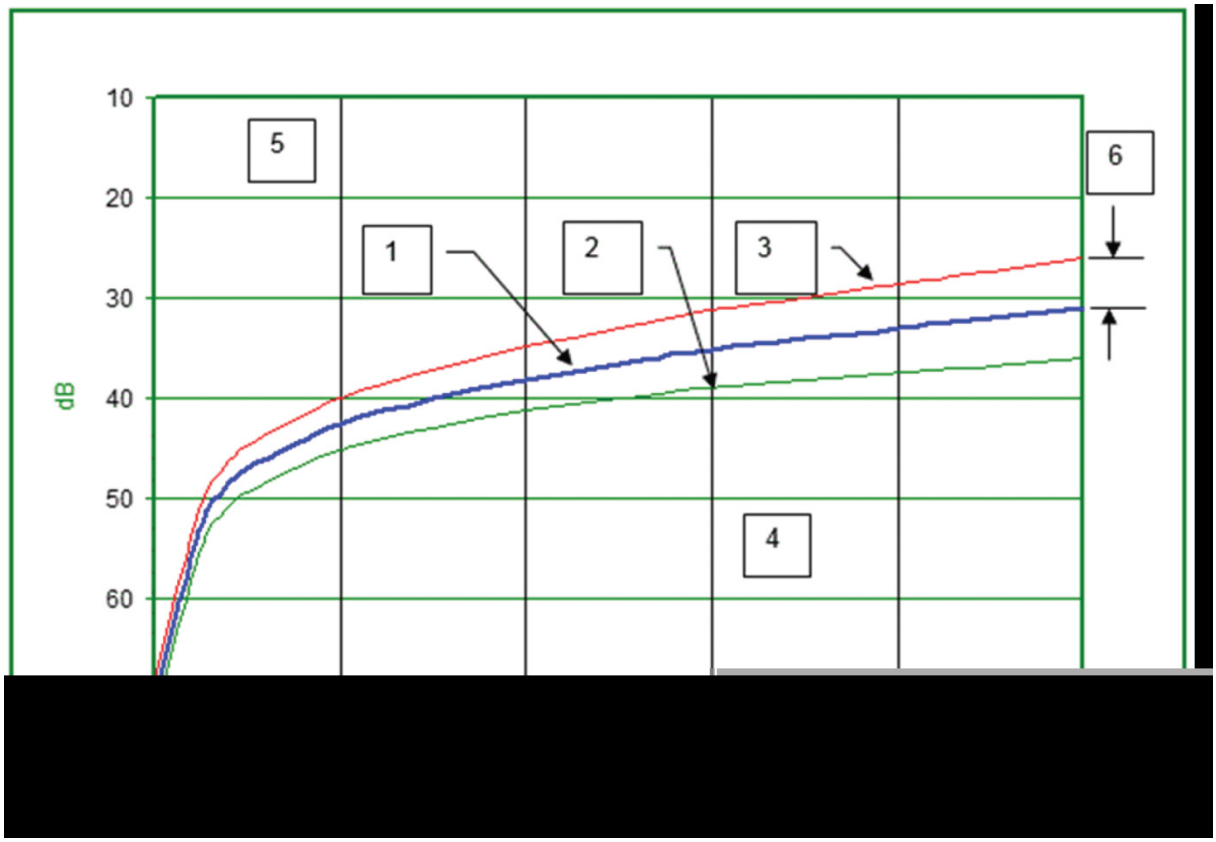
Field test requirements for alien crosstalk parameters PS ANEXT and PS AACR-F are given by Annex E.

5.4 Data reporting and accuracy

5.4.1 General

A pass or fail result for each parameter shall be determined by the allowable limits for that parameter. For Class FA and below, the test result of a parameter shall be marked with an asterisk (*) when the result is closer to the test limit than the measurement accuracy (see Figure 19). See also Clause 6 for detailed information on measurement accuracy requirements.

Annex A contains additional considerations of variability that may occur during field test measurements.



Key

1 test limit line

2 conditional pass limit line (star pass)

3 conditional fail limit line (star fail)

4 test pass area (the area below the conditional pass limit line)

5 test fail area (the area above the conditional pass limit line)

6 measurement accuracy

Figure 19 – Example of equipment tolerance region (NEXT)

NOTE Figure 19 shows an example of a measurement tolerance above and below the NEXT pass/fail test limit. The lines above and below the test limits are offset from the test limit by the value in dB equal to the measurement accuracy. If the measurement falls within the region above the limit, the measurement is marked with a FAIL*. If the measurement falls within the region below the test limit, the measurement is marked with a PASS*.

The field test equipment manufacturer shall provide documentation as an aid to interpret results marked with asterisks.