IEC 61935-1

Edition 4.0 2015-12

INTERNATIONAL STANDARD

colour inside

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

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

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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 and related standards

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

This fourth edition cancels and replaces the third edition, published in 2009, and 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 1 000 MHz;

b) test methods are now included for exogenous (alien) crosstalk;

c) a new Annex A has been added for uncertainty and variability of field test results.

The text of this standard is based on the following documents:

FDIS	Report on voting
46/574/FDIS	46/587/RVD

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

This publication 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.

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

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- withdrawn,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

A bilingual version of this publication may be issued at a later date.

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

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 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. This standard 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 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 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. References in this standard to ISO/IEC 11801 mean ISO/IEC 11801 or equivalent cabling standards.

This International Standard applies when the cable assemblies are constructed of cables complying with the IEC 61156 family of standards, and connecting hardware as specified in the IEC 60603-7 family of standards 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 standard 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 standard 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   Users of this standard are advised to consult with applications standards, equipment manufacturers and system integrators to determine the suitability of these requirements for specific networking applications.

It is assumed that 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.

This standard 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 standard. 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 provide confidence that specific applications will work. Verification testers only verify connectivity.

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

2 Normative references

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

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 60603-7 (all parts), *Connectors for electronic equipment – Part 7: Detail specification for connectors, 8-way, including fixed and free connectors with common mating features, with assessed quality*

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

IEC 60603-7-71, *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 61076-3-104, *Connectors for electronic equipment – Product requirements – Part 3-104: Detail specification for 8-way, shielded free and fixed connectors for data transmissions with frequencies up to 1 000 MHz*

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

IEC TR 61156-1-2:2009/AMD1:2014

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 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-connectorized cables - Absorbing clamp method*

ISO/IEC 11801, *Information technology – Generic cabling for customer premises*

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

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

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 following terms, definitions and abbreviations apply, in addition to those included in ISO/IEC 11801.

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 (or equivalent)

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

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

3.1.5
delay skew
worst case value of the phase delay difference between any pair in the same cable assembly

3.1.6
electrical length
equivalent free-space length of the cable assembly

3.1.7
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.

3.1.8
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: It is expressed in dB relative to the incident square root of signal power.

3.1.9
nominal impedance
impedance for which the system is designed, the nominal impedance being purely resistive

3.1.10
output signal balance
OSB
ratio of the output common mode voltage to the output differential voltage generated by a source port

3.1.11
power sum
NEXT, **FEXT** and **ELFEXT**
power sum cross-talk is the combined cross-talk on a receiving pair from all disturbing links operating simultaneously

3.1.12
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)

3.1.13
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.

3.1.14
reference plane
reference position of the cabling under test or necessary mating connector at which the performance requirements are specified

3.1.15
reflection coefficient
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}

$$C_r = \left(\frac{|Z_{in} - Z_{nom}|}{|Z_{in} + Z_{nom}|} \right) \qquad (1)$$

3.1.16
return loss
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

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

where

u_i is the incident voltage;

u_r is the reflection voltage.

3.1.17
screening attenuation <of the cable assembly>
ratio of the common mode square root of power wave inside a screened cable assembly to the total square root of power that radiates outside the cable assembly

3.1.18
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

3.1.19
verification
measurements of installed cable or cabling for continuity; no other transmission performance parameters other than connectivity are measured

3.2   Abbreviations

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	Direct current
ELFEXT	Equal level FEXT
EI	Equipment interface
ELTCTL	Equal level TCTL
ELFEXT	Equal level FEXT
EMC	Electromagnetic compatibility
ELTCTL	Equal level TCTL
EQP	Equipment
FEXT	Far end crosstalk attenuation (loss)
LCL	Longitudinal to differential conversion loss
LCTL	Longitudinal to differential conversion transfer loss
LCL	Longitudinal to differential conversion loss
NEXT	Near end crosstalk attenuation (loss)
LCTL	Longitudinal to differential conversion transfer loss
PS AACR-F	Power sum attenuation to alien crosstalk ratio at the far-end
PS AACR-F$_\mathrm{avg}$	Average power sum attenuation to alien crosstalk ratio at the far-end
PS AACR-F	Power sum attenuation to alien crosstalk ratio at the far-end

PS ACR	Power sum ACR
PS AACR-F$_{avg}$	Average power sum attenuation to alien crosstalk ratio at the far-end
PS ACR-F	Power sum attenuation to 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	Power sum alien far-end crosstalk (loss)
PS ACR-N	Power sum attenuation to crosstalk ratio at the near-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 ANEXT	Power sum alien near-end crosstalk (loss)
PS ELFEXT	Power sum ELFEXT
PS ANEXT$_{avg}$	Average power sum alien near-end crosstalk (loss)
PS FEXT	Power sum FEXT (loss)
PS ELFEXT	Power sum ELFEXT
PS NEXT	Power sum NEXT (loss)
PS FEXT	Power sum FEXT (loss)
RFI	Radio frequency interference
PS NEXT	Power sum NEXT (loss)
RFI	Radio frequency interference
RL	Return loss

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 field testing and appropriate precautions shall be described.

4.2 Balunless

4.2.1 Test equipment considerations

The reference measurement procedures that are described in this standard require the use of a network analyser, 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.

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

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.

NOTE 1   The exact value of the common mode impedance is not critical for most measurements. Normally, a value of 75 Ω is used for unscreened cabling while a value of 25 Ω is used for screened cabling.

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.
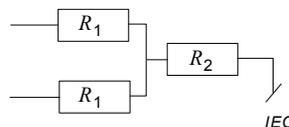
Figure 1 – Resistor load

where

$$R_1 = \frac{R_{\text{dif}}}{2} \tag{3}$$

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

and

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

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

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 2   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 analyzer 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:

–   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 (or equivalent), includes up to 90 m of horizontal cable, a work area equipment cord, a telecommunications outlet/connector, an optional transition 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 as defined in ISO/IEC 11801 (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.
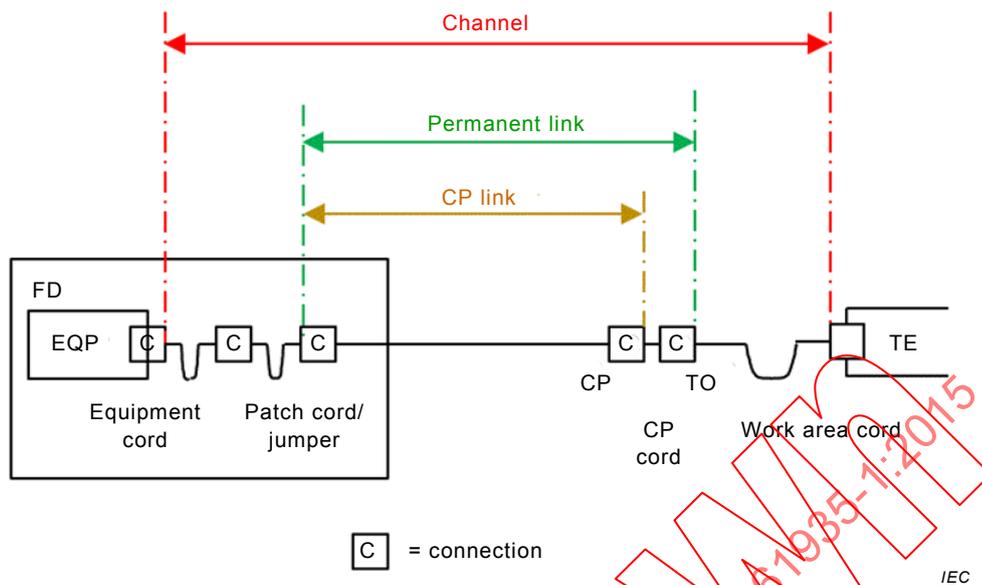
Figure 2 – Reference planes for permanent link, CP link and channel

The test configuration reference planes of a permanent link (see figure 2) 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 analyzer 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 Balunless requirements 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_{CC12}
	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.

Two classes of baluns with different performance levels are defined. This is in order to facilitate measurements up to 1 GHz with commercially available baluns. 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
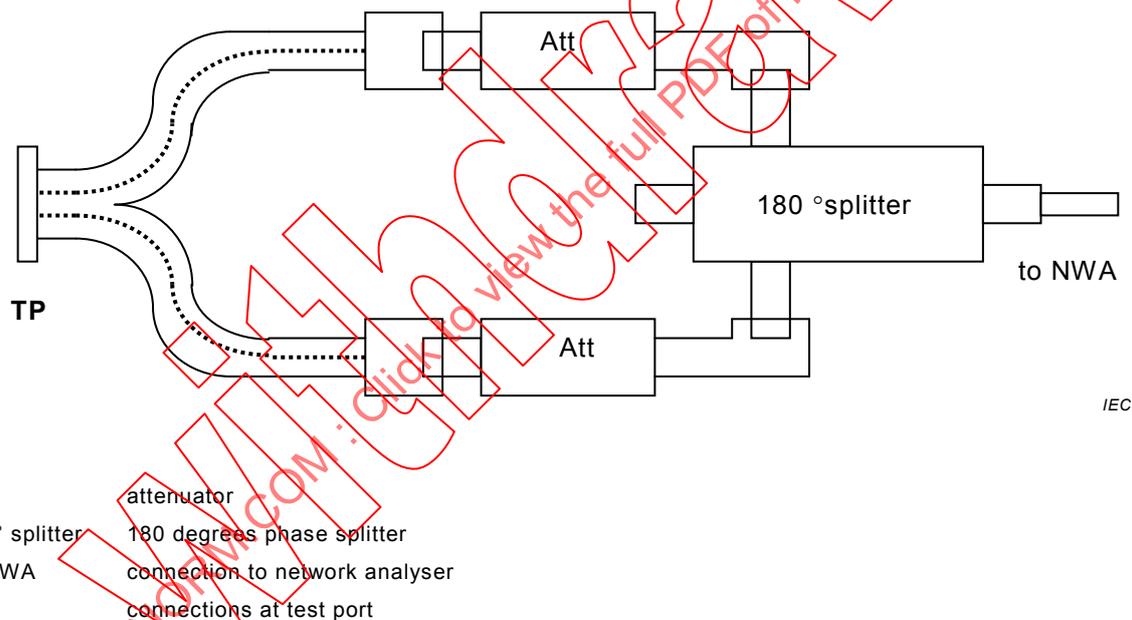
Figure 3 – 180° hybrid used as a balun

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 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 EMI shielded and shall comply with the requirements given in Table 2.

Table 2 – Test balun performance characteristics

Parameter	Class A value	Class B value
Impedance, primary[a]	50 Ω unbalanced	50 Ω unbalanced
Impedance, secondary	Matched balanced	Matched balanced
Insertion loss	3 dB maximum	10 dB maximum
Return loss secondary	12 dB minimum, 1 MHz – 15 MHz 20 dB minimum, 15 MHz – 550 MHz 17,5 dB minimum, 550 MHz – 600 MHz 10 dB minimum, 600 MHz – 1 000 MHz	6 dB minimum
Return loss, Common mode[b]	15 dB minimum, 1 MHz – 15 MHz 20 dB minimum, 15 MHz – 400 MHz 15 dB minimum, 400 MHz – 600 MHz 10 dB minimum, 600 MHz – 1 000 MHz	10 dB minimum
Power rating	0,1 W minimum	0,1 W minimum
Longitudinal balance[c]	60 dB minimum, 15 MHz – 350 MHz 50 dB minimum, 350 MHz – 600 MHz 40 dB minimum, 600 MHz – 1 000 MHz	35 dB minimum
Output signal balance[c]	60 dB minimum, 15 MHz – 350 MHz 50 dB minimum, 350 MHz – 600 MHz 40 dB minimum, 600 MHz – 1 000 MHz	35 dB minimum
Common mode rejection[c]	60 dB minimum, 15 MHz – 350 MHz 50 dB minimum, 350 MHz – 600 MHz 40 dB minimum, 600 MHz – 1 000 MHz	35 dB minimum

Special guidelines for use of baluns:

− For best accuracy, the baluns should be supplied with connectors (for example with IEC 60169-22 connectors).

− Class A baluns are preferred for accuracy.

− Class B baluns can be used in the whole frequency range for which their specifications apply, provided their output signal balance is better than 50 dB below 100 MHz.

− For class B baluns there is a trade-off between insertion loss and return loss. Return loss can be improved by using an attenuator, which then increases insertion loss. If return loss is less than 10 dB, insertion loss shall be less than 5 dB. If Insertion loss is higher than 5 dB, return loss shall be higher than 10 dB.

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.

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

[b] Measured 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.

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

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

4.2.10   Network analyser measurement precautions

To ensure 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 and phase 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 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 ($\pm 0{,}25$ 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.

4.2.11 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:

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

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

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

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.

4.3 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 4.3.4.2) 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 mΩ ± 0,5 mΩ to be able to measure 0,1 Ω accurately.

4.3.4.2　Measurement

The loop resistance for all four pairs shall be measured.

Key
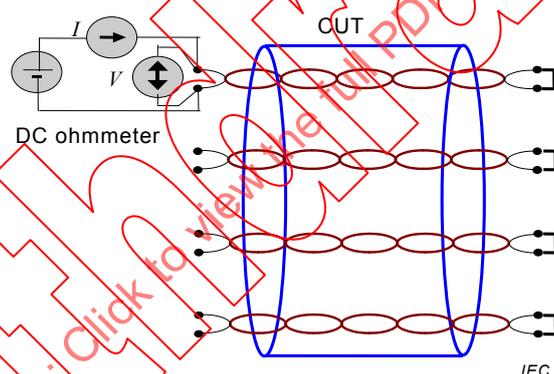
CUT　　　　cabling under test
V　　　　voltage applied to cabling under test
I　　　　current applied to cabling under test

Figure 4 – DC 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 0,5 % + 0,05 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:

$$R20 = \frac{R_t}{1 + \alpha_R (t - 20)}$$

where

R_{20} is the loop resistance at 20 °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 resistance unbalance meets the requirements.

NOTE   This test is applicable to laboratory cabling testing.

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.

$$\Delta R = \frac{R_{max} - R_{min}}{R_{max} + R_{min}} \times 100 \tag{6}$$

where

ΔR is the resistance unbalance expressed in %.

4.4.3 Test equipment and set-up

A four terminal ohmmeter (see 4.4.4.2) 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 mΩ ±1 mΩ to be able to measure 0,1 Ω accurately.

4.4.4.2 Measurement

Measure the DC resistance of each wire of a pair. Then calculate the DC resistance unbalance per Formula (6).

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

Key
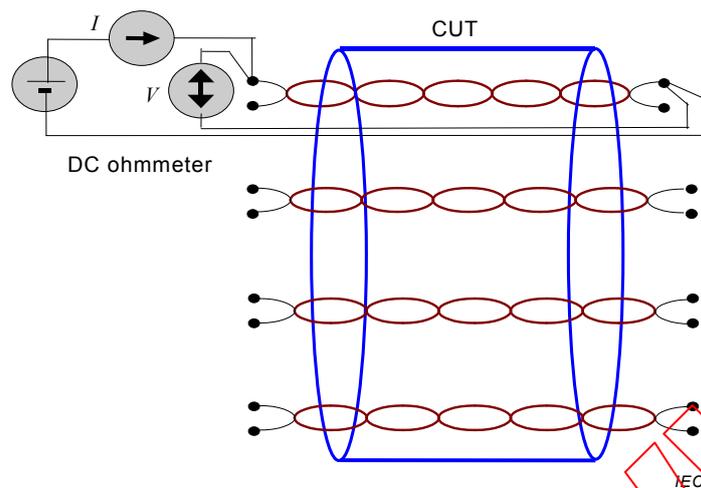
CUT   cabling under test

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 0,5 % + 0,05 Ω in the range from 0 Ω to 50 Ω.

4.5   Insertion loss

4.5.1   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.

4.5.2   Test method

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

4.5.3   Test equipment and set-up

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

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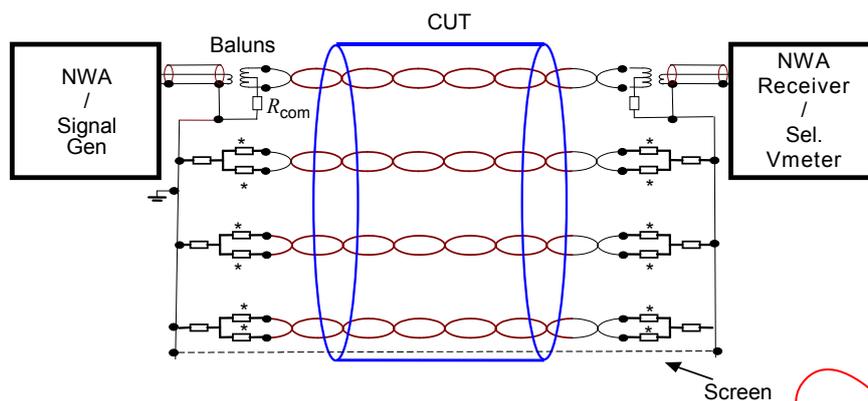
CUT	cabling under test
NWA/Sigl Gen	signal generator of network analyser or signal generator
NWA Receiver/Sel. Vmeter	receiver of network analyser or selective voltmeter
*	matched resistors (in pairs)
Screen	screen (if present)
R_{com}	common mode impedance (optional in insertion loss test)
Baluns	baluns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

Figure 6 – Insertion loss test configuration

4.5.4 Procedure

4.5.4.1 Calibration

A transmission (S21) 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, the minimum is given in Table 5.

4.5.4.2 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. Measurements shall be performed in the specified frequency range. The frequency step size shall be according to Table 11.

4.5.4.3 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.

4.5.5 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 measured 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.

As temperature coefficients for cabling the values given for cables according to the relevant part of IEC 61156 series shall be applied.

4.5.6 Uncertainty

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

4.6 Propagation delay and delay skew

4.6.1 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.

4.6.2 Test method

Propagation delay is measured by determining the phase delay of a signal transmitted through the cabling using Formula (7).

$$\delta = \frac{\phi}{2\pi f} \tag{7}$$

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.

4.6.3 Test equipment and set-up

The set-up is the same as for insertion loss measurements (see 4.5.3). 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}.

4.6.4 Procedure

4.6.4.1 Calibration

See 4.5.4.1.

4.6.4.2 Measurement

See 4.5.4.2, 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. For compliant cabling this is ensured by limiting frequency steps to 1,7 MHz or less. In order to ensure an adequate margin the frequency steps shall be no greater than 1 MHz.

4.6.4.3 Calculation

Some network analysers give a readout of the continuous phase trace of the tested item. This readout can be directly inserted in Formula (8). 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:

$$\varphi_f = \varphi_m - 2n\pi \qquad (8)$$

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 Formula (7).

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

4.6.5 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.

4.6.6 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.

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

4.7.1 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.

4.7.2 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.

4.7.3 Test equipment and set-up

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

Key

CUT   cabling 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

4.7.4   Procedure

4.7.4.1   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 4.2.2. 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.

4.7.4.2   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 cabling 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 cabling 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. 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 up to 100 MHz, 500 kHz up to 250 MHz and 2,5 MHz up to 1 000 MHz.

4.7.4.3   Calculation

NEXT is calculated from:

$$NEXT_{i,k} = -20\log\left|S21_{i,k}\right| \tag{9}$$

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:

$$PS\ NEXT_k = -10\log\left(\sum_{i=1,i\neq k}^{n} 10^{-0,1\times NEXT_{i,k}}\right) \tag{10}$$

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.

4.7.5   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.

4.7.6   Uncertainty

The uncertainty of reference NEXT measurements is defined to be valid at the pass/fail limit for the class F_A permanent link. The measurement accuracy shall be better than 1 dB at 100 MHz, 1,2 dB at 250 MHz and 2 dB at 1 000 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 may be calculated and reported (see 5.5).

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

4.8.1   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.

4.8.2   Test method

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

4.8.3   Test equipment and set-up

Refer to 4.5 and 4.7.

4.8.4   Procedure and calculation

Refer to 4.5 and 4.7.

The ACR-N of disturbed pair k to disturbing pair i is calculated from Formula (11):

$$ACRN_{i,k} = NEXT_{i,k} - IL_k \tag{11}$$

where

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

$NEXT_{i,k}$ is the ACR-N 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.

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

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

4.9.1   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.

4.9.2   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.

4.9.3   Test equipment and set-up

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

Key
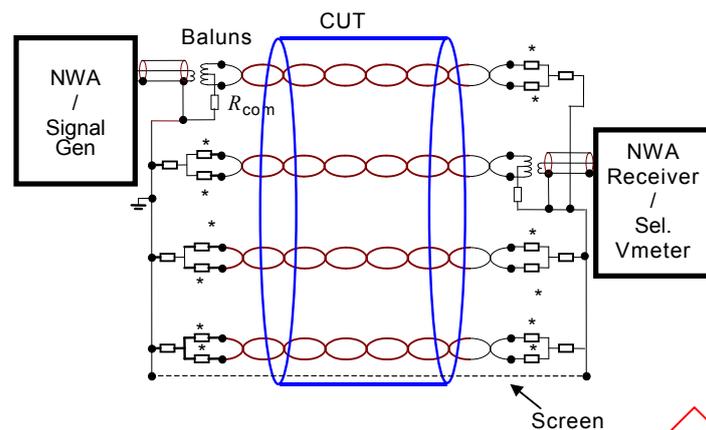
CUT   cabling under test

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 may 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

4.9.4 Procedure

4.9.4.1 Calibration

The method of calibration is the same as for NEXT (see 4.7.4.1).

4.9.4.2 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 4.7.4.2).

4.9.4.3 Calculation

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

$$FEXT_{i,k} = -20\log\left|S21_{i,k}\right| \tag{12}$$

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:

$$PS\ FEXT_k = -10\ \log\left(\sum_{i=1, i \neq k}^{n} 10^{-0,1 \cdot FEXT_{i,k}}\right) \tag{13}$$

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.

4.9.5   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. It shall be explicitly noted if the measured results exceed the requirements.

4.9.6   Uncertainty of FEXT measurements

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

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

4.10.1   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 of IEC 61935-1, this parameter was described as: equal level far end crosstalk (ELFEXT).

4.10.2   Calculation

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

$$ACR-F_{i,k} = FEXT_{i,k} - IL_k \tag{14}$$

where

$ACR-F_{i,k}$ 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 ELFEXT and 12 ACR-F results.

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

$$PS\ ACR-F_k = PS\ FEXT_k - IL_k \tag{15}$$

where

$PS\ ACR-F_k$ 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.

4.10.3 Test report

See 4.8.5.

4.10.4 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.

4.11 Return loss

4.11.1 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.

4.11.2 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.

4.11.3 Test equipment and set-up

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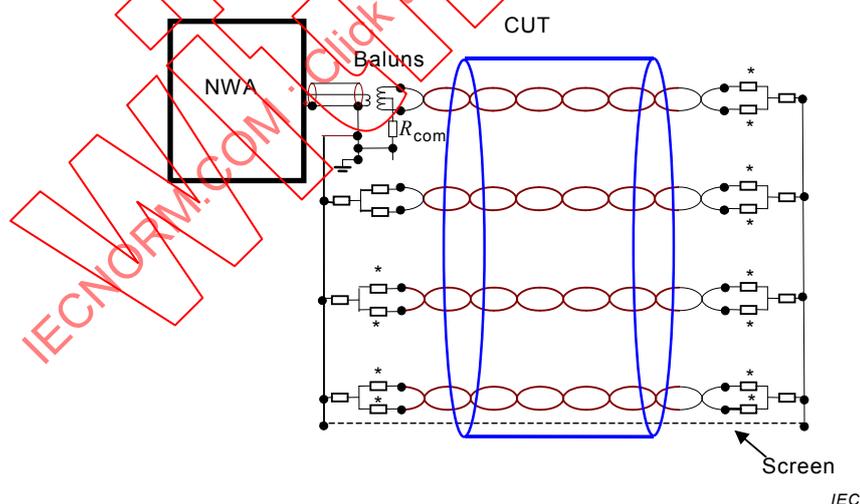
Key

CUT   cabling 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)

Baluns   baluns to interface laboratory equipment and balanced cabling

Figure 9 – Return loss test configuration

4.11.4   Procedure

4.11.4.1   Calibration

A full one port (S11) calibration shall be performed at the reference plane.

4.11.4.2   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.

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

2,5 MHz from 250 MHz up to 1 000 MHz

Return loss for both ends of the cabling shall be measured.

4.11.5   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.

4.11.6   Uncertainty

The uncertainty is specified at the performance limit for a class F_A permanent link.

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

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

4.12   PS Alien near end crosstalk (PS ANEXT – Exogenous crosstalk)

4.12.1   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.

4.12.2   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.

4.12.3   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.
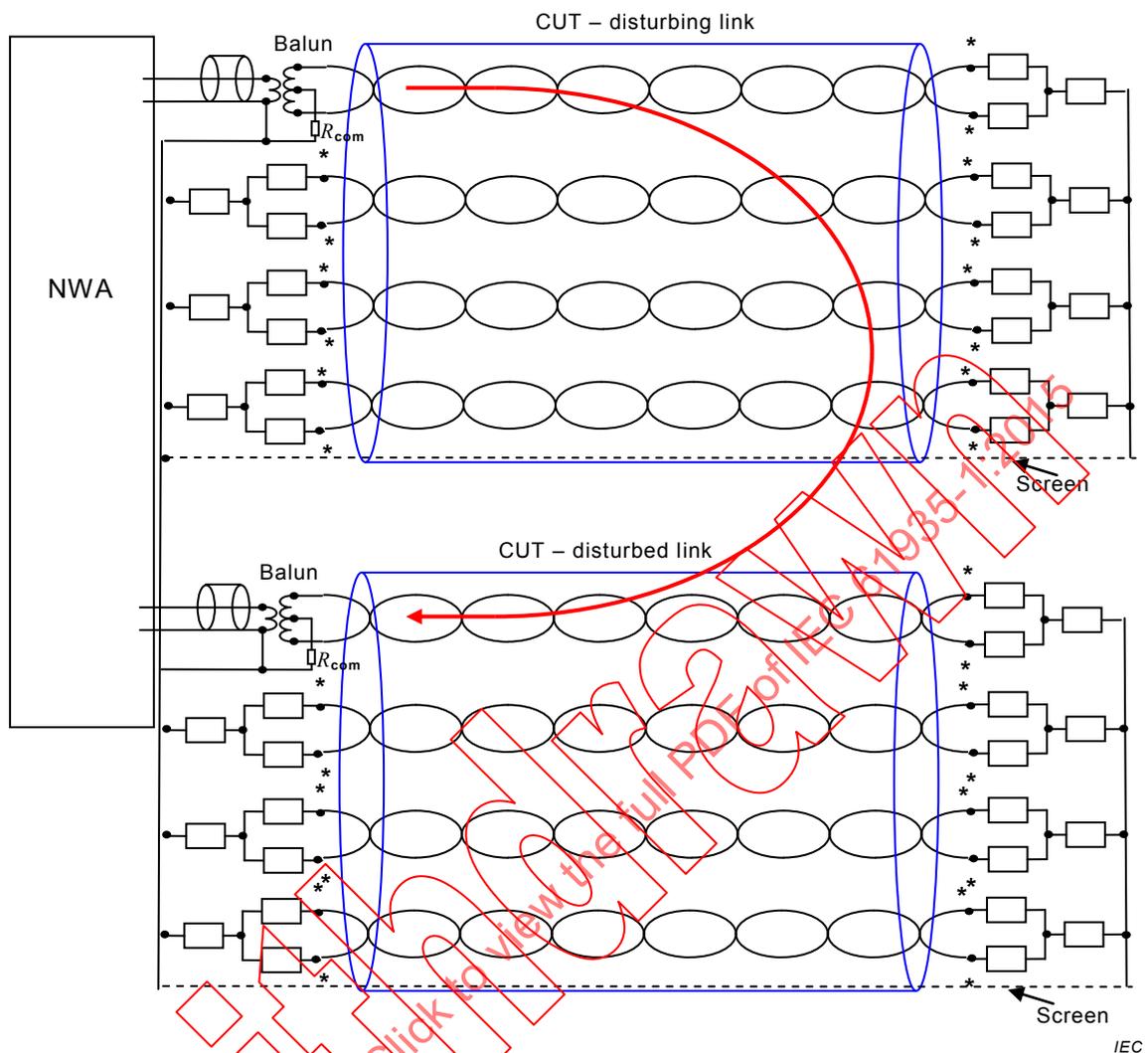
Key

CUT – disturbing link   cabling under test – disturbing link
CUT – disturbed link   cabling under test – disturbed link
NWA   network analyser
*   matched resistors (in pairs)
Screen   screen (if present)
R_com common mode impedance
Baluns   balun to interface laboratory equipment and balanced cabling

Figure 10 – ANEXT measurement

4.12.4 Procedure

4.12.4.1 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 5.4.7.4).

4.12.4.2 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 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 alien NEXT 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 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. 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 up to 100 MHz, 500 kHz up to 250 MHz and 2,5 MHz up to 1 000 MHz.

4.12.4.3 Calculation

The PS ANEXT frequency response of pair k of a disturbed channel is computed per Formula (16).

$$PS\ ANEXT_k(f) = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{n}10^{\frac{-\left(ANEXT_{k,i,j}(f)\right)}{10}}\right)$$ (16)

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 Formula (17).

$$PS\ ANEXT_{\text{avg}}(f) = \frac{1}{4} \sum_{k=1}^{4} PS\ ANEXT_k(f) \tag{17}$$

4.12.4.4   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.

4.12.4.5   Uncertainty

The uncertainty of reference PS ANEXT measurements is defined to be valid at the pass/fail limit. The error equations as in 6.10 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.

4.13   PS Attenuation to alien crosstalk ratio, far end crosstalk (PS AACR-F – Exogenous crosstalk)

4.13.1   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.

4.13.2   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.

4.13.3   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.
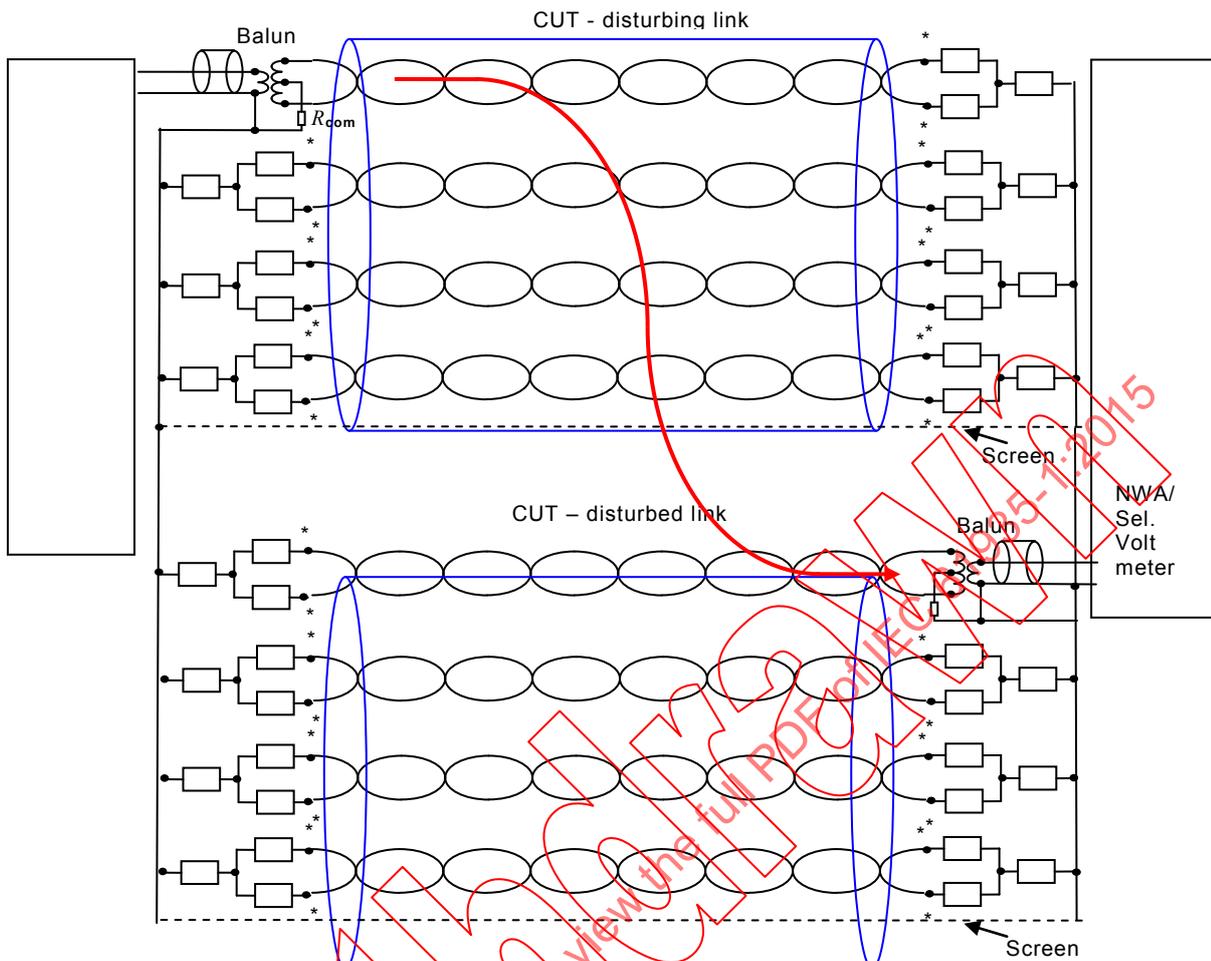
Key

CUT – disturbing link	cabling under test – disturbing link
CUT – disturbed link	cabling under test – disturbed link
NWA/Signal generator	signal generator of network analyser or signal generator
NWA/Sel. Volt meter	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.

4.13.4   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 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 5.4.7.4.

4.13.4.2 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 4.7.4.2).

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. 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 up to 100 MHz, 500 kHz up to 250 MHz and 2,5 MHz up to 1 000 MHz.

4.13.4.3 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 Formulas (18) and (19).

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

$$AFEXT_{\mathsf{norm}\,k,i,j}(f) = AFEXT_{k,i,j}(f) + IL_k(f) - IL_{i,j}(f) - 10\log\left(\frac{IL_k(f)}{IL_{i,j}(f)}\right) \tag{18}$$

Otherwise

$$AFEXT_{\mathsf{norm}\,k,i,j}(f) = AFEXT_{k,i,j}(f) \tag{19}$$

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 the result of Formula (23) shall be used in all cases.

The frequency response of the power sum alien *FEXT* of pair k $PS\ AFEXT_k(f)$ of a disturbed channel is computed per Formula (20).

$$PS\ AFEXT_k(f) = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{n}10^{\frac{-\left(AFEXT_{\text{norm}_{k,i,j}}(f)\right)}{10}}\right) \tag{20}$$

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 Formula (21).

$$PS\ AACRF_k(f) = PS\ AFEXT_k(f) - IL_{\text{avg}}(f) \tag{21}$$

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;

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

When required, it shall be measured according to 4.5.

The frequency response of the average insertion loss is computed per Formula (22).

$$IL_{\text{avg}}(f) = \frac{1}{4}\sum_{n=1}^{4}IL_n(f) \tag{22}$$

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 Formula (23).

$$PS\ AFEXT_{\text{avg}}(f) = \frac{1}{4} \sum_{k=1}^{4} PS\ AFEXT_k(f) \qquad (23)$$

The frequency response of the average PS AACR-F in dB is computed per Formula (24):

$$PS\ AACRF_{\text{avg}}(f) = PS\ AFEXT_{\text{avg}}(f) - IL_{\text{avg}}(f) \qquad (24)$$

where

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

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 AACR-F measurements is defined to be valid at the pass/fail limit. The error equations, as in 6.10.7, 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.

4.14 Unbalance attenuation, near end

4.14.1 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.

4.14.2 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.

4.14.3 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.
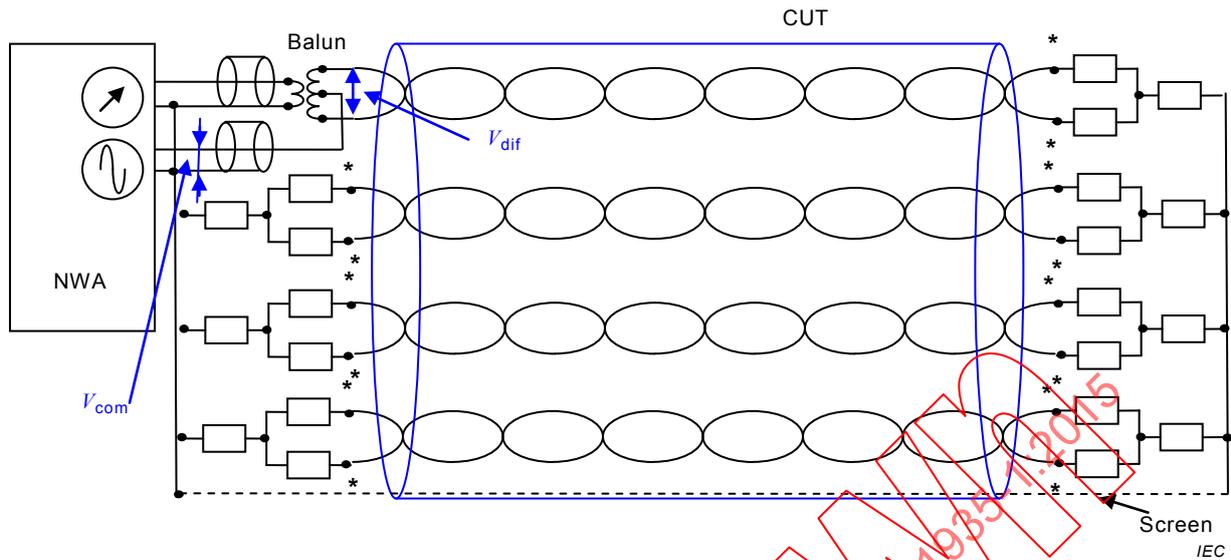
Key

CUT   cabling 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

4.14.4   Procedure

4.14.4.1   Calibration

TCL calibration is performed in three steps.

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 $IL_{bal,DM}$.
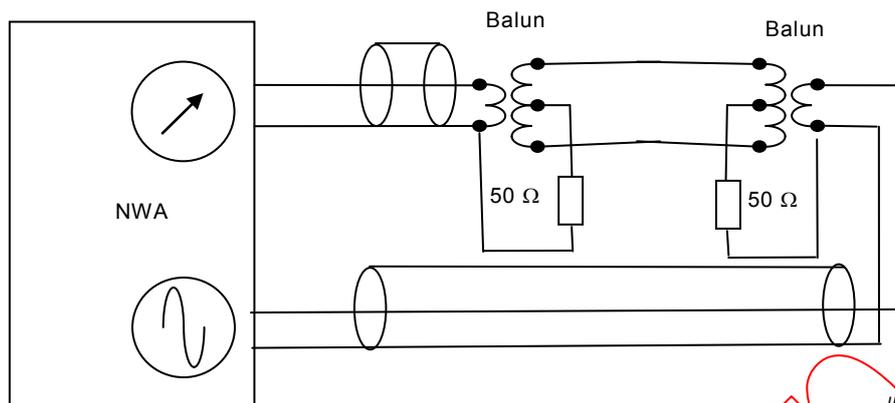
Figure 13 – Back-to-back balun differential mode insertion loss measurement

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 $IL_{bal,CM}$.
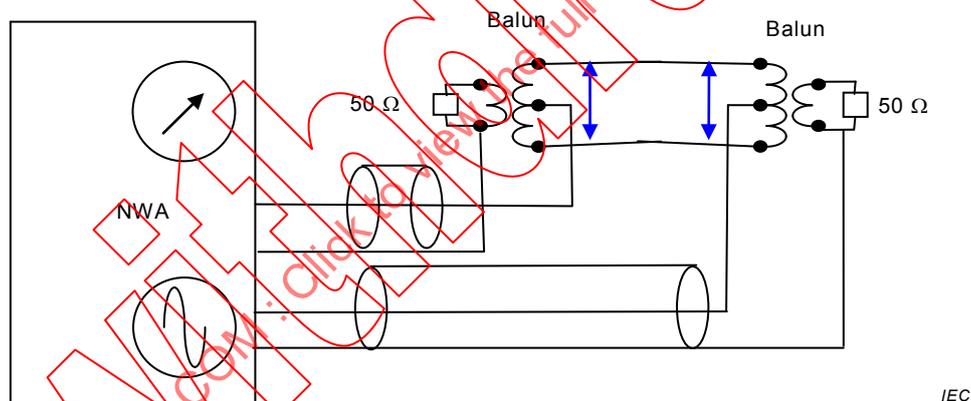
Figure 14 – Back-to-back balun common mode insertion loss measurement

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 4.14.4.2.
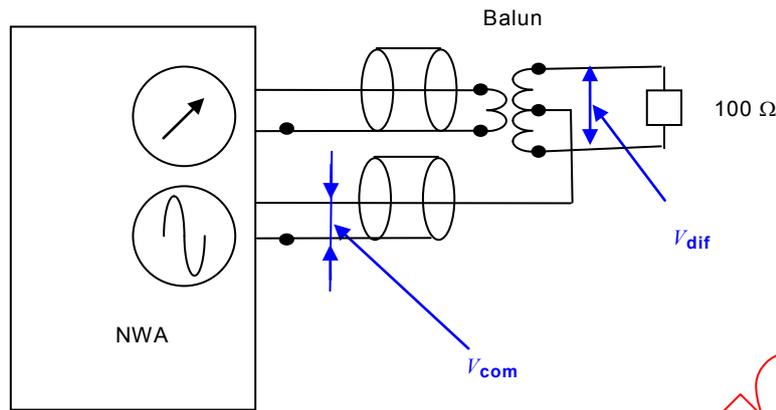
Key

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

4.14.4.2 Measurement

Each pair shall be measured from each end of the CUT. The far end of the cabling shall be terminated with loads according to 4.2.2, 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 4.2.2 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 Formula (25):

$$TCL = IL_{meas,TCL} - IL_{bal,DM} - IL_{bal,CM} \tag{25}$$

where

TCL is the computed unbalance attenuation near end, in dB;

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

$IL_{bal,DM}$ is the insertion loss of balun for differential mode signals, in dB;

$IL_{bal,CM}$ is the insertion loss of balun for common mode signals, in dB.

4.14.5 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.

4.14.6 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

4.15   Unbalance attenuation, far end

4.15.1   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 (EL TCTL) from the measured unbalance attenuation, far end and the insertion loss of the pair under test. Requirements for EL TCTL are specified in cabling standards.

This test is applicable to cabling in a laboratory environment.

4.15.2   Test method

Unbalance attenuation, far end or EL TCTL 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 EL TCTL is obtained by subtracting the insertion loss of the CUT from TCTL. The calculation is based on measured ratio between differential and common mode voltage.

4.15.3   Test equipment and set-up

If both ends of the CUT are in close proximity, a network analyzer can be used for the TCTL measurement. If the ends of the CUT 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 analyzers 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

CUT	cabling 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)
Baluns	baluns 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

4.15.4   Procedure

4.15.4.1   Calibration

The calibration for TCTL measurements shall follow the procedure outlined in 4.14.4.1 for both baluns being used in the measurement and the calibration values should be recorded as $IL_{bal,DM1}$, $IL_{bal,DM2}$, $IL_{bal,CM1}$, and $IL_{bal,CM2}$.

4.15.4.2   Measurement

Each pair shall be measured from both ends of the cabling. Two ends of the same CUT 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 CUT 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 CUT 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 Formula (26).

$$TCTL = IL_{\text{meas},TCTL} - IL_{\text{bal},DM1} - IL_{\text{bal},CM2} \tag{26}$$

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 EL TCTL is computed as in Formula (27).

$$EL\ TCTL = TCTL - IL_{\text{CUT}} \tag{27}$$

where

$EL\ TCTL$ is the computed EL TCTL, in dB;

IL_{CUT} is the measured insertion loss of the cabling under test.

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 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

4.16 Coupling attenuation

Coupling attenuation measurements shall be conducted as per IEC 62153-4-11.

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 (or equivalent).

The information contained in this clause uses the links defined in ISO/IEC 11801 (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 (or equivalent).

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

– 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.

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 this clause are acceptable. Methods to compare results reported by field test equipment with those obtained using laboratory methods are also described.

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 related requirements are specified in this standard:

– inspection of workmanship and connectivity testing;

– propagation delay;

– delay skew;

– length (not a pass/fail requirement parameter per ISO/IEC 11801);

– 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);

– equal level far end crosstalk (ELFEXT) or attenuation-to-crosstalk ratio, far end (ACR-F);

– ELFEXT, power sum (PS ELFEXT) or 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).

5.3.2 Inspection of workmanship and connectivity testing

5.3.2.1 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.

5.3.2.2   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 (or equivalent), and is illustrated in Figure 17 (for four pair cables).
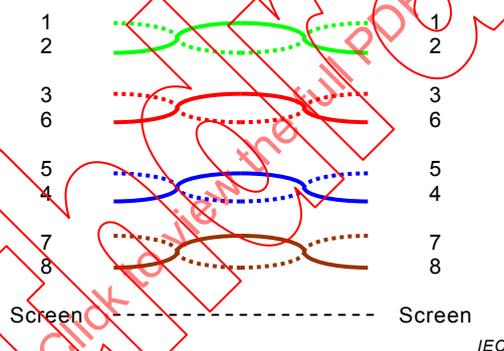
Figure 17 – Correct pairing

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.

a) Reversed pair   b) Transposed pairs   c) Split pairs
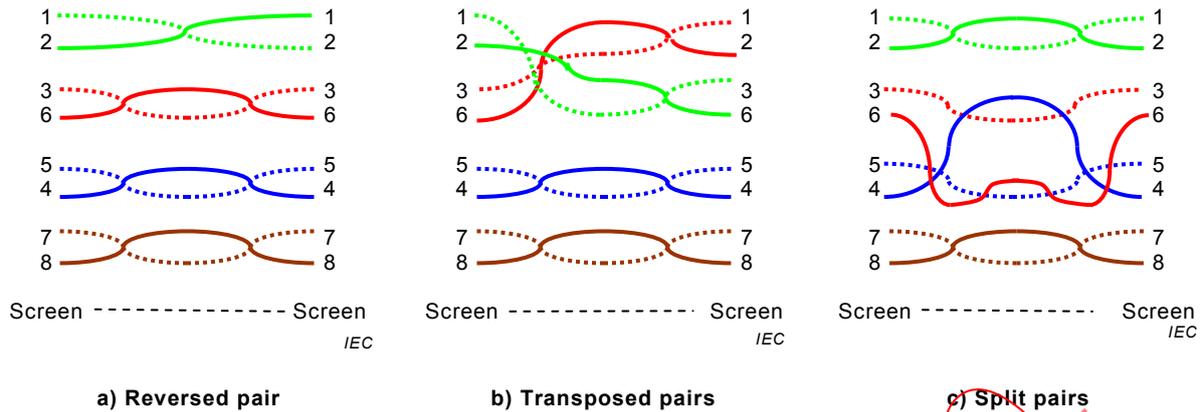
Figure 18 – Incorrect pairing

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

5.3.3 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 (or equivalent). With 2 m long test cords at each end, this additional propagation delay is 22 ns at 10 MHz.

5.3.4 Length

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

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.

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 of at least 15 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:

$$NVP = \frac{Physical\,Length}{Measured\,Propagation\,Delay \cdot Velocity\,of\,light\,in\,vacuum} \tag{28}$$

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.

The maximum lengths of the channel and link are specified in ISO/IEC 11801 (or equivalent).

5.3.5 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 (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 4.5.5 for further information.

5.3.6 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:

$$PS\,NEXT_{12,dB} = -10 * \log \left(10^{\frac{-NEXT_{1,2-3,6}}{10}} + 10^{\frac{-NEXT_{1,2-4,5}}{10}} + 10^{\frac{-NEXT_{1,2-7,8}}{10}} \right) \tag{29}$$

where all NEXT quantities are assumed to be expressed in positive units of dB.

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

5.3.7 ACR-N and power sum ACR-N

5.3.7.1 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 as follows:

$$ACR-N_{i,k} = NEXT_{i,k} - IL_k \tag{30}$$

where

$ACR-N_{i,k}$ is the computed ACR-N from disturbing pair i to disturbed pair k, in dB;

i is the number of the disturbing pair;

k is the number of the disturbed pair;

$NEXT_{i,k}$ is the near end crosstalk loss coupled from pair i into pair k;

IL_k is the insertion loss of pair k.

5.3.7.2 ACR-N, power sum

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

The PS ACR-N of disturbed pair k is computed as follows:

$$PS\ ACR-N_{i,k} = PS\ NEXT_{i,k} - IL_k \tag{31}$$

where

$PS\ ACR-N_{i,k}$ is the computed PS ACR-N from disturbing pair i to disturbed pair k, in dB;

k is the number of the disturbed pair;

$PS\ NEXT_{i,k}$ is the power sum near end crosstalk loss of pair k, in dB;

IL_k is the insertion loss of pair k.

5.3.8 ELFEXT, power sum ELFEXT, ACR-F, power sum ACR-F

ELFEXT and ACR-F are computed from far-end cross-talk (FEXT) (see 4.2.4) 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.

For example, the ELFEXT for a disturbed pair 1,2 pair by a disturbing 3,6 pair is given by:

$$ELFEXT_{12-36} = FEXT_{12-36} - IL_{36} \tag{32}$$

where

$ELFEXT_{12-36}$ is the ELFEXT between disturbing pair 3,6 and disturbed pair 1,2, in dB;

$FEXT_{12-36}$ is the FEXT between disturbing pair 3,6 and disturbed pair 1,2, in dB;

IL_{36} is the insertion loss of disturbing pair 3,6, in dB.

The ACR-F for a disturbed pair 1,2 pair by a disturbing 3,6 pair is given by:

$$ACR-F_{12-36,dB} = FEXT_{12-36,dB} - IL_{12`,dB}$$

(33)

where

$ACR-F_{12-36}$ is the ACR-F between disturbing pair 3,6 and disturbed pair 1,2, in dB;

IL_{12} is the insertion loss of disturbed pair 12, in dB.

Power sum ELFEXT is computed from the ELFEXT to a certain pair. For example, the power sum ELFEXT of the disturbed 1,2 pair is given by:

$$PS\ ELFEXT_{12} = -10 * \log 10 \left(10^{\frac{-ELFEXT_{1,2-3,6}}{10}} + 10^{\frac{-ELFEXT_{1,2-4,5}}{10}} + 10^{\frac{-ELFEXT_{1,2-7,8}}{10}} \right)$$

(34)

where

$PS\ ELFEXT_{12}$ is the PS ELFEXT to disturbed pair 12, in dB.

All ELFEXT quantities are assumed to be expressed in positive units of dB.

Power sum ACR-F is computed from the ACR-F to a certain pair. For example, the power sum ACR-F of the disturbed 1,2 pair is given by:

$$PS\ ACR-F_{12} = -10\log \left(10^{\frac{-ACRF_{1,2-3,6}}{10}} + 10^{\frac{-ACRF_{1,2-4,5}}{10}} + 10^{\frac{-ACRF_{1,2-7,8}}{10}} \right)$$

(35)

where

$PS\ ACR-F_{12}$ is the computed PS ACR-F to disturbed pair 12, in dB.

All 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 (or equivalent). ELFEXT and PS ELFEXT limits are assumed to be identical to those for ACR-F and PS ACR-F respectively.

5.3.9 Return loss

Return loss (see 3.1.16) 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 (or equivalent).

5.3.10 Direct current (DC) loop resistance

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 (or equivalent).

5.4 Power sum alien crosstalk

5.4.1 Objective

Here after are described the field measurement procedures for:

ANEXT,

AFEXT,

and calculations for:

PS ANEXT,

PS AFEXT,

PS AACR-F.

Furthermore, a procedure for selection of ports to be measured is specified.

Note that the number of disturbing links to be included in a power sum alien crosstalk result is often considerably higher than found in reference laboratory test conditions. Therefore, additional computation steps are used for field alien crosstalk data to prevent the accumulation of noise power.

Alien crosstalk measurements in the field can practically only be made on a sampling basis. It is therefore necessary to carry out an initial investigation and conclusion of worst case port positions in order that the limiting alien crosstalk performance of the installation can be identified. Reported in-field alien crosstalk measurements should have an additional margin to the limit reflecting that the selection of test links may not be absolute worst case. The port selection procedure and test requirements specified in 5.4.8 shall be followed when in-field alien crosstalk measurements are carried out. Interactive alien crosstalk measurements and mitigation operations are often the best way to secure compliance of the installation with the alien crosstalk requirements.

5.4.2 Test method

PS ANEXT, PS AFEXT and PS AACR-F are calculated from ANEXT, AFEXT and insertion loss measurements.

5.4.3 Test equipment and set-up

Depending on the test configuration, the test interface shall consist of a channel or link adapter, with the reference plane of measurement located at the location defined for the test configuration.

Before alien crosstalk measurements are performed, all links involved in the alien crosstalk testing shall be tested for their applicable internal transmission parameter performance.

In case of testing the channel configuration, all user cords shall be kept as much as possible in their normal use position during the tests.

5.4.4 Measuring ANEXT loss

Measuring ANEXT loss requires that test instrument A is connected to the disturbed channel and test instrument B is connected to a disturbing channel. See Figure 19. Test Instrument A operates as a receiver and test instrument B operates as a signal source.

Test instrument A and test instrument B communicate as shown with the dotted line labelled "synchronisation". A physical field tester control link is an option of this standard. Other implementations of this measurement are acceptable if equivalence is demonstrated. In case a link topology is tested, the channel adapters are replaced with link adapters.
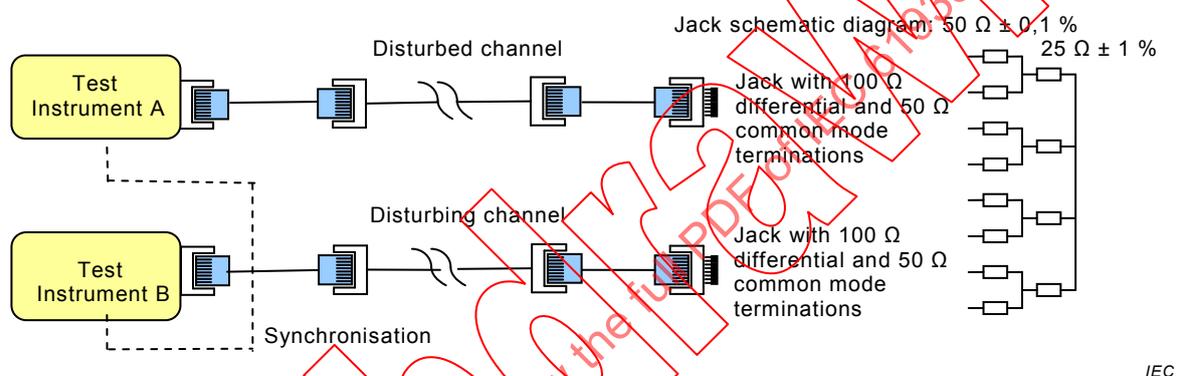
Figure 19 – Schematic diagram to measure channel ANEXT loss

The remote ends of the disturbed channel and a disturbing channel are terminated with jacks that include a 100 Ω differential and 50 Ω common mode termination as shown in Figure 19. User patch cords shall remain as much as possible in their normal use position during the test. The remote end may be terminated using a terminated plug rather than a user patch cord and a terminating jack if the ANEXT contribution from the remote end user patch cord is expected to be reduced to insignificant levels as a result of the round trip insertion loss of the cabling to the remote end.

5.4.5 Measuring AFEXT loss

Measuring AFEXT loss requires that test instrument A is connected to the disturbed channel and test instrument B is connected to a disturbing channel. See Figure 20. Test Instrument A operates as a receiver and test instrument B operates as a signal source.

Test instrument A and test instrument B communicate as shown with the dotted line labelled "synchronization". A physical field tester control link is an option of this standard. If a physical control link is present, it is often possible to use an unused channel in the same cable bundle to connect the control port on test instrument A at the near end with the control port of test instrument B at the remote end. Other implementations of this measurement are acceptable if equivalence is demonstrated. In case a link topology is tested, the channel adapters are replaced with link adapters. In case laboratory equipment is used, the source and load ports are in the same location, and no synchronization link is present. However, in this case the measurement can only be made on cabling that originate and terminate in close proximity.
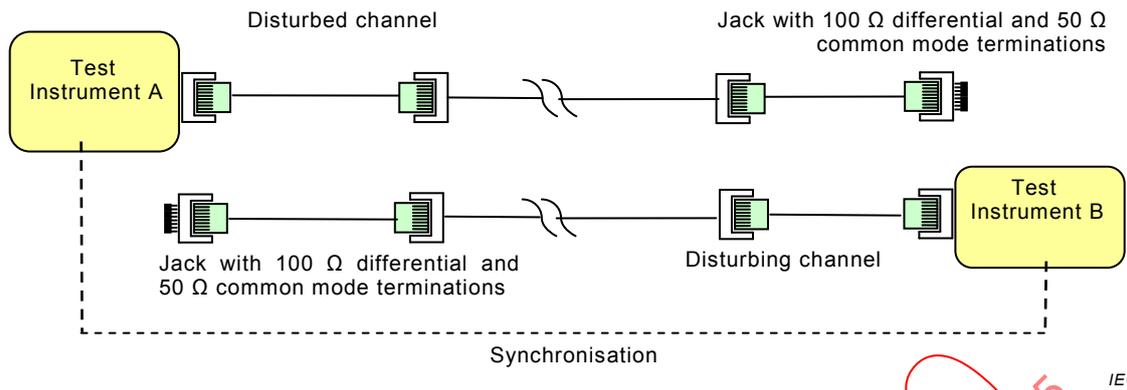
Figure 20 – AFEXT loss measurement test configuration

User patch cords shall remain as much as possible in their normal use position during the test. The remote ends of the disturbed channel and the local end of a disturbing channel may be terminated with plugs that include a 100 Ω differential and 50 Ω common mode termination as shown in Figure 20 if the AFEXT contribution from the user patch cords is demonstrated to be insignificant relative to other AFEXT contributions within the channel.

5.4.6 Procedure

5.4.6.1 Calibration

The test equipment shall be calibrated at the reference plane of measurement for the channel or link.

5.4.7 Calculation of PS ANEXT and PS AACR-F from measured data

5.4.7.1 Significance condition testing

The discrimination between a "real ANEXT or AFEXT" signal and a random signal shall be based on the average of measured values expressed in dB between 100 MHz and 250 MHz. If the average value of the frequency response exceeds the significance condition, the entire ANEXT or AFEXT response is excluded from the power sum computation. If the measured condition is worse than the significance condition, the entire ANEXT or AFEXT response is included in the power sum computation. The significance condition shall be at least 90 dB.

5.4.7.2 Length normalization

To support the laboratory test methods as described in Annex B, the length of disturbed and disturbing channel may be identical. In that case the length normalization will be zero.

When used, length normalization is based on the difference of the insertion losses of disturbing and disturbed pairs and is specified in ISO/IEC 11801. Refer to 5.4.7.3 for a detailed description of computations.

NOTE   Applications standards may specify power back-off algorithms that are based on the insertion losses at 250 MHz of disturbed and disturbing pairs. Tests may affect both PS ANEXT and PS AACR-F results. Refer to these application standards for specific requirements.

5.4.7.3 Computing the PS ANEXT or PS AFEXT results between a disturbed and disturbing links

Each disturbed to disturbing channel or link measurement, PS ANEXT or PS AFEXT contains 16 ANEXT loss or AFEXT loss measurements; for each pair in the disturbed channel or link by the pairs in disturbing link #1. The PS ANEXT loss is calculated by Formula (36).

$$PS\ ANEXT_{X,1} = -10\log\left(\begin{array}{l}10^{-0,1ANEXT_{X,1,1}} + \\ 10^{-0,1ANEXT_{X,2,1}} + \\ 10^{-0,1ANEXT_{X,3,1}} + \\ 10^{-0,1ANEXT_{X,4,1}}\end{array}\right)$$ (36)

where

X is a pair in the disturbed channel or link;

$PS\ ANEXT_{X,1}$ is the PS ANEXT loss to pair X of the disturbed link from the first disturbing channel or link;

$ANEXT_{X,Y,1}$ is the ANEXT loss from pair X in the disturbed channel or link to the pair Y of the disturbing channel or link #1.

When the alien NEXT loss of another disturbing link #2 is added, the sum total PS ANEXT is computed by

$$PS\ ANEXT_{X,total} = -10\log\left(10^{-0,1PS\ ANEXT_{X,1}} + 10^{-0,1PS\ ANEXT_{X,2}}\right)$$ (37)

For PS AFEXT loss, AFEXT measurements with a normalization applied are used before computing the power sum.

In case the insertion loss of pair X of the disturbed link is greater than the insertion loss of pair Y of disturbing link #1.

$$NORM_{X,Y,1} = IL_X - IL_{Y,1} - 10\log\left(\frac{IL_X}{IL_{Y,1}}\right)$$ (38)

otherwise

$$NORM_{X,Y,1} = 0$$ (39)

where

IL_X is the insertion loss in dB of disturbed pair X;

$IL_{Y,1}$ is the insertion loss in dB of pair Y of disturber link #1.

NOTE 1 To determine the use of Formula (41) or (42), the average of all pairs of the disturbed link at 250 MHz and the average of all pairs of the disturbing link at 250 MHz may be used.

NOTE 2 For the determination of the normalization, the average of all pairs of the disturbed link may be used for IL_X and the average of all pairs of the disturbing link may be used for $IL_{Y,1}$. The difference of IL_X and $IL_{Y,1}$ is frequency-dependent.

NOTE 3 For the ratio only portion of Formula (41), for IL_X and $IL_{Y,1}$, the values at 250 MHz may be used, since this ratio does not vary significantly as a function of frequency.

NOTE 4 The overall normalization, if used, is frequency-dependent and different for each disturbed and disturbing link combination.

NOTE 5   For screened cabling meeting coupling attenuation requirements in ISO/IEC 11801, the result of Formula (42) is used in all cases.

The normalized AFEXT value is given by:

$$AFEXTnorm_{X,Y,1} = AFEXT_{X,Y,1} + NORM_{X,Y,1} \tag{40}$$

The PS AFEXT loss in dB is calculated by Formula (41):

$$PS\ AFEXT_{X,1} = -10\log\left(\begin{array}{l}10^{-0,1AFEXTnorm_{X,1,1}} + \\ 10^{-0,1AFEXTnorm_{X,2,1}} + \\ 10^{-0,1AFEXTnorm_{X,3,1}} + \\ 10^{-0,1AFEXTnorm_{X,4,1}}\end{array}\right) \tag{41}$$

where

X is a pair in the disturbed channel or link;

$PSAFEXT_{X,1}$ is the PS AFEXT loss in dB to pair X of the disturbed link from the first disturbing channel or link;

$AFEXTnorm_{X,Y,1}$ is the AFEXT loss in dB from pair X in the disturbed channel or link to the pair Y of the disturbing channel or link #1, normalized based on the insertion loss of disturbed and disturbing pairs.

When the PS AFEXT loss of another disturbing link #2 is added, the sum total PS AFEXT in dB is computed by Formula (42):

$$PS\ AFEXT_{X,total} = -10\log\left(10^{-0,1PS\ AFEXT_{X,1}} + 10^{0,1PS\ AFEXT_{X,2}}\right) \tag{42}$$

To obtain the PS AACR-F result in dB, the insertion loss of the pair of the disturbed channel or link is subtracted from the PS AFEXT loss result as shown in Formula (43):

$$PS\ AACR-F_{X,total} = PS\ AFEXT_{X,total} - IL_X \tag{43}$$

5.4.7.4   Applying the correction for the measurement floor

The frequency response for a large number of PS alien crosstalk floor measurements (Nps) may be used to correct the measured PS ANEXT and PS AFEXT results. Refer to 6.8 for information on how to measure the alien crosstalk floor. If the number of alien crosstalk measurements in a power sum alien crosstalk result is Npp and the number of alien crosstalk measurements in the PS alien crosstalk floor measurements is 4×Nps, then the estimated measurement floor contribution to the overall PS alien crosstalk is 10 × log(4 × Nps/Npp). The measurement floor contribution to the overall PS alien crosstalk result is given in Formula (44):

$$PS\ AXtalk_{floor,Npp}(f) = PS\ AXtalk_{floor,4Nps}(f) + 10\log\left(\frac{4Nps}{Npp}\right) \tag{44}$$

The corrected PS alien crosstalk is computed as in Formula (45):

$$PS\ AXtalk_{final}(f) = -10\log\left(10^{-0,1PS\ AXtalk} - 10^{-0,1PS\ AXtalk_{floor,Npp}(f)}\right) \qquad (45)$$

The corrected PS AXtalk results shall be used to test against pass/fail limits.

5.4.8 Selection of test ports

5.4.8.1 Selection of disturbed links

The following port selection procedure shall be applied as a minimum.

The number of disturbed links to be tested for ISO/IEC 11801 compliance shall be specified in a quality plan as defined in ISO 14763-2.

The disturbed links shall be approximately divided equally between

- links within the group having the highest insertion loss in the installation,
- links within the group having the lowest insertion loss in the installation,
- links within the group having the median insertion loss in the installation.

5.4.8.2 Selection of disturbing links

Disturbing links shall include both of the following:

- all of the links that are in the same cable bundle or the most consistently positioned relative to the disturbed link as disturbing links;
- the disturbing links those that occupy adjacent positions to the left, right, above and below connections on the disturbed link on patch panels or multiple outlets.

5.4.8.3 Procedure

A flow chart of the alien crosstalk test procedure is shown in Figure 21.
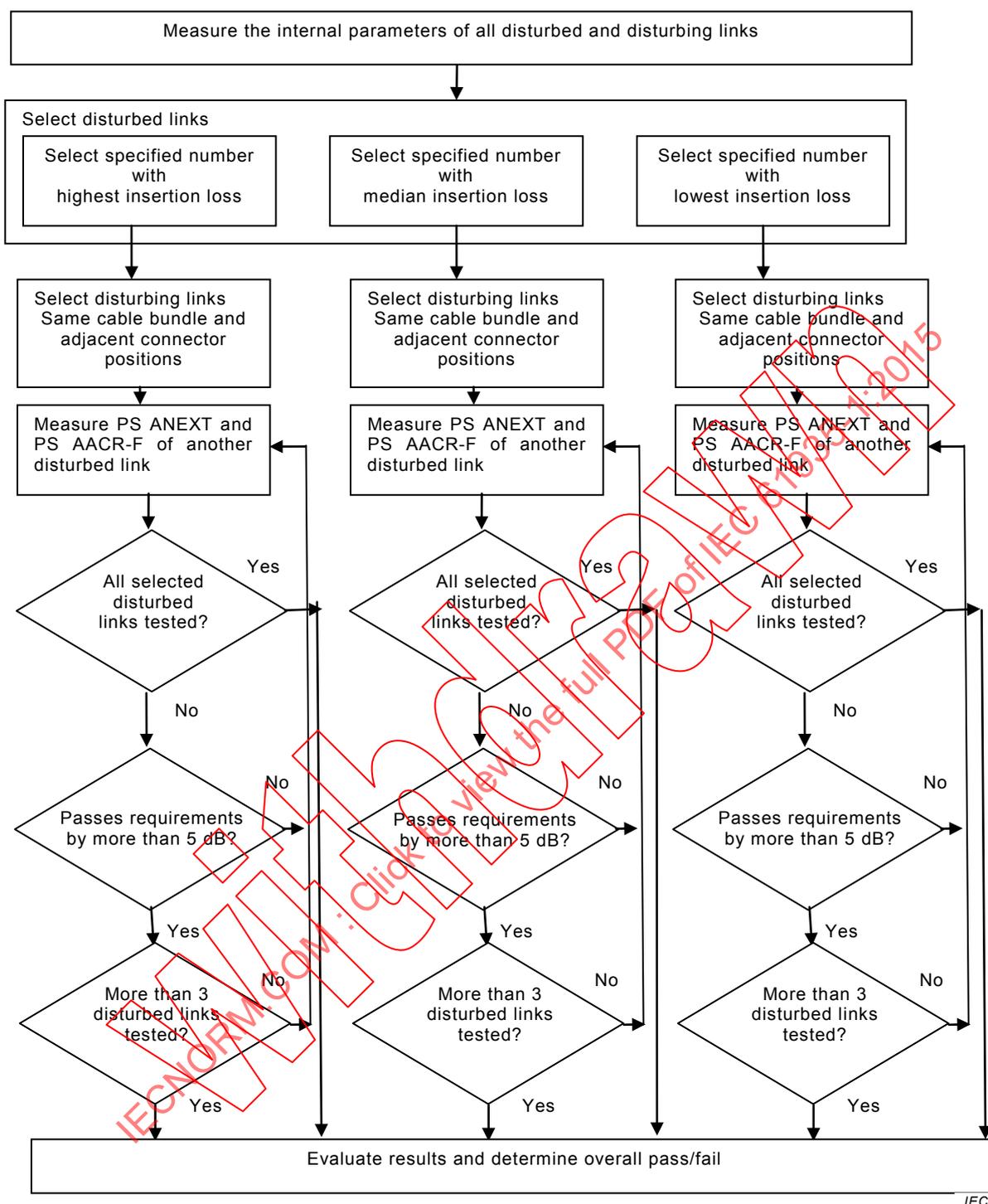
Figure 21 – Flow chart of the alien crosstalk test procedure

Measure the ANEXT and AFEXT as described in 5.4.2 through 5.4.6 and process the data as described in 5.4.7 for the links with the highest insertion loss. When the margin of PS ANEXT and PS AACR-F has reached 5 dB for the links with the highest insertion loss, further alien crosstalk testing of links with the highest insertion loss can be discontinued when the number of measured disturbed links is at least 3.

Measure the ANEXT and AFEXT as described in 5.4.2 through 5.4.6 and process the data as described in 5.4.7 for the links with the lowest insertion loss. When the margin of PS ANEXT and PS AACR-F has reached 5 dB for the links with the lowest insertion loss, further alien

crosstalk testing of links with the lowest insertion loss can be discontinued when the number of measured disturbed links is at least 3.

Measure the ANEXT and AFEXT as described in 5.4.2 through 5.4.6 and process the data as described in 5.4.7 for the links with median insertion loss. When the margin of PS ANEXT and PS AACR-F has reached 5 dB for the links with median insertion loss, further alien crosstalk testing of links with median insertion loss can be discontinued when the number of measured disturbed links is at least 3.

In case different cable types and/or connecting hardware are present in the installation, this selection process and measurement procedure that involve both cable and connecting hardware types should be repeated.

Any alien crosstalk testing in addition to the minimum specified above will contribute to increased confidence of the worst case alien crosstalk result. The worst case alien crosstalk value of all selected disturbed links measured is reported as the alien crosstalk of the installation.

5.4.9   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 of all disturbed channels measured shall be reported.

5.4.10   Uncertainty of PS alien crosstalk measurements

The error equation that is applicable to PS NEXT is also applicable to PS ANEXT and PS AFEXT, except that the random noise floor degrades 3 dB for every doubling of the number of ANEXT results that is contained in a PS ANEXT result.

5.5   Data reporting and accuracy

5.5.1   General

A pass or fail result for each parameter shall be determined by the allowable limits for that parameter. 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 22). 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.
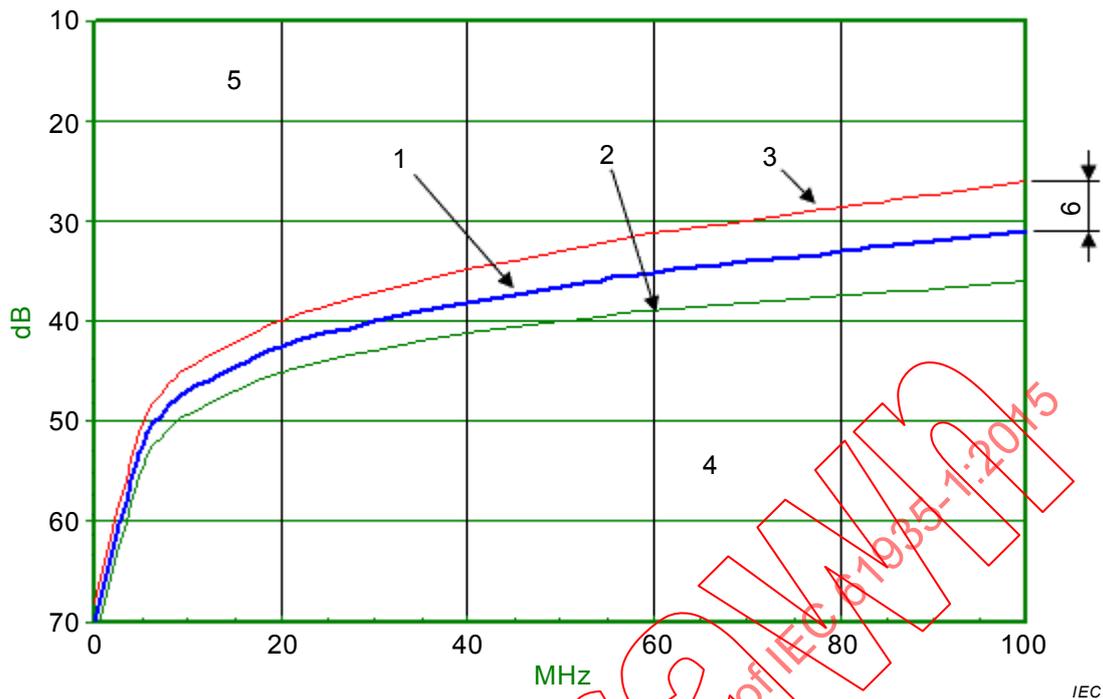
Key

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 22 – Example of equipment tolerance region (NEXT)

NOTE   Figure 22 shows an example of a measurement tolerance above and below the NEXT pass/fail test limit. The dotted 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.

An overall pass or fail condition shall be determined by the results of the required individual tests. Any FAIL or FAIL* shall result in an overall FAIL. Unless specified otherwise in a quality assurance agreement, in order to achieve an overall pass condition, all individual results shall be PASS or PASS*.

Any measurement reported by the test equipment shall have a specified accuracy. For accuracy requirements, see Clause 6. The field test equipment shall be capable of recording data at all measured points and uploading the data to a PC as described in 5.5.2 and provide summary results as described in 5.5.3.

5.5.2   Detailed results

The field test equipment shall be capable of recording all connectivity information, as well as the measured values of every parameter at every frequency data point.

In addition, the detailed results shall include a PASS/FAIL result for each of the following, as applicable for the selected performance level:

– wire map, including screen connection if present;
– insertion loss;
– NEXT, measured from local end;
– NEXT, measured from remote end;
– NEXT, power sum, at local end;
– NEXT, power sum, at remote end;
– ACR-N, at local end;
– ACR-N, at remote end;
– ACR-N, power sum, at local end;
– ACR-N, power sum, at remote end;
– ELFEXT or ACR-F at local end;
– ELFEXT or ACR-F, at remote end power sum;
– return loss, measured from local end;
– return loss, measured from remote end;
– propagation delay;
– delay skew;
– DC loop resistance;
– PS ANEXT;
– PS AACR-F.

5.5.3   Summary results

Detailed information may be required in certain circumstances; however, in general, summary performance information is sufficient. The field test equipment shall be capable of reporting the minimum summary information as shown in Table 5 and Table 6.

Table 5 – Summary of reporting requirements for field test equipment *(1 of 3)*

Function	Measured from local end or remote end (if measurements from both directions are not required)	Measured from remote end (if measurement from remote end is required)
Wire map	All connectivity, including shields (if present) PASS/FAIL	
Insertion loss	Worst case insertion loss (1 of 4 possible) Test limit at worst case insertion loss Frequency at worst case insertion loss Pair with worst case insertion loss PASS/FAIL	
NEXT	Worst case NEXT (1 of 6 possible) Test limit at worst case NEXT Frequency at worst case NEXT Pair combination at worst case NEXT PASS/FAIL	Worst case NEXT (1 of 6 possible) Test limit at worst case NEXT Frequency at worst case NEXT Pair combination at worst case NEXT PASS/FAIL
	Worst case NEXT margin (1 of 6 possible) Test limit at worst case NEXT margin Frequency at worst case NEXT margin Pair combination at worst case NEXT margin PASS/FAIL	Worst case NEXT margin (1 of 6 possible) Test limit at worst case NEXT margin Frequency at worst case NEXT margin Pair combination at worst case NEXT margin PASS/FAIL
NEXT power sum	Worst case power sum NEXT (1 of 4 possible) Test limit at worst case power sum NEXT Frequency at worst case power sum NEXT Pair at worst case power sum NEXT PASS/FAIL Worst case power sum NEXT margin (1 of 4 possible) Test limit at worst case power sum NEXT margin Frequency at worst case power sum NEXT margin Pair at worst case power sum NEXT margin PASS/FAIL	Worst case power sum NEXT (1 of 4 possible) Test limit at worst case power sum NEXT Frequency at worst case power sum NEXT Pair at worst case power sum NEXT PASS/FAIL Worst case power sum NEXT margin (1 of 4 possible) Test limit at worst case power sum NEXT margin Frequency at worst case power sum NEXT margin Pair at worst case power sum NEXT margin PASS/FAIL

Table 5 *(2 of 3)*

Function	Measured from local end or remote end (if measurements from both directions are not required)	Measured from remote end (if measurement from remote end is required)
ACR-N	Worst case ACR-N (1 of 6) Test limit at worst case ACR-N For each pair combination, ACR-N should be computed using the pair with the highest insertion loss for each frequency data point. Frequency at worst case ACR-N Pair combination at worst case ACR-N (disturbing, disturbed) PASS/FAIL Worst case ACR-N margin Test limit at worst case ACR-N margin Frequency at worst case ACR-N margin Pair combination at worst case ACR-N margin (disturbing, disturbed) PASS/FAIL	Worst case ACR-N (1 of 6) Test limit at worst case ACR-N For each pair combination, ACR-N should be computed using the pair with the highest insertion loss for each frequency data point. Frequency at worst case ACR-N Pair combination at worst case ACR-N (disturbing, disturbed) PASS/FAIL Worst case ACR-N margin Test limit at worst case ACR-N margin Frequency at worst case ACR-N margin Pair combination at worst case ACR-N margin (disturbing, disturbed) PASS/FAIL
ACR-N power sum	Worst case power sum ACR-N (1 of 4) For each pair combination, ACR-N should be computed using the pair with the highest insertion loss for each frequency data point. Test limit at worst case power sum ACR-N Frequency at worst case power sum ACR-N Pair combination at worst case power sum ACR-N (disturbing, disturbed) PASS/FAIL Worst case power sum ACR-N margin Test limit at worst case power sum ACR-N margin Frequency at worst case power sum ACR-N margin Pair combination at worst case power sum ACR-N margin (disturbing, disturbed) PASS/FAIL	Worst case power sum ACR-N (1 of 4) For each pair combination, ACR-N should be computed using the pair with the highest insertion loss for each frequency data point. Test limit at worst case power sum ACR-N Frequency at worst case power sum ACR-N Pair combination at worst case power sum ACR-N (disturbing, disturbed) PASS/FAIL-N Worst case power sum ACR-N margin Test limit at worst case power sum ACR-N margin Frequency at worst case power sum ACR-N margin Pair combination at worst case power sum ACR-N margin (disturbing, disturbed) PASS/FAIL

Table 5 *(3 of 3)*

Function	Measured from local end or remote end (if measurements from both directions are not required)	Measured from remote end (if measurement from remote end is required)
ELFEXT or ACR-F	Worst case ELFEXT or ACR-F (1 of 24 possible) Test limit at worst case ELFEXT/ACR-F Frequency at worst case ELFEXT/ACR-F Pair combination at worst case ELFEXT/ACR-F (disturbing, disturbed) PASS/FAIL Worst case ELFEXT/ACR-F margin Test limit at worst case ELFEXT/ACR-F margin Frequency at worst case ELFEXT/ACR-F margin Pair combination at worst case ELFEXT/ACR-F margin (disturbing, disturbed) PASS/FAIL	
ELFEXT power sum or ACR-F power sum	Worst case power sum ELFEXT or ACR-F (1 of 8 possible) Test limit at worst case power sum ELFEXT/ACR-F Frequency at worst case power sum ELFEXT/ACR-F Pairs at worst case power sum ELFEXT/ACR-F (disturbing, disturbed) PASS/FAIL Worst case power sum ELFEXT/ACR-F margin (1 of 8 possible) Test limit at worst case power sum ELFEXT/ACR-F margin Frequency at worst case power sum ELFEXT/ACR-F margin Pair at worst case power sum ELFEXT/ACR-F margin (disturbing, disturbed) PASS/FAIL	
Return loss	Worst case return loss margin (1 of 4 possible) Test limit at worst case return loss margin Return loss at worst case return loss margin Frequency at which worst case margin occurs PASS/FAIL	Worst case return loss margin (1 of 4 possible) Test limit at worst case return loss margin Return loss at worst case return loss margin Frequency at which worst case margin occurs PASS/FAIL
Propagation delay	Worst case propagation delay (1 of 4 possible) Test limit at worst case propagation delay. PASS/FAIL	
Delay skew	Worst case delay skew (1 of 1 possible) Test limit of delay skew PASS/FAIL	
DC loop resistance	Worst case DC loop resistance (1 of 4 possible) Test limit of DC loop resistance PASS/FAIL	

5.5.4 Reporting requirements for power sum alien crosstalk

The minimum requirements are given in Table 6.

Table 6 – Minimum reporting requirement for PS ANEXT and PS AACR-F

Parameter	Reporting requirement
Link information	Listing of all the disturbed links that have been tested
	The direction that the disturbed link has been tested
	A listing of all disturbing links that is contained in a power sum result for PS ANEXT and/or PS AACR-F
PS ANEXT margin	PS ANEXT Worst case margin over the applicable frequency range for every disturbed link tested
PS ANEXT margin magnitude	PS ANEXT Magnitude at which the worst case margin over the applicable frequency range occurs for every disturbed link tested
PS ANEXT margin frequency	PS ANEXT Frequency at which the worst case margin over the applicable frequency range occurs for every disturbed link tested
PS ANEXT margin limit	PS ANEXT limit at which the worst case margin over the applicable frequency range occurs for every disturbed link tested
Result PS ANEXT	PS ANEXT PASS or FAIL result for every disturbed link tested
PS AACR-F margin	PS AACR-F Worst case margin over the applicable frequency range for every disturbed link tested
PS AACR-F margin magnitude	PS AACR-F Magnitude at which the worst case margin over the applicable frequency range occurs for every disturbed link tested
PS AACR-F margin frequency	PS AACR-F Frequency at which the worst case margin over the applicable frequency range occurs for every disturbed link tested
PS AACR-F margin limit	PS AACR-F limit at which the worst case margin over the applicable frequency range occurs for every disturbed link tested
Result PS AACR-F	PS AACR-F PASS or FAIL result for every disturbed link tested

5.5.5 General

All appropriate parameters as specified in ISO/IEC 11801 (or equivalent) shall be tested.

5.5.6 Consistency checks for field testers

5.5.6.1 General

The field test equipment manufacturer shall make available to the user a simple procedure for verifying, reporting and recording the repeatability of the field test in the field. The following procedures shall be followed unless stated otherwise in a relevant specification.

5.5.6.2 Repeatability of tests on a reference link

The end-user of the field test equipment shall construct a reference link. Repeated measurements on this link shall result in the same results within the magnitude of the accuracy specifications. Comparisons shall be made between the worst results across the frequency band.

5.5.6.3 Repeatability of tests by testing the same link in opposite directions

Any link can be measured at first by connecting the main field test unit to one end of the cabling and the remote field test unit to the other end of the cabling. After performing a test, the locations of the main field test unit and the remote field test unit are exchanged.

5.5.7 Evaluation of consistency tests

All worst case magnitudes shall remain the same within twice the accuracy specification of the parameter under test, except for NEXT and return loss measurements. For NEXT and return loss, the local NEXT and return loss results obtained during the first test shall be compared to the remote NEXT and return loss results obtained during the second test. Similarly, the remote NEXT and return loss results obtained during the first test shall be compared to the local NEXT and return loss results during the second test.

5.5.8 Administration system applicability

In addition to PASS/FAIL indications, measured values of the test parameter shall be recorded in the administration system (see ISO/IEC 14763-1). Any reconfiguration of cabling components after testing may change the performance and thereby invalidate previous test results. Such cabling shall require retesting to confirm conformance.

5.5.9 Test equipment adapter cords for link testing

Adapter cords used to attach the field test equipment to the link under consideration shall be as specified by the test equipment manufacturer to be suitable for link measurements. Flexible cable and connecting hardware has a limited life-cycle and shall be inspected periodically for conformance to specifications (see 5.5.6).

The recommended minimum periodicity is 250 insertions.

Furthermore it is recommended to follow the manufacturer's instructions for the change of the tester adapter (e.g.: after 5 000).

5.5.10 User cords and channel testing

User cords are equipment cords, patch cords, or jumpers which are included as part of the channel. User cords shall be tested in place in a channel. A user cord may be verified by inserting the cord in the channel under test. If the channel conforms to the transmission requirements, the user cord is approved for use in that channel only. The patch cord shall remain in place and its orientation not reversed.

6 Field tester measurement accuracy requirements

6.1 General

Accuracy is the difference between the measured value reported by the field test equipment and the actual value. Accuracy is a function of the characteristics of the field test equipment as well as the transmission characteristics of the cabling.

Minimum performance levels have been identified for levels IIE, III, IIIE, IV and V field test equipment. Each accuracy level has it own set of performance requirements which are described hereinafter.

Error models for each of the measurements provide estimates for the measurement accuracy for each parameter to be measured. The error models use the most important performance parameters that are expected to influence measurement accuracy. However, there may be additional sources of measurement error that are not reflected in this error model, depending on the incorporation of the measurement circuitry in the field tester. Furthermore, there are numerous assumptions that may not always be achieved.

In addition to performance requirements for the properties of field testers, methods to compare the results obtained by field test equipment with those using laboratory methods are specified. Laboratory methods are described in 6.11. The deviation of the two results shall be no more than the total sum of the estimated measurement accuracy of the field test

equipment and estimated measurement accuracy of the laboratory measurement system. Since the observed measurement accuracy also depends on the properties of the links that are used in the comparison, the computed measurement accuracy per the error models in 6.10 shall be in harmony with the observed measurement accuracy as described in 6.11.

The following estimated measurement accuracy indicators are applicable to:

– permanent link pass fail limit for baseline and link,

– channel pass/fail limit for the channel,

– at the highest test frequency applicable to class D for level IIE, class E for level III, class E_A for level IIIE, class F for level IV and class F_A for level V.

In cases where measured insertion loss is less than 3 dB, the pass/fail limits for return loss shall not apply. In cases where measured insertion loss is less than 4 dB, the pass/fail limits for insertion loss and NEXT shall not apply.

NOTE 1 The measurement accuracy for all parameters except return loss exhibits worst-case accuracy at the highest test frequency. In case of return loss, the worst case occurs at low frequencies. However, at very low frequencies, the 3 dB rule discards low frequency results.

NOTE 2 The measurement accuracy for all parameters except return loss is dependent on the link or channel pass/fail limit. In case of return loss, the return loss measurement accuracy when computed at the permanent link pass/fail limit rather than the channel limit is degraded by approximately 0,4 dB.

NOTE 3 Practically, performance parameters of field testers are often considerably improved over those minimally required. The field tester manufacturer may specify improved measurement accuracy, and use this improved measurement accuracy to reduce the uncertainty band as depicted in Figure 22.

The actual accuracy specified by instrument manufacturers is called "nominal accuracy" and equals approximately half of the worst case accuracy as reported in Table 7 through Table 11.

Table 7 – Worst case propagation delay, delay skew, DC resistance and length measurement accuracy for level IIE, level III, level IV and level V test instruments

Test parameter Level IIE, III, IV,V	Baseline accuracy at permanent link limit	Link accuracy at permanent link limit	Channel accuracy at channel limit
Propagation delay	27 ns	27 ns	25 ns
Delay skew	10 ns	10 ns	10 ns
Length	4,6 m	4,6 m	5 m
DC resistance	1,2 Ω	1,2 Ω	1,3 Ω

**Table 8 – Worst case insertion loss, NEXT, ACR-N, ELFEXT/ACR-F
and return loss measurement accuracy for Level IIE test instruments**

Test parameter Level IIE	Baseline accuracy at permanent link limit	Link accuracy at permanent link limit	Channel accuracy at channel limit
Frequency	100 MHz	100 MHz	100 MHz
	dB	dB	dB
Insertion loss	1,3	1,7	1,9
NEXT	1,8	2,4	3,6
Power sum NEXT	1,9	2,3	3,8
ACR-N	2,3	3,0	4,2
Power sum ACR-N	2,3	2,9	4,4
ELFEXT	2,3	3,0	4,4
Power sum ELFEXT/ACR-F	2,4	3,1	4,8
Return loss	1,9	2,9	2,4

**Table 9 – Worst case insertion loss, NEXT, ACR-N, ELFEXT/ACR-F
and return loss measurement accuracy for Level III test instruments**

Test parameter Level III	Baseline accuracy at permanent link limit		Link accuracy at permanent link limit		Channel accuracy at channel limit	
Frequency	100 MHz	250 MHz	100 MHz	250 MHz	100 MHz	250 MHz
	dB	dB	dB	dB	dB	dB
Insertion loss	1,2	1,9	1,3	2,3	1,4	2,5
NEXT	1,8	2,8	2,3	3,6	2,9	4,2
Power sum NEXT	2,0	2,9	2,6	3,8	3,2	4,5
ACR-N	2,0	3,2	2,5	4,1	3,1	4,7
Power sum ACR-N	2,0	3,0	2,6	3,9	3,7	4,6
ELFEXT/ACR-F	1,8	3,1	2,2	4,1	3,4	5,0
Power sum ELFEXT/ACR-F	1,9	3,2	2,1	3,8	3,6	4,9
Return loss	2,8	2,5	3,5	4,3	2,9	3,9

**Table 10 – Worst case insertion loss, NEXT, ACR-N, ELFEXT/ACR-F and
return loss measurement accuracy for level IIIE test instruments**

Test parameter Level IIIe	Baseline accuracy at permanent link limit			Link accuracy at permanent link limit			Channel accuracy at channel limit		
Frequency	100 MHz	250 MHz	500 MHz	100 MHz	250 MHz	500 MHz	100 MHz	250 MHz	500 MHz
	dB	dB	dB	dB	dB	dB	dB	dB	dB
Insertion loss	1,2	1,9	2,7	1,3	2,3	2,8	1,4	2,5	3,1
NEXT	1,8	2,8	3,9	2,3	3,6	4,6	2,9	4,2	5,2
Power sum NEXT	1,9	2,9	4,0	2,6	3,8	4,7	3,2	4,5	5,4
ACR-N	2,0	3,2	4,5	2,5	4,1	5,2	3,1	4,7	5,9
Power sum ACR-N	2,0	3,0	4,1	2,6	3,9	4,8	3,3	4,6	5,5
ELFEXT/ACR-F	1,8	2,9	4,2	2,2	3,9	5,2	3,4	4,9	6,0
Power sum ELFEXT/ACR-F	1,8	2,9	4,2	2,1	3,6	4,8	3,5	4,7	5,6
Return loss	2,8	2,5	2,2	3,5	4,3	4,5	3,0	3,8	4,1

**Table 11 – Worst case insertion loss, NEXT, ACR-N, ELFEXT/ACR-F
and return loss measurement accuracy for level IV test instruments**

Test parameter Level IV	Baseline accuracy at permanent link limit			Link accuracy at permanent link limit			Channel accuracy at channel limit		
Frequency	100 MHz	250 MHz	600 MHz	100 MHz	250 MHz	600 MHz	100 MHz	250 MHz	600 MHz
	dB	dB	dB	dB	dB	dB	dB	dB	dB
Insertion loss	1,2	1,9	2,1	1,3	2,3	2,5	1,4	2,5	2,8
NEXT	2,1	2,8	3,7	2,5	3,6	4,7	3,8	4,8	5,4
Power sum NEXT	2,3	2,9	3,8	2,7	3,8	4,9	4,3	5,1	5,7
ACR-N	2,5	3,5	4,4	2,9	4,4	5,5	4,3	5,5	6,2
Power sum ACR-N	2,7	3,6	4,5	3,1	4,5	5,6	4,7	5,9	6,5
ELFEXT/ACR-F	2,3	3,6	4,5	2,9	4,5	5,6	4,3	5,6	6,3
Power sum ELFEXT/ACR-F	2,4	3,7	4,8	3,1	4,8	6,2	4,8	6,1	6,9
Return loss	2,7	2,4	2,4	3,2	2,8	2,7	2,7	2,5	2,4

**Table 12 – Worst case insertion loss, NEXT, ACR-N, ACR-F
and return loss measurement accuracy for level V**

Test parameter Level V	Baseline accuracy at permanent link limit				Link accuracy at permanent link limit				Channel accuracy at channel limit			
Frequency	100 MHz	250 MHz	600 MHz	1000 MHz	100 MHz	250 MHz	600 MHz	1000 MHZ	100 MHz	250 MHz	600 MHz	1000 MHz
	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB
Insertion loss	1,2	1,9	2,1	2,9	1,3	2,3	2,5	3,5	1,4	2,5	2,9	4,2
NEXT	2	2,9	3,7	4,3	2,3	3,7	4,7	5,4	2,6	3,9	5	6,1
Power sum NEXT	2,2	3	3,8	4,3	2,4	3,9	4,9	5,5	2,8	4,1	5,1	6,4
ACR-N	2,4	3,5	4,4	5,1	2,7	4,4	5,5	6,3	3,1	4,7	5,8	7,2
Power sum ACR-N	2,6	3,6	4,4	5,2	2,9	4,6	5,6	6,4	3,3	4,9	5,9	7,4
ACR-F	2,3	3,5	4,3	5,1	2,9	4,3	5,4	6,3	4,1	5,4	6,2	7,2
Power sum ACR-F	2,4	3,6	4,4	5,2	3,1	4,5	5,6	6,5	4,5	5,8	6,5	7,4
Return loss	2,7	2,4	2,4	2,4	3,2	2,8	2,7	2,9	2,7	2,5	2,4	2,6

6.2 Measurement accuracy specifications common to level IIE, level III, level IIIE, level IV and level V field testers

The measurement accuracy requirements for propagation delay, delay skew, and length for level IIE, level III, level IIIE, level IV and level V field testers are identical and shown in Table 13.

**Table 13 – Propagation delay, delay skew, DC resistance
and length accuracy performance specifications**

Performance parameter	Propagation delay	Delay skew	DC resistance	Length [a]
Range	0 µs to 1 µs at 10 MHz	0 ns – 100 ns at 10 MHz	0 Ω – 100 Ω	0 m – 305 m
Resolution	1 ns	1 ns	1 Ω	0,1 m
Accuracy	±(5 ns + 4 %)	±10 ns	±(1 Ω + 1 %)	±(1 m + 4 %)

[a]   Length is not a pass/fail measurement parameter per ISO/IEC 11801. The length accuracy is relative to the NVP calibration.

6.3 Accuracy performance requirements for Level IIE field testers

Level IIE field test equipment intended to test up to class D cabling shall conform to all individual requirements for each of the measurement functions at the reference plane of measurement for the test configuration. The baseline accuracy requirements apply at the measurement ports of the field tester; the link accuracy requirements apply at the reference planes for the permanent link or CP link and includes the impact on accuracy of the link adapter; the channel accuracy requirements apply at the reference planes for the channel and includes the impact on the accuracy of the channel adapter. A depiction of uncertainty bands applicable to NEXT measurements is shown in Figure 22. Table 14 summarises the accuracy performance requirements for this level.

Table 14 – Level IIE field tester accuracy performance parameters per IEC guidelines

Parameter	Baseline field tester	Field tester with Level IIE link adapter	Field tester with Level IIE channel adapter	
Dynamic range	3 dB over test limit (see conditions 1 and 2 below) PP NEXT and FEXT 60 dB, PS NEXT and FEXT 57 dB			dB
Amplitude resolution	0,1			dB
Frequency range and resolution	Insertion loss: 1 MHz – 100 MHz; 1 MHz NEXT, ELFEXT, ACR-F and return loss: 1 MHz – 100 MHz; 1 MHz – 31,25 MHz: 150 kHz 31,25 MHz – 100 MHz: 250 kHz			MHz
Dynamic accuracy NEXT	±0,75 (see condition 3 below)			dB
Dynamic accuracy ELFEXT/ACR-F	±1,0 (see condition 4 below)			dB
Source/load return loss	1 MHz – 5 MHz: 15 dB 5 MHz – 100 MHz: 20 dB	15 dB		dB
Random noise floor	$65 - 15 \log(f/100)$, 80 dB max			dB
Residual NEXT	$60 - 20 \log(f/100)$ (see condition 5 below)	$60 - 20 \log(f/100)$ (see condition 5 below)	$43 - 20 \log(f/100)$ (see condition 5 below)	dB
Residual FEXT	$55 - 20 \log(f/100)$ (see condition 5 below)	$55 - 20 \log(f/100)$ (see condition 5 below)	$35,1 - 20 \log(f/100)$ (see condition 5 below)	dB
Output signal balance and common mode rejection	$37 - 20 \log(f/100)$ (see condition 6 below)	$34 - 20\log(f/100)$ (see condition 6 below)		dB
Tracking	± 0,25 dB (see condition 7 below)	± 0,5 dB (see condition 8 below)		dB
Directivity	1 MHz – 10 MHz: 30 dB 10 MHz – 100 MHz: $30-2\log(f/10)$ (see condition 7 below)	25 dB (see condition 8 below)		dB
Source match	20 dB (see condition 7 below)	$18 - 20\log\left(\dfrac{f}{100}\right)$ 20 dB max (see condition 8 below)		dB
Return loss of termination	1 MHz – 5 MHz: 23 dB 5 MHz – 100 MHz: $35 - 1,5\sqrt{f}$ (see condition 7 below)	1 MHz – 5 MHz: 22 dB 5 MHz – 100 MHz: $15 - 20\log\left(\dfrac{f}{100}\right)$ 25 dB max (see condition 8 below)		dB

Condition 1: The dynamic range for NEXT and FEXT is 60 dB minimum.

Condition 2: The dynamic range for power sum NEXT and power sum FEXT is 57 dB minimum.

Condition 3: Dynamic accuracy requirements shall be tested up to the specified dynamic range for NEXT and FEXT.

Condition 4: Dynamic accuracy ELFEXT or ACR-F assumes a dynamic accuracy requirement of 0,75 dB for FEXT, which shall be tested, and that the dynamic accuracy performance for insertion loss and FEXT add to the ELFEXT or ACR-F dynamic accuracy shown. It is assumed that the dynamic accuracy performance for ACR-F equals the dynamic accuracy for ELFEXT.

Condition 5: The verification of residual NEXT and FEXT is up to 75 dB maximum. It is assumed that the frequency response changes 20 dB/decade.

Condition 6: Performance verification of output signal balance and common mode rejection is up to 60 dB maximum. It is assumed that the frequency response changes at a rate of 20 dB/decade.

Condition 7: Between 1 MHz and 5 MHz, the overall computed accuracy shall be better than 3,8 dB. This value may be achieved by any combination of tracking, directivity, source match and return loss of termination.

Condition 8: Between 1 MHz and 5 MHz, the overall computed accuracy shall be better than 4,8 dB. This value may be achieved by any combination of tracking, directivity, source match and return loss of termination.

6.4   Accuracy performance requirements for level III field testers

Level III field test equipment intended to test up to class E cabling shall conform to all individual requirements for each of the measurement functions at the reference plane of measurement for the test configuration. The baseline accuracy requirements apply at the measurement ports of the field tester. The link accuracy requirements apply at the reference planes for the permanent link or CP link and includes the impact on accuracy of the link plug adapter; the channel accuracy requirements apply at the reference planes for the channel and includes the impact on the accuracy of the channel adapter. A depiction of uncertainty bands applicable to NEXT measurements is shown in Figure 22. Table 15 summarises the accuracy performance requirements for this level.

Table 15 – Level III field tester accuracy performance parameters per IEC guidelines

Parameter	Baseline field tester	Field tester with level III link adapter (see conditions 7 and 8 below)	Field tester with level III channel adapter	
Dynamic range	3 dB over test limit (see conditions 1 and 2 below) PP NEXT and FEXT 65 dB, PS NEXT and FEXT 62 dB			dB
Amplitude resolution	0,1			dB
Frequency range and resolution	Insertion loss: 1 MHz – 100 MHz: 1 MHz NEXT, ELFEXT, ACR-F and return loss: 1 MHz – 100 MHz; 1 MHz – 31,25 MHz: 150 kHz 31,25 MHz – 100 MHz: 250 kHz 100 MHz – 250 MHz: 500 kHz			MHz
Dynamic accuracy NEXT	± 0,75 (see condition 3 below)			dB
Dynamic accuracy ELFEXT/ACR-F	± 1,0 (see condition 4 below)			dB
Source/load return loss	20 – 12,5 log(f/100), 20 dB max.	18 – 12,5 log(f/100), 20 dB max.		dB
Random noise floor	75 – 15 log(f/100), 85 dB max			dB
Residual NEXT	65 – 20 log(f/100) (see condition 5 below)	60 – 20 log(f/100) (see condition 5 below)	54 – 20 log(f/100) (see condition 5 below)	dB
Residual FEXT	65 – 20 log(f/100) (see condition 5 below)	65 – 20 log(f/100) (see condition 5 below)	43,1 – 20 log(f/100) (see condition 5 below)	dB
Output signal balance	40 – 20 log(f/100) (see condition 6 below)	37 –20 log(f/100) (see condition 6 below)		dB
Common mode rejection	40 –20 log(f/100) (see condition 6 below)	37 –20 log(f/100) (see condition 6 below)		dB
Tracking	± 0,5 dB			dB
Directivity	27- – 7 log (f/100), 30 dB max.	25 –20 log(f/100), 25 dB max.		dB
Source match	20 dB	20 –20 log(f/100), 20 dB max.		dB
Return loss of termination	25 –15 log (f/100), 25 dB max.	16 –15 log(f/100), 25 dB max.		dB
Condition 1: The dynamic range for NEXT and FEXT is 65 dB minimum.				
Condition 2: The dynamic range for power sum NEXT and power sum FEXT is 62 dB minimum.				
Condition 3: Dynamic accuracy requirements shall be tested up to the specified dynamic range for NEXT and FEXT.				
Condition 4: Dynamic accuracy ELFEXT or ACR-F assumes a dynamic accuracy requirement of ±0,75 dB for FEXT, which shall be tested, and that the dynamic accuracy performance for insertion loss and FEXT add to the ELFEXT or ACR-F dynamic accuracy shown. It is assumed that the dynamic accuracy performance for ACR-F equals the dynamic accuracy for ELFEXT.				
Condition 5: The verification of residual NEXT and FEXT is up to 85 dB maximum. It is assumed that the frequency response changes 20 dB/decade.				
Condition 6: Performance verification of output signal balance and common mode rejection is up to 60 dB maximum. It is assumed that the frequency response changes at a rate of 20 dB/decade.				
Condition 7: Link plug adapter NEXT shall be between the lower and upper ranges of test plugs as specified for category 6 in IEC 60603-7. Compliance with this requirement can also be demonstrated by performing a comparison test as in 6.11.3. In this case, a reference plug qualified per IEC 60603-7 shall be used to obtain the reference laboratory measurement.				
Condition 8: Link plug adapter FEXT shall be between the lower and upper ranges of test plugs as specified for category 6 in IEC 60603-7. Compliance with this requirement can also be demonstrated by performing a comparison test as in 6.11.3. In this case, a reference plug qualified per IEC 60603-7 shall be used to obtain the reference laboratory measurement.				

6.5   Accuracy performance requirements for level IIIE field testers

Level IIIE field test equipment intended to test up to class E_A cabling shall conform to all individual requirements for each of the measurement functions at the reference plane of measurement for the test configuration. The baseline accuracy requirements apply at the measurement ports of the field tester. The link accuracy requirements apply at the reference planes for the permanent link or CP link and include the impact on accuracy of the link plug adapter. The channel accuracy requirements apply at the reference planes for the channel and include the impact on the accuracy of the channel adapter. A depiction of uncertainty bands applicable to NEXT measurements is shown in Figure 22. Table 16 summarises the accuracy performance requirements for this level.

Table 16 – Level IIIE field tester accuracy performance parameters per IEC guidelines

Parameter	Baseline field tester	Field tester with level IIIE link adapter	Field tester with level IIIE channel adapter	
Dynamic range	3 dB over test limit (see conditions 1 and 2 below) PP NEXT and FEXT 65 dB, PS NEXT and FEXT 62 dB			dB
Amplitude resolution	0,1			dB
Frequency range and resolution	1 MHz – 31,25 MHz: 150 kHz 31,25 MHz – 100 MHz: 250 kHz 100 MHz – 250 MHz: 500 kHz 250 MHz – 500 MHz: 1 MHz			MHz
Dynamic accuracy NEXT	± 0,75 (see condition 3 below)			dB
Dynamic accuracy ELFEXT/ACR-F	± 1,0 (see condition 4 below)			dB
Source/load return loss	20 – 12,5 log(f/100), 20 dB max. 12,5 dB min	18 – 12,5 log(f/100), 20 dB max., 12 dB min		dB
Random noise floor	100 – 15 log(f/100) 90 dB max.	95 – 15 log(f/100) 85 dB max.		dB
Residual NEXT	65 – 20 log(f/100) (see condition 5 below)	60 – 20 log(f/100) (see conditions 5 and 7 below)	54 – 20 log(f/100) (see condition 5 below)	dB
Residual FEXT	65 – 20 log(f/100) (see condition 5 below)	65 – 20 log(f/100) (see conditions 5 and 8 below)	43,1 – 20 log(f/100) (see condition 5 below)	dB
Output signal balance	40 – 20 log(f/100) (see condition 6 below)	37 – 20 log(f/100) (see condition 6) below)		dB
Common mode rejection	40 – 20 log(f/100) (see condition 6 below)	37 – 20 log(f/100) (see condition 6) below)		dB
Tracking	± 0,5 dB	1 MHz – 250 MHz: ± 0,5 dB 250 MHz – 500 MHz: ± {0,5 + 0,000667·(f-250)} dB		dB
Directivity	(applicable when IL > 3 dB) 1 MHz – 300 MHz: 27 – 7 log(f/100), 30 dB max. 300 MHz – 500 MHz: 23,7 dB	25 – 20log(f/100), 25 dB max, 15 dB min		dB
Source match	20 dB	20 – 20 log(f/100), 20 dB max, 12 dB min		dB
Return loss of termination	(applicable when IL > 3 dB) 20 – 15 log(f/100), 25 dB max., 12,5 dB min	16 – 15 log(f/100), 25 dB max, 12 dB min		dB
Condition 1: The dynamic range for NEXT and FEXT is 65 dB minimum.				
Condition 2: The dynamic range for power sum NEXT and power sum FEXT is 62 dB minimum.				
Condition 3: Dynamic accuracy requirements shall be tested up to the specified dynamic range for NEXT and				

FEXT.

Condition 4: Dynamic accuracy ELFEXT or ACR-F assumes a dynamic accuracy requirement of ±0,75 dB for FEXT, which shall be tested, and that the dynamic accuracy performance for insertion loss and FEXT add to the ELFEXT or ACR-F dynamic accuracy shown. It is assumed that the dynamic accuracy performance for ACR-F equals the dynamic accuracy for ELFEXT of ACR-F.

Condition 5: The verification of residual NEXT and FEXT is up to 85 dB maximum. It is assumed that the frequency response changes at a 20 dB/decade rate.

Condition 6: Performance verification of output signal balance and common mode rejection is up to 50 dB maximum. It is assumed that the frequency response changes at a 20 dB/decade rate.

Condition 7: Link adapter plug NEXT loss shall between the lower and upper ranges of test plugs as specified for category 6 in IEC 60603-7. Compliance with this requirement can also be demonstrated by performing a comparison test as in 6.11.3. In this case, a reference plug qualified per IEC 60603-7 shall be used to obtain the reference laboratory measurement.

Condition 8: Link adapter plug FEXT loss shall be between the lower and upper ranges of test plugs as specified for category 6 in IEC 60603-7. Compliance with this requirement can also be demonstrated by performing a comparison test as in 6.11.3. In this case, a reference plug qualified per IEC 60603-7 shall be used to obtain the reference laboratory measurement.

6.6   Accuracy performance requirements for level IV field testers

Level IV field test equipment intended to test up to class F cabling shall conform to all individual requirements for each of the measurement functions at the reference plane of measurement for the test configuration. The baseline accuracy requirements apply at the measurement ports of the field tester. The link accuracy requirements apply at the reference planes for the permanent link or CP link and include the impact on accuracy of the link adapter; the channel accuracy requirements apply at the reference planes for the channel and include the impact on the accuracy of the channel adapter. A depiction of uncertainty bands applicable to NEXT measurements is shown in Figure 22. Table 17 summarises the accuracy performance requirements for this level.

These requirements apply to level IV field test equipment intended to test class F cabling utilizing category 7 connecting hardware either meeting the requirements of IEC 60603-7-7 or IEC 61076-3-104. In the modular 8-pin measurement mode, the Level III performance requirements shall apply.

Table 17 – Level IV field tester accuracy performance parameters per IEC guidelines

Parameter	Baseline field tester	Field tester with level IV link adapter	Field tester with level IV channel adapter	
Dynamic range	3 dB over test limit (see conditions 1 and 2 below) PP NEXT and FEXT loss 65 dB, PS NEXT and FEXT loss 62 dB			dB
Amplitude resolution	0,1			dB
Frequency range and resolution	1 MHz – 31,25 MHz: 150 kHz 31,25 MHz – 100 MHz: 250 kHz 100 MHz – 250 MHz: 500 kHz 250 MHz – 600 MHz: 1 MHz			MHz
Dynamic accuracy NEXT	± 0,75 (see condition 1 below)			dB
Dynamic accuracy ELFEXT/ACR-F	± 1,0 (see condition 2 below)			dB
Source/load return loss	1 MHz – 300 MHz: $20 - 12{,}5 \log(f/100)$, 20 dB max 300 MHz – 600 MHz: 14 dB	1 MHz – 300 MHz: $18 - 12{,}5 \log(f/100)$, 20 dB max 300 MHz – 600 MHz: 12 dB	1 MHz – 300 MHz: $18 - 12{,}5 \log(f/100)$, 20 dB max 300 MHz – 600 MHz: 12 dB	dB
Random noise floor	$100 - 15 \log(f/100)$ 90 dB max	$95 - 15 \log(f/100)$ 85 dB max		dB
Residual NEXT	$90 - 20 \log(f/100)$ (see condition 3 below)	$85 - 20 \log(f/100)$ (see condition 3 below)	$72{,}4 - 15 \log(f/100)$ Note 3	dB
Residual FEXT	$80 - 20 \log(f/100)$ (see condition 4 below)	$75 - 20 \log(f/100)$ (see condition 4 below)	$60 - 15 \log(f/100)$ (see condition 4 below)	dB
Output signal balance	$40 - 20 \log(f/100)$ (see condition 5 below)	$37 - 20 \log(f/100)$ (see condition 5 below)	$37 - 20 \log(f/100)$ (see condition 5 below)	dB
Common mode rejection	$40 - 20 \log(f/100)$ (see condition 5 below)	$37 - 20 \log(f/100)$ (see condition 5 below)	$37 - 20 \log(f/100)$ (see condition 5 below)	dB
Tracking	± 0,5 (see condition 6 below)			dB
Directivity	1 MHz – 300 MHz $27 - 7 \log(f/100)$, 30 dB max (see condition 6 below) 300 MHz – 600 MHz: 23,7 dB	1 MHz – 300 MHz $25 - 7 \log(f/100)$, 30 dB max (see condition 6 below) 300 MHz – 600 MHz: 21,7 dB	1 MHz – 300 MHz $25 - 7 \log(f/100)$, 30 dB max (see condition 6 below) 300 MHz – 600 MHz: 21,7 dB	dB
Source match	20 dB (see condition 6 below)			dB
Return loss of termination	1 MHz – 250 MHz: $20 - 15 \log(f/100)$, 25 dB max (see condition 6 below) 250 MHz – 600 MHz: 14 dB	1 MHz – 250 MHz: $18 - 15 \log(f/100)$, 25 dB max (see condition 6 below) 250 MHz – 600 MHz: 12 dB	1 MHz – 250 MHz: $18 - 15 \log(f/100)$, 25 dB max (see condition 6 below) 250 MHz – 600 MHz: 12 dB	dB

Condition 1: Verification of dynamic accuracy is required up to the specified range for NEXT and FEXT.

Condition 2: The dynamic accuracy is based on dynamic accuracy performance for insertion loss (attenuation) and NEXT, and is assumed to combine the dynamic accuracy for ELFEXT or ACR-F as specified. The FEXT dynamic accuracy is tested to ± 0,75 dB. The highest FEXT value to be measured is 70 dB.

Condition 3: Performance verification of residual NEXT is up to 85 dB maximum. It is assumed that the frequency response changes at a rate that is specified for category 7 connecting hardware. The impact of reflected FEXT effects of the adapter to residual NEXT are to be accommodated within this residual NEXT requirement.

Condition 4: Performance verification of residual FEXT is up to 85 dB maximum. It is assumed that the frequency response changes at a rate that is specified for category 7 connecting hardware.

Condition 5: Performance verification of output signal balance and common mode rejection is up to 50 dB maximum. It is assumed that the frequency response changes at a rate of 20 dB/decade.

Condition 6: The performance requirements for tracking, directivity, source match and return loss of termination are applicable when the insertion loss exceeds 3 dB. It assumed that the performance of link and channel adapters are verified after calibration with the baseline instrument.

6.7 Accuracy performance requirements for level V field testers

Level V field test equipment intended to test up to class F_A cabling shall conform to all individual requirements for each of the measurement functions at the reference plane of measurement for the test configuration. The baseline accuracy requirements apply at the measurement ports of the field tester. The link accuracy requirements apply at the reference planes for the permanent link or CP link and include the impact on accuracy of the link adapter; the channel accuracy requirements apply at the reference planes for the channel and include the impact on the accuracy of the channel adapter. A depiction of uncertainty bands applicable to NEXT measurements is shown in Figure 22. Table 18 summarises the accuracy performance requirements for this level.

These requirements apply to level V field test equipment intended to test class F_A cabling utilizing category 7 connecting hardware either meeting the requirements of IEC 60603-7-71 or IEC 61076-3-104. In the modular 8-pin measurement mode, the level III performance requirements shall apply.

Table 18 – Level V field tester accuracy performance parameters per IEC guidelines

Parameter	Baseline field tester	Field tester with level V link adapter	Field tester with Level V channel adapter	
Dynamic range	3 dB over test limit (see conditions 1 and 2 below) PP NEXT and FEXT loss 65 dB, PS NEXT and FEXT loss 62 dB			dB
Amplitude resolution	0,1			dB
Frequency range and resolution	1 MHz – 31,25 MHz: 150 kHz 31,25 MHz –100 MHz: 250 kHz 100 MHz – 250 MHz: 500 kHz 250 MHz – 600 MHz: 1 MHz 600 MHz –1 000 MHz: 2 MHz			MHz
Dynamic accuracy NEXT	±0,75 (see condition 1 below)			dB
Dynamic accuracy ELFEXT:ACR-F	±1 (see condition 2 below)			dB
Source/load return loss	1 MHz – 300 MHz: $20 - 12,5 \log(f/100)$, 20 dB max 300 MHz – 600 MHz: 14 dB 600 MHz – 1 000 MHz: $21 - 9*\log(f/100)$	1 MHz – 300 MHz: $18 - 12,5 \log(f/100)$, 20 dB 300 MHz – 600 MHz: 12 dB 600 MHz – 1 000 MHz: $19 - 9*\log(f/100)$	1 MHz – 300 MHz: $18 - 12,5 \log(f/100)$, 20 dB max below) 300 MHz – 600 MHz: 12 dB 600 MHz – 1 000 MHz: $19 - 9*\log(f/100)$	dB
Random noise floor	95 dB	90 dB	90 dB	dB
Residual NEXT	$90 - 20 \log(f/100)$ (see condition 3 below)	$85 - 20 \log(f/100)$ (see condition 3 below)	1 MHz – 600 MHz: dB $82,3 - 20 \log(f/100)$ 600 MHz – 1 000 MHz: $97,9 - 40 \log(f/100)$ (see condition 3 below)	dB
Residual FEXT	$80 - 20 \log(f/100)$ (see condition 4 below)	$75 - 20 \log(f/100)$ (see condition 4 below)	$63,9 - 20 \log(f/100)$ (see condition 4 below)	dB
Output signal balance	1 MHz – 600 MHz $40 - 20 \log(f/100)$ 600 MHz – 1 000 MHz 24,4 dB (see condition 5 below)	1 MHz – 600 MHz $37 - 20 \log(f/100)$ 600 MHz – 1 000 MHz 21,4 dB (see condition 5 below)	1 MHz – 600 MHz $37 - 20 \log(f/100)$ 600 MHz – 1 000 MHz 21,4 dB (see condition 5 below)	dB
Common mode rejection ratio	1 MHz – 600 MHz $40 - 20 \log(f/100)$ 600 MHz – 1 000 MHz 24,4 dB (see condition 5 below)	1 MHz – 600 MHz $37 - 20 \log(f/100)$ 600 MHz – 1 000 MHz 21,4 dB (see condition 5 below)	1 MHz – 600 MHz $37 - 20 \log(f/100)$ 600 MHz – 1 000 MHz 21,4 dB (see condition 5 below)	dB
Tracking	± 0,5 (see condition 5 below)			dB
Directivity	1 MHz – 300 MHz $27, 7 \log(f/100)$, 30 dB max 300 MHz – 600 MHz: 23,7 dB 600 MHz – 1 000 MHz: $30,7 - 9*\log(f/100)$ (see condition 6 below)	1 MHz – 300 MHz $25, 7 \log(f/100)$, 30 dB max 300 MHz – 600 MHz: 21,7 dB 600 MHz – 1 000 MHz: $28,7 - 9*\log(f/100)$ (see condition 6 below)	1 MHz – 300 MHz $25, 7 \log(f/100)$, 30 dB max 300 MHz – 600 MHz: 21,7 dB 600 MHz – 1 000 MHz: $28,7 - 9*\log(f/100)$ (see condition 6 below)	dB

Parameter	Baseline field tester	Field tester with level V link adapter	Field tester with Level V channel adapter	
Source match	20 dB (see condition 5 below)			dB
Return loss of termination	1 MHz – 250 MHz: 20-15 log(f/100) 25 dB max 250 MHz – 600 MHz: 14 dB 600 MHz – 1 000 MHz: 21 –9 log(f/100) (see condition 6 below)	1 MHz – 250 MHz: 18-15 log(f/100) 25 dB max 250 MHz – 600 MHz: 12 dB 600 MHz – 1 000 MHz: 19 –9 log(f/100) (see condition 6 below)	1 MHz – 250 MHz: 18-15 log(f/100) 25 dB max 250 MHz – 600 MHz: 12 dB 600 MHz – 1 000 MHz: 19 –9 log(f/100) (see condition 6 below)	dB
Condition 1: Verification of dynamic accuracy is required up to the specified range for NEXT and FEXT.				
Condition 2: The dynamic accuracy is based on dynamic accuracy performance for insertion loss (attenuation) and NEXT, and is assumed to combine the dynamic accuracy for ELFEXT or ACR-F as specified. The FEXT dynamic accuracy is tested to ± 0,75 dB. The highest FEXT value to be measured is 70 dB.				
Condition 3: Performance verification of residual NEXT is up to 85 dB maximum. It is assumed that the frequency response changes at a rate that is specified for category 7A connecting hardware. The impact of reflected FEXT effects of the adapter to residual NEXT are to be accommodated within this residual NEXT requirement.				
Condition 4: Performance verification of residual FEXT is up to 85 dB maximum. It is assumed that the frequency response changes at a rate that is specified for category 7A connecting hardware.				
Condition 5: Performance verification of output signal balance and common mode rejection is up to 50 dB maximum. It is assumed that the frequency response changes at a rate of 20 dB/decade.				
Condition 6: The performance requirements for tracking, directivity, source match and return loss of termination are applicable when the insertion loss exceeds 3 dB. It assumed that the performance of link and channel adapters are verified after calibration with the baseline instrument.				

6.8 Field tester requirements applicable to alien crosstalk measurements

The field tester shall comply to all requirements that are applicable to the regular link measurements as in 6.5, 6.6 or 6.7.

$$\text{Measurement Floor} \geq 95 - 20\log\left(\frac{f}{100}\right), 95 \text{ dB maximum} \tag{46}$$

The power sum measurement floor of the test device using an estimated maximum number of power sum crosstalk measurements shall be determined. The actual power sum correction as a function of the actual number of disturbing pairs is computed from the worst case power sum measurement floor. Refer to 5.4.7.4 for more information.

6.9 Procedures for determining field tester parameters

6.9.1 General

Field test equipment is designed with two units that are attached to opposite ends of the cabling to be tested. Internal to these units are source and load ports that are used for measurements. The following measurements shall be used to determine compliance with the specified requirements, and shall apply to the entire frequency range specified in these tables.

The field test equipment parameters shall be verifiable by independent parties. The field test equipment shall include functionality to make independent verification possible. The field tester manufacturers shall make them available to independent parties for measurement purposes. Elaborate laboratory instrumentation may be required to perform these tests.

6.9.2 Output signal balance (OSB)

This performance requirement is applicable to:

– NEXT and power sum NEXT measurements,

– FEXT and power sum FEXT measurements.

The field test instrument shall be connected to ground for the measurement as near as possible to the port to be measured. This shall provide a low impedance path to instrument ground of the field test instrument over the specified frequency range. The OSB compliance test shall be conducted without and with a polarity reversal. If there is a pass condition with one polarity and a failure with the other polarity, the average value shall be used to determine compliance with the requirements. See Figure 23.

Key
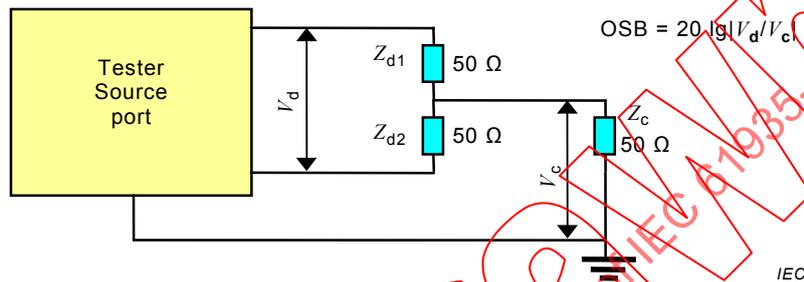
Tester	field tester
Source port	output port connected to the cabling
OSB	output signal balance
V_d	differential mode output voltage
V_c	common mode output voltage
Z_{d1}, Z_{d2}	differential termination (1/2 of nominal impedance each)

$Z_{d1} = Z_{d2} = 50\ \Omega \pm 1\ \%$; Z_{d1} and Z_{d2} are matched to $\pm\ 0,1\ \%$

Z_c termination to common terminal; $Z_c = 50\ \Omega \pm 1\ \%$

total common mode impedance equals $\left(\dfrac{Z_{d1} \cdot Z_{d2}}{Z_{d1} + Z_{d2}} \right) + Z_c$

**Figure 23 – Block diagram for measuring output signal balance**

6.9.3 Common mode rejection (CMR)

This performance requirement is applicable to:

– NEXT and power sum NEXT measurements,

– FEXT and power sum FEXT measurements.

Common mode rejection is defined as the ratio of the measured differential voltage to a common mode voltage applied to the load port. (V_c/V_m is used to make the value positive per convention.) The field test equipment shall be connected to ground for the measurement as near as possible to the port to be measured. This connection shall provide a low impedance path to the signal ground of the field tester over the specified frequency range. The CMR compliance test shall be conducted without and with a polarity reversal. If there is a pass condition with one polarity and a failure with the other polarity, the average value shall be used to determine compliance with the requirements. See figure 24.

$$\text{CMR} = 20 \lg|V_\mathbf{c}/V_\mathbf{m}|$$

IEC

Key
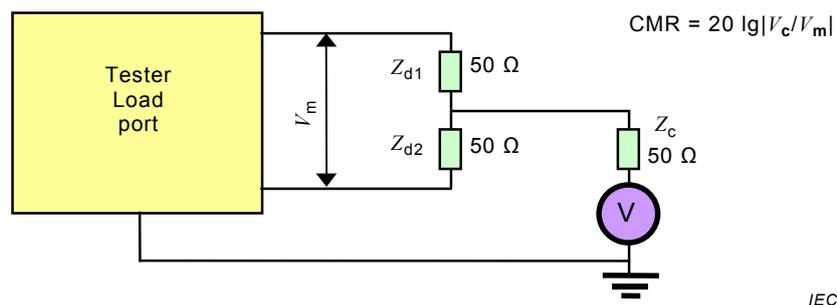
Tester	field tester
Load port	measurement port connected to the cabling
CMR	common mode rejection
V_m	differential mode signal measured by the field tester
V_c	common mode voltage applied to the field tester measurement port connections
$Z_{\mathrm{d}1}$, $Z_{\mathrm{d}2}$	differential termination (1/2 of nominal impedance each)

$Z_{\mathrm{d}1} = Z_{\mathrm{d}2} = 50\ \Omega \pm 1\ \%$; $Z_{\mathrm{d}1}$ and $Z_{\mathrm{d}2}$ are matched to $\pm 0{,}1\ \%$

Z_c	common mode source impedance; $Z_\mathrm{c} = 50\ \Omega \pm 1\ \%$

Figure 24 – Block diagram to measure common mode rejection

6.9.4 Residual NEXT

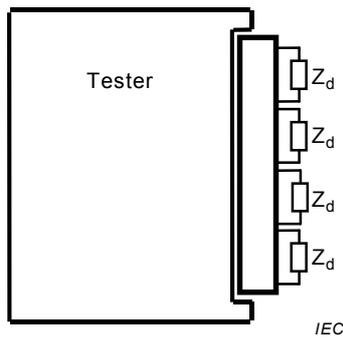This performance requirement is applicable to:

– NEXT and power sum NEXT measurements.

Residual NEXT is the measured voltage, V_m, at the load port due to the source port voltage, V_o, with the field test instrument measuring NEXT, $Z_\mathrm{d} = 100\ \Omega$, with return loss < 20 dB over the specified frequency range. Measured voltage is the voltage determined by the field test equipment. A procedure measuring voltage with an external voltmeter at the output detector is acceptable if equivalency can be demonstrated.

$$\text{Residual NEXT} = -20 \log(V_\mathrm{m}/V_\mathrm{c}) \tag{47}$$

The termination to the field test equipment shall be applied at the same location that a through connection will measure 0 dB reference (excluding additional insertion loss of test leads). In some field test equipment this will be at the end of the test leads.

V_0 is applied to each resistor Z_d, one at a time, while V_m is the measured voltage across another Z_d when the test equipment is measuring NEXT. An appropriate allowance shall be made for FEXT coupling in the adapter, which in combination with reflections of the test configuration will contribute to residual NEXT. This is expected to be significant for a channel test adapter. See Figure 25.

Key

Tester   field tester

Z_d termination load equal to the nominal impedance (100 Ω)

Figure 25 – Block diagram for measuring residual NEXT

6.9.5 Dynamic accuracy

This performance requirement is applicable to:

- NEXT and power sum NEXT measurements,
- FEXT and power sum FEXT measurements,
- insertion loss measurements.

Dynamic accuracy is the accuracy of the measured value to an external voltage input. The voltage input shall provide a minimum source balanced input of 40 dB with a minimum return loss of 20 dB. See Figure 26.

Key
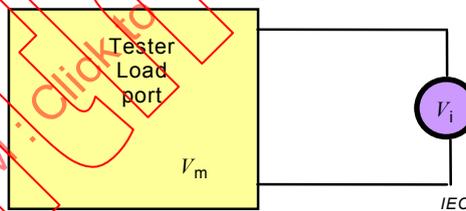
Tester   field tester

Load port   measurement port connected to the cabling

V_m differential mode signal measured by the field tester

V_i input voltage applied to the field tester

Figure 26 – Block diagram for measuring dynamic accuracy

V_i could be sourced by the field instrument under test and injected into the receiver through a resistive attenuator when the residual crosstalk is 30 dB below the injected signal level.

6.9.6 Source/load return loss

This performance requirement is applicable to:

- NEXT and power sum NEXT measurements,
- ELFEXT or ACR-F and power sum ELFEXT or ACR-F measurements,
- insertion loss measurements.

The source and load return loss of the insertion loss, NEXT and ELFEXT measurement functions shall be measured with a network analyzer calibrated to a 100 Ω resistor with return loss of better than 40 dB over the frequency range of interest.

When the calibration includes an impedance matching transformer/balun then a better than 40 dB longitudinal conversion loss shall be required.

$$\text{Return loss} = -20 \log(V_{\text{reflected}} / V_{\text{incident}}) \tag{48}$$

6.9.7 Random noise floor

This performance requirement is applicable to:

- NEXT and power sum NEXT measurements,
- ELFEXT or ACR-F and power sum ELFEXT or ACR-F measurements.

The random noise floor is the ratio of the measured voltage V_{m} when the source port voltage is zero, to the source port voltage V_{o} under normal measurement conditions.

$$\text{Return loss} = -20 \log(V_{\text{m}} / V_{\text{o}}) \tag{49}$$

A procedure measuring voltage with an external voltmeter at the output of the detector is acceptable if it demonstrates equivalency.

6.9.8 Residual FEXT

This performance requirement is applicable to:

- FEXT and power sum FEXT measurements.

The FEXT of the local instrument connector can be determined by measuring the FEXT using an external receiver and the FEXT of the remote instrument connector can be determined using an external signal generator (see Figure 27). The responses can be normalized by connecting the receiver to the stimulus pair and the signal generator to the measurement pair of the local instrument and remote instrument respectively.


Key
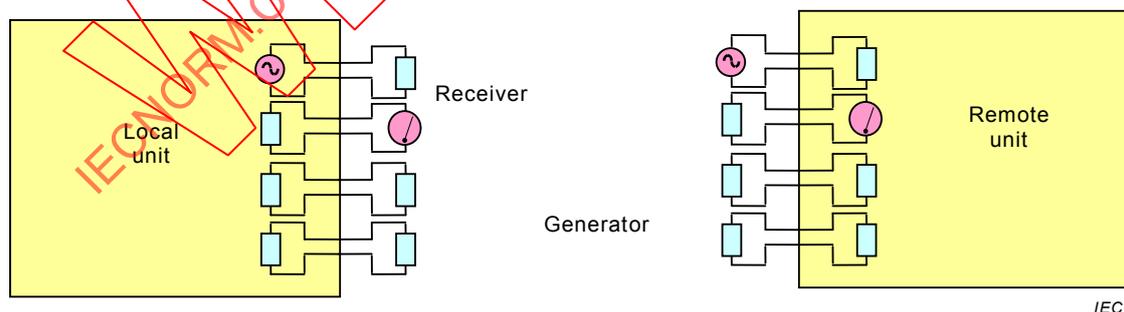
Local unit   local field tester unit

Remote unit   remote field tester unit

Receiver   external receiver measuring signal from local unit

Generator   external generator applying signal to remote unit

Figure 27 – Principle of measurement of residual FEXT

Alternately, the residual FEXT may be measured by interconnecting the local and remote field tester units using individual pairs in multiple cables. In the first measurement configuration the

wires are as short as possible and of equal length. In the second measurement configuration, the length difference between pairs is selected so that a phase delay of approximately 180° at 100 MHz results. This may also be accomplished by a tip/ring reversal in one of the pairs. The worst case residual FEXT of both measurement configurations shall be used, and one half of this amount shall be assigned to the connection at each end. See Figure 28.

Key
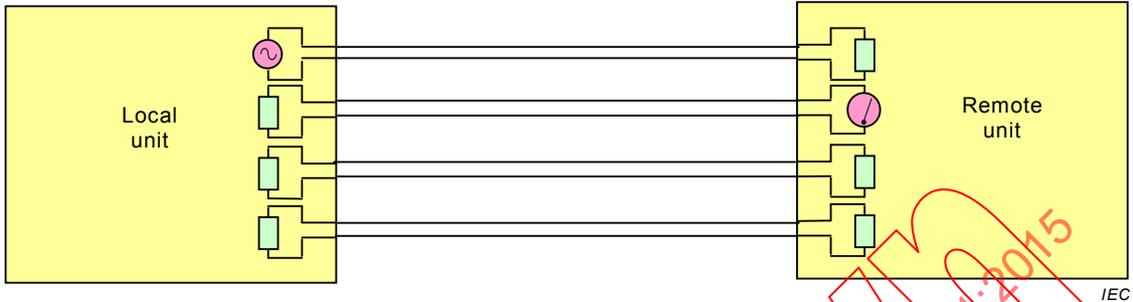
Local unit   local field tester unit

Remote unit   remote field tester unit

Figure 28 – Principle of alternate measurement of residual FEXT

6.9.9 Directivity

This performance requirement is applicable to:

– return loss measurements.

Directivity is a measured of the signal that couples into the measurement channel and adds to the reflected signal that is measured. It is measured by performing a return loss measurement when terminating each wire-pair of the test interface with 100 Ω r.f. chip resistors that have a return loss better than 40 dB from 1 MHz to the upper frequency limit of the class.

6.9.10 Tracking

This performance requirement is applicable to:

– return loss measurements.

Tracking is the response of the transducer used to determine the reflected signal. It is determined from two measurements:

– measurement of return loss with all wire-pairs short-circuited (the actual reflection coefficient is −1) as a function of frequency;

– measurement of return loss with all wire-pairs open-circuit as a function of frequency (the actual reflection coefficient is +1).

The average value of the two measurements is the tracking error in decibels (dB). If the measured results are expressed in positive decibel values, the tracking error is given by the following Formula:

$$Tracking_{dB} = -20 \lg \left(\frac{10^{\frac{-RL_{short,dB}}{20}} + 10^{\frac{-RL_{open,dB}}{20}}}{2} \right) \tag{50}$$

6.9.11 Source match

This performance requirement is applicable to:

– return loss measurements.

Source match is a measurement of the reflected signal that is not absorbed by the return loss measurement circuitry. It is determined from the measurements of directivity, return loss with shorted wire-pairs and return loss with open wire-pairs. With results of all measurements expressed in positive decibel values, the source match error is given by the following Formula:

$$Source\_Match_{\text{dB}} = -20\lg\left(\left|\frac{-10^{\frac{-RL_{\text{short,dB}}}{20}} + 10^{\frac{-RL_{\text{open,dB}}}{20}}}{2}\right| + 10^{\frac{-Directivity_{\text{dB}}}{20}}\right) \tag{51}$$

In case phase information is available, this Formula may be changed to include relevant phase effects.

6.9.12 Return loss of remote termination

This performance requirement is applicable to:

– return loss measurements.

The requirements for return loss of the remote termination exceed those for the source/load return loss of the insertion loss, NEXT and FEXT measurement functions. In order to perform this measurement a network analyser with S-parameter test set, capable of providing one-port calibration, shall be used as described for the source/load return loss measurement of the insertion loss, NEXT and FEXT functions. The return loss of the termination of each pair shall be separately determined.

6.9.13 Constant error term of the propagation delay measurement function

The parameters which affect propagation delay accuracy includes a constant error term E_c and a term E_d.

The constant error term E_c is determined by connecting the main and the remote unit through a shorted possible cable. The measured delay is E_c.

For determining proportional error term E_d, First, the propagation delay Tr,100 of approximately 100 m long cable, is measured using the reference measurement method.

Second, the propagation delay of the same cable is measured using the field tester (Tft,100).

E_d is determined as:

$$E_d = |Tr,100 - Tft,100| / Tr,100 \tag{52}$$

6.9.14 Error constant term proportional to propagation delay of the propagation delay measurement function

The propagation delay of cabling with a total length of approximately 100 m shall be measured using the reference measurement procedure. The propagation delay at 10 MHz is the reference value.

The same cabling shall be connected to the field tester and the propagation delay measured. The reported value by the field tester minus the reported value measured when a very short connection was made to the same field tester shall deviate less from the error constant which is proportional to the propagation delay of the propagation delay measurement function.

6.9.15 Constant error term of the delay skew measurement function

To verify the accuracy of the delay skew measurement, a 100 m ± 5 m link with special patch cords as described in the reference measurement procedure for propagation delay shall be used. The length of the pair with the highest propagation delay shall be extended so that the delay skew of these pairs is approximately 50 ns as measured using the phase delay measurement function of the network analyzer and determined at a frequency of 10 MHz.

When the link is measured with the field tester, the reported delay skew of the two pairs shall be within 10 ns of the value at a frequency of 10 MHz measured using the reference procedure.

6.9.16 Constant error term of the length measurement function

The constant error term of the length measurement function is determined by connecting the main unit to the remote unit through a short test cable and observing the length that is reported. The reported length shall be less than the constant error term of the length measurement function.

6.9.17 Error constant proportional to the length of measurement function (assuming the cables are taken from the same drum)

A length of cabling with a total length of approximately 100 m shall be measured using a tape measure and the NVP calibration shall be performed. A cable with a known length of approximately 50 m shall then be submitted to NVP calibration.

The reported lengths shall deviate from the actual values by less than half the amount of the error constant proportional to length.

6.9.18 Constant error term of the DC resistance measurement function

This procedure is determined by connecting a connector with shorts across each pair. The reported DC resistance in each case shall be less than the constant error term of the DC resistance measurement function.

6.9.19 Error constant term proportional to DC resistance of the DC resistance measurement function

The DC resistance of cabling with a total length of approximately 100 m shall be measured using a four-terminal ohmmeter with a specified accuracy of at least 0,25 %. The reference DC resistance measurement procedure shall be used.

The DC resistance of the same cabling, measured by the field tester, less the observed DC resistance value with the pairs shorted, shall be less than the error constant which is proportional to the DC resistance.

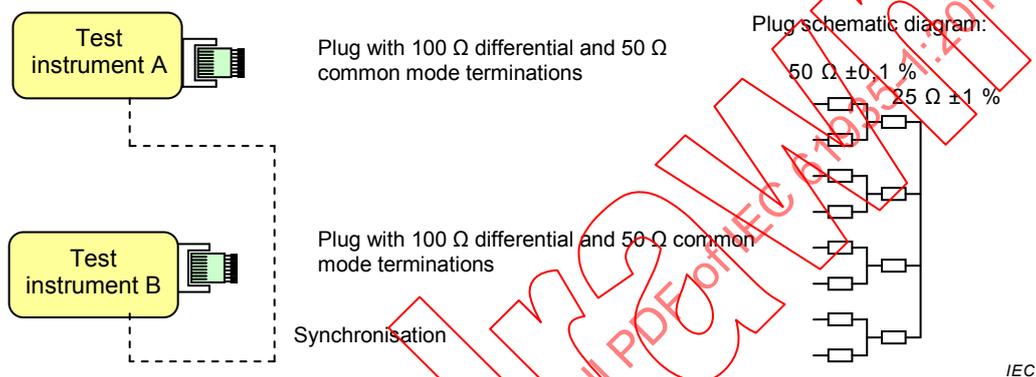### 6.9.20 Measurement floor for alien crosstalk testing during field testing

6.9.20.1 General

The power sum measurement floor of the test device using a maximum number of power sum crosstalk measurements shall be determined. This measurement floor shall be used to compute the baseline power sum correction for the actual number of alien crosstalk results that are included in the overall PS ANEXT or PS AFEXT results, if used. It is suggested that

the power sum measurement floor consists of 100×4 measurements. Refer to 5.4.7.4 for more information.

6.9.20.2 Measurement floor of the test device for the channel test configuration

The measurement floor of the test device shall be established in the channel test configuration by terminating the channel with plugs that have both differential and common mode terminations as shown in Figure 29. Test instrument A operates as a receiver and test instrument B operates as a signal source. Test instrument A and test instrument B communicate as shown with the dotted line labelled "synchronization". A physical field tester control link is an option of this standard. Other implementations of this measurement are acceptable if equivalence is demonstrated. In case a link topology is tested, the channel adapters are replaced with link adapters.
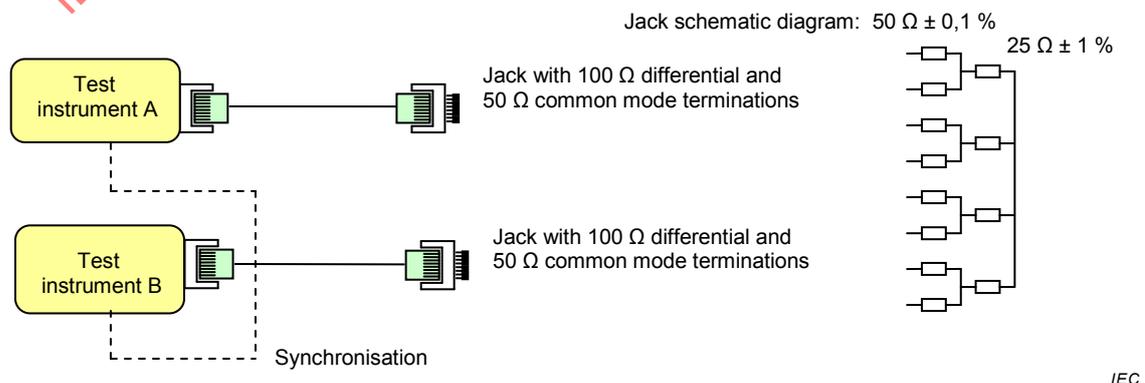

Figure 29 – Alien crosstalk measurement floor test for the channel test configuration

Conduct a single disturbed to disturbing PS ANEXT loss measurement. The power sum measurement floor of any pair shall exceed the specified measurement floor in 6.8: Formula (46) – 6 dB.

6.9.20.3 Measurement floor of the test device with link adapter test cords

A PS ANEXT loss measurement is made by terminating the test cords with differential and common mode terminating jacks as shown in Figure 30. Test instrument A operates as a receiver and test instrument B operates as a signal source. Test instrument A and test instrument B communicate as shown with the dotted line labelled "synchronization". A physical field tester control link is an option of this standard. Other implementations of this measurement are acceptable if equivalence is demonstrated.

Figure 30 – Alien crosstalk measurement floor test for the link test configurations

The power sum measurement floor of any pair shall exceed the specified measurement floor in 6.8: Formula (46) – 6 dB.

6.10 Measurement error models

6.10.1 General

The measurement accuracy for the link and channel is computed from a baseline accuracy and errors caused by test cables and adapters.

The error models used to estimate the baseline measurement accuracy of the field test equipment are based on the twelve parameter error model defined for network analyzer measurements with modifications and simplifications. There is no guarantee that these simplifications and modifications are appropriate in every circumstance and that the error model is complete. Nevertheless, the computed estimated measurement accuracies from the error models shown in this subclause are a reasonable indication of the measurement performance that may be expected from a compliant field tester. The computed estimated measurement accuracy shall be in harmony with the results from network analyser comparisons.

6.10.2 Error model for the insertion loss measurement function

$$Accuracy_{IL} = E_{d,IL} + 20\lg\left[\frac{1+10^{\frac{-E_{RL,\text{tester}}}{10}}}{\left(1+10^{\frac{\left(E_{RL,\text{tester}}+E_{RL,\text{link}}\right)}{20}}\right)^2}\right] \tag{53}$$

where

$Accuracy_{IL}$ is the estimated accuracy of the insertion loss measurement function, in dB;

$E_{d,IL}$ is the dynamic accuracy of the tester for insertion loss, in dB;

$E_{RL,\text{tester}}$ is the source/load return loss of the teste,r in dB;

$E_{RL,\text{link}}$ is the return loss of the link, in dB.

Assumptions:

– the dynamic accuracy adds up to all other error terms;

– the error from the source/load return loss of the tester plus the impact of the source/load interaction with the return loss of the link is added;

– the impact of the test cable for the measurement of the link and connector used for the channel interface are expected to have a significant effect on the source/load return loss of the field tester.

6.10.3 Error model for the NEXT measurement function

$$Accuracy_{NEXT} = E_{d,NEXT} + 20\lg\left[\begin{array}{l}1+10^{\frac{-E_{RL,\text{tester}}}{10}}+2\cdot10^{\frac{-\left(E_{RL,\text{tester}}+E_{RL,\text{link}}\right)}{20}}\\+\sqrt{10^{\frac{A_{NEXT}-E_{RN}}{10}}+10^{\frac{A_{NEXT}-E_{NF}}{10}}+10^{\frac{S_C-E_B}{10}}+10^{\frac{S_D-E_C}{10}}}\end{array}\right] \tag{54}$$