IEC 61935-1

Edition 3.0 2009-07

INTERNATIONAL STANDARD

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

IEC 61935-1:2009(E)

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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 third edition cancels and replaces the second edition published in 2005, and constitutes a technical revision.

This edition differs from the second edition in that it includes test methods for exogenous (alien) crosstalk. It also includes a new annex for uncertainty and variability of field test results.

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

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

FDIS	Report on voting
46/323/FDIS	46/332/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 of the IEC 61935 series, 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 maintenance result 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- withdrawn,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.

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 cables.

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 IEC 60603-7 family of standards or IEC 61076-3-104 and IEC 61076-3-110. In the case 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;
- 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 and IEC 61076-3-110 respectively.

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

NOTE 3 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.

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, IEEE 1394b[1]). 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 document, 4-pair cabling is assumed. The test procedures described in this standard may also be used to evaluate 2-pair balanced cabling. However, 2-pair cabling links that share the same sheath with other links are tested as 4-pair cabling.

[1] IEEE 1394b: 2002, *High Performance Serial Bus (High Speed Supplement)*

2 Normative references

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

IEC 60169-22, *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, *Connectors for electronic equipment – Part 7: Detail specification for 8-way, unshielded, free and fixed connectors*

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

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

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

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

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

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

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

IEC 61156-7, *Multicore and symmetrical pair/quad cables for digital communications – Part 7: Symmetrical pair cables with transmission characteristics up to 1 200 MHz – Sectional specification for digital and analog communication cables*

IEC 61156-8, *Multicore and symmetrical pair/quad cables for digital communications – Part 8: Symmetrical pair/quad cables with transmission characteristics up to 1 200 MHz – Work area wiring – Sectional specification*

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

ISO/IEC/TR 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*

EN 50289-1-15, *Communication cables – Specifications for test methods – Part 1-15: Electromagnetic performance – Coupling attenuation of links and channels (Laboratory conditions)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply, in addition to the definitions included in ISO/IEC 11801.

3.1
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)

NOTE Examples are: patch cord, work area cable, link.

3.2
certification
measurements of installed cabling specified in ISO/IEC 11801 (e.g., class D, class E, class E_A, class F, class F_A)

This requires field testers with traceable accuracy to national standards.

3.3
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)

3.4
d.c. resistance
measure of the sum total of the d.c. resistance of the wires of a pair

3.5
delay skew
worst case value of the phase delay difference between any pair in the same cable assembly

3.6
electrical length
equivalent free-space length of the cable assembly

3.7
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 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 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 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 FEXT is expressed in dB.

3.8
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

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

3.9
nominal impedance
impedance for which the system is designed; the nominal impedance is resistive

3.10
output signal balance
OSB
ratio of the output common mode voltage to the output differential voltage generated by a source port

3.11
power sum (*NEXT* and *FEXT* and *ELFEXT*)
the combined cross-talk on a receiving pair from all disturbing links operating simultaneously

3.12
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)

3.13
qualification
measurements of installed cabling for specific network technologies (e.g., 100BASE-T, IEEE802.3 1000BASE-T, IEEE 1394b)

The measurement accuracy of field testers for qualification tests does not need to be traceable to national standards.

3.14
reference plane
reference position of the cabling under test or necessary mating connector at which the performance requirements are specified

3.15
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}.

$$C_{\mathrm{r}} = \left(\frac{| Z_{\mathrm{in}} - Z_{\mathrm{nom}} |}{| Z_{\mathrm{in}} + Z_{\mathrm{nom}} |} \right) \quad (1)$$

3.16
return loss
RL
ratio of the power delivered to a cable assembly terminated at the far end with its nominal characteristic impedance, to the reflected power at the input port of the cable assembly

$$RL = 20 \times \log_{10}\left(\frac{u_i}{u_r}\right) \quad \text{or} \quad RL = -20 \times \log_{10}\left(\frac{|Z_{in} - Z_{nom}|}{|Z_{in} + Z_{nom}|}\right) \qquad (2)$$

where

u_i is the incident voltage;

u_r is the reflection voltage.

3.17
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

3.18
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

3.19
verification
measurements of installed cable or cabling for continuity

No other transmission performance parameters other than connectivity are measured.

4 Reference measurement procedures for electrical properties

4.1 General

This clause 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 Test equipment considerations

4.2.1 General

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

4.2.2 Network analyzer test requirements

Usually, the input and output terminals of a network analyzer are unbalanced. R.F. transformers with balanced outputs (baluns) are required with unbalanced signal connections to the network analyzer.

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.

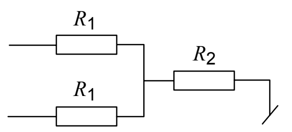
4.2.3 Termination of conductor pairs

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 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 d.c. and have a return loss greater than 40 − 10log(f/100) where f is the frequency in megahertz (MHz). 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.



where

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

R_1 = 50 Ω ± 0,1 %

and

$$R_2 = R_{com} - \frac{R_{dif}}{4} \quad (4)$$

R_2 = 25 Ω ± 1 %

where

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

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

Figure 1 – Resistor load

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.

4.2.4 Reference loads for calibration

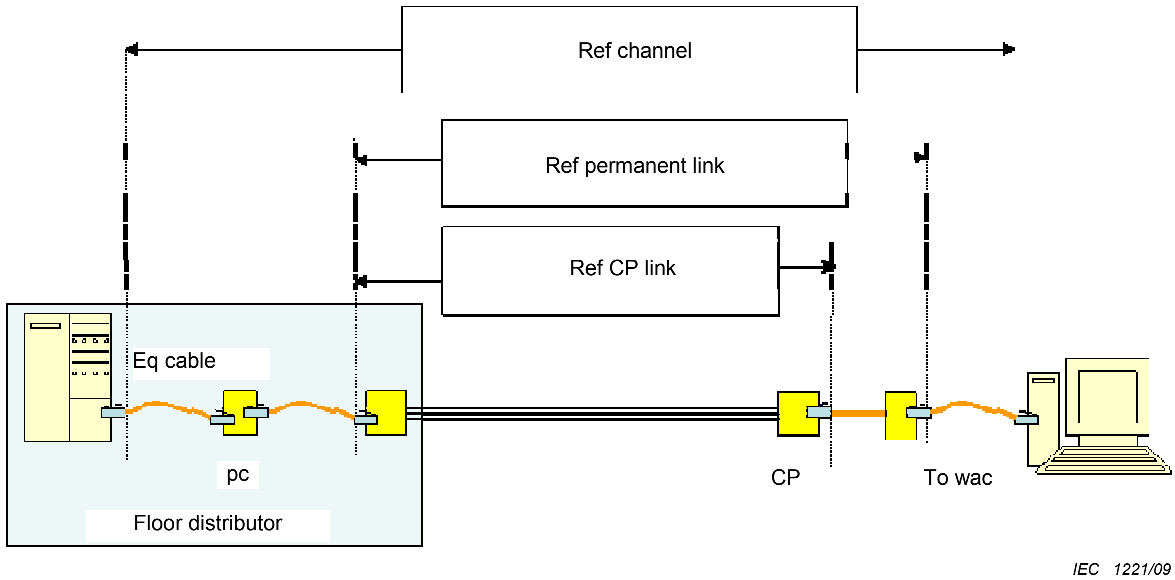
To perform a one or two-port calibration of the test equipment, a short circuit, an open circuit and an impedance termination are required. These devices shall be used to obtain a calibration at the reference plane.

The impedance 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, 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 centre 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 >40 dB at frequencies less than 100 MHz and $>40 - 10\log(f/100)$ at the higher frequencies for which the measurements are to be carried out.

4.2.5 Test configurations

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

- Channel. The channel test configuration is intended to be used by system designers and users of data communication systems to verify the performance of the overall channel. The channel as defined in ISO/IEC 11801 (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 distributor 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.



Key

Ref channel	reference planes for channel
Ref permanent link	reference planes for the permanent link
Ref CP link	reference planes for the CP link
TO	telecommunications outlet
CP	consolidation point
Eq cable	equipment cable
pc	patch cord
wac	work area cable

Figure 2 – Reference planes for permanent link and channel

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

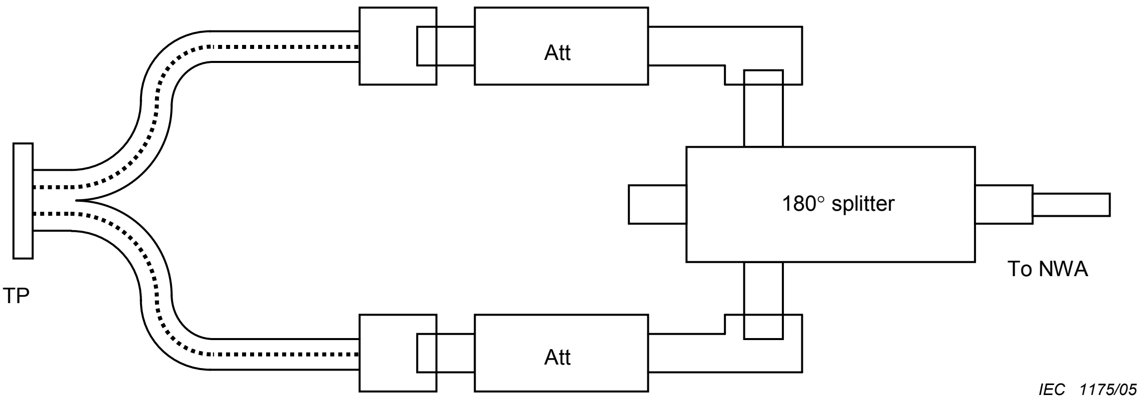
4.2.6 Coaxial cables and test leads for network analyzers

Coaxial cable assemblies between the network analyzer and baluns 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 shall be attached to a common ground plane.

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 each balun and the reference plane of the cabling under test. Pairs shall remain twisted from the baluns to where connections are made, and unscreened balanced test leads shall be separated by 5 mm from any ground plane.

4.2.7 Balun requirements

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° phase splitter
to NWA	connection to network analyzer
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 RFI shielded and shall comply with the requirements given in Table 1.

Table 1 – 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 – 1000 MHz	35 dB minimum
Common mode rejection[c]	60 dB minimum, 15 MHz – 350 MHz 50 dB minimum, 350 MHz – 600 MHz 10 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 analyzer 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

4.2.8 Network analyzer measurement precautions

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

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

b) consistent and stable baluns and resistor loads shall be used for each pair throughout the test sequence (see 4.2.3);

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

i) overload conditions of the network analyzer 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.

4.2.9 Data reporting and accuracy

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

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

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

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

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

This test is applicable to laboratory and installed cabling testing.

4.3.1 Objective

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

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 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.

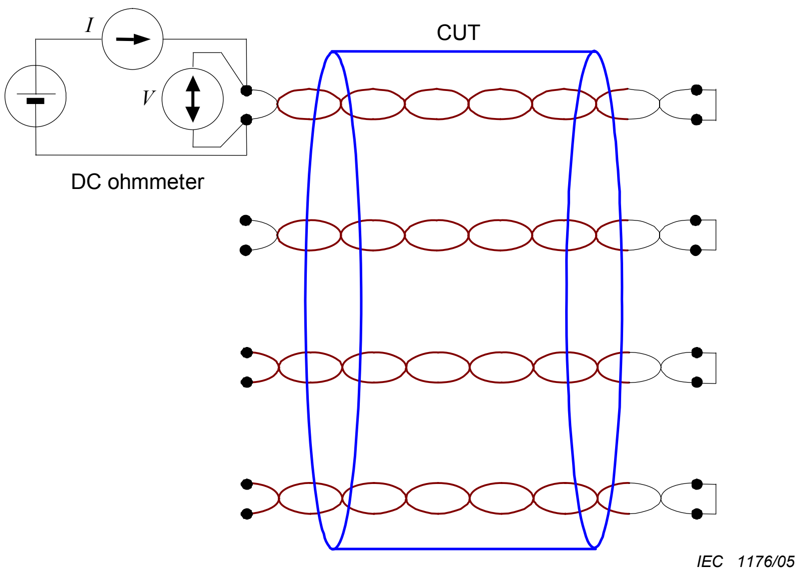
4.3.4 Procedure

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.

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
DC ohmmeter	d.c. ohmmeter

Figure 4 – Loop resistance measurement

4.3.5 Test report

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

4.3.6 Uncertainty

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

4.4 Direct current (d.c.) resistance unbalance

This test is applicable to laboratory cabling testing.

4.4.1 Objective

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

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 d.c. resistance unbalance is the ratio of the difference of the d.c. resistance of each wire within a pair related to the sum of the d.c. resistance of each wire

$$\Delta R = \frac{R_{\text{max}} - R_{\text{min}}}{R_{\text{max}} + R_{\text{min}}} \times 100 \qquad (6)$$

where

ΔR is the resistance unbalance expressed in %.

4.4.3 Test equipment and set-up

A four terminal ohmmeter suitable for low resistance measurements shall be used.

4.4.4 Procedure

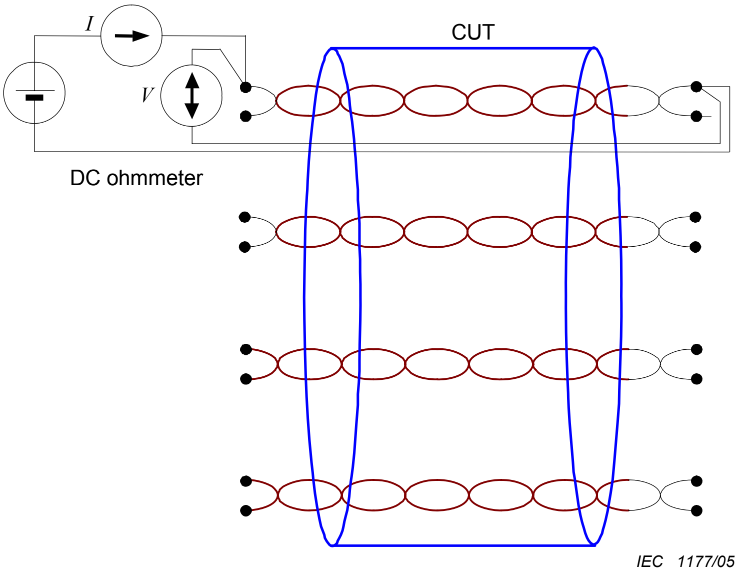
4.4.4.1 Calibration

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.

4.4.4.2 Measurement

Measure the d.c. resistance of each wire of a pair. Then calculate the d.c. resistance unbalance per Equation (6).

The d.c. 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
DC ohmmeter	d.c. ohmmeter

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 d.c. 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

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.

4.5.1 Objective

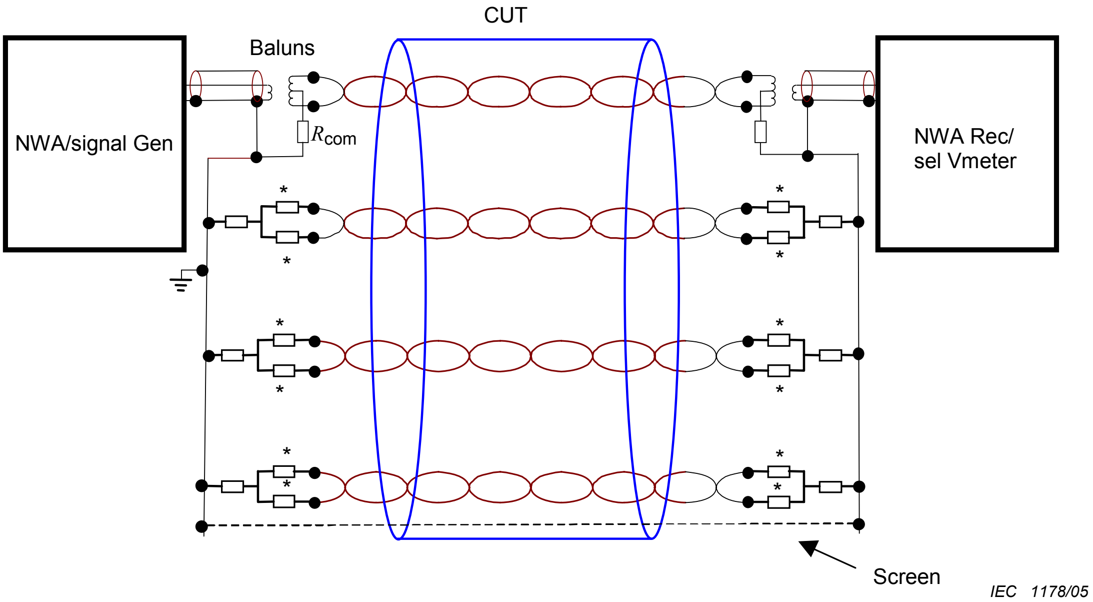
The objective of this test is to measure the insertion loss of the cabling being tested.

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 / Sig gen	signal generator of network analyzer or signal generator
NWA receiver / Sel Vmeter	receiver of network analyzer 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.

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 4.2.3 when not under test. The loads according to 4.2.3 shall be applied at the test cable pairs. Common mode loads are not needed for pairs not under test. Measurements shall be performed in the specified frequency range. The frequency step size shall be no greater than 0,5 MHz up to 100 MHz and 5 MHz up to 1 000 MHz.

4.5.5 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.

4.5.6 Temperature correction

Insertion loss measurements should be conducted at the expected highest operating temperature of the cabling, which may be affected by d.c. 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.

The temperature coefficient for screened cabling is 0,2 %/°C. For unscreened cabling the temperature coefficient is 0,4 %/°C below 250 MHz and 0,6 %/°C above 250 MHz, see IEC 61156-5, IEC 61156-6, IEC 61156-7 and IEC 61156-8.

4.5.7 Uncertainty

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

4.6 Propagation delay and delay skew

The test method is applicable to cabling in a laboratory environment only. The reference test method cannot be used for installed cabling. Field testers use time domain reflectometry (TDR) methods. The performance of field propagation delay measurement accuracy is determined using comparisons with the reference test method described in this subclause.

4.6.1 Objective

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

4.6.2 Test method

Propagation delay is measured by determining the phase delay of a signal transmitted through the cabling using Equation (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 analyzer can measure the complex scattering parameter, S21.

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 assure an adequate margin, the frequency steps shall be no greater than 1 MHz.

4.6.4.3 Calculation

Some network analyzers give a readout of the continuous phase trace of the tested item. This readout can be directly inserted in Equation (8). It is usual for the network analyzer to measure the phase in an interval of ± π. As the ratio of phase versus frequency is a continuously decreasing function, 2π shall be subtracted from the measured phase every time there is a positive step in the measured phase versus frequency trace, therefore:

$$\varphi_f = \varphi_{\mathrm{m}} - 2n\pi \tag{8}$$

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 -π during the measurement from the lowest frequency to the actual frequency f.

The propagation delay is calculated by applying Equation (7).

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

4.6.5 Test report

Propagation delay and 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

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

4.7.1 Objective

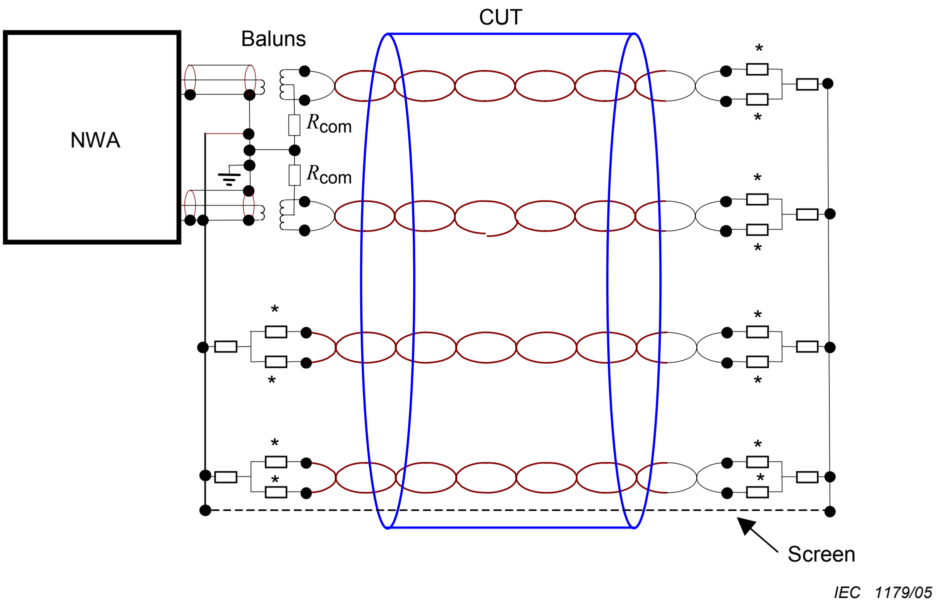
The objective of this test is to determine the coupling between a signal applied at the near end of one pair to the signal received at the near end of a different pair.

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 analyzer
*	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 (S21) 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 4.2.3. 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 4.2.3 when not under test. The loads shall comply with the requirements given in 4.2.3. 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:

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

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:

$$PSNEXT_k = -10\log\left(\sum_{i=1, i \neq k}^{n} 10^{-0{,}1 \cdot NEXT_{i,k}}\right) \qquad (10)$$

where

$PSNEXT_k$ 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 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

This test is applicable to laboratory and installed cabling testing.

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.

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

Refer to 4.5 and 4.7.

4.8.4.1 Calculation

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

$$ACRN_{i,k} = NEXT_{i,k} - IL_k \qquad (11)$$

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 4.2.9.

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

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.

4.9.1 Objective

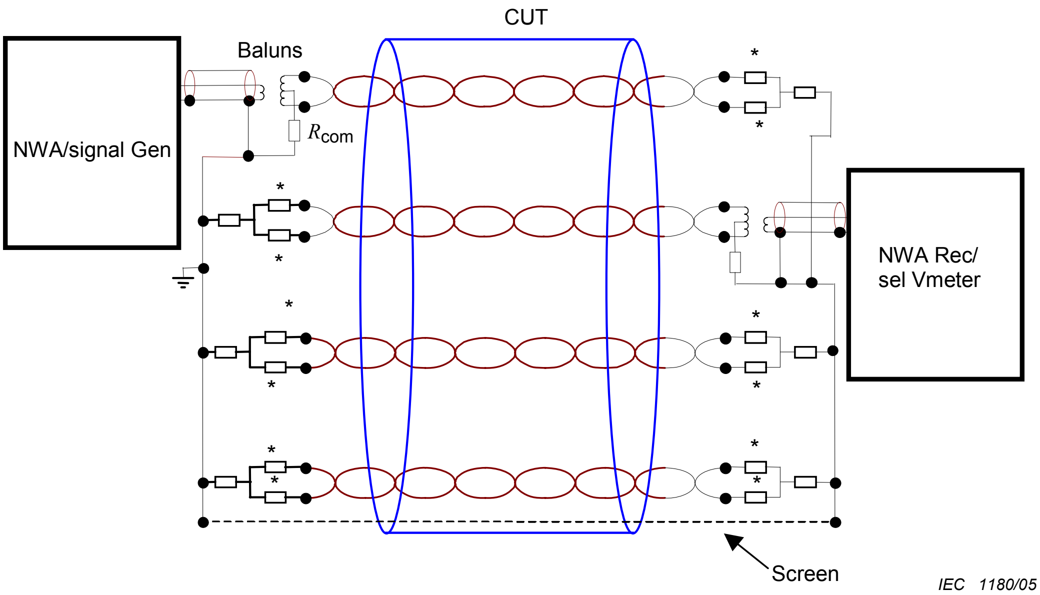
The objective of this test is to determine the coupling between a signal applied at the near end of one pair to the signal received at the far end on a different pair.

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 analyzer or signal generator
NWA receiver / Sel Vmeter	receiver of network analyzer 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 analyzer may be used after determining that a ground connection that exists inside the network analyzer 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 S21 = S12. 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:

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

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.

$$PSFEXT_k = -10\ \log\left(\sum_{i=1, i\neq k}^{n} 10^{-0,1\times FEXT_{i,k}}\right) \qquad (13)$$

where

$PSFEXT_k$ 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 Equal level far end crosstalk (ELFEXT) and 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

4.10.2 Calculation

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

$$ACRF_{i,k} = FEXT_{i,k} - IL_k \qquad (14)$$

where

$ACRF_{i,k}$ 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:

$$PSACRF_k = PSFEXT_k - IL_k \qquad (15)$$

where

$PSACRF_k$ is the calculated power sum ACR-F to pair k in dB;

$PSFEXT_k$ 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 of ELFEXT and ACR-F measurements are the calculated summed uncertainties of insertion loss and FEXT measurements and shall be calculated as shown in 4.2.9.

4.11 Return loss

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

4.11.1 Objective

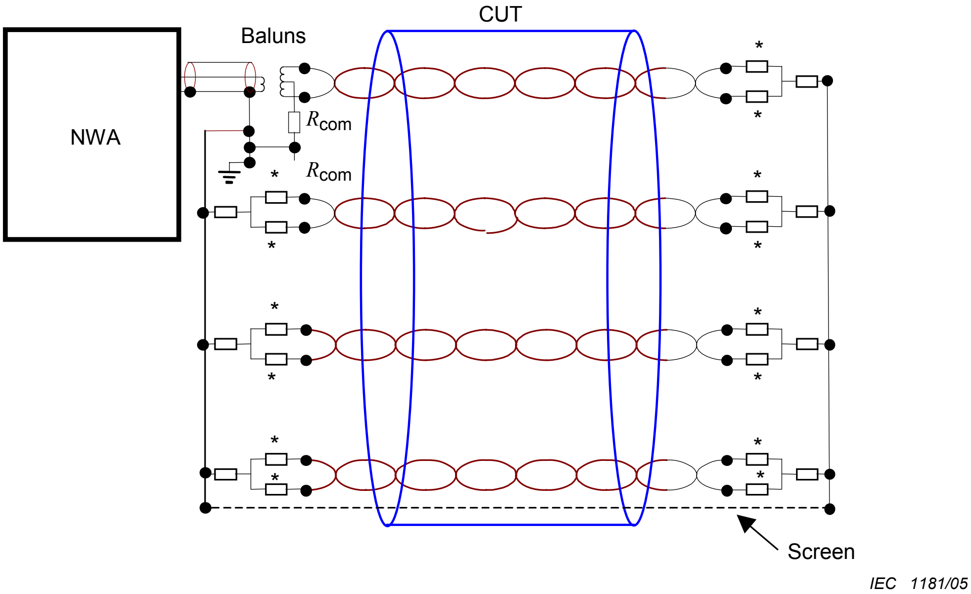
The objective of this test is to measure the return loss of the cable assembly.

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 4.2.3.

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

Figure 9 – Return loss test configuration

4.11.4 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 4.2.3, 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 4.2.3. The near end pairs may be left open when not under test.

Common mode loads are not needed. If the test instrument measures at discrete frequencies, the frequency steps shall be no greater than 250 kHz up to 100 MHz and 2,5 MHz up to 1 000 MHz.

Return loss for both ends of the cabling shall be measured, if required by the relevant detail specification.

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 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 This is based on an accuracy of the reference load for calibration as specified in 4.2.4.

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

4.12.1 Objective

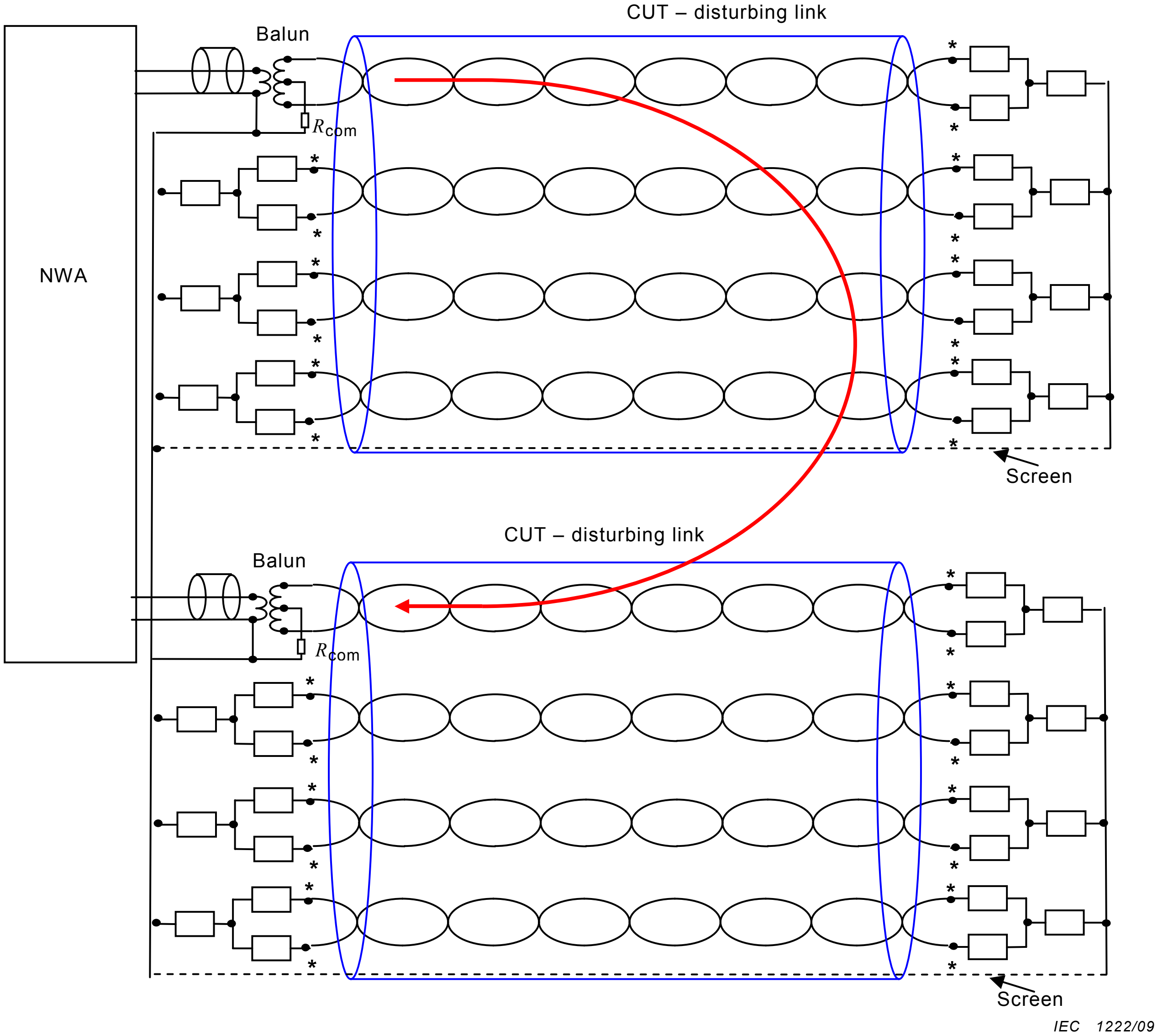
The objective of this test is to determine the PS ANEXT of the cabling. This test is applicable to cabling in a laboratory environment and for installed cabling. A sample laboratory reference measurement assembly is described in Annex B.

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 analyzer
*	matched resistors (in pairs)
Screen	screen (if present)
R_{com}	common mode impedance
Balun	balun to interface laboratory equipment and balanced cabling

Figure 10 – ANEXT measurement

4.12.4 Procedure

4.12.4.1 Calibration

A transmission (S21) 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 16× 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 4.2.3. The loads shall comply with the requirements given in 4.2.3. 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 Equation (16).

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

where

$PSANEXT_k(f)$	is the computed PS ANEXT to pair k as a function of frequency f in dB;
f	is the frequency;
k	is the number of the disturbed pair (in a disturbed channel);
i	is the number of a disturbing pair (in a disturbing channel);
j	is the number of a disturbing channel;
N	is the total number of disturbing channels;
n	is the total number of disturbing pairs (4) in each of N disturbing channels;
$ANEXT_{k,i,j}(f)$	is the frequency response of the ANEXT coupled from pair i of disturbing channel j into pair k of the disturbed channel in dB.

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

The average PS ANEXT frequency response in dB of all pairs is computed by averaging the values of each pair expressed in dB as in Equation (17).

$$PSANEXT_{\text{avg}}(f) = \frac{1}{4} \sum_{k=1}^{4} PSANEXT_k(f) \tag{17}$$

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 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.

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

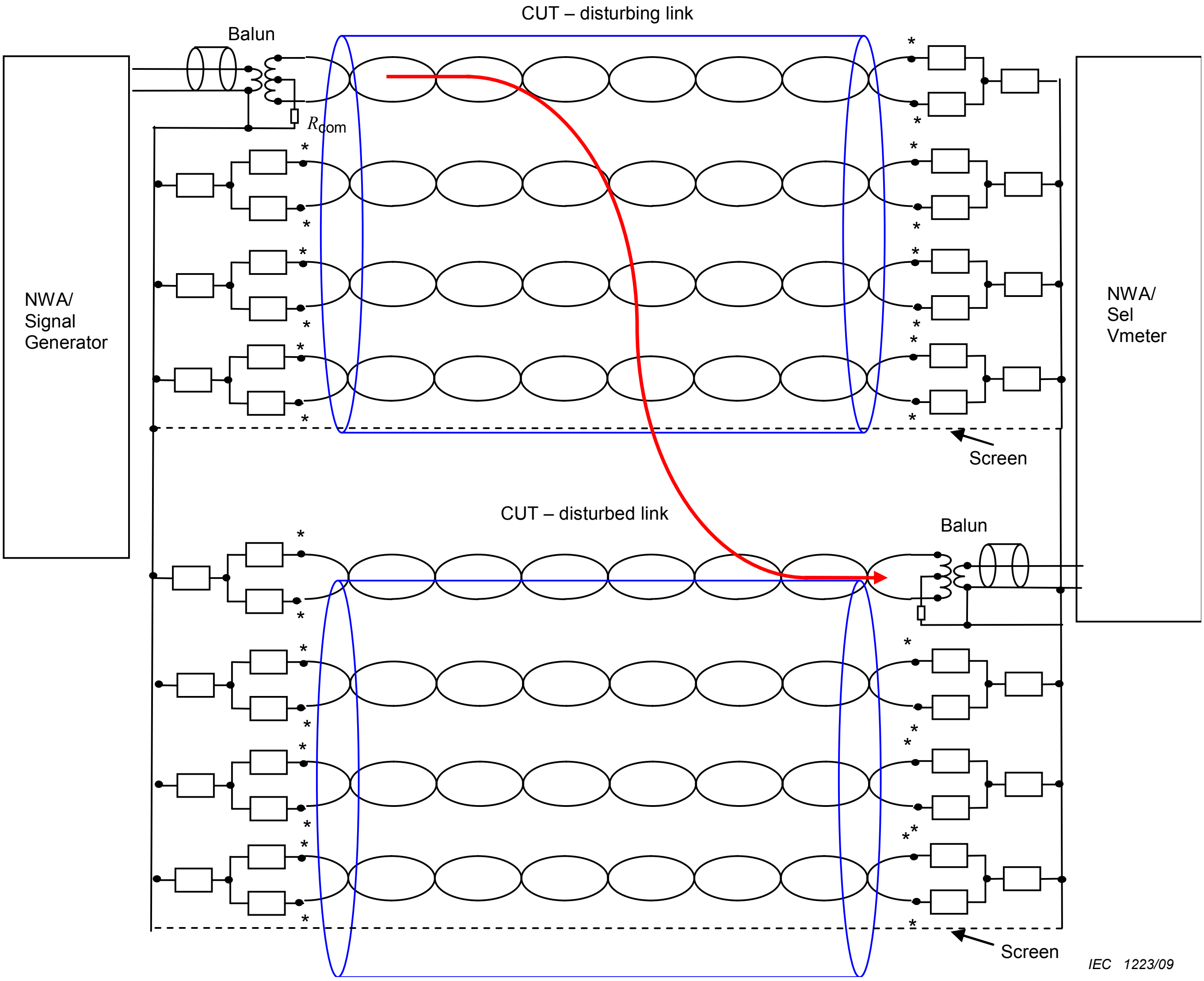
4.13.2 Test method

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 analyzer or signal generator
NWA / Sel Vmeter	receiver of network analyzer 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

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

Figure 11 – Alien far end crosstalk measurement

4.13.4 Procedure

4.13.4.1 Calibration

A transmission (S21) 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 S21 = S12. 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 16× 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 4.2.3. The loads shall comply with the requirements given in 4.2.3. 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 Equations (18) and (19).

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

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

Otherwise

$$AFEXT\text{norm}_{k,i,j}(f) = AFEXT_{k,i,j}(f) \quad (19)$$

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 Equation (23) shall be used in all cases.

The frequency response of the power sum alien FEXT of pair k $PSAFEXT_k(f)$ of a disturbed channel is computed per Equation (20).

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

where

n is the number of pairs in disturbing channel j;

N is the total number of disturbing channels.

The PS AACR-F frequency response to disturbed pair k in dB of pair k of a disturbed link is computed per Equation (21).

$$PSAACRF_k(f) = PSAFEXT_k(f) - IL_{\text{avg}}(f) \tag{21}$$

where

$PSAACRF_k(f)$ 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 Equation (22).

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

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 Equation (23).

$$PSAFEXT_{\text{avg}}(f) = \frac{1}{4} \sum_{k=1}^{4} PSAFEXT_k(f) \qquad (23)$$

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

$$PSAACRF_{\text{avg}}(f) = PSAFEXT_{\text{avg}}(f) - IL_{\text{avg}}(f) \qquad (24)$$

where

$PSAACRF_{\text{avg}}(f)$ 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

This test is applicable to cabling in a laboratory environment.

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).

4.14.2 Test method

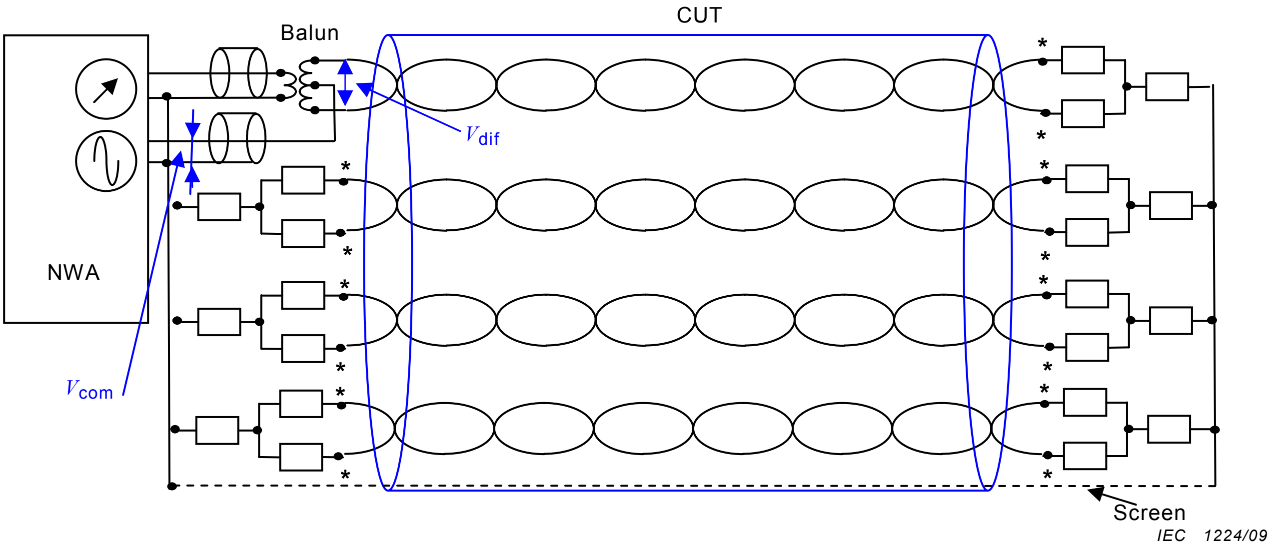
Unbalance attenuation, near end or TCL, is measured by calculating the ratio of differential mode power to common mode power on a pair within a cabling system, which is excited with differential mode power only.

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 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 12. The cabling under test shall be measured at the reference planes shown in 4.2.5.



Key

CUT cabling under test

NWA network analyzer 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. In a 4th step, the unbalance performance of the measurement balun is determined.

a) Step 1

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

b) 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 $IL_{\text{bal},DM}$.

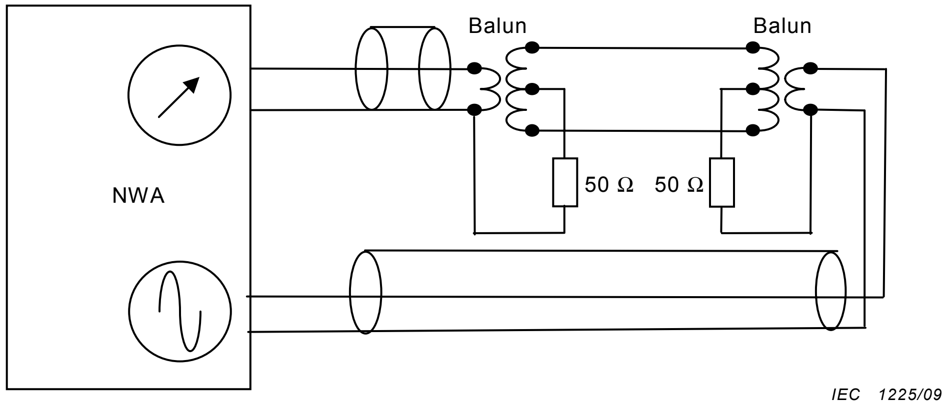


Figure 13 – Back-to-back balun differential mode insertion loss measurement

c) Step 3

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

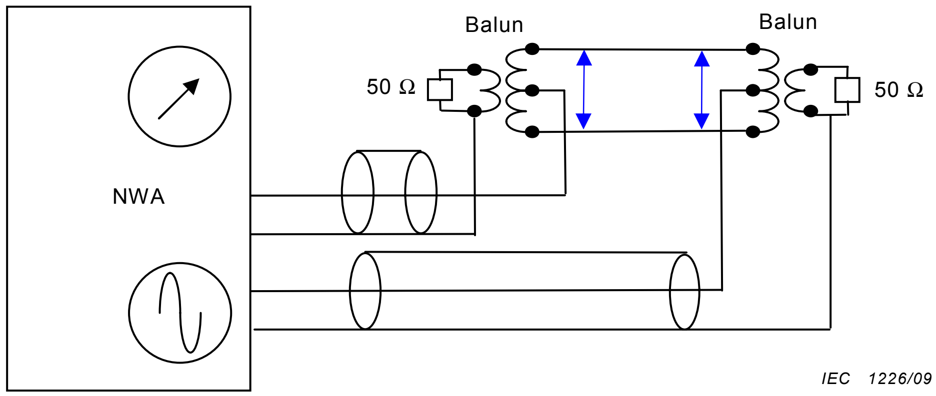
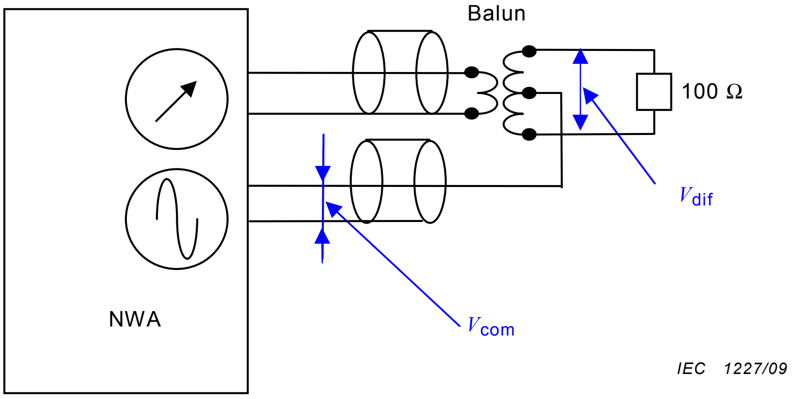


Figure 14 – Back-to-back balun common mode insertion loss measurement

d) 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 analyzer 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 4.2.3, 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 4.2.3 or with balun terminations (the unbalanced and common mode connectors on the balun shall be terminated with 50 Ω coaxial loads). The termination of the pairs not under test provides return path for the common mode signal for unscreened systems. For screened systems, the screen provides this path as well.

Unbalance attenuation near end (or TCL) is calculated using Equation (25).

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

where

TCL	is the computed unbalance attenuation near end in dB;
$IL_{\text{meas},TCL}$	is the measured loss (S21) in dB;
$IL_{\text{bal},DM}$	is the insertion loss of balun for differential mode signals in dB;
$IL_{\text{bal},CM}$	is the insertion loss of balun for common mode signals in dB.

4.14.5 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 2.

Table 2 – 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

This test is applicable to cabling in a laboratory environment.

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

4.15.2 Test method

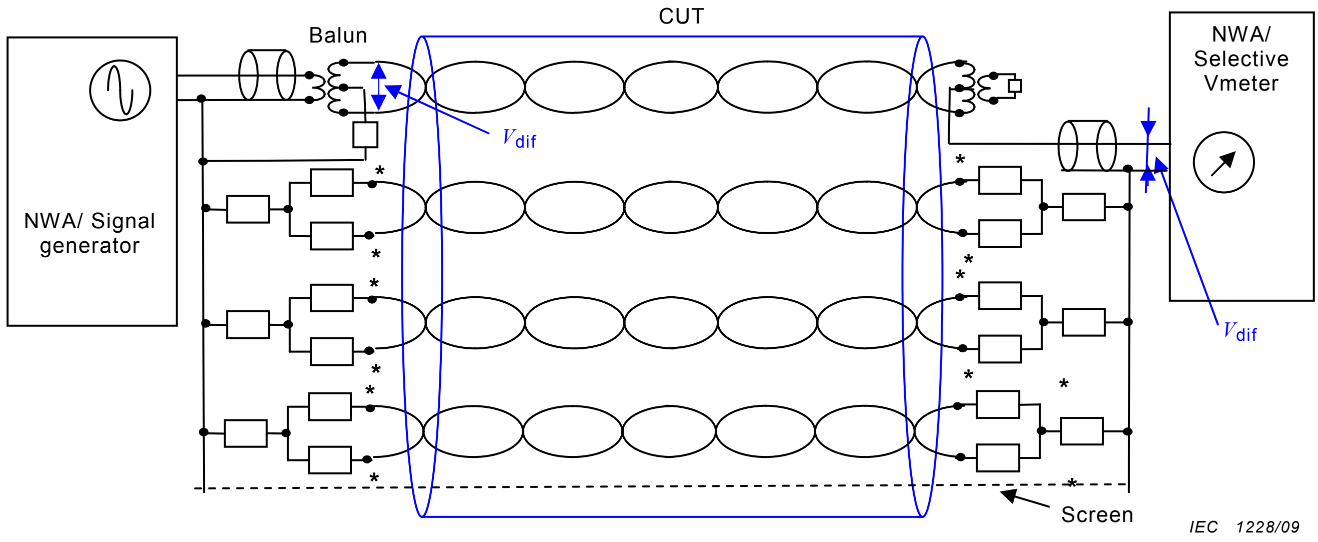
Unbalance attenuation, far end or ELTCTL is measured by calculating the ratio of differential mode power to common mode power in a cabling system, which is exited with differential mode power only. This value is the TCTL. The ELTCTL is obtained by subtracting the insertion loss of the CUT from TCTL. 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 4.2.5.



Key

CUT	cabling under test
NWA/Signal generator	network analyzer with S-parameter test set, signal port or a signal generator
NWA/Selective voltmeter	network analyzer 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 $IL_{\text{bal},DM1}$, $IL_{\text{bal},DM2}$, $IL_{\text{bal},CM1}$, and $IL_{\text{bal},CM2}$.

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 4.2.3. There shall be a common ground at each end. If a network analyzer 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 Equation (26).

$$TCTL = IL_{\text{meas},TCTL} - IL_{\text{bal},DM1} - IL_{\text{bal},CM2} \quad (26)$$

where

$TCTL$	is the computed TCTL in dB;
$IL_{\text{meas},TCTL}$	is the measured loss ($S21$) in dB;
$IL_{\text{bal},DM1}$	is the insertion loss of the input balun for differential mode signals in dB;
$IL_{\text{bal},CM2}$	is the insertion loss of the output balun for common mode signals in dB.

The ELTCTL is computed as in Equation (27).

$$ELTCTL = TCTL - IL_{\text{CUT}} \quad (27)$$

where

$ELTCTL$	is the computed ELTCTL 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 3.

Table 3 – 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 EN 50289-1-15.

5 Field test measurement requirements for electrical properties

5.1 General

This clause 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 and IV 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 and F_A cabling.

This clause 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 4.2.5.

5.3 Field test parameters

5.3.1 General

The following field test measurement parameters and related requirements have been 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;
- d.c. 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).

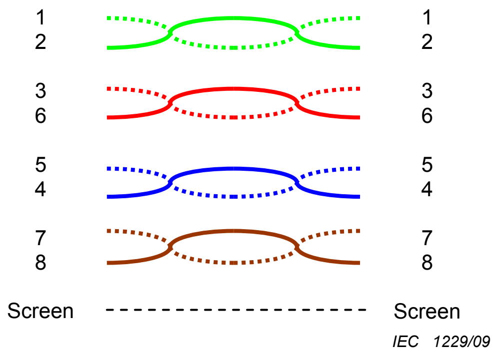


Figure 17 – Correct pairing

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.

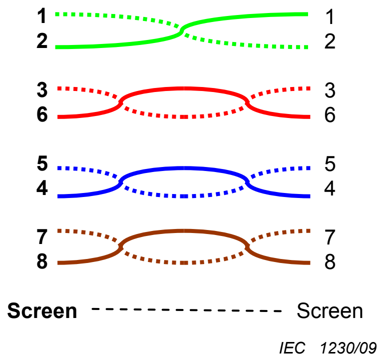


Figure 18a – Reversed pair

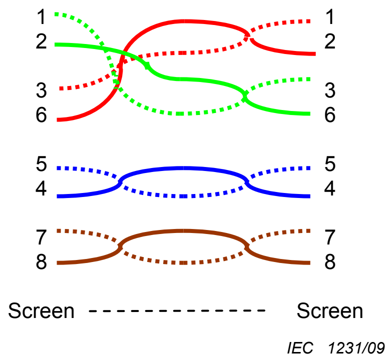


Figure 18b – Transposed pairs

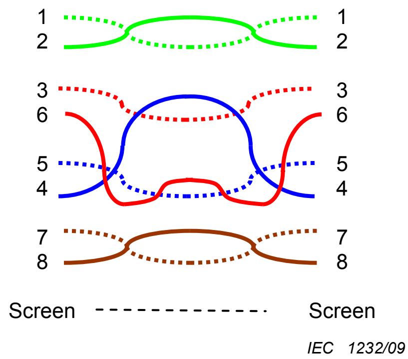


Figure 18c – Split pairs

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:

$$NVP = \frac{Physical\ length}{Measured\ propagation\ delay \times Velocity\ of\ light\ in\ vacuum} \tag{28}$$

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 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 4.5.6 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:

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

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:

$$ACRN_{i,k} = NEXT_{i,k} - IL_k \quad (30)$$

where

$ACRN_{i,k}$	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:

$$PSACRN_{i,k} = PSNEXT_{i,k} - IL_k \quad (31)$$

where

$PSACRN_{i,k}$	is the computed PS ACR-N from disturbing pair i to disturbed pair k in dB;
k	is the number of the disturbed pair;
$PSNEXT_{i,k}$	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 (see 4.10) are computed from far-end cross-talk (FEXT) (see 3.7) 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 36 in dB.

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

$$ACRF_{12-36,\mathrm{dB}} = FEXT_{12-36,\mathrm{dB}} - IL_{12,\mathrm{dB}} \tag{33}$$

where

$ACRF_{12-36}$	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:

$$PSELFEXT_{12} = -10\log\left(10^{\frac{-ELFEXT_{1,2-3,6}}{10}} + 10^{\frac{-ELFEXT_{1,2-4,5}}{10}} + 10^{\frac{-ELFEXT_{1,2-7,8}}{10}}\right) \tag{34}$$

where

$PSELFEXT_{12}$	is the PSELFEXT 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:

$$PSACRF_{12} = -10 \log \left(10^{\frac{-ACRF_{1,2-3,6}}{10}} + 10^{\frac{-ACRF_{1,2-4,5}}{10}} + 10^{\frac{-ACRF_{1,2-7,8}}{10}} \right) \quad (35)$$

where

$PSACRF_{12}$ 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 3.16) 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 (d.c.) loop resistance

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

5.4 Power sum alien crosstalk

5.4.1 Objective

This clause describes 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 this clause 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.

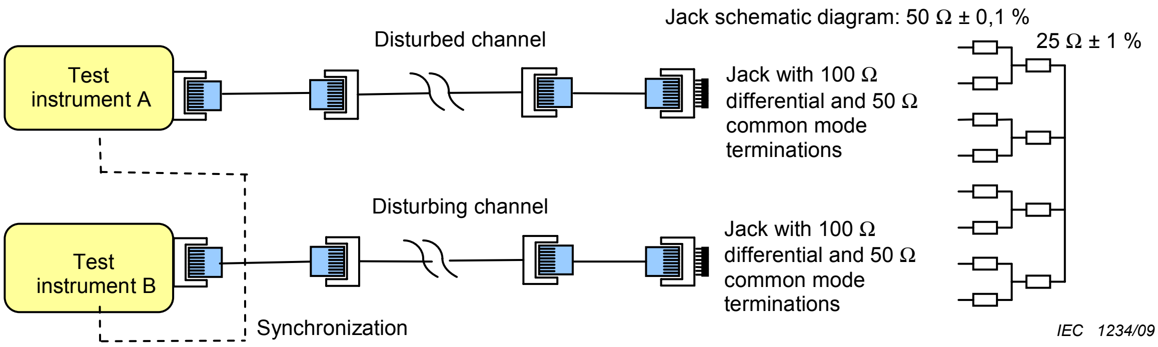


Figure 19 – Schematic diagram to measure channel ANEXT loss

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 "synchronisation". 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.

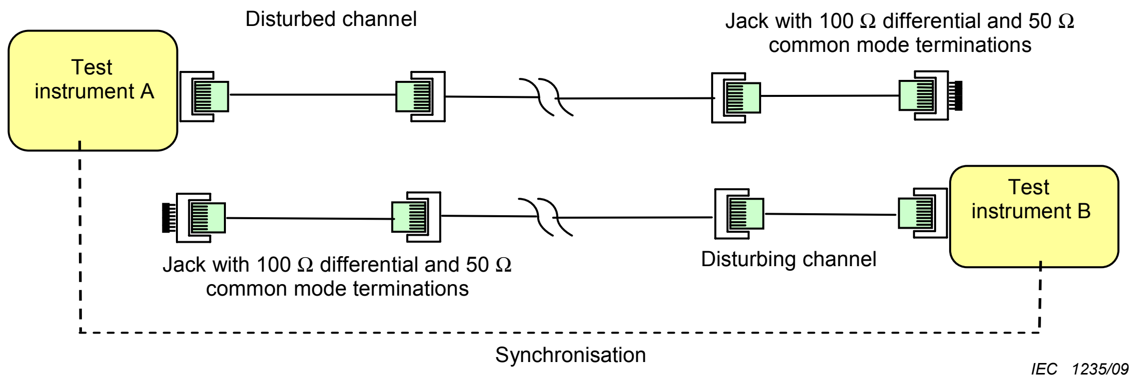


Figure 20 – AFEXT loss measurement test configuration

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 1 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

The processing of the measured ANEXT or AFEXT data follows the following steps.

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 Equation (36).

$$PSANEXT_{X,1} = -10\log\begin{pmatrix} 10^{-0{,}1 ANEXT_{X,1,1}} + \\ 10^{-0{,}1 ANEXT_{X,2,1}} + \\ 10^{-0{,}1 ANEXT_{X,3,1}} + \\ 10^{-0{,}1 ANEXT_{X,4,1}} \end{pmatrix} \quad (36)$$

where

X is a pair in the disturbed channel or link;

$PSANEXT_{X,1}$ 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

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

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

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

otherwise

$$NORM_{X,Y,1} = 0 \tag{39}$$

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 Equation (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 Equation (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 Equation (42) is used in all cases.

The normalized AFEXT value is given by

$$AFEXT\text{norm}_{X,Y,1} = AFEXT_{X,Y,1} + NORM_{X,Y,1} \tag{40}$$

The PS AFEXT loss in dB is calculated by Equation (41).

$$PSAFEXT_{X,1} = -10\log\begin{pmatrix} 10^{-0,1AFEXT\text{norm}_{X,1,1}} + \\ 10^{-0,1AFEXT\text{norm}_{X,2,1}} + \\ 10^{-0,1AFEXT\text{norm}_{X,3,1}} + \\ 10^{-0,1AFEXT\text{norm}_{X,4,1}} \end{pmatrix} \tag{41}$$

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,

$AFEXT\text{norm}_{X,Y,1}$ 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 Equation (42).

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

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 Equation (43).

$$PSAACR-F_{X,\text{total}} = PSAFEXT_{X,\text{total}} - IL_X \quad (43)$$

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 Equation (44).

$$PSAXtalk_{\text{floor},Npp}(f) = PSAXtalk_{\text{floor},4Nps}(f) + 10\log\left(\frac{4Nps}{Npp}\right) \quad (44)$$

The corrected PS alien crosstalk is computed as in Equation (45).

$$PSAXtalk_{\text{final}}(f) = -10\log\left(10^{-0{,}1PSAXtalk} - 10^{-0{,}1PSAXtalk_{\text{floor},Npp}(f)}\right) \quad (45)$$

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

5.4.8 Selection of test ports

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

5.4.8.1 Selection of disturbed links

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

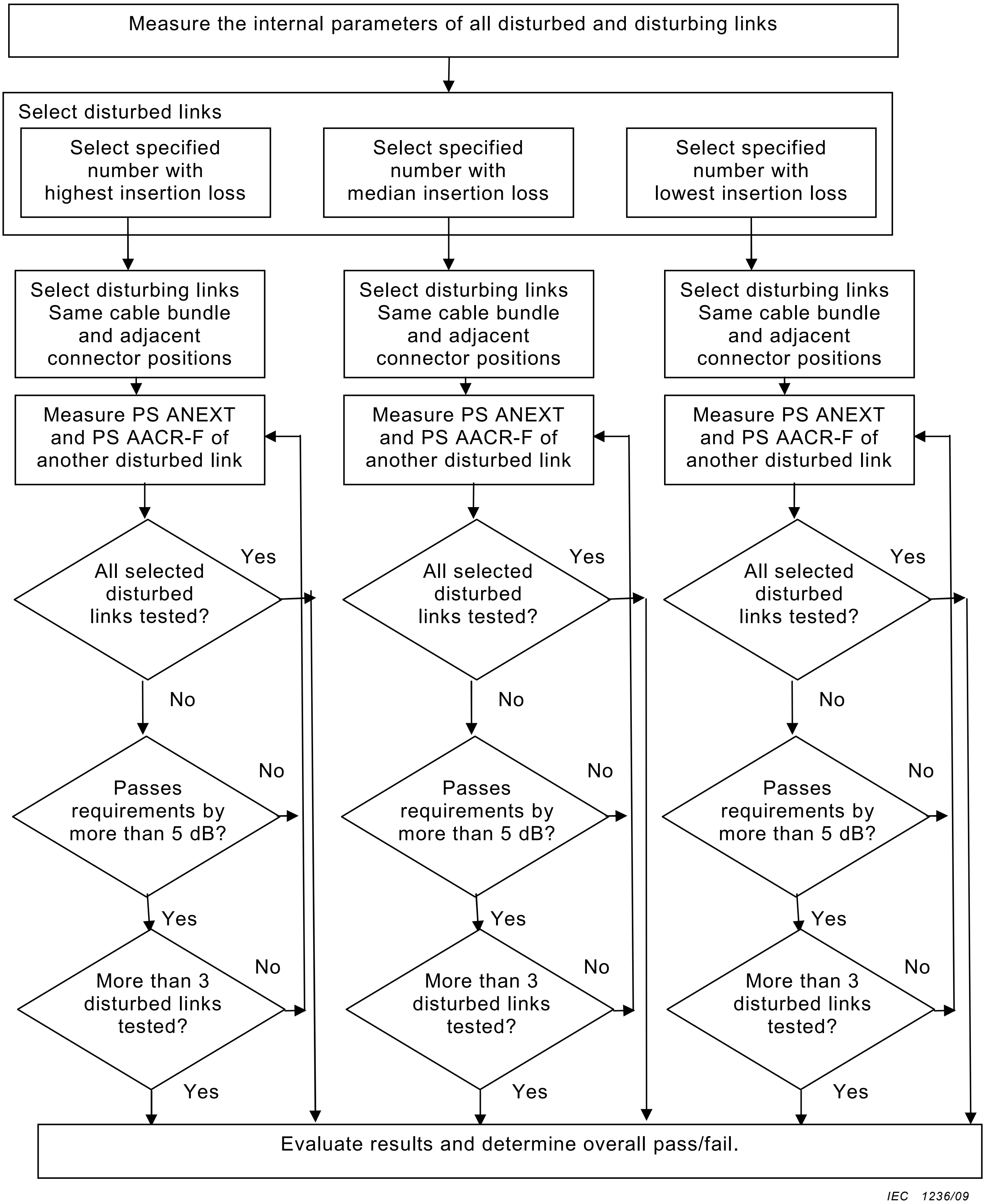


Figure 21 – Flow chart of the alien crosstalk test procedure

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.

NOTE 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

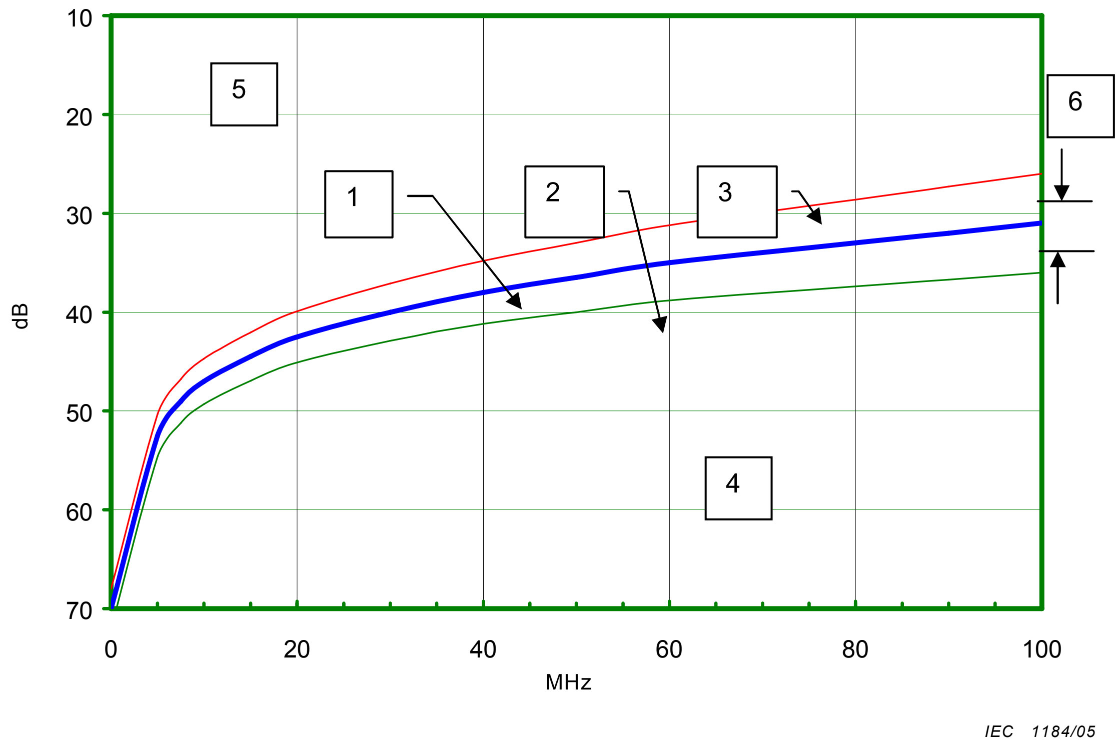
The error equation that is applicable to PS NEXT is also applicable to PS ANEXT and PS AFEXT, except that the random noise floor degrades 3 dB for every doubling of the number of ANEXT results that is contained in a PS ANEXT result.

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 shield 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;
- d.c. 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 4 and Table 5.

Table 4 – Summary of reporting requirements for field test equipment

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 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 (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
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 4 *(continued)*

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)	Worst case ACR-N (1 of 6)
	Test limit at worst case ACR-N	Test limit at worst case ACR-N
	NOTE For each pair, combination ACR-N should be computed using the pair with the highest insertion loss for each frequency data point.	NOTE 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	Frequency at worst case ACR-N
	Pair combination at worst case ACR-N (disturbing, disturbed)	Pair combination at worst case ACR-N (disturbing, disturbed)
	PASS/FAIL	PASS/FAIL
	Worst case ACR-N margin	Worst case ACR-N margin
	Test limit at worst case ACR-N margin	Test limit at worst case ACR-N margin
	Frequency at worst case ACR-N margin	Frequency at worst case ACR-N margin
	Pair combination at worst case ACR-N margin (disturbing, disturbed)	Pair combination at worst case ACR-N margin (disturbing, disturbed)
	PASS/FAIL	PASS/FAIL
ACR-N	Worst case power sum ACR-N (1 of 4)	Worst case power sum ACR-N (1 of 4)
power sum	NOTE For each pair, combination ACR-N should be computed using the pair with the highest insertion loss for each frequency data point.	NOTE 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	Test limit at worst case power sum ACR-N
	Frequency 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)	Pair combination at worst case power sum ACR-N (disturbing, disturbed)
	PASS/FAIL	PASS/FAIL-N
	Worst case power sum ACR-N margin	Worst case power sum ACR-N margin
	Test limit at 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	Frequency at worst case power sum ACR-N margin
	Pair combination at worst case power sum ACR-N margin (disturbing, disturbed)	Pair combination at worst case power sum ACR-N margin (disturbing, disturbed)
	PASS/FAIL	PASS/FAIL

Table 4 *(continued)*

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	

Table 4 *(concluded)*

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)
Delay skew	Worst case delay skew (1 of 1 possible) Test limit of delay skew PASS/FAIL	
DC loop resistance	Worst case d.c. loop resistance (1 of 4 possible) Test limit of d.c. loop resistance PASS/FAIL	

5.5.4 Reporting requirements for power sum alien crosstalk

Table 5 – Minimum reporting requirement for PS ANEXT and PS AACR-F

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

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

5.5.6.1 Repeatability of tests on a reference link

The owner 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.

5.5.6.2 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 100 insertions.

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 and IV field test equipment. Each accuracy level has it own set of performance requirements which are described in this clause.

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, and class F for level IV.

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 exhibit 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 ½ of the worst case accuracy as reported in Table 6 through Table 10.

Table 6 – Worst case propagation delay, delay skew, d.c. resistance and length measurement accuracy for level IIE, level III and level IV test instruments

Test parameter Level IIE, III, IV	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 7 – 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 8 – 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 9 – 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 10 – Worst case insertion loss, NEXT, ACR-N, ELFEXT/ACR-F and return loss measurement accuracy for level IV test instruments

Test parameter	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	1,9	2,8	3,7	2,5	3,6	4,7	3,8	4,8	5,4
Power sum NEXT	2,0	2,9	3,8	2,7	3,8	4,9	4,3	5,1	5,7
ACR-N	2,3	3,5	4,4	2,9	4,4	5,5	4,3	5,5	6,2
Power sum ACR-N	2,4	3,6	4,4	3,1	4,5	5,6	4,7	5,9	6,5
ELFEXT/ACR-F	2,2	3,5	4,5	2,7	4,4	5,6	2,9	4,8	5,9
Power sum ELFEXT/ACR-F	2,3	3,6	4,6	2,9	4,6	5,8	3,1	5,0	6,0
Return loss	2,8	2,5	2,4	3,3	3,2	3,1	2,7	2,8	2,8

For measurement accuracies above 600 MHz, refer to 6.7.

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

The measurement accuracy requirements for propagation delay, delay skew, and length for level IIE, level III, level IIIE and level IV field testers are identical and shown in Table 11.

Table 11 – Propagation delay, delay skew, d.c. 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 (see Table 12). 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 12 – 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	Units
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 MHz – 2 log(f/10) (see condition 7 below)	25 dB (see condition 8 below)		dB
Source match	20 dB (see condition 7 below)	$18-20\log\left(\frac{f}{100}\right)$ 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: $15-20\log\left(\frac{f}{100}\right)$ 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 (see Table 13). 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 13 – 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	Units
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 condition4 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 – 7log(*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 – 15log(*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 60603-7-4 (unshielded) and IEC 60603-7-5 (shielded). 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 60603-7-4 (unshielded) and IEC 60603-7-5 (shielded). 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 (see Table 14). 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 14 – 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	Units
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) [6)]		dB
Common mode rejection	40 – 20 log(*f*/100) (see condition 6 below)	37 – 20 log(*f*/100) [6)]		dB
Tracking	± 0,5 dB	1 MHz – 250 MHz: ± 0,5 dB 250 MHz – 500 MHz: ± {0,5 + 0,000 667× (*f*-250)} dB		dB
Directivity	(applicable when IL > 3 dB) 1 MHz – 300 MHz: 27 – 7log(*f*/100), 30 dB max. 300 MHz – 500 MHz: 23,7 dB	25 – 20 log(*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 – 15log(*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.				

Table 14 *(continued)*

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 be between the lower and upper ranges of test plugs as specified for category 6 in IEC 60603-7-4 (unshielded) and IEC 60603-7-5 (shielded). 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 60603-7-4 (unshielded) and IEC 60603-7-5 (shielded). 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 and 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.

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 or IEC 61076-3-104. In the modular 8-pin measurement mode, the level III performance requirements shall apply.

Table 15 – 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)	$72{,}4 - 15\log(f/100)$ (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)	$60 - 15\log(f/100)$ (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 to 300 MHz $27 - 7\log(f/100)$, 30 dB max. (see condition 6 below) 300 MHz – 600 MHz: 23,7 dB	1 MHz to 300 MHz $25 - 7\log(f/100)$, 30 dB max. (see condition 6 below) 300 MHz – 600 MHz: 21,7 dB	1 MHz to 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

Table 15 *(continued)*

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 IV field testers over 600 MHz

The level IV requirements shall apply to measurements of class F_A cabling up to 600 MHz, and pass/fail evaluation criteria shall apply. Measurement data over 600 MHz shall be provided for information only. Detailed requirements over 600 MHz are for further study.

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.

In addition, the measurement floor of the test device shall exceed the values in Equation (46).

$$Measurement\ floor \geq 95 - 20\lg\left(\frac{f}{100}\right),\ 95\text{ dB maximum} \qquad (46)$$

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.

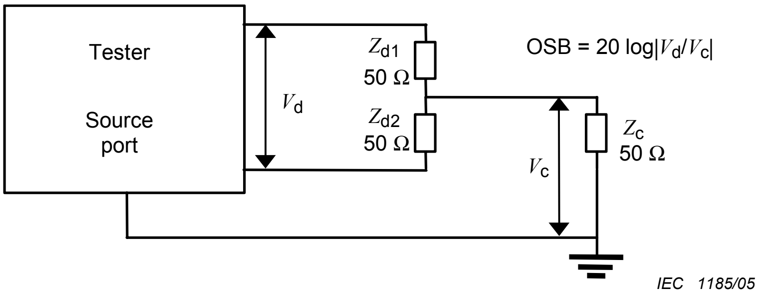
The field test equipment parameters shall be verifiable by independent parties. The field test equipment shall include functionality to make independent verification possible. The field tester manufacturers shall make them available to independent parties for measurement purposes. Elaborate laboratory 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 (see Figure 23) 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.



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 ± 0,1 %

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

total common mode impedance equals ¼ ($Z_{d1} + Z_{d2}$) + Z_c

Figure 23 – Block diagram for measuring output signal balance

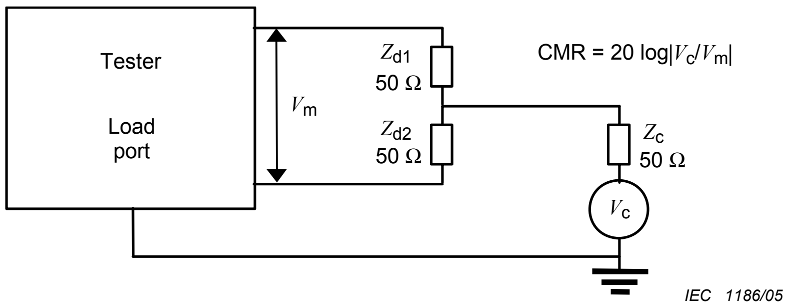
6.9.3 Common mode rejection (*CMR*)

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 (see Figure 24) 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.



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_{d1} , Z_{d2}	differential termination (1/2 of nominal impedance each)

$Z_{d1} = Z_{d2}$ = 50 Ω ± 1 % ; Z_{d1} and Z_{d2} are matched to ± 0,1 %

Z_c	common mode source impedance; Z_c = 50 Ω ± 1 %

Figure 24 – Block diagram to measure common mode rejection

6.9.4 Residual NEXT

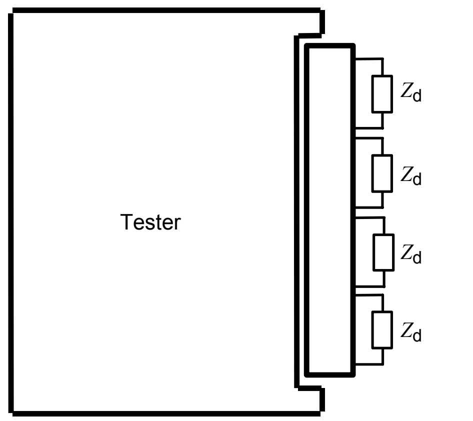
This performance requirement is applicable to

- NEXT and power sum NEXT measurements.

Residual NEXT, see Figure 25, 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_d = 100 Ω, 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.

$$\text{Residual } NEXT = -20 \log(V_m / V_c) \quad (47)$$

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.



Key

Tester field tester

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

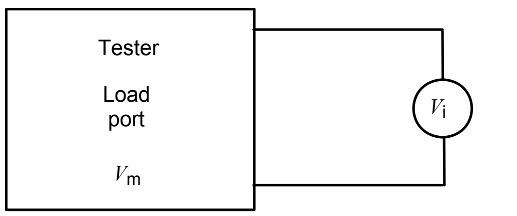
Figure 25 – Block diagram for measuring residual NEXT

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. The calibration shall include an impedance matching transformer/balun with better than 40 dB longitudinal conversion loss.

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

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.

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

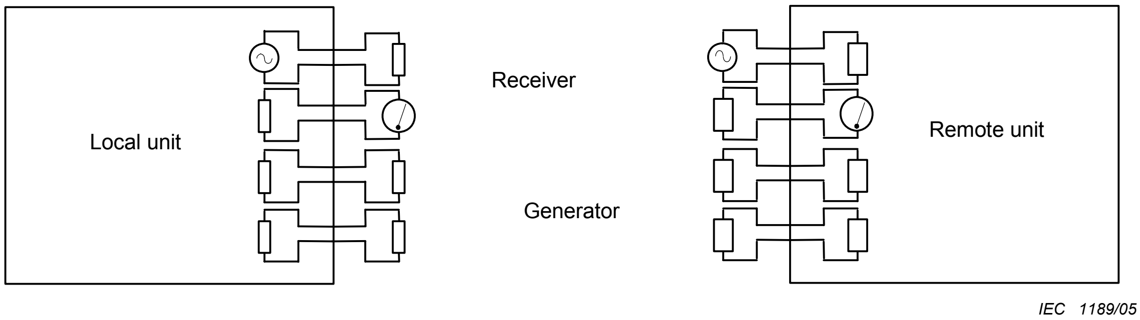
A procedure measuring voltage with an external voltmeter at the output of the detector is acceptable if it demonstrates equivalency.

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.

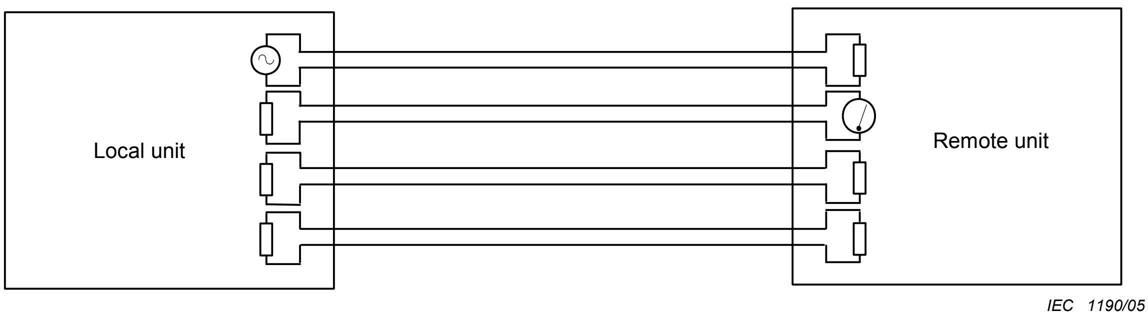


Key

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 NEXT

Alternately, the residual FEXT may be measured, see Figure 28, 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.



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 measure 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 equation:

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

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 equation:

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

In case phase information is available, this equation 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 analyzer 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 include a constant error term E_c and a term E_d which is proportional to the length of the link.

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

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 length of the length measurement function

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 d.c. resistance measurement function

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

6.9.19 Error constant term proportional to d.c. resistance of the d.c. resistance measurement function

The d.c. 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 d.c. resistance measurement procedure shall be used.

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

6.9.20 Measurement floor for alien crosstalk testing during field testing

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.

6.9.21 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 "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.

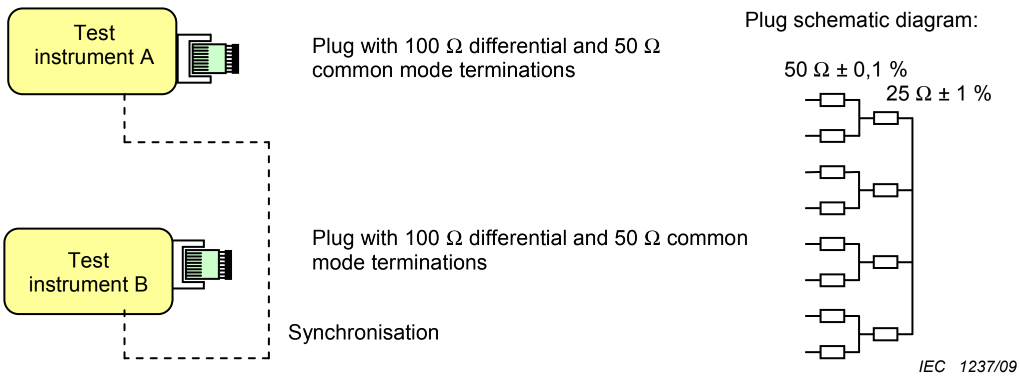


Figure 29 – Alien crosstalk measurement floor test for the channel test configuration

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: Equation (46) – 6 dB.

6.9.21.1 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 "synchronisation". A physical field tester control link is an option of this standard. Other implementations of this measurement are acceptable if equivalence is demonstrated.

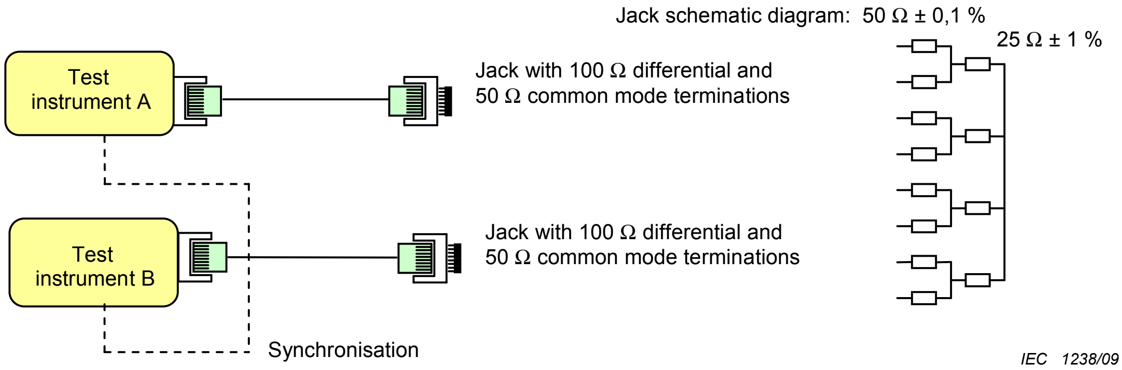


Figure 30 – Alien crosstalk measurement floor test for the link test configurations

The power sum measurement floor of any pair shall exceed the specified measurement floor in 6.8: Equation (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 clause 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 analyzer comparisons.

6.10.2 Error model for the insertion loss measurement function

$$Accuracy_{IL} = E_{d,IL} + 20\log\left[1 + 10^{\frac{-E_{RL,\text{tester}}}{10}} + 2\times 10^{\frac{-\left(E_{RL,\text{tester}} + E_{RL,\text{link}}\right)}{20}}\right] \quad (52)$$

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 tester 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

$$Accuracy_{NEXT} = E_{d,NEXT} + 20\log\left[\begin{array}{l} 1 + 10^{\frac{-E_{RL,\text{tester}}}{10}} + 2\times 10^{\frac{-\left(E_{RL,\text{tester}} + E_{RL,\text{link}}\right)}{20}} \\ + \sqrt{10^{\frac{A_{NEXT} - E_{RN}}{10}} + 10^{\frac{A_{NEXT} - E_{NF}}{10}} + 10^{\frac{S_C - E_B}{10}} + 10^{\frac{S_D - E_C}{10}}} \end{array}\right] \quad (53)$$

where

$Accuracy_{NEXT}$	is the estimated accuracy of the NEXT measurement function in dB;
A_{NEXT}	is the NEXT signal amplitude for accuracy in dB;
$E_{d,NEXT}$	is the dynamic accuracy of the tester for NEXT in dB;
$E_{RL,\text{tester}}$	is the source/load return loss of the tester in dB;
$E_{RL,\text{link}}$	is the return loss of the link in dB;
E_{RN}	is the residual NEXT in dB;
E_{NF}	is the random noise floor in dB;
E_B	is the output signal balance (OSB) of the tester in dB;
E_C	is the common mode rejection ration (*CMR*) of the tester in dB;
S_D	is the common mode to differential coupling gain of the link (relative to the measured value of NEXT, 10 dB is assumed);
S_C	is the differential mode to common mode coupling of the link (relative to the measured value of NEXT, 5 dB is assumed).

6.10.4 Error model for the power sum NEXT measurement function

The estimated accuracy for power sum NEXT is identical to the NEXT, except that for the amplitude, $A_{NEXT} - A_{NEXT} + 4{,}77$ shall be substituted.

6.10.5 Error model for the ACR-N measurement function

The error model for ACR-N depends on the error models for NEXT and insertion loss. These are independent measurements, each with their own error model. The error model for insertion loss is in 6.10.2. The error model for FEXT is like the error model for NEXT in 6.10.3. A combined error model for ACR-N, which includes a total dynamic accuracy equal to approximately the square root of the dynamic accuracy for insertion loss and NEXT, and twice the power of return loss is given by

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

where

$Accuracy_{ACR}$	is the estimated accuracy of the ACR measurement function in dB;
A_{NEXT}	is the NEXT signal amplitude for accuracy in dB;
$E_{d,ACR}$	is the dynamic accuracy of the tester for ACR in dB;
$E_{RL,\text{tester}}$	is the source/load return loss of the tester in dB;
$E_{RL,\text{link}}$	is the return loss of the link in dB;
E_{RN}	is the residual NEXT in dB;
E_{NF}	is the random noise floor in dB;
E_B	is the output signal balance (OSB) of the tester in dB;
E_C	is the common mode rejection ration (*CMR*) of the tester in dB;
S_D	is the common mode to differential coupling gain of the link (relative to the measured value of NEXT, 10 dB is assumed);
S_C	is the differential mode to common mode coupling of the link (relative to the measured value of NEXT, 5 dB is assumed).

6.10.6 Error model for the power sum ACR-N measurement function

The estimated accuracy for power sum ACR-N is identical to the ACR-N, except that for the amplitude, $A_{\text{ACR-N}} - A_{\text{ACR-N}} + 4{,}77$ shall be substituted.

6.10.7 Error model for the ELFEXT or ACR-F measurement function

The error model for ELFEXT and ACR-F depends on the error models for FEXT and insertion loss. These are independent measurements, each with their own error model. The error model for insertion loss is in 6.10.2. The error model for FEXT is like the error model for NEXT in 6.10.3. A combined error model for ELFEXT and ACR-F, which includes a total dynamic accuracy equal to approximately the square root of the dynamic accuracy for insertion loss and FEXT, and twice the power of return loss is given by

$$Accuracy_{ELFEXT} = Accuracy_{ACRF} =$$

$$E_{d,ELFEXT} + 20\log\left[1+\sqrt{2}\left(10^{\frac{-E_{RL,\text{tester}}}{10}} + 2\cdot 10^{\frac{-\left(E_{RL,\text{tester}}+E_{RL,\text{link}}\right)}{20}}\right) + \sqrt{10^{\frac{A_{ELFEXT}+A_{IL}-E_{NF}}{10}} + 10^{\frac{A_{ELFEXT}+6-E_{RF}}{10}} + 10^{\frac{S_C-E_B}{10}} + 10^{\frac{S_D-E_C}{10}}}\right] \qquad (55)$$

where

$Accuracy_{ELFEXT}$	is the estimated accuracy of the ELFEXT measurement function in dB;
$Accuracy_{ACRF}$	is the estimated accuracy of the ACR-F measurement function in dB;
A_{ELFEXT}	is the ELFEXT or ACR-F signal amplitude for accuracy in dB;
A_{IL}	is the insertion loss signal amplitude for accuracy in dB;

$E_{d,ELFEXT}$	is the dynamic accuracy of the tester for ELFEXT of ACR-F in dB (includes the impact of making both an insertion loss and FEXT measurement, power sum addition of dynamic accuracies);
$E_{RL,\text{tester}}$	is the source/load return loss of the tester in dB;
$E_{RL,\text{link}}$	is the return loss of the link in dB;
E_{RF}	is the residual FEXT in dB, per connection;
E_{NF}	is the random noise floor in dB;
E_B	is the output signal balance (OSB) of the tester in dB;
E_C	is the common mode rejection ration (*CMR*) of the tester in dB;
S_D	is the common mode to differential coupling gain of the link (relative to the measured value of NEXT, 10 dB is assumed);
S_C	is the differential mode to common mode coupling of the link (relative to the measured value of NEXT, 5 dB is assumed).

Assumptions:

- Dynamic accuracy adds up to all other error items.
- An ELFEXT or ACR-F computation is made from the measurement of FEXT and insertion loss. For ELFEXT or ACR-F dynamic accuracy, the dynamic accuracies of insertion loss and FEXT are added in a power sum manner.
- The error from source/load return loss of the tester plus the impact of the source/load interaction with the return loss of the link is added.
- Both the insertion loss and FEXT measurements are subject to errors from return loss. The total impact is estimated by adding in a power sum manner these error contributions. Assuming the return loss contributions are equal, a multiplication factor of $\sqrt{2}$ is used.
- Errors from random noise floor, residual FEXT, output signal balance and common mode rejection are added in a power sum manner.
- Random noise floor errors are based on a signal level equal to the pass/fail limit for ELFEXT/ACR-F plus the insertion loss.
- Residual FEXT errors are caused by both the FEXT in the local and the remote connector. This is represented by the 6 dB constant in the error factor for residual FEXT.
- Errors from output signal balance and common mode rejection are assumed identical to those in the case of NEXT.
- Dynamic accuracy and random noise floor performance is assumed to be independent of the type of link.
- The impact from the test cable for the measurement of the link and connector used for the channel interface are expected to have a significant impact on the source/load return loss, residual FEXT, output signal balance and common mode rejection of the field tester.

6.10.8 Error model for the power sum ELFEXT and PS ACR-F measurement functions

The estimated accuracy for power sum ELFEXT or ACR-F is identical to the ELFEXT or ACR-F, except that for the amplitude, $A_{\text{ELFEXT}} - A_{\text{ELFEXT}} + 4{,}77$ shall be substituted.

6.10.9 Error model for the return loss measurement function

The error model for the return loss measurement relates to contributions to inaccuracy at the input, related to measurement of the reflected signal and contributions which are the result of reflections at the remote termination of the cabling.

$$Error_{RL} = TR + 20\log\left(1 + \sqrt{\left(10^{\frac{A_{RL} - E_{DIR}}{20}} + 10^{\frac{-(A_{RL} + E_{SM})}{20}}\right)^2 + \left(10^{\frac{A_{RL} - E_{\text{TERM}} - \sqrt{f}}{20}}\right)^2}\right) \tag{56}$$

where

$Error_{RL}$	is the estimated accuracy of the return loss measurement function in dB;
A_{RL}	is the return loss amplitude at which the error is computed;
TR	is tracking error in dB;
E_{DIR}	is the directivity in dB;
E_{SM}	is the source match in dB;
E_{TERM}	is the return loss of the remote termination in dB in return loss mode;
f	is the frequency in MHz.

Assumptions:

- The tracking error (like dynamic accuracy) is added directly to the remaining error terms.
- The error from directivity and source match are added worst case, since the phase of one component changes slowly while the other changes much faster. Therefore an "envelope" worst case condition is assumed. The impact from the source match error is practically minor.
- The error caused by the reflection at the remote termination is added in a power sum manner to the remainder of the error terms. It is attenuated by the assumed minimum round trip insertion loss of the link under test. Insertion loss is approximately 2,2 $\sqrt{f}$ per 100 m (with f in MHz). For a 20 m long link (40 m round trip insertion loss), the remote reflection is attenuated by approximately $\sqrt{f}$.

6.10.10 Error model for the propagation delay measurement function

The error of the propagation delay contains a constant error term and an error which is proportional to propagation delay of the measured cabling. For a 100 m limited distance, this error is approximately proportional to length; see the following equation:

$$Error_{propagation\_delay} = E_c + E_d \times propagation\ delay \tag{57}$$

where

$Error_{propagation\_delay}$	is the estimated error of the propagation delay function in seconds;
E_c	is the constant error term in seconds;
E_d	is the error term proportional to the propagation delay of the cabling.

6.10.11 Error model for the delay skew measurement function

The error of the delay skew measurement function is the differential to time of the error term E_d of the propagation delay measurement. For a 100 m distance, the maximum error is approximately constant, see the following:

$$Error_{delay\_skew} = \frac{\mathrm{d}E_d}{\mathrm{d}t} \tag{58}$$

where

$Error_{delay\_skew}$	is the estimated error of the delay skew measurement function in seconds;
E_d	is the error term of propagation delay proportional to the length of the cabling.

6.10.12 Error model for the length measurement function

The error model for length is identical to the error model for propagation delay since the length is a constant times the NVP.

6.10.13 Error model for the d.c. loop resistance measurement function

The error of the d.c. loop resistance contains a constant error term and an error which is proportional to d.c. loop resistance of the measured cabling. For a 100 m limited distance, this error is approximately proportional to length, see Equation (62).

$$Error_{DC\_loop\_resistance} = E_{c,DC\_r} + E_{d,DC\_r} \times DCloopresistance \tag{59}$$

where

$Error_{DC\_loop\_resistance}$	is the estimated error of the d.c. loop resistance function in Ω;
E_{c,DC_r}	is the constant error term of the d.c. loop resistance in Ω;
E_{d,DC_r}	is the error term proportional to the d.c. loop resistance of the cabling.

6.11 Network analyzer measurement comparisons

6.11.1 General

Field test and network analyzer results can be compared using ISO/IEC 11801 (or equivalent) compliant cabling whose transmission test performance falls within the dynamic range of the field test equipment. It is desirable that a number of links be used. The interfaces required to make the measurements are described in 6.11.3. These interfaces are based on the formal definitions of the reference planes for defined test configurations (channel, permanent link CP link and basic link). The laboratory equipment based measurement shall be performed as for the reference procedures described in Clause 4.

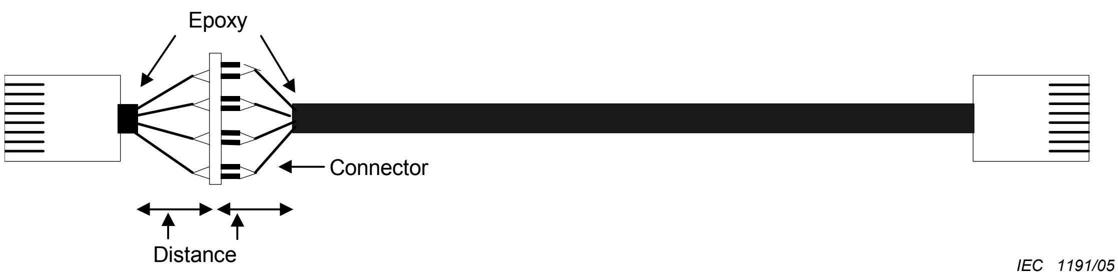
Methods for comparing results are described in 6.11.3. The results shall agree within the sum of the measurement accuracy of the laboratory measurement and the estimated measurement accuracy computed from the applicable error model.

6.11.2 Adapters

In order to perform the network analyzer comparison, two special test cords are needed. These special patch cords may be constructed by first constructing a patch cord using solid core category 5 or category 6 compliant cable and terminating this cable with compliant modular plugs. This patch cord should be tested for connectivity and electrical performance.

Thereafter, this assembly is cut at a distance of 5 mm maximum from one of the plugs. Then the jacket material is removed to within 5 mm of the plug that was cut off and over approximately 40 mm from the long end of the patch cable. A high quality jack is connected to the patch cable. The crosstalk properties of this jack should be at least 30 dB better than the test limit for the cabling link to be used for the network analyzer comparison. Also, the return loss caused by this high quality connection should be at least 25 dB over the specified frequency range and the insertion loss of this high quality connector should be less than 0,25 dB over the frequency range. A socket similar to those used for integrated circuits may be used. Such a socket will accept the wires with the insulation material removed from the ends.

Epoxy should be applied at the location where pairs exit the jacket material at both the plug and the cable sides. Also, shrink tubing should be applied around the individual pairs, except at the very end in order to prevent untwisting while making connections. This will improve the consistency of repeated measurements (see Figure 31).



Key

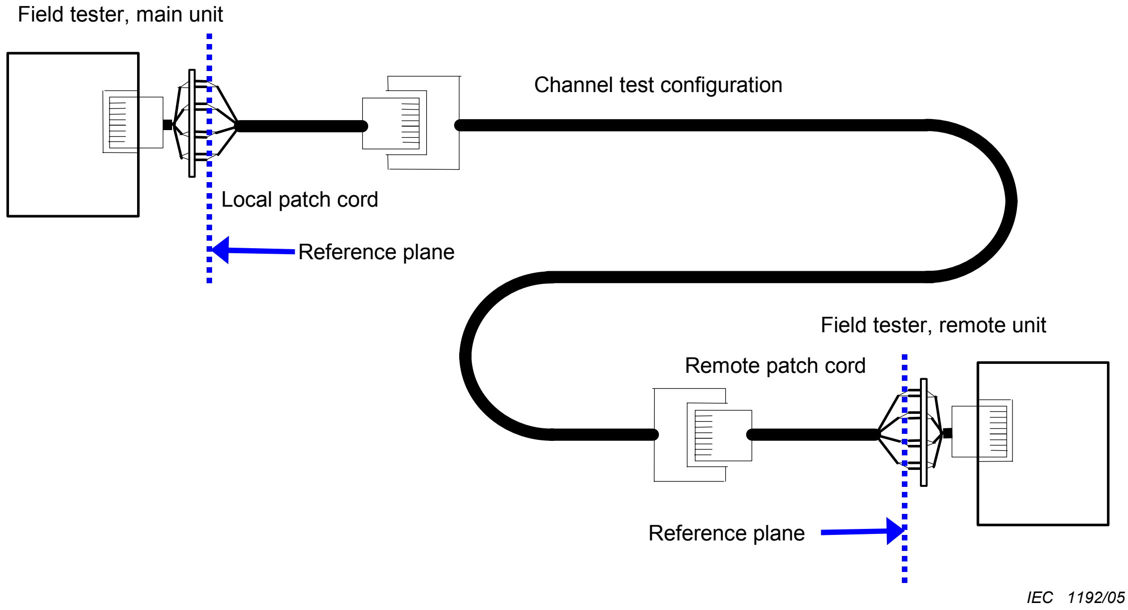
Epoxy	location to apply epoxy to stabilize the orientation of wires relative to each other
Connector	high quality connector to connect both parts of the special patch cord during channel measurements by the field tester
Distance	distance to cable jack: shall be 45 mm or less

Figure 31 – Construction details of special patch cord adapter

The reference plane defined for the test configuration to be tested shall be at the location of the high quality connector. To obtain the reference measurement, the connection at the location of the high quality connection shall be severed and the defined link shall be connected to the laboratory test equipment. When measuring the same test configuration with the field tester, the high quality connection shall be made again.

When performing a network analyzer comparison with a field test equipment on a channel or baseline test configuration, the positioning of the reference planes relative to the location of the high quality connector is as shown in Figure 31.

The interface to laboratory test equipment generally consists of copper posts, which are designed to accept copper cable ends of twisted pair cabling to be tested. To connect to laboratory equipment, short segments of pairs (< 5 cm) shall be used with a mating high quality connector plug.

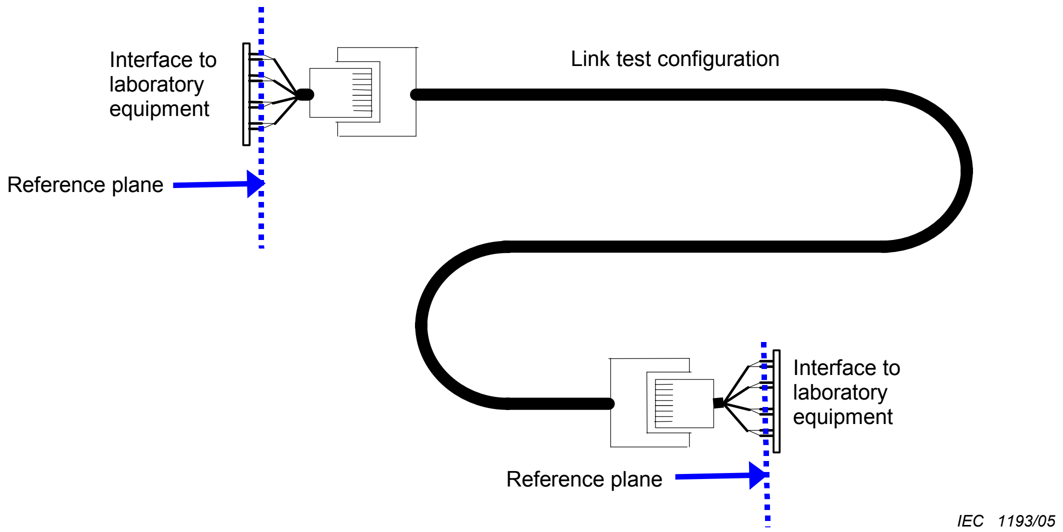


Key

Field tester, main unit	connection to the main unit of the field tester
Field tester, remote unit	connection to the remote unit of the field tester
Reference plane	location of the reference plane of measurement as defined in Figure 2
Local patch cord	special patch cord used for connections at the local end of the test link
Remote patch cord	special patch cord used for connections at the remote end of the test link
Channel test configuration	sample channel used for comparison of field tester and network analyzer measurements

Figure 32 – Interfaces to channel by field test and laboratory equipment to compare test results

When performing a network analyzer comparison with a field tester on a link test configuration, the special patch cord is turned at the local and remote ends, as is shown in Figure 32.



Key

Interface to laboratory equipment	location where connections to laboratory equipment are made
Reference plane	location of the reference plane of measurement as defined in Figure 2
Link test configuration	sample test link used for comparison of field tester and network analyzer measurements

Figure 33 – Interfaces to link test configuration by field test and laboratory equipment to compare test results

The network analyzer should be calibrated at the location of the high quality connection by using identical jacks with the required open circuits, shorts and terminations. This will cause the exact location of the reference plane to be towards the side of the high quality connection away from the laboratory equipment and thereby reduce the impact of the high quality connector, if any.

6.11.3 Comparison methods

6.11.3.1 General

Most transmission parameters required to be tested are measured as a function of frequency. Some parameters, such as propagation delay, delay skew and d.c. resistance produce a single result. Comparison of single value test results is straightforward by observing the differences measured by laboratory equipment and reported by the field tester. The difference of the single value results shall agree within the sum of the measurement accuracies of the laboratory equipment and the field tester at the signal level the measurement took place.

For the parameters that involve the measurement of a frequency response, one of the following three requirements shall be satisfied. One requirement option as described in 6.11.3.2 relates to the agreement of reported worst case conditions. This is the minimum requirement. The second requirement relates to agreement of results of all data points in the frequency responses as described in 6.11.3.3. The third requirement option describes the required agreement in terms of an equivalent noise floor. Refer to 6.11.3.4.

6.11.3.2 Comparison method using worst case performance margin

The results obtained from the laboratory equipment and field tester over the frequency range specified for the cabling class are compared only at the worst case performance condition relative to the test limit for the cabling. These are the minimally required summary reporting requirements for compliant field test equipment as described in 5.5.3. These worst case performance values computed from the laboratory test results shall agree with the results reported by the field tester within the sum of the measurement accuracies of the network analyzer and the field test equipment at the signal level of the worst case condition.

6.11.3.3 Comparison method using the full frequency responses using scatter plots

6.11.3.3.1 General

This method is useful in case the measurement accuracy does not significantly depend on frequency. In case of level IIE compliant field testers, it was assumed that worst case accuracy is relatively constant and the accuracy at 100 MHz was used as a constant. The scatter plot method uses all data from the frequency response of the laboratory equipment and field test measurements that are within the minimum reporting range of the field tester as specified in 5.5.2 and 5.5.3. It should not be used for comparisons over 100 MHz and is inappropriate for comparisons over 250 MHz.

For some parameters, NEXT loss in particular, small differences in the set-up can cause shifts in the nulls of the frequency response and only slight variations in the maximum values between the results. Therefore, a data point to data point comparison as described in the X-Y scatter plot is not a compliance requirement, but a very effective method to observe small differences in the responses measured by laboratory equipment and field testers.

However, to assure frequency resolution requirements, identifiable peaks in the frequency response shall be evaluated for frequency resolution.

6.11.3.3.2 X-Y scatter plot frequency response evaluation

Plot both data results relative to the test limit for the test configuration (channel, permanent link, CP link or basic link) by creating an X-Y scatter plot. For each frequency data point, use X-co-ordinate equal to the distance from the network analyzer response to the test limit. The Y-co-ordinate is equal to the difference between the network analyzer and field tester results. Add to the scatter plot an upper bound, which is the positive sum of the accuracy of the laboratory test equipment and the field tester, and a lower bound which equals the negative value of the upper bound. The measurement accuracy of the laboratory test equipment shall be calculated using the relevant equations in 6.10.

A sample scatter plot is shown in Figure 34. Acceptable results are between the lower and upper bounds, and to the left of the reporting range limit.

Figure 34 – Sample scatter plot

6.11.3.3.3 Frequency resolution evaluation

The frequency response of a narrow band filter measured with laboratory test equipment and a field test equipment shall be compared. The bandwidth of the narrow band filter shall be at least 5× the required frequency resolution. The width of the response shall be observed at 6 dB below the peak response. The difference of the width measured by the field tester and the width measured by the laboratory equipment shall be less than twice the required frequency resolution.

Alternatively, a peak in the frequency response of cabling measured with laboratory equipment may be used for frequency resolution evaluation. A suitable peak in the response of the laboratory measurement shall have a floor less than 20 dB below the peak value. The response of the field tester shall exhibit a peak in the response at approximately the same frequency. The widths of the peak at 6 dB levels below the peak values shall agree within 2× the required frequency resolution.

6.11.3.4 Comparison method using the full frequency responses using equivalent noise floor method of evaluation

This method is useful for level III, level IIIE and IV compliant field testers and in situations where the measurement accuracy significantly depends on the frequency. The scatter plot method is not appropriate in this case. The equivalent noise floor is established by

- computing the measurement accuracy at the pass/fail limit for the measurement function and class,
- determining a noise floor above the pass/fail limit, which causes an error equal to the measurement error:

$$NF_{\text{nominal}} = -20\log\left(10^{\frac{-(Limit - Accuracy)}{20}} - 10^{\frac{-Limit}{20}}\right) \quad (60)$$

where

NF_{nominal}	is the nominal equivalent noise floor in positive values of dB;
$Limit$	is the pass/fail limit in positive values of dB of the measurement parameter for the applicable class and test configuration (permanent link, CP link or channel);
$Accuracy$	is the computed measurement accuracy in positive values of dB of the measurement parameter at the pass/fail limit for the applicable class and test configuration.

- when evaluating the difference between the reference laboratory measurement and the field tester result, this difference can also be expressed as a measured noise floor:

$$NF_{\text{observed}} = -20\log\left(\left|10^{\frac{-measured_{NWA}}{20}} - 10^{\frac{-measured_{\text{tester}}}{20}}\right|\right) \quad (61)$$

where

NF_{observed}	is the nominal equivalent noise floor in positive values of dB;
$measured_{NWA}$	is the measured value by the laboratory equipment in positive values of dB of the measurement parameter for the applicable class and test configuration (permanent link, CP link or channel);
$measured_{\text{tester}}$	is the measured value by field tester in positive values of dB of the measurement parameter at the pass/fail limit for the applicable class and test configuration.

- when using this method of evaluation, at every frequency data point:

$$NF_{\text{observed}} \geq NF_{\text{nominal}} \quad (62)$$

Annex A
(informative)

Uncertainty and variability of field test results

A.1 General

Careful consideration should be given to the measurement accuracy of the field tester. This does not only apply to the accuracy claims as specified by the level performances in this standard, but also to the actual nominal accuracy performance that is specified by field tester manufacturers. It is generally difficult to verify actual accuracy performance to the ultimate accuracy specifications, but it is recommended that simple means be used to provide confidence that the field tester is operating properly, is within calibration accuracy and provides reliable test results.

This annex clarifies requirements for reporting marginal results, nominal accuracy and explains sources of variability in test results that are not included in measurement accuracy, which do occur during link measurements. Also additional techniques to assess the accuracy of field test are described.

A.2 Marginal results reporting

According to the requirements of this standard, individual test results that are closer to the pass/fail limit than the nominal accuracy specified by the field tester manufacturer shall be flagged by an asterisk. It is not required that the overall pass/fail result be identified with an asterisk when any of the individual results has an asterisk. Often it is up to quality requirements that are applicable for a particular cabling installation whether such results are acceptable or not. If they are not acceptable, selections on the operation of a field tester shall determine whether marginal pass/fail conditions did occur at the summary test result that is displayed to the operator and reported in the final results.

A.3 Nominal accuracy

The worst case conditions for measurement accuracy do not all occur at the same time and therefore nominal accuracy performance specifications are often used to determine results that are closer to the pass/fail limit than this worst case accuracy. One can expect this nominal accuracy to be at least 2× better than the worst case accuracy that is computed based on worst case assumptions for all the key field tester and link performance parameters that are defined for the applicable level. In many cases, field tester manufacturers may specify even tighter nominal accuracy performance than 2× better than the worst case accuracy.

Since the reporting of marginal pass/fail conditions by showing asterisks is generally considered undesirable, field tester manufacturers generally use the tighter nominal accuracy to establish conditions for marginal PASS/FAIL. It is appropriate for the user to understand the basis for such accuracy performance and its characteristics.

- The nominal accuracy shall be based on a large number of accuracy performance evaluations by the field tester manufacturer. These are generally not easily performed by an independent party. However, it is possible to assess field tester accuracy, as described in Clause A.6.
- The nominal accuracy is frequency-dependent. As the frequency increases, the measurement accuracy generally declines for all parameters, with the possible exception of return loss.

- The measurement accuracy significantly depends on the test configuration, link or channel. The accuracy is generally worse for the channel test configuration, since all measurements have to occur through a mated plug (of the user patch cord) and jack (of the channel adapter of the field tester), while the impact of the mated connection should be suppressed in the end result.

Field tester manufacturers should specify in detail what the nominal accuracies are for every measurement parameter and test configuration that are used for the purpose of establishing pass/fail conditions in results reported by the field tester. The user should obtain this information and include this information in the quality requirements.

A.4 Variability in link measurements not included in the measurement accuracy

The formal definition of a link includes the mated connections at the local and remote ends, see Figure A.1.

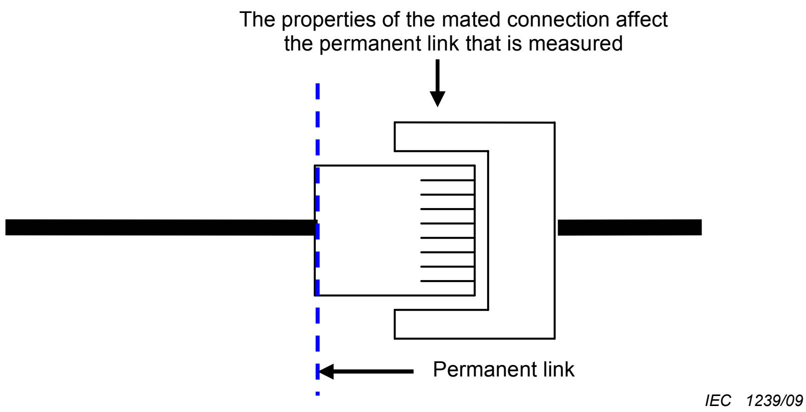


Figure A.1 – Source of variability during link testing

The plugs of the link adapter at the local and remote ends of the field tester mate with the local and remote telecommunication outlets. According to the formal definition of a link, it includes the properties of the mated connection. It is well known for modular 8-pin RJ-45 style connecting hardware that the mated NEXT depends strongly on the properties of the plug. Requirements of this standard include that the plugs of link adapters of field testers shall be within the range of test plugs that are defined for the purpose of qualifying modular 8-pin connecting hardware. Even with plug properties contained within the specified range, one may expect, in particular for the 3,6 to 4,5 pair combination, 4 dB variations of the link test NEXT result are possible.

This variability can only be reduced by tighter test plug NEXT properties. Field tester manufacturers should provide information on the values and tolerances of the plug NEXT properties for at least the 3,6 to 4,5, 1,2 to 3,6, and 3,6 to 7,8 pair combinations.

A.5 Variability in channel measurements

The channel test result excludes the mated connection at the channel adapter of the field tester. Often the measurement accuracy of the channel configuration is reduced relative to the measurement accuracy for the link. The mated connection at the other end of the user patch cord is included in the channel test result. The measurement accuracy of the field tester includes the impact of the mated connection of user patch cord and the channel adapter. Since mated NEXT of a connection can be strongly impacted by the plug properties, the user patch cord should not be exchanged or reversed to avoid changing the mated NEXT at the connection at the first telecommunication outlet of the channel. In case a patch cord is changed or reversed, the channel performance should be retested.

A.6 Field tester accuracy checks

A.6.1 General

Field tester accuracy checks may be conducted in several ways:

- manipulating cords of link adaptor;
- exchanging adapters to main and remote field tester units;
- exchanging the location of main and remote field tester units;
- use of previously characterized links;
- use of separately characterized links using laboratory equipment.

A.6.2 Manipulating cords of link adaptor

Variability from the cordage of a link adapter mainly affects return loss. This variability is included in the accuracy requirements for field testers. The variability can be tested by manipulating the cord of the link adapter and leaving all other connections stable and observing the return loss result. The variability is unacceptable when it is a substantial portion of the nominal return loss accuracy of the field tester and should result in replacing the link adapter. It is also desirable to test the return loss calibration of the link adapter. Contact the field tester manufacturer for more information.

A.6.3 Exchanging adapters to main and remote field tester units

A measurement of a test link is conducted. Then the main adapter is connected to the remote unit at the remote end of the link, and the remote adapter is connected to the main unit at the local end. Then the measurement is repeated and the results compared to the results of the first test. The consistency of main and remote adapters is established. The difference should be well within the nominal accuracy specified by the field tester manufacturer.

A.6.4 Location of main and remote field tester units

A measurement of a test link is conducted. Then the main unit along with its adapter is connected to the remote end of the link and the local unit along with its adapter is connected to the local end of the link. What were previously the local NEXT and return loss results become the remote NEXT and return loss results during the second measurement and vice-versa. The measurement systems of main and remote units have the same measurement capability and any defects are likely only to show up in one, and not both units. The difference should be well within the nominal accuracy specified by the field tester manufacturer.

A.6.5 Use of previously characterized links

It is highly recommended to measure a sample link after a field tester has been newly acquired or after calibration. A channel configuration should maintain its patch cords in place and measured each time in the same orientation. The difference of each consecutive measurement should be well within the nominal accuracy specified by the field tester manufacturer.

A.6.6 Use separately characterized links using laboratory equipment

The link configuration is best suited to be characterized using laboratory equipment. Reason is that the properties of the reference test plug can be well controlled during reference laboratory measurements. This method has also the advantage that it provides an independent reference to national standards. When comparing the reference link measurement with the field tester link measurement, the difference should not exceed the nominal measurement accuracy specified by the field tester manufacturer. If the difference exceeds the nominal accuracy, this can indicate either reduced measurement accuracy of the field tester measurement circuitry and/or a significant deviation from nominal of link adapter plug properties. In this connection, it should for instance be noted that allowed variability of a Category 6 plug may result in 4 dB NEXT accuracy variation of field testing (see Clause A.4).

Obtaining reference data for channel configurations is more difficult since the laboratory test involves a destructive (user patch cord) test and involves the use of special adapters from the field tester manufacturer. Since the user patch cord is part of the channel test configuration, it should remain in position with the remainder of the test channel. This may not occur in practice. The use of the channel configuration is not recommended for this reason.

A.6.7 Guidelines for correct installation testing

The following guidelines should be used to establish the correct performance of an installation.

a) Define how to handle asterisk results before testing is started. This should be done in the contract phase since acceptance or non-acceptance of asterisk results may otherwise become a significant cost issue.

b) Verify the performance of the field tester using one of the methods discussed in Clause A.6. The method should be defined during the contract phase.

c) Recognize that variability of test results does exist. In any case, the difference between two results that should be identical cannot exceed the sum total of nominal measurement accuracies of the field tester or field testers that are actually used during the test. If the difference exceeds the sum total of nominal measurement accuracies, the field testers that are involved in this measurement should be checked against independent references as described in A.6.6. Use of different field testers, whose accuracy is unknown, and/or different test adapters is not appropriate to resolve test result issues.

Annex B
(normative)

Reference laboratory test configuration for alien crosstalk testing

B.1 General

If used, laboratory testing shall be conducted as described in this annex to assure consistency of test results. Laboratory testing of alien crosstalk is a way to investigate the performance of links and channels in one controlled worst case configuration. Laboratory testing is not intended to replace field testing. The measurement is carried out on representative samples of links or channels, assembled according to the manufacturer's instruction as applied in the installation type to be covered by the laboratory testing.

This procedure is intended for use in the laboratory, to verify that a link or channel complies with the PS ANEXT and PS AACR-F requirements, when properly installed. It is also used to test installation practices, to assure that they do not degrade PS ANEXT and PS AACR-F performance. A different procedure and way to assess alien crosstalk performance is specified for field testing of alien crosstalk of cabling installations in 5.4.

Alien crosstalk is not only influenced by the components of the link and channel, but may also be significantly affected by the way the cables are arranged relative to each other and the mounting system of the connecting hardware. Consequently, the testing result is specific for the applied panels and outlets of the link or channel being tested.

B.2 Test parameters

Tested parameters are PS ANEXT and PS AACR-F. Testing procedures and calculation of results from measured data are specified in 4.12 and 4.13. This annex only defines a reference laboratory test configuration and the minimum number of disturbing links or channels that need to be included in this test.

B.3 Link and channel construction

The link and channel shall be constructed to satisfy the following conditions.

a) There shall be one disturbed link or channel of the desired configuration.
b) There shall be at least 6 disturbing links or channels. More than 6 disturbing links or channels will be required if the connecting hardware in the applied mounting system has significant alien crosstalk contribution from more than 6 disturbing positions, see Clause B.4.
c) Both a long and short link or channel shall be included in the testing. Both long and short links or channels shall be similarly configured.
   - The long link or channel shall have the maximum length and shall be configured for the intended field application, except that the length of consolidation point cable, if applied, shall always be 5,0 m.
   - The short link or channel shall be configured in the same way as the long link or channel, except that the length of horizontal cable shall be reduced.
   - If a consolidation point is applied, the length of horizontal cable between patch panel (nearest patch panel in case of a crossconnect) and consolidation point shall be 15,0 m and the length of cable between consolidation point and telecommunication outlet shall be 5,0 m.

- If no consolidation point is applied, the length of horizontal cable between patch panel (nearest patch panel in case of a crossconnect) and telecommunication outlet shall be 10,0 m.
- No other change in configuration of the tested short link or channel shall apply, i.e., compared with the long link or channel, it will contain the same number and types of applied connecting hardware, and the same lengths of equipment cables (for channels) and crossconnect cable (if applicable).

d) All disturbing cable lengths shall be arranged 6 around the disturbed cable for the first 6 disturbing links or channels. This means that also cables of patch cords are arranged as "6-around-1". Any additionally required disturbing links or channels may have cable placed separately from the "6-around-1" cable bundles.

e) All disturbing cables shall touch the disturbed cable throughout the bundled length. The touching condition is secured by using helical wrapping of all "6-around-1" cable bundles using a maximum of 8,0 cm lay length.

f) Cables may be separated where connected to measuring equipment and connecting hardware of the link or channel. Maximum 1,0 m shall be unbundled where connected to measuring equipment and a maximum of 0,3 m shall be unbundled at the connection to each connecting hardware sample.

g) In the reference test configuration, the cable bundles are placed on a non-conductive surface.

h) For the purpose of practical testing, the cable bundles may be bent or otherwise arranged to fit into a laboratory environment. It shall then be demonstrated that the arrangement of the cable bundles gives the same result as when measured with cable bundles stretched on non-conductive surface for the total length. When a cable bundle is bent, it shall be verified that the cables do not separate in the bent area.

i) The worst case alien crosstalk position of all connecting hardware, i.e. usually a central position of a panel or outlet in the tested mounting system, shall be used as the disturbed port. Disturbing ports are all neighbour ports over, under and at each side of the disturbed port that have a significant contribution to the alien near or far end crosstalk, see Clause B.4. This means for instance, that also port positions in panels mounted over and under the panel containing the disturbed connecting hardware position will need to be considered.

j) Each type of connecting hardware of a tested link or channel shall be evaluated for positions giving significant contribution to alien crosstalk. The connecting hardware type having the worst performance will determine the number of disturbing links or channels. The minimum number will always be 6, see item b).

k) For screened modular connectors, a general worst case mounting method is to arrange the modular connectors in direct metallic contact, i.e. the minimum 6 disturbing cables around the disturbed cable. The 6 connectors shall then include one on each side, one on top and one under the disturbed modular connector. The last two minimum required 6 connectors shall be mounted in any two of the four corners. If more connectors are having significant contribution of alien crosstalk, they shall be mounted as specified in Clause B.4. This way of worst case mounting of screened modular connectors will cover all possible types of panel and outlet mountings. The same situation does not apply for unscreened connecting hardware as mounting method, for instance panel material and shape may significantly affect the alien crosstalk properties.

l) Port positions having significant contribution to alien crosstalk may include a large number of ports. The number of disturbing ports shall be determined as specified in Clause B.4.

m) Disturbing links or channels shall have the same length and configuration as the disturbed link or channel.

B.4 Determination of number of disturbing links or channels

The number of disturbing ports to be included in the alien crosstalk measurements is dependent on the connector mounting system. A minimum 6 disturbing links or channels will have to be applied due the requirement to always have 6 disturbing cables around the disturbed cable. More disturbing links or channels will be required in case that more than 6 ports of any applied connecting hardware type have significant alien crosstalk contribution.

For any given connector mounting system, the determination of which ports to include shall be made based on the ANEXT and AFEXT contribution to the disturbed port. All ANEXT or AFEXT data that exceed the significance condition as defined in 5.4.7.1 shall be included in the power sum result.

Significantly contributing connector ports may be located in other panels in close proximity and these shall be assessed accordingly.

Alien crosstalk testing procedure for connecting hardware is specified in IEC 60512-25-9.

B.5 Computation of results

The computation of PS ANEXT and PS AACR-F shall be carried out as specified in 4.12.4.3 and 4.13.4.3, respectively.

B.6 Test report

The measured results shall be reported as specified in 4.12.4.4 and 4.13.4.4, respectively.

Annex C
(informative)

General information on power sum alien crosstalk performance of installations

This annex contains considerations to identify worst case alien crosstalk conditions in a cabling system.

a) The toughest alien crosstalk requirements are applicable to links with the highest insertion loss when application standards adjust power sum alien crosstalk requirements based on insertion loss. In these cases, if maximum length links pass the alien crosstalk requirements, one may estimate that links shorter in length will pass with higher margins. In all other cases, samples of short length links and medium length links should be tested. Refer to 5.4.8.

b) Disturbing links within the same cable bundle as the disturbed link will be dominating compared with disturbing links in adjacent bundles. Most often, alien crosstalk contributions from disturbing links in adjacent cable bundles are insignificant.

c) Consistency is expected of alien crosstalk results from different disturbed links in the same cable bundle. If differences are well below the alien crosstalk margin that has been obtained from selected disturbed links, other links may be expected to pass alien crosstalk requirements.

d) A certain amount of knowledge is to be applied to the cabling topology. Only cables that are in the same cabling bundle are expected to contribute a significant amount of power sum alien crosstalk, see item b).

e) Most of the alien NEXT loss occurs within the first 20 m of the near end of the cabling. PS ANEXT loss further away from the near end of measurement has virtually no impact on overall PS ANEXT loss.

f) AFEXT contributions can occur along the full length of the cabling bundle.

g) PS ANEXT loss contributions that are from cables that contain some distance between the location where they start running in parallel can be ignored. This is the result of the round-trip insertion loss between the location from where the measurement is conducted and the location where PS ANEXT loss is present.

h) Screened cabling with separately screened links or channels will normally have alien crosstalk below the noise level, and consequently only a few representative links or channels need to be measured to demonstrate the alien crosstalk level. Separately screened means that no patch panel or outlet contains more than one port within an overall screen.

i) The dominating contribution to the alien crosstalk of the installation originates in most cases from the cables, especially when bundled. However, each type of applied connecting hardware needs to be evaluated for its alien crosstalk performance. This is done by measuring a number of neighbour positions of the connecting hardware in question and concluding whether the alien crosstalk is in average reduced with increasing distance. Variation may occur within specific positions due to influence from a cable bundle, but if the average value of alien crosstalk falls with distance to the disturbing port, it may be concluded that the connecting hardware in question has significant alien crosstalk contribution.

j) Start testing using disturbing links next to the disturbed link. Add disturbing links to the result as long as it appears that the PS ANEXT loss result is affected. Significant amounts of alien crosstalk contributions are most often confined to links within the same cable bundle.

k) Start testing alien FEXT loss using disturbing links next to the disturbed link. Add disturbing channels to the result, as long as it appears that the PS AFEXT loss result appears to be no longer affected. Significant amounts of alien crosstalk contributions are most often confined to links within the same cable bundle.

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