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TIA/EIA STANDARD

Commercial Building Telecommunications Cabling Standard

Part 2: Balanced Twisted-Pair Cabling Components

TIA/EIA-568-B.2

(Revision of TIA/EIA-568-A)

MAY 2001

TELECOMMUNICATIONS INDUSTRY ASSOCIATION

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(From Standards Proposal Nos.4426-B and 4426-B.1, formulated under the cognizance of the TIA TR-42 Committee on User Premises Telecommunications Infrastructure.)

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COMMERCIAL BUILDING TELECOMMUNICATIONS CABLING STANDARD
PART 2: BALANCED TWISTED-PAIR CABLING COMPONENTS

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FOREWORD

(This forward is not a part of this Standard.)

This Standard was approved by Telecommunications Industry Association (TIA) Sub-Committee TR-42.7, TIA Engineering Committee TR-42, and the American National Standards Institute (ANSI). ANSI/TIA/EIA reviews standards every 5years. At that time, standards are reaffirmed, rescinded, or revised according to the submitted updates. Updates to be included in the next revision should be sent to the committee chair or to TIA.

More than 30 organizations within the telecommunications industry contributed their expertise to the development of this Standard (including manufacturers, consultants, end users, and other organizations).

This Standard replaces the ANSI/TIA/EIA-568-A standard dated October 6, 1995. Since the original publication of ANSI/EIA/TIA-568 in July of 1991, the office environment has undergone a period of rapid change marked by the growth of increasingly powerful personal computers, the access to more sophisticated applications and the need to interconnect different systems. These changes place increased demands on the transmission capacity of balanced twisted-pair cabling. This has led to the development of twisted-pair copper cables and optical fiber cables and associated, corresponding compatible connecting hardware with enhanced transmission characteristics.

This Standard incorporates and refines the technical content of:

- TIA/EIA TSB67
- TIA/EIA TSB72
- TIA/EIA TSB75
- TIA/EIA TSB95
- ANSI/TIA/EIA-568-A-1
- ANSI/TIA/EIA-568-A-2
- ANSI/TIA/EIA-568-A-3
- ANSI/TIA/EIA-568-A-4
- ANSI/TIA/EIA-568-A-5
- TIA/EIA/IS-729

This document takes precedence over the technical contents of the aforementioned bulletins, addenda and interim standards.

This Standard is related to the following TIA standards and documents:

- Commercial Building Telecommunications Cabling Standard (ANSI/TIA/EIA-568-B-1);
- Commercial Building Standard for Telecommunications Pathways and Spaces (ANSI/TIA/EIA-569-A);
- Residential and Light Commercial Telecommunications Wiring Standard (ANSI/TIA/EIA-570);
- Administration Standard for the Telecommunications Infrastructure of Commercial Buildings (ANSI/TIA/EIA-606);
- Commercial Building Grounding and Bonding Requirements for Telecommunications (ANSI/TIA/EIA-607).

In addition, the following documents may be useful to the reader:

- National Electrical Safety Code® (NESC®)
  (IEEE C 2)
- National Electrical Code® (NEC®)
  (NFPA 70)

Useful supplements to this Standard include the Building Industry Consulting Service International (BICSI) *Telecommunications Distribution Methods Manual,* the *Customer-owned Outside Plant Methods Manual,* and the *Cabling Installation Manual*. These manuals provide practices and methods by which many of the requirements of this standard are implemented. Other references are provided in annex P.

Annexes A, B, C, D, E, F, I, J, K, and M are normative and considered requirements of this Standard. Annexes G, H, L, N, O and P are informative and are not considered requirements of this Standard.

1 INTRODUCTION

The transmission performance of a cabling system depends upon the characteristics of the horizontal cable, connecting hardware, patch cords, equipment cords, work area cords, cross-connect wiring, the total number of connections, and the care with which they are installed and maintained. The development of high-speed applications requires that cabling systems be characterized by transmission parameters such as insertion loss, PSNEXT loss, return loss, and PSELFEXT. System designers use these performance criteria to develop applications that utilize all four pairs in a cabling system for simultaneous bi-directional transmission. This Standard provides minimum cabling component performance criteria as well as procedures for component and cabling performance validation.

1.1 Purpose

This Standard specifies cabling components, transmission performance, system models, and the measurement procedures needed for verification of balanced twisted pair cabling. Requirements for four-pair balanced cabling systems are provided. This Standard also specifies field test instruments and applicable reference measurement procedures for all transmission parameters.

1.2 Specification of criteria

In accordance with EIA Engineering Publication EP-7B, two categories of criteria are specified; mandatory and advisory. The mandatory requirements are designated by the word "shall"; advisory requirements are designated by the words "should”, "may", or "desirable" which are used interchangeably in this Standard. Mandatory criteria generally apply to protection, performance, administration and compatibility; they specify the absolute minimum acceptable requirements. Advisory or desirable criteria are presented when their attainment will enhance the general performance of the cabling system in all its contemplated applications. A NOTE in the text, table, or figure is used for emphasis or offering informative suggestions.

1.3 Metric equivalents of US customary units

The majority of the metric dimensions in this Standard are soft conversions of US customary units; e.g., 100 mm is the soft conversion of 4 inches.

1.4 Life of the Standard

This Standard is a living document. The criteria contained in this Standard are subject to revisions and updating as warranted by advances in building construction techniques and telecommunications technology.

2 SCOPE

2.1 Applicability

This Standard specifies minimum requirements for balanced twisted-pair telecommunications cabling components that are used up to and including the telecommunications outlet/connector and between buildings in a campus environment. This Standard specifies the minimum performance requirements for recognized balanced twisted-pair cabling components as described in ANSI/TIA/EIA-568-B.1 (i.e. cable, connectors, connecting hardware, patch cords, equipment cords, work area cords, and jumpers) and for the field test equipment used to verify the performance of these components as installed.

2.2 Normative references

The following standards contain provisions that, through reference in this text, constitute provisions of this Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision; parties to agreements based upon this Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated. ANSI and TIA maintain registers of currently valid national standards published by them.

ANSI/ICEA S-80-576, *Communications Wire and Cable for Wiring Premises,* 1994

ANSI/ICEA S-84-608*, Telecommunications Cable Filled, Polyolefin Insulated, Copper Conductor - Technical Requirements*, 1994

ANSI/ICEA S-90-661, *Individually Unshielded Twisted Pair Indoor Cable For Use Communication Wiring Systems*, 1994

ANSI/IEEE 802.5, *Information Technology - Telecommunications And Information Exchange Between Systems - Local And Metropolitan Area Networks - Specific Requirements - Part 5: Token Ring Access Method And Physical Layer Specifications,* 1998

ANSI/TIA/EIA-570-A, *Residential Telecommunications Cabling Standard,* 1999

ANSI/TIA/EIA-568-B.1, *Commercial Building Telecommunications Cabling Standard, Part 1, General Requirements,* 2001

ANSI/TIA/EIA-568-B.3, *Commercial Building Telecommunications Cabling Standard, Part 3, Optical Fiber Cabling Components Standard,* 2000

ANSI/TIA/EIA-606, *Administration Standard For The Telecommunications Infrastructure Of Commercial Buildings*, 1993

ASTM D 4565, *Test Methods For Physical And Environmental Performance Properties of Insulations And Jackets For Telecommunications Wire And Cable, 1999*

ASTM D 4566-98, *Electrical Performance Properties of Insulations and Jackets for Telecommunications Wire and Cable, 1998*

IEC 60068-1, *Environmental Testing Part 1: General And Guidance, 1988*

IEC 60068-2-2, *Basic Environmental Testing Procedures - Part 2: Tests - Tests B: Dry Heat, 1974*

IEC 60068-2-6, *Environmental Testing - Part 2: Tests - Test F: Vibration [Sinusoidal]*, 1995

IEC 60068-2-14, *Basic Environmental Testing Procedures Part 2: Tests - Test N: Change Of Temperature*, 1984

IEC 60068-2-38*, Environmental Testing - Part 2: Tests - Test Z/Ad: Composite Temperature/Humidity Cyclic Test, 1974*

IEC 60512-2, *Electromechanical Components For Electronic Equipment; Basic Testing Procedures And Measuring Methods - Part 2: General Examination, Electrical Continuity And Contact Resistance Tests, Insulation Tests And Voltage Stress Tests, 1985*

IEC 60603-7, *Connectors for frequencies below 3 MHz for use with printed boards – Part 7: Detailed specifications for connectors, 8-way, including fixed and free connectors with common mating features, with assessed quality,* 1996

IEC 60807-8, *Rectangular Connectors For Frequencies Below 3 MHz - Part 8: Detail Specification For Connectors, Four Signal Contacts And Earthing Contacts For Cable Screen*, 1992

IEC 60807-9, *Rectangular Connectors For Frequencies Below 3 MHz - Part 9: Detail Specification For A Range Of Peritelevision Connectors*, 1993

UL 444, *Communication Cables 2nd Edition*, 1994

UL 1863, *Communications Circuit Accessories*, 1995

3 DEFINITIONS, ABBREVIATIONS AND ACRONYMS, UNITS OF MEASURE

3.1 General

This clause contains definitions of terms, acronyms, and abbreviations that have a special meaning or that are unique to the technical content of this Standard. The terms that are used in only one clause may be defined within that clause. The generic definitions in this section have been formulated for use by the entire family of telecommunications infrastructure standards. As such, the definitions do not contain mandatory requirements of the Standard. Specific requirements are to be found in the normative sections of the Standard.

administration: The method for labeling, identification, documentation and usage needed to implement moves, additions and changes of the telecommunications infrastructure.

backbone: A facility (e.g., pathway, cable or conductors) between telecommunications rooms, or floor distribution terminals, the entrance facilities, and the equipment rooms within or between buildings.

bundled cable: An assembly of two or more cables continuously bound together to form a single unit.

cable: An assembly of one or more insulated conductors or optical fibers, within an enveloping sheath.

cable run: A length of installed media which may include other components along its path.

cable sheath: A covering over the optical fiber or conductor assembly that may include one or more metallic members, strength members, or jackets.

cabling: A combination of all cables, jumpers, cords, and connecting hardware.

campus: The buildings and grounds having legal contiguous interconnection.

centralized cabling: A cabling configuration from the work area to a centralized cross-connect using pull through cables, an interconnect, or splice in the telecommunications room.

connecting hardware: A device providing mechanical cable terminations.

consolidation point: A location for interconnection between horizontal cables extending from building pathways and horizontal cables extending into furniture pathways.

cross-connect: A facility enabling the termination of cable elements and their interconnection or cross-connection.

cross-connection: A connection scheme between cabling runs, subsystems, and equipment using patch cords or jumpers that attach to connecting hardware on each end.

equal level far-end crosstalk: A measure of the unwanted signal coupling from a transmitter at the near-end into another pair measured at the far-end, and relative to the received signal level.

equipment cable; cord: A cable or cable assembly used to connect telecommunications equipment to horizontal or backbone cabling.

far-end crosstalk loss: A measure of the unwanted signal coupling from a transmitter at the near end into another pair measured at the far end, and relative to the transmitted signal level.

horizontal cabling: 1)The cabling between and including the telecommunications outlet/connector and the horizontal cross-connect. 2) The cabling between and including the building automation system outlet or the first mechanical termination of the horizontal connection point and the horizontal cross-connect.

hybrid cable: An assembly of two or more cables, of the same or different types or categories, covered by one overall sheath.

infrastructure (telecommunications): A collection of those telecommunications components, excluding equipment, that together provide the basic support for the distribution of all information within a building or campus.

insertion loss: The signal loss resulting from the insertion of a component, or link, or channel, between a transmitter and receiver (often referred to as attenuation).

interconnection: A connection scheme that employs connecting hardware for the direct connection of a cable to another cable without a patch cord or jumper.

jumper: An assembly of twisted pairs without connectors, used to join telecommunications circuits/links at the cross-connect.

keying: The mechanical feature of a connector system that guarantees correct orientation of a connection, or prevents the connection to a jack, or to an optical fiber adapter of the same type intended for another purpose.

link: A transmission path between two points, not including terminal equipment, work area cables, and equipment cables.

listed: Equipment included in a list published by an organization, acceptable to the authority having jurisdiction, that maintains periodic inspection of production of listed equipment, and whose listing states either that the equipment or material meets appropriate standards or has been tested and found satiable for use in a specified manner.

media (telecommunications): Wire, cable, or conductors used for telecommunications.

open office: A floor space division provided by furniture, moveable partitions, or other means instead of by building walls.

outlet box (telecommunications): A housing used to hold telecommunications outlet/connectors.

outlet cable: A cable placed in a residential unit extending directly between the telecommunications outlet/connector and the distribution device.

outlet/connector (telecommunications): A connecting device in the work area on which horizontal or outlet cable terminates.

outside plant: Telecommunications infrastructure designed for installation exterior to buildings.

patch cord: A length of cable with a plug on one or both ends.

patch panel: A connecting hardware system that facilitates cable termination and cabling administration using patch cords.

power sum equal level far-end crosstalk: A computation of the unwanted signal coupling from multiple transmitters at the near-end into a pair measured at the far-end, and normalized to the received signal level.

power sum near-end crosstalk loss: A computation of the unwanted signal coupling from multiple transmitters at the near-end into a pair measured at the near-end.

pull strength: See **pull tension**.

pull tension: The pulling force that can be applied to a cable.

return loss: A ratio expressed in dB of the power of the outgoing signal to the power of the reflected signal.

screen: An element of a cable formed by a shield.

sheath: See **cable sheath**.

shield: A metallic layer placed around a conductor or group of conductors.

telecommunications: Any transmission, emission, and reception of signs, signals, writings, images, and sounds, that is information of any nature by cable, radio, optical, or other electromagnetic systems.

transfer impedance: A measure of shielding performance determined by the ratio of the voltage on the conductors enclosed by a shield to the surface currents on the outside of the shield.

work area (work station): A building space where the occupants interact with telecommunications terminal equipment.

3.2 Abbreviations and acronyms

ANSI	American National Standards Institute
BICSI	Building Industry Consulting Service International
CMR	Common mode rejection
EIA	Electronic Industries Alliance
ELFEXT	Equal Level Far-end Crosstalk
FEXT	Far-end Crosstalk
ICEA	Insulated Cable Engineers Association
IEC	International Electrotechnical Commission
NEXT	Near-end Crosstalk
OSB	Output signal balance
PSELFEXT	Power Sum Equal Level Far-end Crosstalk
PSNEXT	Power Sum Near-end Crosstalk
ScTP	Screened Twisted-pair
SRL	structural return loss
STP-A	Shielded Twisted-Pair
TIA	Telecommunications Industry Association
UTP	unshielded twisted-pair

3.3 Units of measure

dB	decibel
°C	degree Celsius
g	gram
in	inch
kg	kilogram
km	kilometer
MHz	megahertz
µm	micron or micrometer
mm	millimeter
nm	nanometer
N	Newton
Ω	ohm
lb	pound
lbf	pound-force

4 100 W BALANCED TWISTED-PAIR CABLES

4.1 General

This clause contains the mechanical and transmission performance specifications for balanced twisted-pair cables used in balanced twisted-pair cabling. Annex K contains additional specifications for ScTP cables. Compliance with this Standard does not imply compatibility with cabling having nominal impedance values other than 100 Ω.

4.2 Cable transmission performance

4.2.1 Recognized categories

The recognized categories of twisted-pair cabling are:

> Category 5e: This designation applies to 100 Ω cables whose transmission characteristics are specified up to 100 MHz.
> Category 3: This designation applies to 100 Ω cables whose transmission characteristics are specified up to 16 MHz.

Category 1, 2, 4 and 5 cables are not recognized as part of this Standard and, therefore, their transmission characteristics are not specified. Category 5 transmission characteristics, used in “legacy” cabling installations, are provided for reference in annex N.

4.2.2 Multi-disturber environment

To serve a multi-disturber environment, this Standard specifies transmission parameters as both worst-case pair-to-pair measurements and power sum calculations that approximate multi-disturber effects.

4.2.3 Measurements points and spacing

The total number of measurement points within the specified frequency range shall be a minimum of 100 times the number of decades covered by the specified frequency range.

4.3 Horizontal cable

4.3.1 General

Covered herein are the requirements for balanced twisted-pair cables used in horizontal cabling. The cable shall consist of 22 AWG to 24 AWG thermoplastic insulated solid conductors that are formed into four individually twisted-pairs and enclosed by a thermoplastic jacket. The cable shall meet all of the mechanical requirements of ANSI/ICEA S-80-576 applicable to four-pair inside wiring cable for plenum or general cabling within a building.

> NOTE – Additional requirements for 100 Ω ScTP cables are located in annex K.

4.3.2 Applicability

Horizontal cables shall consist of four balanced twisted-pairs of minimum 24 AWG thermoplastic insulated solid conductors enclosed by a thermoplastic jacket. Bundled and hybrid cables may be used for horizontal cabling in accordance with clause 4.3.6. Four-pair horizontal cables containing conductor diameters larger than 24 AWG, up to and including 22 AWG, that meet or exceed the requirements of this Standard may also be used.

4.3.3 Mechanical

In addition to the applicable requirements of ANSI/ICEA S-90-661-1994, the physical design of horizontal cables shall meet the requirements of clauses 4.3.3.1 to 4.3.3.6.

4.3.3.1 Insulated conductor

The diameter of the insulated conductor shall be 1.22 mm (0.048 in) maximum.

4.3.3.2 Pair assembly

The cable shall be restricted to four twisted-pair conductors. The pair twist lengths shall be chosen to ensure compliance with the transmission requirements of this Standard.

4.3.3.3 Color codes

The color code shall be as shown in table 1.

Table 1 - Color codes for 4-pair horizontal cables

Conductor identification	Color code	Abbreviation
Pair 1	White-Blue Blue	(W-BL) (BL)
Pair 2	White-Orange Orange	(W-O) (O)
Pair 3	White-Green Green	(W-G) (G)
Pair 4	White-Brown Brown	(W-BR) (BR)

The wire insulation is white and a colored marking is added for identification. For cables with tightly twisted-pairs [all pairs less than 38 mm (1.5 in) per twist] the mate conductor may serve as the marking for the white conductor. A white marking is optional.

4.3.3.4 Cable diameter

The diameter of the completed cable shall be less than 6.35 mm (0.25 in).

4.3.3.5 Breaking strength

The ultimate breaking strength of the cable, measured in accordance with ASTM D4565, shall be 400 N (90 lbf) minimum.

4.3.3.6 Bending radius

Twisted-pair cables shall withstand a bend radius of 25.4 mm (1 in) at a temperature of -20 °C ± 1 °C, without jacket or insulation cracking, when tested in accordance with ASTM D4565, Wire and Cable Bending Test. For certain applications (e.g., pre-cabling buildings in cold climate), the use of cables with a lower temperature bending performance of -30 °C ± 1 °C should be considered.

4.3.4 Transmission

4.3.4.1 DC resistance

The resistance of any conductor, measured in accordance with ASTM D4566, shall not exceed 9.38 Ω per 100 m (328 ft) at or corrected to a temperature of 20 °C.

4.3.4.2 DC resistance unbalance

The resistance unbalance between the two conductors of any cable pair, measured in accordance with ASTM D 4566, shall not exceed 5% when measured at, or corrected to, a temperature of 20 °C.

4.3.4.3 Mutual capacitance

The mutual capacitance of any horizontal cable pair at 1 kHz, measured at or corrected to a temperature of 20 °C, should not exceed 6.6 nF per 100 m (328 ft) for category 3 cables or 5.6 nF per 100 m (328 ft) for category 5e horizontal cables. Measurements shall be performed in accordance with ASTM D 4566. Mutual capacitance recommendations are provided for engineering design purposes.

4.3.4.4 Capacitance unbalance: pair-to-ground

The capacitance unbalance to ground of any horizontal cable pair at 1 kHz, measured in accordance with ASTM D 4566 at or corrected to a temperature of 20 °C, shall not exceed 330 pF per 100 m (328 ft).

4.3.4.5 Characteristic impedance and structural return loss (SRL) for category 3 cable

Category 3 horizontal cables shall exhibit a characteristic impedance of 100 Ω ±15% in the frequency range from 1 MHz up to the highest referenced frequency when measured in accordance with ASTM D 4566 Method 3. Characteristic impedance has a specific meaning for an ideal transmission line (i.e., a cable whose geometry is fixed and does not vary along the length of cable).

> NOTE - Characteristic impedance is commonly derived from swept frequency input impedance measurements using a network analyzer with an s-parameter test set. As a result of structural non-uniformities, the measured input impedance for an electrically long length of cable (greater than 1/8 of a wavelength) fluctuates as a function of frequency. These random fluctuations are superimposed on the curve for characteristic impedance, which asymptotically approaches a fixed value at frequencies above 1 MHz. Characteristic impedance can be derived from these measurements by using a smoothing function over the bandwidth of interest.

Fluctuations in input impedance are related to the structural return loss for a cable that is terminated in its own characteristic impedance. The values of structural return loss are dependent upon frequency and cable construction. Structural return loss shall be measured for all pairs in accordance with ASTM D4566, Method 3. For all frequencies from 1 MHz to 16 MHz, category 3 horizontal cable structural return loss shall meet or exceed the values given in table 2.

Table 2 - Category 3 horizontal cable structural return loss, worst pair

Frequency (MHz)	Category 3 (dB)
$1 \le f < 10$	12
$10 \le f < 16$	$12-10\log(f/10)$

(1)

4.3.4.6 Return loss

Return loss is a measure of the reflected energy caused by impedance variations in the cable and is especially important for applications that use simultaneous bi-directional transmission. Return loss is expressed in dB relative to the reflected signal level. Return loss shall be measured for all cable pairs in accordance with annex C. For all frequencies from 1 MHz to 100 MHz, category 5e horizontal cable return loss shall meet or exceed the values specified in table 3. Return loss is not specified for category 3 horizontal cables.

Table 3 - Category 5e horizontal cable return loss @ 20 °C ± 3 °C (68 °F ± 5.5°F), worst pair

For a length of 100 m (328 ft)

Frequency (MHz)	Category 5e (dB)	
$1 \le f < 10$	$20 + 5\log(f)$	(2)
$10 \le f < 20$	25	
$20 \le f \le 100$	$25 - 7\log(f/20)$	(3)

4.3.4.7 Insertion loss

Insertion loss is a measure of the signal loss resulting from the insertion of a cable length between a transmitter and receiver. It is often referred to as attenuation. Insertion loss is expressed in dB relative to the received signal level. Insertion loss shall be measured for all cable pairs in accordance with ASTM D4566 and 4.3.4.14 at 20 ± 3°C or corrected to a temperature of 20 °C using a 0.4%/°C correction factor for category 5e cables for the measured insertion loss. Category 3 horizontal cable insertion loss shall meet the values determined using equation (4) for all frequencies from .772 MHz to the highest referenced frequency. Category 5e horizontal cable insertion loss shall meet the values determined using equation (4) from 1 MHz to the highest referenced frequency. The values in table 5 are provided for information only.

$$InsertionLoss_{cable,100m} \le \mathrm{k1}\sqrt{f} + \mathrm{k2}\cdot f + \frac{\mathrm{k3}}{\sqrt{f}} \quad \textit{dB/100m (328 ft)} \qquad (4)$$

The constants in table 4 shall be used in conjunction with equation (4) to compute worst case cable insertion loss values.

Table 4 - Constants for horizontal cable insertion loss formula

	k1	k2	k3
Category 3	2.320	0.238	0.000
Category 5e	1.967	0.023	0.050

NOTE - Equation (4) is applicable only from 0.772 MHz to the highest referenced frequency for each category and is not valid outside of this range.

Category 5e horizontal cable insertion loss shall be verified at a temperature of 40 °C and 60 °C and shall meet the requirements of equation (4) after adjusting for temperature. The maximum insertion loss determined using the equation (4) shall be adjusted at elevated temperatures using a factor of 0.4 % increase per °C for category 5e cables.

Table 5 - Horizontal cable insertion loss @ 20 °C ± 3 °C (68 °F ± 5.5°F), worst pair

For a length of 100 m (328 ft)

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)
0.772	2.2	1.8
1.0	2.6	2.0
4.0	5.6	4.1
8.0	8.5	5.8
10.0	9.7	6.5
16.0	13.1	8.2
20.0	-	9.3
25.0	-	10.4
31.25	-	11.7
62.5	-	17.0
100.0	-	22.0

NOTE - The insertion loss of some category 3 UTP cables, such as those constructed with PVC insulation, exhibits significant temperature dependence. A temperature coefficient of insertion loss of 1.5 % per °C is not uncommon for such cables. In installations where the cable will be subjected to higher temperatures, a less-temperature dependent cable should be considered.

4.3.4.8 Near-end crosstalk (NEXT) loss

NEXT loss is a measure of the unwanted signal coupling from a transmitter at the near-end into neighboring pairs measured at the near-end. NEXT loss is expressed in dB relative to the launched signal level. NEXT loss shall be measured for all cable pair combinations in accordance with ASTM D4566. For all frequencies from 0.772 MHz to the highest referenced frequency in MHz, category 3 horizontal cable NEXT loss shall meet the values determined using equation (5). For all frequencies from 0.772 MHz to the highest referenced frequency in MHz, category 5e horizontal cable NEXT loss shall meet the values determined using equation (6). NEXT loss shall be measured at 100 meter or longer lengths. The values in table 6 are provided for information only.

$$NEXT_{cat.3cable} \geq NEXT(16) - 15\log(f/100) \ dB \qquad (5)$$

$NEXT(16)$ shall be 23.2 dB for category 3 horizontal cable.

$$NEXT_{cat5e\_cable} \geq NEXT(100) - 15\log(f/100) \ dB \qquad (6)$$

$NEXT(100)$ shall be 35.3 dB for category 5e horizontal cable.

Table 6 - Horizontal cable NEXT loss @ 20 °C ± 3 °C (68 °F ± 5.5°F), worst pair-to-pair

For a length of 100 m (328 ft)

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)
0.772	43.0	67.0
1.0	41.3	65.3
4.0	32.3	56.3
8.0	27.8	51.8
10.0	26.3	50.3
16.0	23.2	47.2
20.0	-	45.8
25.0	-	44.3
31.25	-	42.9
62.5	-	38.4
100.0	-	35.3

4.3.4.9 Power sum near-end crosstalk (PSNEXT) loss

Since each duplex channel can be disturbed by more than one duplex channel, PSNEXT loss is specified for horizontal cables. PSNEXT loss takes into account the combined crosstalk (statistical) on a receive pair from all near-end disturbers operating simultaneously. The PSNEXT loss is calculated in accordance with ASTM D4566 as a power sum on a selected pair from all other pairs as shown in equation (7) for a 4-pair cable.

$$PSNEXT = -10\log(10^{-X1/10} + 10^{-X2/10} + 10^{-X3/10})\ dB \tag{7}$$

where:

X1, X2, X3 are the pair-to-pair near-end crosstalk measurements in dB between the selected pair and the other three pairs.

For all frequencies from 0.772 MHz to 100 MHz, category 5e horizontal cable PSNEXT loss shall meet the values determined using equation (8). The values in table 7 are provided for information only. PSNEXT loss is not specified for category 3 horizontal cables.

$$PSNEXT_{cable} \geq 32.3 - 15\log(f/100)\ dB \tag{8}$$

Table 7 - Horizontal cable PSNEXT loss @ 20 °C ± 3 °C (68 °F ± 5.5°F)

For length of 100 m (328 ft)

Frequency (MHz)	Category 5e (dB)
0.150	74.7
0.772	64.0
1.0	62.3
4.0	53.3
8.0	48.8
10.0	47.3
16.0	44.2
20.0	42.8
25.0	41.3
31.25	39.9
62.5	35.4
100.0	32.3

4.3.4.10 Equal level far-end crosstalk (ELFEXT)

FEXT loss is a measure of the unwanted signal coupling from a transmitter at the far-end into neighboring pairs measured at the near-end. ELFEXT is expressed in dB as the difference between the measured FEXT loss and the insertion loss of the disturbed pair. FEXT loss shall be measured and ELFEXT calculated for all cable pair combinations in accordance with ASTM D4566 FEXT measurement procedure. For all frequencies from 1 MHz to 100 MHz, category 5e horizontal cable ELFEXT, for a length of 100 m (328 ft), shall meet the values determined using equation (9). The values in table 8 are provided for information only.

$$ELFEXT_{cable} \geq 23.8 - 20\log(f/100) \text{ dB} \qquad (9)$$

Table 8 - Horizontal cable ELFEXT @ 20 °C ± 3 °C (68 °F ± 5.5°F), worst pair-to-pair

For length of 100 m (328 ft)

Frequency (MHz)	Category 5e (dB)
1.0	63.8
4.0	51.8
8.0	45.7
10.0	43.8
16.0	39.7
20.0	37.8
25.0	35.8
31.25	33.9
62.5	27.9
100.0	23.8

4.3.4.11 Power sum equal level far-end crosstalk (PSELFEXT)

Since each duplex channel can be disturbed by more than one duplex channel, equal level far-end crosstalk (ELFEXT) is specified for horizontal cables. Power sum equal level far-end crosstalk loss takes into account the combined crosstalk (statistical) on a receive pair from all far-end disturbers operating simultaneously. The power sum equal level far-end crosstalk (PSELFEXT) is calculated in accordance with ASTM D4566 as a power sum on a selected pair from all other pairs as shown in equation (10) for a 4-pair cable.

$$PSELFEXT = -10\log(10^{-X1/10} + 10^{-X2/10} + 10^{-X3/10})\ dB \qquad (10)$$

where:

X1, X2, X3 are the pair-to-pair crosstalk measurements in dB between the selected pair and the other three pairs.

For all frequencies from 1 MHz to 100 MHz, category 5e horizontal cable power sum ELFEXT, for a length of 100 m (328 ft), shall meet the values determined using equation (11). The values in table 9 are provided for reference only. Power sum ELFEXT is not specified for category 3 horizontal cables.

$$PSELFEXT_{cable} \geq 20.8 - 20\log(f/100)\ dB \qquad (11)$$

Table 9 - Horizontal cable PSELFEXT @ 20 °C ± 3 °C (68 °F ± 5.5°F)

For a length of 100 m (328 ft)

Frequency (MHz)	**Category 5e (dB)**
1.0	60.8
4.0	48.8
8.0	42.7
10.0	40.8
16.0	36.7
20.0	34.8
25.0	32.8
31.25	30.9
62.5	24.9
100.0	20.8

4.3.4.12 Propagation delay for 4-pair horizontal cables

Propagation delay is the time it takes for a signal to propagate from one end to the other. Propagation delay is expressed in nanoseconds (ns). Propagation delay shall be measured for all cable pairs in accordance with ASTM D4566.

The values determined using equation (11) shall be used to compute the maximum allowable propagation delay, for a length of 100 m (328 ft), for all frequencies between 1.0 MHz and the highest referenced frequency for a given category. The values in table 10 are provided for information only. See annex L for the derivation of equation (12).

$$delay_{cable} \leq 534 + \frac{36}{\sqrt{f}}\ ns/100m\ (328\ ft) \qquad (12)$$

Table 10 - Propagation delay, velocity of propagation and propagation delay skew for 4-pair horizontal cables @ 20 °C ± 3 °C (68 °F ± 5.5°F)

Frequency (MHz)	Maximum Propagation Delay (ns/100 m)	Minimum Velocity of Propagation (%)	Maximum Propagation Delay Skew (ns/100 m)
1	570	58.5%	45
10	545	61.1%	45
100	538	62.0%	45

4.3.4.13 Propagation delay skew for 4-pair horizontal cables

Propagation delay skew is a calculation of the signaling delay difference from the fastest pair to the slowest. Propagation delay skew is expressed in nanoseconds (ns). Propagation delay skew shall be measured for all cable pairs in accordance with ASTM D4566.

For all frequencies between 1 MHz and the highest referenced frequency in MHz, category 3 and category 5e cable propagation delay skew shall not exceed 45 ns/100m at 20 °C, 40 °C, and 60 °C. In addition, the propagation delay skew between all pairs shall not vary more than +/-10 ns from the measured value at 20 °C when measured at 40 °C and 60 °C. Compliance shall be determined using a minimum 100 m of cable.

4.3.4.14 Measurement precautions

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

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

4.3.5 Performance marking

Horizontal cables should be marked to designate transmission performance.

> NOTE - Performance markings are in addition to, and do not replace, other markings required by listing agencies or those needed to satisfy electrical code or local building code requirements.

4.3.6 Bundled and hybrid cables

Bundled and hybrid cables may be used for horizontal cabling provided that each cable type is recognized (see ANSI/TIA/EIA-568-B.1) and meets the transmission and color-code specifications for that cable type as given in clause 4, ANSI/TIA/EIA-568-B.3, and annex M of this Standard. Additionally, power sum NEXT loss for any disturbed pair and all pairs external to that pair's jacket within the bundled or hybrid cable shall be 3 dB better than the specified pair-to-pair NEXT loss of that recognized cable type at all of the specified frequencies (or ranges). Calculated power sum NEXT loss limit values that exceed 65 dB shall revert to a limit of 65 dB.

NOTES,
1 Hybrid UTP cables (color coded per 4.3.3.3) can be distinguished from multipair UTP backbone cables (color coded per 4.4.3.3) by the color coding scheme and by the transmission requirements.
2 Hybrid cables consisting of optical fiber and copper conductors are sometimes referred to as composite cables.

The individual cables within a bundled cable shall meet the applicable requirements in clause 4, ANSI/TIA/EIA-568-B.3, and annex M of this Standard after bundle formation.

4.4 Backbone cable

4.4.1 General

Covered herein are the requirements for multipair backbone cables in pair sizes greater than 4 pairs for use in the backbone cabling system. Multipair backbone cables consist of 22 AWG to 24 AWG thermoplastic insulated solid conductors that are formed into one or more units of balanced twisted pairs. The units are assembled into binder groups of 25 pairs or part thereof following the standard industry color code (ANSI/ICEA S-80-576). The groups are identified by distinctly colored binders and assembled to form the core. The core shall be covered by a protective sheath. The sheath consists of an overall thermoplastic jacket and may contain an underlying metallic shield and one or more layers of dielectric material applied over the core.

4.4.2 Applicability

Backbone cables shall meet the mechanical requirements of ANSI/ICEA S-80-576 applicable to multipair cable. Backbone cables shall be listed and marked as required by the applicable code requirements.

NOTES,
1 Backbone cables containing conductor diameters larger than 24 AWG, up to and including 22 AWG, that meet or exceed the requirements of this Standard may also be used.
2 Additional requirements for multipair 100 Ω ScTP cables are located in annex K.

4.4.3 Mechanical

In addition to the applicable mechanical requirements of ANSI/ICEA S-80-576, the physical design of backbone cables shall meet the requirements of clauses 4.4.3.1 to 4.4.3.7.

4.4.3.1 Insulated conductor

The diameter of the insulation shall be 1.22 mm (0.048 in) maximum.

4.4.3.2 Pair assembly

The pair twist lengths shall be specified to ensure compliance with the transmission requirements of this Standard.

4.4.3.3 Color code

The twisted-pair conductor color code shall follow the industry standard color code composed of 10 distinct colors to identify 25 pairs (refer to ANSI/ICEA S-80-576 for appropriate colors). For backbone cables with fewer than 25 pairs, colors shall be consistent with the industry standard color code starting from pair 1 up to the number of pairs in the cable. For cables with tightly twisted-pairs [all pairs less than 38 mm (1.5 in) per twist] the mate conductor may serve as the marking for the white conductor. For cables with tightly twisted-pairs [all pairs less than 38 mm (1.5 in) per twist] the mate conductor may serve as the marking for the white conductor.

4.4.3.4 Core assembly

For backbone cables with more than 25 pairs, the core shall be assembled in units or sub-units of up to 25 pairs. Each unit or sub-unit shall be identified by a color-coded binder. Color coding should be in accordance with ANSI/ICEA S-80-576. Binder color-code integrity shall be maintained whenever cables are spliced.

4.4.3.5 Core wrap

The core may be covered with one or more layers of dielectric material of adequate thickness to ensure compliance with the dielectric strength requirements.

4.4.3.6 Core shield

When an electrically continuous shield is applied over the core wrap, it shall comply with requirements in 4.4.5.

> NOTE - UL 444, ANSI/ICEA S-80-576 and ANSI/ICEA S-84-608 provide additional information regarding shield mechanical criteria.

4.4.3.7 Jacket

The core shall be enclosed by a uniform, continuous thermoplastic jacket.

4.4.4 Transmission

4.4.4.1 DC resistance

The resistance of any conductor, measured in accordance with ASTM D 4566, shall not exceed 9.38 Ω per 100 m (328 ft) at, or corrected to, a temperature of 20 °C.

4.4.4.2 DC resistance unbalance

The resistance unbalance between the two conductors of any cable pair, measured in accordance with ASTM D 4566, shall not exceed 5% measured at, or corrected to, a temperature of 20 °C.

4.4.4.3 Mutual capacitance

The mutual capacitance of any backbone cable pair at 1 kHz, measured at or corrected to a temperature of 20 °C, should not exceed 6.6 nF per 100 m (328 ft) for category 3 cables or 5.6 nF per 100 m (328 ft) for category 5e horizontal cables. Measurements shall be performed in accordance with ASTM D 4566. Mutual capacitance recommendations are provided for engineering design purposes.

4.4.4.4 Capacitance unbalance: pair-to-ground

The capacitance unbalance to ground of any backbone cable pair at 1 kHz, measured in accordance with ASTM D 4566 at, or corrected to, a temperature of 20 °C, shall not exceed 330 pF per 100 m (328 ft).

4.4.4.5 Characteristic impedance and structural return loss for category 3 cable

Category 3 backbone cables shall exhibit a characteristic impedance of 100 Ω ±15% in the frequency range from 1 MHz up to the highest referenced frequency when measured in accordance with ASTM D 4566 Method 3. Characteristic impedance has a specific meaning for an ideal transmission line (i.e., a cable whose geometry is fixed and does not vary along the length of cable).

> NOTE - Characteristic impedance is commonly derived from swept frequency input impedance measurements using a network analyzer with an s-parameter test set. As a result of structural non-uniformities, the measured input impedance for an electrically long length of cable (greater than 1/8 of a wavelength) fluctuates as a function of frequency. These random fluctuations are superimposed on the curve for characteristic impedance, which asymptotically approaches a fixed value at frequencies above 1 MHz. Characteristic impedance can be derived from these measurements by using a smoothing function over the bandwidth of interest.

Fluctuations in input impedance are related to the structural return loss for a cable that is terminated in its own characteristic impedance. The values of structural return loss are dependent upon frequency and cable construction. Structural return loss shall be measured for all pairs in accordance with ASTM D4566, Method 3. For all frequencies from 1 MHz to 16 MHz, category 3 backbone cable structural return loss shall meet or exceed the values given in table 11. Structural return loss is not specified for category 5e backbone cables.

Table 11 - Category 3 backbone cable structural return loss@ 20 °C ± 3 °C (68 °F ± 5.5°F), worst pair

Frequency (MHz)	Category 3 (dB)
$1 \le f < 10$	12
$10 \le f < 16$	$12-10\log(f/10)$

(13)

4.4.4.6 Return loss

Category 5e backbone cable return loss shall meet the category 5e horizontal cable return loss specified in clause 4.3.4.6. Return loss is not specified for category 3 backbone cables.

4.4.4.7 Insertion loss

Backbone cable insertion loss shall meet the insertion loss requirements for horizontal cables as specified in 4.3.4.7. The maximum insertion loss shall be adjusted at elevated temperatures using a factor of 0.4% increase per °C for category 5e cables. The cable insertion loss shall also be verified at the temperatures of 40 °C and 60 °C and shall meet the requirements of 4.3.4.7 after adjusting for temperature. Due to practical considerations related to the testing of cables with multiple 25 pair bundles, insertion loss testing at elevated temperatures is not required provided that each pair in the binder group exhibits compliant insertion loss performance.

4.4.4.8 NEXT loss

To assess performance between adjacent 4-pair units, category 5e multipair backbone cables are evaluated in groups (i.e. group 1 = pairs 1 to 4, group 2 = pairs 5 to 8, group 3 = pairs 9 to 12, group 4 = pairs 13 to 16, group 5 = pairs 17 to 20, group 6 = pairs 21 to 24, etc.). Groups are comprised of consecutive pairs, marked per the standard color code. For 25-pair and multiple of 25-pair binder groups, the twenty-fifth pair shall satisfy all other transmission parameters when used within any 4-pair group.

For all frequencies from 0.772 MHz to 100 MHz, NEXT loss for any pair-to-pair combination within each category 5e multipair cable 4-pair group shall meet the values determined using equation (14). In addition, for all frequencies from 0.772 MHz to 100 MHz, NEXT loss between the 25th pair and all other pairs within the 25-pair binder group shall meet the values determined using equation (15).

$$NEXT_{within\_4-pair\_group,100m} \geq NEXT_{within\_4-pair\_group(100)} - 15\log(f/100) \ dB \quad (14)$$

$$NEXT_{25th\_to\_all\_other\_pairs,100m} \geq NEXT_{25th\_to\_all-other-pairs(100)} - 15\log(f/100) \ dB \quad (15)$$

$NEXT_{within\_4\text{-}pair\_group(100)}$ shall be 35.3 dB for category 5e multipair cable 4-pair groups.

$NEXT_{25th\_to\_all\_other\_pairs(100)}$ shall be 35.3 dB for category 5e multipair cables.

The values in table 12 are provided for information only.

Table 12 - Category 5e backbone cable NEXT loss @ 20 °C ± 3 °C (68 °F ± 5.5°F)

For a length of 100 m (328 ft)

Frequency (MHz)	Category 5e (within 4-pair group) (dB)	Category 5e (25th to all other pairs) (dB)
0.772	67.0	67.0
1.0	65.3	65.3
4.0	56.3	56.3
8.0	51.8	51.8
10.0	50.3	50.3
16.0	47.2	47.2
20.0	45.8	45.8
25.0	44.3	44.3
31.25	42.9	42.9
62.5	38.4	38.4
100.0	35.3	35.3

4.4.4.9 PSNEXT loss

Since each duplex channel can be disturbed by more than one duplex channel, power sum near-end crosstalk (PSNEXT) loss is specified for backbone cables. Power sum near-end crosstalk (PSNEXT) loss takes into account the combined crosstalk (statistical) on a receive pair from all near-end disturbers operating simultaneously. The power sum near-end crosstalk (PSNEXT) loss is calculated in accordance with ASTM D4566 as a power sum on a selected pair from all other pairs as shown in equation (16) for a 25-pair cable.

$$PSNEXT = -10\log(10^{-X1/10} + 10^{-X2/10} + 10^{-X3/10} + ... + 10^{-X24/20})\ dB \qquad (16)$$

where:

X1, X2, X3,…,X24 are the pair-to-pair crosstalk measurements in dB between the selected pair and the other twenty-four pairs within a twenty-five pair group.

For all frequencies from 0.772 MHz to 100 MHz, category 5e multipair cable power sum NEXT loss within a 25-pair binder group, tested in accordance with ASTM D4566, shall meet the values determined using equation (17).

$$PSNEXT_{category5e\_multipair,100m} \geq 32.3 - 15\log(f/100)\ dB \qquad (17)$$

For all frequencies from 0.772 MHz to 16 MHz, category 3 multipair cable power sum NEXT loss within a 25-pair binder group, tested in accordance with ASTM D4566, shall meet the values determined using equation (18).

$$PSNEXT_{category3\_multipair,100m} \geq 23 - 15\log(f/16)\ dB \qquad (18)$$

The values in table 13 are provided for information only.

Table 13 - Backbone cable PSNEXT loss @ 20 °C ± 3 °C (68 °F ± 5.5°F)

For a length of 100 m (328 ft)

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)
0.772	43	64.0
1.0	41	62.3
4.0	32	53.3
8.0	28	48.8
10.0	26	47.3
16.0	23	44.2
20.0	-	42.8
25.0	-	41.3
31.25	-	39.9
62.5	-	35.4
100.0	-	32.3

NOTE - Generally, power sum crosstalk energy is dominated by the coupling between pairs in close proximity and is relatively unaffected by pairs in separate binder groups. Therefore, it is desirable to separate services with different signal levels or services that are susceptible to impulse noise into separate binder groups. See ANSI/TIA/EIA-568 B-1 for more information.

In cases where backbone cables consist of more than one 25-pair binder group, NEXT loss and PSNEXT loss shall be determined for each individual 25 pair binder group. There are no NEXT or PSNEXT requirements between 25 pair groups. The cable shall be tested only as individual 25 pair units.

4.4.4.10 ELFEXT

To assess performance between adjacent 4-pair units, category 5e multipair backbone cables are evaluated in groups (i.e. group 1 = pairs 1 to 4, group 2 = pairs 5 to 8, group 3 = pairs 9 to 12, group 4 = pairs 13 to 16, group 5 = pairs 17 to 20, group 6 = pairs 21 to 24, etc.). Groups are comprised of consecutive pairs, marked per the standard color code. For 25-pair and multiple of 25-pair binder groups, the twenty-fifth pair shall satisfy all other transmission parameters when used within any 4-pair group.

For all frequencies from 1 MHz to 100 MHz, ELFEXT for any pair-to-pair combination within each category 5e multipair cable 4-pair group shall meet the values determined using equation (19). In addition, for all frequencies from 1 MHz to 100 MHz, ELFEXT between the 25th pair and all other pairs within the 25-pair binder group shall meet the values determined using equation (20).

$$ELFEXT_{within\_4-pair\_group,100m} \geq ELFEXT_{within\_4-pair\_group(100)} - 20\log(f/100) \text{ dB} \tag{19}$$

$$ELFEXT_{25th\_to\_all\_other\_pairs,100m} \geq ELFEXT_{25th\_to\_all-other-pairs(100)} - 20\log(f/100) \text{ dB} \tag{20}$$

$ELFEXT_{within\_4\text{-}pair\_group(100)}$ shall be 23.8 dB for category 5e multipair cable 4-pair groups.

$ELFEXT_{25th\_to\_all\_other\_pairs(100)}$ shall be 23.8 dB for category 5e multipair cables.

The values in table 14 are provided for information only.

Table 14 - Category 5e backbone cable ELFEXT @ 20 °C ± 3 °C (68 °F ± 5.5°F)

For a length of 100 m (328 ft)

Frequency (MHz)	Category 5e (within 4-pair group) (dB)	Category 5e (25th to all other pairs) (dB)
1.0	63.8	63.8
4.0	51.8	51.8
8.0	45.7	45.7
10.0	43.8	43.8
16.0	39.7	39.7
20.0	37.8	37.8
25.0	35.8	35.8
31.25	33.9	33.9
62.5	27.9	27.9
100.0	23.8	23.8

4.4.4.11 PSELFEXT

Since each duplex channel can be disturbed by more than one duplex channel, power sum equal level far-end crosstalk (PSELFEXT) is specified for backbone cables. Power sum equal level far-end crosstalk (PSELFEXT) takes into account the combined crosstalk (statistical) on a receive pair from all far-end disturbers operating simultaneously. The power sum equal level far-end crosstalk (PSELFEXT) is calculated in accordance with ASTM D4566 as a power sum on a selected pair from all other pairs as shown in equation (21) for a 25-pair cable.

$$PSELFEXT = -10\log(10^{-X1/10} + 10^{-X2/10} + 10^{-X3/10} + ... + 10^{-X24/20})\ dB \tag{21}$$

where:

X1, X2, X3,…,X24 are the pair-to-pair crosstalk measurements in dB between the selected pair and the other twenty-four pairs within a twenty-five pair group.

For all frequencies from 1 MHz to 100 MHz, category 5e multipair cable power sum ELFEXT within a 25-pair binder group, tested in accordance with ASTM D4566, shall meet the values determined using equation (22).

$$PSELFEXT_{category5e\_multipair,100m} \geq 20.8 - 20\log(f/100)\ dB \tag{22}$$

The values in table 15 are provided for information only.

Table 15 – Category 5e backbone cable PSELFEXT @ 20 °C ± 3 °C (68 °F ± 5.5°F)

For a length of 100 m (328 ft)

Frequency (MHz)	Category 5e (dB)
1.0	60.8
4.0	48.8
8.0	42.7
10.0	40.8
16.0	36.7
20.0	34.8
25.0	32.8
31.25	30.9
62.5	24.9
100.0	20.8

NOTE - In cases where backbone cables consist of more than one 25-pair binder group, ELFEXT loss and PSELFEXT loss shall be determined for each individual 25 pair binder group. There are no FEXT or PSELFEXT requirements between 25 pair groups. The cable shall be tested only as individual 25 pair units.

4.4.4.12 Propagation delay of category 5e backbone cables

Propagation delay is the time it takes for a signal to propagate from one end to the other. Propagation delay is expressed in nanoseconds (ns). Propagation delay shall be measured for all cable pairs in accordance with ASTM D4566.

Category 5e backbone cable pair propagation delay shall meet the propagation delay requirements for horizontal cables as specified in clause 4.3.4.12. Propagation delay is not specified for category 3 backbone cables.

4.4.4.13 Propagation delay skew for category 5e backbone cables

Propagation delay skew is a measurement of the signaling delay difference from the fastest pair to the slowest. Propagation delay skew is expressed in nanoseconds (ns). Propagation delay skew shall be measured for all cable pairs in accordance with ASTM D4566.

Category 5e backbone cable propagation delay skew within all sequential 4-pair groups (i.e. group 1 = pairs 1 to 4, group 2 = pairs 5 to 8, group 3 = pairs 9 to 12, group 4 = pairs 13 to 16, group 5 = pairs 17 to 20, group 6 = pairs 21 to 24, etc.) shall meet the propagation delay skew requirements for horizontal cables as specified in 4.3.4.13. For 25-pair and multiple of 25-pair binder groups, the 25th pair shall be designed to support the propagation delay and delay requirements when used with any other pair within the binder group. Propagation delay skew is not specified for category 3 backbone cables.

4.4.4.14 Dielectric strength

The insulation between each conductor and the core shield, when present, shall be capable of withstanding a minimum DC potential of 5 kV for 3 seconds in accordance with ASTM D4566.

4.4.5 Core shield resistance

When a shield is present around the core, the DC resistance of the core shield shall not exceed the value given by the following equation(s):

$$R\ (\Omega\ /\text{km}) = 62.5/D\ (\text{mm}) \tag{23}$$

or

$$R\ (\Omega\ /1000\ \text{ft}) = 0.75/D\ (\text{in}) \tag{24}$$

where:

R = maximum core shield resistance
D = outside diameter of the shield

This requirement is applicable to outside plant cables or inside building cables having their shields bonded to the shields of outside plant cables at building entrances. The electrical and physical requirements of the shields of inside building cables are found in annex K.

4.4.5.1 Measurement precautions

The measurement precautions specified in clause 4.3.4.14 apply to the measurement of unshielded multipair backbone cables.

4.4.6 Performance marking

Backbone cables should be marked to designate transmission performance.

> NOTE - Performance markings are in addition to, and do not replace, other markings required by listing agencies or those needed to satisfy electrical code or local building code requirements.

4.5 Stranded conductor cable

This clause contains the transmission requirements for the bulk cable used to construct patch, equipment, and work area cords.

4.5.1 Mechanical

Stranded cables shall meet the mechanical performance requirements specified for horizontal cable in clause 4.3.3.

4.5.2 Transmission

Stranded cables shall meet the transmission performance requirements specified for horizontal cable in clause 4.3.4, with the exception of the return loss requirements of clause 4.3.4.6 and the insertion loss requirements of clause 4.3.4.7.

4.5.3 Return loss

Return loss is a measure of the reflected energy caused by impedance variations in the cable and is especially important for applications that use simultaneous bi-directional transmission. Return loss is expressed in dB relative to the reflected signal level. Return loss shall be measured for all cable pairs in accordance with annex C. For all frequencies from 1 MHz to 100 MHz, category 5e stranded cable return loss shall meet or exceed the values determined using equations specified in table 16. The values in table 17 are provided for information only. Return loss is not specified for category 3 stranded cables.

Table 16 - Category 5e stranded cable return loss @ 20 °C +/-3 °C (68 °F ± 5.5°F), worst pair

For a length of 100 m (328 ft)

Frequency (MHz)	Category 5e (dB)	
$1 \le f < 10$	$20 + 5\log(f)$	(25)
$10 \le f < 20$	25	
$20 \le f \le 100$	$25 - 8.6\log(f/20)$	(26)

Table 17 - Category 5e stranded cable return loss @ 20 °C ± 3 °C (68 °F ± 5.5°F), worst pair

For a length of 100 m (328 ft)

Frequency (MHz)	Category 5e (dB)
1.0	20.0
4.0	23.0
8.0	24.5
10.0	25.0
16.0	25.0
20.0	25.0
25.0	24.2
31.25	23.3
62.5	20.7
100.0	19.0

4.5.4 Insertion loss

Insertion loss is a measure of the signal loss resulting from the insertion of a cable length, greater than or equal to 100 m (328 ft), between a transmitter and receiver. It is often referred to as attenuation. Insertion loss is expressed in dB relative to the received signal level. Insertion loss shall be measured for all cable pairs in accordance with ASTM D 4566 and clause 4.3.4.7 at, or corrected to, a temperature of 20 °C.

Category 3 stranded conductor cable shall meet the value computed by multiplying the horizontal cable insertion loss requirement in clause 4.3.4.7 by a factor of 1.2 (the de-rating factor), for all frequencies from .772 MHz to 16 MHz. Category 5e stranded conductor cable shall meet the values computed by multiplying the horizontal cable insertion loss requirement in clause 4.3.4.7 by a factor of 1.2 (the de-rating factor), for all frequencies from 1 MHz to 100 MHz. The de-rating factor is to allow a 20% increase in insertion loss for stranded construction and design differences. Stranded cables shall satisfy the elevated temperature requirements specified in clause 4.3.4.7. The values in table 18 are provided for information only.

Table 18 - Stranded cable insertion loss @ 20 °C ± 3 °C (68 °F ± 5.5°F), worst pair

For a length of 100 m (328 ft)

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)
.772	2.7	-
1.0	3.1	2.4
4.0	6.7	4.9
8.0	10.2	6.9
10.0	11.7	7.8
16.0	15.7	9.9
20.0	-	11.1
25.0	-	12.5
31.25	-	14.1
62.5	-	20.4
100.0	-	26.4

4.5.5 Performance marking

Stranded cables should be marked to designate transmission performance.

> NOTE - Performance markings are in addition to, and do not replace, other markings required by listing agencies or those needed to satisfy electrical code or local building code requirements.

5 100 W BALANCED TWISTED-PAIR CONNECTING HARDWARE

5.1 General

Specified herein are mechanical and transmission performance requirements for connecting hardware that are consistent with the cable (s) specified in clause 4.3. Compliance to these requirements will ensure that properly installed connectors will have minimal effects on cable performance. These requirements are applicable to individual connectors and connector assemblies that include, but are not limited to, telecommunications outlet/connectors, patch panels, consolidation points, transition points and cross-connect blocks. Annex E contains additional specifications for ScTP connecting hardware.

> NOTE - The residential outlet has the same requirements as the telecommunications outlet/connector described in this clause.

See ANSI/TIA/EIA-568-B-1 for guidance and requirements on connector termination practices, cable management, the use of patch cords or cross-connect jumpers, and the effects of multiple connections. It is desirable that hardware used to terminate cables be of the insulation displacement contact (IDC) type. Connecting hardware for the 100 Ω UTP cabling system is installed at the following locations:

a) main cross-connect;
b) intermediate cross-connect;
c) horizontal cross-connect;
d) horizontal cabling transition points;
e) consolidation point;
f) telecommunications outlet/connectors.

Typical cross-connect facilities consist of cross-connect jumpers or patch cords and terminal blocks or patch panels that are connected directly to horizontal or backbone cabling.

5.2 Applicability

Connecting hardware shall terminate to 100 Ω balanced twisted-pair cables as specified in clauses 4.3 and 4.3.6. Compliance with this Standard does not imply compatibility with cables that are not in full compliance with clauses 4.3 Unless otherwise specified, all products with plug and socket connections (e.g. modular jacks and plugs) shall be tested in a mated state.

> NOTE- This Standard does not address requirements for equipment connectors, media adapters or other devices utilizing passive or active electronic circuitry (i.e., impedance matching transformers, ISDN resistors, MAUs, filters, network interface devices, and protection devices) whose main purpose is to serve a specific application or provide safety compliance. Such cabling adapters and protection devices are regarded as premises equipment that are not considered to be part of the cabling system.

5.3 Mechanical

5.3.1 Environmental compatibility

Connecting hardware used to terminate to 100 Ω balanced twisted-pair cabling shall be functional for continuous use over the temperature range from -10 °C to 60 °C. Connecting hardware shall be protected from physical damage and from direct exposure to moisture and other corrosive elements. This protection may be accomplished by installation indoors or in an appropriate enclosure for the environment.

5.3.2 Mounting

Connecting hardware used to terminate to 100 Ω balanced twisted-pair cabling should be designed to provide flexibility for mounting on walls, in racks or on other types of distribution frames and standard mounting hardware. Telecommunications outlet/connectors shall be securely mounted at planned locations. Cables intended for future connections shall be covered with a faceplate that identifies the outlet box for telecommunications use.

5.3.3 Mechanical termination density

Connecting hardware used to terminate to 100 Ω balanced twisted-pair cabling should have a high density to conserve space, but should also be of a size consistent with ease of cable management. To ensure that cross-connect fields may be properly administered as a means of field termination for jumpers, contact center spacing (front side only) should not be less than 3.1 mm (0.123 in). Other field terminated connecting hardware not classified as cross-connect devices, such as those providing direct means of terminating cable stubs with connectors, may have closer contact spacing as required by the interface constraints of the connector.

5.3.4 Design

Cross-connect hardware used to terminate to 100 Ω balanced twisted-pair cabling shall be designed to provide:

a) means to cross-connect cables with cross-connect jumpers or patch cords;
b) means to connect premises equipment to the 100 Ω UTP network;
c) means to identify circuits for administration in accordance with ANSI/TIA/EIA-606;
d) means to use standard colors as specified in ANSI/TIA/EIA-606 to functionally identify mechanical termination fields;
e) means of handling wire and cable to permit orderly management;
f) means of access to monitor or test cabling and premises equipment;
g) means for protecting exposed terminals, an insulating barrier, such as a cover or a plastic shroud, for protecting terminals from accidental contact with foreign objects that may disturb electrical continuity.

Transition points, consolidation points and telecommunications outlet/connectors for 100 Ω cable shall be designed to provide:

a) appropriate mechanical termination means for horizontal cable runs, and
b) means of conductor identification to promote pin-pair practices consistent with clause 5.5.

Connecting hardware used to terminate to 100 Ω balanced twisted-pair cabling shall not result in or contain any transposed pairs (e.g., transposition of pairs 2 and 3) or reversed pairs (also called tip/ring reversals).

> NOTE - While some network applications require that the transmit and receive pairs be swapped, such application-specific adaptations are accomplished using adapters, work area cords or equipment cords that are beyond the scope of this standard.

5.3.5 Reliability

To assure reliable operation over the usable life of the cabling system, the connecting hardware used to terminate to 100 Ω balanced twisted-pair cabling shall meet all requirements of annex A. This annex specifies test procedures and performance requirements for contact resistance, insulation resistance, durability, environmental conditioning and other test designed to assure consistently dependable and safe operation. For connecting hardware with 8-position modular connectors, the modular connection shall comply with Level A reliability requirements of IEC 60603-7. Plug and socket connections that conform to IEC 60603-7 are exempt from the reliability test requirements specified in annex A.

5.4 Transmission

Connecting hardware used to terminate to 100 Ω balanced twisted-pair cabling shall be tested in accordance with the transmission test methods specified in annex D. This annex describes set-up requirement and procedures necessary for accurate and repeatable transmission testing of connecting hardware used to terminate to 100 Ω balanced twisted-pair cabling.

5.4.1 Recognized categories

The recognized categories of twisted-pair connecting hardware are:

> Category 5e: This designation applies to 100 Ω connecting hardware whose transmission characteristics are specified up to 100 MHz.
> Category 3: This designation applies to 100 Ω connecting hardware whose transmission characteristics are specified up to 16 MHz.

Category 1, 2, 4 and 5 connecting hardware are not recognized as part of this Standard and, therefore, their transmission characteristics are not specified. Category 5 transmission characteristics, used in “legacy” cabling installations, are provided for reference in annex N.

5.4.2 Insertion loss

Insertion loss is a measure of the signal loss resulting from the insertion of a connector between a transmitter and receiver. It is often referred to as attenuation. Insertion loss is expressed in dB relative to the launched signal level. Insertion loss shall be measured for all connecting hardware pairs in accordance with annex D. For all frequencies from 1 MHz to the highest referenced frequency in MHz, connecting hardware insertion loss shall meet the values determined using equation (27).

$$InsertionLoss_{conn} \leq k1 \cdot \sqrt{f} \text{ dB} \qquad (27)$$

$k1$ = 0.10 for category 3 connecting hardware and $k1$ = 0.04 for category 5e connecting hardware.

The values listed in table 19 are for information only. Calculations that result in connecting hardware insertion loss values less than 0.1 dB shall revert to a requirement of 0.1 dB maximum.

Table 19 - Connecting hardware insertion loss, worst pair

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)
1.0	0.1	0.1
4.0	0.2	0.1
8.0	0.3	0.1
10.0	0.3	0.1
16.0	0.4	0.2
20.0	-	0.2
25.0	-	0.2
31.25	-	0.2
62.5	-	0.3
100.0	-	0.4

5.4.3 Near-end crosstalk (NEXT) loss

NEXT loss is a measure of the unwanted signal coupling from a transmitter at the near-end into neighboring pairs measured at the near-end. NEXT loss is expressed in dB relative to the launched signal level. NEXT loss shall be measured for all connecting hardware pair combinations in accordance with annex D. Connecting hardware shall be tested for NEXT loss in a similar manner to return loss for connecting hardware. For all frequencies from 1 MHz to 16 MHz, category 3 connecting hardware NEXT loss shall meet the values determined using equation (28). For all frequencies from 1 MHz to 100 MHz, category 5e connecting hardware NEXT loss shall meet the values determined using equation (29). The values in table 20 are provided for information only. Calculations that result in NEXT loss values greater than 65 dB shall revert to a requirement of 65 dB minimum.

$$NEXT_{cat3conn} \geq NEXT(16) - 20\log(f/16)\ dB \tag{28}$$

$NEXT(16)$ shall be 18 dB for category 3 connecting hardware.

$$NEXT_{cat5econn} \geq NEXT(100) - 20\log(f/100)\ \text{dB} \tag{29}$$

$NEXT(100)$ shall be 43 dB for category 5e connecting hardware.

Table 20 - Connecting hardware NEXT loss, worst pair-to-pair

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)
1.0	58.0	65.0
4.0	46.0	65.0
8.0	39.9	64.9
10.0	38.0	63.0
16.0	33.9	58.9
20.0	-	57.0
25.0	-	55.0
31.25	-	53.1
62.5	-	47.1
100.0	-	43.0

5.4.4 Return loss

Return loss is a measure of the reflected energy. Return loss is expressed in dB relative to the reflected signal level. Return loss shall be measured for all connecting hardware pairs in accordance with annex D. Connecting hardware shall be tested for return loss with a reference plug constructed and qualified for return loss in accordance with clause D.4.1.1. For all frequencies from 1 MHz to 100 MHz, category 5e connecting hardware return loss shall meet or exceed the values determined by the equations specified in table 21. The values in table 22 are provided for information only. Because the return loss characteristics of connecting hardware are not considered to have a significant effect on the link performance of category 3 twisted-pair cabling, return loss is not specified for category 3 connecting hardware.

Table 21 - Category 5e connecting hardware return loss

Frequency (MHz)	Return Loss (dB)
$1 \le f < 31.5$ $31.5 \le f \le 100$	30 $20 - 20\log(f/100)$

(30)

Table 22 - Category 5e connecting hardware return loss

Frequency (MHz)	Category 5e (dB)
1.0	30.0
4.0	30.0
8.0	30.0
10.0	30.0
16.0	30.0
20.0	30.0
25.0	30.0
31.5	30.0
62.5	24.1
100.0	20.0

5.4.5 Far-end crosstalk (FEXT) loss

FEXT loss is a measure of the unwanted signal coupling from a transmitter at the far-end into neighboring pairs measured at the near-end. FEXT loss is expressed in dB. FEXT loss shall be measured in accordance with annex D. For all frequencies from 1 MHz to 100 MHz, category 5e connecting hardware FEXT loss shall meet the values determined using equation (31). The values in table 23 are provided for information only. Calculations that result in FEXT loss values greater than 65 dB shall revert to a requirement of 65 dB minimum. FEXT loss is not specified for category 3 connecting hardware.

$$FEXT_{conn} \geq 35.1 - 20\log(f/100) \text{ dB} \tag{31}$$

Table 23 - Category 5e connecting hardware FEXT loss, worst pair-to-pair

Frequency (MHz)	Category 5e (dB)
1.0	65.0
4.0	63.1
8.0	57.0
10.0	55.1
16.0	51.0
20.0	49.1
25.0	47.1
31.25	45.2
62.5	39.2
100.0	35.1

5.4.6 Propagation delay

In determining the channel and basic link propagation delay, the propagation delay contribution of each installed mated connection is assumed to not exceed 2.5 ns from 1 MHz to 100 MHz.

5.4.7 Propagation delay skew

For each installed mated connection, the propagation delay skew is assumed not to exceed 1.25 ns.

5.4.8 DC resistance

The DC resistance between the input and the output connections of the connecting hardware (not including the cable stub, if any) used to terminate 100 Ω twisted-pair cabling shall not exceed 0.3 Ω for category 3 connecting hardware and 0.2 Ω for category 5e connecting hardware at 20 °C ± 3 °C when tested in accordance with ASTM D4566.

> NOTE – DC resistance is a separate measurement from contact resistance as specified in annex A. Whereas DC resistance is measured to determine the connector's ability of transmit direct current and low frequency signals, contact resistance is measured to determine the reliability and stability of individual electrical connections.

5.5 Telecommunications outlet/connector

Each four-pair horizontal cable shall be terminated in an eight-position modular jack at the work area. The telecommunications outlet/connector shall meet the modular interface requirements specified in IEC 60603-7. In addition, the telecommunications outlet/connector shall meet the requirements of clauses 5.3 and 5.4 and the terminal marking and mounting requirements specified in ANSI/TIA/EIA-570. Pin/pair assignments shall be as shown in figure 1 or, optionally, per figure 2 if necessary to accommodate certain 8-pin cabling systems. The colors shown are associated with the horizontal distribution cable shown in table 1. These illustrations depict the front view of the telecommunications outlet/connector.

> NOTES
> 1 Although the title of IEC 60603-7 appears to limit the bandwidth of the 8-way modular connectors to 3 MHz or less, these types of connectors may be qualified for use at higher frequencies when tested and proven to be compliant with the performance requirements specified in clause 5.4.
> 2 U.S. Federal Government publication NCS, FTR 1090-1977 recognizes the T568A designation only.

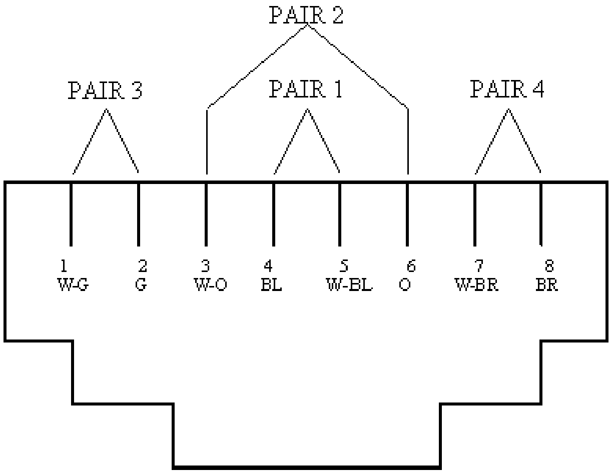


Figure 1 - Eight-position jack pin/pair assignment (T568A)

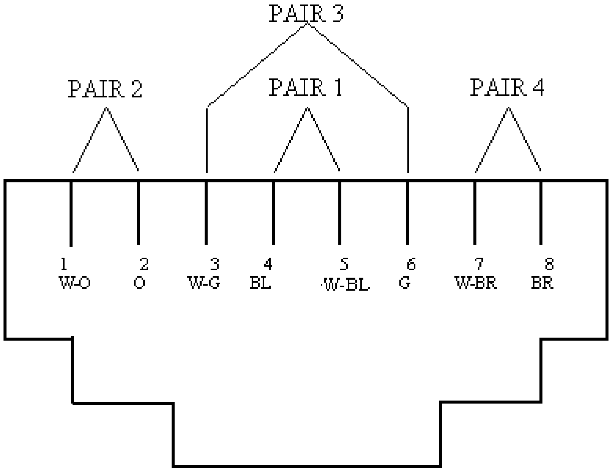


Figure 2 - Optional eight-position jack pin/pair assignment (T568B)

5.6 Performance marking

Connecting hardware should be marked to designate transmission performance at the discretion of the manufacturer or the approval agency. The markings, if any, shall be visible during installation. It is suggested that such markings consist of:

“cat 3” or ”  “ for category 3 components.

“cat 5e” or “  ” for category 5e components.

NOTES,

1 Performance markings are in addition to, and do not replace, other markings required by listing agencies or those needed to satisfy electrical code or local building code requirements.

2 Performance marking requirements for 100 Ω balanced twisted-pair cabling runs are specified in ANSI/TIA/EIA-568-B-1.

6 CORDS AND CROSS-CONNECT JUMPERS

6.1 General

Patch cords, work area cords, equipment cords, and cross-connect jumpers used for system moves, adds, and changes are critical to transmission performance. Annex K contains additional specifications for ScTP patch cords and cross-connect jumpers.

6.2 Applicability

These requirements are applicable to twisted-pair conductors and cables used for patch, work area, and equipment cords and cross-connect jumpers. Modular plugs and other connectors used for 100 Ω twisted-pair cable assemblies shall meet the requirements specified in clause 5.

6.3 Mechanical

Cables used to construct patch, work area, and equipment cords should have stranded conductors and shall meet the requirements of clause 4.5. Stranded conductor cable may be used to increase flexibility of cords. Cables used for patch cords shall meet the conductor size and color coding specified in clauses 6.3.1 and 6.3.2, respectively. Twisted-pair conductor lay lengths for 24 AWG or larger stranded conductors shall not exceed 15 mm (0.6 in).

6.3.1 Insulated conductor

Cables used to construct patch, work area, and equipment cords terminated with modular plug connectors as specified in IEC 60603-7 should have an insulated conductor diameter in the range of 0.8 mm (0.032 in) to 1 mm (0.039 in) and shall not exceed 1.22 mm (0.048 in). Cross-connect jumpers shall meet the requirements of clause 4.3.3.1 and the applicable requirements of ANSI/ICEA-S-90-661-1994.

> NOTE – A special modular plug connector may be required for cables with insulated conductor diameter greater than 1 mm (0.39 in) or less than 0.8 mm (0.032 in).

6.3.2 Color codes

Color coding of cross-connect jumpers shall consist of one conductor with white insulation and another conductor with a visibly distinct color such as red or blue. Color coding of cross-connect jumpers shall consist of one conductor with white insulation and another conductor with a visibly distinct color such as red or blue or option 1 of table 24.

Table 24 - Color codes for stranded cordage

Conductor identification	Color code (Abbreviation) Option 1	Color code (Abbreviation) Option 2
Pair 1	White-Blue (W-BL) Blue (BL)	Green(G) Red (R)
Pair 2	White-Orange (W-O) Orange (O)	Black (BK) Yellow (Y)
Pair 3	White-Green (W-G) Green (G)	Blue (BL) Orange (O)
Pair 4	White-Brown (W-BR) Brown (BR)	Brown (BR) Slate (S)

NOTES
1 A white marking is optional.
2 Because of their identical pair groupings, patch cords terminated in either T568A or T568B may be used interchangeably, provided that both ends are terminated with the same pin/pair scheme.
3 The flex life of work area, patch, and equipment cords is under study.

6.3.3 Transmission requirements

Cross-connect jumpers shall meet the requirements of 4.3.4.
Cross-connect jumpers shall meet the requirements of 4.3.3.1.

6.3.3.1 Near-end crosstalk (NEXT) loss

The NEXT loss of category 5e patch, work area and equipment cords with modular plugs shall be measured for all pair combinations in accordance with clause F.2. For all frequencies from 1 MHz to 100 MHz, category 5e modular plug, work area, and equipment cord NEXT loss shall meet or exceed the values specified in equation (33). The values in table 25 are provided for information only. Calculations that result in NEXT loss values greater than 65 dB shall revert to a requirement of 65 dB minimum. NEXT loss is not specified for category 3 modular plug, work area, and equipment cords.

> NOTE - The test jack described in annex J was designed to test category 5 modular plug, work area, and equipment cords and should be adequate for category 5e modular plug cord qualification. The development of a specific test jack for category 5e modular plug, work area, and equipment cords is under study.

The test limit is given by:

$$NEXT_{cord} \geq -10\log\left(10^{\frac{-NEXT_{connectors}}{10}} + 10^{\frac{-\left(NEXT_{cable} + 2 \cdot Ins\_Loss_{conn}\right)}{10}}\right) \qquad (32)$$

where:

$$NEXT_{connectors} = -20\log\left(10^{\frac{-NEXT_{local}}{20}} + 10^{\frac{-\left(NEXT_{remote} + 2 \cdot \left(Ins\_Loss_{cable} + Ins\_Loss_{conn}\right)\right)}{20}}\right) \qquad (33)$$

$$NEXT_{local} = NEXT_{local,100MHz} - 20\log\left(\frac{f}{100}\right) \qquad (34)$$

$$NEXT_{remote} = NEXT_{remote,100MHz} - 20\log\left(\frac{f}{100}\right) \qquad (35)$$

$$Ins\_Loss_{cable} = DeRating_{Ins\_Loss} \cdot Ins\_Loss_{cable,100m} \cdot \frac{CableLength}{100} \qquad (36)$$

$$NEXT_{cable} = NEXT_{cable,100m} - 10\log\left(1 - e^{-0.46 \cdot Ins\_Loss_{cable}}\right) \qquad (37)$$

where:

f is the frequency in MHz, NEXT is in dB, and cable length is in meters,

$NEXT_{local,100MHz}$ is the mated NEXT loss at 100 MHz assigned to the local test jack in dB, and

$NEXT_{remote,100MHz}$ is the mated NEXT loss at 100 MHz assigned to the remote test jack in dB.

For the test head described in clause F.6, $NEXT_{local,100\ MHz}$ and $NEXT_{remote,100MHz}$ equals 41.0 dB.

$Ins\_Loss_{cable,100m}$ is the insertion loss of 100 meters of horizontal cable as specified in clause 4.3.4.7.

$Derating_{Ins\_Loss}$ is the de-rating factor specified for stranded cable as specified in clause 4.5.4.

Ins_Loss_{conn} is the insertion loss of a compliant connector as specified in clause 5.4.2.

$NEXT_{cable}$ is the cable NEXT loss computed from the NEXT loss requirements for 100 meters of horizontal cable, the insertion loss requirements for 100 meters of stranded cable, and the length correction formula in ASTM D 4566.

$NEXT_{cable,100m}$ is the test limit for 100 m cable per clause 4.3.4.8.

Table 25 - Example category 5e cord NEXT loss limits using the test head in clause F.6

Frequency (MHz)	2 m cord Limit (dB)	5 m Cord Limit (dB)	10 m Cord Limit (dB)
1.0	65.0	65.0	65.0
4.0	62.3	61.5	60.4
8.0	56.4	55.6	54.7
10.0	54.5	53.7	52.8
16.0	50.4	49.8	48.9
20.0	48.6	47.9	47.1
25.0	46.7	46.0	45.3
31.25	44.8	44.2	43.6
62.5	39.0	38.5	38.1
100.0	35.1	34.8	34.6

6.3.3.2 Return loss

The return loss of category 5e patch, work area and equipment cords with modular plugs shall be measured for all pairs in accordance with clause F.4. For all frequencies from 1 MHz to 100 MHz, category 5e modular plug, work area, and equipment cords shall meet or exceed the values specified in table 26. The values in table 27 are provided for information only. Return loss is not specified for category 3 modular plug, work area, and equipment cords.

Table 26 - Category 5e cord return loss, worst pair

Frequency (MHz)	Category 5e (dB)
$1 \le f < 25$	$24+3\log(f/25)$
$25 \le f \le 100$	$24-10\log(f/25)$

(39)

Table 27 - Category 5e cord return loss, worst pair

Frequency (MHz)	Category 5e (dB)
1.0	19.8
4.0	21.6
8.0	22.5
10.0	22.8
16.0	23.4
20.0	23.7
31.25	23.0
62.5	20.0
100.0	18.0

Annex A Reliability testing of connecting hardware for 100 Ω balanced twisted-pair cabling (normative)

A.1 General

Connecting hardware reliability is critical to the overall cabling system operation. Changes in contact resistance due to operational and environmental stress can negatively affect the transmission characteristics of the building cabling system. Product life testing shall be accomplished by subjecting the connecting hardware to various mechanical and environmental conditions and measuring any resistance deviation that may occur during and after completion of the test cycle. In addition, connecting hardware shall not show evidence of degradation with respect to ease of mechanical termination, safety, or other functional attributes at any time during or after testing.

> NOTE - The modular connectors and cable terminations may be tested separately when connecting hardware consists of modular connector assemblies and/or cable terminations.

Connecting hardware used for 100 Ω balanced twisted-pair cabling shall be qualified per the test sequence, illustrated in figure A-1, when mounted and connected in accordance with manufacturer's guidelines. Unless otherwise specified, the measuring atmosphere should be room climate in accordance with IEC 60068-1, clause 5.3.1. For connecting hardware with 8-position modular connectors, the modular connection shall comply with the Level A reliability requirements of IEC 60603-7. When connecting hardware consists of assemblies of modular connectors and cable terminations, the modular connectors and cable terminations may be tested separately as components. For each of the four test sequences shown in figure A.1, a minimum of 100 test contacts shall be tested without failure. Unless otherwise specified, all products shall be tested in a mated or terminated state.

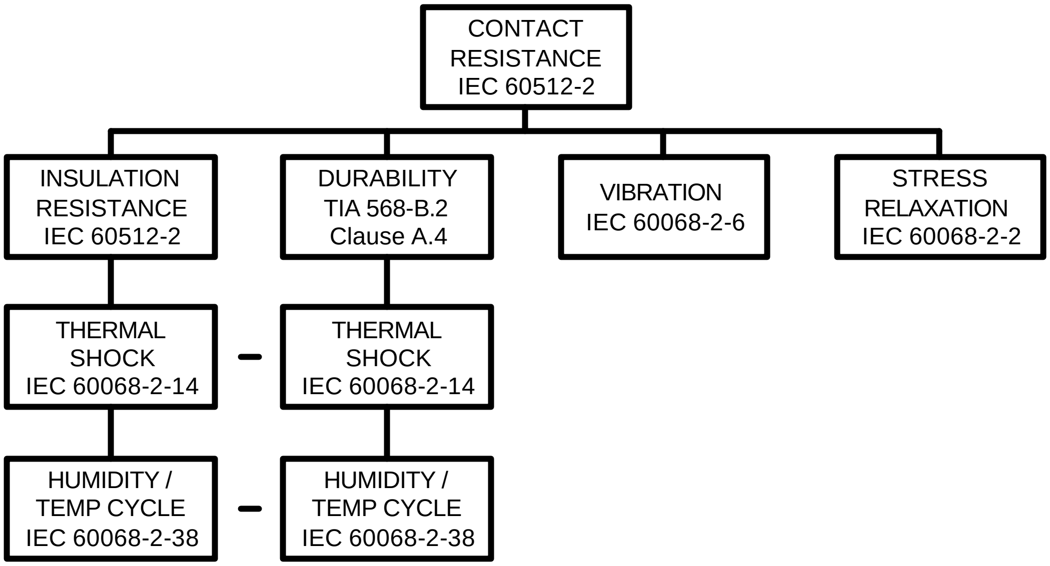


Figure A.1 - Reliability test program

A.2 Contact resistance measurement

Connecting hardware contact resistance shall be measured in accordance with IEC 60512-2, Test Method 2A, Millivolt Level Method and shall conform with the following requirements:

a) If voltage probes cannot be placed within 1.3 mm (0.051 in) from the connection point, bulk resistance should be measured and subtracted out to determine contact resistance.
b) Initial contact resistance (the electrical connection, not including bulk resistance) between elements of connecting hardware and between connecting hardware and cabling shall not exceed 2.5 mΩ. Also, elements of a connecting system that are subject to more than a single connecting operation throughout normal use shall not exhibit contact resistance in excess of 2.5 mΩ when initially terminated, or when re-terminated at prescribed intervals during or after environmental conditioning.
c) Whenever contact resistance measurements are required for contacts subject to the following environmental conditions in the terminated state, contact resistance shall not change by more than 5 mΩ from the initial value.

For 2-piece connectors and shield terminations, the interface resistance of the mated contact or shield connection shall not exceed 20 mΩ initially, or 40 mΩ at the prescribed measurement interval during or after the environmental conditioning. As stated in clause 5.3.5, 2-piece connector interfaces that comply with IEC 60603-7 or IEC 60807-8 are exempt from this annex.

A.3 Insulation resistance

Insulation resistance shall be measured in accordance with IEC 60512-2, Test 3a, Method C, Test Voltage 500 VDC. Insulation resistance between any two conductors shall be at least 100 MΩ. These specimens shall be used as Sample Group A.

A.4 Durability

Elements of the connecting system that are subject to more than a single connecting operation throughout normal use shall withstand at least 200 insertion and withdrawal cycles without failing. 100 cycles are performed before thermal shock and humidity/temperature cycling tests, and an additional 100 cycles are performed during and after these environmental tests. Contacts shall be inspected and contact resistance shall be measured after 100 cycles. These specimens shall be used as Sample Group B.

A.5 Vibration

Vibration tests shall be performed in accordance with IEC 60068-2-6, Test Method Fc and Guidance.

a) Test Conditions:

1) Frequency Range:	10 Hz – 55 Hz
2) Displacement Amplitude:	0.75 mm (0.03 in)
3) Sweep Cycles:	20 (each of 3 linear axes)
4) Elapsed Time:	1 hour 45 minutes (each axis)

Contacts shall be inspected and contact resistance shall be measured after vibration cycling of each axis.

A.6 Stress relaxation

Stress relaxation tests shall be performed in accordance with IEC 60068-2-2, Test Method Ba.

a) Test Conditions:

1) Test Temperature:	70 °C ± 2 °C
2) Test Period:	500 hours

Contacts shall be inspected and contact resistance shall be measured at 168 hour ± 10 hour intervals.

A.7 Thermal shock

Thermal shock testing shall be performed in accordance with IEC 60068-2-14. Test Method Nb. One-half of the Sample Group A terminals shall be tested in a mated (terminated) state. The remaining Sample Group A terminals shall be tested in an unmated (un-terminated) state. Sample Group B terminals shall be tested in mated (terminated) state only.

a) Test Conditions:

  1) Low Temperature: -40 °C ± 2 °C
  2) High Temperature: 70 °C ± 2 °C
  3) Minimum Average Transition Rate: 3 °C/min.
  4) Exposure Time: 30 min.
  5) (each temperature)
  6) Number of cycles: 100
  7) Sample Group B shall be subjected to 33 insertion and withdrawal cycles after 50 temperature cycles.

Contacts shall be inspected and contact resistance shall be measured after 50 cycles ± 5 cycles and at the completion of test cycling. These specimens shall be used for humidity/temperature cycle testing.

A.8 Humidity/temperature cycle

Humidity/temperature cycle testing shall be performed in accordance with IEC 60068-2-38, Test Method Z/AD with cold subcycle. One-half of the Sample Group A terminals shall be tested in a mated (terminated) state. The remaining Sample Group A terminals shall be tested in an unmated (un-terminated) state. Sample Group B terminals shall be tested in mated (terminated) state only.

a) Test conditions:

This test is performed only on product that has passed thermal shock testing.

  1) Low temperature: 25 °C ± 2 °C
  2) High temperature: 65 °C ± 2 °C
  3) Cold sub-cycle: -10 °C ± 2 °C
  4) Relative humidity: 93% ± 3%
     (at high and low temperatures)
  5) Cycle time: 24 hours
  6) Number of cycles: 21
  7) Sample group B shall be subjected to 33 insertion and withdrawal cycles after 7 days and an additional 34 cycles after 21 days.

Contacts shall be inspected and contact resistance shall be measured for Groups A and B and insulation resistance shall be measured for Group A only immediately upon removal from the test chamber at seven-day intervals and after final drying. Recovery of insulation resistance from a humid state to least 100 MΩ shall occur within 1 hour.

A.9 Other testing

Connecting hardware that is used for termination to 100 Ω balanced twisted-pair cabling shall comply with the safety and performance requirements of UL 1863 and other applicable codes.

Annex B Test equipment overview (normative)

B.1 General test configuration

The transmission tests described in this standard typically require the use of a network analyzer or equivalent, coaxial cables, baluns, UTP test leads, and impedance matching terminations. Network analyzers provide capability to correct for source and load port inaccuracies and measurement errors due to output port gain errors and measurement port sensitivity. In addition, signal leakage from the output port to measurement port can be compensated. Each setup component shall be qualified to a measurement bandwidth of at least 1MHz to the highest test frequency that is specified. Equivalent test set-ups may be used. This annex discusses in detail:

- Network analyzer requirements
- Balun requirements
- Impedance matching termination requirements
- Other interconnect cabling requirements

B.2 Balun requirements

Balun transformers are used to convert the unbalanced measurement capability of the network analyzer to the balanced terminals of the cabling interface. The performance of baluns used during testing shall be specified over the frequency range of interest and exhibit minimum performance specified as in table B-1.

Table B.1 - Test balun performance characteristics

(1 MHz-100 MHz)

Parameter:	**Value:**
Impedance, Primary 1)	50 Ω unbalanced
Impedance, Secondary	100 Ω balanced
Insertion loss	1.2 dB maximum
Return Loss, Bi-directional 2)	20 dB minimum
Return Loss, Common Mode 2)	20 dB minimum
Power Rating	0.1 watt minimum
Longitudinal Balance 3)	60 dB minimum
Output Signal Balance 2)	50 dB minimum
Common Mode Rejection 2)	50 dB minimum

1) Primary impedance may differ, if necessary, to accommodate analyzer outputs other than 50 Ω.
2) Measured per ITU-T (formerly CCITT) Recommendation G.117 with the network analyzer calibrated using a 50 Ω load.
3) This parameter is measured at the center tap input with the balanced terminals and ground connected together through two 50 Ω resistors in a “Y” or equivalent configuration line to line and a 25 Ω resistor to ground. The primary balun input should be connected to a 50 Ω termination.

B.3 Ground plane requirements

The baluns at the near-end shall be bonded to a ground plane. Any baluns and common mode nodes used at the far-end shall also be bonded to a ground plane. Refer to clause G.6 for further ground plane considerations.

B.4 Network analyzer requirements

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

B.5 Impedance matching terminations

Either balun terminations or resistive terminations may be used for the termination of far-end pairs under test and for the termination of the unused near-end and far-end pairs, although resistor terminations are recommended for improved measurement accuracy. For every measurement parameter, all ports of the device under test (both near-end and far-end) shall be terminated as specified (i.e. differential only terminations are required for some tests, while other tests may require common mode terminations at the near-end and differential only terminations at the far-end of the DUT). In all cases, the type of termination shall be consistent between all pairs at each end (i.e. common mode and differential only terminations are not mixed for the near-end of the DUT or the far-end of the DUT).

B.5.1 Balun terminations

Baluns used for termination shall comply with the requirements of clause B.2. The common mode termination resistor applied to the common mode port of the balun shall be 50 Ω ±1 %.

B.5.2 Resistor terminations

Resistors used for differential mode termination shall exhibit impedance of 100 Ω ± 0.1 % (two times 50 Ω ± 0.1 %) as shown in figure B.1. The resistors used for common mode terminations shall include the addition of a common mode 25 Ω ± 1 % resistor as shown in figure B.1. In this case, the common mode impedance formed by the 25 Ω resistor in series with the two 50 Ω resistors in parallel provides for a total common mode impedance of 50 Ω.

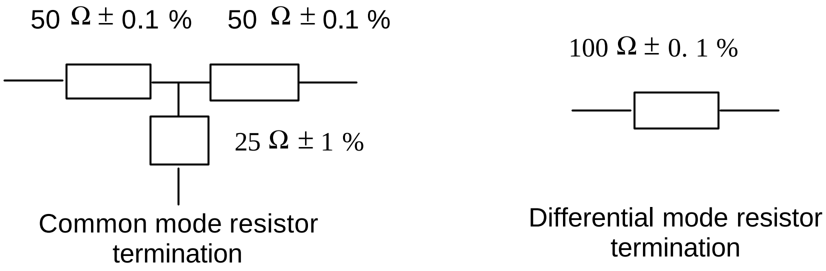


Figure B.1 – Resistor termination networks

Additionally,

1) Small geometry chip resistors shall be used for the construction of resistor terminations.
2) The two 50 Ω differential mode terminating resistors shall be matched to within 0.1 % at DC.
3) The length of connections to impedance terminating resistors shall be minimized (lead lengths of 2 mm (.08 in) or less are recommended).

B.5.3 Termination performance at test interface

The performance of impedance matching terminations shall be verified by measuring the return loss of the termination at the test interface to the device under test. For this measurement, a one port calibration is required using the calibration reference load. The return loss of the load termination shall be 20 dB or better over the frequency range of the measurement. (There is a relaxation of the return loss requirement to 15 dB from 1 to 3 MHz for balun terminations.)

> NOTE - The 20 dB return loss requirement above results in better performance at frequencies below the upper frequency limit for resistor terminations versus balun terminations. It is for this reason that resistor terminations are recommended, even though the performance requirements (as specified here) are essentially the same.

B.6 General calibration and reference plane of measurements

For all measurement configurations, the reference plane represents the location where calibration devices are connected to the test setup (see figure B.2). The reference plane is defined at the test interface and is the point of connection between the device under test and the fixed portion of the test fixture.

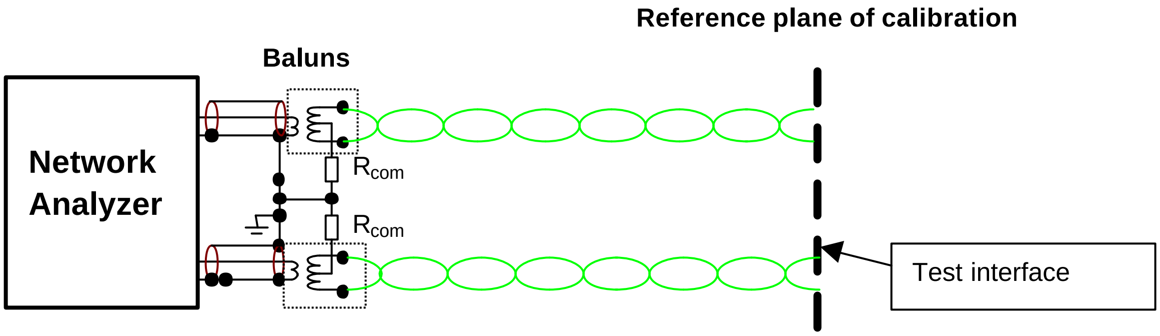


Figure B.2 - Reference plane of measurement

The reference plane location can be established based on:

- Formal definitions of reference planes for cabling (e.g., reference plane for the channel or permanent link).
- Proximity to the cabling or cabling component under test to avoid introduction of measurement errors (i.e. from the network analyzer, baluns and interconnect wiring).
- Convenience of connecting devices to be tested.
- Minimizing disruption of the transmission performance at the location where devices are connected, particularly to avoid reflections and parasitic crosstalk effects.

> NOTE - The reference plane can be at the location of the balun terminals. In this case, the measurement system does not include a segment of twisted pair wires.

There are two commonly used calibration methods:

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

Both one-port and two-port calibrations require reflection calibration that corrects for imperfect source and load impedance of the measurement system, including the near- and far-end measurement ports of the network analyzer, baluns and interconnections up to the location of the reference plane. Reflection calibration typically involves connecting open, short, and load calibration devices at the location of the reference plane. Absolute measurement accuracy is determined by the accuracy of the calibration load. Refer to clause B.6.1.1 for additional information.

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

B.6.1 Calibration references

Internal test calibration standards within the instrument shall be adjusted to reflect the characteristics of the actual standards used for calibration as specified by the instrument manufacturer. Typical parameters for a network analyzer using open-short-load-through calibration standards are open circuit capacitance, short circuit inductance, through offset delay and offset Z_0. Test facilities should maintain appropriate documentation detailing the calibration procedures and calibration standard values used and the expected accuracy. See annex H for typical test equipment performance parameters.

B.6.1.1 100 W reference load measurement procedure

Impedance terminations shall be calibrated against a 50 Ω coaxial load, traceable to an international reference standard.

The calibration reference load shall be equal to the nominal impedance of twisted-pair cabling defined in this Standard, which is 100 Ω. The reference load(s) for calibration shall be placed in an N-type connector according to IEC 60169-16 (i.e. designed for panel mounting and machined flat on the back side). The load(s) shall be fixed to the flat side of the connector and distributed evenly around the center conductor. One port full calibrations shall utilize the 50 Ω coaxial calibration reference.

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

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

B.6.1.2 100 W reference load return loss requirement

The verified return loss of the 100 Ω reference load shall be >40 dB from 1 MHz to the highest referenced frequency in MHz.

Annex C Testing of cable (normative)

C.1 Insertion loss of cable

C.1.1 Test configuration for cable insertion loss

The following requirements apply to the test configuration for cable insertion loss and for other components, assemblies, and test parameters as indicated by reference.

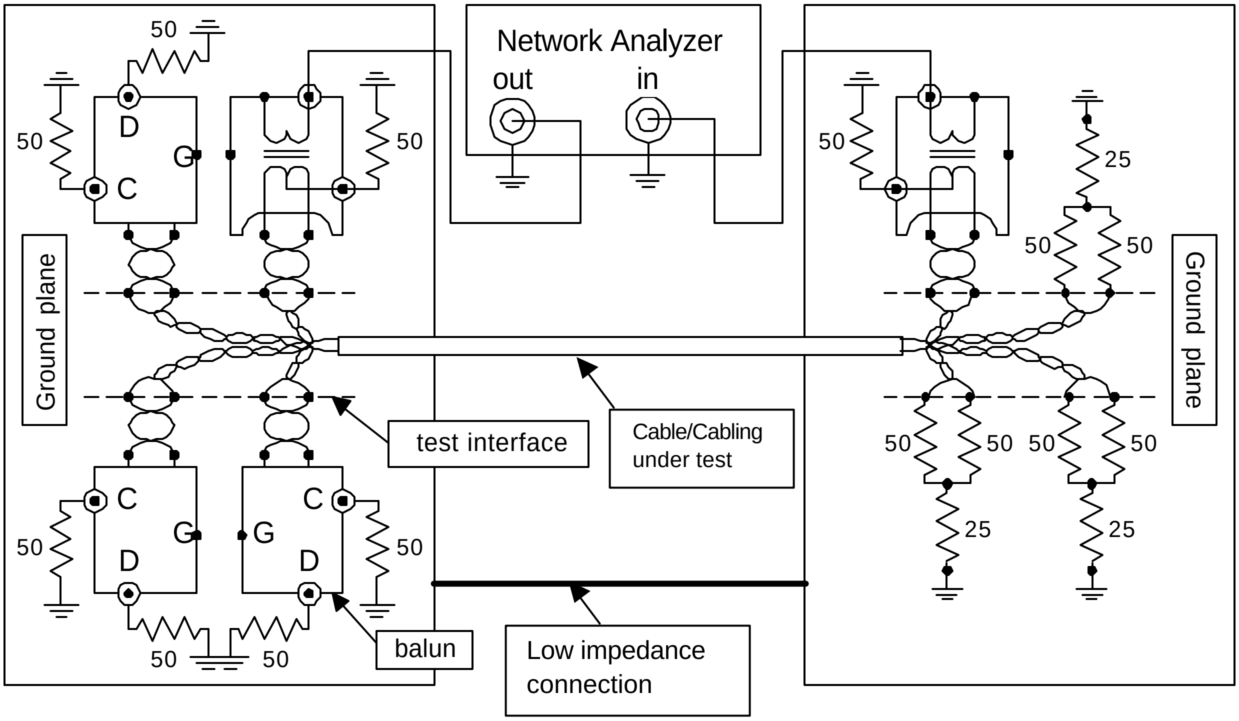


Figure C.1 - Schematic diagram of the laboratory test configuration for insertion loss, FEXT loss or ELFEXT, and propagation delay

The detailed schematic diagram of the balun is shown once in figure C.1. The connection labeled “C” represents the connection to the common mode port, the connection labeled “D” represents the connection to the unbalanced port, and the connection labeled “G” represents a connection to the ground plane.

NOTES,

1 If 2-port calibration is used, and the remote end of the same twisted-pair tested is connected to the load input of the S-parameter test set, the result reported by the network analyzer will be corrected for source and load return losses.

2 Shields and screens, if any, should be bonded (low inductance connections) to the local and remote measurement grounds.

3 The connection of local and remote grounds through the network analyzer is not expected to have a significant influence on the measured results.

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

C.1.2 Calibration for cable

The following requirements apply to calibration for cable insertion loss, and for other components, assemblies, and test parameters as indicated by reference. Two-port calibration and measurement methods, which include compensation for the balun response, shall be used for insertion loss, NEXT loss and FEXT loss measurements.

C.1.2.1 Two-port calibration of the test system

A two-port calibration utilizing load, open, and short reference calibration devices shall be specified when calibrating reflections. Transmission calibration requires interconnecting the near- and far-end measurement ports at the location of the reference plane with a known reference. The reference may be a short piece of twisted-pair conductors. Isolation calibration is only required if there is significant crosstalk between the near- and far-end measurement ports at the location of the reference plane. If the level of uncompensated crosstalk at this location is near the noise floor of the network analyzer, then the isolation calibration may be omitted. If used, during isolation calibration, the near- and far-end measurement ports should be terminated into 100 Ω at the location of the reference plane.

C.1.3 Measurement of cable insertion loss

Measure the S21 parameter with the pair under test connected to the network analyzer at both the near-end and the far-end.

C.2 NEXT loss of cable

C.2.1 Test configuration of cable NEXT loss

Figure C-2 depicts the typical schematic diagram for testing cable NEXT loss and return loss. Resistive type terminations are generally preferred for unused pairs at the far-end because of better return loss performance. The detailed schematic diagram of the balun is shown once in figure C.2. The connection labeled “C” represents the connection to the common mode port, the connection labeled “D” represents the connection to the unbalanced port, and connection labeled “G” represents a connection to the ground plane.

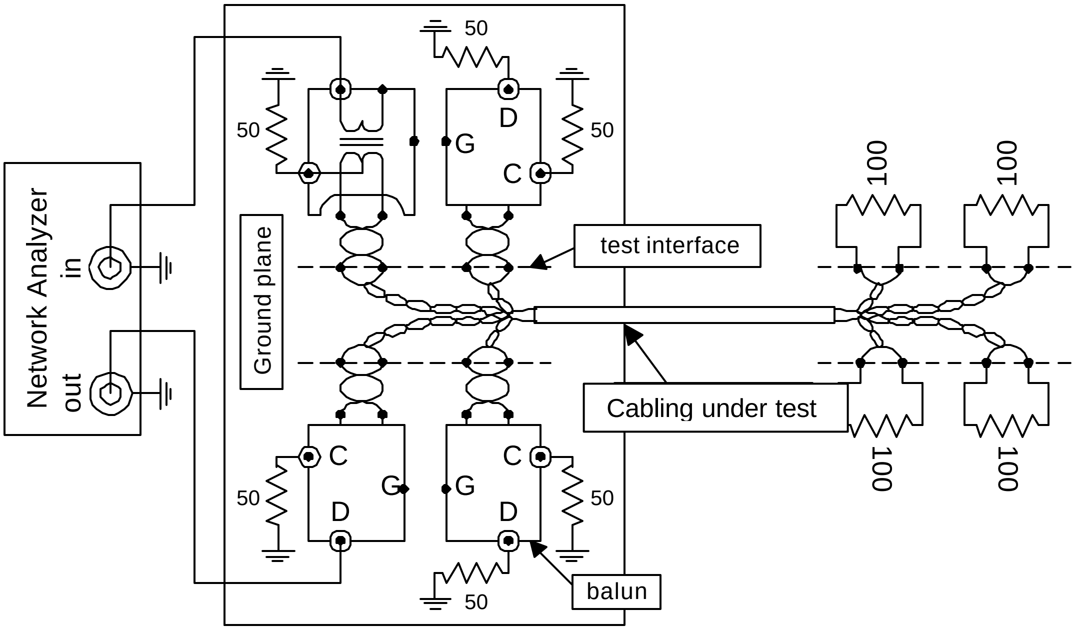


Figure C.2 - Schematic diagram of the laboratory test configuration for NEXT loss and return loss

C.2.2 Calibration of cable NEXT loss

A two-port port calibration, as described in clause C.1.2, is required to calibrate NEXT loss. A two-port calibration is required between all six pair combinations at the near-end of the cable test interface if four baluns are used.

C.2.3 Measurement of cable NEXT loss

Measure the S21 parameter with the network analyzer connected to each of the 6 pair combinations in a four pair cable, or each pair combination in a multi-pair cable.

C.3 ELFEXT of cable

C.3.1 Test configuration of cable ELFEXT

The cable ELFEXT test configuration shall be as described in clause C.1.1. ELFEXT is a calculation of the measurements of FEXT loss and insertion loss.

C.3.2 Calibration of cable FEXT loss

A two-port calibration, as described in clause C.1.2, is required to calibrate FEXT loss. A two-port calibration is required between all 12 pair combinations of the cable if more than two baluns are used.

C.3.3 Measurement of cable FEXT loss

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

C.4 Return loss of cable

C.4.1 Test configuration of cable return loss

The cable return loss test configuration shall be the same as the insertion loss test configuration described in clause C.2.1.

C.4.2 Calibration of cable return loss

A one- or two-port calibration, as described in clause C.1.2, may be used to calibrate return loss.

C.4.2.1 One-port calibration of the test system

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

C.4.3 Measurement of cable return loss

Measure the S11 parameter with the network analyzer connected to each pair on the near-end.

Annex D Testing of connecting Hardware (normative)

D.1 Insertion loss of connecting hardware

D.1.1 Test configuration for connecting hardware insertion loss

The following requirements apply to the test configuration for connecting hardware insertion loss and for other test parameters as indicated by reference. The test methods and setup requirements described herein apply to one (1) or more pairs of twisted-pair conductors. The nature of these tests is such that, when conducted properly, worst case transmission performance may be determined for a specific connector, regardless of the number of pairs that it is capable of terminating. Connecting hardware transmission testing shall be conducted upon products terminated per manufacturer's guidelines and recommended installation methods unless otherwise specified. For connecting hardware with modular interface components (i.e. plug and jack connectors), transmission tests shall be performed in a mated state. Test plug requirements are specified in clauses D.4 and D.5 using the de-embedding method specified in clause D.6.4.

UTP test leads are used for connections between the test interface and the test sample. Test leads may be 24 AWG and should be taken from cables that meet or exceed requirements for the same category of the connector to be tested. Test leads for modular test plugs may also be taken from the same category patch cable. UTP test leads shall be limited to a length of 75 mm (3 in) between each balun and the connector under test. Test leads connecting to the plug and jack shall be pre-qualified before they are attached to the device under test. Test leads shall be part of the transmission calibration in order to exclude their insertion loss contribution from the data. Each test lead shall be terminated with a terminating reference 100 Ω load as specified in clause B.5 and the return loss when connected to the test header shall exceed 35 dB from 1 MHz to 100 MHz. The test configuration for insertion loss is shown in figure D.1.

For the purpose of testing connecting hardware mated performance, the reference plane shall be as defined in clause B.6. Connecting hardware shall be defined as a mated plug and jack, with cable terminated to both. The connector is considered to begin at the point where the sheath of the cable is cut or the point inside the sheath where the cable conductor geometry is no longer maintained. The portion of the cable [typically 12 mm (0.5 in) or less] that is disturbed by the termination shall be considered to be part of the connector under test. Unless otherwise specified for a specific test, the performance of the entire mated connector shall be assessed.

D.1.2 Calibration

The calibration requirements of clause C.1.2 are applicable to connecting hardware.

D.1.3 Measurement of connecting hardware insertion loss

Measure connecting hardware insertion loss per the requirements of clause C.1.3. A low RF impedance connection between the local and remote ground planes should be provided for the measurement of connecting hardware insertion loss.

D.2 NEXT loss of connecting hardware

D.2.1 Test configuration for connecting hardware NEXT loss

Because many telecommunications networking implementations employ common mode terminations in active equipment, it is important that the cabling components perform consistently and meet transmission requirements both with and without common mode terminations in place. For this reason, it is necessary to specify a transmission test setup that will allow for testing NEXT loss both with and without common mode terminations on the active and inactive test leads. Connecting hardware transmission testing for NEXT loss shall be performed with the following test configurations:

a) Without common mode terminations on either end. (Connection labeled "C" in figure D-2 remains open).
b) With common mode terminations at least on the near-end. (Connection labeled "C" in figure D-2 is connected to a 50 Ω termination, as shown). Common mode terminations on the far end are optional.

All inactive pairs on the test sample shall be terminated with differential mode terminations in a) and differential plus common mode terminations in b). Modular test plugs used for the transmission testing of connecting hardware shall be qualified per clause D.5 and table D.4. There are no requirements for category 3 modular test plugs – any test plug may be used for category 3 connecting hardware qualification. Category 5e connecting hardware shall be tested and meet all of the requirements for NEXT loss with a complete set of worst case test plugs (there are 9 worst case values).

The measurement setups shown in figures D.1 and D.2 may be used to assess NEXT loss for various types of connectors. Although this method may not be directly applicable to all types of connecting hardware, it is shown to illustrate a setup that is accurate, simple to implement and that will allow a large number of connectors to be characterized in a short period of time. Setup variations that yield equivalent results are also acceptable. The four twisted-pair test leads extending beyond the cable jacket are oriented 90° with respect to one another. The ends of the twisted-pair conductors are connected to measurement baluns. The lengths of the pairs are adjusted to just reach the reference plane with the two pairs being measured in opposite directions coming out of the test plug (180° apart).

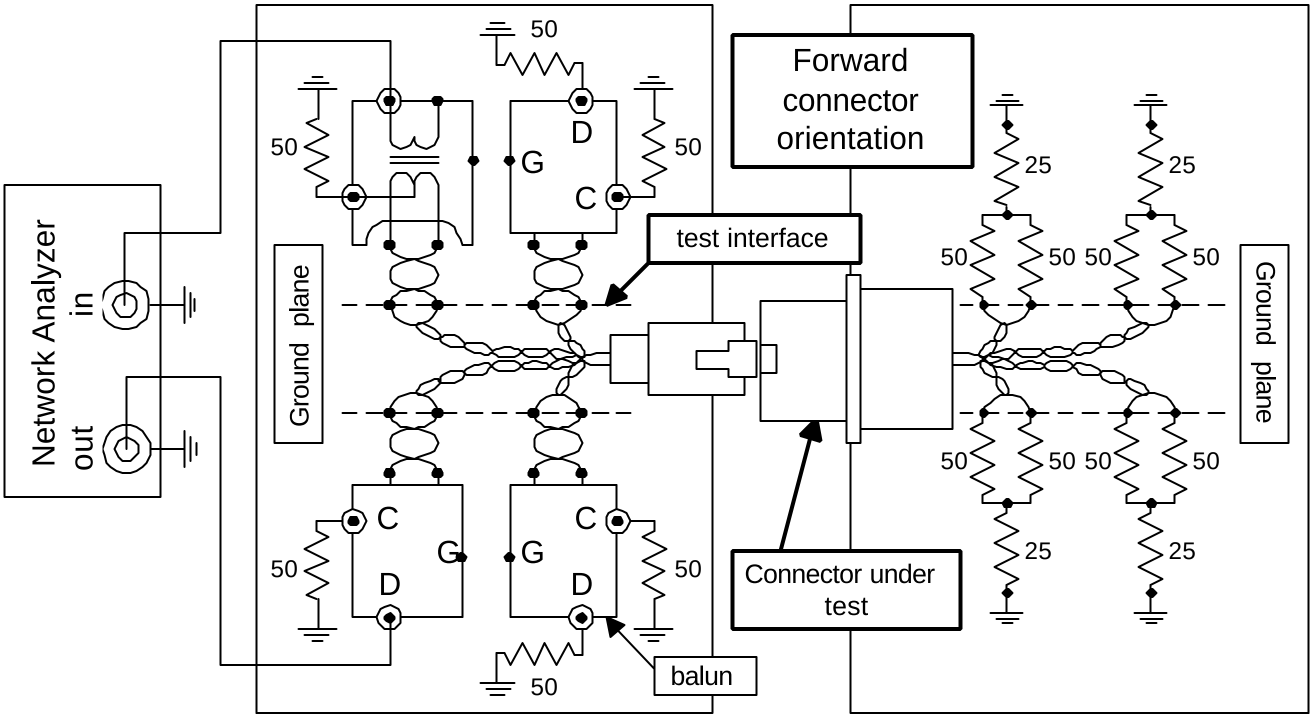


Figure D.1 - NEXT loss measurement setup with common mode terminations

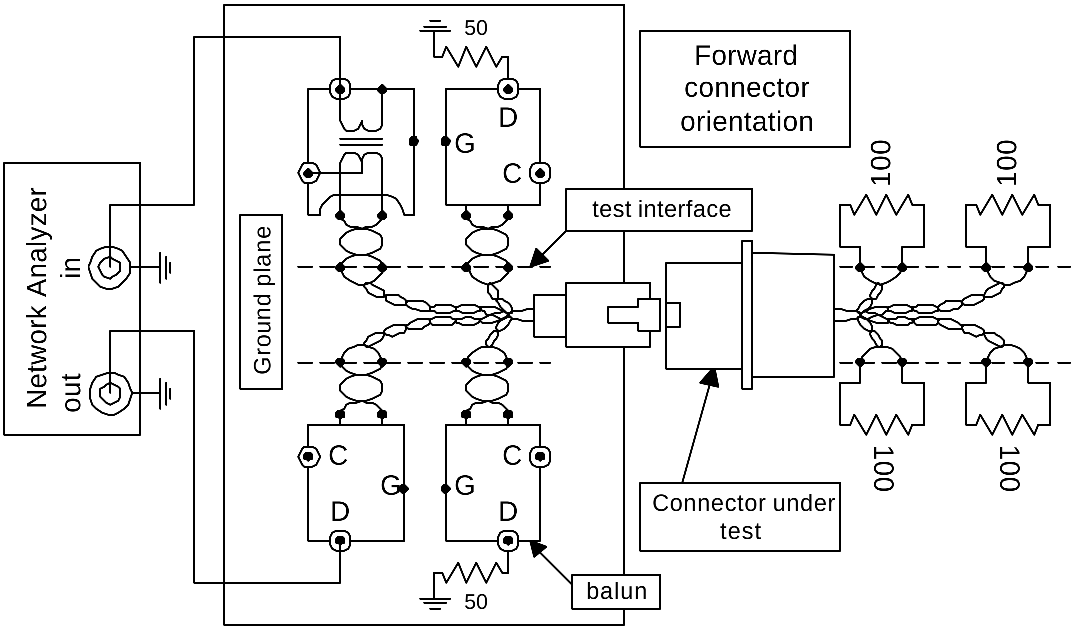


Figure D.2 - NEXT loss measurement setup with differential terminations

D.2.2 Calibration of connecting hardware NEXT loss

Connecting hardware NEXT loss calibrations shall be performed in accordance with clause C.1.2.

D.2.3 Measurement of connecting hardware NEXT loss

Product orientation, with respect to the near- and far-end, may affect measurement results. Due to these effects, the connector shall be tested in both test directions for NEXT loss. Measure the S21 parameter with the network analyzer connected to each of the 6 pair combinations in a four pair connector. For multi-pair connectors, all pair combinations at each end shall be measured.

D.3 FEXT loss of connecting hardware

D.3.1 Test configuration of connecting hardware FEXT loss

Test leads shall be connected to both ends of the test sample. The connecting hardware FEXT loss measurement procedure is similar to the standard setup for testing near-end crosstalk. Figure D-3 depicts a schematic version of a test setup that provides accurate and repeatable results. This figure shows four balun terminations to the near-end of the test fixture with 50 Ω common mode terminations to center tap of the balun. The common mode terminations are removed for testing with differential mode only terminations. Common mode terminations at the far-end of the test sample are optional for category 5e. Refer to clause B.5 for information on the construction of the common mode termination. A low RF impedance connection between the local and remote ground planes should be provided for FEXT loss measurements of connecting hardware.

Test plugs qualified per clause D.5 shall be used in determining the FEXT loss performance for the category of connecting hardware under test. The full set of worst-case modular test plugs covering all nine worst-case NEXT loss conditions shall be used when testing a modular outlet connector for FEXT loss.

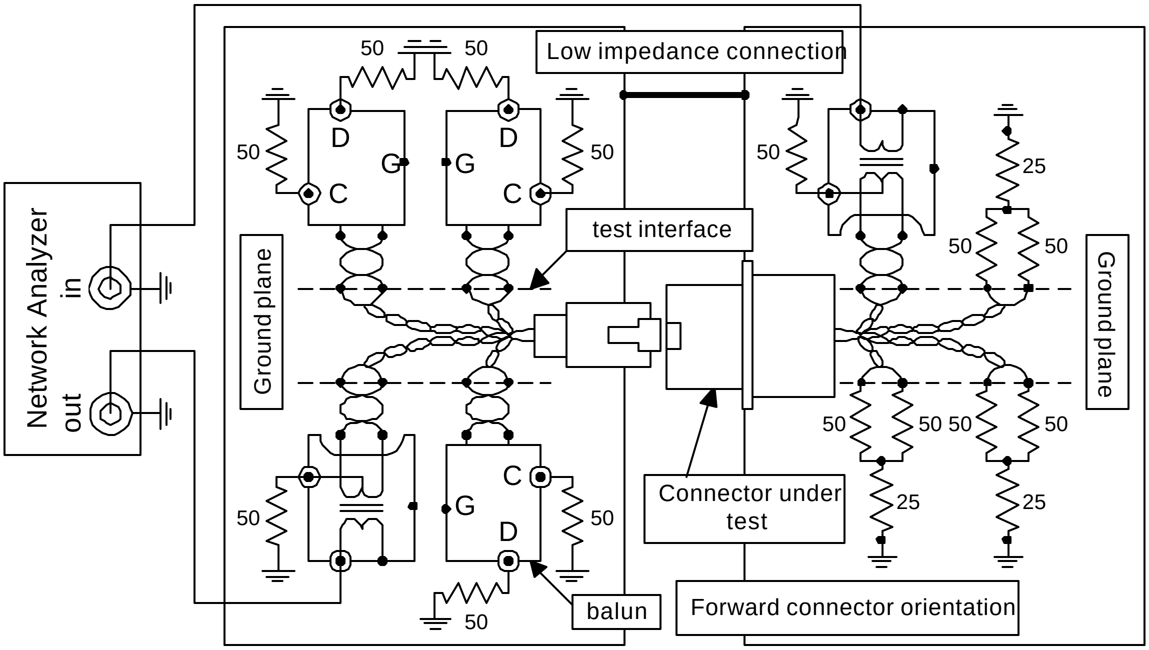


Figure D.3 - Network analyzer FEXT test setup

D.3.2 Calibration of connecting hardware FEXT loss

Connecting hardware FEXT loss calibrations shall be performed in accordance with clause C.1.2.

D.3.3 Measurement of connecting hardware FEXT loss

Connecting hardware FEXT loss measurements shall be performed in accordance with clause C.3.3.

D.4 Return loss of connecting hardware

D.4.1 Test configuration of connecting hardware return loss

A 75 mm (3 in) maximum length twisted-pair lead shall be used to connect the device under test to the network analyzer balun interface. The twisted-pair lead shall have a return loss of greater than 35 dB for all frequencies from 1 MHz to 100 MHz when measured with a 100 Ω reference load as specified in clause B.5. The conductor pairs shall be disturbed to the minimum extent possible after verification of return loss and when making connections to the device under test.

D.4.1.1 Return loss reference plug

A return loss reference plug shall be constructed following the practices specified for the de-embedded reference plug described in clause D.5.4. The return loss reference plug shall be verified to exhibit return loss as shown in table D.1 prior to removing the load resistors. If the measured return loss of the reference plug is worse than specified, then the test leads may be adjusted until the return loss satisfies the requirements of table D.1.

NOTE – One method to adjust the test lead return loss is to alter the twist rate.

Table D.1 - Performance of the return loss reference plug

Plug Pin Combination	Return Loss (dB)
3,6	30-32 dB
1,2	> 35 dB
4,5	> 35 dB
7,8	> 35 dB

After the return loss performance of the reference plug is verified, the load resistors are removed from the reference plug. The connecting hardware return loss shall be measured with the jack mated to the qualified return loss reference plug.

D.4.2 Calibration of connecting hardware return loss

Connecting hardware return loss calibrations shall be performed in accordance with clause C.4.2.

D.4.3 Measurement of connecting hardware return loss

Product orientation, with respect to the near- and far-end, may affect measurement results. Due to these effects, the connector shall be tested in both test directions for return loss. Measure the S11 parameter with the network analyzer connected to each pair on each end.

D.5 Test plugs for connecting hardware

D.5.1 Scope

This clause specifies the test procedure for 100 Ω UTP modular test plugs that are intended for the transmission performance verification of eight- position modular (IEC 60603-7 compatible) connecting hardware. Construction techniques and qualification of both de-embedded reference plugs and modular test plugs is provided. When implemented properly, this qualification procedure assures that accurate and repeatable transmission test measurements will be performed with minimal variations between test facilities and personnel. It should be noted that the same plug qualification requirements apply to transmission testing in either direction.

D.5.2 Applicability

For the purposes of this Standard, a modular test plug consists of short lengths of solid or stranded UTP twisted-pair conductors with a modular plug terminated on one end. Modular test plugs may be constructed from cross-connect (patch) and equipment cords. Clause D.7 specifies a systematic termination procedure that may be used to manufacture a set of plugs likely to satisfy the modular test plug requirements of clause D.6.10.

D.5.3 General test plug requirements

Because of variations that are inherent to terminating twisted-pair cables to modular plugs (and to a lesser extent, modular jacks), the following requirements and guidelines have been developed to verify modular connecting hardware performance. The de-embedding procedure is expected to yield a mated NEXT loss accuracy of ±1 dB at the category 5e connecting hardware test limit. Any test plug may be used for category 3 connecting hardware qualification. Modular test plug requirements are not specified for category 3 connecting hardware.

D.5.4 De-embedding reference NEXT plug construction

De-embedded reference plugs are constructed from solid twisted-pair conductors from category 5 (or better) cross-connect wire. All twisted-pairs shall be of the same color, design, and twist rate. Caution shall be used to minimize air gaps between the conductors of the pair. A 152 mm (6 in) piece and four 89 mm (3.5 in) pieces of twisted-pair conductors are selected. These twisted pair lengths shall have return loss in excess of 35 dB from 1 MHz to 100 MHz when measured using a terminating reference 100 Ω load as specified in clause B.5.2.

The de-embedded reference plug shall be 76 mm (3.0 in) long, including the test leads as shown in figure D.4. The normalizing jumper shall be 152 mm (6.0 in) long. The completed conductors will extend 6.4 mm (.25 in) +/- 1 mm (.04 in) beyond the nose of the plug.

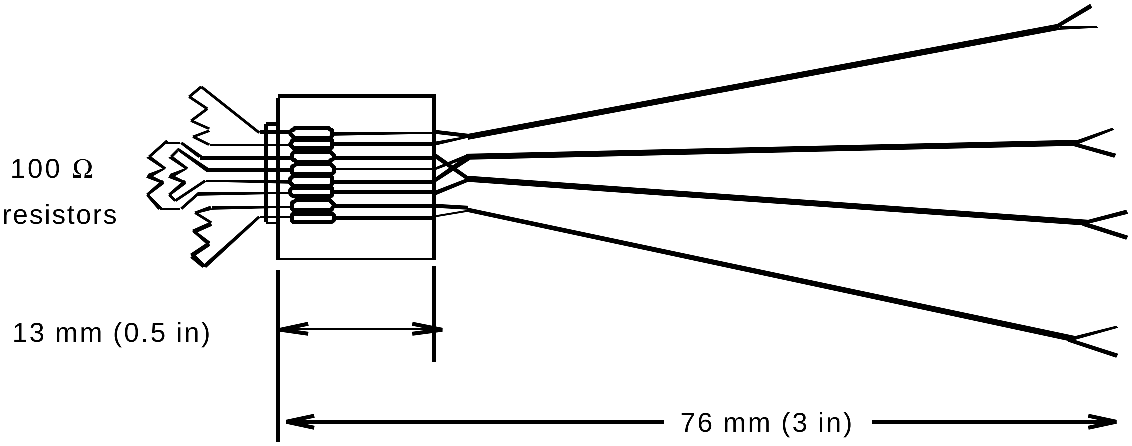


Figure D.4 - De-embedding plug reference

To construct the reference plug, take a standard plug body that conforms to the dimensional requirements of IEC 60603-7 in which the 8 conductors are parallel for 13 mm (0.5 in) and at the same height. Mill off the back end, where the strain relief is, so that the plug is 13 mm (0.5 in) long from the plug nose where the contacts are to the back of the plug. Using a 1.0 mm (0.04 in) diameter drill, drill 8 conductor paths through the nose, so that the individual wires can be extended through the nose. Untwist about 25 mm (1.0 in) of one end of the four 89 mm (3.5 in) long twisted pair wires. Strip off 1.0 mm (.04 in) of insulation from the untwisted end, so that chip resistors can be soldered there later. Place the leads in the plug. They shall be inserted far enough so that exactly 63 mm (2.5 in) of twisted-pair conductors exit at the rear of the plug. All of this twisted-pair lead length shall remain twisted. The pair terminated on pins 3,6 will have to be split apart, but the pair should be bent together as soon as practical after it exits from the nose. On the back end of the plug, insert the pair terminated on pins 3,6 toward the locking tab and the pair terminated on pins 4,5 away from the locking tab.

Set the plug blades into the wires.

Verify continuity.

Trim the leads protruding from the nose of the plug to 6.4 mm (0.25 in) ± 1.0 mm (0.04 in). Arrange the conductors according to figure D.5.

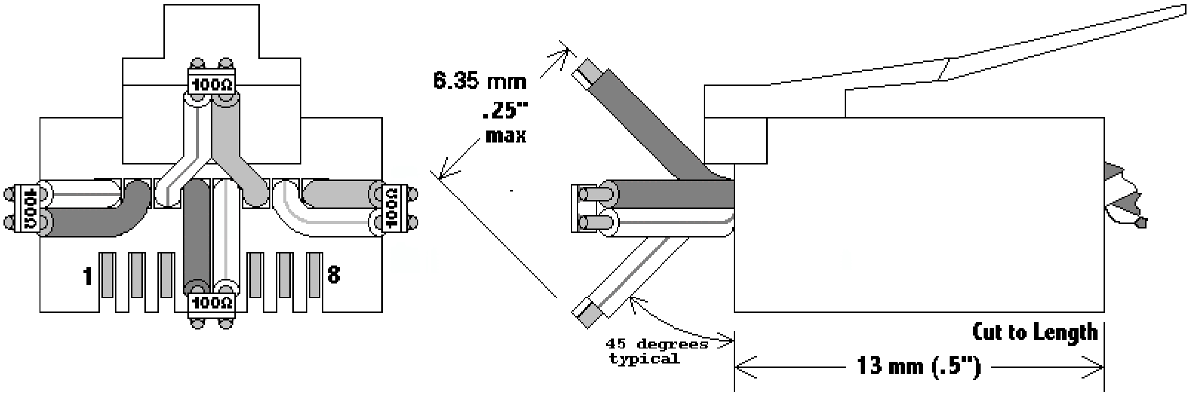


Figure D.5 - Orientations of wires on de-embedding reference plug

NOTES,

1 The insulation of the twisted pairs are touching one another throughout their length.
2 The pair terminated on pins 3,6 is bent back together as quickly as possible after it exits the plug nose.
3 Conductors 2 and 7 are bent away from conductors 3 and 6, respectively to maximize the distance and minimize the coupling between loops 3,6 and 1,2 and 3,6 and 7,8.
4 The twisted-pair conductors are bent at a 45 degree angle to the plug axis. This ensures that all of the pairs are orthogonal and minimizes their coupling.
5 Conductors 3 and 6 are bent toward the locking tab and conductors 4 and 5 are bent toward the blades.

Solder 0603 package size precision 100 Ω +/- 0.1 % chip resistors to the conductor tips as shown.

When the twisted-pairs exit from the back of the plug body, they are bent at a 45 degree angle away from the plug axis. The pair terminated on pins 3,6 is bent towards the plug tab and the pair terminated on pins 4,5 is bent away from the plug tab. The back of the plug should be stabilized with encapsulant.

D.5.5 Set up and calibration

Network analyzer source power shall be set to +10 dBm minimum. Since test plug characterization involves three measurements and subtractions between the measurements, it is necessary to collect all three measurements at the same frequencies. Frequency steps shall be no greater than 1 MHz.

Calibrate the network analyzer using a full two-port calibration. Use open, short, and load standards directly on the balun, and use a 152 mm (6 in) twisted-pair test lead as the through calibration standard.

After physically re-terminating with the load, cable and switching apparatus shall maintain measurement stability as shown in table D.2 throughout the frequency range of 1 MHz to 100 MHz.

Table D.2 - De-embedding measurement stability

Measurement parameter	**Reference value**
Insertion loss	± 0.02 dB
Return loss	≥ 55 dB

D.5.6 De-embedding reference plug NEXT loss measurement

Measure the NEXT loss of the de-embedding reference plug on all 6 pair combinations. Remove the resistors and the wires coming from the nose to the resistors.

Care must be exercised in measuring the real and imaginary components of crosstalk to ensure that pin polarity is maintained when connecting the test leads to the test balun terminals (e.g. use the convention of attaching the white lead to pin 1 of the terminal connection throughout). For all measurements, data may be collected in 1 MHz increment steps from 1MHz to 100 MHz. It is recommended that the terminal connections be labeled for polarity.

D.5.7 De-embedding reference NEXT jack construction

Construct a de-embedding reference jack as follows:

Mount a Molex part number 52018-8845 right angle PWB mountable jack onto a PWB with 100 Ω controlled impedance traces leading to mounting places for resistors. An example PWB is shown in figure D.6. Mount precision 100 Ω +/- 1 % chip resistors on the jack PWB.

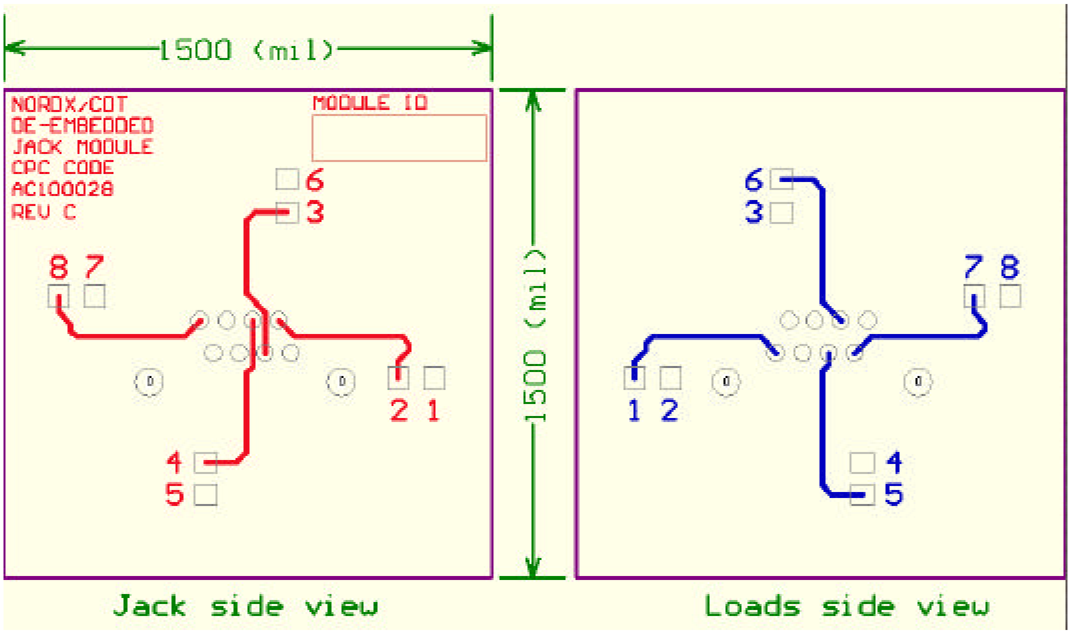


Figure D.6 - Example of PWB with impedance matched traces

The de-embedding reference jack consists of an uncompensated printed wiring board mountable jack with 100 Ω resistors connected to its terminals, as shown in figure D.7. The resistors shall be oriented orthogonally to each other.

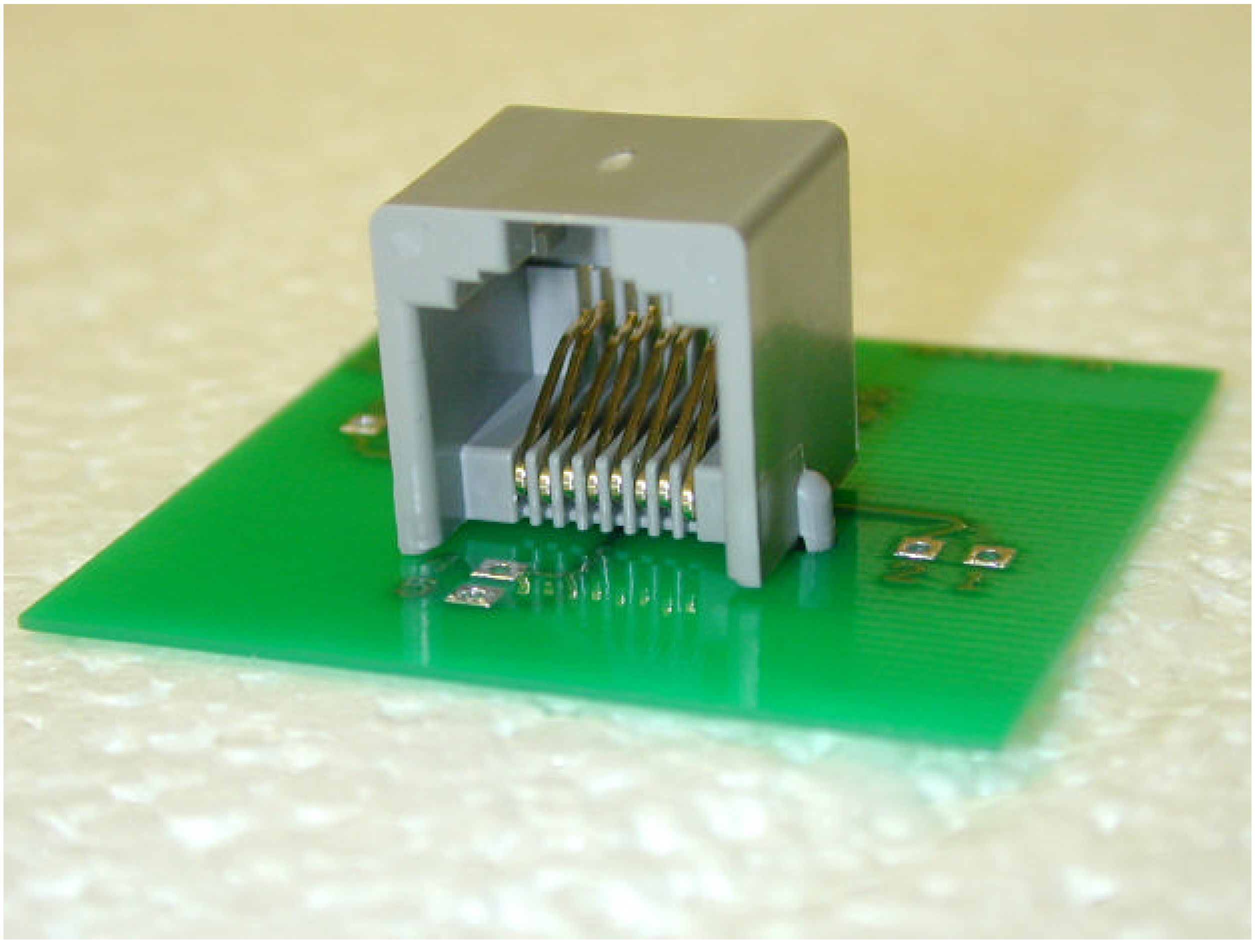


Figure D.7 - De-embedding reference jack

D.5.8 De-embedding reference jack NEXT loss measurement

Measure the NEXT loss of the de-embedding reference plug mated to the de-embedding reference jack for all 6 pair combinations as shown in figure D.8. Maintain correct wire pair polarity as specified in clause D.6.5.

Calculate the NEXT loss vector of the reference jack as the difference between the mated plug and jack vector and the reference plug vector at each measurement frequency.

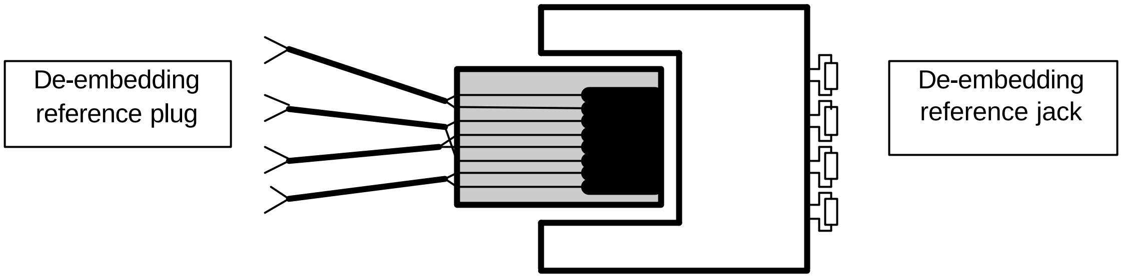


Figure D.8 - De-embedding reference plug mated with the de-embedding reference jack

The real and imaginary de-embedding reference plug results shall be subtracted from the real and imaginary mated plug and jack results. This yields a NEXT loss value at each frequency point from 1 MHz to 100 MHz for the reference jack de-embedded from the reference plug.

The NEXT loss components of the unmated reference jack, Re_J and Im_J, are calculated using equations (D-1) and (D-2).

$$\text{Re}_j = (\text{Re}_{PJ} - \text{Re}_P) \quad \text{(D-1)}$$

$$\text{Im}_J = (\text{Im}_{PJ} - \text{Im}_P) \quad \text{(D-2)}$$

D.5.9 Test plug NEXT measurement

Measure the NEXT loss of the test plug mated to the de-embedding reference jack on all 6 pair combinations as shown in figure D.9.

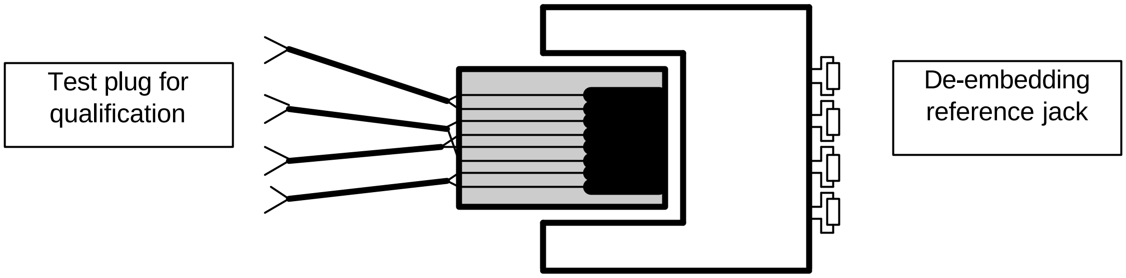


Figure D.9 - Test plug mated to the de-embedding reference jack

The test plug NEXT loss vector is the difference between mated test plug and reference jack vector and the reference jack vector calculated in clause D.5.8.

The NEXT components of the test plug, Re_{TP} and Im_{TP} are calculated using equations (D-3) and (D-4):

$$\mathrm{Re}_{TP} = (\mathrm{Re}_{TP\&J} - \mathrm{Re}_{J}) \tag{D-3}$$

$$\mathrm{Im}_{TP} = (\mathrm{Im}_{TP\&J} - \mathrm{Im}_{J}) \tag{D-4}$$

The logarithmic magnitude of the NEXT loss, in dB's, of the unmated modular test plug NEXT loss, is calculated using equation (D-5).

$$NEXT = -20\log\left(\sqrt{\mathrm{Re}_{TP}{}^{2} + \mathrm{Im}_{TP}{}^{2}}\right) \tag{D-5}$$

The phase of the resultant is calculated using equation D-6.

$$phase\ \deg = \tan^{-1}\frac{\mathrm{Im}_{TP}}{\mathrm{Re}_{TP}} \tag{D-6}$$

Phase shall be recorded with consideration that phase angle sign information is not dropped. The guidelines in table D.3 will help to ensure that phase angle sign is calculated correctly.

Table D.3 - Guidelines on phase angle sign calculation

Magnitude of Real Component	Magnitude of Imaginary Component	Phase Angle (degrees)
0	> 0	90
0	< 0	-90
> 0	any magnitude	$\tan^{-1}\frac{\mathrm{Im}_{TP}}{\mathrm{Re}_{TP}}$
< 0	> 0	$\tan^{-1}\frac{\mathrm{Im}_{TP}}{\mathrm{Re}_{TP}}+180$
< 0	< 0	$\tan^{-1}\frac{\mathrm{Im}_{TP}}{\mathrm{Re}_{TP}}-180$
< 0	0	180

D.5.10 Modular test plug qualification

Once the test plug is terminated, its characteristics shall be verified by measuring its de-embedded NEXT loss as described in this clause. For each of the six (6) pair combinations, the measured de-embedded NEXT loss at 100 MHz shall fall in the ranges shown in table D.4. At least one test plug shall exhibit worst case performance at or outside the compliant range for each pair combination (for a total of 9 worst cases). In addition, for the pairs terminated on pins 4&5 – 3&6, the difference between the test plug de-embedded NEXT loss measured at 100 MHz and the test plug de-embedded NEXT loss measured at 10 MHz should be 20 dB ± 0.5 dB.

Table D.4 - Test plug de-embedded NEXT loss selection at 100 MHz

Pin Combination	**Category 5e**	
	Range (dB)	Phase (degrees)
4&5 – 3&6	34.4 – 37.6	-90 ± 10
3&6 – 1&2	42 – 50	-90 ± 20
3&6 – 7&8	42 – 50	-90 ± 20
4&5 – 1&2	≥ 50	90 ± 30 or –90 ± 30
4&5 – 7&8	≥ 50	90 ± 30 or –90 ± 30
1&2 – 7&8	≥ 60	90 ± 30 or –90 ± 30

When a test plug is selected that exhibits worst case performance for one pair combination, it shall be verified that all other pair combinations fall within the total range specified.

D.6 Modular test plug construction

It is necessary to obtain a set of test plugs that complies with clause D.6.10, to perform connecting hardware testing. It is acceptable to obtain these test plugs by cutting them from the ends of production patch cords. Because of the variation in production cords, and the large number of plugs that might be required to obtain test plugs, the following alternate procedure is suggested.

D.6.1 Test plug termination

Two types of plug style, a one-piece design and a two-piece (insert) design are recommended for constructing modular test plugs. The one-piece modular plug maintains the conductors parallel and co-planar within the plug body for a length of approximately 12 mm (0.5 in) as shown in figure D-10. The two-piece (insert) design maintains the conductors parallel and situated in two planes in which alternate conductors are in each plane as shown in figure D-11. Some one-piece and two-piece (insert) modular plugs are supplied with an additional insert that can maintain the conductor positions within the plug body in the same orientation as in the nose of the plug. These inserts may also be used to re-orient the conductors within the plug body. For some of the plugs constructed by this method, it will be necessary to use more than one insert inside of the plug body to maintain the conductor orientation.

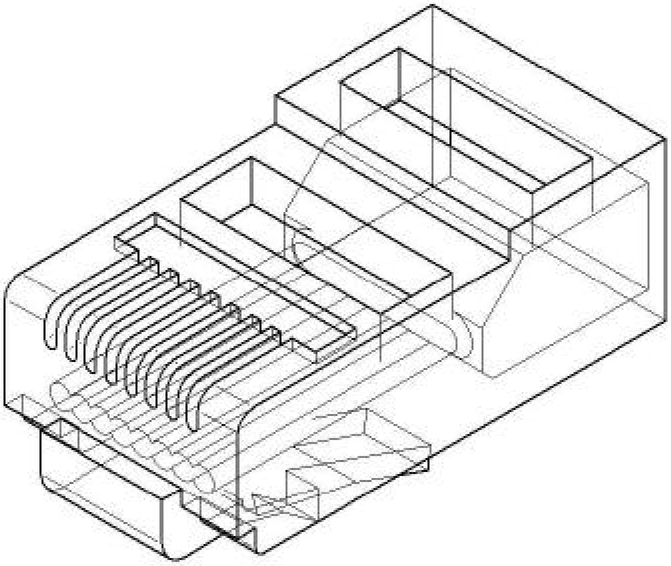


Figure D.10 - Example of a one-piece modular plug

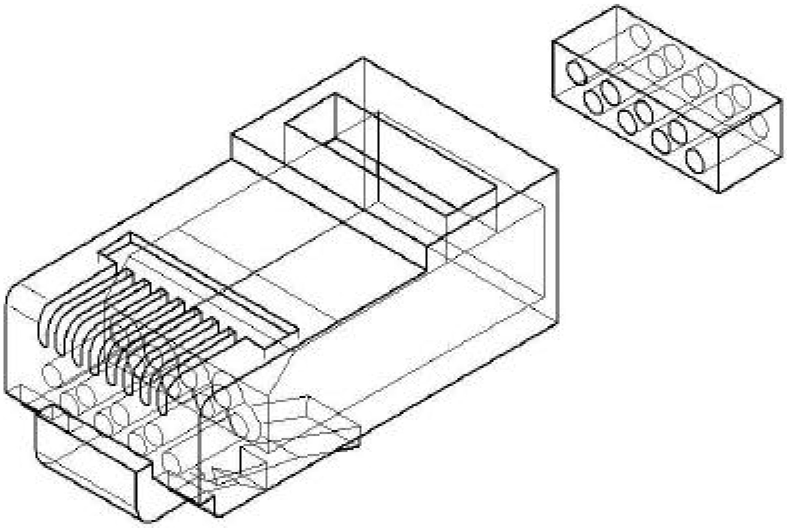


Figure D.11 - Example of a two-piece (insert) modular plug

D.6.1.1 Test plug construction

One plug can be constructed that will satisfy the worst case conditions of table D.4 for pin combinations 1&2 – 3&6, 4&5 – 3&6, and 3&6 - 7&8. Begin with a standard plug and cut the plug to 11 mm (0.45 in) in length as shown in figure D.12. Insert 75 mm (3.0 in) twisted-pair conductors into the plug so that the pairs are parallel within the plug body. As the conductors exit the plug body, bend them so that they are orthogonal to each other. Crimp the plug contacts and trim the conductors to approximately 64 mm (2.5 in) for connection to the test equipment. Measure the de-embedded NEXT loss values of the plug and adjust the conductors as necessary where they exit the plug to achieve the desired values. When these values are obtained, carefully remove the plug from the test apparatus without disturbing the relationship of the conductors. Apply hot-melt glue around the conductors where they exit the plug body to secure them in place. Re-measure the plug. If the values are now outside of the desired ranges, the plug may be re-heated using a hot-air source to soften the hot-melt glue enough to adjust the conductors. Alternatively, another sample may be constructed.

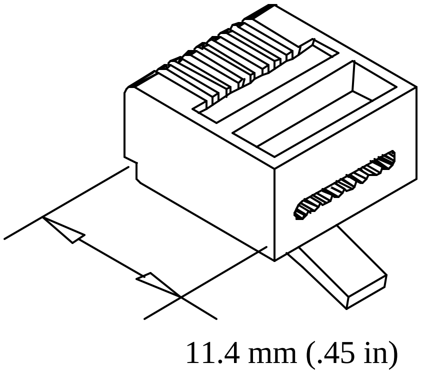


Figure D.12 - Plug dimension for worst case 1&2 - 3&6, 4&5 - 3&6, and 3&6 - 7&8 pin combinations

A second plug may be constructed that embodies the best case requirement for pin combination 3&6 - 4&5. For this plug, begin with an two-piece (insert) modular plug and remove the strain relief section of the plug body 7.6 mm (0.3 in) from the nose of the plug as shown in figure D.13. Position one wire guide insert into the plug body (depending on plug design) and then insert 75 mm (3.0 in) twisted-pair conductors into the proper holes of the plug insert. Carefully crimp the modular plug contacts. As the conductors exit the plug body, bend them so that they are orthogonal to each other. Crimp the plug contacts and trim the conductors to approximately 68 mm (2.7 in) for connection to the test equipment. Measure the de-embedded NEXT loss value of the plug and adjust the conductors as necessary where they exit the plug to achieve the desired values. When these values are obtained, carefully remove the plug from the test apparatus without disturbing the relationship of the conductors. Apply hot-melt glue around the conductors where they exit the plug body to fix them in place. Re-measure the plug. If the values are now outside of the desired ranges, the plug may be re-heated using a hot-air source to soften the hot-melt glue enough to adjust the conductors. Alternatively, another sample may be constructed.

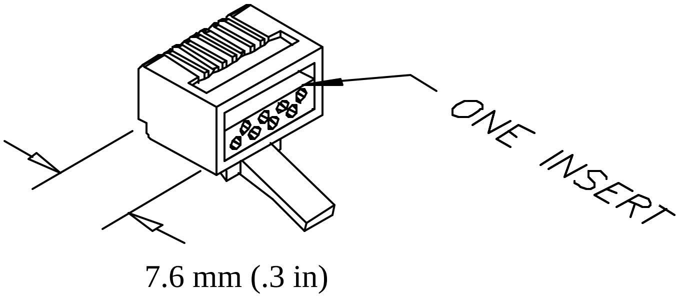
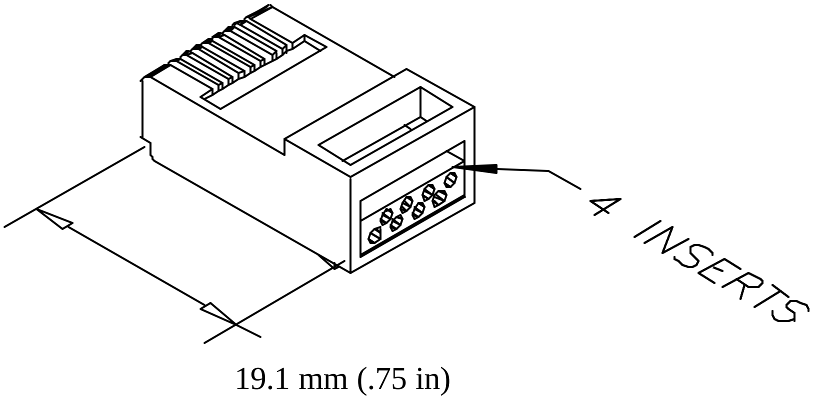


Figure D.13 - Plug dimension for best case 4&5 - 3&6 pin combination

A third plug may be constructed that will satisfy the worst case requirements for pin combinations 1&2 - 4&5 and 4&5 - 7&8. Begin with the two-piece (insert) modular plug and cut the plug to 19 mm (0.75 in) in length as shown in figure D-14. Position four wire guide inserts into the plug body and, if necessary, trim flush with the end of the plug body. Insert 75 mm (3.0 in) twisted-pair conductors into the plug through the wire guide inserts so that the pairs are parallel within the plug body. As the conductors exit the plug body, bend them so that they are orthogonal to each other. Crimp the plug contacts and trim the conductors to approximately 57 mm (2.25 in) for connection to the test equipment. Measure the de-embedded NEXT loss values of the plug and adjust the conductors as necessary where they exit the plug to achieve the desired values. When these values are obtained, carefully remove the plug from the test apparatus without disturbing the relationship of the conductors. Apply hot-melt glue around the conductors where they exit the plug body to fix them in place. Re-measure the plug. If the values are now outside of the desired ranges, the plug may be re-heated using a hot-air source to soften the hot-melt glue enough to adjust the conductors.



Alternatively, another sample may be constructed.

Figure D.14 - Plug dimension for worst case 1&2 - 4&5 and 4&5 - 7&8 pin combinations

A best case test plug for the 1&2 - 3&6 and 3&6 - 7&8 pin combinations and a worst case test plug for the 1&2 - 7&8 pin combination are necessary to complete the range of test plug requirements. Both of these plugs can be constructed by starting with the two-piece (insert) modular plug. In these instances, the conductors must be twisted within the plug body so that the capacitive and inductive coupling between the conductors is altered. With some experimentation, an arrangement of conductors within the plug can be created that will achieve the desired results. This arrangement can be documented and repeated to create subsequent test plugs. A more detailed description of these plugs would add too much complexity to this Standard and could not be ensured to deliver the desired results given the variation in plug designs available.

D.7.1 Test plug lead length

Trim the test plug leads so that the total length of the test plug body and leads is 76 mm (3.0 in), the same as the total length of the de-embedding reference plug and leads. This is important so that the de-embedded phase and magnitude will be correct.

Annex E Testing of cabling (normative)

E.1 Insertion loss of cabling

E.1.1 Test configuration of cabling insertion loss

The test configuration for cabling insertion loss shall comply with clause C.1.1.

E.1.2 Calibration of cabling insertion loss

The calibration for cabling insertion loss shall comply with clause C.1.2.

E.1.3 Measurement of cabling insertion loss

Cabling insertion loss measurement shall comply with clause C.1.2.

E.2 NEXT loss of cabling

E.2.1 Test configuration of cabling NEXT loss

The test configuration for cabling NEXT loss shall comply with clause C.2.1.

E.2.2 Calibration of cabling NEXT loss

The calibration of NEXT loss shall comply with clause C.1.2.

E.2.3 Measurement of cabling NEXT loss

Cabling NEXT loss measurement shall comply with clause C.2.3.

E.3 ELFEXT of cabling

E.3.1 Test configuration of cabling ELFEXT

The test configuration for cabling ELFEXT shall comply with clause C.1.1. ELFEXT is a calculation of the measurements of the FEXT loss and insertion loss.

E.3.2 Calibration of cabling FEXT loss

The calibration of FEXT loss shall comply with clause C.1.2.

E.3.3 Measurement of cabling FEXT loss

Cabling FEXT loss measurement shall comply with clause C.3.3.

E.4 Return loss of cabling

E.4.1 Test configuration of cabling return loss

The test configuration for cabling return loss shall comply with clause C.2.2.

E.4.2 Calibration of cabling return loss

The calibration of return loss shall comply with clause C.4.2.

E.4.3 Measurement of cabling return loss

Cabling return loss measurement shall comply with clause C.4.3.

Annex F Testing of patch cords (normative)

F.1 Insertion loss of patch cords

Test methods for insertion loss of patch cords have not been developed at this time.

F.2 NEXT loss of patch cords

F.2.1 Test configuration for patch cord NEXT loss

A test head qualified per clause F.5 shall be used at both the near- and the far-ends of the patch cord under test. The design described in clause F.6 is preferred.

> NOTE - Test heads other than the one described in clause F.6 are allowed if they meet the requirements in clause F.5. In case of conflict between results, the test head described in clause F.6 shall be used to determine conformance to the minimum requirements of the standard.

The test setup shall be per figure F.1.

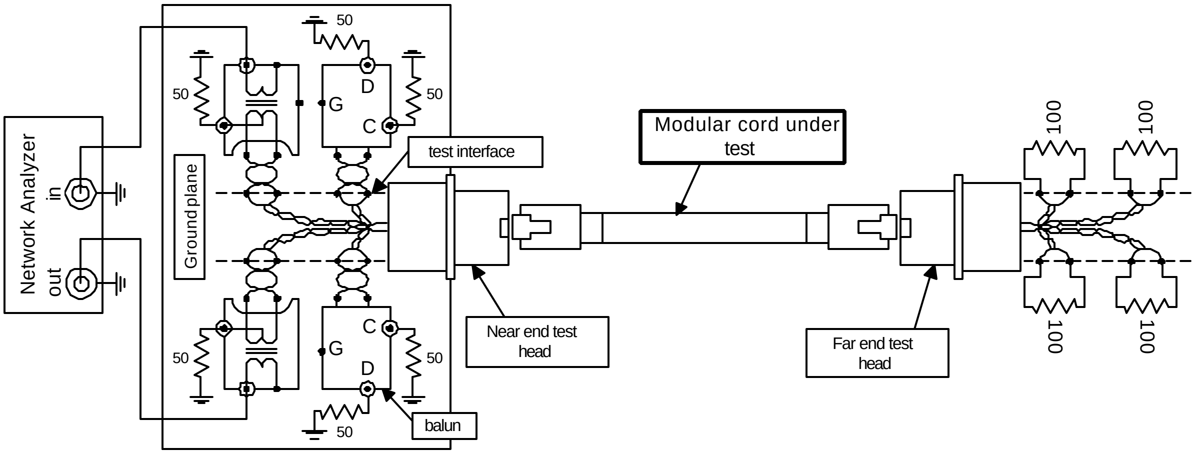


Figure F.1 - Patch cord test configuration

Common mode terminations for all near-end pairs shall be applied as shown in figure F-1. The test jack located at each end of the test configuration shall be of the same design. The detailed schematic diagram of the balun is shown once. The connection labeled “C” represents the connection to the common mode port, the connection labeled “D” represents the connection to the unbalanced port, and the connection labeled “G” represents a connection to the ground plane.

F.2.2 Calibration for patch cord NEXT loss

The calibration of NEXT loss shall comply with clause C.2.2.

F.2.3 Measurement for patch cord NEXT loss

A minimum of 200 data points using a linear sweep shall be measured for each pair combination. Pass/fail qualification shall be determined by comparing the resulting sweeps to the pass/fail NEXT loss limits for the applicable frequency range. The pass/fail margin and the frequency at which it occurs shall be reported for each pair combination.

All test leads should be constructed from twisted-pairs that have been verified to exhibit a return loss of greater than 35 dB relative to the load reference from 1 MHz to 100 MHz.

F.3 ELFEXT of patch cords

Test methods for ELFEXT of patch cords have not been developed at this time.

F.4 Return loss of patch cords

F.4.1 Test configuration for patch cord return loss

The return loss of the modular patch cord shall be measured using the test configuration shown in figure C.1. Test heads qualified per clause F.5 shall be used to test modular patch cords. The test head located at each end of the test configuration shall be of the same design. In the case that four baluns are not available, one balun may be used providing that differential and common mode resistive terminations are implemented for the unused near-end pairs in addition to the common mode terminations applied to the baluns.

F.4.2 Calibration for patch cord return loss

The calibration of return loss shall comply with clause C.4.2.

F.4.3 Measurement for patch cord return loss

A minimum of 200 data points, using a linear sweep, shall be measured for each pair combination. Pass or Fail qualification shall be determined by comparing the resulting sweeps to the Pass or Fail return loss limits in clause 6.

F.4.3.1 Mechanical stress test

Modular patch cords shall comply with the return loss requirements of clause 6.3.4 after each step listed below. For all test conditions, a maximum 150 mm (6.0 in) of undisturbed cable shall be allowed to enter the test fixture at both ends.

1 Test the patch cord uncoiled.
2 Loop the cord (following the natural cable lay) into a 150 mm (6 in.) diameter loop, up to 10 loops total, and test.
3 Compress the coil into a 63 mm (2.5 in) wide non-conductive trough to form an ellipse and test.
4 Rotate one end on the coiled ellipse by 180° (following the natural cable lay) to form a figure eight in the non-conductive trough and test.

F.5 Test heads for patch cords

Test heads shall be qualified for return loss when mated to the return loss reference plug specified in clause D.4.1.1. Test heads shall meet all requirements of clauses F.5.1 through F.5.3. The test head design given in clause F.6 is preferred. Other test heads are allowed if they meet the requirements. In case of conflict, the test head described in clause F.6 shall be used to determine compliance to the minimum requirements of this Standard.

F.5.1 Test head NEXT qualification

F.5.1.1 Test plugs for test head NEXT qualification

Test head qualification requires the use of an adequate number of test plugs to ensure statistical confidence. For this application, at least 30 plugs shall be used with de-embedded NEXT loss values for each pair combination that fully represent the range of values in table F.1. These 30 plugs shall include at least 5 five plugs with de-embedded NEXT loss values in each of the ranges in table F.1 for the given pair combination. Thus, for the 4,5-3,6 pair combination, de-embedded NEXT loss plug values are required to fall within the range of 31.5 dB to 32.75 dB. These plugs may encompass several different designs and manufacturers' parts.

Table F.1 - Qualification plug de-embedded ranges at 100 MHz, dB

Pair Combination	Range 1 (dB)	Range 2 (dB)	Range 3 (dB)	Range 4 (dB)	Range 5 (dB)	Range 6 (dB)
1,2 – 3,6	40 – <42	42 – <44	44 – <46	46 – <48	None	None
1,2 – 4,5	50 – <60	60 – <70	70 – <80	None	None	None
1,2 – 7,8	60 – <70	70 – <80	80 – <90	None	None	None
3,6 – 4,5	31.5– <32.75	32.75 – <34	34 – <35.25	35.25 – <36.5	36.5 – <37.75	37.75 – 39
3,6 – 7,8	40 – <42	42 – <44	44 – <46	46 – <48	None	None
4,5 – 7,8	50 – <60	60 – <70	70 – <80	None	None	None

F.5.1.2 Test head setup

The far-end of the test head shall be terminated with precision metal film or chip 100 Ω ± 1% resistors. Through connection normalization shall be done with a twisted-pair jumper equal in length to the total of the twisted-pair test leads. The reference plane shall be at the near-end of the test head.

F.5.1.3 NEXT loss – differential termination

The NEXT loss of the test head used in the modular plug cord testing shall conform to the limits shown in figure F.2 when tested in both directions. The test pairs shall be terminated to the test header and the common mode termination removed. All unused pairs are terminated in 100 Ω ± 1% as illustrated in clause B.5.

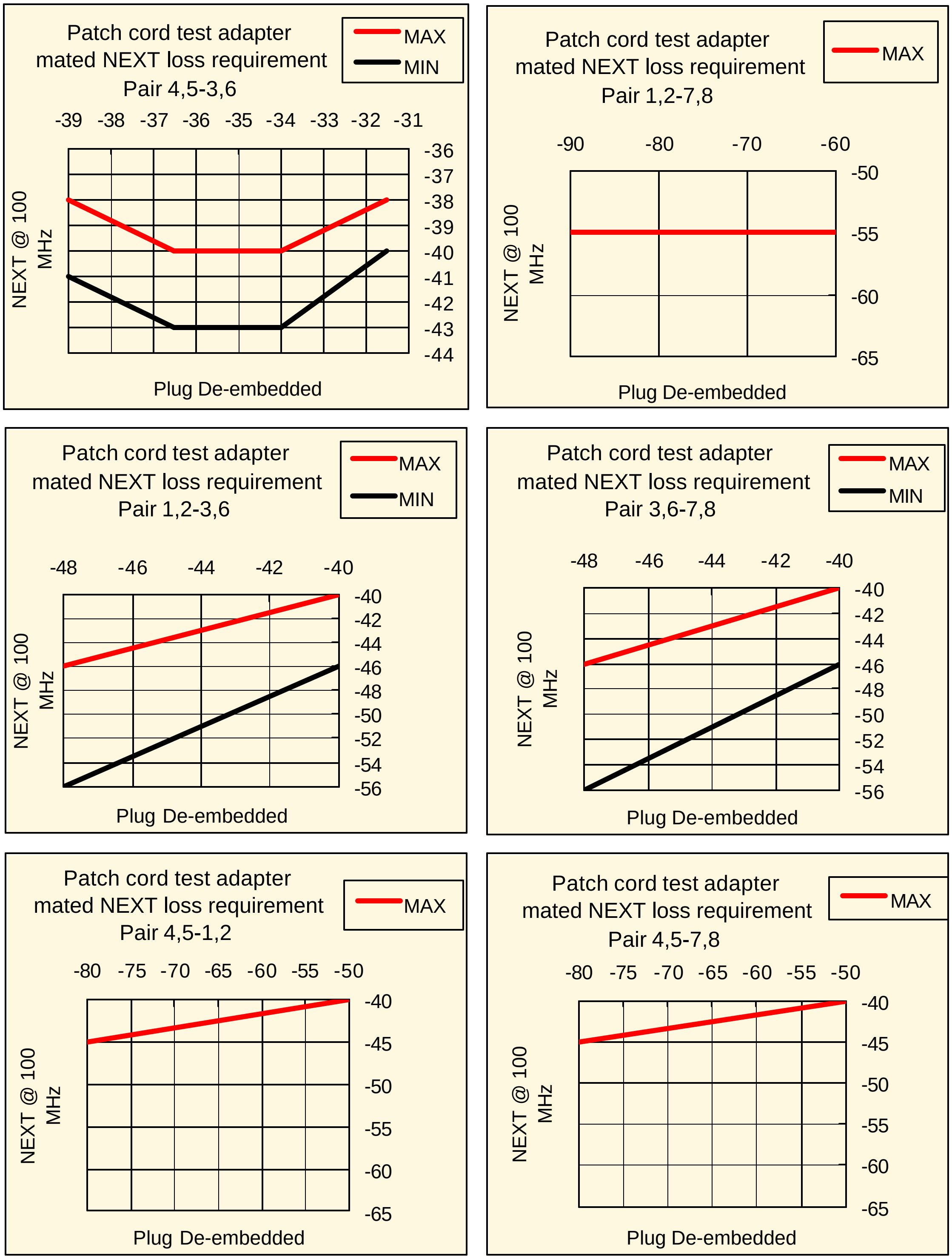


Figure F.2 - Test head loss limits at 100 MHz, dB

F.5.1.4 NEXT loss – differential and common mode termination

The NEXT loss of the test jack used in the modular plug cord testing shall conform to the limits shown in figure F.2 when tested in both directions. The test pairs shall be terminated to the balun (common mode ports terminated in 50 Ω) and all unused pairs terminated in 100 Ω ± 1% differentially and in 50 Ω at the common mode port as described in clause B.5.

F.5.1.5 NEXT loss difference

The difference between differential mode and differential and common mode NEXT loss measured in the same direction at 100 MHz shall be calculated for each plug. The calculation shall be based upon the difference in mV/V between the two readings. The resulting difference value shall be expressed in dB. The average difference calculated for all plugs used in testing shall not be greater than -55 dB for any pair combination.

F.5.2 Test head FEXT loss

From 1 MHz to 100 MHz, the pair-to-pair FEXT loss of the test head shall be greater than equation (F-1) when measured per the test method specified in annex D.

$$FEXT_{p-p} \geq 38 - 20\log(f/100)\ dB \qquad \text{(F-1)}$$

F.5.3 Test head return loss

The minimum return loss of the test head shall be 35 dB for all frequencies between 1MHz and 100 MHz when mated to the return loss reference plug and measured in accordance to clause D.4. The return loss of the twisted-pairs tested alone shall be greater than 40 dB for all frequencies between 1MHz and 20 MHz and 35 dB for all frequencies from 20 MHz to 100 MHz. Twisted-pair test leads shall not exceed 150 mm (6.0 in).

> NOTE – One method to adjust the test lead return loss is to alter the twist rate.

F.6 Test head design

The test head design shown in figure F.3 is included to establish a reference test head. For this test head design, $NEXT_{local,100\ MHz}$ and $NEXT_{remote,100\ MHz}$ shall be equal to the mean value on the worst case pair combination as calculated in clause F.7. A detailed instruction on how to scale the test limits for test head is also included in clause F.7. For the test head design shown in this clause, $NEXT_{local,100\ MHz}$ in equation (34) and $NEXT_{remote,100\ MHz}$ in equation (35) shall be defined as 41.0 dB for all pair combinations.

> NOTE - A test head that meets these requirements may be obtained from: Superior Modular Products, Swannanoa, NC 28778. Any alternate test head that meets the requirements of clause F.5 may also be used.

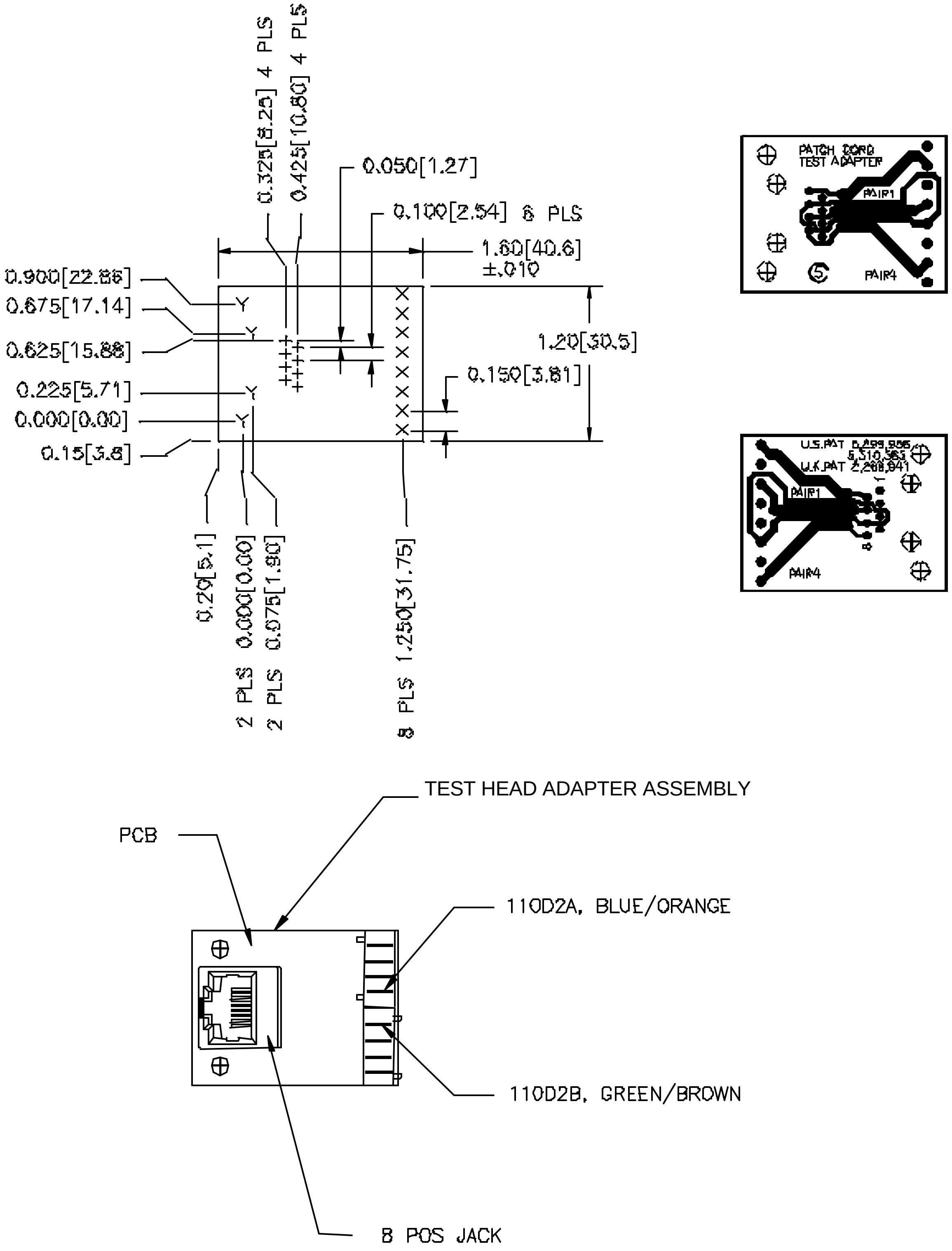


Figure F.3 - Category 5e test head design

Sample test results are included for reference in figure F.4. To reduce the amount of reported data, only values at 100 MHz are shown.

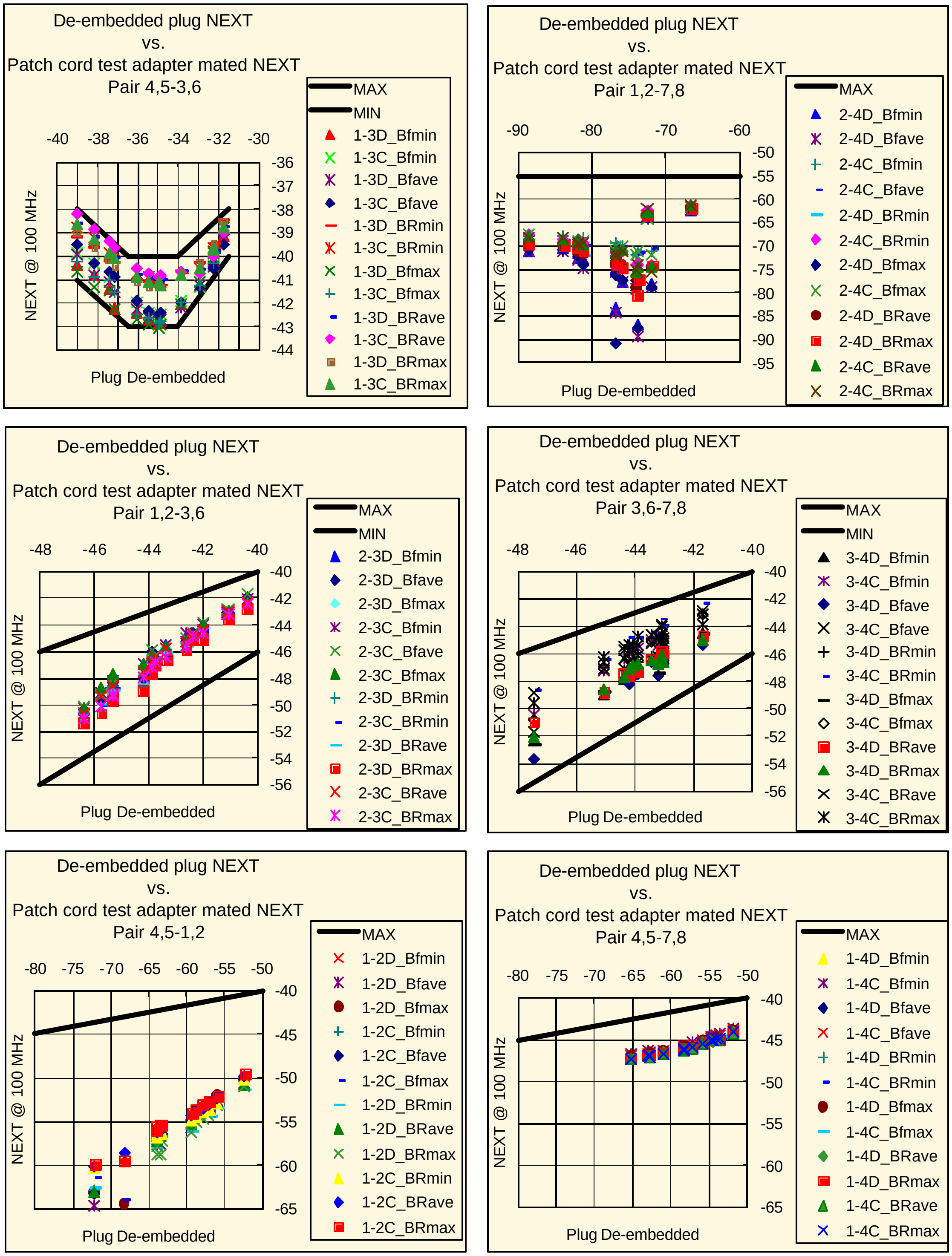


Figure F.4 - Category 5e test head NEXT loss performance at 100 MHz, dB

This device exhibits NEXT loss responses for pair combinations 1,2-4,5 4,5-7,8 and 1,2-7,8 that are better than worst case as defined in clause 6. Table F.2 shows the FEXT loss and return loss data for the test head.

Table F.2 - Test head FEXT loss and return loss, dB

Test Head FEXT loss											
	1 MHz	**4 MHz**	**8 MHz**	**10 MHz**	**16 MHz**	**20 MHz**	**25 MHz**	**31 MHz**	**31.5 MHz**	**62.5 MHz**	**100 MHz**
1,2-4,5	-87.4	-73.9	-67.8	-65.8	-61.9	-59.8	-57.9	-56.0	-55.8	-49.9	-45.6
3,6-4,5	-80.5	-69.3	-63.9	-62.1	-58.5	-56.4	-54.5	-52.7	-52.6	-47.1	-43.0
4,5-7,8	-92.1	-79.2	-74.1	-71.5	-68.2	-65.5	-64.0	-62.0	-61.8	-55.9	-52.0
1,2-3,6	-100.8	-93.6	-87.1	-84.7	-76.3	-75.6	-73.5	-70.9	-70.4	-63.9	-60.0
1,2-7,8	-103.5	-101.2	-88.5	-88.2	-80.5	-82.8	-79.7	-79.5	-77.6	-72.1	-69.1
3,6-7,8	-90.1	-81.2	-75.3	-73.1	-70.2	-68.1	-65.9	-64.6	-64.1	-58.6	-55.2
Test Head Return Loss											
Forward											
	1 MHz	**4 MHz**	**8 MHz**	**10 MHz**	**16 MHz**	**20 MHz**	**25 MHz**	**31 MHz**	**31.5 MHz**	**62.5 MHz**	**100 MHz**
4,5	-61.6	-54.5	-49.9	-48.3	-45.0	-43.1	-41.4	-39.7	-39.6	-34.4	-31.2
1,2	-30.4	-30.2	-30.0	-29.9	-29.4	-29.1	-28.7	-28.1	-28.0	-25.1	-22.3
3,6	-63.1	-58.7	-54.9	-53.3	-50.0	-48.6	-46.6	-45.1	-45.0	-39.4	-34.9
7,8	-60.0	-52.9	-48.0	-46.5	-43.0	-41.3	-39.6	-38.0	-37.9	-32.6	-29.1
Reverse											
4,5	-47.5	-45.0	-42.0	-40.7	-37.7	-36.0	-34.4	-32.9	-32.8	-27.8	-24.8
1,2	-34.1	-33.7	-32.9	-32.5	-31.2	-30.4	-29.3	-28.1	-28.0	-23.7	-20.6
3,6	-46.6	-45.2	-43.2	-42.2	-39.8	-38.5	-37.0	-35.5	-35.4	-30.4	-27.1
7,8	-60.2	-48.8	-43.3	-41.7	-37.9	-36.1	-34.4	-32.7	-32.5	-27.2	-23.9

F.7 Calculating test head contribution for NEXT loss limits from data

To calculate the test head NEXT loss value to determine the patch cord NEXT loss limit, the test head is measured when mated to a range of test plugs to obtain a data distribution similar to figure F.5. For each pair combination, a function fit curve is generated that represents the mean value of data for the range. The mated NEXT loss value for each of the selected pair combinations is determined by evaluating the function fit for the plug value given in table F.3. The NEXT loss value for limits calculation is equal to the greater in magnitude of the mean value (see figure F.5) of the selected data or 43.0 dB. In no case, shall the value be less than 41 dB.

Table F.3 - Test plug de-embedded NEXT loss contribution, dB

Pins 1,2-4,5 De-embedded plug value	**Pins 4,5-3,6 De-embedded plug value**	**Pins 4,5-7,8 De-embedded plug value**
50	34.4	50

Pins 1,2-3-6 De-embedded plug value	**Pins 1,2-7,8 De-embedded plug value**	**Pins 3,6-7,8 De-embedded plug value**
42	65	42

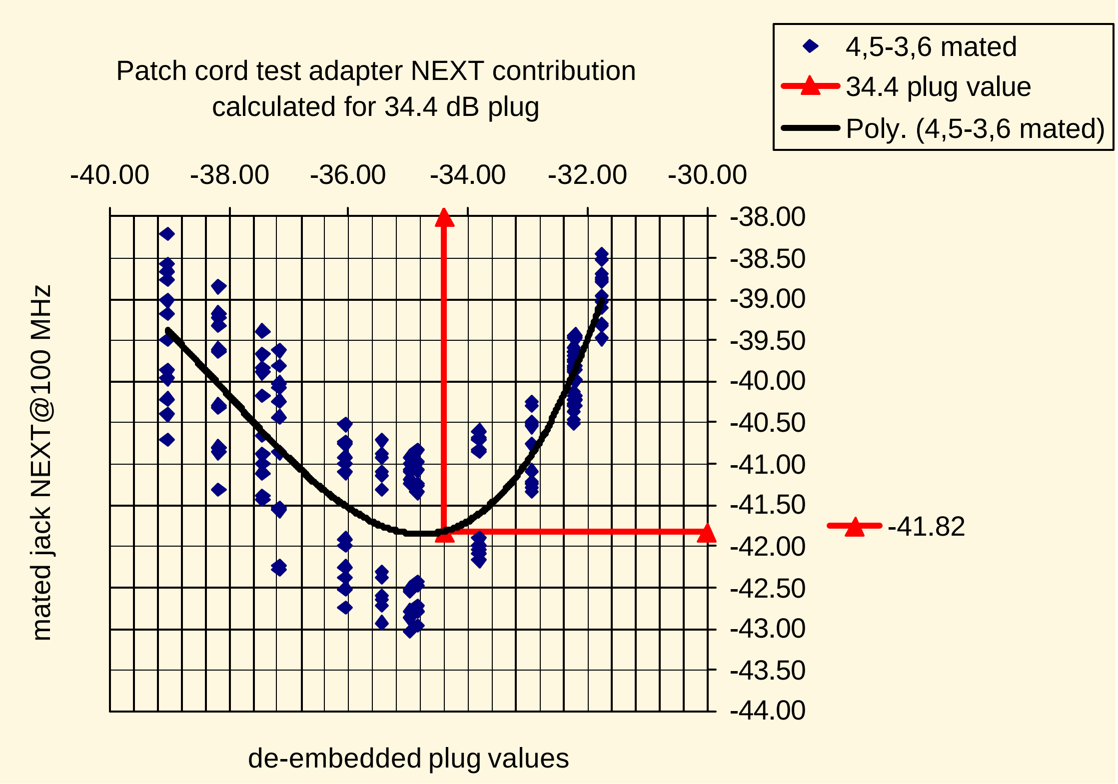


Figure F.5 - Example of NEXT loss limit calculations

F.8 Test head re-qualification procedure

To re-qualify a test head, perform de-embedding per clauses D.6.4 through D.6.8.

The values shall be per table F.5.

Table F.5 - Test head re-qualification limits, dB

Pair Combination	4&5-3&6	1&2-3&6	3&6-7&8
maximum	34.6	57.3	57.3
minimum	33.7	49.4	49.4

Annex G Multiport measurement considerations (informative)

G.1 Multiport test configuration, general

The network analyzer referenced in this Standard supports one port and two port measurements. It injects a signal into one port of a device and measures the response on either that same port, or a second port of the device. In the case of balanced measurements on twisted-pairs, a balun is used to convert the 50 Ω unbalanced output of the network analyzer to 100 Ω balanced output. Thus the network analyzer presents to the device under test two balanced ports, which can be configured either as output or input via standard two port switching. The typical cable or connector consists of 4 balanced pairs totaling 8 balanced ports (4 input and 4 output). In order to fully characterize this device for balanced measurements only, a total of 128 separate measurements must be taken (2^8/2). When each of the measurements is made, the remaining ports of the device must be properly terminated in the characteristic impedance of the line to avoid the possibility of reflected signals altering the measurements. It is for this reason that terminations are specified for the inactive pairs of the cabling device under test.

G.2 Terminology

A port refers to a 100 Ω balanced twisted-pair input or output. Differential mode terminations consists of 100 Ω applied across the two terminals of the port with no connection to ground reference. Common mode termination consists of the combination of 100 Ω differential termination with the addition of 50 Ω common mode termination to a ground reference. This is accomplished with either balun or resistor terminations as described in annex B. Near-end generally applies to the device port that is connected to the output of the network analyzer, while far-end generally applies to the device ports that are remote from the analyzer connections or are connected to the input of the network analyzer.

G.3 Two port measurement of multiport device

When a two port measurement is made on a multiport device, the network analyzer calibration compensates for imperfections in the measurement path up to the reference plane of measurement. For near-end crosstalk, the input and output ports are two ports at the near-end of the device. The far-end ports of the device are attached to impedance matching terminations. The far-end ports, not being in the measurement path, are not part of the calibration matrix. Thus, any imperfections that are present at the far-end terminations will cause a measurement error. For this reason the properties of the remote terminations must be assessed. The termination requirements are specified in annex B. Similarly, the terminations attached to the two inactive near-end ports of the device as well as the far-end terminations of the inactive ports must be assessed or measurement errors will result. Insertion loss and FEXT loss measurements only differ in that the measurement path includes the near-end and the far-end of the device. All of the remaining ports must be terminated in an impedance matching termination or measurement errors will result.

G.4 Common mode termination

Common mode terminations are required for many tests due to the imperfect balance of the transmission path. Imperfect balance may be caused by imperfect balun transformers, unbalanced couplings in connectors and cables, and proximity of conductors to a ground path. If a common mode signal is present on a device, then a common mode termination must be provided or a reflection will occur which will affect the measurement. Differential terminations provide no termination for a common mode signal. The common mode signal return path in cabling is typically formed by the inactive pairs of the cabling through stray inductive and capacitive coupling. Thus, ideally, there should be common mode terminations on all ports at both ends of the cabling device.

G.5 Measurement topology

The diagrams showing measurement topology typically depict balun connections at the near-end and resistor terminations at the far-end of the device under test. Resistor terminations are preferred for all inactive ports both at the near-end and the far-end. This is due to the better return loss characteristics of a well-matched resistor termination as compared to a balun termination. Setting up and performing a complete test of all device parameters may be difficult, however because excessive plugging and unplugging of the device to the termination resistors is required. Figures G.1 and G.2 depict preferred topologies for specific measurement parameters.

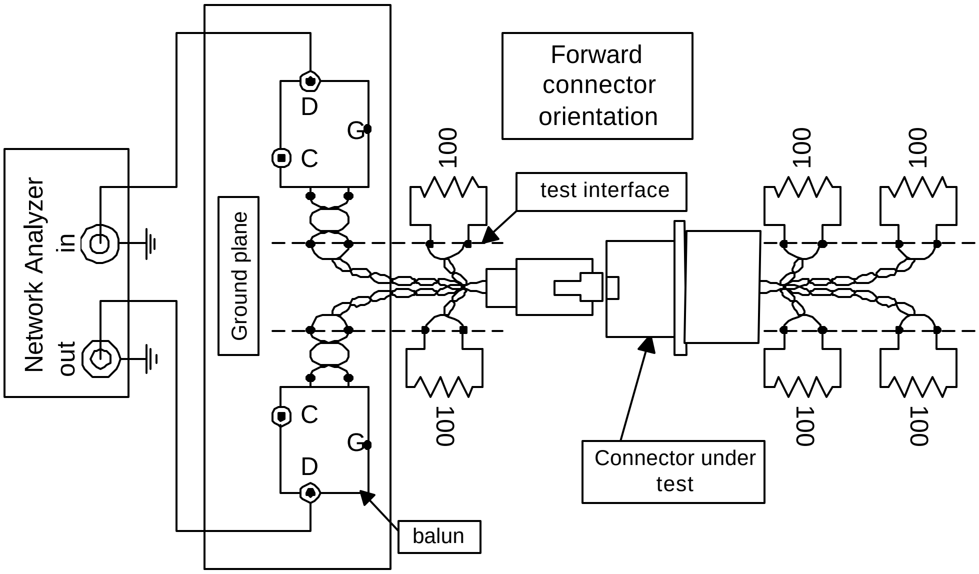


Figure G.1 - Preferred topology for NEXT measurement with differential terminations on connecting hardware (may also be used for return loss measurements)

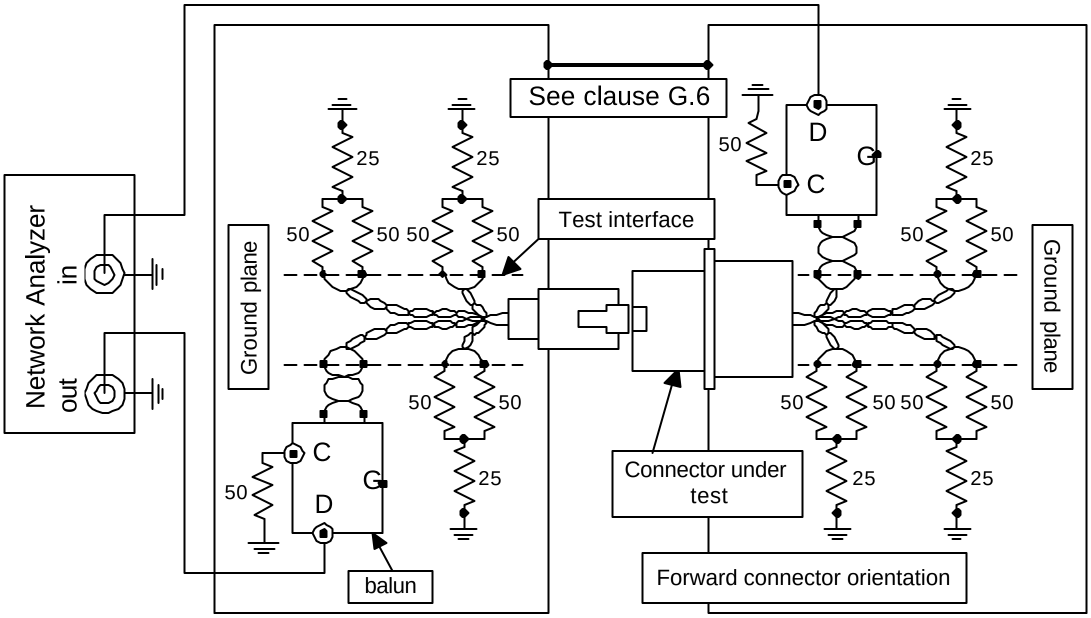


Figure G.2 - Preferred topology for FEXT loss and insertion loss measurement on connecting hardware (NEXT loss test with common mode termination is similar)

G.6 Ground plane considerations

Balun cases should always be firmly bonded to a low impedance ground plane. The physical configuration of the ground plane may vary from one test configuration to another, but this does not appear to be critical. When common mode terminations are used, the ground leg is attached to the same ground plane. Test configurations including common mode terminations dictate that the far-end of the device is also terminated to a ground plane. All far-end common mode terminations are attached to this ground plane as well as any far-end balun cases. The connection between near-end and far-end balun planes is a subject for further study. In general, the installed cabling system provides no direct current ground path between the near-end and far-end common mode ground nodes. Field testing of installed cabling does not provide direct connection between the far-end and near-end common mode ground nodes. In contrast, the network analyzer provides a short DC path from the near-end to the far-end ground planes via the coaxial cabling. There may be a different propagation path for common mode signals through the cabling device when tested in a laboratory setting versus the installed setting.

Annex H Measurement accuracy (informative)

H.1 Test system measurement accuracy estimates

Test system measurement accuracy is based upon the assumptions for key performance parameters as shown in table H.1. These are assumed to be valid after two-port calibration of the test system. The procedure to measure output signal balance and common mode rejection is shown this annex.

Table H.1 - Test equipment performance parameters

Test parameter	Parameter	Performance (dB)	Frequency (MHz)	Value (dB)
Insertion loss	Dynamic accuracy	0.2	100/250	0.2/0.2
	Source/load RL	39 – 15 log(f/100), 43 dB max.	100/250	39/33
NEXT loss	Dynamic accuracy	0.2	100/250	0.2
	Source/load RL	39 – 15 log(f/100), 43 dB max.	100/250	39/33
	Random Noise Floor	110 – 15 log(f/100)	100/250	90/84
	Residual NEXT	90 – 20 log(f/100)	100/250	90/82
	Output Signal Balance	50 – 20 log(f/100)	100/250	50/42
	Common Mode Rej.	50 – 20 log(f/100)	100/250	50/42
ELFEXT	Dynamic accuracy	0.3	100/250	0.3
	Source/load RL	39 – 15 log(f/100), 43 dB max.	100/250	39/33
	Random Noise Floor	90 – 15 log(f/100)	100/250	90/84
	Residual FEXT	90 – 20 log(f/100)	100/250	90/82
	Output Signal Balance	50 – 20 log(f/100)	100/250	50/42
	Common Mode Rej.	50 – 20 log(f/100)	100/250	50/42
Return loss	Tracking	0.2	100/250	0.2/0.2
	Directivity	39 – 15 log(f/100), 43 dB max.	100/250	
	Source Match	50	100/250	50
	RL of termination	45 – 15 log(f/100), 49 dB max.	100/250	45/39

Assumptions for the device under test are as shown in table H.2. These will have to be modified depending on the cabling or cabling components under test.

Table H.2 - Assumptions for cabling or cabling component under test

Parameter	Performance (dB)	Frequency (MHz)	Value at frequency (dB)
Insertion loss (limit)	$1.82\sqrt{f}+0.017f+0.2/\sqrt{f}$	100	19.8
		250	32.8
Insertion loss (for RL)	0	100	0
		250	0
NEXT loss	$54 - 20\log(f/100)$	100	54
		250	46
ELFEXT	$43.1 - 20\log(f/100)$	100	43.1
		250	35.1
Return loss (limit)	$24 - 20\log(f/100)$	100	24
		250	16
Return loss (source/load)	20	100	20
		250	20

Using the equations in annex I and using the assumptions shown in table H.1 and table H.2, measurement accuracies are computed as shown in table H.3. Note that test procedures may require different assumptions resulting in different measurement accuracies than shown.

Table H.3 - Computed test system measurement accuracy

Frequency (MHz)	Insertion loss (dB)	NEXT loss (dB)	ELFEXT (dB)	Return loss (dB)
1	0.2	0.3	0.4	2.1
4	0.2	0.4	0.4	2.1
8	0.2	0.5	0.4	2.1
10	0.2	0.5	0.4	2.1
16	0.2	0.5	0.4	2.1
20	0.2	0.4	0.4	2.1
25	0.2	0.4	0.4	2.1
31.25	0.2	0.4	0.4	2.1
62.5	0.2	0.4	0.4	2.0
100	0.2	0.4	0.4	1.8
125	0.2	0.4	0.5	1.7
150	0.2	0.5	0.5	1.6
200	0.2	0.5	0.5	1.5
250	0.3	0.6	0.6	1.5

The absolute accuracy of termination depends largely upon the properties of the termination resistor, connection to the resistor, and the calibration standard. At low frequencies, the absolute performance is limited by the RF calibration standards. At high frequencies, the absolute performance is limited by the frequency response of the chip resistors and quality of termination. With appropriate care, 2 mm (.1 in) maximum untwist and using the calibration procedure shown in clause C.1.1, an absolute return loss measurement floor as shown in table H.4 can be expected. The performance requirements in table H.1 are based on this information.

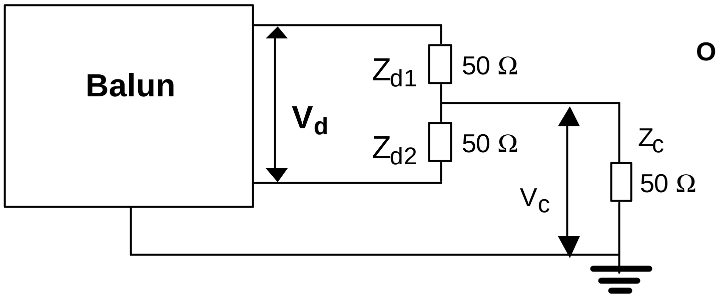
Table H.4 - Absolute return loss measurement floor

Frequency (MHz)	Load absolute worst case return loss (dB)
1	> 43
4	> 43
8	> 43
10	> 43
16	> 43
20	> 43
25	> 42
31.25	> 42
62.5	> 41
100	> 39
150	> 37
200	> 35
250	> 33

This performance is used as the value of directivity and return loss of the remote termination in the determination of return loss measurement accuracy, and the source/load impedance for the determination of measurement accuracy for all other measurements.

H.2 Measurement procedures for output signal balance and common mode rejection

Figure H.1 illustrates the balun output signal balance test circuit for the reference test configuration. Figure H.2 illustrates balun common mode signal rejection test circuit for the reference test configuration.



Output Signal Balance = 20 log|V_d/V_c|

$Z_{d1} = Z_{d2} = Z_c = 50\ \Omega \pm 1\ \%$

Z_{d1} and Z_{d2} matched to ± 0.01 %

Figure H.1 - Electrical block diagram for balun output signal balance

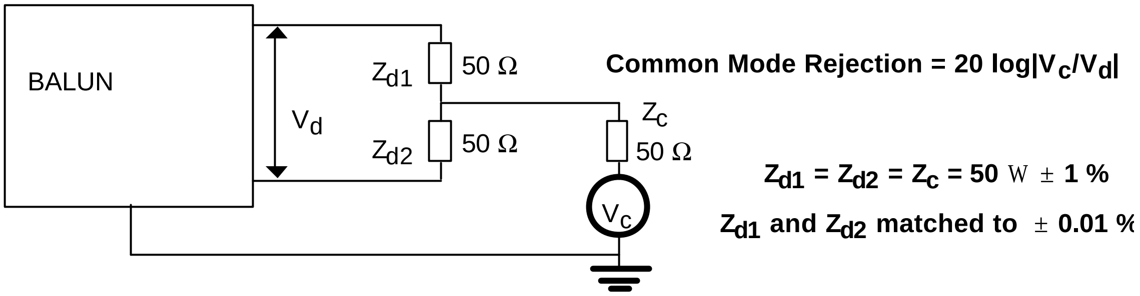


Figure H.2 - Electrical block diagram for balun common mode rejection

H.3 Impact of test lead return loss on connecting hardware return loss measurements.

The reference plane of measurement of the connecting hardware return loss procedure is located at the test interface. The plug and jack are connected to this test interface through 75 mm (3 in) test leads, and therefore, the test leads represent a possible source of error in the measurement. Table H.5 shows the magnitude of the error as a function of the return loss of the test leads at 100 MHz. The return loss of the test leads is relative to the return loss of the calibration termination.

Table H.5 - Connecting hardware return loss accuracy as a function of lead length

Impedance of test leads	Return loss of test leads at 100 MHz	Return loss of connector At 100 MHz	One-port measurement 50 mm / 75 mm dB	Two-port measurement 50 mm / 75 mm dB
100 Ω	> 49 dB	20 dB low[1)] 20 dB high[1)]	20.13 / 20.19 19.92 / 19.88	20.15 / 20.22 19.89 / 19.84
101.6 Ω	> 40 dB	20 dB low[1)] 20 dB high[1)]	20.32 / 20.47 19.74 / 19.62	20.55/20.78 19.53 / 19.33
103.4 Ω	> 35 dB	20 dB low[1)] 20 dB high[1)]	20.54 / 20.79 19.54 / 19.34	21.00 / 21.46 19.14 / 18.80
105 Ω	> 32 dB	20 dB low[1)] 20 dB high[1)]	20.74 / 21.08 19.37 / 19.10	21.42 / 22.10 18.82 / 18.37
1) Two sets of accuracy data are shown corresponding to a 20 dB return loss connector having either a low impedance or a high impedance relative to a 100 Ω termination.				

Annex I Test instruments (normative)

I.1 General

This annex specifies the reporting and accuracy performance requirements of field testers and provides additional guidelines for field testing procedures.

I.2 Data reporting requirements

I.2.1 Parameters to be reported

The field tester shall be able to measure and report the following link parameters for the permanent link and channel test configurations as defined in ANSI/TIA/EIA-568-B.1.

Wire map, including shield connection if present
Insertion loss
Length
NEXT loss, pair-to-pair, measured from local end
NEXT loss, pair-to-pair, measured from far-end
NEXT loss, power sum, measured from local end
NEXT loss, power sum, measured from far-end
ELFEXT, pair-to-pair
ELFEXT, power sum
Return loss, measured from local end
Return loss, measured from far-end
Propagation delay
Delay skew

I.2.2 Pass/Fail results

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 published by the field tester manufacturer for the permanent link and channel. Refer to clause I.4 for detailed information on measurement accuracy requirements. The field test 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. In order to achieve an overall Pass condition, all individual results shall be Pass or Pass*. Measurements reported by the field tester shall have a specified accuracy. Accuracy is the difference between the measured value reported by the field tester from the actual value. Refer to clause I.4 for accuracy specifications. The field tester shall be capable of reporting data at all measured points and uploading the data to a PC as defined in clause I.2.3 and provide summary results as defined in clause I.2.4.

NOTE – The tester accuracy model does not contain an allowance for the plug variability of different adapters connected to the permanent link under test.

I.2.3 Detailed results

The field tester shall be capable of reporting 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 parameters, as applicable.

I.2.4 Summary results

Detailed information may be required or desired in certain circumstances. In general, summary performance information is sufficient. The field tester shall be capable of reporting the summary information in Table I.1 as a minimum.

Table I.1 - Field tester summary reporting requirements

Function	**Measured from either end (if measurement from both directions is not required)**	**Measured from opposite end (if measurement from both ends 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 Frequency at worst case Pair with worst case Pass/fail	
Length	Length Test limit Pass/fail	
NEXT loss pair-to-pair	Worst case margin (1 of 6 possible) Test limit at worst case margin Frequency at worst case margin Pair combination at worst case margin Pass/fail AND Worst case (1 of 6 possible) Test limit @ worst case Frequency @ worst case Pair combination with worst case	Worst case margin (1 of 6 possible) Test limit at worst case margin Frequency at worst case margin Pair combination at worst case margin Pass/fail AND Worst case (1 of 6 possible) Test limit at worst Frequency at worst case Pair combination with worst case

Table I.1 - (continued) Summary reporting requirements for field testers

Function	Measured from either end (if measurement from both directions is not required)	Measured from opposite end (if measurement from both ends is required)
NEXT loss power sum	Worst case margin (1 of 4 possible) Test limit at worst case margin Frequency at worst case margin Pair with worst case margin Pass/fail AND Worst case power sum NEXT loss (1 of 4 possible) Test limit at worst case Frequency at worst case Pair with worst case	Worst case margin (1 of 4 possible) Test limit at worst case margin Frequency at worst case margin Pair with worst case margin Pass/fail AND Worst case power sum NEXT loss (1 of 4 possible) Test limit at worst case Frequency at worst case Pair with worst case
ELFEXT pair-to-pair	Worst case margin (1 of 12 possible [Note 1]) Test limit at worst case margin Frequency at worst case margin Pair combination at worst case margin (disturber, disturbed) Pass/fail AND Worst case pair-to-pair ELFEXT Test limit at worst case Frequency at worst case Pair combination with worst case	Worst case margin (1 of 12 possible [Note 1]) Test limit at worst case margin Frequency at worst case margin Pair combination at worst case margin (disturber, disturbed) Pass/fail AND Worst case pair-to-pair ELFEXT Test limit at worst case Frequency at worst case Pair combination with worst case
ELFEXT power sum	Worst case margin (1 of 4 possible [Note 2]) Test limit at worst case margin Frequency at worst case margin Pair combination with worst case margin (disturber, disturbed) Pass/fail AND Worst case power sum ELFEXT Test limit at worst case Frequency at worst case Pair combination with worst case	Worst case margin (1 of 4 possible [Note 2]) Test limit at worst case margin Frequency at worst case margin Pair combination with worst case margin (disturber, disturbed) Pass/fail AND Worst case power sum ELFEXT Test limit at worst case Frequency at worst case Pair combination with worst case

Table I.1- (continued) Summary reporting requirements for field testers

Function	Measured from either end (if measurement from both directions is not required)	Measured from opposite end (if measurement from both ends is required)
Return loss Note 3	Worst case margin (1 of 4 possible) Return loss Note 4 at worst case margin. Test limit at worst case margin. Frequency at worst case margin Pair with worst case margin Pass/fail AND Worst case return loss Note 4 (1 of 4 possible) Test limit at worst case Return loss at worst case Frequency at worst case Pair with worst case	Worst case margin (1 of 4 possible) Return loss Note 4 at worst case margin. Test limit at worst case margin. Frequency at worst case margin Pair with worst case margin Pass/fail AND Worst case return loss Note 4 (1 of 4 possible) Test limit at worst case Return loss at worst case Frequency at which worst case occurs. Pair with worst case
Propagation Delay	Worst case propagation delay (1 of 4 possible) Test limit at worst case Pair with worst case Pass/fail	
Delay skew	Worst case (1 of 1 possible) Test limit Pass/fail	

Table I.1 (concluded)

NOTES,

1 There are 24 pair (12 “local” & 12 “remote”) combinations for pair-to-pair ELFEXT.

Measured FEXT loss	**ELFEXT Calculation**	
FEXT$_{\text{(pair1-pair2)}}$	FEXT$_{\text{(pair1-pair2)}}$-Attn$_{\text{(pair2)}}$	FEXT$_{\text{(pair1-pair2)}}$-Attn$_{\text{(pair1)}}$
FEXT$_{\text{(pair1-pair3)}}$	FEXT$_{\text{(pair1-pair3)}}$-Attn$_{\text{(pair3)}}$	FEXT$_{\text{(pair1-pair3)}}$-Attn$_{\text{(pair1)}}$
FEXT$_{\text{(pair1-pair4)}}$	FEXT$_{\text{(pair1-pair4)}}$-Attn$_{\text{(pair4)}}$	FEXT$_{\text{(pair1-pair4)}}$-Attn$_{\text{(pair1)}}$
FEXT$_{\text{(pair2-pair1)}}$	FEXT$_{\text{(pair2-pair1}}$)-Attn$_{\text{(pair1)}}$	FEXT$_{\text{(pair2-pair1)}}$-Attn$_{\text{(pair2)}}$
FEXT$_{\text{(pair2-pair3)}}$	FEXT$_{\text{(pair2-pair3}}$)-Attn$_{\text{(pair3)}}$	FEXT$_{\text{(pair2-pair3)}}$-Attn$_{\text{(pair2)}}$
FEXT$_{\text{(pair2-pair4)}}$	FEXT$_{\text{(pair2-pair4}}$)-Attn$_{\text{(pair4)}}$	FEXT$_{\text{(pair2-pair4)}}$-Attn$_{\text{(pair2)}}$
FEXT$_{\text{(pair3-pair1)}}$	FEXT$_{\text{(pair3-pair1)}}$-Attn$_{\text{(pair1)}}$	FEXT$_{\text{(pair3-pair1)}}$-Attn$_{\text{(pair3)}}$
FEXT$_{\text{(pair3-pair2)}}$	FEXT$_{\text{(pair3-pair2)}}$-Attn$_{\text{(pair2)}}$	FEXT$_{\text{(pair3-pair2)}}$-Attn$_{\text{(pair3)}}$
FEXT$_{\text{(pair3-pair4)}}$	FEXT$_{\text{(pair3-pair4)}}$-Attn$_{\text{(pair4)}}$	FEXT$_{\text{(pair3-pair4)}}$-Attn$_{\text{(pair3)}}$
FEXT$_{\text{(pair4-pair1)}}$	FEXT$_{\text{(pair4-pair1)}}$-Attn$_{\text{(pair1)}}$	FEXT$_{\text{(pair4-pair1)}}$-Attn$_{\text{(pair4)}}$
FEXT$_{\text{(pair4-pair2)}}$	FEXT$_{\text{(pair4-pair2)}}$-Attn$_{\text{(pair2)}}$	FEXT$_{\text{(pair4-pair2)}}$-Attn$_{\text{(pair4)}}$
FEXT$_{\text{(pair4-pair3)}}$	FEXT$_{\text{(pair4-pair3)}}$-Attn$_{\text{(pair3)}}$	FEXT$_{\text{(pair4-pair3)}}$-Attn$_{\text{(pair4)}}$

The first pair referenced in the subscript is the disturbing pair and the second pair referenced in the subscript is the disturbed pair. By transmission matrix reciprocity, FEXT(pair1(LocalEnd)-pair2(RemoteEnd)) is identical to FEXT(pair2(RemoteEnd)-pair1(LocalEnd)). Thus, measurements of insertion loss and FEXT may be made in one direction and ELFEXT results computed as shown.

2 There are 8 pair (4 “local” & 4 “remote”) combinations for power-sum ELFEXT calculations.

Local power sum ELFEXT	**Pair-to-pair ELFEXT components used in calculation**
PSEFLEXT(pair1-L)	ELFEXT (pair2-R,pair1-L), (pair3-R,pair1-L), (pair4-R,pair1-L)
PSEFLEXT(pair2-L)	ELFEXT (pair1-R,pair2-L), (pair3-R.pair2-L), (pair4-R,pair2-L)
PSEFLEXT(pair3-L)	ELFEXT (pair1-R,pair3-L), (pair2-R,pair3-L), (pair4-R,pair3-L)
PSEFLEXT(pair4-L)	ELFEXT (pair1-R,pair4-L), (pair2-R,pair4-L), (pair3-R,pair4-L)
Remote power sum ELFEXT	**Pair-to-pair ELFEXT components used in calculation**
PSEFLEXT(pair1-R)	ELFEXT (pair2-L,pair1-R), (pair3-L,pair1-R), (pair4-L,pair1-R)
PSEFLEXT(pair2-R)	ELFEXT (pair1-L,pair2-R), (pair3-L.pair2-R), (pair4-L,pair2-R)
PSEFLEXT(pair3-R)	ELFEXT (pair1-L,pair3-R), (pair2-L,pair3-R), (pair4-L,pair3-R)
PSEFLEXT(pair4-R)	ELFEXT (pair1-L,pair4-R), (pair2-L,pair4-R), (pair3-L,pair4-R)

The first pair referenced in the subscript is the disturbing pair and the second pair referenced in the subscript is the disturbed pair. “L” subscript is “Local,” “R” is “Remote.” As with ELFEXT, measurements of insertion loss and FEXT may be made in one direction and PSELFEXT results computed as shown.

Due to accuracy considerations, when the measured insertion loss is less than 3 dB, the measured return loss shall not be used in determining a fail. Return loss values greater than 25 dB may be reported as “>25 dB”.

I.3 Field measurement procedures

I.3.1 Consistency checks for field testers

The field tester manufacturer shall make available to the user a simple procedure for verifying, reporting, and recording the consistency of the field tester in the field. The following procedures are recommended.

1. Repeatability of tests on a reference link
   The owner of the field tester should construct a reference link. Repeated measurements on this link should result in the same results within the magnitude of the accuracy specifications. Comparisons should be made at the worst case results across the frequency band.
2. Consistency of tests by testing the same link in opposite directions
   Any link can be measured at first by connecting the local field tester unit to one end of the cabling and the remote field tester unit to the other end of the cabling. After performing a test, the locations of local field tester unit and remote field tester unit are exchanged.

All worst case magnitudes should remain the same within 1.4 times the accuracy specification of the test function, except for NEXT loss and return loss measurements. For NEXT loss and return loss, the local NEXT loss and return loss results obtained during the first test should be compared to the remote NEXT loss and return loss results obtained during the second test. Similarly, the remote NEXT loss and return loss results obtained during the first test should be compared to the local NEXT loss and return loss results during the second test. These results should not differ by more than 1.4 times the relevant accuracy specifications.

I.3.2 Administration

In addition to Pass/Fail indications, worst case measured values of test parameters should be recorded. Any reconfiguration of cabling components after testing may change the performance and thus invalidates previous test results. Such cabling shall require re-testing to regain conformance.

I.3.3 Test equipment connectors and cords

To maintain measurement accuracy, only test cords and adapters that are qualified by the test equipment manufacturer for the channel or link test configuration shall be used.

Connecting hardware has a limited life-cycle and should be periodically inspected for wear resulting from multiple mating cycles. Consult with test equipment manufacturers for the life cycle of the connectors.

I.4 Field tester measurement accuracy requirements

I.4.1 General

Minimum performance levels have been identified for Level II-E field testers applicable to the baseline, permanent link and channel configuration. The performance requirements for Level II-E are as further described in this clause. Accuracy is the difference between the measured value reported by the field tester and the actual value. Accuracy is a function of the characteristics of the field tester as well as the transmission characteristics of the cabling. Minimum performance levels have been identified for Level II-E field testers. Each accuracy level has it own set of performance requirements as further 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, which are not reflected in this error model, depending on the implementation of the measurement circuitry in the field tester.

Therefore, in addition to performance requirements for the properties of field testers, methods to compare the results obtained by field testers with those using laboratory methods are specified. Laboratory methods are described in annex J. The deviation of the two results shall be no more than the sum total of the estimated measurement accuracy of the field tester and estimated measurement accuracy of the laboratory measurement system.

The estimated measurement accuracy at the Pass/Fail test limit at 100 MHz for each parameter can be derived from the information in this clause and test limits in ANSI/TIA/EIA-568-B.1. Table I.2 shows the measurement accuracy using a compliant Level II-E field tester.

Table I.2 - Measurement accuracies at 100 MHz

Test parameter	Baseline accuracy at channel limits (dB)	Permanent link measurement accuracy at channel limits (dB)	Channel measurement accuracy at channel limits (dB)
Insertion loss	± 1.3	± 1.7	± 1.9
Pair-to-pair NEXT loss	± 1.8	± 2.4	± 3.6
Power sum NEXT loss	± 1.8	± 2.5	± 3.9
Pair-to-pair ELFEXT	± 2.4	± 3.1	± 4.4
Power sum ELFEXT	± 2.5	± 3.2	± 4.8
Return loss	± 1.7	± 2.6	± 2.4

NOTES,

1 The measurement accuracies in table I-2 are derived by substituting the requirements as defined in tables I-3, table I-4 and table I-6 in the appropriate error model in clause I-6

2 Performance requirements for Level I and Level II field testers were defined in TIAEIA TSB67.

I.4.2 Performance parameters for Level II-E field testers

Level II-E field testers shall conform to all individual requirements for each of the measurement functions. The baseline configuration and each test configuration have its own separate set performance requirements. The channel performance parameters include the effects of the modular jack mating with the local end of the user patch cord. Minimum performance levels have been identified for Level II-E field testers applicable to the baseline, permanent link and channel configuration. The performance requirements for Level II-E are as further described in this clause. Measurement accuracy requirements are shown in table format. Requirements for the basic link and channel test configurations and the insertion loss, NEXT loss, ELFEXT and return loss measurement functions are shown in tables I.3, I.4, and I.6. Notes in tables I.3, I.4, and I.5 are explained in table I.6. Length, propagation delay, and delay skew requirements are not dependent on which link configuration is tested and are shown in tables I.7, I.8 and I.9 respectively. Methods to verify compliance of the field tester requirements are specified in clause I.5.

Table I.3 - Minimum requirements for baseline measurement accuracy of Level II-E field testers

Parameter	Insertion loss	NEXT Loss PSNEXT Loss	ELFEXT PSELFEXT	Return Loss	
Amplitude Range	0 – 30 dB	3 dB over test limit$^{\text{Notes 1,2}}$	3 dB over test limit$^{\text{Notes 1,2}}$	0 - 25 dB	dB
Amplitude Resolution	0.1				dB
Frequency Range	1 –100 MHz				
Frequency Resolution	1 MHz	150 kHz, 1 MHz to 31.25 MHz 250 kHz, 31.25 MHz to 100 MHz			
Dynamic Accuracy	± 0.75 $^{\text{Note 3}}$		± 1 $^{\text{Notes 3, 4}}$		dB
Source/load Return Loss	1 – 5 MHz: 15 dB 5 – 100 MHz: 20 dB				dB
Random Noise Floor	65 – 15log(f/100), 80 dB max				dB
Residual NEXT		60–20log(f/100) Note 5			dB
Residual FEXT			55–20log (f/100) Note 5		dB
Output Signal Balance		37-15log(f/100) $^{\text{Note 6}}$			dB
Common Mode Rejection		37-15log(f/100) $^{\text{Note 6}}$			dB
Tracking				± 0.25 $^{\text{Note 7}}$	dB
Directivity				1-10 MHz: 30 10 – 100 MHz: 30-2log(f/10) Note 7	dB
Source Match				20 $^{\text{Note 7}}$	dB
Termination Return Loss				1-5 MHz: 23 5-100 MHz: $35\text{-}1.5\sqrt{f}$ **Note 7**	dB

Table I.4 - Minimum requirements for permanent link measurement accuracy of Level II-E field testers (includes the permanent link adapter)

Parameter	Insertion loss	NEXT Loss PSNEXT Loss	ELFEXT PSELFEXT	Return Loss	
Amplitude Range	0 - 30 dB	3 dB over test limit[Notes 1,2]	3 dB over test limit[Notes 1,2]	0 - 25 dB	dB
Amplitude Resolution	0.1				dB
Frequency Range	1 –100 MHz				
Frequency Resolution	1 MHz	150 kHz, 1 MHz to 31.25 MHz 250 kHz, 31.25 MHz to 100 MHz			
Dynamic Accuracy	± 0.75 [Note 3]		± 1 [Notes 3,4]		dB
Source/load Return Loss	15 dB				dB
Random Noise Floor	65 – 15log(f/100), 80 dB max				dB
Residual NEXT loss		60–20log(f/100) [Note 5]			dB
Residual FEXT loss			50–20log (f/100) [Note 5]		dB
Output Signal Balance		34-15log(f/100) [Note 6]			dB
Common Mode Rejection		34-15log(f/100) [Note 6]			dB
Tracking				± 0.5 [Note 8]	dB
Directivity				25 [Note 8]	dB
Source Match				18-20log(f/100), 20 dB max.) [Note 8]	dB
Termination Return Loss				1 –5 MHz:22 dB 5 – 100 MHz: $15-20\log\left(\frac{f}{100}\right)$ 25 dB max [Note 8]	dB

Table I.5 - Minimum requirements for channel measurement accuracy of Level II-E field testers (includes the channel adapter)

Parameter	Insertion loss	NEXT Loss PSNEXT Loss	ELFEXT PSELFEXT	Return Loss	
Amplitude Range	0 - 30 dB	3 dB over test limit$^{\text{Notes 1,2}}$	3 dB over test limit$^{\text{Notes 1,2}}$	0 - 25 dB	dB
Amplitude Resolution	0.1				dB
Frequency Range	1 –100 MHz				
Frequency Resolution	1 MHz	150 kHz, 1 MHz to 31.25 MHz 250 kHz, 31.25 MHz to 100 MHz			
Dynamic Accuracy	± 0.75 $^{\text{Note 3}}$		± 1 $^{\text{Notes 3, 4}}$		dB
Source/load Return Loss	15 dB max				dB
Random Noise Floor	65 – 15log(f/100), 80 dB max				dB
Residual NEXT loss		43–20log(f/100) $^{\text{Note 5}}$			dB
Residual FEXT loss			35.1–20log (f/100) $^{\text{Note 5}}$		dB
Output Signal Balance		34-15log(f/100) $^{\text{Note 6}}$			dB
Common Mode Rejection		34-15log(f/100) $^{\text{Note 6}}$			dB
Tracking				± 0.5 $^{\text{Note 8}}$	dB
Directivity				25 dB $^{\text{Note 8}}$	dB
Source Match				18-20log(f/100), 20 dB max.) $^{\text{Note 8}}$	dB
Termination Return Loss				1 –5 MHz:22 dB 5 – 100 MHz: $15-20\log\left(\frac{f}{100}\right)$ 25 dB max $^{\text{Note 8}}$	dB

Performance and measurements for more stringent limits than shown in table I-6 are not required.

Table I.6 - Explanation of notes in tables I-3, I-4, and I.5

NOTE	Explanation
1	The dynamic range for NEXT and FEXT is 60 dB minimum.
2	The dynamic range for PS NEXT and PS FEXT is 57 dB minimum.
3	Dynamic accuracy requirements shall be tested up to the specified dynamic range for NEXT and FEXT.
4	Dynamic Accuracy ELFEXT assumes a dynamic accuracy requirement of 0.75 dB for FEXT, which shall be tested, and that dynamic accuracy performance for insertion loss and FEXT add to the ELFEXT requirement shown.
5	The verification of Residual NEXT and FEXT is up to 75 dB maximum. It is assumed that the frequency response changes at a rate of 20 dB/decade.
6	The verification of Output Signal Balance and Common Mode Rejection is up to 60 dB maximum.
7	Between 1 and 5 MHz, the overall computed accuracy shall be better than 3.8 dB. This value may be achieved through any combination of Tracking, Directivity, Source Match and Return Loss of Termination.
8	Between 1 and 5 MHz, the overall computed accuracy shall be better than 4.8 dB. This value may be achieved through any combination of Tracking, Directivity, Source Match and Return Loss of Termination.

Table I.7 - Level II-E field tester requirements for length

Performance Parameter	**Requirement**
Length measurement range	0 m - 305 m
Length resolution	0.1 m
Constant error term length	1 m up to 100 m
Error constant proportional to length	4 % up to 100 m

Table I.8 - Level II-E field tester requirements for propagation delay

Performance Parameter	**Requirement**
Propagation Delay measurement range	0 µs – 1 µs @ 10 MHz
Propagation Delay resolution	1 ns
Constant error term propagation delay	5 ns
Error constant proportional to propagation delay	4 %

Table I.9 - Level II-E field tester requirements for delay skew

Performance Parameter	**Requirement**
Delay skew measurement range	0 ns – 100 ns @ 10 MHz
Delay skew resolution	1 ns
Constant error term delay skew	10 ns

I.5 Procedures for determining field tester parameters

I.5.1 General

Field testers are 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 applicable requirements, and shall apply to the entire frequency range specified in these tables. The field tester parameters shall be verifiable by independent parties. The field testers shall include functionality to make independent verification possible.

I.5.2 Output signal balance (OSB)

This performance requirement is applicable to:

- Pair-to-pair and power sum NEXT loss measurements
- Pair-to-pair and power sum FEXT loss measurements

Output Signal Balance (OSB) is defined as the ratio of the output common mode voltage to the output differential voltage generated by a source port. (V_d / V_c is used instead to make the value positive per convention) as shown in figure I.1. The field test instrument shall be connected to ground for the measurement as near as possible to the port to be measured. This shall provide a low impedance path to instrument ground of the field test instrument over the specified frequency range. The OSB compliance test shall be conducted without and with a polarity reversal. If there is a pass condition with one polarity and a failure with the other polarity, the average value shall be used to determine compliance with the requirements.

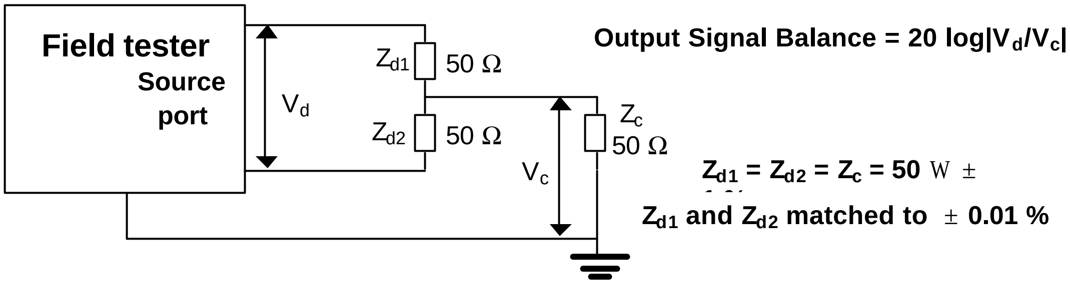


Figure I.1 - Block diagram to measuring output signal balance

I.5.3 Common mode rejection (CMR)

This performance requirement is applicable to:

- Pair-to-pair and power sum NEXT loss measurements
- Pair-to-pair and power sum FEXT loss 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) as shown in figure I.2. The field test instrument shall be connected to measurement ground 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.

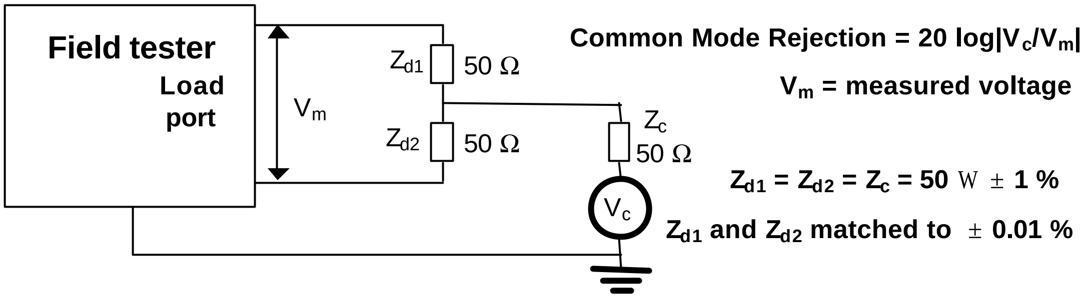


Figure I.2 - Block diagram to measuring common mode rejection

I.5.4 Residual NEXT loss

This performance requirement is applicable to:

- Pair-to-pair and power sum NEXT loss measurements

Residual NEXT loss 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 loss, Z_d = 100 Ω, with return loss < 20 dB over the specified frequency range as shown in figure I.3. Measured voltage is the voltage determined by the field test instrument. A procedure measuring voltage with an external voltmeter at the output detector is acceptable if equivalency can be demonstrated.

$$\text{Residual NEXT loss} = -20 \log(V_m / V_c) \qquad \text{(I-3)}$$

The termination to the field test instruments shall be applied at the same location that a through connection will measure 0dB reference (excluding additional insertion loss of test leads). In some field test instruments this will be at the end of the test leads. In figure I.3, V_o is applied to each resistor Z_d, one at a time, while V_m is the measured voltage across another Z_d when the tester is measuring NEXT loss.

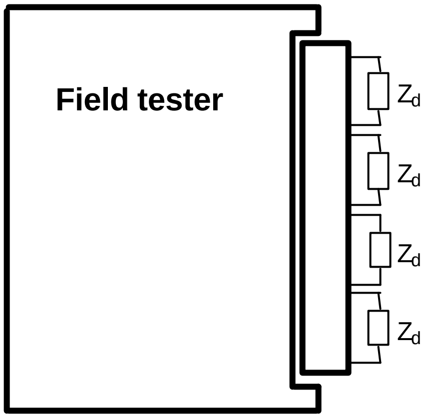


Figure I.3 - Block diagram for measuring residual NEXT loss

I.5.5 Dynamic accuracy

This performance requirement is applicable to:

- Pair-to-pair and power sum NEXT loss measurements
- Pair-to-pair and power sum FEXT loss measurements
- Insertion loss measurements

Dynamic accuracy is the accuracy of the measured value to an external voltage input as shown in figure I.4. The voltage input shall provide a minimum source balanced input of 40 dB with a minimum return loss of 20 dB.

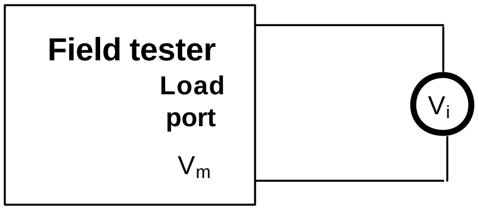


Figure I.4 - Block diagram for measuring dynamic accuracy

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.

I.5.6 Source/load return loss

This performance requirement is applicable to:

- Pair-to-pair and power sum NEXT loss measurements
- Pair-to-pair and power sum ELFEXT measurements
- Insertion loss measurements

The source and load return loss of the insertion loss, NEXT loss 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.

$$\text{Return loss} = -20 \log(V_{reflected} / V_{incident}) \qquad \text{(I-2)}$$

I.5.7 Random noise floor

This performance requirement is applicable to:

- Pair-to-pair and power sum NEXT loss measurements
- Pair-to-pair and power sum ELFEXT 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.

$$Return\ loss = -20 \log(V_m / V_o) \qquad \text{(I-3)}$$

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

I.5.8 Residual FEXT loss

This performance requirement is applicable to:

- Pair-to-pair and power sum FEXT loss measurements

The FEXT loss of the local instrument connector can be determined by measuring the FEXT loss using an external receiver and the FEXT loss of the remote instrument connector can be determined using an external signal generator as shown in figures I.5 and I.6. The responses can be normalized by connecting the receiver to the stimulus pair and the signal generator to the measurement pair to the local instrument and remote instrument respectively.

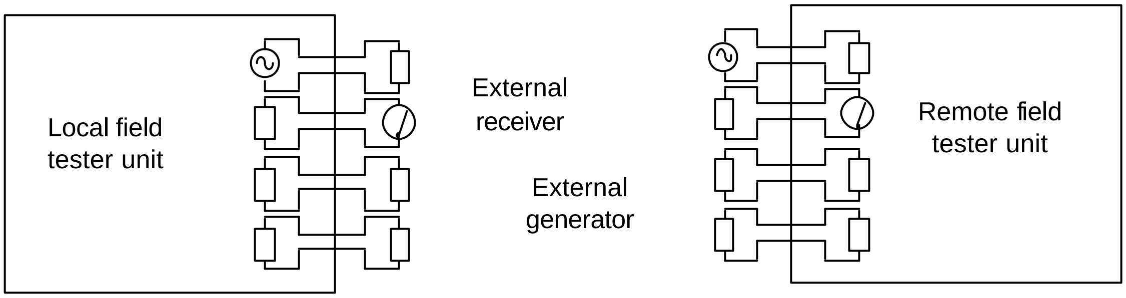


Figure I.5 - Principle of measurement of residual FEXT loss

Alternately, the residual FEXT loss may be measured by interconnecting the local and remote field tester units using individual wire pairs in multiple cables. In the first measurement configuration the wires are as short as possible and equal length. In the second measurement configuration, the length difference between wire 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 wire pairs. The worst case residual FEXT loss of both measurement configurations shall be used, and one half of this amount shall be assigned to the connection at each end.

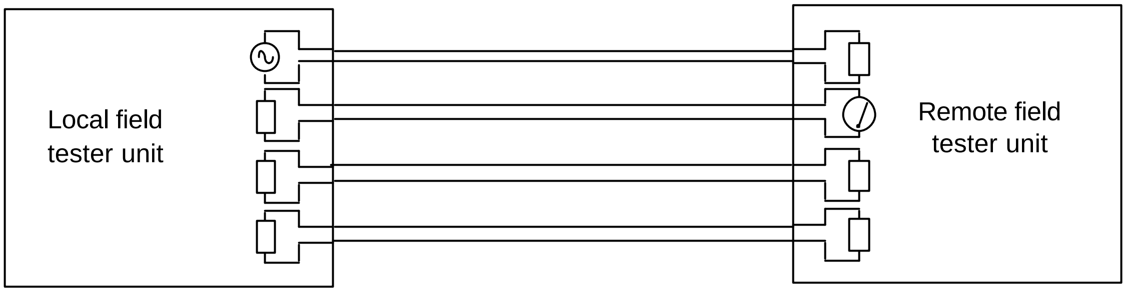


Figure I.6 - Principle of alternate measurement of residual FEXT loss

I.5.9 Directivity

This performance requirement is applicable to:

- Return loss measurements

Directivity is 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 RF chip resistors that have return loss better than 40 dB from 1 MHz to the upper frequency limit of the category.

I.5.10 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 shorted (the actual reflection coefficient is -1) as a function of frequency, and
- Measurement of return loss with all wire-pairs open as a function of frequency (the actual reflection coefficient is +1).

The absolute value of the sum of the two measurements divided by two is the tracking error in dB. If the measured results are expressed in positive values of dB, the tracking error is given by equation (I-4).

$$Tracking_{dB} = -20 \cdot \log\left(\left| \frac{10^{\frac{-RL_{short},dB}{20}} + 10^{\frac{-RL_{open},dB}{20}}}{2} \right| \right) \tag{I-4}$$

I.5.11 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 values of dB, the source match error is given by equation (I-5)

$$Source\_Match_{dB} = -20 \cdot \log\left(\left| \frac{-10^{\frac{-RL_{short},dB}{20}} + 10^{\frac{-RL_{open},dB}{20}}}{2} + 10^{\frac{-Directivity,dB}{20}} \right|\right)$$

(I-5)

I.5.12 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 loss and FEXT loss 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 loss and FEXT loss functions. The return loss of the termination of each wire pair shall be separately determined.

I.5.13 Constant error term of the length measurement function

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

I.5.14 Error constant proportional to length of the length measurement function

The length of cabling with a total length of 100 m +/- 1% shall be measured using a tape measure. The NVP calibration shall be performed. Then cabling with a known length of approximately 50 m shall be measured. The reported length shall deviate from the actual value by less than 1/2 the amount of the error constant proportional to length.

I.5.15 Constant error term of the propagation delay measurement function

The parameters that affect propagation delay accuracy include a constant error term E_c and a term E_d that is proportional to length of the link. The constant error term of the propagation delay measurement function is determined by connecting the local unit to the remote unit through a short test cable and measuring the propagation delay. The reported propagation delay shall be less than the constant error term of the propagation delay.

I.5.16 Error constant of the proportional to propagation delay measurement function proportional to the propagation delay

The propagation delay of cabling with a total length of 100 m +/- 1% shall be measured using the reference measurement procedure. The propagation delay at 10 MHz is the reference value. Then 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 that is proportional to the propagation delay of the propagation delay measurement function.

I.5.17 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 propagation delays of two wire pairs in this link shall be measured per clause 5.2.2. The length of the wire pair with the highest propagation delay shall be extended so that the delay skew of these wire pairs is 50 ns +/- 2 ns as measured using the phase delay measurement function of the network analyzer and determined at a 10 MHz frequency. When the link is measured with the field tester, the reported delay skew of the two wire pairs shall be within 10 ns of the value at a frequency of 10 MHz measured using the reference procedure.

I.6 Measurement error models

I.6.1 General

The measurement accuracy for the permanent link and channel is computed using the parameters in table I.3 through table I.9. The error models used to estimate the baseline measurement accuracy of the field tester are based upon the 12-parameter error model defined for network analyzer measurements with modifications and simplifications. There is no assurance that these simplifications and modifications are appropriate in every circumstance or 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.

I.6.2 Error model for the insertion loss measurement function of level II-E field testers

$$Accuracy_{IL,dB} = E_{d,IL} + 20\log\left[1 + 10^{\frac{-E_{RL,tester}}{10}} + 2\cdot 10^{\frac{-\left(E_{RL,tester} + E_{RL,link}\right)}{20}}\right] \qquad \text{(I-6)}$$

where:

$\mathrm{Accuracy}_{\mathrm{IL,dB}}$	is the estimated accuracy of the insertion loss measurement function in dB
$\mathrm{E}_{\mathrm{d,IL}}$	is the dynamic accuracy of the tester for insertion loss in dB
$E_{RL,tester}$	is the return loss of the tester in dB
$E_{RL,link}$	is the return loss of the link in dB

Assumptions:

- Dynamic accuracy adds directly to all other error terms.
- 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.
- Impact from the test cable for the measurement of the connector used for the channel interface are expected to have a significant impact on the source/load return loss of the field tester.

I.6.3 Error model for the pair-to-pair NEXT loss measurement function of level II-E field testers

$$Accuracy_{NEXT,dB} = E_{d,\,NEXT} + 20 \cdot \log \Bigg[1 + 10^{\frac{-E_{RL,tester}}{10}} + 2 \cdot 10^{\frac{-\left(E_{RL,tester} + E_{RL,link}\right)}{20}} + \sqrt{10^{\frac{A_{NEXT} - E_{RN}}{10}} + 10^{\frac{A_{NEXT} - E_{NF}}{10}} + 10^{\frac{S_C - E_B}{10}} + 10^{\frac{S_D - E_C}{10}}} \Bigg] \tag{I-7}$$

where:

$Accuracy_{NEXT,dB}$	is the estimated accuracy of the NEXT measurement function
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
$E_{RL,tester}$	is the return loss of the tester in dB
$E_{RL,link}$	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 ratio (CMR) of the tester in dB
S_D	is the common mode to differential coupling gain of the link (relative to the measured NEXT loss value, 10 dB is assumed)
S_C	is the differential mode to common mode coupling of the link (relative to measured NEXT loss value, 5 dB is assumed)

Assumptions:

- The common mode to differential coupling gain S_{Df} = 5 dB.
- The differential mode to common mode coupling of the cabling S_{Cf} = 10 dB
- Common mode to common mode coupling effects are neglected.
- Dynamic accuracy adds up to all other error terms.
- 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.
- Errors from random noise floor, residual NEXT, output signal balance and common mode rejection are added in a power sum manner.
- Dynamic accuracy and random noise floor performance is assumed to be independent of the type of link.
- Impact from the test cable for the measurement of the connector used for the channel interface are expected to have a significant impact on the source/load return loss, residual NEXT, output signal balance and common mode rejection of the field tester.

I.6.4 Error model for the power sum NEXT loss measurement function of Level II-E field testers

The error model for power sum NEXT loss is similar to that for pair-to-pair NEXT loss. The measurement accuracy for this function can be found from equation I-7 by setting A_{NEXT} equal to the PSNEXT at the pass/fail limit plus 4.77 dB.

I.6.5 Error model for the pair-to-pair ELFEXT measurement function of level II-E field testers

The error model for ELFEXT depends on the error models for FEXT loss and insertion loss. These are independent measurements, each with their own error model. The error model for insertion loss is in clause I.6.2. The error model for FEXT loss is like the error model for NEXT loss in clause I.6.3. A combined error model for ELFEXT, which includes a total dynamic accuracy equal to approximately the square root of the dynamic accuracy for insertion loss and FEXT loss, and twice the power of return loss is as shown in equation (I-8).

$$
\begin{aligned}
Accuracy_{ELFEXT,dB} = E_{d,ELFEXT} + 20\cdot\log\Bigg[1 \\
&+ \sqrt{2}\cdot\left(10^{\frac{-E_{RL,tester}}{10}} + \sqrt{2}\cdot 10^{\frac{-\left(E_{RL,tester}+E_{RL,link}\right)}{20}}\right) \\
&+ \sqrt{10^{\frac{A_{ELFEXT}+A_{IL}-E_{NF}}{10}} + 10^{\frac{A_{ELFEXT}+6-E_{RF}}{10}} + 10^{\frac{S_C-E_B}{10}} + 10^{\frac{S_D-E_C}{10}}}\,\Bigg]
\end{aligned}
\qquad \text{(I-8)}
$$

where:

$Accuracy_{ELFEXT,dB}$	is the estimated accuracy of the ELFEXT measurement function
A_{ELFEXT}	is the ELFEXT signal amplitude for accuracy in dB
$\mathrm{A}_{\mathrm{IL,dB}}$	is the insertion loss signal amplitude for accuracy in dB
$E_{d,ELFEXT}$	is the dynamic accuracy of the tester for ELFEXT in dB (includes the impact of making both an insertion loss and FEXT loss measurement, power sum addition of dynamic accuracies)
$E_{RL,tester}$	is the return loss of the tester in dB (includes the impact of making both an insertion loss and FEXT loss measurement, power sum addition of source/load return losses)
$E_{RL,link}$	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 ratio (CMR) of the tester in dB
S_{D}	is the common mode to differential coupling gain of the link (relative to the measured FEXT loss value)
S_{C}	is the differential mode to common mode coupling of the link (relative to measured FEXT loss value)

Assumptions:

- Dynamic accuracy adds up to all other error terms.
- An ELFEXT computation is made from the measurement of FEXT loss and insertion loss. For ELFEXT dynamic accuracy, the dynamic accuracies of insertion loss and FEXT loss 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 loss 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 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.
- Impact from the test cable for the measurement of the 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.

I.6.6 Error model for the power sum ELFEXT measurement function of level II-E field testers

The error model for power sum ELFEXT is similar to the error model for pair-to-pair ELFEXT. The measurement accuracy for the power sum ELFEXT measurement function can be found by substituting for the amplitude A in the pair-to-pair ELFEXT error equation, the pass/fail limit of the power sum ELFEXT measurement function plus 4.77 dB.

I.6.7 Error model for the return loss measurement function of level II-E field testers

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 that are the result of reflections at the remote termination of the cabling. The estimated return loss measurement error is given by equation (I-9).

$$Error_{rl,dB} = TR + 20 * \log\left(1 + \sqrt{\left(10^{\frac{A_{RL} - E_{DIR}}{20}} + 10^{\frac{-\left(A_{RL} + E_{SM}\right)}{20}}\right)^2 + \left(10^{\frac{A_{RL} - E_{TERM} - \sqrt{f}}{20}}\right)^2}\right) \qquad \text{(I-9)}$$

where:

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 meters (with f in MHz). For a 20-meter length link (40 meters round trip insertion loss), the remote reflection is attenuated approximately by $\sqrt{f}$.

I.6.8 Error model for the propagation delay measurement function of level II-E field testers

The error of the propagation delay contains a constant error term and an error that is proportional to propagation delay of the measured cabling. For a 100 m limited distance, this error is approximately proportional to length; see equation (I-10).

$$Error_{propagation\_delay} = E_c + E_d \cdot propagation\_delay \qquad \text{(I-10)}$$

where:

E_c is the constant error term and

E_d is the error term proportional to the propagation delay of the cabling.

I.6.9 Error model for the delay skew measurement function of level II-E field testers

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 equation (I-11).

$$Error_{delay\_skew} = \frac{dE_d}{dt} \qquad \text{(I-11)}$$

where:

E_d is the error term of propagation delay proportional to the length of the cabling.

I.6.10 Error model for the length measurement function of level II-E field testers

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

Annex J Comparison measurement procedures (normative)

J.1 General

This annex describes procedures used to compare the results obtained using laboratory equipment with those obtained with a field tester.
The accuracy of this comparison is limited by the uncertainty in the reference or laboratory measurement. It has been demonstrated that the results of different test configurations can vary by as much as ±1 dB at the category 5e channel NEXT limit. Measurements made below the category 5e channel NEXT loss limit may have increased uncertainty. The results of this comparison can differ by as much as the specified field tester accuracy plus the uncertainty in the reference measurement.

Field test requirements include the following parameters for which a measurement accuracy is specified:

- Insertion loss (attenuation)
- Near-end crosstalk (NEXT)
- Return loss
- Far-end crosstalk (FEXT)
- Propagation Delay

The reference test setup is as described in annex B.

J.2 Test setup and apparatus required for comparison measurements

J.2.1 General requirements

The reference test setup, calibration and measurement procedures are as described in annex E.

J.3 Test adapters

J.3.1 General

The following clauses describe a method for measuring link parameters in such a way that measurements from the reference test setup can be compared directly with the results obtained from a field tester. The NEXT loss measurement procedure is described in detail and the measurement procedures for other parameters are similar.

The interface to laboratory test equipment is designed to accept copper cable ends of the balanced twisted-pair cabling to be tested or a mating connector. The interface to a field tester, however, depends upon whether a permanent link, channel or the baseline configuration is to be tested.

Special patch cords are needed to compare the test results from a field tester and reference test setup and are described in clause J.3.2.

J.3.2 Special patch cords

A set of special patch cords is used in order to be able to compare the results obtained with laboratory equipment and field testers. The special patch cords have a high quality connection inserted into the patch cord cable. This high quality connection consists of a test interface connector and a mating connector. This connection is a low insertion loss (< 0.1 dB), low NEXT loss (> 80 dB @ 100 MHz) connection.

For the channel and baseline test configurations, the length of the cable between the mating type connector and the plug mating with the field tester shall be 50 mm (2 in) maximum. The instrument connector shall be a modular connector when the channel configuration is tested. The instrument connector shall be a type that mates directly with the high quality measurement port of the field tester as shown in figure J.1.

Figure J.1 - Special patch cord for the baseline and channel test comparison

For the permanent link test configurations, the length of the cable between the modular connector and the plug mating with the link under test shall be 50 mm (2 in) maximum. The instrument connector shall be a type that mates directly with the high quality measurement port of the field tester as shown in figure J.2. Some methods used by field testers for permanent link measurements rely on special calibration factors that are associated to a manufacturer's link adapter (patch cord). The permanent link compensation can be rendered invalid if the link adapter is physically modified or a test is run without valid calibration factors. Contact the fields test manufacturer for any special precautions.

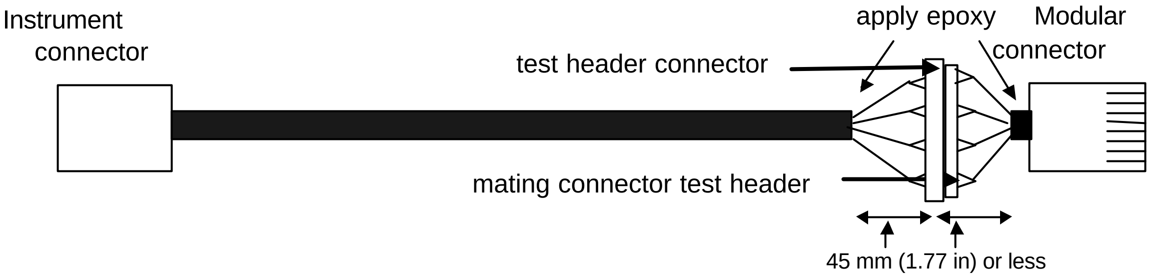


Figure J.2 - Special patch cord for permanent link test comparison

When measuring a reference channel or permanent link with the field tester, the two sections of the special patch cord shall be mated with the test connector and mating connector. When measuring the same link with the network analyzer, the two segments shall be separated and the mating connector directly inserted into the test interface as described in annex B.

J.4 Comparison methods

Field tester and network analyzer results can be compared using ANSI/TIA/EIA-568-B.1 compliant links whose transmission test performance falls within the dynamic range of the field tester. It is desirable that a number of links be used. A set of special patch cords, that is appropriate for the type of comparison as described in clause J.3.2, shall be used. The results from the network analyzer and the field tester shall be compared using methods described in clause J.4.1 or clause J.4.2. The results shall agree within the sum of the measurement accuracy of the network analyzer measurement and the measurement accuracy of the field tester, as determined per the requirements of clause I.4.

The requirements of insertion loss, NEXT loss, ELFEXT, and return loss are specified as a function of frequency. The comparison may be applied to all frequency data points as described in clause J.4.2. Alternately, a simple comparison based upon the worst case margin between measured performance and test limit may be used as described in clause J.4.1. The performance of length, propagation delay, and delay skew is expressed as a single number and comparison of measurement performance is described in clause J.4.1.

J.4.1 Comparison method using worst case performance margin

The results obtained from the network analyzer and field tester over the 1 MHz to 100 MHz frequency band are compared only at the worst case performance condition relative to the test limit for the link. It has been shown that small differences in the setup can cause shifts in the nulls in the frequency spectrum and slight variations in the maximum values between the nulls. The worst case performance margins shall agree within the sum of the measurement accuracies of the network analyzer and the field tester at the signal level of the worst case condition.

J.4.2 Comparison method using full NEXT loss spectrum

The full NEXT loss spectrum method uses all data from the frequency response of the network analyzer and field tester measurements that are within the minimum reporting range of the field tester as specified in annex B. Data results relative to the test limit for the basic link or channel configuration are graphed by on an X-Y scatter plot. For each frequency data point, the X-coordinate equals the distance from the network analyzer spectrum to the test limit. The Y-coordinate 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 network analyzer and the field tester and a lower bound, which equals the negative value of the upper bound. The accuracy of the network analyzer and field tester shall be calculated using the equations in clause I.4. A sample scatter plot is shown in figure J.3. Acceptable results are between the lower and upper bounds and to the left of the reporting range limit.

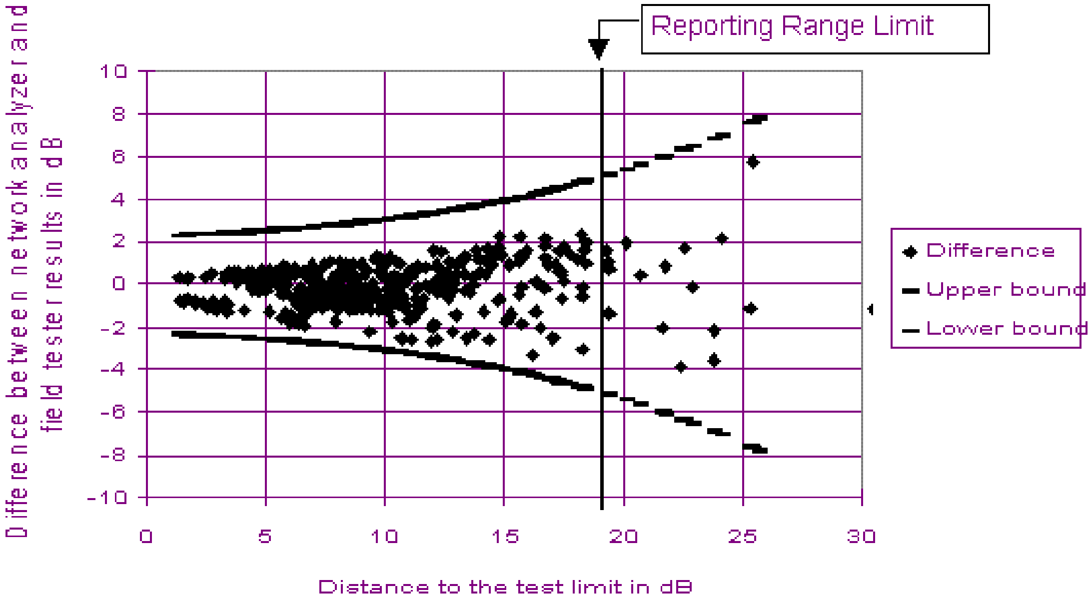


Figure J.3 - Example of X-Y scatter plot

Annex K 100 Ω screened twisted-pair (ScTP) cabling (normative)

K.1 Introduction

The use of twisted-pair cables to support telecommunications applications sometimes includes the option of an overall shield. When this option is exercised, and an overall shield is present, it can improve the control of electromagnetic radiation from the signal carriers and immunity to electromagnetic interference from external sources. However, the ability of the shield to provide these benefits depends on a variety of factors. These factors include the characteristics of the cabling components, such as connectors and cables, as well as the methods and care with which they are installed and the design of the connected equipment. The specifications provided herein are intended to define transmission characteristics and shield effectiveness for screened cabling systems.

K.2 Purpose and scope

The purpose of this annex is to establish the minimum technical requirements for a 100 Ω ScTP cabling system, in order to ensure compatibility and inter-mateability. It specifies an end-to-end screened system based on 100 Ω twisted-pair cable and connectors with an overall shield. It includes all the elements that make up such a system including screened horizontal cables, screened backbone cables, screened work area connecting hardware, screened telecommunication room connecting hardware, and screened patch cords. It defines the shield mateability and shield grounding requirements that will result in optimum electromagnetic compatibility (EMC) performance.

K.3 General requirements

The cables, connecting hardware, and patch cords or jumper wire used in a 100 Ω ScTP cabling system shall meet the mechanical, transmission, and performance marking requirements specified for 100 Ω horizontal UTP cabling in clauses 4 through 7, except as modified by the additional requirements of clauses K.4-K.7.

NOTE - Field testing of ScTP cabling at frequencies up to 100 MHz is covered in annex I.

The installation of a 100 Ω ScTP system shall meet the requirements in ANSI/TIA/EIA-568-B.1, clause 10.6. While this annex specifies requirements and provides guidance on grounding and bonding of shields from an EMC functional perspective, it does not replace or take precedence over any code or regulation, either partially or wholly. The reader should be aware of applicable authorities or local codes in that jurisdiction which may impact the use of this document.

K.4 100 Ω ScTP horizontal cable

K.4.1 Applicability

The horizontal cables covered by this specification shall consist of four twisted-pairs of 24 AWG solid conductor, screened cable. Four-pair, solid conductor, screened cables of conductor diameters larger than 24 AWG, up to and including 22 AWG, that meet or exceed the requirements of this Standard may also be used.

K.4.2 Additional mechanical requirements

The following are additional mechanical requirements for 100 Ω ScTP horizontal cable.

K.4.2.1 Core wrap

The core may be covered with one or more layers of dielectric material of adequate thickness to ensure compliance with the dielectric strength requirements of clause K.4.3.1.

K.4.2.2 Core shield

An electrically continuous shield shall be applied over the core, or core wrap if one is present, and shall comply with the surface transfer impedance requirements of clause K.4.3.2. The core shield shall consist of a helical or longitudinal plastic and metal laminated tape, and one or more longitudinal, helical, or braided non-insulated solid tin-coated copper conductor(s) [drain wire(s)] of 26 AWG equivalent or larger that are in contact with the metal side of the tape.

K.4.2.3 Bending radius

The cable, when tested in accordance with ASTM D 4565, shall withstand a bend radius of 50 mm (2 in.) at a temperature of -20 °C ± 1°C without jacket, shield, or insulation cracking. For certain applications (e.g., pre-wiring buildings in cold climate) a cable with a lower temperature bending performance of -30 °C ± 1 °C may be required.

K.4.3 Additional electrical requirements

K.4.3.1 Dielectric strength

The insulation between each conductor and the core shield shall be capable of withstanding a minimum DC potential of 2.5 kV for 2 seconds or an AC potential of 1.7 kV for 2 seconds in accordance with IEC 60189-1.

K.4.3.2 Surface transfer impedance

The surface transfer impedance per unit length of the core shield, measured in accordance with IEC 61196-1 (terminated triaxial or line injection method), shall not exceed the values determined using the formula:

$$Z_{Tcable} = 37 + 4f + 4\sqrt{f} + 5\sqrt[3]{f} \qquad \text{(K-1)}$$

Where:

Z_{Tcable} is surface transfer impedance in mΩ/m

f is the frequency in MHz over the range of 1 MHz to 16 MHz for category 3 cables and 1 MHz to 100 MHz for category 5e cables

NOTE - Although the IEC 61196-1 test method is intended for coaxial cables, it may be applied to measurements on balanced cables with an overall shield when the signal carriers are excited in the common mode (e.g. all 8 conductors are shorted together and excited with a 50 Ω source). This test method is applicable for cable lengths of 1 meter and frequencies up to 30 MHz. For higher frequencies, shorter cable lengths may be required.

The values in table K.1 are derived from the above formula and provided for information only.

Table K.1 - Maximum cable surface transfer impedance

Frequency MHz	Category 3 mW/m	Category 5e mW/m
1	50	50
10	100	100
16	130	130
20	-	148
100	-	500

K.4.3.3 Measurement precaution

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

K.5 100 W ScTP backbone cable

K.5.1 Applicability

The backbone cables used for 100 Ω ScTP cabling shall consist of 22 AWG to 24 AWG thermoplastic insulated solid copper conductors that are formed into one or more units of twisted-pairs. The units are assembled into binder groups of 25 pairs, or part thereof, following the standard industry color code in ANSI/ICEA S-90-661. For cables with more than 25 pairs, the 25-pair groups are identified by distinctly colored binders and assembled to form the core. The core is enclosed by an electrically continuous shield and a thermoplastic jacket. Transmission performance shall meet the requirements of clause 4.4. Multipair thermoplastic insulated solid copper, screened cables containing conductor diameters larger than 24 AWG, up to and including 22 AWG that meet or exceed the transmission requirements may also be used.

K.5.2 Additional requirements

The insulated conductor diameters, the core wrap, the core shield, and related electrical characteristics of 100 Ω ScTP backbone cables shall meet the requirements for horizontal 100 Ω ScTP cables as specified in clause K.4, with the exception that outside plant cables or inside building cables having their shields bonded to the shields of outside plant cables at building entrances shall meet the core shield requirements of clause 4.4.3.6.

K.6 100 W ScTP connecting hardware

K.6.1 Applicability

Connecting hardware shall be designed for use with 100 Ω ScTP cables specified in clauses K.4, K.5, and K.7. These performance specifications are only applicable when ScTP connecting hardware is terminated to 100 Ω ScTP cables.

K.6.2 Additional electrical requirements

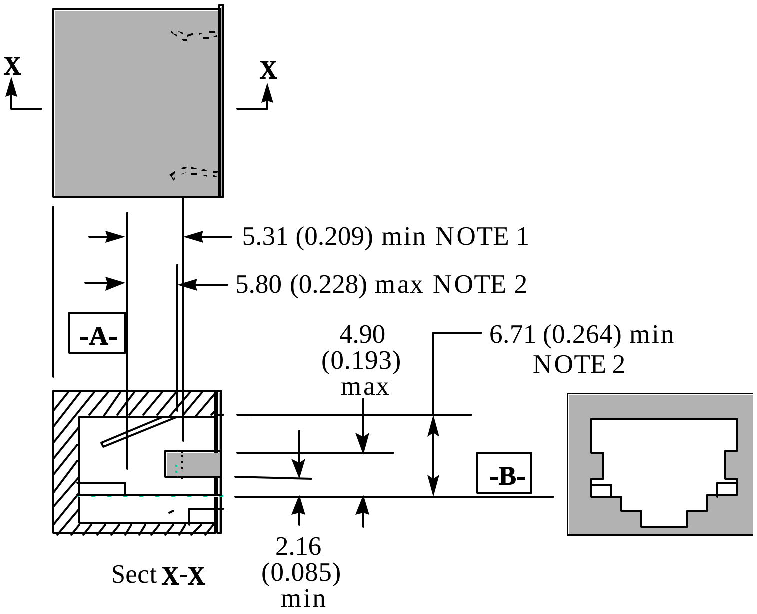
K.6.2.1 Transmission performance testing

A balun ground plane, allowed as an option in annex B, shall be provided as part of the test setup and apparatus, and the shield of the connecting hardware shall be bonded to the ground plane during the testing of transmission characteristics.

K.6.2.2 Shield mating, 8-position modular connectors

K.6.2.2.1 Shield mating interface

The shields of shielded 8-position modular connectors (plugs and jacks) shall be designed to ensure shield continuity when mated. The shield mating interface shall conform to the requirements in figure K.1. Dimensions are in mm (inches). Shields are represented by shaded areas.



Modular Jack

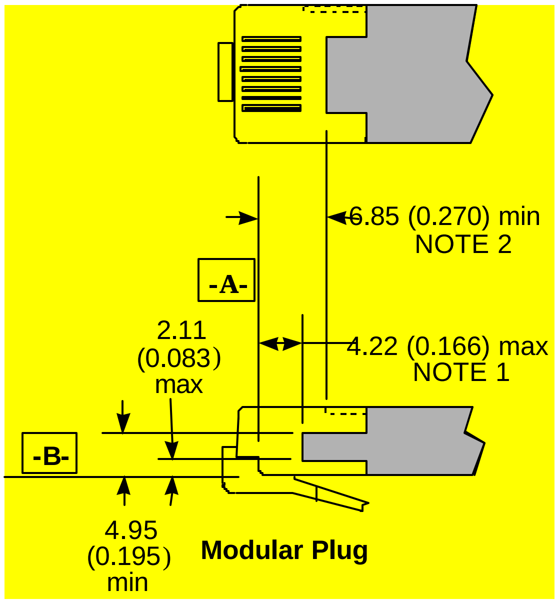


Figure K.1 -Shield interface requirements for 8-position modular connectors

NOTES,
1) For adequate contact wipe (sliding engagement between mating contacts), the plug and jack contact designs should provide a minimum of 2 mm (0.08 in) of contact wipe.
2) The jack contact positioning dimension in figure K-1 applies when mated to the plug. The dimensions provided in the figure will maintain clearance between the plug shield and jack contacts.

Modular jack shields shall not encroach upon the connector opening dimensions defined by IEC 60603-7 with the exception of shield mating contacts internal to the jack. Plug shields shall not extend beyond the plug housing dimensions defined by IEC 60603-7 in areas mating to the jack.

K.6.2.2.2 Shield mating reliability

The shield mating interface shall meet the applicable reliability requirements for connecting hardware with the exception that the interface resistance of the mated shield contacts or shield connection shall not exceed 20 mΩ initially and 40 mΩ after environmental testing or at the prescribed measurement intervals during or after environmental conditioning.

K.6.2.3 Shield continuity

Effective shielding requires that all cabling components be shielded, meeting the requirements for transfer impedance given in clauses K.4.3.2 or K.6.2.4, and that all shields be properly bonded. Shielding shall be continuous for the complete channel. Work area cords, cross-connect cords, equipment cords and the equipment connection, while not part of the generic cabling, shall provide shield continuity. ScTP telecommunications outlet/connectors shall be labeled or otherwise identified to differentiate them from UTP connectors and indicate the need for screened work area cords.

K.6.2.4 Shield transfer impedance

The shield transfer impedance of ScTP connecting hardware, measured in accordance with clause K.8 shall not exceed the values determined using the formula

$$Z_{Tconn} = 40\sqrt{f} \text{ from 1 MHz to 4 MHz} \qquad \text{(K-2)}$$

$$Z_{Tconn} = 20f \text{ from 4 MHz to 100 MHz} \qquad \text{(K-3)}$$

Where: Z_{Tconn} is the transfer impedance of the connecting hardware shield in mΩ
f is the frequency in MHz.

NOTE - The shielding efficiency of connecting hardware may also be measured as a dB change in the total emitted power of a length of cable before and after the connecting hardware is inserted into that length if the cable surface transfer impedance meets the requirements of clause K.4.3.2 and the maximum dB change can be demonstrated to be equivalent to the transfer impedance requirement.

The values in table K.2 are derived from equations (K-2) and (K-3) and are provided for information only.

Table K.2 - Maximum connecting hardware shield transfer impedance (mW)

Frequency MHz	Category 3 mW	Category 5e mW
1	40	40
4	80	80
10	200	200
16	320	320
20		400
100		2000

> NOTE - The maximum possible transfer impedance slope is 20 dB/decade and is evident when magnetic field coupling is the dominant coupling mode. A slope less than this value indicates a mixture of coupling modes. A slope of 10 dB/decade is characteristic at low frequencies when contact resistance at metallic contact points is the dominant coupling mode.

Compliant transfer impedance performance of cables and connecting hardware is not sufficient to ensure proper link and channel transfer impedance. Cable shields shall be terminated to the connecting hardware shields following manufacturer's instructions. The termination methods are dependent on the shield design of both the cable and the connecting hardware. Connecting hardware shall be supplied with instructions on applicable cable shield termination procedures.

K.7 100 W ScTP patch cords and cross-connect jumpers

K.7.1 Applicability

These requirements apply only to the wire or cables used for 100 Ω ScTP patch cords and cross-connect jumpers. Modular plugs and other connectors used for 100 Ω ScTP cable assemblies shall meet the requirements specified in clause K.6. ScTP work area cords, equipment cords, and patch cords shall meet the mechanical and transmission requirements for 100 Ω UTP patch cords in clause 6 except as modified by the additional requirements of clause K.7.2.

K.7.2 Additional general requirements

Cables used for 100 Ω ScTP patch cords and cross-connect jumpers shall consist of either 24 AWG or 26 AWG thermoplastic insulated stranded conductors enclosed by a shield meeting the requirements of clauses K.4.2 and K.4.3.

K.7.3 Additional electrical requirements

K.7.3.1 DC resistance

For 26 AWG conductors, the resistance of the conductors, measured in accordance with ASTM D 4566, shall not exceed 14 Ω per 100 m (328 ft) at or corrected to a temperature of 20°C.

K.7.3.2 Insertion loss

For cords or jumpers using stranded 26 AWG conductors, the insertion loss of any pair shall be less than or equal to the value computed by multiplying the result of the insertion loss equation in clause 4.3.4.7 by a factor of 1.5. This is to allow a 50% increase in insertion loss for stranded construction, AWG differences, and design differences. Table K.3 shows values of insertion loss at specific frequencies. Values for cords or jumpers using 24 AWG stranded conductors, taken from table K.3, are also shown for reference. These values are provided for information only and are derived using their respective computations.

Table K.3 - ScTP patch cable insertion loss @ 20 °C ± 3 °C (68 °F ± 5.5°F), worst pair

[dB per 100 m (328 ft) @ 20 °C]

Frequency (MHz)	Category 3		Category 5e	
	26 AWG	24 AWG	26 AWG	24 AWG
0.772	3.3	2.7	2.7	2.2
1	3.8	3.1	3.0	2.4
4	8.4	6.7	6.2	4.9
8	12.7	10.2	8.7	6.9
10	14.6	11.7	9.8	7.8
16	19.6	15.7	12.3	9.9
20	-	-	14.0	11.1
25	-	-	15.7	12.5
31.25	-	-	17.7	14.1
62.5	-	-	25.6	20.5
100	-	-	33.0	26.5

K.7.3.3 ScTP patch cord terminations

It shall be the responsibility of the patch cord manufacturer to ensure that the termination of shielded modular plugs follows the plug manufacturer's instructions.

K.7.4 Additional mechanical requirements

K.7.4.1 Flex life

Cables used for 100 Ω ScTP patch cords and cross-connect jumpers shall meet the transfer impedance requirements of this document after being subjected to 500 flex cycles. Flex tests shall be performed on a minimum of 1/3 meter (13 in) lengths of un-terminated cables. The cable sample shall be clamped to a rotatable arm and suspended between two 51 mm (2 in) diameter mandrels located to either side of the center of arm rotation and spaced so as to touch but not hold the cable sample. A weight exerting greater than 10 N (2 lbf) shall be attached to the free end of the cable. A flex cycle shall consist of one + 90° rotation around the mandrels, and the cycling rate shall be 10 cycles ± 2 cycles per minute.

K.8 Transfer impedance measurement method

K.8.1 General

This clause describes the measurement method used in verifying the shield transfer impedance requirements of 100 Ω ScTP connecting hardware contained in clause k.6.2.4. It is not intended for conformance testing of installed cabling. The measurement method requires the use of a network analyzer or equivalent, coaxial cables, ScTP test leads, impedance matching terminations, and a high frequency (HF) sealed case. The setup is qualified to a measurement bandwidth of at least 10 kHz to 100 MHz. Calibration procedures for insertion loss are specified by the manufacturer of the test equipment. Transfer impedance relates to the shielding efficiency (quality of shielding against influences by electromagnetic fields) of screened cables and connecting hardware. Transfer impedance values can be calculated from laboratory shielding insertion loss measurements collected using a HF sealed case (refer to clause K.8.2). The equivalent circuit diagram for the HF sealed case is shown in figure K.2.

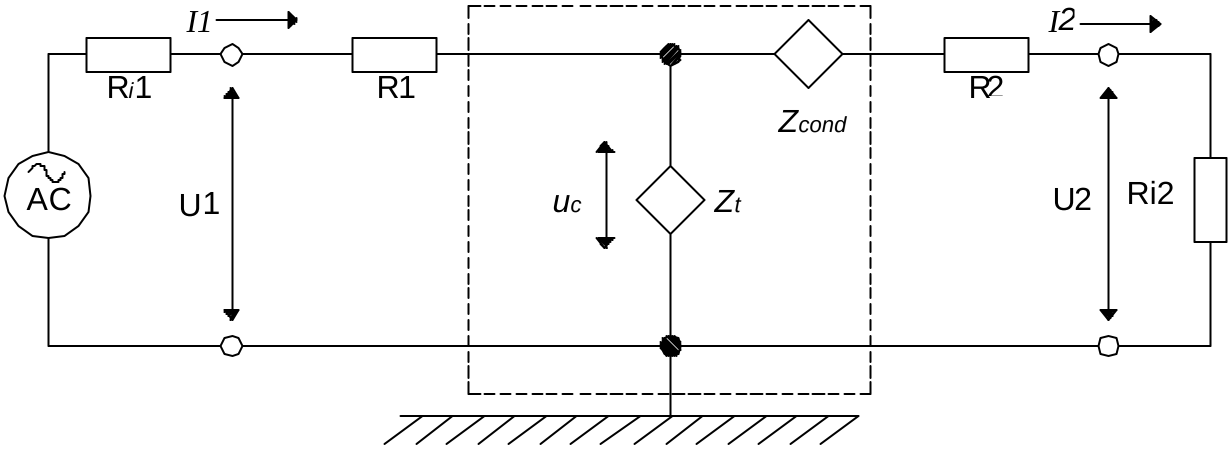


Figure K.2 - Equivalent circuit diagram for HF sealed case

Where:

Ri1 = Ri2 = characteristic impedance of the network analyzer = 50 Ω
R1 = feeding resistor = 50 Ω
R2 = terminating resistor = 50 Ω
U1 = transmitter voltage (volts)
U2 = receiver voltage (volts)
Uc = voltage across device under test (volts)
Zcond = characteristic impedance of conductors (Ω)
Zt = transfer impedance (Ω)

Under the following assumptions:

Zcond « R2, and
I2 « I1,

The following equations describe the circuit equation in figure K.3.

$$U1 = I1 \cdot R_i1 \qquad \text{(K-4)}$$

$$U2 = I2 \cdot R_i2 \qquad \text{(K-5)}$$

$$U_c = I2 \cdot (R2 + R_i2) \qquad \text{(K-6)}$$

$$U_c = Z_t \cdot I1 \qquad \text{(K-7)}$$

From a substitution operation follows:

$$Z_t = \frac{1}{l_{cable}} \cdot \frac{R_i1}{R_i2} \cdot (R2 + R_i2) \cdot \frac{U2}{U1} \qquad \text{(K-8)}$$

Measured shield insertion loss a_s, in decibels, is described by the relation:

$$a_s = 20 \cdot \log\left(\frac{U2}{U1}\right) dB \qquad \text{(K-9)}$$

By applying this relation and entering values for $R2$ and R_i2, the resultant transfer impedance in ohms is expressed as:

$$Z_t = 2 \cdot R_i 1 \cdot \frac{U2}{U1} = 2 \cdot R_i 1 \cdot 10^{\frac{a_s}{20}} = 100 \cdot 10^{\frac{a_s}{20}} \quad \Omega \qquad \text{(K-10)}$$

K.8.2 Test setup and apparatus

Equipment list:

- Network analyzer (50 Ω characteristic impedance)
- Coaxial adapters as required to make network analyzer port connections. Sub-miniature type A (SMA) adapters are recommended, however, other adapters may also be acceptable.
- HF sealed case
- Rosin core solder (Tin-Lead)
- Aluminum soldering flux
- Precision ±1% 50 Ω metal film resistors
- EMI/RFI foil shielding tape (adhesive backing optional)

Connecting hardware shall be tested with the cable shield construction with which it is designed to be used. If the connecting hardware is designed for several cable shield constructions, it shall be tested with the construction of single foil with drain wire. The diagrams in figure K.3 and figure K.4 provide a detailed reference to the dimensional characteristics of the HF sealed case. The HF sealed case shall be constructed from sheet copper or brass of 2 mm (0.08 in) minimum thickness.

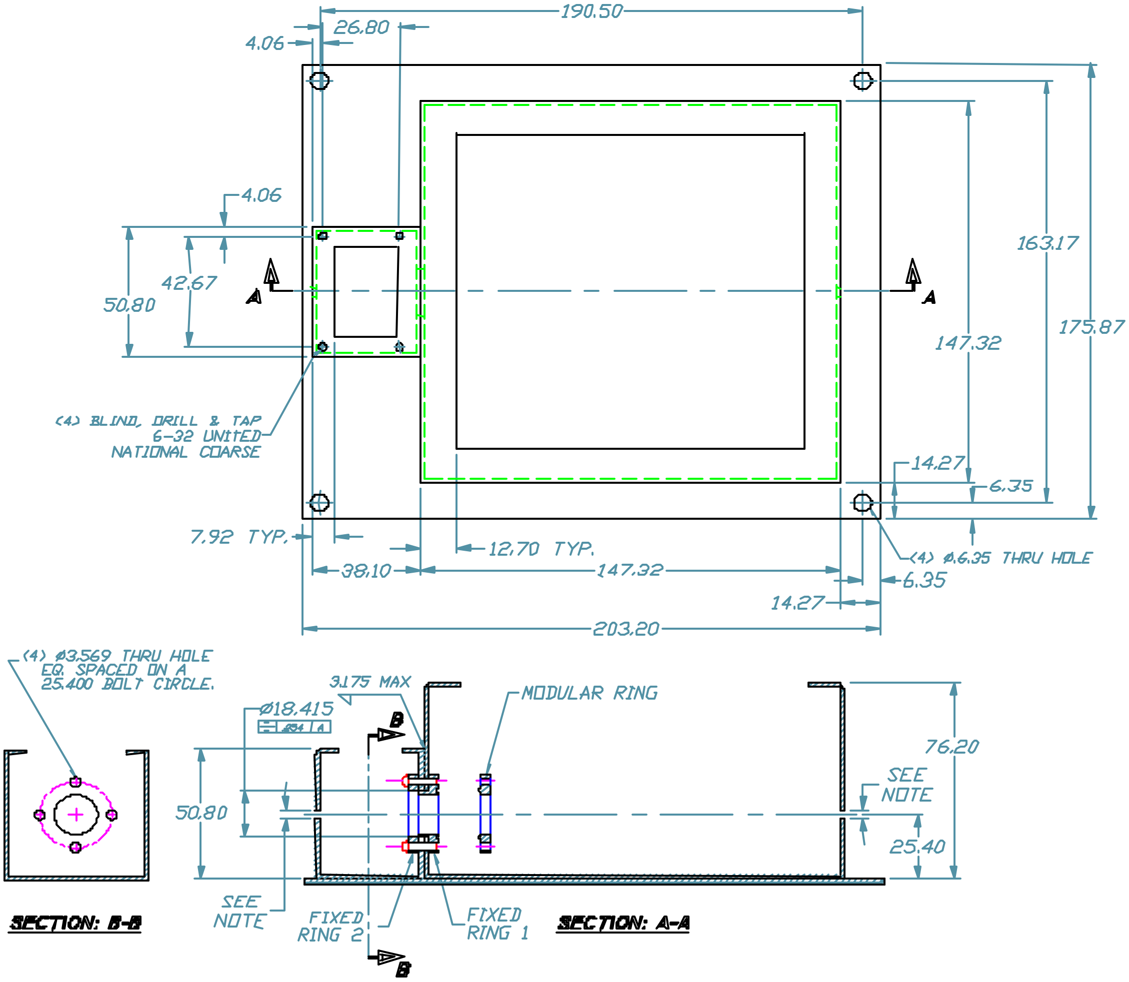


Figure K.3 - HF sealed case dimensional characteristics

(Dimensions are in mm)

NOTE - A coaxial adapter (not shown) is mounted on each end of the HF sealed case at the locations indicated for connection to a network analyzer. A 50 Ω ± 1% metal film resistor (not shown) is soldered to the center conductor of each adapter inside the HF sealed case in order to match the characteristic impedance of the network analyzer and minimize cable to fixture power loss.

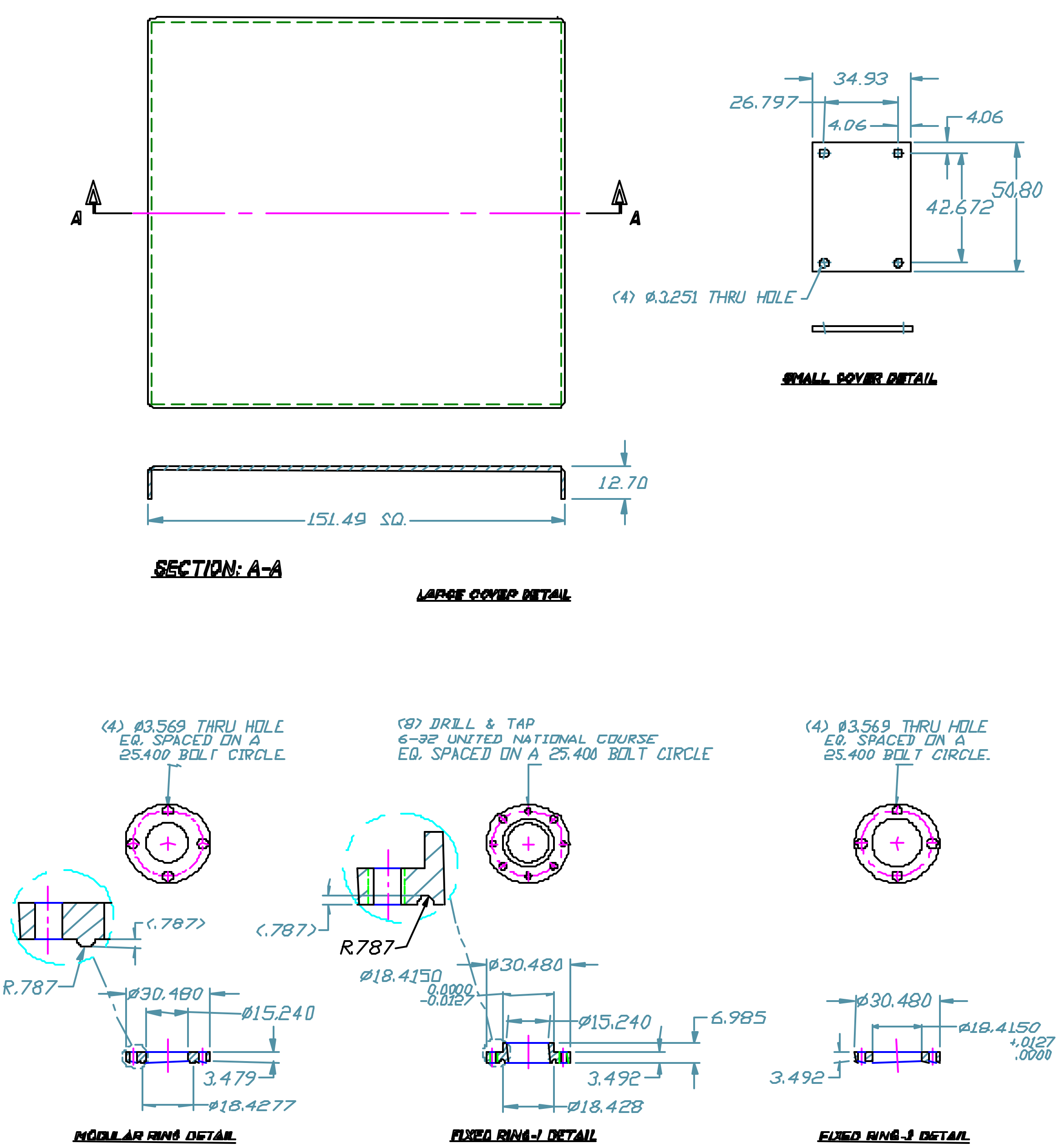


Figure K.4 - HF sealed case covers, fixed and modular ring details

(Dimensions are in mm)

K.8.3 Test method

K.8.3.1 Connecting hardware and cable preparation

Products under test may consist of ScTP connecting hardware terminated on either end by 75 mm (3 in) lengths of ScTP cable. Connecting hardware intended to be mated with a shielded modular plug shall be terminated with 75 mm (3 in) of ScTP patch cable on the mated plug end and 75 mm (3 in) of ScTP horizontal cable terminated to the insulation displacement contact (IDC) end.

1. The device under test is prepared by designating one end of the connecting hardware (typically, the stranded cable/shielded modular plug end for mated plug/jack connectors) as the ‘input’ end and the opposite end as the ‘output’ end.
2. Strip off 25 mm (1 in) of jacket from the ‘input’ end of the product sample.
3. Carefully peel back the foil, drain wire, and braid (if present) from the input end. Remove any secondary insulator materials (e.g. dielectric wrap) surrounding the twisted-pair conductors. Strip off 15 mm (0.5 in) of insulation from each of the inner conductors. Twist the exposed copper ends together and solder to form a fused conductor core. Snip 7 mm (.25 in) from the tips of the soldered conductor core.
4. Solder the drain wire to the fused conductor core
5. Fold the shielding materials over the soldered conductor core and drain wire. Solder shielding materials to the conductor core such that a 360º solder contact (use aluminum soldering flux if necessary) is present. Foil or braid should not extend beyond the fused conductors. To maintain shield integrity during testing and handling, tightly wrap a piece of heat resistant tape around the unjacketed portion of the screened cable under test (optional). Any metallic tape should not make contact with the connections.
6. Affix a 25 mm (1 in) square or circular segment of EMI/RFI foil tape to the grooved side of the modular ring (reference figure K.5). Punch a hole the diameter of the screened cable under test through the middle of the foil tape.
7. Pass the ‘output’ end of the stripped cable portion through the modular ring and through the hole in the EMI/RFI foil tape (maintain the proper modular ring orientation such that the foil tape and modular ring groove will be in direct contact with the fixed ring upon assembly).
8. Carefully peel back the cable foil, drain wire, and braid (if present) and lay flat against the foil taped modular ring. Trim back excess shielding materials such that there is no interference with the modular ring groove. Solder shielding materials to the foil tape such that a 360º solder contact (use aluminum solder flux if necessary) is present.
9. Strip 15 mm (0.5 in) from the insulation of each of the inner conductors. Twist the exposed copper ends together and solder to form a fused conductor core. This fused core shall not be in contact with the shield or the test fixture on the output end.
10. Insert the prepared sample under test into the main case (the larger of the two HF sealed case enclosures). Fasten the modular ring to the fixed ring using four screws (‘finger-tight’).
11. Solder the conductor core of the ‘input’ side of the sample under test to the 50 Ω ± 1% terminating resistor located inside the main case.
12. Solder the conductor core of the ‘output’ side of the sample under test to the 50 Ω ±1% terminating resistor located inside the secondary case (the smaller of the two HF sealed case enclosures).

K.8.3.2 Calibration and measurement

Perform a ‘through’ normalization calibration on the network analyzer to compensate for the insertion loss of the 50 Ω coaxial test leads. Connect the transmit coaxial test lead to the input coaxial adapter of the main case and connect the receive coaxial test lead to the output coaxial adapter of the secondary case. Perform a shield insertion loss measurement. Calculate the corresponding transfer impedance from the shielding insertion loss.

K.8.4 Measurement reliability tests

K.8.4.1 Test orientation summary

Swapping the input and output side of the network analyzer should not change the results by more than 4%.

K.8.4.2 AC and DC resistance correlation

When connected correctly, the DC resistance (measured with a milli-ohmmeter) of the device under investigation shall correlate to the AC resistance at low frequencies (i.e. 10 kHz) to within ±20%.

K.8.4.3 Open shield test

The results of performing an open test (shield on the output side left unconnected) should be a flat insertion loss waveform correlating to a transfer impedance of 50 Ω ± 4%.

K.8.4.4 Measurement slope verification

The slope of the measured shield insertion loss should be between 18 dB/decade and 20 dB/decade above 10 MHz.

K.8.5 Product compliance testing

Connecting hardware used for product compliance shall be terminated per manufacturer-provided guidelines and manufacturer-recommended installation methods. Product compliance shall be determined using worst case measured values based on a minimum of five (5) of each component (i.e. 5 plugs and 5 jacks) in a minimum of ten (10) combinations total. All test specimens shall be randomly selected from production samples. It is recommended that test plugs be assembled in the test laboratory.

Annex L Derivation of propagation delay from insertion loss equation (informative)

L.1 Factoring the insertion loss equation

Factoring the insertion loss equation

The transmission line complex propagation constant, γ, is defined in terms of the distributed transmission line parameters, R, L, G and C, as:

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = \alpha + j\beta \tag{L-1}$$

Factoring out the term, $j\omega\sqrt{LC}$, the expression for γ may be written,

$$\gamma = j\omega\sqrt{LC}\sqrt{\left(1 + \frac{R}{j\omega L}\right)\left(1 + \frac{G}{j\omega C}\right)} \tag{L-2}$$

Multiplying out the terms in equation. (L-2):

$$\gamma = j\omega\sqrt{LC}\sqrt{1 - \frac{RG}{\omega^2 LC} + \frac{R}{j\omega L} + \frac{G}{j\omega C}} \tag{L-3}$$

At high frequencies, R << ωL, and G << ωC, dropping the ω^2 term

$$\gamma \approx j\omega\sqrt{LC}\sqrt{1 + \frac{R}{j\omega L} + \frac{G}{j\omega C}} \tag{L-4}$$

Since R << ωL, and G << ωC, we can further approximate equation (L-4), by:

$$\gamma \approx j\omega\sqrt{LC}\left[1 + \frac{R}{j2\omega L} + \frac{G}{j2\omega C}\right] \tag{L-5}$$

So the approximation for γ, explicitly showing α and β becomes:

$$\gamma = \alpha + j\beta \approx j\omega\sqrt{LC}\left[1 + \frac{R}{j2\omega L} + \frac{G}{j2\omega C}\right] \tag{L-6}$$

Multiplying out the terms in equation (L-6), we have:

$$\gamma = \alpha + j\beta \approx \left[\frac{R}{2}\sqrt{\frac{C}{L}} + \frac{G}{2}\sqrt{\frac{L}{C}}\right] + j\omega\sqrt{LC} \tag{L-7}$$

Separating real and imaginary parts in equation (L-7) we have:

$$\alpha \approx \left[\frac{R}{2}\sqrt{\frac{C}{L}} + \frac{G}{2}\sqrt{\frac{L}{C}}\right] \tag{L-8}$$

$$\beta \approx \omega\sqrt{LC} \tag{L-9}$$

Explicitly writing the expression for the transmission line's distributed inductance, L, in terms of its external and internal inductance, $L = L_\infty + L_{INT}$, where:

$$L = L_\infty + L_{INT} = L_\infty \left[1 + \frac{R}{\omega L_\infty} \right] \tag{L-10}$$

Substituting the expression for L given above, into equation (L-8):

$$\alpha \approx \left[\frac{R\sqrt{C}}{2\sqrt{L_\infty \left[1 + \frac{R}{\omega L_\infty} \right]}} + \frac{G}{2}\sqrt{\frac{L}{C}} \right] \tag{L-11}$$

Factoring out $\sqrt{L_\infty}$, from the denominator of the first part of equation (L-11):

$$\alpha \approx \left[\frac{R\sqrt{C}}{2\sqrt{L_\infty}\sqrt{\left[1 + \frac{R}{\omega L_\infty} \right]}} + \frac{G}{2}\sqrt{\frac{L}{C}} \right] \tag{L-12}$$

For $\left(\frac{R}{\omega L_\infty} \right) << 1$, $\frac{1}{\sqrt{\left[1 + \frac{R}{\omega L_\infty} \right]}}$ may be further approximated by:

$$\frac{1}{\sqrt{\left[1 + \frac{R}{\omega L_\infty} \right]}} \approx \left[1 - \frac{R}{2\omega L_\infty} \right] \tag{L-13}$$

Applying this approximation for $\frac{1}{\sqrt{\left[1 + \frac{R}{\omega L_\infty} \right]}}$ in equation (L-12):

$$\alpha \approx \left[\frac{R\sqrt{C}}{2\sqrt{L_\infty}} \left[1 - \frac{R}{2\omega L_\infty} \right] + \frac{G}{2}\sqrt{\frac{L}{C}} \right] \tag{L-14}$$

Multiplying out the terms in equation (L-14):

$$\alpha \approx \left[\underset{(1)}{\frac{R\sqrt{C}}{2\sqrt{L_\infty}}} - \underset{(2)}{\frac{R^2\sqrt{C}}{4\omega\left(L_\infty\right)^{3/2}}} + \underset{(3)}{\frac{G}{2}\sqrt{\frac{L}{C}}} \right] \tag{L-15}$$

In equation (L-15), the value for the loss term, R, in the first term, comes mainly from the skin effect at high frequencies, which has a square root dependence upon the signal frequency: $R \propto \sqrt{f}$. In the third term, G is the dielectric dissipation term, $G = \omega C \tan\delta$, where tan δ is the loss tangent for the dielectric.

Applying these relationships, and using $\omega = 2\,\pi\,f$ to equation (L-15):

$$\alpha \approx \left[\frac{R\left(\sqrt{f}\right)}{2}\sqrt{\frac{C}{L_\infty}} - \frac{\left(R\left(\sqrt{f}\right)\right)^2\sqrt{C}}{4\,(2\,\pi\,f)\,(L_\infty)^{3/2}} + \frac{(2\,\pi\,f)\,C\tan\delta}{2}\sqrt{\frac{L}{C}} \right] \qquad \text{(L-16)}$$

The first term containing R exhibits a root frequency dependence. This is the copper loss term, k1, in the formula given in clause 4.3.4.7. Noting the root frequency dependence of R, the second term is independent of frequency. It is so small that it may be neglected. The third term, containing G, exhibits a direct frequency dependence. This is the material dissipation loss term, k2, in the formula given in clause 4.3.4.7.

L.2 Developing the phase delay equation

The expression for the phase delay is given by:

$$\text{Delay} = \frac{b}{w} = \sqrt{L\,C} \qquad \text{(L-17)}$$

Substituting, for $L = L_\infty + L_{INT} = L_\infty\left[1 + \frac{R}{\omega L_\infty}\right]$

$$\text{Delay} = \frac{b}{w} = \sqrt{L_\infty\left[1 + \frac{R}{w\,L_\infty}\right]C} \qquad \text{(L-18)}$$

Applying the approximation for $\left(\frac{R}{\omega L_\infty}\right) << 1$, $\sqrt{\left[1 + \frac{R}{\omega L_\infty}\right]}$ may be written as:

$$\sqrt{\left[1 + \frac{R}{\omega L_\infty}\right]} \approx 1 + \frac{R}{2\,\omega L_\infty} \qquad \text{(L-19)}$$

Then the expression for delay may be written:

$$\frac{\beta}{\omega} = \sqrt{C\,L_\infty}\left[1 + \frac{R}{2\,\omega\,L_\infty}\right] \qquad \text{(L-20)}$$

Multiplying out equation (L-20):

$$\frac{\beta}{\omega} = \sqrt{C\,L_\infty} + \frac{R}{2\,\omega}\sqrt{\frac{C}{L_\infty}} \qquad \text{(L-21)}$$

Writing the expression for delay to indicate the frequency dependent terms:

$$\frac{\beta}{\omega} = \sqrt{C\,L_\infty} + \frac{R\left(\sqrt{f}\right)}{2\,(2\,\pi\,f)}\sqrt{\frac{C}{L_\infty}} \qquad \text{(L-22)}$$

Since C and L_∞ are independent of frequency, the first term in equation (L-22) is a constant. The second term has a $1/\sqrt{f}$ frequency dependence, due to the ratio of $\frac{R(\sqrt{f})}{f}$ which results in the following expression for delay:

$$Delay = \frac{\beta}{\omega} = \text{Const} + \frac{k1/8.686}{2\pi\sqrt{f}} \qquad \text{(L-23)}$$

The units for delay in equation (L-23) are s/100m (seconds/100m), with frequency, f, expressed in MHz. Note that for constant capacitance cables, this approximation for delay holds, independently of wire gauge and cable impedance.

If the insertion loss is known, the rate of decrease in delay as a function of frequency is also known.

Using the defined k1 coefficient for category 5e cables we find:

$$\text{Delay(ns/100m)} = \text{Const} + \frac{36}{\sqrt{f_{MHz}}} \qquad \text{(L-24)}$$

Note that K1, for category 5e, is 1967 for *f* in Hz.

By anchoring the delay at *f* = 1 MHz, to be 570 ns/100m, we find:

$$\text{Delay(ns/100m)} = 534 + \frac{36}{\sqrt{f_{MHz}}} \qquad \text{(L-25)}$$

In these equations, the following terms are defined as:

R = Resistance per unit length of cable

L = Inductance per unit length of cable

L_∞ = External inductance per unit length of cable

L_{INT} = Internal inductance per unit length of cable

G = Conductance per unit length of cable

C = Capacitance per unit length of cable

α = Insertion loss constant per unit length of cable

β = Phase constant per unit length of cable

f = Frequency in Hertz

f_{MHz} = Frequency in MHz

$\omega = 2\pi f$ = radian frequency in radians/second

Annex M 150 W shielded twisted-pair cabling (normative)

M.1 General

The requirements in this annex are for 150 Ω STP-A cabling components.

150 Ω STP-A cable is assembled using 2 pairs of 22 AWG insulated copper wires, individual pair shields, and an overall braided copper screen.

150 Ω STP-A cabling mates with connecting hardware as specified in ANSI/IEEE 802.5 and IEC 60807-8.

150 Ω STP-A Component transmission requirements performance shall be determined using impedance matching baluns with 50 Ω unbalanced (primary) and 150 Ω balanced (secondary) ports as specified in clause M.8.

150 Ω STP-A cabling transmission requirements performance shall be determined according to ANSI/TIA/EIA-568-B.1 using impedance matching transformers with 100 Ω balanced (primary) and 150 Ω balanced (secondary) ports as specified in clause M.8.

150 Ω STP-A cabling shall meet the requirements of 100 Ω UTP cabling (ANSI/TIA/EIA-568-B.2) and 100 Ω ScTP cabling as specified in K with the following exceptions.

M.2 Horizontal 150 W STP-A cable

Horizontal 150 Ω STP-A cable shall meet the requirements of clause 4.3 and annex K with the additional requirements of clauses M.1 through M.4.

M.2.1 Mechanical requirements

M.2.1.1 Insulated conductor

The diameter of the insulated conductor shall not exceed 2.6 mm (0.1 in).

M.2.1.2 Pair assembly

The cable shall be assembled with two pairs.

M.2.1.3 Color code

Cable shall meet the color code given in table M.1.

Table M.1 - Horizontal 150 W STP-A cable color code

Conductor Identification	Color Code
Pair 1	Red - Green
Pair 2	Orange - Black

M.2.1.4 Cable diameter

The diameter of the completed cable shall be less than or equal to 11 mm (0.4 in).

M.2.1.5 Marking

The cable should be marked with “150 Ω STP-A”.

M.2.1.6 Backbone 150 W STP-A cable

The requirements for backbone 150 Ω STP-A cable shall be the same as the requirements given for horizontal 150 Ω STP-A cable.

M.3 Transmission requirements

M.3.1 DC resistance

The DC resistance of any conductor measured in accordance with ASTM D4566 and corrected to a temperature of 20 °C shall not exceed 5.71 Ω/100 m (Ω/328 ft).

M.3.2 Characteristic impedance and return loss

Structural return loss requirements are not applicable to 150 Ω STP-A cable. Characteristic Impedance shall be 150 Ω ± 10% from 1 MHz to 300 MHz when measured in accordance with ASTM D4566. Cable return loss shall meet or exceed the values determined by the equations given in table M.2 when measured in accordance with ASTM D4566.

Table M.2 - Horizontal 150 W STP-A cable return loss

$1 \le f < 10$	$20 + 4\log(f)$ dB	(M-1)
$10 \le f < 20$	24 dB	(M-2)
$20 \le f < 300$	$24 - 10\log(f/20)$ dB	(M-3)

M.3.3 Insertion loss

For all frequencies from 1MHz to 300 MHz, cable insertion loss shall meet the values determined by equation (M-4) when measured in accordance with ASTM D4566.

$$InsertionLoss_{cable,100m} \le 1.067\sqrt{f} + 0.018 \cdot f + \frac{0.18}{\sqrt{f}} \text{ dB/100 m (328 ft)} \tag{M-4}$$

M.3.4 Near-end crosstalk (NEXT) loss

For all frequencies from 1MHz to 300 MHz, cable NEXT loss shall meet the values determined by equation (M-5) when measured in accordance with ASTM D4566.

$$NEXT_{cable.100m} \ge 38.5 - 15\log(f/100) \text{ dB} \tag{M-5}$$

M.3.5 Equal level far-end crosstalk (ELFEXT)

ELFEXT requirements are not applicable to 150 Ω STP cabling cable components.

M.4 Connecting hardware for 150 W STP-A cable

Connecting hardware for 150 Ω STP-A cable shall meet the requirements of clauses 5 and K.6 with the additional requirements of clauses M.4.1 through M.4.2.3.

M.4.1 Mechanical requirements

The connector shall meet the interface requirements specified in IEC 60807-8

M.4.2 Transmission requirements

Connecting hardware for 150 Ω STP-A cable shall meet the transmission requirements specified in ANSI/IEEE 802.5, IEC 60807-8, IEC 60603-7 and the following additional requirements.

M.4.2.1 Insertion loss

For all frequencies from 1 MHz to 300 MHz, connector insertion loss shall meet the values determined by equation (M-6) when measured in accordance with clause C.1, except using 150 Ω test leads.

$$InsertionLoss_{conn} \le 0.025\sqrt{f} \ \ dB \qquad \text{(M-6)}$$

M.4.2.2 NEXT loss

For all frequencies from 1MHz to 300 MHz, connector NEXT loss shall meet the values determined by equation (M-7) when measured in accordance with clause C.2, except using 150 Ω test leads.

$$NEXT_{conn} \ge 46.5 - 20\log(f/100) \ \ dB \qquad \text{(M-7)}$$

M.4.2.3 Return loss

For all frequencies from 1MHz to 300 MHz, connector return loss shall meet the values determined by the equations given in table M-3 when measured in accordance with clause C.4, except using 150 Ω test leads.

Table M.3 - 150 W STP-A connector return loss

$1 \le f < 16$	36 dB	(M-8)
$16 \le f < 300$	36 - 20log(f / 16) dB	(M-9)

M.4.2.4 Far-end crosstalk (FEXT) loss

FEXT loss requirements are not applicable to 150 Ω STP cabling connecting hardware components.

M.4.3 Shielding effectiveness

For all frequencies from 1MHz to 1000 MHz, connector shielding effectiveness shall meet the values determined by the equations given in table M.4 when measured in accordance with coupling insertion loss test method given in IEC 60603-7.

Table M.4 - Shielding effectiveness 150 W STP-A connector

$1 \le f \le 400$	87 – 25 log(f) dB	(M-10)
$400 < f \le 1000$	22 dB	(M-11)

M.4.4 Marking

The connector should be marked with the designation “E”

M.5 150 W STP-A patch cords

150 Ω STP-A patch cable shall meet the requirements of clauses M.2, 4.5 and K.7 with the additional requirements of M.5.1 through M.5.2.3.

M.5.1 Mechanical requirements

M.5.1.1 Insulated conductor

The conductor shall be 26 AWG stranded tin-coated copper. The diameter of the insulated conductor shall not exceed 1.9 mm (0.075 in).

M.5.1.2 Cable diameter

The diameter of the completed cable shall be less than or equal to 9.5 mm (0.374 in).

M.5.2 Transmission requirements

M.5.2.1 DC resistance

The DC resistance of any conductor, measured in accordance with ASTM D 4566 and corrected to a temperature of 20 °C, shall not exceed 14.5 Ω /100 m (Ω /328 ft).

M.5.2.2 Insertion loss

For all frequencies from 1MHz to 300 MHz, cable insertion loss shall meet the values determined by equation (M-12) when measured in accordance with ASTM D 4566.

$$InsertionLoss_{cable,100m} \leq 1.614\sqrt{f} + 0.018 \cdot f + \frac{0.18}{\sqrt{f}} \text{ dB/100 m (328 ft)} \qquad \text{(M-12)}$$

M.5.2.3 NEXT

For all frequencies from 1MHz to 300 MHz, cable NEXT loss shall meet the values determined by equation (M-13) when measured in accordance with ASTM D 4566.

$$NEXT_{cable,100m} \geq 32.5 - 15\log(f/100) \text{ dB} \qquad \text{(M-13)}$$

M.6 Reliability testing of connecting hardware used for 150 W STP cabling

150 Ω STP cabling connecting hardware components shall satisfy the requirements of annex A.

M.7 Transmission testing of connecting hardware used for 150 W STP cabling

150 Ω STP cabling connecting hardware shall be tested according to the requirements of IEC 60807-8 and ANSI/IEEE 802.5.

M.8 Test instruments

150 Ω STP cabling links are tested in the field using level IIe field test instruments. 150 Ω STP cabling links are adapted to the 100 Ω UTP cabling field test instrument by means of transformers (2:3) inserted in test instrument adapter cords. The requirements for 100 Ω UTP cabling field test instruments apply to 150 Ω STP cabling and are found in ANSI/TIA/EIA-568-B.1.

M.9 Reference measurement procedures

150 Ω STP cables shall be measured in accordance with annex C, connecting hardware in accordance with annexes D and E and clauses M.9.1 and M.9.2.

M.9.1 Test setup and apparatus

M.9.1.1 Test setup

The test setup provides for the termination of two pairs.

M.9.1.2 Balun requirements

The balun secondary impedance shall be 150 Ω (balanced).

M.9.1.3 Balun and test lead qualification

The balun termination resistor shall be 150 Ω.

M.9.1.4 Impedance matching terminations

The termination of pairs during measurements shall be 150 Ω. The common mode terminations may be a resistor network of 50 Ω resistors in a “Y” configuration. The differential resistors shall be 75 Ω.

M.9.2 Test adapters

Test adapters shall be constructed using 150 Ω STP connecting hardware.

M.10 150 W STP cabling screen requirements references to ScTP

150 Ω STP cabling conforms to the requirements of 100 Ω ScTP cabling insofar as shield related requirements with the following exceptions.

M.10.1 150 W STP horizontal cable

M.10.1.1 Bending radius

The 150 Ω STP horizontal cable shall conform to the bending radius of clause K.4.2.3.

M.10.1.2 Dielectric strength

The 150 Ω STP horizontal cable shall conform to the dielectric strength requirements of clause K.4.3.1.

M.10.1.3 Surface transfer impedance

The 150 Ω STP horizontal sable shield shall conform to the surface transfer impedance requirements of clause K.4.3.2.

M.10.2 150 W STP connecting hardware screen

The 150 Ω STP connecting hardware conforms to requirements entirely independent of 100 Ω ScTP.

M.10.3 150 W STP patch cable screen

The 150 Ω STP patch cable conforms to requirements entirely independent of 100 Ω ScTP.

Annex N Category 5 cabling (informative)

N.1 Introduction

Category 5 cabling has been superseded by category 5e cabling. This annex lists category 5 component and cabling transmission parameters. The information in this clause comes from ANSI/TIA/EIA-568-A and TSB95 and is provided for reference for “legacy” installations.

N.2 Purpose and scope

The purpose of this annex is to detail existing category 5 component cabling systems performance. Field testing for category 5 cabling should be conducted in the same manner as field testing for category 5e cabling, using the transmission parameters in this annex.

N.3 Transmission parameters

N.3.1 Mutual capacitance

Mutual capacitance information is provided for engineering design.

N.3.1.1 Category 5 horizontal 100 Ω UTP cable

The mutual capacitance of any pair at 1 kHz and measured at, or corrected to, a temperature of 20 °C, should not exceed 5.6 nF per 100 m (328 ft) when measured in accordance with ASTM D 4566.

N.3.1.2 Category 5 backbone 100 Ω UTP cable

The mutual capacitance of any pair at 1 kHz and measured at, or corrected to, a temperature of 20 °C, should not exceed 5.6 nF per 100 m (328 ft) when measured in accordance with ASTM D 4566.

N.3.2 Category 5 structural return loss (SRL)

N.3.2.1 Category 5 horizontal 100 Ω UTP cable

From 1 MHz to 100 MHz, the SRL for category 5 horizontal 100 Ω UTP cables should meet or exceed the values determined using the equations in table N.1.

Table N.1 - Category 5 horizontal cable structural return loss, worst pair

For a length of 100 m (328 ft)

Frequency (f) (MHz)	Category 5 (dB)
$1 \le f < 20$	23
$20 \le f \le 100$	$16 - 10 \log(f / 100)$

(N-1)

N.3.2.2 Category 5 backbone 100 Ω UTP cables

From 1 MHz to 100 MHz, the SRL for category 5 backbone 100 Ω UTP cables should meet or exceed the values in table N.2.

Table N.2 - Category 5 backbone cable structural return loss, worst pair

For a length of 100 m (328 ft)

Frequency (f) (MHz)	Category 5 (dB)	
1 ≤ f < 20	23	
20 ≤ f ≤ 100	16 – 10 log(f / 100)	(N-2)

N.3.3 Category 5 return loss

N.3.3.1 Category 5 horizontal 100 W UTP cable

The return loss of category 5 horizontal 100 Ω UTP cables should meet or exceed the values determined using the equations specified in table N.3.

Table N.3 - Category 5 horizontal cable return loss @ 20 °C ± 3 °C (68 °F ± 5.5°F), worst pair

For a length of 100 m (328 ft)

Frequency (f) (MHz)	Category 5 (dB)	
1≤ f < 10	17 + 3log(f)	(N-3)
10 ≤ f< 20	20	
20 ≤ f ≤ 100	20 – 7log(f / 20)	(N-4)

N.3.3.2 Category 5 connecting hardware for 100 W UTP cable

For category 5 connectors, from 1 MHz to 100 MHz, the minimum return loss should be 23 dB or greater for all frequencies between 1 MHz and 20 MHz. For all frequencies from 20 MHz to 100 MHz, category 5 connectors, should exhibit a minimum return loss of 14 dB or greater. These return loss values were chosen to limit peak reflected voltages to 7% or less up to 20 MHz and to 20% or less from 20 MHz to 100 MHz.

N.3.4 Category 5 insertion loss

N.3.4.1 Category 5 horizontal 100 W UTP cable

From 1 MHz to 100 MHz, the maximum category 5 insertion loss of any cable pair, in dB per 100 m, measured at, or corrected to, a temperature of 20 °C in accordance with ASTM D4566 should be less than or equal to the value determined using equation (N-5).

$$InsertionLoss_{cable,100m} \le 1.967\sqrt{f} + 0.023 \cdot f + \frac{0.050}{\sqrt{f}}\,\mathrm{dB} \tag{N-5}$$

N.3.4.2 Category 5 backbone 100 W UTP cable

From 1 MHz to 100 MHz, the maximum category 5 insertion loss of any cable pair, in dB per 100 m, measured at, or corrected to, a temperature of 20 °C in accordance with ASTM D 4566 should be less than or equal to the value determined using equation (N-6).

$$InsertionLoss_{cable,100m} \leq 1.967\sqrt{f} + 0.023 \cdot f + \frac{0.050}{\sqrt{f}} \text{dB} \qquad \text{(N-6)}$$

N.3.4.3 Category 5 connecting hardware for 100 W UTP cable

Worst case insertion loss of any pair within a category 5 connector should not exceed the values listed in table N-4 at each specified frequency for a given performance category.

Table N.4 - Category 5 connecting hardware insertion loss, worst pair

Frequency (MHz)	Category 5 (dB)
1.0	0.1
4.0	0.1
8.0	0.1
10.0	0.1
16.0	0.2
20.0	0.2
25.0	0.2
31.25	0.2
62.5	0.3
100.0	0.4

N.3.4.4 Category 5 100 W UTP patch cords

Category 5 UTP patch cords should have stranded conductors. For stranded wire cables, the insertion loss of any pair should be less than or equal to the value computed by multiplying the result of the insertion loss equation (N-6) by a factor of 1.2 for all frequencies (f) in MHz from 0.772 MHz to 100 MHz.

N.3.5 Category 5 near-end crosstalk (NEXT) loss

In order to limit the crosstalk coupled onto a pair from an adjacent disturbing pair, NEXT loss and ELFEXT requirements are specified. The crosstalk parameters are specified on a worst case pair-to-pair basis. NEXT loss decreases as the frequency increases.

N.3.5.1 Category 5 horizontal 100 W UTP cables

N.3.5.1.1 Category 5 horizontal 100 W UTP cables NEXT loss

From 1 MHz to 100 MHz, the minimum category 5 NEXT loss for any pair combination at room temperature should be greater than the value determined using equation (N-7).

$$NEXT_{cable,100m} \geq 32.3 - 15\log(f/100) \ \textit{dB} \qquad \text{(N-7)}$$

N.3.5.1.2 Category 5 horizontal 100 W UTP cables pair-to-pair FEXT or ELFEXT loss

From 1 MHz to 100 MHz, category 5 ELFEXT should meet the values determined using equation (N-8).

$$ELFEXT_{cable,100m} \geq 20.8 - 20\log(f/100) \ \textit{dB/100 m (328 ft)} \qquad \text{(N-8)}$$

N.3.5.2 Category 5 backbone 100 W cables

N.3.5.2.1 Category 5 backbone 100 W cables power sum near-end cross talk (PSNEXT) loss

From 1 MHz to 100 MHz, the minimum category 5 power sum NEXT loss within a 25-pair binder group, tested in accordance with ASTM D4566, shall be greater than the value determined using equation (N-9).

$$PSNEXT_{cable,100m} \geq 32.3 - 15\log(f/100)\ dB \qquad \text{(N-9)}$$

N.3.5.3 Category 5 connecting hardware

N.3.5.3.1 Category 5 connecting hardware NEXT loss

From 1 MHz to 100 MHz, the worst case category 5 NEXT loss for any combination of disturbing and disturbed pairs should be determined using equation (N-10).

$$NEXT_{conn} = 40 - 20\log(f/100)\ dB \qquad \text{(N-10)}$$

Connecting hardware NEXT should be tested per annex D using TOC test plugs qualified per clause N.3.5.3.2.

N.3.5.3.2 TOC test plug qualification

Once the test plug is terminated, its characteristics should be verified by measuring its crosstalk loss in an unmated state with 100 Ω resistors connected in parallel with 100 Ω test leads where they connect to the baluns. For each of the six (6) test plug pair combinations, connect a 100 Ω resistor in parallel with the test leads (where they connect to the baluns) and measure NEXT as shown in figure N.1. In order to minimize inductive effects, the resistor leads should be kept as short as possible [5 mm (0.2 in) or less per side]. For each of the six (6) pair combinations, the measured NEXT loss of the open circuit plug, with 100 Ω resistors connected in parallel with the UTP test leads, shall measure in the range shown in table N.5. This measurement is sometimes referred to as a "terminated open circuit" or TOC test. In addition, for pin combination 4&5 - 3&6, the difference between the NEXT loss measured at 100 MHz and the NEXT loss measured at 10 MHz for this setup shall be 20 ± 0.5 dB.

Table N.5 - Category 5 test plug NEXT loss requirements

Pin combination	Test plug NEXT loss at 100 MHz
4&5 - 3&6	≥ 40 dB
3&6 - 1&2	≥ 45 dB
3&6 - 7&8	≥ 45 dB
4&5 - 1&2	≥ 55 dB
4&5 - 7&8	≥ 55 dB
1&2 - 7&8	≥ 55 dB

The 100 Ω resistors shall be removed from the baluns before any mated plug/jack measurements are made. For product qualification testing, a minimum of five (5) test plugs shall be used. TOC NEXT results may be rounded to the nearest 0.1 dB. Of the minimum five (5) test plugs used, three (3) are subject to the following additional TOC requirements for pin combination 4&5 - 3&6.

a) At least one of the five (5) test plugs used shall exhibit TOC NEXT loss in the range from greater than or equal to 40.0 dB to less than 40.5 dB at 100 MHz.
b) At least one of the five (5) test plugs used shall exhibit TOC NEXT loss in the range from greater than or equal to 40.5 dB to less than 41.5 dB at 100 MHz.
c) At least one of the five (5) test plugs used shall exhibit TOC NEXT loss in the range from greater than or equal to 41.5 dB at 100 MHz.

NOTE - The test plug should be periodically examined for physical wear and mechanical degradation.

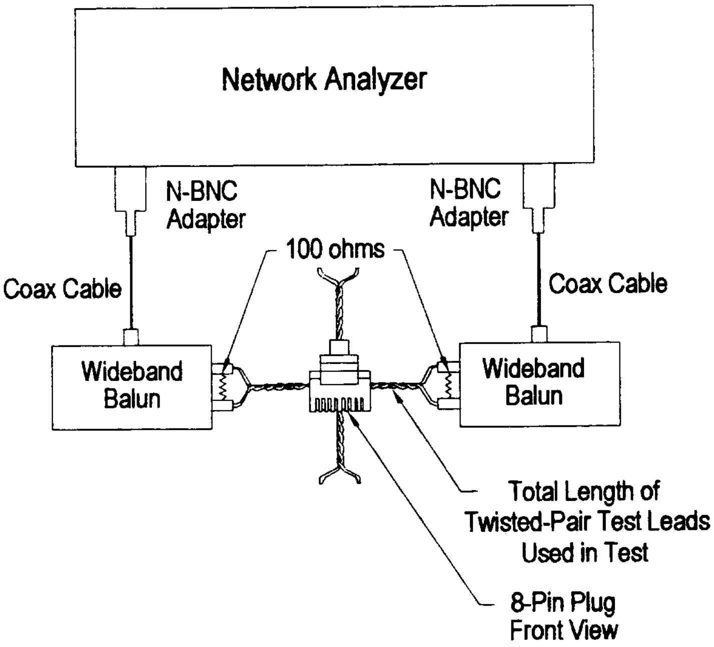


Figure N.1 - Test plug qualification measurement

N.3.5.3.3 Category 5 connecting hardware FEXT loss

From 1 MHz to 100 MHz, category 5 connector FEXT loss should meet the values determined using equation (N-11).

$$FEXT_{conn} \geq 30.0 - 20\log(f/100) \text{ dB} \qquad \text{(N-11)}$$

N.3.6 Category 5 propagation delay

N.3.6.1 Category 5 horizontal 100 Ω UTP cables

From 1 MHz to 100 MHz, the category 5 propagation delay of any pair of a category 5 100 Ω 4-pair cable should be determined using swept frequency measurements in accordance with ASTM D 4566. Equation (N-12) should be used to compute the maximum allowable propagation delay at all frequencies between 1 MHz and 100 MHz.

$$delay \leq 534 + \frac{36}{\sqrt{f}} (ns/100m) \qquad \text{(N-12)}$$

N.3.6.2 Category 5 backbone 100 Ω cable

The category 5 propagation delay of any pair at 10 MHz should not exceed 5.7 ns/m.

N.3.7 Category 5 propagation delay skew for 4-pair cables

N.3.7.1 Category 5 horizontal 100 Ω UTP cables

The difference in propagation delay between the fastest and slowest pair in a category 5 cable should not exceed 45 ns/100 m between 1 MHz and 100 MHz.

Annex O Development of channel and component return loss limits (informative)

O.1 General

Return loss is a measure of the reflected signal expressed in decibels (dB). The magnitude of the return loss is affected by the characteristic impedance mismatches between the various components comprising a channel, including the horizontal cable, patch cable and connectors as well as structural impedance variations in the cable. The channel or permanent link return loss is computed by multiplication of transmission matrices for each component in the link using the circuit analysis method. Each component is modeled by its transmission matrix as shown in equation (O-1).

$$\begin{bmatrix} \cosh(g\ l) & Z\sinh(g\ l) \\ \frac{\sinh(g\ l)}{Z} & \cosh(g\ l) \end{bmatrix} \qquad \text{(O-1)}$$

where: $g = a + jb$ is the complex propagation constant and Z is the complex characteristic impedance.

$a = \frac{IL_{dB}}{20\log(e)}$ with: IL_{dB} is the insertion loss of the component per m in dB.

e = 2.71828 (base of natural logarithm)

$b = \frac{2p\ f\ 10^6}{NVP\ c}$ with: f is the frequency in MHz.

c is the speed of light in vacuum $3 10^8$ m/s.

l is the length of the component in meters.

NVP is the nominal velocity of propagation relative to the speed of light. In turn, NVP is related to the propagation delay:

$$NVP = \frac{100}{prop\_delay \cdot c}$$

The fequency dependency of $prop\_delay$ can be ignored in most simulations.

The return loss is computed from the overall transmission matrix $\begin{bmatrix} A & B \\ C & D \end{bmatrix}$ by:

$$Z_{in} = \frac{A\,Z_{ref} + B}{C\,Z_{ref} + D}, \text{ and } RL = -20\log\left(\left|\frac{Z_{in} - Z_{ref}}{Z_{in} + Z_{ref}}\right|\right), \qquad \text{(O-2)}$$

with the nominal characteristic impedance $Z_{ref} = 100\,\Omega$.

O.2 Assumptions

O.2.1 Assumptions for the transmission matrix for cable

For cable, the specified insertion loss per unit length is given by:

$$IL_{dB} = \frac{k_1\sqrt{f} + k_2 f + \frac{k_3}{\sqrt{f}}}{100} \tag{O-3}$$

where $k_1, k_2, and\ k_3$ are the constants in the equation for cable insertion loss.

The properties of the characteristic impedance Z include a fitted (average) characteristic impedance Z_{fit}, which is assumed constant along the length of the cable, and a random variation around the fitted characteristic impedance. The fitted characteristic impedance can be represented by:

$$Z_{fit} = Z_o\left(1 + 0.055\frac{1-j}{\sqrt{f}}\right) \tag{O-4}$$

with Z_o is the asymptotic value of the fitted characteristic impedance.

The highest allowed value for Z_o can be determined by assuming that contributions to cable return loss from structural variations may be ignored at low frequencies. The return loss of a 100 m cable segment are computed and the value of Z_o adjusted so that at the lowest possible frequency the computed return loss matches the return loss specification for cable (the test length is 100 m). The lowest allowed value for Z_o is limited by the insertion loss requirements. As a result, it is assumed that the allowed range of asymptotic impedance is symmetrical around 100 Ω.

Pair structural variations may be represented by dividing the cable into many unit interval segments of randomly varying impedance, and performing a Monte-Carlo analysis of the cable return loss. The amplitude of these variations is adjusted so that the overall return loss is approximated. This is rather computation intensive and requires many iterations.

A simpler way is to assume that return loss caused by structural variations is uncorrelated with the computed return loss from the cable interfaces. The Distributed Return Loss (DRL, a statistical approximation of structural return loss) is obtained by power sum subtracting the computed interface return loss from the specified return loss and computed interface return loss of cable.

$$DRL = -10\log\left(10^{\frac{-RL_{cable}}{10}} - 10^{\frac{-RL_{interface}}{10}}\right) \tag{O-5}$$

DRL is approximated by:

$$DRL_{100m} = K_{DRL} - 10\log\left(\frac{f}{20}\right) \tag{O-6}$$ where: K_{DRL} is a constant.

This approximation may be used to represent the contributions from all distributed sources of return loss in cabling for most lengths of cabling. The contribution from DRL over a short length of cable may be approximated using the same formula as that used for scaling NEXT per IEC 61156-1. The DRL from all of the cable segments are added together in a power sum manner to obtain the DRL for the whole link. Since the DRL contributions from all cable segments are uncorrelated, the same DRL from the previous cable addition can also be obtained directly by assuming the total length in the length dependency formula and computing the correction only once. The changes caused by the length dependency formula are minimal when the total length of cabling exceeds 30 meters, and therefore one may use the DRL approximation for all practical cabling lengths.

The typical value of K_{DRL} is 28 dB for solid core cable and 26 dB for stranded cable. Assuming the total length of solid core cable far exceeds the total length of stranded jumpers and patch cable, one may assume the value K_{DRL} of solid core cable for the entire channel.

O.2.2 Assumptions for the transmission matrix for connectors

For a connector, the product of the propagation delay constant and length is used.

$$g\ l = a\ l + jb\ l \qquad \text{(O-7)}$$

The electrical length l_{conn} is obtained from: $l_{conn} = NVP\ c\,\dfrac{f_x}{360\ f_x}$ (O-8)

where:

f_x is the measured phase angle in degrees between the output and input of the connector at a high frequency f_x (e.g., 50 MHz)

The connector is now modeled as a short transmission line of electrical length l_{conn}. The frequency response exhibits a 20 dB/decade slope within the frequency range of interest. The value of the characteristic impedance Z_{conn} for the connector is adjusted so that the specified return loss at a certain frequency is matched. Practical values of l_{conn} lie between 5 cm and 10 cm.

The attenuation constant $a\ l = k_c\sqrt{f}$ (O-9)

where k_c is the constant in the connector insertion loss equation.

The phase constant $b\ l = \dfrac{p}{180} f_x \dfrac{f}{f_x}$ (O-10)

O.3 Return loss modeling results

A reasonable worst case channel configuration used to develop the return loss limits is shown in figure O.1. All flexible cable segments are assumed to have a asymptotic fitted characteristic impedance value of 95 Ω. The solid core cable segments are assumed to have a 105 Ω asymptotic fitted characteristic impedance. All connecting hardware is assumed to have return loss performance at the return loss limit for connecting hardware.

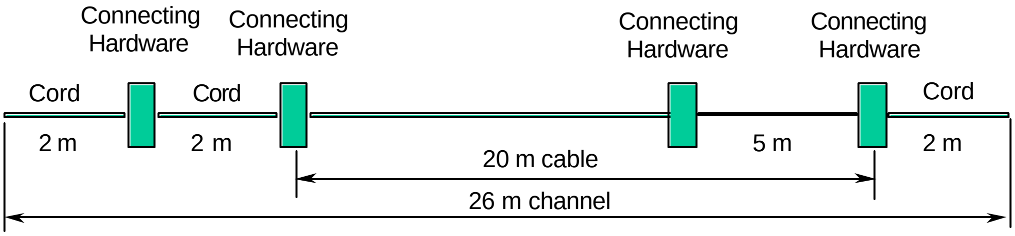


Figure O.1 - Modeling configuration

Reflections at the cable interfaces may result from characteristic impedance mismatches between cable segments or from the mismatch between connectors and cable segments. The phase dependencies and potential for in-phase addition of return loss between the different components in the channel are very much dependent on the physical separation of these interfaces from each other. Worst case in-phase addition most likely occurs in the frequency range from 15 to 30 MHz frequency range, where physical distances, typical for patch cords, match ¼ wavelengths. If distances between connections are multiples of a fixed low value, then it is possible, but unlikely, that the return loss will exceed the pass/fail limits for the channels or permanent links under the following conditions:

- In channels that use a cross-connect.
- In channels and permanent links which use a consolidation point.

In case, a return loss failure occurs in a channel:

1) Verify the operation and calibration of the field tester.
2) Determine the source of major reflections.
3) Reduce the number of connectors in the channel.
4) Select components with better return loss performance.

Annex P Bibliography (informative)

This annex contains information on the documents that are related to or have been referenced in this document. Many of the documents are in print and are distributed and maintained by national or international standards organizations. These documents can be obtained through contact with the associated standards body or designated representatives. The applicable electrical code in the United States is the National Electrical Code.

ANSI/IEEE C 62.11, *Metal Oxide Surge Arrestors for AC Power Circuits*

ANSI X3.166-1990, *ANSI Standard for Token Ring FDDI Physical Layer Medium Dependent (PMD) 23*

ASTM B539-90, *Measuring Contact Resistance of Electrical Connections (Static Contacts)*

Federal Communications Commission (FCC) Washington D.C., *"The Code of Federal Regulations, FCC 47 CFR 68*

Federal Telecommunications Recommendation 1090-1997, *"COMMERCIAL BUILDING TELECOMMUNICATIONS CABLING STANDARD", 11 August 1997, by National Communications System (NCS).*

IEEE 802.3-1990 (also known as ANSI/IEEE Std 802.3-1990 or ISO 8802-3: 1990(E), *Carrier Sense Multiple Access with* Collision *Detection (CSMA/CD) Access Method and Physical Layer Specifications*

IEEE 802.4, *Standard* for *Local Area Network Token Passing Bus Access Method, Physical Layer Specification*

IEEE 802.5-1992 (also known as ANSI/IEEE Std 802.5-1992), *Token Ring Access Method and Physical Layer Specifications*

IEEE 802.7, (also known as) Recommended Practices for Broadband Local Area Networks

NEMA-250-1985, Enclosures *for Electrical Equipment (1000 Volts Maximum)*

NQ-EIA/IS-AH, *Cable for LAN Twisted-pair Data Communications-Detail Specification for Type 8, Undercarpet Cable, September 1988*

Society of Cable Telecommunications Engineers, Inc., Document #IPS-SP-001, *Flexible RF Coaxial Dropcable Specification*

TIA/EIA TSB-31-B, FCC 47 CFR 68, *Rationale and Measurement Guidelines*

UL 444 UL *Standard for Safety Communications Cables*

The organizations listed below can be contacted to obtain reference information.

ANSI

American National Standards Institute (ANSI)
430 Broadway
New York, NY 10018
USA
(212) 642-4900

ASTM

American Society for Testing and Materials (ASTM)
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
USA
(610) 832-9500

BICSI

8610 Hidden River Parkway
Tampa, FL 33637
USA
(813) 979-1991

Telcordia Technologies (formerly Bellcore)

Telcordia Technologies
8 Corporate Place Room 3C-183
Piscataway, NJ 08854-4156
USA
(800) 521-2673

CSA

Canadian Standards Association (CSA)
178 Rexdale Blvd.
Rexdale (Toronto), Ontario
Canada M9W 1R3
(416) 747-4363

EIA/TIA

Electronic Industries Alliance (EIA)
2500 Wilson Blvd., Suite 400
Arlington, VA 22201-3836
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(703) 907-7500


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