TIA STANDARD

Balanced Twisted-Pair Telecommunications Cabling and Components Standards

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**TELECOMMUNICATIONS
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(From Standards Proposal No. 3-4426-RV3-B-2, formulated under the cognizance of the TIA TR-42 User Premises Telecommunications Cabling Requirements, TR-42.7 Subcommittee on Telecommunications Copper Cabling Systems.)

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Balanced Twisted-Pair Telecommunications Cabling and Components Standard

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FOREWORD

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

This Standard was developed by TIA Subcommittee TR-42.7.

Approval of this Standard

This Standard was approved by TIA Sub-Committee TR-42.7, TIA Engineering Committee TR-42, and the American National Standards Institute (ANSI).

ANSI/TIA reviews standards every 5 years. At that time, standards are reaffirmed, rescinded, or revised according to the submitted updates.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 ANSI/TIA.

Contributing Organizations

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).

Documents superseded

This Standard replaces the ANSI/TIA/EIA-568-B.2 standard dated March 16, 2001. 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:

- ANSI/TIA/EIA-568-B.2
- ANSI/TIA/EIA-568-B.2-1
- ANSI/TIA/EIA-568-B.2-2
- ANSI/TIA/EIA-568-B.2-3
- ANSI/TIA/EIA-568-B.2-4
- ANSI/TIA/EIA-568-B.2-5
- ANSI/TIA/EIA-568-B.2-6
- ANSI/TIA-568-B.2-7
- ANSI/TIA-568-B.2-9
- ANSI/TIA-568-B.2-10
- ANSI/TIA-568-B.2-11

This document takes precedence over the technical contents of the aforementioned bulletins, addenda and interim standards. In addition, this Standard incorporates parts of the content of ANSI/TIA/EIA-568-B.1. Specifically, requirements related to permanent link and channel performance of category 3 and category 5e cabling are incorporated in to this Standard.

Significant technical changes from the previous edition

- Incorporation of the above mentioned TSBs, Addenda, and Interim Standard.

- Definitions have been harmonized across all of TIA's telecommunications infrastructure standards.

- Performance specifications are provided for category 6 and 6A balanced twisted-pair cabling.

- Laboratory test measurement methodologies have been consolidated for all categories of cabling and components.

- Test fixturing requirements have been consolidated for all categories of cabling and components.

- Information on modeling configurations has been added.

- Field tester requirements have been removed from this Standard and moved to ANSI/TIA-1152.

Relationship to other TIA standards and documents

The following are related Standards regarding various aspects of structured cabling that were developed and are maintained by Engineering Committee TIA TR-42. An illustrative diagram TIA-568-C series and other relevant TIA Standards is given in figure i.

- *Generic Telecommunications Cabling for Customer Premises* (ANSI/TIA-568-C.0);
- *Commercial Building Telecommunications Cabling Standard* (ANSI/TIA-568-C.1);
- *Optical Fiber Cabling Components Standard* (ANSI/TIA-568-C.3);
- *Commercial Building Standard for Telecommunications Pathways and Spaces* (ANSI/TIA/-569-B);
- *Residential Telecommunications Infrastructure Standard* (ANSI/TIA-570-B);
- *Administration Standard for Commercial Telecommunications Infrastructure* (ANSI/TIA/EIA-606-A);
- *Commercial Building Grounding (Earthing) and Bonding Requirements For Telecommunications* (ANSI-J-STD-607-A);
- *Telecommunications Infrastructure Standard for Data Centers* (TIA-942)

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 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 N.

Common Standards	**Premises Standards**	**Component Standards**

ANSI/TIA-568-C.0
Generic Telecommunications Cabling for Customer Premises

TIA-569-B
Commercial Building Standard for Telecommunications Pathways and Spaces

ANSI/TIA-606-A
Administration Standard for Commercial Telecommunications Infrastructure

ANSI/TIA-607-B
Telecommunications Grounding (Earthing) and Bonding for Customer Premises

ANSI/TIA-758-A
Customer-Owned Outside Plant Telecommunications Infrastructure Standard

ANSI/TIA-862
Building Automation Systems Cabling Standard for Commercial Buildings

ANSI/TIA-568-C.1
Commercial Building Telecommunications Cabling Standard

ANSI/TIA-570-B
Residential Telecommunications Infrastructure Standard

ANSI/TIA-942
Telecommunications Infrastructure Standard for Data Centers

ANSI/TIA-1005
Telecommunications Infrastructure Standard for Industrial Premises

ANSI/TIA-568-C.2
Balanced Twisted-Pair Telecommunications Cabling and Components Standard

ANSI/TIA-568-C.3
Optical Fiber Cabling Components Standard

Figure i - Illustrative relationship between the TIA-568-C series and other relevant TIA standards

Annexes

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

Introduction

This Standard provides requirements for 100 Ω category 3, category 5e, category 6, and category 6A (augmented category 6) balanced twisted-pair cabling and components and for the field test procedures used to verify the performance of installed cabling.

Purpose

This Standard specifies a generic telecommunications cabling system for commercial buildings that will support a multi-product, multi-vendor environment. It also provides information that may be used for the design of telecommunications products for commercial enterprises.

The purpose of this Standard is to enable the planning and installation of a structured cabling system for commercial buildings. Installation of cabling systems during building construction or renovation is significantly less expensive and less disruptive than after the building is occupied.

This Standard establishes performance and technical criteria for balanced twisted-pair cabling system configurations and their respective components. In order to determine the requirements of a generic cabling system, performance requirements for various telecommunications services were considered.

The diversity of services currently available, coupled with the continual addition of new services, means that there may be cases where limitations to desired performance occur. When applying specific applications to these cabling systems, the user is cautioned to consult application standards, regulations, equipment vendors, and system and service suppliers for applicability, limitations, and ancillary requirements.

Specification of criteria

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.

Metric equivalents of US customary units

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

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.

1   SCOPE

This Standard specifies minimum requirements for balanced twisted-pair telecommunications cabling (e.g. channels and permanent links) and components (e.g. cable, connectors, connecting hardware, patch cords, equipment cords, work area cords, and jumpers) that are used up to and including the telecommunications outlet/connector and between buildings in a campus environment. This Standard also specifies field test procedures and applicable laboratory reference measurement procedures for all transmission parameters.

2   NORMATIVE AND INFORMATIVE 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, *Standard for Category 1 & 2 Individually Unshielded Twisted Pair Indoor Cables (With or Without an Overall Shield) for use in Communications Wiring Systems Technical Requirements,* 2002

ANSI/ICEA S-84-608, *Telecommunications Cable Filled, Polyolefin Insulated Copper Conductor*, 2007

ANSI/ICEA S-90-661-2006, *Category 3, 5, & 5e Individually Unshielded Twisted Pair Indoor Cables (With or Without an Overall Shield) for Use in General Purpose and LAN Communication Wiring Systems Technical Requirements,* 2006

ANSI/ICEA S-102-732-2009, *Standard for Category 6 and 6A, 100 Ohm Individually Unshielded Twisted Pairs, Indoor Cables (With or Without an Overall Shield) for Use in LAN Communication Wiring Systems Technical Requirements,* 2009

ANSI/TIA-568-B.2-10, *Transmission Performance Specifications for 4-Pair 100 Ω Augmented Categiry 6 Cabling*, 2008

ANSI/TIA-570-B, *Residential Telecommunications Cabling Standard,* 2004

ANSI/TIA-568-C.1, *Commercial Building Telecommunications Cabling Standard,* 2008

ANSI/TIA-568-C.3, *Optical Fiber Cabling Components Standard,* 2008

ANSI/TIA/EIA-606-A, *Administration Standard for Commercial Telecommunications Infrastructure*, 2002

ANSI/TIA-1152, *Requirements for Field Test Instruments and Measurements for Balance Twisted-Pair Cabling*, 2009

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

ASTM D 4566, *Standard Test Methods for Electrical Performance Properties of Insulations and Jackets for Telecommunications Wire and Cable*, 2005

IEC 60352-2, *Solderless Connections - Part 2: Crimped Connections - General Requirements, Test Methods and Practical Guidance*, 2007

IEC 60352-3, *Solderless Connections - Part 3: Solderless Accessible Insulation Displacement Connections - General Requirements, Test Methods and Practical Guidance,* 1993

IEC 60352-4, *Solderless Connections - Part 4: Solderless Non-accessible Insulation Displacement Connections - General Requirements, Test Methods and Practical Guidance,* 1994

IEC 60352-5, *Solderless Connections - Part 5: Press-in Connections - General Requirements, Test Methods and Practical Guidance*, 2008

IEC 60352-6, *Solderless Connections - Part 6: Insulation Piercing Connections - General Requirements, Test Methods and Practical Guidance,* 1997

IEC 60352-7, *Solderless Connections - Part 7: Spring Clamp Connections - General Requirements, Test Methods and Practical Guidance,* 2002

IEC 60352-8, *Solderless connections - Part 8: Compression Mount Connections - General Requirements, Test Methods and Practical Guidance*, pending publication

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

IEC 60603-7-1, *Connectors for electronic equipment – Part 7-1: Detail specification for 8-way, shielded, free and fixed connectors with common mating features, with assessed quality*, 2002

IEC 60603-7-2, *Connectors for electronic equipment – Part 7-2: Detail specification for 8-way, unshielded, free and fixed connectors, for data transmissions with frequencies up to 100 MHz*, 2002

IEC 60603-7-3, *Connectors for electronic equipment – Part 7-3: Detail specification for 8-way, shielded, free and fixed connectors, for data transmissions with frequencies up to 100 MHz*, 2008

IEC 60603-7-4, *Connectors for electronic equipment – Part 7-4: Detail specification for 8-way, unshielded, free and fixed connectors, for data transmissions with frequencies up to 250 MHz*, 2005

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

IEC 60603-7-41, *Connectors for electronic equipment - Part 7-41: Detail specification for 8-way, unshielded, free and fixed connectors, for data transmission with frequencies up to 500 MHz,*2009

IEC 60603-7-51, *Connectors for electronic equipment - Part 7-51: Detail specification for 8-way, shielded, free and fixed connectors, for data transmission with frequencies up to 500 MHz*, 2009

IEC 61156-1, *Multicore and Symmetrical Pair/Quad Cables for Digital Communications – Part 1: Generic Specification,* 2007

IEC 62153-4-3, *Metallic communication cables test methods – Part 4-3: Electromagnetic compatibility (EMC) - Surface transfer impedance – Triaxial method,* 2006

IEC 62153-4-5, *Metallic communication cables test methods – Part 4-5: Electromagnetic compatibility (EMC) – Coupling or screening attenuation – Absorbing Clamp method,* 2006

IEC 62153-4-9 *Metallic communication cables test methods – Part 4-9: Electromagnetic compatibility (EMC) – Coupling of screened balanced cables, triaxial method,* 2008

TIA TSB-155, *Guidelines for the Assessment and Mitigation of Installed Category 6 Cabling to Support 10GBASE-T*, 2007

TIA TSB-184, *Guidelines for Supporting Power Delivery over Balanced Twisted-Pair Cabling*, 2009

UL 444, *Communication Cables*, 2002

3 DEFINITIONS, ABBREVIATIONS AND ACRONYMS, UNITS OF MEASURE

3.1 General

For the purpose of this Standard the following definitions, acronyms, abbreviations and units of measure apply.

3.2 Definitions

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.

compression mount connection: A solderless connection between a contact and a contact pad (i.e. a conductive element on a printed board) which is established by a continuous compression force of contact.**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.

coupling attenuation: Coupling attenuation is the ratio, in dB, of the transmitted power in the signal conductors and the maximum radiated peak power, conducted and generated by the excited common mode currents.

crimped connection: A solderless connection made by permanently attaching a termination to a conductor by pressure deformation or by reshaping the crimp barrel around the conductor to establish good electrical and mechanical connection.

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.

equal level transverse conversion transfer loss: A calculation, expressed in dB, of the difference between measured TCTL and the differential mode insertion loss of the disturbed pair.

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).

insulation displacement connection: An electrical connection made by inserting an insulated wire into a metallic slot.

insulation displacement connection, accessible: An IDC in which it is possible to access test points for carrying out mechanical tests and electrical measurements without de-activation of any design feature intended to establish or maintain the insulation displacement connection.

insulation displacement connection, non-accessible: An IDC in which it is not possible to access test points for carrying out mechanical tests and electrical measurements without de-activation of any design feature.

insulation displacement contact: See insulation displacement termination.

insulation piercing connection: An electrical connection made by piercing an insulated wire with a metallic element.

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): The fixed connector in an equipment outlet.

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.

press-in connection: A solderless connection made by inserting a press-in terminal into a conductive hole of a printed circuit board.**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.

spring clamp connection: A solderless connection achieved by clamping a single conductor to a contact or termination by means of a spring.

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.

transverse conversion transfer loss: A ratio, expressed in dB, of the measured common mode voltage on a pair relative to the differential mode voltage applied at the opposite end of the same pair, or on either end of another pair.

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

3.3   Acronyms and abbreviations

ACRF	Attenuation to crosstalk ratio, far-end
ANSI	American National Standards Institute
CM	Common mode
CMR	Common mode rejection
DM	Differential mode
DMCM	Differential mode plus common mode
DUT	Device under test
EIA	Electronic Industries Alliance
ELTCTL	Equal level transverse conversion transfer loss
FEXT	Far-end crosstalk
F/UTP	Foil (surrounding) unscreened twisted-pairs
ICEA	Insulated Cable Engineers Association
IDC	Insulation displacement connection
IEC	International Electrotechnical Commission
IPC	Insulation piercing connection
NEXT	Near-end crosstalk
OSB	Output signal balance
PSAACRF	Power sum attenuation to alien crosstalk ratio, far-end
PSACRF	Power sum attenuation to crosstalk ratio, far-end
PSANEXT	Power sum alien near-end crosstalk
PSFEXT	Power sum far-end crosstalk
PSNEXT	Power sum near-end crosstalk
SRL	Structural return loss
TCL	Tranverse conversion loss
TCTL	Transverse conversion transfer loss
TIA	Telecommunications Industry Association
UTP	Unshielded twisted-pair

3.4   Units of measure

dB	decibel
°C	degree Celsius
ºF	degrees Fahrenheit
ft	feet, foot

g	gram
in	inch
kg	kilogram
kHz	kilohertz
km	kilometer
kV	kilovolt
MHz	megahertz
m	meter
μm	micron or micrometer
mm	millimeter
mV	millivolt
nm	nanometer
N	newton
Ω	ohm
pF	picofarad
lb	pound
lbf	pound-force
V	volt

3.5 Variables

f Frequency, in MHz

4   GENERAL

Transmission performance depends upon the characteristics of cable, connecting hardware, cords and cross-connect jumpers, the total number of connections, and the care in which they are installed and maintained. This Standard provides minimum cabling and component performance criteria as well as procedures for component and cabling performance validation.

4.1   Backward compatibility and interoperability

The requirements in this Standard are for 100 Ω category 3, 5e, 6, and 6A balanced twisted-pair cabling components. Higher grades of cabling recognize advances in cabling technology such as full-duplex transmission and the operation of high-speed applications, such as IEEE 802.3 10GBASE-T, over up to 100 meters of structured balanced cabling. Higher categories of cabling shall be backward compatible with lower categories of cabling as specified in this Standard. Applications running on lower category cabling shall be supported by higher category cabling. If different category components are to be mixed, then the combination shall meet the transmission requirements of the lowest performing category.   See Table 1 for an example matrix of mated component performance representative of backward compatibility. To ensure generic cabling system performance, component requirements are specified to support interoperability when products from different manufacturers are mated.

Table 1 - Matrix of backward compatible mated component performance

		Category of Modular Connecting Hardware Performance			
		Category 3[1)	Category 5e	Category 6	Category 6A
Modular Plug & Cord Performance	Category 3 [1)	Category 3	Category 3	Category 3	Category 3
	Category 5e	Category 3	Category 5e	Category 5e	Category 5e
	Category 6	Category 3	Category 5e	Category 6	Category 6
	Category 6A	Category 3	Category 5e	Category 6	Category 6A

[1) Category 3 plug performance requirements not specified and are assumed to be less restrictive than category 5e.

NOTE – Category 6A was referred to as augmented category 6 in ANSI/TIA-568-B.2-10.

Testing according to the procedures of this Standard is intended to ensure backward compatibility with lower categories.

4.2   Recognized categories

The recognized categories of balanced twisted-pair cabling and components are:

Category 3: This designation applies to 100 Ω balanced twisted-pair cabling and components whose transmission characteristics are specified from 1 to 16 MHz.

Category 5e: This designation applies to 100 Ω balanced twisted-pair cabling and components whose transmission characteristics are specified from 1 to 100 MHz.

Category 6: This designation applies to 100 Ω balanced twisted-pair cabling and components whose transmission characteristics are specified from 1 to 250 MHz.

Category 6A: This designation applies to 100 Ω balanced twisted-pair cabling and components whose transmission characteristics are specified from 1 to 500 MHz.

Category 1, 2, 4 and 5 cabling and components 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 M.

5 MECHANICAL REQUIREMENTS

This clause contains the mechanical performance specifications for 100 Ω balanced twisted-pair cabling and components.

5.1 Channel mechanical performance

The mechanical performance of channels is achieved through the use of compliant components.

5.2 Permanent link mechanical performance

The mechanical performance of permanent links is achieved through the use of compliant components.

5.3 Horizontal cable mechanical performance

Horizontal cable shall consist of four balanced twisted-pairs of 22 AWG to 24 AWG thermoplastic insulated solid conductors enclosed by a thermoplastic jacket. Horizontal cables shall comply with the mechanical performance requirements, testing and test methods in ANSI/ICEA S-90-661-2006 for category 3, ANSI/ICEA S-90-661-2006 for category 5e, ANSI/ICEA S-102-732-2009 for category 6, and ANSI/ICEA S-102-732-2009 for category 6A.

In addition to the applicable requirements of ANSI/ICEA S-90-661-2006 and ANSI/ICEA S-102-732-2009, the physical design of category 3, 5e, 6, and 6A horizontal cables shall meet the additional requirements of this clause.

5.3.1 Insulated conductor

The diameter of the insulated conductor shall be 1.53 mm (0.060 in) maximum.

> NOTE - Insulated conductors above 1.22 mm (0.048 in) may not be compatible with all connecting hardware.

5.3.2 Pair assembly

The cable shall be restricted to four twisted-pair conductors.

5.3.3 Insulated conductor color code

The insulated conductor color code shall be as shown in Table 2.

Table 2 – Insulated conductor color code for 4-pair horizontal cables

Pair designation[1]	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)
[1] See clause 5.7.5 for corresponding connecting hardware pair assignments.		

The conductor 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 solid colored conductor of the twisted-pair can serve as the marking for the white conductor. A white marking is optional.

5.3.4   Cable diameter

The diameter of the completed cable shall be less than or equal to 9.0 mm (0.354 in).

> NOTE - Larger cable diameter cables may not be compatible with certain designs of modular connecting hardware. For example, the termination caps in some modular outlet designs may not accommodate larger diameter cables. When 4-pair cables with overall diameters of greater than 6.35 mm (0.25 in.) are used, compatibility with connecting hardware should be considered.

5.3.5   Breaking strength

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

5.3.6   Cold bend radius

Twisted-pair cables shall withstand a bend radius of 4x cable diameter for UTP constructions and 8x cable diameter for screened constructions, at a temperature of -20 °C ± 1 °C, without jacket, insulati on, or shield (if applicable) 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 sh ould be considered.

5.3.7   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.

5.3.8   Core wrap

The core may be covered with one or more layers of dielectric material.

5.3.9   Core shield (screened only)

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 6.4.20. 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.

5.3.10 Dielectric strength (screened only)

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.

5.4   Bundled and hybrid cable mechanical performance

Mechanical performance is not specified for bundled and hybrid cables.

5.5   Cord cable mechanical performance

5.5.1   General

Cord cable shall consist of four balanced twisted-pairs of 22 AWG to 26 AWG thermoplastic insulated solid or stranded conductors enclosed by a thermoplastic jacket. Cord cables shall comply with the mechanical performance requirements, testing and test methods in ANSI/ICEA S-90-661-2006 for category 3, ANSI/ICEA S-90-661-2006 for category 5e, ANSI/ICEA S-102-732-2009 for category 6, and ANSI/ICEA S-102-732-2009 for category 6A. Cord cables used for 100 ohm screened cords and cross-connect jumpers shall be enclosed by a shield meeting the requirements of clauses 5.3.9, 5.3.10, and 6.4.20.

5.5.2   Cord cable flex life (screened only)

Cables used for 100 Ω screened cords and screened 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.

5.6   Backbone cable mechanical performance

Four-pair and multipair backbone cables are recognized for use in category 3 and 5e backbone cabling. Four-pair horizontal cables are recognized for use in category 6 and 6A backbone cabling.

Multipair backbone cable shall consist of 22 AWG to 24 AWG thermoplastic insulated solid conductors that are formed into one or more units of balanced twisted-pairs and shall meet the requirements of this clause. 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.

Backbone cables shall comply with the mechanical performance requirements, testing and test methods in ANSI/ICEA S-90-661-2006 for category 3, ANSI/ICEA S-90-661-2006 for category 5e, ANSI/ICEA S-102-732-2009 for category 6, and ANSI/ICEA S-102-732-2009 for category 6A.

5.6.1   Insulated conductor

The diameter of the insulated conductor shall be 1.53 mm (0.060 in) maximum.

> NOTE - Insulated conductors above 1.22 mm (0.048 in) may not be compatible with all connecting hardware.

5.6.2   Pair assembly

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

5.6.3   Insulated conductor color code

The twisted-pair insulated 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 multipair 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 multipair backbone cables with tightly twisted-pairs [i.e. all pairs less than 38 mm (1.5 in) per twist] the mate conductor may serve as the marking for the white conductor.

5.6.4 Core assembly

For multipair 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.

5.6.5 Core shield

When an electrically continuous shield is applied over the core wrap, it shall comply with requirements in clause 5.6.9.

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

5.6.6 Jacket

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

5.6.7 Performance marking

Multipair 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.

5.6.8 Dielectric strength (screened only)

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.

5.6.9 Core shield resistance

When a shield is present around the core, the DC resistance of the core shield shall not exceed the value determined using equation (1):

$$R = 62.5/D \hspace{4cm} (1)$$

where:
R = maximum core shield resistance in Ω/km
D = outside diameter of the shield in mm

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 clauses 5.3.9, 5.3.10, and 6.4.20.

5.7 Connecting hardware mechanical performance

5.7.1 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 ℃ to 60 ℃. 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.

5.7.2 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.

5.7.3 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.

5.7.4 Design

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

a) a means to cross-connect cables with cross-connect jumpers or patch cords,
b) a means to connect premises equipment to the 100 Ω UTP network,
c) a means to identify circuits for administration in accordance with ANSI/TIA/EIA-606-A,
d) a means to use standard colors as specified in ANSI/TIA/EIA-606-A to functionally identify mechanical termination fields,
f) a means of handling wire and cable to permit orderly management,
g) a means of access to monitor or test cabling and premises equipment, and
h) a 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.

Consolidation points and telecommunications outlet/connectors used to terminate to 100 Ω balanced twisted-pair cabling shall be designed to provide:

a) appropriate mechanical termination means for horizontal cable runs, and
b) a means of conductor identification to promote pin-pair practices consistent with clause 5.7.5.

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.

5.7.5   Work area 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 60603-7-1, IEC 60603-7-2, IEC 60603-7-3, IEC 60603-7-4, and IEC 60603-7-5. In addition, the telecommunications outlet/connector shall meet the requirements of clause 5.7 and the terminal marking and mounting requirements specified in ANSI/TIA-570-B. Pin/pair assignments shall be as shown in Figure 1 or, optionally, per Figure 2 if necessary to accommodate certain cabling systems. The colors shown are associated with the horizontal distribution cable shown in Table 2. These figures depict the front view of the telecommunications outlet/connector.
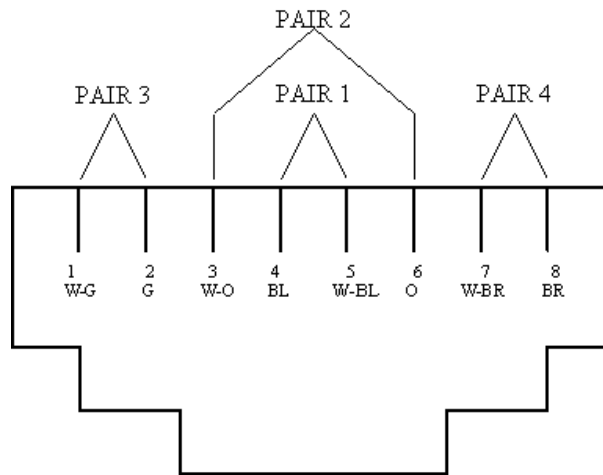
NOTE – See Table 3 for an explanation of color codes.

Figure 1 - Eight-position modular jack pin/pair assignment (T568A)
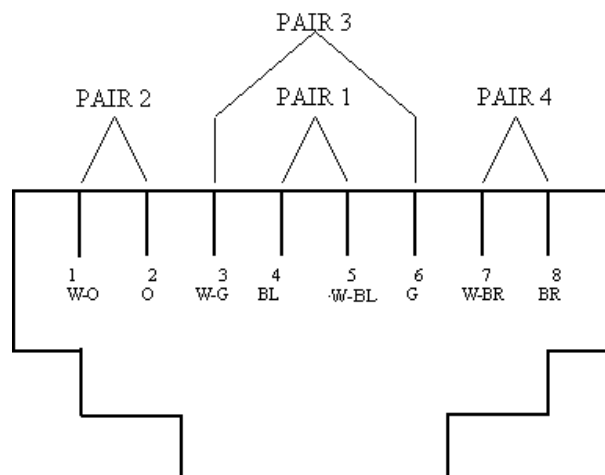
NOTE – See Table 3 for an explanation of color codes.

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

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5.7.6   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 "   **C3**   " for category 3 components

"cat 5e" or "   **C5e**   " for category 5e components

"cat 6" or "   **C6**   " for category 6 components

"cat 6A" or "   **C6A**   " for category 6A components

> 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.

5.7.7   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, transfer impedance (screened only), insulation resistance, durability, environmental conditioning and other tests designed to assure consistently dependable operation. For connecting hardware with 8-position modular connectors, the modular connection shall comply with Level A reliability requirements of IEC 60603-7 series.   The shield mating interface shall meet the applicable reliability requirements for connecting hardware as defined by IEC 60603-7 series of Standards.

5.7.8   Shield mating interface (screened only)

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 the IEC 60603-7 series of Standards.

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.

5.7.9 Shield continuity (screened only)

Effective shielding requires that all cabling components be shielded, meeting the requirements for transfer impedance given in clause 6.8.20 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. Screened telecommunications outlet/connectors shall be labeled or otherwise identified to differentiate them from UTP connectors and indicate the need for screened work area cords.

5.8 Cords and jumpers mechanical performance

Cables used to construct work area cords, equipment cords, and patch cords should have stranded conductors. Cables used for cord assemblies shall meet the conductor size and color coding specified in clauses 5.8.1 and 5.8.2, respectively.

5.8.1 Insulated conductor

Cables used to construct work area cords, equipment cords, and patch 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). Cables used to construct cross-connect jumpers shall meet the requirements of clause 5.3.1 and the applicable requirements of ANSI/ICEA-S-90-661-2006.

> NOTE – A special modular plug connector may be required for cables with insulated conductor diameter greater than 1 mm (0.039 in) or less than 0.8 mm (0.032 in).

5.8.2 Insulated conductor color codes

The insulated conductor color coding for cord cable and cross-connect jumpers shall comply with Table 3.

Table 3 – Insulated conductor color codes for cord cable and cross-connect jumpers

Pair designation[1]	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)
[1] See clause 5.7.5 for corresponding connecting hardware pair assignments.		

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.

6   TRANSMISSION REQUIREMENTS

6.1   General

This clause contains the transmission performance specifications for 100 Ω balanced twisted-pair cabling and components.

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.

Transmission parameters are applicable to channels, permanent links, cables, cords, and connecting hardware. This clause describes the transmission parameters and develops the applicable "generic" equations for each parameter.

6.1.1   Return loss

Return loss shall be measured for all pairs of the DUT from 1 MHz up to the maximum specified frequency for the category using the procedures in Annex C.

6.1.2   Insertion loss

Insertion loss shall be measured for all pairs of the DUT from 1 MHz up to the maximum specified frequency for the category using the procedures in Annex C.

6.1.3   NEXT loss

NEXT loss shall be measured for all pair combinations of the DUT from 1 MHz up to the maximum specified frequency for the category using the procedures in Annex C.

6.1.4   PSNEXT loss

PSNEXT loss takes into account the combined crosstalk (statistical) on a receive pair from all near-end disturbers operating simultaneously. PSNEXT loss is calculated in accordance with ASTM D 4566 as a power sum on a selected pair from all other pairs as shown in equation (2) for the case of an n-pair DUT.

$$PSNEXT_k = -10\log\left(\sum_{i=1,i\neq k}^{n}10^{-\frac{NEXT_{k,i}}{10}}\right)dB \qquad (2)$$

where:

n is the total number of pairs under test (DUT).

$NEXT_{k,i}$ is the measured NEXT loss, in dB, to pair k from pair i.

k is the number of the disturbed pair.

i is the number of a disturbing pair.

PSNEXT loss shall be calculated for all pairs of the DUT.

6.1.5   FEXT loss

FEXT loss shall be measured for all pair combinations of the DUT from 1 MHz up to the maximum specified frequency for the category using the procedures in Annex C.

6.1.6   ACRF

ACRF shall be calculated for all DUT pair combinations by subtracting the insertion loss of the disturbed pair of the DUT from the FEXT loss as shown in equation (3).

$$ACRF_{k,i} = FEXT_{k.i} - IL_k \quad dB \tag{3}$$

where:

IL_k is the insertion loss of the disturbed pair.

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

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

$i \neq k$.

> NOTE - ACRF has been referred to as ELFEXT in previous editions of this Standard.

6.1.7   PSACRF

PSACRF takes into account the combined crosstalk (statistical) on a receive pair from all far-end disturbers operating simultaneously. PSACRF is calculated as a power sum on a selected pair k from all other pairs as shown in equation (4) for the case of an n-pair DUT.

$$PSACRF_k = \sum_{i=1, i \neq k}^{n} FEXT_{k.i} - IL_k \quad dB \tag{4}$$

where:

n is the total number of pairs under test (DUT).

IL_k is the insertion loss of the disturbed pair.

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

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

> NOTE - PSACRF has been referred to as PSELFEXT in previous editions of this Standard.

6.1.8   TCL

Where specified, TCL shall be measured for all pairs of the DUT from 1 MHz up to the maximum specified frequency for the category using the procedures in Annex C

Category 6 channel TCL is provided for information only.

> NOTES,
> 1   TCL and LCL parameters have reciprocity.   LCL can be determined using a TCL measurement.
> 2   When achievable, a 50 dB measurement plateau is recommended.

6.1.9   ELTCTL

Where specified, TCTL shall be measured for all pairs of the DUT from 1 MHz up to the maximum specified frequency for the category using the procedures in Annex C

ELTCTL shall be calculated for all DUT pairs as shown in equation (5). ELTCTL is specified for the opposite ends of the same pair. ELTCTL between pairs is not specified.

$$ELTCTL_{DUT} = TCTL_{DUT} - IL_{DUT\_DM} \tag{5}$$

where:

IL_{DUT_DM} is the differential mode DUT insertion loss measured in accordance with Annex C.

6.1.10   Coupling attenuation

Coupling attenuation is under study.

Coupling attenuation shall be measured in accordance with IEC 62153-4-5 or IEC 62153-4-9 for all screened pairs of horizontal cable from 30 MHz up to the maximum specified frequency for the specified category.

> NOTE - Measurements are made from 30 MHz to 1000 MHz for all devices under test, but the measurements above the upper frequency of the specified category are for information only.

6.1.11   Propagation delay

Propagation delay shall be measured for all pairs of the DUT from 1 MHz up to the maximum specified frequency for the category using the procedures in Annex C.

6.1.12   Propagation delay skew

Propagation delay skew shall be calculated for all pair combinations of the DUT from 1 MHz up to the maximum specified frequency for the category using the procedures in Annex C

6.1.13 PSANEXT loss

PSANEXT loss takes into account the combined alien crosstalk (statistical) on a receive pair from all external near-end disturbers operating simultaneously. PSANEXT loss is calculated as a power sum on a selected pair k from all other pairs as shown in equation (6) for the case of a 4-pair DUT.

$$PSANEXT_k = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{4}10^{-\frac{ANEXT_{k,i,j}}{10}}\right) \; dB \qquad (6)$$

where:

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

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

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

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

j is the number of a disturbing DUT.

ANEXT loss shall be measured for all DUT pair combinations and PSANEXT loss shall be calculated for all DUT pairs. DUT ANEXT loss shall be measured in accordance with Annex C.

6.1.14 Average PSANEXT loss

Average PSANEXT loss is calculated by averaging the individual PSANEXT loss values, in dB, for all four pairs in the disturbed DUT at each frequency point as shown in equation (7).

$$AVERAGE\_PSANEXT = \frac{\sum_{k=1}^{4}PSANEXT_k}{4} \; dB \qquad (7)$$

where:

$PSANEXT_k$ is the magnitude, in *dB*, of PSANEXT loss as determined by equation (6).

6.1.15 PSAFEXT loss (connecting hardware only)

PSAFEXT loss takes into account the combined alien crosstalk (statistical) on a receive pair from all external far-end disturbers operating simultaneously. PSAFEXT loss is calculated as a power sum on a selected pair from all other pairs as shown in equation (8) for connecting hardware.

$$PSAFEXT_k = \sum_{j=1}^{N} \sum_{i=1}^{4} AFEXT_{k,i,j} \ dB \tag{8}$$

where:

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

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

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

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

j is the number of a disturbing DUT.

AFEXT loss shall be measured for all connecting hardware pairs and PSAFEXT loss shall be calculated for all connecting hardware pairs. Category 6A connecting hardware AFEXT loss shall be measured in accordance with clause C.4.6 for all frequencies from 1 to 500 MHz.

6.1.16 PSAACRF

AFEXT loss is the coupling of crosstalk at the far-end from external DUT pairs into a disturbed pair of the 4-pair DUT under test. PSAACRF is the calculated power sum from all external pairs into the disturbed pair. Annex L provides additional information on PSAACRF and AFEXT loss normalization. PSAACRF for a DUT is determined using equation (9) for the case of a 4-pair DUT.

$$PSAACRF_k = PSAFEXT_k - IL_k \ dB \tag{9}$$

For channels and permanent links, the calculations in equations (10) through (12) shall be used to determine PSAFEXT loss when the disturbed pair has greater insertion loss than the disturbing pair.

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

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

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

$$AFEXTnorm_{k,i,j} = AFEXT_{k,i,j} \ dB \qquad (11)$$

where:

$$PSAFEXT_k = -10 \log \left(\sum_{j=1}^{N} \sum_{i=1}^{n} 10^{-\frac{AFEXTnorm_{k,i,j}}{10}} \right) dB \qquad (12)$$

$PSAACRF_k$ is the PSAACRF of disturbed pair k.

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

IL_k is the insertion loss of disturbed pair k.

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

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

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

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

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

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

j is the number of a disturbing DUT.

ACRF shall be measured for all DUT pair combinations and PSAACRF shall be calculated for all DUT pairs. ACRF shall be measured in accordance with Annex C.

6.1.17 Average PSAACRF

Average PSAACRF is calculated by averaging the individual PSAACRF values, in dB, for all four pairs in the disturbed DUT at each frequency point as shown in equation (13).

$$AVERAGE\_PSAACRF = \frac{\sum_{k=1}^{4} PSAACRF_k}{4} \ dB \qquad (13)$$

where:

$PSAACRF_k$ is the magnitude, in dB, of PSAACRF as determined by equation (9)

6.2   Channel transmission performance

This clause contains the transmission performance specifications for balanced twisted-pair channels. The channel test configuration is illustrated in figure 3.   See Annex J for worst case modeling configurations.
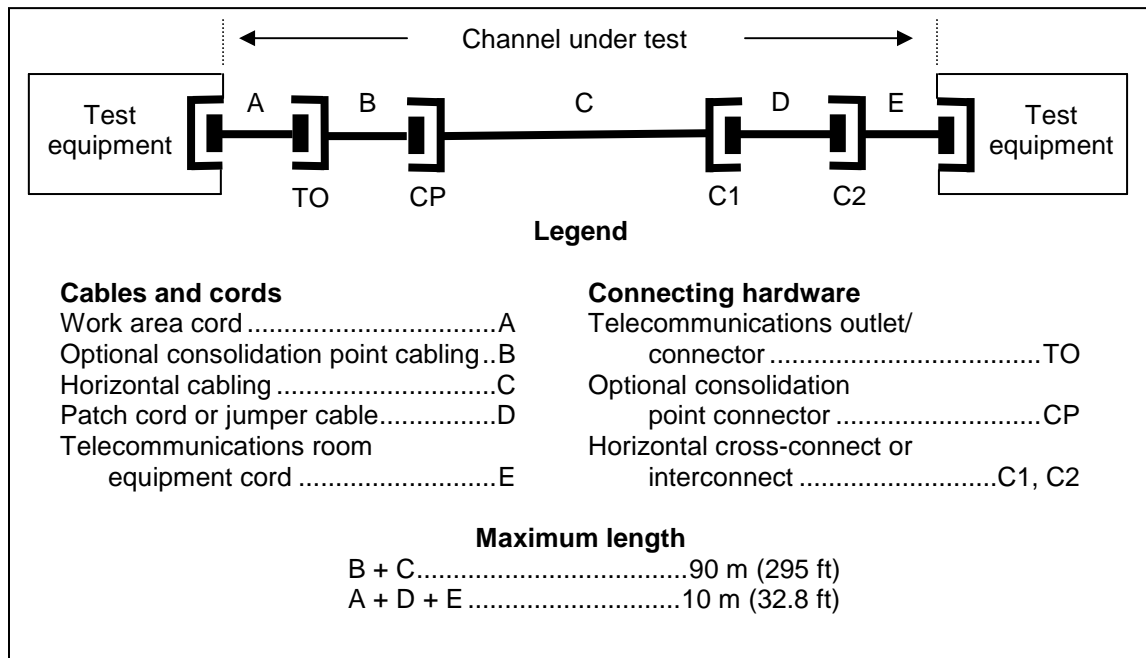
Figure 3 - Supplemental schematic representation of a channel test configuration

6.2.1   DC loop resistance

DC loop resistance for category 3, 5e, 6, and 6A channels shall not exceed 25 Ω.   Refer to TIA TSB-184 for additional information on channel resistance related to guidance on delivering power.

6.2.2   DC resistance unbalance

DC resistance shall be measured for all channel conductors.   DC resistance unbalance shall be calculated for each pair of the channel in accordance with equation (14) and shall not exceed the greater of 3% or 200 milliohms. DC resistance unbalance is not specified for category 3 channels.

$$Resistance\_Unbalance_{pair} = \left(\frac{|R_1 - R_2|}{R_1 + R_2} \right) \cdot 100\% \tag{14}$$

where:

R_1 is the DC resistance of conductor 1.

R_2 is the DC resistance of conductor 2.

6.2.3   Mutual capacitance

Mutual capacitance is not specified for channels.

6.2.4   Capacitance unbalance: pair-to-ground

Capacitance unbalance is not specified for channels.

6.2.5 Characteristic impedance and structural return loss (SRL)

Characteristic impedance and structural return loss (SRL) are not applicable for channels.

6.2.6 Return loss

Channel return loss shall meet or exceed the values determined using the equations shown in Table 4 for all specified frequencies.

Table 4 - Channel return loss

	Frequency (MHz)	Return loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f < 20$ $20 \leq f \leq 100$	17 $17 - 10\log(f/20)$
Category 6	$1 \leq f < 10$ $10 \leq f < 40$ $40 \leq f \leq 250$	19 $24-5\log(f)$ $32-10\log(f)$
Category 6A	$1 \leq f < 10$ $10 \leq f < 40$ $40 \leq f < 398.1$ $398.1 \leq f \leq 500$	19 $24-5\log(f)$ $32-10\log(f)$ 6

The channel return loss values in Table 5 are provided for information only.

Table 5 - Minimum channel return loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	17.0	19.0	19.0
4.00	n/s	17.0	19.0	19.0
8.00	n/s	17.0	19.0	19.0
10.00	n/s	17.0	19.0	19.0
16.00	n/s	17.0	18.0	18.0
20.00	-	17.0	17.5	17.5
25.00	-	16.0	17.0	17.0
31.25	-	15.1	16.5	16.5
62.50	-	12.1	14.0	14.0
100.00	-	10.0	12.0	12.0
200.00	-	-	9.0	9.0
250.00	-	-	8.0	8.0
300.00	-	-	-	7.2
400.00	-	-	-	6.0
500.00	-	-	-	6.0

6.2.7   Insertion loss

Channel insertion loss limits are derived from equation (15).

$$InsertionLoss_{channel} = \sum InsertionLoss_{conn} + \sum InsertionLoss_{cable} + ILD_{channel} \quad dB \tag{15}$$

where:

$$InsertionLoss_{cable} = 1.02 \cdot InsertionLoss_{cable,100m} \quad dB, \tag{16}$$

$InsertionLoss_{cable,100m}$ is the insertion loss of 100m of the appropriate category of cable, see clause 6.4.7,

$InsertionLoss_{conn}$ is the insertion loss of the appropriate category of connecting hardware, see clause 6.8.7, and

$$ILD_{channel} = 0 \quad dB \text{ for category 3 and 5e channels} \tag{17}$$

$$ILD_{channel} = 0.0003 \cdot f^{1.5} \quad dB \text{ for category 6 channels} \tag{18}$$

$$ILD_{channel} = 0.03(1.82\sqrt{f} + 0.091f + \frac{0.25}{\sqrt{f}}) \quad dB \text{ for category 6A channels} \tag{19}$$

where,

$ILD_{channel}$ is the insertion loss deviation allowance for a channel.

> NOTES,
> 1   A 20 % increase in insertion loss is allowed for cord cable.
> 2   The insertion loss of the channel does not take into consideration the 0.1 dB measurement floor of the connecting hardware insertion loss requirement.
> 3   The channel insertion loss requirement is derived using the insertion loss contribution of 4 connections.
> 4   For the purposes of field measurements, calculated channel limits that result in insertion loss values less than 3 dB revert to a requirement of 3 dB maximum (see ANSI/TIA-1152).

Channel insertion loss shall meet or be less than the values determined using the equations shown in Table 6 for all specified frequencies.

Table 6 - Channel insertion loss

	Frequency (MHz)	Insertion loss (dB)
Category 3	$1 \leq f \leq 16$	$1.02(2.32\sqrt{f} + 0.238f) + 4 \cdot 0.1\sqrt{f}$
Category 5e	$1 \leq f \leq 100$	$1.02(1.967\sqrt{f} + 0.023f + \dfrac{0.05}{\sqrt{f}}) + 4 \cdot 0.04\sqrt{f}$
Category 6	$1 \leq f \leq 250$	$1.02(1.808\sqrt{f} + 0.017f + \dfrac{0.2}{\sqrt{f}}) + 4 \cdot 0.02\sqrt{f} + 0.0003 \cdot f^{1.5}$
Category 6A	$1 \leq f \leq 500$	$1.05(1.82\sqrt{f} + 0.0091f + \dfrac{0.25}{\sqrt{f}}) + 4 \cdot 0.02\sqrt{f}$

The channel insertion loss values in Table 7 are provided for information only.

Table 7 - Maximum channel insertion loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	3.0	2.2	2.1	2.3
4.00	6.5	4.5	4.0	4.2
8.00	9.8	6.3	5.7	5.8
10.00	11.2	7.1	6.3	6.5
16.00	14.9	9.1	8.0	8.2
20.00	-	10.2	9.0	9.2
25.00	-	11.4	10.1	10.2
31.25	-	12.9	11.4	11.5
62.50	-	18.6	16.5	16.4
100.00	-	24.0	21.3	20.9
200.00	-	-	31.5	30.1
250.00	-	-	35.9	33.9
300.00	-	-	-	37.4
400.00	-	-	-	43.7
500.00	-	-	-	49.3

6.2.8   NEXT loss

Channel NEXT loss shall meet or exceed the values determined using the equations shown in Table 8 for all specified frequencies. Calculations that result in category 3 and 5e channel NEXT loss values greater than 60 dB shall revert to a requirement of 60 dB minimum. Calculations that result in category 6 and 6A channel NEXT loss values greater than 65 dB shall revert to a requirement of 65 dB minimum.

Table 8 - Channel NEXT loss

	Frequency (MHz)	NEXT loss (dB)
Category 3	$1 \leq f \leq 16$	$-20\log\left(10^{\frac{-(23.2-15\log(f/16))}{20}} + 2\cdot10^{\frac{-(33.9-20\log(f/16))}{20}}\right)$
Category 5e	$1 \leq f \leq 100$	$-20\log\left(10^{\frac{-(35.3-15\log(f/100))}{20}} + 2\cdot10^{\frac{-(43-20\log(f/100))}{20}}\right)$
Category 6	$1 \leq f \leq 250$	$-20\log\left(10^{\frac{-(44.3-15\log(f/100))}{20}} + 2\cdot10^{\frac{-(54-20\log(f/100))}{20}}\right)$
Category 6A	$1 \leq f < 330$	$-20\log\left(10^{\frac{-(44.3-15\log(f/100))}{20}} + 2\cdot10^{\frac{-(54-20\log(f/100))}{20}}\right)$
	$330 \leq f \leq 500$	$31-27.15\log(f/330)$

The channel NEXT loss values in Table 9 are provided for information only.

Table 9 - Minimum channel NEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	39.1	60.0	65.0	65.0
4.00	29.3	53.5	63.0	63.0
8.00	24.3	48.6	58.2	58.2
10.00	22.7	47.0	56.6	56.6
16.00	19.3	43.6	53.2	53.2
20.00	-	42.0	51.6	51.6
25.00	-	40.3	50.0	50.0
31.25	-	38.7	48.4	48.4
62.50	-	33.6	43.4	43.4
100.00	-	30.1	39.9	39.9
200.00	-	-	34.8	34.8
250.00	-	-	33.1	33.1
300.00	-	-	-	31.7
400.00	-	-	-	28.7
500.00	-	-	-	26.1

6.2.9   PSNEXT loss

Channel PSNEXT loss shall meet or exceed the values determined using the equations shown in Table 10 for all specified frequencies. Calculations that result in category 5e channel PSNEXT loss values greater than 57 dB shall revert to a requirement of 57 dB minimum. Calculations that result in category 6 and 6A channel PSNEXT loss values greater than 62 dB shall revert to a requirement of 62 dB minimum.

Table 10 - Channel PSNEXT loss

	Frequency (MHz)	PSNEXT loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$-20\log\left(10^{\frac{-(32.3-15\log(f/100))}{20}} + 2\cdot10^{\frac{-(40-20\log(f/100))}{20}}\right)$
Category 6	$1 \leq f \leq 250$	$-20\log\left(10^{\frac{-(42.3-15\log(f/100))}{20}} + 2\cdot10^{\frac{-(50-20\log(f/100))}{20}}\right)$
Category 6A	$1 \leq f < 330$	$-20\log\left(10^{\frac{-(42.3-15\log(f/100))}{20}} + 2\cdot10^{\frac{-(50-20\log(f/100))}{20}}\right)$
	$330 \leq f \leq 500$	$28 - 26.43\log(f/330)$

The channel PSNEXT loss values in Table 11 are provided for information only.

Table 11 - Minimum channel PSNEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	57.0	62.0	62.0
4.00	n/s	50.5	60.5	60.5
8.00	n/s	45.6	55.6	55.6
10.00	n/s	44.0	54.0	54.0
16.00	n/s	40.6	50.6	50.6
20.00	-	39.0	49.0	49.0
25.00	-	37.3	47.3	47.3
31.25	-	35.7	45.7	45.7
62.50	-	30.6	40.6	40.6
100.00	-	27.1	37.1	37.1
200.00	-	-	31.9	31.9
250.00	-	-	30.2	30.2
300.00	-	-	-	28.8
400.00	-	-	-	25.8
500.00	-	-	-	23.2

6.2.10 FEXT loss

FEXT loss is not specified for channels.

6.2.11 ACRF

Channel ACRF shall meet or exceed the values determined using the equations shown in Table 12 for all specified frequencies. Due to measurement considerations, channel ACRF values that correspond to measured channel FEXT loss values of greater than 70 dB are for information only.

Table 12 - Channel ACRF

	Frequency (MHz)	ACRF (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$-20\log\left(10^{\frac{-(23.8-20\log(f/100))}{20}} + 4 \cdot 10^{\frac{-(35.1-20\log(f/100))}{20}}\right)$
Category 6	$1 \leq f \leq 250$	$-20\log\left(10^{\frac{-(27.8-20\log(f/100))}{20}} + 4 \cdot 10^{\frac{-(43.1-20\log(f/100))}{20}}\right)$
Category 6A	$1 \leq f \leq 500$	$-20\log\left(10^{\frac{-(27.8-20\log(f/100))}{20}} + 4 \cdot 10^{\frac{-(43.1-20\log(f/100))}{20}}\right)$

The channel ACRF values in Table 13 are provided for information only.

Table 13 - Minimum channel ACRF

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	57.4	63.3	63.3
4.00	n/s	45.4	51.2	51.2
8.00	n/s	39.3	45.2	45.2
10.00	n/s	37.4	43.3	43.3
16.00	n/s	33.3	39.2	39.2
20.00	-	31.4	37.2	37.2
25.00	-	29.4	35.3	35.3
31.25	-	27.5	33.4	33.4
62.50	-	21.5	27.3	27.3
100.00	-	17.4	23.3	23.3
200.00	-	-	17.2	17.2
250.00	-	-	15.3	15.3
300.00	-	-	-	13.7
400.00	-	-	-	11.2
500.00	-	-	-	9.3

6.2.12 PSFEXT loss

PSFEXT loss is not specified for channels.

6.2.13 PSACRF

Channel PSACRF shall meet or exceed the values determined using the equations shown in Table 14 for all specified frequencies.

Table 14 - Channel PSACRF

	Frequency (MHz)	PSACRF (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$-20\log\left(10^{\frac{-(20.8-20\log(f/100))}{20}} + 4 \cdot 10^{\frac{-(32.1-20\log(f/100))}{20}}\right)$
Category 6	$1 \leq f \leq 250$	$-20\log\left(10^{\frac{-(24.8-20\log(f/100))}{20}} + 4 \cdot 10^{\frac{-(40.1-20\log(f/100))}{20}}\right)$
Category 6A	$1 \leq f \leq 500$	$-20\log\left(10^{\frac{-(24.8-20\log(f/100))}{20}} + 4 \cdot 10^{\frac{-(40.1-20\log(f/100))}{20}}\right)$

The channel PSACRF values in Table 15 are provided for information only.

Table 15 - Minimum channel PSACRF

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	54.4	60.3	60.3
4.00	n/s	42.4	48.2	48.2
8.00	n/s	36.3	42.2	42.2
10.00	n/s	34.4	40.3	40.3
16.00	n/s	30.3	36.2	36.2
20.00	-	28.4	34.2	34.2
25.00	-	26.4	32.3	32.3
31.25	-	24.5	30.4	30.4
62.50	-	18.5	24.3	24.3
100.00	-	14.4	20.3	20.3
200.00	-	-	14.2	14.2
250.00	-	-	12.3	12.3
300.00	-	-	-	10.7
400.00	-	-	-	8.2
500.00	-	-	-	6.3

6.2.14   TCL

Channel TCL shall meet or exceed the values determined using the equations shown in Table 16 for all specified frequencies. Calculations that result in category 6A channel TCL values greater than 40 dB shall revert to a requirement of 40 dB minimum. Compliance to these requirements is intended to be verified by laboratory measurements.

Table 16 - Channel TCL

	Frequency (MHz)	TCL (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6[1)]	$1 \leq f \leq 250$	$50 - 15\log(f)$
Category 6A	$1 \leq f \leq 500$	$50 - 15\log(f)$
[1)] This limit was not specified in ANSI/TIA/EIA-568-B.2-1 or ANSI/TIA-568-B.2-9 and represents expected performance that is provided for information only.		

The channel TCL values in Table 17 are provided for information only.

Table 17 - Minimum channel TCL

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	40.0	40.0
4.00	n/s	n/s	40.0	40.0
8.00	n/s	n/s	36.5	36.5
10.00	n/s	n/s	35.0	35.0
16.00	n/s	n/s	31.9	31.9
20.00	-	n/s	30.5	30.5
25.00	-	n/s	29.0	29.0
31.25	-	n/s	27.6	27.6
62.50	-	n/s	23.1	23.1
100.00	-	n/s	20.0	20.0
200.00	-	-	15.5	15.5
250.00	-	-	14.0	14.0
300.00	-	-	-	12.8
400.00	-	-	-	11.0
500.00	-	-	-	9.5

31

6.2.15 TCTL

TCTL is not specified for channels.

6.2.16 ELTCTL

Channel ELTCTL shall meet or exceed the values determined using the equations shown in Table 18 for all specified frequencies. Compliance to these requirements is intended to be verified by laboratory measurements.

Table 18 - Channel ELTCTL

	Frequency (MHz)	ELTCTL (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	n/s
Category 6[1)]	$1 \leq f \leq 30$ $30 < f \leq 250$	$30 - 20\log(f)$ n/s
Category 6A	$1 \leq f \leq 30$ $30 < f \leq 500$	$30 - 20\log(f)$ n/s
[1)] This limit was not specified in ANSI/TIA/EIA-568-B.2-1 or ANSI/TIA-568-B.2-9 and represents expected performance that is provided for information only.		

The channel ELTCTL values in Table 19 are provided for information only.

Table 19 - Minimum channel ELTCTL

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	30.0	30.0
4.00	n/s	n/s	18.0	18.0
8.00	n/s	n/s	11.9	11.9
10.00	n/s	n/s	10.0	10.0
16.00	n/s	n/s	5.9	5.9
20.00	-	n/s	4.0	4.0
25.00	-	n/s	2.0	2.0
31.25	-	n/s	n/s	n/s
62.50	-	n/s	n/s	n/s
100.00	-	n/s	n/s	n/s
200.00	-	-	n/s	n/s
250.00	-	-	n/s	n/s
300.00	-	-	-	n/s
400.00	-	-	-	n/s
500.00	-	-	-	n/s

6.2.17 Coupling attenuation (screened only)

Coupling attenuation for channels is under study.

6.2.18 Propagation delay

Channel propagation delay shall meet or be less than the values determined using the equations shown in Table 20 for all specified frequencies. For field testing channels, it is sufficient to test at 10 MHz only and channel propagation delay at 10 MHz shall not exceed 555 ns.

Table 20 - Channel propagation delay

	Frequency (MHz)	Propagation delay (ns)
Category 3	$1 \leq f \leq 16$	$(534 + \dfrac{36}{\sqrt{f}}) + (4 \cdot 2.5)$
Category 5e	$1 \leq f \leq 100$	$(534 + \dfrac{36}{\sqrt{f}}) + (4 \cdot 2.5)$
Category 6	$1 \leq f \leq 250$	$(534 + \dfrac{36}{\sqrt{f}}) + (4 \cdot 2.5)$
Category 6A	$1 \leq f \leq 500$	$(534 + \dfrac{36}{\sqrt{f}}) + (4 \cdot 2.5)$

The channel propagation delay values in Table 21 are provided for information only.

Table 21 - Maximum channel propagation delay

Frequency (MHz)	Category 3 (ns)	Category 5e (ns)	Category 6 (ns)	Category 6A (ns)
1.00	580	580	580	580
4.00	562	562	562	562
8.00	557	557	557	557
10.00	555	555	555	555
16.00	553	553	553	553
20.00	-	552	552	552
25.00	-	551	551	551
31.25	-	550	550	550
62.50	-	549	549	549
100.00	-	548	548	548
200.00	-	-	547	547
250.00	-	-	546	546
300.00	-	-	-	546
400.00	-	-	-	546
500.00	-	-	-	546

6.2.19 Propagation delay skew

Channel propagation delay skew shall be less than 50 ns for all frequencies from 1 MHz to the upper frequency limit of the category. For field testing channels, it is sufficient to test at 10 MHz only and channel propagation delay skew at 10 MHz shall not exceed 50 ns.

6.2.20 ANEXT loss

ANEXT loss is not specified for channels.

6.2.21 PSANEXT loss

Channel PSANEXT loss shall meet or exceed the values determined using the equations shown in Table 22 for all specified frequencies. Calculations that result in category 6A channel PSANEXT loss values greater than 67 dB shall revert to a requirement of 67 dB minimum.

Table 22 - Channel PSANEXT loss

	Frequency (MHz)	PSANEXT loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	n/s
Category 6A	$1 \leq f < 100$ $100 \leq f \leq 500$	$60 - 10\log(f/100)$ $60 - 15\log(f/100)$ [1]

[1] If the average insertion loss of all disturbed pairs at 100 MHz, $IL_{100MHz,avg}$, is less than 7 dB, subtract:

$$\text{minimum}\left(7 \cdot \frac{f-100}{400} \cdot \frac{7 - IL_{100MHz,avg}}{IL_{100MHz,avg}}, 6 \cdot \frac{f-100}{400} \right)$$

where:

f is the frequency in MHz

$$IL_{100MHz,avg} = \frac{1}{4} \sum_{i=1}^{4} IL_{100MHz,i}$$

and

$IL_{100MHz,i}$ is the insertion loss of a pair i at 100 MHz

The channel PSANEXT loss values in Table 23 are provided for information only.

Table 23 - Minimum channel PSANEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	n/s	67.0
4.00	n/s	n/s	n/s	67.0
8.00	n/s	n/s	n/s	67.0
10.00	n/s	n/s	n/s	67.0
16.00	n/s	n/s	n/s	67.0
20.00	-	n/s	n/s	67.0
25.00	-	n/s	n/s	66.0
31.25	-	n/s	n/s	65.1
62.50	-	n/s	n/s	62.0
100.00	-	n/s	n/s	60.0
200.00	-	-	n/s	55.5
250.00	-	-	n/s	54.0
300.00	-	-	-	52.8
400.00	-	-	-	51.0
500.00	-	-	-	49.5

6.2.22 Average PSANEXT loss

Channel average PSANEXT loss shall meet or exceed the values determined using the equations shown in Table 24 for all specified frequencies. Calculations that result in category 6A channel average PSANEXT loss values greater than 67 dB shall revert to a requirement of 67 dB minimum.

Table 24 - Channel average PSANEXT loss

	Frequency (MHz)	Average PSANEXT loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	n/s
Category 6A	$1 \leq f < 100$ $100 \leq f \leq 500$	$62.25 - 10\log(f/100)$ $62.25 - 15\log(f/100)$ [1]

[1] If the average insertion loss of all disturbed pairs at 100 MHz, $IL_{100MHz,avg}$, is less than 7 dB, subtract:

$$\mathrm{minimum}\left(7 \cdot \frac{f-100}{400} \cdot \frac{7 - IL_{100MHz,avg}}{IL_{100MHz,avg}}, 6 \cdot \frac{f-100}{400} \right)$$

where:

f is the frequency in MHz

$$IL_{100MHz,avg} = \frac{1}{4}\sum_{i=1}^{4} IL_{100MHz,i}$$

and

$IL_{100MHz,i}$ is the insertion loss of a pair i at 100 MHz

The channel average PSANEXT loss values in Table 25 are provided for information only.

Table 25 - Minimum channel average PSANEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	n/s	67.0
4.00	n/s	n/s	n/s	67.0
8.00	n/s	n/s	n/s	67.0
10.00	n/s	n/s	n/s	67.0
16.00	n/s	n/s	n/s	67.0
20.00	-	n/s	n/s	67.0
25.00	-	n/s	n/s	67.0
31.25	-	n/s	n/s	67.0
62.50	-	n/s	n/s	64.3
100.00	-	n/s	n/s	62.3
200.00	-	-	n/s	57.7
250.00	-	-	n/s	56.3
300.00	-	-	-	55.1
400.00	-	-	-	53.2
500.00	-	-	-	51.8

6.2.23 AFEXT loss

AFEXT loss is not specified for channels.

6.2.24 PSAFEXT loss

PSAFEXT loss is not specified for channels.

6.2.25 PSAACRF

Channel PSAACRF shall meet or exceed the values determined using the equations shown in Table 26 for all specified frequencies. Channel PSAACRF shall be for information only when channel PSAFEXT loss is greater than either 72-15log(f/100) dB or 67 dB. Calculations that result in category 6A channel PSAACRF values greater than 67 dB shall revert to a requirement of 67 dB minimum.

Table 26 - Channel PSAACRF

	Frequency (MHz)	PSAACRF (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	n/s
Category 6A	$1 \leq f \leq 500$	37-20log(f/100)

The channel PSAACRF values in Table 27 are provided for information only.

Table 27 - Minimum channel PSAACRF

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	n/s	67.0
4.00	n/s	n/s	n/s	65.0
8.00	n/s	n/s	n/s	58.9
10.00	n/s	n/s	n/s	57.0
16.00	n/s	n/s	n/s	52.9
20.00	-	n/s	n/s	51.0
25.00	-	n/s	n/s	49.0
31.25	-	n/s	n/s	47.1
62.50	-	n/s	n/s	41.1
100.00	-	n/s	n/s	37.0
200.00	-	-	n/s	31.0
250.00	-	-	n/s	29.0
300.00	-	-	-	27.5
400.00	-	-	-	25.0
500.00	-	-	-	23.0

6.2.26 Average PSAACRF

Channel average PSAACRF shall meet or exceed the values determined using the equations shown in Table 28 for all specified frequencies. Channel average PSAACRF shall be for information only when channel PSAFEXT loss is greater than either 72-15log(f/100) dB or 67 dB. Calculations that result in category 6A channel average PSAACRF values greater than 67 dB shall revert to a requirement of 67 dB minimum.

Table 28 - Channel average PSAACRF

	Frequency (MHz)	Average PSAACRF (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f \le 100$	n/s
Category 6	$1 \le f \le 250$	n/s
Category 6A	$1 \le f \le 500$	41-20log(f/100)

The channel average PSAACRF values in Table 29 are provided for information only.

Table 29 - Minimum channel average PSAACRF

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	n/s	67.0
4.00	n/s	n/s	n/s	67.0
8.00	n/s	n/s	n/s	62.9
10.00	n/s	n/s	n/s	61.0
16.00	n/s	n/s	n/s	56.9
20.00	-	n/s	n/s	55.0
25.00	-	n/s	n/s	53.0
31.25	-	n/s	n/s	51.1
62.50	-	n/s	n/s	45.1
100.00	-	n/s	n/s	41.0
200.00	-	-	n/s	35.0
250.00	-	-	n/s	33.0
300.00	-	-	-	31.5
400.00	-	-	-	29.0
500.00	-	-	-	27.0

6.3 Permanent link transmission performance

This clause contains the transmission performance specifications for balanced twisted-pair permanent links. The permanent link test configuration is illustrated in figure 4. See Annex J for worst case modeling configurations.
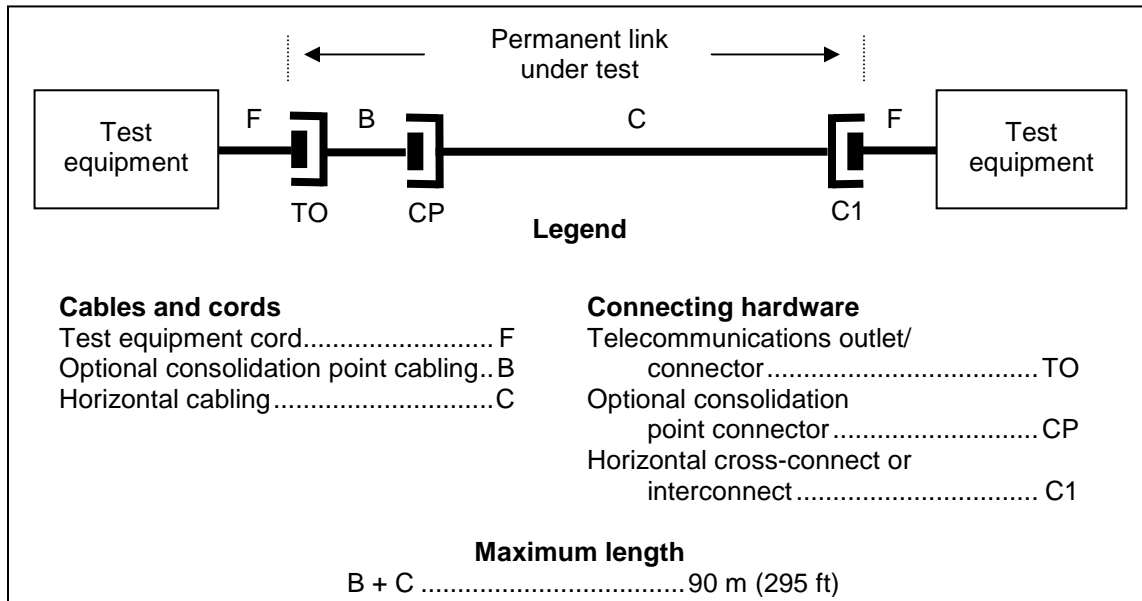
Figure 4 - Supplemental schematic representation of a permanent link test configuration

6.3.1 DC loop resistance

DC loop resistance for category 3, 5e, 6, and 6A permanent links shall not exceed 21 Ω.

6.3.2 DC resistance unbalance

DC resistance unbalance is not specified for permanent links.

6.3.3 Mutual capacitance

Mutual capacitance is not specified for permanent links.

6.3.4 Capacitance unbalance: pair-to-ground

Capacitance unbalance is not specified for permanent links.

6.3.5 Characteristic impedance and structural return loss (SRL)

Characteristic impedance and structural return loss (SRL) are not applicable for permanent links.

6.3.6 Return loss

Permanent link return loss shall meet or exceed the values determined using the equations shown in Table 30 for all specified frequencies.

Table 30 – Permanent link return loss

	Frequency (MHz)	Return loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f < 20$ $20 \leq f \leq 100$	19 $19 - 10\log(f/20)$
Category 6	$1 \leq f < 3$ $3 \leq f < 10$ $10 \leq f < 40$ $40 \leq f \leq 250$	$21+4\log(f/3)$ 21 $26-5\log(f)$ $34-10\log(f)$
Category 6A	$1 \leq f < 3$ $3 \leq f < 10$ $10 \leq f < 40$ $40 \leq f < 398.1$ $398.1 \leq f \leq 500$	$21+4\log(f/3)$ 21 $26-5\log(f)$ $34-10\log(f)$ 8

The permanent link return loss values in Table 31 are provided for information only.

Table 31 - Minimum permanent link return loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	19.0	19.1	19.1
4.00	n/s	19.0	21.0	21.0
8.00	n/s	19.0	21.0	21.0
10.00	n/s	19.0	21.0	21.0
16.00	n/s	19.0	20.0	20.0
20.00	-	19.0	19.5	19.5
25.00	-	18.0	19.0	19.0
31.25	-	17.1	18.5	18.5
62.50	-	14.1	16.0	16.0
100.00	-	12.0	14.0	14.0
200.00	-	-	11.0	11.0
250.00	-	-	10.0	10.0
300.00	-	-	-	9.2
400.00	-	-	-	8.0
500.00	-	-	-	8.0

6.3.7 Insertion loss

Permanent link insertion loss limits are derived from equation (20).

$$InsertionLoss_{perm\_link} = \sum InsertionLoss_{conn} + \sum InsertionLoss_{cable} + ILD_{perm\_link} \quad dB \tag{20}$$

where:

$$InsertionLoss_{cable} = 0.9 \cdot InsertionLoss_{cable,100m} \quad dB, \tag{21}$$

$InsertionLoss_{cable,100m}$ is the insertion loss of 100m of the appropriate category of cable, see clause 6.4.7,

$InsertionLoss_{conn}$ is the insertion loss of the appropriate category of connecting hardware, see clause 6.8.7, and

$$ILD_{perm\_link} = 0 \quad dB \text{ for category 3 and 5e channels} \tag{22}$$

$$ILD_{perm\_link} = 0.00015 \cdot f^{1.5} \quad dB \text{ for category 6 and 6A channels} \tag{23}$$

NOTES,
1   The insertion loss of the permanent link does not take into consideration the 0.1 dB measurement floor of the connecting hardware insertion loss requirement.
2   The permanent link insertion loss requirement is derived using the insertion loss contribution of 3 connections
3   For the purposes of field measurements, calculated permanent link limits that result in insertion loss values less than 3 dB revert to a requirement of 3 dB maximum (see ANSI/TIA-1152).

Permanent link insertion loss shall meet or be less than the values determined using the equations shown in Table 32 for all specified frequencies.

Table 32 – Permanent link insertion loss

	Frequency (MHz)	Insertion loss (dB)
Category 3	$1 \leq f \leq 16$	$0.9(2.32\sqrt{f} + 0.238f) + 3 \cdot 0.1\sqrt{f}$
Category 5e	$1 \leq f \leq 100$	$0.9(1.967\sqrt{f} + 0.023f + \dfrac{0.05}{\sqrt{f}}) + 3 \cdot 0.04\sqrt{f}$
Category 6	$1 \leq f \leq 250$	$1.687\sqrt{f} + 0.0153 \cdot f + \dfrac{0.18}{\sqrt{f}} + 0.00015 \cdot f^{1.5}$
Category 6A	$1 \leq f \leq 500$	$1.698\sqrt{f} + 0.00819f + \dfrac{0.225}{\sqrt{f}} + 0.00015f^{1.5}$

The permanent link insertion loss values in Table 33 are provided for information only.

Table 33 - Maximum permanent link insertion loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	2.6	2.1	1.9	1.9
4.00	5.6	3.9	3.5	3.5
8.00	8.5	5.5	5.0	5.0
10.00	9.7	6.2	5.5	5.5
16.00	13.0	7.9	7.0	7.0
20.00	-	8.9	7.9	7.8
25.00	-	10.0	8.9	8.8
31.25	-	11.2	10.0	9.8
62.50	-	16.2	14.4	14.0
100.00	-	21.0	18.6	18.0
200.00	-	-	27.4	26.1
250.00	-	-	31.1	29.5
300.00	-	-	-	32.7
400.00	-	-	-	38.4
500.00	-	-	-	43.8

6.3.8 NEXT loss

Permanent link NEXT loss shall meet or exceed the values determined using the equations shown in Table 34 for all specified frequencies. Calculations that result in category 3 and 5e permanent link NEXT loss values greater than 60 dB shall revert to a requirement of 60 dB minimum. Calculations that result in category 6 and 6A permanent link NEXT loss values greater than 65 dB shall revert to a requirement of 65 dB minimum.

Table 34 - Permanent link NEXT loss

	Frequency (MHz)	NEXT loss (dB)
Category 3	$1 \le f \le 16$	$-20\log\left(10^{\frac{-(23.2-15\log(f/16))}{20}}+10^{\frac{-(33.9-20\log(f/16))}{20}}\right)$
Category 5e	$1 \le f \le 100$	$-20\log\left(10^{\frac{-(35.3-15\log(f/100))}{20}}+10^{\frac{-(43-20\log(f/100))}{20}}\right)$
Category 6	$1 \le f \le 250$	$-20\log\left(10^{\frac{-(44.3-15\log(f/100))}{20}}+10^{\frac{-(54-20\log(f/100))}{20}}\right)$
Category 6A	$1 \le f < 300$	$-20\log\left(10^{\frac{-(44.3-15\log(f/100))}{20}}+10^{\frac{-(54-20\log(f/100))}{20}}\right)$
	$300 \le f \le 500$	$34-33.13\log(f/300)$

NOTE - Permanent link NEXT loss test limits are more stringent than channel NEXT loss test limits to ensure that permanent links can be extended into compliant channels using additional cabling components that meet the minimum specifications in this Standard. When a consolidation point is present in the permanent link, the modeling predictions of permanent link NEXT loss performance using worst case components show margins that can be below the measurement accuracy for the permanent link. NEXT loss performance can be improved by ensuring at least a 5 m (16.4 ft) distance between the consolidation point and the telecommunications outlet connector. Alternatively, channel testing can be performed with compliant channel cabling components that remain in place.

The permanent link NEXT loss values in Table 35 are provided for information only.

Table 35 - Minimum permanent link NEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	40.1	60.0	65.0	65.0
4.00	30.7	54.8	64.1	64.1
8.00	25.9	50.0	59.4	59.4
10.00	24.3	48.5	57.8	57.8
16.00	21.0	45.2	54.6	54.6
20.00	-	43.7	53.1	53.1
25.00	-	42.1	51.5	51.5
31.25	-	40.5	50.0	50.0
62.50	-	35.7	45.1	45.1
100.00	-	32.3	41.8	41.8
200.00	-	-	36.9	36.9
250.00	-	-	35.3	35.3
300.00	-	-	-	34.0
400.00	-	-	-	29.9
500.00	-	-	-	26.7

6.3.9 PSNEXT loss

Permanent link PSNEXT loss shall meet or exceed the values determined using the equations shown in Table 36 for all specified frequencies. Calculations that result in category 5e permanent link PSNEXT loss values greater than 57 dB shall revert to a requirement of 57 dB minimum. Calculations that result in category 6 and 6A permanent link PSNEXT loss values greater than 62 dB shall revert to a requirement of 62 dB minimum.

Table 36 - Permanent link PSNEXT loss

	Frequency (MHz)	PSNEXT loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$-20\log\left(10^{\frac{-(32.3-15\log(f/100))}{20}} + 10^{\frac{-(40-20\log(f/100))}{20}}\right)$
Category 6	$1 \leq f \leq 250$	$-20\log\left(10^{\frac{-(42.3-15\log(f/100))}{20}} + 10^{\frac{-(50-20\log(f/100))}{20}}\right)$
Category 6A	$1 \leq f < 300$	$-20\log\left(10^{\frac{-(42.3-15\log(f/100))}{20}} + 10^{\frac{-(50-20\log(f/100))}{20}}\right)$
	$300 \leq f \leq 500$	$31.4 - 34.44\log(f/300)$

NOTE - Permanent link PSNEXT loss test limits are more stringent than channel PSNEXT loss test limits to ensure that permanent links can be extended into compliant channels using additional cabling components that meet the minimum specifications in this Standard. When a consolidation point is present in the permanent link, the modeling predictions of permanent link PSNEXT loss performance using worst case components show margins that can be below the measurement accuracy for the permanent link. PSNEXT loss performance can be improved by ensuring at least a 5 m (16.4 ft) distance between the consolidation point and the telecommunications outlet connector. Alternatively, channel testing can be performed with compliant channel cabling components that remain in place.

The permanent link PSNEXT loss values in Table 37 are provided for information only.

Table 37 - Minimum permanent link PSNEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	57.0	62.0	62.0
4.00	n/s	51.8	61.8	61.8
8.00	n/s	47.0	57.0	57.0
10.00	n/s	45.5	55.5	55.5
16.00	n/s	42.2	52.2	52.2
20.00	-	40.7	50.7	50.7
25.00	-	39.1	49.1	49.1
31.25	-	37.5	47.5	47.5
62.50	-	32.7	42.7	42.7
100.00	-	29.3	39.3	39.3
200.00	-	-	34.3	34.3
250.00	-	-	32.7	32.7
300.00	-	-	-	31.4
400.00	-	-	-	27.1
500.00	-	-	-	23.8

6.3.10   FEXT loss

FEXT loss is not specified for permanent links.

6.3.11 ACRF

Permanent link ACRF shall meet or exceed the values determined using the equations shown in Table 38 for all specified frequencies. Due to measurement considerations, permanent link ACRF values that correspond to measured channel FEXT loss values of greater than 67 dB are for information only.

Table 38 - Permanent link ACRF

	Frequency (MHz)	ACRF (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$-20\log\left(10^{\frac{-(23.8-20\log(f/100))}{20}} + 3\cdot10^{\frac{-(35.1-20\log(f/100))}{20}}\right)$
Category 6	$1 \leq f \leq 250$	$-20\log\left(10^{\frac{-(27.8-20\log(f/100))}{20}} + 3\cdot10^{\frac{-(43.1-20\log(f/100))}{20}}\right)$
Category 6A	$1 \leq f \leq 500$	$-20\log\left(10^{\frac{-(27.8-20\log(f/100))}{20}} + 3\cdot10^{\frac{-(43.1-20\log(f/100))}{20}}\right)$

The permanent link ACRF values in Table 39 are provided for information only.

Table 39 - Minimum permanent link ACRF

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	58.6	64.2	64.2
4.00	n/s	46.6	52.1	52.1
8.00	n/s	40.6	46.1	46.1
10.00	n/s	38.6	44.2	44.2
16.00	n/s	34.5	40.1	40.1
20.00	-	32.6	38.2	38.2
25.00	-	30.7	36.2	36.2
31.25	-	28.7	34.3	34.3
62.50	-	22.7	28.3	28.3
100.00	-	18.6	24.2	24.2
200.00	-	-	18.2	18.2
250.00	-	-	16.2	16.2
300.00	-	-	-	14.6
400.00	-	-	-	12.1
500.00	-	-	-	10.2

6.3.12 PSFEXT loss

PSFEXT loss is not specified for permanent links.

6.3.13 PSACRF

Permanent link PSACRF shall meet or exceed the values determined using the equations shown in Table 40 for all specified frequencies.

Table 40 - Permanent link PSACRF

	Frequency (MHz)	PSACRF (dB)		
Category 3	$1 \le f \le 16$	n/s		
Category 5e	$1 \le f \le 100$	$-20\log\left(10^{\dfrac{-(20.8-20\log(f/100))}{20}} + 3\cdot 10^{\dfrac{-(32.1-20\log(f/100))}{20}}\right)$		
Category 6	$1 \le f \le 250$	$-20\log\left(10^{\dfrac{-(24.8-20\log(f/100))}{20}} + 3\cdot 10^{\dfrac{-(40.1-20\log(f/100))}{20}}\right)$		
Category 6A	$1 \le f \le 500$	$-20\log\left(10^{\dfrac{-(24.8-20\log(f/100))}{20}} + 3\cdot 10^{\dfrac{-(40.1-20\log(f/100))}{20}}\right)$		

The permanent link PSACRF values in Table 41 are provided for information only.

Table 41 - Minimum permanent link PSACRF

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	55.6	61.2	61.2
4.00	n/s	43.6	49.1	49.1
8.00	n/s	37.5	43.1	43.1
10.00	n/s	35.6	41.2	41.2
16.00	n/s	31.5	37.1	37.1
20.00	-	29.6	35.2	35.2
25.00	-	27.7	33.2	33.2
31.25	-	25.7	31.3	31.3
62.50	-	19.7	25.3	25.3
100.00	-	15.6	21.2	21.2
200.00	-	-	15.2	15.2
250.00	-	-	13.2	13.2
300.00	-	-	-	11.6
400.00	-	-	-	9.1
500.00	-	-	-	7.2

6.3.14 TCL

TCL is not specified for permanent links.

6.3.15 TCTL

TCTL is not specified for permanent links.

6.3.16 ELTCTL

ELTCL is not specified for permanent links.

6.3.17 Coupling attenuation (screened only)

Coupling attenuation is not specified for permanent links.

6.3.18 Propagation delay

Permanent link propagation delay shall meet or be less than the values determined using the equations shown in Table 42 for all specified frequencies. For field testing permanent links, it is sufficient to test at 10 MHz only and permanent link propagation delay at 10 MHz shall not exceed 498 ns.

Table 42 - Permanent link propagation delay

	Frequency (MHz)	Propagation delay (ns)
Category 3	$1 \leq f \leq 16$	$0.9 \cdot \left((534 + \dfrac{36}{\sqrt{f}} \right) + (3 \cdot 2.5)$
Category 5e	$1 \leq f \leq 100$	$0.9 \cdot \left((534 + \dfrac{36}{\sqrt{f}} \right) + (3 \cdot 2.5)$
Category 6	$1 \leq f \leq 250$	$0.9 \cdot \left((534 + \dfrac{36}{\sqrt{f}} \right) + (3 \cdot 2.5)$
Category 6A	$1 \leq f \leq 500$	$0.9 \cdot \left((534 + \dfrac{36}{\sqrt{f}} \right) + (3 \cdot 2.5)$

The permanent link propagation delay values in Table 43 are provided for information only.

Table 43 - Maximum permanent link propagation delay

Frequency (MHz)	Category 3 (ns)	Category 5e (ns)	Category 6 (ns)	Category 6A (ns)
1.00	521	521	521	521
4.00	504	504	504	504
8.00	500	500	500	500
10.00	498	498	498	498
16.00	496	496	496	496
20.00	-	495	495	495
25.00	-	495	495	495
31.25	-	494	494	494
62.50	-	492	492	492
100.00	-	491	491	491
200.00	-	-	490	490
250.00	-	-	490	490
300.00	-	-	-	490
400.00	-	-	-	490
500.00	-	-	-	490

6.3.19 Propagation delay skew

Permanent link propagation delay skew shall be less than 44 ns for all frequencies from 1 MHz to the upper frequency limit of the category. For field testing channels, it is sufficient to test at 10 MHz only and permanent link propagation delay skew at 10 MHz shall not exceed 44 ns.

6.3.20 ANEXT loss

ANEXT loss is not specified for permanent links.

6.3.21 PSANEXT loss

Permanent link PSANEXT loss shall meet or exceed the values determined using the equations shown in Table 44 for all specified frequencies. Calculations that result in category 6A permanent link PSANEXT loss values greater than 67 dB shall revert to a requirement of 67 dB minimum.

Table 44 – Permanent link PSANEXT loss

	Frequency (MHz)	PSANEXT loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	n/s
Category 6A	$1 \leq f < 100$ $100 \leq f \leq 500$	$60 - 10\log(f/100)$ $60 - 15\log(f/100)$ [1]

[1] If the average insertion loss of all disturbed pairs at 100 MHz, $IL_{100MHz,avg}$, is less than 7 dB, subtract:

$$\text{minimum}\left(7 \cdot \frac{f-100}{400} \cdot \frac{7 - IL_{100MHz,avg}}{IL_{100MHz,avg}} , 6 \cdot \frac{f-100}{400} \right)$$

where:

f is the frequency in MHz

$$IL_{100MHz,avg} = \frac{1}{4}\sum_{i=1}^{4} IL_{100MHz,i}$$

and

$IL_{100MHz,i}$ is the insertion loss of a pair i at 100 MHz

The permanent link PSANEXT loss values in Table 45 are provided for information only.

Table 45 - Permanent link PSANEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	n/s	67.0
4.00	n/s	n/s	n/s	67.0
8.00	n/s	n/s	n/s	67.0
10.00	n/s	n/s	n/s	67.0
16.00	n/s	n/s	n/s	67.0
20.00	-	n/s	n/s	67.0
25.00	-	n/s	n/s	66.0
31.25	-	n/s	n/s	65.1
62.50	-	n/s	n/s	62.0
100.00	-	n/s	n/s	60.0
200.00	-	-	n/s	55.5
250.00	-	-	n/s	54.0
300.00	-	-	-	52.8
400.00	-	-	-	51.0
500.00	-	-	-	49.5

6.3.22 Average PSANEXT Loss

Permanent link average PSANEXT loss shall meet or exceed the values determined using the equations shown in Table 46 for all specified frequencies. Calculations that result in category 6A permanent link average PSANEXT loss values greater than 67 dB shall revert to a requirement of 67 dB minimum.

Table 46 - Permanent link average PSANEXT loss

	Frequency (MHz)	Average PSANEXT loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	n/s
Category 6A	$1 \leq f < 100$ $100 \leq f \leq 500$	$62.25 - 10\log(f/100)$ $62.25 - 15\log(f/100)$ [1]

[1] If the average insertion loss of all disturbed pairs at 100 MHz, $IL_{100MHz,avg}$, is less than 7 dB, subtract:

$$\text{minimum}\left(7 \cdot \frac{f-100}{400} \cdot \frac{7 - IL_{100MHz,avg}}{IL_{100MHz,avg}}, 6 \cdot \frac{f-100}{400} \right)$$

where:

f is the frequency in MHz

$$IL_{100MHz,avg} = \frac{1}{4}\sum_{i=1}^{4} IL_{100MHz,i}$$

and

$IL_{100MHz,i}$ is the insertion loss of a pair i at 100 MHz

The permanent link average PSANEXT loss values in Table 47 are provided for information only.

Table 47 - Minimum permanent link average PSANEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	n/s	67.0
4.00	n/s	n/s	n/s	67.0
8.00	n/s	n/s	n/s	67.0
10.00	n/s	n/s	n/s	67.0
16.00	n/s	n/s	n/s	67.0
20.00	-	n/s	n/s	67.0
25.00	-	n/s	n/s	67.0
31.25	-	n/s	n/s	67.0
62.50	-	n/s	n/s	64.3
100.00	-	n/s	n/s	62.3
200.00	-	-	n/s	57.7
250.00	-	-	n/s	56.3
300.00	-	-	-	55.1
400.00	-	-	-	53.2
500.00	-	-	-	51.8

6.3.23 AFEXT loss

AFEXT loss is not specified for permanent links.

6.3.24 PSAFEXT loss

PSAFEXT loss is not specified for permanent links.

6.3.25 PSAACRF

Permanent link PSAACRF shall meet or exceed the values determined using the equations shown in Table 48 for all specified frequencies. Permanent link PSAACRF shall be for information only when permanent link PSAFEXT loss is greater than either 72-15log(f/100) dB or 67 dB. Calculations that result in category 6A permanent link PSAACRF values greater than 67 dB shall revert to a requirement of 67 dB minimum.

Table 48 - Permanent link PSAACRF

	Frequency (MHz)	PSAACRF (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f \le 100$	n/s
Category 6	$1 \le f \le 250$	n/s
Category 6A	$1 \le f \le 500$	37.7-20log(f/100)

The permanent link PSAACRF values in Table 49 are provided for information only.

Table 49 - Minimum permanent link PSAACRF

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	n/s	67.0
4.00	n/s	n/s	n/s	65.7
8.00	n/s	n/s	n/s	59.6
10.00	n/s	n/s	n/s	57.7
16.00	n/s	n/s	n/s	53.6
20.00	-	n/s	n/s	51.7
25.00	-	n/s	n/s	49.7
31.25	-	n/s	n/s	47.8
62.50	-	n/s	n/s	41.8
100.00	-	n/s	n/s	37.7
200.00	-	-	n/s	31.7
250.00	-	-	n/s	29.7
300.00	-	-	-	28.2
400.00	-	-	-	25.7
500.00	-	-	-	23.7

6.3.26 Average PSAACRF loss

Permanent link average PSAACRF shall meet or exceed the values determined using the equations shown in Table 50 for all specified frequencies. Permanent link average PSAACRF shall be for information only when permanent link PSAFEXT loss is greater than either 72-15log(f/100) dB or 67 dB. Calculations that result in category 6A permanent link average PSAACRF values greater than 67 dB shall revert to a requirement of 67 dB minimum.

Table 50 - Permanent link average PSAACRF

	Frequency (MHz)	Average PSAACRF (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	n/s
Category 6A	$1 \leq f \leq 500$	41.7-20log(f/100)

The permanent link average PSAACRF values in Table 51 are provided for information only.

Table 51 - Minimum permanent link average PSAACRF

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	n/s	67.0
4.00	n/s	n/s	n/s	67.0
8.00	n/s	n/s	n/s	63.6
10.00	n/s	n/s	n/s	61.7
16.00	n/s	n/s	n/s	57.6
20.00	-	n/s	n/s	55.7
25.00	-	n/s	n/s	53.7
31.25	-	n/s	n/s	51.8
62.50	-	n/s	n/s	45.8
100.00	-	n/s	n/s	41.7
200.00	-	-	n/s	35.7
250.00	-	-	n/s	33.7
300.00	-	-	-	32.2
400.00	-	-	-	29.7
500.00	-	-	-	27.7

6.4   Horizontal cable transmission performance

6.4.1   DC resistance

DC resistance shall be measured in accordance with ASTM D4566 for all horizontal cable pairs. For all categories of horizontal cable, the resistance of any conductor shall not exceed 9.38 Ω per 100 m (328 ft) at or corrected to a temperature of 20 °C.

6.4.2   DC resistance unbalance

For category 3, 5e, and 6 horizontal cable, 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.

> NOTE – This requirement is equivalent to a 2.5% cable dc resistance unbalance when measured in accordance with IEC 61156-1.

For category 6A horizontal cable, the resistance unbalance between the two conductors of any cable pair, measured in accordance with ASTM D 4566, shall not exceed 4% when measured at, or corrected to, a temperature of 20 °C.

> NOTE – This requirement is equivalent to a 2% cable dc resistance unbalance when measured in accordance with IEC 61156-1.

6.4.3   Mutual capacitance

Mutual capacitance shall be measured in accordance with ASTM D4566 for all horizontal cable pairs.

The mutual capacitance of a category 3 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). The mutual capacitance of a category 5e, 6, or 6A horizontal cable pair at 1 kHz, measured at or corrected to a temperature of 20 °C, should not exceed 5.6 nF per 100 m (328 ft).

6.4.4   Capacitance unbalance: pair-to-ground

Capacitance unbalance to ground shall be measured in accordance with ASTM D4566 for all horizontal cable pairs.   For all categories of horizontal cable, the capacitance unbalance to ground at 1 kHz, measured shall not exceed 330 pF per 100 m (328 ft) at or corrected to a temperature of 20 °C.

6.4.5   Characteristic impedance and structural return loss (SRL)

Characteristic impedance shall be measured for all cable pairs. Characteristic impedance is not specified for category 5e, 6, and 6A horizontal cables. Category 3 horizontal cables shall exhibit a characteristic impedance of 100 Ω ±15% when measured in accordance with ASTM D 4566 Method 3 for all frequencies from 1 to 16 MHz. 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 is not specified for category 5e, 6, and 6A horizontal cables.

Structural return loss shall be measured for all horizontal cable pairs. Category 3 horizontal cable structural return loss shall be measured in accordance with ASTM D 4566 Method 3 for all frequencies from 1 to 16 MHz. Horizontal cable structural return loss shall meet or exceed the values determined using the equations shown in Table 52 for all specified frequencies.

Table 52 – Horizontal cable structural return loss

	Frequency (MHz)	Structural return loss (dB)
Category 3	$1 \leq f \leq 10$ $10 < f \leq 16$	12 12-10log(f/10)
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	n/s
Category 6A	$1 \leq f \leq 500$	n/s

The horizontal cable structural return loss values in Table 53 are provided for information only.

Table 53 - Minimum horizontal cable structural return loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	12.0	n/s	n/s	n/s
4.00	12.0	n/s	n/s	n/s
8.00	12.0	n/s	n/s	n/s
10.00	12.0	n/s	n/s	n/s
16.00	10.0	n/s	n/s	n/s
20.00	-	n/s	n/s	n/s
25.00	-	n/s	n/s	n/s
31.25	-	n/s	n/s	n/s
62.50	-	n/s	n/s	n/s
100.00	-	n/s	n/s	n/s
200.00	-	-	n/s	n/s
250.00	-	-	n/s	n/s
300.00	-	-	-	n/s
400.00	-	-	-	n/s
500.00	-	-	-	n/s

6.4.6 Return loss

Horizontal cable return loss shall meet or exceed the values determined using the equations shown in Table 54 for all specified frequencies.

Table 54 - Horizontal cable return loss

	Frequency (MHz)	Return loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f < 10$ $10 \leq f < 20$ $20 \leq f \leq 100$	$20+5\log(f)$ 25 $25-7\log(f/20)$
Category 6	$1 \leq f < 10$ $10 \leq f < 20$ $20 \leq f \leq 250$	$20+5\log(f)$ 25 $25-7\log(f/20)$
Category 6A	$1 \leq f < 10$ $10 \leq f < 20$ $20 \leq f \leq 500$	$20+5\log(f)$ 25 $25-7\log(f/20)$

The horizontal cable return loss values in Table 55 are provided for information only.

Table 55 - Minimum horizontal cable return loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	20.0	20.0	20.0
4.00	n/s	23.0	23.0	23.0
8.00	n/s	24.5	24.5	24.5
10.00	n/s	25.0	25.0	25.0
16.00	n/s	25.0	25.0	25.0
20.00	-	25.0	25.0	25.0
25.00	-	24.3	24.3	24.3
31.25	-	23.6	23.6	23.6
62.50	-	21.5	21.5	21.5
100.00	-	20.1	20.1	20.1
200.00	-	-	18.0	18.0
250.00	-	-	17.3	17.3
300.00	-	-	-	16.8
400.00	-	-	-	15.9
500.00	-	-	-	15.2

6.4.7   Insertion loss

Insertion loss shall be measured for all horizontal cable pairs at 20 ± 3℃ or corrected to a temperat ure of 20 ℃ using the correction factors specified in thi s clause. The insertion loss for category 5e, 6, and 6A UTP horizontal cables shall be adjusted at elevated temperatures using a factor of 0.4 % increase per ℃ from 20 ℃ to 40 ℃ and 0.6% increase per ℃ for te mperatures from 40 ℃ to 60 ℃. The insertion loss for category 5e, 6, and 6A screened horizontal cables shall be adjusted at elevated temperatures using a factor of 0.2% increase per ℃ from 20 ℃ to 60 ℃.   See Annex G for additional information on cable installation in higher temperature environments.

Horizontal cable insertion loss shall meet or be less than the values determined using the equations shown in Table 56 for all specified frequencies. In addition, category 6 and 6A horizontal cable insertion loss shall also be verified at temperatures of 40 ± 3 ℃ and 60 ± 3 ℃ and shall meet the requirements of Table 56 after adjusting for temperature.

Table 56 - Horizontal cable insertion loss, for a length of 100m (328 ft)

	Frequency (MHz)	**Insertion loss (dB)**
Category 3	$0.772 \leq f \leq 16$	$2.320\sqrt{f} + 0.238 \cdot f$
Category 5e	$1 \leq f \leq 100$	$1.967\sqrt{f} + 0.023 \cdot f + \dfrac{0.050}{\sqrt{f}}$
Category 6	$1 \leq f \leq 250$	$1.808\sqrt{f} + 0.017 \cdot f + \dfrac{0.2}{\sqrt{f}}$
Category 6A	$1 \leq f \leq 500$	$1.82\sqrt{f} + 0.0091 \cdot f + \dfrac{0.25}{\sqrt{f}}$

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 ℃ is not uncommon for such cable s. In installations where the cable will be subjected to higher temperatures, a less-temperature dependent cable should be considered.

The horizontal cable insertion loss values in Table 57 are provided for information only.

Table 57 - Maximum horizontal cable insertion loss, for a length of 100m (328 ft)

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
0.772	2.2	n/s	n/s	n/s
1.00	2.6	2.0	2.0	2.1
4.00	5.6	4.1	3.8	3.8
8.00	8.5	5.8	5.3	5.3
10.00	9.7	6.5	6.0	5.9
16.00	13.1	8.2	7.6	7.5
20.00	-	9.3	8.5	8.4
25.00	-	10.4	9.5	9.4
31.25	-	11.7	10.7	10.5
62.50	-	17.0	15.4	15.0
100.00	-	22.0	19.8	19.1
200.00	-	-	29.0	27.6
250.00	-	-	32.8	31.1
300.00	-	-	-	34.3
400.00	-	-	-	40.1
500.00	-	-	-	45.3

6.4.8   NEXT loss

Horizontal cable NEXT loss shall meet or exceed the values determined using the equations shown in Table 58 for all specified frequencies.

Table 58 - Horizontal cable NEXT loss

	Frequency (MHz)	NEXT loss (dB)
Category 3	$0.772 \leq f \leq 16$	$23.2 - 15\log(f/16)$
Category 5e	$1 \leq f \leq 100$	$35.3 - 15\log(f/100)$
Category 6	$1 \leq f \leq 250$	$44.3 - 15\log(f/100)$
Category 6A	$1 \leq f \leq 500$	$44.3 - 15\log(f/100)$

The horizontal cable NEXT loss values in Table 59 are provided for information only.

Table 59 - Minimum horizontal cable NEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
0.772	43.0	n/s	n/s	n/s
1.00	41.3	65.3	74.3	74.3
4.00	32.3	56.3	65.3	65.3
8.00	27.8	51.8	60.8	60.8
10.00	26.3	50.3	59.3	59.3
16.00	23.2	47.2	56.2	56.2
20.00	-	45.8	54.8	54.8
25.00	-	44.3	53.3	53.3
31.25	-	42.9	51.9	51.9
62.50	-	38.4	47.4	47.4
100.00	-	35.3	44.3	44.3
200.00	-	-	39.8	39.8
250.00	-	-	38.3	38.3
300.00	-	-	-	37.1
400.00	-	-	-	35.3
500.00	-	-	-	33.8

6.4.9 PSNEXT loss

Horizontal cable PSNEXT loss shall meet or exceed the values determined using the equations shown in Table 60 for all specified frequencies.

Table 60 - Horizontal cable PSNEXT loss

	Frequency (MHz)	PSNEXT loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$32.3 - 15\log(f/100)$
Category 6	$1 \leq f \leq 250$	$42.3 - 15\log(f/100)$
Category 6A	$1 \leq f \leq 500$	$42.3 - 15\log(f/100)$

The horizontal cable PSNEXT loss values in Table 61 are provided for information only.

Table 61 - Minimum horizontal cable PSNEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	62.3	72.3	72.3
4.00	n/s	53.3	63.3	63.3
8.00	n/s	48.8	58.8	58.8
10.00	n/s	47.3	57.3	57.3
16.00	n/s	44.2	54.2	54.2
20.00	-	42.8	52.8	52.8
25.00	-	41.3	51.3	51.3
31.25	-	39.9	49.9	49.9
62.50	-	35.4	45.4	45.4
100.00	-	32.3	42.3	42.3
200.00	-	-	37.8	37.8
250.00	-	-	36.3	36.3
300.00	-	-	-	35.1
400.00	-	-	-	33.3
500.00	-	-	-	31.8

6.4.10 FEXT loss

FEXT loss is not specified for horizontal cables.

6.4.11 ACRF

Horizontal cable ACRF shall meet or exceed the values determined using the equations shown in Table 62 for all specified frequencies, for a length of 100 m (328 ft) or longer.

Table 62 - Horizontal cable ACRF

	Frequency (MHz)	ACRF (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$23.8 - 20\log(f/100)$
Category 6	$1 \leq f \leq 250$	$27.8 - 20\log(f/100)$
Category 6A	$1 \leq f \leq 500$	$27.8 - 20\log(f/100)$

The horizontal cable ACRF values in Table 63 are provided for information only.

Table 63 - Minimum horizontal cable ACRF

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	63.8	67.8	67.8
4.00	n/s	51.8	55.8	55.8
8.00	n/s	45.7	49.7	49.7
10.00	n/s	43.8	47.8	47.8
16.00	n/s	39.7	43.7	43.7
20.00	-	37.8	41.8	41.8
25.00	-	35.8	39.8	39.8
31.25	-	33.9	37.9	37.9
62.50	-	27.9	31.9	31.9
100.00	-	23.8	27.8	27.8
200.00	-	-	21.8	21.8
250.00	-	-	19.8	19.8
300.00	-	-	-	18.3
400.00	-	-	-	15.8
500.00	-	-	-	13.8

6.4.12 PSFEXT loss

PSFEXT loss is not specified for horizontal cable.

6.4.13 PSACRF

Horizontal cable PSACRF shall meet or exceed the values determined using the equations shown in Table 64 for all specified frequencies.

Table 64 - Horizontal cable PSACRF

	Frequency (MHz)	PSACRF (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$20.8 - 20\log(f/100)$
Category 6	$1 \leq f \leq 250$	$24.8 - 20\log(f/100)$
Category 6A	$1 \leq f \leq 500$	$24.8 - 20\log(f/100)$

The horizontal cable PSACRF values in Table 65 are provided for information only.

Table 65 - Minimum horizontal cable PSACRF

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	60.8	64.8	64.8
4.00	n/s	48.8	52.8	52.8
8.00	n/s	42.7	46.7	46.7
10.00	n/s	40.8	44.8	44.8
16.00	n/s	36.7	40.7	40.7
20.00	-	34.8	38.8	38.8
25.00	-	32.8	36.8	36.8
31.25	-	30.9	34.9	34.9
62.50	-	24.9	28.9	28.9
100.00	-	20.8	24.8	24.8
200.00	-	-	18.8	18.8
250.00	-	-	16.8	16.8
300.00	-	-	-	15.3
400.00	-	-	-	12.8
500.00	-	-	-	10.8

6.4.14 TCL

Horizontal cable TCL shall meet or exceed the values determined using the equations shown in Table 66 for all specified frequencies. Calculations that result in category 6 and 6A horizontal cable TCL values greater than 40 dB shall revert to a requirement of 40 dB minimum.

Table 66 - Horizontal cable TCL

	Frequency (MHz)	TCL (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	$30 - 10\log(f/100)$
Category 6A	$1 \leq f \leq 500$	$30 - 10\log(f/100)$

The horizontal cable TCL values in Table 67 are provided for information only.

Table 67 - Minimum horizontal cable TCL

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	40.0	40.0
4.00	n/s	n/s	40.0	40.0
8.00	n/s	n/s	40.0	40.0
10.00	n/s	n/s	40.0	40.0
16.00	n/s	n/s	38.0	38.0
20.00	-	n/s	37.0	37.0
25.00	-	n/s	36.0	36.0
31.25	-	n/s	35.1	35.1
62.50	-	n/s	32.0	32.0
100.00	-	n/s	30.0	30.0
200.00	-	-	27.0	27.0
250.00	-	-	26.0	26.0
300.00	-	-	-	25.2
400.00	-	-	-	24.0
500.00	-	-	-	23.0

6.4.15 TCTL

TCTL is not specified for horizontal cables.

6.4.16 ELTCTL

Horizontal cable ELTCTL shall meet or exceed the values determined using the equations shown in Table 68 for all specified frequencies.

Table 68 – Horizontal cable ELTCTL

	Frequency (MHz)	ELTCTL (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 30$ $30 < f \leq 250$	$35 - 20\log(f)$ n/s
Category 6A	$1 \leq f \leq 30$ $30 < f \leq 500$	$35 - 20\log(f)$ n/s

The horizontal cable ELTCTL values in Table 69 are provided for information only.

Table 69 - Minimum horizontal cable ELTCL

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	35.0	35.0
4.00	n/s	n/s	23.0	23.0
8.00	n/s	n/s	16.9	16.9
10.00	n/s	n/s	15.0	15.0
16.00	n/s	n/s	10.9	10.9
20.00	-	n/s	9.0	9.0
25.00	-	n/s	7.0	7.0
30.00		n/s	5.5	5.5
31.25	-	n/s	n/s	n/s
62.50	-	n/s	n/s	n/s
100.00	-	n/s	n/s	n/s
200.00	-	n/s	n/s	n/s
250.00	-	-	n/s	n/s
300.00	-	-	n/s	n/s
400.00	-	-	-	n/s
500.00	-	-	-	n/s

6.4.17 Coupling attenuation (screened only)

Coupling attenuation is under study.

Horizontal cable coupling attenuation shall meet or exceed the values determined using the equations shown in Table 70 for all specified frequencies. Calculations that result in horizontal cable coupling attenuation values greater than 55 dB shall revert to a requirement of 55 dB minimum.

Table 70 - Horizontal cable coupling attenuation

	Frequency (MHz)	Coupling attenuation (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 30$ $30 \leq f \leq 100$	n/s $55 - 20\log(f/100)$
Category 6	$1 \leq f < 30$ $30 \leq f \leq 250$	n/s $55 - 20\log(f/100)$
Category 6A	$1 \leq f < 30$ $30 \leq f \leq 500$	n/s $55 - 20\log(f/100)$

The horizontal cable coupling attenuation values in Table 71 are provided for information only.

Table 71 - Minimum horizontal cable coupling attenuation

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	n/s	n/s
4.00	n/s	n/s	n/s	n/s
8.00	n/s	n/s	n/s	n/s
10.00	n/s	n/s	n/s	n/s
16.00	n/s	n/s	n/s	n/s
20.00	-	n/s	n/s	n/s
25.00	-	n/s	n/s	n/s
30.00	-	55.0	55.0	55.0
31.25	-	55.0	55.0	55.0
62.50	-	55.0	55.0	55.0
100.00	-	55.0	55.0	55.0
200.00	-	-	49.0	49.0
250.00	-	-	47.0	47.0
300.00	-	-	-	45.5
400.00	-	-	-	43.0
500.00	-	-	-	41.0

6.4.18 Propagation delay

Horizontal cable propagation delay shall meet or be less than the values determined using the equations shown in Table 72 for all specified frequencies for a length of 100 m (328 ft). See Annex H for the derivation of the equations shown in Table 72.

Table 72 – Horizontal cable propagation delay

	Frequency (MHz)	Propagation delay (ns/100m)
Category 3	$1 \leq f \leq 16$	$(534 + \dfrac{36}{\sqrt{f}})$
Category 5e	$1 \leq f \leq 100$	$(534 + \dfrac{36}{\sqrt{f}})$
Category 6	$1 \leq f \leq 250$	$(534 + \dfrac{36}{\sqrt{f}})$
Category 6A	$1 \leq f \leq 500$	$(534 + \dfrac{36}{\sqrt{f}})$

The horizontal cable propagation delay values in Table 73 are provided for information only.

Table 73 - Maximum horizontal cable propagation delay

Frequency (MHz)	Category 3 (ns/100m)	Category 5e (ns/100m)	Category 6 (ns/100m)	Category 6A (ns/100m)
1.00	570	570	570	570
4.00	552	552	552	552
8.00	547	547	547	547
10.00	545	545	545	545
16.00	543	543	543	543
20.00	-	542	542	542
25.00	-	541	541	541
31.25	-	540	540	540
62.50	-	539	539	539
100.00	-	538	538	538
200.00	-	-	537	537
250.00	-	-	536	536
300.00	-	-	-	536
400.00	-	-	-	536
500.00	-	-	-	536

6.4.19 Propagation delay skew

Horizontal cable propagation delay skew shall be less than 45ns/100m at 20 ℃, 40 ℃, and 60 ℃ for all frequencies from 1 MHz to the upper frequency limit of the category. In addition, the propagation delay skew between all pairs shall not vary more than ± 10 ns from the measured value at 20 ℃ when measured at 40 ℃ and 60 ℃. Compliance shall be determined using a minimum 100 m (328 ft) of cable.

6.4.20 Surface transfer impedance (screened only)

The surface transfer impedance per unit length of the core shield, measured in accordance with IEC 62153-4-3 (surface transfer impedance triaxial method), shall not exceed the values determined using equation (24). Calculations that result in surface transfer impedance values less than 50 mΩ/m shall revert to a requirement of 50 mΩ/m minimum.

$$Z_{Tcable} = 10f \quad \text{mΩ/m} \tag{24}$$

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, 6, and 6A cables.

The values in Table 74 are derived from the above formula and provided for information only.

Table 74 - Maximum cable surface transfer impedance

Frequency (MHz)	Category 3 (mΩ/m)	Category 5e (mΩ/m)	Category 6 (mΩ/m)	Category 6A (mΩ/m)
1	50	50	50	50
10	100	100	100	100
16	160	160	160	160
20	-	200	200	200
100	-	1,000	1,000	1,000

6.4.21 ANEXT loss

ANEXT loss is not specified for horizontal cables.

6.4.22 PSANEXT loss

Horizontal cable PSANEXT loss shall meet or exceed the values determined using the equations shown in Table 75 for all specified frequencies. Calculations that result in PSANEXT loss values greater than 67 dB shall revert to a requirement of 67 dB minimum.

Table 75 - Horizontal cable PSANEXT loss

	Frequency (MHz)	PSANEXT loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	n/s
Category 6A	$1 \leq f \leq 500$	62.5 - 15log(f/100)

The horizontal cable PSANEXT loss values in Table 76 are provided for information only.

Table 76 - Minimum horizontal cable PSANEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	n/s	67.0
4.00	n/s	n/s	n/s	67.0
8.00	n/s	n/s	n/s	67.0
10.00	n/s	n/s	n/s	67.0
16.00	n/s	n/s	n/s	67.0
20.00	-	n/s	n/s	67.0
25.00	-	n/s	n/s	67.0
31.25	-	n/s	n/s	67.0
62.50	-	n/s	n/s	65.6
100.00	-	n/s	n/s	62.5
200.00	-	-	n/s	58.0
250.00	-	-	n/s	56.5
300.00	-	-	-	55.3
400.00	-	-	-	53.5
500.00	-	-	-	52.0

6.4.23 Average PSANEXT loss

Average PSANEXT loss is not specified for horizontal cables.

6.4.24 AFEXT loss

AFEXT loss is not specified for horizontal cables.

6.4.25 PSAFEXT loss

PSAFEXT loss is not specified for horizontal cables.

6.4.26 PSAACRF

Horizontal cable PSAACRF shall meet or exceed the values determined using the equations shown in Table 77 for all specified frequencies. Calculations that result in horizontal cable PSAACRF values greater than 67 dB shall revert to a requirement of 67 dB minimum

Table 77 - Horizontal cable PSAACRF

	Frequency (MHz)	PSAACRF (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f \le 100$	n/s
Category 6	$1 \le f \le 250$	n/s
Category 6A	$1 \le f \le 500$	$38.2 - 20\log(f/100)$

The horizontal cable PSAACRF values in Table 78 are provided for information only.

Table 78 - Minimum horizontal cable PSAACRF

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	n/s	67.0
4.00	n/s	n/s	n/s	66.2
8.00	n/s	n/s	n/s	60.1
10.00	n/s	n/s	n/s	58.2
16.00	n/s	n/s	n/s	54.1
20.00	-	n/s	n/s	52.2
25.00	-	n/s	n/s	50.2
31.25	-	n/s	n/s	48.3
62.50	-	n/s	n/s	42.3
100.00	-	n/s	n/s	38.2
200.00	-	-	n/s	32.2
250.00	-	-	n/s	30.2
300.00	-	-	-	28.7
400.00	-	-	-	26.2
500.00	-	-	-	24.2

6.4.27 Average PSAACRF

Average PSAACRF is not specified for horizontal cable.

6.5 Bundled and hybrid cable transmission performance

Bundled and hybrid cables may be used for horizontal and backbone cabling provided that each cable type is recognized (see clause 4.2 of this Standard) and meets the transmission and color-code specifications for that cable type as given in clause 5.3 and clause 6.4 of this Standard and ANSI/TIA-568-C.3, The individual cables within a bundled cable shall meet the applicable requirements in clause 6.4 of this Standard after bundle formation.

> NOTES,
> 1   Hybrid UTP cables (color coded per clause 5.3.3) can be distinguished from multipair UTP backbone cables (color coded per clause 5.6.3) 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.

6.5.1 PSNEXT loss

The PSNEXT 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 PSNEXT loss limit values that exceed 65 dB shall revert to a limit of 65 dB.

6.5.2 PSNEXT loss from internal and external pairs (category 6 cables only)

For category 6 bundled and hybrid cables, for all frequencies from 1 MHz to 250 MHz, the total power sum NEXT loss for any disturbed pair from all pairs internal and external to that pair's jacket within the bundled or hybrid cable shall not exceed the values determined using equation (25). Calculated power sum NEXT loss limit values that exceed 65 dB shall revert to a limit of 65 dB.

$$PSNEXT_{bundled\_and\_htbrid,all\_pairs} \geq 41.1 - 15\log(f/100) \qquad\qquad (25)$$

6.6 Cord cable

Cord cables shall meet the transmission performance requirements specified for horizontal cable in clause 6.4, with the exception of the requirements of this clause.

6.6.1 DC resistance

DC resistance shall be measured in accordance with ASTM D4566 for all cord cable pairs. For all categories of cord cable, the resistance of any UTP or screened cord cable conductor shall not exceed 14 Ω per 100 m (328 ft) at or corrected to a temperature of 20 ℃.

6.6.2 Return loss

Cord cable return loss, for a length of 100 m (328 ft), shall meet or exceed the values determined using the equations shown in Table 79 for all specified frequencies.

Table 79 - Cord cable return loss

	Frequency (MHz)	Return loss (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f < 10$ $10 \le f < 20$ $20 \le f \le 100$	$20+5\log(f)$ 25 $25-8.6\log(f/20)$
Category 6	$1 \le f < 10$ $10 \le f < 20$ $20 \le f \le 250$	$20+5\log(f)$ 25 $25-8.6\log(f/20)$
Category 6A	$1 \le f < 10$ $10 \le f < 20$ $20 \le f \le 500$	$20+5\log(f)$ 25 $25-8.6\log(f/20)$

The cord return loss values in Table 80 are provided for information only.

Table 80 - Minimum cord cable return loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	20.0	20.0	20.0
4.00	n/s	23.0	23.0	23.0
8.00	n/s	24.5	24.5	24.5
10.00	n/s	25.0	25.0	25.0
16.00	n/s	25.0	25.0	25.0
20.00	-	25.0	25.0	25.0
25.00	-	24.2	24.2	24.2
31.25	-	23.3	23.3	23.3
62.50	-	20.7	20.7	20.7
100.00	-	19.0	19.0	19.0
200.00	-	-	16.4	16.4
250.00	-	-	15.6	15.6
300.00	-	-	-	14.9
400.00	-	-	-	13.8
500.00	-	-	-	13.0

6.6.3   Insertion loss

Cord cable insertion loss limits are derived by multiplying the applicable horizontal cable insertion loss requirements in clause 6.4.7 by a factor of 1.2 (the de-rating factor). The de-rating factor is to allow a 20% increase in insertion loss for stranded construction and design differences.   An insertion loss de-rating factor of 1.5 for cord cable is allowed with the appropriate length adjustment such that the combined length of equipment cords, patch cords, and work area cords that use 50% insertion loss de-rating (e.g. cables with twisted-pairs having 26 AWG conductors) shall not be greater than 8.0 m (25.7 ft).

The maximum insertion loss for UTP cord cables shall be adjusted at elevated temperatures using a factor of 0.4 % increase per ℃ from 20 ℃ to 40 ℃   and 0.6% increase per ℃ for temperatures from 40 ℃ to 60 ℃.   The maximum insertion loss for sc reened cord cables shall be adjusted at elevated temperatures using a factor of 0.2% increase per ℃ from 20 ℃ to 60 ℃. See Annex G for additional information on cable installation in higher temperature environments.

Cord cable insertion loss shall meet or be less than the values determined using the equations shown in Table 81 for all specified frequencies. In addition, category 6 and 6A cord cable insertion loss shall also be verified at temperatures of 40 ± 3 ℃ and 60 ± 3 ℃ and shall meet the requirements of Table 81 af ter adjusting for temperature.

Table 81 - Cord cable insertion loss, for a length of 100m (328 ft)

	Frequency (MHz)	Insertion loss (dB)
Category 3	$0.772 \leq f \leq 16$	$1.2 \cdot \left(2.320\sqrt{f} + 0.238 \cdot f \right)$
Category 5e	$1 \leq f \leq 100$	$1.2 \cdot \left(1.967\sqrt{f} + 0.023 \cdot f + \dfrac{0.050}{\sqrt{f}} \right)$
Category 6	$1 \leq f \leq 250$	$1.2 \cdot \left(1.808\sqrt{f} + 0.017 \cdot f + \dfrac{0.2}{\sqrt{f}} \right)$
Category 6A	$1 \leq f \leq 500$	$1.2 \cdot \left(1.82\sqrt{f} + 0.0091 \cdot f + \dfrac{0.25}{\sqrt{f}} \right)$

The cord cable insertion loss values in Table 82 are provided for information only.

Table 82 - Maximum cord cable insertion loss, for a length of 100m (328 ft)

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
0.772	2.7	n/s	n/s	n/s
1.00	3.1	2.4	2.4	2.5
4.00	6.7	4.9	4.5	4.6
8.00	10.2	6.9	6.4	6.4
10.00	11.7	7.8	7.1	7.1
16.00	15.7	9.9	9.1	9.0
20.00	-	11.1	10.2	10.0
25.00	-	12.5	11.4	11.3
31.25	-	14.1	12.8	12.6
62.50	-	20.4	18.5	18.0
100.00	-	26.4	23.8	22.9
200.00	-	-	34.8	33.1
250.00	-	-	39.4	37.3
300.00	-	-	-	41.2
400.00	-	-	-	48.1
500.00	-	-	-	54.4

6.7   Backbone cable transmission performance

Backbone cables shall meet the transmission performance requirements specified for horizontal cable in clause 6.4, with the exception of the requirements of this clause.

> NOTE – Only four-pair horizontal cables are recognized for use in category 6 and 6A backbone cabling.

6.7.1   Insertion loss

Insertion loss for all pairs shall comply with the requirements of clause 6.4.7 with the following exception: due to practical considerations related to the testing of cables with multiple 25-pair bundles, insertion loss testing at elevated temperatures is not required for multipair backbone cables provided that each pair in the binder group exhibits compliant insertion loss performance.

6.7.2   NEXT loss

NEXT loss shall be measured for all adjacent 4-pair combinations. Backbone cable NEXT loss shall be measured in accordance with clause C.3.6 and the ASTM D 4566 NEXT loss measurement procedure for all frequencies from 1 MHz up to the maximum frequency specified for the category of the cable under test.

To assess performance between adjacent 4-pair units, 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.

NEXT loss shall be measured at 100 meter or longer lengths. In cases where multipair backbone cables consist of more than one 25-pair binder group, NEXT loss shall be determined for each individual 25-pair binder group. There are no NEXT loss requirements between 25-pair groups. The cable shall be tested only as individual 25-pair units. Test fixtures shall provide for consistent common and differential mode impedance matching for the unjacketed twisted-pairs between the cable jacket and the balun terminations.

Backbone cable NEXT loss shall meet or exceed the values determined using the equations shown in Table 83 for all specified frequencies, for a length of 100 m (328 ft) or longer.

Table 83 – Backbone cable NEXT loss

	Frequency (MHz)	NEXT loss (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e (pair-to-pair combinations within each category 5e multipair cable 4-pair group)	$1 \le f \le 100$	$35.3 - 15\log(f/100)$
Category 5e (between the 25th pair and all other pairs within the 25-pair binder group)	$1 \le f \le 100$	$35.3 - 15\log(f/100)$
Category 6 (4-pair cables only)	$1 \le f \le 250$	$44.3 - 15\log(f/100)$
Category 6A (4-pair cables only)	$1 \le f \le 500$	$44.3 - 15\log(f/100)$

The backbone cable NEXT loss values in Table 84 are provided for information only.

Table 84 - Minimum backbone cable NEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (within 4-pair group) (dB)	Category 5e (25th to all other pairs) (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	65.3	65.3	74.3	74.3
4.00	n/s	56.3	56.3	65.3	65.3
8.00	n/s	51.8	51.8	60.8	60.8
10.00	n/s	50.3	50.3	59.3	59.3
16.00	n/s	47.2	47.2	56.2	56.2
20.00	-	45.8	45.8	54.8	54.8
25.00	-	44.3	44.3	53.3	53.3
31.25	-	42.9	42.9	51.9	51.9
62.50	-	38.4	38.4	47.4	47.4
100.00	-	35.3	35.3	44.3	44.3
200.00	-	-	-	39.8	39.8
250.00	-	-	-	38.3	38.3
300.00	-	-	-	-	37.1
400.00	-	-	-	-	35.3
500.00	-	-	-	-	33.8

6.7.3 PSNEXT loss

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

Backbone cable PSNEXT loss shall meet or exceed the values determined using the equations shown in Table 85 for all specified frequencies, for a length of 100 m (328 ft) or longer.

Table 85 - Backbone cable PSNEXT loss

	Frequency (MHz)	PSNEXT loss (dB)
Category 3	$1 \leq f \leq 16$	$23 - 15\log(f/16)$
Category 5e	$1 \leq f \leq 100$	$32.3 - 15\log(f/100)$
Category 6 (4-pair cables only)	$1 \leq f \leq 250$	$42.3 - 15\log(f/100)$
Category 6A (4-pair cables only)	$1 \leq f \leq 500$	$42.3 - 15\log(f/100)$

The backbone cable PSNEXT loss values in Table 86 are provided for information only.

Table 86 - Minimum backbone cable PSNEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	41.3	62.3	72.3	72.3
4.00	32.3	53.3	63.3	63.3
8.00	27.8	48.8	58.8	58.8
10.00	26.3	47.3	57.3	57.3
16.00	23.2	44.2	54.2	54.2
20.00	-	42.8	52.8	52.8
25.00	-	41.3	51.3	51.3
31.25	-	39.9	49.9	49.9
62.50	-	35.4	45.4	45.4
100.00	-	32.3	42.3	42.3
200.00	-	-	37.8	37.8
250.00	-	-	36.3	36.3
300.00	-	-	-	35.1
400.00	-	-	-	33.3
500.00	-	-	-	31.8

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6.7.4   ACRF

FEXT loss shall be measured for all adjacent 4-pair combinations in accordance with the ASTM D4566 FEXT loss measurement procedure and annex C. Backbone cable FEXT loss shall be measured in accordance with clause C.3.8 and the ASTM D 4566 FEXT loss measurement procedure for all frequencies from 1 MHz up to the maximum frequency specified for the category of the cable under test..

To assess performance between adjacent 4-pair units, 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.

ACRF shall be calculated for all backbone cable pair combinations by subtracting the insertion loss of the disturbed pair of the backbone cable from the FEXT loss. In cases where multipair backbone cables consist of more than one 25-pair binder group, ACRF shall be determined for each individual 25-pair binder group. There are no ACRF requirements between 25-pair groups. The cable shall be tested only as individual 25-pair units. Test fixtures shall provide for consistent common and differential mode impedance matching for the unjacketed twisted-pairs between the cable jacket and the balun terminations.

> NOTE - ACRF has been referred to as ELFEXT in previous editions of this Standard.

Backbone cable ACRF shall meet or exceed the values determined using the equations shown in Table 87 for all specified frequencies, for a length of 100 m (328 ft) or longer.

Table 87 - Backbone cable ACRF

	Frequency (MHz)	ACRF (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e (pair-to-pair combinations within each category 5e multipair cable 4-pair group)	$1 \le f \le 100$	$23.8 - 20\log(f/100)$
Category 5e (between the 25th pair and all other pairs within the 25-pair binder group)	$1 \le f \le 100$	$23.8 - 20\log(f/100)$
Category 6 (4-pair cables only)	$1 \le f \le 250$	$27.8 - 20\log(f/100)$
Category 6A (4-pair cables only)	$1 \le f \le 500$	$27.8 - 20\log(f/100)$

The backbone cable ACRF values in Table 88 are provided for information only.

Table 88 - Minimum backbone cable ACRF

Frequency (MHz)	Category 3 (dB)	Category 5e (within 4-pair group) (dB)	Category 5e (25th to all other pairs) (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	63.8	63.8	67.8	67.8
4.00	n/s	51.8	51.8	55.8	55.8
8.00	n/s	45.7	45.7	49.7	49.7
10.00	n/s	43.8	43.8	47.8	47.8
16.00	n/s	39.7	39.7	43.7	43.7
20.00	-	37.8	37.8	41.8	41.8
25.00	-	35.8	35.8	39.8	39.8
31.25	-	33.9	33.9	37.9	37.9
62.50	-	27.9	27.9	31.9	31.9
100.00	-	23.8	23.8	27.8	27.8
200.00	-	-	-	21.8	21.8
250.00	-	-	-	19.8	19.8
300.00	-	-	-	-	18.3
400.00	-	-	-	-	15.8
500.00	-	-	-	-	13.8

6.7.5   PSACRF

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

> 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-568-C.1 for more information.

Backbone cable PSACRF shall meet or exceed the values determined using the equations shown in Table 89 for all specified frequencies, for a length of 100 m (328 ft) or longer.

Table 89 - Backbone cable PSACRF

	Frequency (MHz)	PSACRF (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$20.8 - 20\log(f/100)$
Category 6 (4-pair cables only)	$1 \leq f \leq 250$	$24.8 - 20\log(f/100)$
Category 6A (4-pair cables only)	$1 \leq f \leq 500$	$24.8 - 20\log(f/100)$

The backbone cable PSACRF values in Table 90 are provided for information only.

Table 90 - Minimum backbone cable PSACRF

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	60.8	64.8	64.8
4.00	n/s	48.8	52.8	52.8
8.00	n/s	42.7	46.7	46.7
10.00	n/s	40.8	44.8	44.8
16.00	n/s	36.7	40.7	40.7
20.00	-	34.8	38.8	38.8
25.00	-	32.8	36.8	36.8
31.25	-	30.9	34.9	34.9
62.50	-	24.9	28.9	28.9
100.00	-	20.8	24.8	24.8
200.00	-	-	18.8	18.8
250.00	-	-	16.8	16.8
300.00	-	-	-	15.3
400.00	-	-	-	12.8
500.00	-	-	-	10.8

6.7.6 Propagation delay

Backbone cable propagation delay shall meet or be less than the values determined using the equations shown in Table 91 for all specified frequencies for a length of 100 m (328 ft). See Annex H for the derivation of the equations shown in Table 91.

Table 91 – Backbone cable propagation delay

	Frequency (MHz)	Propagation Delay (ns/100m)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$(534 + \dfrac{36}{\sqrt{f}})$
Category 6 (4-pair cables only)	$1 \leq f \leq 250$	$(534 + \dfrac{36}{\sqrt{f}})$
Category 6A (4-pair cables only)	$1 \leq f \leq 500$	$(534 + \dfrac{36}{\sqrt{f}})$

The backbone propagation delay values in Table 92 are provided for information only.

Table 92 - Maximum backbone cable propagation delay

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	570	570	570
4.00	n/s	552	552	552
8.00	n/s	547	547	547
10.00	n/s	545	545	545
16.00	n/s	543	543	543
20.00	-	542	542	542
25.00	-	541	541	541
31.25	-	540	540	540
62.50	-	539	539	539
100.00	-	538	538	538
200.00	-	-	537	537
250.00	-	-	536	536
300.00	-	-	-	536
400.00	-	-	-	536
500.00	-	-	-	536

6.7.7 Propagation delay skew

Category 5e, 6, and 6A 4-pair backbone cable propagation delay skew shall meet the requirements for horizontal cables as specified in clause 6.4.19. Category 5e backbone multipair 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 requirements for horizontal cables as specified in clause 6.4.19. For 25-pair and multiples 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.

6.8 Connecting hardware transmission performance

Compliance to the requirements of this clause shall ensure that properly installed connecting hardware 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 and work area, patch, and equipment cords.

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

See ANSI/TIA-568-C.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 connection (IDC) type. Connecting hardware for the 100 Ω balanced twisted-pair 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, and
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.

> 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.

Unless otherwise specified, all products with plug and socket connections (e.g. modular jacks and plugs) shall be tested in a mated state.

6.8.1 DC resistance

DC resistance shall be measured in accordance with ASTM D4566 at 20 ℃ ± 3 ℃ for all connecting hardware cable pairs.

> 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.

Category 3 connecting hardware 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.

Category 5e, 6, and 6A connecting hardware 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 0.2 Ω.

6.8.2 DC resistance unbalance

DC resistance unbalance shall be calculated as the maximum difference in DC resistance between any two conductors of a connector pair measured in accordance with IEC 60512, Test 2a.

Category 3 connecting hardware DC resistance unbalance should not exceed 50 mΩ. Category 5e, 6 and 6A connecting hardware DC resistance unbalance shall not exceed 50 mΩ.

6.8.3 Mutual capacitance

Mutual capacitance is not specified for connecting hardware.

6.8.4 Capacitance unbalance: pair-to-ground

Capacitance unbalance to ground is not specified for connecting hardware.

6.8.5 Characteristic impedance and structural return loss (SRL)

Characteristic impedance is not specified for connecting hardware.

6.8.6 Return loss

Connecting hardware return loss shall meet or exceed the values determined using the equations shown in Table 93 for all specified frequencies.

Table 93 - Connecting hardware return loss

	Frequency (MHz)	Return loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 31.5$ $31.5 < f \leq 100$	30 $20\text{-}20\log(f/100)$
Category 6	$1 \leq f \leq 50$ $50 < f \leq 250$	30 $24\text{-}20\log(f/100)$
Category 6A	$1 \leq f \leq 79$ $79 < f \leq 500$	30 $28\text{-}20\log(f/100)$

The connecting hardware return loss values in Table 94 are provided for information only.

Table 94 - Minimum connecting hardware return loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	30.0	30.0	30.0
4.00	n/s	30.0	30.0	30.0
8.00	n/s	30.0	30.0	30.0
10.00	n/s	30.0	30.0	30.0
16.00	n/s	30.0	30.0	30.0
20.00	-	30.0	30.0	30.0
25.00	-	30.0	30.0	30.0
31.25	-	30.0	30.0	30.0
62.50	-	24.1	28.1	30.0
100.00	-	20.0	24.0	28.0
200.00	-	-	18.0	22.0
250.00	-	-	16.0	20.0
300.00	-	-	-	18.5
400.00	-	-	-	16.0
500.00	-	-	-	14.0

6.8.7   Insertion loss

Connecting hardware insertion loss shall meet or be less than the values determined using the equations shown in Table 95 for all specified frequencies. Calculations that result in insertion loss values less than 0.1 dB shall revert to a requirement of 0.1 dB maximum.

Table 95 – Connecting hardware insertion loss

	Frequency (MHz)	Insertion loss (dB)
Category 3	$1 \leq f \leq 16$	$0.10\sqrt{f}$
Category 5e	$1 \leq f \leq 100$	$0.04\sqrt{f}$
Category 6	$1 \leq f \leq 250$	$0.02\sqrt{f}$
Category 6A	$1 \leq f \leq 500$	$0.02\sqrt{f}$

The connecting hardware insertion loss values in Table 96 are provided for information only.

Table 96 - Maximum connecting hardware insertion loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	0.10	0.10	0.10	0.10
4.00	0.20	0.10	0.10	0.10
8.00	0.28	0.11	0.10	0.10
10.00	0.32	0.13	0.10	0.10
16.00	0.40	0.16	0.10	0.10
20.00	-	0.18	0.10	0.10
25.00	-	0.20	0.10	0.10
31.25	-	0.22	0.11	0.11
62.50	-	0.32	0.16	0.16
100.00	-	0.40	0.20	0.20
200.00	-	-	0.28	0.28
250.00	-	-	0.32	0.32
300.00	-	-	-	0.35
400.00	-	-	-	0.40
500.00	-	-	-	0.45

6.8.8 NEXT loss

Connecting hardware NEXT loss shall meet or exceed the values determined using the equations shown in Table 97 for all specified frequencies. Category 3 and 5e NEXT loss calculations that result in NEXT loss values greater than 65 dB shall revert to a requirement of 65 dB minimum. Category 6 and 6A NEXT loss calculations that result in NEXT loss values greater than 75 dB shall revert to a requirement of 75 dB minimum.

Table 97 – Connecting hardware NEXT loss

	Frequency (MHz)	NEXT loss (dB)
Category 3	$1 \le f \le 16$	$34 - 20 \log(f/16)$
Category 5e	$1 \le f \le 100$	$43 - 20 \log(f/100)$
Category 6	$1 \le f \le 250$	$54 - 20 \log(f/100)$
Category 6A	$1 \le f \le 250$	$54 - 20 \log(f/100)$
	$250 < f \le 500$	$46.04 - 40 \log(f/250)$

The connecting hardware NEXT loss values in Table 98 are provided for information only.

Table 98 - Minimum connecting hardware NEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	58.1	65.0	75.0	75.0
4.00	46.0	65.0	75.0	75.0
8.00	40.0	64.9	75.0	75.0
10.00	38.1	63.0	74.0	74.0
16.00	34.0	58.9	69.9	69.9
20.00	-	57.0	68.0	68.0
25.00	-	55.0	66.0	66.0
31.25	-	53.1	64.1	64.1
62.50	-	47.1	58.1	58.1
100.00	-	43.0	54.0	54.0
200.00	-	-	48.0	48.0
250.00	-	-	46.0	46.0
300.00	-	-	-	42.9
400.00	-	-	-	37.9
500.00	-	-	-	34.0

6.8.9   PSNEXT loss

PSNEXT loss for connecting hardware does not need to be separately verified.

The connecting hardware PSNEXT loss values shown in Table 99 are used to derive channel and permanent link PSNEXT loss requirements for all specified frequencies.

Table 99 – Connecting hardware PSNEXT loss assumptions

	Frequency (MHz)	PSNEXT loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$40 - 20\log(f/100)$
Category 6	$1 \leq f \leq 250$	$50 - 20\log(f/100)$
Category 6A	$1 \leq f \leq 250$ $250 < f \leq 500$	$50 - 20\log(f/100)$ $42.04 - 40\log(f/250)$

6.8.10 FEXT loss

Connecting hardware FEXT loss shall meet or exceed the values determined using the equations shown in Table 100 for all specified frequencies. Category 5e calculations that result in FEXT loss values greater than 65 dB shall revert to a requirement of 65 dB minimum. Category 6 and 6A calculations that result in FEXT loss values greater than 75 dB shall revert to a requirement of 75 dB minimum.

Table 100 - Connecting hardware FEXT loss

	Frequency (MHz)	FEXT loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$35.1 - 20\log(f/100)$
Category 6	$1 \leq f \leq 250$	$43.1 - 20\log(f/100)$
Category 6A	$1 \leq f \leq 500$	$43.1 - 20\log(f/100)$

The connecting hardware FEXT loss values in Table 101 are provided for information only.

Table 101 - Minimum connecting hardware FEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	65.0	75.0	75.0
4.00	n/s	63.1	71.1	71.1
8.00	n/s	57.0	65.0	65.0
10.00	n/s	55.1	63.1	63.1
16.00	n/s	51.0	59.0	59.0
20.00	-	49.1	57.1	57.1
25.00	-	47.1	55.1	55.1
31.25	-	45.2	53.2	53.2
62.50	-	39.2	47.2	47.2
100.00	-	35.1	43.1	43.1
200.00	-	-	37.1	37.1
250.00	-	-	35.1	35.1
300.00	-	-	-	33.6
400.00	-	-	-	31.1
500.00	-	-	-	29.1

6.8.11 ACRF

ACRF is not specified for connecting hardware.

6.8.12 PSFEXT loss

PSFEXT loss for connecting hardware does not need to be separately verified.

The connecting hardware PSFEXT loss values shown in Table 102 are used to derive channel and permanent link PSACRF requirements for all specified frequencies.

Table 102 – Connecting hardware PSFEXT loss assumptions

	Frequency (MHz)	PSFEXT loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$32.1 - 20\log(f/100)$
Category 6	$1 \leq f \leq 250$	$40.1 - 20\log(f/100)$
Category 6A	$1 \leq f \leq 500$	$40.1 - 20\log(f/100)$

6.8.13 PSACRF

PSACRF is not specified for connecting hardware.

6.8.14 TCL

Connecting hardware TCL shall meet or exceed the values determined using the equations shown in Table 103 for all specified frequencies. Calculations that result in category 6 and 6A connecting hardware TCL values greater than 40 dB shall revert to a requirement of 40 dB minimum.

Table 103 - Connecting hardware TCL

	Frequency (MHz)	TCL (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	$28 - 20\log(f/100)$
Category 6A	$1 \leq f \leq 500$	$28 - 20\log(f/100)$

The connecting hardware TCL values in Table 104 are provided for information only.

Table 104 - Minimum connecting hardware TCL

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	40.0	40.0
4.00	n/s	n/s	40.0	40.0
8.00	n/s	n/s	40.0	40.0
10.00	n/s	n/s	40.0	40.0
16.00	n/s	n/s	40.0	40.0
20.00	-	n/s	40.0	40.0
25.00	-	n/s	40.0	40.0
31.25	-	n/s	38.1	38.1
62.50	-	n/s	32.1	32.1
100.00	-	n/s	28.0	28.0
200.00	-	-	22.0	22.0
250.00	-	-	20.0	20.0
300.00	-	-	-	18.5
400.00	-	-	-	16.0
500.00	-	-	-	14.0

6.8.15 TCTL

TCTL shall be measured for all connecting hardware pairs. Connecting hardware TCTL shall be measured in accordance with clause C.4.8 for all frequencies from 1 MHz up to the maximum frequency specified for the category of the connecting hardware under test.

Connecting hardware TCTL shall meet or exceed the values determined using the equations shown in Table 105 for all specified frequencies. Calculations that result in category 6 and 6A connecting hardware TCTL values greater than 40 dB shall revert to a requirement of 40 dB minimum.

Table 105 - Connecting hardware TCTL

	Frequency (MHz)	TCL (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	$28 - 20\log(f/100)$
Category 6A	$1 \leq f \leq 500$	$28 - 20\log(f/100)$

The connecting hardware TCTL values in Table 106 are provided for information only.

Table 106 - Minimum connecting hardware TCTL

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	40.0	40.0
4.00	n/s	n/s	40.0	40.0
8.00	n/s	n/s	40.0	40.0
10.00	n/s	n/s	40.0	40.0
16.00	n/s	n/s	40.0	40.0
20.00	-	n/s	40.0	40.0
25.00	-	n/s	40.0	40.0
31.25	-	n/s	38.1	38.1
62.50	-	n/s	32.1	32.1
100.00	-	n/s	28.0	28.0
200.00	-	n/s	22.0	22.0
250.00	-	-	20.0	20.0
300.00	-	-	-	18.5
400.00	-	-	-	16.0
500.00	-	-	-	14.0

6.8.16 ELTCTL

ELTCTL is not specified for connecting hardware.

6.8.17 Coupling attenuation (screened only)

Coupling attenuation for connecting hardware is under study.

6.8.18 Propagation delay

For all categories of connecting hardware, the propagation delay contribution of each installed mated connection is assumed to not exceed 2.5 ns from 1 MHz to the highest referenced frequency.

6.8.19 Propagation delay skew

For all categories of connecting hardware, the propagation delay skew of each installed mated connection is assumed to not exceed 1.25 ns from 1 MHz to the highest referenced frequency.

6.8.20 Shield transfer impedance (screened only)

The shield transfer impedance of screened connecting hardware, measured in accordance with Annex D shall not exceed the values determined using equations (26) and (27).

$$Z_{Tconn} = 40\sqrt{f} \text{ from 1 MHz to 4 MHz} \tag{26}$$

$$Z_{Tconn} = 20f \text{ from 4 MHz to 100 MHz} \tag{27}$$

Where:

Z_{Tconn} is the transfer impedance of the connecting hardware shield in mΩ

f is the frequency in MHz.

The values in Table 107 are derived from equations (26) and (27) and are provided for information only.

Table 107 - Maximum connecting hardware shield transfer impedance

Frequency (MHz)	Category 3 (mΩ)	Category 5e (mΩ)	Category 6 (mΩ)	Category 6A (mΩ)
1.00	n/s	40	40	40
4.00	n/s	80	80	80
8.00	n/s	160	160	160
10.00	n/s	200	200	200
16.00	n/s	320	320	320
20.00	-	400	400	400
25.00	-	500	500	500
30.00	-	600	600	600
31.25	-	625	625	625
62.50	-	1,250	1,250	1,250
100.00	-	2,000	2,000	2,000

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.

6.8.21 ANEXT loss

ANEXT loss is not specified for connecting hardware.

6.8.22 PSANEXT loss

Connecting hardware PSANEXT loss shall meet or exceed the values determined using the equations shown in Table 108 for all specified frequencies. Calculations that result in PSANEXT loss values greater than 67 dB shall revert to a requirement of 67 dB minimum.

Table 108 – Connecting hardware PSANEXT loss

	Frequency (MHz)	PSANEXT loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	n/s
Category 6A	$1 \leq f \leq 500$	$70.5 - 20\log(f/100)$

The connecting hardware PSANEXT loss values in Table 109 are provided for information only.

Table 109 - Minimum connecting hardware PSANEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	n/s	67.0
4.00	n/s	n/s	n/s	67.0
8.00	n/s	n/s	n/s	67.0
10.00	n/s	n/s	n/s	67.0
16.00	n/s	n/s	n/s	67.0
20.00	-	n/s	n/s	67.0
25.00	-	n/s	n/s	67.0
31.25	-	n/s	n/s	67.0
62.50	-	n/s	n/s	67.0
100.00	-	n/s	n/s	67.0
200.00	-	-	n/s	64.5
250.00	-	-	n/s	62.5
300.00	-	-	-	61.0
400.00	-	-	-	58.5
500.00	-	-	-	56.5

6.8.23 Average PSANEXT loss

Average PSANEXT loss is not specified for connecting hardware.

6.8.24 AFEXT loss

AFEXT loss is not specified for connecting hardware.

6.8.25 PSAFEXT loss

Connecting hardware PSAFEXT loss shall meet or exceed the values determined using the equations shown in Table 110 for all specified frequencies. Calculations that result in PSANEXT loss values greater than 67 dB shall revert to a requirement of 67 dB minimum.

Table 110 – Connecting hardware PSAFEXT loss

	Frequency (MHz)	PSANEXT loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	n/s
Category 6	$1 \leq f \leq 250$	n/s
Category 6A	$1 \leq f \leq 500$	67 - 20log(f/100)

The connecting hardware PSAFEXT loss values in Table 111 are provided for information only.

Table 111 - Minimum connecting hardware PSAFEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	n/s	n/s	67.0
4.00	n/s	n/s	n/s	67.0
8.00	n/s	n/s	n/s	67.0
10.00	n/s	n/s	n/s	67.0
16.00	n/s	n/s	n/s	67.0
20.00	-	n/s	n/s	67.0
25.00	-	n/s	n/s	67.0
31.25	-	n/s	n/s	67.0
62.50	-	n/s	n/s	67.0
100.00	-	n/s	n/s	67.0
200.00	-	-	n/s	61.0
250.00	-	-	n/s	59.0
300.00	-	-	-	57.5
400.00	-	-	-	52.0
500.00	-	-	-	53.0

6.8.26 PSAACRF

PSAACRF is not specified for connecting hardware.

6.8.27 Average PSAACRF

Average PSAACRF is not specified for connecting hardware.

6.9   Cords and jumpers transmission performance

Modular plugs and other connectors used for 100 Ω twisted-pair cable assemblies shall meet the requirements specified in clause 6.8. Cables used to construct work area, equipment, and patch cords shall meet the transmission performance requirements for cord cable specified in clause 6.6.

6.9.1   Return loss

Return loss shall be measured for all work area, equipment, and patch cord pairs. Work area, equipment, and patch cord return loss shall be measured in accordance with clause C.5.3 for all frequencies from 1 MHz up to the maximum frequency specified for the category of the cable under test.

Work area, equipment, and patch cord return loss shall meet or exceed the values determined using the equations shown in Table 112 for all specified frequencies.

Table 112 - Work area, equipment, and patch cord return loss

	Frequency (MHz)	Return loss (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f < 25$ $25 \leq f \leq 100$	$24 + 3\log(f/25)$ $24 - 10\log(f/25)$
Category 6	$1 \leq f < 25$ $25 \leq f \leq 250$	$24 + 3\log(f/25)$ $24 - 10\log(f/25)$
Category 6A	$1 \leq f < 25$ $25 \leq f \leq 250$ $250 < f \leq 500$	$24 + 3\log(f/25)$ $24 - 10\log(f/25)$ $14 - 15\log(f/250)$

The work area, equipment, and patch cord return loss values in Table 113 are provided for information only.

Table 113 - Minimum work area, equipment, and patch cord return loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	19.8	19.8	19.8
4.00	n/s	21.6	21.6	21.6
8.00	n/s	22.5	22.5	22.5
10.00	n/s	22.8	22.8	22.8
16.00	n/s	23.4	23.4	23.4
20.00	-	23.7	23.7	23.7
25.00	-	24.0	24.0	24.0
31.25	-	23.0	23.0	23.0
62.50	-	20.0	20.0	20.0
100.00	-	18.0	18.0	18.0
200.00	-	-	15.0	15.0
250.00	-	-	14.0	14.0
300.00	-	-	-	12.8
400.00	-	-	-	10.9
500.00	-	-	-	9.5

6.9.2 NEXT loss

NEXT loss shall be measured for all work area, equipment, and patch cord pair combinations. Work area, equipment, and patch cord NEXT loss shall be measured in accordance with clause C.5 for all frequencies from 1 MHz up to the maximum frequency specified for the category of the cable under test.

For all frequencies from 1 MHz to the upper limit of each category, work area, equipment, and patch cord NEXT loss shall meet the values determined using equation (28). Calculations that result in NEXT loss values greater than 65 dB shall revert to a requirement of 65 dB minimum.

$$NEXT_{cord} \geq -10\log\left(10^{\frac{-NEXT_{connectors}}{10}} + 10^{\frac{-\left(NEXT_{cord\_cable} + 2 \cdot IL_{conn}\right)}{10}}\right) - RFEXT \tag{28}$$

where:

$$NEXT_{connectors} = -20\log\left(10^{\frac{-NEXT_{conn\_spec}}{20}} + 10^{\frac{-\left(NEXT_{conn\_spec} + 2\left(IL_{cord\_cable} + IL_{conn}\right)\right)}{20}}\right) \tag{29}$$

$$IL_{cord\_cable} = IL_{cord\_cable,100m} \cdot \frac{CableLength}{100} \tag{30}$$

$$NEXT_{cord\_cable} = NEXT_{hor\_cable} - 10\log\left(1 - e^{-0.46 \cdot IL_{cord\_cable}}\right) \tag{31}$$

$NEXT_{conn\_spec}$ is the NEXT loss assigned to the local and remote test jacks. The value for category 6 and category 6A test heads is specified in Table 97. The value for category 5e test heads is 47-20log (f/100) dB.

$IL_{cord\_cable,100m}$ is the insertion loss of 100 meters of cord cable as specified in Table 81

$NEXT_{cord\_cable}$ 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 cord cable, and the length correction formula in ASTM D 4566.

$NEXT_{hor\_cable}$ is the NEXT loss of horizontal cable as specified in Table 58

$CableLength$ is the length of the cable in the cord in meters

IL_{conn} is the insertion loss of one connector as specified in Table 95

 $RFEXT$ is the reflected signal cross talk. For category 5e cords RFEXT = 0 dB, and for category 6 and 6A cords RFEXT = 0.5 dB.

NOTE - All variables are expressed in dB, except "CableLength", which is expressed in meters.

The work area, equipment, and patch cord NEXT loss values in Table 114, Table 115, and Table 116 are calculated from equation (28) and are provided for information only.

Table 114 - Minimum 2 meter work area, equipment, and patch cord NEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	65.0	65.0	65.0
4.00	n/s	65.0	65.0	65.0
8.00	n/s	60.6	65.0	65.0
10.00	n/s	58.7	65.0	65.0
16.00	n/s	54.7	62.0	62.0
20.00	-	52.8	60.1	60.1
25.00	-	50.9	58.1	58.2
31.25	-	49.0	56.2	56.3
62.50	-	43.2	50.4	50.4
100.00	-	39.3	46.4	46.4
200.00	-	-	40.6	40.7
250.00	-	-	38.8	38.9
300.00	-	-	-	36.2
400.00	-	-	-	31.9
500.00	-	-	-	28.4

Table 115 - Minimum 5 meter work area, equipment, and patch cord NEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	65.0	65.0	65.0
4.00	n/s	64.5	65.0	65.0
8.00	n/s	58.6	65.0	65.0
10.00	n/s	56.7	64.5	64.5
16.00	n/s	52.8	60.5	60.5
20.00	-	50.9	58.6	58.7
25.00	-	49.1	56.8	56.8
31.25	-	47.2	54.9	54.9
62.50	-	41.6	49.2	49.2
100.00	-	37.8	45.3	45.4
200.00	-	-	39.8	39.9
250.00	-	-	38.1	38.1
300.00	-	-	-	35.9
400.00	-	-	-	32.1
500.00	-	-	-	29.0

Table 116 - Minimum 10 meter work area, equipment, and patch cord NEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	n/s	65.0	65.0	65.0
4.00	n/s	62.5	65.0	65.0
8.00	n/s	56.7	64.8	64.8
10.00	n/s	54.9	62.9	63.0
16.00	n/s	51.0	59.0	59.1
20.00	-	49.2	57.2	57.3
25.00	-	47.4	55.4	55.4
31.25	-	45.6	53.6	53.6
62.50	-	40.2	48.1	48.1
100.00	-	36.7	44.4	44.5
200.00	-	-	39.3	39.3
250.00	-	-	37.6	37.7
300.00	-	-	-	35.8
400.00	-	-	-	32.5
500.00	-	-	-	29.8

Annex A (normative) - Reliability testing of connecting hardware

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 electrical transmission characteristics and performance of the building telecommunications cabling system.   Connecting hardware reliability testing shall be accomplished by subjecting the connecting hardware to various mechanical and environmental conditions, measuring parameters such as changes in contact resistance during and after individual test sequences.

Connecting hardware often contains a combination of solderless connections and a separable contact interface (jack/plug interface).   All connections shall be tested.   Each connection that comprises the connecting hardware may be isolated and tested independently or all connections may be tested as an assembly.   When tested as an assembly, the total combined change in contact resistance may be used to determine pass and fail criteria in place of isolating individual effects of the various connections.   If this method is employed, care should be taken to ensure the use of the most stringent test schedule as the test schedules vary by type of connection.

Cable portions used in testing should comply with clauses 29-31 of ASTM D 4566.

Refer to local and national standards and codes for safety considerations.

A.2   Solderless connections

To ensure reliable solderless terminations of balanced twisted pair cable insulated conductors, and to ensure reliable solderless connections between component parts within connecting hardware, solderless connections shall meet the requirements of the applicable standards specified in Table A.1.

Table A.1 – Standards for solderless connections

Connection type	Standard
Crimped connection	IEC 60352-2
Accessible IDC	IEC 60352-3
Non-accessible IDC	IEC 60352-4
Press-in connection	IEC 60352-5
IPC	IEC 60352-6
Spring clamp connection	IEC 60352-7
Compression mount connection	IEC 60352-8

A typical test schedule for IEC 60352 series of standards is outlined in clause A.5.2 of this Standard.

The default criteria and conditions in the relevant standards in Table A.1 apply, except as specified in the remainder of this clause.

The maximum initial contact resistance for an insulation displacement connection shall be 2.5 mΩ and the maximum change in contact resistance during and after conditioning shall be 5 mΩ from the initial value.

The following test conditions are specified, as detailed by the type test requirements of IEC 60352 series of standards.

> Vibration test severity: 10 to 500 Hz.
> Low temperature (LCT): -40 °C (-40 °F).
> Electrical load and temperature, test current: 1A dc.

A.3   Modular plugs and jacks

Modular plugs and jacks shall comply with the reliability requirements of the applicable standard specified in Table A.2.

Table A.2 – Standards for modular plugs and jacks

Category and type	Standard
Category 3, unscreened	IEC 60603-7
Category 3, screened	IEC 60603-7-1
Category 5e, unscreened	IEC 60603-7-2
Category 5e, screened	IEC 60603-7-3
Category 6, unscreened	IEC 60603-7-4
Category 6, screened	IEC 60603-7-5
Category 6A, unscreened	IEC 60603-7-41
Category 6A, screened	IEC 60603-7-51

A typical test schedule for IEC 60603-7 series of standards is outlined in clause A.5.3 of this Standard.

The default criteria and conditions in the relevant standards in Table A.2 apply, except as specified in the remainder of this clause.

The number of mating cycles (insertions and withdrawals) for modular plugs and jacks and the number of conductor re-terminations per solderless connection shall comply with the specifications in Table A.3.

Table A.3 – Modular plugs and jacks operations matrix

Connecting hardware type	Insertion and withdrawal, and conductor re-termination, operations	Minimum number of operations
Modular plug	Insertion / withdrawal with modular jack	750
	Cable re-termination	0
Modular jack	Insertion / withdrawal with modular plug	750
	Cable re-termination	20 [1]
[1] Unless not intended for re-termination, in which case this value equals 0.		

Between terminations, the solderless connection should be inspected for debris and extraneous material should be removed.

A.4   Other connecting hardware

Examples of other connecting hardware include:

1) cross-connect blocks and plugs
2) pin and socket connectors

The reliability of connecting hardware, other than modular plugs and jacks shall be demonstrated by complying with the applicable requirements of the standards specified in Table A.4. The connecting hardware shall be terminated, mounted, and operated in accordance with the manufacturer's instructions for use. A minimum of 100 individual electrical contact paths (e.g. connecting hardware, input to output) shall be tested without failure.

The following tests shall be as per the manufacturer's specification:
a) Examination of dimensions and mass
b) Insertion and withdrawal force requirements
c) Effectiveness of any connector coupling device requirements
d) Gauging and gauging continuity requirements
e) Arrangement for contact resistance test
f) Arrangement for vibration (dynamic stress) test

Table A.4 – Standards for other connecting hardware

Category and type	Standard	
Category 3, unscreened	IEC 60603-7	Clause 6 and Clause 7[1]
Category 3, screened	IEC 60603-7-1	
Category 5e, unscreened	IEC 60603-7-2	
Category 5e, screened	IEC 60603-7-3	
Category 6, unscreened	IEC 60603-7-4	
Category 6, screened	IEC 60603-7-5	
Category 6A, unscreened	IEC 60603-7-41	
Category 6A, screened	IEC 60603-7-51	
[1] Excluding sub-clauses addressing pin and pair grouping assignment, creepage and clearance distances, transmission characteristics, transfer impedance, and test group EP (transmission testing).		

The default criteria and conditions in the relevant standards in Table A.4 apply, unless otherwise specified in this clause.

The number of mating cycles (insertions and withdrawals) for other connecting hardware and the number of conductor re-terminations per solderless connection shall comply with the specifications in Table A.5.

Table A.5 – Other connecting hardware operations matrix

Connecting hardware type	Insertion and withdrawal, and conductor re-termination, operations	Minimum number of operations
Other connecting hardware "plug"	Insertion / withdrawal operations with "jack"	200
	Cable re-termination	0
Other connecting hardware "jack"	Insertion / withdrawal operations with "plug"	200
	Cable re-termination	20 [1]
	Jumper re-termination	200
[1] Unless not intended for re-termination, in which case this value equals 0.		

Between terminations, the solderless connection should be inspected for debris and extraneous material should be removed.

A.5 Informative examples of referenced test schedules

A.5.1 General

As an example, the reliability of a modular jack with accessible insulation displacement connections is demonstrated by complying with the applicable requirements of both IEC 60352-3 and IEC 60603-7-4. The test schedules described in IEC 60352-3 and IEC 60603-7-4 at the time of this Standard's publication are outlined in clause A.5.2, as depicted in figure A.1, and clause A.5.3, as depicted in figure A.2. It is advisable to refer to the IEC Standards for updates and revisions.

A.5.2 Non-accessible IDC, IEC 60352-3

This full test schedule is used for qualification purposes where accessible insulation displacement connections have not been demonstrated to conform to all of the requirements in section 2 of IEC 60352-3. Where requirements covering workmanship, tools, termination (materials, dimensions, surface finish, design features), wires (materials, dimensions, surface finish, wire insulation) and connection are conformant, a basic (significantly reduced) test schedule is used for qualification purposes.

KEY:

Assessment test

Conditioning test

General examination

| Transverse extraction force | Contact resistance | Contact resistance | Contact resistance | *Conductor re-terminations* | *Conductor re-terminations* | *Conductor re-terminations* |

Bending of the wire — *Vibration plus contact disturbance* — *Corrosion, industrial atmosphere* — Transverse extraction force — Contact resistance — Contact resistance

Electrical load & temperature — *Rapid change of temperature* — Contact resistance — *Vibration plus contact disturbance* — *Corrosion, industrial atmosphere*

Contact resistance — *Climatic sequence* — *Rapid change of temperature* — Contact resistance

Contact resistance — *Climatic sequence*

Contact resistance

Figure A.1 - Reference test schedule for non-accessible IDC

A.5.3 Modular plug and jack, IEC 60603-7 series

```
                        ┌─────────────────────┐              KEY:
                        │ General examination │
                        └─────────────────────┘         ┌──────────────────┐
                                   │                     │ Assessment test  │
                        ┌─────────────────────┐          └──────────────────┘
                        │ Polarization    (if │
                        │ applicable)         │          ┌──────────────────┐
                        └─────────────────────┘          │ Conditioning test│
                                   │                     └──────────────────┘
                        ┌─────────────────────┐
                        │ Contact resistance  │
                        └─────────────────────┘
                                   │
                        ┌─────────────────────┐
                        │ Insulation resistance│
                        └─────────────────────┘
                                   │
                        ┌─────────────────────┐
                        │ Voltage proof       │
                        └─────────────────────┘
```

General examination

Polarization (if applicable)

Contact resistance

Insulation resistance

Voltage proof

Insertion & withdrawal forces
- Connector coupling
- *Rapid change of temperature*
- Insulation resistance
- Contact resistance
- Voltage proof
- Visual examination
- *Cyclic damp heat*
- Contact resistance
- Insertion & withdrawal forces
- Connector coupling
- Visual Examination
- Solderability
- Resistance to soldering heat
- Voltage Proof

Locking device mechanical operation
- *Mechanical operation*
- *Flowing mixed gas corrosion*
- Contact resistance
- *Mechanical operation*
- Contact resistance
- Insulation resistance
- Voltage proof
- Visual examination

Vibration with contact disturbance
- Contact resistance
- Insulation resistance
- Visual examination

Electrical load & temperature
- Insulation resistance
- Voltage proof
- Visual examination
- Contact resistance
- Mechanical gauging
- Continuity gauging & contact disturbance

Surge test
- Insulation resistance
- Visual examination

KEY:
- Assessment test
- *Conditioning test*

Figure A.2 - Reference test schedule for modular plugs and jacks

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Annex B (normative) - Measurement requirements

B.1   General test configuration

This annex describes the requirements by which 4-pair 100 Ω components and cabling systems are to be measured from 1 MHz to the highest referenced frequency using laboratory equipment.

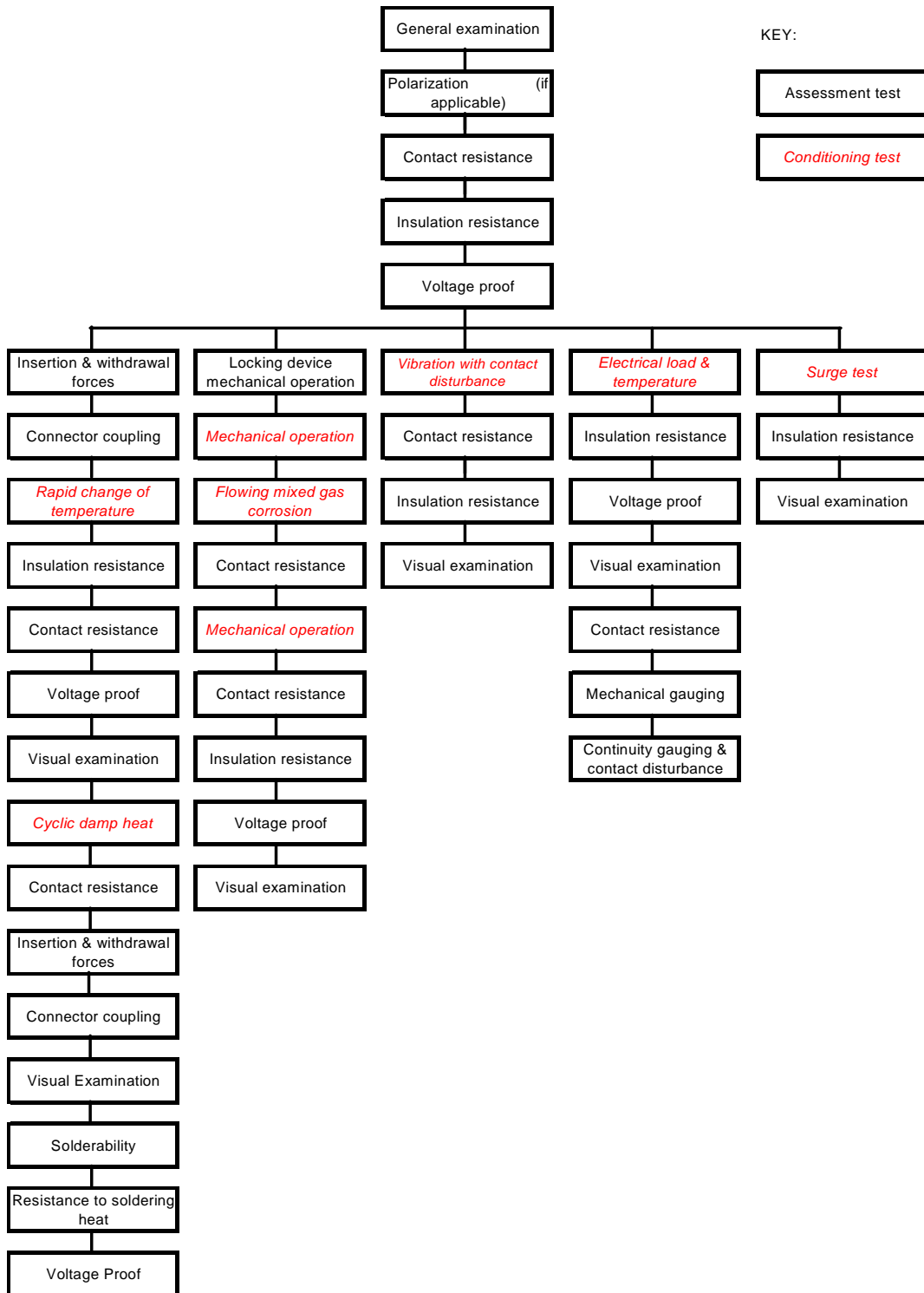The transmission tests described in this Standard typically require the use of a network analyzer or equivalent, coaxial cables, baluns, UTP test leads, and impedance matching terminations. Network analyzers provide capability to correct for source and load port inaccuracies and measurement errors due to output port gain errors and measurement port sensitivity. In addition, signal leakage from the output port to measurement port can be compensated. Each component of the test setup shall be qualified over the frequency range specified for the category to which the DUT is being evaluated. Equivalent test setups may be used. 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. Baluns shall be RFI shielded and shall comply with the specifications listed in table B.1 up to the highest referenced frequency for the category of component or cabling system under test.

Table B.1 - Test balun performance characteristics

Parameter	Frequency (MHz)	Value
Impedance, primary [1]	$1 \leq f \leq 500$	50 Ω unbalanced
Impedance, secondary	$1 \leq f \leq 500$	100 Ω balanced
Insertion loss	$1 \leq f \leq 500$	2.0 dB maximum
Return loss, bi-directional [2]	$1 \leq f < 15$ $15 \leq f \leq 500$	12 dB minimum 20 dB minimum
Return loss, common mode [2]	$1 \leq f < 15$ $15 \leq f < 400$ $400 \leq f \leq 500$	15 dB minimum 20 dB minimum 15 dB minimum
Power rating	$1 \leq f \leq 500$	0.1 watt minimum
Longitudinal balance [2]	$1 \leq f < 100$ $100 \leq f \leq 500$	60 dB minimum 50 dB minimum
Output signal balance [2]	$1 \leq f \leq 500$	50 dB minimum
Common mode rejection [2]	$1 \leq f \leq 500$	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.			

For ease of interfacing to test fixtures, the balun should present a pin and socket interface with dimensions as shown in figure B.1. Sockets should be gold plated contact material and compatible with Mill-Max part number 1001-0-15-15-30-27-04-0 shown in figure B.2.

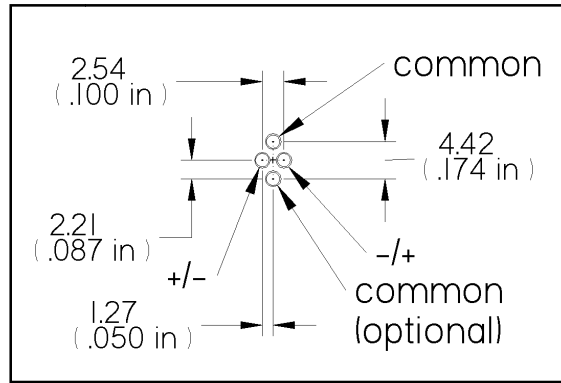**Figure B.1 - Differential test fixture interface pattern**
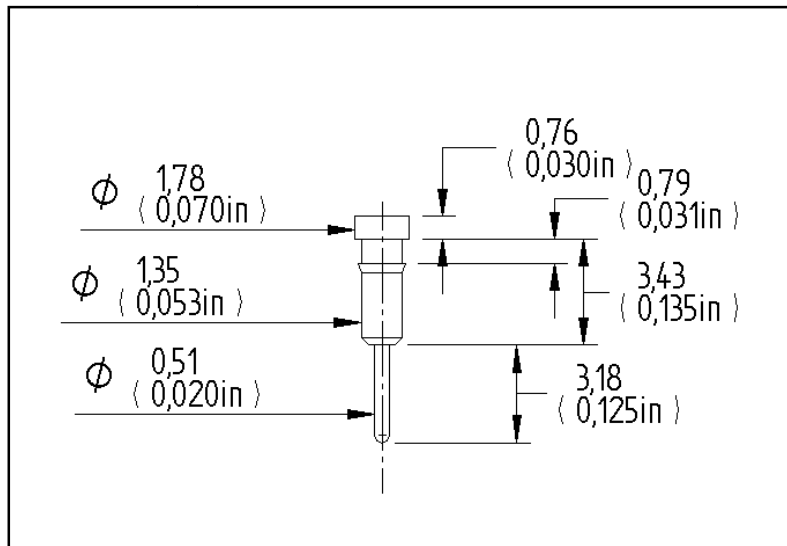

Figure B.2 - Example pin and socket dimension

Example socket description:
Mill-Max 1001-0-15-15-30-27-04-0
Material=Brass alloy
Contact: 30=Standard 4 finger contact
Contact material: Beryllium copper
Shell plating: 15=10 µ" gold over nickel
Contact plating: 27=30 µ" gold over nickel
Press fit in 1.45 mm (0.057 in) mounting hole

Figure B.3 depicts the proper test configurations for qualifying test baluns to the requirements of this Standard.
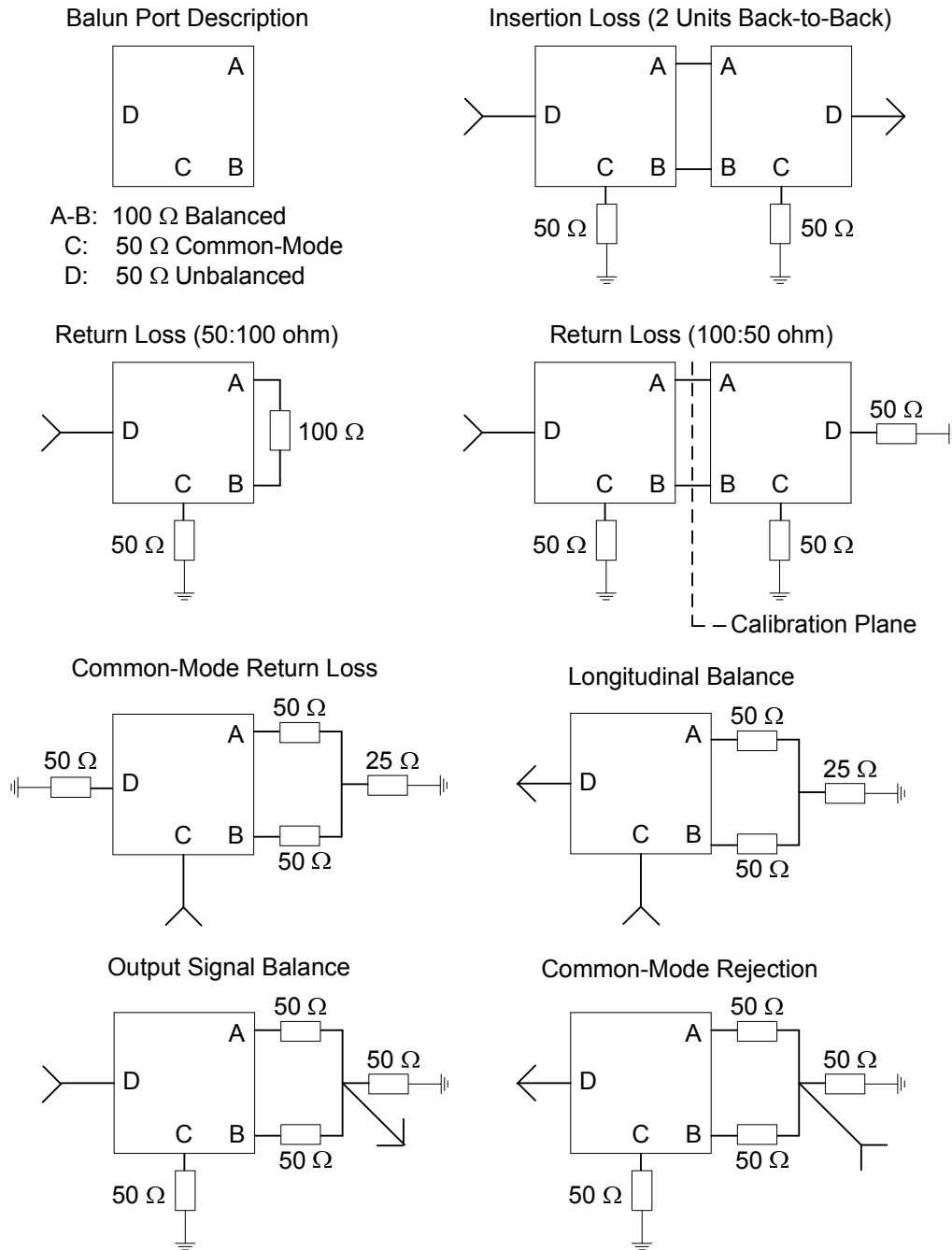

Figure B.3 - Measurement configurations for test balun qualification

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 F.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   Measurement points and spacing

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

Table B.2 – Minimum number of measurement points

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

B.6   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 mode (DM) only terminations are required for some tests, while other tests may require differential mode plus common mode (DMCM) terminations at the near-end and DM 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. DMCM only terminations are not mixed for the near-end of the DUT or the far-end of the DUT).

B.6.1   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.6.2   Resistor terminations

Resistors used for DM terminations shall exhibit impedance of 100 Ω ± 0.1 % (two times 50 Ω ± 0.1 %) as shown in figure B.4. The resistors used for common mode (CM) terminations shall include the addition of a common mode 25 Ω ± 1 % resistor as shown in figure B.4. 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.

50 Ω ± 0.1 %   50 Ω ± 0.1 %   100 Ω ± 0. 1 %

25 Ω ± 1 %

Differential mode plus
common mode resistor termination
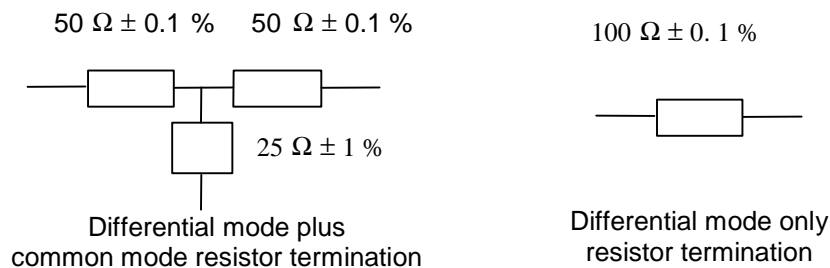
Differential mode only
resistor termination

Figure B.4 – Resistor termination networks

Additionally,

1) Small geometry chip resistors shall be used for the construction of resistor terminations.
2) The two 50 Ω DM 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.6.3   Termination performance at the calibration plane

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

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

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

B.7   General calibration plane

For all measurement configurations, the calibration plane represents the location where calibration devices are connected to the test setup as shown in figure B.5. The calibration 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.
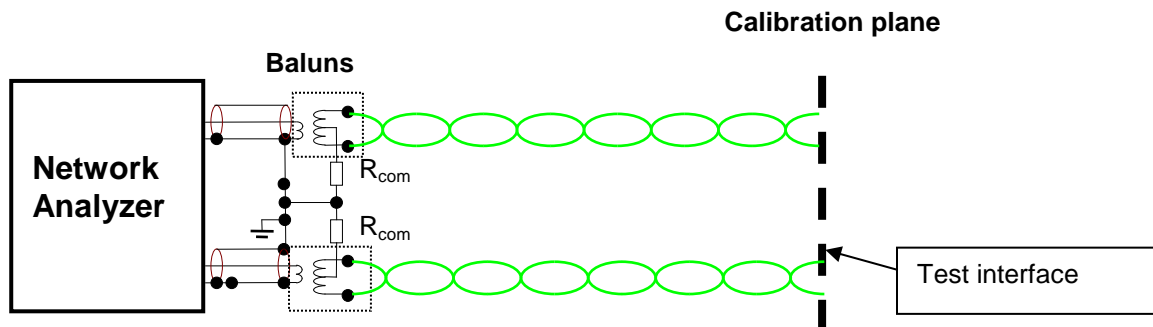
Figure B.5 - Calibration plane

The calibration plane location can be established based on:

1) Formal definitions of calibration planes for cabling (e.g., reference plane for the channel or permanent link).
2) 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).
3) Convenience of connecting devices to be tested.
4) Minimizing disruption of the transmission performance at the location where devices are connected, particularly to avoid reflections and parasitic crosstalk effects.

> NOTE – The calibration 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:

1) Two-port calibration used for through measurements that involve an output port and a measurement port (insertion loss, NEXT loss, and FEXT loss).
2) 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.7.1.1 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.7.1   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.

B.7.1.1   100 Ω 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.7.1.2   100 Ω 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.

B.7.2   Typical test equipment performance parameters

See ANSI/TIA-1152 for typical test equipment performance parameters.

Annex C (normative) - Cabling and component test procedures

C.1   Measurement test setup and apparatus

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

The transmission tests described in this annex typically require the use of a network analyzer or equivalent, coaxial cables, baluns, UTP test leads, and impedance matching terminations. Each setup component shall be qualified to a measurement bandwidth of at least 1 to 500 MHz. Test equipment design, calibration and fixturing should be such as to ensure a measurement floor of 20 dB below the required measurement limit.

C.1.1   Interconnections between the device under test (DUT) and the calibration plane

Twisted-pair test leads, printed circuits or other interconnections may be used between the DUT and the calibration plane. It is necessary to control the characteristics of these interconnections to the best extent possible as they are beyond the calibration plane. These interconnections should be as short as practical and their CM and DM impedances shall be managed to minimize their effects on measurements. The return loss performance of the interconnections shall meet the requirements of table C.1. The insertion loss performance of the interconnections is assumed to be less than 0.1 dB over the frequency range from 1 MHz to 500 MHz.

C.1.1.1   Impedance matched test leads

When used, twisted-pair test leads shall have 100 Ω nominal characteristic impedance. The twisted-pairs should not exhibit gaps between the conductors insulation. Test leads shall be qualified for DM return loss. There are two different methods to obtain twisted-pair test leads: they may be obtained as individual twisted-pairs, or they may be part of a cable. If CM terminations are required, the test leads shall be placed in an impedance managing system, as described in Annex E.   The maximum length of the test leads extending from each end of the device shall be 51 mm (2 in).

C.1.1.1.1 Individual twisted-pair test leads

Twisted-pair test leads may be obtained from discrete twisted-pair stock or removed from jacketed cable. Prior to attachment to the device, the return loss of each twisted-pair shall be tested. For this test, 100 mm (4 in) lengths of twisted-pair shall be used. The test leads shall be DM terminated across each pair with a precision 0.1% 0603 or similar chip resistor as described in clause B.6.2. The resistor shall be attached directly to the conductors of the pair in such a way as to minimize the disturbance of the twisted-pair. Potential disturbances include gaps between the conductor insulation in the twisted-pair, melted insulation, and excess solder. When tested, the test lead shall be attached to the balun or DM test port using the same fixtures as when testing the device. The test leads are then trimmed for attachment to the DUT and the test fixtures. See Annex E for an appropriate test fixture. It is recommended to use the same load for both calibration and termination of the test lead during measurement.

C.1.1.1.2 Test leads as part of cables

Test leads may also be obtained from a section of twisted-pair cable where the four twisted-pair test leads are maintained in the cable jacket. This method will most often be used with test plugs, cut from the ends of assembled cords, but can also be used with jacks. Prior to attachment to the DUT, the return loss of the cable twisted-pairs (within the cable) shall be tested. For this test, a 100 mm (4 in) length of cable shall be selected. Each twisted-pair of the cable shall be DM terminated across each pair with a precision 0.1% 0603 or similar chip resistor as described in clause B.6.2. The cable shall then be terminated to the device per manufacturer's instructions and trimmed for attachment to the measurement system.

C.1.1.2 Interconnection return loss requirements

For connecting hardware return loss measurements, the interconnection shall meet the requirements in table C.1 relative to the calibration resistor specified in annex B.

Table C.1 - Interconnection return loss

Frequency (MHz)	Return loss (dB)
$1 \leq f < 80$ $80 \leq f \leq 500$	40 dB $38 - 20\log(f/100)$ dB

C.1.2 Calibration methods

One-port and two-port calibrations are acceptable for return loss measurements. Two-port calibration and measurement methods, which include compensation for the balun response, shall be used for insertion loss, NEXT loss and FEXT loss measurements. See clause B.7 for more information on calibration methods and types.

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 isolation calibration is used, the near-end and far-end measurement ports should be terminated into 100 Ω at the location of the reference plane.

C.1.2.2 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.2   Testing of cabling

C.2.1   Cabling DC resistance

DC resistance shall be measured in accordance with ASTM D4566.

C.2.2   Return loss of channels and permanent links

C.2.2.1   Test configuration of channel and permanent link return loss

Figure C.1 depicts the typical schematic diagram for testing return loss. Resistor terminations are generally preferred for unused pairs at the far-end because of better return loss performance. See clause B.6.2 for information on resistor terminations. DM terminations are recommended for return loss measurements. 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 connection labeled "G" represents a connection to the ground plane.
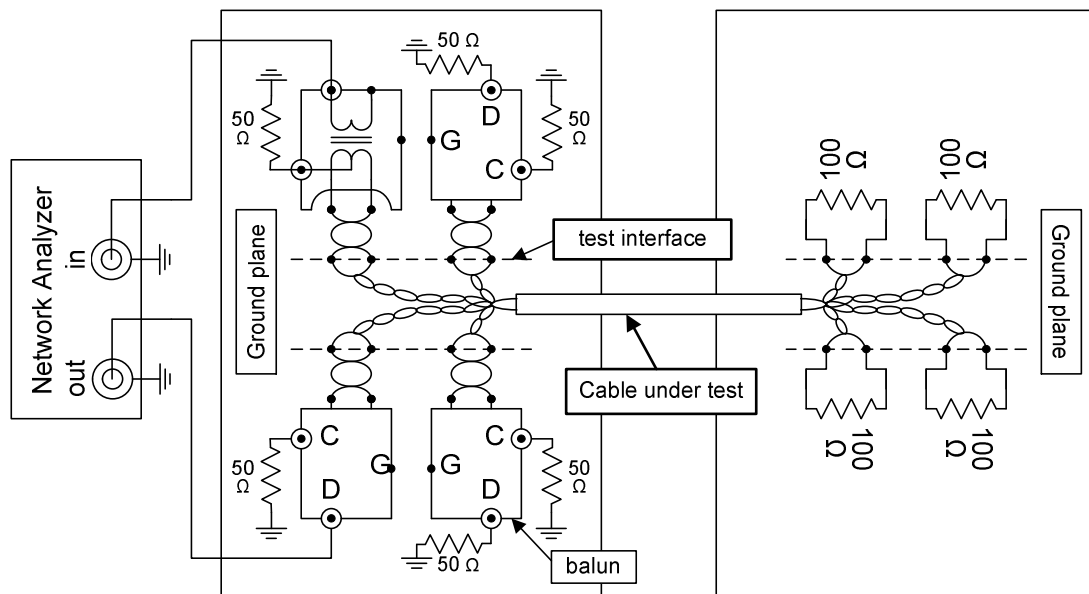

Figure C.1 - Laboratory test configuration for return loss

C.2.2.2   Measurement of channel and permanent link return loss

Calibrate in accordance with C.1.2. Measure the S11 parameter with the network analyzer connected to each pair on the near-end. Cable return loss shall be tested in both directions.

C.2.3   Insertion loss of channels and permanent links

C.2.3.1   Test configuration of channel and permanent link insertion loss

Figure C.2 depicts the typical schematic diagram for testing insertion loss, FEXT loss, ACRF, and propagation delay.
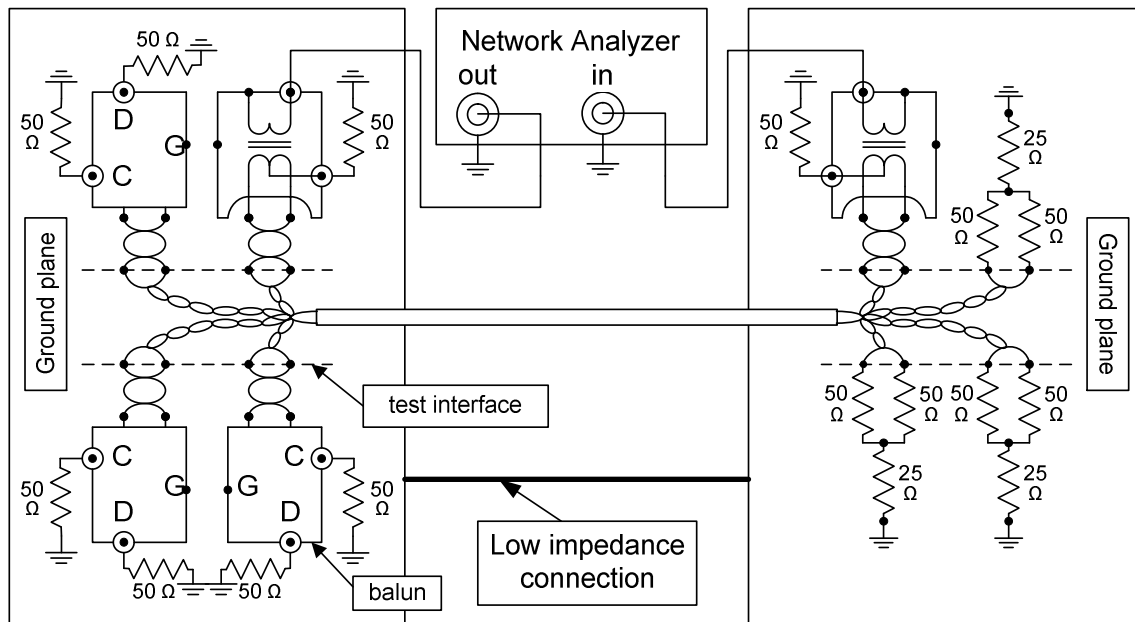

Figure C.2 - Laboratory test configuration for insertion loss, FEXT loss, ACRF, and propagation delay measurements

The internal schematic diagram of the balun is shown twice 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 the connection labeled "G" represents a connection to the ground plane.

> NOTES,
> 1   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.2.3.2   Calibration of channel and permanent link insertion loss

The calibration for channel and permanent link insertion loss shall comply with clause C.1.2.

C.2.3.3 Measurement of channel and permanent link insertion loss

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

C.2.4 NEXT loss of channels and permanent links

C.2.4.1 Test configuration of channel and permanent link NEXT loss

Figure C.3 depicts the typical schematic diagram for testing NEXT loss. Resistor terminations are generally preferred for unused pairs at the far-end because of better return loss performance. See clause B.6.2 for information on resistor terminations. DMCM terminations shall be used for NEXT loss measurements. The detailed schematic diagram of the balun is shown once in figure C.3. 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.
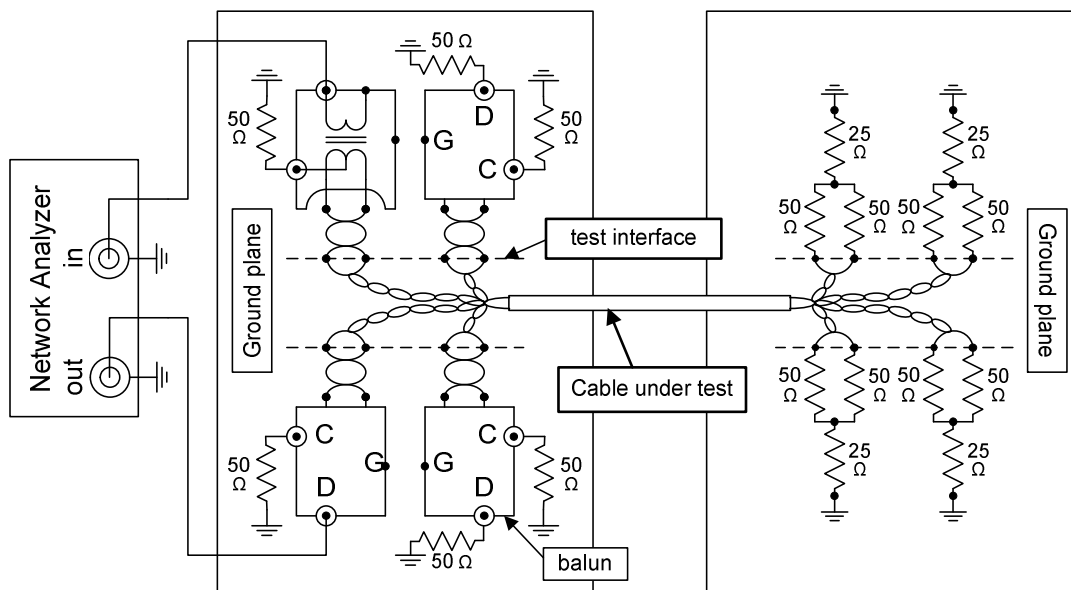
.

Figure C.3 - Laboratory test configuration for NEXT loss

C.2.4.2 Calibration of channel and permanent link NEXT loss

The calibration for channel and permanent link NEXT loss shall comply with clause C.1.2.

C.2.4.3 Measurement of channel and permanent link NEXT loss

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

C.2.5 FEXT loss of channels and permanent links

C.2.5.1 Test configuration of channel and permanent link FEXT loss

See clause C.2.3.1 for the test configuration of channel and permanent link FEXT loss. DMCM terminations shall be used for all unused pairs.

C.2.5.2 Calibration of channel and permanent link FEXT loss

The calibration for channel and permanent link FEXT loss shall comply with clause C.1.2.

C.2.5.3   Measurement of channel and permanent link FEXT loss

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

C.2.6   Cabling ANEXT loss and AFEXT loss laboratory measurement procedures

The method in the following sections is provided to investigate the performance of cabling (channels and permanent links) to the cabling PSANEXT loss and PSAACRF specifications in this Standard. When laboratory testing is used, the procedures in this normative annex shall be followed to ensure consistency.

This procedure is intended for use in the laboratory, to evaluate that cabling complies with the PSANEXT loss and PSAACRF requirements, when properly installed. Separate procedures are provided for field testing and for the design verification of components.

The elements that affect the cabling PSANEXT loss and PSAACRF result include cable, cords, connectors, and their mounting systems (e.g. pathways, patch panels, faceplates, and mounting boxes). Lengths of cable segments and proximity and density of connectors are among the factors that can affect compliance. Additionally, this procedure can be used to verify that the mathematical models used to derive channel performance from component performance are valid. This procedure is also used to test installation practices, to assure they do not degrade PSANEXT loss and PSAACRF performance.

C.2.6.1   Test configuration of channel and permanent link ANEXT loss

C.2.6.1.1   Termination of pairs

During all testing, all pairs of all channels or permanent links that are not being tested, including the unused pairs of the channels under test, should be terminated with both DMCM terminations at both ends. The nodes from the opposite ends should be connected with an appropriate low impedance path.

C.2.6.1.2   Cabling construction

Cabling shall be constructed to satisfy the following conditions:

1. There shall be a disturbed channel or permanent link of the desired topology.
2. Select the worst alien crosstalk position in the connector hardware mounting system as the disturbed position. Connect that connector to the center cable in the 6-around-1 bundle.
3. There shall be at least 6 disturbing channels or permanent links. If there are fewer than 6 disturbing positions in the connecting hardware mounting system, the additional connectors needed to make 6 disturbers shall be placed in a similar mounting system nearby. If there are more than 6 significant disturbing positions in the connecting hardware mounting system, the disturbing cables in the 6-around-1 bundle shall be connected to the 6 most significant connectors in the connecting hardware mounting system. Any additional cables beside the 6-around-1 bundle shall be routed nearby. See clause C.3.7.1 for assembly of cable bundle.

Disturbing and disturbed cabling configurations should be specified at the time of measurement. Refer to Annex J for cabling configurations that were used to develop channel and permanent link limits.

Construct the disturbed and disturbing cablings such that the required number of disturbing elements are placed as close as possible to the disturbed elements. Both the cable and the cords shall be touching or shall be in as close proximity as physically possible. For connectors, this shall mean they are mounted in the mounting system, at all the positions where they may significantly disturb the disturbed channel.

It shall be acceptable to have a short length, up to 0.3 m (1.0 ft), of the cable not tightly bundled, for the purpose of connecting it to a connector that is some distance away from the disturbing connector. At the ends of the cabling where the cable is connected to the measurement system, it shall be acceptable, to have up to 0.6 m (2.0 ft) of cable, not in contact, for the purposes of connecting to the measurement system.

C.2.6.1.3 Determining number of disturbing components

The configuration of mounted connectors that results in worst case ANEXT loss and AFEXT loss shall be used. The number of disturbing channels or permanent links shall be determined by using the larger number from the following:

a) the number of cable disturbers is defined in clause C.3.7 as six 4-pair cables or
b) the number of connector disturbers determined using the procedure specified in clause C.4.6.5.

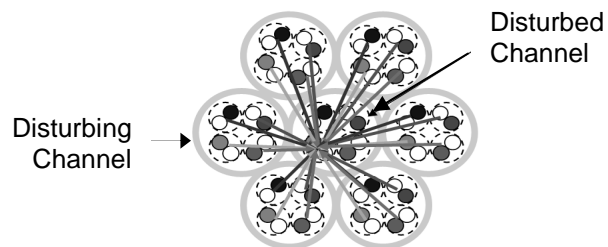An example of a configuration is shown in figure C.4.

Figure C.4 - Example of a "6-around-1" cable arrangement in a channel

Significant connectors may be located in other panels in close proximity and these shall be assessed accordingly.

C.2.6.2 Calibration of channel and permanent link ANEXT loss or AFEXT loss

Calibrate per clause C.1.2.

C.2.6.3   Measurement of channel and permanent link ANEXT loss or AFEXT loss

Measure the ANEXT loss of all pairs in the disturbing channels or permanent links to all pairs in the disturbed channel or permanent link as shown in figure C.5. See figure C.16 and clause C.4.6.4 for details on the connection and termination of disturbed and disturbing channels or permanent links to the measurement system. Measure the insertion loss of each pair of the disturbed channel or permanent link, and of each pair of the disturbing channels or permanent links.

Measure the AFEXT loss of all pairs in the disturbing channels or permanent links to all pairs in the disturbed channel or permanent link as shown in figure C.6. See figure C.17 and clause C.4.6.4 for details on the connection and termination of disturbed and disturbing channels or permanent links to the measurement system. The power sum shall be calculated for each of the four pairs of the disturbed channel or permanent link, from all of the pairs of all disturbing channels or permanent links. See clause 6.1.16 for information on how to calculate PSAACRF.
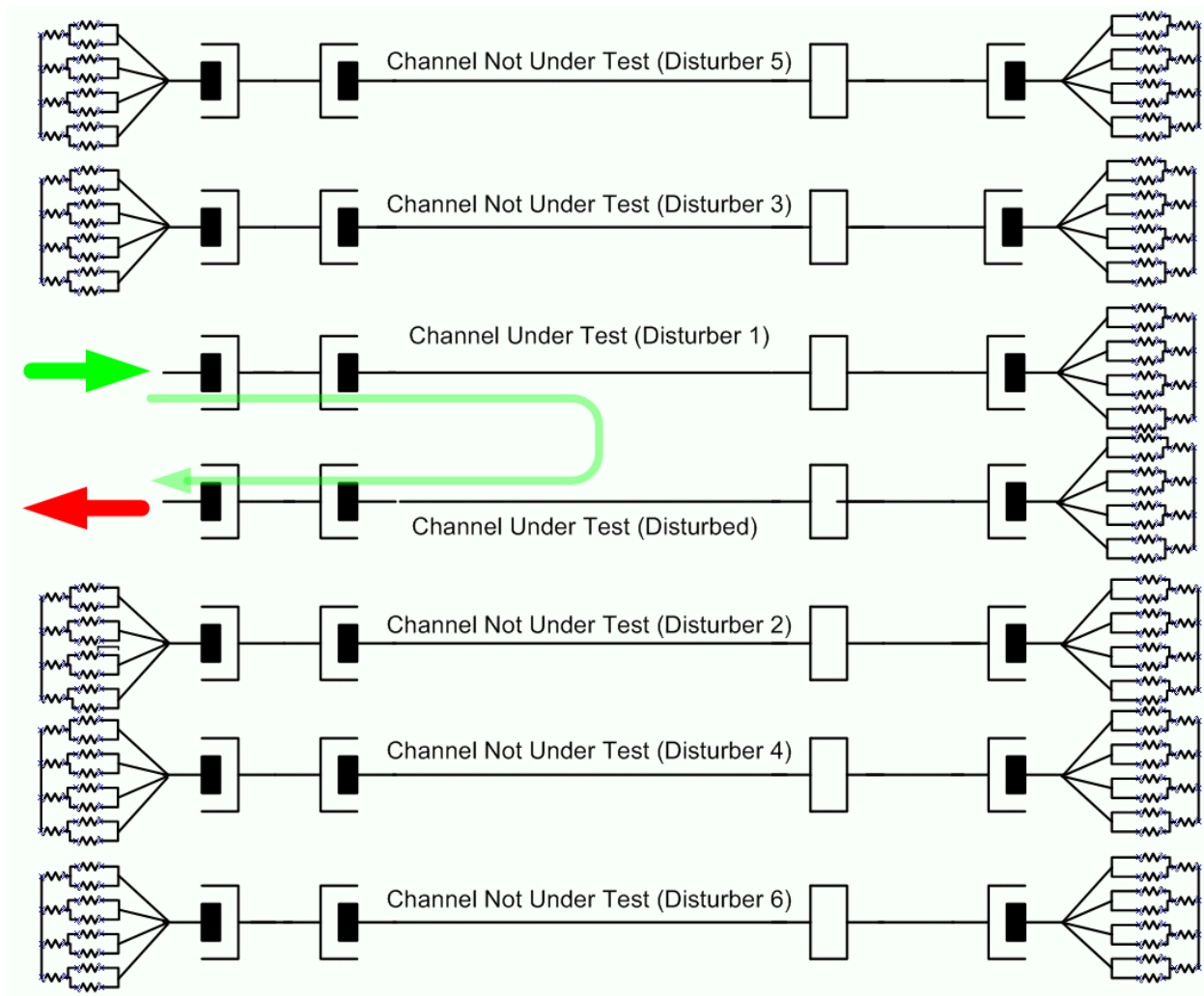

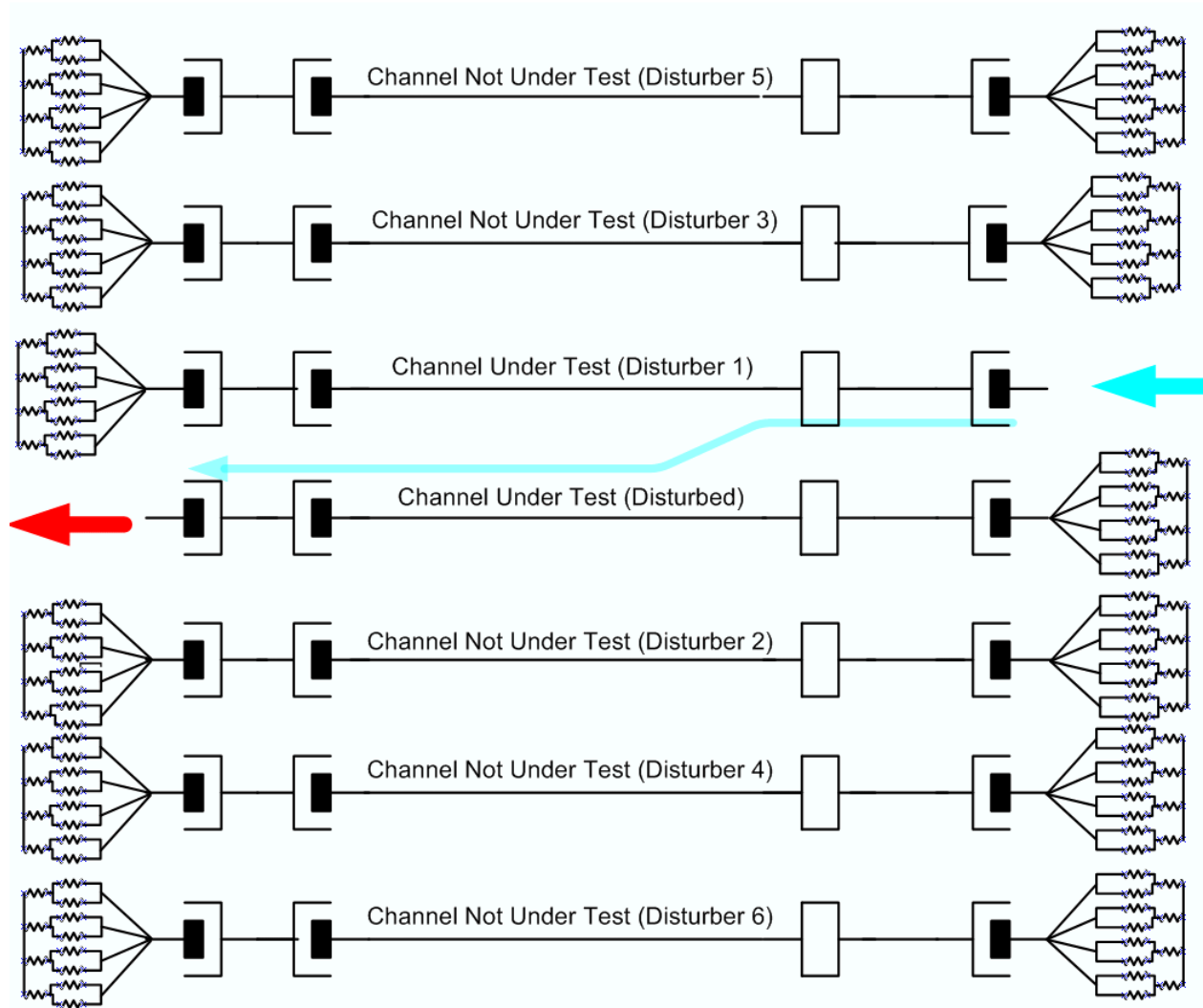**Figure C.5 - Schematic diagram of cabling ANEXT loss measurements**

Figure C.6 - Schematic diagram of cabling AFEXT loss measurements

C.2.7   ACRF and FEXT loss of channels and permanent links

C.2.7.1   Test configuration of channel and permanent link FEXT loss

The test configuration for channel and permanent link FEXT shall comply with clause C.2.3.1. ACRF is a calculation of the measurements of the FEXT loss and insertion loss.

C.2.7.2   Calibration of channel and permanent link FEXT loss

The calibration for channel and permanent link FEXT loss shall comply with clause C.1.2.

C.2.7.3   Measurement of channel and permanent link FEXT loss

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

C.2.8   TCL of channels

C.2.8.1   Test configuration of channel TCL

Figure C.7 depicts the typical schematic diagram for testing TCL. The cabling or DUT pair under test shall be connected to the differential mode balun output terminals. All unused near-end pairs shall be terminated with DMCM resistor terminations (see clause B.6.2) or baluns as shown in figure C.7. All far-end pairs shall be terminated with DMCM resistor terminations (see clause B.6.2). The near-end terminating resistor networks shall be bonded and connected to the measurement ground plane. The far-end resistor networks shall be bonded together.
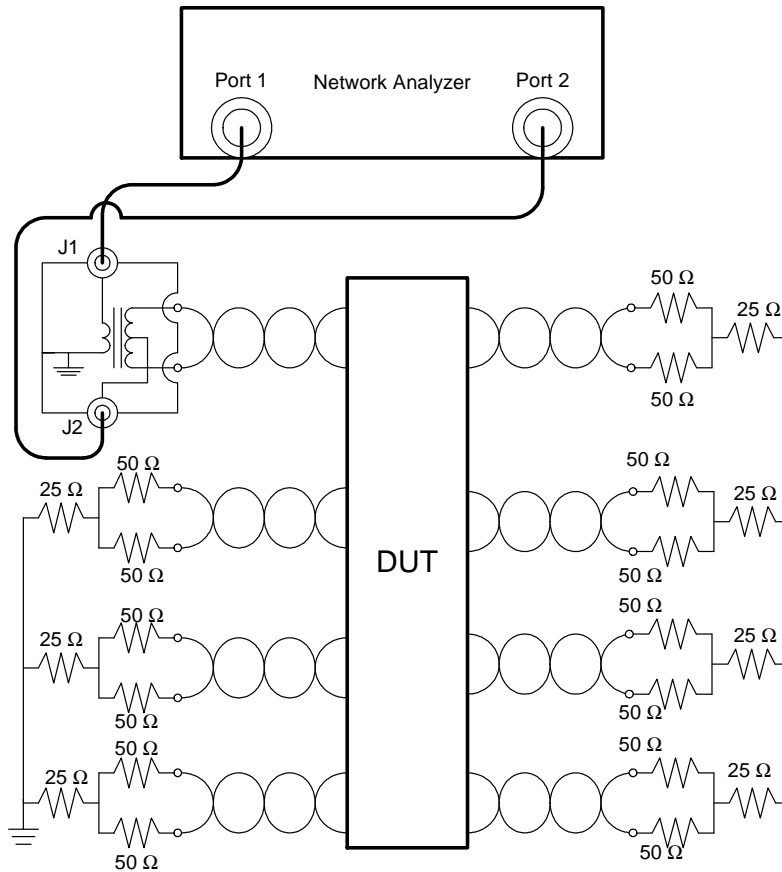

Figure C.7 - Laboratory test configuration for TCL

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

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C.2.8.2   Calibration of channel TCL

TCL calibration is performed in three steps.

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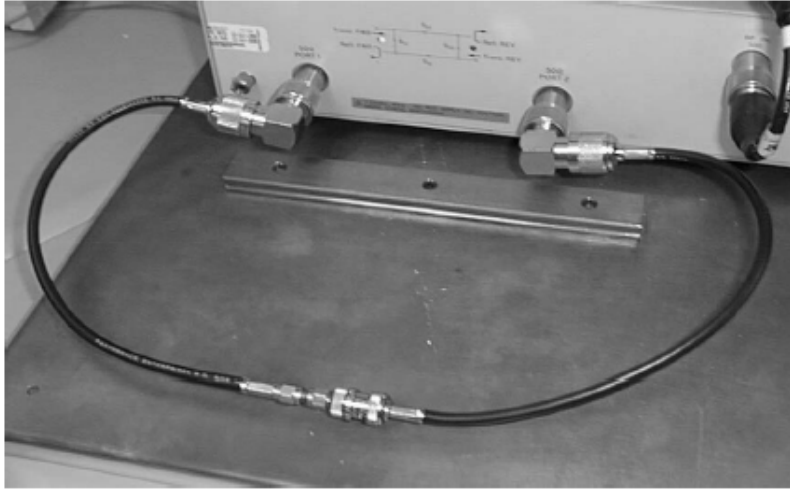

Figure C.8 - Coaxial lead through calibration

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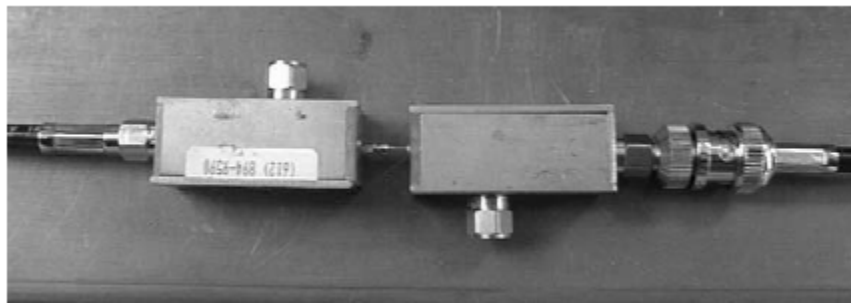
Figure C.9 - Back-to-back balun insertion loss measurement

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

Figure C.10 - Output terminal connection

Additionally, a correction term for the impedance ratio of the balun transformer converting from 50Ω on the network analyzer to 100Ω on the DUT is needed. The correction value is 3 dB.
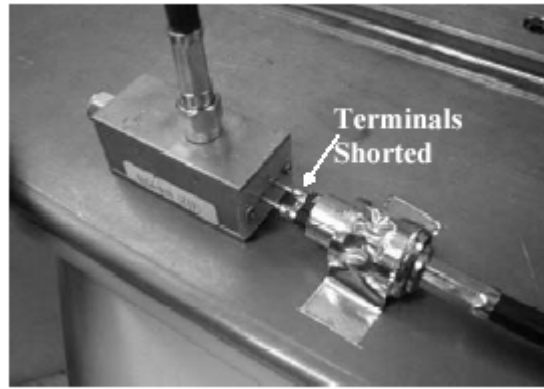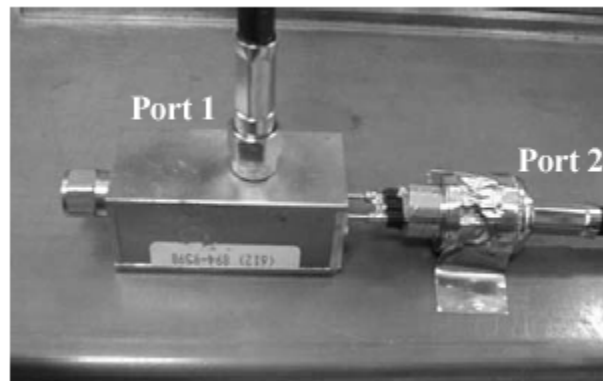

Figure C.11 - Outer shield grounding position

C.2.8.3   Measurement of channel TCL

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

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

$$TCL = (IL_{meas} - IL_{bal,DM} - IL_{bal,CM} + 3) \ dB \tag{C-1}$$

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

TCL shall be tested in both directions.

C.2.9   TCTL of channels

C.2.9.1   Test configuration of channel TCTL

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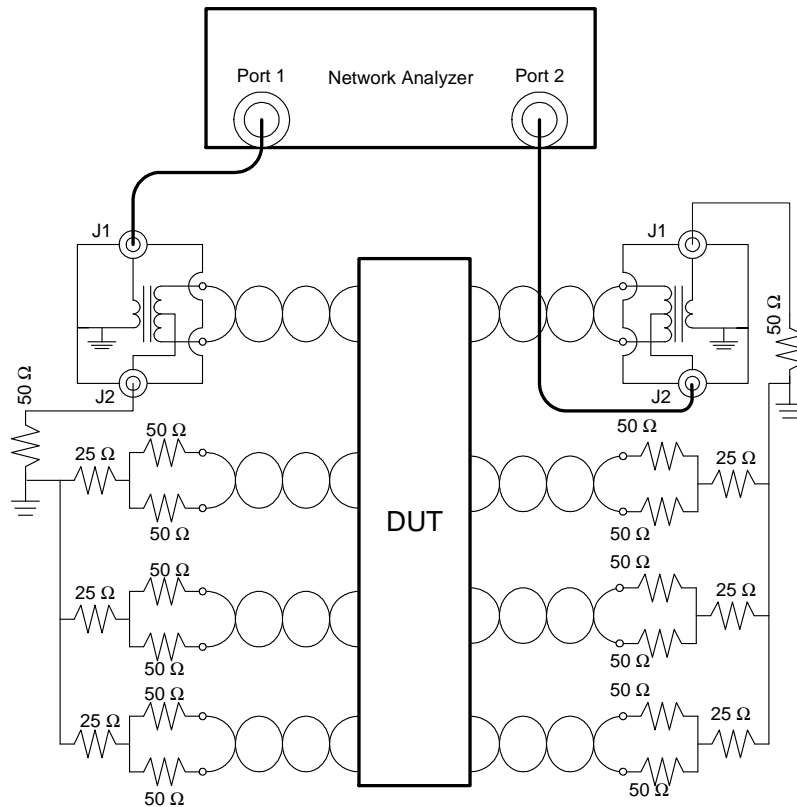

Figure C.12 - Laboratory test configuration for TCTL

C.2.9.2   Calibration of channel TCTL

The calibration of the test hardware for TCTL measurements shall follow the procedure outlined in clause C.4.8 for both baluns being used in the measurement and the calibration values should be recorded as $IL_{bal,DM.1}$, $IL_{bal,DM.2}$, $IL_{bal,CM.1}$, and $IL_{bal,CM.2}$.

C.2.9.3 Measurement of channel TCTL

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

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

$$TCTL = (IL_{meas2} - IL_{bal,DM,1} - IL_{bal,CM,2} + 3) \ dB \hspace{4cm} \text{(C-2)}$$

TCTL shall be tested in both directions.

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

C.3 Cable test procedures

This clause describes test and calibration procedures for cables.

C.3.1 Cable measurement precautions

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

C.3.2 Cable measurement configurations

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

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

C.3.2.1 Configuration for insertion loss, FEXT loss, AFEXT loss, and propagation delay measurements of cable

The measurement configurations for cable insertion loss, FEXT loss, AFEXT loss, and propagation delay measurements shall comply with clause C.2.3.1.

C.3.2.2 Configuration for TCL measurements of cable

The measurement configurations for cable TCL shall comply with clause C.2.8.1.

C.3.2.3 Configuration for TCTL measurements of cable

The measurement configurations for cable TCTL shall comply with clause C.2.9.1.

C.3.3   Calibration of cable measurements

The calibration of cable measurements shall comply with clause C.2.2.2.

C.3.4   Return loss of cable

C.3.4.1   Test configuration of cable return loss

The cable return loss measurement configuration shall comply with the requirements of clause C.2.2.1.

C.3.4.2   Calibration of cable return loss

A one- or two-port calibration, as described in clause C.3.3, may be used to calibrate return loss.

C.3.4.3   Measurement of cable return loss

Measure the S11 parameter with the network analyzer connected to each pair on the near-end. Cable return loss shall be tested in both directions.

C.3.5   Insertion loss of cable

C.3.5.1   Test configuration for cable insertion loss

The cable insertion loss measurement configuration shall comply with the requirements of clause C.3.2.1.

C.3.5.2   Calibration of cable insertion loss

A two-port calibration, as described in clause C.1.2 shall be used to calibrate insertion loss.

C.3.5.3   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. It is not necessary to measure cable insertion loss from both ends due to reciprocity.

C.3.6   NEXT loss of cable

C.3.6.1   Test configuration for cable NEXT loss

The cable NEXT loss measurement configuration shall comply with the requirements of clause C.2.4.1.

C.3.6.2   Calibration of cable NEXT loss

A two-port calibration, as described in clause C.1.2, shall be used 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.3.6.3   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. Cable NEXT loss shall be tested in both directions.

C.3.7   ANEXT loss and AFEXT loss of cable

This clause describes a procedure for measuring ANEXT loss and AFEXT loss between pairs of adjacent cables in a 7-cable assembly consisting of cables of the same design. The frequency range is 1 to 500 MHz. In addition to the procedures in this annex, cable should be verified for compliant channel alien crosstalk performance in accordance with clauses C.2.6.3 using short and long channels (see channel configurations 3 and 1 as specified in Annex J).

C.3.7.1   Test configuration for cable ANEXT loss and AFEXT loss

The cable ANEXT loss and AFEXT loss measurement configuration shall comply with the requirements of this clause. Prepare the cables to be tested in the form of an assembly consisting of seven cables. The seven cables shall be maintained in a 6-around-1 parallel configuration throughout the length to be tested as shown in figure C.13. Non-metallic bindings shall be longitudinally spaced no more than 200 mm (8 in) apart for the entire length of cable except for the last 1.0 m (3.3 ft) from each end of the cable bundle. The 6 cables shall not be deformed by the non-metallic bindings. The assembly shall be arranged such that a minimum separation of 100 mm (3.9 in) is maintained between sections of the assembly. The pairs at each end of the assembly shall be terminated with DMCM resistors as described in clause B.6.2.
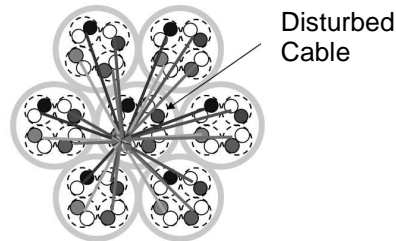

Disturbed Cable

Figure C.13 - 6-around-1 cable test configuration

C.3.7.2   Calibration of cable ANEXT loss

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

C.3.7.3   Measurement of cable ANEXT loss

Measure the S21 parameter with the network analyzer connected to each pair of the disturbed cable and each pair of every disturbing cable. This will result in 96 measurements each for ANEXT loss and AFEXT loss.

C.3.7.4   Cable PSAFEXT loss and PSAACRF calculation

To calculate PSAFEXT loss from the measured data, power sum the appropriate 24 measurements for each disturbed pair. PSAACRF is calculated in accordance with equation (C-3).

$$PSAACRF_k = PSAFEXT_k - IL_k \ dB \tag{C-3}$$

where k is the disturbed pair.

C.3.8   FEXT loss of cable

C.3.8.1   Test configuration of cable FEXT loss

The cable FEXT loss measurement configuration shall comply with the requirements of clause C.2.5.1. ACRF is a calculation of the measurements of FEXT loss and insertion loss.

C.3.8.2   Calibration of cable FEXT loss

A two-port calibration, as described in clause C.1.2 shall be used 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.3.8.3 Measurement of cable FEXT loss

Cable FEXT loss shall be measured in accordance with clause C.2.5.3. 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.3.9   TCL of cable

C.3.9.1 Test configuration of cable TCL

The cable TCL measurement configuration shall comply with the requirements of clause C.3.2.2.

C.3.9.2 Calibration of cable TCL

Cable TCL shall be calibrated in accordance with clause C.2.8.2.

C.3.9.3 Measurement of cable TCL

Cable TCL shall be measured in accordance with clause C.2.8.3.

C.3.10 TCTL of cable

C.3.10.1 Test configuration of cable TCTL

The cable TCTL measurement configuration shall comply with the requirements of clause C.3.2.3.

C.3.10.2 Calibration of cable TCTL

The calibration of the test hardware for TCTL measurements shall follow the procedure outlined in clause C.3.9.2 for both baluns being used in the measurement and the calibration values should be recorded as $a_{bal,DM.1}$, $a_{bal,DM.2}$, $a_{bal,CM.1}$, and $a_{bal,CM.2}$.

C.3.10.3 Measurement of cable TCTL

Cable TCTL shall be measured in accordance with clause C.2.9.3.

C.3.11 Propagation delay of cable

C.3.11.1 Test configuration of cable propagation delay

The cable propagation delay measurement configuration shall comply with the requirements of clause C.3.2.1.

C.3.11.2 Calibration of cable propagation delay

A one- or two-port calibration, as described in clause C.3.3, may be used to calibrate propagation delay.

C.3.11.3 Measurement of cable propagation delay

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

C.4   Connecting hardware test procedures

This clause describes test and calibration procedures for connecting hardware. Test equipment design calibration and fixturing should ensure a noise level 30 dB better than the required measurement limit over the frequency range of 1 MHz to the highest specified frequency for the category of connecting hardware being tested.

C.4.1   Connecting hardware measurement configurations

The following requirements apply to the test configurations for connecting hardware measurements and for other components, assemblies, and test parameters as indicated by reference. The test methods and setup requirements described herein apply to one (1) or more pairs of twisted-pair conductors. The nature of these tests is such that, when conducted properly, worst case transmission performance may be determined for a specific connector, regardless of the number of pairs that it is capable of terminating. Connecting hardware transmission testing shall be conducted upon products terminated per manufacturer's guidelines and recommended installation methods unless otherwise specified.   For connecting hardware with modular interface components (i.e. plug and jack connectors), transmission tests shall be performed in a mated state. Test plug requirements are specified in clause C.4.10.

DM only and DMCM resistor terminations are shown in figure B.4. DMCM terminations shall be used on all active pairs under test except when measuring return loss, where DM only resistor terminations are recommended. DMCM resistor terminations shall be used on all inactive pairs and on the opposite ends of active pairs for NEXT loss and FEXT loss testing. DMCM terminations shall be used on inactive pairs for insertion loss testing. Inactive pairs for return loss testing may be terminated with DM or DMCM resistor terminations, or left unterminated. Balun terminations may be used on the far-end of all pairs and the near-end of all inactive pairs provided that their differential mode and common mode return loss performance characteristics meet the minimum performance of the specified resistor networks.

Interconnection (including test lead) requirements are specified in clause C.1.1.

For the purpose of testing connecting hardware mated performance, the test plug phase reference plane and calibration planes shall be as defined in clause C.4.1.1. Connecting hardware shall be defined as a mated plug and jack, with cable terminated to both. The connector is considered to begin at the point where the sheath of the cable is cut or the point inside the sheath where the cable conductor geometry is no longer maintained. The portion of the cable [typically 12 mm (0.5 in) or less] that is disturbed by the termination shall be considered to be part of the connector under test. Unless otherwise specified for a specific test, the performance of the entire mated connector shall be assessed.

For testing screened connecting hardware, a balun ground plane, 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.

C.4.1.1 Test plug phase reference plane and calibration planes

For categories 5e, 6, and 6A, connecting hardware measurements of return loss, insertion loss, NEXT loss, and FEXT loss are conducted by mating connecting hardware with a test plug that complies with clause C.4.10. Certain plug parameters include phase requirements, and certain connecting hardware requirements are based on calculations that involve both test plug and connecting hardware phase data. There are no test plug requirements for category 3 connecting hardware. To maintain a consistent phase reference, a "test plug phase reference plane" must be used, as explained below.

The test plug phase reference plane shall be at the tip of the plug where it connects to the jack contacts. This is accomplished with a calibration at the calibration plane plus port extension. The calibration planes should be as close as possible to the test plug phase reference plane as shown in figure C.14. Refer to clause C.1.1 for requirements of the interconnections between each appropriate calibration plane and the DUT.   Alternatively, the direct fixture (see clause C.4.9.1) can be calibrated at the tips of the coaxial probes (see figures E.4, E.5, and E.6) using suitable calibration artifacts.   Examples are shown in figure C.15.
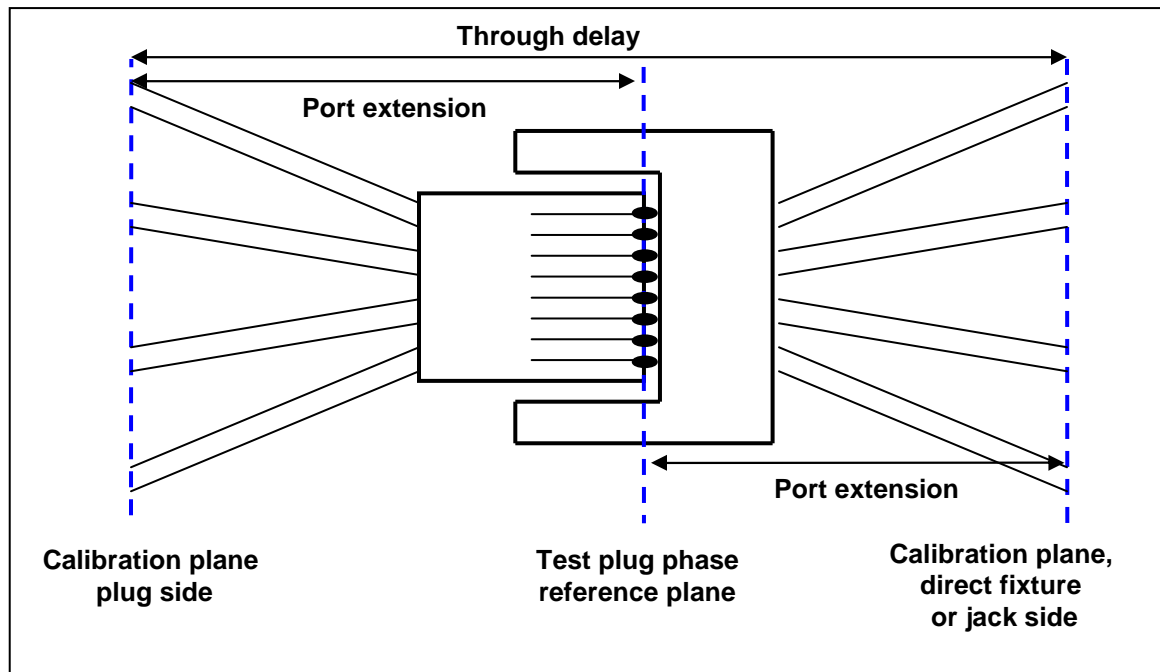

Figure C.14 - Calibration planes, test plug phase reference plane, and port extensions

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C.4.1.1.1 Device delay measurements

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

The port extension values calculated according to equation (C-5) are applied to each port (for each pair) to align measurement reference planes to the location where contact is made with the jack contacts.

For all measurements subsequently used in vector or matrix calculations and/or where phase requirements are specified, the appropriate port extensions shall be applied after calibration to adjust the measurement to the test plug phase reference plane. This may be done by applying the calculated port extensions directly to the network analyzer or by adjusting the phase after measurement using equation (C-4).

$$phase_{(testplugphase\_ref\_plane)} \, (\mathrm{deg}) = phase_{(calibration\_plane)} \, (\mathrm{deg})...$$

$$...+ 360 \cdot frequency \,(\mathrm{Hz}) \cdot delay \,(\mathrm{sec}) \qquad\qquad (\text{C-4})$$

C.4.1.1.2 Network analyzer settings for delay measurement

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

1 Measurement function is S11 delay
2 Averaging 4x or higher
3 Intermediate frequency bandwidth (IFBW) 300 Hz or less
4 Output power level in the range of –5 dBm to 0 dBm for phase critical measurements

C.4.1.1.3 Test plug delay and port extension

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

1 With the test plug connected to the test baluns, measure the S11 delay for each pair determined with an open circuit at the test plug phase reference plane.
2 Place a short on the test plug. This short shall connect the contacts of the pair under test at the test plug phase reference plane and be no further than 3 mm (0.12 in) from the point of contact with the jack. Measure the S11 delay for each pair shorted in this manner.
3 The delay value for each pair is calculated by averaging the open and short delay measurements over the frequency range of 100 MHz to 500 MHz using linear spacing and a minimum of 100 frequency points. These delay measurements represent round-trip delays. The one-way delay is half of the round trip S11 delay.

C.4.1.1.3.1 Calculation of port extension

The one-way measured delays (open and short) shall be used to calculate the port extension for each pair as determined by equation (C-5). It is recognized that there is an inherent error in the delay measurements due to the finite length of the short. To correct this error, a correction factor $TD_{shortingjack}$ described in clause (C-6) shall be applied for each port extension.

$$PortExtension = average(\frac{TD_{open} + TD_{short} - TD_{shortingjack}}{4}) \qquad\qquad (\text{C-5})$$

C.4.1.1.3.2 Plug delay correction

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

1. Select a plug that can be used for this procedure and is then discarded. Three or more plugs are recommended.
2. Mount the plug rigidly onto a pyramid or other suitable impedance management fixture.
3. Measure the S11 round trip delay of the plug mated to the shorting jack (see clause E.3.2.7.3 of ANSI/TIA/EIA-568-B.2-1 for a description of the shorting jack) on all pairs and record these value as $Delay_{round\ trip\ plug\ jack}$.
4. Without removing the plug from the pyramid, trim the plastic ribs separating the contacts, and solder a wire across all 8 contacts where they make contact with a mating jack.
5. Measure the S11 round trip delay of the plug on each pair and record these values as $Delay_{round\ trip\ plug}$.
6. Subtract 14 ps for pair 3,6 and 5 ps for the other three pairs (1,2 and 4,5 and 7,8) from $Delay_{round\ trip\ plug}$ to account for the delay of the short spanning the plug contacts. Record these values as $Delay_{adjusted\ round\ trip\ plug}$.
7. Determine the difference in round trip delay for each pair of the shorting jack as follows:

$$TD_{shortingjack} = Delay_{roundtripplugjack} - Delay_{adjustedroundtripplug}$$ (C-6)

NOTES,
1   The delay measurements are dependent on the proximity to ground planes. The positioning of the interconnections (e.g. twisted-pairs) should remain fixed during all measurements.
2   The measurement accuracy of this method is approximately 20 ps in a round-trip measurement, corresponding to a one-way distance of approximately 2 mm (0.08 in).

C.4.1.1.4   Direct fixture delay and port extension

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

1. Insert a short artifact into the direct fixture and measure the S11 delay for each pair of the direct fixture.
2. Subtract 14 ps for pair 3,6 and 5 ps for the other three pairs (1,2 and 4,5 and 7,8) from the measured short delay to account for the delay of the short spanning the coaxial probes.
3. Remove the short artifact, insert an open artifact into the direct fixture and measure the S11 delay for each pair of the direct fixture.
4. The delay value for each pair is calculated by averaging the open and short delay measurements over the frequency range of 100 MHz to 500 MHz using linear spacing and a minimum of 100 frequency points. These delay measurements represent round-trip delays. The one-way delay is half of the round trip S11 delay.

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

Short and open artifacts shall be compatible with the dimensional requirements of the direct fixture as shown in figures C.19, C.20 , and C.21 . The mating surface of these artifacts to the coaxial probes of the direct fixture shall be the same as the terminated modular plug contact height specified in IEC 60603-7 series (i.e. 5.89 – 6.17 mm). Examples of these are shown in figure C.15. Artifacts can also be created from modular plugs as long as they meet these requirements.

NOTE – For calculating port extension, only the open and the short artifacts are necessary. The remaining artifacts can be used for other calibrations.
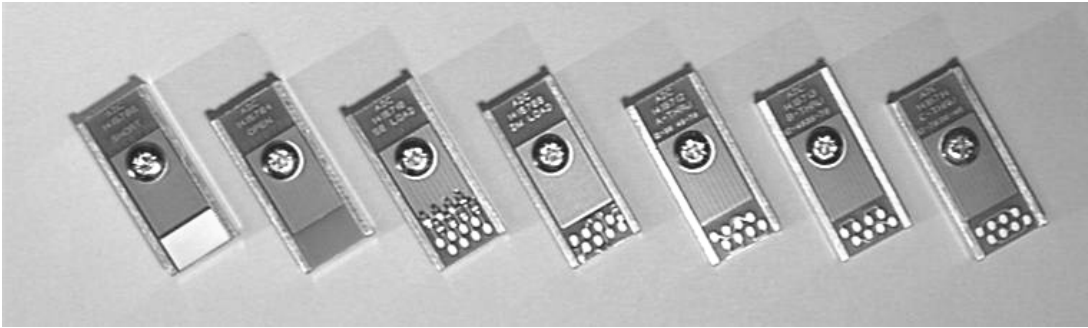
Figure C.15 - Examples of direct fixture short, open, load, and through artifacts

NOTES,
1   The direct fixture artifacts shown in figure C.15 may be obtained from industry sources.
2   Photos are for illustrative purposes only and do not constitute an endorsement by TIA.

C.4.1.1.5   Alternative delay procedure for a test plug

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

C.4.2   Return loss measurements

Connecting hardware shall be tested in both directions for return loss. Connecting hardware return loss is determined by measuring connecting hardware when mated to a test plug qualified per clause C.4.10. When possible, it is recommended to use the same resistor terminations at the far-end as were used for instrument calibration.

C.4.3   Insertion loss measurements

Connecting hardware insertion loss shall be measured in accordance with the requirements of clause C.3.5. Measure connecting hardware insertion loss with interconnections prepared and controlled in accordance with clause C.1. Connecting hardware shall be measured with at least one test plug in at least one direction. There are no insertion loss requirements for test plugs and the insertion loss contribution of the interconnections at each end of the mated connection is assumed to be negligible. For improved accuracy, the insertion loss of the interconnections at each end of the mated connection may be subtracted from the measurement of the DUT.

NOTE - Balanced attenuation pads, meeting the requirements of clause C.1.2 with the exception of insertion loss, may be used inline with the DUT on both ends provided that they are calibrated out of the measurement. The insertion loss of the balanced attenuation pads should be 2 to 10 dB over the applicable frequency range.

C.4.4   NEXT loss measurements

The measurement set up shall comply with clause B.6 and with clause C.3.2. A two-port calibration is required per clause C.3.3. For category 3 testing, any plug may be used, and the results shall comply with the requirements of clause 6.8.8. For categories 5e, 6, and 6A, a "re-embedding" process is used to assure compliance with a range of plugs, as described below.

Connecting hardware shall be tested in both directions for NEXT loss using at least one test plug. In addition, connecting hardware NEXT loss on all pair combinations shall be qualified with the full set of 14 test plug limit vectors specified in table C.2 for category 6 or 6A or table C.3 for category 5e when mated to a qualified test plug specified in clause C.4.10.2.

C.4.4.1 **Connecting hardware NEXT loss measurement and calculation of plug limit vector responses in the forward direction**

1 Measure the NEXT loss vector (magnitude and phase) for the jack mated to the test plug, in the forward direction (launch signal into the test plug).

2 Correct the phase to the test plug phase reference plane using the delay procedures in clause C.4.1.1.3.

3 Subtract the corrected test plug NEXT loss forward vectors obtained using clause C.4.10.4 from the corrected mated NEXT loss vectors obtained in steps 1 and 2. This will yield de-embedded jack vectors.

4 Add the plug NEXT loss limit vectors in table C.2 to the de-embedded jack vectors obtained in step 3. This yields 14 "re-embedded" mated connecting hardware NEXT loss responses.

5 Pass-fail qualification is determined by comparing the results in step 4 to the corresponding mated connecting hardware requirements.

C.4.4.2 **Connecting hardware NEXT loss measurement and calculation of plug limit vector responses in the reverse direction**

1 Determine the delay of the jack by measuring the test plug delay, mating the test plug to the jack, and measuring the delay of the assembly. Subtract the test plug delay from the delay of the assembly to get the jack delay.

2 Measure the NEXT loss vector (magnitude and phase) for the jack mated to the test plug, in the reverse direction (launch signal into the jack).

3 Correct the phase to the test plug phase reference plane using the results obtained in step 1.

4 Subtract the corrected test plug NEXT loss reverse vectors obtained using clause C.4.10.4 from the corrected mated NEXT loss vectors obtained in steps 2 and 3. This will yield de-embedded jack vectors.

5 Add the plug NEXT loss limit vectors in table C.2 to the de-embedded jack vectors obtained in step 4. This yields 14 "re-embedded" mated connecting hardware NEXT loss responses.

6 Pass-fail qualification is determined by comparing the results in step 5 to the corresponding mated connecting hardware requirements.

C.4.4.3 Determining the plug NEXT loss limit vectors

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

Table C.2 - Category 6A and 6 test plug NEXT loss limit vectors

Case #	Pair combination	Limit	Plug NEXT loss limit magnitude (dB)	Plug NEXT loss limit phase (degrees)[1), 2)]
Case 1	3,6-4,5	Low	$38.1-20\log(f/100)$	Test plug NEXT loss phase
Case 2	3,6-4,5	Central	$38.6-20\log(f/100)$	Test plug NEXT loss phase
Case 3	3,6-4,5	Central	$39.0-20\log(f/100)$	Test plug NEXT loss phase
Case 4	3,6-4,5	High	$39.5-20\log(f/100)$	Test plug NEXT loss phase
Case 5	1,2-3,6	Low	$46.5-20\log(f/100)$	Test plug NEXT loss phase
Case 6	1,2-3,6	High	$49.5-20\log(f/100)$	Test plug NEXT loss phase
Case 7	3,6-7,8	Low	$46.5-20\log(f/100)$	Test plug NEXT loss phase
Case 8	3,6-7,8	High	$49.5-20\log(f/100)$	Test plug NEXT loss phase
Case 9	1,2-4,5	Low	$57-20\log(f/100)$	+90
Case 10	1,2-4,5	High	$70-20\log(f/100)$	-90
Case 11	4,5-7,8	Low	$57-20\log(f/100)$	+90
Case 12	4,5-7,8	High	$70-20\log(f/100)$	-90
Case 13	1,2-7,8	Low	$66-20\log(f/100)$	Test plug NEXT loss phase
Case 14	1,2-7,8	High	$66-20\log(f/100)$	Test plug NEXT loss phase minus 180°

[1)] Test plug NEXT loss phase is determined by following the procedure in clause C.4.10.4.
[2)] The reference plane for measuring test plug NEXT loss phase and mated NEXT loss shall be the test plug phase reference plane as described in clause C.4.1.1.

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

Case #	Pair combination	Limit	Plug NEXT loss limit magnitude (dB)	Plug NEXT loss limit phase (degrees)[1), 2)]
Case 1	3,6-4,5	Low	35.8-20log(f/100)	Test plug NEXT loss phase
Case 2	3,6-4,5	Central	n/a	n/a
Case 3	3,6-4,5	Central	n/a	n/a
Case 4	3,6-4,5	High	39.5-20log(f/100)	Test plug NEXT loss phase
Case 5	1,2-3,6	Low	42-20log(f/100)	Test plug NEXT loss phase
Case 6	1,2-3,6	High	50-20log(f/100)	Test plug NEXT loss phase
Case 7	3,6-7,8	Low	42 -20log(f/100)	Test plug NEXT loss phase
Case 8	3,6-7,8	High	50 -20log(f/100)	Test plug NEXT loss phase
Case 9	1,2-4,5	Low	50 -20log(f/100)	90° or -90°
Case 10	1,2-4,5	High	n/a	n/a
Case 11	4,5-7,8	Low	50 -20log(f/100)	90° or -90°
Case 12	4,5-7,8	High	n/a	n/a
Case 13	1,2-7,8	Low	60 -20log(f/100)	90° or -90°
Case 14	1.2-7,8	High	n/a	n/a

[1)] Test plug NEXT loss phase is determined by following the procedure in clause C.4.10.4.
[2)] The reference plane for measuring test plug NEXT loss phase and mated NEXT loss shall be the test plug phase reference plane as described in clause C.4.1.1.

C.4.4.4   Connecting hardware NEXT loss requirements

Verify that the mated response with the qualified test plug meets the requirements of clause 6.8.8 with the exception that pair combination 3,6 - 4,5 shall meet the values in table C.4.

The re-embedded response for case 2, case 3, and cases 5 – 14, as specified in table C.2, shall meet the connecting hardware NEXT loss requirements of Table 97 of clause 6.8.8. The re-embedded response for case 1 and case 4, as specified in table C.2, shall meet the requirements of table C.4.

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

Frequency (MHz)	NEXT loss (dB)
$1 \leq f \leq 250$	52.5 - 20log(f/100)
$250 < f \leq 500$[1)]	44.54 - 40log(f/250)
[1)] Category 6A only.	

C.4.5   FEXT loss measurements

Test leads shall be connected to both ends of the test sample. The measurement set up shall comply with clause B.6 and with clause C.2.3. A two-port calibration is required per clause C.3.3. Connecting hardware FEXT loss is determined by measuring connecting hardware when mated to a test plug qualified per clause C.4.10.2. Test all 12 pair combinations in at least one direction.

C.4.6   Connecting Hardware ANEXT loss and AFEXT loss measurements

This clause describes the reference test procedure for measuring ANEXT loss and AFEXT loss between pairs of connecting hardware of the same design. The frequency range is 1-500 MHz. In addition to the procedures in this clause, the connecting hardware should be verified for compliant channel alien crosstalk performance in accordance with clause 6.2.10 using short and long channels (see channel configurations 3 and 1 as specified in Annex J.

C.4.6.1   Measurement outline

1   Network analyzer setup and calibration
2   Measurement floor (including fixturing) determination and measurement
3   Terminate DUTs
4   Measure ANEXT loss
5   Determine region of influence
6   Calculate PSANEXT loss
7   Measure AFEXT loss
8   Determine region of influence
9   Calculate PSAFEXT loss

C.4.6.2   Network analyzer and test fixture settings

Frequency sweep: 1 MHz to 500 MHz

C.4.6.3   Measurement floor

The measurement floor includes the effects of the fixturing that is used and the random noise floor of the network analyzer. The measurement floor for the test fixture should be measured with the terminating cables and resistor terminations in place. The fixture/measurement setup, including network analyzer settings, should be designed and positioned such that the desired measurement floor is achieved. The recommended measurement floor is 30 dB better than the connecting hardware PSANEXT loss or PSAFEXT loss requirement, as appropriate.

C.4.6.4   DUT setup for ANEXT loss and AFEXT loss measurement

Select the worst alien crosstalk position in the connecting hardware mounting system as the disturbed position. The ANEXT loss measurement is performed between two DUTs as shown in figure C.16. The AFEXT loss measurement is performed between two DUTs as shown in figure C.17. Each DUT consists of a mated modular plug and socket combination and shall be mounted in its specified mounting arrangement (e.g. patch panel, TO) according to the manufacturers instructions. Each modular test plug should be of a design known to meet the test plug requirements detailed in clause C.4.10. Cables between the baluns and the DUT should be less than 300 mm (12 in). In case those cables need to be longer than 300 mm (12 in) (e.g. testing large multi-port panels), their insertion loss shall be accounted for. For ANEXT loss measurements, it is recommended that the far-end of each modular plug and socket mated combination be terminated with a minimum of 40 m (131 ft) of cable.   For AFEXT loss measurement, it is recommended that the far-end of the disturbing modular plug and socket and near-end of the disturbed modular plug and socket are terminated with a minimum of 40 m (131 ft) of cable. The use of minimum category 6A-rated S/FTP cable (as defined by ISO/IEC 11801, 2nd Ed.) is recommended. However, it is possible to use F/UTP, UTP or other cable types if the recommended measurement floor can be demonstrated.

The far-end of each of the terminating cables should be DMCM terminated, with the CM terminations of the four pairs in each cable connected together. The far-end CM terminations of the two cables should not be connected together or to the CM termination of the near-end and should be left floating.
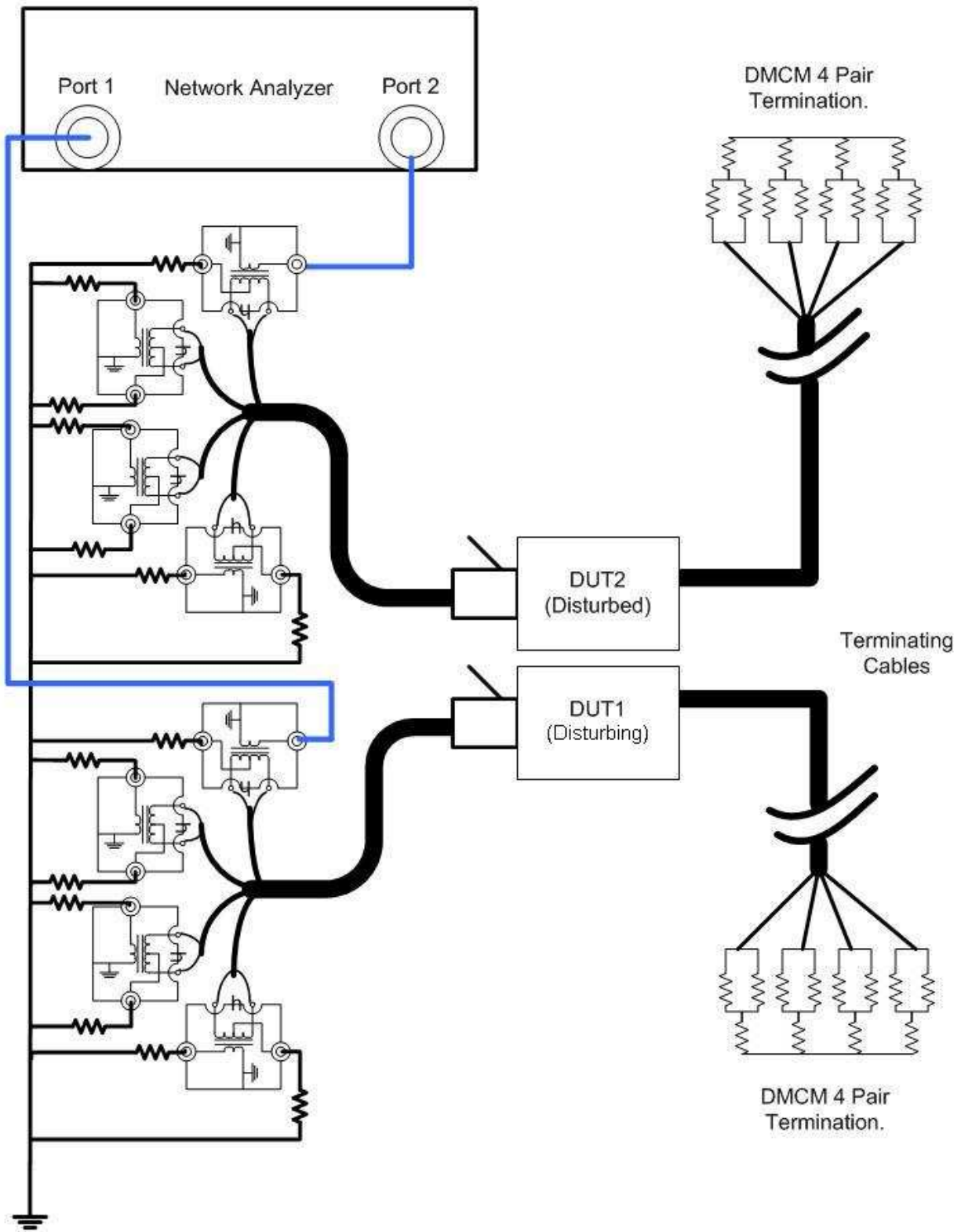
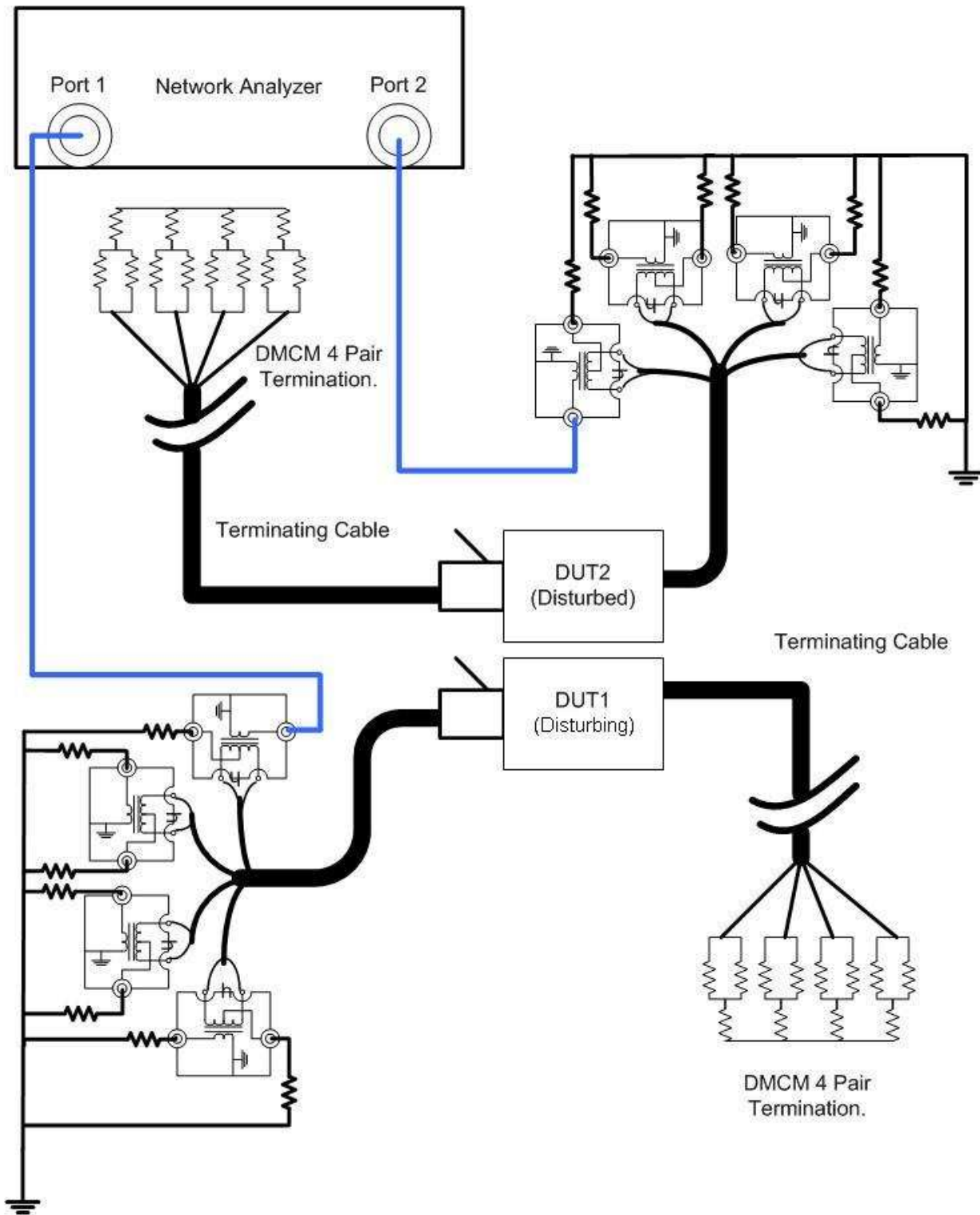**Figure C.16 – Connecting hardware ANEXT loss measurement setup**

Figure C.17 - Connecting hardware AFEXT loss measurement setup

C.4.6.5   Region of influence

The number of disturbing ports to be included in the power sum calculation is dependent on the configuration.   Significant connectors may be located in the same or other mounting systems in close proximity and shall be assessed as follows. An example configuration is shown in figure C.18.
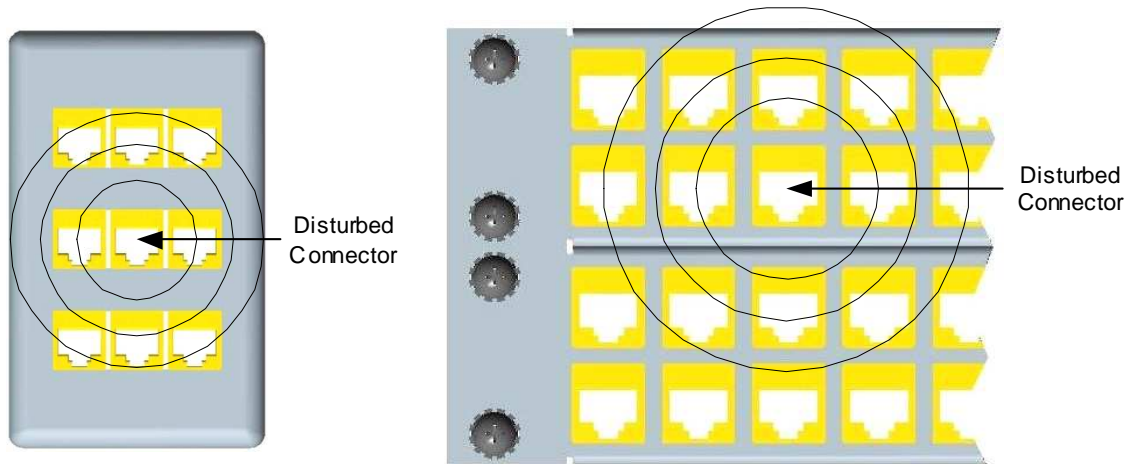

Figure C.18 - Example connector configurations for alien crosstalk

For any given configuration, the determination of which ports to be included can be made based on the ANEXT loss contribution to the disturbed port. If at any frequency point the ANEXT measurement is less than 90-20log(f/100), then the entire ANEXT loss response of that connector combination shall be included in the overall power sum result. Calculations that result in a significance limit greater than 90 dB shall revert to a value of 90 dB.

C.4.6.6   PSANEXT loss and PSAFEXT loss calculation

For each port, the determination of including the individual ANEXT loss measurements should be made as follows:

Let X_1 through X_n be the ANEXT loss contribution of all disturbing pairs that are worse than the significance limit. The PSANEXT loss of the disturbed port (DUT) is calculated as shown in equation (8). The PSAFEXT loss of the disturbed port (DUT) is calculated as shown in equation (7).

C.4.7   TCL measurements

Test set up, calibration, and measurement shall be done per clause C.2.8 except for differences specified in this clause.

Test plugs used in connecting hardware TCL testing should comply with the test plug requirements given in clause C.4.10.

> NOTE - For connecting hardware TCL measurements, the far-end common mode termination should not be connected to ground.

C.4.8   TCTL measurements

Test set up, calibration, and measurement shall be done per clause C.3.10. In addition, test plugs used in connecting hardware TCTL testing should comply with the test plug requirements given in clause C.4.10.

C.4.9   Test plug qualification fixtures

The direct fixture (see figure C.19) is used during test plug NEXT loss and FEXT loss measurements and may also be used for test plug return loss measurements. Refer to Annex E for additional information about the direct fixture and other test fixtures used to facilitate impedance control of interconnections for measurement of connecting hardware performance parameters. Impedance controlled measurement fixtures may be used when the use of unjacketed pair leads is necessary between the connecting hardware under test and the calibration plane.

C.4.9.1   Direct fixture

A direct fixture is specified for measurement of test plug performance. The direct fixture provides for electrical connection of the test plug to measurement equipment with minimal residual effect on the measurement properties of the test plug. The direct fixture is a precision device with properties controlled by design and manufacture. The direct fixture shall conform to the dimensional requirements of figures C.19, C.20 , and C.21 . It is recommended to use the direct fixture as shown in figures E.4, E.5, and E.6. The direct fixture residual NEXT loss, FEXT loss, and return loss shall comply with the requirements of table C.5.
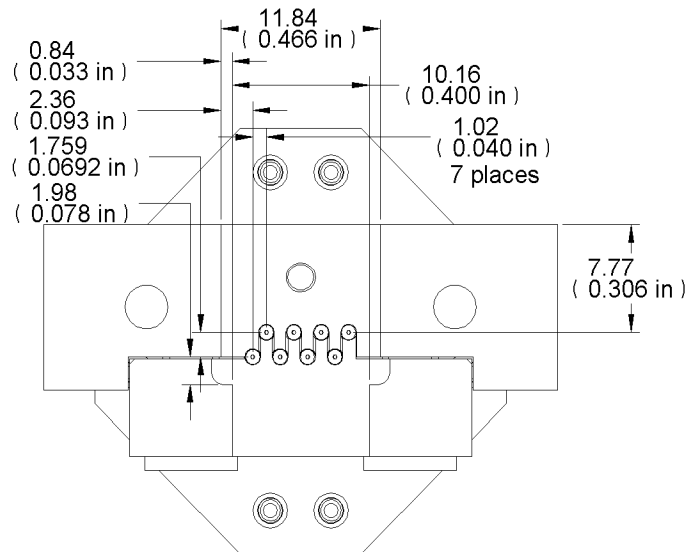

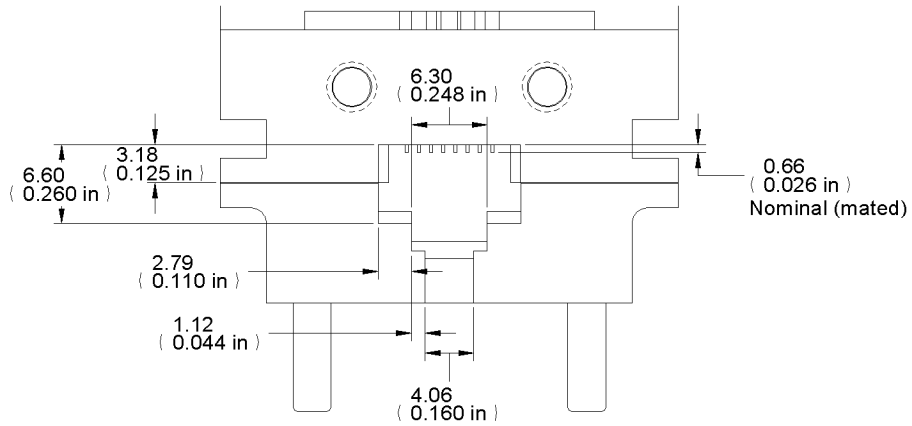**Figure C.19 - Direct fixture mating dimensions, top view**

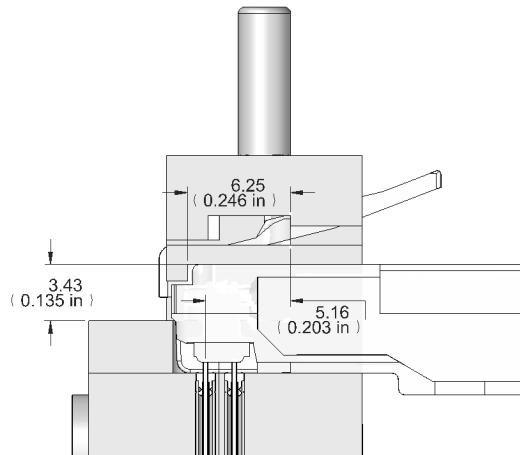**Figure C.20 - Direct fixture mating dimensions, front view**

Figure C.21 - Direct fixture mating dimensions, side view

Dimension tolerances for figures C.19, C.20 , and C.21 are $\pm$ .025 mm (.001 in).

Table C.5 - Direct fixture performance

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

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C.4.9.2   Impedance matched balun interface fixtures

See Annex E for impedance matching test fixtures that interface between the connecting hardware under test and the calibration plane.

C.4.10 Test plug characterization

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

C.4.10.1 Test plug construction

For the purposes of this Standard, a modular test plug consists of an assembly that meets the dimensional requirements of IEC 60603-7 with suitable connections from the electrical contacts. The modular test plug for category 6A jack qualification may be PCB based, an example of which is shown in figure C.26, or wire terminated using a suitable modular plug or plug assembly. A test fixture that uses a PCB based modular test plug is shown in clause E.4.

> NOTE - The direct fixture, as specified in clause C.4.9.1, is compatible with plugs having a contact area ≥ 2.60 mm (0.102 in) as defined by dimension H2 of IEC 60603-7, clause 3.2.2.

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

1   Use of modular plugs with centered NEXT loss and FEXT loss performance.
2   Use of a PCB based modular test plug an example of which is shown in clause C.4.10.8.2.
3   Use of test fixtures having terminations that provide improved isolation and return loss.
4   Minimizing the electrical length of the test plug interconnections as described in clause C.1.1.
5   Improvement of the wire management in the test fixture of any test leads used as part of plug construction and mounting. See clause C.1.1.

Test fixtures described in Annex E are designed to provide suitable interface and termination.

C.4.10.2 Test plug qualification

Test plugs shall be qualified for all requirements of clauses C.4.10.3 (NEXT loss), C.4.10.5 (FEXT loss) and C.4.10.7 (return loss) up to the maximum specified frequency for the category.

NEXT loss and FEXT loss, of test plugs shall be measured using the direct fixture or equivalent described in clause C.4.9.1.

C.4.10.2.1   Test plug measurement

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

C.4.10.2.2   **Procedure for mating a test plug to the direct fixture**

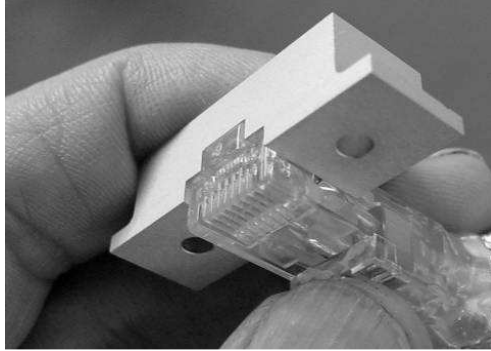1   Place the test plug into the plug clamp as shown in figure C.22.

Figure C.22 - Modular plug placed into the plug clamp

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

2   Holding the test plug in place, slide the plug clamp onto the clamp block guide pins as shown in figure C.23

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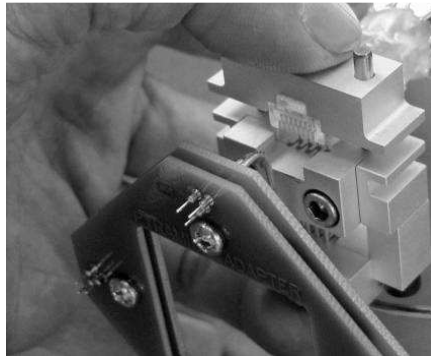

Figure C.23 - Guiding the plug into position

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

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

4   Secure the plug clamp and the clamp block together using suitable spring clips as shown in figure E.4.

C.4.10.3 Test plug NEXT loss requirements

The corrected NEXT loss vectors (magnitude and phase) of the test plug in the forward direction shall be within the test plug NEXT loss ranges of table C.6. Test plug NEXT loss requirements apply in the forward direction only. Test plug NEXT loss in the reverse direction shall also be measured so that the data can be used in the reverse direction connecting hardware NEXT loss qualification procedure as described in clause C.4.4.4.

Table C.6 - Test plug NEXT loss ranges

Pair combination	NEXT loss magnitude range (dB) [1]	NEXT loss phase range (degrees)[2]
3,6-4,5	$38.1 - 20\log(f/100) \le$ NEXT loss $\le 39.5 - 20\log(f/100)$ [5]	50 – 100 MHz: $(-90 + 1.5 \cdot f/100) \pm 1$ 100 – 500 MHz: $(-90 + 1.5 \cdot f/100) \pm f/100$
1,2-3,6	$46.5 - 20\log(f/100) \le$ NEXT loss $\le 49.5 - 20\log(f/100)$	$(-90 + 1.5 f/100) \pm 3 \cdot f/100$
3,6-7,8	$46.5 - 20\log(f/100) \le$ NEXT loss $\le 49.5 - 20\log(f/100)$	$(-90 + 1.5 \cdot f/100) \pm 3 \cdot f/100$
1,2-4,5	NEXT loss $\ge 57 - 20\log(f/100)$ [4]	$90 \pm (30 \cdot f/100)$ [3]
4,5-7,8	NEXT loss $\ge 57 - 20\log(f/100)$ [4]	$90 \pm (30 \cdot f/100)$ [3]
1,2-7,8	NEXT loss $\ge 66 - 20\log(f/100)$ [4]	Any phase

[1] Magnitude limits apply over the frequency range from 10 MHz to 500 MHz.
[2] Phase limits apply over the frequency range from 50 MHz to 500 MHz.
[3] When the measured test plug NEXT loss magnitude is greater than $70 - 20\log(f/100)$ or 70 dB, the phase limit does not apply.
[4] When the NEXT loss magnitude limit calculation results in a value greater than 70 dB, the limit shall revert to 70 dB.
[5] When the fixture described in Annex E or an equivalent is used, the magnitude high limit for pair combination 36-45, $39.5 - 20\log(f/100)$, shall be $39.5 - 20\log(f/100) + 0.5(f-300)/200$ for the frequency range from 300 MHz to 500 MHz.

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

C.4.10.4 Test plug NEXT loss measurement

Measure the test plug NEXT loss vectors for all pair combinations in both directions. Use the direct fixture specified in clause C.4.9.1 or equivalent. Correct the phase of all NEXT loss measurements to the test plug phase reference plane, as shown in figure C.14, using the procedures in clause C.4.1.1.   An example of a measurement setup for test plug NEXT loss is shown in figure C.24.
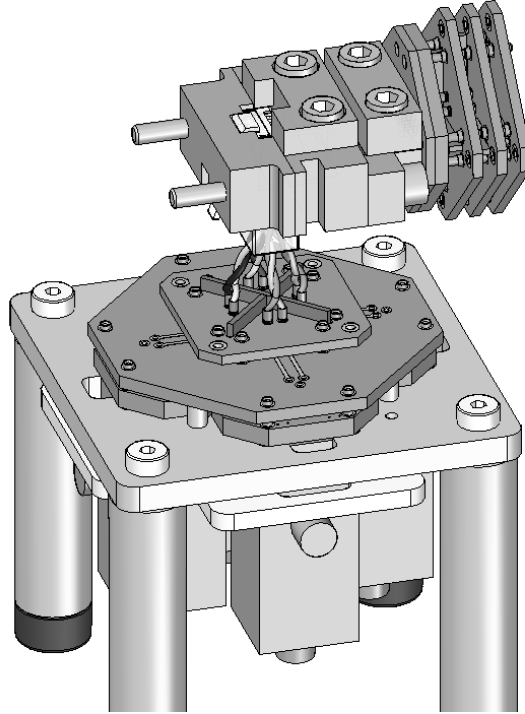

Figure C.24 - Example of a measurement setup for test plug NEXT loss

C.4.10.5 Test plug FEXT loss requirements

The corrected FEXT loss vectors (magnitude and phase) of all 12 pair combinations of the test plug shall be within the test plug FEXT loss ranges of table C.7.

Table C.7 - Test plug FEXT loss ranges

Pair combination	Frequency range (MHz)	FEXT loss magnitude range (dB)	Phase (degrees)
3,6-4,5	10-500	$46-20\log(f/100) \leq$ FEXT loss $\leq 56-20\log(f/100)$ [3]	$-90 \pm (30 \cdot f/100)$ [1,2]
1,2-3,6	10-500	$46-20\log(f/100) \leq$ FEXT loss $\leq 56-20\log(f/100)$ [3]	$-90 \pm (30 \cdot f/100)$ [1,2]
3,6-7,8	10-500	$46-20\log(f/100) \leq$ FEXT loss $\leq 56-20\log(f/100)$ [3]	$-90 \pm (30 \cdot f/100)$ [1,2]
1,2-4,5	10-500	FEXT loss $\geq 55-20\log(f/100)$ [4]	any phase
4,5-7,8	10-500	FEXT loss $\geq 55-20\log(f/100)$ [4]	any phase
1,2-7,8	10-500	FEXT loss $\geq 55-20\log(f/100)$ [4]	any phase

[1] When the measured test plug FEXT loss is greater than 70 dB, the phase requirement does not apply.
[2] Phase limits apply over the frequency range from 100 MHz to 500 MHz.
[3] When upper limit FEXT loss calculations result in values greater than 70 dB, there shall be no upper limit for FEXT loss.
[4] When lower limit FEXT loss calculations result in values greater than 70 dB, the lower limit FEXT shall revert to a limit of 70 dB.

C.4.10.6 Test plug FEXT loss measurement

Measure the test plug FEXT loss vectors for all pair combinations. Use the direct fixture specified in clause C.4.9.1 or equivalent. Correct the phase of all FEXT loss measurements to the test plug phase reference plane, as shown in figure C.14, using the procedures specified in clause C.4.1.1. An example of a measurement setup for test plug FEXT loss is shown in figure C.25.
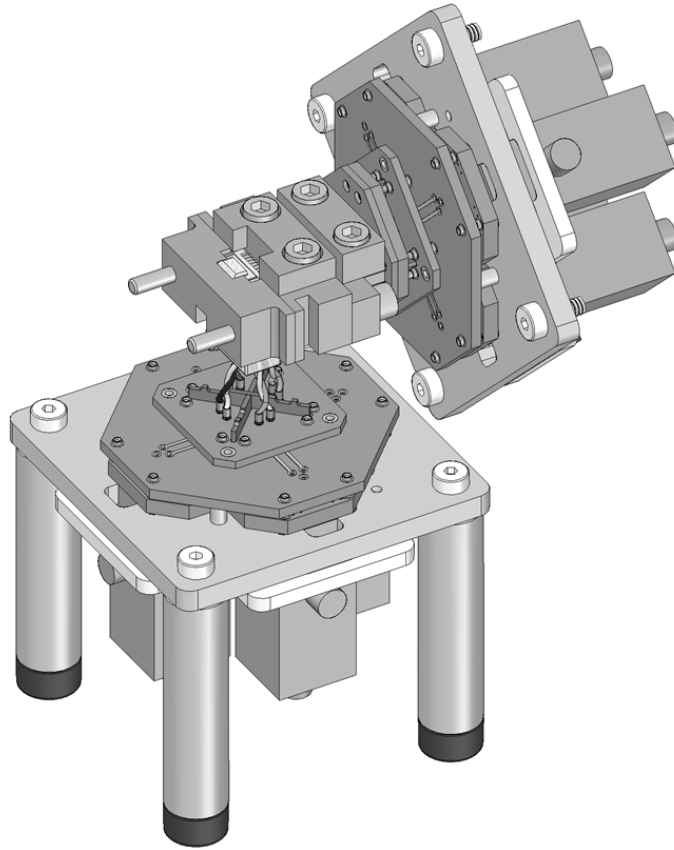
Figure C.25 - Example of a measurement setup for test plug FEXT loss

C.4.10.7 Test plug return loss requirements

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

Table C.8 – Test plug return loss requirements

Pair	Frequency range (MHz)	Return loss magnitude (dB) [2]	Return loss phase (degrees) [1]
1,2	10-500	$\geq 33.5\text{-}20\log(f/100)$	negative phase
3,6	10-500	$\geq 33.5\text{-}20\log(f/100)$ [3]	positive phase
4,5	10-500	$\geq 33.5\text{-}20\log(f/100)$	negative phase
7,8	10-500	$\geq 33.5\text{-}20\log(f/100)$	negative phase

[1] The phase requirement does not apply when the measured magnitude is greater than $35\text{-}20\log(f/100)$.
[2] Calculations that result in return loss requirements greater than 40 dB shall revert to a requirement of 40 dB minimum.
[3] For category 5e test plugs, the return loss magnitude shall be $\geq 30\text{-}20\log(f/100)$.

The test plug return loss requirements are not intended to reflect the return loss performance properties of plugs terminated at the ends of cords. The transmission properties of modular cords are included in the requirements of clause 6.9.1 describing cord and jumper cord return loss.

### C.4.10.8 Test plug return loss measurement

This clause describes procedures for test plug return loss testing. At least one test plug shall be qualified for connecting hardware return loss testing. Test plug return loss shall be qualified in at least one direction, in the reverse direction per clause C.4.10.8.3 or in the forward direction per clause C.4.10.8.4.

C.4.10.8.1   Test plug return loss interconnections and termination

The interconnections used to construct the test plug shall be qualified using the procedure in clause C.1.1. The test plug may be terminated with the direct fixture or another suitable reference jack provided that qualified reference load terminations are used. The far-end of the reference jack or direct fixture should be terminated with the calibration reference load resistor terminations. The impedance effects of the reference jack or direct measurement fixture shall be removed using the procedure in clause C.4.10.8.4.

C.4.10.8.2   Test plug construction for return loss testing

A test plug that uses a PCB substrate may be used. Refer to figure C.26.
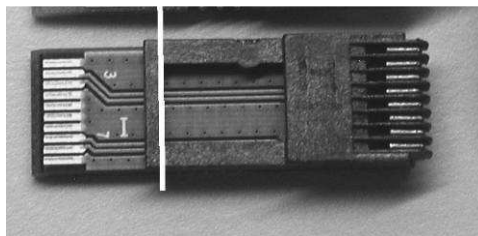
Figure C.26 - Example of a test plug using a PCB substrate

NOTES,
1   Plugs of this type may be obtained from industry sources. Alternative equivalent components may also be used.
2   Photos are for illustrative purposes only and do not constitute an endorsement by TIA.

C.4.10.8.3   Test plug return loss reverse direction qualification procedure

Test plug return loss may be verified by testing in the reverse direction, with load resistors applied to the interconnections of the test plug and the test plug attached to the test ports through a direct fixture that has been calibrated to the test plug phase reference plane. The test plug reference plane is shown in figure C.14. The calibration procedure is described in clause C.4.1.1. Use precision 0.1% 0603 or similar chip resistors as described in clause B.6.2 for DM terminations. Application of the resistors at the far-end of the test plug shall be done in such a way as to minimize the disturbance of the interconnections. An interconnection length of 12 mm (0.5 in) is suggested.

C.4.10.8.4   Test plug return loss forward direction qualification procedure (with matrix de-embedding)

The forward direction test plug return loss test procedure is applicable for determination of test plug return loss properties when measured in the forward direction and where a reference jack is used for termination. This procedure relies on the consistency of 3 selected return loss de-embedding reference jacks (reference jacks); one terminated as short, one terminated as open, and one terminated with a DMCM load. The properties of the reference jack are mathematically removed using a matrix de-embedding process.

This method assumes that it is difficult or inconvenient to terminate a modular plug with chip resistors directly across its contacts where connection is made with the jack contacts.   However, for the following de-embedding method to work, a modular plug must be terminated in this way (return loss reference plug), here done by soldering chip resistors to the modular plug contacts. Since this is a destructive operation, it is obviously not useful for general test plug return loss measurements.

An alternative procedure that facilitates connection of chip resistors directly to the contacts of a test plug without soldering, or other destructive technique, may be used and the de-embedding calculations avoided. If this procedure is used, correct the phase of all return loss measurements to the test plug phase reference plane as, shown in figure C.14, using the procedures specified in clause C.4.1.1.

C.4.10.8.4.1 Procedure overview

Measurement of the return loss vectors (magnitude and phase) of a test plug for each pair involves the following steps:

1   Measure the return loss (S11) of the return loss reference plug mated with each of the open, short, and load reference jacks.
2   Measure the return loss (S11) of the return loss reference plug for each of the cases as follows:
  a   Leave each pair of the return loss reference plug unterminated.
  b   Terminate each pair at the tips of the contacts with a short.
  c   Terminate each pair at the tips of the contacts with a 100 Ω ± 0.1 % chip resistor.
3   Calculate the S-parameters of the reference jack from the measurements of steps 1 and 2 using the return loss reference plug S-parameters (step 2) and the mated S-parameters (step 1) using the matrix method of clause C.4.10.8.4.4.
4   As an alternative to steps 1 - 3, the reference jack vectors provided in table C.9, which have been measured using steps 1 - 3, may be used in the reference jack matrix if the reference jack described in clause C.4.10.8.4.2 is used.
5   Measure the return loss (S11) of a test plug mated with each of the open, short, and load reference jacks.
6   Calculate the S-parameters of this test plug using the result in step 3 or 4 and step 5 using the matrix method of clause C.4.10.8.4.5.

C.4.10.8.4.2 Selection of a return loss de-embedding reference jack

This procedure can be applied to any terminating fixture (e.g. jack or the direct fixture). The use of a reference jack is described in this clause. The ideal terminating fixture should have transparent return loss performance. The reference jack should have minimal length from the test plug phase reference plane to the point where precision termination loads are connected. In addition, a PCB mount type return loss reference jack takes advantage of the consistency of surface mount resistors and dimensionally controlled interconnects (traces) to the loads. An example of a reference jack assembly that satisfies these parameters is Fluke Networks p/n DTX-PLCAL. Figure C.27 shows a rear view of a reference jack assembly (with OPEN, SHORT and LOAD terminations on each reference jack) and a front view of the reference jack opening.
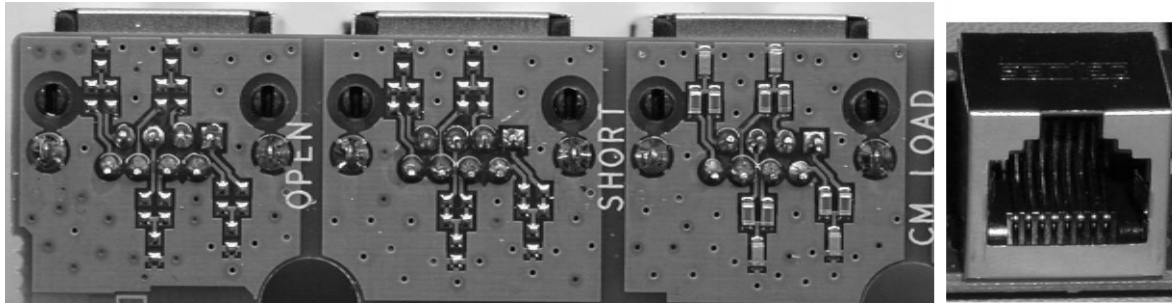

Figure C.27 - Example of suitable return loss de-embedding reference jack assembly

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

Table C.9 defines the nominal S-parameter matrix values of the Fluke Networks DTX-PLCAL reference jack assembly as shown in figure C.27. The polynomials are defined for all frequencies from 1 MHz to 500 MHz.

The S parameters are computed using equation (C-7).

$$Sxx = k + a \cdot f + b \cdot f^2 \qquad\qquad \text{(C-7)}$$

where f is the frequency in MHz.

Table C.9 - Fluke Networks return loss de-embedding reference jack assembly standard vectors

	Poly Coef	12 real	12 imag	36 real	36 imag	45 real	45 imag	78 real	78 imag
S11	k	0	0	0	0	0	0	0	0
and	a	0	-1.778E-5	1.21E-5	1.61E-4	0	-1.778E-5	0	-1.778E-5
S22	b	0	0	6.64E-8	-8.18E-8	0	0	0	0

	Poly Coef	12 real	12 imag	36 real	36 imag	45 real	45 imag	78 real	78 imag
S12	k	1	0	1	0	1	0	1	0
and	a	-1.61E-05	-6.44E-04	-2.51E-05	-6.63E-04	-1.95E-05	-6.21E-04	-1.92E-05	-6.30E-04
S21	b	-2.11E-07	0	-2.31E-07	0	-1,82E-07	0	-1.97E-07	0

NOTE - For purposes of the development of the standard reference jack vectors, S22 is assumed equal to S11.

C.4.10.8.4.3 Return loss de-embedding reference jack S-parameters

The S-parameters of a reference jack are determined by first mating the reference jack with a return loss reference plug. The S-parameters of this return loss reference plug will be determined destructively after the mated return loss measurements have been obtained.
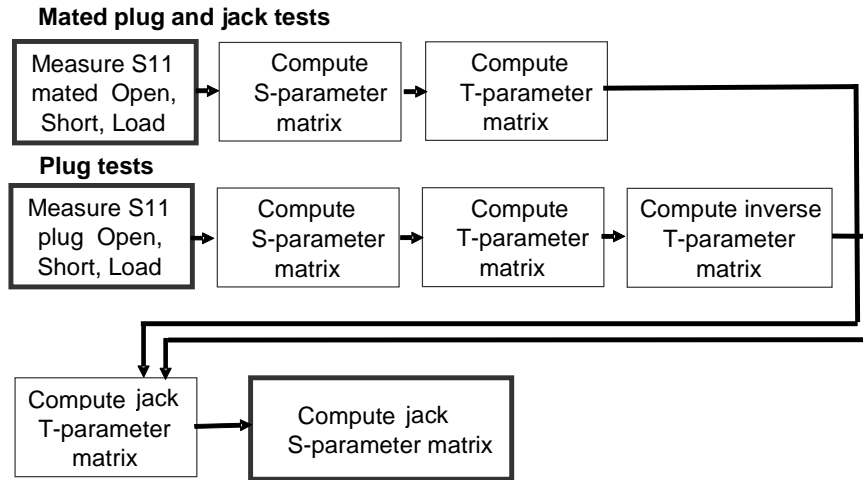
Mated plug and jack tests

| Measure S11 mated Open, Short, Load | → | Compute S-parameter matrix | → | Compute T-parameter matrix | → |

Plug tests

| Measure S11 plug Open, Short, Load | → | Compute S-parameter matrix | → | Compute T-parameter matrix | → | Compute inverse T-parameter matrix |

| Compute jack T-parameter matrix | → | Compute jack S-parameter matrix |

Figure C.28 - Flow chart for return loss de-embedding reference jack S-parameters

C.4.10.8.4.4 Calculation of return loss de-embedding reference jack S-parameters

A mated plug and jack can be mathematically represented by two cascaded networks, P (plug) and J (jack) with the output of J terminated with a known impedance R as shown in figure C.29. Measurements can be performed on the network and the input parameter S11 can be recorded with various loads. A method to determine network parameters is to vary the load from the 100 Ω nominal impedance to OPEN and SHORT conditions.
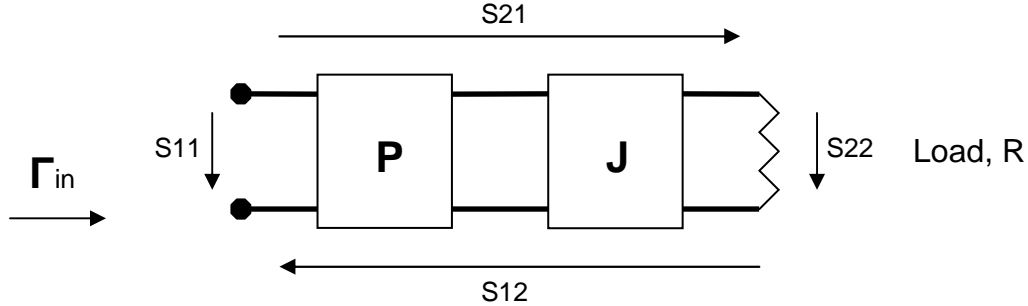

Figure C.29 - Representation of a mated connection by two cascaded networks

From the three load conditions, the composite scattering parameters can be derived as shown in equations (C-8), (C-9), (C-10), and (C-11). This derivation assumes that forward and reverse transmission parameters S12 and S21 are reciprocal.

$$S11_{PJ} = \Gamma_{load} \tag{C-8}$$

$$S12_{PJ} = \sqrt{\frac{2\left(\Gamma_{load} - \Gamma_{short}\right)\left(\Gamma_{open} - \Gamma_{load}\right)}{\left(\Gamma_{open} - \Gamma_{short}\right)}} \tag{C-9}$$

$$S21_{PJ} = \sqrt{\frac{2\left(\Gamma_{load} - \Gamma_{short}\right)\left(\Gamma_{open} - \Gamma_{load}\right)}{\left(\Gamma_{open} - \Gamma_{short}\right)}} \tag{C-10}$$

$$S22_{PJ} = \frac{\left(\Gamma_{open} + \Gamma_{short}\right) - 2\Gamma_{load}}{\left(\Gamma_{open} - \Gamma_{short}\right)} \tag{C-11}$$

After the S-parameters of the mated plug and jack have been measured and calculated, the return loss reference plug S-parameters must be determined. It is necessary to make mated measurements prior to determining the return loss reference plug S-parameters since the return loss reference plug measurement is destructive. The return loss of the reference plug is measured with OPEN, SHORT and LOAD (100 Ω) impedances connected at the test plug phase reference plane as shown in figures C.30 and C.31.
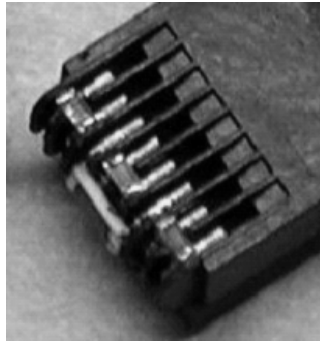
Figure C.30 - Return loss de-embedding reference plug terminated with LOAD resistors

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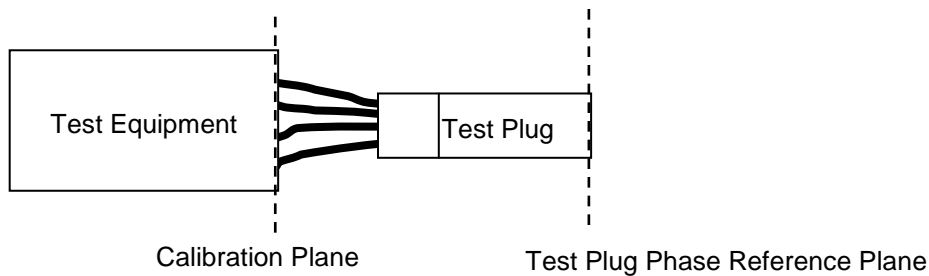

Figure C.31 - Return loss test plug calibration and phase reference planes

Similar to equations (C-8), (C-9), (C-10), and (C-11), a set of S-parameters for the return loss reference plug can be determined. From the OPEN, SHORT and LOAD measurements, the S-parameters of the return loss reference plug and of the mated plug and jack are given by equations (C-12) and (C-13).

$$S_P = \begin{bmatrix} S11_P & S12_P \\ S21_P & S22_P \end{bmatrix}$$
(C-12)

$$S_{PJ} = \begin{bmatrix} S11_{PJ} & S12_{PJ} \\ S21_{PJ} & S22_{PJ} \end{bmatrix}$$
(C-13)

In order to extract the S-parameters of the reference jack, the S-parameters must be converted to Transfer Scattering Parameters (T-parameters). The T-parameter matrix of cascaded networks is the product of the individual T-parameter matrices of each individual network as given in equation (C-14).

$$T_{PJ} = T_P \cdot T_J$$
(C-14)

The T-parameter matrix of the reference jack is given by equation (C-15).

$$T_J = Ti_P \cdot T_{PJ}$$
(C-15)

where Ti_P represents the inverse T-parameter matrix

In order to determine the reference jack S-parameters, both the plug and mated plug and jack S-parameters are converted into T-parameters as in equation (C-16) and the inverse T-parameters as in equation (C-17).

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$$T11 = \frac{1}{S21} \qquad T12 = \frac{-S22}{S21} \qquad T21 = \frac{S11}{S21} \qquad T22 = \frac{-\Delta S}{S21} \tag{C-16}$$

where: $\Delta S = (S11 \cdot S22 - S12 \cdot S21)$

$$Ti11 = \frac{T22}{\Delta T} \qquad Ti12 = \frac{-T12}{\Delta T} \qquad Ti21 = \frac{-T21}{\Delta T} \qquad Ti22 = \frac{T11}{\Delta T} \tag{C-17}$$

where: $\Delta T = (T11 \cdot T22 - T12 \cdot T21)$

Using equation (C-15) the properties of the reference jack are obtained using equation (C-18).

$$T_J = \begin{bmatrix} (Ti11_P T11_{PJ} + Ti12_P T21_{PJ}) & (Ti11_P T12_{PJ} + Ti12_P T22_{PJ}) \\ (Ti21_P T11_{PJ} + Ti22_P T21_{PJ}) & (Ti21_P T12_{PJ} + Ti22_P T22_{PJ}) \end{bmatrix} \tag{C-18}$$

where:

$Ti\text{XX}_P$ are the plug inverse T-parameters.

$T\text{XX}_{PJ}$ are the mated plug and jack T-parameters.

If required, the jack T-parameters can be converted back into S-parameters using equations (C-19).

$$S21_J = \frac{1}{T11_J} \qquad S12_J = \frac{\Delta T_J}{T11_J} \qquad S11_J = \frac{T21_J}{T11_J} \qquad S22_J = \frac{-T12_J}{T11_J} \tag{C-19}$$

where

$$\Delta T_J = (T11_J \cdot T22_J - T12_J \cdot T21_J) \tag{C-20}$$

C.4.10.8.4.5 Determining the return loss of a test plug

Once the T-parameters of the reference jack have been calculated, equations (C-21) and (C-22) can be used to obtain the return loss (S11) of a test plug.
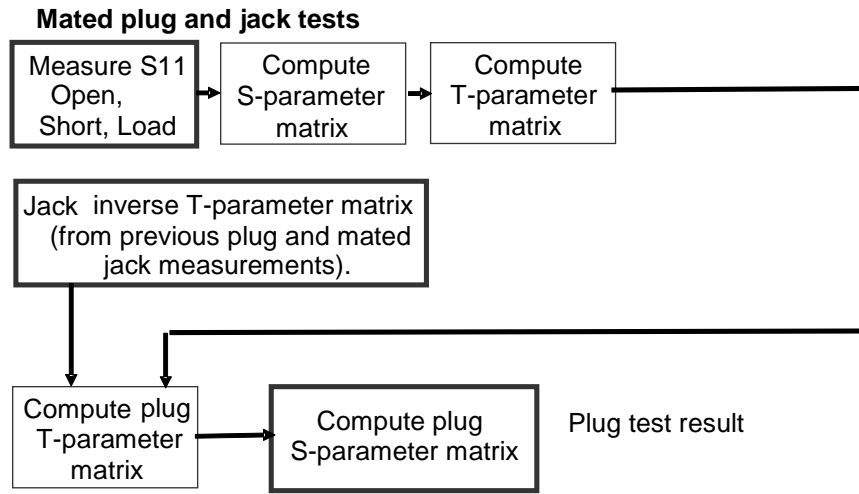
Mated plug and jack tests

Figure C.32 - Flow chart of determination of test plug return loss

In order to determine the return loss of a test plug, the mated test plug and reference jack S-parameters are measured and converted to T-parameters as in equation (C-16) to yield T_{PJ} then solve for the test plug T-parameters using equations (C-21) and (C-22).

$$T_P = T_{PJ} \cdot Ti_J \tag{C-21}$$

$$T_P = \begin{bmatrix} \left(T11_{PJ}Ti11_J + T12_{PJ}Ti21_J\right) & \left(T11_{PJ}Ti12_J + T12_{PJ}Ti22_J\right) \\ \left(T21_{PJ}Ti11_J + T22_{PJ}Ti21_J\right) & \left(T21_{PJ}Ti12_J + T22_{PJ}Ti22_J\right) \end{bmatrix} \tag{C-22}$$

where

$TiXX_J$ are the jack inverse T-parameters.

TXX_{PJ} are the mated plug and jack T-parameters.

The plug reflection coefficient can be computed per equation (C-23).

$$\Gamma_{plug} = S11_P = \frac{T21_P}{T11_P} \tag{C-23}$$

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C.4.11 Category 6A measurement reproducibility

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

C.4.11.1 NEXT loss measurement reproducibility between laboratories

The measurement reproducibility of category 6A connecting hardware NEXT loss is primarily limited by the measurement reproducibility and variability of the test plugs. Controlled experiments have demonstrated that the test plug measurement process is reproducible within the noise floor levels indicated in informative table C.10. The variability of test plugs is controlled by the test plug requirements of tables C.6, C.7, and C.8.

Table C.10 – Category 6A NEXT loss measurement reproducibility between laboratories

Pair combination	Frequency range (MHz)	Measurement noise floor (dB)	Maximum error at the limit		
			Test plug requirement at 100 MHz (dB)	Test plug reproducibility (dB)	Reproducibility for mated NEXT loss at the test limit (dB)
3,6 - 4,5	10 – 500	$66 - 20\log(f/100)$	(38.77) nominal	0.2	3.0
1,2 - 3,6	10 – 500	$66 - 20\log(f/100)$	(47.87) nominal	0.5	1.5
3,6 - 7,8	10 – 500	$66 - 20\log(f/100)$	(47.87) nominal	0.5	1.5
1,2 - 4,5	10 – 500	$68 - 20\log(f/100)$	(57.00) minimum	2.0	1.5
4,5 - 7,8	10 – 500	$68 - 20\log(f/100)$	(57.00) minimum	2.0	1.5
1,2 - 7,8	10 – 500	$72 - 20\log(f/100)$	(66.00) minimum	3.0	1.5

## C.4.11.2 FEXT loss test plug measurement reproducibility between laboratories

The measurement reproducibility of category 6A connecting hardware FEXT loss is primarily limited by the measurement reproducibility and variability of the test plugs. Controlled experiments have demonstrated that the test plug measurement process is reproducible within the noise floor levels indicated in table C.11.

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

Pair combination	Frequency range (MHz)	Measurement noise floor (dB)	Maximum error at the limit	
			Test plug requirement at 100 MHz (dB)	Test plug reproducibility (dB)
3,6-4,5	10 – 500	$66 - 20\log(f/100)$	(49.6) nominal	1.0
1,2-3,6	10 – 500	$66 - 20\log(f/100)$	(49.6) nominal	1.0
3,6-7,8	10 – 500	$66 - 20\log(f/100)$	(49.6) nominal	1.0
1,2-4,5	10 – 500	$68 - 20\log(f/100)$	n/a	-
4,5-7,8	10 – 500	$68 - 20\log(f/100)$	n/a	-
1,2-7,8	10 – 500	$72 - 20\log(f/100)$	n/a	-

C.4.11.3 Return loss measurement reproducibility between laboratories

Laboratory-to-laboratory measurement accuracy is highly affected by the accuracy of the reference load. The variability as a function of frequency that may be expected in the results at the pass/fail limit for category 6A connecting hardware return loss is in shown in figure C.33.
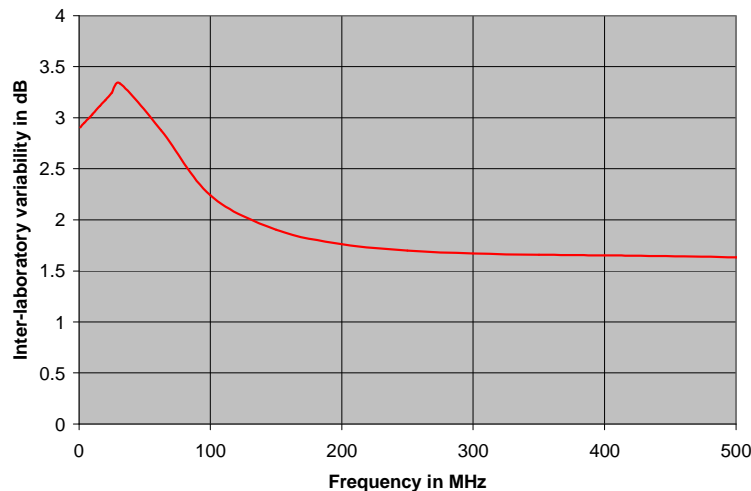
Figure C.33 - Inter-laboratory return loss variability for testing category 6A connecting hardware

C.5 Modular cord test procedures

C.5.1 Network analyzer test configuration

The network analyzer configuration for modular cord testing is depicted in figure C.34. Four baluns should be used to connect the modular cord under test to the network analyzer and test heads that are qualified in accordance with clause C.5.2. DMCM terminations shall be applied to all pairs on both ends. Balun cases and resistor networks shall be bonded to a ground plane. Interconnections shall be prepared and qualified per clause C.1.1.1.
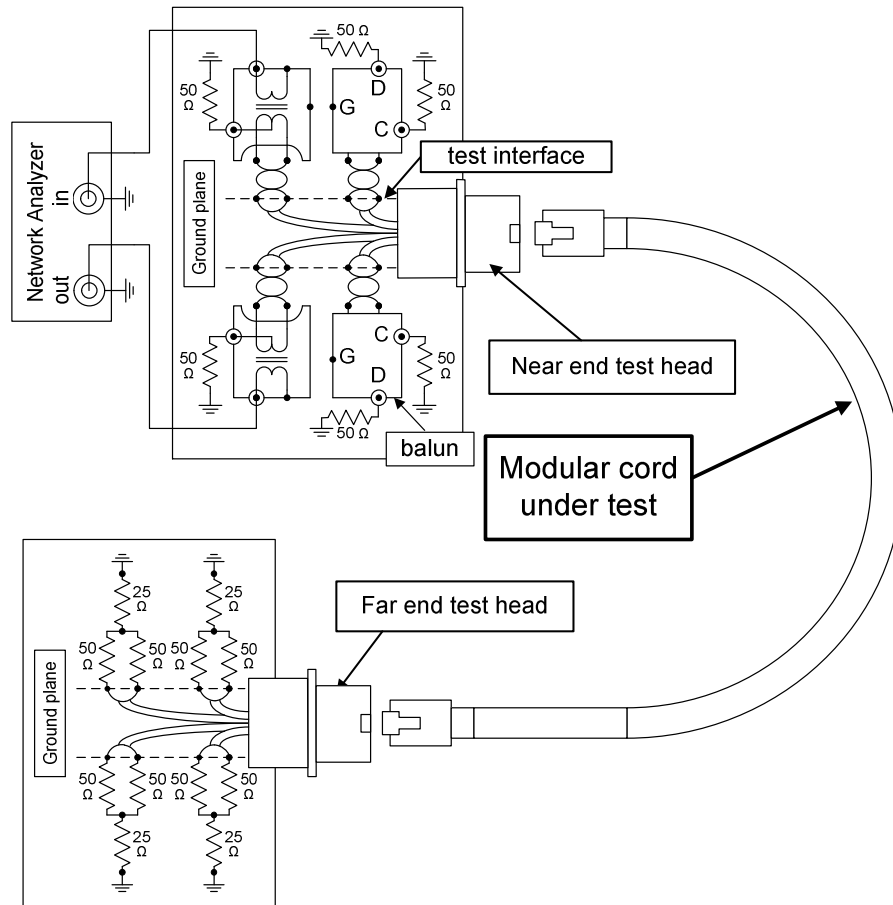

Figure C.34 - Network analyzer configuration

C.5.2 Test fixturing for modular cords

Modular cord test head NEXT loss, FEXT loss, and return loss requirements are specified in this clause. For the purpose of testing modular cord NEXT, the modular cord test head shall meet all of the requirements of this clause. For the purpose of measuring modular cord return loss, it is sufficient for the test head to meet only the requirements of clause C.5.2.3. The test head used at each end of the test configuration shall be of the same design.

C.5.2.1   Modular cord test head NEXT loss

Mated modular cord test head NEXT loss shall be measured for all pair combinations in accordance with clause C.4.4.. For all frequencies from 10 MHz to 500 MHz, modular test head NEXT loss performance shall meet the connecting hardware NEXT loss requirements specified in clause 6.8.8 for categories 6 and 6A, and shall exceed 47-20log(f/100) from 10 to 100 MHz for category 5e. In addition, for categories 6 and 6A, the best case NEXT loss performance of the mated modular cord test head shall be centered for pair combinations 3,6-4,5, 1,2-3,6, and 3,6-7,8 as verified by the following procedure.

1   Measure the mated NEXT loss throughout the frequency range from 10 to 500 MHz for the low and high limit-value virtual test plugs per the procedures in clause C.4.4.4.
2   Determine the minimum margin (dB) to the category 6 or 6A connecting hardware NEXT loss requirements as specified in table C.4 for pair combination 3,6-4,5 and clause 6.8.8 for pair combinations 1,2-3,6 and 3,6-7,8 from 10 to the upper frequency of the category for both the low and high test plug limit vectors. Use the correct table for category 6 or 6A, or category 5e.
3   The difference between these minimum margins for the high and low limit-value test plugs shall be less than 2 dB for the pair combination terminated on pins 3,6 4,5 and 4 dB for the pair combinations terminated on pins 1,2-3,6 and 3,6-7,8.

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

C.5.2.2   Modular cord test head FEXT loss

Mated modular cord test head FEXT loss shall be measured for all pair combinations in accordance with clause C.4.5.. For all frequencies from 10 MHz to the upper frequency of the category, modular test head FEXT loss performance shall exceed the values determined using equation (C-24).

$$FEXT_{Test\_Head} \geq 48.1 - 20\log(f/100) \ dB \tag{C-24}$$

C.5.2.3   Modular cord test head return loss

Mated modular cord test head return loss shall be measured for all pair combinations in accordance with clause C.4.2.. For all frequencies from 10 MHz to the upper frequency of the category, modular test head return loss performance shall meet the values determined using table C.12.

Table C.12 - Modular cord test head return loss

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

C.5.3   Modular cord test procedure

The pass or fail margin and the frequency at which it occurs shall be reported for each pair combination.

NEXT loss requirements are given in clause 6.9.2 and return loss in clause 6.9.1.

Annex D (normative) - Connecting hardware transfer impedance test method

D.1   Introduction

Transfer impedance relates to the shielding efficiency (quality of shielding against influences by electromagnetic fields) of screened cables and connecting hardware.

D.2   Purpose and scope

This annex describes a test method for connecting hardware transfer impedance. Transfer impedance is not intended for conformance testing of installed cabling. Setup variations that yield equivalent results are also acceptable.

D.3   Transfer impedance test method

D.3.1   General

This clause describes the measurement method used in verifying the shield transfer impedance requirements of 100 Ω screened connecting hardware contained in clause 6.8.20. The measurement method requires the use of a network analyzer or equivalent, coaxial cables, screened 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 values can be calculated from laboratory shielding insertion loss measurements collected using a HF sealed case (refer to clause D.3.2). The equivalent circuit diagram for the HF sealed case is shown in figure D.1.
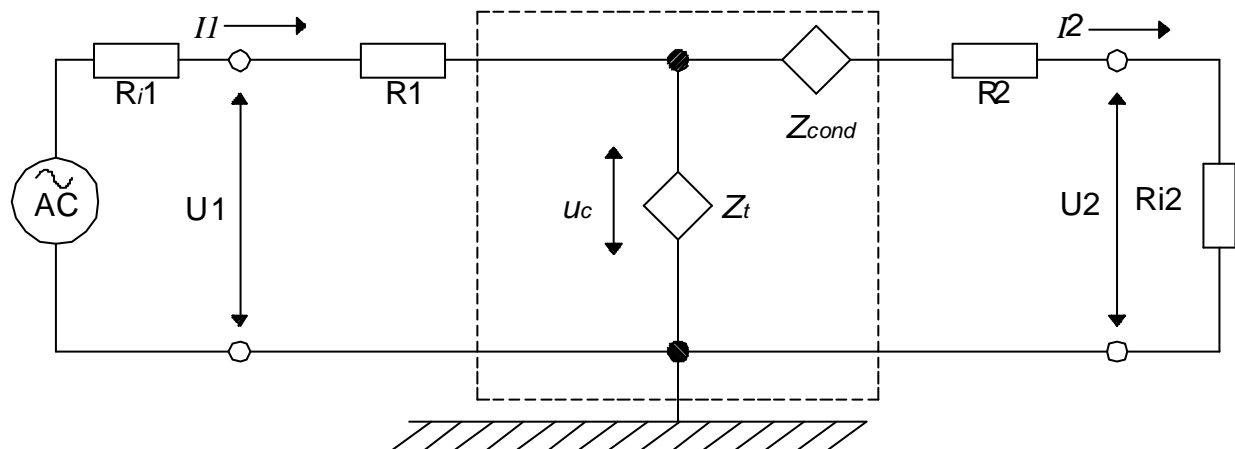

Figure D.1 - Equivalent circuit diagram for HF sealed case

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 is significantly less than R2, and

I2 is significantly less than I1,

The following equations describe the circuit equation in figure D.1.

$$U1 = I1 \cdot R_i1 \tag{D-1}$$

$$U2 = I2 \cdot R_i2 \tag{D-2}$$

$$U_c = I2 \cdot (R2 + R_i2) \tag{D-3}$$

$$U_c = Z_t \cdot I1 \tag{D-4}$$

From a substitution operation follows:

$$Z_t = \frac{1}{l_{cable}} \cdot \frac{R_i1}{R_i2} \cdot (R2 + R_i2) \cdot \frac{U2}{U1} \tag{D-5}$$

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

$$a_s = 20 \cdot \log\left(\frac{U2}{U1}\right) dB \tag{D-6}$$

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

$$Z_t = 2 \cdot R_i1 \cdot \frac{U2}{U1} = 2 \cdot R_i1 \cdot 10^{\frac{a_s}{20}} = 100 \cdot 10^{\frac{a_s}{20}} \quad \Omega \tag{D-7}$$

D.3.2   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
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 D.2and figure D.3 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.
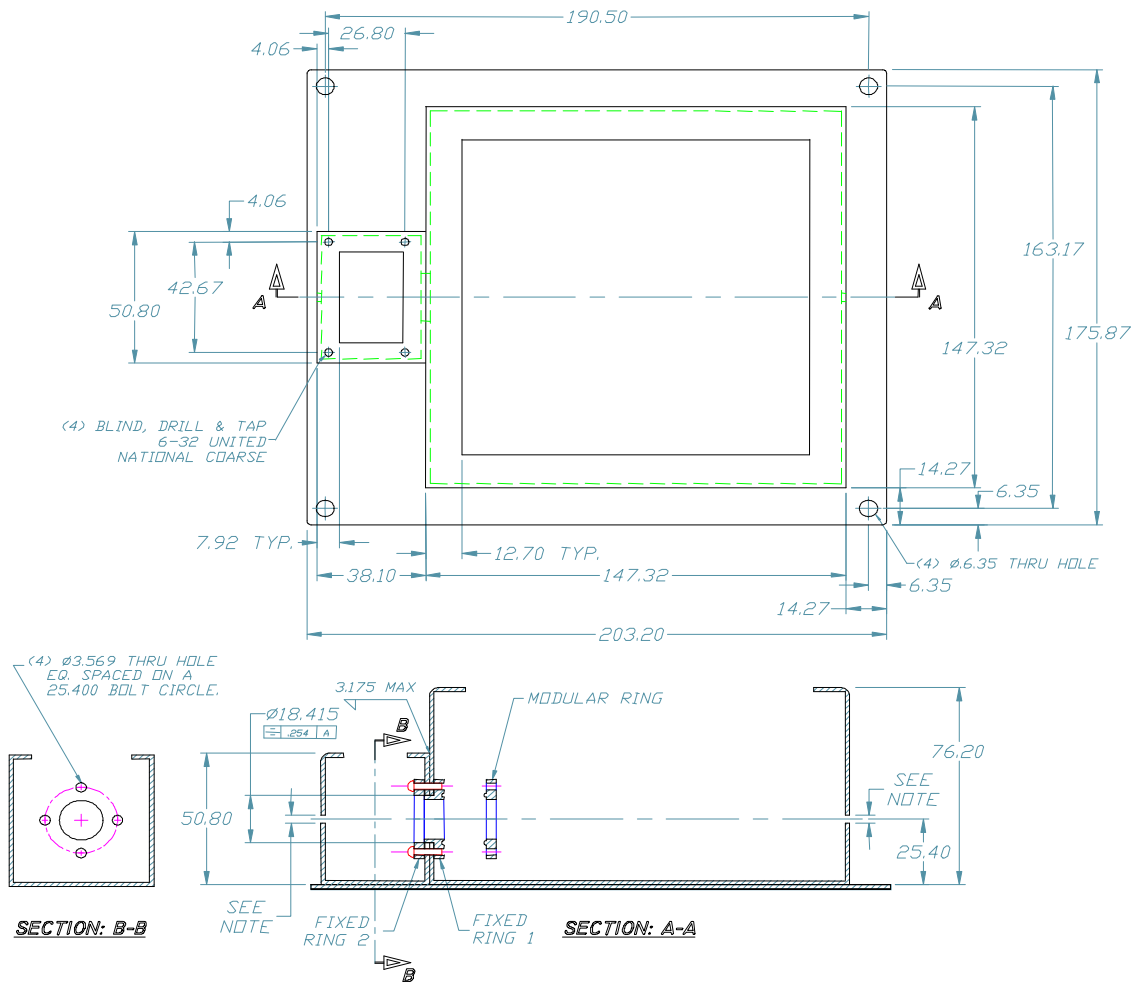
Figure D.2 - HF sealed case dimensional characteristics

(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.
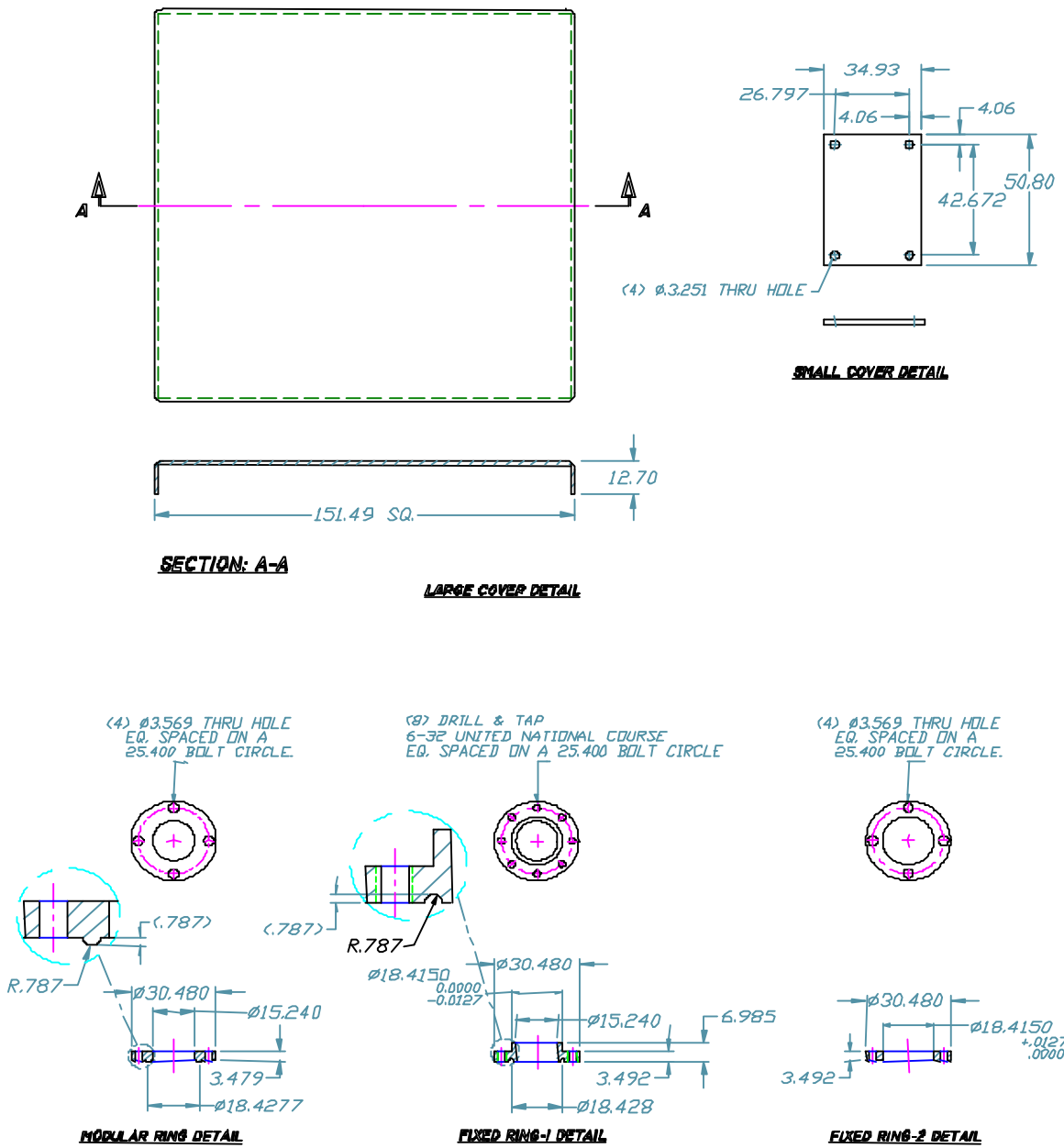
Figure D.3 - HF sealed case covers, fixed and modular ring details

(Dimensions are in mm)

D.3.3   Test method

D.3.3.1   Connecting hardware and cable preparation

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

D.3.3.2   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.

D.3.4 Transfer impedance measurement consistency tests

D.3.4.1 Test orientation summary

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

D.3.4.2 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%.

D.3.4.3 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%.

D.3.4.4 Measurement slope verification

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

Annex E (informative) - Connecting hardware test fixtures

E.1   General

An impedance controlled measurement fixture consists of a device designed to provide controlled interconnections to the DUT. The fixture provides an interface that is designed to maintain correct DM and CM impedance of the pairs in the transmission line when they are separated for interfacing between the DUT and the port interfaces of test equipment. The port interfaces of test equipment, which are typically 50 Ω, coaxial ports are further conditioned by the use of balun transformers presenting a 100 Ω balanced port to the DUT. The interface, in addition to providing impedance control of the balanced leads of the DUT, also provides shielding for the pairs to reduce unwanted pair-to-pair couplings. The interface is electrically connected to the balun and instrument ground reference through pin and socket connectors.

An example fixture, as shown in figure E.1, provides pin and socket connections to the DUT. Termination adapters which provide DMCM resistor terminations for the inactive ports are provided for making NEXT loss and FEXT loss measurements where the highest accuracy is required.
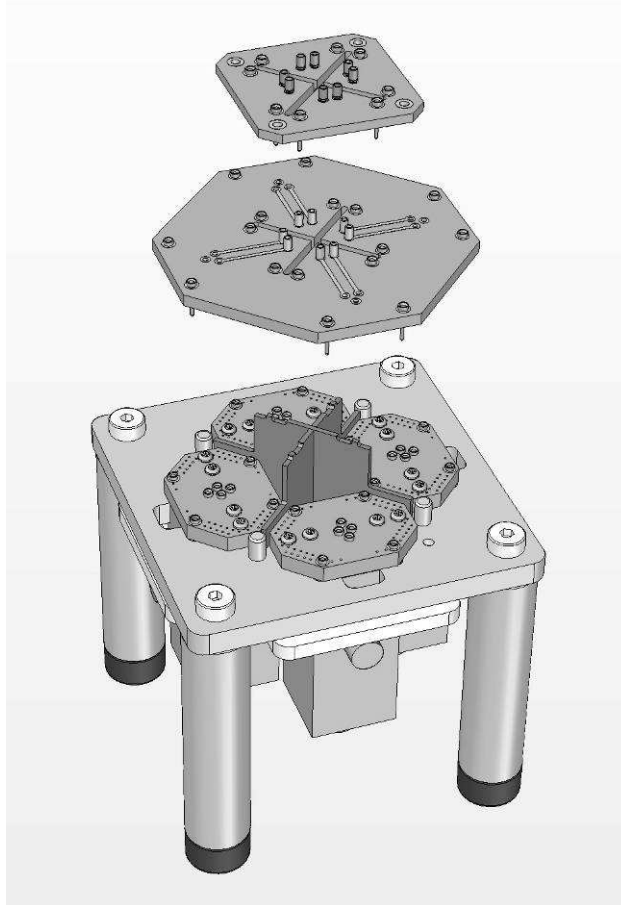
Figure E.1 - Test head assembly with baluns attached

Calibration standards are provided which use the same materials and positioning. The calibration plane is thereby located at the top (open end) of the sockets of the adapter mounting plate. A mounting plate with socket interfaces connects directly to the test baluns. Two such fixtures will provide 8 test ports for connection to both near and far ends of a four pair DUT.

NOTES,
1   The balun interfaces are designed to mate to BH electronics 040-0192 baluns.
2   All test fixture components referenced in this annex may be obtained from industry sources. These test fixtures are provided in kit form including adapter plates, balun mounting plates, baluns and calibration references. Alternative equivalent components may also be used. Photos are for illustrative purposes only and do not constitute an endorsement by TIA.
3   Future developments of test fixtures are expected. Such fixtures may be used in place of or in addition to those specified and recommended in this Standard, if they meet the relevant requirements specified in this Standard.

E.2   Additional components for connection to a network analyzer

SMA cables, connectors, 50Ω SMA terminations, are necessary for interfacing the coaxial ports of the baluns to network analyzer ports. Mounting brackets are recommended for holding the test interface assemblies at convenient positions for attachment to connectors under test.

Foil tape with conductive adhesive (3M 5012C or equivalent) may be used for where additional shielding is needed for various components.
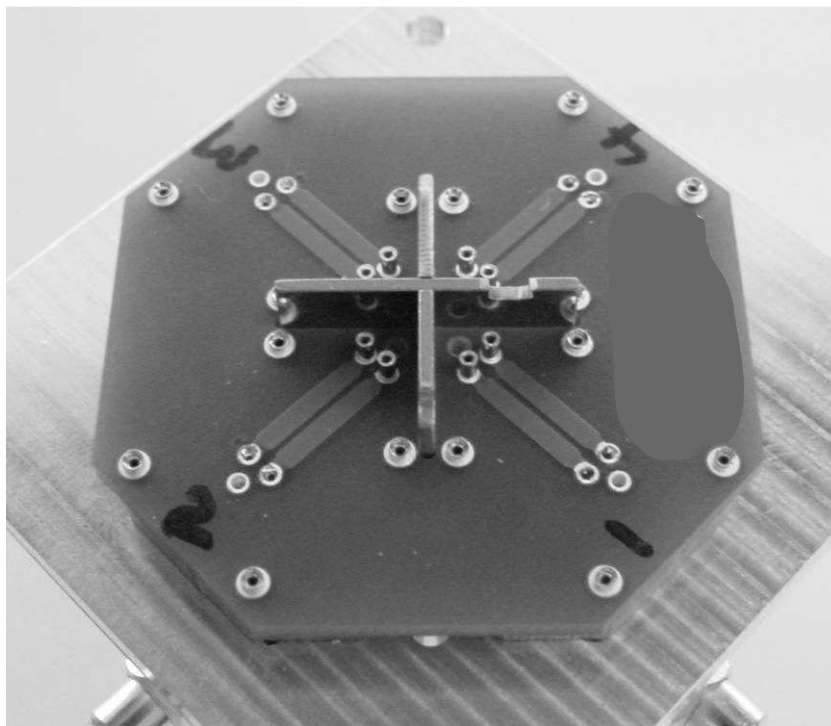

Figure E.2 - Test head assembly showing shielding between baluns

NOTE - Photos are for illustrative purposes only and do not constitute an endorsement by TIA.
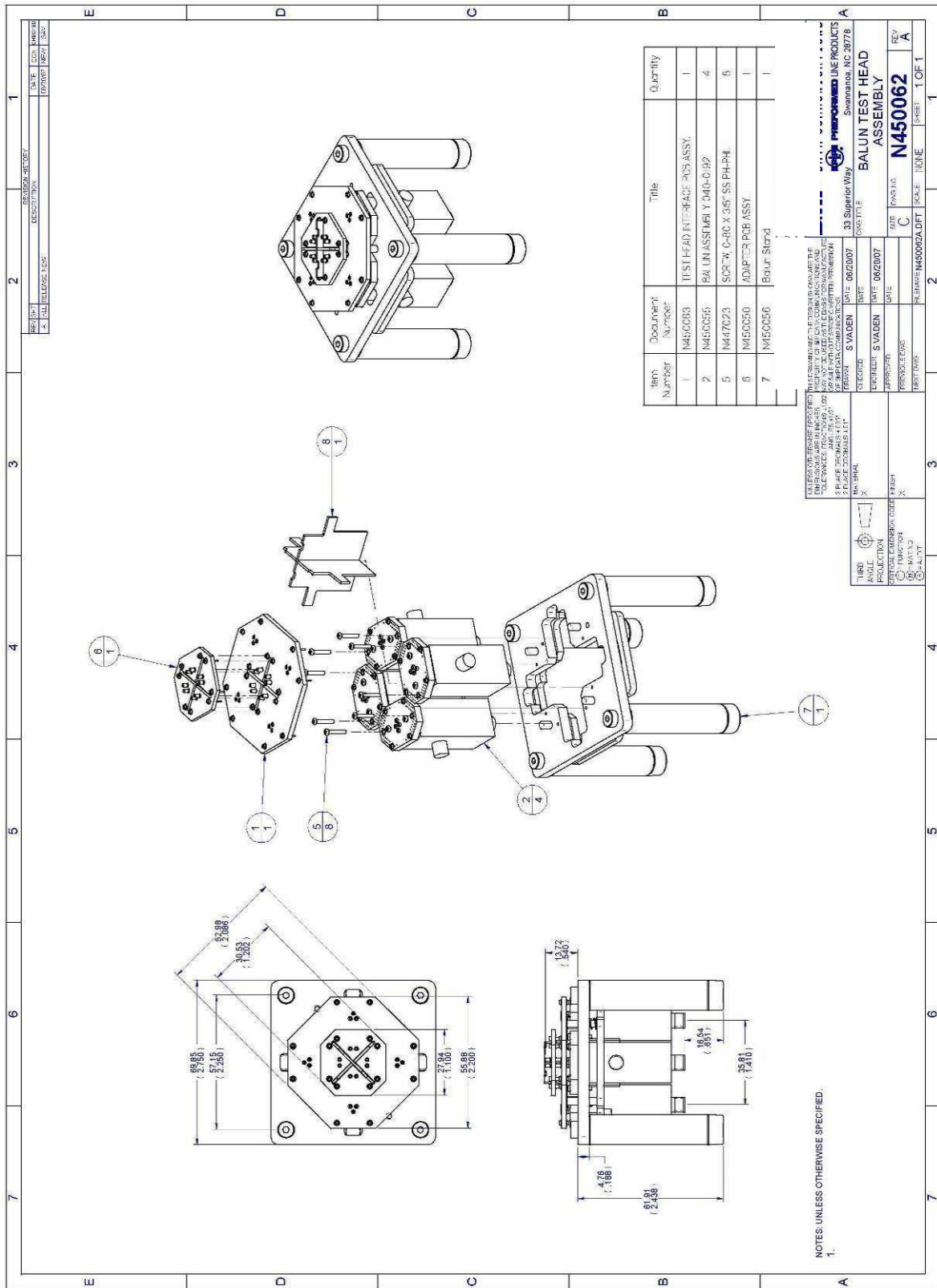
Figure E.3 - Balun test fixture assembly

E.3   Direct fixture

A fixture for direct measurement of modular test plug properties has shielded coaxial probes that make contact with the modular plug contacts as shown in figures E.4 and E.5. The fixture has levels of crosstalk and return loss compliant with table C.5. Insertion loss, NEXT loss, FEXT loss, and return loss measurements can be made using this fixture.

Figure E.4 - Plug direct fixture, DPMF-2 view 1

NOTES,
1   The direct fixture DPMF-2 may be obtained from industry sources.
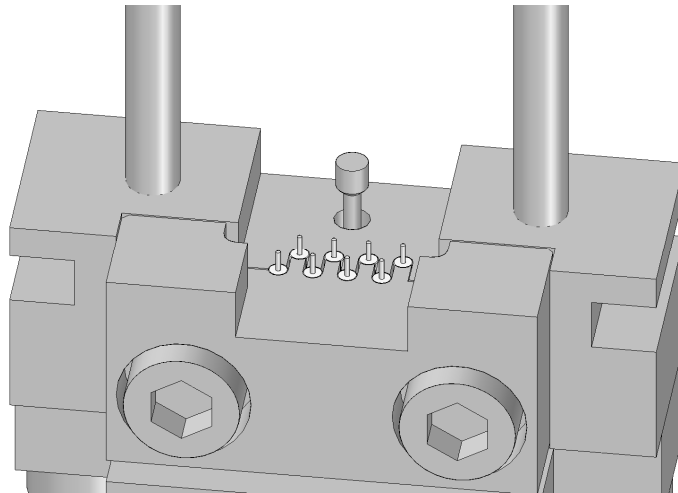2   Photos are for illustrative purposes only and do not constitute an endorsement by TIA.

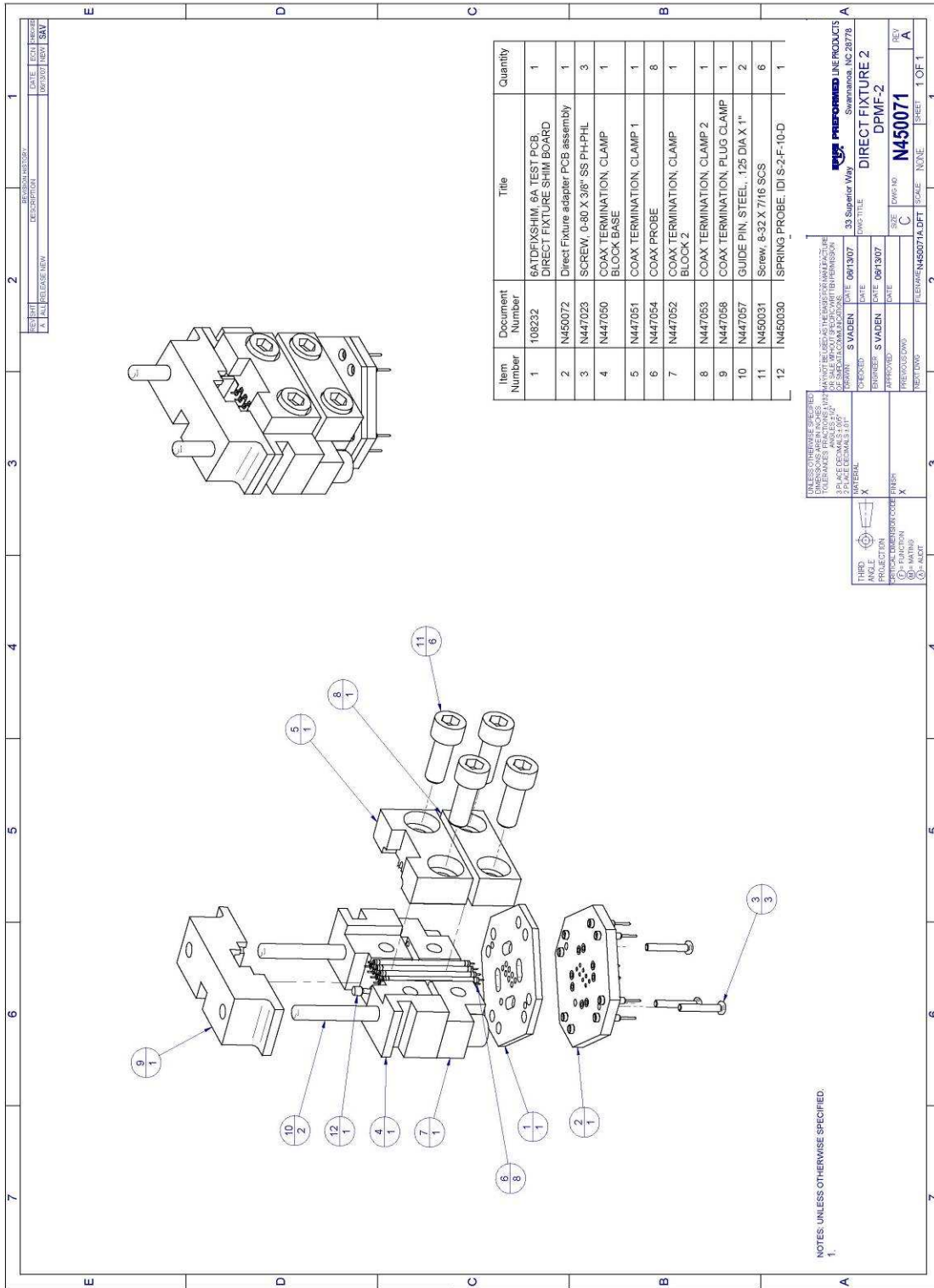**Figure E.5 - Plug direct fixture, DPMF-2 view 2**

Item Number	Document Number	Title	Quantity
1	108232	6ATDFIXSHIM, 6A TEST PCB, DIRECT FIXTURE SHIM BOARD	1
2	N450072	Direct Fixture adapter PCB assembly	1
3	N447023	SCREW, 0-80 X 3/8" SS PH-PHL	3
4	N447050	COAX TERMINATION, CLAMP BLOCK BASE	1
5	N447051	COAX TERMINATION, CLAMP 1	1
6	N447054	COAX PROBE	8
7	N447052	COAX TERMINATION, CLAMP BLOCK 2	1
8	N447053	COAX TERMINATION, CLAMP 2	1
9	N447058	COAX TERMINATION, PLUG CLAMP	1
10	N447057	GUIDE PIN, STEEL, .125 DIA X 1"	2
11	N450031	Screw, 8-32 X 7/16 SCS	6
12	N450030	SPRING PROBE, IDI S-2-F-10-D	1

Figure E.6 - Exploded assembly of the direct fixture

E.4   PCB based test plug assembly

A PCB (printed circuit based) test plug constructed for mating to the test fixture assembly is shown in figure E.7. The plug consists of three parts, an insert assembly and two cover pieces. The potential advantage of using the PCB based plug shown is that:

1) Its properties have been designed to comply with electrical properties of the test plug described in clause C.4.10.
2) The construction is repeatable and consistent.
3) It is mounted to the test fixture without the use of twisted wire test leads, yielding a more consistent measurement result.

The plug is mounted using an adapter plate as shown in figure E.8. There are five adapter plates: one with four through connections, one with two opposite DMCM terminations, one with two adjacent DMCM terminations, one with three DMCM terminations, and one with four DMCM terminations.
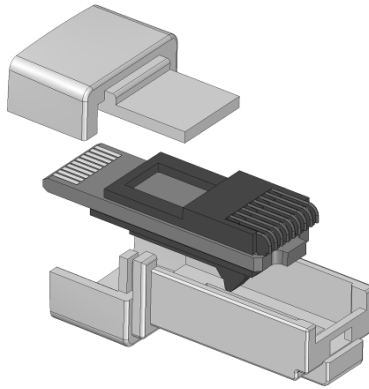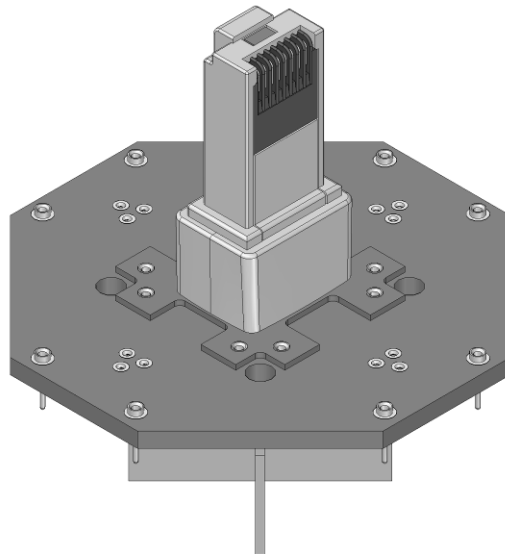

Figure E.7 - PCB based plug

Figure E.8 - TP6A PCB based plug assembly with adapter

NOTE - The PCB based plug TP6A assembly with adapter may be obtained from industry sources.

E.5   Connecting hardware measurement configuration

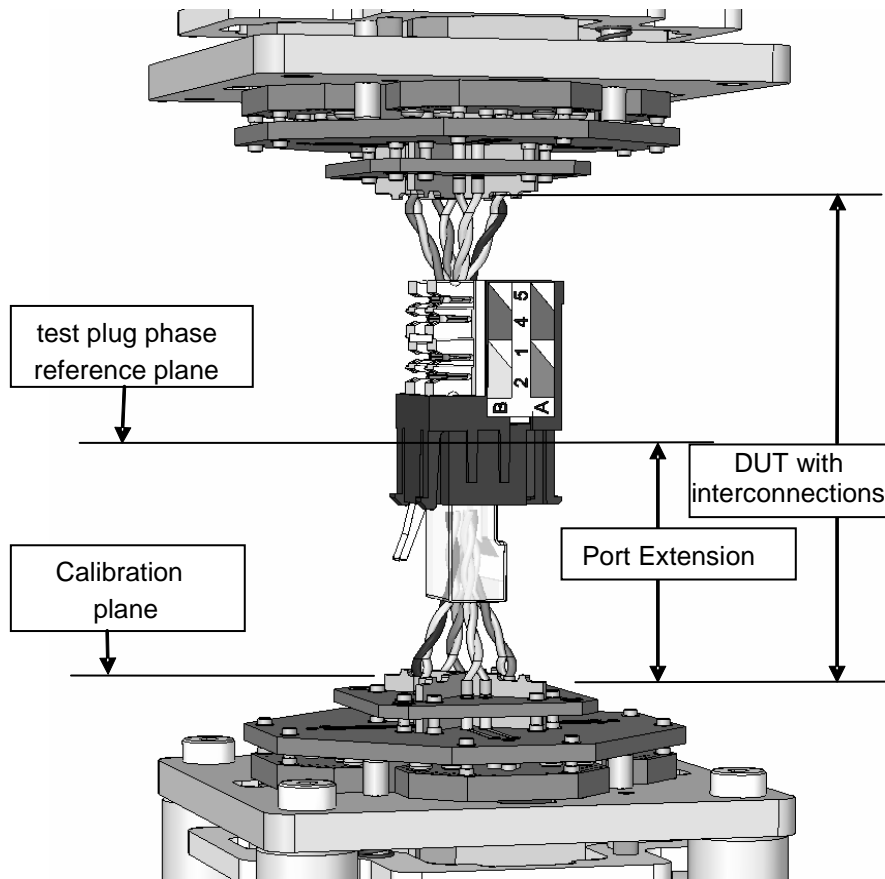Figure E.9 shows an example of a connecting hardware measurement configuration.

Figure E.9 - An example of a connecting hardware measurement configuration

E.6   Test fixture calibration

A one-port calibration of any of the four ports is accomplished using the open, short, and load calibration standards applied to the test fixture interface. A full two-port calibration of any of 8 ports can be obtained using open, short, and load calibration standards and the back-to-back through standard.

A four-port test fixture interface is shown in figure E.10. Two of these are required to do a full 2-port calibration of 8 ports.   The "through" measurements of the back-to-back through for any 1N-1F (port-1-near to port-1-far) port arrangement may be applied to the calibration of adjacent 1N-2N, 1N-3N, etc… (port-1-near to port-2-near, etc…) ports.
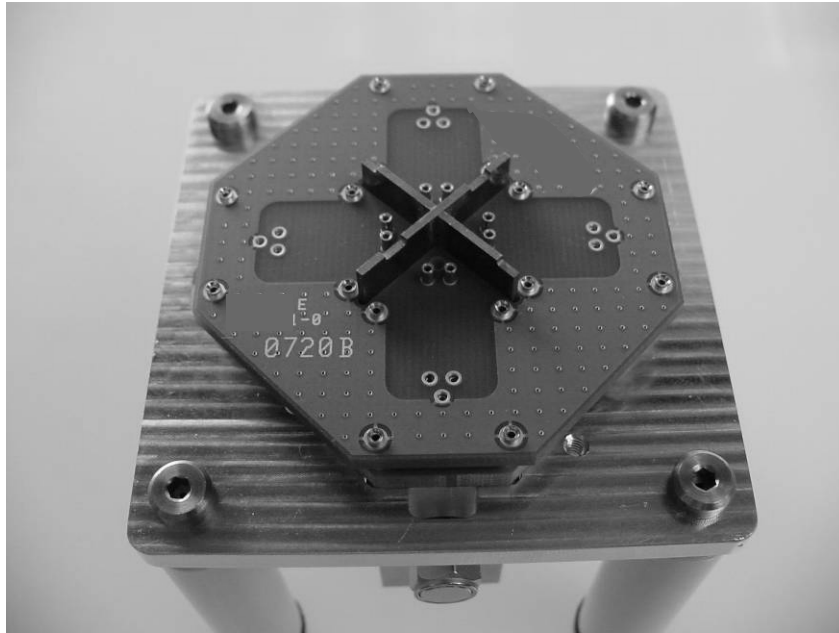

Figure E.10 - Test fixture interface

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

The open and short calibration standards are applied directly to the test fixture interface with no intermediary adapters as shown in figures E.11 and E.12 respectively. When an adapter is attached to the interface during testing, the calibration plane will be located at the ends of the sockets of the adapter.
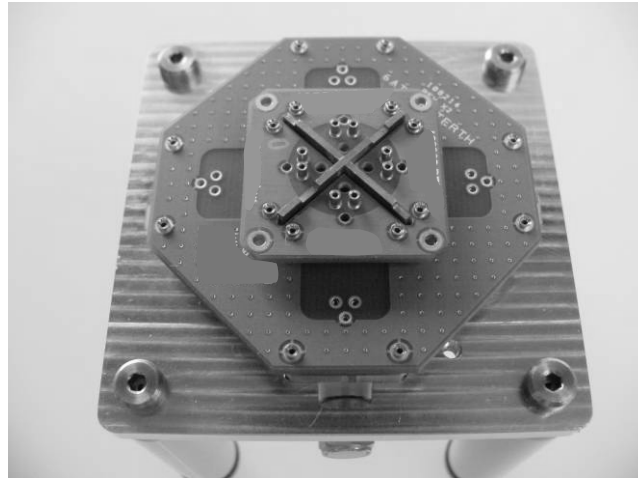

Figure E.11 - Open calibration standard applied to test interface

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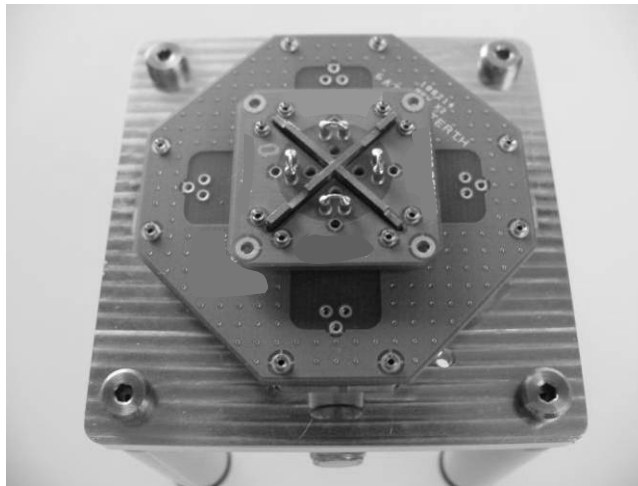

Figure E.12 - Short calibration standard applied to test interface

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

The load and through calibration standards are applied directly to the test fixture interface with no intermediary adapters as shown in figures E.13 and E.14 respectively.
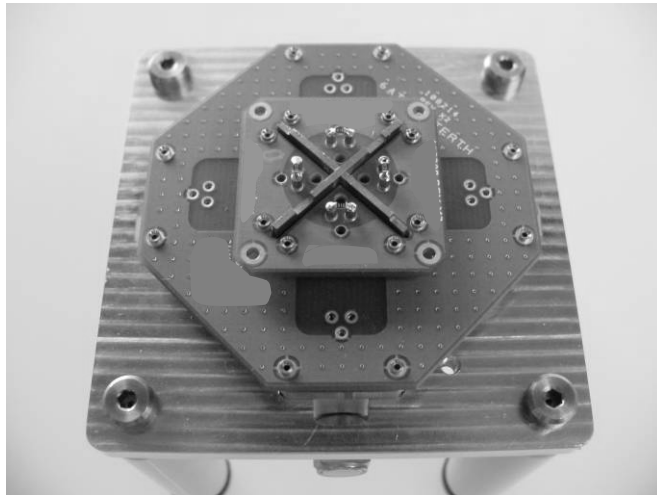

Figure E.13 - Load calibration standard applied to test interface

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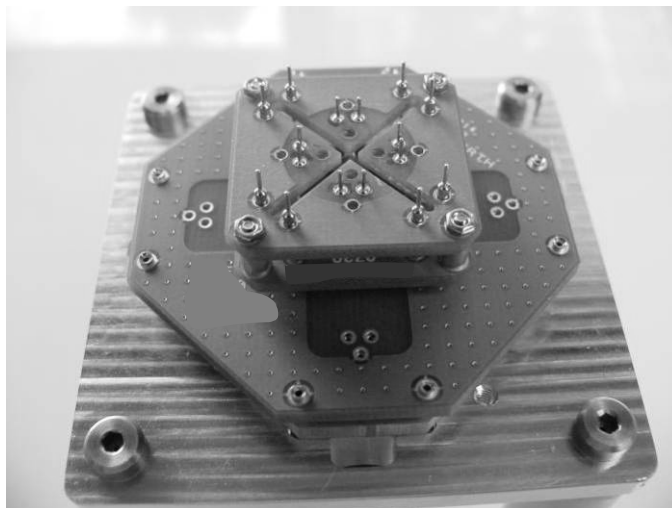

Figure E.14 - Back-to-back through standard applied to test interface

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

When the test plug is attached to the test fixture interface for measurement, the calibration plane will be at the tips of the adapter sockets for all measurements if the back-to-back through calibration artifact is used as shown in figure E.15.
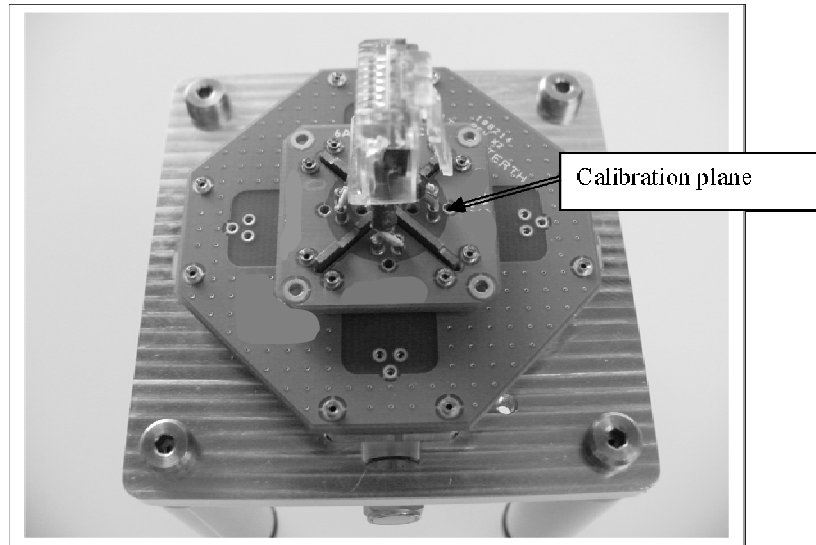

Figure E.15 - Test plug attached to the test interface

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

When the direct fixture is attached to the test head interface, an adapter is placed in between the direct fixture and the interface as shown in figure E.16. The shield plates (not shown) must remain in position under the direct fixture.
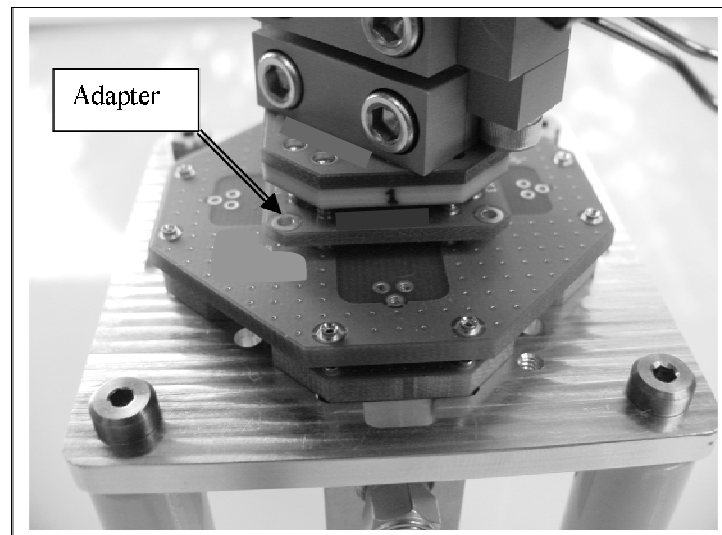
Figure E.16 - Direct fixture mounted to the test head interface

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

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E.6.1   Calibration and reference plane location

A calibration is performed to establish a reference plane location as shown in figure E.17.
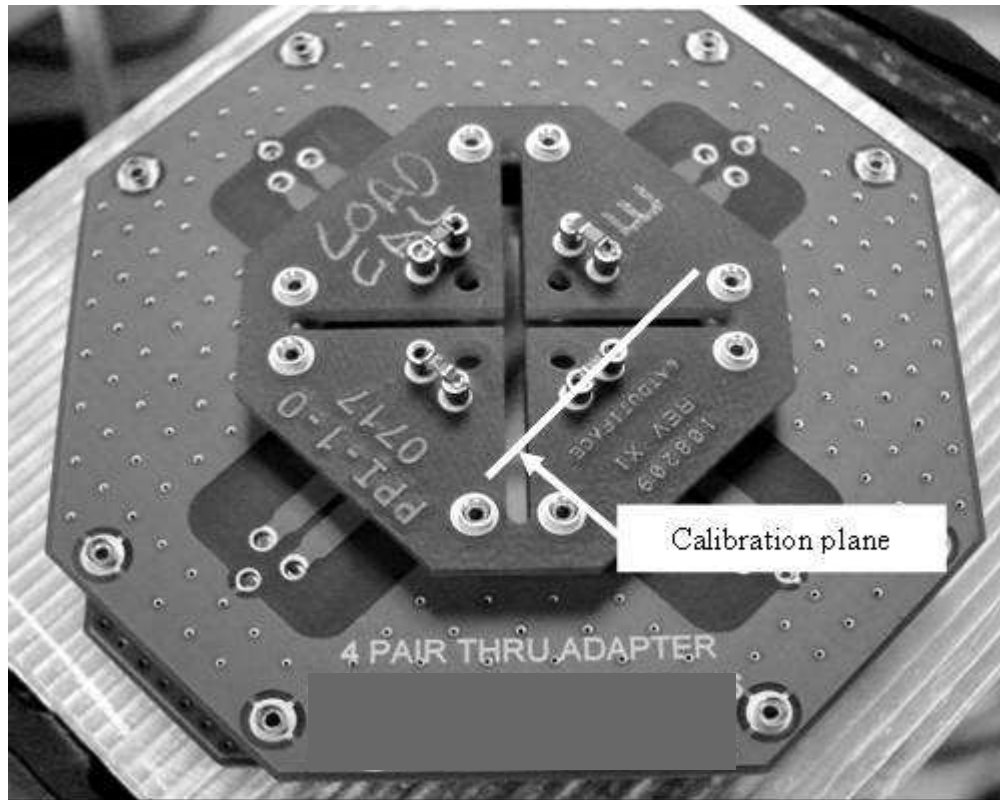

Figure E.17 - Calibration reference plane

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

Through calibration is performed using a back-to-back through adapter as shown in figure E.18. This method causes a 180 degree phase rotation of all through phase measurements. To avoid physical re-arrangements of the baluns, and the 180 degree phase rotation, it is possible to measure a jumper, based on a full two-port calibration with a zero-length through, use it as the through, and subtract its effects from the measured data.
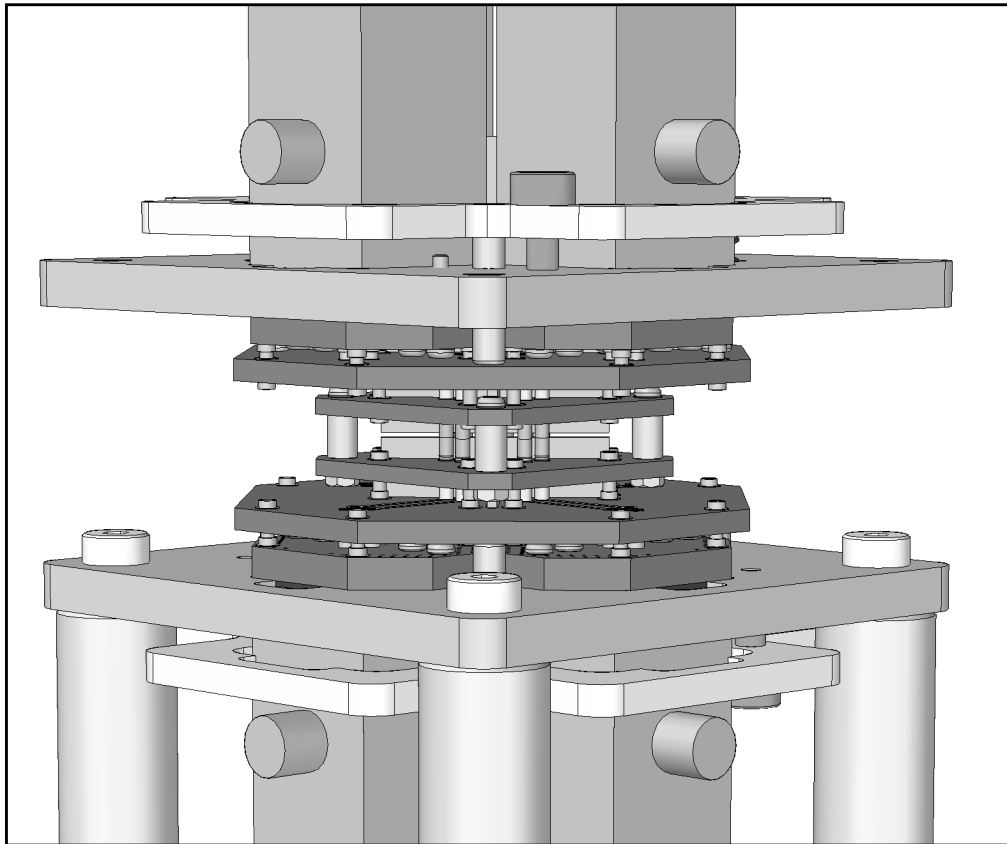

Figure E.18 - Through calibration

E.7   Test lead, 100 mm (4 in) twisted-pair return loss measurement on a pyramid

The following method is recommended for qualification of test leads when the pyramid interface is used. Perform a one port (open-short-load) calibration of the near-end measurement port. The reference plane of calibration should coincide with the socket-to-twisted-pair lead transition point. Trim the twisted-pair used to construct the test leads to fit into the pyramid slot as shown in figure E.19. The length of twisted-pair from socket to socket is approximately 100 mm (4 in). Attach a precision differential mode resistor termination to the pyramid adapter so that the through connecting pins connect to the near-end of the twisted-pair and the precision chip resistor terminates the far-end. Attach the pyramid assembly with the twisted-pair inserted to the balun mounting plate and measure the test lead return loss.
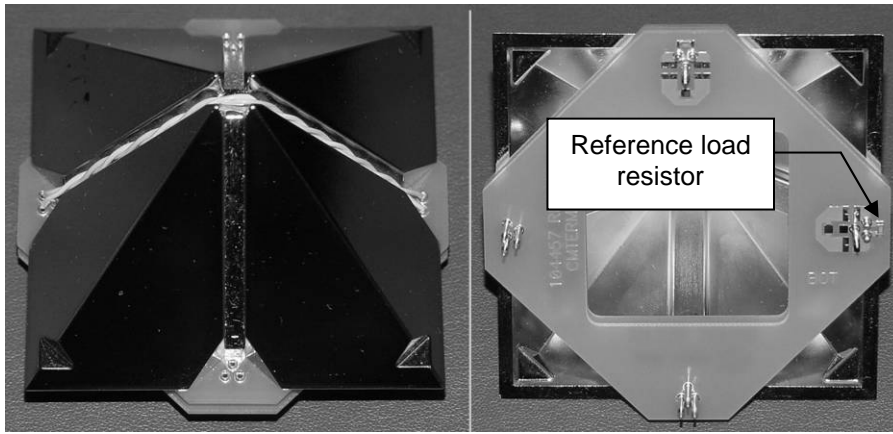
Figure E.19 - Test setup for twisted-pair return loss measurement

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

E.8   DUT connections using header PCB assemblies

One method to minimize the effects of interconnecting leads is to use dedicated PCB header assemblies to connect between the DUT and the test equipment. These PCB headers contain connections to interface to the test port and also connections to interface to the DUT terminals or IDC slots.

Figure E.20 - Method to minimize distance between planes

Annex F (informative) - Multiport measurement considerations

F.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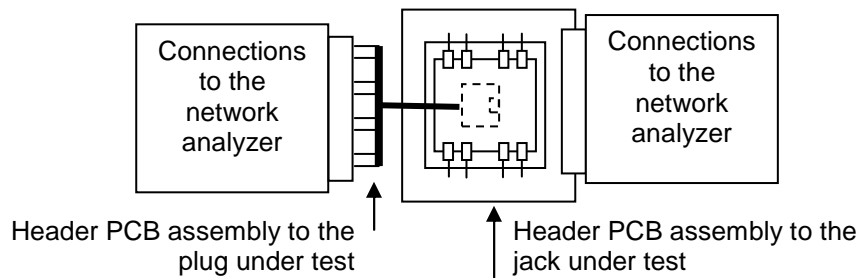 to convert the 50 Ω unbalanced output of the network analyzer to 100 Ω balanced output. Thus the network analyzer presents to the device under test two balanced ports, which can be configured either as output or input via standard two port switching. The typical cable or connector consists of 4 balanced 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.

F.2   Terminology

A port refers to a 100 Ω balanced twisted-pair input or output. DM 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.

F.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.

F.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. DM 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.

F.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 F.1 and F.2 depict preferred topologies for specific measurement parameters.
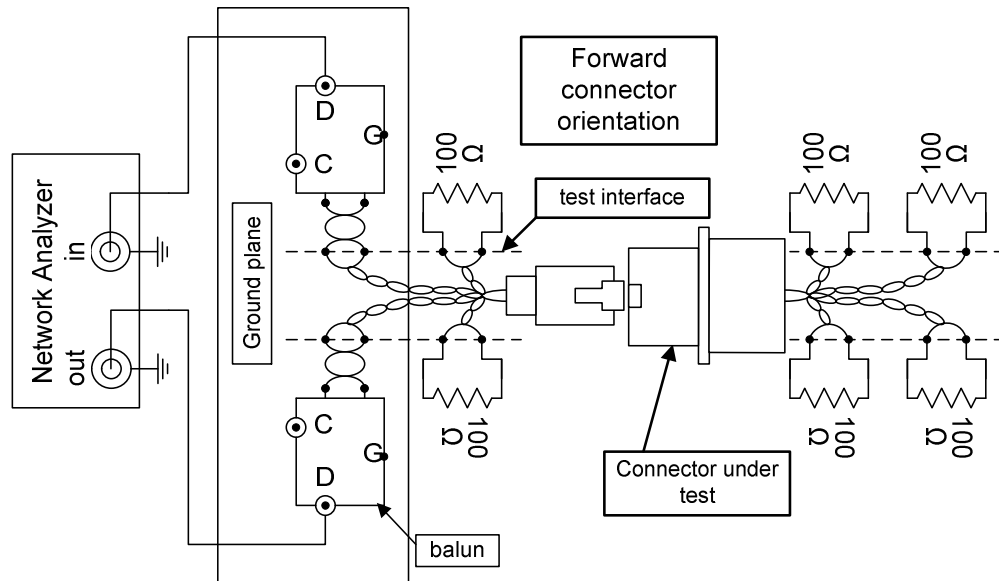

Figure F.1 - Preferred topology for NEXT measurement with DM terminations on connecting hardware (may also be used for return loss measurements)
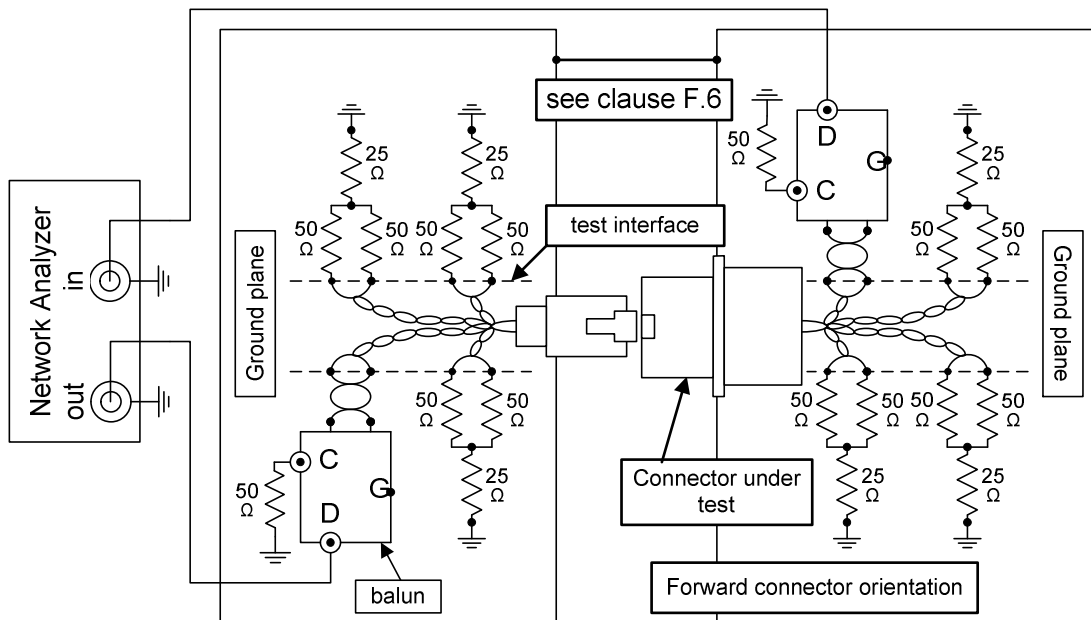

Figure F.2 - Preferred topology for FEXT loss and insertion loss measurement on connecting hardware (NEXT loss test with DMCM termination is similar)

F.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. Unless otherwise specified, the connection between near-end and far-end balun planes is allowed (see figure F.2). 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 G   (informative) - Cable installation in higher temperature environments

G.1   General

Cables may be installed in return air plenums, in ceiling spaces, riser shafts and non air-conditioned buildings such as warehouses and manufacturing plants where the temperature can be significantly higher than 20° C. In order to ensure compliance with the channel insertion loss specified in clause 6.2.7, the horizontal cable distance may need to be reduced below 90 meters depending upon the average temperature of the environment over the length of the cable, the insertion loss margin of the installed cabling, and the insertion loss temperature coefficient of the cable.

G.2   Insertion loss

Equation (G-1) defines the insertion loss dependence on temperature:

$$IL_{20} = \frac{IL_T}{1 + \delta_1 (T - 20) + \delta_2 (T - 40)}$$

(G-1)

where:

IL_T = Measured insertion loss at temperature T

IL_{20} = Insertion loss corrected to 20°C

T = Measured temperature in °C

The correction factors, δ_1 and δ_2, are shown in table G.1.

Table G.1 – Maximum horizontal cable length de-rating factor for different temperatures

	Temperature (º C)	δ_1	δ_2
UTP	20 ≤ T ≤ 40	0.004	0
	40 < T ≤ 60	0.004	0.00248
F/UTP	20 ≤ T ≤ 60	0.002	0

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G.3 Allowance for cable temperature

Table G.2 shows the maximum horizontal cable length de-rating at various temperatures assuming a cable insertion loss temperature coefficient specified in clause 6.4.7.

Table G.2 – Maximum horizontal cable length de-rating factor for different temperatures

Temperature (℃ (℉))	Maximum horizontal unscreened cable length (m)	Maximum horizontal screened cable length (m)	Length de-rating (m) (unscreened)	Length de-rating (m) (screened)
20 (68)	90.0	90.0	0	0
25 (77)	89.0	89.5	1.0	0.5
30 (86)	87.0	88.5	3.0	1.5
35 (95)	85.5	87.7	4.5	2.3
40 (104)	84.0	87.0	6.0	3.0
45 (113)	81.7	86.5	8.3	3.5
50 (122)	79.5	85.5	10.5	4.5
55 (131)	77.2	84.7	12.8	5.3
60 (140)	75.0	83.0	15.0	6.0

NOTE - This table assumes that the channel includes 10 meters of patch and equipment cords at 20° C.

G.4 Installation example

If a cable is installed in an environment where the temperature averaged over the length of the cable can be as high as 40° C, then the maximum horizontal cable distance should be reduced from 90 meters to 84 meters.

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

H.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:

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

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

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

Multiplying out the terms in equation (H-2):

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

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

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

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

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

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

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

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

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

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

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

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

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:

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

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

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

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

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

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

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

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

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

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

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

In equation (H-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 $\tan \delta$ is the loss tangent for the dielectric.

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

$$\alpha \approx \left[\frac{R\left(\sqrt{f}\right)}{2}\sqrt{\frac{C}{L_\infty}} - \frac{\left(R\left(\sqrt{f}\right)\right)^2\sqrt{C}}{4\left(2\,\pi\,f\right)\left(L_\infty\right)^{3/2}} + \frac{\left(2\,\pi\,f\right)C\tan\delta}{2}\sqrt{\frac{L}{C}}\right] \quad\text{(H-16)}$$

The first term containing R exhibits a root frequency dependence. This is the copper loss term, which is the constant for the first term in the insertion loss equations in Table 56. 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, which is the constant for the second term in the insertion loss equations in Table 56.

H.2   Developing the phase delay equation

The expression for the phase delay is given by:

$$\text{Delay} = \frac{\beta}{\omega} = \sqrt{LC} \quad\text{(H-17)}$$

Substituting, for $L = L_\infty + L_{INT} = L_\infty\left[1 + \dfrac{R}{\omega L_\infty}\right]$

$$\text{Delay} = \frac{\beta}{\omega} = \sqrt{L_\infty\left[1 + \frac{R}{\omega L_\infty}\right]C} \quad\text{(H-18)}$$

Applying the approximation for $\left(\dfrac{R}{\omega L_\infty}\right) << 1$, $\sqrt{\left[1 + \dfrac{R}{\omega L_\infty}\right]}$ may be written as:

$$\sqrt{\left[1 + \frac{R}{\omega L_\infty}\right]} \approx 1 + \frac{R}{2\,\omega L_\infty} \quad\text{(H-19)}$$

Then the expression for delay may be written:

$$\frac{\beta}{\omega} = \sqrt{CL_\infty}\left[1 + \frac{R}{2\,\omega L_\infty}\right] \quad\text{(H-20)}$$

Multiplying out equation (H-20):

$$\frac{\beta}{\omega} = \sqrt{CL_\infty} + \frac{R}{2\,\omega}\sqrt{\frac{C}{L_\infty}} \quad\text{(H-21)}$$

Writing the expression for delay to indicate the frequency dependent terms:

$$\frac{\beta}{\omega} = \sqrt{CL_\infty} + \frac{R\left(\sqrt{f}\right)}{2\left(2\,\pi f\right)}\sqrt{\frac{C}{L_\infty}} \quad\text{(H-22)}$$

Since C and L_∞ are independent of frequency, the first term in equation (H-22) is a constant. The second term has a $1/\sqrt{f}$ frequency dependence, due to the ratio of $\dfrac{R(\sqrt{f})}{f}$ which results in the following expression for delay:

$$Delay = \frac{\beta}{\omega} = \text{Const} + \frac{k1/8.686}{2\pi\sqrt{f}} \tag{H-23}$$

The units for delay in equation (H-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 copper loss coefficient for category 5e from Table 56::

$$Delay(\text{ns/100m}) = \text{Const} + \frac{36}{\sqrt{f_{MHz}}} \tag{H-24}$$

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:

$$Delay(\text{ns/100m}) = 534 + \frac{36}{\sqrt{f_{MHz}}} \tag{H-25}$$

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 I   (informative) - Development of channel and component return loss limits

I.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 (I-1).

$$\begin{bmatrix} \cosh(\gamma l) & Z \sinh(\gamma l) \\ \dfrac{\sinh(\gamma l)}{Z} & \cosh(\gamma l) \end{bmatrix}$$

(I-1)

where: $\gamma = \alpha + j\beta$ is the complex propagation constant and Z is the complex characteristic impedance.

$\alpha = \dfrac{IL_{dB}}{20\log(e)}$ with: IL_{dB} is the insertion loss of the component per m in dB.

e = 2.71828 (base of natural logarithm)

$\beta = \dfrac{2\pi f\, 10^6}{NVP\, c}$ 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:

$$NVP = \dfrac{100}{prop\_delay \cdot c}$$

The frequency 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:

$$Z_{in} = \dfrac{A Z_{ref} + B}{C Z_{ref} + D}, \text{ and } RL = -20\log\left(\left|\dfrac{Z_{in} - Z_{ref}}{Z_{in} + Z_{ref}}\right|\right),$$

(I-2)

with the nominal characteristic impedance $Z_{ref} = 100\,\Omega$.

I.2 Assumptions

I.2.1 Assumptions for the transmission matrix for cable

For cable, the specified insertion loss per unit length is given by:

$$IL_{dB} = \frac{k_1\sqrt{f} + k_2 f + \dfrac{k_3}{\sqrt{f}}}{100}$$
(I-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:

$$Z_{fit} = Z_O\left(1 + 0.055\frac{1-j}{\sqrt{f}}\right)$$
(I-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.

$$DRL = -10\log\left(10^{\frac{-RL_{cable}}{10}} - 10^{\frac{-RL_{interface}}{10}}\right)$$
(I-5)

DRL is approximated by:

$$DRL_{100m} = K_{DRL} - 10\log\left(\frac{f}{20}\right)$$ where: K_{DRL} is a constant.
(I-6)

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 loss 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.

I.2.2   Assumptions for the transmission matrix for connectors

For a connector, the product of the propagation delay constant and length is used.

$$\gamma l = \alpha\, l + j\beta l \tag{I-7}$$

The electrical length l_{conn} is obtained from: $l_{conn} = NVP\, c\, \dfrac{\phi_x}{360\, f_x}$ (I-8)

where:

ϕ_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 $\alpha l = k_c \sqrt{f}$ (I-9)

where k_c is the constant in the connector insertion loss equation.

The phase constant $\beta l = \dfrac{\pi}{180}\phi_x \dfrac{f}{f_x}$ (I-10)

For the purpose of establishing category 6A permanent link and channel return loss limits, a connecting hardware return loss performance of 26–20log(f/100) is assumed to account for the variability of patch cord connections.

I.3   Return loss modeling results

A reasonable worst case channel configuration used to develop the return loss limits is shown in figure I.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.
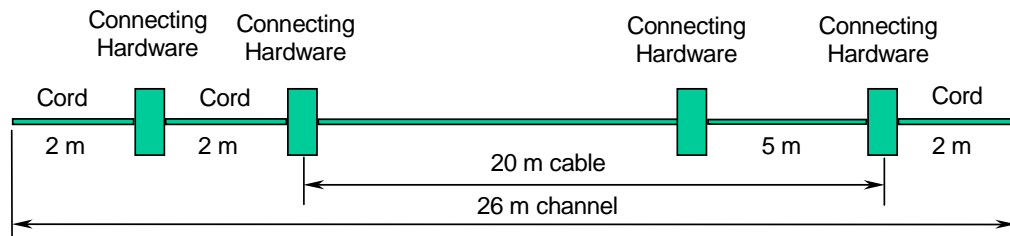

Figure I.1 - Modeling configuration

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.

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Annex J (informative) - Modeling configurations

Figure J.1 shows five channel modeling configurations that are used for worst-case analysis.
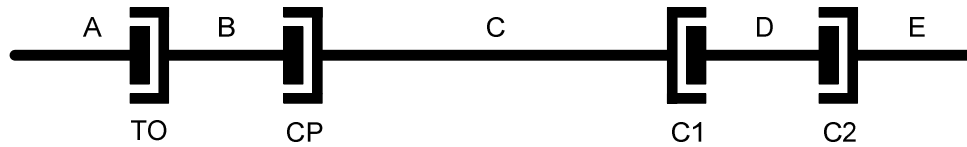
ID	Description	Channel configuration				
		1	2	3	4	5
A	Work area cord	5 m	2 m	1 m	1 m	1 m
TO	Telecommunications outlet / connector	P	P	P	P	P
B	Consolidation point cabling	5 m	5 m	5 m	NP	NP
CP	Consolidation point connector	P	P	P	NP	NP
C	Horizontal cabling	85 m	15 m	15 m	15 m	10 m
C1	Horizontal cross-connect or interconnect	P	P	P	P	P
D	Patch cord or jumper cable	2 m	1 m	1 m	1 m	1 m
C2	Horizontal cross-connect or interconnect	P	P	P	P	NP
E	Telecommunications room equipment cord	3 m	2 m	2 m	2 m	NP

NP = Not present in this channel model
P = Present in this channel model

Figure J.1 - Channel configuration

Similarly, figure J.2 shows four permanent link modeling configurations that are used for worst-case analysis.

ID	Description	Permanent link configuration			
		1	2	3	4
TO	Telecommunications outlet / connector	P	P	P	P
B	Consolidation point cabling	5 m	5 m	NP	NP
CP	Consolidation point connector	P	P	NP	NP
C	Horizontal cabling	85 m	15 m	15 m	10 m
C1	Horizontal cross-connect or interconnect	P	P	P	P

NP = Not present in this permanent link model
P = Present in this permanent link model

Figure J.2 - Permanent link configuration

Annex K (informative) - Additional information on channel and permanent link NEXT loss limits

K.1 General

This annex describes the reflected FEXT contribution to overall measured NEXT loss, and provides guidelines to avoid conditions that may cause a NEXT loss failure from this phenomenon.

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. The magnitude of the measured NEXT loss is affected by the NEXT loss, FEXT loss, insertion loss, and return loss properties of the components comprising a channel or permanent link.

The model used in this standard to compute NEXT loss limits for cabling from the properties of the components is simplified and does not take into account all potential disturbers and reflection paths. The model has generally been conservative, in that computations based on a more detailed model result in the potential for tighter specifications. However, for category 6, and in particular at high frequencies, the FEXT loss and return loss properties increase in significance. When FEXT loss properties in connecting hardware and/or ACRF properties of cable are close to minimum specified requirements, failures in NEXT performance testing on cabling assemblies can occur.

K.2 Reflected FEXT contributions to measured NEXT loss

This source of indirect NEXT is caused by FEXT in the cabling components between a source of a reflection and the near-end. Two pairs are shown in figure K.1 for simplicity. The signal applied to one pair causes NEXT in an adjacent pair. In addition, the same test signal causes reflections throughout the cabling on the stimulus pair. These reflected signals couple through FEXT into the same pair as the NEXT and, thereby, are a source of indirect NEXT .
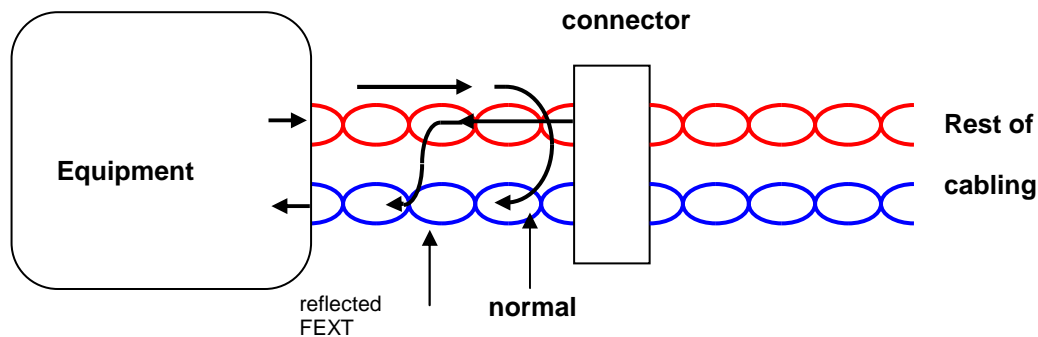

Figure K.1 - Principle of reflected FEXT effects adding to NEXT

A similar indirect NEXT contribution is through FEXT from the stimulus pair to the disturbed pair, and reflections causing the signals return with the NEXT loss (this path is not shown in figure K.1).

The magnitude of reflected FEXT is affected by:

1   The magnitude of major reflections, which generally occur at connecting hardware termination points (where mismatches between the impedance of the connector and the characteristic impedance of adjacent cable segments contribute to reflections).
2   The length of cable segments. Generally, reflections further away from the near-end are attenuated and insignificant. However, near-end reflections remain significant.
3   The magnitude of FEXT loss in connecting hardware and magnitude of ACRF in cable.

K.3   Guidelines for determining the impact of reflected FEXT effects

Reflected FEXT effects can affect pass/fail conditions of channel and permanent link NEXT loss under the following conditions:

1   The cable and/or connecting hardware NEXT loss is close to minimally required values. This condition is generally detected by NEXT loss showing low margin relative to the pass/fail requirements of the channel or permanent link.
2   Major reflections occur near the beginning of the link. This condition is generally detected by return loss performance close to channel or permanent link pass fail limits, most often in the 10 MHz to 30 MHz frequency range.
3   The cable segments near the beginning of the link are short (a few meters).
4   The connector FEXT loss and/or cable ACRF is close to minimally required component values. This condition is generally found by observing the ACRF property of the channel or permanent link. A significant impact of reflected FEXT is generally avoided when the ACRF of the channel or permanent link exceeds the pass/fail limits by at least 5 dB.

Annex L (informative) - PSAACRF and AFEXT loss normalization

L.1   General

This annex provides additional information on the derivation of PSAACRF related to AFEXT loss normalization. It specifically addresses conditions where disturbed and disturbing channel or permanent links have different lengths. Unlike the parameters that apply to the internal transmission parameters and PSANEXT loss, the PSAACRF properties are affected by the length of disturbed and disturbing channels or permanent links.

> NOTE - PSAACRF, as defined in this Standard is equivalent to the PSAELFEXT computation, as defined in IEEE Std 802.3an™.

L.2   Coupled length

The alien FEXT loss, $AFEXT_{k,i,j}$, coupling from the 4 pairs of a disturbing channel or permanent link j with pairs 1 through 4 to a pair k of a disturbed channel or permanent link is shown in figure L.1.
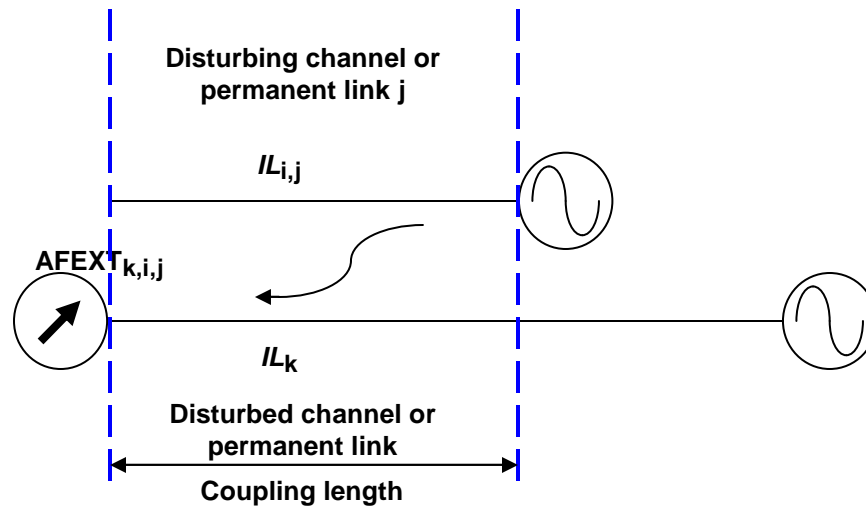

Figure L.1 - Unequal lengths of disturbing and disturbed channels or permanent links

In case the disturbed permanent link or channel k, is longer than the disturbing permanent link or channel j, then the AFEXT loss noise coupling only occurs over the length of disturbing permanent link or channel j. Normally the signal strengths applied to each permanent link or channel (shown in figure L.1 at the right side) have equal magnitudes. A worst case condition occurs when both the disturbed and disturbing permanent links or channels terminate at the same location (on the left side of figure L.1). This is commonly the case for a patch panel in an equipment room. At the location where the disturbed and disturbing permanent links or channels are joined in a cable bundle, the source signal strength is nominal for the disturbing FEXT loss noise and lower by the nominal minus attenuated signal for a worst case condition where the signal source is at the location where the disturbing permanent links or channels joins the cable bundle. This relative loss of signal equals the difference of the insertion IL_k loss of pair k of the disturbed permanent links or channels and the insertion loss $IL_{i,j}$ of disturbing permanent link or channel j. Adjustment is only applied when the disturbed permanent link or channel is longer than the disturbing permanent link or channel. This adjustment is referred to as AFEXT loss normalization.

L.3 AFEXT loss normalization

Normalization includes the adjustment for signal strengths that can be applied to the coupled permanent links or channels for different lengths of disturbed and disturbing permanent links or channels. AACRF of the coupled permanent link or channel is determined using equations (L-1) and (L-2) with reference to figure L.2.
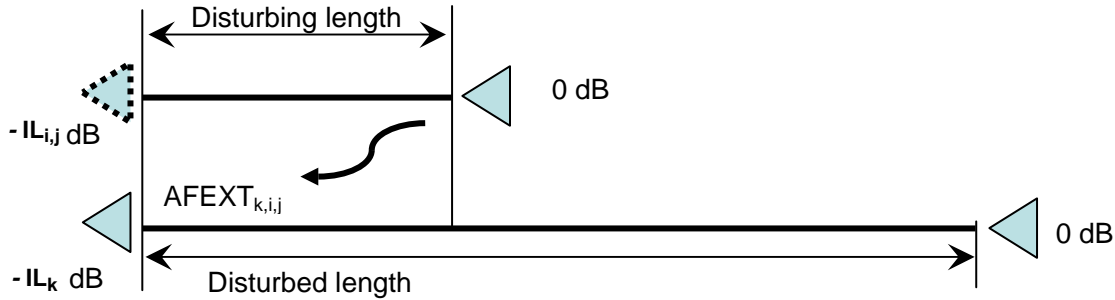

Figure L.2 - AACRF for the coupled permanent link or channel

$$IL_{coupling\_length} = \min(IL_k, IL_{i,j}) \ dB \tag{L-1}$$

For the example shown in figure L.2, $IL_{coupling\_length} = IL_{i,j}$ and the AACRF of the coupled permanent link or channel is given by equation (L-2).

$$AACRF_{k,i,j} = AFEXT_{k,i,j} - IL_{i,j} \ dB \tag{L-2}$$
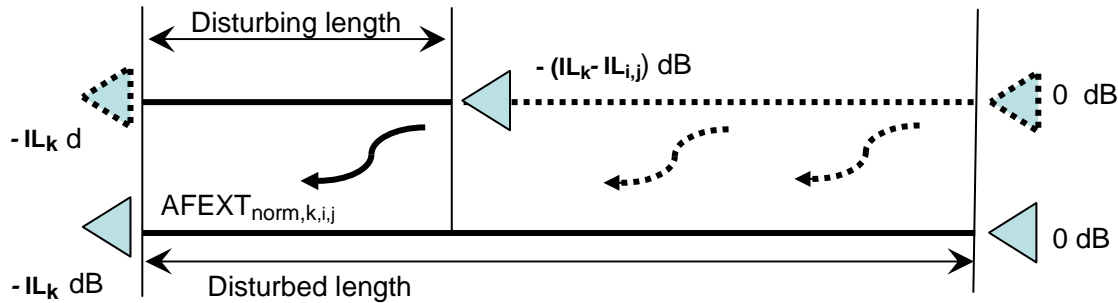

Figure L.3 - AACRF normalized for the length of the disturbed permanent link or channel

AACRF of the coupled permanent link or channel is then scaled to the length of the disturbed permanent link or channel using equations (L-3) to (L-7) with reference to figure L.3.

$$AACRF_{norm,k,i,j} = AACRF_{k,i,j} - 10\log\left[\frac{Length_{disturbed}}{Length_{disturbing}}\right] \ dB \tag{L-3}$$

$$\left(AFEXT_{norm,k,i,j} - IL_k\right) = \left(AFEXT_{k,i,j} - IL_{i,j}\right) - 10\log\left[\frac{Length_{disturbed}}{Length_{disturbing}}\right] \ dB \tag{L-4}$$

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The ratio of lengths can be approximated by using the ratio of insertion losses. Since the ratio does not change significantly over frequency, it is recommended to use the insertion loss values at 250 MHz.

$$AFEXT_{norm,k,i,j} = AFEXT_{k,i,j} + \left(IL_k - IL_{i,j}\right) - 10\log\left[\frac{IL_k}{IL_{i,j}}\right] \ dB \qquad \text{(L-5)}$$

$$PSAFEXT_{norm,k} = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{n}10^{-\frac{AFEXTnorm_{k,i,j}}{10}}\right) \ dB \qquad \text{(L-6)}$$

$$PSAACRF_k = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{n}10^{\frac{-AFEXTnorm_{K,i,j}}{10}}\right) - IL_k \ dB \qquad \text{(L-7)}$$

NOTE - The computation using equation (L-7) is equivalent to the computation of PSAACRF specified in TIA TSB-155 and the computation of PSAELFEXT in IEEE Std 802.3an™.

Annex M (informative) - Category 5 channel parameters

Category 5 has been superseded by category 5e and is no longer recognized by this Standard. The use of category 5e or better cabling is recommended for all new installations characterized for operation over the frequency range of 1 to 100 MHz. Table M.1 provides reference performance values for legacy category 5 channels.

Table M.1 - Category 5 channel parameters

Parameter	Frequency (MHz)	Channel performance
Insertion loss	$1 \leq f \leq 100$	$\leq 1.02\left(1.967\sqrt{f} + 0.023f + \dfrac{0.05}{\sqrt{f}}\right) + 4 \cdot 0.04\sqrt{f}\ \ dB$
NEXT loss[3]	$1 \leq f \leq 100$	$\geq -20\log\left(10^{-\left(\frac{64-15\log\left(\frac{f}{0.772}\right)}{20}\right)} + 2\cdot 10^{-\left(\frac{40-20\log\left(\frac{f}{100}\right)}{20}\right)}\right)\ dB$
Return loss	$1 \leq f < 20$	$\geq 15\ dB$
	$20 \leq f \leq 100$	$\geq 15 - 20\log\left(\dfrac{f}{20}\right)\ dB$
ELFEXT[1]	$1 \leq f \leq 100$	$\geq 17 - 20\log\left(\dfrac{f}{100}\right)\ dB$
PSELFEXT[2]	$1 \leq f \leq 100$	$\geq 14.4 - 20\log\left(\dfrac{f}{100}\right)\ dB$
Propagation delay	10	≤ 555 ns
Delay skew	10	≤ 50 ns
[1] ELFEXT is referred to as ACRF in other sections of this Standard. [2] PSELFEXT is referred to as PSACRF in other sections of this Standard. [3] Calculations that result in NEXT loss values greater than 60 dB revert to 60 dB.		

The category 5 channel parameter values in table M.2 are provided for information only.

Table M.2 – Category 5 channel performance at key frequencies

Frequency (MHz)	Insertion Loss (dB)	NEXT loss (dB)	Return loss (dB)	ELFEXT (dB)	PSELFEXT (dB)
1.00	3.0	60.0	15.0	57.0	54.4
4.00	4.5	50.6	15.0	45.0	42.4
8.00	6.3	45.6	15.0	38.9	36.3
16.00	9.1	40.6	15.0	32.9	30.3
20.00	10.2	39.0	15.0	31.0	28.4
25.00	11.4	37.4	14.0	29.0	26.4
31.25	12.9	35.7	13.1	27.1	24.5
62.50	18.6	30.6	10.1	21.1	18.5
100.00	24.0	27.1	8.0	17.0	14.4

Annex N (informative) - Bibliography

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
www.ansi.org

ASTM
www.astm.org

BICSI
www.bicsi.org

CENELEC
www.cenelec.eu

CSA
www.csa.ca

FCC
www.fcc.gov

ICEA
www.icea.net

IEC
www.iec.ch

IEEE
www.ieee.org

Global Engineering Documents
www.global.ihs.com

Telcordia Technologies (formerly Bellcore)
www.telcordia.com

TIA
www.tiaonline.org

UL
www.ul.com

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