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TIA STANDARD

Balanced Twisted-Pair Telecommunications Cabling and Components Standard

TIA-568.2-D **September 2018**

TELECOMMUNICATIONS INDUSTRY ASSOCIATION
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Balanced Twisted-Pair Telecommunications Cabling and Components Standard

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FOREWORD

(This foreword 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 At that time, standards are reaffirmed, rescinded, or revised according to the submitted updates.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Documents superseded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 ANSI/TIA/EIA-568-C.2 standard dated August 11, 2009. Since the original publication of ANSI/EIA/TIA-568 in July of 1991, telecommunications cabling has undergone a period of rapid change marked by the growth of increasingly powerful personal computers, 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-C.2
- ANSI/TIA/EIA-568-C.2-1
- ANSI/TIA/EIA-568-C.2-2

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

Significant technical changes from the previous edition

- Incorporation of the above mentioned TSBs, Addenda, and Interim Standards.
- Performance specifications are provided for category 8 shielded balanced twisted-pair cabling and components.
- Laboratory test measurement methodologies have been updated for category 8 cabling and components. These test procedures may also be applied to lower categories.
- Information on modeling configurations has been added.
- Balunless test methods have been added.

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-568.0-D);
- *Commercial Building Telecommunications Cabling Standard* (ANSI/TIA-568.1-D);
- *Optical Fiber Cabling and Components Standard* (ANSI/TIA-568.3-D);
- *Broadband Coaxial Cabling and Components Standard* (ANSI/TIA-568-C.4);
- *Telecommunications Pathways and Spaces* (ANSI/TIA-569-D);
- *Residential Telecommunications Infrastructure Standard* (ANSI/TIA-570-C);
- *Administration Standard for Telecommunications Infrastructure* (ANSI/TIA -606-C);
- *Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises* (ANSI/TIA-607-C);
- *Telecommunications Infrastructure Standard for Data Centers* (ANSI/TIA-942-B)
- *Customer-Owned Outside Plant Telecommunications Infrastructure Standard* (ANSI/TIA-758-B);
- *Structured Cabling Infrastructure Standard for Intelligent Building Systems* (ANSI/TIA-862-B);
- *Healthcare Facility Telecommunications Infrastructure Standard* (ANSI/TIA-1179);
- *Telecommunications Infrastructure Standard for Educational Facilities* (ANSI/TIA-4966);
- *Telecommunications Physical Network Security Standard* (ANSI/TIA-5017)

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 *Outside Plant Design Reference Manual,* and the *Information Technology Systems Installation Methods Manual*. These manuals provide practices and methods by which many of the requirements of this standard are implemented. Other references are provided in Annex P.

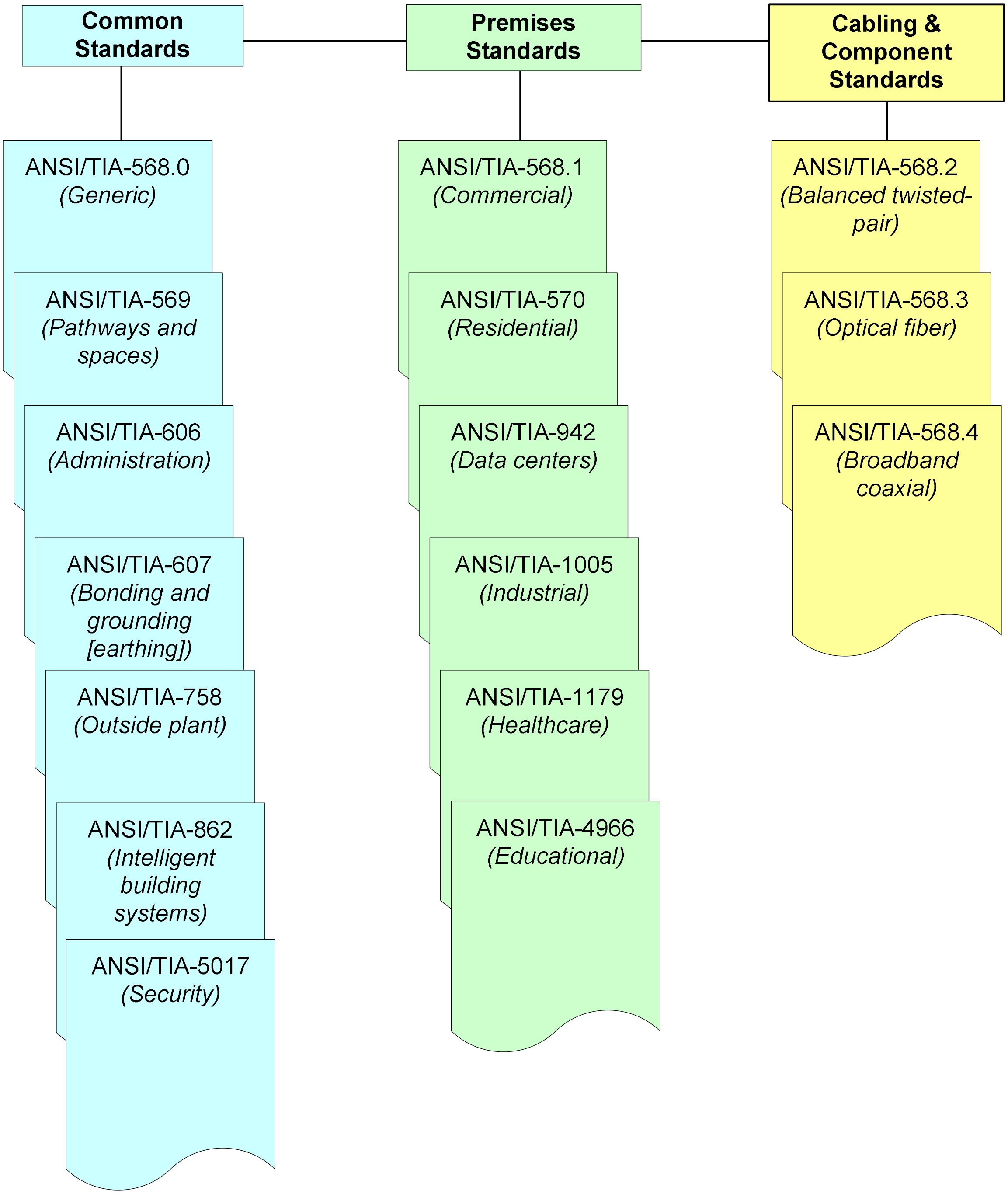


Figure i - Illustrative relationship between the TIA-568 series and other relevant TIA standards

Annexes

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

Introduction

This Standard provides requirements for 100 Ω category 3, category 5e, category 6, category 6A and category 8 balanced twisted-pair cabling and components and for the test procedures used to verify the performance of installed cabling.

Purpose

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

The purpose of this Standard is to enable the planning and installation of a structured cabling system. 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.

Stewardship

Telecommunications infrastructure affects raw material consumption. The infrastructure design and installation methods also influence product life and sustainability of electronic equipment life cycling. These aspects of telecommunications infrastructure impact our environment. Since building life cycles are typically planned for decades, technological electronic equipment upgrades are necessary. The telecommunications infrastructure design and installation process magnifies the need for sustainable infrastructures with respect to building life, electronic equipment life cycling and considerations of effects on environmental waste. Telecommunications designers are encouraged to research local building practices for a sustainable environment and conservation of fossil fuels as part of the design process.

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 dimensions in this Standard are metric or US customary with approximate conversion to the other.

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 (channels and permanent links) and components (cable, connectors, connecting hardware, 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 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-84-608-2010, *Telecommunications Cable, Filled Polyolefin Insulated Copper Conductor*

ANSI/ICEA S-90-661-2012, *Category 3, 5, & 5e Individually Unshielded Twisted Pair Indoor Cable for Use In General Purpose and LAN Communication Wiring Systems*

ANSI/ICEA S-118-746 (draft) *Standard for Category 8, 100 Ohm Indoor Cables for Use In LAN Communication Wiring Systems.*

ANSI/NEMA WC 66/ICEA S-116-732-2013, *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*

ANSI/TIA-568.0-D 2015, *Generic Telecommunications Cabling for Customer Premises*

ANSI/TIA-568.3-D 2016, *Optical Fiber Cabling and Components Standard*

ANSI/TIA-570-C 2012, *Residential Telecommunications Cabling Standard*

ANSI/TIA-606-B 2012, *Administration Standard for Telecommunications Infrastructure*

ANSI/TIA-1152-A 2016, *Requirements for Field Test Instruments and Measurements for Balance Twisted-Pair Cabling,*

ANSI/TIA-1183-A, *Measurement Methods And Test Fixtures For Balun-less Measurements Of Balanced Components And Systems,* draft

ASTM D4565-2015, *Standard Test Methods For Physical And Environmental Performance Properties of Insulations And Jackets For Telecommunications Wire And Cable*

ASTM D4566-2014, *Standard Test Methods for Electrical Performance Properties of Insulations and Jackets for 640 Telecommunications Wire and Cable*

IEC 60189-1:2007, *Low-Frequency Cables and Wires with PVC Insulation and PVC Sheath - Part 1: General Test and Measuring Methods*

IEC 60352-2:2006, *Solderless Connections - Part 2: Crimped Connections - General Requirements, Test 642 Methods and Practical Guidance*

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 60352-5:2012, *Solderless Connections - Part 5: Press-in Connections - General Requirements, Test 648 Methods and Practical Guidance*

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 60352-8:2011, *Solderless connections - Part 8: Compression Mount Connections - General Requirements, Test Methods and Practical Guidance*, pending publication

IEC 60603-7:2011*, Connectors for Electronic Equipment - Part 7: Detail Specification for 8-way, Unshielded, Free and Fixed Connectors*

IEC 60603-7-1:2011, *Connectors for Electronic Equipment - Part 7-1: Detail Specification for 8-way, Shielded, Free and Fixed Connectors*

IEC 60603-7-2:2010, *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*

IEC 60603-7-3:2010, *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*

IEC 60603-7-4:2010, *Connectors for Electronic Equipment – Part 7-4: Detail Specification for 8-way, Unshielded, Free and Fixed Connectors, for Data Transmissions with Frequencies up to 250 MHz*

IEC 60603-7-5:2010, *Connectors for Electronic Equipment – Part 7-5: Detail Specification for 8-way, Shielded, Free and Fixed Connectors, for Data Transmissions with Frequencies up to 250 MHz*

IEC 60603-7-41:2010, *Connectors for Electronic Equipment – Part 7-41: Detail Specification for 8-way, Unshielded, Free and Fixed Connectors, for Data Transmissions with Frequencies up to 500 MHz*

IEC 60603-7-51:2010, *Connectors for Electronic Equipment – Part 7-51: Detail Specification for 8-way, Shielded, Free and Fixed Connectors, for Data Transmissions with Frequencies up to 500 MHz*

IEC 60603-7-81:2015, *Connectors for Electronic Equipment - Part 7-81: Detail Specification for 8-way, Shielded, Free and Fixed Connectors, for Data Transmissions with Frequencies up to 2000 MHz*

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

IEC 62153-4-3:2013, *Metallic Communication Cables Test Methods – Part 4-3: Electromagnetic Compatibility (EMC) – Surface Transfer Impedance – Triaxial Method*

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

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

IEC 62153-4-13: 2009, Metallic Communication Cable Test Methods - Part 4-13: Electromagnetic Compatibility (EMC) - Coupling Attenuation of Links and Channels (Laboratory Conditions) - Absorbing Clamp Method

IEC 62153-4-14: 2012, Metallic Communication Cable Test Methods - Part 4-14: Electromagnetic Compatibility (EMC) - Coupling Attenuation of Cable Assemblies (Field Conditions) - Absorbing Clamp Method

IEC 62153-4-15: 2015, Metallic Communication Cable Test Methods - Part 4-15: Electromagnetic Compatibility (EMC) - Test Method for Measuring Transfer Impedance and Screening Attenuation or Coupling Attenuation with Triaxial Cell

IEEE Std 802.3™-2012, *IEEE Standard for Ethernet*

TIA TSB-155-A 2010, *Guidelines for the Assessment and Mitigation of Installed Category 6 Cabling to Support 681 10GBASE-T* (Informative)

TIA TSB-184-A, *Guidelines for Supporting Power Delivery over Balanced Twisted-Pair Cabling*, 2017 (Informative)

UL 444 2008, *Communication Cables*

ANSI/TIA-568.2-D

TIA TSB-5019, *High Performance Structured Cabling Use Cases for Data Centers and Other Premises*, 2015 (Informative)

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: A group of cables that are tied together or in contact with one another in a closely packed configuration for at least 1 m (3.28 ft).

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: 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.

direct attach: A reduced length channel definition that includes plug connectors at the beginning and end of the channel and does not contain connecting hardware within the channel.

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.

equipment outlet: outermost connection facility in a hierarchical star topology.

equipment outlet connector: Connecting hardware contained within the equipment outlet.

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: A contact suitable for making an electrical connection with an insulated conductor.

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.

modular plug terminated link: a type of link terminated with a modular plug on one end.

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
AFEXT	Alien far-end crosstalk
ANSI	American National Standards Institute
CM	Common mode
DM	Differential mode
DMCM	Differential mode plus common mode
DPMF	Direct plug measurement fixture
DUT	Device under test
EIA	Electronic Industries Alliance
ELTCTL	Equal level transverse conversion transfer loss
EO	Equipment outlet
FEXT	Far-end crosstalk
F/UTP	Foil (surrounding) unscreened twisted-pairs
ICEA	Insulated Cable Engineers Association
IDC	Insulation displacement contact
IEC	International Electrotechnical Commission
IPC	Insulation piercing connection
MPTL	Modular plug terminated link.
NEXT	Near-end crosstalk
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
MHz	megahertz
m	meter
mm	millimeter
mV	millivolt
N	newton
Ω	ohm
pF	picofarad
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, 6A and 8 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 and as high as 40GBASE-T over up to 30 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, 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				
		Cat 3 1)	Cat 5e	Cat 6	Cat 6A	Cat 8 2)
Modular Plug & Cord Performance	Cat 3 1)	Cat 3	Cat 3	Cat 3	Cat 3	Cat 3
	Cat 5e	Cat 3	Cat 5e	Cat 5e	Cat 5e	Cat 5e
	Cat 6	Cat 3	Cat 5e	Cat 6	Cat 6	Cat 6
	Cat 6A	Cat 3	Cat 5e	Cat 6	Cat 6A	Cat 6A
	Cat 8	Cat 3	Cat 5e	Cat 6	Cat 6A	Cat 8

1) Category 3 plug performance requirements are not specified and are assumed to be less restrictive than category 5e.
2) When measuring category 8 cabling for backwards compatibility for lower categories of TCL, the Category 8 TCL limits shall be applied.

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 8: This designation applies to 100 Ω balanced twisted-pair cabling and components whose transmission characteristics are specified from 1 to 2000 MHz. See TIA TSB-5019 for possible cases where Category 8 may be deployed in data centers and other premises.

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 has been superseded by category 5e and is no longer recognized by this standard. Category 5 transmission characteristics, used in “legacy” cabling installations, are provided for reference in Annex O.

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 (cabling subsystem 1) mechanical performance

Horizontal cable shall consist of four balanced twisted-pairs of 22 AWG to 24 AWG thermoplastic insulated solid copper conductors enclosed by a thermoplastic jacket. Copper clad aluminum is not allowed. Horizontal cables shall comply with the mechanical performance requirements, testing and test methods in ANSI/ICEA S-90-661 for category 3, ANSI/ICEA S-90-661 for category 5e, ANSI/NEMA WC 66/ICEA S-116-732 for category 6, and ANSI/NEMA WC 66/ICEA S-116-732 for category 6A. Category 8 horizontal cables shall comply with the mechanical performance requirements, testing and test methods specified in ANSI/ICEA S-118-746 (draft).

In addition to the applicable requirements of ANSI/ICEA S-90-661-2006 and ANSI/NEMA WC 66/ICEA S-116-732, and ANSI/ICEA S-118-746 (draft) the physical design of category 3, 5e, 6,6A and category 8 horizontal cables shall meet the additional requirements of this clause.

5.3.1 Insulated conductor

The diameter of the insulated conductor shall be 1.64 mm (0.065 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. Pairs may or may not have individual pair shields.

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 or White Blue	(W-BL) (BL)
Pair 2	White-Orange or White Orange	(W-O) (O)
Pair 3	White-Green or White Green	(W-G) (G)
Pair 4	White-Brown or White 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 Horizontal 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 Horizontal cable 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 Horizontal cable 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, insulation, 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 should be considered.

5.3.7 Horizontal cable 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 Horizontal cable core wrap

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

5.3.9 Horizontal cable 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 6.6.23.

5.3.10 Horizontal cable dielectric strength

The cable shall meet the dielectric strength requirements of UL-444.

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 Cord cable general

Cord cable shall consist of four balanced twisted-pairs of 22 AWG to 28 AWG thermoplastic insulated solid or stranded conductors enclosed by a thermoplastic jacket. Copper clad aluminum shall not be used. 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/NEMA WC 66/ICEA S-116-732 for category 6, ANSI/NEMA WC 66/ICEA S-116-732 for category 6A and ANSI/ICEA S-118-746 (draft) for category 8. Cord cables used for 100 Ω screened cords and cross-connect jumpers shall be enclosed by a shield meeting the requirements of clauses 5.3.9, 5.3.10, and 6.6.23. Refer to Annex G for 28 AWG cord cable characteristics.

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 (cabling subsystem 2 and 3) 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 copper 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-90-661-2012 for category 3, ANSI/ICEA S-90-661-2012 for category 5e, ANSI/NEMA WC 66/ICEA S-116-732 for category 6, and ANSI/NEMA WC 66/ICEA S-116-732 for category 6A.

5.6.1 Backbone cable insulated conductor

The diameter of the insulated conductor shall be 1.64 mm (0.065 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-90-661-2012 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-90-661-2012. 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-90-661-2012 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

The cable shall meet the dielectric strength requirements of UL-444.

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):

$$R = 62.5/D \tag{1}$$

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 6.6.23.

5.7 Connecting hardware mechanical performance

5.7.1 Connecting hardware environmental compatibility

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

5.7.2 Connecting hardware 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 Connecting hardware 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 Connecting hardware 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-C,
d) a means to use standard colors as specified in ANSI/TIA/EIA-606-C 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:

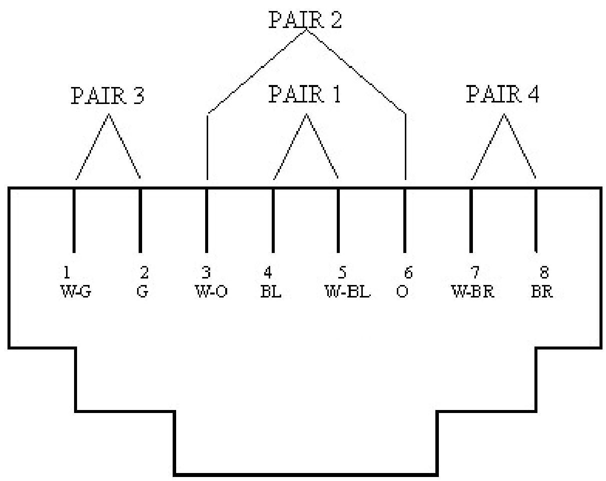
a) appropriate mechanical termination means for horizontal cable runs, and
b) a means of conductor identification to promote pin-pair practices consistent with clause 5.7.5.

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.

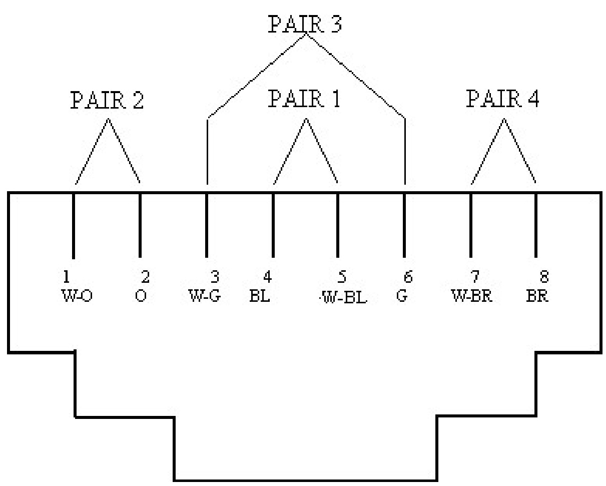
5.7.5 Work area telecommunications/equipment outlet/connector

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, 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. Pin/pair assignments shall be as shown in Figure 1 or 2. 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)

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 “3” for category 3 components

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

“cat 6” or “6” for category 6 components

“cat 6A” or “6A” for category 6A components

“cat 8” or “8” for category 8 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 Connecting hardware 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 Connecting hardware 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 Connecting hardware shield continuity (screened only)

Effective shielding requires that all cabling components be shielded, meeting the requirements for transfer impedance given in clause 6.10.21 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 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 Cords and jumpers 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). 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 Cords and jumpers 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, 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, direct attach channels, permanent links, cables, cords, and connecting hardware. This clause describes the transmission parameters and develops the applicable generic equations for each parameter. All requirements apply at both ends or in both directions.

The test methods in Annex C, for balun based measurements, or in Annex D, for balun-less measurements, may be used.

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.

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.

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.

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.

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

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.

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).

$$ACRF_{k,i} = FEXT_{k,i} - IL_k \text{ dB} \quad (3)$$

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.

$$PSACRF_k = -10\log\left(\sum_{i=1, i\neq k}^{n} 10^{-\frac{FEXT_{k,i}}{10}}\right) - IL_k \text{ dB} \quad (4)$$

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.

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.

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.

6.1.10 Coupling attenuation

Coupling attenuation is 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 2000 MHz depending on the Category of cable under test 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.

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.

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.

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

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.

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).

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

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.

$$PSAFEXT_k = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{4} 10^{-\frac{AFEXT_{k,i,j}}{10}}\right) \text{ dB} \quad (8)$$

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 and category 8 connecting hardware AFEXT loss shall be measured in accordance with Annex C or D.

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 N 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.

$$PSAACRF_k = PSAFEXT_k - IL_k \text{ dB} \quad (9)$$

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:

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

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

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

where:

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

$PSAACRF_k$ 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.

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).

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

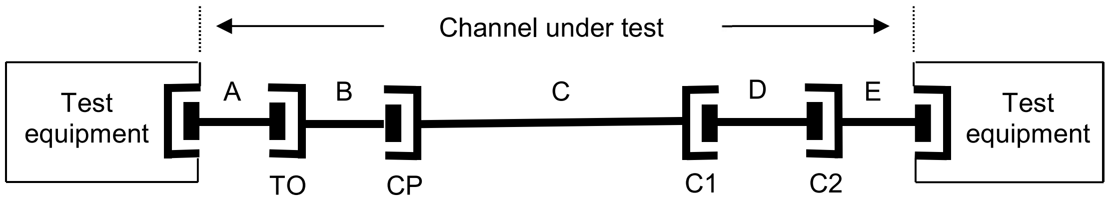
where:

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

6.2 Channel configurations

6.2.1 Category 3 through category 6A channel configuration

This clause contains the transmission performance specifications for balanced twisted-pair channels. The channel test configuration is illustrated in figure 3. See Annex L for worst case modeling configurations.



Legend

Cables and cords
Work area cord .... A
Optional consolidation point cabling . B
Horizontal cabling C
Patch cord or jumper cable............... D
Telecommunications room equipment cord.......................... E

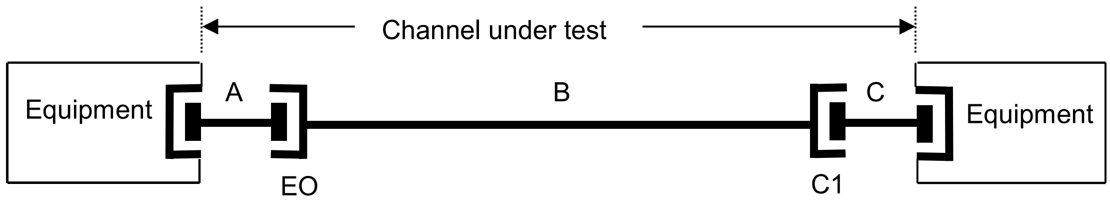
Connecting hardware
Telecommunications outlet/ connector ....TO
Optional consolidation point connector ....CP
Horizontal cross-connect or interconnect C1, C2

Maximum length
B + C.................................... 90 m (295 ft)
A + D + E .... 10 m (32.8 ft)

Figure 3 - Supplemental schematic representation of a channel test configuration

6.2.2 Category 8 channel configuration

The channel test configuration is defined by this clause.



Legend

Cables and cords
Equipment cord............................A, C
Horizontal cabling ....B

Connecting hardware
Equipment Outlet ....EO
Interconnect C1

Maximum length

A + C .... see table 4
B .... 24 m (79 ft)

Figure 4 - Supplemental schematic representation of a category 8 channel configuration

Horizontal Channel topology shall consist of a maximum of two connectors, horizontal cable and two equipment cords as shown in Figure 4.

For the maximum (24 m) permanent link length, the maximum total patch cord length is based upon the insertion loss de-rating of the modular cord cable when compared to the horizontal cable insertion loss. This de-rating factor is generally based upon the wire gauge (AWG) of the conductors used in the modular cord cable. Typically 22/23 AWG conductors have a 0% de-rating factor, 24 AWG conductors have a 20% de-rating factor, and 26 AWG conductors have a 50% de-rating factor. The maximum total length of equipment cords for a channel built from a 24 m permanent link are shown in Table 4.

Table 4 - Equipment cord de-rating and allowed length for 24 m permanent Link

Equipment cord de-rating factor (%)	length of cordage allowed (m)
0	7.2
20	6
50	4.8

6.3 Channel transmission performance

6.3.1 Category 3 through category 6A dc loop resistance

DC loop resistance for category 3, 5e, 6, and 6A channels shall not exceed 25 Ω at any temperature from 20 °C to 60 °C. Refer to TIA TSB-184-A for additional information on channel resistance related to guidance on delivering power.

6.3.2 Category 8 channel dc loop resistance

DC loop resistance for category 8 channels shall not exceed 6.4 Ω when measured at 20 °C or corrected to a temperature of 20 °C using the correction factors specified in ASTM-D4566. Using a temperature coefficient of resistance of 0.00393 for copper, the resistance at 60 °C is 7.22 Ω. Refer to TIA TSB-184-A for additional information on channel resistance related to guidance on delivering power.

6.3.3 Channel dc resistance unbalance

DC resistance unbalance shall be calculated for each pair of the channel in accordance with equation (14). This requirement is satisfied if the result of equation 14 is less than 3 % or if the difference between R1 and R2 is less than 200 mΩ. DC resistance unbalance is not specified for category 3 channels.

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

where:

R_1 is the dc resistance of conductor 1.

R_2 is the dc resistance of conductor 2.

6.3.4 Channel dc resistance unbalance between pairs

For categories 3 through 6A, dc resistance unbalance between pairs is not specified. Guidelines are provided in TIA TSB-184-A.

For Category 8, dc resistance unbalance between pairs shall be calculated for the channel in accordance with equation (15) This requirement is satisfied if the result of equation (15) is less than 7 % or if the difference between R_{P1} and R_{P2} is less than 50 mΩ. This applies to all 6 combinations of any 2 of the 4 pairs.

For the purposes of field testing, whenever the difference between R_{P1} and R_{P2} is less than 200 mΩ, the DC resistance unbalance requirement between pairs is met.

$$Resistance\_Unbalance_{Between\_pairs} = \left(\frac{|R_{P1} - R_{P2}|}{R_{P1} + R_{P2}}\right)100\% \tag{15}$$

Where:

R_{P1} is the dc parallel resistance of the conductors of a pair.

R_{P2} is the dc parallel resistance of the conductors of another pair.

The resistance for any pair PX may be calculated from individual conductor resistance values using equation (16).

$$R_{PX} = \frac{(R_{C1} R_{C2})}{(R_{C1} + R_{C2})} \tag{16}$$

6.3.5 Channel mutual capacitance

Mutual capacitance is not specified for channels.

6.3.6 Channel capacitance unbalance: pair-to-ground

Capacitance unbalance is not specified for channels.

6.3.7 Channel characteristic impedance and structural return loss (SRL)

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

6.3.8 Channel return loss

Channel return loss shall meet or exceed the values determined using the equations shown in Table 5 for all specified frequencies.

Table 5 - Channel return loss

	Frequency (MHz)	**Return loss (dB)**
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f < 20$ $20 \le f \le 100$	17 $17 - 10\log(f/20)$
Category 6	$1 \le f < 10$ $10 \le f < 40$ $40 \le f \le 250$	19 $24\text{-}5\log(f)$ $32\text{-}10\log(f)$
Category 6A	$1 \le f < 10$ $10 \le f < 40$ $40 \le f < 398.1$ $398.1 \le f \le 500$	19 $24\text{-}5\log(f)$ $32\text{-}10\log(f)$ 6
Category 8	$1 \le f < 10$ $10 \le f < 40$ $40 \le f < 130$ $130 \le f < 1000$ $1000 \le f \le 2000$	19.0 $24\text{-}5\log(f)$ 16.0 $35\text{-}9\log(f)$ 8 dB

The channel return loss values in Table 6 are provided for information only.

Table 6 - Minimum channel return loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	17.0	19.0	19.0	19.0
4.00	17.0	19.0	19.0	19.0
8.00	17.0	19.0	19.0	19.0
10.00	17.0	19.0	19.0	19.0
16.00	17.0	18.0	18.0	18.0
20.00	17.0	17.5	17.5	17.5
25.00	16.0	17.0	17.0	17.0
31.25	15.1	16.5	16.5	16.5
62.50	12.1	14.0	14.0	16.0
100.00	10.0	12.0	12.0	16.0
200.00	-	9.0	9.0	14.3
250.00	-	8.0	8.0	13.4
300.00	-	-	7.2	12.7
400.00	-	-	6.0	11.6
500.00	-	-	6.0	10.7
600.00	-	-	-	10.0
1000.00	-	-	-	8.0
1500.00	-	-	-	8.0
2000.00	-	-	-	8.0

6.3.9 Channel insertion loss

Channel insertion loss limits are derived from equation (17).

$$InsertionLoss_{channel} = 4(InsertionLoss_{conn}) + (InsertionLoss_{cable}) + ILD_{channel}\ dB \quad (17)$$

where:

$$InsertionLoss_{cable} = 1.02 \cdot InsertionLoss_{cable,100m}\ dB, \quad (18)$$

$InsertionLoss_{cable,100m}$ is the insertion loss of 100m of the appropriate category of cable, see clause 6.6.8,

$InsertionLoss_{conn}$ is the insertion loss of the appropriate category of connecting hardware, see clause 6.10.8, and

$$ILD_{channel} = 0\ dB \text{ for category 3 and 5e channels} \quad (19)$$

$$ILD_{channel} = 0.0003 f^{1.5}\ dB \text{ for category 6 channels} \quad (20)$$

$$ILD_{channel} = 0.03(1.82\sqrt{f} + 0.091f + \frac{0.25}{\sqrt{f}})$$ *dB* for category 6A channels (21)

where,

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

NOTES,
1 The Insertion loss of the channel allows for a 20% increase of insertion loss 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-A).

Category 8 Channel insertion loss limits are derived from the modeling equation (22).

$$InsertionLoss_{channel} = 2(InsertionLoss_{conn}) + B(InsertionLoss_{cable\_30m}) + ILD_{channel}$$ *dB* (22)

Where:

B is the insertion loss scaling factor for horizontal cable including a 20% equipment cord de-rating for 6 m of cord cable and including 24 m of horizontal cable as shown in equation (23).

$$B = 1.2 \times 6/100 + 24/100 = 0.312$$ (23)

And:

$InsertionLoss_{cable\_30m}$ is the insertion loss of the horizontal cable, see clause 6.6.8.

And:

$InsertionLoss_{conn}$ is the insertion loss of the connecting hardware, see clause 6.10.8.

$ILD_{channel}$ is the insertion loss deviation allowance for a channel, see equation (24).

$$ILD_{channel} = 0.0324\sqrt{f}$$ *dB* for category 8 channels (24)

NOTES:
1 Table 7 allows a 20% de-rating of insertion loss 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.

Channel insertion loss shall meet or be less than the values determined using the equations shown in Table 7 for all specified frequencies.

Table 7 - Channel insertion loss

	Frequency (MHz)	Insertion loss (dB)
Category 3	$1 \le f \le 16$	$1.02(2.32\sqrt{f} + 0.238f) + 4 \cdot 0.1\sqrt{f}$
Category 5e	$1 \le f \le 100$	$1.02(1.967\sqrt{f} + 0.023f + \frac{0.05}{\sqrt{f}}) + 4 \cdot 0.04\sqrt{f}$
Category 6	$1 \le f \le 250$	$1.02(1.808\sqrt{f} + 0.017f + \frac{0.2}{\sqrt{f}}) + 4 \cdot 0.02\sqrt{f} + 0.0003 \cdot f^{1.5}$
Category 6A	$1 \le f \le 500$	$1.05(1.82\sqrt{f} + 0.0091f + \frac{0.25}{\sqrt{f}}) + 4 \cdot 0.02\sqrt{f}$
Category 8	$1 \le f \le 2000$	$0.312(1.80\sqrt{f} + 0.005f + \frac{0.25}{\sqrt{f}}) + 2IL_{conn} + 0.0324\sqrt{f}$
Note: See clause 6.10.8 for Category 8 connector insertion loss ILconn.		

The channel insertion loss values in Table 8 are provided for information only.

Table 8 - Maximum channel insertion loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	3.0	2.2	2.1	2.3	3.0
4.00	6.5	4.5	4.0	4.2	3.0
8.00	9.8	6.3	5.7	5.8	3.0
10.00	11.2	7.1	6.3	6.5	3.0
16.00	14.9	9.1	8.0	8.2	3.0
20.00	-	10.2	9.0	9.2	3.0
25.00	-	11.4	10.1	10.2	3.2
31.25	-	12.9	11.4	11.5	3.6
62.50	-	18.6	16.5	16.4	5.1
100.00	-	24.0	21.3	20.9	6.5
200.00	-	-	31.5	30.1	9.3
250.00	-	-	35.9	33.9	10.4
300.00	-	-	-	37.4	11.5
400.00	-	-	-	43.7	13.3
500.00	-	-	-	49.3	15.0
600.00	-	-	-	-	16.5
1000.00	-	-	-	-	22.0
1500.00	-	-	-	-	27.7
2000.00	-	-	-	-	32.7

6.3.10 Channel NEXT loss

Channel NEXT loss shall meet or exceed the values determined using the equations shown in Table 9 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, 6A and 8 channel NEXT loss values greater than 65 dB shall revert to a requirement of 65 dB minimum.

Table 9 - Channel NEXT loss

	Frequency (MHz)	**NEXT loss (dB)**
Category 3	$1 \le f \le 16$	$-20\log\left(10^{\frac{-(23.2-15\log(f/16))}{20}} + 2\cdot 10^{\frac{-(33.9-20\log(f/16))}{20}}\right)$
Category 5e	$1 \le f \le 100$	$-20\log\left(10^{\frac{-(35.3-15\log(f/100))}{20}} + 2\cdot 10^{\frac{-(43-20\log(f/100))}{20}}\right)$
Category 6	$1 \le f \le 250$	$-20\log\left(10^{\frac{-(44.3-15\log(f/100))}{20}} + 2\cdot 10^{\frac{-(54-20\log(f/100))}{20}}\right)$
Category 6A	$1 \le f < 330$	$-20\log\left(10^{\frac{-(44.3-15\log(f/100))}{20}} + 2\cdot 10^{\frac{-(54-20\log(f/100))}{20}}\right)$
	$330 \le f \le 500$	$31 - 27.15\log(f/330)$
Category 8	$1 \le f \le 440$	$-20\log\left(10^{\frac{-(45.3-15\log(f/100))}{20}} + 2\cdot 10^{\frac{-(54-20\log(f/100))}{20}}\right)$
	$440 < f \le 2000$	$-20\log\left(10^{\frac{-(45.3-15\log(f/100))}{20}} + 2\cdot 10^{\frac{-(39.12-36.14\log(f/500))}{20}}\right)$

The channel NEXT loss values in Table 10 are provided for information only.

Table 10 - Minimum channel NEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	39.1	60.0	65.0	65.0	65.0
4.00	29.3	53.5	63.0	63.0	63.8
8.00	24.3	48.6	58.2	58.2	58.9
10.00	22.7	47.0	56.6	56.6	57.3
16.00	19.3	43.6	53.2	53.2	53.9
20.00	-	42.0	51.6	51.6	52.3
25.00	-	40.3	50.0	50.0	50.7
31.25	-	38.7	48.4	48.4	49.1
62.50	-	33.6	43.4	43.4	44.0
100.00	-	30.1	39.9	39.9	40.5
200.00	-	-	34.8	34.8	35.3
250.00	-	-	33.1	33.1	33.6
300.00	-	-	-	31.7	32.3
400.00	-	-	-	28.7	30.1
500.00	-	-	-	26.1	27.9
600.00	-	-	-	-	25.7
1000.00	-	-	-	-	19.3
1500.00	-	-	-	-	13.9
2000.00	-	-	-	-	9.8

6.3.11 Channel PSNEXT loss

Channel PSNEXT loss shall meet or exceed the values determined using the equations shown in Table 11 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, 6A and 8 channel PSNEXT loss values greater than 62 dB shall revert to a requirement of 62 dB minimum.

Table 11 - Channel PSNEXT loss

	Frequency (MHz)	**PSNEXT loss (dB)**
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f \le 100$	$-20\log\left(10^{\frac{-(32.3-15\log(f/100))}{20}}+2\cdot 10^{\frac{-(40-20\log(f/100))}{20}}\right)$
Category 6	$1 \le f \le 250$	$-20\log\left(10^{\frac{-(42.3-15\log(f/100))}{20}}+2\cdot 10^{\frac{-(50-20\log(f/100))}{20}}\right)$
Category 6A	$1 \le f < 330$	$-20\log\left(10^{\frac{-(42.3-15\log(f/100))}{20}}+2\cdot 10^{\frac{-(50-20\log(f/100))}{20}}\right)$
	$330 \le f \le 500$	$28 - 26.43\log(f/330)$
Category 8	$1 \le f \le 500$	$-20\log\left(10^{\frac{-(42.3-15\log(f/100))}{20}}+2\cdot 10^{\frac{-(50.0-20\log(f/100))}{20}}\right)$
	$500 < f \le 2000$	$-20\log\left(10^{\frac{-(42.3-15\log(f/100))}{20}}+2\cdot 10^{\frac{-(35.95-34.85\log(f/500))}{20}}\right)$

The channel PSNEXT loss values in Table 12 are provided for information only.

Table 12 - Minimum channel PSNEXT loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	57.0	62.0	62.0	62.0
4.00	50.5	60.5	60.5	60.5
8.00	45.6	55.6	55.6	55.6
10.00	44.0	54.0	54.0	54.0
16.00	40.6	50.6	50.6	50.6
20.00	39.0	49.0	49.0	49.0
25.00	37.3	47.3	47.3	47.3
31.25	35.7	45.7	45.7	45.7
62.50	30.6	40.6	40.6	40.6
100.00	27.1	37.1	37.1	37.1
200.00	-	31.9	31.9	31.9
250.00	-	30.2	30.2	30.2
300.00	-	-	28.8	28.8
400.00	-	-	25.8	26.6
500.00	-	-	23.2	24.8
600.00	-	-	-	22.7
1000.00	-	-	-	16.5
1500.00	-	-	-	11.2
2000.00	-	-	-	7.3

6.3.12 Channel FEXT loss

FEXT loss is not specified for channels.

6.3.13 Channel ACRF

Channel ACRF shall meet or exceed the values determined using the equations shown in Table 13 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. For measurement purposes, calculations that result in category 8 channel ACRF loss values greater than 65 dB shall revert to a requirement of 65 dB minimum.

Table 13 - Channel ACRF

	Frequency (MHz)	**ACRF (dB)**
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f \le 100$	$-20\log\left(10^{\frac{-(23.8-20\log(f/100))}{20}}+4\cdot 10^{\frac{-(35.1-20\log(f/100))}{20}}\right)$
Category 6	$1 \le f \le 250$	$-20\log\left(10^{\frac{-(27.8-20\log(f/100))}{20}}+4\cdot 10^{\frac{-(43.1-20\log(f/100))}{20}}\right)$
Category 6A	$1 \le f \le 500$	$-20\log\left(10^{\frac{-(27.8-20\log(f/100))}{20}}+4\cdot 10^{\frac{-(43.1-20\log(f/100))}{20}}\right)$
Category 8	$1 \le f \le 2000$	$-20\log\left(10^{\frac{-(39.0-20\cdot\log(f/100))}{20}}+2\cdot 10^{\frac{-(43.1-20\cdot\log(f/100))}{20}}\right)$

The channel ACRF values in Table 14 are provided for information only.

Table 14 - Minimum channel ACRF

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	57.4	63.3	63.3	65.0
4.00	45.4	51.2	51.2	59.9
8.00	39.3	45.2	45.2	53.9
10.00	37.4	43.3	43.3	52.0
16.00	33.3	39.2	39.2	47.9
20.00	31.4	37.2	37.2	45.9
25.00	29.4	35.3	35.3	44.0
31.25	27.5	33.4	33.4	42.1
62.50	21.5	27.3	27.3	36.0
100.00	17.4	23.3	23.3	32.0
200.00	-	17.2	17.2	25.9
250.00	-	15.3	15.3	24.0
300.00	-	-	13.7	22.4
400.00	-	-	11.2	19.9
500.00	-	-	9.3	18.0
600.00	-	-	-	16.4
1000.00	-	-	-	12.0
1500.00	-	-	-	8.4
2000.00	-	-	-	5.9

6.3.14 Channel PSFEXT loss

PSFEXT loss is not specified for channels.

6.3.15 Channel PSACRF

Channel PSACRF shall meet or exceed the values determined using the equations shown in Table 15 for all specified frequencies. Due to measurement considerations, for frequencies greater than 200 MHz category 8 channel PSACRF values that correspond to measured channel FEXT loss values of greater than 67 dB are for information only. For measurement purposes, calculations that result in category 8 channel PSACRF loss values greater than 62 dB shall revert to a requirement of 62 dB minimum.

Table 15 - 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	$1 \leq f \leq 500$	$-20\log\left(10^{\frac{-(24.8-20\log(f/100))}{20}}+4\cdot 10^{\frac{-(40.1-20\log(f/100))}{20}}\right)$
Category 8	$1 \leq f \leq 2000$	$-20\log\left(10^{\frac{-(36.0-20\log(f/100))}{20}}+2\cdot 10^{\frac{-(40.1-20\log(f/100))}{20}}\right)$

The channel PSACRF values in Table 16 are provided for information only.

Table 16 - Minimum channel PSACRF

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	54.4	60.3	60.3	62.0
4.00	42.4	48.2	48.2	56.9
8.00	36.3	42.2	42.2	50.9
10.00	34.4	40.3	40.3	49.0
16.00	30.3	36.2	36.2	44.9
20.00	28.4	34.2	34.2	42.9
25.00	26.4	32.3	32.3	41.0
31.25	24.5	30.4	30.4	39.1
62.50	18.5	24.3	24.3	33.0
100.00	14.4	20.3	20.3	29.0
200.00	-	14.2	14.2	22.9
250.00	-	12.3	12.3	21.0
300.00	-	-	10.7	19.4
400.00	-	-	8.2	16.9
500.00	-	-	6.3	15.0
600.00	-	-	-	13.4
1000.00	-	-	-	9.0
1500.00	-	-	-	5.4
2000.00	-	-	-	2.9

6.3.16 Channel TCL

Channel TCL shall meet or exceed the values determined using the equations shown in Table 17 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.

Table 17 - Channel TCL

	Frequency (MHz)	TCL (dB)[2,3]
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	$1 \leq f \leq 500$	$50 - 15\log(f)$
Category 8	$1 \leq f \leq 2000$	$23 - 17\log(f/100)$

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.

2 Calculations that result in category 8 channel TCL values greater than 40 dB shall revert to a requirement of 40 dB minimum.

3 Calculations that result in category 8 channel TCL values less than 3 dB shall revert to a requirement of 3 dB minimum.

The channel TCL values in Table 18 are provided for information only.

Table 18 - Minimum channel TCL

Frequency (MHz)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	40.0	40.0	40.0
4.00	40.0	40.0	40.0
8.00	36.5	36.5	40.0
10.00	35.0	35.0	40.0
16.00	31.9	31.9	36.5
20.00	30.5	30.5	34.9
25.00	29.0	29.0	33.2
31.25	27.6	27.6	31.6
62.50	23.1	23.1	26.5
100.00	20.0	20.0	23.0
200.00	15.5	15.5	17.9
250.00	14.0	14.0	16.2
300.00	-	12.8	14.9
400.00	-	11.0	12.8
500.00	-	9.5	11.1
600.00	-	-	9.8
1000.00	-	-	6.0
1500.00	-	-	3.0
2000.00	-	-	3.0

6.3.17 Channel TCTL

TCTL is not specified for channels.

6.3.18 Channel ELTCTL

Channel ELTCTL shall meet or exceed the values determined using the equations shown in Table 19 for all specified frequencies.

Table 19 - 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
Category 8	$1 \leq f \leq 155$ $155 < f \leq 2000$	$46.8 - 20\log(f)$ 3
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 20 are provided for information only.

Table 20 - Minimum channel ELTCTL

Frequency (MHz)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	30.0	30.0	46.8
4.00	18.0	18.0	34.8
8.00	11.9	11.9	28.7
10.00	10.0	10.0	26.8
16.00	5.9	5.9	22.7
20.00	4.0	4.0	20.8
25.00	2.0	2.0	18.8
31.25	n/s	n/s	16.9
62.50	n/s	n/s	10.9
100.00	n/s	n/s	6.8
200.00	n/s	n/s	3.0
250.00	n/s	n/s	3.0
300.00	-	n/s	3.0
400.00	-	n/s	3.0
500.00	-	n/s	3.0
600.00	-	-	3.0
1000.00	-	-	3.0
1500.00	-	-	3.0
2000.00	-	-	3.0

6.3.19 Category 3 through 6A channel coupling attenuation

Category 3 through category 6A channel coupling attenuation is not specified.

6.3.20 Category 8 channel coupling attenuation

Channel coupling attenuation should meet or exceed the values determined using the equations shown in Table 21 for all specified frequencies. Compliance to these requirements is intended to be verified by laboratory measurements when measured using absorbing clamp method IEC 62153-4-13 or tri-axial method IEC 62153-4-15.

Compliance to this parameter in the field may be assured through careful adherence to installation best practices or when measured using absorbing clamp method IEC 62153-4-14.

Table 21 - Category 8 channel coupling attenuation

	Frequency (MHz)	Coupling attenuation (dB)
Category 8	$1 \leq f \leq 30$	n/s
	$30 < f \leq 100$	50
	$100 < f \leq 2000$	$50 - 20\log(f/100)$

The minimum channel coupling attenuation values in Table 22 are provided for information only.

Table 22 - Minimum Category 8 channel coupling attenuation

Frequency (MHz)	Category 8 (dB)
1.00	n/s
4.00	n/s
8.00	n/s
10.00	n/s
16.00	n/s
20.00	n/s
25.00	n/s
31.25	50.0
62.50	50.0
100.00	50.0
200.00	44.0
250.00	42.0
300.00	40.5
400.00	38.0
500.00	36.0
600.00	34.4
1000.00	30.0
1500.00	26.5
2000.00	24.0

6.3.21 Channel propagation delay

Channel propagation delay shall meet or be less than the values determined using the equations shown in Table 23 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 for category 3 - 6A channels. For category 8 channels, channel propagation delay at 10 MHz shall not exceed 179 ns.

Table 23 - Channel propagation delay

	Frequency (MHz)	Propagation delay (ns)
Category 3	$1 \le f \le 16$	$(534 + \frac{36}{\sqrt{f}}) + (4 \cdot 2.5)$
Category 5e	$1 \le f \le 100$	$(534 + \frac{36}{\sqrt{f}}) + (4 \cdot 2.5)$
Category 6	$1 \le f \le 250$	$(534 + \frac{36}{\sqrt{f}}) + (4 \cdot 2.5)$
Category 6A	$1 \le f \le 500$	$(534 + \frac{36}{\sqrt{f}}) + (4 \cdot 2.5)$
Category 8	$1 \le f \le 2000$	$\left(\frac{32}{30}\right)(160 + \frac{11}{\sqrt{f}}) + (2 \times 2.5)$

The channel propagation delay values in Table 24 are provided for information only.

Table 24 - Maximum channel propagation delay

Frequency (MHz)	Category 3 (ns)	Category 5e (ns)	Category 6 (ns)	Category 6A (ns)	Category 8 (ns)
1.00	580	580	580	580	187.4
4.00	562	562	562	562	181.5
8.00	557	557	557	557	179.8
10.00	555	555	555	555	179.4
16.00	553	553	553	553	178.6
20.00	-	552	552	552	178.3
25.00	-	551	551	551	178.0
31.25	-	550	550	550	177.8
62.50	-	549	549	549	177.2
100.00	-	548	548	548	176.8
200.00	-	-	547	547	176.5
250.00	-	-	546	546	176.4
300.00	-	-	-	546	176.3
400.00	-	-	-	546	176.3
500.00	-	-	-	546	176.2
600.00	-	-	-	-	176.1
1000.00	-	-	-	-	176.0
1500.00	-	-	-	-	176.0
2000.00	-	-	-	-	175.9

6.3.22 Channel propagation delay skew

Category 3 through 6A channel propagation delay skew shall be less than 50 ns for all frequencies from 1 MHz to the upper frequency limit of the category. The delay skew of any given category 3 through 6A channel shall not vary by more than +/- 10 ns within this requirement due to environmental effects such as the daily temperature variation. 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. Channel propagation delay skew for category 8 channels shall be less than 17 ns for all frequencies from 1 MHz to 2000 MHz. The delay skew of any given category 8 channel shall not vary by more than +/- 3 ns within this requirement due to environmental effects such as the daily temperature variation.

6.3.23 Channel ANEXT loss

ANEXT loss is not specified for channels.

6.3.24 Channel PSANEXT loss

Channel PSANEXT loss shall meet or exceed the values determined using the equations shown in Table 25 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. For measurement purposes, calculations that result in category 8 channel PSANEXT loss values greater than 75 dB shall revert to a requirement of 75 dB minimum.

Table 25 - Channel PSANEXT loss

	Frequency (MHz)	**PSANEXT loss (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	$1 \le f < 100$ $100 \le f \le 500$	$60 - 10\log(f/100)$ $60 - 15\log(f/100)$ [1)]
Category 8	$1 \le f < 100$ $100 \le f \le 2000$	$85 - 10\log(f/100)$ $85 - 15\log(f/100)$

[1)] If the average insertion loss of all disturbed pairs at 100 MHz, $IL_{100MHz,avg}$, is less than 7 dB, over the frequency range from 100 to 500 MHz,, 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

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

The channel PSANEXT loss values in Table 26 are provided for information only.

Table 26 - Minimum channel PSANEXT loss

Frequency (MHz)	Category 6A (dB)	Category 8 (dB)
1.00	67.0	75.0
4.00	67.0	75.0
8.00	67.0	75.0
10.00	67.0	75.0
16.00	67.0	75.0
20.00	67.0	75.0
25.00	66.0	75.0
31.25	65.1	75.0
62.50	62.0	75.0
100.00	60.0	75.0
200.00	55.5	75.0
250.00	54.0	75.0
300.00	52.8	75.0
400.00	51.0	75.0
500.00	49.5	74.5
600.00	-	73.3
1000.00	-	70.0
1500.00	-	67.4
2000.00	-	65.5

6.3.25 Channel average PSANEXT loss

Channel average PSANEXT loss shall meet or exceed the values determined using the equations shown in Table 27 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. Average PSANEXT requirements are not specified for category 8 channels.

Table 27 - 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, over the frequency range from 100 to 500 MHz,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

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

The channel average PSANEXT loss values in Table 28 are provided for information only.

Table 28 - Minimum channel average PSANEXT loss

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

6.3.26 Channel AFEXT loss

AFEXT loss is not specified for channels.

6.3.27 Channel PSAFEXT loss

PSAFEXT loss is not specified for channels.

6.3.28 Channel PSAACRF

Channel PSAACRF shall meet or exceed the values determined using the equations shown in Table 29 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. Category 8 channel PSAACRF shall be for information only when the frequency is greater than 200 MHz and the channel PSAFEXT loss is greater than 80 dB.

Table 29 - Channel 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	$1 \le f \le 500$	$37 - 20\log(f/100)$
Category 8	$1 \le f \le 2000$	$61 - 20\log(f/100)$
1 Calculations that result in category 8 channel PSAACRF values greater than 75 dB shall revert to a requirement of 75 dB minimum.		

The channel PSAACRF values in Table 30 are provided for information only.

Table 30 - Minimum channel PSAACRF

Frequency (MHz)	Category 6A (dB)	Category 8 (dB)
1.00	67.0	75.0
4.00	65.0	75.0
8.00	58.9	75.0
10.00	57.0	75.0
16.00	52.9	75.0
20.00	51.0	75.0
25.00	49.0	73.0
31.25	47.1	71.1
62.50	41.1	65.1
100.00	37.0	61.0
200.00	31.0	55.0
250.00	29.0	53.0
300.00	27.5	51.5
400.00	25.0	49.0
500.00	23.0	47.0
600.00	-	45.4
1000.00	-	41.0
1500.00	-	37.5
2000.00	-	35.0

6.3.29 Channel average PSAACRF

Channel average PSAACRF for category 6A shall meet or exceed the values determined using the equations shown in Table 31 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.
Average PSAACRF requirements are not specified for category 3 through 6 or category 8 channels.

Table 31 - Channel average PSAACRF

	Frequency (MHz)	Average PSAACRF (dB)
Category 6A	$1 \le f \le 500$	$41 - 20\log(f/100)$

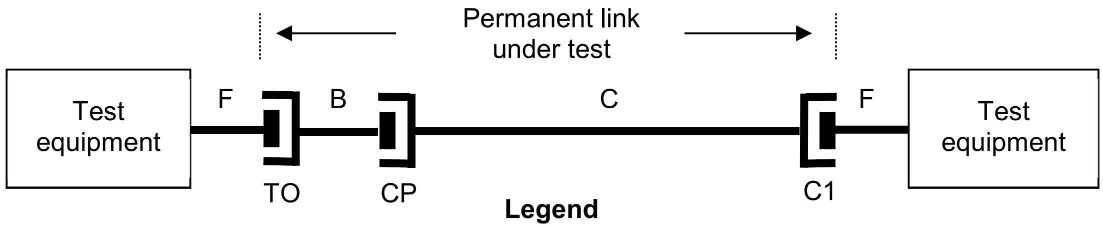
The channel average PSAACRF values in Table 32 are provided for information only.

Table 32 - Minimum category 6A channel average PSAACRF

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

6.4 Permanent link transmission performance

This clause contains the transmission performance specifications for balanced twisted-pair permanent links. The category 3 through 6A permanent link test configuration is illustrated in figure 5. See Annex L for worst case modeling configurations.



Legend

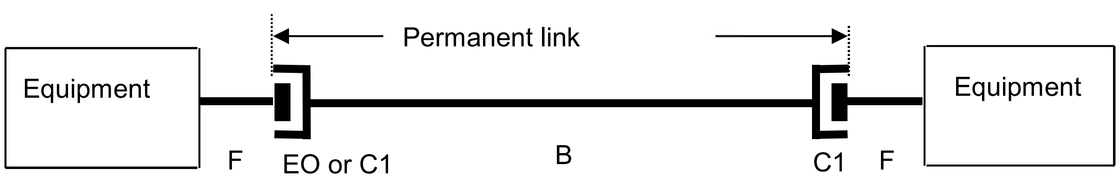
Cables and cords
Test equipment cord ....F
Optional consolidation point cabling . B
Horizontal cabling C

Connecting hardware
Telecommunications outlet/ connector ....TO
Optional consolidation point connector ....CP
Horizontal cross-connect or interconnect C1

Maximum length
B + C................................... 90 m (295 ft)

Figure 5 - Schematic representation of a permanent link test configuration

The category 8 permanent link configuration shall consist of two connectors and horizontal cable as shown in Figure 6. The permanent link configuration does not include equipment cords.



Legend

Cables and cords
Test equipment cords F
Horizontal or backbone cabling ....B

Connecting hardware
Equipment Outlet............................EO
Interconnect.................................... C1

Maximum length

B 24 m (79 ft)

Figure 6 - Schematic representation of a category 8 permanent link

6.4.1 Category 3 through 6A permanent link dc loop resistance

DC loop resistance for category 3, 5e, 6, and 6A permanent links shall not exceed 21 Ω at any temperature from 20 °C to 60 °C.

6.4.2 Category 8 permanent link dc loop resistance

DC loop resistance for category 8 permanent links shall not exceed 5.6 Ω when measured at 20 ± 3 °C or corrected to a temperature of 20 C using the correction factors specified in ASTM-D4566. Using a temperature coefficient of resistance of 0.00393 for copper, the resistance at 60°C is 6.15 Ω. In addition, the dc loop resistance PL_dc_Loop_R(L) shall meet the requirements of equation (25) for the actual length of the permanent link.

PL_dc_Loop_R(L)=2((2.4/30)Length_horizontal+2(0.2)) (25)

Where:

Length_horizontal is the length of the horizontal cable.

6.4.3 Category 3 through 6A permanent link dc resistance unbalance

DC resistance unbalance is not specified for category 3 through 6A permanent links.

6.4.4 Category 8 permanent link dc resistance unbalance within a pair

DC resistance unbalance shall be calculated for each pair of the permanent link in accordance with equation (24). This requirement is satisfied if the result of equation (26) is less than 3 % or if the difference between RC1 and RC2 is less than 100 mΩ.

$$Resistance\_Unbalance_{pair} = \left(\frac{|R_{C1} - R_{C2}|}{R_{C1} + R_{C2}} \right) 100\% \quad (26)$$

Where:

R_{C1} is the dc resistance of conductor 1.

R_{C2} is the dc resistance of conductor 2.

Where conductor 1 and conductor 2 are the two conductors of the same pair.

6.4.5 Category 8 permanent link dc resistance unbalance between pairs

DC resistance unbalance between pairs shall be calculated for the permanent link in accordance with equation (27). This requirement is satisfied if the result of equation (27) is less than 7 % or if the difference between RP1 and RP2 is less than 50 mΩ.
For the purposes of field testing, whenever the difference between RP1 and RP2 is less than 200 mΩ, the dc resistance unbalance requirement between pairs is met.

$$Resistance\_Unbalance_{Between\_pairs} = \left(\frac{|R_{P1} - R_{P2}|}{R_{P1} + R_{P2}} \right) 100\% \quad (27)$$

Where:

R_{P1} is the dc parallel resistance of the conductors of a pair.
R_{P2} is the dc parallel resistance of the conductors of another pair.

The resistance for any pair PX may be calculated from individual conductor resistance values using equation (28)

$$R_{PX} = \frac{(R_{C1} R_{C2})}{(R_{C1} + R_{C2})} \quad (28)$$

6.4.6 Permanent link mutual capacitance

Mutual capacitance is not specified for permanent links.

6.4.7 Permanent link capacitance unbalance: pair-to-ground

Capacitance unbalance is not specified for permanent links.

6.4.8 Permanent link characteristic impedance and structural return loss (SRL)

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

6.4.9 Permanent link return loss

Permanent link return loss shall meet or exceed the values determined using the equations shown in Table 33 for all specified frequencies.

Table 33 - Permanent link return loss

	Frequency (MHz)	Return loss (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f < 20$ $20 \le f \le 100$	19 $19 - 10\log(f/20)$
Category 6	$1 \le f < 3$ $3 \le f < 10$ $10 \le f < 40$ $40 \le f \le 250$	$21+4\log(f/3)$ 21 $26 - 5\log(f)$ $34 - 10\log(f)$
Category 6A	$1 \le f < 3$ $3 \le f < 10$ $10 \le f < 40$ $40 \le f < 398.1$ $398.1 \le f \le 500$	$21+4\log(f/3)$ 21 $26 - 5\log(f)$ $34 - 10\log(f)$ 8
Category 8	$1 \le f < 3$ $3 \le f < 10$ $10 \le f < 40$ $40 \le f \le 100$ $100 < f \le 682$ $682 < f \le 2000$	$21+4\log(f/3)$ 21 $26 - 5\log(f)$ 18 $42 - 12\log(f)$ 8

The permanent link return loss values in Table 34 are provided for information only.

Table 34 - Minimum permanent link return loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	19.0	19.1	19.1	19.1
4.00	19.0	21.0	21.0	21.0
8.00	19.0	21.0	21.0	21.0
10.00	19.0	21.0	21.0	21.0
16.00	19.0	20.0	20.0	20.0
20.00	19.0	19.5	19.5	19.5
25.00	18.0	19.0	19.0	19.0
31.25	17.1	18.5	18.5	18.5
62.50	14.1	16.0	16.0	18.0
100.00	12.0	14.0	14.0	18.0
200.00	-	11.0	11.0	14.4
250.00	-	10.0	10.0	13.2
300.00	-	-	9.2	12.3
400.00	-	-	8.0	10.8
500.00	-	-	8.0	9.6
600.00	-	-	-	8.7
1000.00	-	-	-	8.0
1500.00	-	-	-	8.0
2000.00	-	-	-	8.0

6.4.10 Permanent link Insertion loss

Permanent link insertion loss limits are derived from equation (29).

$$InsertionLoss_{perm\_link} = 2(InsertionLoss_{conn}) + InsertionLoss_{cable} + ILD_{perm\_link} \ dB \quad (29)$$

where:

$$InsertionLoss_{cable} = 0.9 \cdot InsertionLoss_{cable,100m} \ dB, \quad (30)$$

$InsertionLoss_{cable,100m}$ is the insertion loss of 100m of the appropriate category of cable, see clause 6.6.8,

$InsertionLoss_{conn}$ is the insertion loss of the appropriate category of connecting hardware, see clause 6.10.8, and

$ILD_{perm\_link} = 0$ *dB* for category 3 and 5e channels (31)

$ILD_{perm\_link} = 0.00015 \cdot f^{1.5}$ *dB* for category 6 and 6A channels (32)

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-A).

Category 8 permanent link insertion loss limits are derived from equation (33).

$$InsertionLoss_{Perm\_link} = \frac{24}{30}\left(InsertionLoss_{cable\_30m}\right) + 2\left(InsertionLoss_{conn}\right) + ILD_{Perm\_link} \ dB \quad (33)$$

$InsertionLoss_{cable,30m}$ is the insertion loss of 30 m of category 8 cable, see clause 6.6.8,

$InsertionLoss_{conn}$ is the insertion loss of category 8 connecting hardware, see clause 6.10.8.

ILD_{perm_link} is the insertion loss deviation allowance for a permanent link.

$ILD_{perm\_link} = 0.0324\sqrt{f}$ *dB* for category 8 permanent links (34)

NOTE,

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.

Permanent link insertion loss shall meet or be less than the values determined using the equations shown in Table 35 for all specified frequencies.

Table 35 - Permanent link insertion loss

	Frequency (MHz)	Insertion loss (dB)
Category 3	$1 \le f \le 16$	$0.9(2.32\sqrt{f}+0.238f)+3\cdot 0.1\sqrt{f}$
Category 5e	$1 \le f \le 100$	$0.9(1.967\sqrt{f}+0.023f+\frac{0.05}{\sqrt{f}})+3\cdot 0.04\sqrt{f}$
Category 6	$1 \le f \le 250$	$1.687\sqrt{f}+0.0153\cdot f+\frac{0.18}{\sqrt{f}}+0.00015\cdot f^{1.5}$
Category 6A	$1 \le f \le 500$	$1.698\sqrt{f}+0.00819f+\frac{0.225}{\sqrt{f}}+0.00015f^{1.5}$
Category 8	$1 \le f \le 2000$	$0.8(0.54\sqrt{f}+0.0015f+\frac{0.075}{\sqrt{f}})+2B+0.0324\sqrt{f}$

Where B is the connecting hardware insertion loss specified in Table 124

The permanent link insertion loss values in Table 36 are provided for information only.

Table 36 - Maximum permanent link insertion loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	2.6	2.1	1.9	1.9	3.0
4.00	5.6	3.9	3.5	3.5	3.0
8.00	8.5	5.5	5.0	5.0	3.0
10.00	9.7	6.2	5.5	5.5	3.0
16.00	13.0	7.9	7.0	7.0	3.0
20.00	-	8.9	7.9	7.8	3.0
25.00	-	10.0	8.9	8.8	3.0
31.25	-	11.2	10.0	9.8	3.0
62.50	-	16.2	14.4	14.0	4.1
100.00	-	21.0	18.6	18.0	5.2
200.00	-	-	27.4	26.1	7.4
250.00	-	-	31.1	29.5	8.3
300.00	-	-	-	32.7	9.1
400.00	-	-	-	38.4	10.6
500.00	-	-	-	43.8	11.9
600.00	-	-	-	-	13.1
1000.00	-	-	-	-	17.5
1500.00	-	-	-	-	22.1
2000.00	-	-	-	-	26.2

6.4.11 Permanent link NEXT loss

Permanent link NEXT loss shall meet or exceed the values determined using the equations shown in Table 37 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 37 - 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	$1 \le f < 300$	$-20\log\left(10^{\frac{-(44.3-15\log(f/100))}{20}}+10^{\frac{-(54-20\log(f/100))}{20}}\right)$
	$300 \le f \le 500$	$34 - 33.13\log(f/300)$
Category 8	$1 \le f \le 440$	$-20\log\left(10^{\frac{-(45.3-15\log(f/100))}{20}}+2\cdot 10^{\frac{-(54-20\log(f/100))}{20}}\right)$
	$440 < f \le 2000$	$-20\log\left(10^{\frac{-(45.3-15\log(f/100))}{20}}+2\times 10^{\frac{-(39.12-36.14\log(f/500))}{20}}\right)$

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 38 are provided for information only.

Table 38 - Minimum permanent link NEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	40.1	60.0	65.0	65.0	73.5
4.00	30.7	54.8	64.1	64.1	63.8
8.00	25.9	50.0	59.4	59.4	58.9
10.00	24.3	48.5	57.8	57.8	57.3
16.00	21.0	45.2	54.6	54.6	53.9
20.00	-	43.7	53.1	53.1	52.3
25.00	-	42.1	51.5	51.5	50.7
31.25	-	40.5	50.0	50.0	49.1
62.50	-	35.7	45.1	45.1	44.0
100.00	-	32.3	41.8	41.8	40.5
200.00	-	-	36.9	36.9	35.3
250.00	-	-	35.3	35.3	33.6
300.00	-	-	-	34.0	32.3
400.00	-	-	-	29.9	30.1
500.00	-	-	-	26.7	27.9
600.00	-	-	-	-	25.7
1000.00	-	-	-	-	19.3
1500.00	-	-	-	-	13.9
2000.00	-	-	-	-	9.8

6.4.12 Permanent link PSNEXT loss

Permanent link PSNEXT loss shall meet or exceed the values determined using the equations shown in Table 39 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 39 - Permanent link PSNEXT loss

	Frequency (MHz)	PSNEXT loss (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f \le 100$	$-20\log\left(10^{\frac{-(32.3-15\log(f/100))}{20}}+10^{\frac{-(40-20\log(f/100))}{20}}\right)$
Category 6	$1 \le f \le 250$	$-20\log\left(10^{\frac{-(42.3-15\log(f/100))}{20}}+10^{\frac{-(50-20\log(f/100))}{20}}\right)$
Category 6A	$1 \le f < 300$	$-20\log\left(10^{\frac{-(42.3-15\log(f/100))}{20}}+10^{\frac{-(50-20\log(f/100))}{20}}\right)$
	$300 \le f \le 500$	$31.4 - 34.44\log(f/300)$
Category 8	$1 \le f \le 500$	$-20\log\left(10^{\frac{-(42.3-15\log(f/100))}{20}}+2\times10^{\frac{-(50.0-20\log(f/100))}{20}}\right)$
	$500 < f \le 2000$	$-20\log\left(10^{\frac{-(42.3-15\log(f/100))}{20}}+2\times10^{\frac{-(35.95-37.5\log(f/500))}{20}}\right)$

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 40 are provided for information only.

Table 40 - Minimum permanent link PSNEXT loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	57.0	62.0	62.0	62.0
4.00	51.8	61.8	61.8	60.5
8.00	47.0	57.0	57.0	55.6
10.00	45.5	55.5	55.5	54.0
16.00	42.2	52.2	52.2	50.6
20.00	40.7	50.7	50.7	49.0
25.00	39.1	49.1	49.1	47.3
31.25	37.5	47.5	47.5	45.7
62.50	32.7	42.7	42.7	40.6
100.00	29.3	39.3	39.3	37.1
200.00	-	34.3	34.3	31.9
250.00	-	32.7	32.7	30.2
300.00	-	-	31.4	28.8
400.00	-	-	27.1	26.6
500.00	-	-	23.8	24.8
600.00	-	-	-	22.6
1000.00	-	-	-	15.9
1500.00	-	-	-	10.2
2000.00	-	-	-	6.0

6.4.13 Permanent link FEXT loss

FEXT loss is not specified for permanent links.

6.4.14 Permanent link ACRF

Permanent link ACRF shall meet or exceed the values determined using the equations shown in Table 41 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. For frequencies greater than 200 MHz, category 8 permanent link ACRF values that correspond to measured permanent link FEXT loss values of greater than 75 dB are for information only.

Table 41 - Permanent link ACRF

	Frequency (MHz)	ACRF (dB)
Category 3	$1 \leq f \leq 16$	n/s
Category 5e	$1 \leq f \leq 100$	$-20\log\left(10^{\frac{-(23.8-20\log(f/100))}{20}}+3\cdot 10^{\frac{-(35.1-20\log(f/100))}{20}}\right)$
Category 6	$1 \leq f \leq 250$	$-20\log\left(10^{\frac{-(27.8-20\log(f/100))}{20}}+3\cdot 10^{\frac{-(43.1-20\log(f/100))}{20}}\right)$
Category 6A	$1 \leq f \leq 500$	$-20\log\left(10^{\frac{-(27.8-20\log(f/100))}{20}}+3\cdot 10^{\frac{-(43.1-20\log(f/100))}{20}}\right)$
Category 8	$1 \leq f \leq 2000$	$-20\log\left(10^{\frac{-(40.0-20\log(f/100))}{20}}+2\times 10^{\frac{-(43.1-20\log(f/100))}{20}}\right)$

The permanent link ACRF values in Table 42 are provided for information only.

Table 42 - Minimum permanent link ACRF

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	58.6	64.2	64.2	72.4
4.00	46.6	52.1	52.1	60.4
8.00	40.6	46.1	46.1	54.3
10.00	38.6	44.2	44.2	52.4
16.00	34.5	40.1	40.1	48.3
20.00	32.6	38.2	38.2	46.4
25.00	30.7	36.2	36.2	44.4
31.25	28.7	34.3	34.3	42.5
62.50	22.7	28.3	28.3	36.5
100.00	18.6	24.2	24.2	32.4
200.00	-	18.2	18.2	26.4
250.00	-	16.2	16.2	24.4
300.00	-	-	14.6	22.9
400.00	-	-	12.1	20.4
500.00	-	-	10.2	18.4
600.00	-	-	-	16.8
1000.00	-	-	-	12.4
1500.00	-	-	-	8.9
2000.00	-	-	-	6.4

6.4.15 Permanent link PSFEXT loss

PSFEXT loss is not specified for permanent links.

6.4.16 Permanent link PSACRF

Permanent link PSACRF shall meet or exceed the values determined using the equations shown in Table 43 for all specified frequencies. Due to measurement considerations, when the frequency is greater than 200 MHz, category 8 permanent link PSACRF values that correspond to permanent link PSFEXT loss values of greater than 72 dB are for information only.

Table 43 - Permanent link PSACRF

	Frequency (MHz)	PSACRF (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f \le 100$	$-20\log\left(10^{\frac{-(20.8-20\log(f/100))}{20}}+3\cdot 10^{\frac{-(32.1-20\log(f/100))}{20}}\right)$
Category 6	$1 \le f \le 250$	$-20\log\left(10^{\frac{-(24.8-20\log(f/100))}{20}}+3\cdot 10^{\frac{-(40.1-20\log(f/100))}{20}}\right)$
Category 6A	$1 \le f \le 500$	$-20\log\left(10^{\frac{-(24.8-20\log(f/100))}{20}}+3\cdot 10^{\frac{-(40.1-20\log(f/100))}{20}}\right)$
Category 8	$1 \le f \le 2000$	$-20\log\left(10^{\frac{-(37.0-20\log(f/100))}{20}}+2\times 10^{\frac{-(40.1-20\log(f/100))}{20}}\right)$

The permanent link PSACRF values in Table 44 are provided for information only.

Table 44 - Minimum permanent link PSACRF

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	55.6	61.2	61.2	69.4
4.00	43.6	49.1	49.1	57.4
8.00	37.5	43.1	43.1	51.3
10.00	35.6	41.2	41.2	49.4
16.00	31.5	37.1	37.1	45.3
20.00	29.6	35.2	35.2	43.4
25.00	27.7	33.2	33.2	41.4
31.25	25.7	31.3	31.3	39.5
62.50	19.7	25.3	25.3	33.5
100.00	15.6	21.2	21.2	29.4
200.00	-	15.2	15.2	23.4
250.00	-	13.2	13.2	21.4
300.00	-	-	11.6	19.9
400.00	-	-	9.1	17.4
500.00	-	-	7.2	15.4
600.00	-	-	-	13.8
1000.00	-	-	-	9.4
1500.00	-	-	-	5.9
2000.00	-	-	-	3.4

6.4.17 Permanent link TCL

TCL is not specified for category 3 through 6A permanent links.

Category 8 permanent link TCL shall meet or exceed the values determined using the equations shown in Table 45 for all specified frequencies.

Table 45 - Category 8 permanent link TCL

	Frequency (MHz)	Permanent link TCL (dB)[1,2]
Category 8	$1 \leq f \leq 2000$	23 – 17log(f/100)
1 Calculations that result in category 8 permanent link TCL values greater than 40 dB shall revert to a requirement of 40 dB minimum. 2 Calculations that result in category 8 permanent link TCL values less than 3 dB shall revert to a requirement of 3 dB minimum.		

The minimum permanent link TCL values in Table 46 are provided for information only.

Table 46 - Minimum Category 8 permanent link TCL

Frequency (MHz)	Category 8 (dB)
1.00	40.0
4.00	40.0
8.00	40.0
10.00	40.0
16.00	36.5
20.00	34.9
25.00	33.2
31.25	31.6
62.50	26.5
100.00	23.0
200.00	17.9
250.00	16.2
300.00	14.9
400.00	12.8
500.00	11.1
600.00	9.8
1000.00	6.0
1500.00	3.0
2000.00	3.0

6.4.18 Permanent link TCTL

TCTL is not specified for permanent links.

6.4.19 Permanent link ELTCTL

ELTCTL is not specified for category 3 through 6A permanent links.

Category 8 permanent link ELTCTL shall meet or exceed the values determined using the equations shown in table 47 for all specified frequencies.

Table 47 - Category 8 permanent link ELTCTL

	Frequency (MHz)	Permanent link ELTCTL (dB)
Category 8	$1 \leq f \leq 155$	46.8 – 20log(f)
	$155 < f \leq 2000$	3

The minimum permanent link ELTCTL values in table 48 are provided for information only.

Table 48 - Minimum Category 8 permanent link ELTCTL

Frequency (MHz)	Category 8 (dB)
1.00	46.8
4.00	34.8
8.00	28.7
10.00	26.8
16.00	22.7
20.00	20.8
25.00	18.8
31.25	16.9
62.50	10.9
100.00	6.8
200.00	3.0
250.00	3.0
300.00	3.0
400.00	3.0
500.00	3.0
600.00	3.0
1000.00	3.0
1500.00	3.0
2000.00	3.0

6.4.20 Permanent link coupling attenuation

Coupling attenuation is not specified for category 3 through 6A permanent links.

Category 8 permanent link coupling attenuation should meet or exceed the values determined using the equations shown in table 49 for all specified frequencies. Compliance to these requirements is intended to be verified by laboratory measurements when measured using absorbing clamp method IEC 62153-4-13 or tri-axial method IEC 62153-4-15.

Compliance to this parameter in the field may be assured through careful adherence to installation best practices or when measured using absorbing clamp method IEC 62153-4-14.

Table 49 - Category 8 permanent link coupling attenuation

	Frequency (MHz)	Permanent link coupling attenuation (dB)
Category 8	$1 \le f \le 30$	N/A
	$30 < f \le 100$	50
	$100 < f \le 2000$	$90 - 20\log(f)$

The minimum permanent link coupling attenuation values in table 50 are provided for information only.

Table 50 - Minimum Category 8 permanent link coupling attenuation

Frequency (MHz)	Category 8 (dB)
30.00	50.0
31.25	50.0
62.50	50.0
100.00	50.0
200.00	44.0
250.00	42.0
300.00	40.5
400.00	38.0
500.00	36.0
600.00	34.4
1000.00	30.0
1500.00	26.5
2000.00	24.0

6.4.21 Permanent link propagation delay

Permanent link propagation delay shall meet or be less than the values determined using the equations shown in Table 51 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 for Category 3 through 6A and 136 ns for category 8.

Table 51 - Permanent link propagation delay

	Frequency (MHz)	Propagation delay (ns)
Category 3	$1 \le f \le 16$	$0.9 \cdot \left((534 + \frac{36}{\sqrt{f}} \right) + (3 \cdot 2.5)$
Category 5e	$1 \le f \le 100$	$0.9 \cdot \left((534 + \frac{36}{\sqrt{f}} \right) + (3 \cdot 2.5)$
Category 6	$1 \le f \le 250$	$0.9 \cdot \left((534 + \frac{36}{\sqrt{f}} \right) + (3 \cdot 2.5)$
Category 6A	$1 \le f \le 500$	$0.9 \cdot \left((534 + \frac{36}{\sqrt{f}} \right) + (3 \cdot 2.5)$
Category 8	$1 \le f \le 2000$	$\left(128 + \frac{8.8}{\sqrt{f}} \right) + (2 \times 2.5)$

The permanent link propagation delay values in Table 52 are provided for information only.

Table 52 - Maximum permanent link propagation delay

Frequency (MHz)	Category 3 (ns)	Category 5e (ns)	Category 6 (ns)	Category 6A (ns)	Category 8 (ns)
1.00	521	521	521	521	142
4.00	504	504	504	504	137
8.00	500	500	500	500	136
10.00	498	498	498	498	136
16.00	496	496	496	496	135
20.00	-	495	495	495	135
25.00	-	495	495	495	135
31.25	-	494	494	494	135
62.50	-	492	492	492	134
100.00	-	491	491	491	134
200.00	-	-	490	490	134
250.00	-	-	490	490	134
300.00	-	-	-	490	134
400.00	-	-	-	490	133
500.00	-	-	-	490	133
600.00	-	-	-	-	133
1000.00	-	-	-	-	133
1500.00	-	-	-	-	133
2000.00	-	-	-	-	133

6.4.22 Permanent link propagation delay skew

Permanent link propagation delay skew for category 3 through 6A shall be less than 44 ns for all frequencies from 1 MHz to the upper frequency limit of the category. The delay skew of any given permanent link shall not vary by more than +/- 9 ns within this requirement due to environmental effects such as the daily temperature variation. For field testing permanent links, it is sufficient to test at 10 MHz only and permanent link propagation delay skew at 10 MHz shall not exceed 44 ns.
Permanent link propagation delay skew for category 8 permanent links shall be less than 13.3 ns for all frequencies from 1 MHz to 2000 MHz. The delay skew of any given category 8 permanent link shall not vary by more than +/- 3 ns within this requirement due to environmental effects such as the daily temperature variation. For field testing category 8 permanent links, it is sufficient to test at 10 MHz only and permanent link propagation delay skew at 10 MHz shall not exceed 13.3 ns.

6.4.23 Permanent link ANEXT loss

ANEXT loss is not specified for permanent links.

6.4.24 Permanent link PSANEXT loss

Permanent link PSANEXT loss shall meet or exceed the values determined using the equations shown in Table 53 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. For measurement purposes calculations that result in category 8 permanent link PSANEXT loss values greater than 75 dB shall revert to a requirement of 75 dB minimum.

Table 53 - Permanent link PSANEXT loss

	Frequency (MHz)	**PSANEXT loss (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	$1 \le f < 100$ $100 \le f \le 500$	$60 - 10\log(f/100)$ $60 - 15\log(f/100)$ [1)]
Category 8	$1 \le f \le 2000$	$85 - 15\log(f/100)$

1) If the average insertion loss of all disturbed pairs at 100 MHz, $IL_{100MHz,avg}$, is less than 7 dB, over the frequency range from 100 to 500 MHz, 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 54 are provided for information only.

Table 54 - Permanent link PSANEXT loss

Frequency (MHz)	Category 6A (dB)	Category 8 (dB)
1.00	67.0	75.0
4.00	67.0	75.0
8.00	67.0	75.0
10.00	67.0	75.0
16.00	67.0	75.0
20.00	67.0	75.0
25.00	66.0	75.0
31.25	65.1	75.0
62.50	62.0	75.0
100.00	60.0	75.0
200.00	55.5	75.0
250.00	54.0	75.0
300.00	52.8	75.0
400.00	51.0	75.0
500.00	49.5	74.5
600.00	-	73.3
1000.00	-	70.0
1500.00	-	67.4
2000.00	-	65.5

6.4.25 Permanent link average PSANEXT Loss

Permanent link average PSANEXT loss shall meet or exceed the values determined using the equations shown in Table 55 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.

Average PSANEXT requirements are not specified for category 8 permanent links.

Table 55 - 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)
Category 8	$1 \leq f \leq 2000$	n/s

1) If the average insertion loss of all disturbed pairs at 100 MHz, $IL_{100MHz,avg}$, is less than 7 dB, over the frequency range from 100 to 500 MHz, 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

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

and

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

The permanent link average PSANEXT loss values in Table 56 are provided for information only.

Table 56 - Minimum permanent link average PSANEXT loss

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

6.4.26 Permanent link AFEXT loss

AFEXT loss is not specified for permanent links.

6.4.27 Permanent link PSAFEXT loss

PSAFEXT loss is not specified for permanent links.

6.4.28 Permanent link PSAACRF

Permanent link PSAACRF shall meet or exceed the values determined using the equations shown in Table 57 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. For measurement purposes calculations that result in category 8 permanent link PSAACRF loss values greater than 75 dB shall revert to a requirement of 75 dB minimum. Category 8 permanent link PSAACRF shall be for information only when permanent link PSAFEXT loss is greater than 80 dB

Table 57 - Permanent link 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	$1 \leq f \leq 500$	$37.7 - 20\log(f/100)$
Category 8	$1 \leq f \leq 2000$	$62 - 20\log(f/100)$

The permanent link PSAACRF values in Table 58 are provided for information only.

Table 58 - Minimum permanent link PSAACRF

Frequency (MHz)	Category 6A (dB)	Category 8 (dB)
1.00	67.0	75.0
4.00	65.7	75.0
8.00	59.6	75.0
10.00	57.7	75.0
16.00	53.6	75.0
20.00	51.7	75.0
25.00	49.7	74.0
31.25	47.8	72.1
62.50	41.8	66.1
100.00	37.7	62.0
200.00	31.7	56.0
250.00	29.7	54.0
300.00	28.2	52.5
400.00	25.7	50.0
500.00	23.7	48.0

6.4.29 Permanent link average PSAACRF loss

Permanent link average PSAACRF shall meet or exceed the values determined using the equations shown in Table 59 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.

Average PSAACRF requirements are not specified for category 8 permanent links.

Table 59 - Permanent link 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	$1 \le f \le 500$	$41.7 - 20\log(f/100)$
Category 8	$1 \le f \le 2000$	n/s

The permanent link average PSAACRF values in Table 60 are provided for information only.

Table 60 - Minimum permanent link average PSAACRF

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

6.5 Category 8 direct attach channel transmission performance

This clause contains the transmission performance specifications for category 8 direct attach channels with a maximum length of 5 m. A direct attach channel does not contain any connecting hardware within the channel such as an equipment outlet, consolidation point, interconnect or other connecting hardware. Direct attach channels are composed of compliant plug connectors and flexible cable.

Category 8 direct attach channels shall meet the requirements specified for category 8 permanent links in clause 6.4 with the exceptions in this clause taking precedence.

DC loop resistance is not specified for direct attach channels. DC Resistance unbalance is not specified for direct attach channels.

For the purposes of measurement, the test configuration for direct attach channel includes the test head connectors at both ends. Test configurations of direct attach channels are provided in annexes C and D. The test configuration is based on the use of a test reference jack, not the specific jack used in equipment.

All transmission parameters shall be measured on all pairs or pair combinations, unless otherwise specified. All transmission parameters shall be measured for all frequencies from 1 MHz up to 2000 MHz unless otherwise specified.

6.5.1 Category 8 direct attach channel return loss

Direct attach channel return loss shall meet or exceed the values determined using the equations shown in table 33 for all specified frequencies.

Table 61 - Direct attach channel return loss

	Frequency (MHz)	**Return loss (dB)**
Category 8	$1 \le f < 25$ $25 \le f < 1000$ $1000 \le f \le 2000$	$24+3\log(f/25)$ $8 - 10\log(f/1000)$ 8

The minimum direct attach channel return loss values in table 34 are provided for information only.

Table 62 - Minimum direct attach channel return loss

Frequency (MHz)	Category 8 (dB)
1.00	19.8
4.00	21.6
8.00	22.5
10.00	22.8
16.00	23.4
20.00	23.7
25.00	24.0
31.25	23.0
62.50	20.0
100.00	18.0
200.00	15.0
250.00	14.0
300.00	13.2
400.00	12.0
500.00	11.0
600.00	10.2
1000.00	8.0
1500.00	8.0
2000.00	8.0

6.5.2 Category 8 direct attach channel insertion loss

Direct attach channel insertion loss shall meet or be less than the values determined using the equations shown in table 63 for all specified frequencies. For measurement purposes calculations that result in category 8 direct attach insertion loss values less than 3 dB shall revert to a requirement of 3 dB maximum.

Table 63 - Direct attach channel insertion loss

	Frequency (MHz)	Insertion loss (dB)
Category 8	$1 \leq f < 2000$	$0.05(1.5)\left(1.8\sqrt{f} + 0.005f + \frac{0.25}{\sqrt{f}}\right) + 2B + ILD$

Where *B* is the connecting hardware insertion loss specified in 6.10.8, and *ILD* is the ILD of the channel, $0.0324\sqrt{f}$ *dB* for Category 8 channels.

The direct attach channel insertion loss values in table 64 are provided for information only.

Table 64 - Maximum direct attach channel insertion loss

Frequency (MHz)	Category 8 (dB)
1.00	3.0
4.00	3.0
8.00	3.0
10.00	3.0
16.00	3.0
20.00	3.0
25.00	3.0
31.25	3.0
62.50	3.0
100.00	3.0
200.00	3.0
250.00	3.4
300.00	3.7
400.00	4.3
500.00	4.8
600.00	5.4
1000.00	7.3
1500.00	9.4
2000.00	11.2

6.5.3 Category 8 direct attach channel NEXT loss

For all frequencies from 1 MHz to 2000 MHz, direct attach NEXT loss shall meet the values determined using Table 65.

Calculations that result in NEXT loss values greater than 65 dB shall revert to a requirement of 65 dB minimum.

Table 65 - Direct attach channel NEXT loss

Frequency (MHz)	NEXT (dB)
$1 \leq f < 250$	$82.9-18.5\log(f)$
$250 \leq f < 383$	$93-22.72\log(f)$
$383 \leq f < 500$	$109-28.92\log(f)$
$500 \leq f \leq 2000$	$133.5-38\log(f)$

The direct attach channel NEXT loss values in Table 66 are provided for information only.

Table 66 - Minimum direct attach channel NEXT loss

Frequency (MHz)	Category 8 (dB)
1.00	65.0
4.00	65.0
8.00	65.0
10.00	64.4
16.00	60.6
20.00	58.8
25.00	57.0
31.25	55.2
62.50	49.7
100.00	45.9
200.00	40.3
250.00	38.5
300.00	36.7
400.00	33.7
500.00	30.9
600.00	27.9
1000.00	19.5
1500.00	12.8
2000.00	8.1

6.5.4 Category 8 direct attach channel PSNEXT loss

For all frequencies from 1 MHz to 2000 MHz, direct attach PSNEXT loss shall meet the values determined using Table 67.

Calculations that result in NEXT loss values greater than 65 dB shall revert to a requirement of 65 dB minimum.

Table 67 - Direct attach channel PSNEXT loss

Frequency (MHz)	PSNEXT (dB)
$1 \le f < 250$	$79.4-18.5\log(f)$
$250 \le f < 331$	$90.65-23.2\log(f)$
$331 \le f < 500$	$105.26-29\log(f)$
$500 \le f \le 2000$	$129.5-38\log(f)$

The direct attach channel PSNEXT loss values in Table 68 are provided for information only.

Table 68 - Minimum direct attach channel PSNEXT loss

Frequency (MHz)	Category 8 (dB)
1.00	65.0
4.00	65.0
8.00	65.0
10.00	60.9
16.00	57.1
20.00	55.3
25.00	53.5
31.25	51.7
62.50	46.2
100.00	42.4
200.00	36.8
250.00	35.0
300.00	33.2
400.00	29.8
500.00	26.9
600.00	23.9
1000.00	15.5
1500.00	8.8
2000.00	4.1

6.5.5 Category 8 direct attach channel ACRF

Direct attach ACRF shall meet or exceed the values determined using the equations shown in table 69 for all specified frequencies.

Due to measurement considerations, for frequencies greater than 200 MHz category 8 direct attach channel ACRF values that correspond to measured direct attach channel FEXT loss values of greater than 75 dB are for information only.

Table 69 - Direct attach channel ACRF

	Frequency (MHz)	ACRF (dB)
Category 8	$1 \le f < 2000$	$-20\log\left(10^{\frac{-(10\log(24/5)+40-20\log(f/100))}{20}}+2\times10^{\frac{-(48.1-20\log(f/100))}{20}}\right)$

Notes:

- The term 24/5 is derived based on scaling a 24 m reference length to 5 m.
- The above equation uses the FEXT value for modular cord test heads given in clause C.6.2.2, and also scales the length to 5 m using the methods given in Annex L.

The minimum direct attach channel ACRF values in table 70 are provided for information only.

Table 70 - Minimum direct attach channel ACRF

Frequency (MHz)	Category 8 (dB)
1.00	70.0
4.00	66.1
8.00	60.0
10.00	58.1
16.00	54.0
20.00	52.1
25.00	50.1
31.25	48.2
62.50	42.2
100.00	38.1
200.00	32.1
250.00	30.1
300.00	28.6
400.00	26.1
500.00	24.1
600.00	22.5
1000.00	18.1
1500.00	14.6
2000.00	12.1

6.5.6 Category 8 direct attach channel PSACRF

Direct attach PSACRF shall meet or exceed the values determined using the equations shown in table 71 for all specified frequencies.

Table 71 - Direct attach channel PSACRF

	Frequency (MHz)	PSACRF (dB)
Category 8	$1 \le f < 2000$	$-20\log\left(10^{\frac{-(10\log(24/5)+37-20\log(f/100))}{20}}+2\times10^{\frac{-(45.1-20\log(f/100))}{20}}\right)$

Notes:
- The term 24/5 is derived based on scaling a 24 m reference length to 5 m.
- The above equation uses the FEXT value for modular cord test heads given in clause C.6.2.2 converted to power sum by subtracting 3 from 48.1, and also scales the length to 5m using the methods given in Annex L.

The minimum direct attach channel PSACRF values in table 72 are provided for information only.

Table 72 - Minimum direct attach channel PSACRF

Frequency (MHz)	Category 8 (dB)
1.00	75.1
4.00	63.1
8.00	57.0
10.00	55.1
16.00	51.0
20.00	49.1
25.00	47.1
31.25	45.2
62.50	39.2
100.00	35.1
200.00	29.1
250.00	27.1
300.00	25.6
400.00	23.1
500.00	21.1
600.00	19.5
1000.00	15.1
1500.00	11.6
2000.00	9.1

6.5.7 Category 8 direct attach channel propagation delay

Direct attach propagation delay shall meet or be less than the values determined using the equations shown in table 73 for all specified frequencies. For field testing, it is sufficient to test at 10 MHz only and direct attach propagation delay at 10 MHz shall not exceed 32 ns.

Table 73 - Direct attach channel propagation delay

	Frequency (MHz)	Direct attach propagation delay (ns)
Category 8	$1 \le f \le 2000$	$\left(\frac{5}{24}\right)\left(128+\left(\frac{8.8}{\sqrt{f}}\right)\right)+(2\times 2.5)$

The maximum direct attach propagation delay values in table 74 are provided for information only.

Table 74 - Maximum direct attach channel propagation delay

Frequency (MHz)	Category 8 (ns)
1.00	34
4.00	33
8.00	32
10.00	32
16.00	32
20.00	32
25.00	32
31.25	32
62.50	32
100.00	32
200.00	32
250.00	32
300.00	32
400.00	32
500.00	32
600.00	32
1000.00	32
1500.00	32
2000.00	32

6.5.8 Category 8 direct attach channel propagation delay skew

Direct attach propagation delay skew for category 8 shall be less than 4.8 ns for all frequencies from 1 MHz to 2000 MHz. The delay skew of any given category 8 direct attach shall not vary by more than +/- 0.5 ns within this requirement due to environmental effects such as the daily temperature variation.

For field testing direct attach, it is sufficient to test at 10 MHz only and direct attach propagation delay skew at 10 MHz shall not exceed 4.8 ns for category 8 direct attach.

6.6 Horizontal cable transmission performance

Unless otherwise specified, requirements for categories 3-6A horizontal cable apply over a length of 100 m, and category 8 over 30 m.

6.6.1 Horizontal cable dc resistance

For categories 3 through 6A horizontal cable, dc resistance shall not exceed 9.38 Ω per 100 m (328 ft) for each conductor when measured in accordance with ASTM D4566 at or corrected to a temperature of 20 °C.
For category 8 horizontal cable, dc resistance shall not exceed 2.4 Ω per 30 m (98 ft) for each conductor when measured in accordance with ASTM D4566 at or corrected to a temperature of 20 °C.

6.6.2 Horizontal cable 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 and 8 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.

$$Resistance\_Unbalance_{pair} = \left(\frac{R_{\max} - R_{\min}}{R_{\min}}\right)100\% \qquad (35)$$

6.6.3 Category 8 horizontal cable dc resistance unbalance pair-to-pair

DC resistance unbalance pair-to-pair shall be calculated for the cable in accordance with equation (36) and shall not exceed 5%. This applies to all 6 combinations of any 2 of the 4 pairs.

$$Resistance\_Unbalance_{Between\_pairs} = \left(\frac{|R_{P1} - R_{P2}|}{R_{P1} + R_{P2}}\right)100\% \qquad (36)$$

Where:

R_{P1} is the dc parallel resistance of the conductors of a pair.
R_{P2} is the dc parallel resistance of the conductors of another pair.

The resistance for any pair PX may be calculated from individual conductor resistance values using equation (37)

$$R_{PX} = \frac{(R_{C1} R_{C2})}{(R_{C1} + R_{C2})} \qquad (37)$$

6.6.4 Horizontal cable Mutual capacitance

Mutual capacitance shall be measured in accordance with ASTM D4566.

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). The mutual capacitance of category 8 cable is not specified.

6.6.5 Horizontal cable Capacitance unbalance: pair-to-ground

Capacitance unbalance to ground shall be measured in accordance with ASTM D4566. For all categories of horizontal cable, the capacitance unbalance to ground at 1 kHz, shall not exceed 330 pF per 100 m (328 ft) at or corrected to a temperature of 20 °C. The maximum capacitance unbalance pair to ground of category 8 horizontal cable shall not exceed 99 pF/30 m at the frequency of 1 kHz.

6.6.6 Horizontal cable Characteristic impedance and structural return loss (SRL)

Characteristic impedance is not specified for category 5e, 6, 6A and 8 horizontal cables. Category 3 horizontal cables shall exhibit a characteristic impedance of 100 Ω ±15% on all cable pairs 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, 6A and 8 horizontal cables.

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 75 for all specified frequencies.

Table 75 - Horizontal cable structural return loss

	Frequency (MHz)	Structural return loss (dB)
Category 3	$1 \le f \le 10$ $10 < f \le 16$	12 $12 - 10\log(f/10)$
Category 5e	$1 \le f \le 100$	n/s
Category 6	$1 \le f \le 250$	n/s
Category 6A	$1 \le f \le 500$	n/s
Category 8	$1 \le f \le 2000$	n/s

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

Table 76 - Minimum Category 3 horizontal cable structural return loss

Frequency (MHz)	Category 3 (dB)
1.00	12.0
4.00	12.0
8.00	12.0
10.00	12.0
16.00	10.0

6.6.7 Horizontal cable Return loss

Horizontal cable return loss shall meet or exceed the values determined using the equations shown in Table 77 for all specified frequencies.

Table 77 - 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 $25 - 7\log(f/20)$
Category 8	$1 \leq f < 10$ $10 \leq f < 40$ $40 \leq f \leq 2000$	$20+5\log(f)$ 25 $25 - 7\log(f/40)$

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

Table 78 - Minimum horizontal cable return loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	20.0	20.0	20.0	20.0
4.00	23.0	23.0	23.0	23.0
8.00	24.5	24.5	24.5	24.5
10.00	25.0	25.0	25.0	25.0
16.00	25.0	25.0	25.0	25.0
20.00	25.0	25.0	25.0	25.0
25.00	24.3	24.3	24.3	25.0
31.25	23.6	23.6	23.6	25.0
62.50	21.5	21.5	21.5	23.6
100.00	20.1	20.1	20.1	22.2
200.00	-	18.0	18.0	20.1
250.00	-	17.3	17.3	19.4
300.00	-	-	16.8	18.9
400.00	-	-	15.9	18.0
500.00	-	-	15.2	17.3
600.00	-	-	-	16.8
1000.00	-	-	-	15.2
1500.00	-	-	-	14.0
2000.00	-	-	-	13.1

6.6.8 Horizontal cable Insertion loss

Insertion loss shall be measured at 20 ± 3 °C or corrected to a temperature of 20 °C using the correction factors specified in this 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 °C from 20 °C to 40 °C and 0.6% increase per °C for temperatures from 40 °C to 60 °C. The insertion loss for category 5e, 6, 6A and 8 screened horizontal cables shall be adjusted at elevated temperatures using a factor of 0.2% increase per °C from 20 °C to 60 °C. See H.1 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 79 and table 80 for all specified frequencies. In addition, category 5e, 6, 6A and 8 horizontal cable insertion loss shall also be verified at temperatures of 40 ± 3 °C and 60 ± 3 °C and shall meet the requirements of Table 79 and table 80 after adjusting for temperature.

Table 79 - Horizontal cable insertion loss, for a length of 100m (328 ft)

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

Table 80 - Category 8 horizontal cable insertion loss, for a length of 30 m (98 ft)

	Frequency (MHz)	**Horizontal cable insertion loss (dB)**
Category 8	$1 \le f \le 2000$	$0.540\sqrt{f} + 0.00150f + \frac{0.075}{\sqrt{f}}$

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

The horizontal cable insertion loss values in Table 81 are provided for information only.

Table 81 - Maximum horizontal cable insertion loss

Frequency (MHz)	Category 3 (dB) 100m (328 ft)	Category 5e (dB) 100m (328 ft)	Category 6 (dB) 100m (328 ft)	Category 6A (dB) 100m (328 ft)	Category 8 (dB) 30 m (98 ft)
0.772	2.2	n/s	n/s	n/s	n/s
1.00	2.6	2.0	2.0	2.1	2.0
4.00	5.6	4.1	3.8	3.8	2.0
8.00	8.5	5.8	5.3	5.3	2.0
10.00	9.7	6.5	6.0	5.9	2.0
16.00	13.1	8.2	7.6	7.5	2.2
20.00	-	9.3	8.5	8.4	2.5
25.00	-	10.4	9.5	9.4	2.8
31.25	-	11.7	10.7	10.5	3.1
62.50	-	17.0	15.4	15.0	4.4
100.00	-	22.0	19.8	19.1	5.6
200.00	-	-	29.0	27.6	7.9
250.00	-	-	32.8	31.1	8.9
300.00	-	-	-	34.3	9.8
400.00	-	-	-	40.1	11.4
500.00	-	-	-	45.3	12.8
600.00	-	-	-	-	14.1
1000.00	-	-	-	-	18.6
1500.00	-	-	-	-	23.2
2000.00	-	-	-	-	27.2

6.6.9 Horizontal cable NEXT loss

Horizontal cable NEXT loss shall meet or exceed the values determined using the equations shown in Table 82 for all specified frequencies.

Table 82 - Horizontal cable NEXT loss

	Frequency (MHz)	NEXT loss (dB)
Category 3	$0.772 \le f \le 16$	$23.2 - 15\log(f/16)$
Category 5e	$1 \le f \le 100$	$35.3 - 15\log(f/100)$
Category 6	$1 \le f \le 250$	$44.3 - 15\log(f/100)$
Category 6A	$1 \le f \le 500$	$44.3 - 15\log(f/100)$
Category 8	$1 \le f \le 2000$	$45.3 - 15\log(f/100)$

The minimum horizontal cable NEXT loss values in Table 83 are provided for information only.

Table 83 - Minimum horizontal cable NEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
0.772	43.0	n/s	n/s	n/s	n/s
1.00	41.3	65.3	74.3	74.3	75.3
4.00	32.3	56.3	65.3	65.3	66.3
8.00	27.8	51.8	60.8	60.8	61.8
10.00	26.3	50.3	59.3	59.3	60.3
16.00	23.2	47.2	56.2	56.2	57.2
20.00	-	45.8	54.8	54.8	55.8
25.00	-	44.3	53.3	53.3	54.3
31.25	-	42.9	51.9	51.9	52.9
62.50	-	38.4	47.4	47.4	48.4
100.00	-	35.3	44.3	44.3	45.3
200.00	-	-	39.8	39.8	40.8
250.00	-	-	38.3	38.3	39.3
300.00	-	-	-	37.1	38.1
400.00	-	-	-	35.3	36.3
500.00	-	-	-	33.8	34.8
600.00	-	-	-	-	33.6
1000.00	-	-	-	-	30.3
1500.00	-	-	-	-	27.7
2000.00	-	-	-	-	25.8

6.6.10 Horizontal cable PSNEXT loss

Horizontal cable PSNEXT loss shall meet or exceed the values determined using the equations shown in Table 84 for all specified frequencies.

Table 84 - 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	$1 \leq f \leq 500$	$42.3 - 15\log(f/100)$
Category 8	$1 \leq f \leq 2000$	$42.3 - 15\log(f/100)$

The horizontal cable PSNEXT loss values in Table 85 are provided for information only.

Table 85 - Minimum horizontal cable PSNEXT loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	62.3	72.3	72.3	72.3
4.00	53.3	63.3	63.3	63.3
8.00	48.8	58.8	58.8	58.8
10.00	47.3	57.3	57.3	57.3
16.00	44.2	54.2	54.2	54.2
20.00	42.8	52.8	52.8	52.8
25.00	41.3	51.3	51.3	51.3
31.25	39.9	49.9	49.9	49.9
62.50	35.4	45.4	45.4	45.4
100.00	32.3	42.3	42.3	42.3
200.00	-	37.8	37.8	37.8
250.00	-	36.3	36.3	36.3
300.00	-	-	35.1	35.1
400.00	-	-	33.3	33.3
500.00	-	-	31.8	31.8
600.00	-	-	-	30.6
1000.00	-	-	-	27.3
1500.00	-	-	-	24.7
2000.00	-	-	-	22.8

6.6.11 Horizontal cable FEXT loss

FEXT loss is not specified for horizontal cables.

6.6.12 Horizontal cable ACRF

Horizontal cable ACRF shall meet or exceed the values determined using the equations shown in Table 86 for all specified frequencies, for a length of 100 m (328 ft) or longer. Category 8 horizontal cable ACRF is for a length of 30 m (98 ft) or longer.

Table 86 - Horizontal cable ACRF

	Frequency (MHz)	ACRF (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f \le 100$	$23.8 - 20\log(f/100)$
Category 6	$1 \le f \le 250$	$27.8 - 20\log(f/100)$
Category 6A	$1 \le f \le 500$	$27.8 - 20\log(f/100)$
Category 8	$1 \le f \le 2000$	$39.0 - 20\log(f/100)$

The horizontal cable ACRF values in Table 87 are provided for information only.

Table 87 - Minimum horizontal cable ACRF

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	63.8	67.8	67.8	75.0
4.00	51.8	55.8	55.8	67.0
8.00	45.7	49.7	49.7	60.9
10.00	43.8	47.8	47.8	59.0
16.00	39.7	43.7	43.7	54.9
20.00	37.8	41.8	41.8	53.0
25.00	35.8	39.8	39.8	51.0
31.25	33.9	37.9	37.9	49.1
62.50	27.9	31.9	31.9	43.1
100.00	23.8	27.8	27.8	39.0
200.00	-	21.8	21.8	33.0
250.00	-	19.8	19.8	31.0
300.00	-	-	18.3	29.5
400.00	-	-	15.8	27.0
500.00	-	-	13.8	25.0
600.00	-	-	-	23.4
1000.00	-	-	-	19.0
1500.00	-	-	-	15.5
2000.00	-	-	-	13.0

6.6.13 Horizontal cable PSFEXT loss

PSFEXT loss is not specified for horizontal cable.

6.6.14 Horizontal cable PSACRF

Horizontal cable PSACRF shall meet or exceed the values determined using the equations shown in Table 88 for all specified frequencies. Category 8 horizontal cable PSACRF is for a length of 30 m (98 ft) or longer.

Table 88 - Horizontal cable PSACRF

	Frequency (MHz)	PSACRF (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f \le 100$	$20.8 - 20\log(f/100)$
Category 6	$1 \le f \le 250$	$24.8 - 20\log(f/100)$
Category 6A	$1 \le f \le 500$	$24.8 - 20\log(f/100)$
Category 8	$1 \le f \le 2000$	$36.0 - 20\log(f/100)$

The horizontal cable PSACRF values in Table 89 are provided for information only.

Table 89 - Minimum horizontal cable PSACRF

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	60.8	64.8	64.8	76.0
4.00	48.8	52.8	52.8	64.0
8.00	42.7	46.7	46.7	57.9
10.00	40.8	44.8	44.8	56.0
16.00	36.7	40.7	40.7	51.9
20.00	34.8	38.8	38.8	50.0
25.00	32.8	36.8	36.8	48.0
31.25	30.9	34.9	34.9	46.1
62.50	24.9	28.9	28.9	40.1
100.00	20.8	24.8	24.8	36.0
200.00	-	18.8	18.8	30.0
250.00	-	16.8	16.8	28.0
300.00	-	-	15.3	26.5
400.00	-	-	12.8	24.0
500.00	-	-	10.8	22.0
600.00	-	-	-	20.4
1000.00	-	-	-	16.0
1500.00	-	-	-	12.5
2000.00	-	-	-	10.0

6.6.15 Horizontal cable TCL

Category 6 through 8 horizontal cable TCL shall meet or exceed the values determined using the equations shown in Table 90 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. Calculations that result in category 8 cable TCL values less than 7 dB shall revert to a requirement of 7 dB minimum.

Table 90 - Category 6 through 8 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	$1 \leq f \leq 500$	$30 - 10\log(f/100)$
Category 8	$1 \leq f \leq 2000$	$20 - 15\log(f/100)$

The horizontal cable TCL values in Table 91 are provided for information only.

Table 91 - Minimum horizontal cable TCL

Frequency (MHz)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	40.0	40.0	40.0
4.00	40.0	40.0	40.0
8.00	40.0	40.0	36.5
10.00	40.0	40.0	35.0
16.00	38.0	38.0	31.9
20.00	37.0	37.0	30.5
25.00	36.0	36.0	29.0
31.25	35.1	35.1	27.6
62.50	32.0	32.0	23.1
100.00	30.0	30.0	20.0
200.00	27.0	27.0	15.5
250.00	26.0	26.0	14.0
300.00	-	25.2	12.8
400.00	-	24.0	11.0
500.00	-	23.0	9.5
600.00	-	-	8.3
1000.00	-	-	7.0
1500.00	-	-	7.0
2000.00	-	-	7.0

6.6.16 Horizontal cable TCTL

TCTL is not specified for horizontal cables.

6.6.17 Horizontal cable ELTCTL

Category 6 through 8 horizontal cable ELTCTL shall meet or exceed the values determined using the equations shown in Table 92 for all specified frequencies.

Table 92 - Category 6 through 8 horizontal cable ELTCTL

	Frequency (MHz)	ELTCTL (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f \le 100$	n/s
Category 6	$1 \le f \le 30$ $30 < f \le 250$	$35 - 20\log(f)$ n/s
Category 6A	$1 \le f \le 30$ $30 < f \le 500$	$35 - 20\log(f)$ n/s
Category 8	$1 \le f \le 56$ $56 < f \le 2000$	$40 - 20\log(f)$ 5

The horizontal cable ELTCTL values in Table 93 are provided for information only.

Table 93 - Minimum horizontal cable ELTCTL

Frequency (MHz)	Category 6 (dB)	Category 6A (dB)	Category (dB)
1.00	35.0	35.0	40.0
4.00	23.0	23.0	28.0
8.00	16.9	16.9	21.9
10.00	15.0	15.0	20.0
16.00	10.9	10.9	15.9
20.00	9.0	9.0	14.0
25.00	7.0	7.0	12.0
30.00	5.5	5.5	10.5
31.25	n/s	n/s	10.1
62.50	n/s	n/s	5.0
100.00	n/s	n/s	5.0
200.00	n/s	n/s	5.0
250.00	n/s	n/s	5.0
300.00	n/s	n/s	5.0
400.00	-	n/s	5.0
500.00	-	n/s	5.0
600.00	-	-	5.0
1000.00	-	-	5.0
1500.00	-	-	5.0
2000.00	-	-	5.0

6.6.18 Horizontal cable coupling attenuation (screened only)

Horizontal cable coupling attenuation shall meet or exceed the values determined using the equations shown in Table 94 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 94 - 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 $55 - 20\log(f/100)$
Category 8	$1 \leq f \leq 30$ $30 < f \leq 100$ $100 < f \leq 2000$	n/s 55 $55 - 20\log(f/100)$

The horizontal cable coupling attenuation values in Table 95 are provided for information only.

Table 95 - Minimum horizontal cable coupling attenuation

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
30.00	55.0	55.0	55.0	55.0
31.25	55.0	55.0	55.0	55.0
62.50	55.0	55.0	55.0	55.0
100.00	55.0	55.0	55.0	55.0
200.00	-	49.0	49.0	49.0
250.00	-	47.0	47.0	47.0
300.00	-	-	45.5	45.5
400.00	-	-	43.0	43.0
500.00	-	-	41.0	41.0
600.00	-	-	-	39.4
1000.00	-	-	-	35.0
1500.00	-	-	-	31.5
2000.00	-	-	-	29.0

6.6.19 Horizontal cable Propagation delay

Horizontal cable propagation delay shall meet or be less than the values determined using the equations shown in Table 96 for all specified frequencies for a length of 100 m (328 ft). See Annex J for the derivation of the equations shown in Table 96.

Table 96 - Horizontal cable propagation delay

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

6.6.20 Category 8 horizontal cable propagation delay

Category 8 horizontal cable propagation delay shall meet or be less than the values determined using the equations shown in table 97 for all specified frequencies for a length of 30 m (98 ft.).

Table 97 - Category 8 horizontal cable propagation delay

	Frequency (MHz)	Horizontal cable propagation delay (ns/30 m)
Category 8	$1 \le f \le 2000$	$(160+\frac{11}{\sqrt{f}})$

The horizontal cable propagation delay values in Table 98 are provided for information only.

Table 98 - Maximum horizontal cable propagation delay

Frequency (MHz)	Category 3 (ns/100 m)	Category 5e (ns/100 m)	Category 6 (ns/100 m)	Category 6A (ns/100 m)	Category 8 (ns/30 m)
1.00	570	570	570	570	171.0
4.00	552	552	552	552	165.5
8.00	547	547	547	547	163.9
10.00	545	545	545	545	163.5
16.00	543	543	543	543	162.8
20.00	-	542	542	542	162.5
25.00	-	541	541	541	162.2
31.25	-	540	540	540	162.0
62.50	-	539	539	539	161.4
100.00	-	538	538	538	161.1
200.00	-	-	537	537	160.8
250.00	-	-	536	536	160.7
300.00	-	-	-	536	160.6
400.00	-	-	-	536	160.6
500.00	-	-	-	536	160.5
600.00					160.4
1000.00					160.3
1500.00					160.3
2000.00					160.2

6.6.21 Category 3 through 6A horizontal cable propagation delay skew

Category 3 through 6A horizontal cable propagation delay skew shall be less than 45 ns/100 m at 20 °C, 40 °C, and 60 °C 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 °C when measured at 40 °C and 60 °C. Compliance shall be determined using a minimum 100 m (328 ft) of cable.

6.6.22 Category 8 horizontal cable propagation delay skew

Category 8 horizontal cable propagation delay skew for category 8 horizontal cable shall be less than 13.5 ns/30 m at 20 °C, 40 °C, and 60 °C for all frequencies from 1 MHz to 2000 MHz. In addition, the propagation delay skew between all pairs shall not vary more than ±3 ns from the measured value at 20 °C when measured at 40 °C and 60 °C. Compliance shall be determined using a minimum 30 m (98 ft.) of cable.

6.6.23 Horizontal cable 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 (38). Calculations that result in surface transfer impedance values less than 50 mΩ/m shall revert to a requirement of 50 mΩ/m minimum.

$$Z_{Tcable} = 10f \text{ m}\Omega\text{/m} \qquad (38)$$

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, 6A and 8 cables.

The values in Table 99 are derived from the above formula and provided for information only.

Table 99 - Maximum cable surface transfer impedance

Frequency (MHz)	Category 3 (mΩ/m)	Category 5e (mΩ/m)	Category 6 (mΩ/m)	Category 6A (mΩ/m)	Category 8 (mΩ/m)
1	50	50	50	50	50
10	100	100	100	100	100
16	160	160	160	160	160
20	-	200	200	200	200
100	-	1,000	1,000	1,000	1,000

6.6.24 Horizontal cable ANEXT loss

ANEXT loss is not specified for horizontal cables.

6.6.25 Horizontal cable PSANEXT loss

Horizontal cable PSANEXT loss shall meet or exceed the values determined using the equations shown in table 100 or Table 101 for all specified frequencies. Calculations that result in category 6A PSANEXT loss values greater than 67 dB shall revert to a requirement of 67 dB minimum. Calculations that result in category 8 PSANEXT loss values greater than 80 dB shall revert to a requirement of 80 dB minimum.

Table 100 - Horizontal cable PSANEXT loss

	Frequency (MHz)	PSANEXT loss (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	$1 \le f \le 500$	$62.5 - 15\log(f/100)$
Category 8	$1 \le f \le 2000$	$87.5 - 15\log(f/100)$

The horizontal cable PSANEXT loss values in Table 101 are provided for information only.

Table 101 - Minimum horizontal cable PSANEXT loss

Frequency (MHz)	Category 6A (dB)	Category 8 (dB)
1.00	67.0	80.0
4.00	67.0	80.0
8.00	67.0	80.0
10.00	67.0	80.0
16.00	67.0	80.0
20.00	67.0	80.0
25.00	67.0	80.0
31.25	67.0	80.0
62.50	65.6	80.0
100.00	62.5	80.0
200.00	58.0	80.0
250.00	56.5	80.0
300.00	55.3	80.0
400.00	53.5	78.5
500.00	52.0	77.0
600.00	-	75.8
1000.00	-	72.5
1500.00	-	69.9
2000.00	-	68.0

6.6.26 Horizontal cable Average PSANEXT loss

Average PSANEXT loss is not specified for horizontal cables.

6.6.27 Horizontal cable AFEXT loss

AFEXT loss is not specified for horizontal cables.

6.6.28 Horizontal cable PSAFEXT loss

PSAFEXT loss is not specified for horizontal cables.

6.6.29 Horizontal cable PSAACRF

Horizontal cable PSAACRF shall meet or exceed the values determined using the equations shown in Table 102 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 102 - 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	$1 \le f \le 500$	$38.2 - 20\log(f/100)$

6.6.30 Category 8 horizontal cable PSAACRF

Category 8 horizontal cable PSAACRF for a length of 30 m (98 ft) shall meet or exceed the values determined using the equations shown in table 103 for all specified frequencies.

Table 103 - Category 8 horizontal cable PSAACRF

	Frequency (MHz)	Horizontal cable PSAACRF (dB)[1]
Category 8	$1 \leq f \leq 2000$	$62.2 - 20\log(f/100)$
1 Calculations that result in horizontal cable PSAACRF values greater than 80 dB shall revert to a requirement of 80 dB minimum.		

The horizontal cable PSAACRF values in Table 104 are provided for information only.

Table 104 - Minimum horizontal cable PSAACRF

Frequency (MHz)	Category 6A (dB)	Category 8 (dB)
1.00	67.0	80.0
4.00	66.2	80.0
8.00	60.1	80.0
10.00	58.2	80.0
16.00	54.1	78.1
20.00	52.2	76.2
25.00	50.2	74.2
31.25	48.3	72.3
62.50	42.3	66.3
100.00	38.2	62.2
200.00	32.2	56.2
250.00	30.2	54.2
300.00	28.7	52.7
400.00	26.2	50.2
500.00	24.2	48.2
600.00	-	46.6
1000.00	-	42.2
1500.00	-	38.7
2000.00	-	36.2

6.6.31 Horizontal cable Average PSAACRF

Average PSAACRF is not specified for horizontal cable.

6.7 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 6.6 of this Standard and ANSI/TIA-568.3-D, for optical fiber cables. The individual cables within a bundled cable shall meet the applicable requirements in clause 6.6 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.

6.7.1 Bundled and hybrid cable 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 at least 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.

6.7.2 Bundled and hybrid cable 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 (39). Calculated power sum NEXT loss limit values that exceed 65 dB shall revert to a limit of 65 dB.

$$PSNEXT_{bundled\_and\_hybrid,all\_pairs} \geq 41.1 - 15\log(f/100) \quad (39)$$

6.8 Cord cable transmission performance

Cord cables shall meet the transmission performance requirements specified for horizontal cable in clause 6.6, with the exception of the requirements of this clause.

6.8.1 Cord cable dc resistance

DC resistance shall be measured in accordance with ASTM D4566. For categories 3 through 6A of cord cable, the resistance of any conductor shall not exceed 14 Ω per 100 m (328 ft) at or corrected to a temperature of 20 °C. Using a temperature coefficient of resistance of 0.00393 for copper, the resistance at 60 °C is 16.23 Ω or less per 100 m for all category 3 through 6A cord cable conductors.
For category 8 cord cable, the resistance of any cord cable conductor shall not exceed 4.2 Ω per 30 m (98 ft) at or corrected to a temperature of 20 °C. Using a temperature coefficient of resistance of 0.00393 for copper, the resistance at 60 °C is 4.87 Ω.

6.8.2 Cord cable return loss

Cord cable return loss, for a length of 100 m (328 ft) for categories 3 through 6A, and 30 m (98 ft) for category 8, shall meet or exceed the values determined using the equations shown in Table 105 for all specified frequencies.

Table 105 - Cord 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 $25 - 8.6\log(f/20)$
Category 6	$1 \leq f < 10$ $10 \leq f < 20$ $20 \leq f \leq 250$	$20+5\log(f)$ 25 $25 - 8.6\log(f/20)$
Category 6A	$1 \leq f < 10$ $10 \leq f < 20$ $20 \leq f \leq 500$	$20+5\log(f)$ 25 $25 - 8.6\log(f/20)$
Category 8	$1 \leq f < 10$ $10 \leq f < 40$ $40 \leq f \leq 2000$	$20+5\log(f)$ 25 $25 - 7\log(f/40)$

The cord return loss values in Table 106 are provided for information only.

Table 106 - Minimum cord cable return loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	20.0	20.0	20.0	20.0
4.00	23.0	23.0	23.0	23.0
8.00	24.5	24.5	24.5	24.5
10.00	25.0	25.0	25.0	25.0
16.00	25.0	25.0	25.0	25.0
20.00	25.0	25.0	25.0	25.0
25.00	24.2	24.2	24.2	25.0
31.25	23.3	23.3	23.3	25.0
62.50	20.7	20.7	20.7	23.6
100.00	19.0	19.0	19.0	22.2
200.00	-	16.4	16.4	20.1
250.00	-	15.6	15.6	19.4
300.00	-	-	14.9	18.9
400.00	-	-	13.8	18.0
500.00	-	-	13.0	17.3
600.00	-	-	-	16.8
1000.00	-	-	-	15.2
1500.00	-	-	-	14.0
2000.00	-	-	-	13.1

6.8.3 Category 3 through 6A cord cable insertion loss

Cord cable insertion loss limits are derived by multiplying the applicable horizontal cable insertion loss requirements in clause 6.6.8 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 (50% de-rating, e.g. cables with twisted-pairs having 26 AWG conductors) is allowed with the appropriate attention paid to the maximum allowable permanent link length. For example, when only 50% de-rated cords are used with a 90 m permanent link, the combined length of all 50% de-rated cords should not be greater than 8.0 m (25.7 ft). If longer total length of de-rated patch cords are desired, the permanent link maximum length is reduced accordingly.

The maximum insertion loss for UTP cord cables shall be adjusted at elevated temperatures using a factor of 0.4 % increase per °C from 20 °C to 40 °C and 0.6% increase per °C for temperatures from 40 °C to 60 °C. The maximum insertion loss for screened cord cables shall be adjusted at elevated temperatures using a factor of 0.2% increase per °C from 20 °C to 60 °C. See H.1 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 107 for all specified frequencies. In addition, category 5e, 6 and 6A cord cable insertion loss shall also be verified at temperatures of 40 ± 3 °C and 60 ± 3 °C and shall meet the requirements of Table 107 after adjusting for temperature.

Table 107 - 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	$1 \leq f \leq 100$	$1.2 \cdot \left(1.967\sqrt{f} + 0.023 \cdot f + \frac{0.050}{\sqrt{f}}\right)$
Category 6	$1 \leq f \leq 250$	$1.2 \cdot \left(1.808\sqrt{f} + 0.017 \cdot f + \frac{0.2}{\sqrt{f}}\right)$
Category 6A	$1 \leq f \leq 500$	$1.2 \cdot \left(1.82\sqrt{f} + 0.0091 \cdot f + \frac{0.25}{\sqrt{f}}\right)$

The cord cable insertion loss values in table 109 are provided for information only.

Table 108 - Maximum category 3 through 6A 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

6.8.4 Category 8 cord cable insertion loss

The maximum insertion loss for category 8 cord cables shall be adjusted at elevated temperatures using a factor of 0.2% increase per °C from 20 °C to 60 °C. In addition, category 8 cord cable insertion loss shall also be verified at temperatures of 40 ± 3 °C and 60 ± 3 °C and shall meet the requirement of Table 109 after adjusting for temperature.

Category 8 cord cable insertion loss for 30 m (98 ft.) shall meet or be less than the values determined using the equations shown in table 109 for all specified frequencies.

Table 109 - Category 8 cord cable insertion loss, for a length of 30 m (98 ft.)

	Frequency (MHz)	Cord cable insertion loss (dB)
Category 8	$1 \le f \le 2000$	$IL_{Derating} \cdot \left(0.540\sqrt{f} + 0.0015f + \frac{0.075}{\sqrt{f}} \right)$

Where $IL_{Derating}$ is the de-rating factor of the cord cable.

Typical wire gauges which correspond to de-rating factors of cord cables are shown in table 110

Table 110 - Cord cable insertion loss de-rating factor

Cord cable de-rating factor %	$IL_{Derating}$	Nominal wire gauge (AWG)
0	1.0	22/23
20	1.2	24
50	1.5	26

The maximum cord cable insertion loss values in table 111 are provided for information only.

Table 111 - Maximum category 8 cord cable insertion loss, for a length of 30 m (98 ft)

Frequency (MHz)	0% de-rated cord cable	20% de-rated cord cable	50% de-rated cord cable
1.00	0.6	0.7	0.9
4.00	1.1	1.3	1.7
8.00	1.6	1.9	2.3
10.00	1.7	2.1	2.6
16.00	2.2	2.6	3.3
20.00	2.5	3.0	3.7
25.00	2.8	3.3	4.1
31.25	3.1	3.7	4.6
62.50	4.4	5.2	6.6
100.00	5.6	6.7	8.3
200.00	7.9	9.5	11.9
250.00	8.9	10.7	13.4
300.00	9.8	11.8	14.7
400.00	11.4	13.7	17.1
500.00	12.8	15.4	19.2
600.00	14.1	17.0	21.2
1000.00	18.6	22.3	27.9
1500.00	23.2	27.8	34.7
2000.00	27.2	32.6	40.7

6.9 Backbone cable transmission performance

Backbone cables shall meet the transmission performance requirements specified for horizontal cable in clause 6.6, with the exception of the requirements of this clause. Transmission performance of category 8 backbone cables shall meet the requirements for category 8 horizontal cables.

NOTE – Only four-pair horizontal cables are recognized for use in category 6, 6A and category 8 backbone cabling.

6.9.1 Backbone cable insertion loss

Insertion loss for all pairs shall comply with the requirements of clause 6.6.8 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.

6.9.2 Backbone cable NEXT loss

NEXT loss applies to all adjacent 4-pair combinations. Backbone cable NEXT loss shall be measured in accordance with Annex C or D 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. Category 3 through 6A backbone cable NEXT loss shall meet or exceed the values determined using the equations shown in Table 112 for all specified frequencies, for a length of 100 m (328 ft) or longer.

Table 112 - Category 3 through 6A backbone cable NEXT loss

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

The backbone cable NEXT loss values in Table 113 are provided for information only.

Table 113 - Minimum Category 3 through 6A backbone cable NEXT loss

Frequency (MHz)	Category 5e (within 4-pair group) (dB)	Category 5e (25th to all other pairs) (dB)	Category 6 (dB)	Category 6A (dB)
1.00	65.3	65.3	74.3	74.3
4.00	56.3	56.3	65.3	65.3
8.00	51.8	51.8	60.8	60.8
10.00	50.3	50.3	59.3	59.3
16.00	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

6.9.3 Category 3 through 6A backbone cable 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.

Category 3 through 6A backbone cable PSNEXT loss shall meet or exceed the values determined using the equations shown in Table 114 for all specified frequencies, for a length of 100 m (328 ft) or longer.

Table 114 - Category 3 through 6A backbone cable PSNEXT loss

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

The backbone cable PSNEXT loss values in Table 115 are provided for information only.

Table 115 - Minimum Category 3 through 6A 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

6.9.4 Category 3 through 6A backbone cable ACRF

FEXT loss applies to all adjacent 4-pair combinations in accordance with the ASTM D4566 FEXT loss measurement procedure and Annex C or D. Category 3 through 6A backbone cable FEXT loss shall be measured in accordance with Annex C or D 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.

Category 3 through 6A backbone cable ACRF shall be calculated for all 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 116 for all specified frequencies, for a length of 100 m (328 ft) or longer.

Table 116 - Category 3 through 6A 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 117 are provided for information only.

Table 117 - Minimum Category 3 through 6A backbone cable ACRF

Frequency (MHz)	Category 5e (within 4-pair group) (dB)	Category 5e (25th to all other pairs) (dB)	Category 6 (dB)	Category 6A (dB)
1.00	63.8	63.8	67.8	67.8
4.00	51.8	51.8	55.8	55.8
8.00	45.7	45.7	49.7	49.7
10.00	43.8	43.8	47.8	47.8
16.00	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

6.9.5 Category 3 through 6A backbone cable 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-568.0-D for more information.

Category 3 through 6A backbone cable PSACRF shall meet or exceed the values determined using the equations shown in Table 118 for all specified frequencies, for a length of 100 m (328 ft) or longer.

Table 118 - Category 3 through 6A 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 119 are provided for information only.

Table 119 - Minimum Category 3 through 6A backbone cable PSACRF

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	60.8	64.8	64.8
4.00	48.8	52.8	52.8
8.00	42.7	46.7	46.7
10.00	40.8	44.8	44.8
16.00	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

6.9.6 Category 3 through 6A backbone cable propagation delay

Category 3 through 6A backbone cable propagation delay shall meet or be less than the values determined using the equations shown in Table 120 for all specified frequencies for a length of 100 m (328 ft). See Annex J for the derivation of the equations shown in Table 120.

Table 120 - Category 3 through 6A backbone cable propagation delay

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

The backbone propagation delay values in Table 121 are provided for information only.

Table 121 - Maximum Category 3 through 6A backbone cable propagation delay

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	570	570	570
4.00	552	552	552
8.00	547	547	547
10.00	545	545	545
16.00	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

6.9.7 Category 5e through 6A backbone cable 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 6.6.21. 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 6.6.21. 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.

6.10 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-568.0-D for guidance and requirements on connector termination practices, cable management, the use of cords or 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.

6.10.1 Connecting hardware dc resistance

DC resistance shall be measured in accordance with ASTM D4566 at 20 °C ± 3 °C 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, 6A and 8 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.

For all categories, if a shield is present, the shield input to output resistance shall not exceed 100 mΩ.

6.10.2 Connecting hardware dc contact resistance

Shield contact resistance is specified in IEC 60603-7-1 and signal contact resistance in IEC 60603-7.

6.10.3 Connecting hardware 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 60512-2-1, 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.

6.10.4 Connecting hardware mutual capacitance

Mutual capacitance is not specified for connecting hardware.

6.10.5 Connecting hardware capacitance unbalance: pair-to-ground

Capacitance unbalance to ground is not specified for connecting hardware.

6.10.6 Connecting hardware characteristic impedance and structural return loss (SRL)

Characteristic impedance is not specified for connecting hardware.

6.10.7 Connecting hardware return loss

Connecting hardware return loss shall meet or exceed the values determined using the equations shown in Table 122 for all specified frequencies.

Table 122 - 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 $20 - 20\log(f/100)$
Category 6	$1 \leq f \leq 50$ $50 < f \leq 250$	30 $24 - 20\log(f/100)$
Category 6A	$1 \leq f \leq 79$ $79 < f \leq 500$	30 $28 - 20\log(f/100)$
Category 8	$1 \leq f \leq 1000$ $1000 < f \leq 2000$	$32 - 20\log(f/100)$ 12

The connecting hardware return loss values in Table 123 are provided for information only.

Table 123 - Minimum connecting hardware return loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	30.0	30.0	30.0	30.0
4.00	30.0	30.0	30.0	30.0
8.00	30.0	30.0	30.0	30.0
10.00	30.0	30.0	30.0	30.0
16.00	30.0	30.0	30.0	30.0
20.00	30.0	30.0	30.0	30.0
25.00	30.0	30.0	30.0	30.0
31.25	30.0	30.0	30.0	30.0
62.50	24.1	28.1	30.0	30.0
100.00	20.0	24.0	28.0	30.0
200.00	-	18.0	22.0	26.0
250.00	-	16.0	20.0	24.0
300.00	-	-	18.5	22.5
400.00	-	-	16.0	20.0
500.00	-	-	14.0	18.0
600.00	-	-	-	16.4
1000.00	-	-	-	12.0
1500.00	-	-	-	12.0
2000.00	-	-	-	12.0

6.10.8 Connecting hardware insertion loss

Connecting hardware insertion loss shall meet or be less than the values determined using the equations shown in Table 124 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 124 - Connecting hardware insertion loss

	Frequency (MHz)	Insertion loss (dB)
Category 3	$1 \le f \le 16$	$0.10\sqrt{f}$
Category 5e	$1 \le f \le 100$	$0.04\sqrt{f}$
Category 6	$1 \le f \le 250$	$0.02\sqrt{f}$
Category 6A	$1 \le f \le 500$	$0.02\sqrt{f}$
Category 8	$1 \le f \le 500$	$0.02\sqrt{f}$
	$500 < f \le 2000$	$\left(0.00649\sqrt{f} + 0.000605f\right)$

The connecting hardware insertion loss values in Table 125 are provided for information only.

Table 125 - Maximum connecting hardware insertion loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	0.10	0.10	0.10	0.10	0.10
4.00	0.20	0.10	0.10	0.10	0.10
8.00	0.28	0.11	0.10	0.10	0.10
10.00	0.32	0.13	0.10	0.10	0.10
16.00	0.40	0.16	0.10	0.10	0.10
20.00	-	0.18	0.10	0.10	0.10
25.00	-	0.20	0.10	0.10	0.10
31.25	-	0.22	0.11	0.11	0.11
62.50	-	0.32	0.16	0.16	0.16
100.00	-	0.40	0.20	0.20	0.20
200.00	-	-	0.28	0.28	0.28
250.00	-	-	0.32	0.32	0.32
300.00	-	-	-	0.35	0.35
400.00	-	-	-	0.40	0.40
500.00	-	-	-	0.45	0.45
600.00	-	-	-	-	0.52
1000.00	-	-	-	-	0.81
1500.00	-	-	-	-	1.16
2000.00	-	-	-	-	1.50

6.10.9 Connecting hardware NEXT loss

Connecting hardware NEXT loss shall meet or exceed the values determined using the equations shown in Table 126 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 126 - 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	$1 \le f \le 250$ $250 < f \le 500$	$54 - 20\log(f/100)$ $46.04 - 40\log(f/250)$
Category 8	$1 \le f \le 250$ $250 < f \le 500$ $500 < f \le 2000$	$54 - 20\log(f/100)$ $46.04 - 30\log(f/250)$ $37.01 - 40\log(f/500)$

The connecting hardware NEXT loss values in Table 127 are provided for information only.

Table 127 - Minimum connecting hardware NEXT loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	58.1	65.0	75.0	75.0	75.0
4.00	46.0	65.0	75.0	75.0	75.0
8.00	40.0	64.9	75.0	75.0	75.0
10.00	38.1	63.0	74.0	74.0	74.0
16.00	34.0	58.9	69.9	69.9	69.9
20.00	-	57.0	68.0	68.0	68.0
25.00	-	55.0	66.0	66.0	66.0
31.25	-	53.1	64.1	64.1	64.1
62.50	-	47.1	58.1	58.1	58.1
100.00	-	43.0	54.0	54.0	54.0
200.00	-	-	48.0	48.0	48.0
250.00	-	-	46.0	46.0	46.0
300.00	-	-	-	42.9	43.7
400.00	-	-	-	37.9	39.9
500.00	-	-	-	34.0	37.0
600.00	-	-	-	-	33.8
1000.00	-	-	-	-	25.0
1500.00	-	-	-	-	17.9
2000.00	-	-	-	-	12.9

6.10.10 Connecting hardware PSNEXT loss

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

The connecting hardware PSNEXT loss values shown in Table 128 are used to derive channel and permanent link PSNEXT loss requirements for all specified frequencies.

Table 128 - 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	$1 \leq f \leq 250$ $250 < f \leq 500$	$50 - 20\log(f/100)$ $42.04 - 40\log(f/250)$
Category 8	$1 \leq f \leq 250$ $250 < f \leq 500$ $500 < f \leq 2000$	$50 - 20\log(f/100)$ $42.04 - 30\log(f/250)$ $33.0 - 40\log(f/500)$

The connecting hardware NEXT loss values in Table 129 are provided for information only.

Table 129 - Minimum connecting hardware PSNEXT loss assumptions

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	80.0	90.0	90.0	90.0
4.00	68.0	78.0	78.0	78.0
8.00	61.9	71.9	71.9	71.9
10.00	60.0	70.0	70.0	70.0
16.00	55.9	65.9	65.9	65.9
20.00	54.0	64.0	64.0	64.0
25.00	52.0	62.0	62.0	62.0
31.25	50.1	60.1	60.1	60.1
62.50	44.1	54.1	54.1	54.1
100.00	40.0	50.0	50.0	50.0
200.00	-	46.5	44.0	44.0
250.00	-	44.0	42.0	42.0
300.00	-	-	38.9	39.7
400.00	-	-	33.9	35.9
500.00	-	-	30.0	33.0
600.00	-	-	-	29.8
1000.00	-	-	-	21.0
1500.00	-	-	-	13.9
2000.00	-	-	-	8.9

6.10.11 Connecting hardware FEXT loss

Connecting hardware FEXT loss shall meet or exceed the values determined using the equations shown in Table 130 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 130 - Connecting hardware FEXT loss

	Frequency (MHz)	FEXT loss (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f \le 100$	$35.1 - 20\log(f/100)$
Category 6	$1 \le f \le 250$	$43.1 - 20\log(f/100)$
Category 6A	$1 \le f \le 500$	$43.1 - 20\log(f/100)$
Category 8	$1 \le f \le 2000$	$43.1 - 20\log(f/100)$

The connecting hardware FEXT loss values in Table 131 are provided for information only.

Table 131 - Minimum connecting hardware FEXT loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	65.0	75.0	75.0	75.0
4.00	63.1	71.1	71.1	71.1
8.00	57.0	65.0	65.0	65.0
10.00	55.1	63.1	63.1	63.1
16.00	51.0	59.0	59.0	59.0
20.00	49.1	57.1	57.1	57.1
25.00	47.1	55.1	55.1	55.1
31.25	45.2	53.2	53.2	53.2
62.50	39.2	47.2	47.2	47.2
100.00	35.1	43.1	43.1	43.1
200.00	-	37.1	37.1	37.1
250.00	-	35.1	35.1	35.1
300.00	-	-	33.6	33.6
400.00	-	-	31.1	31.1
500.00	-	-	29.1	29.1
600.00	-	-	-	27.5
1000.00	-	-	-	23.1
1500.00	-	-	-	19.6
2000.00	-	-	-	17.1

6.10.12 Connecting hardware ACRF

ACRF is not specified for connecting hardware.

6.10.13 Connecting hardware PSFEXT loss

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

The connecting hardware PSFEXT loss values shown in Table 132 are used to derive channel and permanent link PSACRF requirements for all specified frequencies.

Table 132 - 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	$1 \leq f \leq 500$	$40.1 - 20\log(f/100)$
Category 8	$1 \leq f \leq 2000$	$40.1 - 20\log(f/100)$

Table 133 - Minimum connecting hardware PSFEXT loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	72.1	80.1	80.1	80.1
4.00	60.1	68.1	68.1	68.1
8.00	54.0	62.0	62.0	62.0
10.00	52.1	60.1	60.1	60.1
16.00	48.0	56.0	56.0	56.0
20.00	46.1	54.1	54.1	54.1
25.00	44.1	52.1	52.1	52.1
31.25	42.2	50.2	50.2	50.2
62.50	36.2	44.2	44.2	44.2
100.00	32.1	40.1	40.1	40.1
200.00	-	36.6	34.1	34.1
250.00	-	34.1	32.1	32.1
300.00	-	-	30.6	30.6
400.00	-	-	28.1	28.1
500.00	-	-	26.1	26.1
600.00	-	-	-	24.5
1000.00	-	-	-	20.1
1500.00	-	-	-	16.6
2000.00	-	-	-	14.1

6.10.14 Connecting hardware PSACRF

PSACRF is not specified for connecting hardware.

6.10.15 Connecting hardware TCL

Connecting hardware TCL shall meet or exceed the values determined using the equations shown in Table 134 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 134 - Connecting hardware TCL

	Frequency (MHz)	**TCL (dB)**
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f \le 100$	n/s
Category 6	$1 \le f \le 250$	$28 - 20\log(f/100)$
Category 6A	$1 \le f \le 500$	$28 - 20\log(f/100)$
Category 8	$1 \le f \le 2000$	$34 - 20\log(f/100)$

The connecting hardware TCL values in Table 135 are provided for information only.

Table 135 - Minimum connecting hardware TCL

Frequency (MHz)	**Category 6 (dB)**	**Category 6A (dB)**	**Category 8 (dB)**
1.00	40.0	40.0	40.0
4.00	40.0	40.0	40.0
8.00	40.0	40.0	40.0
10.00	40.0	40.0	40.0
16.00	40.0	40.0	40.0
20.00	40.0	40.0	40.0
25.00	40.0	40.0	40.0
31.25	38.1	38.1	40.0
62.50	32.1	32.1	38.1
100.00	28.0	28.0	34.0
200.00	22.0	22.0	28.0
250.00	20.0	20.0	26.0
300.00	-	18.5	24.5
400.00	-	16.0	22.0
500.00	-	14.0	20.0
600.00	-	-	18.4
1000.00	-	-	14.0
1500.00	-	-	10.5
2000.00	-	-	8.0

6.10.16 Connecting hardware TCTL

Connecting hardware TCTL shall meet or exceed the values determined using the equations shown in Table 136 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. Calculations that result in category 8 connecting hardware TCTL values greater than 50 dB shall revert to a requirement of 50 dB minimum.

Table 136 - Connecting hardware TCTL

	Frequency (MHz)	TCL (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f \le 100$	n/s
Category 6	$1 \le f \le 250$	$28 - 20\log(f/100)$
Category 6A	$1 \le f \le 500$	$28 - 20\log(f/100)$
Category 8	$1 \le f \le 2000$	$38 - 20\log(f/100)$

The connecting hardware TCTL values in Table 137 are provided for information only.

Table 137 - Minimum connecting hardware TCTL

Frequency (MHz)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	40.0	40.0	50.0
4.00	40.0	40.0	50.0
8.00	40.0	40.0	50.0
10.00	40.0	40.0	50.0
16.00	40.0	40.0	50.0
20.00	40.0	40.0	50.0
25.00	40.0	40.0	50.0
31.25	38.1	38.1	48.1
62.50	32.1	32.1	42.1
100.00	28.0	28.0	38.0
200.00	22.0	22.0	32.0
250.00	20.0	20.0	30.0
300.00	-	18.5	28.5
400.00	-	16.0	26.0
500.00	-	14.0	24.0
600.00	-	-	22.4
1000.00	-	-	18.0
1500.00	-	-	14.5
2000.00	-	-	12.0

6.10.17 Connecting hardware ELTCTL

ELTCTL is not specified for connecting hardware.

6.10.18 Connecting hardware coupling attenuation (screened only)

Connecting hardware coupling attenuation is assured through compliance with channel coupling attenuation requirements.

6.10.19 Connecting hardware 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.

6.10.20 Connecting hardware 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.

6.10.21 Connecting hardware shield transfer impedance (screened only)

The shield transfer impedance of screened connecting hardware, measured in accordance with Annex C or D shall not exceed the values determined using Table 138.

Table 138 - Connecting hardware shield transfer impedance (screened only)

Frequency (MHz)	Z_{Tconn} (dB)
$1 \le f \le 4$	$40\sqrt{f}$
$4 < f \le 100$	$20f$

Where:

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

The values in Table 139 are derived from Table 138 and are provided for information only.

Table 139 - Maximum connecting hardware shield transfer impedance

Frequency (MHz)	Category 5e (mΩ)	Category 6 (mΩ)	Category 6A (mΩ)
1.00	40	40	40
4.00	80	80	80
8.00	160	160	160
10.00	200	200	200
16.00	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.

6.10.22 Connecting hardware ANEXT loss

ANEXT loss is not specified for connecting hardware.

6.10.23 Connecting hardware PSANEXT loss

Connecting hardware PSANEXT loss shall meet or exceed the values determined using the equations shown in Table 140 for all specified frequencies. Calculations that result in PSANEXT loss values greater than 67 dB shall revert to a requirement of 67 dB minimum. Category 8 connecting hardware PSANEXT loss calculations that result in PSANEXT loss values greater than 80 dB shall revert to a requirement of 80 dB minimum.

Table 140 - Connecting hardware PSANEXT loss

	Frequency (MHz)	**PSANEXT loss (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	$1 \le f \le 500$	$70.5 - 20\log(f/100)$
Category 8	$1 \le f \le 2000$	$95.5 - 20\log(f/100)$

The connecting hardware PSANEXT loss values in Table 141 are provided for information only.

Table 141 - Minimum connecting hardware PSANEXT loss

Frequency (MHz)	Category 6A (dB)	Category 8 (dB)
1.00	67.0	80.0
4.00	67.0	80.0
8.00	67.0	80.0
10.00	67.0	80.0
16.00	67.0	80.0
20.00	67.0	80.0
25.00	67.0	80.0
31.25	67.0	80.0
62.50	67.0	80.0
100.00	67.0	80.0
200.00	64.5	80.0
250.00	62.5	80.0
300.00	61.0	80.0
400.00	58.5	80.0
500.00	56.5	80.0
600.00	-	79.9
1000.00	-	75.5
1500.00	-	72.0
2000.00	-	69.5

6.10.24 Connecting hardware Average PSANEXT loss

Average PSANEXT loss is not specified for connecting hardware.

6.10.25 Connecting hardware AFEXT loss

AFEXT loss is not specified for connecting hardware.

6.10.26 Connecting hardware PSAFEXT loss

Connecting hardware PSAFEXT loss shall meet or exceed the values determined using the equations shown in Table 142 for all specified frequencies. Calculations that result in PSANEXT loss values greater than 67 dB shall revert to a requirement of 67 dB minimum. Category 8 connecting hardware PSAFEXT loss calculations that result in PSAFEXT loss values greater than 80 dB shall revert to a requirement of 80 dB minimum.

Table 142 - Connecting hardware PSAFEXT loss

	Frequency (MHz)	PSANEXT loss (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	$1 \le f \le 500$	$67 - 20\log(f/100)$
Category 8	$1 \le f \le 2000$	$91 - 20\log(f/100)$

The connecting hardware PSAFEXT loss values in Table 143 are provided for information only.

Table 143 - Minimum connecting hardware PSAFEXT loss

Frequency (MHz)	Category 6A (dB)	Category 8 (dB)
1.00	67.0	80.0
4.00	67.0	80.0
8.00	67.0	80.0
10.00	67.0	80.0
16.00	67.0	80.0
20.00	67.0	80.0
25.00	67.0	80.0
31.25	67.0	80.0
62.50	67.0	80.0
100.00	67.0	80.0
200.00	61.0	80.0
250.00	59.0	80.0
300.00	57.5	80.0
400.00	52.0	79.0
500.00	53.0	77.0
600.00	-	75.4
1000.00	-	71.0
1500.00	-	67.5
2000.00	-	65.0

6.10.27 Connecting hardware PSAACRF

PSAACRF is not specified for connecting hardware.

6.10.28 Connecting hardware Average PSAACRF

Average PSAACRF is not specified for connecting hardware.

6.11 Cord transmission performance

Modular plugs and other connectors used for 100 Ω twisted-pair cable assemblies shall meet the requirements specified in clause 6.10. Cables used to construct cords shall meet the transmission performance requirements for cord cable specified in clause 6.8.

6.11.1 Cord return loss

Cord return loss shall meet or exceed the values determined using the equations shown in Table 144 for all specified frequencies.

Table 144 - Cord return loss

	Frequency (MHz)	Return loss (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f < 25$ $25 \le f \le 100$	$24 + 3\log(f/25)$ $24 - 10\log(f/25)$
Category 6	$1 \le f < 25$ $25 \le f \le 250$	$24 + 3\log(f/25)$ $24 - 10\log(f/25)$
Category 6A	$1 \le f < 25$ $25 \le f \le 250$ $250 < f \le 500$	$24 + 3\log(f/25)$ $24 - 10\log(f/25)$ $14 - 15\log(f/250)$
Category 8	$1 \le f < 25$ $25 \le f \le 1000$ $1000 < f \le 2000$	$24 + 3\log(f/25)$ $8 - 10\log(f/1000)$ 8

The cord return loss values in Table 145 are provided for information only.

Table 145 - Minimum cord return loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	19.8	19.8	19.8	19.8
4.00	21.6	21.6	21.6	21.6
8.00	22.5	22.5	22.5	22.5
10.00	22.8	22.8	22.8	22.8
16.00	23.4	23.4	23.4	23.4
20.00	23.7	23.7	23.7	23.7
25.00	24.0	24.0	24.0	24.0
31.25	23.0	23.0	23.0	23.1
62.50	20.0	20.0	20.0	20.0
100.00	18.0	18.0	18.0	18.0
200.00	-	15.0	15.0	15.0
250.00	-	14.0	14.0	14.0
300.00	-	-	12.8	13.2
400.00	-	-	10.9	12.0
500.00	-	-	9.5	11.0
600.00	-	-	-	10.2
1000.00	-	-	-	8.0
1500.00	-	-	-	8.0
2000.00	-	-	-	8.0

6.11.2 Cord NEXT loss

For all frequencies from 1 MHz to the upper limit of each category, cord NEXT loss shall meet the values determined using equation (40). Calculations that result in NEXT loss values greater than 65 dB shall revert to a requirement of 65 dB minimum.

$$NEXT_{cord} \geq -10\log\left(10^{\frac{-NEXT_{connectors}}{10}} + 10^{\frac{-\left(NEXT_{cord\_cable} + 2\cdot IL_{conn}\right)}{10}}\right) - RFEXT \qquad (40)$$

where:

$$NEXT_{connectors} = -20\log\left(10^{\frac{-NEXT_{conn\_spec}}{20}} + 10^{\frac{-\left(NEXT_{conn\_spec} + 2\left(IL_{cord\_cable} + IL_{conn}\right)\right)}{20}}\right) \qquad (41)$$

$$IL_{cord\_cable} = IL_{cord\_cable,100m} \cdot \frac{CableLength}{100} \qquad (42)$$

$$NEXT_{cord\_cable} = NEXT_{hor\_cable} - 10\log\left(1 - e^{-0.46 \cdot IL_{cord\_cable}}\right) \quad (43)$$

$NEXT_{conn\_spec}$ 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 126. 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 107

$NEXT_{cord\_cable}$ 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 82

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

IL_{conn} is the insertion loss of one connector as specified in Table 124

$RFEXT$ is the reflected signal cross talk. For category 5e cords RFEXT = 0 dB, and for category 6, 6A and 8 cords RFEXT = 0.5 dB.

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

The cord NEXT loss values in tables 145 through 148 are calculated from equation (40) and are provided for information only.

Table 146 - Minimum category 3 through 6A
2 meter cord NEXT loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	65.0	65.0	65.0
4.00	65.0	65.0	65.0
8.00	60.6	65.0	65.0
10.00	58.7	65.0	65.0
16.00	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 147 - Minimum category 3 through 6A
5 meter cord NEXT loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	65.0	65.0	65.0
4.00	64.5	65.0	65.0
8.00	58.6	65.0	65.0
10.00	56.7	64.5	64.5
16.00	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 148 - Minimum category 3 through 6A
10 meter cord NEXT loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1.00	65.0	65.0	65.0
4.00	62.5	65.0	65.0
8.00	56.7	64.8	64.8
10.00	54.9	62.9	63.0
16.00	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

Table 149 - Minimum category 8
1 meter, 2 meter and 3 meter equipment cord NEXT loss

Frequency (MHz)	1 meter cord NEXT loss (dB)	2 meter cord NEXT loss (dB)	3 meter cord NEXT loss (dB)
1.00	65.0	65.0	65.0
4.00	65.0	65.0	65.0
8.00	65.0	65.0	65.0
10.00	65.0	65.0	65.0
16.00	62.8	62.3	61.8
20.00	60.9	60.4	59.9
25.00	59.0	58.5	58.0
31.25	57.1	56.6	56.2
62.50	51.2	50.7	50.3
100.00	47.2	46.8	46.4
200.00	41.3	41.0	40.8
250.00	39.5	39.2	39.0
300.00	37.3	37.1	37.0
400.00	33.8	33.8	33.8
500.00	31.0	31.1	31.3
600.00	28.1	28.3	28.6
1000.00	19.8	20.3	20.7
1500.00	13.2	13.8	14.4
2000.00	8.6	9.3	9.9

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 assurance is an integral part of the requirements for connecting hardware. Reliability testing and qualification is no less important for connecting hardware than the performance parameters specified in clause 6.10. Connecting hardware shall meet the requirements of this annex.

Connecting hardware reliability is the ability to conduct electronic signals without impairment over a long period of time. During this time the device may be exposed to varying environmental conditions, such as temperature, humidity, vibration, and wear. To assess and qualify connecting hardware reliability, accelerated life testing is performed on sample connectors. Accelerated life testing subjects the DUT's to temperature and humidity cycling, extremes of temperature, humidity, voltage and durability, to simulate long term exposure within a shortened test procedure. DUT's are conditioned using a standard sequence of stress variables. Low level dc contact resistance measurement is the primary qualification requirement. Prior to conditioning, the contact resistance of a mated connector is measured. After conditioning, the contact resistance is re-measured and the change in resistance is calculated. Limits are prescribed for initial contact resistance, the difference after conditioning, and the maximum after conditioning. Some environmental conditions, such as vibration testing, require that the contact disturbance is monitored during the conditioning phase. Some qualifications require a visual inspection of the DUT for conformance. In addition to low level dc contact resistance measurements, connecting hardware is qualified by high voltage dielectric withstand testing and by insulation resistance testing.

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, the test report shall state all test sequences used and which sequences are appropriate for qualification of each contact type. Procedures 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 Modular plugs and jacks

Modular connecting hardware reliability requirements and procedures for qualification are specified in ISO/IEC 60603-7 Clauses 6 and 7. Modular connecting hardware shall complete satisfactorily all test schedules as stated in Clause 7 of ISO/IEC 60603-7. Shielded and screened connecting hardware shall additionally comply with the requirements of IEC 60603-7-1 clause 6 and complete satisfactorily the test schedules of IEC 60603-7-1 clause 7.

Modular plugs and jacks shall comply with the reliability requirements of the applicable standard specified in Table A.1.

Table A.1 - 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
Category 8, screened	IEC 60603-7-81

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.1 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.2.

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

Table A.2 - Modular connecting hardware durability 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-terminations	0
Modular jack	Insertion / withdrawal with modular plug	750
	Cable re-terminations	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.3 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.3.

The number of conductor re-terminations for solderless connections included in modular connecting hardware shall comply with the specifications in Table A.3.

Table A.3 - 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.3 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.4 Other connecting hardware

Other connecting hardware can generally be classified into two categories:

1. Separable connectors incorporating spring contact elements with gold or gold-equivalent finishes.
2. IDC connectors for direct cable termination.

The screen connections of the above connector types shall comply with the requirements of IEC 60603-7-1.

Examples of other connecting hardware include:

1) cross-connect blocks and plugs
2) pin and socket connectors
3) hermaphroditic connectors
4) card-edge 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

Connector type	Standard
Separable male and female (or hermaphroditic)	IEC 60603-7[1]
Separable male and female (or hermaphroditic) screened	IEC 60603-7[1] IEC 60603-7-1[1]
Accessible IDC	IEC 60352-3
Accessible IDC, screened	IEC 60352-3 IEC 60603-7-1
Non-accessible IDC	IEC 60352-4
Non-accessible IDC, screened	IEC 60352-4 IEC 60603-7-1
Spring clamp connection	IEC 60352-7
Spring clamp connection, screened	IEC 60352-7 IEC 60603-7-1

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.

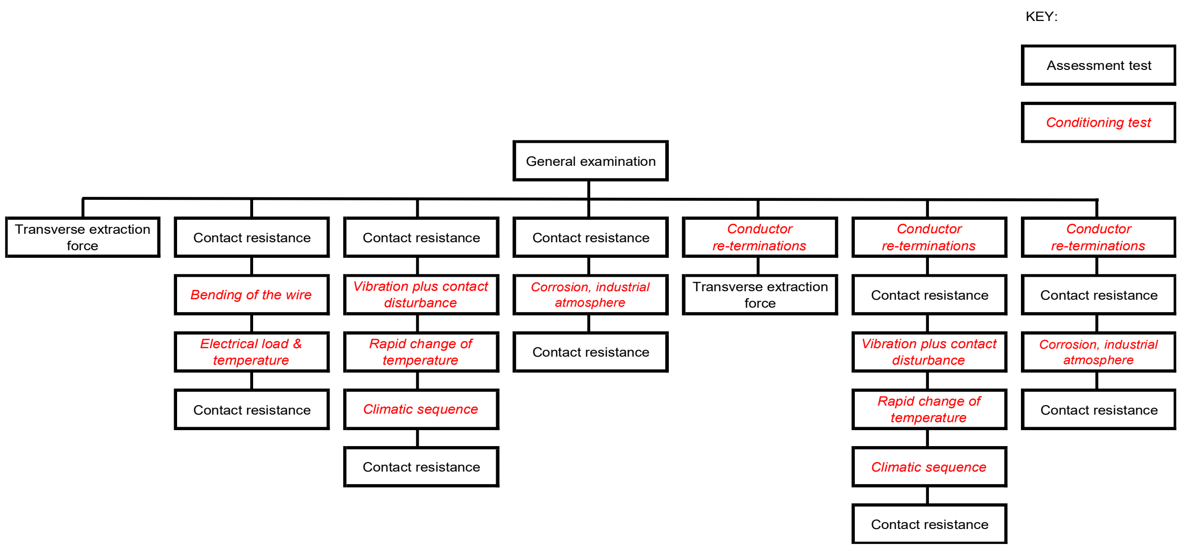


Figure A.1 - Reference test schedule for non-accessible IDC

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

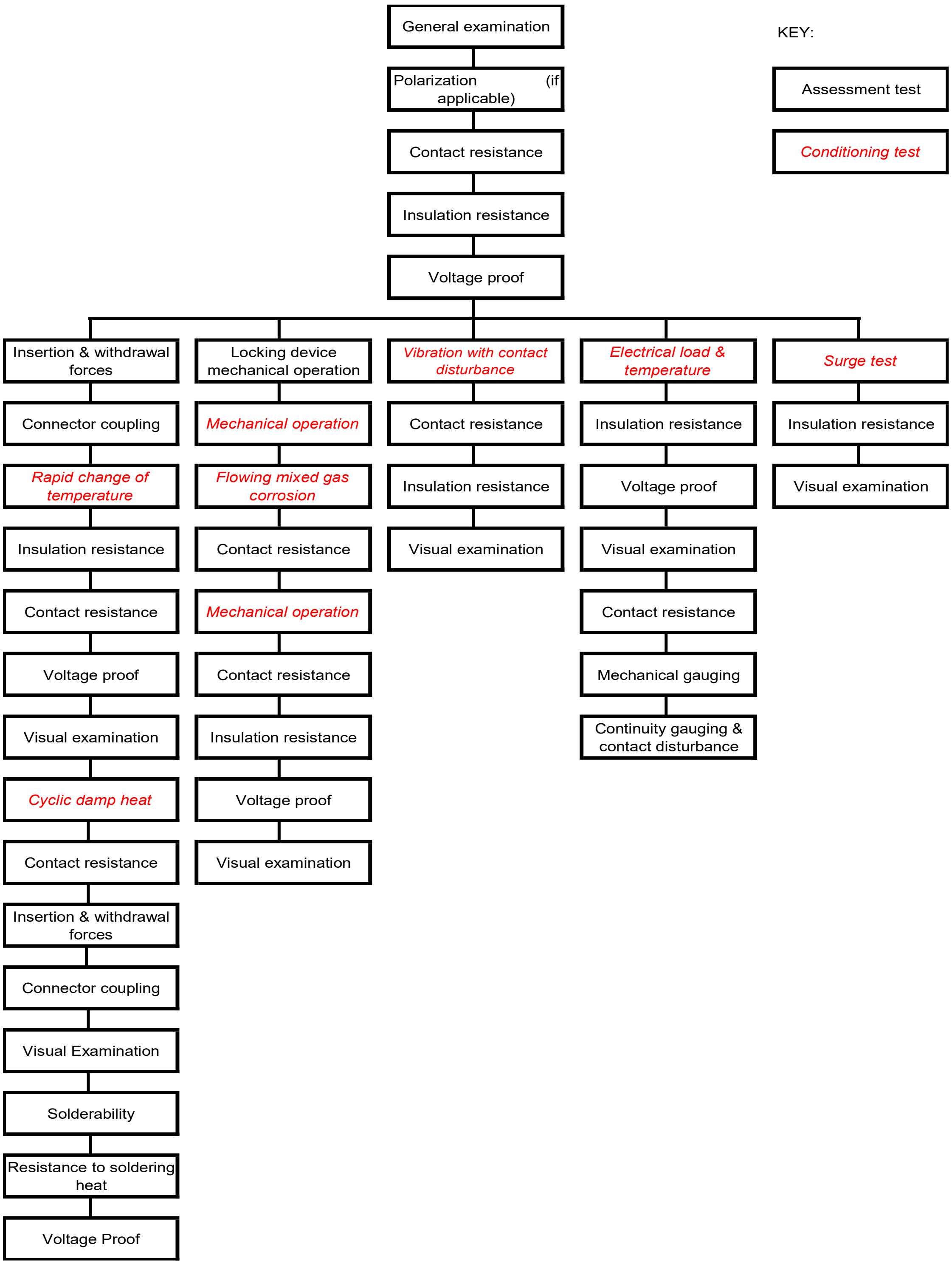


Figure A.2 - Reference test schedule for modular plugs and jacks

Annex B (normative) - Measurement requirements (general)

B.1 General test configuration

This annex describes general measurement requirements for 4-pair 100 Ω components and cabling systems 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. For the case of balunless measurements, the general requirements for wire termination, test setup, configurations, and performance are detailed in ANSI/TIA-1183-A from 1 MHz to 2000 MHz.

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

This document discusses in detail:

Network analyzer requirements
Test fixture requirements
Impedance matching termination requirements
Calibration artifacts and calibration procedures
Port identification and nomenclature
Other requirements

All of the requirements of this annex apply up to the maximum frequency of the DUT category.

B.2 Termination of a cable DUT to test system

The DUT connection point is to a cable pair. To minimize length of the termination and disturbance of the cable pairs, the cable pair should be connected to the reference plane with less than 5 mm (0.2”) of wire or pair unjacketed or untwisted. Shield terminations including individual pair shield terminations should be within 5 mm (0.2”) of the reference plane. Pair twist and spacing should be maintained to the reference plane as much as possible. Shield terminations should provide a 360 degree contact with the overall cable shield as close to the end of the screen as is possible. Example cable and shield terminations are shown in Figure B.1 and B.2.

B.2.1 Interconnections between the device under test (DUT) and the calibration plane

When testing DUT’s that do not present naturally a cable pair to the test interface, test leads may be constructed to provide that connection.

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 clause B.2.1.1. 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 and less than 0.2 dB for the frequency range from 500 MHz to 2.0 GHz.

When used, twisted-pair test leads shall have 100 Ω nominal characteristic impedance. The twisted-pairs should not exhibit gaps between the conductors insulation. The maximum length of the test leads extending from each end of the device shall be 51 mm (2 in).

Prior to attachment to the DUT, 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 at the far end with a precision 0.1% 0603 or similar chip resistor as described in clause B.6.1. 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 H for an example of an appropriate test fixture. It is recommended to use the same load for both calibration and termination of the test lead during measurement.

B.2.1.1 Test lead return loss requirements

For connecting hardware return loss measurements, the interconnection shall meet the requirements in B.2.1 relative to the specified calibration resistor termination. These requirements apply up to the maximum frequency of the category of the DUT.

Table B.1 - Interconnection return loss

Frequency (MHz)	Return loss (dB)
$1 \le f < 80$	40 dB
$80 \le f \le 2000$	$38 - 20\log(f/100)$ dB

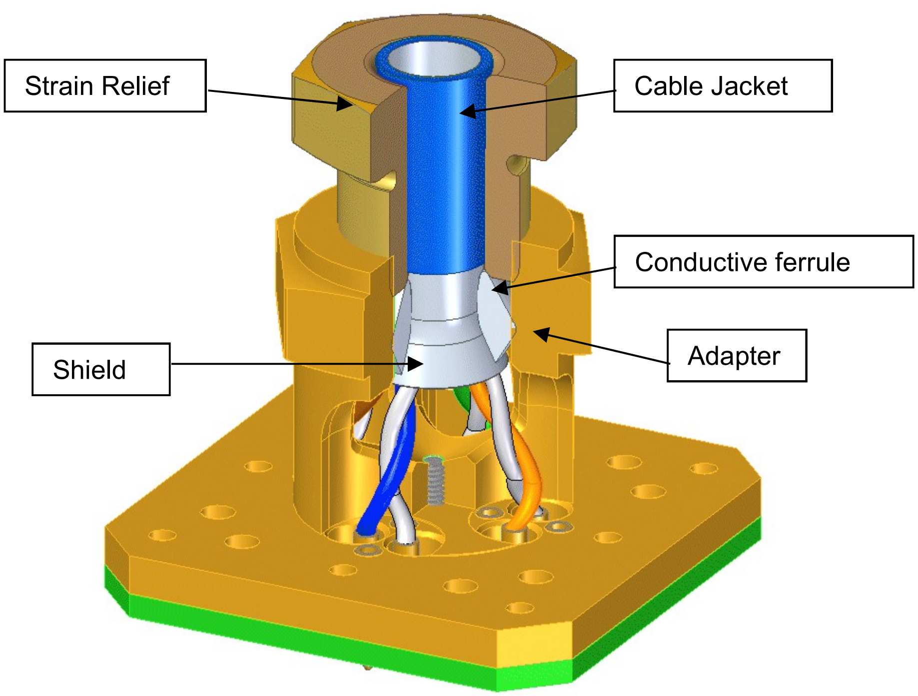


Figure B.1 - Example 360 degree shielded cable termination

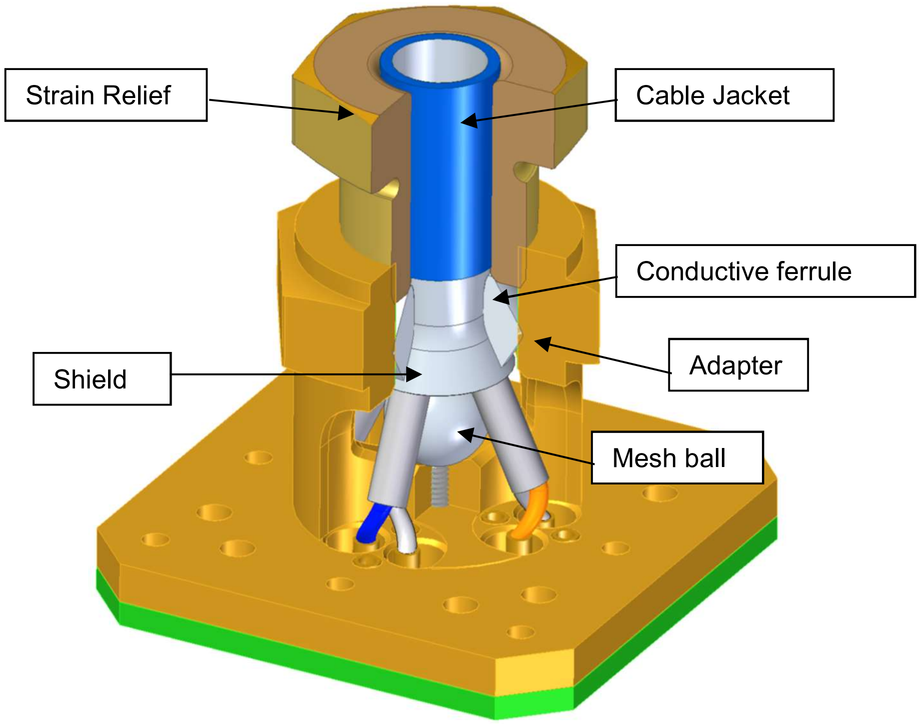


Figure B.2 - Example individually shielded pair cable termination

For ease of interfacing to test fixtures, the balun or balunless test interface should present a pin and socket interface with dimensions as shown in Figure B.3. Sockets should be gold plated contact material and should be compatible with an example socket as shown in Figure B.4.

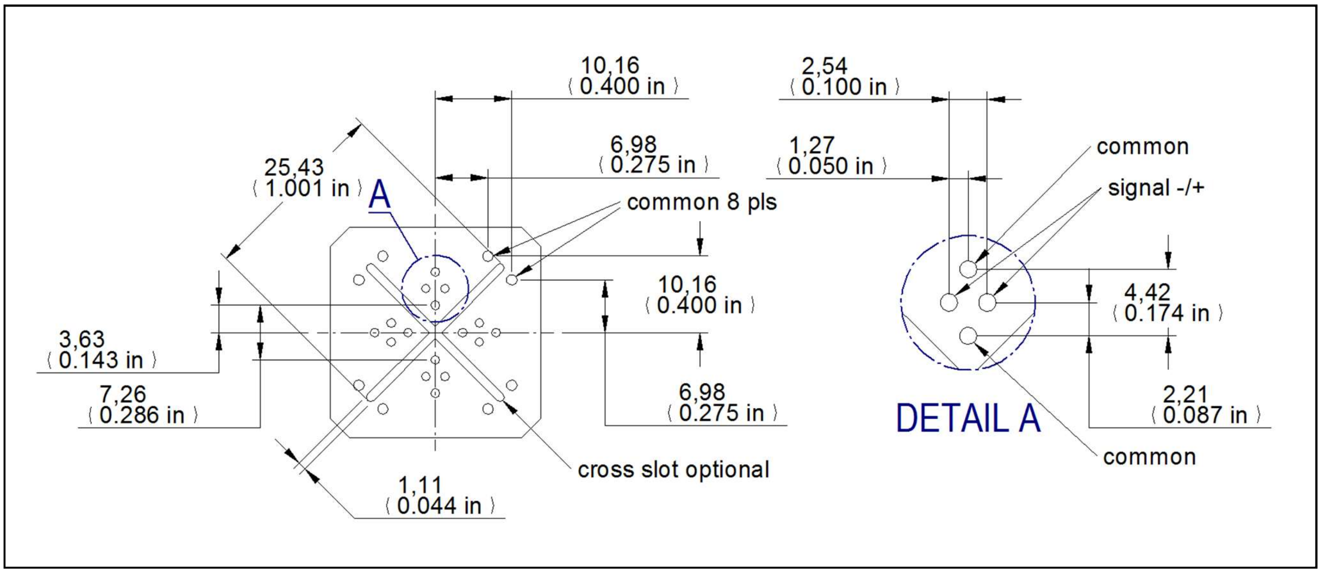
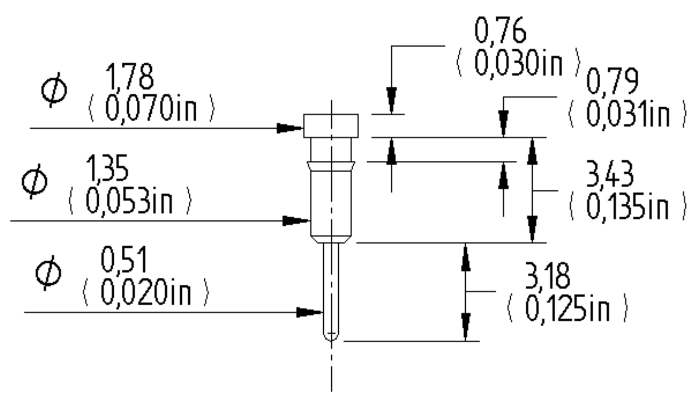


Figure B.3 - Example test fixture interface pattern



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.4 - Example pin and socket dimension

B.3 Ground plane requirements

The balun or balunless test fixture common mode nodes shall be bonded to a ground plane. The common mode nodes of passive terminations shall also be bonded to the ground plane.

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 per decade of specified frequency range
L ≤ 10	100
10 < L ≤ 20	200
L > 20	300

B.6 Impedance matching terminations

Either balun terminations, direct network analyzer terminations, or resistive terminations may be used for the termination of far-end ports of active pairs under test and for the termination of inactive pair near-end and far-end ports. Resistor terminations are recommended for termination unless the port is included in the current active measurement calibration. Improving the return loss of port terminations will improve measurement accuracy. In all cases, the type of termination shall be consistent between all pairs at each end and consistent with the common mode termination value of the test system. (i.e. DMCM terminations are not mixed with DM terminations for the near-end of the DUT or the far-end of the DUT). Annex C provides diagrams for terminations for balun systems and Annex D provides diagrams of terminations for balunless systems.

B.6.1 Resistor terminations

Resistors shall be 0603 or smaller wideband chip resistors. 0.01% tolerance chip resistors should be used for calibration references and also for all DUT resistor terminations.

Resistor DM terminations shall exhibit impedance of 100 Ω ± 0.1% (two times 50 Ω ± 0.1%) as shown in figure B.5. The resistors used for common mode (CM) terminations shall include the addition of a common mode 25 Ω ± 1% or better resistor as shown in figure B.5. In this case, the common mode impedance formed by the 25 Ω resistor in series with the two 50 Ω resistors in parallel provides a common mode impedance of 50 Ω.

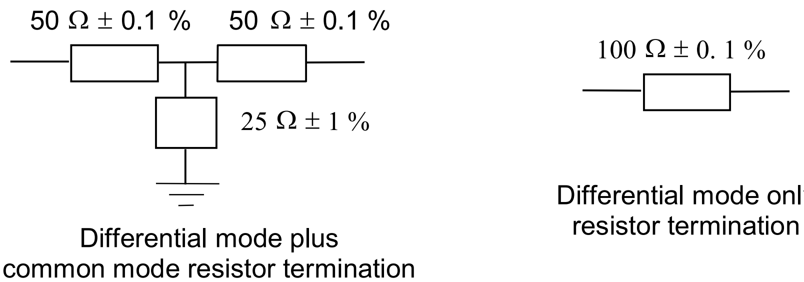


Figure B.5 - Resistor termination networks for balun testing

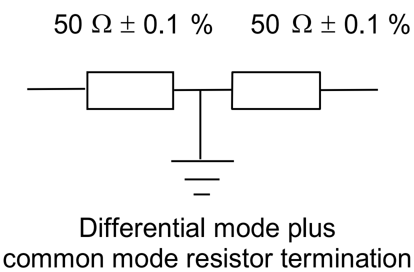


Figure B.6 - Balunless resistor termination network

B.6.2 Termination return loss 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. The DM return loss of the load termination shall meet or exceed 20-20log(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.

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

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.6.3 Termination TCL performance at the calibration plane

The resistor terminations should be verified by testing TCL up to the highest frequency of testing for each category or 2 GHz and should meet the requirements of equation (B-2).

TCL_{Rterm} >= 56-20*log(f/100) or 50dB min. (B-2)

B.6.4 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.

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

B.6.4.1 Two-port calibration of the test system

A two-port calibration utilizing load, open, and short and through calibration references shall be specified. Transmission through calibration requires interconnecting the near-end and far-end measurement ports at the location of the reference plane with a known reference through calibration artifact. Isolation calibration is required if there is significant crosstalk between measurement ports. If the level of residual crosstalk is compliant to test system performance requirements, then isolation calibration may be omitted.

B.6.4.2 One-port calibration of the test system

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

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.7. The calibration plane is defined at the test interface and is the point of connection between the device under test and the test fixture.

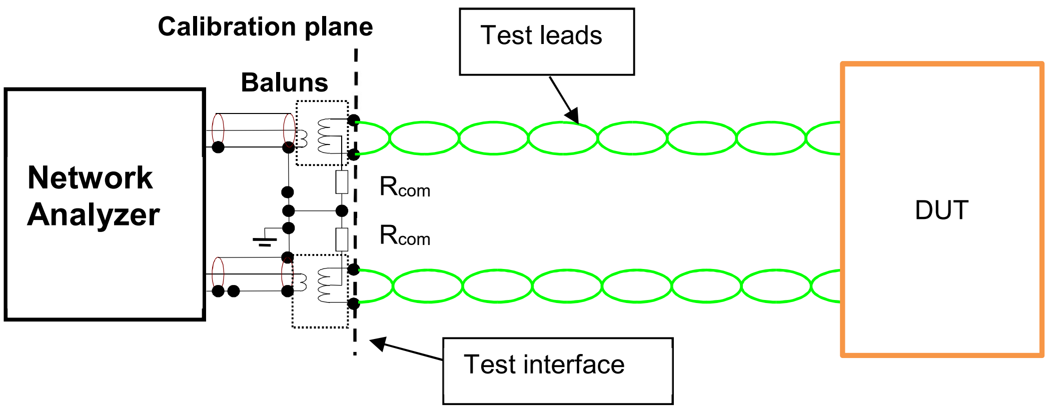


Figure B.7 - Calibration plane

The calibration plane location can be established based on:

Formal definitions of calibration planes for cabling (e.g., reference plane for the channel or permanent link).

These measurement considerations should be taken into account:

1) 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).
2) Convenience of connecting devices to be tested.
3) Minimizing disruption of the transmission performance at the location where devices are connected, particularly to avoid reflections and parasitic crosstalk effects.

B.7.1 Calibration references

Internal test calibration standards reference values within the network analyzer shall be selected 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 impedance 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 50 Ω and 100 Ω calibration reference load requirements

Calibration reference load impedance terminations can be compared against a 50 Ω coaxial load, which is traceable to an international reference standard using the following procedure. The calibration reference load shall be equal to the nominal differential impedance of twisted-pair cabling defined in this Standard, which is 100 Ω. This may be achieved by using a single 100 Ω resistor or with the network shown in Figure B.5.

The following procedure can be used for reference load verification.
The reference load(s) for calibration are 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 Calibration reference load return loss requirement

The verified return loss of the calibration reference load shall meet the requirements of Table B.3 from 1 MHz to the highest referenced frequency of measurement for the cabling category.

Table B.3 - Calibration reference load return loss requirement

Frequency (MHz)	Return loss (dB)
$1 \leq f < 1000$	≥ 40
$1000 \leq f \leq 2000$	$\geq 40 - 20\log(f/1000)$

B.7.2 Typical test equipment performance parameters

See ANSI/TIA-1183-A for typical test equipment performance parameters.

Annex C (normative) - Cabling and component test procedures using baluns

C.1 Measurement test setup and apparatus

The measurement requirements in this annex, apply to categories 3, 5e, 6, 6A, and 8 up to the upper frequencies of those categories. In some cases, there are specific requirements for specific categories, and those are so noted.

C.1.1 Balun terminations

Baluns used for termination shall comply with the requirements of clause C.1.2. The common mode termination resistor applied to the common mode port of the balun shall be 50 Ω ±1 %.

C.1.2 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 C.1 up to the highest referenced frequency for the category of component or cabling system under test.

Table C.1 - Test balun performance characteristics

Parameter	Frequency[3)] (MHz)	Value
Impedance, primary [1)]	$1 \le f \le 2000$	50 Ω unbalanced
Impedance, secondary	$1 \le f \le 2000$	100 Ω balanced
Insertion loss	$1 \le f \le 1000$ $1000 < f \le 2000$	2.0 dB maximum 3.0 dB maximum
Return loss, bi-directional [2)]	$1 \le f < 15$ $15 \le f \le 1000$ $1000 < f \le 2000$	12 dB minimum 20 dB minimum 15 dB minimum
Return loss, common mode [2)]	$1 \le f < 15$ $15 \le f \le 400$ $400 < f \le 2000$	15 dB minimum 20 dB minimum 15 dB minimum
Power rating	$1 \le f \le 2000$	0.1 watt minimum
Longitudinal balance [2)]	$1 \le f < 100$ $100 \le f \le 500$ $500 < f \le 1000$ $1000 < f \le 2000$	60 dB minimum 50 dB minimum 42 dB minimum 40 dB minimum
Output signal balance [2)]	$1 \le f \le 1000$ $1000 < f \le 2000$	50 dB minimum 40 dB minimum
Common mode rejection [2)]	$1 \le f \le 1000$ $1000 < f \le 2000$	50 dB minimum 40 dB minimum

1) Primary impedance may differ, if necessary, to accommodate analyzer outputs other than 50 Ω.
2) Measured per ITU-T (formerly CCITT) Recommendation G.117 with the network analyzer calibrated using a 50 Ω load.
3) Up to the highest reference frequency of the cabling system under test.

Figure C.1 depicts the proper test configurations for qualifying test baluns to the requirements of this standard.

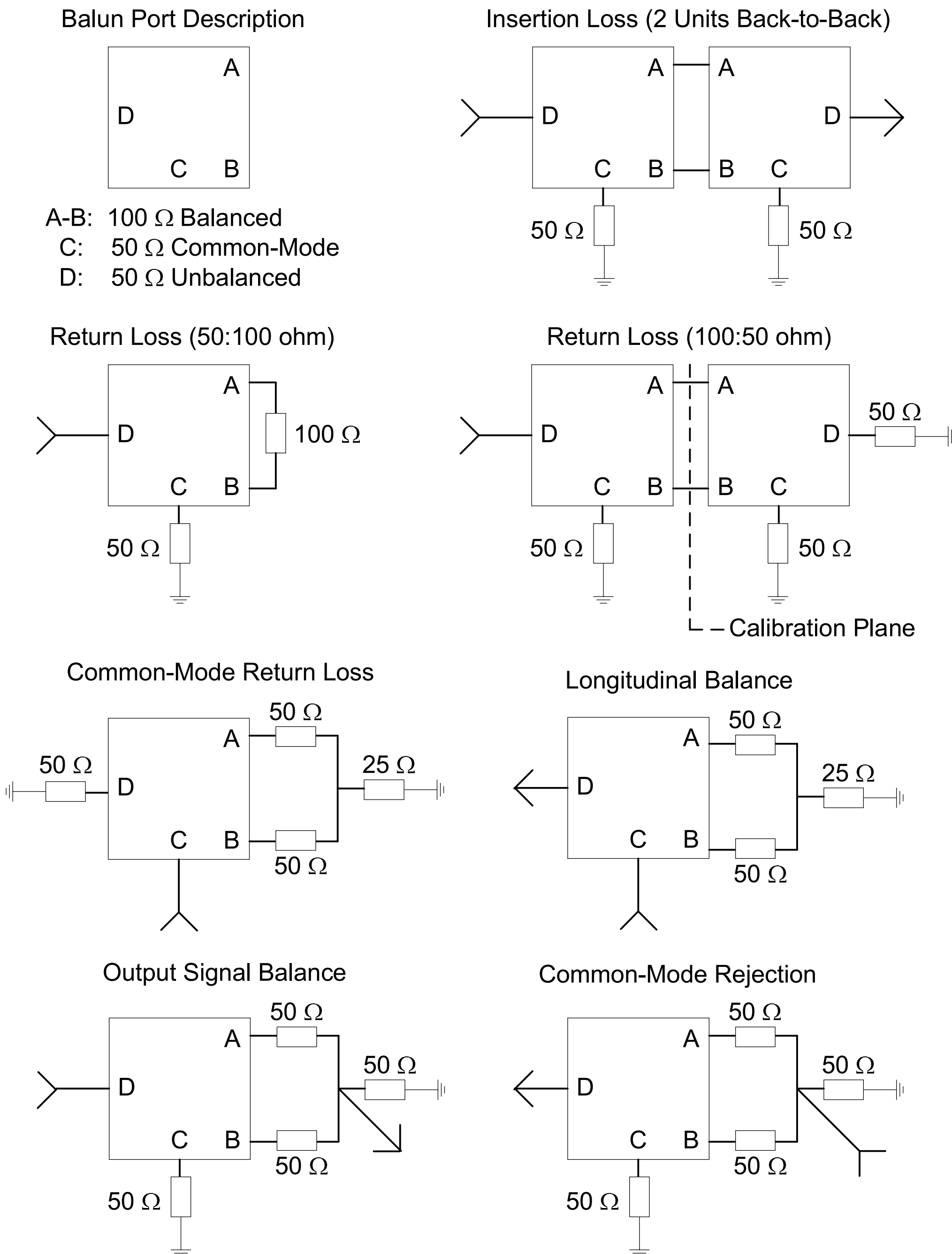


Figure C.1 - Measurement configurations for test balun qualification

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 testing of cables and channels

C.2.2.1 Test configuration of cable and channel return loss

Figure C.3 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.6.1 for information on resistor terminations. DMCM terminations are recommended for return loss measurements although DM terminations are acceptable. The detailed schematic diagram of the balun is shown 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 50 Ω unbalanced port, and ports labeled "A and B" represent a connection to the 100 Ω differential mode port of the DUT.

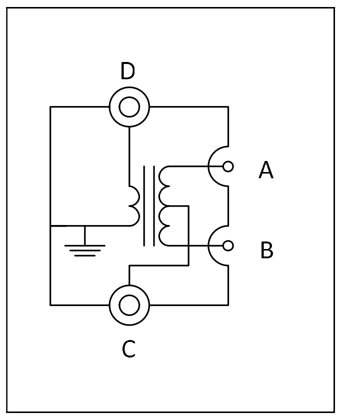


Figure C.2 - Balun schematic diagram

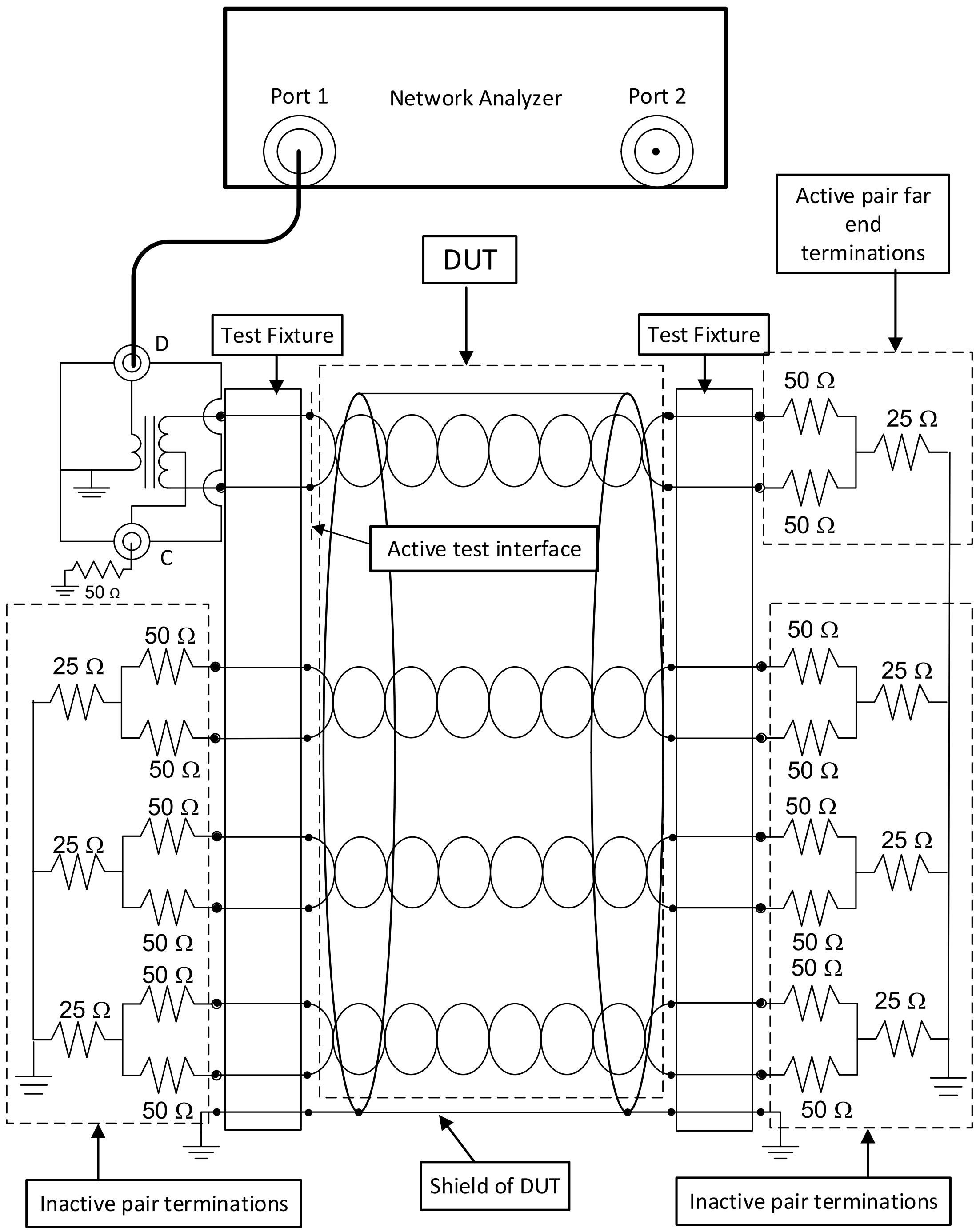


Figure C.3 - Laboratory test configuration for return loss

C.2.2.2 Measurement of cable and channel return loss

Calibrate in accordance with B.6.4. Measure the S11 parameter with the network analyzer connected to each pair on the near-end. Return loss shall be tested in both directions.

C.2.3 Insertion loss of cables and channels

C.2.3.1 Test configuration of cable and channel insertion loss

Figure C.4 depicts the typical schematic diagram for testing insertion loss, FEXT loss, ACRF, and propagation delay.

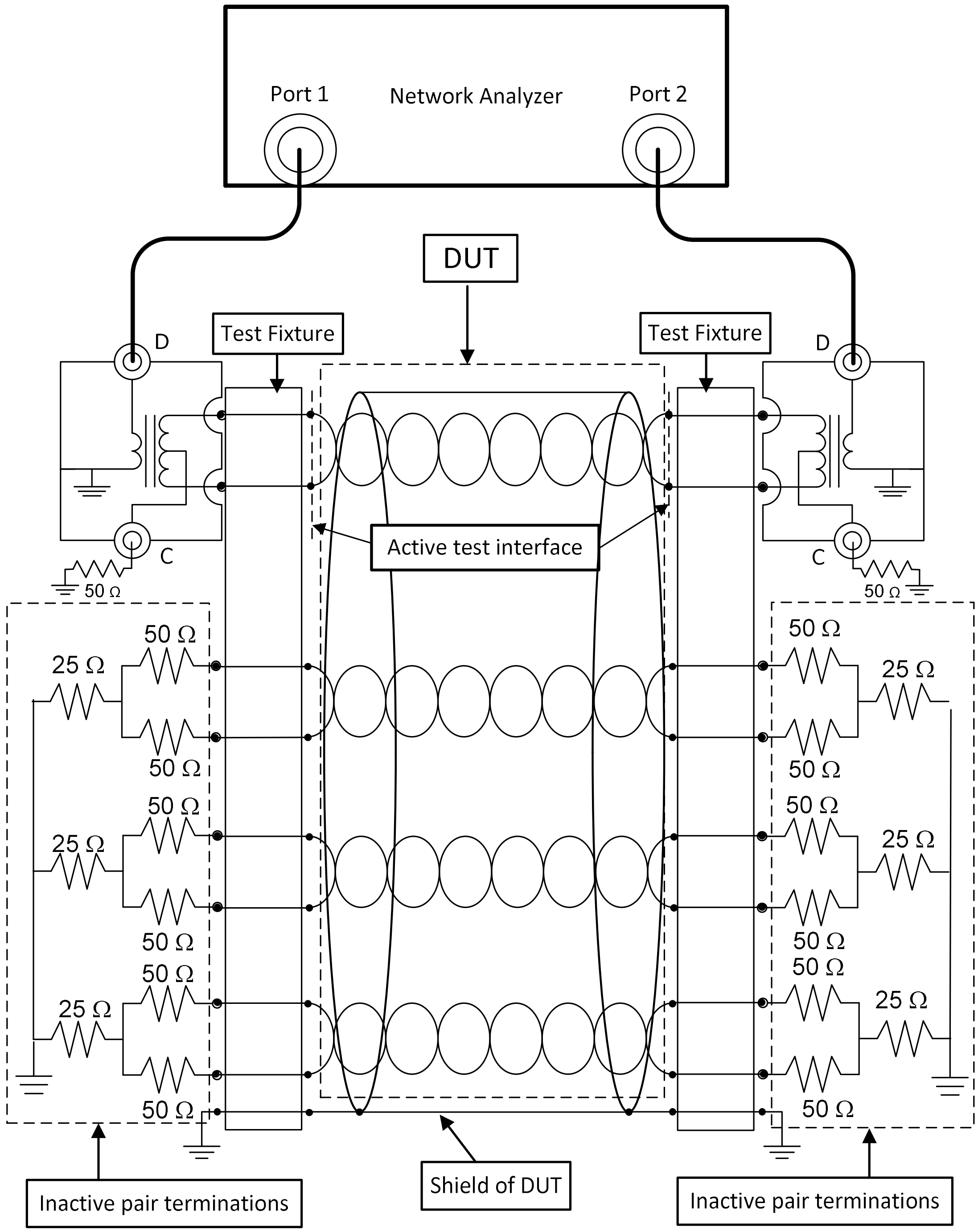


Figure C.4 - Laboratory test configuration for insertion loss and propagation delay measurements

NOTE: Shields and screens, if any, should be bonded (low inductance connections) to the measurement ground.

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 cable and channel insertion loss

The calibration for cable and channel insertion loss shall comply with B.6.4.

C.2.3.3 Measurement of cable and channel 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 cables and channels

C.2.4.1 Test configuration of cable and channel NEXT loss

Figure C.5 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.6.1 for information on resistor terminations. DMCM terminations shall be used for NEXT loss measurements.

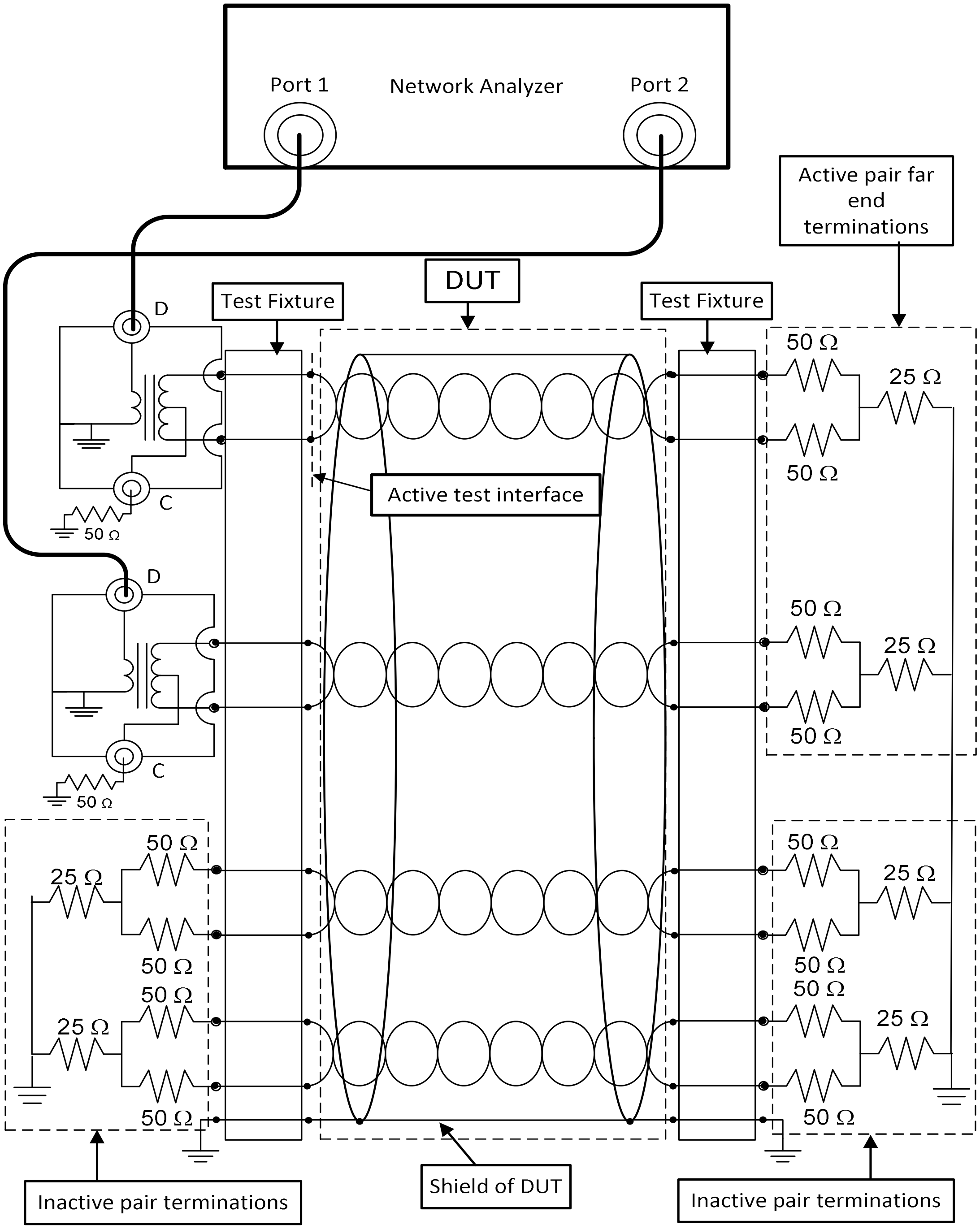


Figure C.5 - Laboratory test configuration for cable and channel NEXT loss

C.2.4.2 Calibration of cable and channel NEXT loss

The calibration for cable and channel NEXT loss shall comply with clause B.6.4

C.2.4.3 Measurement of cable and channel 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 cables and channels

C.2.5.1 Test configuration of cable and channel FEXT loss

Figure C.6 shows the test configuration of cable and channel FEXT loss. DMCM terminations shall be used for all inactive pairs and active pairs.

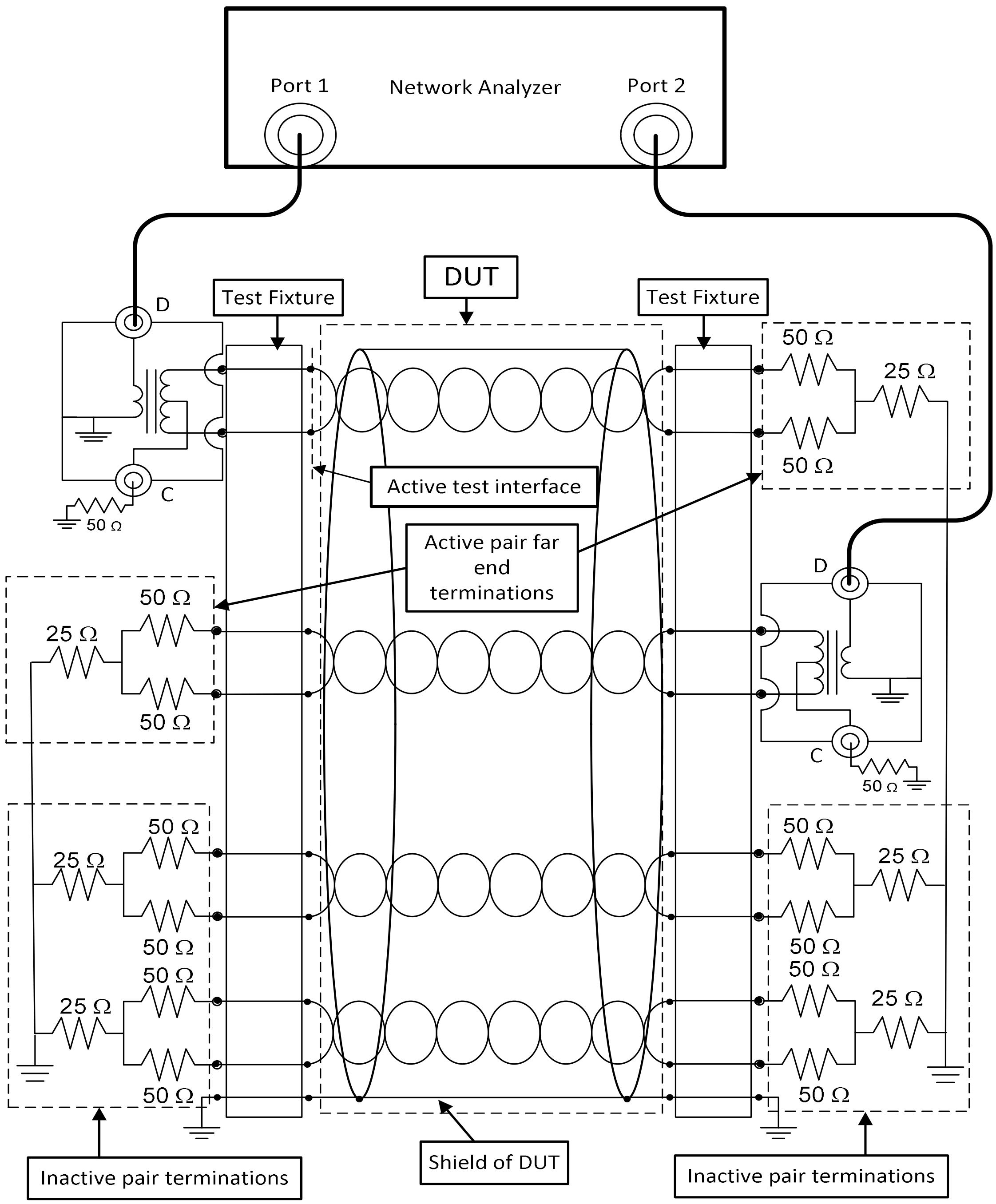


Figure C.6 - Laboratory test configuration for FEXT loss

C.2.5.2 Calibration of cable and channel FEXT loss

The calibration for cable and channel FEXT loss shall comply with clause B.6.4.

C.2.5.3 Measurement of cable and channel 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 Cable and channel propagation delay

C.2.6.1 Test configuration of cable and channel propagation delay

The propagation delay measurement configuration shall comply with the requirements of clause C.2.3.1

C.2.6.2 Calibration of cable and channel propagation delay

A one or two-port calibration, as described in clause B.6.4, may be used to calibrate propagation delay.

C.2.6.3 Measurement of cable and channel 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.2.7 TCL of cables and channels

Balunless techniques are recommended for measurement of TCL, however balun techniques may be used.

C.2.7.1 Test configuration of cable and 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.6.1) or baluns shall be bonded together and connected to ground as shown in Figure C.7.

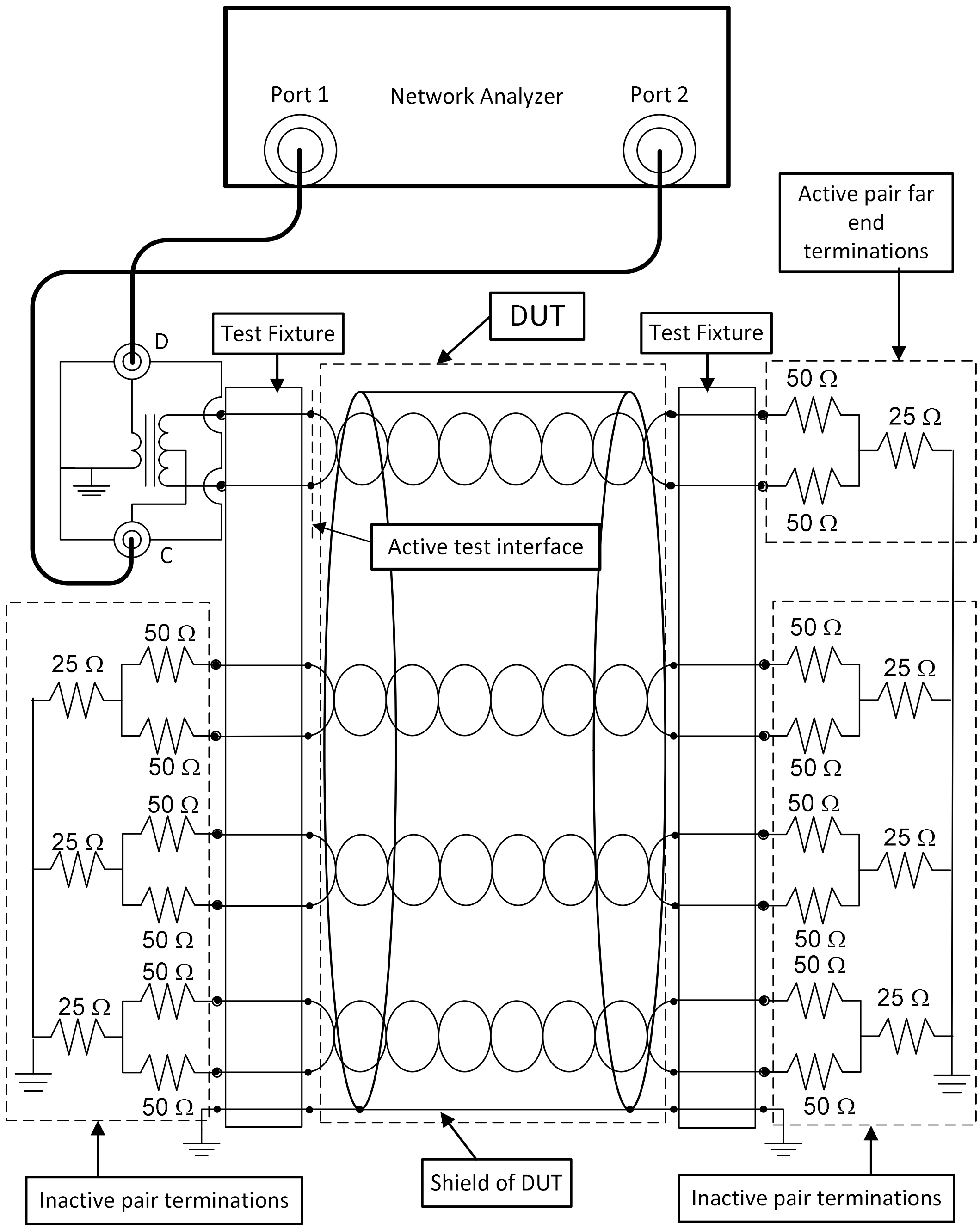


Figure C.7 - Laboratory test configuration for TCL

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

C.2.7.2 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 Figure C.8.

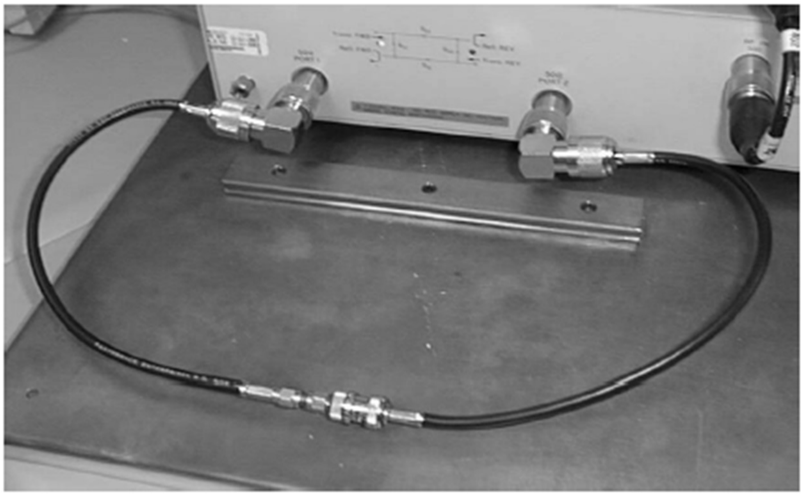


Figure C.8 - Coaxial lead through calibration

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 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 $IL_{bal,DM}$.

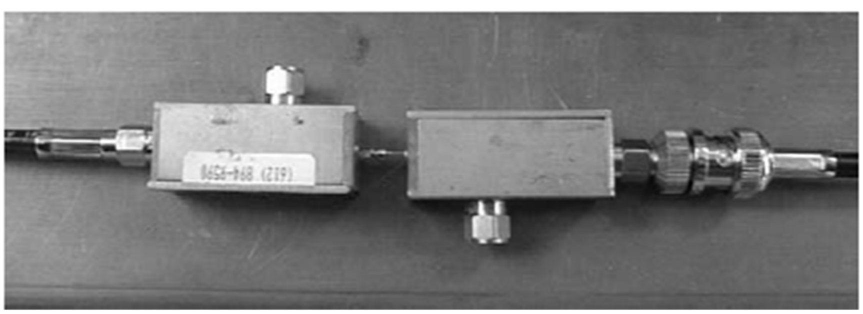


Figure C.9 - Back-to-back balun insertion loss measurement

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 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 Figure C.11 The measured insertion loss is recorded as $IL_{bal,CM}$.

Figure C.10 - Output terminal connection

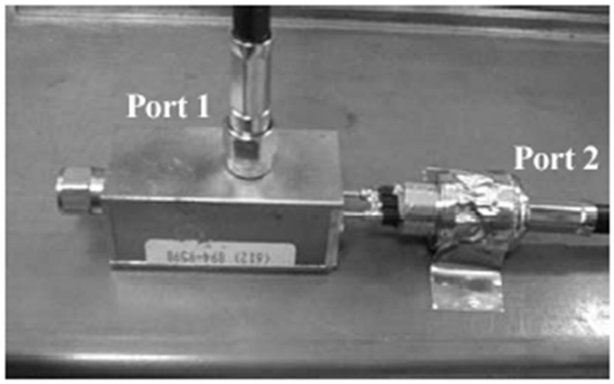


Figure C.11 - Outer shield grounding position

C.2.7.3 Measurement of cable and 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 50 Ω 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).

$$TCL = (IL_{meas} - IL_{bal,DM} - IL_{bal,CM})\ dB \qquad \text{(C-1)}$$

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.2.8 TCTL of cables and channels

Balunless techniques are recommended for measurement of TCTL, however balun techniques may be used.

C.2.8.1 Test configuration of channel TCTL

Figure 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 B.6.1. There shall be a common ground at each end. The grounds of the two ends shall be connected securely to the same ground plane.

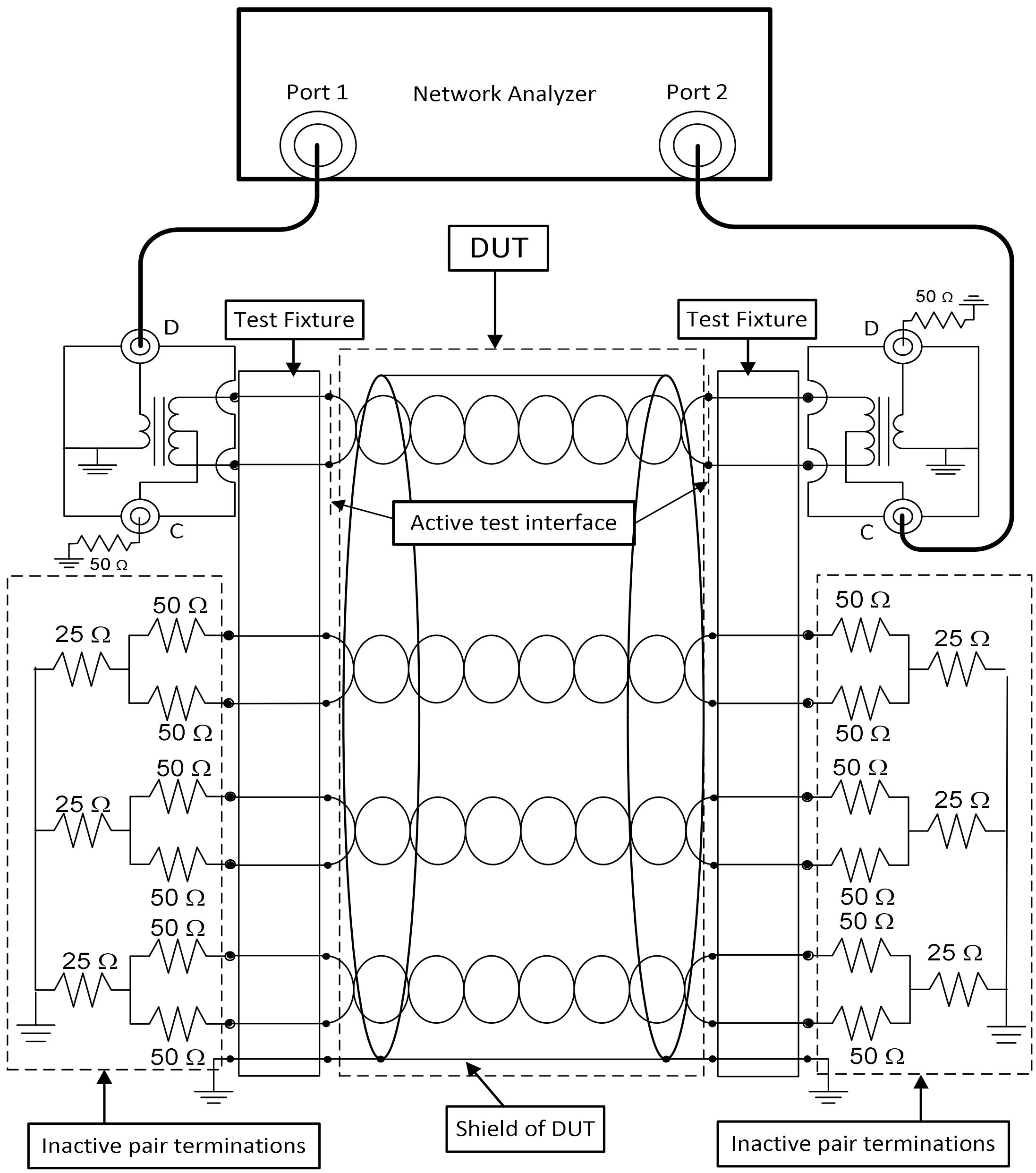


Figure C.12 - Laboratory test configuration for TCTL

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C.2.8.2 Calibration of cable and channel TCTL

The calibration of the test hardware for TCTL measurements shall follow the procedure outlined in clause C.6.4.7 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.2.8.3 Measurement of cable and 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).

$$TCTL = (IL_{meas2} - IL_{bal,DM,1} - IL_{bal,CM,2}) \text{ dB} \quad \text{(C-2)}$$

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.2.9 Cable and channel 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) (or 30 m for category 8) 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 or 30 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) or 30 m (98 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 (10 ft) of each cable end should exit the oven for connection to the measurement equipment.

C.2.10 Screened or shielded cable and channel measurement configurations

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 Permanent link test procedures

This clause describes test and calibration procedures for permanent links.

C.3.1 Permanent link measurement configurations

The following requirements apply to the test configurations for permanent link 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.

Testing shall be carried out using a modular test plug compliant with clause C.6.5 inserted between the test interface and the permanent link under test. The crosstalk, insertion loss and return loss of the modular test plug shall not be calibrated out.

C.3.2 Calibration of permanent link test configurations.

The permanent link test configuration shall be calibrated by applying appropriate open, short, load and through calibration artifacts to the test interface between the test system and the modular test plug.

C.3.3 Return loss of permanent links

C.3.3.1 Test configuration of permanent link return loss

The permanent link return loss measurement configuration shall comply with the requirements of Figure C.13.

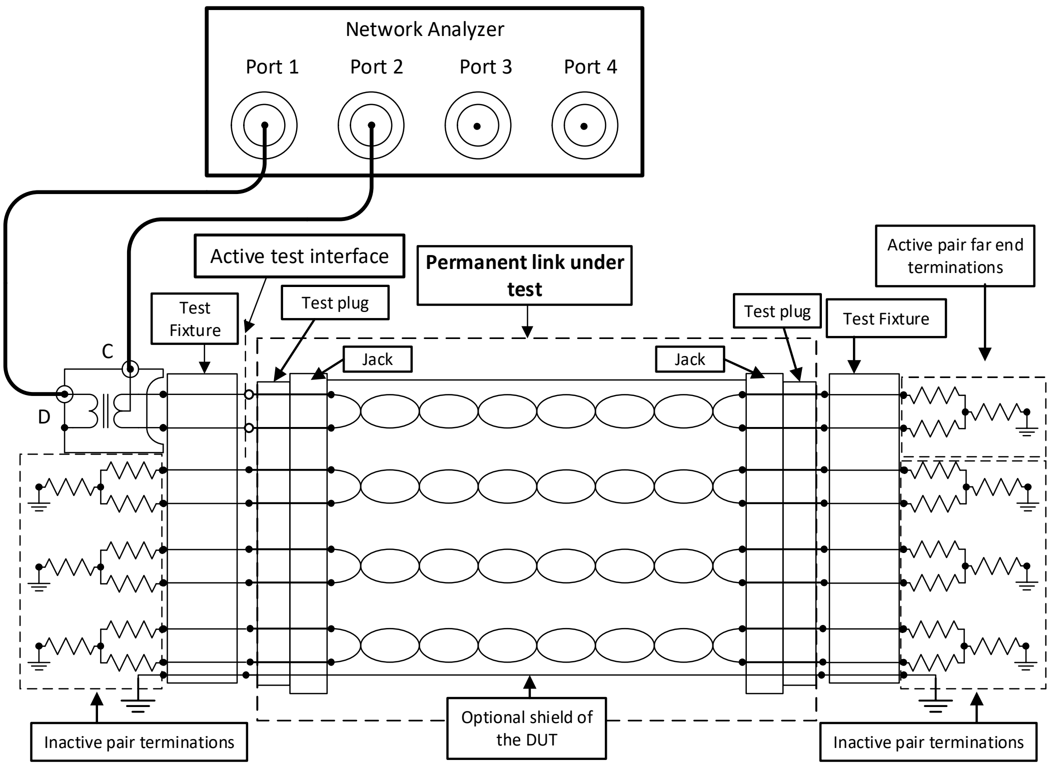


Figure C.13 - Laboratory test configuration for permanent link return loss and TCL measurements

C.3.3.2 Calibration of permanent link return loss

The calibration for permanent link return loss shall comply with clause B.6.4.

C.3.3.3 Measurement of permanent link return loss

Measure the Sdd11 parameter with the network analyzer connected to each pair on each end; permanent link return loss shall be tested in both directions.

C.3.4 Insertion loss of permanent link

C.3.4.1 Test configuration for permanent link insertion loss, (also used for FEXT loss, ACRF, and propagation delay)

The permanent link insertion loss measurement configuration shall comply with the requirements of Figure C.14.

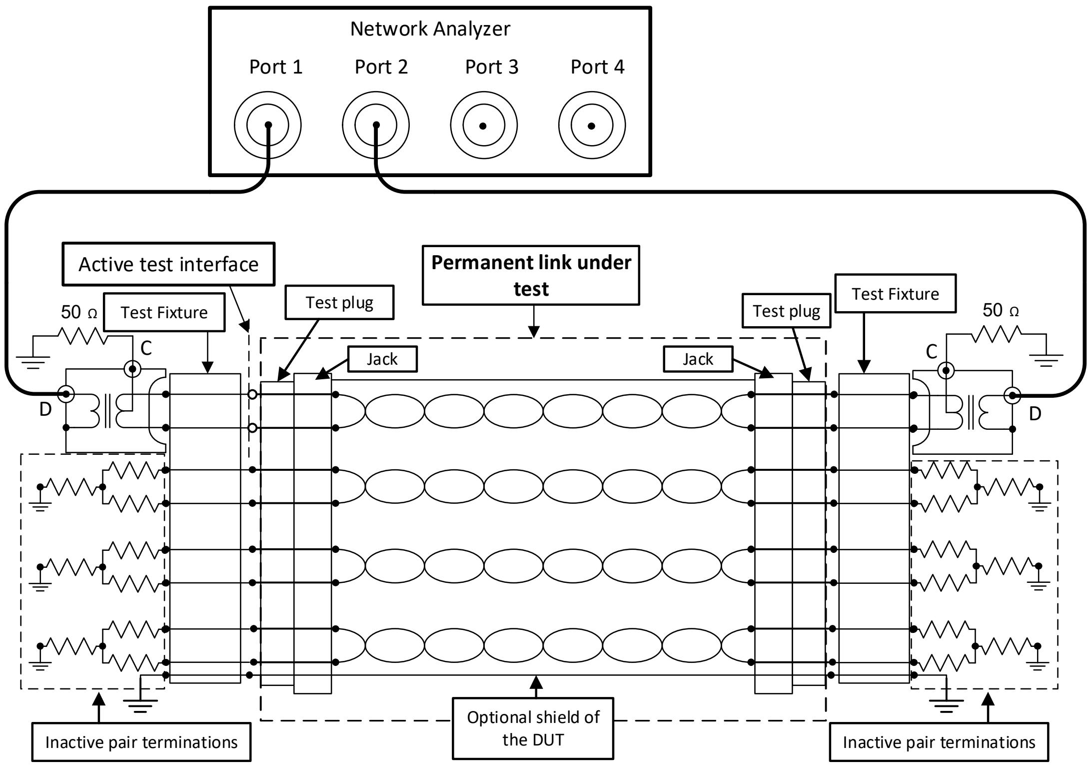


Figure C.14 - Laboratory test configuration for permanent link insertion loss and propagation delay measurements.

C.3.4.2 Calibration of permanent link insertion loss

The calibration for permanent link return loss shall comply with clause B.6.4.

C.3.4.3 Measurement of permanent link insertion loss

Measure the Sdd21 parameter with the pair under test connected to the network analyzer at both the near-end and the far-end. Permanent link insertion loss shall be tested in both directions.

C.3.5 NEXT loss of permanent link

C.3.5.1 Test configuration for permanent link NEXT loss

The permanent link NEXT loss measurement configuration shall comply with the requirements of Figure C.15.

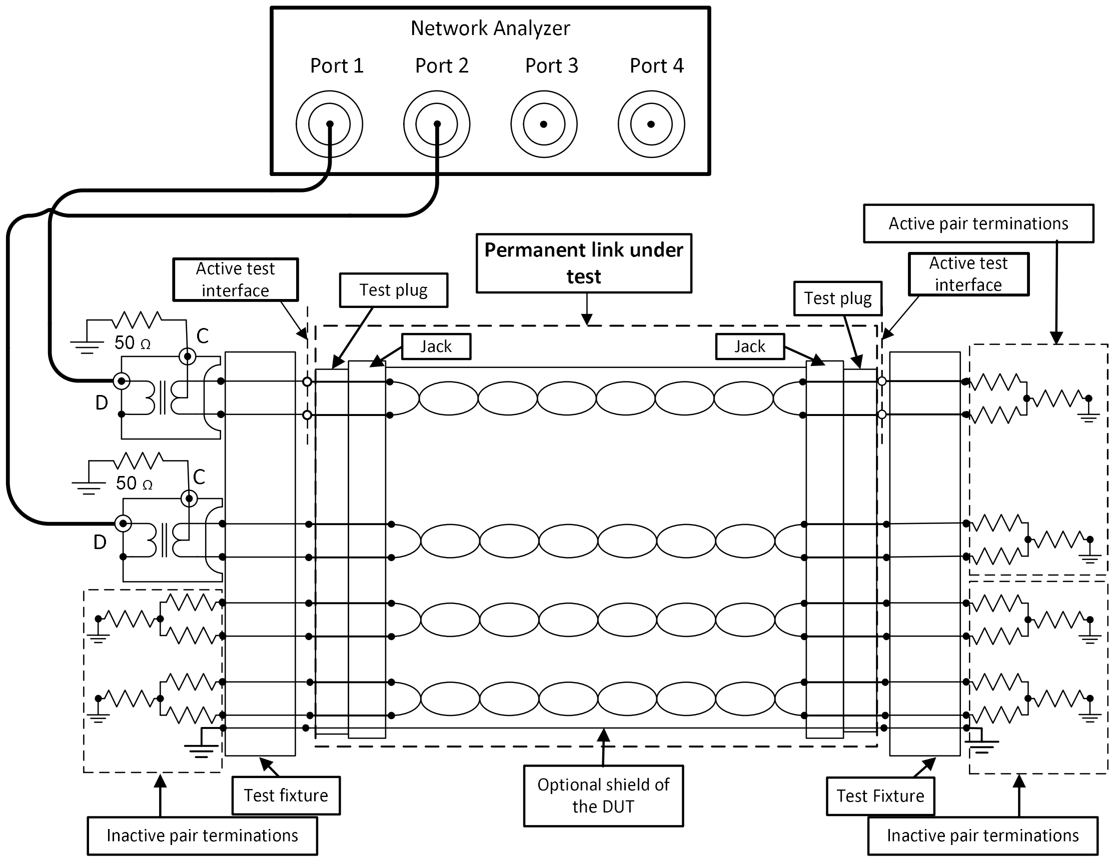


Figure C.15 - Laboratory test configuration for permanent link NEXT loss measurements

C.3.5.2 Calibration of permanent link NEXT loss

The calibration for permanent link NEXT loss shall comply with clause B.6.4.

C.3.5.3 Measurement of permanent link NEXT loss

Measure the Sdd21 parameter with the network analyzer connected to each of the 6 pair combinations in a four pair permanent link. Permanent link NEXT loss shall be tested in both directions.

C.3.6 FEXT loss of permanent link

C.3.6.1 Test configuration of permanent link FEXT loss

The permanent link FEXT loss measurement configuration shall comply with the requirements of Figure C.16.

C.3.6.2 Calibration of permanent link FEXT loss

The calibration of permanent link FEXT loss shall comply with B.6.4.

C.3.6.3 Measurement of permanent link FEXT loss

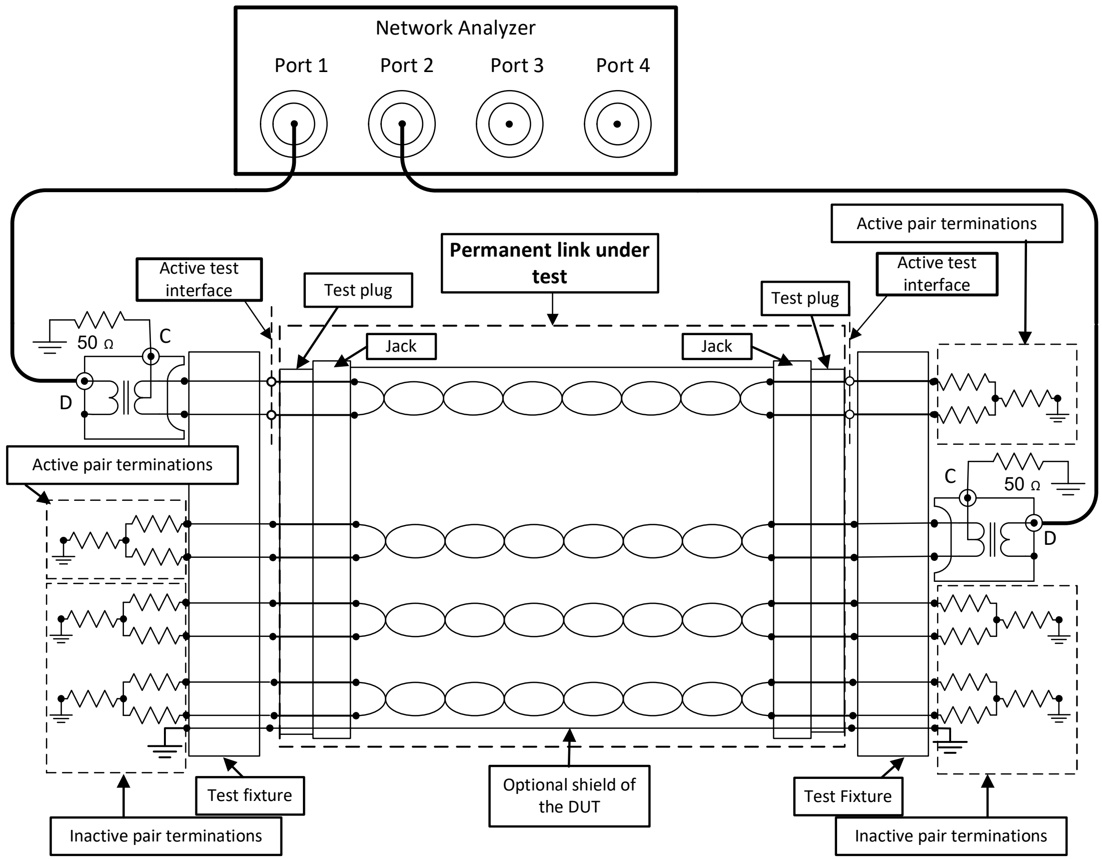


Figure C.16 - Laboratory test configuration for permanent link FEXT loss (ACRF)

Measure Sdd21 for all of the 12 pair combinations for permanent link FEXT loss, launching from one end only. It is not necessary to measure permanent link FEXT loss from both ends due to reciprocity.

C.3.7 TCL of permanent link

C.3.7.1 Test configuration of permanent link TCL

The permanent link TCL measurement configuration is shown in Figure C.17.

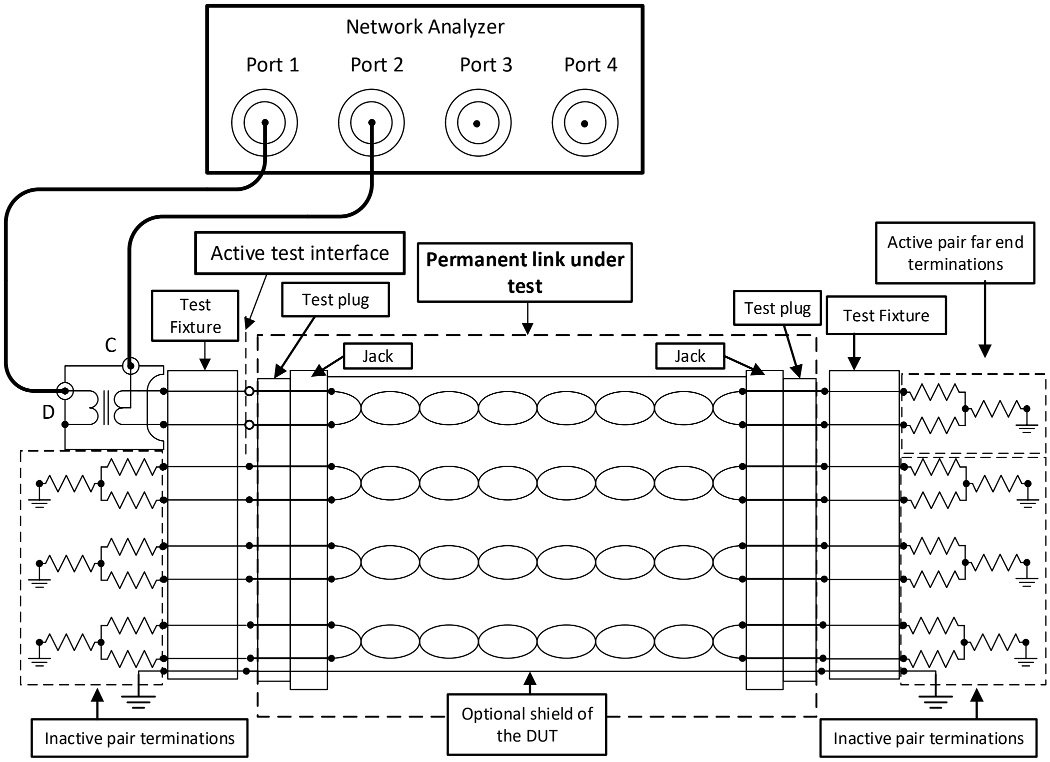


Figure C.17 - Laboratory test configuration for permanent link TCL measurements

C.3.7.2 Calibration of permanent link TCL

The calibration of permanent link TCL shall comply with clause C.2.7.2.

C.3.7.3 Measurement of permanent link TCL

Measure permanent link TCL on each pair in both directions.

C.3.8 TCTL of permanent link

C.3.8.1 Test configuration of permanent link TCTL

The permanent link TCTL measurement configuration is shown in Figure C.18.

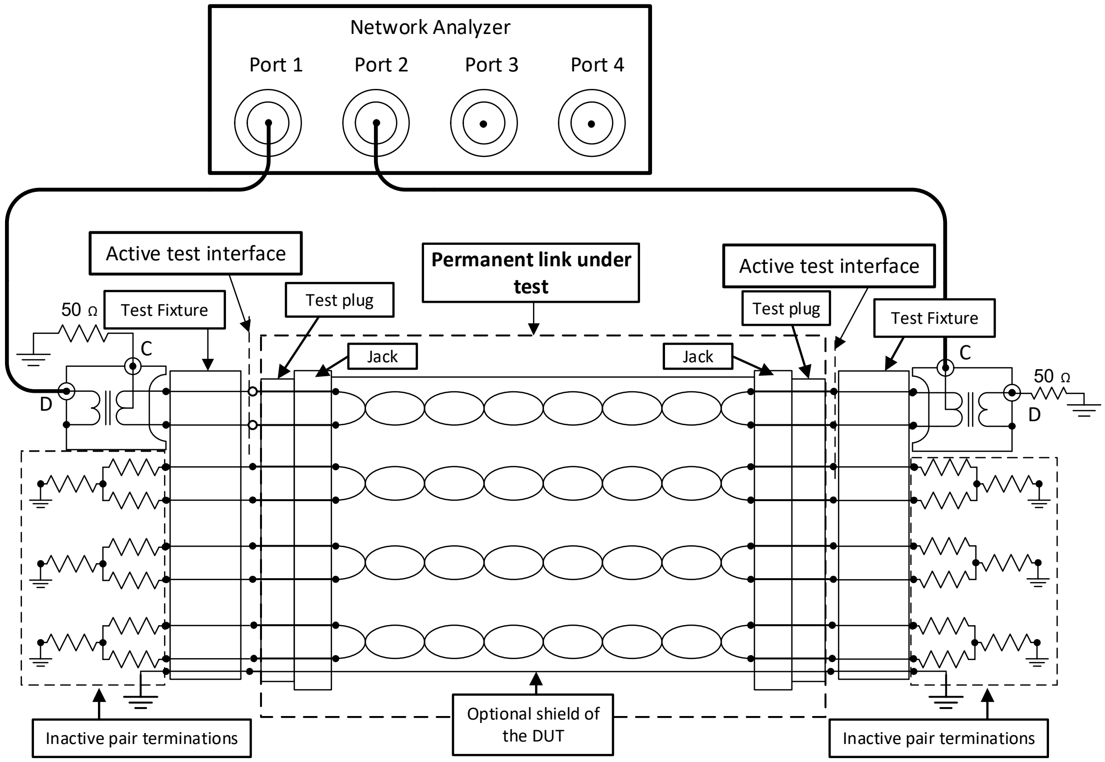


Figure C.18 - Laboratory test configuration for permanent link TCTL.

C.3.8.2 Calibration of permanent link TCTL

The calibration of permanent link TCTL shall comply with C.2.8.2.

C.3.8.3 Measurement of permanent link TCTL

Measure permanent link TCTL on each pair in both directions.

C.3.9 Propagation delay of permanent link

C.3.9.1 Test configuration of permanent link propagation delay

The permanent link propagation delay measurement configuration shall comply with the requirements of Figure C.14.

C.3.9.2 Calibration of permanent link propagation delay

The calibration of permanent link propagation delay shall comply with B.6.4

C.3.9.3 Measurement of permanent link propagation delay

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

C.4 Direct Attach measurement procedures

C.4.1 Direct attach test configurations

In the figures, the far end termination is shown combined with the test fixture. It is acceptable to configure the far end terminations within the test fixture, or attached to the test fixture. Switching may be used and that switching may configured within the test fixture. See ANSI/TIA 1183-1 for a more detailed discussion of wire termination test fixture configurations. The test jacks shall be compliant to the category patch cord test head requirements in clause C.7.

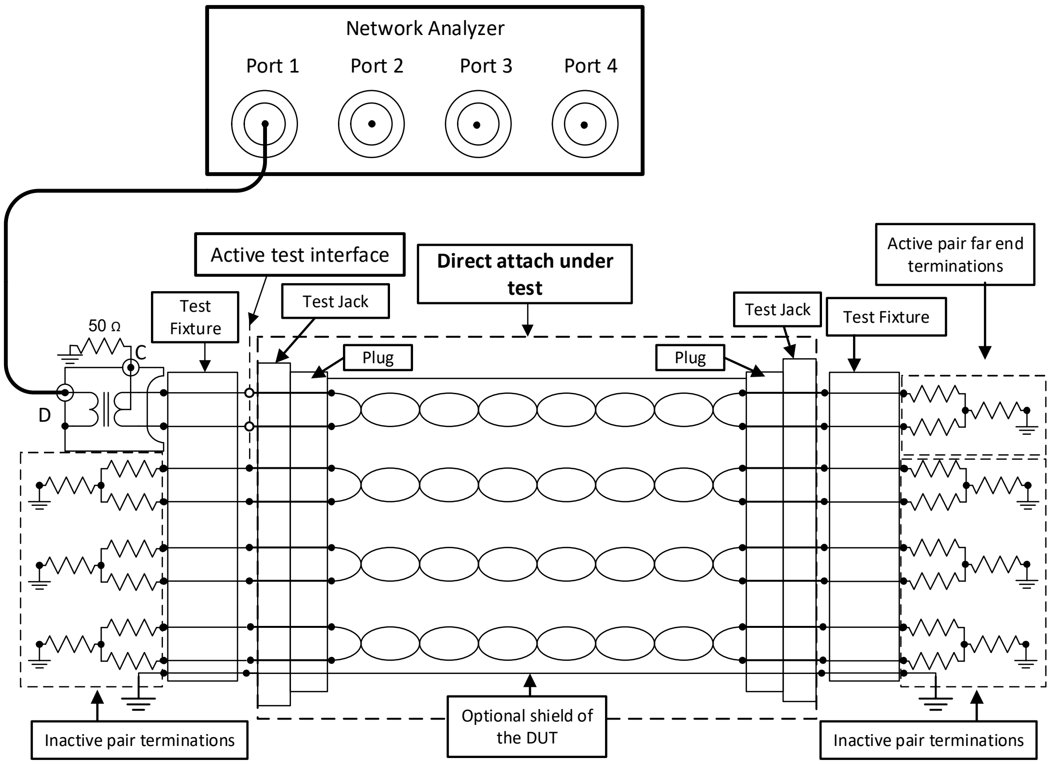


Figure C.19 - Direct attach return loss test configuration.

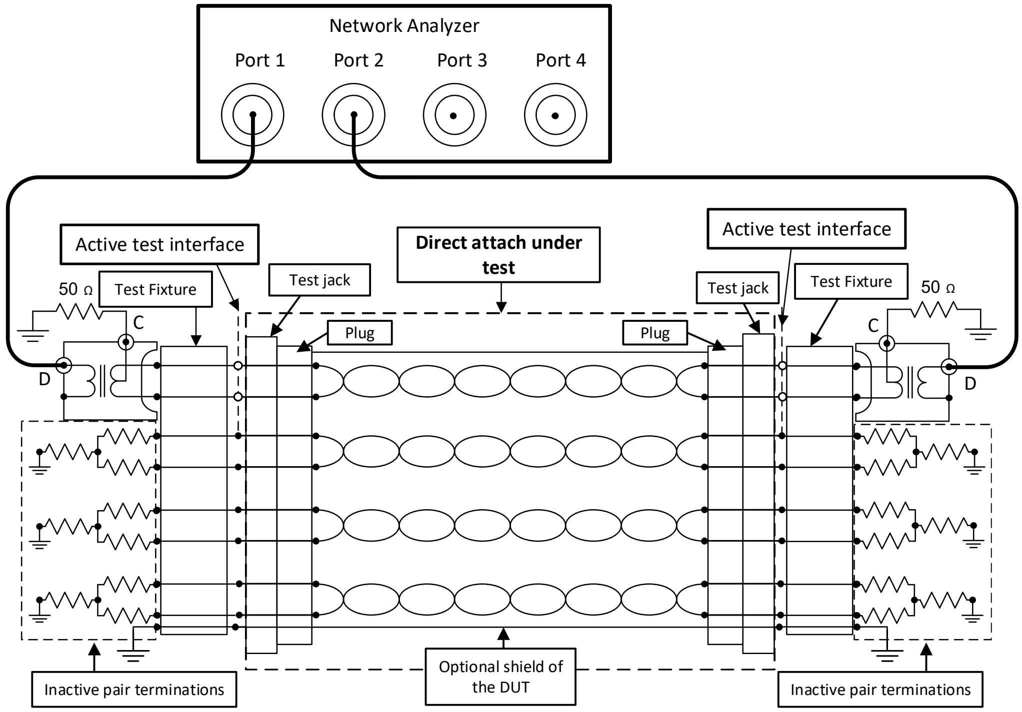


Figure C.20 - Direct attach cord insertion loss test configuration

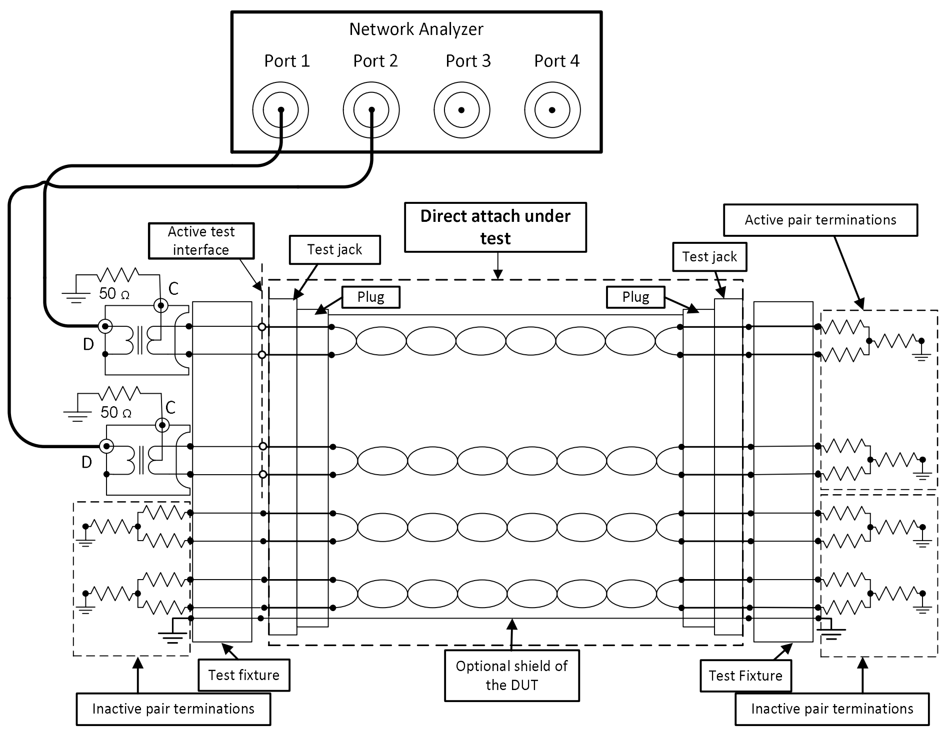


Figure C.21 - Direct attach cord NEXT loss test configuration

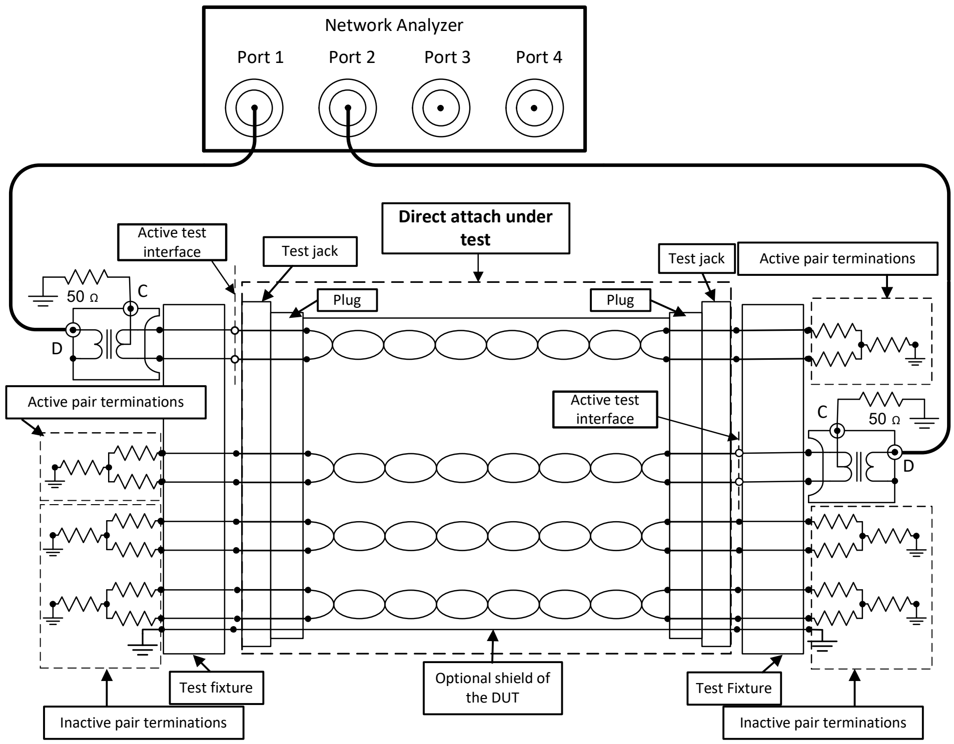


Figure C.22 - Direct attach cord FEXT loss, (ACRF) test configuration

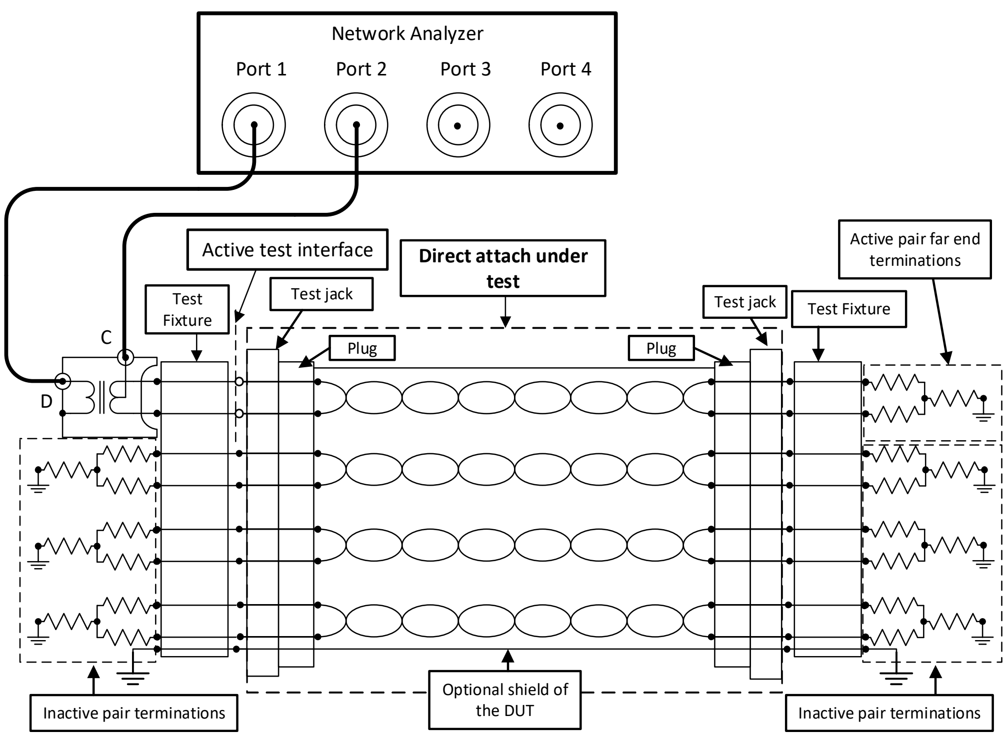


Figure C.23 - Direct attach cord TCL test configuration

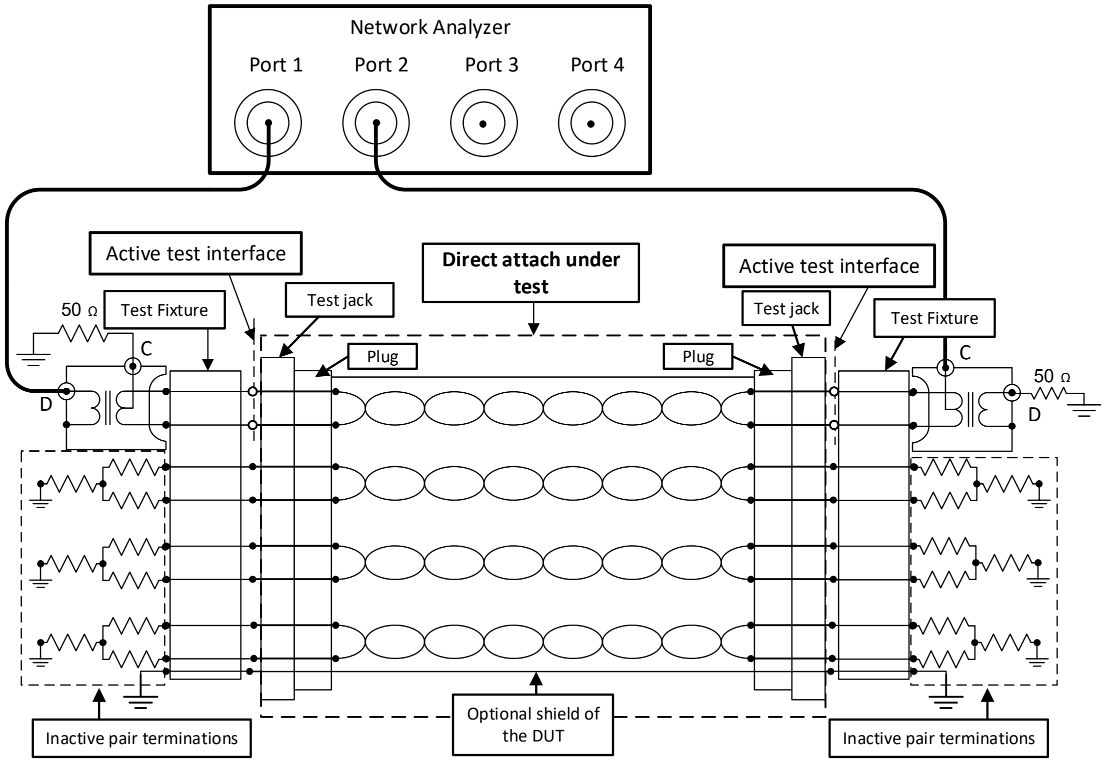


Figure C.24 - Direct attach cord TCTL test configuration

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.25, Figure C.26, and Figure C.27 which show balun configurations for the three required tests.

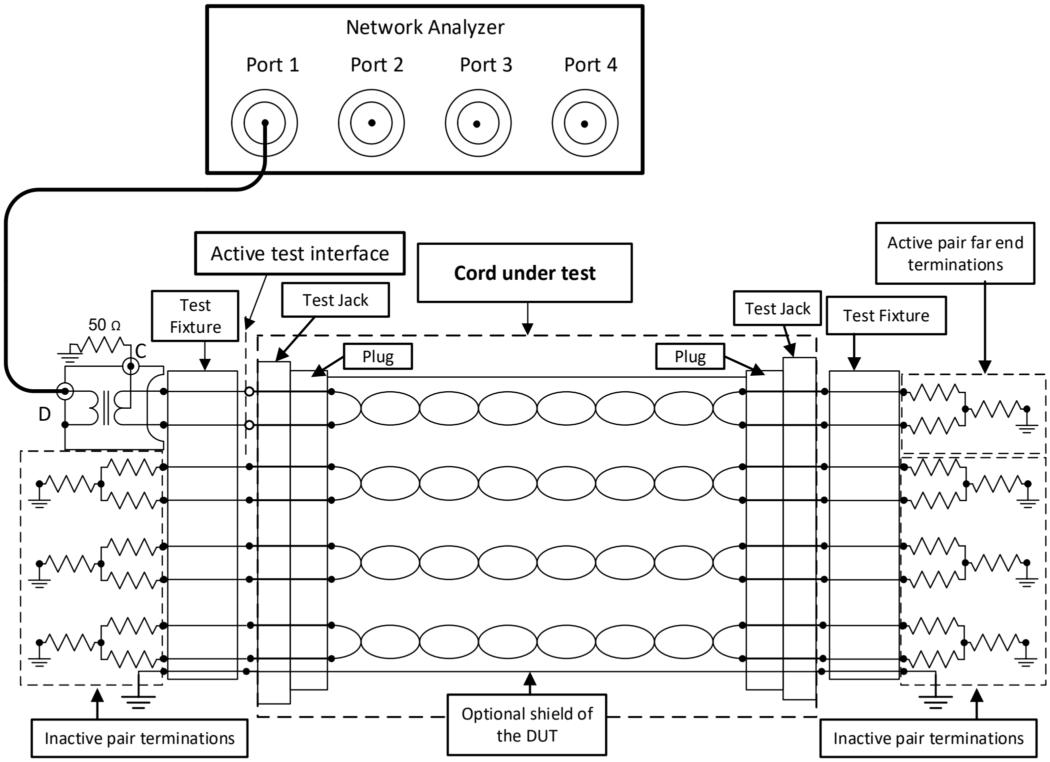


Figure C.25 - Modular cord return loss test configuration

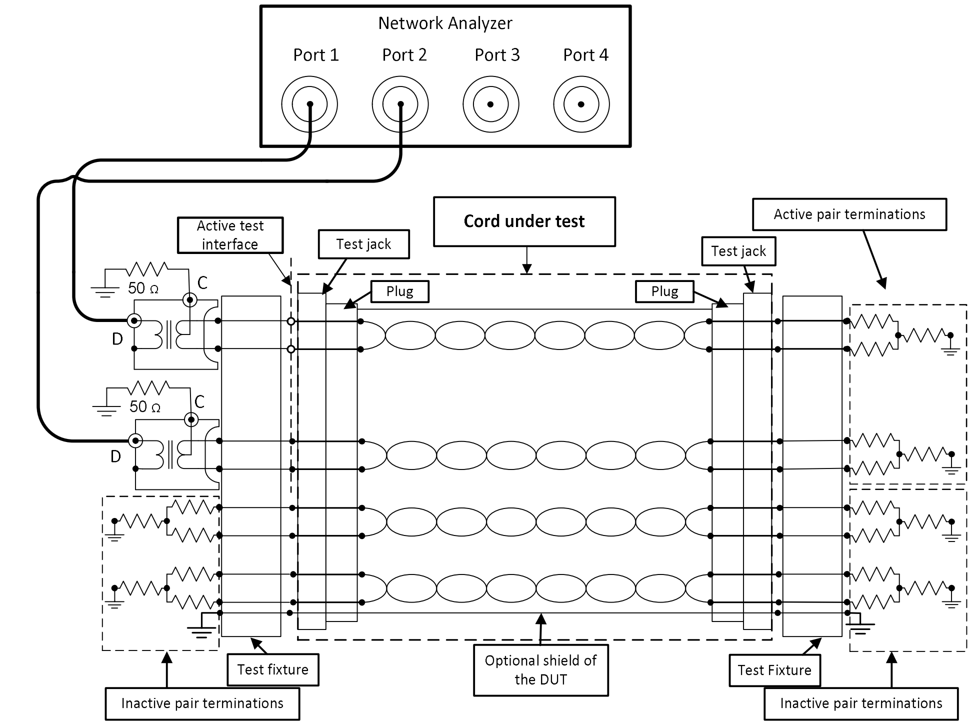


Figure C.26 - Modular cord NEXT loss test configuration

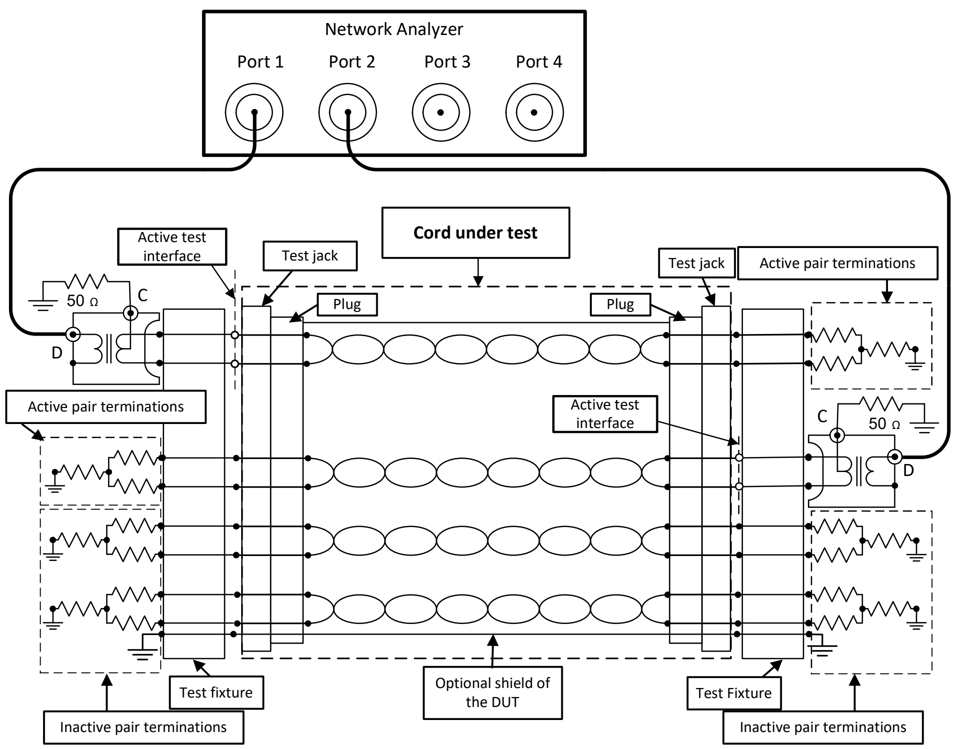


Figure C.27 - Modular cord FEXT loss, (ACRF) test configuration

C.5.2 Test fixturing for modular cords

Modular cord test head NEXT loss, FEXT loss, and return loss requirements are specified in clause C.7. For the purpose of testing modular cord NEXT loss, 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.7.3. The test head used at each end of the test configuration shall be of the same design.

C.5.3 Modular cord measurements.

NEXT loss and return loss are required for modular cords.
NEXT loss requirements are given in clause 6.11.2 and return loss in clause 6.11.1.

For measurement considerations related to category 6A and 8 modular cord test head selection see clause C.7

C.6 Connecting hardware testing

This clause describes test and calibration procedures for connecting hardware.

C.6.1 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.6.5.

DM only and DMCM resistor terminations are shown in Figure B.5 and Figure B.6. 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 B.2.1.

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.6.5.11. 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 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.6.2 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.6.5. When possible, it is recommended to use the same resistor terminations at the far-end as were used for instrument calibration.

C.6.3 Insertion loss measurements

Connecting hardware insertion loss shall be measured in accordance with the requirements of clause C.6.3. Measure connecting hardware insertion loss with interconnections prepared and controlled in accordance with clause B.2.1. 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 B.6.2 with the exception of insertion loss, may be used in line 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.6.4 NEXT loss measurements

The measurement set up shall comply with clause B.1 and with clause C.2.10. A two-port calibration is required per clause B.6.4. For category 3 testing, any plug may be used. For categories 5e, 6, and 6A, qualified test plugs are required and 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 Table C.2 for category 6 or 6A or table Table C.3 for category 5e when mated to a qualified test plug specified in clause C.6.5.3.

C.6.4.1 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.6.5.11.
3. Subtract the corrected test plug NEXT loss forward vectors obtained using clause 0 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.6.4.2 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 Table C.2 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 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.6.4.3 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 for categories 6, 6A, and 8, and Table C.3 for category 5e.

Table C.2 - Category 6, 6A and 8 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	38.1-20log(f/100)	Test plug NEXT loss phase
Case 2	3,6-4,5	Central	38.6-20log(f/100)	Test plug NEXT loss phase
Case 3	3,6-4,5	Central	39.0-20log(f/100)	Test plug NEXT loss phase
Case 4	3,6-4,5	High	39.5-20log(f/100)	Test plug NEXT loss phase
Case 5	1,2-3,6	Low	46.5-20log(f/100)	Test plug NEXT loss phase
Case 6	1,2-3,6	High	49.5-20log(f/100)	Test plug NEXT loss phase
Case 7	3,6-7,8	Low	46.5-20log(f/100)	Test plug NEXT loss phase
Case 8	3,6-7,8	High	49.5-20log(f/100)	Test plug NEXT loss phase
Case 9	1,2-4,5	Low	57-20log(f/100)	+90
Case 10	1,2-4,5	High	70-20log(f/100)	-90
Case 11	4,5-7,8	Low	57-20log(f/100)	+90
Case 12	4,5-7,8	High	70-20log(f/100)	-90
Case 13	1,2-7,8	Low	66-20log(f/100)	Test plug NEXT loss phase
Case 14	1,2-7,8	High	66-20log(f/100)	Test plug NEXT loss phase minus 180°

1) Test plug NEXT loss phase is determined by following the procedure in C.6.4.1.
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.6.5.11.

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 C.6.4.1.
[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.6.5.11.

C.6.4.4 Connecting hardware NEXT loss requirements

The re-embedded response for case 2, case 3, and cases 5 - 14, as specified in Table C.3, shall meet the connecting hardware NEXT loss requirements of clause 6.10.9. For categories 6, 6A, and 8, the re-embedded response for pair combination 3,6 - 4,5 case 1 and case 4, as specified in Table C.2, shall meet the requirements of table Table C.4.

Table C.4 - Category 6, 6A and 8 connecting hardware NEXT loss requirements for case 1 and case 4

	Frequency (MHz)	NEXT loss (dB)
Category 6 and 6A	$1 \le f \le 250$ $250 < f \le 500$	52.5 - 20log(f/100) 44.54 - 40log(f/250)
Category 8	$1 \le f \le 250$ $250 < f \le 500$ $500 < f \le 2000$	52.5 - 20log(f/100) 44.54 - 30log(f/250) 35.51 - 40log(f/500)

C.6.4.5 FEXT loss measurements

Test leads shall be connected to both ends of the test sample. The measurement set up shall comply with clause B.1 and with clause C.2.3. A two-port calibration is required per clause B.6.4. Connecting hardware FEXT loss is determined by measuring connecting hardware when mated to a test plug qualified per clause C.6.5.3. Test all 12 pair combinations in at least one direction.

C.6.4.6 TCL measurements

Test set up, calibration, and measurement shall be done per clause C.2.7 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.6.5.

NOTE - For connecting hardware TCL measurements, the near end and far-end common mode ground terminations should ensure a low impedance connection over the frequency range of test.

C.6.4.7 TCTL measurements

Test set up, calibration, and measurement shall be done per clause B.1. In addition, test plugs used in connecting hardware TCTL testing should comply with the test plug requirements given in clause C.6.5.

C.6.5 Test plug characterization

This clause describes the construction, qualification, and requirements for test plugs for verifying category 5e, 6, 6A and 8 connecting hardware performance.

C.6.5.1 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.6.5.2 Test plug construction

Testing low loss devices to RF frequencies requires the use of stable and predictable connectors and interconnecting leads between the device under test, the test fixtures and equipment. A reasonably stable interface is a printed circuit board designed to mate to device connections and fixture connections. The characteristic impedance, both differential and common mode, of the circuit board traces can be controlled, and multiple copies can be produced which will have similar performance. Figure C.28 and Figure C.29 describe dimensions for a connector interface to mate a circuit board test artifact to a test fixture. This connector design has excellent crosstalk and outstanding return loss performance and is rugged enough for repeated mating cycles without loss of performance.

Figure C.28 shows the female connector interface, including pin-pair number designations which are based upon standard TIA T568B modular connector pin-pair designations. This is an example pin-out, and other pin-outs are also allowed. Figure C.30 describes the mating dimensions of a PCB layout (paddle card) that mates to the connector. The dimensions shown are nominal dimensions that are suggested for the interface and suitable mating tolerances are the responsibility of the user to determine. These tolerances will necessarily depend on the manufacturing capabilities of the PCB supplier and the connector vendor selected. The connector is based upon a specific connector interface however it is assumed there are multiple suppliers of similar products.

Connector total number of contacts: 20 in two rows of 10.
Connector nominal contact spacing: 0.8 mm
Connector nominal PCB mating board thickness: 1.6 mm

Ground connections are placed between active circuit connections for guarding purposes. The mating PCB also includes ground planes between the two rows of connections for impedance control and guarding purposes.

This connector interface is useful especially for modular test plug artifacts and for paddle card interfaces to IDC connecting points on modular connecting hardware.

The connector shown is for vertical surface mounting to a printed circuit board that interfaces to a test fixture. Locating pins are included on the connector housing for physical stability and orientation. Other types of connector PCB mounting are possible, such as a horizontal orientation or an edge card orientation.

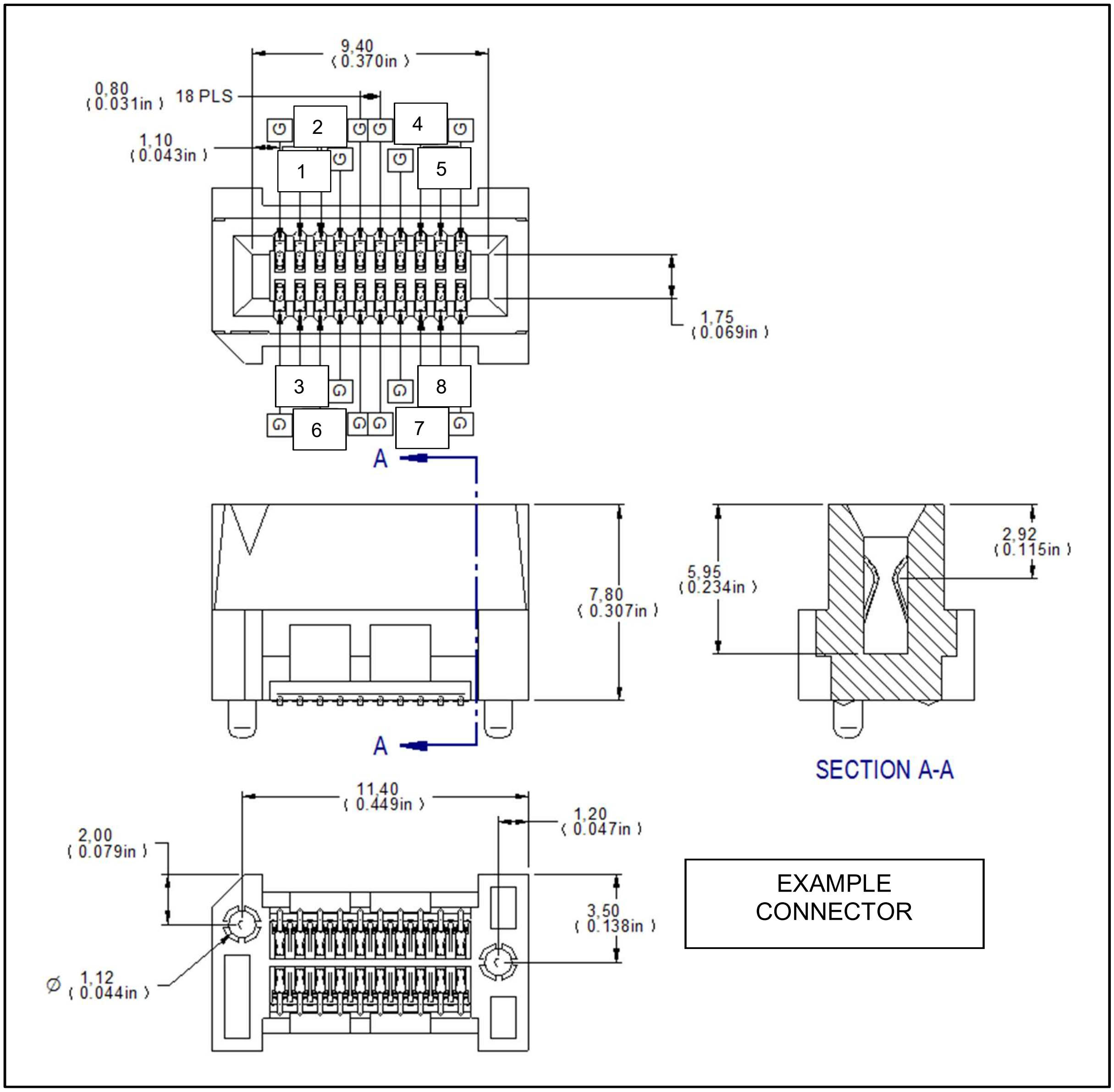


Figure C.28 - Example female test connector interface mating dimensions

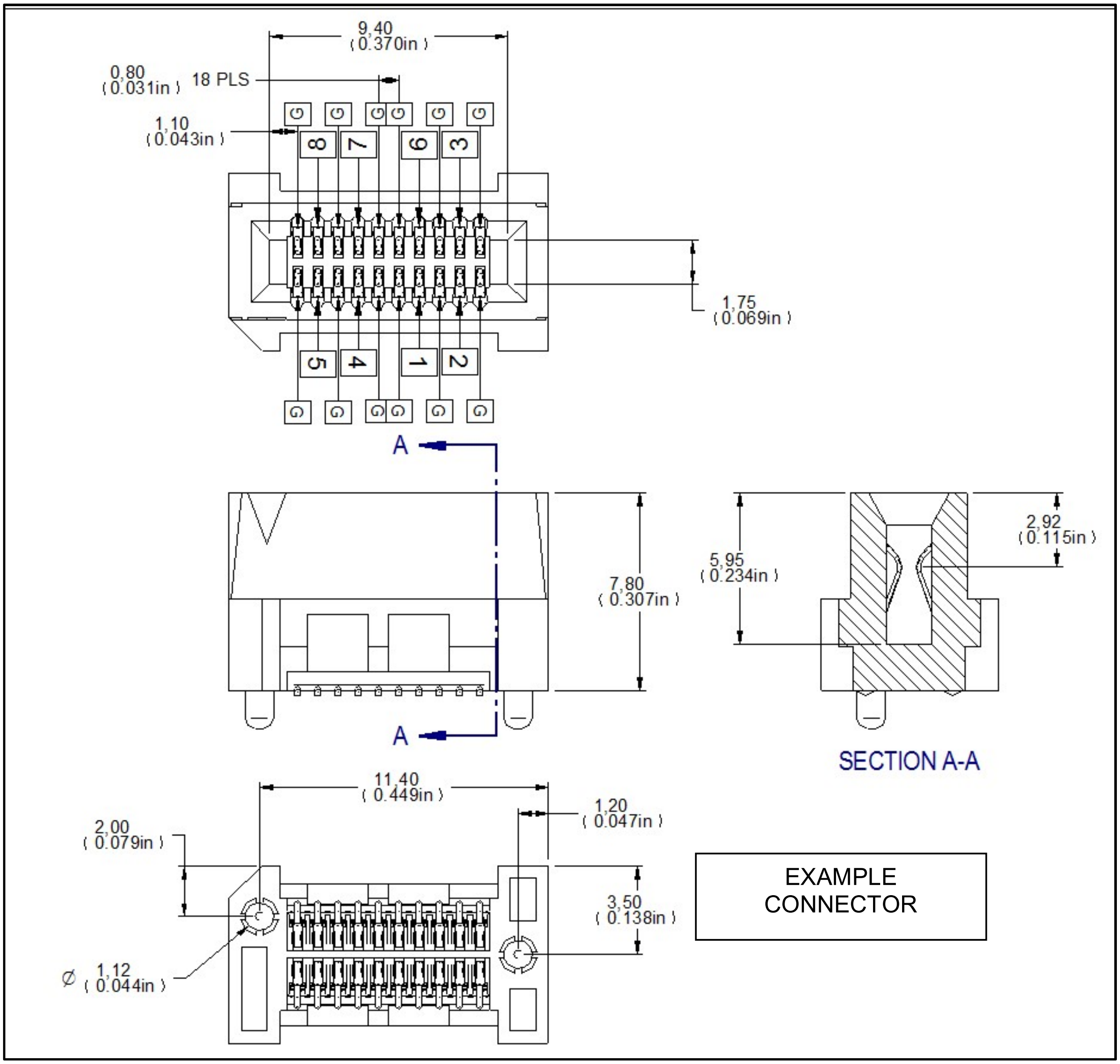


Figure C.29 - Example female test connector interface mating dimensions

Refer to clause 5.7.5 for pin numbers in this diagram.

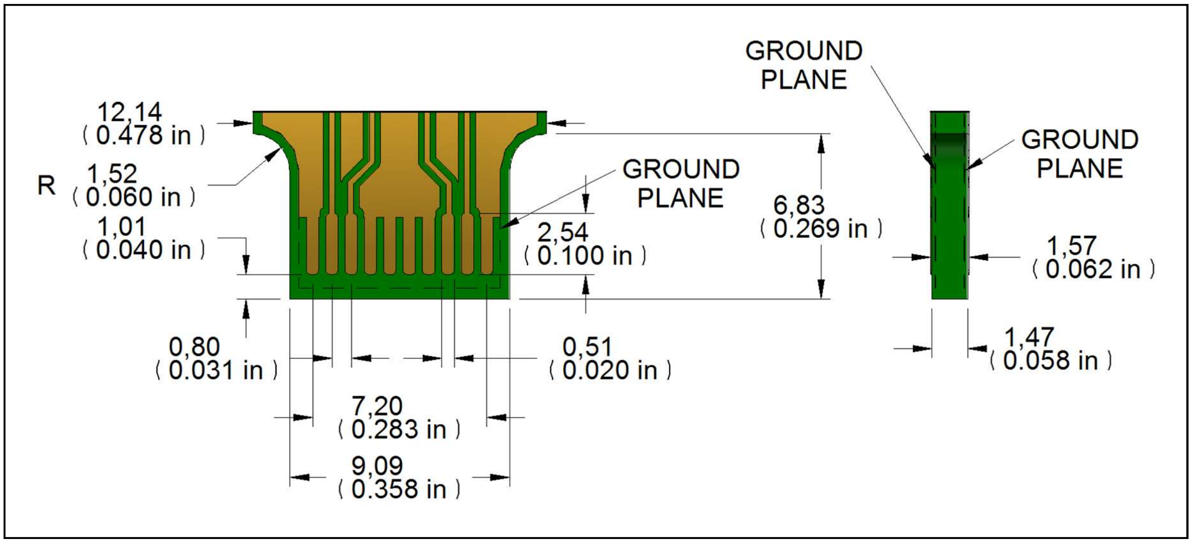


Figure C.30 - Example balun fixture PCB paddle card interface mating dimensions

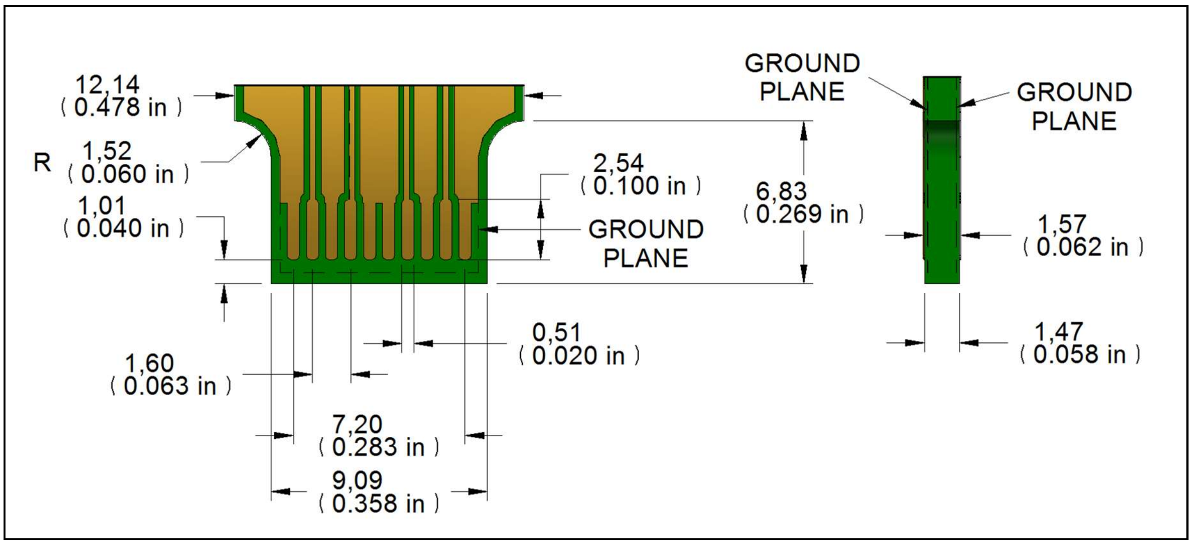


Figure C.31 - Example balunless fixture PCB paddle card interface mating dimensions

Notes:

1. The design goal for printed circuit board signal conductors is 50 Ω nominal impedance (single-ended), and 100 Ω (differential) impedance.
2. Hard gold plating of paddle card contact pads is recommended for durability.

Other methods of interface between the PWB of the test-plug and the PWB interface between DUT and the test equipment are also allowed.

NOTE - The direct plug measurement fixture, as specified in clause C.6.5.10, 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.

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.6.
5 Improvement of the wire management in the test fixture of any test leads used as part of plug construction and mounting.

PCB fixtures shall conform to the requirements of clause 8.3 of TIA 1183-A (overall test setup performance after calibration).
Where a cable is used to terminate a plug, test fixtures described in TIA 1183-A are designed to provide suitable interface and termination.

Example test fixtures and devices described in 0 are designed to provide suitable interface and termination.

C.6.5.3 Test plug qualification

Test plugs shall be qualified for all requirements of clauses C.6.5.4 (NEXT loss), C.6.5.6 (FEXT loss) and C.6.5.8 (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.6.5.10.

C.6.5.4 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.5. 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.6.4.4.

Table C.5 - Category 5e, 6, and 6A test plug NEXT loss ranges

Pair combination	NEXT loss magnitude range (dB) 1)	NEXT loss phase range (degrees)2)
3,6-4,5	10 – 300 MHz: $38.1-20\log(f/100) \le$ NEXT loss $\le 39.5-20\log(f/100)$ 5) 300 – 500 MHz: $38.1-20\log(f/100) \le$ NEXT loss $\le 39.5-20\log(f/100) + 0.5(f-300)/200$	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 C.6.5.10 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.

Table C.6 - Category 8 test plug NEXT loss ranges

Pair combination	NEXT loss magnitude range (dB) [1]	NEXT loss phase range (degrees)[2]
3,6-4,5	10 – 300 MHz: 38.1-20log(f/100) ≤ NEXT loss ≤ 39.5-20log(f/100) 300 – 2000 MHz: 38.1-20log(f/100) ≤ NEXT loss ≤ 39.5-20log(f/100) + 0.5(f-300)/200	50 – 100 MHz: (-90 + 1.5· f/100) ± 1 100 – 500 MHz: (-90 + 1.5· f/100) ± f/100
1,2-3,6	10 – 300 MHz: 46.5-20log(f/100) ≤ NEXT loss ≤ 49.5-20log(f/100) 300 – 2000 MHz: 46.5-20log(f/100) ≤ NEXT loss ≤ 49.5-20log(f/100) + 0.5(f-300)/200	(-90 +1.5 f/100) ± 3· f/100
3,6-7,8	10 – 300 MHz: 46.5-20log(f/100) ≤ NEXT loss ≤ 49.5-20log(f/100) 300 – 2000 MHz: 46.5-20log(f/100) ≤ NEXT loss ≤ 49.5-20log(f/100) + 0.5(f-300)/200	(-90 +1.5· f/100) ± 3· f/100
1,2-4,5	NEXT loss ≥ 57-20log(f/100) [4]	90 ± (30· f/100) [3]
4,5-7,8	NEXT loss ≥ 57-20log(f/100) [4]	90 ± (30· f/100) [3]
1,2-7,8	NEXT loss ≥ 66-20log(f/100) [4]	Any phase

1) Magnitude limits apply over the frequency range from 10 MHz to 2000 MHz.
2) Phase limits apply over the frequency range from 50 MHz to 2000 MHz.
3) When the measured test plug NEXT loss magnitude is greater than 70-20log(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.

C.6.5.5 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.6.5.10 or equivalent. Correct the phase of all NEXT loss measurements to the test plug phase reference plane, as shown in Figure C.39, using the procedures in clause C.6.5.11. An example of a measurement setup for test plug NEXT loss is shown in Figure C.32.

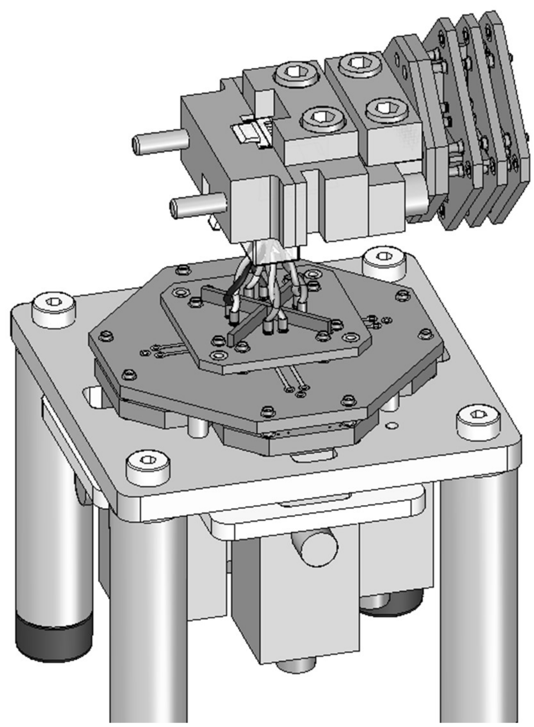


Figure C.32 - Example of a measurement setup for test plug NEXT loss

C.6.5.6 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. Test plug requirements apply over the frequency ranges from 10 MHz to the upper frequency of the category.

Table C.7 - Test plug FEXT loss ranges

Pair combination	Frequency range (MHz)	FEXT loss magnitude range (dB)	Phase (degrees)
3,6-4,5	10-2000	$46-20\log(f/100) \leq$ FEXT loss $\leq 56-20\log(f/100)$ [3]	$-90 \pm (30 \cdot f/100)$ [1), 2)]
1,2-3,6	10-2000	$46-20\log(f/100) \leq$ FEXT loss $\leq 56-20\log(f/100)$ [3]	$-90 \pm (30 \cdot f/100)$ [1), 2)]
3,6-7,8	10-2000	$46-20\log(f/100) \leq$ FEXT loss $\leq 56-20\log(f/100)$ [3]	$-90 \pm (30 \cdot f/100)$ [1), 2)]
1,2-4,5	10-2000	FEXT loss $\geq 55-20\log(f/100)$ [4]	any phase
4,5-7,8	10-2000	FEXT loss $\geq 55-20\log(f/100)$ [4]	any phase
1,2-7,8	10-2000	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 2000 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.6.5.7 Test plug FEXT loss measurement

Measure the test plug FEXT loss vectors for all pair combinations. Use the direct fixture specified in clause C.6.5.10 or equivalent. Correct the phase of all FEXT loss measurements to the test plug phase reference plane, as shown in Figure C.39, using the procedures specified in clause C.6.5.11. An example of a measurement setup for test plug FEXT loss is shown in Figure C.33.

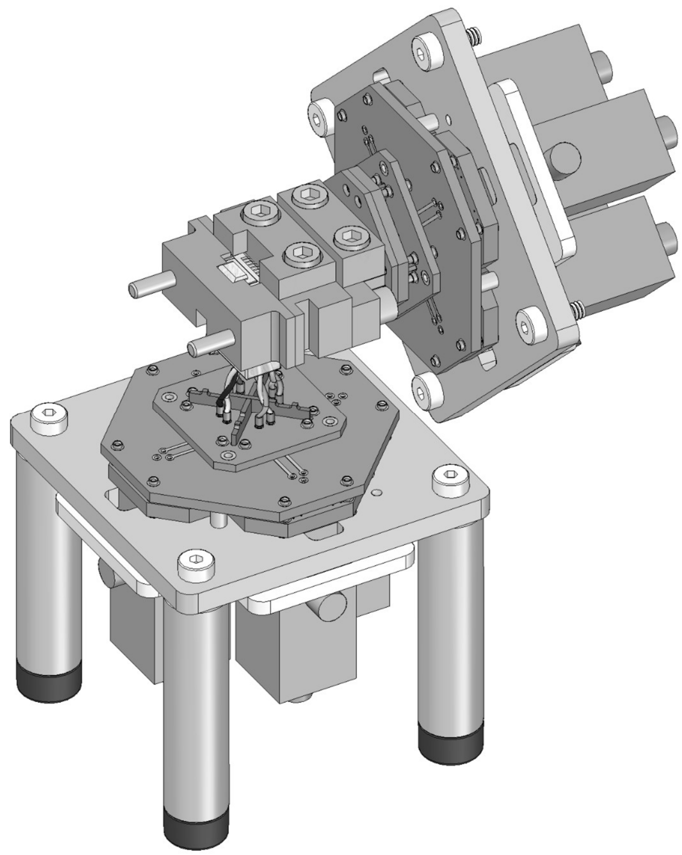


Figure C.33 - Example of a measurement setup for test plug FEXT loss

C.6.5.8 Test plug return loss requirements

The return loss, magnitude and phase, of the test plug shall meet the values specified in Table C.8 or Table C.9 per the applicable category.

Test plug return loss requirements apply over the frequency ranges from 10 MHz to the upper frequency of the category.

Table C.8 - Category 5e, 6 and 6A test plug return loss requirements

Pair	Frequency range (MHz)	Return loss magnitude (dB) [2]	Return loss phase (degrees) [1]
1,2	10-500	≥ 33.5-20log(f/100)	negative phase
3,6	10-500	≥ 33.5-20log(f/100) [3]	positive phase
4,5	10-500	≥ 33.5-20log(f/100)	negative phase
7,8	10-500	≥ 33.5-20log(f/100)	negative phase

[1] The phase requirement does not apply when the measured magnitude is greater than 35-20log(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 ≥ 30-20log(f/100).

Table C.9 - Category 8 test plug return loss requirements

Pair	Frequency range (MHz)	Return loss magnitude (dB) [1]
1,2	10-2000	≥ 35-20log(f/100) min 14
3,6	10-2000	≥ 35-20log(f/100) min 14
4,5	10-2000	≥ 35-20log(f/100) min 14
7,8	10-2000	≥ 35-20log(f/100) min 14

[1] Calculations that result in return loss requirements greater than 40 dB shall revert to a requirement of 40 dB minimum.

It is impractical to verify return loss properties of plugs while they are attached to cords. The transmission properties of modular cords are included in the requirements of clause 6.11 describing cord and jumper cord return loss.

C.6.5.9 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 the reverse direction

C.6.5.9.1 Test plug return loss interconnections and termination

The interconnections used to construct the test plug shall be qualified, in the reverse direction, using the procedure in clause B.2.1.1. The direct fixture shall be connected to the measurement equipment. The test plug shall be mounted in the direct fixture. The far-end of the plug should be terminated with the calibration reference load resistor terminations. The impedance effects of the direct plug measurement fixture shall be removed.

The impedance effects of the direct plug measurement fixture shall be removed by calibration. For balunless measurements, a minimum of a full 2-port calibration shall be performed for each pair under test. For measurements using baluns, a minimum of a 1-port calibration shall be performed for each pair under test. Clause B.6.4 describes calibration methods.

The extensions of the coaxial probes shall be controlled during calibration, to match their positions during the measurement of a plug. To achieve this, the calibration standards should be constructed in such a way so that once the calibration has been completed; the calibration reference plane is at the tips of the probes when extended to 0.66 mm (0.026 in) as shown in Figure C.39

The direct fixture 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 F 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.6.5.10 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 Figure C.34, Figure C.35, and Figure C.36. It is recommended to use the direct fixture as shown in figures Figure C.36, Figure C.37, and Figure C.38. The direct fixture residual NEXT loss, FEXT loss, and return loss shall comply with the requirements of Table C.10.

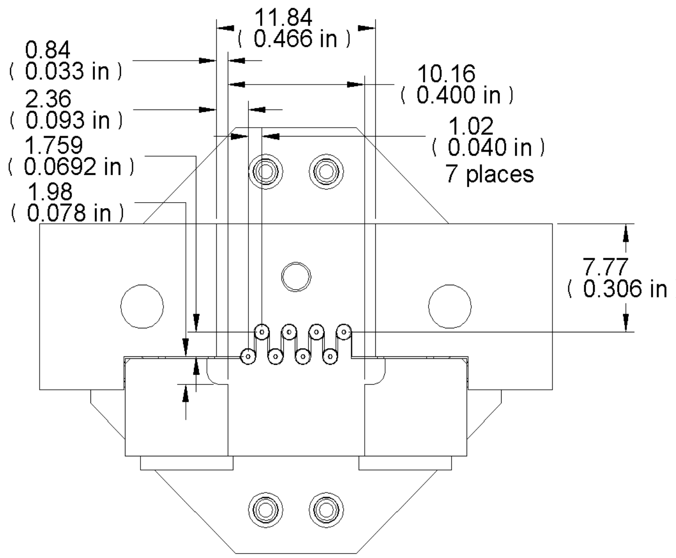


Figure C.34 - Direct fixture mating dimensions, top view

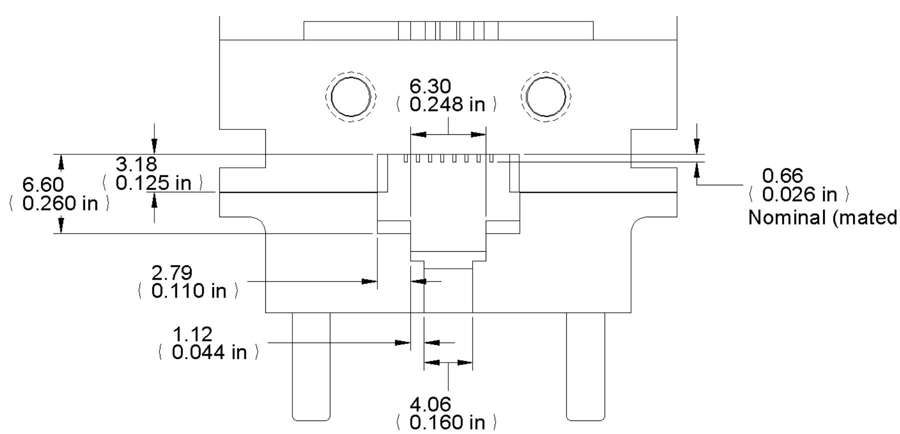


Figure C.35 - Direct fixture mating dimensions, front view

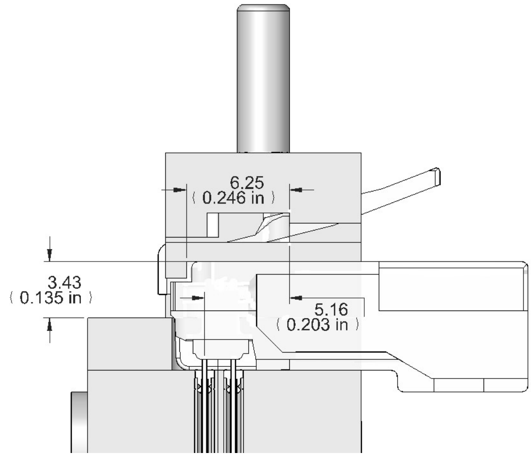


Figure C.36 - Direct fixture mating dimensions, side view

Dimension tolerances for figures Figure C.34, Figure C.35, and Figure C.36 are ± .025 mm (.001 in).

Table C.10 - Direct fixture performance

Direct fixture performance parameter	Value (dB)
Pair-to-pair residual NEXT loss and FEXT loss	$\geq$ 74 – 20log(f/100), 75 dB max.
Return loss	$\geq$ 34 – 20log(f/100), 40 dB max.

C.6.5.10.1 Procedure for mating a test plug to the direct fixture

1 Place the test plug into the plug clamp as shown in Figure C.37.

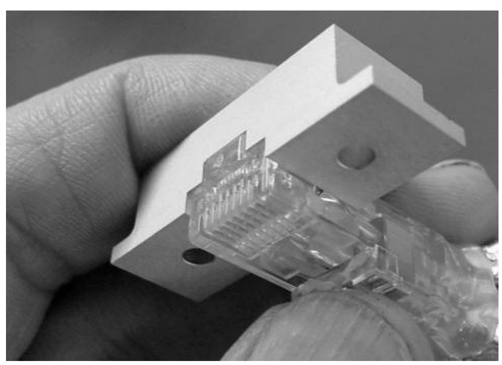


Figure C.37 - Modular plug placed into the plug clamp

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.38.

NOTE - The spring loaded pin in the clamp block pushes against the test plug and holds it in position against the plug clamp.

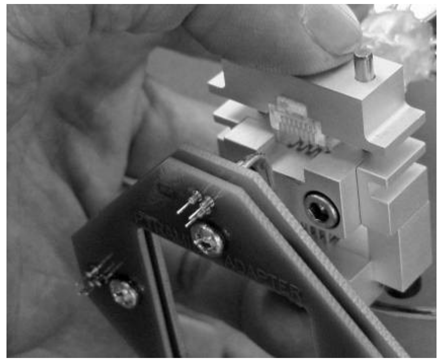


Figure C.38 - Guiding the plug into position

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 Figure H..

C.6.5.11 Test plug phase reference plane and calibration planes

For categories 5e, 6, 6A and 8 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.6.5. 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.39. Refer to clause B.2.1 for requirements of the interconnections between each appropriate calibration plane and the DUT. Alternatively, the direct fixture (see clause C.6.5.10) can be calibrated at the tips of the coaxial probes (see figures Figure C.34, Figure C.35, and Figure C.36) using suitable calibration artifacts. Examples are shown in Figure C.40.

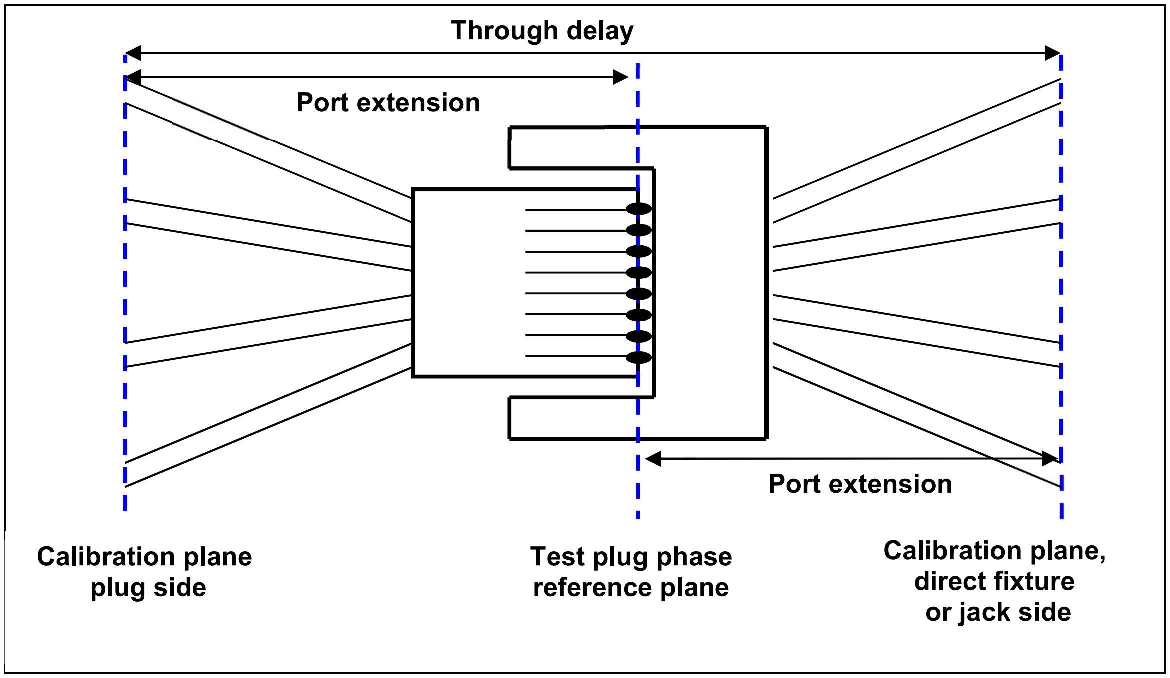


Figure C.39 - Calibration planes, test plug phase reference plane, and port extensions

C.6.5.11.1 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-4) 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-3).

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

$$... + 360 \cdot frequency\ (\text{Hz}) \cdot delay\ (\text{sec}) \qquad \text{(C-3)}$$

C.6.5.11.2 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.6.5.11.3 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.6.5.11.3.1 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-4). 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-5) shall be applied for each port extension.

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

C.6.5.11.3.2 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:

$$TD_{shortingjack} = Delay_{roundtripplugjack} - Delay_{adjustedroundtripplug} \qquad \text{(C-5)}$$

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.6.5.11.4 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 Figure C.34, Figure C.35 and Figure C.36. 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.40. 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.

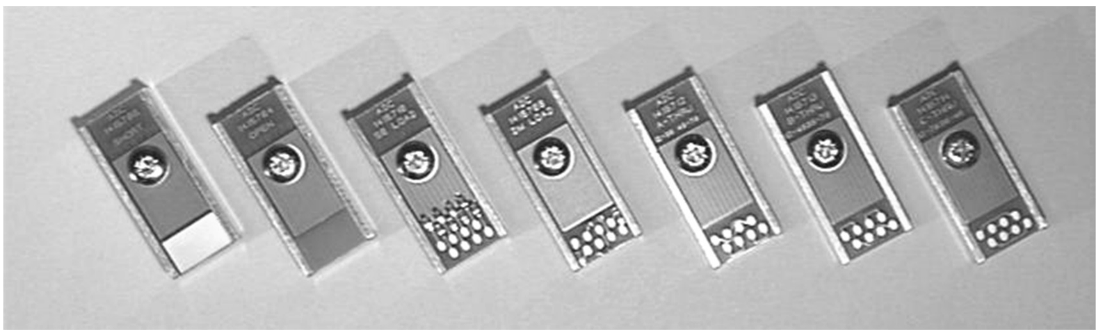


Figure C.40 - Examples of direct fixture short, open, load, and through artifacts

NOTES,

1 The direct fixture artifacts shown in Figure C.40 may be obtained from industry sources.

2 Photos are for illustrative purposes only and do not constitute an endorsement by TIA.

C.6.5.11.5 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.6.6 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.6.6.1 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.11. The variability of test plugs is controlled by the test plug requirements of Table C.6, Table C.7, and Table C.9.

Table C.11 - 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 – 20log(f/100)	(38.77) nominal	0.2	3.0
1,2 - 3,6	10 – 500	66 – 20log(f/100)	(47.87) nominal	0.5	1.5
3,6 - 7,8	10 – 500	66 – 20log(f/100)	(47.87) nominal	0.5	1.5
1,2 - 4,5	10 – 500	68 – 20log(f/100)	(57.00) minimum	2.0	1.5
4,5 - 7,8	10 – 500	68 – 20log(f/100)	(57.00) minimum	2.0	1.5
1,2 - 7,8	10 – 500	72 – 20log(f/100)	(66.00) minimum	3.0	1.5

C.6.6.2 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.12.

Table C.12 - 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 – 20log(f/100)	(49.6) nominal	1.0
1,2-3,6	10 – 500	66 – 20log(f/100)	(49.6) nominal	1.0
3,6-7,8	10 – 500	66 – 20log(f/100)	(49.6) nominal	1.0
1,2-4,5	10 – 500	68 – 20log(f/100)	n/a	-
4,5-7,8	10 – 500	68 – 20log(f/100)	n/a	-
1,2-7,8	10 – 500	72 – 20log(f/100)	n/a	-

C.6.6.3 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.41.

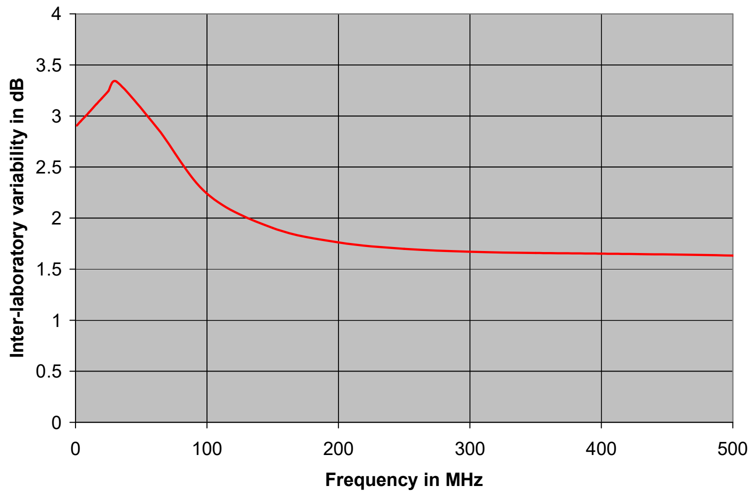


Figure C.41 - Inter-laboratory return loss variability for testing category 6A connecting hardware

C.7 Modular cord test head requirements

Refer to clause C.5 for modular cord test procedures.

For category 6A and category 8 modular cord pair combination 3,6-4,5 NEXT measurements, the modular cord limits determined in section 6.11.2 shall be calculated using the connector contributions in table C.4 to account for modular plug pair combination 3,6-4,5 NEXT range and measurement repeatability.

When the alternative category 6A test head is used, the category 6A modular cord combination 3,6-4,5 modular cord limits determined in section 6.11.2 shall be calculated using the connector contributions in table C.14 to account for modular plug pair combination 3,6-4,5 NEXT range and measurement repeatability.

When the alternative category 6A test head is used, the category 6A modular cord combination 1,2-3,6, 1,2-4,5, 1,2-7,8, 3,6-78 and 4,5-7,78 modular cord limits determined in section 6.11.2 shall be calculated using the connector contributions in table C.13.

C.7.1 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.6.4 for all frequencies from 10 MHz to the upper frequency of the category.

Modular test head NEXT loss performance shall meet the connecting hardware NEXT loss requirements specified in clause 6.10.9 for categories 6 and 8.

Modular test head NEXT loss performance shall exceed 47-20log(f/100) from 10 to 100 MHz for category 5e.

Modular test head NEXT loss performance shall meet the connecting hardware NEXT loss requirements specified in clause 6.10.9 for categories 6A, however when testing a category 6A patch cords according to ANSI/TIA-568.2-D it is permitted to use an alternative test head that complies to the connecting hardware NEXT loss requirements of table C.13 and table C.14.

Table C.13 - Alternative category 6A test head NEXT loss requirements

	Frequency (MHz)	NEXT loss (dB)
Category 6A	$10 \le f \le 250$	$54 - 20\log(f/100)$
	$250 < f \le 500$	$46.04 - 30\log(f/250)$

Table C.14 - Alternative test head NEXT loss requirements when using high and low 36-45 virtual test plugs

	Frequency (MHz)	NEXT loss (dB)
Category 6A	$10 \le f \le 250$	$52.5 - 20\log(f/100)$
	$250 < f \le 500$	$44.54 - 30\log(f/250)$

In addition, for either test head, 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 the upper frequency of the category 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, 6A or 8 connecting hardware NEXT loss requirements as specified in Table C.4 for pair combination 3,6-4,5 and clause 6.10.9 for pair combinations 1,2-3,6 and 3,6-7,8 from 10 MHz to the upper frequency of the category for both the low and high test plug limit vectors. Use the correct table for category 6, 6A, 8, 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.7.2 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.6.4.5. 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-6).

$$FEXT_{Test\_Head} \ge 48.1 - 20\log(f/100)\ dB \qquad \text{(C-6)}$$

C.7.3 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.6.2. 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.15.

Table C.15 - Category 5e, 6, and 6A modular cord test head return loss

Frequency (MHz)	Return loss (dB)
$10 \leq f < 50$	≥ 35
$50 \leq f \leq 500$	$\geq 29 - 20\log(f/100)$

Table C.16 - Category 8 modular cord test head return loss

Frequency (MHz)	Return loss (dB)
$10 \leq f < 70$	≥ 35
$70 \leq f < 1000$	$\geq 32 - 20\log(f/100)$
$1000 \leq f \leq 2000$	≥ 12

C.8 Alien crosstalk measurements

C.8.1 Cabling ANEXT loss and AFEXT loss laboratory measurement procedures

C.8.1.1 Cabling test configuration for ANEXT and AFEXT loss

C.8.1.1.1 Termination of pairs

During all testing, the unused pairs, and the opposite end of the used pairs, of the disturbed and disturbers, of the channels under test, shall be terminated with DMCM terminations at both ends.

C.8.1.2 Calibration of cabling ANEXT loss or AFEXT loss

Calibrate according to the methods outlined in clause B.6.4.

C.8.1.3 Calculation of cabling PSANEXT loss or PSAFEXT loss

For each port, the power sum alien crosstalk shall be calculated using the 6 worst disturber channels.

C.8.1.3.1 PSANEXT calculation procedure

Using measured ANEXT data from disturber channels to disturbed channel:

1. Calculate single disturbing channel PSANEXT from each disturbing channel to the disturbed channel at each frequency.
2. At each frequency point, identify the 6 channels with highest PSANEXT to the disturbed channel.
3. For each frequency point, power sum the PSANEXT from the worst 6 channels identified in step 2 into the disturber and calculate the margin.
4. Identify the frequency point with the lowest PSANEXT margin. When the lowest margin occurs at more than one frequency, select the highest frequency point.
5. Utilize the six channels corresponding to that frequency point and calculate 6-to-1 PSANEXT into the disturbed channel at all frequency points. Report these PSANEXT values as the PSANEXT performance of that disturbed port.

C.8.1.3.2 PSAACRF calculation procedure

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. PSAACRF for a DUT is determined using equation C-7 for the case of a 4-pair DUT.

$$PSAACRF_k = PSAFEXT_k - IL_k \text{ dB} \tag{C-7}$$

For channels and permanent links, the calculations in equations C-8 through C-10 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:

$$AFEXTnorm_{k,i,j} = AFEXT_{k,i,j} + (IL_k - IL_{i,j}) - 10\log\left(\frac{IL_k}{IL_{i,j}}\right) \text{ dB} \tag{C-8}$$

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

$$AFEXTnorm_{k,i,j} = AFEXT_{k,i,j} \ dB \tag{C-9}$$

where:

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

$PSAACRF_k$ 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 B.1.

Using AFEXT data from disturber channels to disturbed channel and measured IL:

1. Using equations 9-12 from clause 6.1.16, normalize the AFEXT for insertion loss.
2. Using the normalized AFEXT, calculate single disturbing channel PSAFEXT from each disturbing channel to the disturbed channel at each frequency.
3. Convert this to PSAACRF from the single disturbing channel, using equation 9 from clause 6.1.16, to subtract the IL.
4. At each frequency point, identify the 6 channels with the worst PSAACRF to the disturbed channel.
5. Identify the frequency point with the lowest PSAACRF margin. When the lowest margin occurs at more than one frequency, select the highest frequency point.
6. Utilize the 6 channels with the worst PSAACRF that were identified in step 4 at that frequency point to calculate 6-to-1 PSAACRF into the disturbed channel at all frequency points. Use the channel PSAACRF values from step 3 which were calculated using the normalized AFEXT values from step 1. Report these PSAACRF values as the PSAACRF performance of that disturbed port.

C.8.2 ANEXT loss and AFEXT loss of cable

This clause describes requirements 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 MHz to the upper frequency of the category.

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.42. 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.6.1.

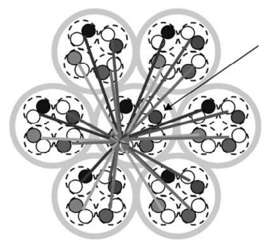


Figure C.42 - 6-around-1 cable test configuration

C.8.2.1 Test configuration for cable ANEXT loss and AFEXT loss

During all testing, the unused pairs, and the opposite end of the used pairs, of the disturbed and disturber cables, of the channels under test, shall be terminated with DMCM terminations at both ends.

C.8.2.2 Calibration of cable ANEXT and AFEXT loss

The calibration for ANEXT and AFEXT loss shall comply with B.6.4. A calibration is required between all ports under test.

C.8.2.3 Measurement of cable ANEXT and AFEXT loss

Measure the Sdd21 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.8.2.4 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-11

$$PSAACRF_k = PSAFEXT_k - IL_k \text{ dB} \quad \text{(C-11)}$$

where k is the disturbed pair.

C.8.2.5 Optional screened cable alien crosstalk testing method using two cables

This clause describes an optional screened cable alien crosstalk test method using two cables. Controlled experiments have demonstrated that these cables provide an alien crosstalk performance that is free of statistical contribution and near the measurement floor. Therefore, the power sum of a 6-around-1 bundle can be accurately predicted using two cables bundled together.

The two cables shall be attached together at every 200 mm (8 in) and one cable shall be designated to act as the disturbed cable. The ANEXT and AFEXT loss shall be determined per clause C.8.2.3 and will result in 16 measurements per direction for each ANEXT and AFEXT loss. The cable PSANEXT and

PSAACRF shall then be calculated using four combinations for each disturbed pair and then adjusted by an offset of 10log(6) to predict the 6-around-1 performance.

$$PSANEXT_{PREDICTED_k} = PSANEXT_{1CABLE_k} - 10\log(6)\ dB$$

Where: $PSANEXT_{1CABL\ \ k}$ $is\ the\ PSANEXT\ loss\ of\ a\ pair\ calculated\ in\ accordance\ with\ equation\ (6)$

And: $PSAFEXT_{PREDICTED_k} = PSAFEXT_{1CABL\ \ k} - 10\log(6)\ dB$

And: $PSAFEXT_{1CABLE_k}$ $is\ the\ PSAFEXT\ loss\ of\ a\ pair\ calculated\ in\ accordance\ with\ equation\ (8)$

If the margin of PSANEXT(predicted(k)) to equation (PSANEXT Limit) obtained with this method is less than 10 dB, then the cable PSANEXT and PSAACRF performance shall be determined using the complete 6-around-1 test configuration.
This optional method only applies to screened cables and does not apply to screened channels or permanent links to take into account connector contributions and installation factors.

C.8.3 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 separate connecting hardware, or different ports of the same multiport connector assembly.

C.8.3.1 Measurement outline

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

C.8.3.2 Network analyzer settings

Maximum IF bandwidth should be 100 Hz.

C.8.3.3 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. Due to the improved alien crosstalk requirement of category 8 connecting hardware the recommended measurement floor is 20 dB better than the connecting hardware PSANEXT loss or PSAFEXT loss requirement, as appropriate.

C.8.3.4 DUT setup for ANEXT loss and AFEXT loss measurement

The ANEXT loss measurement is performed between two DUTs as shown in Figure C.43. The AFEXT loss measurement is performed between two DUTs as shown in Figure C.44. 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 manufacturer’s instructions. Each modular test plug should be of a design known to meet the test plug requirements detailed in clause C.6.5. Cables between the baluns and the DUT should be less than 300 mm (12 in). If interconnecting 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 other end of each of the terminating cables should be DMCM terminated, with the CM terminations of the four pairs in each cable connected to ground.

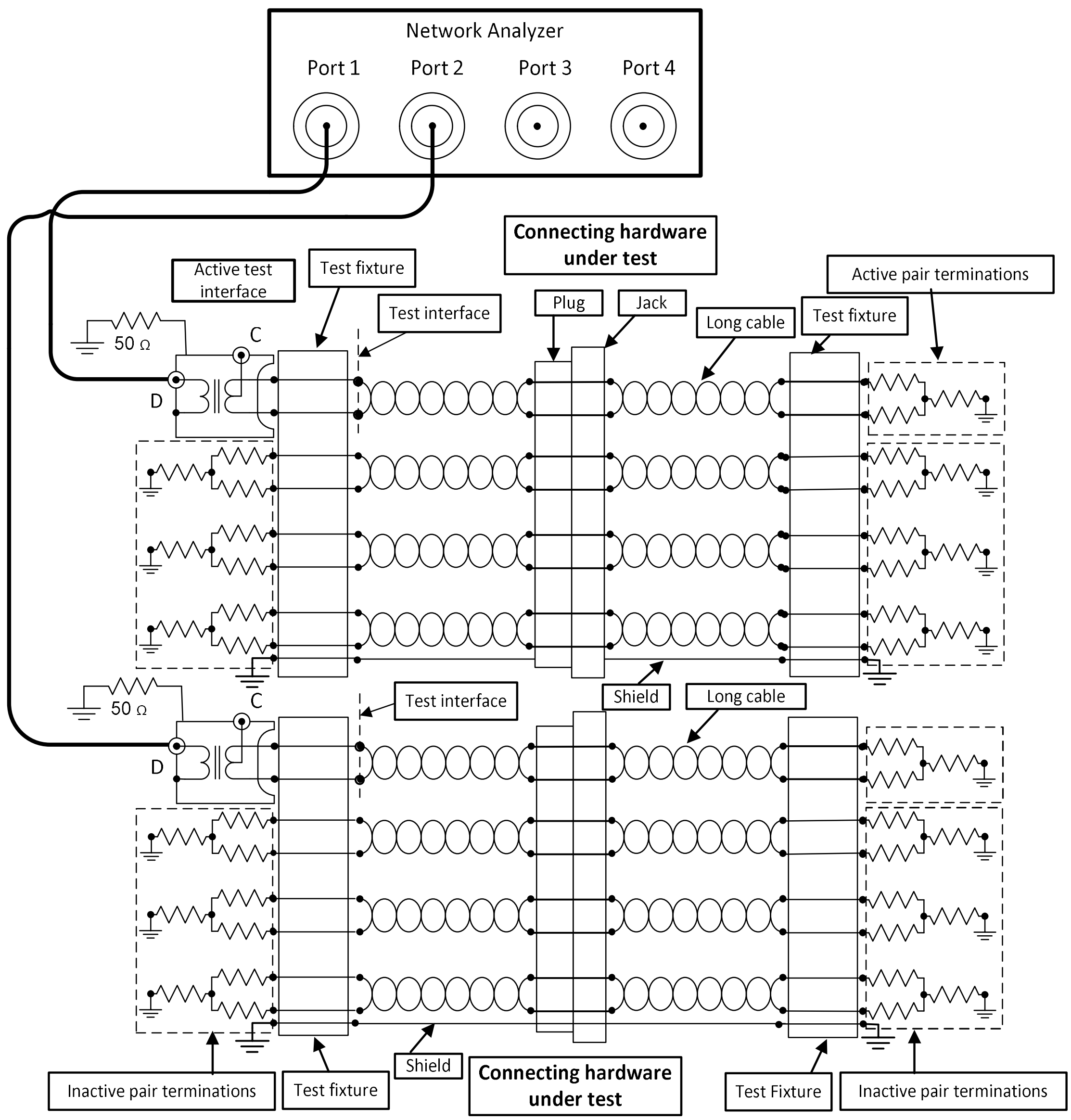


Figure C.43 - Connecting hardware ANEXT loss measurement setup

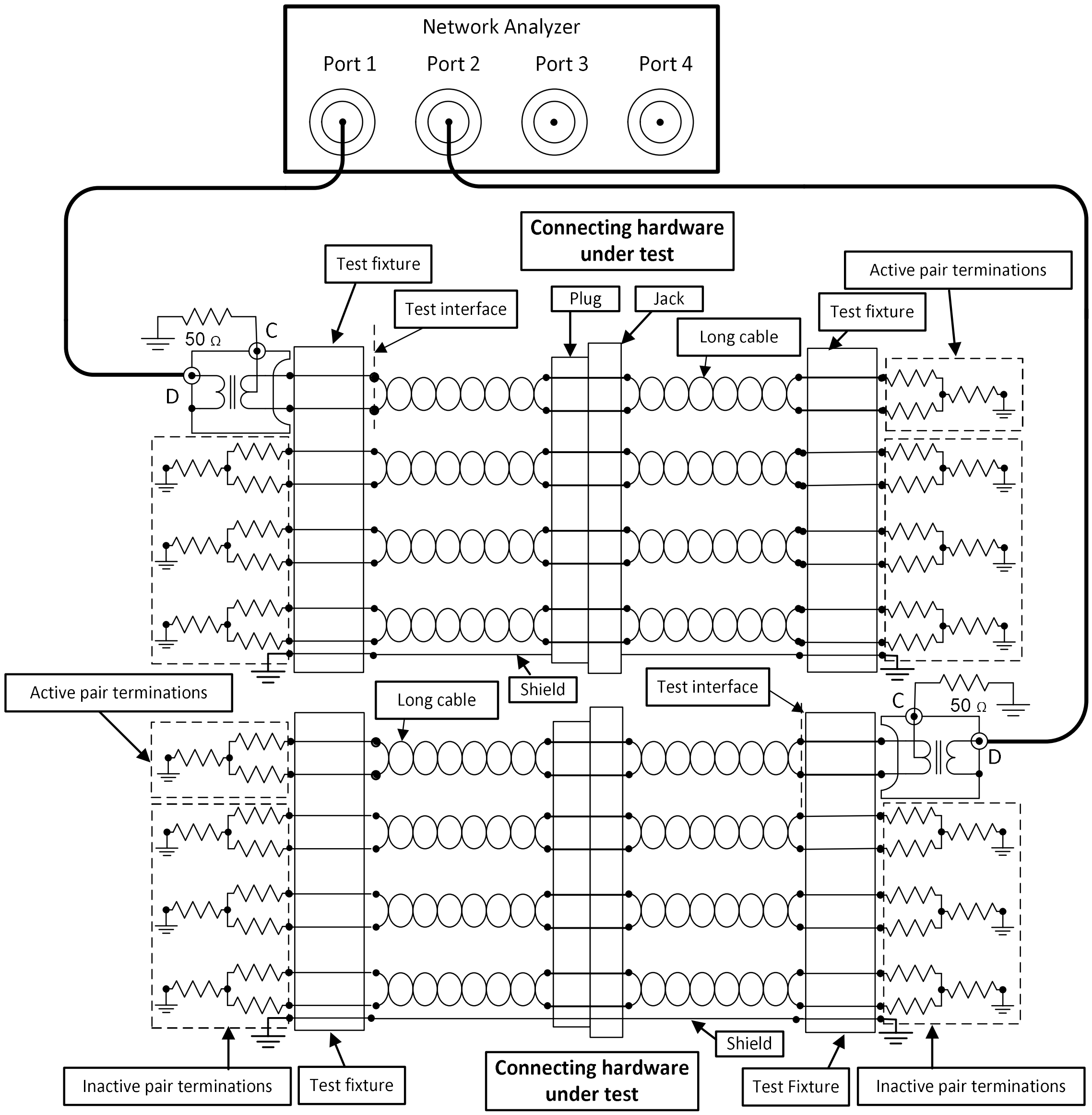


Figure C.44 - Connecting hardware AFEXT loss measurement setup

C.8.3.5 Disturbing connectors included

A port is included if it is one of the adjacent connectors, either above, below, left, or right, or one of four diagonally adjacent connectors, if present, as shown in Figure C.45 or a port that is part of the same multiport connector assembly.

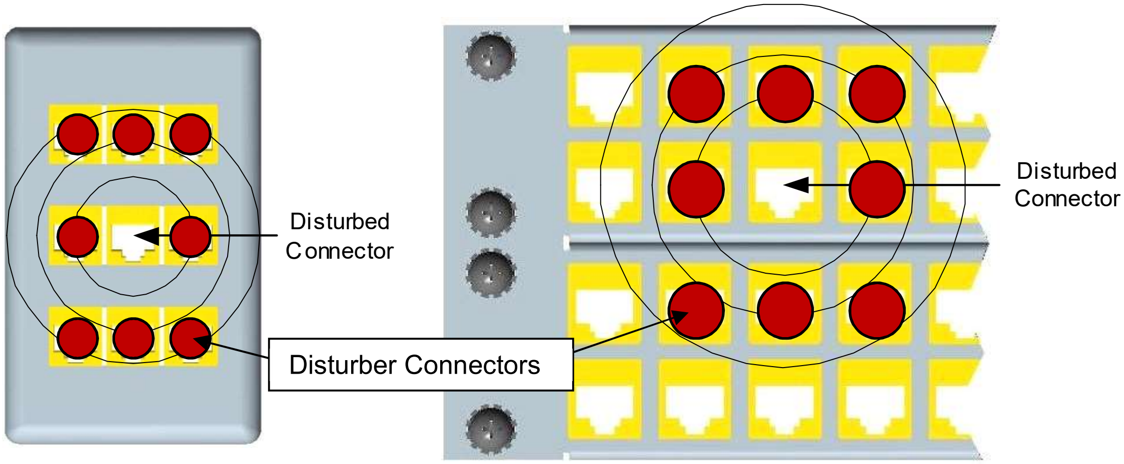


Figure C.45 - Example connector configurations for alien crosstalk

C.8.3.6 PSANEXT loss and PSAFEXT loss calculation

From the ANEXT or AFEXT loss contribution of all disturbing pairs, calculate the respective PSANEXT or PSAFEXT loss of the disturbed port (DUT).

Annex D (normative) - Cabling and component balunless test procedures

D.1 Balunless measurement requirements

When performing measurements using balunless methods, the procedures and wire termination fixturing shall be in accordance with ANSI/TIA-1183-A.

The measurement requirements in this annex, can be applied to any category of cabling. Refer to Annex B as well as ANSI/TIA-1183-A for wire termination fixturing, and general setup requirements. The requirements of this clause focus on specific test interfaces unique to this test method.

It is acceptable to configure the far end terminations within the test fixture, or attached to the test fixture. Switching may be used and that switching may configured within the test fixture. See ANSI/TIA 1183-A for a more detailed discussion of wire termination test fixture configurations.

Each setup component shall be qualified to a measurement bandwidth of at least 1 MHz to the upper frequency of the category.

Measurements of cabling performance parameters to 2000 MHz for category 8 are facilitated by use of four port network analyzers. In addition, four port network analyzers can directly measure balance (TCL, TCTL), common mode, and cross-modal coupling parameters. General measurement methods using four port network analyzers are described in ANSI/TIA-1183-A.

These standards include test fixture performance requirements, calibration methods, port nomenclature, and general procedures and precautions.

Other measurements methods that are demonstrated to show equivalence to the methods in this annex are allowed.

Balunless measurement results shall be converted to a termination impedance of 100 Ω differential mode, 50 Ω common mode. The terminations given below for balunless measurements result in a 25 Ω common mode impedance. Instructions are given in ANSI/TIA 1183-A.

D.1.1 Resistor terminations used with balunless measurement systems

Resistors used for terminations shall exhibit impedance of 50 Ω ± 0.1 % or better as shown in Figure D.1. Each single wire, 50 Ω port is terminated to ground. The differential impedance between two single wire, 50 Ω ports is 100 Ω. SMA terminations shall meet the requirements of ANSI/TIA-1183-A.

Terminations of inactive conductors and far end ports of active conductors shall provide the equivalent of 50 Ω at the interface to the cable under test. See ANSI/TIA-1183-A for performance requirements of test fixtures and systems.

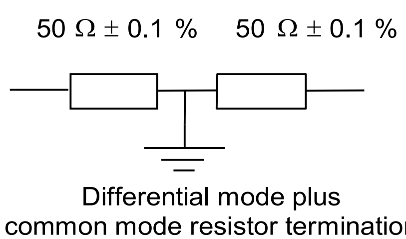


Figure D.1 - Balunless resistor termination network

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.

D.2 Calibration methods

When using balunless measurement methods, a two-port or four port calibration is the minimum requirement. For insertion loss, NEXT loss, and FEXT loss measurements, a four-port calibration is the minimum requirement when using balunless test methods. Multiport n-port calibration is considered an extension of two-port calibration. See ANSI/TIA-1183-A for more information on balunless measurement calibration methods.

D.3 Testing of cables and cabling

D.3.1 Cabling and cable measurement procedures

Mutual capacitance, capacitance unbalance, return loss, insertion loss, NEXT loss, ACRF, TCL, and TCTL measurements and calculations shall be performed on cable samples of 100m (328ft) for Categories up through 6A, or 30 m (98.4 ft) for category 8 removed from the reel or packaging. The test sample shall be laid out along a non-conducting surface, loosely coiled, supported in aerial spans, or wound around a non-conducting drum with 13 mm minimum separation between cables. 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 (30 m, off-reel, resistor termination of inactive ports) 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 100m (328ft) for Categories up through 6A, or 30 m (98.4 ft) for category 8 in order to improve measurement accuracy at lower frequencies. For example, when measuring insertion loss, it is recommended that the sample length exhibit no less than 1 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.

Shields and screens should be bonded (low inductance connections) to the measurement grounds at both ends.

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

The measurement result shall be mathematically transformed to convert the measured values in the native common mode impedance of 25 Ω to the resultant values which are referenced to the common mode impedance of 50 Ω which are required by this standard. Instructions are given in ANSI/TIA 1183-A Annex C.

The figures in this clause illustrate a single wire test method using a 4-port network analyzer.

D.3.2 Cabling and cable dc resistance

DC resistance shall be measured in accordance with ASTM D4566.

D.3.3 Cabling and cable return loss

D.3.3.1 Test configuration of cabling and cable return loss

The test configuration is as shown in Figure D.2

Each wire shall be terminated with 50 Ω to ground per ANSI/TIA-1183-1. Maximum length of cable jacket removal shall be 13 mm (0.5"), unless the un-jacketed cable pair impedance is maintained by other means such as fixturing. The length of pair untwist shall be minimized.

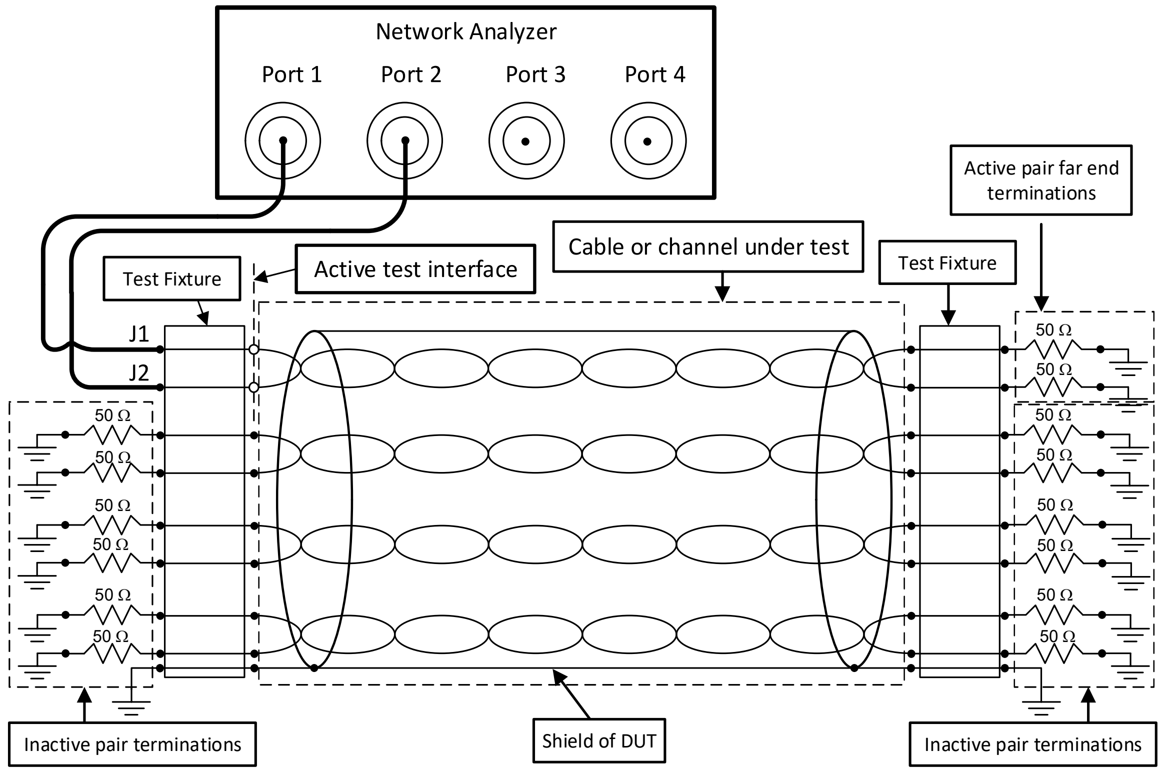


Figure D.2 - Laboratory test configuration for cabling and cable return loss and TCL measurements

D.3.3.2 Calibration of cabling and cable return loss

The calibration for cabling and cable return loss shall comply with clause D.2.

D.3.3.3 Measurement of cabling and cable return loss

Terminate cable ends in accordance with B.2. Measure the Sdd11 parameter with the network analyzer connected to each pair on the near-end. Return loss shall be tested in both directions. Transform the measurement result common mode impedance from the native 25 Ω to 50 Ω. Instructions are given in ANSI/TIA 1183-A Annex C.

D.3.4 Insertion loss of cables and channels

D.3.4.1 Test configuration of cabling and cable insertion loss

Figure D.3 depicts the typical schematic diagram of a balun-less test interface for testing insertion loss, TCTL, and propagation delay.

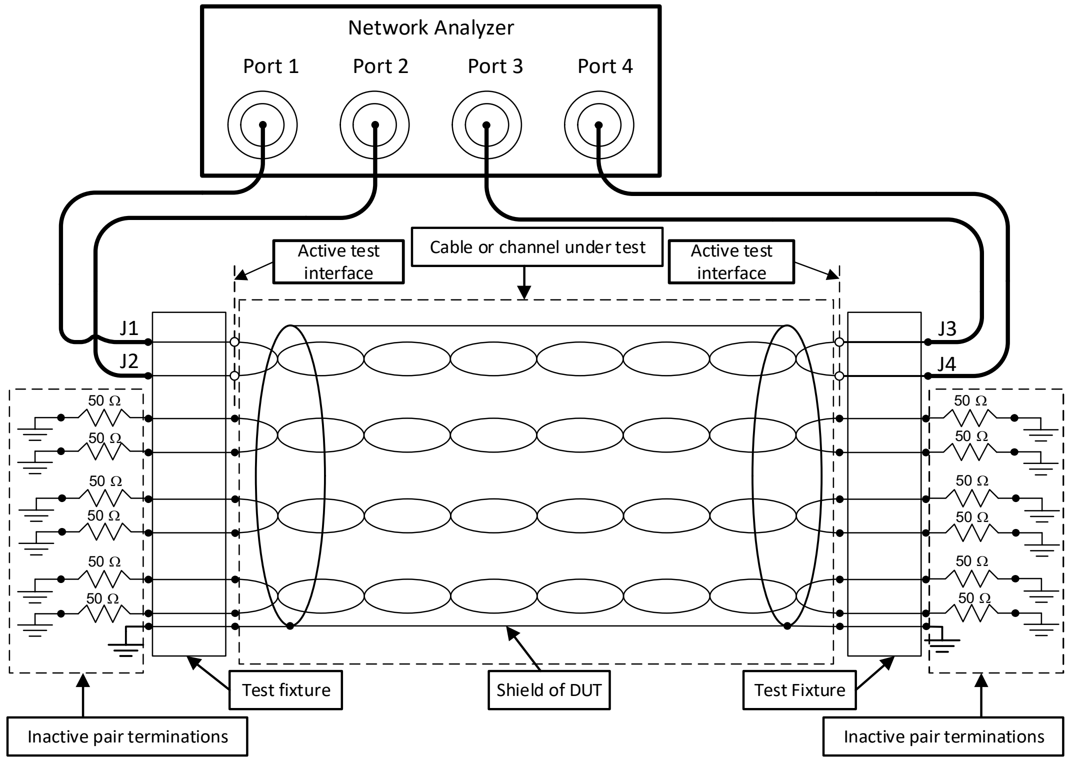


Figure D.3 - Laboratory test configuration for cabling and cable insertion loss, TCTL, and propagation delay measurements. Alternate test configuration for return loss and TCL.

D.3.4.2 Calibration of cabling and cable insertion loss

The calibration for cabling and cable insertion loss shall comply with clause D.2.

D.3.4.3 Measurement of cabling and cable insertion loss

Terminate cable ends in accordance with B.2. Measure the Sdd21 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.

D.3.5 NEXT loss of cables and channels

D.3.5.1 Test configuration of cabling and cable NEXT loss

Figure D.4 depicts the typical schematic diagram for testing NEXT loss. Resistor terminations are preferred for unused pairs at the far-end.

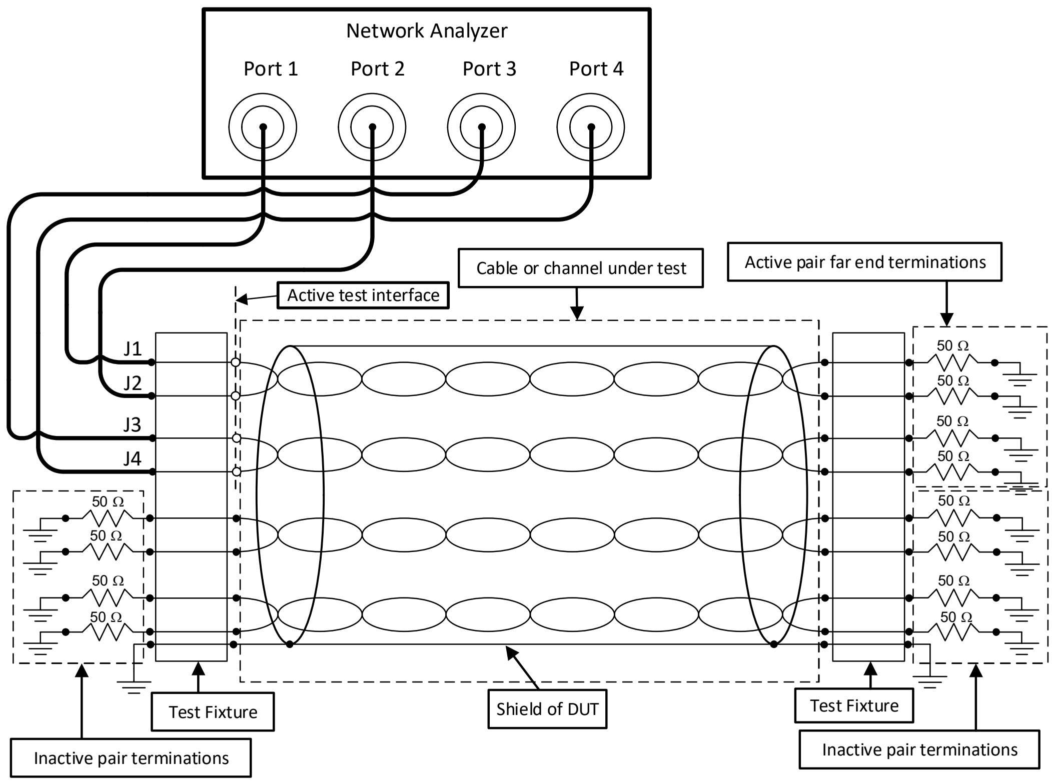


Figure D.4 - Laboratory test configuration for cabling and cable NEXT loss

D.3.5.2 Calibration of cabling and cable NEXT loss

The calibration for cabling and cable NEXT loss shall comply with clause D.2.

D.3.5.3 Measurement of cabling and cable NEXT loss

Measure the Sdd21 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.

D.3.6 FEXT loss of cables and channels

D.3.6.1 Test configuration of cabling and cable FEXT loss

Figure D.5 depicts the typical schematic diagram for testing FEXT loss of cables and channels.

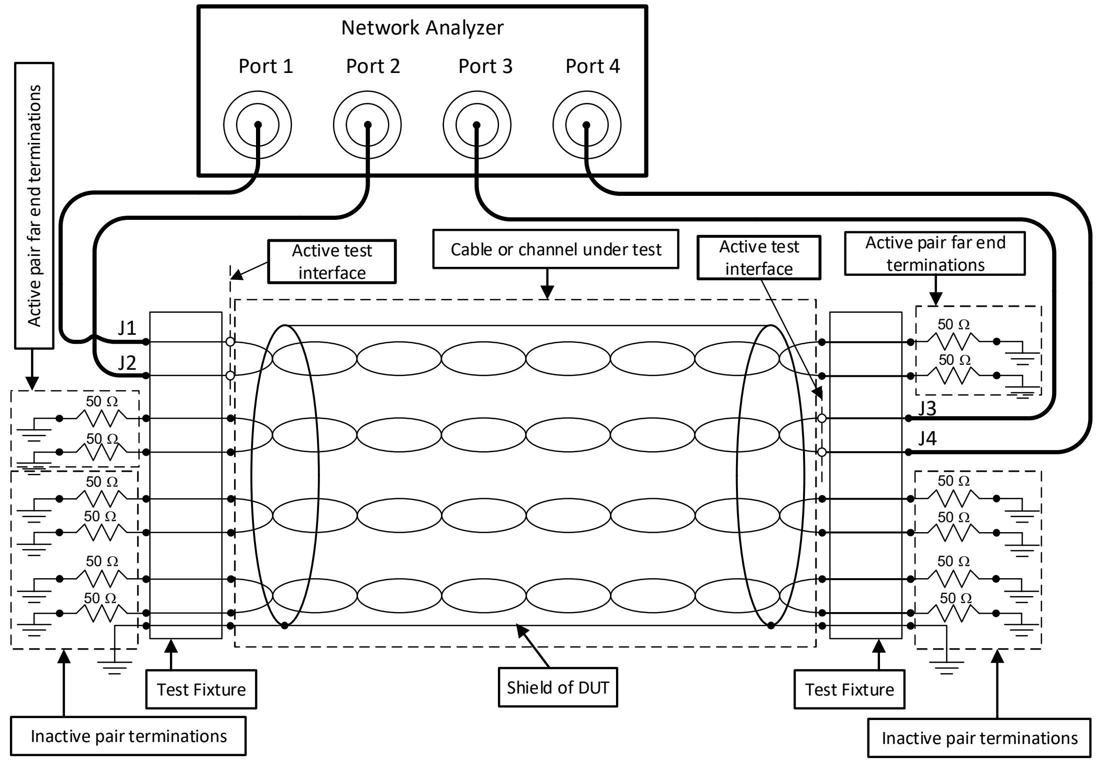


Figure D.5 - Laboratory test configuration for cabling and cable FEXT loss (ACRF)

D.3.6.2 Calibration of cabling and cable FEXT loss

The calibration for cabling and cable FEXT loss shall comply with clause D.2.

D.3.6.3 Measurement of cabling and cable FEXT loss

Measure Sdd21 for all of the 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.

D.3.7 TCL of cabling and cables

D.3.7.1 Test configuration of cabling and cable TCL

Figure D.2 depicts the typical schematic diagram for measurement of TCL. 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. Alternatively, the test configuration of Figure D.2 may be used for TCL measurements.

D.3.7.2 Calibration for measurement of cabling and cable TCL

The calibration for cabling and cable TCL shall comply with clause D.2.

D.3.8 TCTL of cabling and cables

D.3.8.1 Test configuration of cabling and cable TCTL

Figure D.3 depicts the typical schematic diagram for testing TCTL.

D.3.8.2 Calibration of cabling and cable TCTL

The calibration of the test hardware for TCTL measurements shall follow the procedures outlined in clause D.2.

D.3.8.3 Measurement of cabling and cable TCTL

TCTL shall be tested in both directions.

D.3.9 Propagation delay of cabling and cable

D.3.9.1 Test configuration of cabling and cable propagation delay

The cabling and cable propagation delay measurement configuration shall comply with the requirements of clause D.3.4

D.3.9.2 Calibration of cabling and cable propagation delay

The calibration of cabling and cable propagation delay shall comply with clause D.2.

D.3.9.3 Measurement of cabling and cable propagation delay

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

D.4 Permanent link test procedures

This clause describes test and calibration procedures for permanent links.

D.4.1 Permanent link measurement configurations

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

For all laboratory and field transmission measurements of screened permanent links, the 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.

Testing shall be carried out using a modular test plug compliant with clause C.6.5 inserted between the test interface and the permanent link under test. The crosstalk, insertion loss and return loss of the modular test plug shall not be calibrated out.

D.4.2 Calibration of permanent link test configurations.

The permanent link test configuration shall be calibrated by applying appropriate open, short, load and through calibration artifacts to the test interface between the test system and the modular test plug.

D.4.3 Return loss of permanent links

D.4.3.1 Test configuration of permanent link return loss

The permanent link return loss measurement configuration shall comply with the requirements of clause D.2.

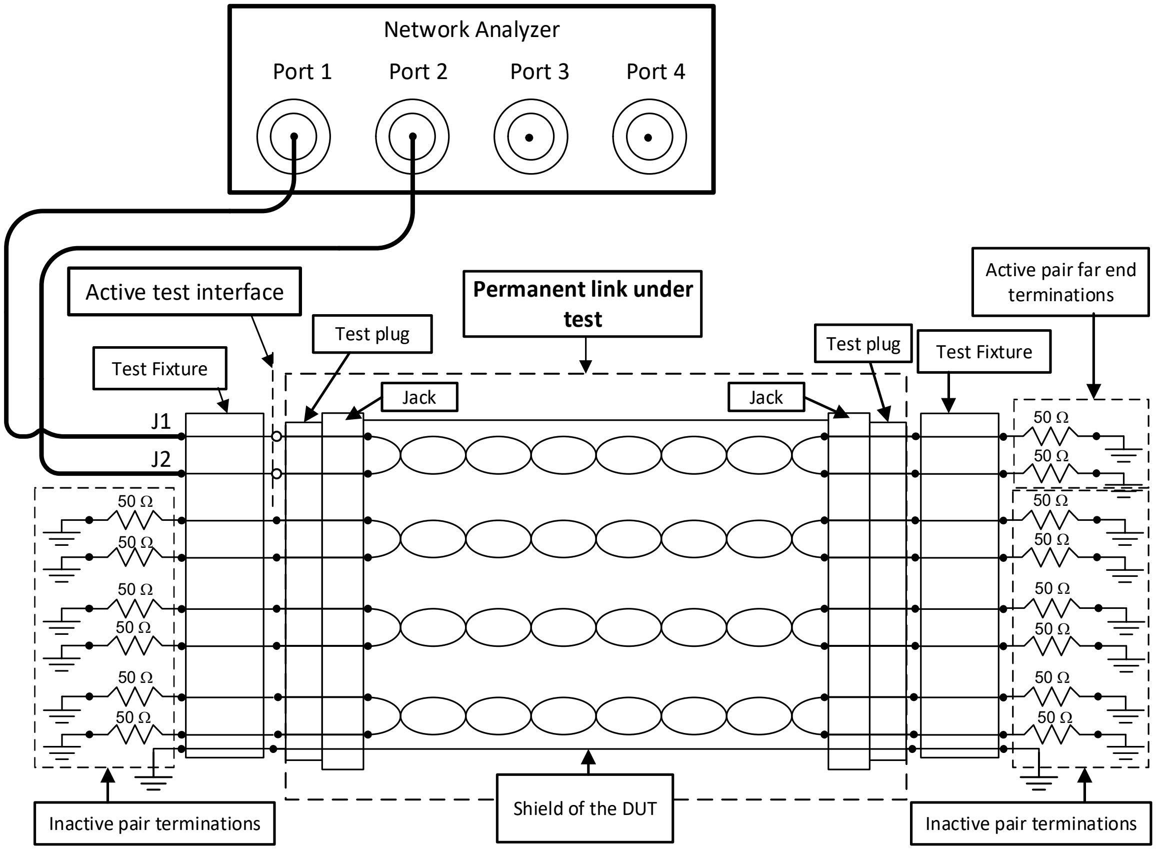


Figure D.6 - Laboratory test configuration for permanent link return loss and TCL measurements

D.4.3.2 Calibration of permanent link return loss

The calibration for permanent link return loss shall comply with clause D.2.

D.4.3.3 Measurement of permanent link return loss

Measure the Sdd11 parameter with the network analyzer connected to each pair on each end; permanent link return loss shall be tested in both directions.

D.4.4 Insertion loss of permanent link

D.4.4.1 Test configuration for permanent link insertion loss, (also used for FEXT loss, ACRF, and propagation delay)

The permanent link insertion loss measurement configuration shall comply with Figure D.7.

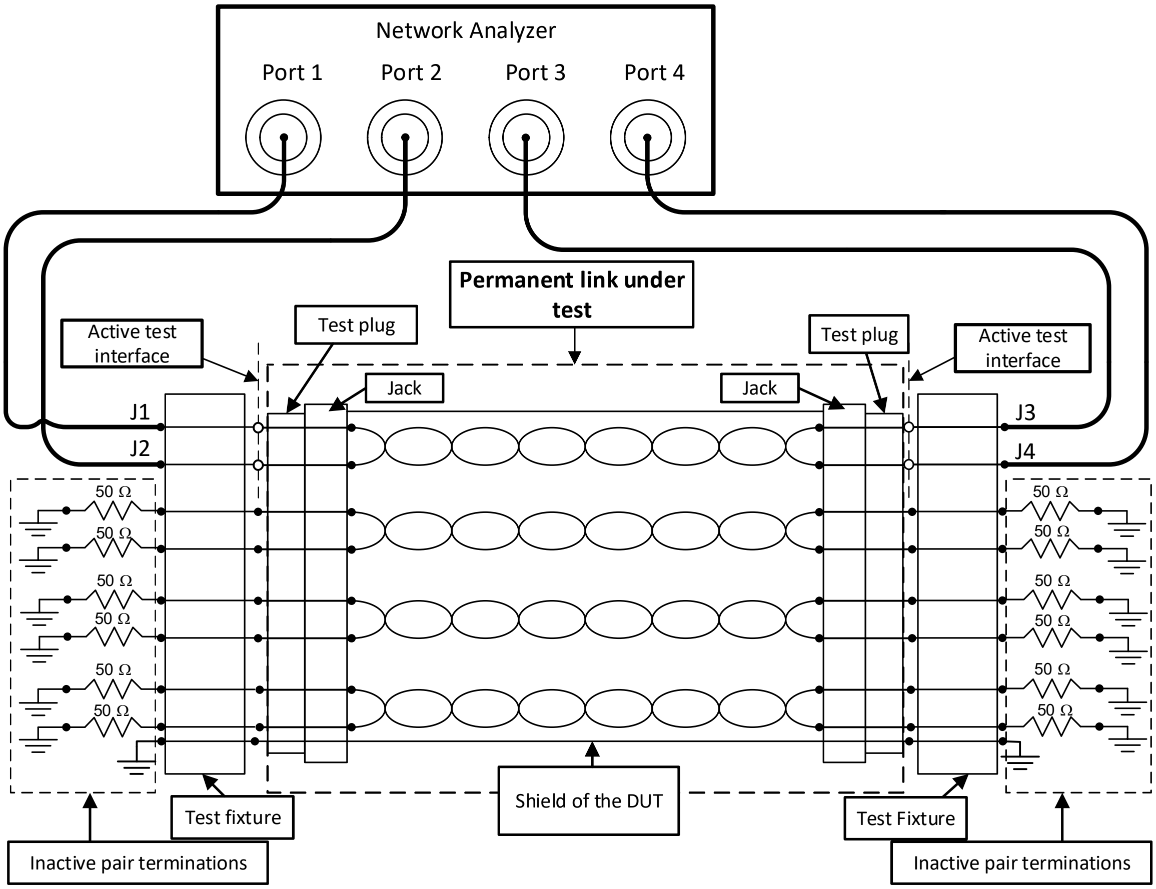


Figure D.7 - Laboratory test configuration for permanent link insertion loss, TCTL, and propagation delay measurements. Alternate test configuration for return loss and TCL.

D.4.4.2 Calibration of permanent link insertion loss

The calibration for permanent link return loss shall comply with D.2.

D.4.4.3 Measurement of permanent link insertion loss

Measure the Sdd21 parameter with the pair under test connected to the network analyzer at both the near-end and the far-end. Permanent link insertion loss shall be tested in both directions.

D.4.5 NEXT loss of permanent link

D.4.5.1 Test configuration for permanent link NEXT loss

The permanent link NEXT loss measurement configuration shall comply with Figure D.8.

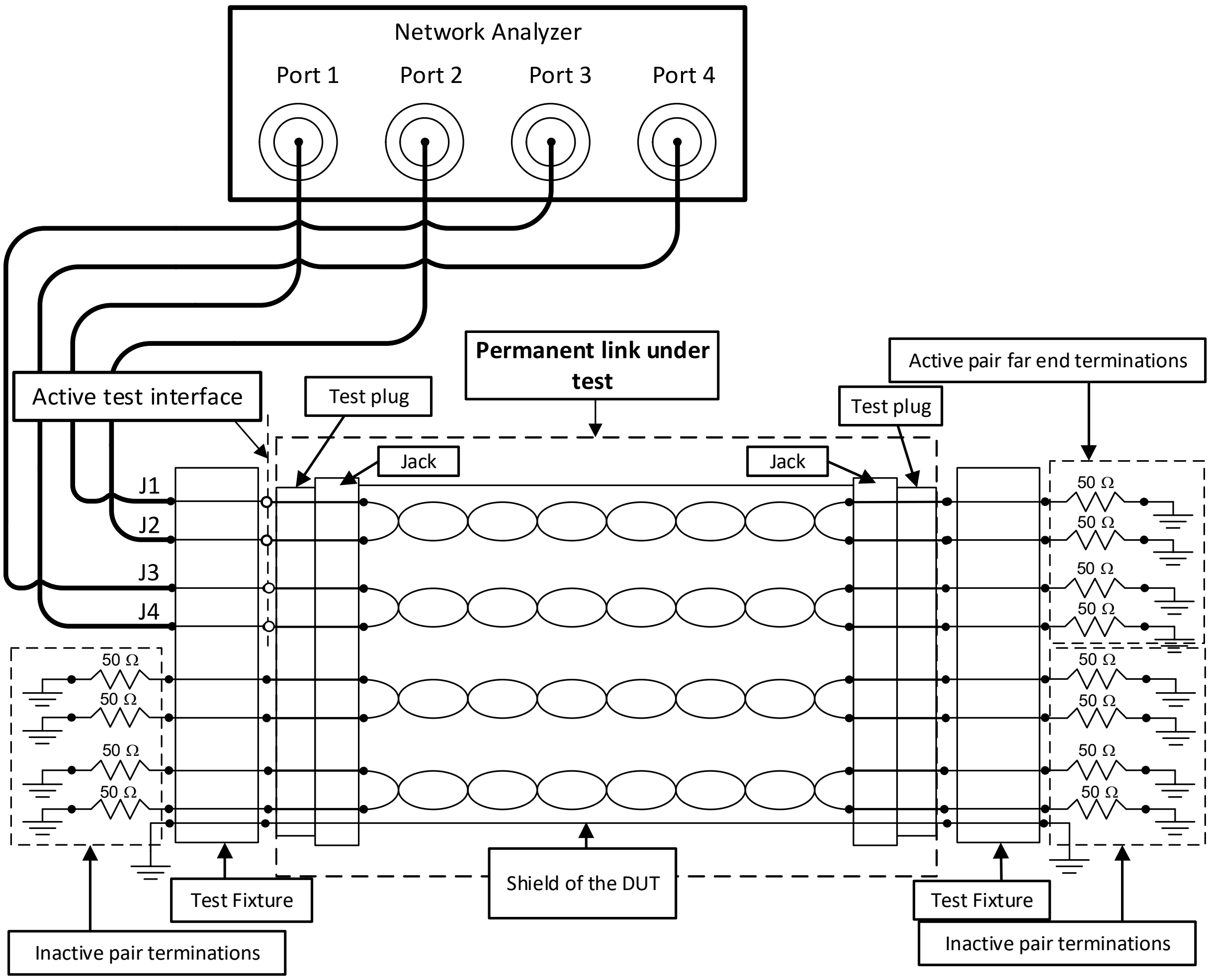


Figure D.8 - Laboratory test configuration for permanent link NEXT loss measurements

D.4.5.2 Calibration of permanent link NEXT loss

The calibration for permanent link NEXT loss shall comply with D.2.

D.4.5.3 Measurement of permanent link NEXT loss

Measure the Sdd21 parameter with the network analyzer connected to each of the 6 pair combinations in a four pair permanent link. Permanent link NEXT loss shall be tested in both directions.

D.4.6 FEXT loss of permanent link

D.4.6.1 Test configuration of permanent link FEXT loss

The permanent link FEXT loss measurement configuration shall comply with Figure D.9.

D.4.6.2 Calibration of permanent link FEXT loss

The calibration of permanent link FEXT loss shall comply with D.2.

D.4.6.3 Measurement of permanent link FEXT loss

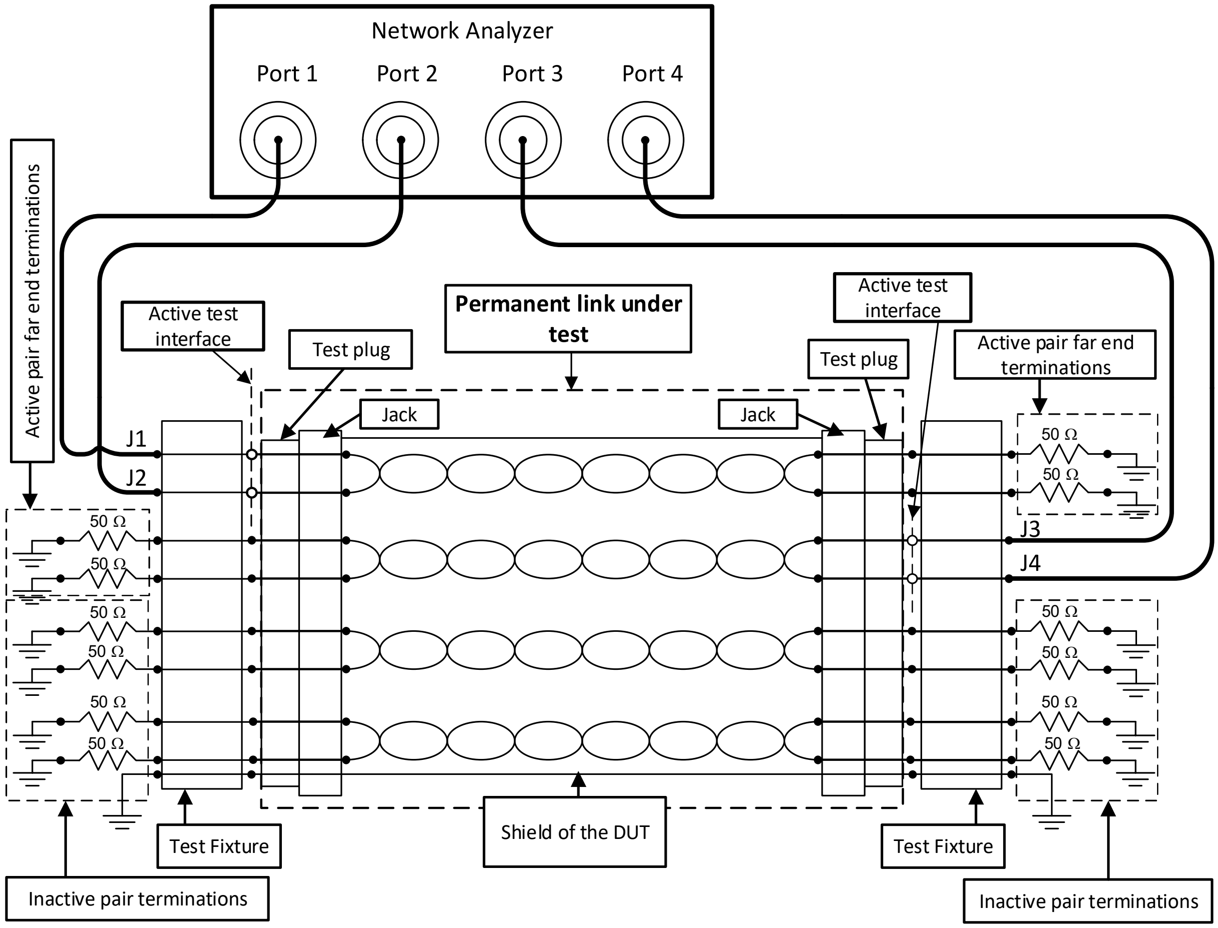


Figure D.9 - Laboratory test configuration for permanent link FEXT loss (ACRF)

Measure Sdd21 for all of the 12 pair combinations for permanent link FEXT loss, launching from one end only. It is not necessary to measure permanent link FEXT loss from both ends due to reciprocity.

D.4.7 TCL of permanent link

D.4.7.1 Test configuration of permanent link TCL

The permanent link TCL measurement configuration is shown in Figure D.6.

D.4.7.2 Calibration of permanent link TCL

The calibration of permanent link TCL shall comply with D.2.

D.4.7.3 Measurement of permanent link TCL

Measure permanent link TCL on each pair in both directions.

D.4.8 TCTL of permanent link

D.4.8.1 Test configuration of permanent link TCTL

The permanent link TCTL measurement configuration is shown in Figure D.7.

D.4.8.2 Calibration of permanent link TCTL

The calibration of permanent link TCTL shall comply with D.2.

D.4.8.3 Measurement of permanent link TCTL

Measure permanent link TCTL on each pair in both directions.

D.4.9 Propagation delay of permanent link

D.4.9.1 Test configuration of permanent link propagation delay

The permanent link propagation delay measurement configuration shall comply with Figure D.3.

D.4.9.2 Calibration of permanent link propagation delay

The calibration of permanent link propagation delay shall comply with D.2.

D.4.9.3 Measurement of permanent link propagation delay

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

D.5 Balunless direct attach measurement procedures

D.5.1 Balunless direct attach test configurations

In Figure D.11, Figure D.12 and Figure D.13, the far end terminations are shown combined with the test fixture. The test jacks shall be compliant to the category patch cord test head requirements in clause C.7.

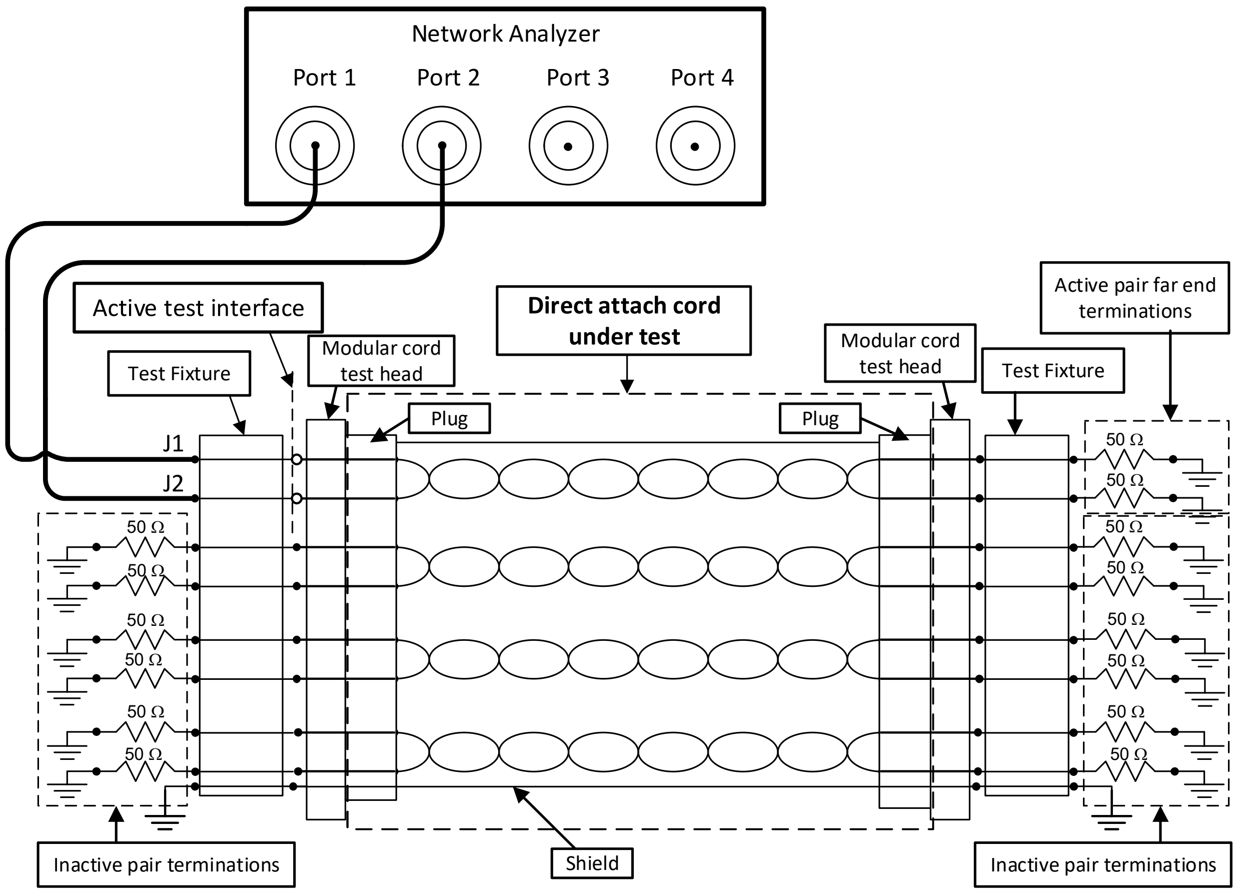


Figure D.10 - Balunless direct attach cord return loss test configuration

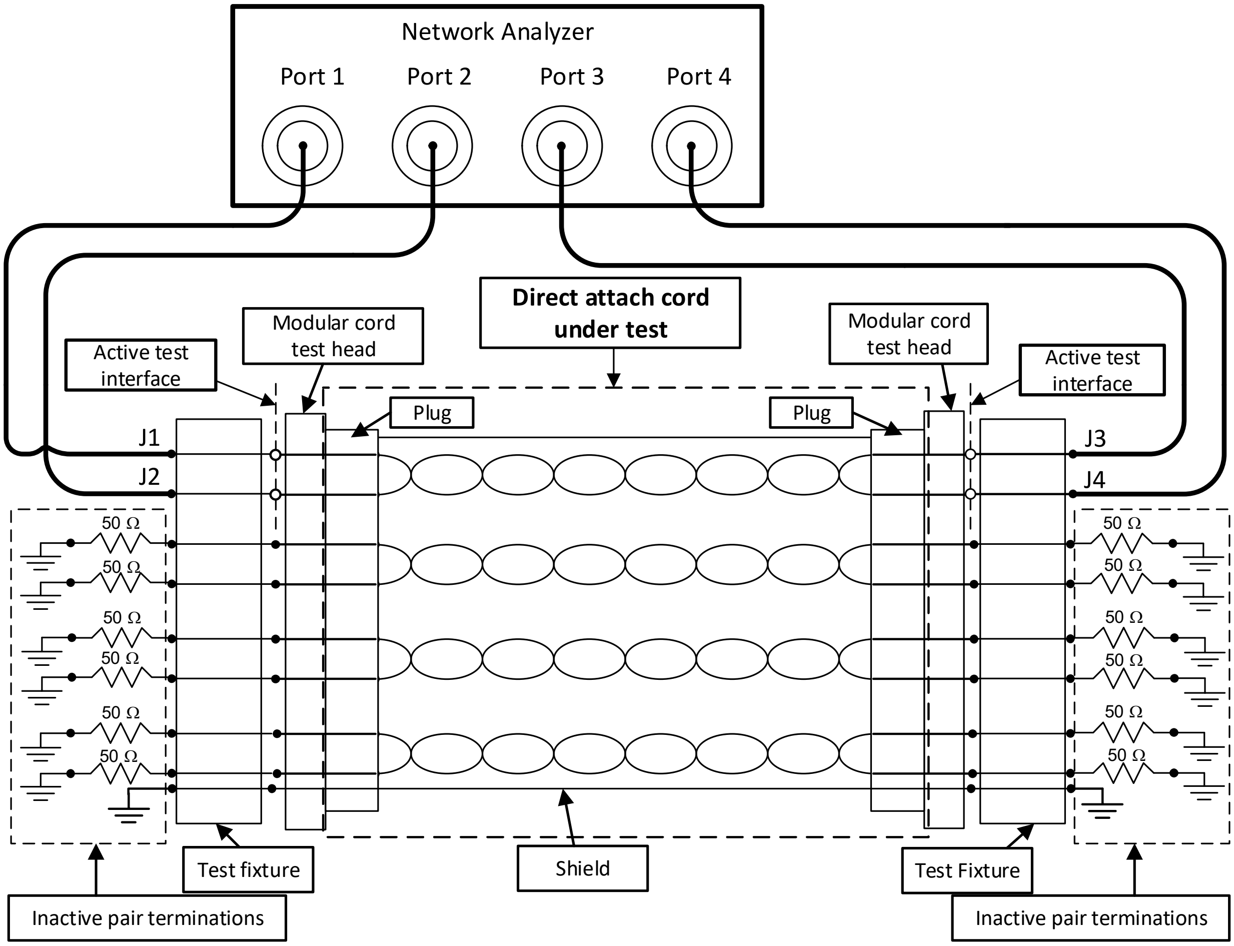


Figure D.11 - Balunless direct attach insertion loss, TCTL, and propagation delay test configuration. Alternate test configuration for return loss and TCL.

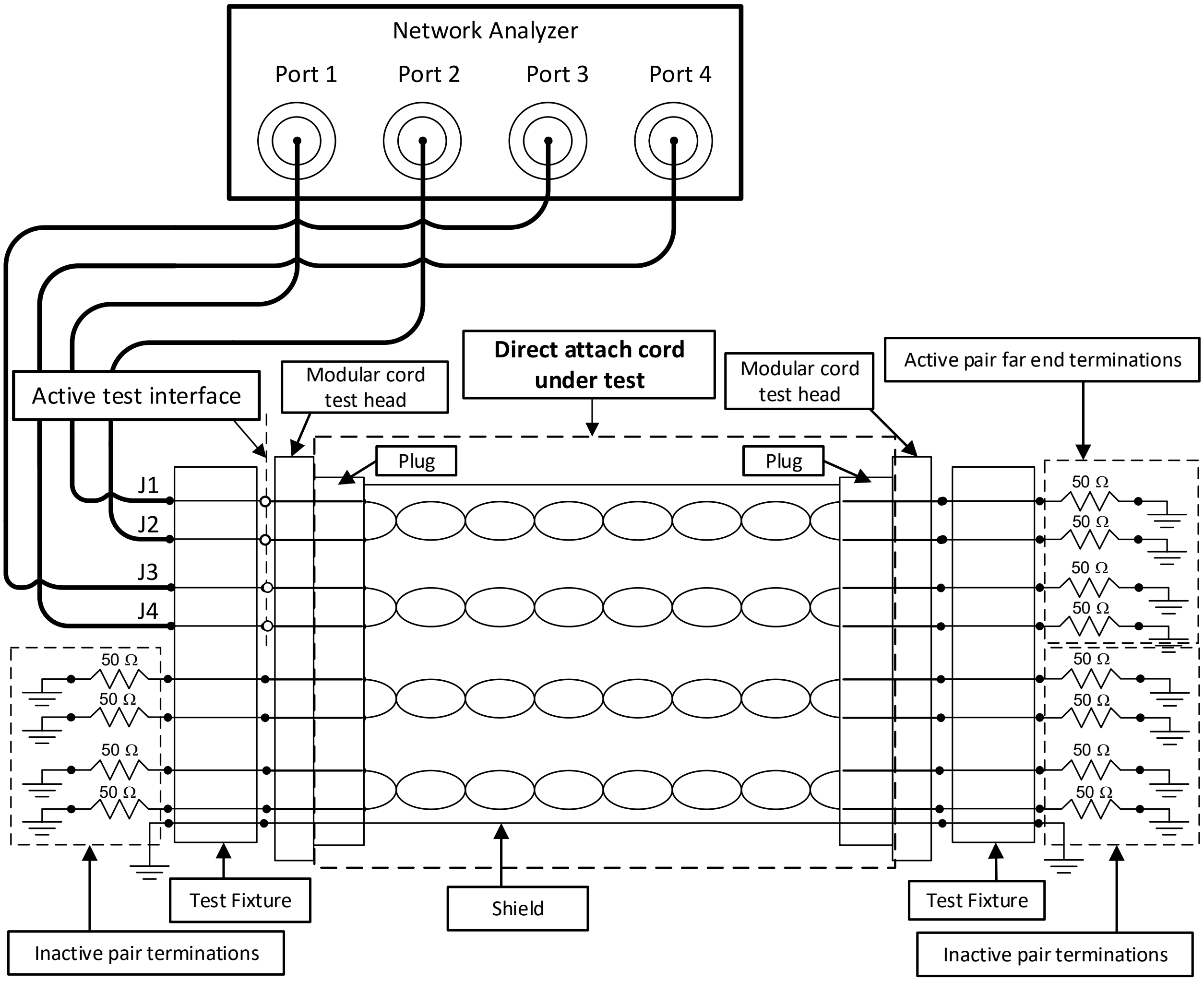


Figure D.12 - Balunless direct attach cord NEXT loss test configuration

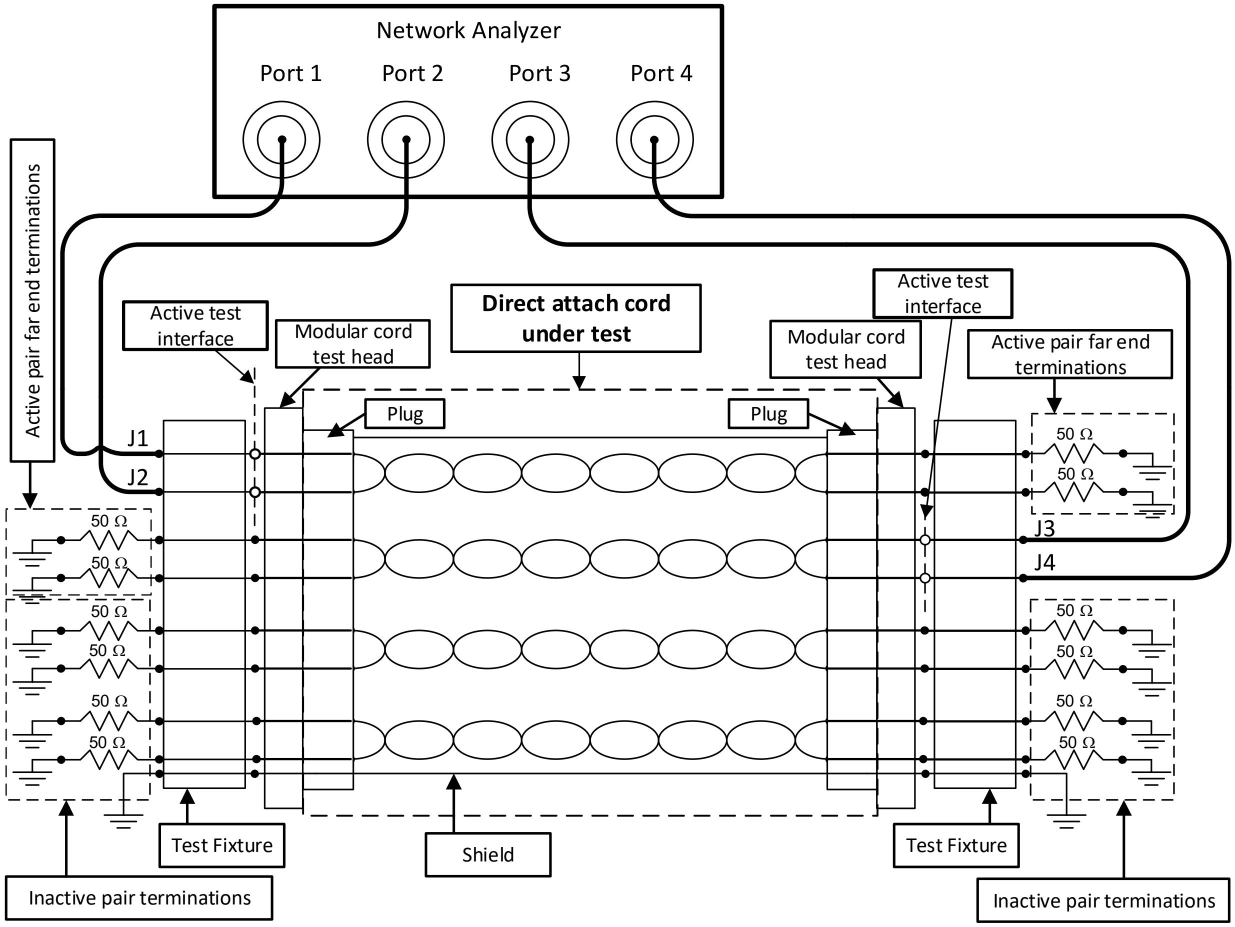


Figure D.13 - Balunless direct attach cord FEXT loss, (ACRF) test configuration

D.6 Balunless modular cord test procedures

D.6.1 Balunless network analyzer test configuration

The balunless network analyzer configuration for modular cord testing is depicted in Figure D.14 and Figure D.15.
This measurement is shown using single-ended balunless measurements described in TIA-1183-A.
50 Ω terminations shall be applied to all conductors on both ends.

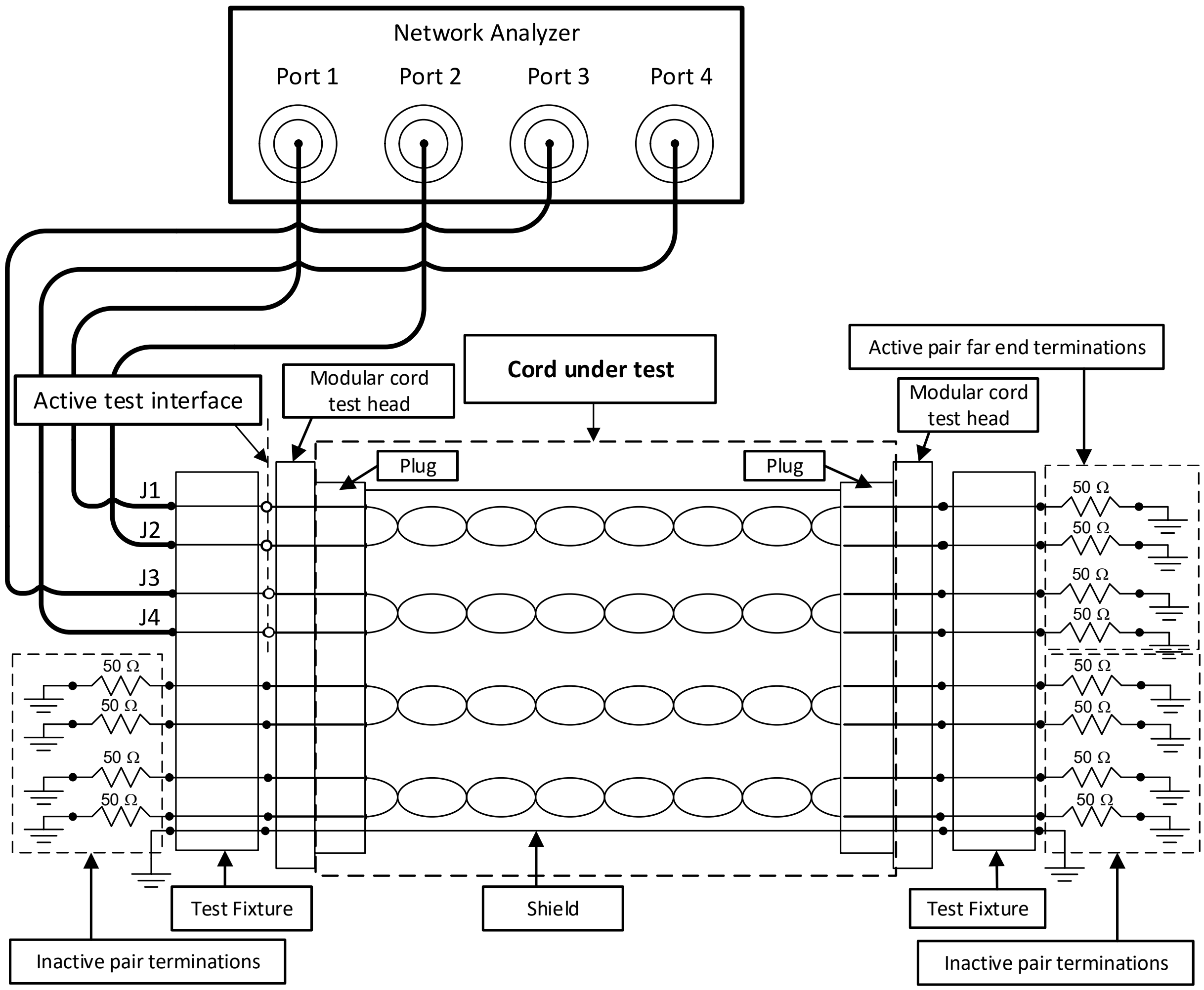


Figure D.14 - Balunless modular cord NEXT loss test configuration

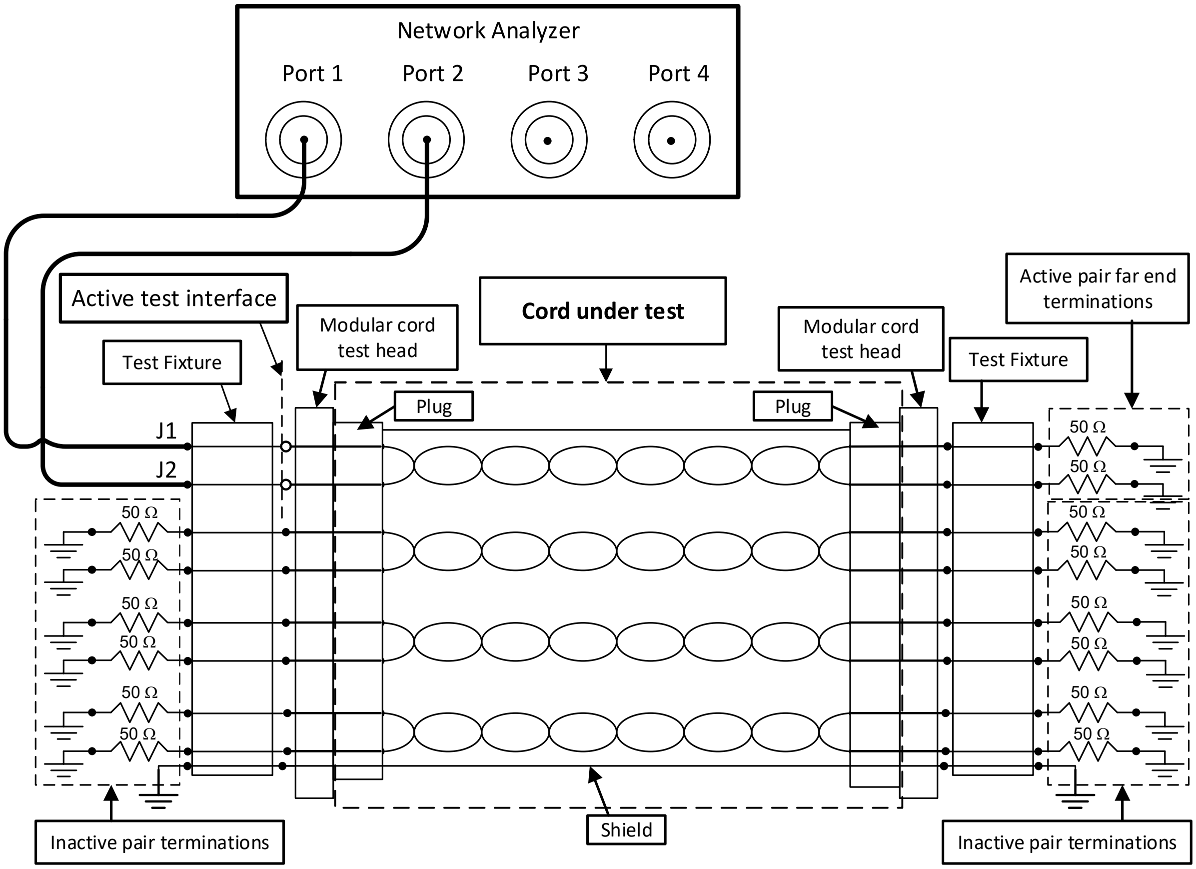


Figure D.15 - Balunless modular cord return loss test configuration

D.7 Connecting hardware test procedures

This clause describes test and calibration procedures for connecting hardware using balunless test configurations. Test equipment design calibration and fixturing should ensure a noise level 20 dB better than the required measurement limit over the frequency range of 1 MHz to the upper frequency of the category.

All requirements of clauses C.1 and C.2 that are not superseded by this clause apply.

D.7.1 Connecting hardware measurement configurations

For balunless measurements:
Each SE port shall be terminated using 50 Ω to ground according to ANSI/TIA-1183-A.

The measurement results shall be mathematically transformed to convert the measured values in the native common mode impedance of 25 Ω to the resultant values which are referenced to the common mode impedance of 50 Ω which are required by this standard.

Interconnection (including test lead) requirements are specified in clause B.2.

D.8 Balunless alien crosstalk for cabling, cable and connecting hardware.

D.8.1 Balunless ANEXT loss and AFEXT loss laboratory measurement procedures

Refer to the procedures in clause C.8 for alien crosstalk testing procedures using the network analyzer configurations of this clause.

D.8.1.1 Balunless connecting hardware ANEXT loss and AFEXT loss procedures

The ANEXT loss measurement is performed between two DUTs as shown in Figure D.16. The AFEXT loss measurement is performed between two DUTs as shown in Figure D.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 manufacturer's instructions. Each modular test plug should be of a design known to meet the test plug requirements detailed in clause C.6.5. Cables between the baluns and the DUT should be less than 300 mm (12 in). If interconnecting cables need to be longer than 300 mm (12 in) (e.g. testing large multi-port panels), their insertion loss shall be accounted for.

The other end of each of the terminating cables should be DMCM terminated, with the CM terminations of the four pairs in each cable connected to ground.

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.

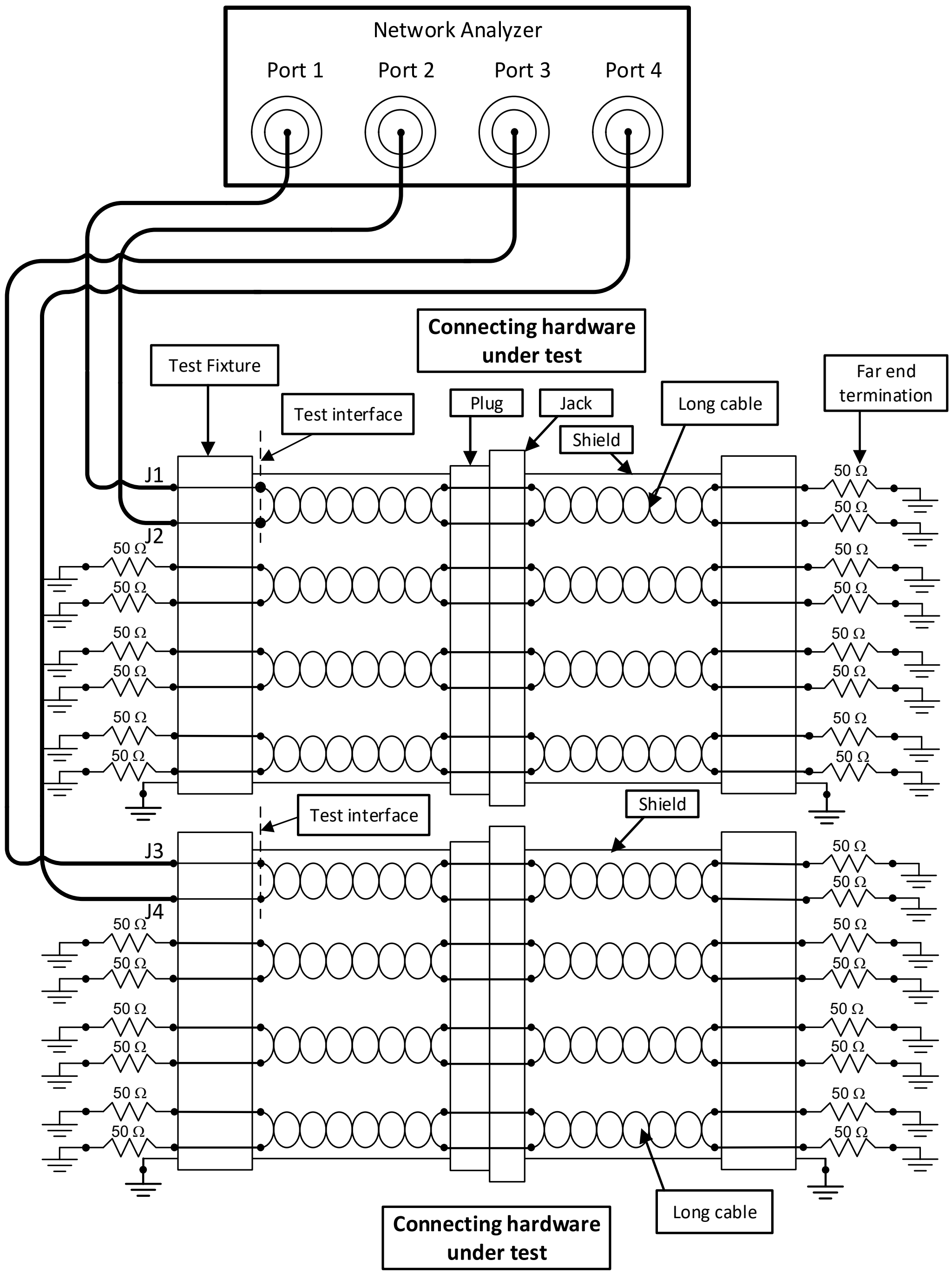


Figure D.16 - Connecting hardware ANEXT loss measurement setup

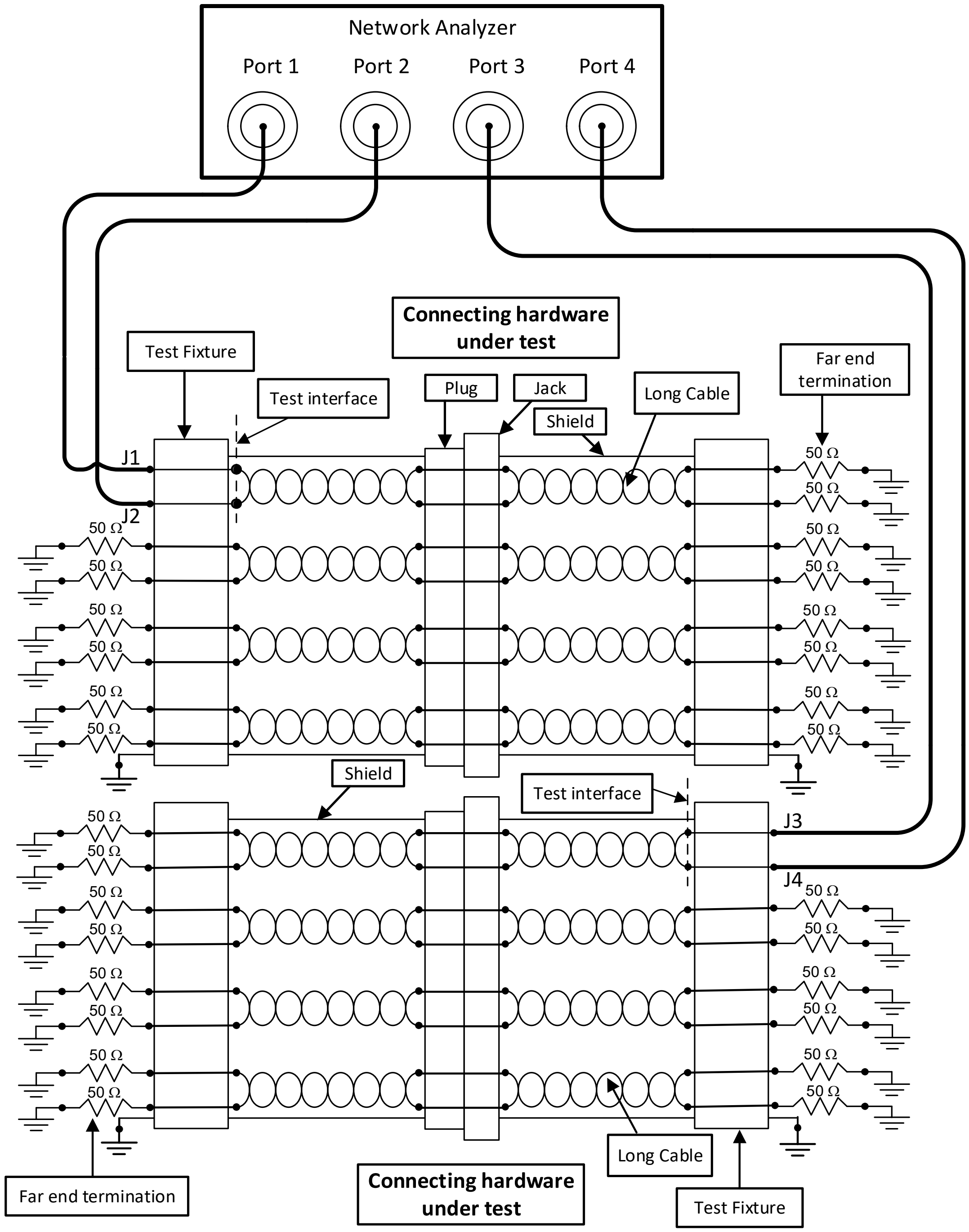


Figure D.17 - Connecting hardware AFEXT loss measurement setup

Annex E (normative) - Connecting hardware transfer impedance test method

E.1 Introduction

Transfer impedance relates to the shielding efficiency (quality of shielding against influences by electromagnetic fields) of screened cables and connecting hardware.

E.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.

E.3 Transfer impedance test method

E.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 6.10.21. 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 E.3.2). The equivalent circuit diagram for the HF sealed case is shown in Figure E.1.

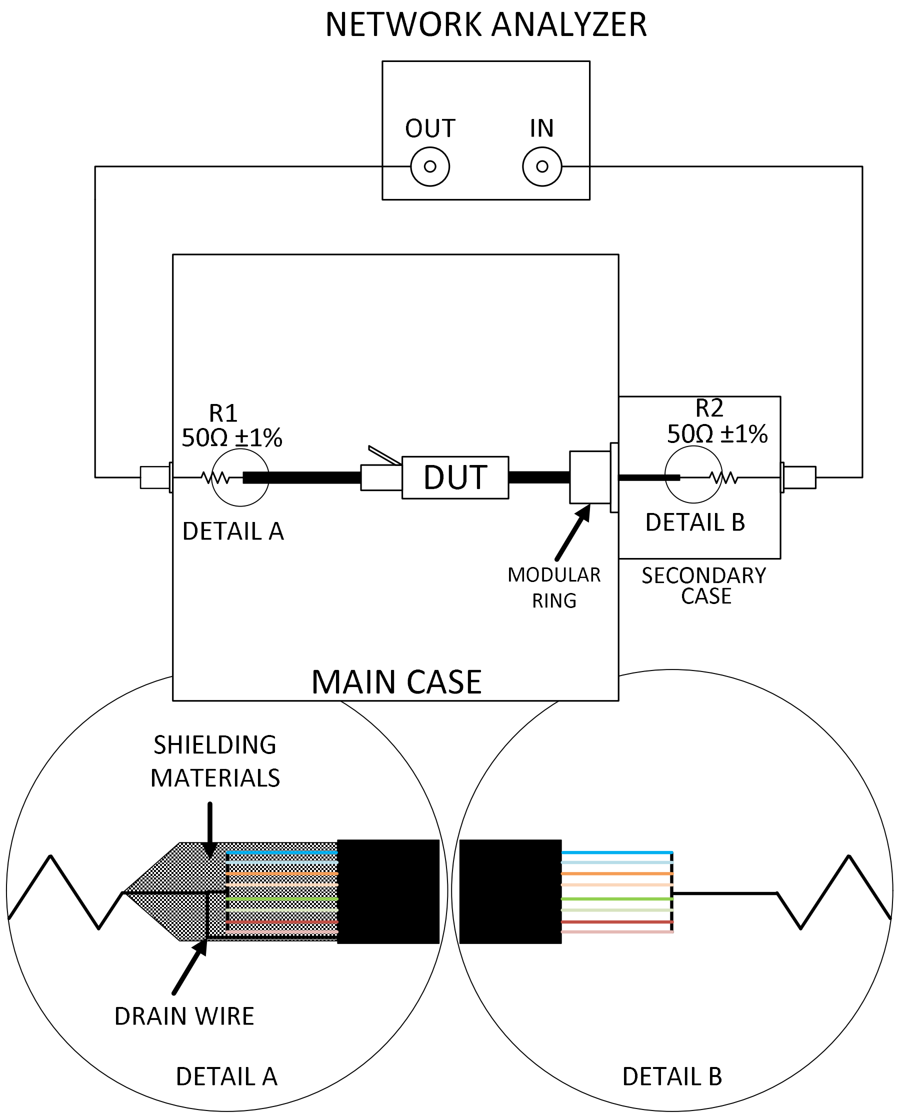


Figure E.1 - Equivalent circuit diagram for HF sealed case

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)
- U_c = voltage across device under test (volts)
- Z_{cond} = characteristic impedance of conductors (Ω)
- Z_t = transfer impedance (Ω)

Under the following assumptions:

Z_{cond} is significantly less than $R2$, and
$I2$ is significantly less than $I1$,

The following equations describe the circuit equation in Figure E.1.

$$U1 = I1 \cdot R_i 1 \quad \text{(E-1)}$$

$$U2 = I2 \cdot R_i 2 \quad \text{(E-2)}$$

$$U_c = I2 \cdot (R2 + R_i 2) \quad \text{(E-3)}$$

$$U_c = Z_t \cdot I1 \quad \text{(E-4)}$$

From a substitution operation follows:

$$Z_t = \frac{R_i 1}{R_i 2} \cdot (R2 + R_i 2) \cdot \frac{U2}{U1} \quad \text{(E-5)}$$

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

$$a_s = 20 \cdot \log\left(\frac{U2}{U1}\right) \; dB \quad \text{(E-6)}$$

By applying this relation and entering values for $R2$ and $R_i 2$, the resultant transfer impedance in Ohms is expressed as:

$$Z_t = 2 \cdot R_i 1 \cdot \frac{U2}{U1} = 2 \cdot R_i 1 \cdot 10^{\frac{a_s}{20}} = 100 \cdot 10^{\frac{a_s}{20}} \; \Omega \quad \text{(E-7)}$$

E.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 E.4 through Figure E.7 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.

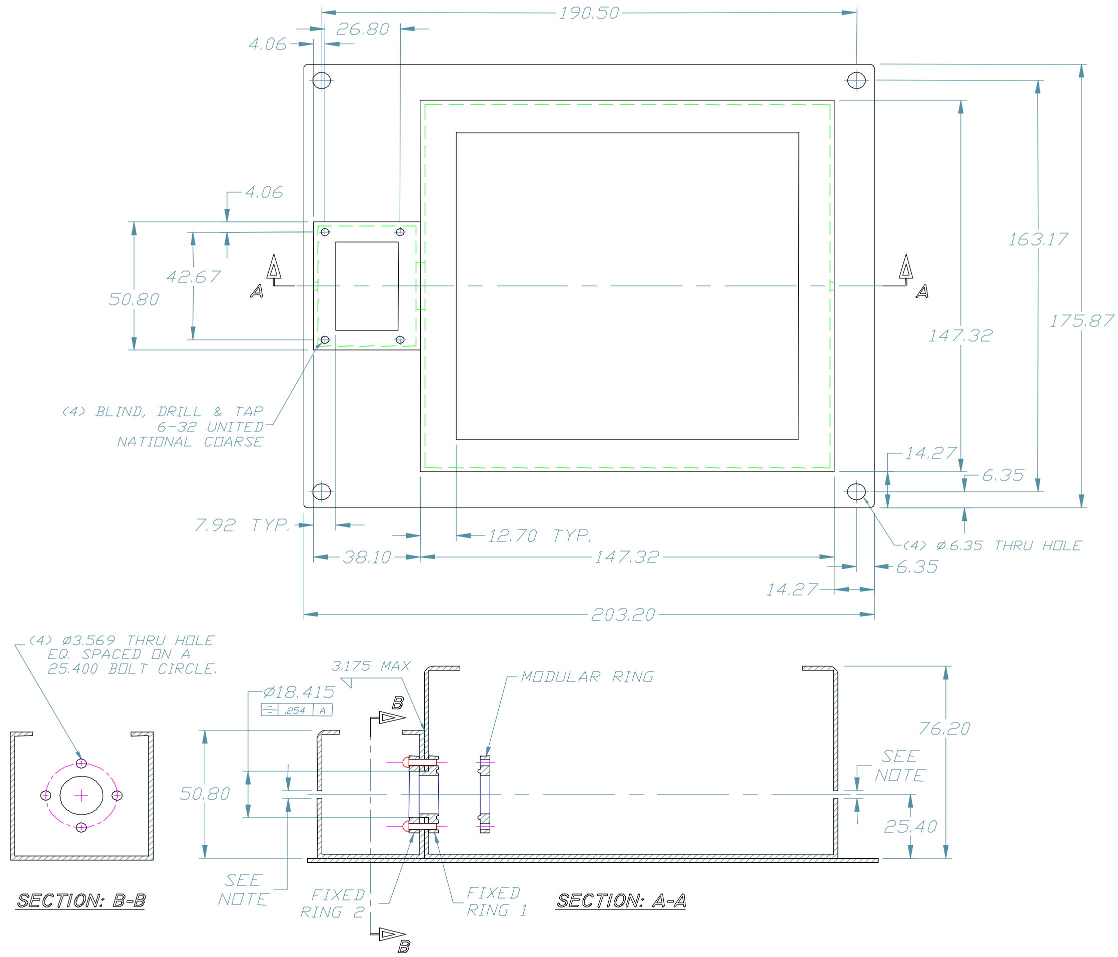


Figure E.2 - Example HF sealed case covers, assembly details

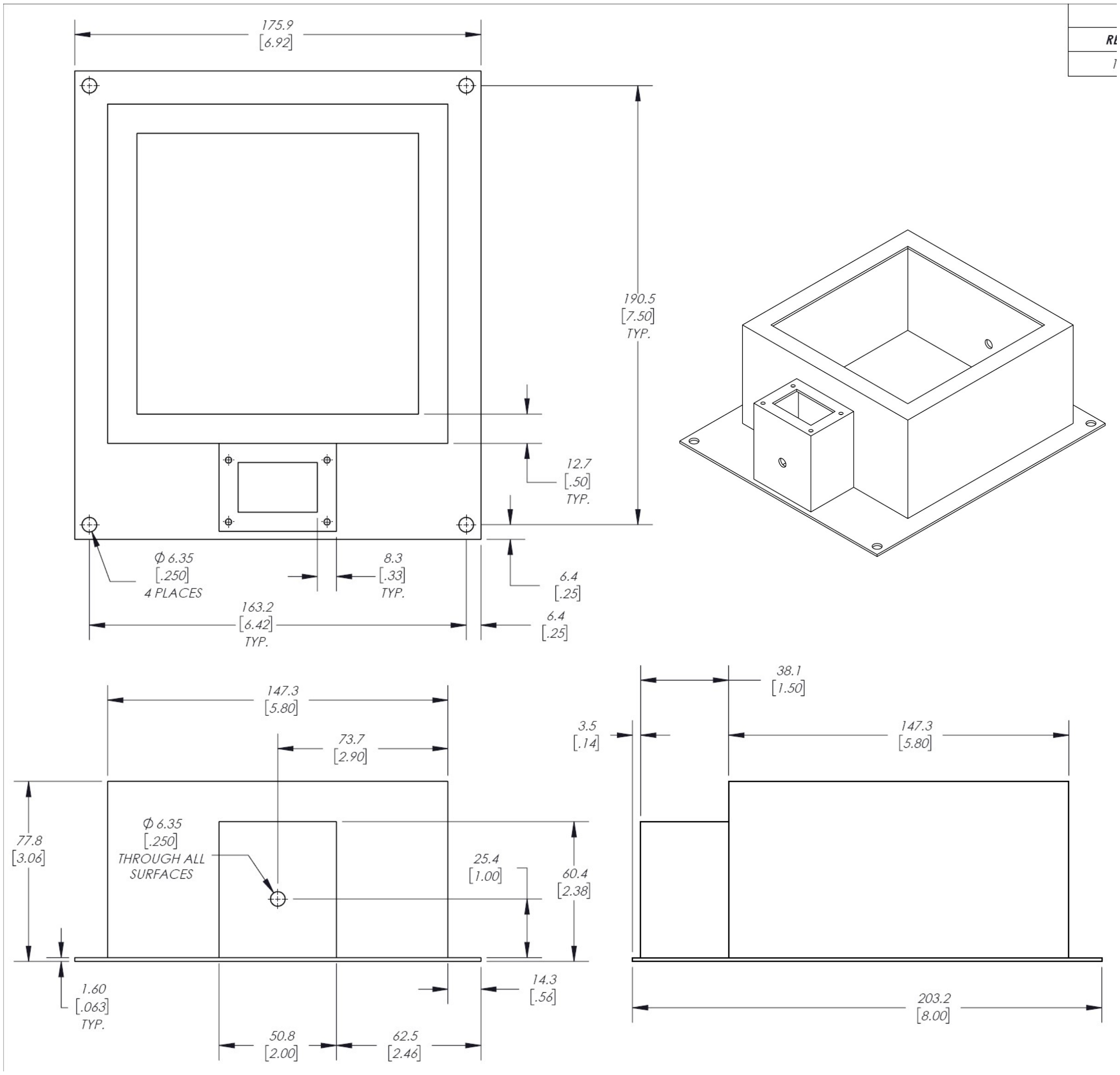


Figure E.3 - Example HF sealed case covers, case dimensions

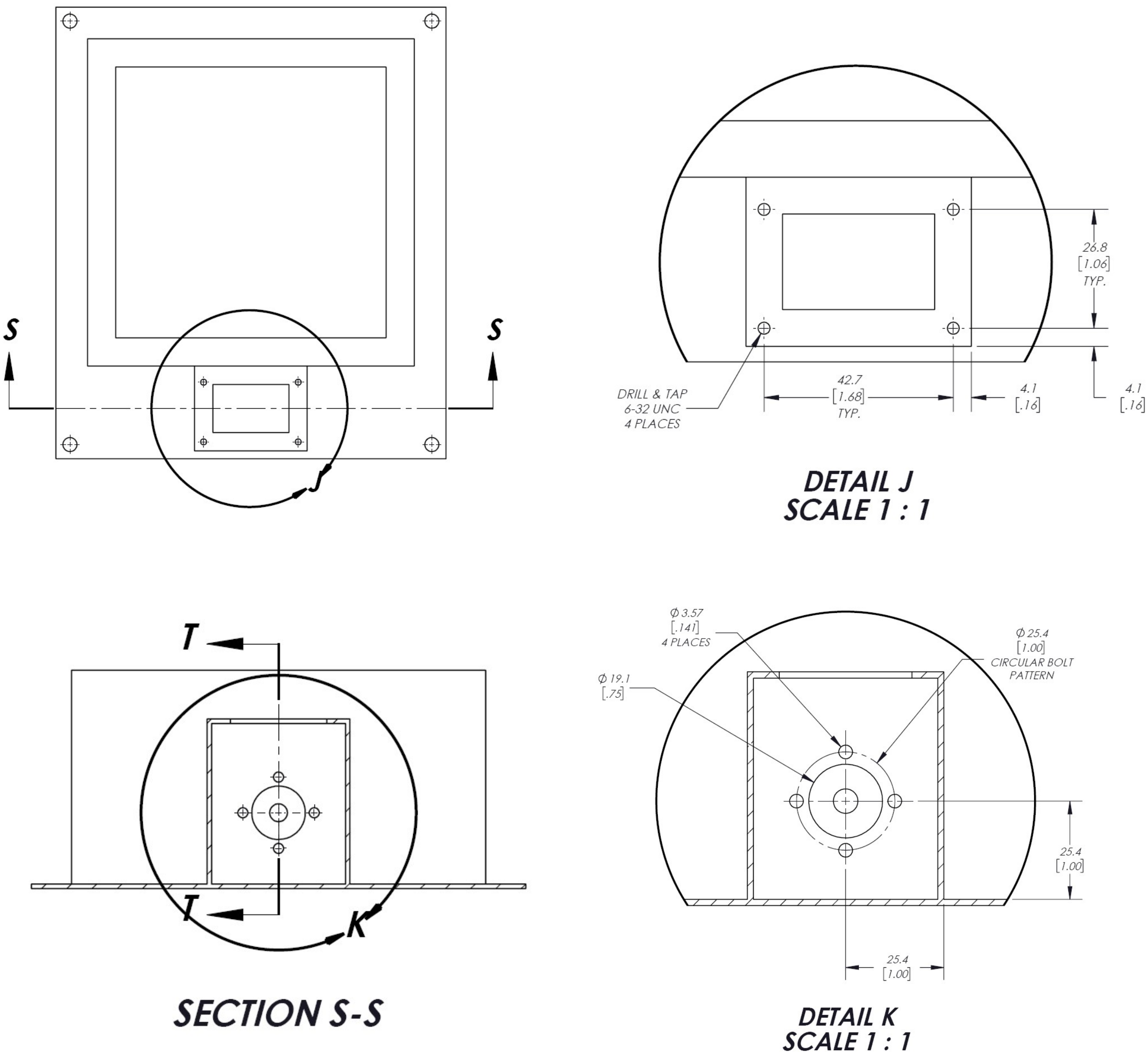


Figure E.4 - Example HF sealed case dimensional details

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.

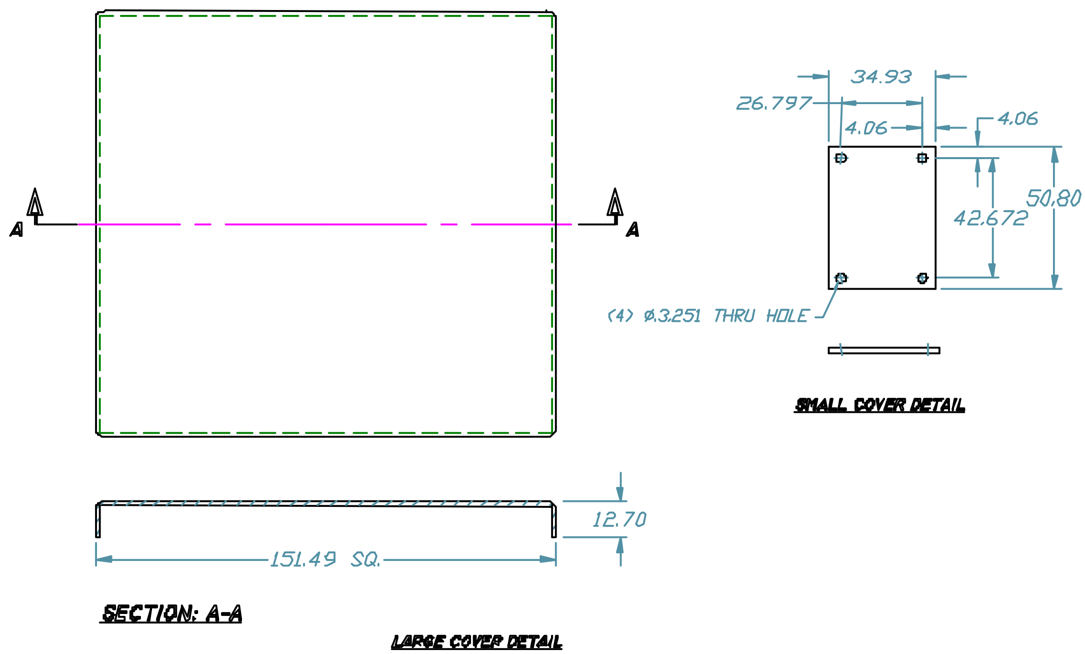


Figure E.5 - Example HF sealed case covers details

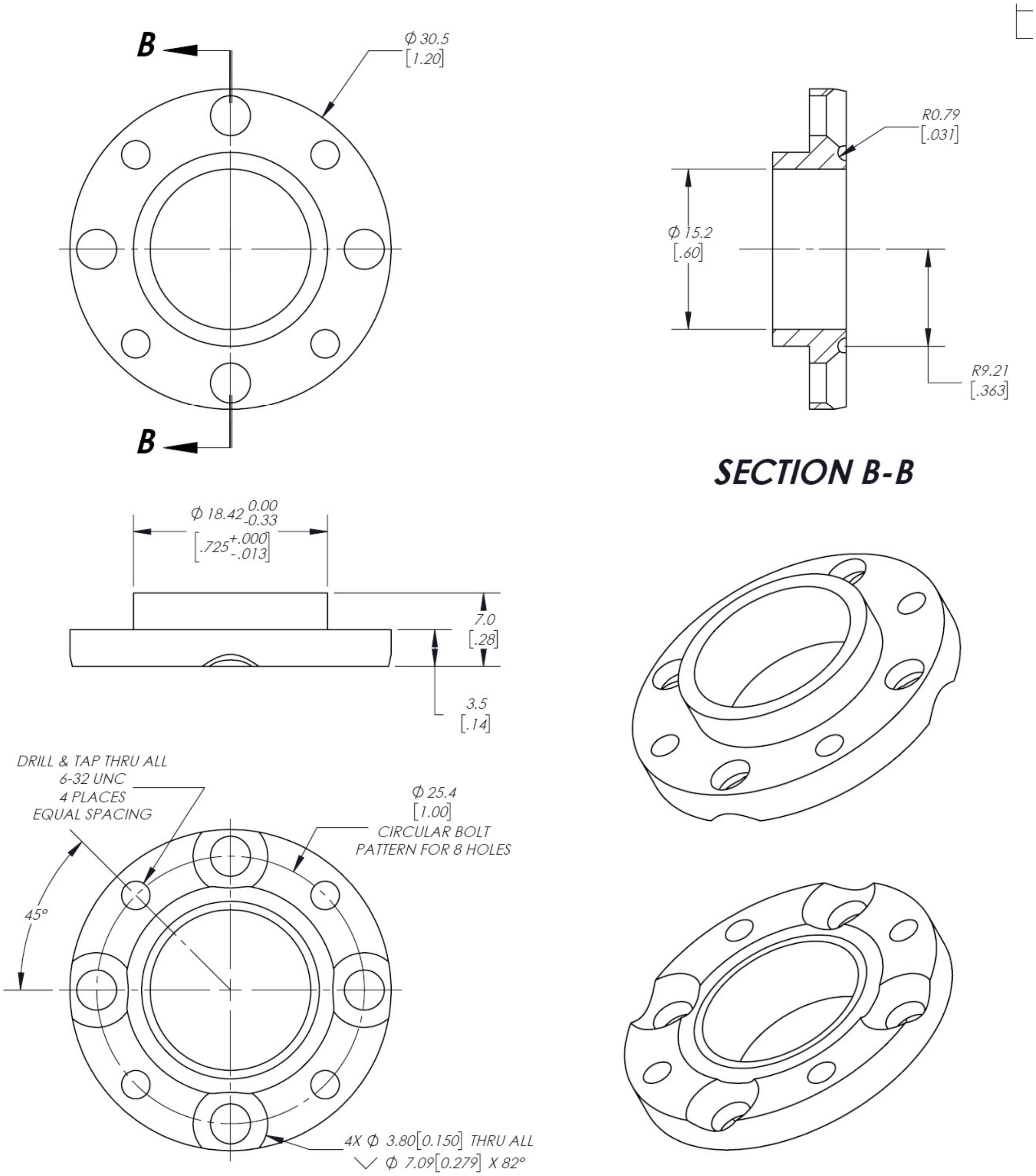


Figure E.6 - Example HF fixed and inner ring detail

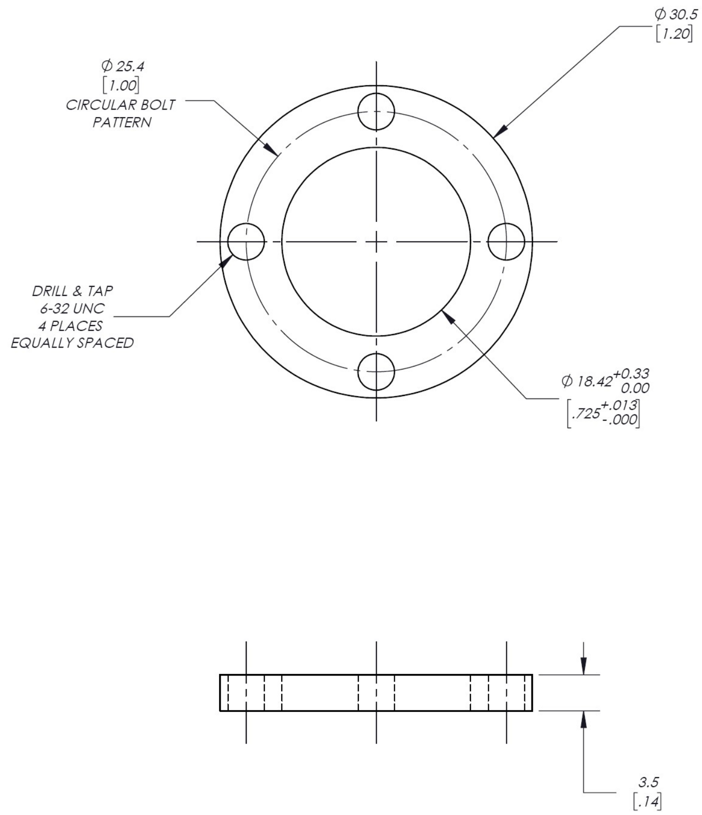


Figure E.7 - Example HF sealed case outer ring detail

(Dimensions are in mm)

E.3.3 Test method

E.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 E.6). 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 R1 located inside the main case, see Figure E.1 .
12 Solder the conductor core of the ‘output’ side of the sample under test to the 50 Ω ±1% terminating resistor R2 located inside the secondary case as shown in Figure E.1 (the smaller of the two HF sealed case enclosures).

E.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.

E.3.4 Transfer impedance measurement consistency tests

E.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%.

E.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%.

E.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%.

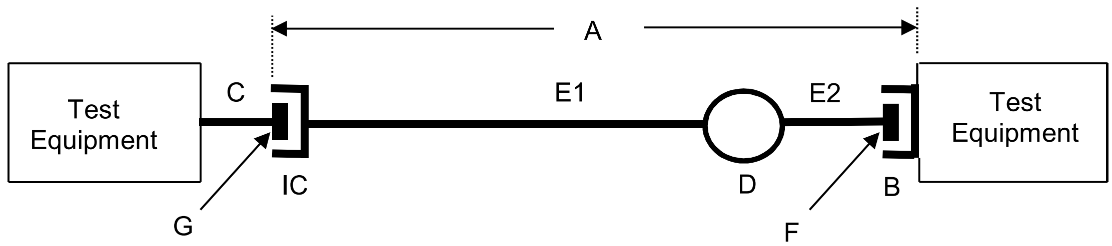
E.3.4.4 Measurement slope verification

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

Annex F (normative) - Modular Plug Terminated Link

This standard requires that horizontal cable be terminated on a telecommunications outlet to provide flexible access to the user. In certain limited cases there may be a need to terminate horizontal cables to a plug that is directly plugged into a device. This will sometimes be done to service a security camera, a radio enabled wireless access device, or another device which is not often moved or rearranged. This annex provides guidance to assure the proper functioning of such a cabling arrangement.

F.1 Test configuration for modular plug terminated link



Legend

Cables and cords
Horizontal cabling E1, E2
Connecting hardware
Interconnect IC
Optional consolidation point .... D
Maximum length
E1 + E2 .... 90 m

A: MPTL Under Test (MUT)
B: Patch cord test head as qualified per Annex C or D
C: Test equipment cord
F: Modular plug termination
G: Test plug qualified per Annex C or D

Figure F.1 - Topology of Modular Plug Terminated Link

A: Modular Plug Terminated Link Under Test (MUT)
B: Patch cord test head qualified per Annex C or D
C: Test equipment cord
D: Optional consolidation point
E: Horizontal cable
F: Modular plug terminates the modular plug terminated link
G: Test plug qualified per Annex C or D

F.2 Modular plug terminated link transmission requirements

Modular plug terminated link shall comply with the permanent link transmission requirements of this standard.

Annex G (Normative) – 28 AWG cord cable performance

This clause contains performance requirements for 28 AWG patch cords. TIA-568.2-D generally requires conductor sizes of AWG 22-24 for horizontal cable and AWG 22-26 for cord cable. In certain cases, it may be necessary to make cords from 28 AWG cable. This is allowed, if the requirements of this annex are followed. Certain requirements will be changed due to the smaller conductor size, as indicated below.

The connectors of TIA-568-2.D are typically designed to terminate to horizontal cable made of 22-24 AWG conductors. If terminating 28 AWG cord cable to a connector, the connector shall be designed for termination of 28 AWG conductors. The connectors shall meet the requirements of Annex A when terminated with 28 AWG conductors.

For guidelines and limitations on using 28 AWG cord for power delivery, see TIA-TSB-184-A-1.

G.1 28 AWG cord cable transmission performance

Cord cables shall meet the transmission performance requirements specified for cord cables in clause 6.6, with the exception of the requirements in this clause.

G.1.1 28 AWG cord cable dc resistance

DC resistance shall be measured in accordance with ASTM D4566. For all categories of cord cable, the resistance of any UTP or screened cord cable conductor shall not exceed 23.6 Ω per 100 m (328 ft) at or corrected to a temperature of 20 °C. Based on a temperature coefficient of resistance of 0.00393 per °C for copper, the dc resistance of 28 AWG cord cable conductors at 60 °C shall be 27.3 Ω or less per 100 m (328 ft).

G.1.2 28 AWG cord cable insertion loss

Cord cable insertion loss limits are derived by multiplying the applicable horizontal cable insertion loss requirements in clause 6.6.10 by a factor of 1.95 (the de-rating factor). The de-rating factor allows a 95% increase in insertion loss to account for smaller wire gauge and design differences.

The maximum insertion loss for UTP cord cables shall be adjusted at elevated temperatures using a factor of 0.4 % increase per °C from 20 °C to 40 °C and 0.6% increase per °C for temperatures from 40 °C to 60 °C. The maximum insertion loss for screened cord cables shall be adjusted at elevated temperatures using a factor of 0.2% increase per °C from 20 °C to 60 °C. Note: Power delivery can result in elevated cord temperatures.

Cord cable insertion loss shall meet or be less than the values determined using the equations shown in Table G.1 for all specified frequencies. In addition, category 6 and 6A cord cable insertion loss shall also be verified at temperatures of 40 ± 3 °C and 60 ± 3 °C and shall meet the requirements of Table G.1 after adjusting for temperature.

Table G.1 – 28 AWG cord cable insertion loss, for a length of 100m (328 feet)

	Frequency (MHz)	Insertion loss (dB)
Category 5e	$1 \le f \le 100$	$1.95 \cdot \left(1.967\sqrt{f} + 0.023 \cdot f + \frac{0.050}{\sqrt{f}}\right)$
Category 6	$1 \le f \le 250$	$1.95 \cdot \left(1.808\sqrt{f} + 0.017 \cdot f + \frac{0.2}{\sqrt{f}}\right)$
Category 6A	$1 \le f \le 500$	$1.95 \cdot \left(1.82\sqrt{f} + 0.0091 \cdot f + \frac{0.25}{\sqrt{f}}\right)$

The 28 AWG cord cable insertion loss values in Table G.2 are provided for information only.

Table G.2 – Maximum category 5e through 6A 28 AWG cord cable insertion loss, for a length of 100m (328 ft)

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)
1	4.0	3.9	4.1
4	7.9	7.4	7.4
8	11.2	10.4	10.4
10	12.6	11.6	11.6
16	16.1	14.7	14.6
20	18.1	16.5	16.3
25	20.3	18.5	18.3
31.25	22.9	20.8	20.5
62.5	33.1	30.0	29.2
100	42.9	38.6	37.3
200	-	56.5	53.8
250	-	64.1	60.6
300	-	-	66.8
400	-	-	78.1
500	-	-	88.3

G.1.3 28 AWG cord cable use cases

The maximum length of 28 AWG cords shall not exceed 15 m (49.2 ft) and is determined using equation G-1 with link temperature of 20 °C and equation G-3 for link temperatures of 60 °C. Table G.3 gives some example use cases with the corresponding maximum permanent link length and maximum channel length at 20 °C . Table G.4 gives maximum permanent link and maximum channel length at 60 °C.

$$P = \frac{102-H}{D} \qquad \text{(G-1)}$$

And

$$C = H + P \qquad \text{(G-2)}$$

Where:

H is the length (m) of the permanent link (horizontal cable).
D is the insertion loss de-rating factor for the cord type (1.95 for 28 AWG cords)
P is the length of 28 AWG patch cords
C is the total length of the channel

Table G.3 – 28 AWG cord cable example use cases at 20 °C

Maximum permanent link length m(ft)	Maximum length of 28 AWG cord cable m(ft)	Maximum channel length m(ft)
90.0 (295.3)	6.2 (20.2)	96.2 (315.5)
82.5 (270.7)	10.0 (32.8)	92.5 (303.5)
72.8 (238.7)	15.0 (49.2)	87.8 (287.9)

At 60 °C the maximum permanent link and channel lengths are decreased due to the increased insertion loss in the horizontal cable as shown in the following equations.

$$P_{60} = \frac{102-1.2 \cdot H}{D} \qquad \text{(G-3)}$$

And

$$C_{60} = H + P_{60} \qquad \text{(G-4)}$$

Where:

H is the length (m) of the permanent link (horizontal cable).
D is the insertion loss de-rating factor for the cord type (1.95 for 28 AWG cords)
P_{60} is the length of 28 AWG patch cords
C_{60} is the total length of the channel at with the permanent link at 60 °C

Table G.4 – 28 AWG cord cable example use cases with permanent link at 60 °C

Maximum permanent link length m(ft)	Maximum length of 28 AWG cord cable m(ft)	Maximum channel length m(ft)
75.0 (246.1)	6.2 (20.2)	81.2 (266.4)
68.8 (225.7)	10.0 (32.8)	78.8 (258.5)
60.7 (199.1)	15.0 (49.2)	75.7 (248.4)
NOTE - This table assumes that the patch cords included in the channel are at 20 °C.		

Annex H (informative) - Connecting hardware test fixtures

H.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 H.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.

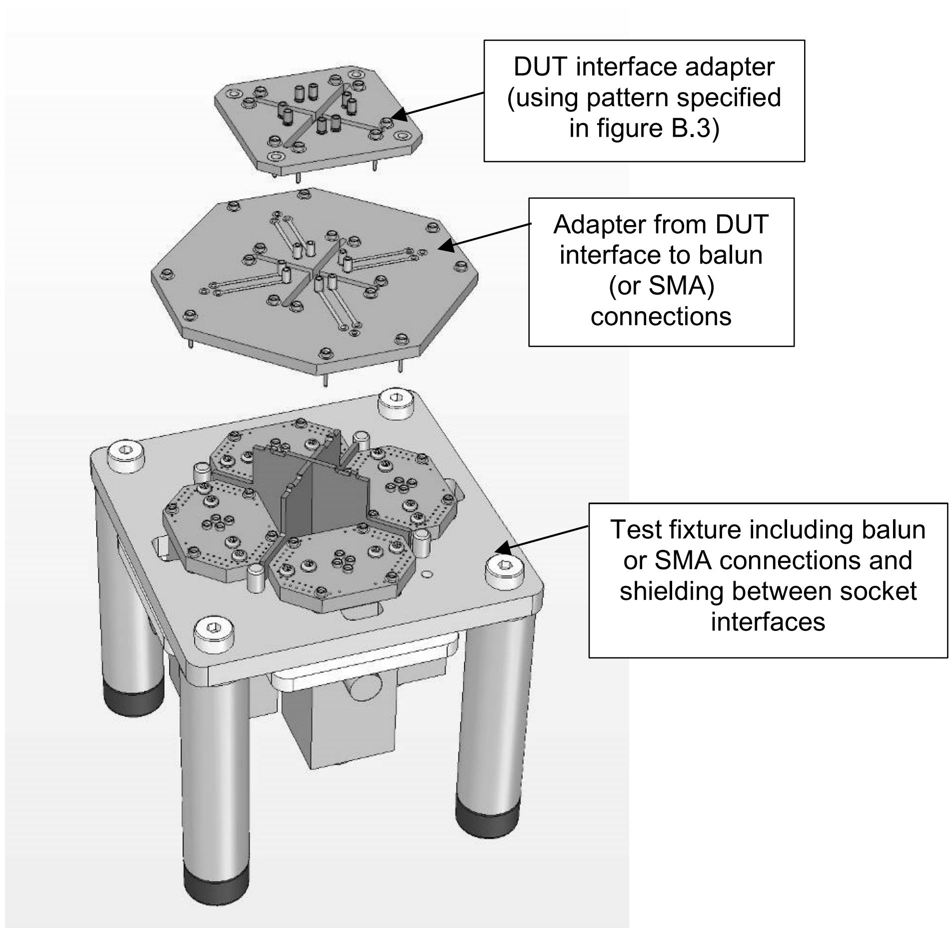


Figure H.1 - Test head assembly with baluns attached

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.

H.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 where additional shielding is needed for various components.

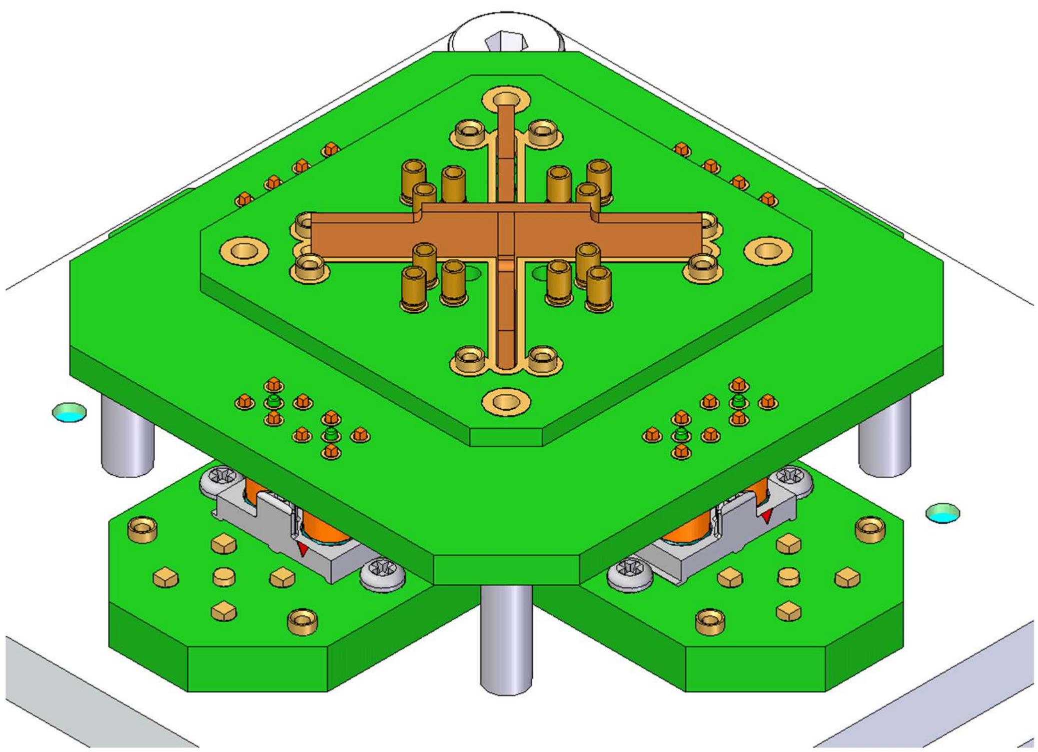


Figure H.2 - Test head assembly showing shielding between interconnecting sockets

NOTE - Photos are for illustrative purposes only and do not constitute an endorsement by TIA.

H.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. Refer to clause C.6.5.10 for direct fixture specifications.

Figure H.3 - Plug direct fixture

H.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 H. Its properties have been designed to comply with electrical properties of the test plug described in clause C.6.5.
The plug is mounted using an adapter plate as shown in Figure H.

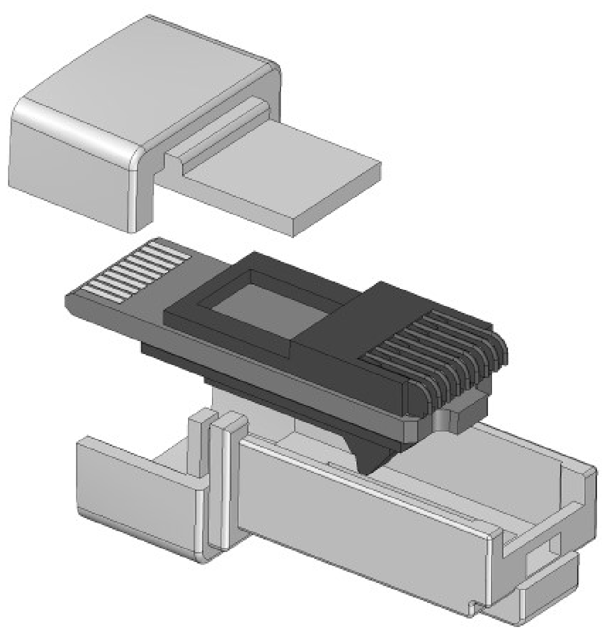


Figure H.4 - PCB based plug

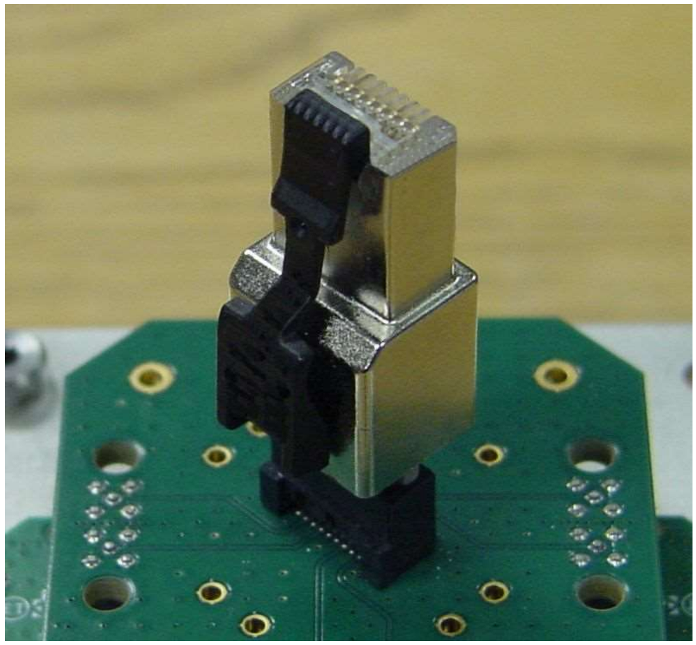


Figure H.5 - PCB based plug assembly with adapter

NOTE - Photos are for illustrative purposes only and do not constitute an endorsement by TIA.

H.5 Connecting hardware measurement configuration

Figure H.6 shows an example of a connecting hardware measurement configuration.

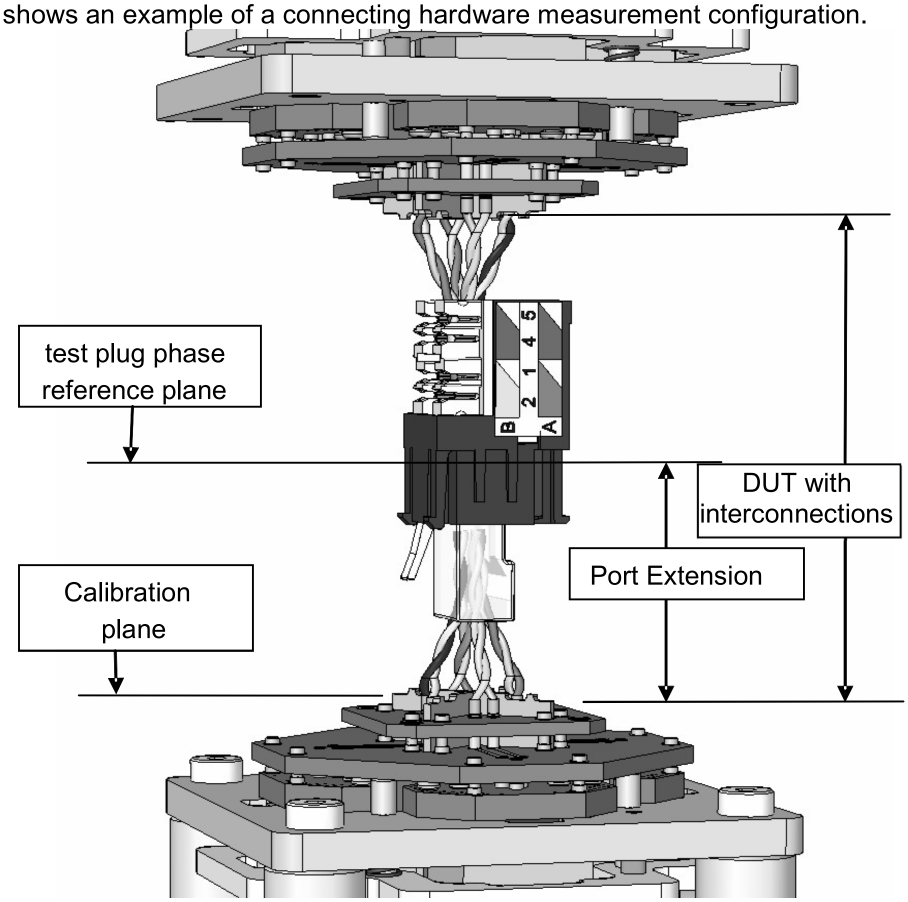


Figure H.6 - An example of a connecting hardware measurement configuration

H.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 H.7. 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.

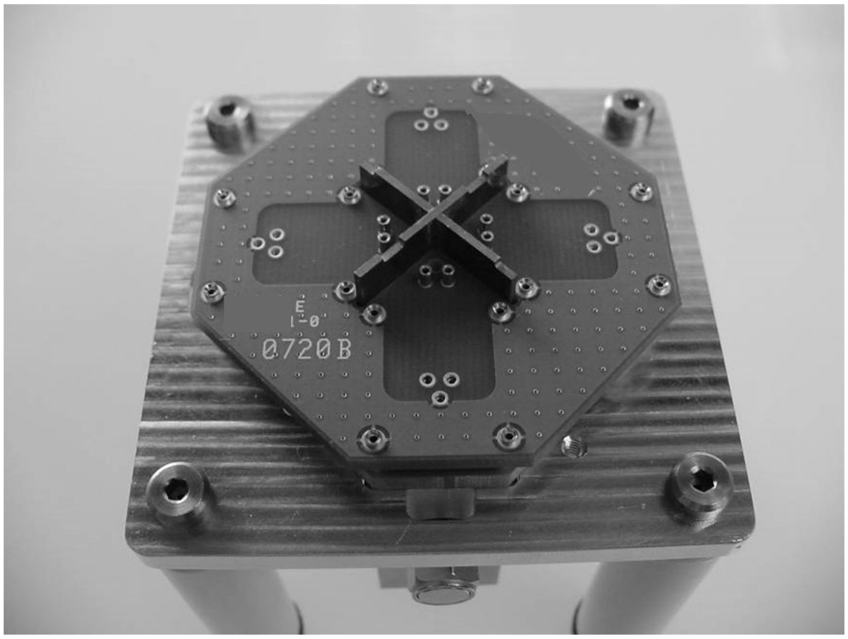


Figure H.7 - Test fixture interface

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 Figure H.8 and Figure H.9 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.

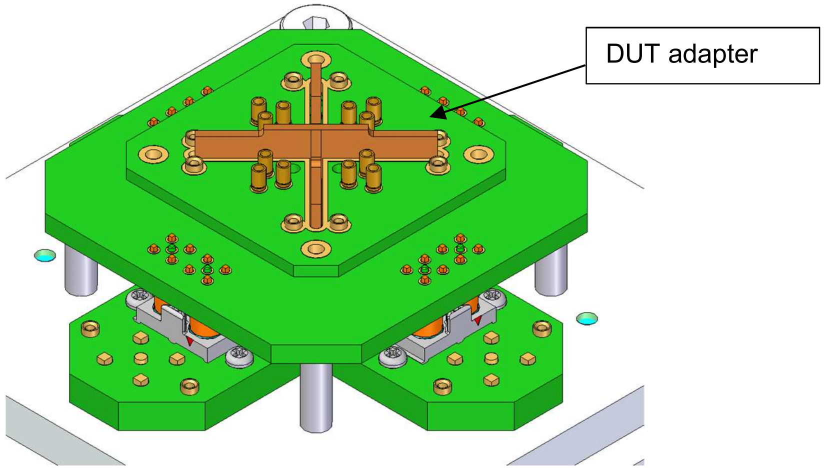


Figure H.8 - Open calibration standard applied to balunless test interface

NOTE - Photos are for illustrative purposes only and do not constitute an endorsement by TIA.

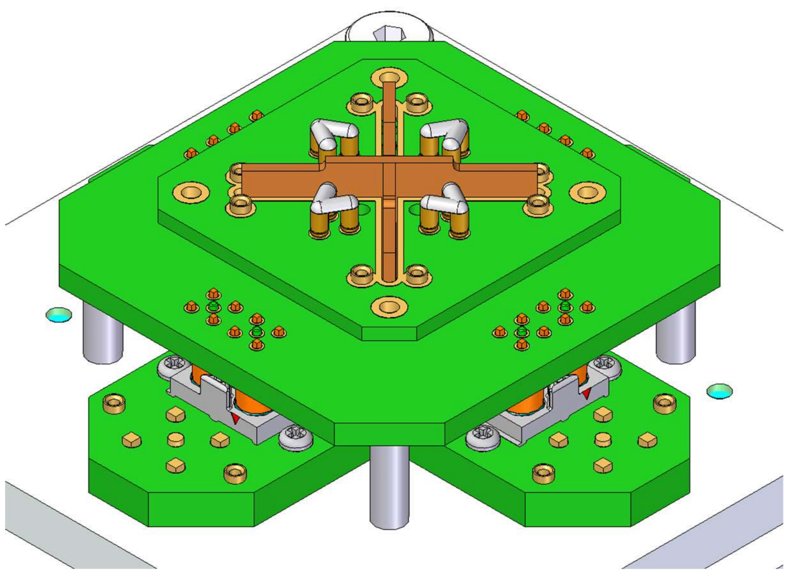


Figure H.9 - Short calibration standard applied to balunless test interface

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 Figure H.10 and Figure H.11 respectively.

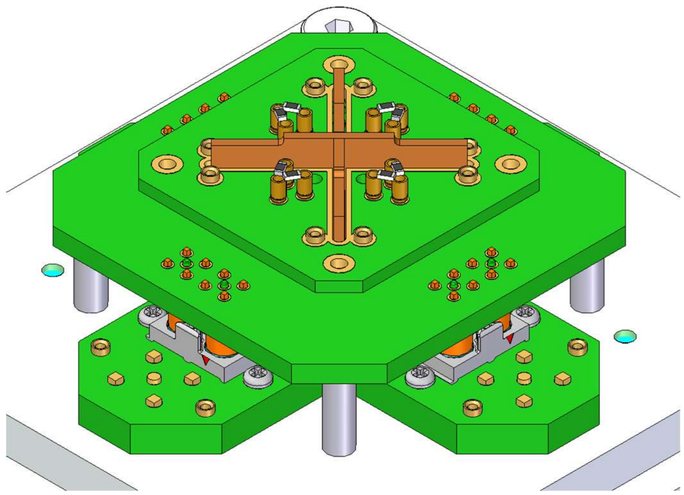


Figure H.10 - Load calibration standard applied to test interface

NOTE - Photos are for illustrative purposes only and do not constitute an endorsement by TIA.

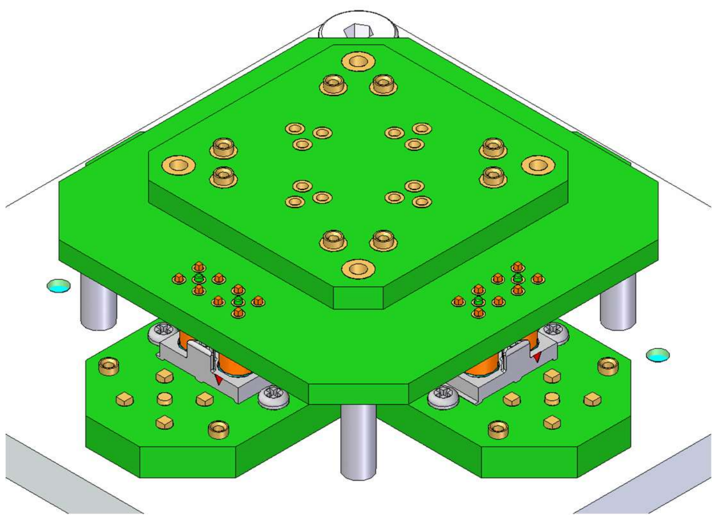


Figure H.11 - A loop back through standard applied to a balunless test interface

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 H.12.

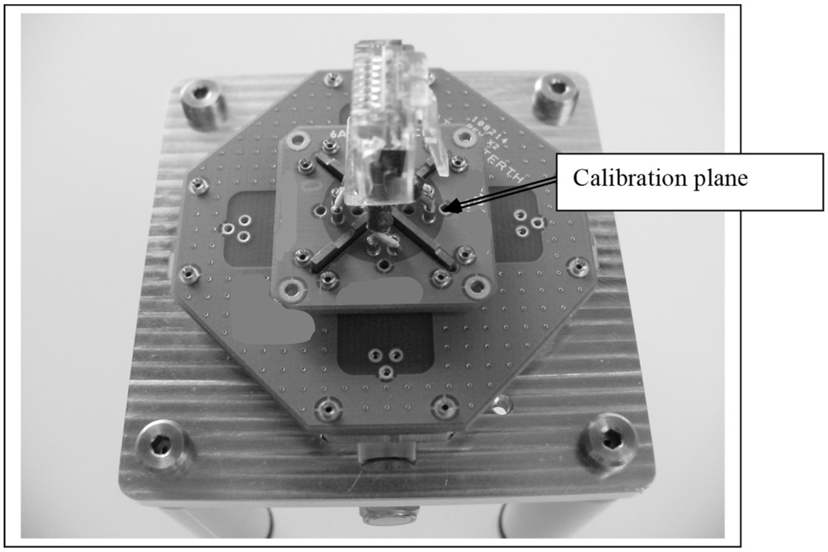


Figure H.12 - Test plug attached to the test interface

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 H.13. The shield plates (not shown) must remain in position under the direct fixture.

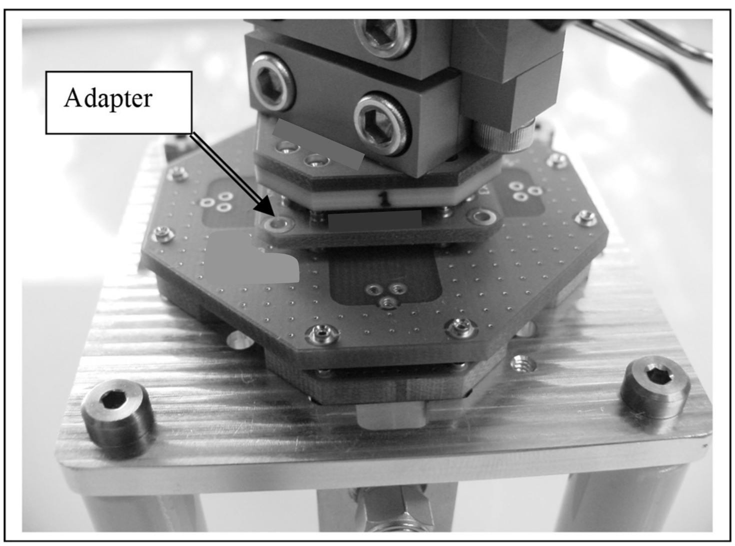


Figure H.13 - Direct fixture mounted to the test head interface

NOTE - Photos are for illustrative purposes only and do not constitute an endorsement by TIA.

H.6.1 Calibration and reference plane location

A calibration is performed to establish a reference plane location as shown in Figure H.14.

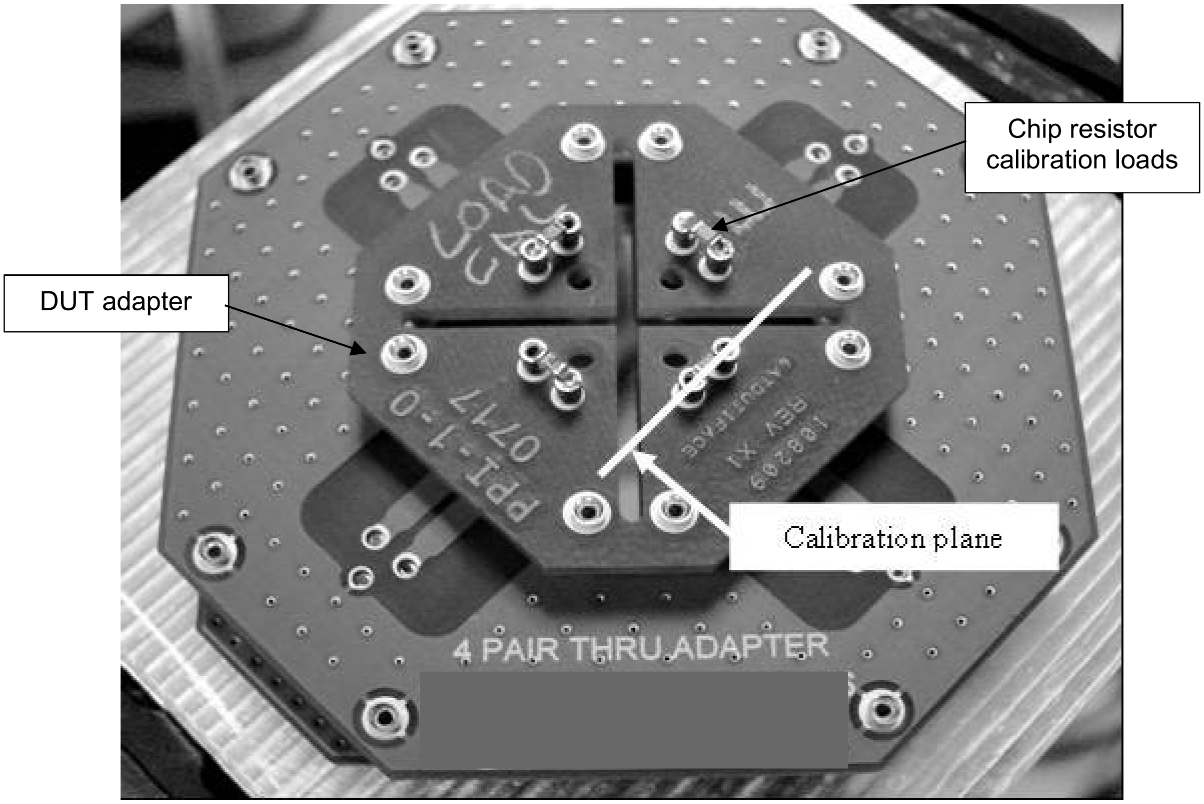


Figure H.14 - Calibration reference plane

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 constructed from two DUT adapter assemblies as shown in Figure H.15. 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.

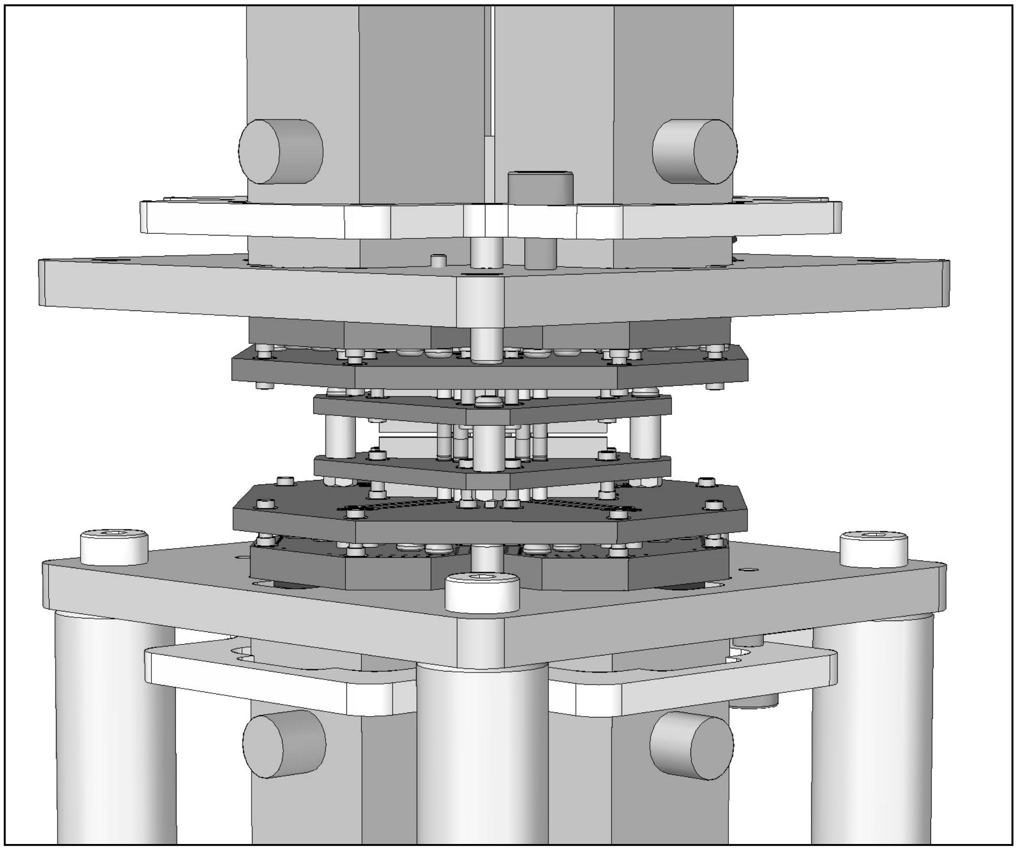


Figure H.15 - Back-to-back through calibration

H.7 DUT connections using header PCB assemblies

Dedicated PCB header assemblies may be used to connect between the DUT and the test equipment. These PCB headers may contain connections to interface to the test port and also connections to interface to the DUT terminals or IDC slots, thus eliminating the need for test leads.

Annex I (informative) - Cable installation in higher temperature environments

I.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 6.3.9, 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.

I.2 Insertion loss

Equation (H1) defines the insertion loss dependence on temperature:

$$IL_{20} = \frac{IL_T}{1 + \delta_1 (T - 20) + \delta_2 (T - 40)} \qquad \text{(H1)}$$

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 I.1.

Table I.1- Maximum horizontal cable length de-rating factor for different temperatures

	Temperature (° C)	δ_1	δ_2
UTP	20 ≤ T ≤ 40	0.00393	0.00000
	40 < T ≤ 60	0.00393	0.00248
F/UTP	20 ≤ T ≤ 60	0.00200	0.00000

I.3 Allowance for cable temperature

Table I. shows the maximum horizontal cable length de-rating at various temperatures assuming a cable insertion loss temperature coefficient specified in clause 6.6.8.

Table I.2 - Maximum horizontal cable length de-rating factor for different temperatures

Temperature (°C (°F))	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.

I.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 and unscreened cable is used, then the maximum horizontal cable distance should be reduced from 90 meters to 84 meters.

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

J.1 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:

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = \alpha + j\beta \tag{J1}$$

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

$$\gamma = j\omega\sqrt{LC}\sqrt{\left(1 + \frac{R}{j\omega L}\right)\left(1 + \frac{G}{j\omega C}\right)} \tag{J2}$$

Multiplying out the terms in equation (J2):

$$\gamma = j\omega\sqrt{LC}\sqrt{1 - \frac{RG}{\omega^2 LC} + \frac{R}{j\omega L} + \frac{G}{j\omega C}} \tag{J3}$$

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

$$\gamma \approx j\omega\sqrt{LC}\sqrt{1 + \frac{R}{j\omega L} + \frac{G}{j\omega C}} \tag{J4}$$

Since R << ωL, and G << ωC, we can further approximate equation (J4), by:

$$\gamma \approx j\omega\sqrt{LC}\left[1 + \frac{R}{j2\omega L} + \frac{G}{j2\omega C}\right] \tag{J5}$$

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

$$\gamma = \alpha + j\beta \approx j\omega\sqrt{LC}\left[1 + \frac{R}{j2\omega L} + \frac{G}{j2\omega C}\right] \tag{J6}$$

Multiplying out the terms in equation (J6), we have:

$$\gamma = \alpha + j\beta \approx \left[\frac{R}{2}\sqrt{\frac{C}{L}} + \frac{G}{2}\sqrt{\frac{L}{C}}\right] + j\omega\sqrt{LC} \tag{J7}$$

Separating real and imaginary parts in equation (J7) we have:

$$\alpha \approx \left[\frac{R}{2}\sqrt{\frac{C}{L}} + \frac{G}{2}\sqrt{\frac{L}{C}}\right] \tag{J8}$$

$$\beta \approx \omega\sqrt{LC} \tag{J9}$$

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:

$$L = L_\infty + L_{INT} = L_\infty \left[1 + \frac{R}{\omega L_\infty} \right] \quad \text{(J10)}$$

Substituting the expression for L given above, into equation (J8):

$$\alpha \approx \left[\frac{R\sqrt{C}}{2\sqrt{L_\infty \left[1 + \frac{R}{\omega L_\infty} \right]}} + \frac{G}{2}\sqrt{\frac{L}{C}} \right] \quad \text{(J11)}$$

Factoring out $\sqrt{L_\infty}$, from the denominator of the first part of equation (J11):

$$\alpha \approx \left[\frac{R\sqrt{C}}{2\sqrt{L_\infty}\sqrt{\left[1 + \frac{R}{\omega L_\infty} \right]}} + \frac{G}{2}\sqrt{\frac{L}{C}} \right] \quad \text{(J12)}$$

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

$$\frac{1}{\sqrt{\left[1 + \frac{R}{\omega L_\infty} \right]}} \approx \left[1 - \frac{R}{2\omega L_\infty} \right] \quad \text{(J13)}$$

Applying this approximation for $\frac{1}{\sqrt{\left[1 + \frac{R}{\omega L_\infty} \right]}}$ in equation (J12):

$$\alpha \approx \left[\frac{R\sqrt{C}}{2\sqrt{L_\infty}} \left[1 - \frac{R}{2\omega L_\infty} \right] + \frac{G}{2}\sqrt{\frac{L}{C}} \right] \quad \text{(J14)}$$

Multiplying out the terms in equation (I14):

$$\alpha \approx \left[\underset{(1)}{\frac{R\sqrt{C}}{2\sqrt{L_\infty}}} - \underset{(2)}{\frac{R^2\sqrt{C}}{4\omega\left(L_\infty\right)^{3/2}}} + \underset{(3)}{\frac{G}{2}\sqrt{\frac{L}{C}}} \right] \quad \text{(J15)}$$

In equation (J15), 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 (J15):

$$\alpha \approx \left[\frac{R\left(\sqrt{f}\right)}{2}\sqrt{\frac{C}{L_\infty}} - \frac{\left(R\left(\sqrt{f}\right)\right)^2\sqrt{C}}{4\left(2\,\pi\,f\right)\left(L_\infty\right)^{3/2}} + \frac{\left(2\,\pi\,f\right)C\tan\delta}{2}\sqrt{\frac{L}{C}} \right] \qquad \text{(J16)}$$

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 79. 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 79.

J.2 Developing the phase delay equation

The expression for the phase delay is given by:

$$\text{Delay} = \frac{\beta}{\omega} = \sqrt{L\,C} \qquad \text{(J17)}$$

Substituting, for $L = L_\infty + L_{INT} = L_\infty \left[1 + \frac{R}{\omega\,L_\infty} \right]$

$$\text{Delay} = \frac{\beta}{\omega} = \sqrt{L_\infty \left[1 + \frac{R}{\omega\,L_\infty} \right] C} \qquad \text{(J18)}$$

Applying the approximation for $\left(\frac{R}{\omega\,L_\infty} \right) << 1$, $\sqrt{\left[1 + \frac{R}{\omega L_\infty} \right]}$ may be written as:

$$\sqrt{\left[1 + \frac{R}{\omega L_\infty} \right]} \approx 1 + \frac{R}{2\,\omega L_\infty} \qquad \text{(J19)}$$

Then the expression for delay may be written:

$$\frac{\beta}{\omega} = \sqrt{C L_\infty} \left[1 + \frac{R}{2\,\omega L_\infty} \right] \qquad \text{(J20)}$$

Multiplying out equation (J20):

$$\frac{\beta}{\omega} = \sqrt{C\,L_\infty} + \frac{R}{2\,\omega}\sqrt{\frac{C}{L_\infty}} \qquad \text{(J21)}$$

Writing the expression for delay to indicate the frequency dependent terms:

$$\frac{\beta}{\omega} = \sqrt{C\,L_\infty} + \frac{R\left(\sqrt{f}\right)}{2\left(2\,\pi\,f\right)}\sqrt{\frac{C}{L_\infty}} \qquad \text{(J22)}$$

Since C and L_{∞} are independent of frequency, the first term in equation (J22) is a constant. The second term has a $1/\sqrt{f}$ frequency dependence, due to the ratio of $\frac{R(\sqrt{f})}{f}$ which results in the following expression for delay:

$$Delay = \frac{\beta}{\omega} = \text{Const} + \frac{k1/8.686}{2\pi\sqrt{f}} \quad \text{(J23)}$$

The units for delay in equation (J23) 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 **79**:

$$\text{Delay}(\text{ns/100m}) = \text{Const} + \frac{36}{\sqrt{f_{MHz}}} \quad \text{(J24)}$$

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:

$$\text{Delay}(\text{ns/100m}) = 534 + \frac{36}{\sqrt{f_{MHz}}} \quad \text{(J25)}$$

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 K (informative) - Development of channel and component return loss limits

K.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 (K1).

$$\begin{bmatrix} \cosh(\gamma\, l) & Z \sinh(\gamma\, l) \\ \frac{\sinh(\gamma\, l)}{Z} & \cosh(\gamma\, l) \end{bmatrix} \quad \text{(K1)}$$

where: $\gamma = \alpha + j\beta$ is the complex propagation constant and Z is the complex characteristic impedance.

$\alpha = \frac{IL_{dB}}{20\log(e)}$ with: IL_{dB} is the insertion loss of the component per m in dB.

e = 2.71828 (base of natural logarithm)

$\beta = \frac{2\pi\ f\ 10^6}{NVP\ c}$ 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:

$$NVP = \frac{100}{prop\_delay \cdot c}$$

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:

$$Z_{in} = \frac{A\,Z_{ref} + B}{C\,Z_{ref} + D}, \text{ and } RL = -20\log\left(\left|\frac{Z_{in} - Z_{ref}}{Z_{in} + Z_{ref}}\right|\right), \quad \text{(K2)}$$

with the nominal characteristic impedance $Z_{ref} = 100\ \Omega$.

K.2 Assumptions

K.2.1 Assumptions for the transmission matrix for cable

For cable, the specified insertion loss per unit length is given by:

$$IL_{dB} = \frac{k_1\sqrt{f} + k_2 f + \frac{k_3}{\sqrt{f}}}{100} \quad \text{(K3)}$$

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:

$$Z_{fit} = Z_o\left(1 + 0.055\frac{1-j}{\sqrt{f}}\right) \quad \text{(K4)}$$

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 is 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.

$$DRL = -10\log\left(10^{\frac{-RL_{cable}}{10}} - 10^{\frac{-RL_{interface}}{10}}\right) \quad \text{(K5)}$$

DRL is approximated by:

$$DRL_{100m} = K_{DRL} - 10\log\left(\frac{f}{20}\right) \quad \text{(K6)}$$

where: K_{DRL} is a constant.

This approximation may be used to represent the contributions from all distributed sources of return loss in cabling for most lengths of cabling. The contribution from DRL over a short length of cable may be approximated using the same formula as that used for scaling NEXT 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.

K.2.2 Assumptions for the transmission matrix for connectors

For a connector, the product of the propagation delay constant and length is used.

$$\gamma l = \alpha \ l + j\beta l \qquad \text{(K7)}$$

The electrical length l_{conn} is obtained from: $l_{conn} = NVP\ c \dfrac{\phi_x}{360\ f_x}$ (K8)

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 $\alpha\ l = k_c \sqrt{f}$ (K9)

where k_c is the constant in the connector insertion loss equation.

The phase constant $\beta\ l = \dfrac{\pi}{180} \phi_x \dfrac{f}{f_x}$ (K10)

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.

K.3 Return loss modeling results

A reasonable worst case channel configuration used to develop the return loss limits is shown in Figure K.. 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.

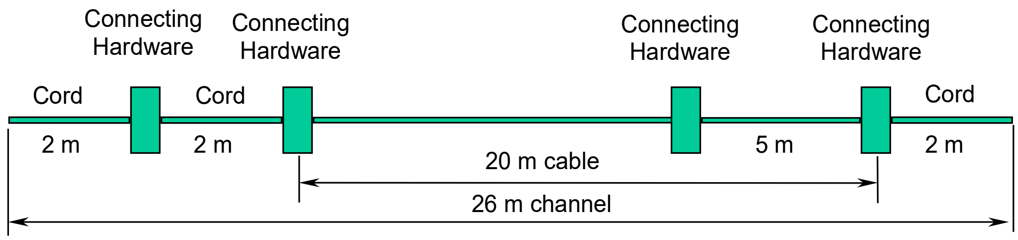


Figure K.1 - Modeling configuration

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 cords, match ¼ wavelengths. If distances between connections are multiples of a fixed low value, then it is possible, but unlikely, that the return loss will exceed the pass/fail limits for the channels or permanent links under the following conditions:

- In channels that use a cross-connect.
- In channels and permanent links which use a consolidation point.

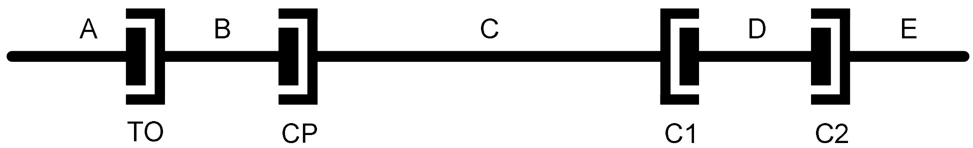
In case, a return loss failure occurs in a channel:

1 Verify the operation and calibration of the field tester.
2 Determine the source of major reflections.
3 Reduce the number of connectors in the channel.
4 Select components with better return loss performance.

Annex L (informative) - Modeling configurations and length scaling

L.1 Category 3 through 6A channel modeling configurations

Figure L. shows five channel modeling configurations that are used for worst-case analysis.

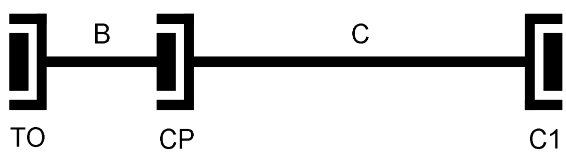


ID	Description	Channel configuration 1	2	3	4	5
A	Work area cord	5 m	2 m	1 m	1 m	1 m
TO	Telecommunications outlet / connector	P	P	P	P	P
B	Consolidation point cabling	5 m	5 m	5 m	NP	NP
CP	Consolidation point connector	P	P	P	NP	NP
C	Horizontal cabling	85 m	15 m	15 m	15 m	10 m
C1	Horizontal cross-connect 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 L.1 - Channel configuration

Similarly, Figure L. 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 L.2 - Permanent link configuration

L.2 Category 8 channel modeling configurations

Figure L. shows four channel modeling configurations that are used for worst-case analysis.

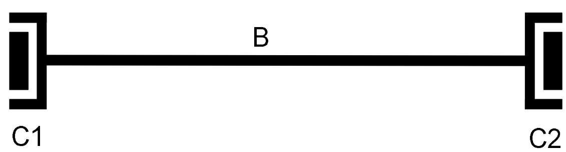
ID	Description	1	2	3	4
A	Equipment cord	0.5 m	1.0 m	3.0 m	1.0 m
C1	Horizontal interconnect 1	P	P	P	P
B	Horizontal cable	3.0 m	3.0 m	24.0 m	24.0 m
C2	Horizontal interconnect 2	P	P	P	P
C	Equipment cord	0.5 m	1.0 m	1.0 m	5.0 m

P = Present in this channel model
NP = Not present in this channel model

Figure L.3 - Category 8 channel configuration

L.3 Permanent link modeling configurations

Similarly, Figure L. shows two permanent link modeling configurations that are used for worst-case analysis.



ID	Description	1	2
C1	Horizontal interconnect 1	P	P
B	Horizontal cable	3.0 m	24.0 m
C2	Horizontal interconnect 2	P	P

P = Present in this permanent link model
NP = Not present in this permanent link model

Figure L.4 - Category 8 permanent link configuration

Category 8 permanent link limits are worse than the channel limits over part of the frequency range. This is due to the improvements of the channel return loss due to the insertion loss of the cords. These limits were determined from modeling.

L.4 Direct attach modeling configurations

Direct attach modeling configurations and use cases for worst case analysis are provided by Table L.1.

Table L.1 - Direct attach channel modeling configurations

Modeling configurations	1	2
Direct attach cord cable length	0.5 m	5.0 m

L.5 Length scaling

Several of the performance parameters are dependent upon the length of the horizontal cable and/or the equipment cords used. This annex provides equations for length scaling. The scaled parameters include:

- Insertion loss
- DC resistance
- Delay
- Delay skew
- Return loss
- Power Sum Near end crosstalk loss (PSNEXT)
- Power Sum Attenuation to crosstalk ratio, far end (PSACRF)

This clause will focus on length scaled equations for dc resistance, Insertion loss, return loss, NEXT, PSNEXT, FEXT, ACRF, PSACRF and propagation delay performance parameters.

Several of the parameters are either not substantially affected by length scaling, or are difficult to determine without a full matrix analysis.

- Transverse conversion loss (TCL)
- Longitudinal conversion loss (LCL)
- Common mode parameters (excluding insertion loss)
- Mutual capacitance
- Characteristic impedance
- TCTL
- Coupling attenuation

Category 8 is illustrated as an example

L.5.1 Channel configuration and variables

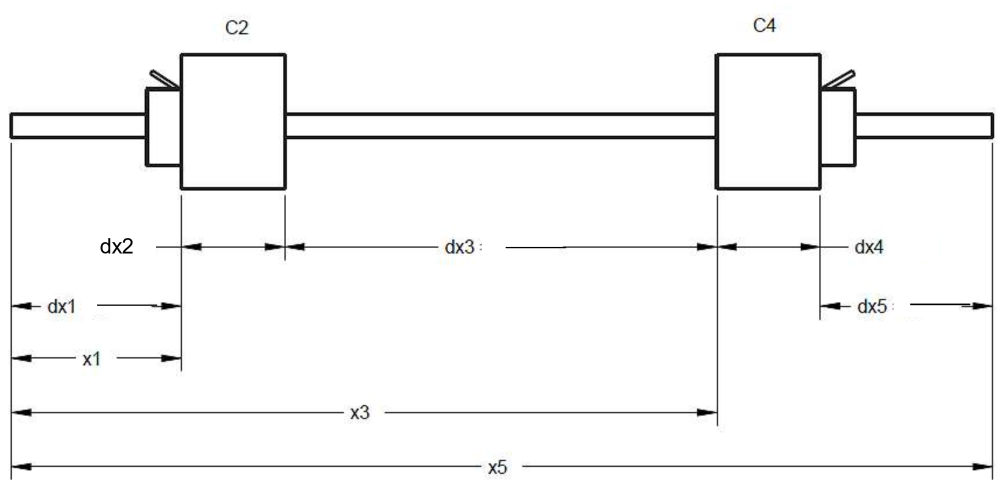


Figure L.5 - Channel configuration and variables

Variables

f is frequency in MHz
$dx_2 = dx_4 = xc = 0.04$ is electrical length of connector in meters
dx_1, dx_5 are cord lengths in meters
dx_3 is the cable length in meters
$x1 = dx_1$

$x3 = dx_1 + dx_2 + dx_3$

$x5 = dx_1 + dx_2 + dx_3 + dx_4 + dx_5$

$$IL\_Cbl = \frac{1.80\sqrt{f} + 0.005f + \frac{0.25}{\sqrt{f}}}{100}$$ (L1)

$IL_{Crd} = (DF)(IL_{Cbl})$

Where DF = flexible cable de-rating factor, 1.0, 1.2, or 1.5. (L2)

$IL\_Conn = 0.02\sqrt{f}$	$f \leq 500$
$IL\_Conn = 0.00649\sqrt{f} + 0.000605f$	$500 < f \leq 2000$

(L3)

$a3 = (ILCrd)(dx1) + ILConn + (ILCbl)(dx3)$ (L4)

Where a3 is the insertion loss per meter of the x3 section of the channel, as shown in figure D.1.

L.5.2 Channel insertion loss length scaling

$$Channel\ insertion\ loss = [Length_{horizonta} + (DF)(Length_{cordage})](IL_{Cbl}) + 2(IL_{Conn}) + ILD_{Channel}$$ (L5)

Where:

$L = x5$ is the channel length in meters

and

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

$ILD_{Channel} = (0.0324)\sqrt{f}$ for channels (L6)

L.5.3 Channel dc resistance scaling

$$Channel\_dc\_Loop\_R(L) = 2[(2.4/30)Length\_horizontal + (4.2/30)Length\_cordage + 2(0.2)]$$ (L7)

Where:

Channel_dc_Loop_R(L) is the dc loop resistance of the channel as a function of length.
Length_horizontal is the length of the horizontal cable in the channel in meters.
Length_cordage is the length of the cordage in the channel in meters.
The numbers 2.4, 4.2, and 0.2 are the resistance requirements of those components.
The number 2 is for 2 connectors in the channel.

L.5.4 Channel return loss scaling

$$RLche = -20log\left[10^{-\left(\frac{RL\_Cbl\_lim}{10}\right)} + 10^{-\left(\frac{RLcne}{10}\right)}\right]$$ (L8)

Where:

$RLche$ = return loss of the channel
$RLcne$ = return loss in the channel due to the connectors

$$RLcne = -20log\left[\left(10^{(-10)(ILCrd)(x1)}\right)\left(10^{-\left(\frac{RL\_Conn\_lim}{20}\right)}\right) + (10^{(-10)(a3)})(10^{-\left(\frac{RL\_Conn\_lim}{20}\right)})\right] \quad \text{(L9)}$$

$RL\_Cbl\_lim = 20 + 5\log(f)$	$f < 10$
$RL\_Cbl\_lim = 25$	$10 \le f < 40$
$RL\_Cbl\_lim = 25 - 7\log(\frac{f}{40})$	$40 \le f < 2000$

(L10)

$RL\_Conn\_lim = 32 - 20\log\left(\frac{f_k}{100}\right)$	$f \le 1000$
$RL\_Conn\_lim = 12$	$1000 < f \le 2000$

(L11)

L.5.5 Channel NEXT length scaling

$$NEXTche = -20log\left[10^{-\left(\frac{NEXT\_Cbl\_lim}{10}\right)} + 10^{-\left(\frac{NEXTcne}{10}\right)}\right] \quad \text{(L12)}$$

$NEXT\_Cbl\_lim = 45.3 - 15\log(\frac{f}{100})$	$1 \le f \le 2000$

(L13)

Channel NEXT loss is scaled by evaluating the components due to connectors ($NEXTcne$) and cable ($NEXT\_Cbl\_lim$) and power summing the two. The individual connector contributions ($NEXT\_Conn\_lim$) are attenuated by the appropriate length-scaled channel segments (x1 and x3) with the two contributions from the two connectors voltage summed ($NEXTcne$).

$NEXT\_Conn\_lim = 54 - 20\log(\frac{f}{100})$	$f \le 250$
$NEXT\_Conn\_lim = 46.04 - 30\log(\frac{f}{250})$	$250 < f \le 500$
$NEXT\_Conn\_lim = 37 - 40\log(\frac{f}{500})$	$500 < f \le 2000$

(L14)

$$NEXTcne = -20log\left[(10^{(-10)(ILCrd)(x1)})(10^{-\left(\frac{NEXT\_Conn\_lim}{20}\right)}) + (10^{(-10)(a3)})(10^{-\left(\frac{NEXT\_Conn\_lim}{20}\right)})\right] \quad \text{(L15)}$$

Where:

$NEXTcne$ = the NEXT in the channel due to the connectors

L.5.6 Channel PSNEXT length scaling

$$PSNEXTche = -20log\left[10^{-\left(\frac{PSNEXT\_Cbl\_lim}{10}\right)} + 10^{-\left(\frac{PSNEXTcne}{10}\right)}\right]$$ (L16)

$PSNEXT\_Cbl\_lim = 42.3 - 15\log(\frac{f}{100})$	$1 \leq f \leq 2000$

(L17)

Channel PSNEXT loss is scaled by evaluating the components due to connectors ($PSNEXTcne$) and cable ($PSNEXT\_Cbl\_lim$) and power summing the two. The individual connector contributions ($PSNEXT\_Conn\_lim$) are attenuated by the appropriate length-scaled channel segments (x1 and x3) with the two contributions from the two connectors voltage summed ($PSNEXTcne$).

$PSNEXT\_Conn\_lim = 50 - 20\log(\frac{f}{100})$	$f \leq 250$
$PSNEXT\_Conn\_lim = 42.04 - 30\log(\frac{f}{250})$	$250 < f \leq 500$
$PSNEXT\_Conn\_lim = 33 - 40\log(\frac{f}{500})$	$500 < f \leq 2000$

(L18)

$$PSNEXTcne = -20log\left[(10^{(-10)(ILCrd)(x1)})\left(10^{-\left(\frac{PSNEXT\_Conn\_lim}{20}\right)}\right) + (10^{(-10)(a3)})(10^{-\left(\frac{PSNEXT\_Conn\_lim}{20}\right)})\right]$$ (L19)

Where:

$PSNEXTcne$ = the power sum NEXT in the channel due to the connectors

L.5.7 Channel PSACRF length scaling

$$PSACRF\_Cbl\_lim = 36 - 20\log\left(\frac{f}{100}\right) - 10\log\left(\frac{x5}{30}\right)$$ (L20)

$$PSACRF\_Conn\_lim = 40.1 - 20\log\left(\frac{f}{100}\right) - IL\_Conn$$ (L21)

$$PSACRF\_Ch\_lim = -20log\left[10^{-\left(\frac{PSACRF\_Cbl\_lim}{20}\right)} + (2)(10^{-\left(\frac{PSACRF\_Conn\_lim}{20}\right)})\right]$$ (L22)

L.5.8 Channel ACRF length scaling

Length scaling. The cable ACRF scales as a 10log(newlength/reflength) function.

$$ACRF_{Channel\_scaled} = -20\log\left(10^{\frac{(10\log(L/l)+39-20\log(f/100))}{-20}} + (2)(10^{\frac{(43.1-20\log(f/100))}{-20}})\right)$$ (L23)

Where: l represents the scaled length of the channel

And

L represents the original unscaled length of the channel.

This analysis assumes a uniform insertion loss distribution throughout the channel and relatively uniform FEXT couplings along the channel. This results in some error compared to a true cascaded (matrix) analysis where there may be point source FEXT couplings (connectors) and varying insertion loss profiles (cables vs cords) of the transmission media.

L.5.9 Channel FEXT length scaling

Channel FEXT for any length can be calculated from the addition of the scaled ACRF result and the channel insertion loss.

$$FEXT_{Channel\_scaled} = ACRF_{Channel\_scaled} + IL_{Channel} \quad \text{(L24)}$$

L.5.10 Channel propagation delay scaling

$$\text{Channel propagation delay} = (L/30)(160 + \frac{11}{\sqrt{f}}) + (2)(2.5) \quad \text{(L25)}$$

Where:

$L =$ Channel Length in meters and maximum channel length L is 32 meters.

L.6 Category 8 direct attach channel NEXT and PSNEXT calculation

$$NEXT_{direct\_attach} \geq -10\log\left(10^{\frac{-NEXT_{connectors}}{10}} + 10^{\frac{-\left(NEXT_{cord\_cable} + 2 \cdot IL_{conn}\right)}{10}}\right) - RFEXT \quad \text{(L26)}$$

where:

$$NEXT_{connectors} = -20\log\left(10^{\frac{-NEXT_{conn\_spec}}{20}} + 10^{\frac{-\left(NEXT_{conn\_spec} + 2\left(IL_{cord\_cable} + IL_{conn}\right)\right)}{20}}\right) \quad \text{(L27)}$$

$$IL_{cord\_cable} = IL_{cord\_cable,30m} \cdot \frac{5}{30} \quad \text{(L28)}$$

$$NEXT_{cord\_cable} = NEXT_{hor\_cable} - 10\log\left(1 - e^{-0.46 \cdot IL_{cord\_cable}}\right) \quad \text{(L29)}$$

$NEXT_{conn\_spec}$ is the NEXT loss assigned to the local and remote test head connectors. The equation for category 8 test head connectors is specified in Annex C.

$IL_{cord\_cable,30m}$ is the insertion loss of 30 meters of cord cable as specified in table 109.

$NEXT_{cord\_cable}$ is the cable NEXT loss computed from the NEXT loss requirements for 30 meters of horizontal cable, the insertion loss requirements for 30 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 clause 6.6.9.

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

IL_{conn} is the insertion loss of one connector as specified in 6.10.8.

$RFEXT$ is the reflected signal cross talk. For category 8 direct attach RFEXT = 0.5 dB.

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

L.7 Category 8 direct attach channel PSNEXT loss calculation

For all frequencies from 1 MHz to 2000 MHz, direct attach PSNEXT loss shall meet the values determined using equation (L30).

$$PSNEXT_{direct\_attach} \geq -10\log\left(10^{\frac{-PSNEXT_{connectors}}{10}} + 10^{\frac{-\left(PSNEXT_{cord\_cable} + 2\cdot IL_{conn}\right)}{10}}\right) - RFEXT \qquad \text{(L30)}$$

Where:

$$PSNEXT_{connectors} = -20\log\left(10^{\frac{-PSNEXT_{conn\_spec}}{20}} + 10^{\frac{-\left(PSNEXT_{conn\_spec} + 2\left(IL_{cord\_cable} + IL_{conn}\right)\right)}{20}}\right) \qquad \text{(L31)}$$

$$IL_{cord\_cable} = IL_{cord\_cable,30m} \cdot \frac{CableLength}{30} \qquad \text{(L32)}$$

$$PSNEXT_{cord\_cable} = PSNEXT_{hor\_cable} - 10\log\left(1 - e^{-0.46\cdot IL_{cord\_cable}}\right) \qquad \text{(L33)}$$

$PSNEXT_{conn\_spec}$ is the PSNEXT loss assigned to the local and remote test head connectors, see Annex C.

$IL_{cord\_cable,30m}$ is the insertion loss of 30 meters of cord cable as specified in table 109.

$PSNEXT_{cord\_cable}$ is the cable PSNEXT loss computed from the PSNEXT loss requirements for 30 meters of horizontal cable, the insertion loss requirements for 30 meters of cord cable, and the length correction formula in ASTM D 4566.

$PSNEXT_{hor\_cable}$ is the PSNEXT loss of horizontal cable as specified in 6.6.10.

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

IL_{conn} is the insertion loss of one connector as specified in 6.10.8.

$RFEXT$ is the reflected signal cross talk. For category 8 direct attach RFEXT = 0.5 dB.

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

Annex M (informative) - Additional information on channel and permanent link NEXT loss limits

M.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.

M.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 M.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 .

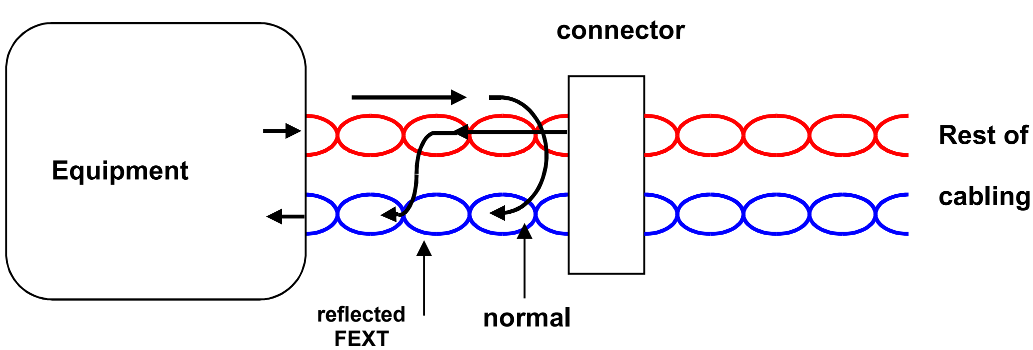


Figure M.1 - Principle of reflected FEXT effects adding to NEXT

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 M.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.

M.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 N (informative) - PSAACRF and AFEXT loss normalization

N.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 802.3™.

N.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 N.1.

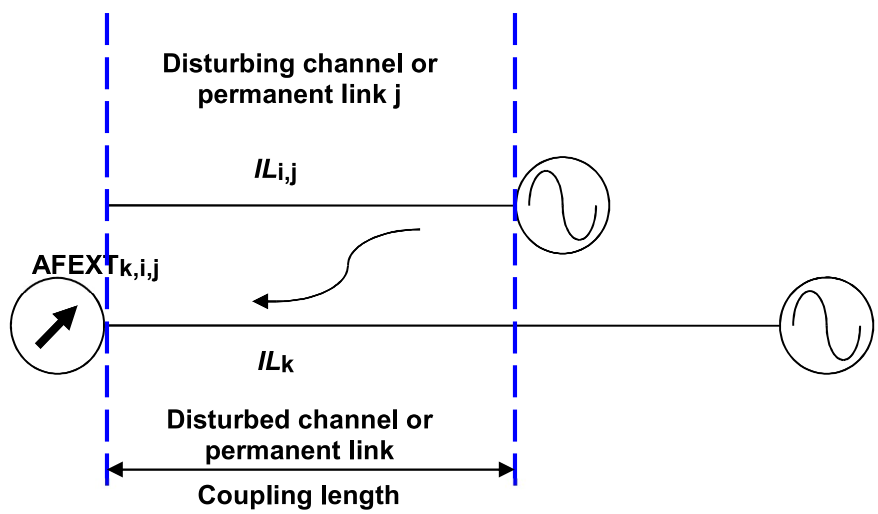


Figure N.1 - Unequal lengths of disturbing and disturbed channels or permanent links

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 N.2 at the right side) have equal magnitudes. A worst case condition occurs when both of the disturbed and disturbing permanent links or channels terminate at the same location (on the left side of Figure N.2. 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.

N.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 (N1) and (N2) with reference to Figure N.2.

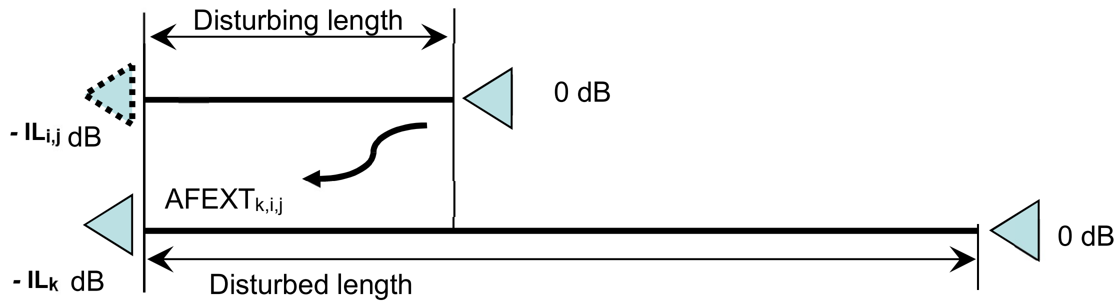


Figure N.2 - AACRF for the coupled permanent link or channel

$$IL_{coupling\_length} = \min(IL_k, IL_{i,j}) \text{ dB} \quad \text{(N1)}$$

For the example shown in Figure N.2, $IL_{coupling\_length} = IL_{i,j}$ and the AACRF of the coupled permanent link or channel is given by equation (N2).

$$AACRF_{k,i,j} = AFEXT_{k,i,j} - IL_{i,j} \text{ dB} \quad \text{(N2)}$$

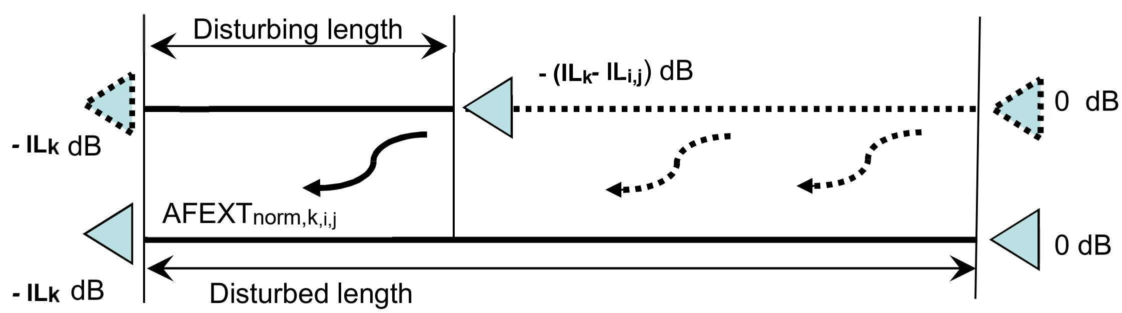


Figure N.3 - AACRF normalized for the length of the disturbed permanent link or channel

AACRF of the coupled permanent link or channel is then scaled to the length of the disturbed permanent link or channel using equations (N3) to (N7) with reference to Figure N.3.

$$AACRF_{norm,k,i,j} = AACRF_{k,i,j} - 10\log\left[\frac{Length_{disturbed}}{Length_{disturbing}}\right] \text{ dB} \quad \text{(N3)}$$

$$\left(AFEXT_{norm,k,i,j} - IL_k\right) = \left(AFEXT_{k,i,j} - IL_{i,j}\right) - 10\log\left[\frac{Length_{disturbed}}{Length_{disturbing}}\right] \text{ dB} \quad \text{(N4)}$$

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.

$$AFEXT_{norm,k,i,j} = AFEXT_{k,i,j} + \left(IL_k - IL_{i,j}\right) - 10\log\left[\frac{IL_k}{IL_{i,j}}\right] \ dB \qquad \text{(N5)}$$

$$PSAFEXT_{norm,k} = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{n} 10^{-\frac{AFEXTnorm_{k,i,j}}{10}}\right) \ dB \qquad \text{(N6)}$$

$$PSAACRF_k = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{n} 10^{\frac{-AFEXTnorm_{K,i,j}}{10}}\right) - IL_k \ dB \qquad \text{(N7)}$$

NOTE - The computation using equation (N7) is equivalent to the computation of PSAACRF specified in TIA TSB-155 and the computation of PSAELFEXT in IEEE Std 802.3™.

Annex O (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 O.1 provides reference performance values for legacy category 5 channels.

Table O.1 - Category 5 channel parameters

Parameter	Frequency (MHz)	Channel performance
Insertion loss	$1 \le f \le 100$	$\le 1.02\left(1.967\sqrt{f} + 0.023f + \frac{0.05}{\sqrt{f}}\right) + 4 \cdot 0.04\sqrt{f}$ dB
NEXT loss[3)]	$1 \le f \le 100$	$\ge -20\log\left(10^{\frac{-\left(64-15\log\left(\frac{f}{0.772}\right)\right)}{20}} + 2 \cdot 10^{\frac{-\left(40-20\log\left(\frac{f}{100}\right)\right)}{20}}\right)$ dB
Return loss	$1 \le f < 20$ $20 \le f \le 100$	≥ 15 dB $\ge 15 - 20\log\left(\frac{f}{20}\right)$ dB
ELFEXT[1)]	$1 \le f \le 100$	$\ge 17 - 20\log\left(\frac{f}{100}\right)$ dB
PSELFEXT[2)]	$1 \le f \le 100$	$\ge 14.4 - 20\log\left(\frac{f}{100}\right)$ dB
Propagation delay	10	$\le$ 555 ns
Delay skew	10	$\le$ 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 O. are provided for information only.

Table O.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 P (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 INCITS 166-1990, *Information Systems - Fibre Data Distributed Interface (FDDI) - Token Ring Physical Layer Medium Dependent (PMD)*

ANSI/TIA-4994-2015, *Standard for Sustainable Information Communications Technology*

TIA TSB-5046-2017, *Process for Sustainable Information Communications Technology Manufacturers*

IEEE Std 802.3™-2012*, IEEE Standard for Ethernet*

ISO/IEC 11801-1:201x, *Information technology - Generic cabling for customer premises - Part 1: General requirements*

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The organizations listed below can be contacted to obtain reference information.

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ASTM
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CENELEC
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