SFF specifications are available at http://www.snia.org/sff/specifications
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This specification was developed by the SFF Committee prior to it becoming the SFF TA (Technology Affiliate) TWG (Technical Working Group) of SNIA (Storage Networking Industry Association).

The information below should be used instead of the equivalent herein.

POINTS OF CONTACT:

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If you are interested in participating in the activities of the SFF TWG, the membership application can be found at:
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The complete list of SFF Specifications which have been completed or are currently being worked on can be found at:
http://www.snia.org/sff/specifications/SFF-8000.TXT

The operations which complement the SNIA's TWG Policies & Procedures to guide the SFF TWG can be found at:
http://www.snia.org/sff/specifications/SFF-8032.PDF

Suggestions for improvement of this specification will be welcome, they should be submitted to:
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PLEASE READ EDITOR'S NOTES IN FRONT OF TABLE OF CONTENTS

SFF Committee

SFF-8412 Specification for

HSOI (High Speed Optical Interconnect) Measurement and Performance Requirements for Passive Optical Connections

Rev 12.2 June 18, 2003

Secretariat: SFF Committee

Abstract: This specification defines the testing and performance requirements for high speed optical bidirectional cable assemblies and associated passive system connections operating at high speeds (>1 GBaud in each direction). This architecture is used in most applications requiring high speed serial optical connections such as: Fibre Channel, Ethernet and Infiniband.

Other applications for this general-purpose specification are also possible.

This specification provides a common specification for systems manufacturers, system integrators, and suppliers of components in the referenced area. This is an internal working specification of the SFF Committee, an industry ad hoc group.

This specification is made available for public review, and written comments are solicited from readers. Comments received by the members will be considered for inclusion in future revisions of this specification.

The description of a test procedure in this specification does not assure that the specific hardware necessary for executing the procedure is actually available from instrumentation suppliers. Test procedures must comply with this specification to achieve interoperability and interchangeablity between suppliers of optical cable assemblies.

Support: This specification is supported by the identified member companies of the SFF Committee.

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EXPRESSION OF SUPPORT BY MANUFACTURERS

The following member companies of the SFF Committee voted in favor of this industry specification.

Amphenol
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EMC
ENDL
FCI/Berg
Fujitsu Compnts
Hewlett Packard
Hitachi Cable
Madison Cable
Molex
Sun Microsystems
Toshiba America
TriQuint
Tyco AMP

The following member companies of the SFF Committee voted against this industry specification.

All Best Techniq
Compaq

The following member companies of the SFF Committee voted to abstain on this industry specification.

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Fiberxon
Foxconn Int'l
Fujitsu CPA
IBM
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Seagate
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To save space for SFF Specifications being reviewed, the information on the principles of the SFF Committee and how to join has not been printed.

SFF Committee --

High Speed Optical Interconnect Testing
Measurement and Performance Requirements for Passive Optical Connections

1. Scope

This specification defines the terminology and physical requirements for specifying and enforcing through measurements the optical and associated electrical performance requirements on high-speed serial optical connections. Such performance requirements are in addition to the mechanical and environmental requirements specified elsewhere.

This specification is the first SFF specification to deal with the optical interconnect performance requirements directly. This specification is patterned after a previous SFF specification, SFF-8410, which is directed at copper serial links. Optical performance specifications have previously been left to accredited standards bodies or other forums. In the high-speed serial applications area, however, the existing specifications in standards specifications have been found to be inadequate to produce the same results between independent measurements of the same parameters on the same hardware.

This specification defines measurement specifications that include enough detail to allow the performance specifications to be used effectively. Until such time as standards specifications include such detail this specification can serve as the specification for the measurement methodology.

Passive optical interconnect has traditionally been characterized by a very simple set of d.c. performance requirements such as optical power loss. While such requirements are important they do not consider several high-speed requirements such as bandwidth and cross talk. These high-speed requirements are sensitive to parameters that are not very important to the d.c. performance. One major addition to the suite of requirements for passive optical interconnect are those defined in this specification relating to bandwidth and cross talk.

The numerical performance requirements for specific technologies are formally set by the standards that apply. Where these specifications are directly translatable to the methodologies specified in this specification, this specification should be used in order to achieve transportable results.

The acceptable values for some of these parameters as published in recent standards specifications are included as an annex to this specification. It is the intent of this SFF specification to provide the measurement methodology that should be used to verify these performance parameters for optical interconnect. The numbers presented in this annex represent the values known as of the date of the revision but the presence of a value in the annex to this specification is for convenience only and does not constitute a standards requirement. Please refer to the relevant standard for the most current numerical requirements.

This specification is specifically aimed at the requirements for links where signals are traveling away from the transmitter at the same time other uncorrelated signals are being received by neighboring receivers. The test conditions required for this bi-directional application are somewhat unique - especially with respect to the effects of the signals on the parts of the cable assembly that is not directly under test.

Fortunately, the cross talk interactions between the optical paths involved does not involve direct optical coupling for almost all practical applications (where the interconnect is not defective). On the other hand, the cross talk in the electrical portions of the links may be significant. It is not the intent of this specification to define comprehensive test and performance requirements for optical transceivers. However, since optical measurements must be made using electrical circuitry one cannot avoid considering the cross talk effects when evaluating the optical performance.

The performance requirements include the effects of connectors and all the parts of the connection that are required to make a complete link. These requirements apply directly to several optical connectors specified mechanically in other SFF specifications and in other specifications referenced. The optical connectors SC, ST, LC, SG, MT, MT-RJ, MU, FC, MPO, and SMC are directly affected. (*FC does not mean Fibre Channel when describing this particular optical connector but rather is the accepted name of the connector regardless of the transport protocol used.) These connectors are desirable in GBE, FC-AL, FC-SW, 1394, SSA, Infiniband and other systems where high-speed optical technology is used.

The HSOI testing procedures break down into two levels:

1. Those that are used to verify that the required performance for the desired signals is being delivered while being a good neighbor and not exporting more than specified intensities of undesirable signals to other parts of the system or environment and
2. Those that are needed to diagnose the causes of degraded primary performance but are not directly required for the adequate operation of the link

Most attention is paid to the level 1 requirements. The level 2 measurements are described but no specific performance limits are placed.

The terms interoperability and interchangeability are equivalent in the context of this specification. In common usage interoperability means that the link passes signals with acceptably low error rate as detected by the receiver. In the context of this specification interoperability means (1) that acceptably low error rates are produced and (2) that the margin in the actual signal parameters is also within specifications. Inclusion of the margin as part of interoperability produces the desired interchangeability of optical cable assemblies. However, it is not within the scope of this specification to address actual bit error rates as these only make sense in the context of an active receiver. This specification is aimed at the passive parts of the link.

In an effort to broaden the applications for storage devices, an ad hoc industry group of companies representing system integrators, peripheral suppliers, and component suppliers decided to address the issues involved.

The SFF Committee was formed in August, 1990 and the first working specification was introduced in January, 1991.

1.1 Description of Clauses

Clause 1 contains the introduction.
Clause 2 contains the definitions and abbreviations.
Clause 3 contains the references and related standards and SFF specifications.
Clause 4 contains the general description.
Clause 5 defines the general HSOI measurement requirements.
Clause 6 defines Level 1 tests.
Clause 7 defines Level 2 measurements.
Annex A describes calibration of optical attenuators.
Annex B describes modeling of HSOI.

Annex C describes EIA-455 documents.
Annex D describes measurement type classification.

2. References

The SFF Committee activities support the requirements of the storage industry, and it is involved with several standards.

2.1 Industry Documents

The following interface standards are relevant to this Specification.

- X3.230-1994 FC-PH Fibre Channel Physical Interface
- X3.297-199x FC-PH-2 Fibre Channel Physical Interface -2
- X3.303-199x FC-PH-3 Fibre Channel Physical Interface -3
- FC-PI Fibre Channel Physical Interface
- ANSI-Y14.5M Dimension and Tolerancing
- MIL-STD-1344, Method 3008 Shielding Effectiveness of Multicontact Connectors.
- IEC 96-1, Reverberation Chamber method for measuring the screening effectiveness of passive microwave components.

2.2 SFF Specifications

There are several projects active within the SFF Committee. At the date of printing document numbers had been assigned to the following projects. The status of Specifications is dependent on committee activities.

F = Forwarded	The document has been approved by the members for forwarding to a formal standards body.
P = Published	The document has been balloted by members and is available as a published SFF Specification.
A = Approved	The document has been approved by ballot of the members and is in preparation as an SFF Specification.
C = Canceled	The project was canceled, and no Specification was Published.
D = Development	The document is under development at SFF.
E = Expired	The document has been published as an SFF Specification, and the members voted against re-publishing it when it came up for annual review.
e = electronic	Used as a suffix to indicate an SFF Specification which has Expired but is still available in electronic form from SFF e.g. a specification has been incorporated into a draft or published standard which is only available in hard copy.
i = Information	The document has no SFF project activity in progress, but it defines features in developing industry standards. The document was provided by a company, editor of an accredited standard in development, or an individual. It is provided for broad review (comments to the author are encouraged).
s = submitted	The document is a proposal to the members for consideration to become an SFF Specification.

Spec #	Rev	List of Specifications as of June 18, 2003
SFF-8000		SFF Committee Information
INF-8001i	E	44-pin ATA (AT Attachment) Pinouts for SFF Drives

INF-8002i	E	68-pin ATA (AT Attachment) for SFF Drives
SFF-8003	E	SCSI Pinouts for SFF Drives
SFF-8004	E	Small Form Factor 2.5" Drives
SFF-8005	E	Small Form Factor 1.8" Drives
SFF-8006	E	Small Form Factor 1.3" Drives
SFF-8007	E	2mm Connector Alternatives
SFF-8008	E	68-pin Embedded Interface for SFF Drives
SFF-8009	4.1	Unitized Connector for Cabled Drives
SFF-8010	E	Small Form Factor 15mm 1.8" Drives
INF-8011i	E	ATA Timing Extensions for Local Bus
SFF-8012	3.0	4-Pin Power Connector Dimensions
SFF-8013	E	ATA Download Microcode Command
SFF-8014	C	Unitized Connector for Rack Mounted Drives
SFF-8015	E	SCA Connector for Rack Mounted SFF SCSI Drives
SFF-8016	C	Small Form Factor 10mm 2.5" Drives
SFF-8017	E	SCSI Wiring Rules for Mixed Cable Plants
SFF-8018	E	ATA Low Power Modes
SFF-8019	E	Identify Drive Data for ATA Disks up to 8 GB
INF-8020i	E	ATA Packet Interface for CD-ROMs
INF-8028i	E	- Errata to SFF-8020 Rev 2.5
SFF-8029	E	- Errata to SFF-8020 Rev 1.2
SFF-8030	1.8	SFF Committee Charter
SFF-8031		Named Representatives of SFF Committee Members
SFF-8032	1.5	SFF Committee Principles of Operation
INF-8033i	E	Improved ATA Timing Extensions to 16.6 MBs
INF-8034i	E	High Speed Local Bus ATA Line Termination Issues
INF-8035i	E	Self-Monitoring, Analysis & Reporting Technology
INF-8036i	E	ATA Signal Integrity Issues
INF-8037i	E	Intel Small PCI SIG
INF-8038i	E	Intel Bus Master IDE ATA Specification
INF-8039i	E	Phoenix EDD (Enhanced Disk Drive) Specification
SFF-8040	1.2	25-pin Asynchronous SCSI Pinout
SFF-8041	C	SCA-2 Connector Backend Configurations
SFF-8042	C	VHDCI Connector Backend Configurations
SFF-8043	E	40-pin MicroSCSI Pinout
SFF-8045	4.5	40-pin SCA-2 Connector w/Parallel Selection
SFF-8046	E	80-pin SCA-2 Connector for SCSI Disk Drives
SFF-8047	C	40-pin SCA-2 Connector w/Serial Selection
SFF-8048	C	80-pin SCA-2 Connector w/Parallel ESI
SFF-8049	E	80-conductor ATA Cable Assembly
INF-8050i	1.0	Bootable CD-ROM
INF-8051i	E	Small Form Factor 3" Drives
INF-8052i	E	ATA Interface for 3" Removable Devices
SFF-8053	5.5	GBIC (Gigabit Interface Converter)
SFF-8054		Automation Drive Interface Connector
INF-8055i	E	SMART Application Guide for ATA Interface
SFF-8056	C	50-pin 2mm Connector
SFF-8057	E	Unitized ATA 2-plus Connector
SFF-8058	E	Unitized ATA 3-in-1 Connector
SFF-8059	E	40-pin ATA Connector
SFF-8060	1.1	SFF Committee Patent Policy
SFF-8061	1.1	Emailing drawings over the SFF Reflector
SFF-8062		Rolling Calendar of SSWGs and Plenaries

SFF-8065	C	40-pin SCA-2 Connector w/High Voltage
SFF-8066	C	80-pin SCA-2 Connector w/High Voltage
SFF-8067	3.0	40-pin SCA-2 Connector w/Bidirectional ESI
INF-8068i	1.0	Guidelines to Import Drawings into SFF Specs
SFF-8069	E	Fax-Access Instructions

INF-8070i	1.3	ATAPI for Rewritable Removable Media
SFF-8072	1.2	80-pin SCA-2 for Fibre Channel Tape Applications
SFF-8073	C	20-pin SCA-2 for GBIC Applications
INF-8074i	1.0	SFP (Small Formfactor Pluggable) Transceiver
SFF-8075	1.0	PCI Card Version of SFP Cage
SFF-8076	-	SFP Additional IDs
INF-8077i	3.1	XFP (10 Gbs Small Form Factor Pluggable Module)
SFF-8078		XFP-E
SFF-8080	E	ATAPI for CD-Recordable Media
SFF-8082	0.1	Labeling of Ports and Cable Assemblies
INF-8090i	5.5	ATAPI for DVD (Digital Video Data)

SFF-8101	C	3 Gbs and 4 Gbs Signal Characteristics
SFF-8110	C	5V Parallel 1.8" drive form factor
SFF-8111	1.3	1.8" drive form factor (60x70mm)
SFF-8120	2.6	1.8" drive form factor (78x54mm)
SFF-8130		1.8" drive w/Serial Attached Connector

SFF-8200e	1.1	2 1/2" drive form factors (all of 82xx family)
SFF-8201e	1.3	2 1/2" drive form factor dimensions
SFF-8212e	1.2	2 1/2" drive w/SFF-8001 44-pin ATA Connector
SFF-8221	2.1	Pre-Aligned 2.5" Drive >10mm Form Factor
SFF-8222	1.1	2.5" Drive w/SCA-2 Connector
SFF-8223	0.4	2.5" Drive w/Serial Attachment Connector
SFF-8225	C	2.5" Single Voltage Drive

SFF-8300	1.2	3 1/2" drive form factors (all of 83xx family)
SFF-8301	1.4	3 1/2" drive form factor dimensions
SFF-8302e	1.1	3 1/2" Cabled Connector locations
SFF-8323	0.4	3 1/2" drive w/Serial Attachment Connector
SFF-8332e	1.2	3 1/2" drive w/80-pin SFF-8015 SCA Connector
SFF-8337e	1.2	3 1/2" drive w/SCA-2 Connector
SFF-8342e	1.3	3 1/2" drive w/Serial Unitized Connector
INF-8350i	6.1	3 1/2" Packaged Drives

SFF-8400	C	VHDCI (Very High Density Cable Interconnect)
SFF-8410	16.1	High Speed Serial Testing for Copper Links
SFF-8411		High Speed Serial Testing for Backplanes
SFF-8412	12.2	HSOI (High Speed Optical Interconnect) Testing
SFF-8415	4.1	HPEI (High Performance Electrical Interconnect)
SFF-8416	5.0	HPEI Bulk Cable Measurement/Performance Reqmnts

SFF-8420	11.1	HSSDC-1 Shielded Connections
SFF-8421	2.4	HSSDC-2 Shielded Connections
SFF-8422	C	FCI Shielded Connections
SFF-8423	C	Molex Shielded Connections
SFF-8424	0.1	Dual Row HSSDC-2 Shielded Connections
SFF-8425	0.3	Single Voltage Drives
SFF-8426		HSSDC Double Width

SFF-8430	4.1	MT-RJ Duplex Optical Connections
SFF-8441	14.1	VHDCI Shielded Configurations

SFF-8451	10.1	SCA-2 Unshielded Connections
SFF-8452	3.1	Glitch Free Mating Connections for Multidrop Aps
SFF-8453		Shielded High Speed Serial connectors
SFF-8460	1.2	HSS Backplane Design Guidelines
SFF-8464		VCSEL Performance in HSS Applications
SFF-8470	2.8	Multi Lane Copper Connector
SFF-8471	C	ZFP Multi Lane Copper Connector
SFF-8472	9.3	Diagnostic Monitoring Interface for Optical Xcvrs
INF-8475i	2.2	XPAK Small Formfactor Pluggable Receiver
SFF-8480	2.1	HSS (High Speed Serial) DB9 Connections
SFF-8482	1.2	Internal Serial Attachment Connector
SFF-8483	C	External Serial Attachment Connector
SFF-8500e	1.1	5 1/4" drive form factors (all of 85xx family)
SFF-8501e	1.1	5 1/4" drive form factor dimensions
SFF-8508e	1.1	5 1/4" ATAPI CD-ROM w/audio connectors
SFF-8523	0.4	5 1/4" drive w/Serial Attachment Connector
SFF-8551	3.2	5 1/4" CD Drives form factor
SFF-8572	C	5 1/4" Tape form factor
SFF-8610	C	SDX (Storage Device Architecture)

2.3 Sources

Copies of ANSI standards or proposed ANSI standards may be purchased from Global Engineering.

15 Inverness Way East	800-854-7179 or 303-792-2181
Englewood	303-792-2192Fx
CO 80112-5704	

Copies of SFF Specifications are available by joining the SFF Committee as an Observer or Member.

14426 Black Walnut Ct	408-867-6630x303
Saratoga	408-867-2115Fx
CA 95070	FaxAccess: 408-741-1600

The increasing size of SFF Specifications has made FaxAccess impractical to obtain large documents. Document subscribers and members are automatically updated every two months with the latest specifications.

SFF specifications are available at ftp://ftp.seagate.com/sff

Electronic copies of documents are also made available via CD_Access, a service which provides copies of all the specifications plus SFF reflector traffic. CDs are mailed every 2 months as part of the document service, and provide the letter ballot and paper copies of what was distributed at the meeting as well as the meeting minutes.

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TABLE OF CONTENTS

1. Introduction

This document contains specifications for validating the performance of high speed serial optical interconnects. It is intended specifically to be used in conjunction with the SC, ST, LC, SG, MT, MT-RJ, MU, FC, MPO, SMC, and other connector families used in a bi-directional (duplex) or single direction (simplex) application. These tests may also be useful for other high speed optical interconnects. SFF-8412 is one of the family of SFF documents. The general construction of the cable assembly is limited only by the requirement that there be an optical connector on both ends. This definition explicitly allows inclusion of:

- Short cable assemblies that are not installed as part of building wiring
- Cable assemblies that consist of installed fiber
- Complex links consisting of multiple cable assemblies
- Parallel optical cable assemblies

This document should be treated as a new specification relating to implementing the testing required to meet the requirements for various applications. Optical interconnects that have passed some other test criteria may not pass the new criteria described herein. Failure to meet these new criteria should not be cause for recalling any previous product. These new criteria may be more stringent than some common industry practice due to lack of complete specification of testing methods in the published standards.

This specification is intended to reflect actual system operation and worst case transceivers - this means that all signals that are normally active during system operation must be active at the extreme allowed stress condition during the testing and that the poorest quality compliant transmitters and poorest quality compliant receivers are assumed. Test methods are developed to evaluate component behavior under these worst case conditions. This scheme is needed for implementing an “open” interconnect model where it is not known a priori where the cable assembly will be connected on either end.

Consideration is also given to use of the cable assembly in a concatenated manner where another cable assembly is attached to the IUT (interconnect under test) rather than having transceivers on both ends. This is a common practice where patch panels are used for example.

This more stringent testing is a natural part of the maturation of high-speed serial technology and will be even more important at higher speeds in the future.

In real systems, opportunities for trading off margins between transmitter, cable assemblies, and receivers commonly exist. Therefore it may be possible to qualify a cable assembly for use in specific bounded applications where the cable assembly does not meet the stringent requirements described herein because it is known that other components in the link (for example the receivers) are better than required by the standard. However, taking this same cable assembly into an open, unbounded application may cause link failures because worst case, but still compliant, components happen to be on the connected ports.

The other major opportunity exposed by the methods described herein is the possibility of gaining considerable additional utility from cable assemblies (including installed fiber) by actually knowing what their capability is rather than assuming everything is worst case. Conditions have been described where the lowest performing fibers, for example ordinary 62.5 micron MM, can be used at over 10 times the normally specified length if certain properties of the transmitters and connectors are carefully monitored.

The methods described herein require that one know certain properties of the connectors on the transmitter and receiver devices (or test fixtures) before assuming the observed behavior is due to the properties of the cable assembly under test.

Acknowledgement: This document especially benefited from the technical contributions of Paul Mayercik. Numerous other people also contributed but Paul’s contribution was by far the largest.

2. Definitions and abbreviations

In order to minimize confusion this document considers all of the following terms to be equivalent: patch cord, jumper, and cable assembly. The term cable assembly is used consistently throughout.

Cable assembly - jacketed optical fiber with connectors attached at each end

Compensating degradation - property of the measurement process whereby the measurement result is unintentionally improved by the measurement fixture; i. e. the measurement fixture compensates for the degradation in the IUT

Connector - half of a pair of intermatable elements used for purposes of enabling separation at the mating interface

Fiber mating interface - the parts of the fiber in a connector that directly interact with the fiber in the opposing connector

Link - the optical path between the optical source and optical receiver

Interconnect Under Test (IUT) - the entire optical path between one connector and the other connector in a single cable assembly or between the connector on one end and the connector on the other end in a concatenation of multiple cable assemblies

Instrument - a combination of associated hardware and software that is used to produce a measurement result. It is not required that all the components of an instrument be within the same enclosure.

Measurement result - (generally used interchangeably with the term “measurement”) is the output of an instrument, as presented to the user, that is derived from the stimulus applied to (or through) the IUT. The instrument may execute calculations and conversions internally prior to presenting its output. There are no pass/fail criteria for measurements.

Measurement type - is determined by the nature of the stimulus used in the measurement. If pulse stimulus is used then the measurement is time domain. If sinusoidal stimulus is used then the measurement is frequency domain. The form of the display of the output does not define the measurement type.

Test - the process of executing a measurement of a property of an optical interconnect and comparing the result to a set of defined pass/fail limits.

Following is a more comprehensive selection of definitions that are useful when discussing optical interconnect technology. These definitions may or may not be used in this document.

1x9: A reference to an optical transceiver’s electrical pin configuration. This configuration is one row of 9pins. For Ethernet and Fibre Channel, this term in synonymous with a transceiver with an SC optical interface.

2x5: A reference to an optical transceiver’s electrical pin configuration. This configuration is 2 rows of 5pins. For Ethernet and Fibre Channel, this term is synonymous with a small form factor transceiver with an LC, MT-RJ or SG-45 optical interface.

2x10: A reference to an optical transceiver’s electrical pin configuration. This configuration is 2 rows of 10pins. The additional pins allow for the functionality of the GBIC (serial ID etc) to be included in a small form factor. For Ethernet and Fibre Channel, this term is synonymous with a small form factor transceiver with an LC, MT-RJ or SG-45 optical interface.

8B/10B encoding: A signal modulation scheme in which 8 bits are encoded into a 10-bit word. Encoding is used to ensure some maximum number of consecutive ones or zeros in a serial data stream. This maximum number is important to keep a DC balance signal and sufficient transitions to keep the link locked. 8B/10B encoding results in a 25% overhead on the signaling rate and is used by Ethernet and Fibre Channel protocols.

64B/66B encoding: A signal modulation scheme in which 64 bits are encoded into a 66-bit word. Encoding is used to ensure some maximum number of consecutive ones or zeros in a serial data stream. Thismaximum number is important to keep a DC balance signal and sufficient transitions to keep the link locked. 64B/66B encoding results in a 3% overhead on the signaling rate and is used by 10 Gigabit Ethernet and 10 Gigabit Fibre Channel protocols.

Absorption: That portion of fiber optic attenuation resulting from conversion of optical power to heat. The primary cause of absorption is due to impurities.

Acceptance angle: The angle over which the core of an optical fiber accepts incoming light. The angle creates a cone measured around the fiber axis.

Analog: Signals that are continually changing, as opposed to being digitally encoded.

Angle of incidence: The angle between an incident ray and the normal to a reflecting or refracting surface.

Angular misalignment loss: The optical power loss caused by angular deviation from the optimum alignment of source to optical fiber resulting in additional light falling outside the acceptance angle.

Aramid yarn: A tensile strength element used in cable assemblies to provide support and additional protection to the fibers. Kevlar is a particular brand of Aramid yarn.

Asynchronous Transfer Mode (ATM): A data standard (protocol) that uses many of the same data rates as SONET.

Attenuation Coefficient: Characteristic of the attenuation of an optical fiber per unit length, in dB/km.

Attenuation: The reduction in optical power caused by absorption and scattering as it passes along a fiber, usually expressed in decibels (dB). See optical loss. *******

Attenuator: A device that reduces signal power in a fiber optic link by inducing loss.

Average power: The optical power of a modulated signal measured over time.

Back reflection, optical return loss: Light reflected from the cleaved or polished end of a fiber caused by the difference between the refractive indices of air and glass. Typically 6% of the incident light is reflected back towards the source at an air/fiber interface. Expressed in dB relative to incident power.

Backscattering: The scattering of light in a fiber back toward the source, used to make OTDR measurements.

Bandwidth: The maximum signal frequency or bit rate within which a fiber optic component, link or network will operate before incurring a 3dB optical loss. The modal bandwidth of an optical fiber is a function of its length and therefore expressed in units of MHz-km.

Baud: A unit of signaling speed indicating the maximum number of times per second the state of the signal can change. ******

Bend Radius: A minimum bend radius is the smallest radius a fiber can be bent without incurring additional losses. For cable assemblies, an industry rule of thumb is that the minimum bend radius is 10x the cable diameter for an installed cable not under stress.

Bending loss, microbending loss: Loss in fiber caused by stress on the fiber bent around a restrictive radius. Microbending losses are caused by small distortions of the fiber frequently induced by poor cable management techniques.

Bit-error ratio / Bit error rate (BER): The fraction of data bits transmitted that are received in error. Often expressed as a ratio, the bit-error ratio is the number of received bits that are different from those transmitted, divided by the total number of transmitted bits.

Bit: An electrical or optical pulse that represents binary information.

Buffer: A protective layer over the fiber, such as a coating, an inner jacket, or a hard tube. The fiber strand is initially coated with a 250-micron acrylate polymer coating. For indoor cables, the fiber is then covered with a tight polymer buffer 900 microns in diameter to further protect the fiber during assembly and installation. Both coatings can be color coded for identification purposes in multiple fiber assemblies.

Cable assembly: Specifically optical cable assembly - the combination of a fiber optic cable and the optical connectors installed on both ends. If a connector is attached to only one end of the fiber, the construction is commonly referred to as a pigtail. Pigtails are useful only when combined with other components (such as active optical sources). HSOI does not consider the performance of optical pigtails since they are intrinsically part of more complex, active assemblies. Optical cable assemblies are sometimes referred to as “jumpers” or “patch cords”.

Cable Plant, Fiber Optic: The combination of fiber optic cable sections, connectors and splices forming the optical path between two terminal devices.

Center Wavelength (optical transmitter): The value of the central peak wavelength of the modulated device. This is the wavelength where the effective optical power resides. Optical transceivers of interest have center wavelengths of approximately 850nm, typically for short reach (<300meters) applications; 1310nm typically for mid reach (2-10km) applications; and 1550nm typically for long reach (>40km) applications.

Channel Insertion Loss: That portion of the total loss budget associated with the passive losses in the link. These losses include the fiber attenuation, and losses through connectors and splices.

Chromatic dispersion: The temporal spreading of a pulse in an optical waveguide caused by the wavelength dependence of the velocities of light.

Cladding: The lower refractive index optical coating over the core of the fiber that "traps" light in the core by maintaining an acceptance angle for total internal reflection.

Cladding mode: A mode that is confined to the cladding, a light ray that propagates down the cladding. Attenuation is very high in the cladding; therefore cladding modes are eliminated after a few meters.

Cleaving: The controlled breaking of a fiber so that its end surface is smooth in preparation for splicing or connectorizing.

Connector: A device that provides a re-mateable connection between two fibers or a fiber and an active device and provides protection for the fiber.

Core: The center of the optical fiber through which light is transmitted. The most common core diameters are 50 or 62.5 micron for multimode fiber and 9 micron for single-mode fiber.

Cutoff wavelength: The wavelength beyond which single-mode fiber only supports one mode of
propagation.

Dark current: The thermally induced current that exists in a photodiode used in an optical receiver in the absence of incident optical power.

Decibel (dB): A unit of measurement of power that indicates relative power on a logarithmic scale. dB= 10*log(P1/P2). dBm is a decible referenced to 1 milliwatt optical power.

Detector: A photodiode that converts optical signals to electrical signals.

Dense Wavelength Division Multiplexing (DWDM): A technique for sending signals of several different wavelengths of light into a fiber simultaneously. The wavelengths are different by less than 1.0 nm.

Dichroic filter: An optical filter that passes light selectively according to wavelength.

Differential Modal Delay (DMD): See Dispersion. This effect is exacerbated when laser sources are used on multimode fiber. The IEEE802.3z working group on DMD estimated that 15-20% of installed (pre- 1998) 62.5 micron multimode fiber exhibited significant DMD when excited with laser sources. This limited the achievable link distances with 850nm sources and resulted in the required use of a special mode conditioning (offset) launch optical cable assembly between the optical transmitter and the rest of the link when using 1300nm sources on multimode fibers for Gigabit Ethernet applications.

Dispersion: The temporal spreading of a pulse in an optical fiber. Modal or chromatic effects are the primary causes. Modal dispersion is due to the difference in the propagation velocities and distances traveled by the many modes in a multimode fiber. At signaling rates greater than 1Gbaud, it is often the limiting factor for achieving links of reasonable lengths in 62.5 micron fiber. 50 micron fiber propagates fewer modes, resulting in less dispersion and longer distances for the same baud rate. Chromatic dispersion is due to the difference in propagation velocities of various spectral components or “colors” of an optical source.

Dispersive reference fiber (DRF): An optical cable assembly comprised of fiber that has been verified to have known distribution of optical pulse broadening at different radial positions of the highly constrained (spot size, single mode launch conditions) launch optical signal. The dispersive reference fiber is used as a test load for signal degradation tests on optical cable assemblies.

Duplex cable assembly: A two-fiber cable assembly suitable for duplex (2-way) transmission.

Duplex operation: Transmission on a data link in both directions. Half duplex refers to transmission in a time-shared mode; only one direction can transmit at a time. With full duplex there can be transmission in both directions simultaneously. The HSOI document is concerned mainly with full duplex operation.

Erbium-doped fiber amplifier (EDFA): An all-optical amplifier for 1550nm SM transmission systems.

Edge-emitting diode (E-LED): An LED that emits from the edge of the semiconductor chip.

End finish: The quality of the end surface of a fiber prepared for splicing or terminating in a connector.

ESCON: IBM standard for connecting peripherals to a computer over fiber optics. ESCON is an acronym for Enterprise System Connection.

Extinction Ratio: The ratio of the output power of a transmitter in the logic ‘1’ state to the output power in a logic ‘0’ state expressed in dB. Optical modulation amplitude, which is expressed as the difference between these powers in microwatts, is preferred.

FC Connector: A connector primarily utilized for single-mode fiber optic cable. It features a position locatable notch and a threaded receptacle. Once installed, the position is maintained with high accuracy.

Ferrule - A component of a connector or mechanical splice that holds a fiber in place and aids in its alignment. It is usually cylindrical in shape with a tightly toleranced hole through the center. Most cylindrical ferrules are made of ceramic.

Fiber bandwidth: The lowest frequency at which the magnitude of the fiber transfer function decreases to half, or –3dB of the zero frequency value. Fiber bandwidth is dependent on the wavelength and launch conditions of the source. Existing fiber is measured with an overfilled launch condition, similar to an LED source. Restricted Mode Launch, similar to a Laser source, tested fiber is also now available.

Fiber Distributed Data Interface (FDDI): 100 Mb/s ring architecture data network.

Fiber identifier: A device that clamps onto a fiber and detects light from the fiber by bending the fiber in excess of its minimum bend radius. The identifier can detect high speed traffic of an operating link or a 2 kHz tone injected by a test source.

Fiber optics: Light transmission through flexible transmissive fibers for communications or lighting.

Fiber tracer: An instrument that couples visible light into the fiber to allow visual checking of continuity and tracing of connections.

FO: Common abbreviation for "fiber optic."

Fresnel reflection, back reflection, optical return loss: Light reflected from the cleaved or polished end of a fiber caused by the difference of refractive indices of air and glass. Typically 6% (12dB) of the incident light is reflected back at an air glass interface.

Fusion splicer: An instrument that splices fibers by fusing or welding them, typically by electrical arc.

Gigabaud Link Module (GLM): A transceiver form factor that converts an 8 bit parallel electrical signal to a serial optical signal. At signaling rates of 1.0625/1.25Gbaud, a GLM uses an SC optical connector.

Gigabit Interface Converter (GBIC): A pluggable transceiver form factor that converts a serial electrical signal to a serial optical signal. A GBIC includes a side band accessible EPROM for vendor related information. At signal rates at 1.0625/1.25Gbaud, a GBIC uses a 20-pin electrical connector and an SC optical connector.

Graded index (GI)fiber: A type of multimode fiber that uses a graded refractive index profile in the core material to partially compensate for modal dispersion. This is the multimode fiber type in common use today.

Index of refraction: A property of light transmitting materials defined as the ratio of light velocity in a vacuum to its velocity in a given transmission medium.

Index matching fluid: A liquid or gel with a refractive index similar to that of glass used to eliminate air gaps and match the materials at the ends of two fibers to reduce loss and back reflection.

Index profile: The refractive index of a fiber as a function of position from the geometric center of the core. The profile is typically parabolic to average the propagation velocities.

Insertion loss: The passive loss caused by the insertion of a component such as a cable, splice or connector in an optical link and therefore a portion of the link loss budget.

Intersymbol interference: The effect of dispersion in a bandwidth limited medium causing pulse spreading to the extent that one data bit interferes with the following bit. A major contributor to deterministic jitter caused directly by optical cable assemblies and indirectly by the launch conditions from one optical cable assembly into another.

Jacket: The protective outer coating of the cable.

Jitter: The deviation from the ideal timing of a signal when the signal crosses a specified amplitude level (frequently the nominal receiver switching threshold level). Jitter exists as a combination of deterministic (bounded in size) and Gaussian (random) contributors. Optical cable assemblies only contribute to the deterministic jitter in a link.

Jumper or jumper cable: A single-fiber optical cable assembly with connectors on both ends. Preferred terminology is “optical cable assembly”. Jumpers are usually short compared to fiber installed between rooms or between buildings but may be many meters long. Equivalent to “patch cord”.

Laser diode (ILD): A semiconductor device that emits, coherent light within a narrow range of wavelengths when stimulated by an electrical current. Used in transmitters at baud rates above 1Gbaud for both multimode and single-mode fiber links.

Launch cable: A known good fiber optic jumper cable attached to a source and calibrated for output power used for loss testing. This cable must be made using fiber and connectors of a matching type to the cables to be tested.

LC Connector: A connector type used with both multimode and single-mode fiber optic cables. It is a small form factor connector that provides for accurate alignment using a ceramic ferrule that is one half the diameter of those used in SC connectors.

Light-emitting diode (LED): A semiconductor device that emits light when stimulated by an electrical current. LEDs are used in transmitters for baud rates below 1Gbaud.

Link, fiber optic: A combination of transmitter, receiver and fiber optic cable(s) connecting them and which are capable of transmitting data. Fibre Channel assumes a duplex configuration when defining a link.

Long wavelength: A commonly used term for light in the 1300 to 1550nm range.

Loss, optical: The amount of optical power lost as light is transmitted through fiber, splices, couplers, etc.

Loss budget: The amount of power loss that can be tolerated by a given link. The total loss budget or link power budget is defined as the difference between the minimum launch power of the transmitter and the minimum receiver sensitivity.

Margin: Specifically link power margin - the additional or un-allocated amount of loss that can be tolerated in a link.

Mechanical splice: A semi-permanent connection between two fibers made with an alignment device and index matching fluid or adhesive.

Micron (um): A unit of measure, 10^{-6} meter, used to specify the wavelength of light, and the dimensions of fiber and connectors.

Microscope, fiber optic inspection: A microscope used to inspect the end surface of a connector for flaws or contamination or fibers for cleave quality. Magnification levels of 100-200x are sufficient to observe flaws or contamination that would adversely affect link performance. At higher levels of magnification, polishing marks that typically do not affect performance will be observed.

Modal bandwidth: A measurement of the portion of the total bandwidth in multimode fiber that is due to modal dispersion. Multimode fiber is characterized by its modal bandwidth in two windows at wavelengths of 850 and 1300nm.

Modal dispersion: The temporal spreading of a optical pulse caused by differences in propagation time for light propagating in different modes in a multimode fiber.

Mode field diameter: A measure of the region that supports the propagation of light in single-mode fiber. The mode field diameter is slightly larger than the actual core and is a function of wavelength.

Mode: A single electromagnetic field pattern traveling in a fiber. A single ray of light traveling in a fiber.

Mode filter: A device that removes optical power from the higher order modes in fiber.

Mode scrambler: A device that mixes optical power in fiber to achieve equal power distribution in all modes.

Mode stripper: A device that removes light in the cladding of an optical fiber.

MTP Connector: A ferrule-based connector capable of supporting up to 12 fibers today. A 24-fiber ferrule is in development.

Multimode fiber: A fiber with a core diameter much larger than the wavelength of light transmitted thereby allowing many modes of light to propagate. Multimode fibers have lower bandwidth than single-mode fibers, but the larger core diameters are more tolerant to contamination and misalignment making it a preferred solution for interconnects within a data center. The common core diameters of multimode fiber are 50 and 62.5 microns.

Nanometer (nm): A unit of measure, 10^{-9} meter, used to specify the wavelength of light.

Network: A system of cables, hardware and equipment used for communications.

Numerical aperture (NA): A measure of the light acceptance angle of the fiber or its light gathering ability.

Optical cable: One or more optical fibers enclosed in protective coverings and strength members.

Optical coupler: An optical device that splits or combines light from more than one fiber.

Optical fiber: An optical waveguide, consisting of a light carrying core and a cladding to trap the light in the core.

Optical loss test set (OLTS): An instrument set for optical loss measurements of the fiber and connectors in a link. The test set includes both an optical source and a power meter.

Optical modulation amplitude (OMA): The absolute difference between the optical power in the logic one level and the optical power in the logic zero level.

Optical power: The amount of radiant energy per unit time, expressed in units of Watts or on a logarithmic scale, in dBm (where 0dBm = 1 milliwatt) or dB (where 0dB= 1 microwatt).

Optical return loss, back reflection: Light reflected from the cleaved or polished end of a fiber caused by the difference between the refractive indices of air and glass. Typically 6% of the incident light is reflected back towards the source at an air/fiber interface. Expressed in dB relative to incident power.

Optical switch: A device that routes an optical signal from one or more input ports to one or more output ports.

Optical time domain reflectometer (OTDR): An instrument that uses backscattered light to find faults, splices, and connectors in optical fiber and to measure loss.

Optical window: Wavelength range of a fiber with a very low attenuation. Multimode fiber is specified with sources that work in the first window at 850nm or in the second window at 1300nm. Single-mode fiber is specified with sources that work in the second window at 1310nm or third window at 1550nm.

Overfilled launch: A condition for launching light into the fiber where the incident light has a spot size larger than the NA accepted by the fiber, thus filling all the modes in the fiber. This is the launch condition that is often used to characterize a fiber’s optical bandwidth.

Parallel Optics: A common term for multiple transmitters and/or receivers in one package. The most common configuration today is 1x12; 12 transmitters or 12 receivers in one package.

Patch Cord: An optical cable assembly that is used to connect equipment together, directly or through the use of a patch panel. Indistinguishable from any other type of optical cable assembly. This document discourages the use of the term “patch cord” as the term implies special properties.

Patch Panel: A facility enabling the termination and interconnection of cables to assist in the administration of moves or changes. Interconnections are made with either patch cords or jumpers.

Photodiode: A semiconductor that converts light to an electrical signal, used in fiber optic receivers.

Physical contact (PC) connector: A connector designed with a radius tip to ensure physical contact with the fiber thereby decreasing optical return loss. The SC and LC connectors are examples of physical contact connectors.

Pigtail: A short length of fiber attached to a fiber optic component such as a laser or coupler. A pigtail is usually connectorized at one end.

Plastic optical fiber (POF): An optical fiber made of plastic.

Plastic-clad silica (PCS) fiber: A fiber made with a glass core and plastic cladding.

Plenum: The breathable air handling space between walls, under structural floors and above drop ceilings. This can be used to route intra-building cabling.

Plenum cable: Fiber optic cable whose flammability and smoke characteristic allow it to be routed in a plenum area without being enclosed in a conduit. The cable is OFNP (Optical Fiber Non-conductive Plenum rated).

Power budget: The difference (in dB) between the transmitted optical power (in dBm) and the receiver sensitivity (in dBm).

Power meter, fiber optic: An instrument that measures the optical power emanating from the end of a fiber.

Preform: The large diameter glass rod from which fiber is drawn.

Receive cable: A known good fiber optic jumper cable attached to a power meter used for loss testing. This cable must be made using fiber and connectors, which match the cables to be tested.

Receiver: A device containing a photodiode and signal conditioning circuitry that converts light to an electrical signal in fiber optic links.

Receiver sensitivity: The minimum acceptable value of average received power at the fiber optic cable receiver point, in order to achieve an acceptable Bit Error Rate.

Refractive index: A property of optical materials that relates the velocity of light in a vacuum to the velocity of light in the material.

Repeater, regenerator: A device that receives a fiber optic signal and regenerates it for re-transmission, used for very long fiber optic links.

Riser: The air handling space between floors. It is normally a vertical shaft.

Riser cable: Fiber optic cables whose flammability and smoke characteristic allows it to be routed in a riser area without being enclosed in a conduit. The cable is OFNR (Optical Fiber Non-conductive Riser rated).

SC Connector: A connector type used with both multimode and single-mode fiber optic cables. It offers low cost, simplicity and durability and provides for accurate alignment using a ceramic ferrule It is a push on-pull off connector. With an appropriate coupler, an SC connector mates with an FC or ST with the same PC ferrule.

Scattering: The change of direction of light after striking small particles. This causes loss in optical fibers.

Short wavelength: A commonly used term for light in the 665, 790, or 850nm ranges.

Single-mode fiber: A fiber with a small core, only a few times the wavelength of light transmitted, that only allows one mode of light to propagate. Commonly used with laser sources for high speed, long distance links.

SONET: Synchronous Optical Network.-An international standard for fiber optic cable based telephony.

Source: A laser diode or LED used to inject an optical signal into a fiber.

Small Form Factor (SFF) transceiver: An optical transceiver that is approximately 1/2 the width of the typical 1x9 device. A small form factor device may be a leaded device (requiring being soldered to the board) or may be connectorized at the electrical side. For example, the a small form factor pluggable (SFP) device.

Spectral width: The spread of the wavelength content of an optical spectrum. It is usually based upon the 50% intensity points. When referring to the spectral width of sources, typical spectral widths are 20 to 60nm for a LED and less than 1nm for a laser diode.

Splicer (fusion or mechanical): A device that connects two fibers, typically intended to be permanent.

Splitting ratio: The distribution of power among the output fibers of a coupler.

Steady state modal distribution: Equilibrium modal distribution (EMD) in multimode fiber, achieved some distance from the source, where the relative power in the modes becomes stable with increasing distance.

ST connector: A keyed bayonet connector type similar to a BNC connector. It is used for both multimode and single-mode fiber optic cables. It is widely used in premises wiring and is a push in and twist type connector.

Step index fiber: A multimode fiber where the core is all the same index of refraction. This type of fiber is subject to significant modal dispersion and is not used in today’s environments.

Surface emitter LED: A LED that emits light perpendicular to the semiconductor chip. Most LEDs used in data communications are surface emitters.

Talkset, fiber optic: A communication device that allows conversation over unused fibers.

Termination: Preparation of the end of a fiber to allow connection to another fiber or an active device, sometimes also called "connectorization".

Test cable: A short single fiber jumper cable with connectors on both ends used for testing. This cable must be made of fiber and connectors of a matching type to the cables being tested.

Test kit: A kit of fiber optic instruments, typically including a source, power meter, and test accessories used in the measurement of loss and power.

Test source: A laser diode or LED used to inject an optical signal into fiber for testing loss in the fiber or other components.

Total internal reflection: Confinement of light in the core of a fiber through 100% reflection off the core-cladding boundary.

Transmitter: A device that includes an LED or laser source and signal conditioning electronics, which is used to inject a signal into fiber.

Velocity of light: The velocity of light is 300,000 km/sec in a vacuum. In a physical medium it is slower and dependent on the refractive index and the wavelength.

Vertical Cavity Surface Emitting Laser (VCSEL): A type of laser that emits light vertically out of the chip, not out of the edge. This allows for the testing of the lasers in wafer form, reducing the cost. VCSEL devices are common in 850nm devices at speeds of 1-2.5 GBaud today.

Visual fault locator: A device that couples visible light into the fiber to allow visual tracing and testing of continuity. Some are bright enough to detect breaks in fiber through the cable jacket.

Watt: A linear measure of optical power, usually expressed in milliwatts (mW), microwatts (W) or nanowatts (nW).

Wavelength: A measure of the color of light, usually expressed in nanometers (nm) or microns (um).

Wavelength Division Multiplexing (WDM): A technique of sending signals of several different wavelengths of light into the fiber simultaneously.

XAUI: 10 Gigabit Attachment Unit Interface from IEEE802.3ae 10Gigabit Ethernet. XAUI (pronounced zow-ee) is an optional interface of 4 serial, differential lanes, designed to extend the reach of the 10Gigabit electrical interface to approximately 20” on standard PCB. This interface will be applied to 10 Gigabit Fibre Channel.

XENPAK: 10Gigabit z-axis pluggable device. This device uses an SC optical interface, a 4 lane XAUI electrical interface and supports the IEEE802.3ae and NCITST11.2 10Gigabit compliant devices.

XGP: 10Gigabit Pluggable device. This package form factor is still being defined. It is expected to be about half the size of the XENPAK, z-axis pluggable with an SC connector and 4 lane XAUI electrical interface. It will not support the 1550nm externally modulated transceiver.

3. References

Fiber Optic test and measurements edited by Dennis Derickson, Prentice Hall PTR Upper Saddle River NJ 07458 ISBN 0-13-534330-5 (Ph 800 382-3419)

Fiber Optic Communications by Joseph C. Palais, Chapter 8

List of EIA documents shown in Annex C

4. General

4.1 Overview

Clause 4 describes topics that apply to the approach used in this document. The major headings consider:

- Requirements for linearity and time domain measurement types
- Use of the term ‘high speed’
- Definition of the basic unit under test
- Some general requirements for HSOI performance specifications
- Risks associated with calibration strategy, test fixtures, incomplete specifications, angularity, and spatial confinement

4.2 Requirements for linearity and time domain measurement types

Any type of time/frequency conversion requires that the interconnect behave linearly (meaning, for example, that the index of refraction does not depend on the intensity of the light). Linearity is assumed for all HSOI work due to the relatively low optical power associated with operation in either class 1 or class 1M. Instrumentation shall be operated in its linear region.

This document does not address frequency domain stimuli (measurement types - see Annex D). There are two reasons for this:

- unavailability of good quality sinusoidal optical sources over a broad frequency range
- linearity is not expected in either optical transmitters or optical receivers and this limits the ability to convert the frequency domain measurement into the time domain

Conversion of time domain measurement types into the frequency domain results (using software conversion) is valid provided that only the linear parts of the link are considered.

4.3 High Speed

The boundary where high speed measurement (as opposed to low speed measurement) becomes necessary is not sharp and this document does not attempt to define the boundary. The signals of interest in this document range from a few hundred MBaud to many GBaud. Measurement techniques for HSOI bidirectional optical interconnect in this speed range lack good standardization and methods especially in the bandwidth and connector loss areas. This deficiency leads to unintended incompatibilities between suppliers and users. Further, the specific conditions existing when a bidirectional connection is required, such as especially cross talk, are explicitly addressed. This document is not a general specification for measuring all high speed optical interconnect but rather is aimed at the architectures used in Fibre Channel, Gigabit Ethernet, 1394, Infiniband, and the like.

4.4 Basic unit under test

It is assumed that a completed cable assembly (jacketed optical fiber with connectors on both ends) constitutes the primary interconnect component of interest. The focus of this document includes all the effects of the connectors, of placing ferrule or other fiber constraining parts in housings, and of the effects deriving from the structure of the open fiber ends in the connector.

Test fixturing for testing optical fiber without connectors is not directly addressed in this document.

This document only addresses the optical link performance testing requirements for passive optical cable assemblies and specifically does not directly include transceivers. In general, the effects of system noise not directly part of the optical link under test also need to be considered when specifying test conditions for optical link performance. This system noise derives from the optical and electrical activity on the parts of the link not directly under test and from sources unrelated to the link itself.

For the most common constructions of bi-directional optical links, separate fibers are used for each direction of the signal. These constructions are intended to largely isolate the optical path under test from the portions not under test and also from the rest of the system. Whether this isolation is effectively achieved is part of the performance requirements.

Since optical signals have a direction, and optical fiber is approximately linear, one can envision implementations where the same fiber (using the same nominal wavelength) is used for transmission in both directions simultaneously. By detecting the difference between the known launched signal and the actual signal on the fiber one can, in principle, detect the received signal as the difference. In this type of implementation significant signal processing is required to do the separation and to handle noise. Since this type of implementation is quite complex and is not presently used for mainstream applications it is beyond the scope of SFF-8412.

The applications for the cable assemblies involved in this document assume that physically separate fiber is used to transport the signals in each direction. (The same fiber could be used for both directions by using different wavelengths for the transmitter on each end [using WDM techniques for separating the received light from the transmitted light]. There are significant signal to noise issues and implementation complexities with this scheme and it is not common. If such a scheme were used HSOI considers it to be the same as two separate fibers with the signal to noise specifications left to the application.)

Summarizing, the following properties describe the most important architectural features of HSOI interconnect addressed in this document:

Only two connectors, one on each end
At least two fibers per cable assembly (single fiber constructions may be measured using portions of the bi-directional methodologies)
Signals travel only in one direction on the fiber
Signals are traveling both directions at the same time on different fibers in the same cable assembly
Only analog optical signal properties are used to specify the performance of the cable assembly – no bit error rates apply

4.5 General requirements for HSOI performance

The general requirements are:

- For a launched signal into the cable assembly under test (as delivered to the fiber in the cable assembly under test) with the most degraded allowed parameters to traverse the fiber without further degrading beyond the allowed output specifications for the interconnect (at the exit of the fiber in the cable assembly under test).

- For the signal reflected back to the transmitter to be within the allowed specifications at the fiber interface where the signal was initially launched into the fiber. This measurement is done with a launched signal whose properties are the most aggressive allowed for producing reflections.

- For the interconnect to not export more noise to other parts of the system than specified (anti pollution requirements)

- To behave like a matched optical path for devices and other cable assemblies attached to the ends - this allows concatenation without excessive degradation

- To propagate light only in the core of the fiber

The received signal and exported noise are influenced by the properties of the launched signals, by the degradations occurring during the transmission process, and by the light exit conditions from the fiber in the cable assembly under test. The performance requirements apply in all allowed service conditions.

In the optical systems it is possible for reflections arriving back at the laser sources to affect the laser operation in addition to the primary effects of the reflections on the signals. Therefore the requirements to limit these reflections take on a greater significance than for the copper systems.

4.6 Risks and calibration strategy

4.6.1 Overview

Real launched signals always contain some level of imperfection so it is not practical to require perfect launch signals. Similarly it is essentially impossible to create a launched signal that is degraded to all the allowed limits at the same time. There is a requirement to accommodate these two facts into the testing strategy. Essentially there are four primary risks associated with this issue.

- Signal source characterization and calibration
- High frequency noise and filtering
- Performance specification methodology
- Test fixture compensation and calibration issues

Other risk areas are:
- Incomplete specification of measurement conditions
- Treatment of light angularity
- Assumptions concerning preservation of launched spatial patterns during transmission

Each of these is discussed in this sub-clause.

4.6.2 Signal source characterization and calibration

One primary risk comes from inadequately characterizing the launched signals used in the tests. Since the properties of the signals at the receiver are the only properties that matter to a configured and operating system, it is critical that the tests use launched signals into the interconnect that are the worst allowed. If launched signals used during the test are degraded more than that allowed then the interconnect will be called on to cause less degradation so that the result at the receiver will still be within specification. The use of excessively degraded launched signals places unfair burden on the interconnect.

Conversely, if the launched signals are better than allowed, the interconnect may cause more degradation than allowed for the interconnect but still deliver compliant signals to the receiver. This condition permits defective interconnect to be measured as good interconnect. The way to avoid these risks is to execute an adequate characterization of the launched signals and to compensate in the test requirements for the amount of excess goodness or badness in the launched signals. Figure 1 illustrates this general scheme.

It is the signal actually launched into the interconnect under test that counts. The differences between the signal coming out of the source and the signal delivered into the interconnect under test are considered in 4.6.5.

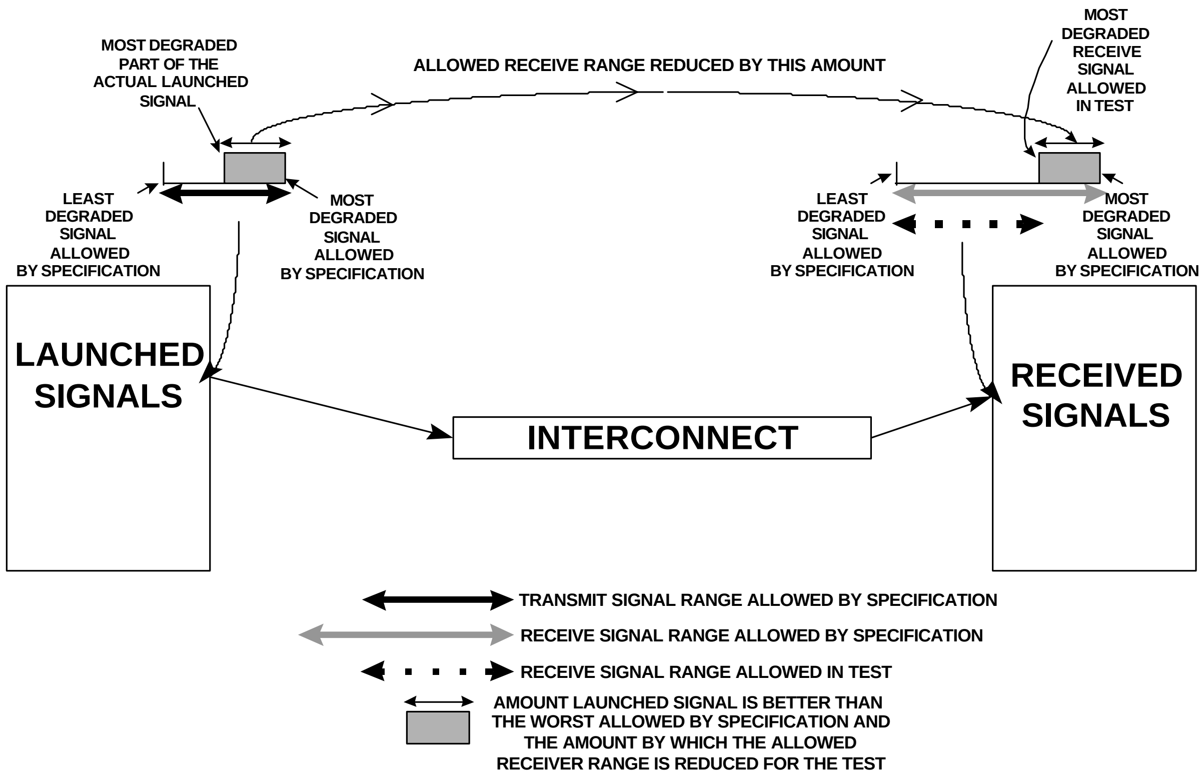


Figure 1 - General allowed range calibration strategy

During the calibration processes for the tests the properties of launched signals are measured. Procedures are specified that do not require the adjustment of the launched signal to the maximum allowed degradation. By noting how much degradation could be added to the actual launched signal before exceeding the maximum degradation and adding this difference to the requirements for the received signals one achieves the equivalent effect as actually degrading the launched signals as far as measuring the properties of the interconnect is concerned. Said differently, if the launched signals are better than allowed (as is usually the case) then the requirements on the received signals are tightened by the same amount that the launched signals were better. Similarly, if the launched signals are more degraded than allowed then the received signal range is broadened.

This process eliminates a major problem with creating calibrated degraded high frequency signals, uses the linear property of optical interconnect to good advantage, and allows the properties of the interconnect to be fairly and accurately measured. However, for optical systems additional calibration is needed as discussed in 4.6.5.

4.6.3 High frequency noise and filtering

The second primary risk is the modifications to the optical signal measurement processes that may be required to accommodate the behavior of real receivers and optical sources. Part of the characterization of the launched optical signals involves anticipating the bandwidth of the receiver to be used. This is required because some optical sources have significant high frequency content in the signal structures that will not be detected by receivers designed to reject high frequencies.

Present practice in standards documents requires the use of a low pass filter between the optical source and the instrument used to observe the optical signal. The fact that the properties of this filter depend mostly on the receiver (and the data rate) creates an undesirable relationship (for testing optical cable assemblies) between the launched signal requirements and the receiver being used that does not exist in the copper HSS testing (assuming that the copper receiver is not required to condition or process the received signal).

The use of a filter also creates the need to carefully specify and calibrate the filter itself since it is an intrinsic part of the measurement. If the filter properties can be determined based only on the data rate then some independence from the receiver is achieved. This requires separate test requirements for every data rate supported.

In order to avoid these intractable issues this document assumes that no filtering is required for HSOI measurements.

4.6.4 Performance specification methodology

Optical link performance is specified in some standards by placing a set of requirements on the launched signal and a different set of requirements on the received signal. These differences go far beyond the simple accounting for different values of the parameters that characterize the launched and the received optical signal. It is assumed that the behavior of the interconnect may be predicted by an optical link model and that various average launched power penalties may used to overcome the degradations occurring in the link including transmitter, receiver and interconnect effects.

Further, it is the present practice in some standards to ensure that the receiver itself is capable of operating satisfactorily with signals that “stress” the receiver beyond its nominal performance.

The methodology used in this document is based on direct measurement of the properties of both the launched and the received optical signals using the same parameter set with different allowed values. This scheme not only is free from the risks of applying models without validation for the specific optical interconnect under test, it also allows reuse of exactly the same equipment and measurement methodology for both the launched and received signals.

4.6.5 Test fixture compensation and calibration issues

The fourth primary risk derives from the fact that some parameters of signals launched into the interconnect can be seriously affected by the test fixture. In some cases the launched signal can be unintentionally improved if the test fixture compensates for the interconnect under test by introducing degradation of the parameter in the opposite sense. This type of degradation is termed compensating degradation. If compensating degradation is present it gives a false sense of goodness in the interconnect under test. When the same interconnect is used with launched signals from other test fixtures and transmitters having non-compensating degradation the resulting interconnect performance may be seen to be much worse.

In the copper case, compensating degradation is most likely due to balance of one sense in the launched signals being of the opposite sense from that caused by the interconnect under test. In the optical case a more mechanical compensation mechanism is likely. A simple example is the direction of mechanical misalignment between axis of the fiber cores in both sides of optical connectors. If the cores on the launched signal side and the core on the cable assembly side are both misaligned by the same amount in the same direction the fiber connection sees no misalignment. If the same cable assembly is tested with a test fixture connector that is misaligned by the same amount but in the opposite direction a major loss of light could occur through the connection. Compensating and non compensating degradations can exist from exactly the same laser but with different connectors.

Other compensating degradations involving the bandwidth performance of the optical cable assembly are also expected.

In the copper case compensating degradations are easy to detect and correct by simply reversing the connection sense and re-measuring as specified in SFF-8410. Granted, a small part of the degradation could be caused by different amounts of misalignment of the copper contacts with resulting slight changes in balance and contact resistance. But in the copper case there is generally only a single direction of misalignment possible. In the optical case there is a continuum of “directions” for the compensating degradation that may exist and that results in a more complicated detection and removal scheme. These schemes are described as part of the testing procedures.

In the optical case the basic approach described in this document is to define and use “golden” hardware for the test fixture side and to develop empirical and theoretical extrapolations to the worst case for application use. The failure limits during the test with the golden hardware are significantly more stringent than for the performance expected with worst case hardware.

Figure 2 shows that in addition to the properties of the optical source being better than allowed, the degradation caused by the test fixture being less than allowed also needs to be subtracted from the allowed receive signals.

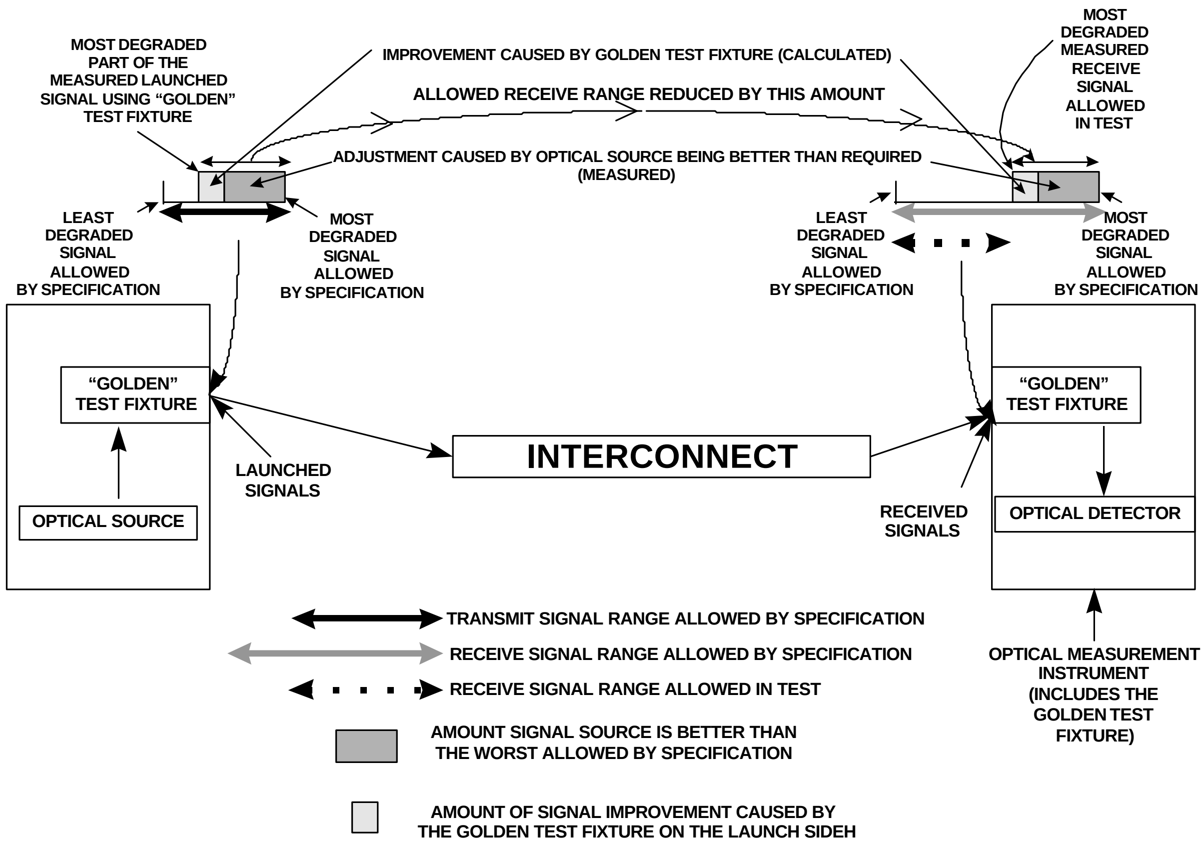


Figure 2 - Compensating degradation calibration strategy

When dealing with real optical systems one is faced with a variety of optical connectors that are incompatible with each other. All of the connectors listed in clause 4, for example, are incompatible. This condition invites the use of adapter connectors that allow sources and instruments to be used with a variety of connectors. If adapter connectors are used they introduce additional interfaces each of which is capable of introducing compensating or non-compensating degradation that must be accounted for.

For this reason it is desirable to design the test fixtures using the same type of optical connector (which needs to be a golden connector since it is part of the test fixture) used on the interconnect under test. If adapters are used then the connector that connects directly to the IUT shall be a golden connector on the adapter. This connector now becomes the new starting point for the test fixture.

Figure 3 illustrates the use of an adapter as part of a test fixture. FUT in this figure means 'fiber under test'. See 5.6.1.

Adapters may be the only practical approach for inputs to optical scopes and other expensive equipment. In this case, the adapters used shall be "calibrated" adapters (traditionally provided by the instrumentation manufacturer) that are considered part of the instrumentation.

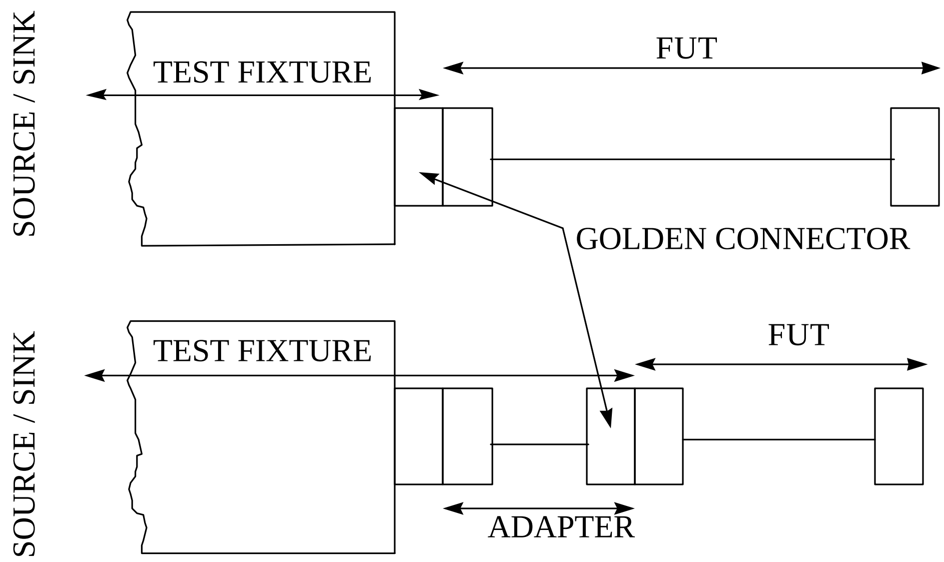


Figure 3 - Use of passive adapters as part of the test fixture

4.6.6 Complete specification of the testing conditions

Optical performance data is often presented without adequate specification of the conditions used for testing. This practice is not limited to optical systems and anytime the conditions used for testing are not adequately described the interpretation of the meaning of the data may not be accurate.

To illustrate the point, a set of typical advertised characteristic waveforms (in the form of eye diagrams) related to optical links were found by a member of the team that developed this document. Based on the information supplied with these waveforms the questions listed below were generated in the quest to determine the significance of the data. The particular link where the data was shown was a parallel fiber scheme.

1. Is this eye diagram display one channel, two channels or a superposition of all channels?
2. What kind of filtering was used?
3. Is signal shown optical out of the fiber or the electrical output of the optical receiver?
4. What are the properties of the launch signal? – specifically, was the launched signal worst case? – What are the effects of the connector at the launched end – Was an overfilled condition used? – purposely off center? – spatial distribution? – golden launch connector?
5. What is the fiber used?
6. What is the spatial distribution of the emitted light? Reference TIA FOTP 203 under development.
7. What is the angular content of the emitted light? [See explanation in clause 4.6.7]
8. Was a golden connector used on the receiving end?
9. How does the signal look with several connectors involved?
10. If this is the copper signal from the O/E, what did the raw optical signal look

like?

11. If a copper signal, how close was the received optical signal amplitude to the sensitivity limit of the receiver?
12. Is this with the stressed receiver optical input (jitter added to produce jitter at the specified limit)?
13. What was the data pattern?
14. Was there any applied stress on the optical connectors or the fibers at the time of the measurement?
15. If any effect of stress is detected, what moved with respect to what? [Without the answer to this question it is not possible to determine which part of the system is responsible for the effects]
16. Where in the tolerance ranges allowed for connectors, fibers, and assembly components such as epoxy did the test fixture fall?

All the areas exposed in the above list of questions need to be specified for accurate interpretation of optical cable assembly testing results. Without these specifications it is possible to make defective and inferior product appear good and to make superior product appear bad.

4.6.7 Angularity issues

When light emits from a fiber end in a connector the light has three properties: local intensity (measured in microwatts/mm^2), local position, and angle of emission. The angle of emission may have a first order effect on the bandwidth performance of other link elements if intimate fiber to fiber contact is not achieved.

There is presently no standard procedure for measuring the angular content. However, the basic idea is to map the intensity profile over different angular positions of the detector using a restricted aperture detector while masking all but the specific local areas of the fiber interface of interest.

This document does not call out any requirements for angular content.

4.6.8 Preservation of launched spatial patterns over distance

Launched spatial confinement may not be preserved under transmission through the fiber because mode conversion may occur during propagation. Preservation of the launched spatial pattern is not a specific criterion for HSOI performance. The effect of spatial confinement loss is included in signal degradation measurements.

4.6.9 Summary

The combination of real launched signal properties and interconnect properties causes additional burden on the testing process. The adjustment for real launched signals being better than worst case is likely to be a one time cost for the same transmitter and test fixture. Test methodologies that do not require optical link performance models for performance specification methodologies are needed.

The schemes to deal with the compensating / non- compensating measurements conditions require that some model for the intensity of the degradations exist. Multiple independent measurements are needed because one cannot be sure which “direction” of degradation is present in the interconnect under test.

The effect of filtering during measurement is an essential part of the calibration processes.

Complete specification of all relevant measurements conditions are required.

This document is perhaps the first attempt in the industry to bring all the requirements for predictably interoperable optical cable assemblies and links into a single place.

5. General requirements for HSOI measurements

5.1 Overview

This sub-clause specifies the high frequency performance requirements and measurement methods to be used for measurement and verification of properties of the interconnect. These requirements apply to the physical connector and to its signal neighborhood. See 5.5.

5.2 Consideration of mechanical influences

Since the performance of the mated connectors and the fiber itself can be affected by mechanical influences, understanding and specifying the following properties are part of the measurement condition requirements.

- the stresses placed on the fiber including effects of bend radius and total angular distortion (of the type experienced when using a mandrel)
- vibration of the fiber that affects the modal distribution or other optical properties is not important to HSOI because vibration induced effects occur at frequencies much lower than any frequency of interest and the bend radii stresses are more severe than any caused by small amplitude vibration.
- stresses on the connector housing that could affect the alignments and fiber spacing at the separable interface
- contamination of the interface
- mechanical stability in service including wear and dimensional stability of materials during temperature and humidity cycling.
- actual position in the allowed tolerances for both sides of the mated optical connector (including the retention elements on both sides)
- relationship of the fiber recess / protrusion properties at the mating interface of the fibers in both the test fixture connector and the FUT connector (this is important to assess whether any preferential mechanical locking is possible for the specific combination of test fixture and FUT)

Notice that if mechanical stress produces changes in the performance measurement then assessment of the root cause of the change is vital to determine whether the FUT, the test fixture, or the specific combination of this particular test fixture with this particular FUT is responsible.

5.3 HSOI measurement levels

Two broad levels of HSOI measurement are described:

5.3.1 Level 1 measurement (test) definition

Level 1 measurements are tests that are needed to ensure that the interconnect is capable of (a) transporting minimum integrity (maximum degradation) launched signals to the far end of the interconnect without excessive additional degradation to the launched signals and without exporting excessive interference to other parts of the system in the process and (b) to operate as an effective transmission line with HSS ports.

5.3.2 Level 2 measurement definition

Level 2 measurements are those that may reveal the source causes of degradations measured in level 1 measurements. Level 2 measurements are expected to be useful for designing and manufacturing interconnect components that satisfy level 1 tests but are not individually required as direct performance measures of the interconnect. It may be required to use specific level 2 tests to establish the test conditions for level 1 tests.

5.3.3 Relationship between level 1 and level 2 measurements

This separation of measurements into two levels is specified in detail in later sub-clauses. By separating the measurements requirements into the two different levels, resources may be more efficiently utilized compared with the former schemes that required all measurements to be individually satisfied. In effect, only the level 1 tests need be used to verify an interconnect for sale or use by both the supplier and the user. The level 2 measurements are available to the interconnect designer and manufacturer to more efficiently create designs and manufacturing processes that produce good interconnect. Figure 4 shows a graphical relationship between the two levels of measurements.

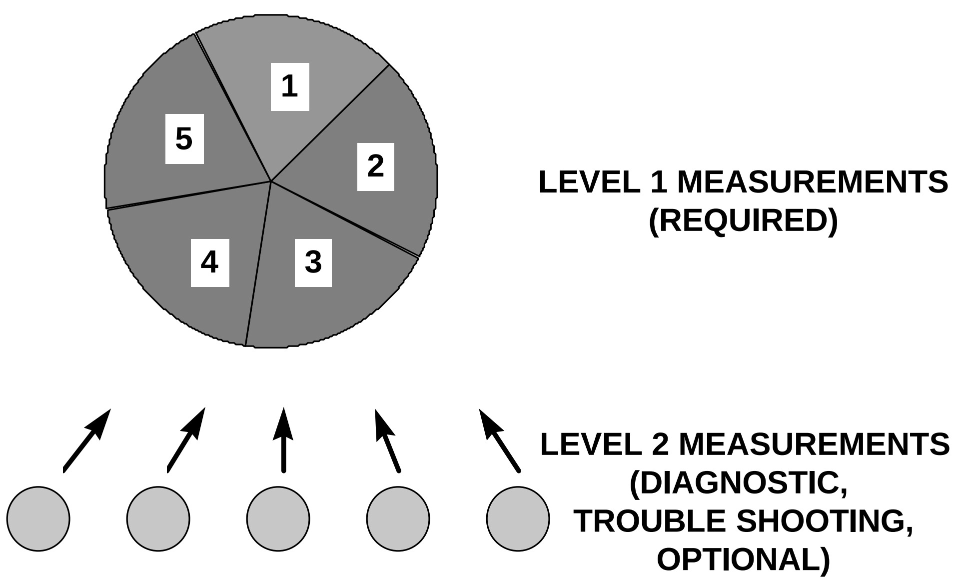


Figure 4 - Two levels of measurement for HSOI

5.4 Applicability to specific connectors

This document contains performance testing requirements for HSOI applications relating to the SC, ST, LC, SG, MT, MT-RJ, MU, FC, MPO, SMC, and other connector families. All of these except the FC have latching or detent type of retention and the user has no control over the forces existing on the optical interface in service. The FC connector has a twist screw retention that allows the user to adjust the mated pressure/stress on the interface to some degree. For this reason the FC connector has additional requirements on the torque of the retention for the tests in this document.

It is assumed in the measurement specifications that the connectors are used in a duplex connection where one fiber is propagating the high speed optical signal through the connector in one direction and fiber is propagating an asynchronous (to the first signal) optical signal through the connector in the opposite direction. Other connectors that may be defined in future specifications when used in a duplex signal application may also be subject to the requirements in this document.

It is a straightforward exercise to adapt the measurement requirements in this document to other optical transmission schemes such as (1) wave division multiplexing where different colors of light are simultaneously launched into the same fiber and (2) parallel fiber paths between the same end points.

5.5 Optical signal neighborhood

In the copper system an electrical neighborhood was defined in terms of the rise length of the signals. The electrical neighborhood is the physical distance away from the connector parts that must be considered during the measurements. Since the optical signal is modulated light the concept of rise length does not apply to most practical systems since the rise length is on the order of a wave length or around a micron. The optical signal neighborhood concept is more associated with the parts of the system that are capable of mechanically altering the fiber mating interface of connectors and of inducing mechanical vibrations or stresses into the fiber itself. For optical systems the properties of the signal neighborhood are largely mechanical, environmental and procedural. Signal neighborhood issues can affect any or all of the following:

- the fiber mating interface in the connectors
- optical signals in the fiber caused by deformation of the fiber (bend radius)
- noise that couples into the optical path
- reflections from splices and the far end of the link (even if it extends beyond the end of the cable assembly under test)

The close proximity signal neighborhood extends to the parts of the system that are capable of altering the fiber mating interface.

The total or extended signal neighborhood may reach far beyond the physical connector. Examples of extended signal neighborhoods are measurements that are affected bend radius well away from any connector and vibration of the fiber.

Features within the close proximity signal neighborhood may act as if they were part of the connector itself as far as contribution to the overall performance of the interconnect is concerned.

5.6 Definition of level 1 HSOI optical performance parameters

This sub-clause gives more detail concerning the level 1 performance requirements.

5.6.1 Definition of FUT and FUT_{NOT}

In the case of duplex cable assemblies there are two basic parts: (1) the half of the duplex containing the signal path under test and (2) the other half of the duplex containing the half NOT under test. The part that is under test is called the “fiber link under test” or the FUT. The part that is not under test is called the “fiber link not under test” or the FUT_{NOT}.

The FUT and the FUT_{NOT} each have an associated transmitter and receiver. Figure 5 illustrates the relationships.

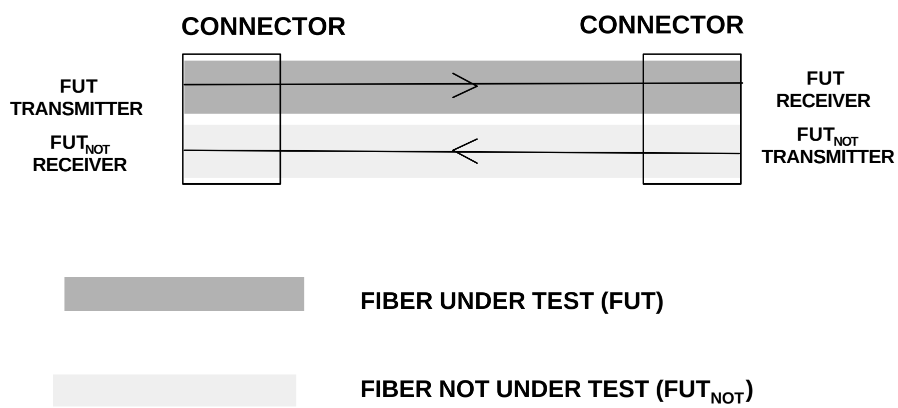


Figure 5 - Terminology for interconnect under test (duplex shown)

Figure 6 shows the conventions and abbreviations used for signals and instruments.

The interconnect under test is end to end and may include installed fiber and multiple cable assemblies. In order to minimize confusion this document considers all of the following terms to be equivalent: patch cord, jumper, and cable assembly. The term cable assembly is used consistently throughout.

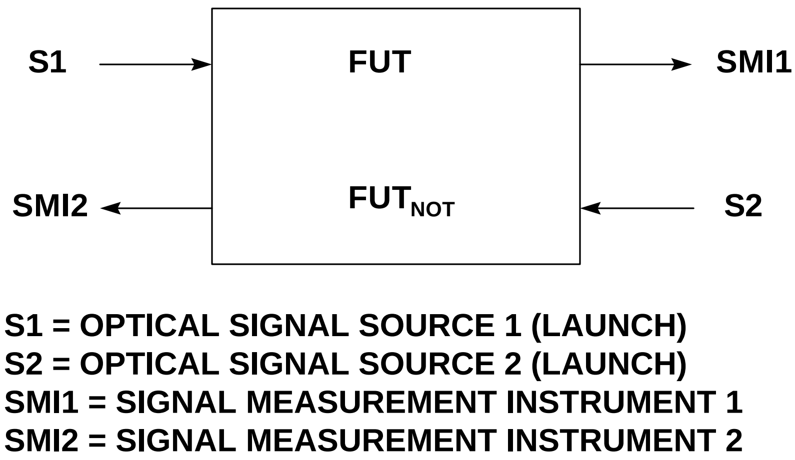


Figure 6 - Definition of abbreviations used for signals and instruments for output measurements (duplex construction shown)

The configuration shown in Figure 6 does not apply to reflection measurements and is limited to a duplex construction. For more complex constructions the general notation, Si (i = 1 to N) and SMIj (j = 1 to M) where N and M are the highest numbers that apply respectively.

5.6.2 Instrumentation filtering requirements

HSOI measurements are all specified without using any instrumentation filtering.

5.6.3 Definition of level 1 optical performance parameters

There are 5 level 1 electrical performance parameters defined. All 5 tests shall be satisfied for all FUT’s.

1. **Optical transmission signal degradation (signal degradation):** optical eye pattern comparison test where launched optical signals into the FUT having minimum allowed amplitude and maximum allowed jitter for transmitters are transferred through the FUT and an attached reference cable assembly. The reference cable assembly produces calibrated dispersion, jitter, and losses over a long distance so that the effects of the FUT on the link may be revealed. The output signal shall not lose amplitude or increase jitter beyond the allowed specification for the FUT.

   The FUT_{NOT} transmitter has asynchronous worst case signals (maximum amplitude) present during the testing. The signals from the FUT_{NOT} transmitter consist of data patterns with both a run length of at least 5 and run length of 1 – e.g. the K28.5 pattern or individually programmed patterns.

   Mechanical stresses near the connector and angular displacements of the fiber are applied during testing. A specified number of turns around a specified diameter round mandrel is required for the FUT while executing the test to simulate the effects of minimum bend radius in actual installations. The number of turns and mandrel diameters depend on the requirements for different IUT designs and applications. This test includes effects of attenuation, cross talk, dispersion, jitter, fiber bandwidth, and launched signal coupling into the fiber.

There are three launch conditions that may be used: (a) overfilled per TIA/EIA-455-54, (b) restricted per TIA/EIA-455-204 [23 micron], and (c,d,e) three different offset single mode launches. The offset shall be 0, 7.5 and 15 micron from the fiber center. Note that TIA/EIA-455-204 uses a 23.5 micron fiber to “filter” the overfilled launch condition described in TIA/EIA-455-54. This automatically prevents excessive power launched into the center of the FUT which could cause DMD.

2. **Optical signal reflection (signal reflection):** Signal reflections are generally concerned with optical energy returning to the transmitter from discontinuities and non-uniformities in the link. This is reverse direction average power measurement taken as a fraction of the launched unmodulated power that is returned to the source. Directional couplers are used to separate the incident from the reflected optical energy. Since reflections are due mostly to connectors, each connector in the assembly is tested separately by reversing the FUT and any contribution from the fiber is thereby somewhat overstated in the results.

3. **Cladding mode transmission/reflection:** Executed using a grossly offset launch into cladding only and measuring the optical power out the far end. If little transmission is detected then no significant cladding mode reflection is likely. If more than 1% of the launched power is detected in the transmission mode the FUT fails. If this test is passed then even very short cable assemblies should be acceptable. With modern fibers failure of this requirement is unlikely and routine testing would normally not be required.

4. **Near end cross talk, NEXT, (Quiescent noise):** the amplitude of the signal at the FUT_{NOT} receiver (adjacent to the FUT transmitter) when no signal is driven into the FUT_{NOT} receiver from the FUT_{NOT} transmitter. The signals from the FUT transmitter are individual isolated pulses that have the maximum permitted amplitude. With modern assemblies failure of this requirement is unlikely and routine testing would normally not be required.

5. **Propagation time and propagation time skew:** skew applies to wave division multiplexing and parallel fiber applications only. The propagation time is the time required for the midpoint of a signal transition to propagate between a physical input and physical output measurement point. The propagation time skew is the difference in the time required for the midpoint of the signal transition to simultaneously propagate down two nominally identical paths between an input and output measurement point. The propagation time skew for different modes within the same multimode fiber is part of the bandwidth reduction of the fiber and is not explicitly considered as skew in this document. Several hundred ns of skew is possible for long cable plants and for parallel constructions where the skew may scale with length. Skew may not scale with length. Skew shall be reported only on the specific lengths of interest.

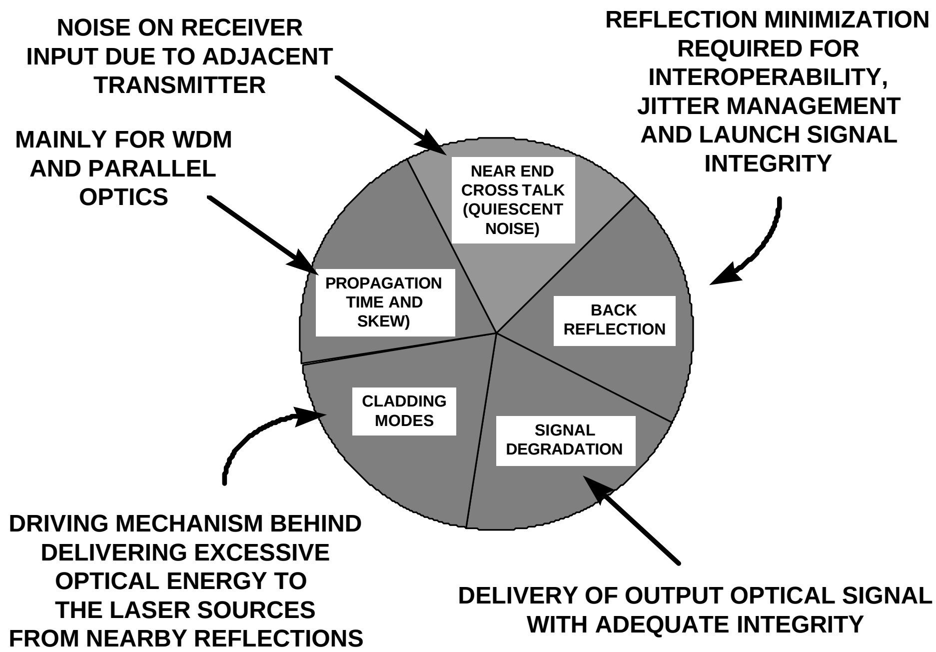


Figure 7 - Level 1 measurements

5.7 Definition of level 2 HSOI performance parameters

The twelve level 2 optical performance parameters listed in Figure 8 are described in this clause.

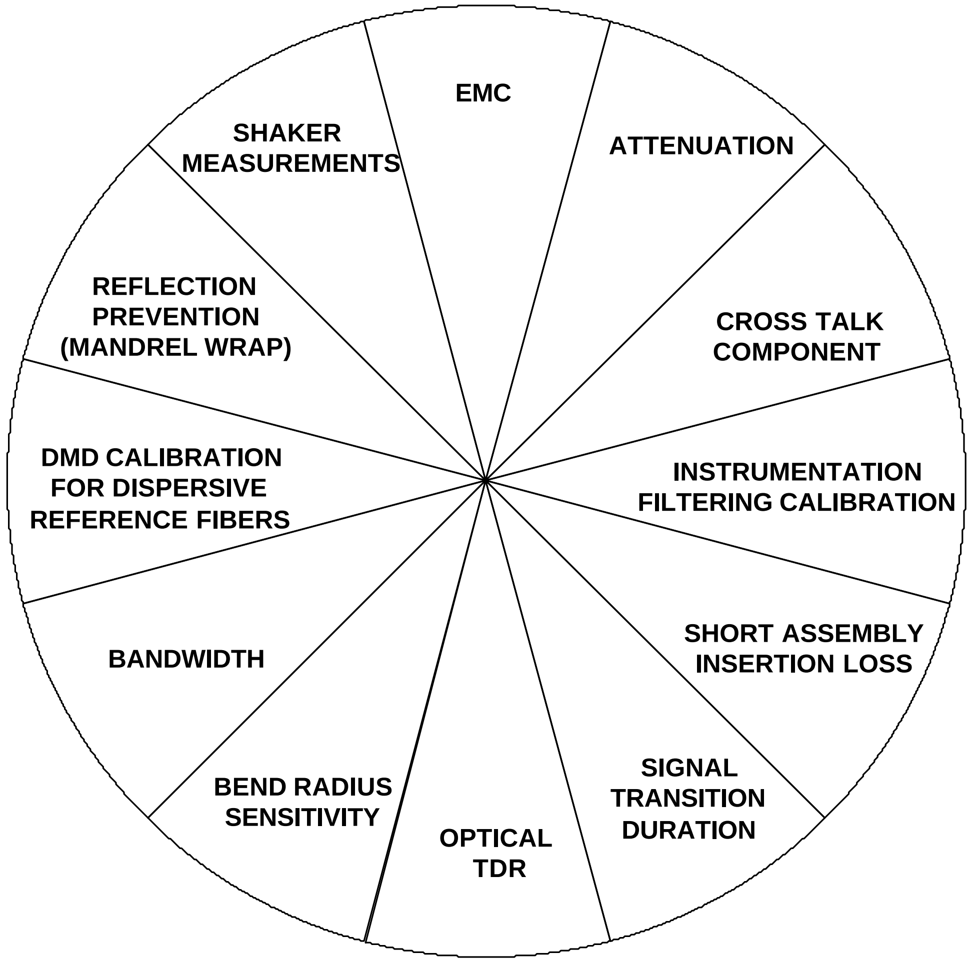


Figure 8 - Level 2 measurements

1. **Attenuation:** the ratio of output to input average power expressed in dB as measured by a power meter. Attenuation is a primary contributor to eye closure and intersymbol interference jitter. Attenuation in dB is expected to scale with length for cases where uniform fiber contributes virtually all of the loss.

   Attenuation is the ratio of output to input average power expressed in dB as measured by a power meter

   Insertion loss is the difference in output power with and without the IUT in place.

2. **Short assembly insertion loss:** the contribution of one mated connector pair in a cable assembly to the overall power loss. The isolation of the connector is possible in short assemblies because the fiber loss may be negligible. The length of the short assembly is such that the contribution to the attenuation from the fiber is negligible.

   Measuring the launch power requires attaching the power meter to an optical source through a mated pair. Placing a cable assembly between the source and the power meter adds an additional pair. The difference in power is effectively the contribution of one mated pair.

This measurement may not precisely isolate which connector has the high loss.

3. **Signal transition duration (rise / fall time):** the time required for an optical signal edge to traverse between 20 and 80 percent of the difference between the low level and the high level in a signal edge (rising edge) or between 80 and 20 percent of the difference for a falling edge – very important parameter in setting up the level 1 tests as it significantly affects the signal degradation measurements.

4. **Instrumentation filtering calibration (not normally required for HSOI):** There are two sources of high frequency noise in the HSOI transmission process: transmitters and differential modal delay in the fiber. Real optical receivers may be designed to filter the high frequency noise in order to meet the BER requirements. Instrumentation quality sources are used for HSOI testing so there is no intrinsic need to burden the cable assembly testing with filtering and associated calibration. The DMD noise is related to the launch conditions and the properties of the FUT and is an intrinsic part of the HSOI performance.

   HSOI signal degradation measurements are taken with no instrumentation filtering. This allows the HSOI cable assembly to be used with any receiver at the data rate regardless of the filtering properties of the receiver.

   If one knows that certain receiver filtering will be present in the application for the HSOI component then the filtering function used in the receiver (which must be known in advance from the receiver manufacturer) may be used in the signal degradation measurements. This method produces HSOI cable assemblies that may not work with other receivers.

5. **Cross talk component of signal degradation:** The effect of asynchronous signals on FUT_{NOT} on the signals in the FUT. Cross talk generally is minimal in defect free assemblies. However, optical leakage at connectors or in the fibers themselves can cause coupling between fibers with resultant cross talk. Cross talk degrades signal quality including increased jitter and amplitude parameters on the optical eye pattern. This effect is detected by removing the optical power on the aggressor signal and noting the effect, if any, on the output signal.

6. **Electromagnetic compatibility (EMC):** any effect of the HSOI assembly on the EMC is due to the method of attachment to the system or to the construction of the optical connector (e.g. metal content). EMC diagnostics, though important, need to be carried out in a systems context and specific measurement methodology is not defined in this document. See SFF-8410 for EMR (electromagnetic radiation) methodologies.

7. **Reflection prevention (mandrel wrap techniques):** Useful for preventing optical reflections by forcing the optical signal into the cladding where it is quickly lost. The general approach is to wrap the jacketed fiber around a mandrel until the optical output is eliminated. It may require many turns for some fibers and the thickness of jacket limits the radius that can be achieved. For some fibers, this technique does not work due to not being able to achieve sufficiently small bend radii. Mandrel wrapping induces some risk of damaging fibers by breaking. The larger the diameter of the mandrel the less the risk of breaking a fiber but the greater the chances that it will not be possible to eliminate the optical signal. Mandrel sizes range from around 0.25 inch to around 1 inch diameter and are hexagonal or square in cross section. The sharp corners are required to achieve adequately small local bend radii (microbends).

8. **Bend radius sensitivity for output optical signals using mandrel wrap techniques:** Useful for determining if a particular IUT is affected by bend radius. Round mandrels are used for this measurement due to requirement for repeatability. Wrap a specified number of turns of the IUT around a specified diameter mandrel to define a known stress condition. Uses for this measurement include: (a) comparing the performance of different fiber designs, (b) determining what it requires to cause significant signal degradation by bending, and (c) as a required part of the signal degradation test.

9. **Shaker measurement:** refer to TIA/EIA-455 for details of execution. The stress produced by the shaker affects very low frequency performance and is not relevant to the HSOI applications. Bending is included as part of the stress required in the signal degradation measurement. The bending around a mandrel far exceeds the stress produced by the TIA/EIA shaker test.

10. **Optical TDR measurement:** Same as copper TDR tests except that optical signals are used. Optical TDR is useful for measuring reflections and losses and determining the approximate position of features in the link. TDR measurements require access at only one end of the HSOI and are especially useful for long installed HSOI components.

11. **Bandwidth measurement:** The bandwidth of the link is formally the signal frequency (optical carrier modulation frequency) at which the modulated signal intensity drops to 3dB below its low frequency value. The bandwidth degradation is observable as a change of STD (signal transition duration) in the optical signal as it traverses the link. The amount of STD degradation is related to the bandwidth of the link. Common time domain approaches to the bandwidth measurement include: single edge STD degradation, Gaussian pulse degradation, or changes in other suitable wave shapes. Subsequent conversion into S21 is required to apply the 3 dB criterion.

    Note that no limiting amplifiers may be used in the optical receive instrumentation. The determined bandwidth may depend strongly on the details of the launch conditions. Three launch conditions are described: overfilled, RML (restricted mode launch), and single mode probe scan.

    TIA/EIA-455-204 describes the preferred methodology.

    The performance is measured at the end of a simulated link that contains the FUT.

12. **DMD calibration for dispersive reference fibers (DRF):**

DRF’s are required as optical loads for the signal degradation tests to ensure that the effect of the FUT on long links is quantified. DRF’s are specified to have certain distributions across the core of single mode launch pulse response. Two types of DRF are required: (1) where the bulk of the dispersion occurs close to the center of the core and (2) where the bulk of the dispersion occurs in higher order modes away from the center of the core. Methods are specified for determining when a candidate DRF is suitable for use as a type 1 or a type 2 DRF.

5.8 Basic requirements for executing a test

Each parameter has specific allowed ranges as determined from a test measurement. Each measurement requires:

- test fixturing to allow connection of instrumentation and FUT

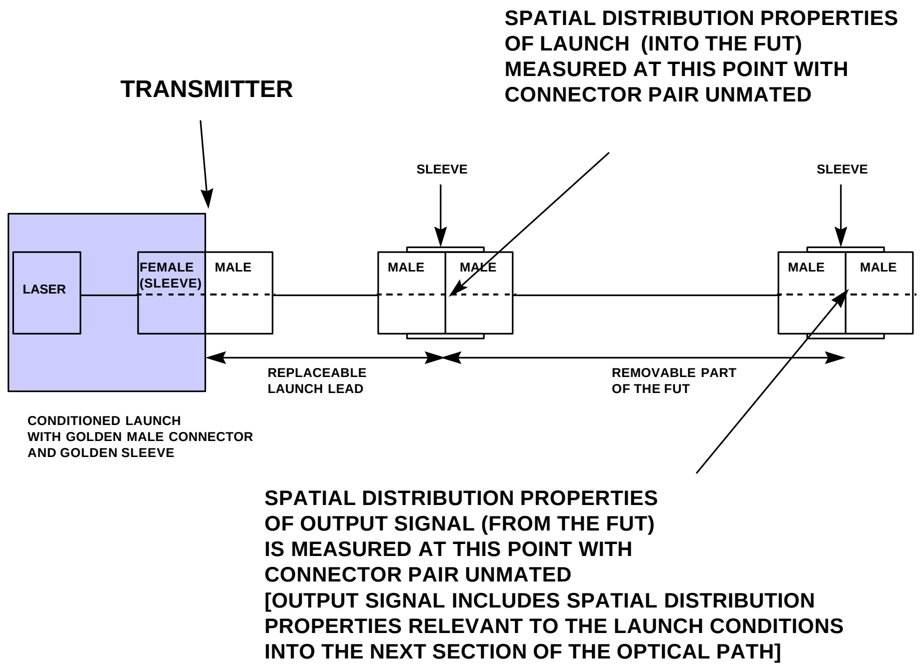
- calibration procedures to account for the effect of fixturing
- applied stimuli and measured responses that contain the results of the measurement

In general, different fixturing and measurement requirements exist for each parameter. In practice, it is very desirable to have the same test fixture for several, if not all, tests.

The calibration procedure is usually different for the different tests.

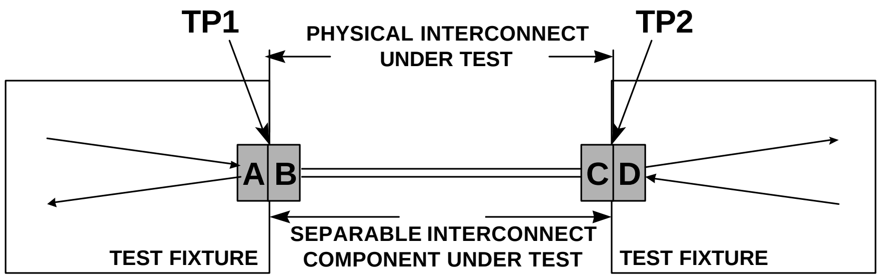
The acceptable range for each parameter may differ for different performance classes.

5.9 Definition of the FUT



- **Figure 9 - Architecture of connecting a FUT to a transmitter**

The FUT is always at least a mated connector pair (for example connectors A and B in Figure 10), the terminations for each side of the mated connector, and the mechanical features within the signal neighborhood for each side of the mated connector. In some cases the FUT is part of a completed cable assembly containing multiple FUT’s where the cable assembly has a specific length, the mated connectors on each end, and the mechanical features within the signal neighborhood of each end.



A, D = PERMANENTLY MOUNTED GOLDEN CONNECTOR
(PART OF TEST FIXTURE)
B, C = PART OF THE SEPARABLE INTERCONNECT UNDER TEST

TEST FIXTURE / MEASUREMENT PROCESS IS CALIBRATED TO REPORT VALUES AT TP1 AND TP2

SEPARABLE INTERCONNECT PERFORMANCE IS JUDGED BY ITS PERFORMANCE AT TP1 AND TP2 (USING MORE STRINGENT LIMITS THAN EXPECTED IN SERVICE WHERE A AND D ARE NOT GOLDEN)

Figure 10 - Definition of the interconnect under test

This definition of the interconnect under test does not allow optical performance specification of a connector outside the context of a specific application in a cable assembly or in a test fixture. If the interconnect system performs adequately according to the tests in this document then the connectors or other pieces of the interconnect system are adequate.

Using the definition of the FUT in this sub-clause the total FUT is separable from the test fixture. This is very different from the test fixture architecture for copper described in SFF-8410.

There is one exception to this, however. Near end cross talk requires (in a manner similar to copper) that the connector interface be included in the FUT definition because the connector interface is a primary source for optical cross talk and there is no known way to make the test fixture golden with respect to cross talk. Fortunately, optical cross talk is expected to be negligible and this distinction for the definition of the FUT for near end cross talk purposes is moot.

The definition for the FUT as the removable part is necessary in order to measure the performance of the total connection but it has several consequences that may not be obvious.

The contribution of the test fixture to the measured result for the total FUT may not be small. The test fixture could compensate for or exacerbate degradations caused by the removable FUT. It is generally expected that different removable parts of the FUT will cause different total FUT test results. What may be less obvious is that FUT’s with the same removable part but with different test fixtures may also yield different results unless the test fixtures are carefully designed and calibrated.

Therefore:

- Differences in the FUT measurement results from different laboratories are to be expected unless the same specifications are used for the golden parts.

- The pass fail results may differ unless the same derating numbers are used to account for the effects of the golden connectors.

- If the test fixture compensates for the performance in the removable parts then it is to be expected that other laboratories testing the same removable part may find that the removable part fails (since their test fixture may not deliver the same level of compensation)

- If the test fixture exacerbates the degradation in the FUT to the extreme allowed without allowing the IUT to fail then a more conservative IUT test results and it becomes unlikely that testing with different test fixtures will show failures in the IUT

- It is not practical in the optical testing to create test fixtures that will always exacerbate the degradations – thus the need for golden hardware

Suppliers of FUT parts (typical cable assemblies) need to carefully understand the effects of the test fixture in their testing so that unintentional compensation of removable parts is not occurring.

Anything within the signal neighborhood of FUT is also part of the FUT and is not part of the test fixture.

5.10 Special considerations for test fixtures

5.10.1 Overview of test fixture architecture

Test fixtures are crucial for accurately measuring the properties of optical assemblies. This is especially true for optical cable assemblies because the connector is such a large part of the performance on an optical cable assembly.

The main properties of text fixtures are golden connector design and the use of special optical cable assemblies instead of printed circuit boards. The optical test fixtures are similar to copper test fixtures where semi rigid coax is used.

The required properties of golden connectors are discussed in 5.10.2. Special optical cable assemblies are also required where the position of the core is offset, where certain bandwidth performance is required, and where the core diameter is different from that of the FUT. The special properties of the optical cable assemblies that form part of the test fixtures are discussed in the sub-clauses where they are used.

5.10.2 Golden connector design

5.10.2.1 Overview

The issues with designing and finding golden connectors for use with the test fixtures are described in this sub-clause.

There are three basic types of connector:

Those that use an alignment sleeve
Those that use guide pins

Those that use V grooves

Each of these types requires a different approach to the golden connector.

5.10.2.2 Basic requirements on endface properties for all connector types

The general shape of the ferrule end of an optical connector polished such that the average plane of the polish is perpendicular to the axis of the ferrule is shown in Figure 11. This figure was adapted from a Telcordia specification. The orientation of the average end face plane demands that the center of curvature be on the ferrule axis. (This point could be the subject of some debate for real ferrules.)

Endface geometry is not presently defined in the industry for multimode connectors but contributes greatly to the variability of performance from one connector to another connector with respect to modal coupling. The endface properties defined in this sub-clause applies to both multimode and single mode applications.

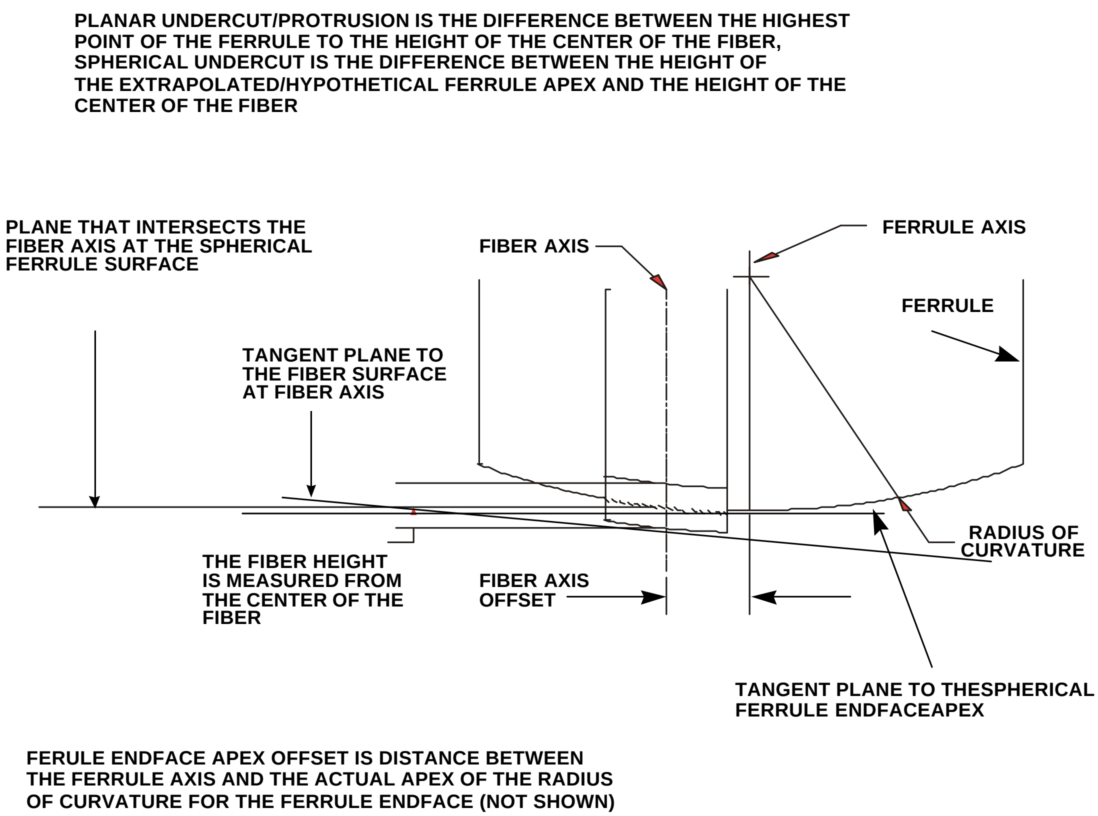


Figure 11 - Schematic endface features

The fiber axis exists at the center of the core of the fiber. A significant issue is how to measure the fiber axis and the ferrule axis without changing the test setup. This is approached practically by doing the measurements in two stages: (1) the outer ferrule to inner ferrule hole concentricity and (2) the outer fiber to core concentricity.

The concentricity required for both ferrule and fiber is on the order of 1 to 3 microns.

A recommended value for the apex fiber offset is 25 um max.

Ferrule apex offset is the distance between the apex of the ferrule/fiber composite and the ferrule axis. The ferrule axis is the center of the circumscribed circle for the actual outer surface of the ferrule. A recommended maximum for this parameter is 25 um.

For the golden connector both the apex fiber offset and the ferrule apex offset are minimized.

The fiber axis offset shall also be minimized. A recommended maximum for this parameter is 2 microns.

It is possible to “tune” the offset with respect to the keys for some connector types, however, the offset minimization approach described above is effectively doing this tuning independent of any keying and is the approach to be used in 8412.

Another golden condition is that the test fixture fiber has a maximum undercut (recommended to be between 0.05 and 0.1 micron) such that even with maximum protrusion from the IUT fiber with respect to the IUT connector ferrule that the golden connector fiber is not touched. This minimizes the possibility of damage to the golden connector and offers maximum separation between fibers. The maximum separation is the worst case for reflection and insertion loss. It does allow the protruding fibers in the IUT to not be detected. Protruding fiber in the IUT connector could cause damage to itself or to mating connectors if the fiber protrusion exceeds the maximum specifications but that is controlled using physical measurements and is not expected to be done as part of a performance test. It is expected that fiber to fiber contact will bear the forces of the connector as long as the protrusion is within specification.

The angle of the fiber interface is determined by the apex offset (the ferrule axis offset) and the radius of curvature (assuming a polishing is used). Therefore there is no need to separately specify the angle of the fiber interface.

The Telcordia specifications call for the radius to be 7 to 25 mm. The golden connector uses the 25mm spec so that imperfections in the IUT would more likely cause separation of the fibers.

For angle polished ends commonly used in single mode applications there are at least four specifications: the basic angle, the axial rotational angle, the ferrule axis offset and the radius of curvature. Goldenness is meeting all the nominal features.

The golden connector has the best possible finish so that the properties of the IUT determine the performance degradation. Presence of any defects in the surface finish inspected when using TIA/EIA-455-57 is cause for rejection of the candidate golden connector.

Other properties relating to the ferrule, alignment sleeve dimensions, guide pins, and V grooves are addressed in 5.10.2.3, 5.10.2.4, and 5.10.2.5.

5.10.2.3 Alignment Sleeve type (AS)

The basic configuration for alignment sleeve constructions is shown in Figure 12.

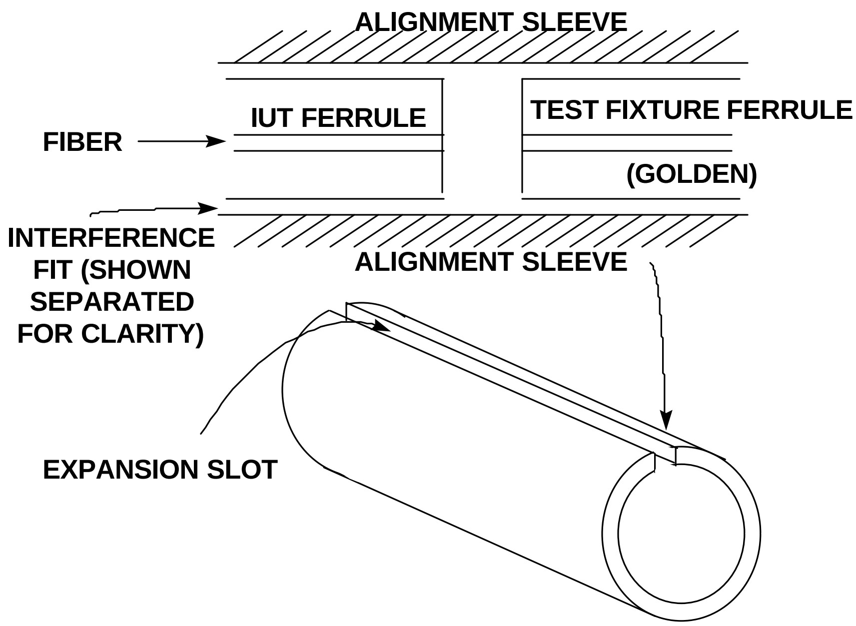


Figure 12 - Architecture of the alignment sleeve scheme

The alignment sleeve construction has certain properties that constitute goldenness. The goal of this sub-clause is to define those properties in terms of which direction to specify the golden alignment sleeve and the golden connector. Should the golden connector be at the maximum material condition, the minimum material condition or what? Similar questions apply for the alignment sleeve.

When the ferrule of either the test fixture (golden) or the FUT connector is placed into the alignment sleeve an interference fit is expected. This interference fit causes the slot in the alignment sleeve to expand slightly (deform) as the ferrule is inserted into the sleeve. The following two figures are looking directly down on the slot in the alignment sleeve and illustrate a key question: how far from the end of the ferrule does the deformation produced by the ferrule extend?

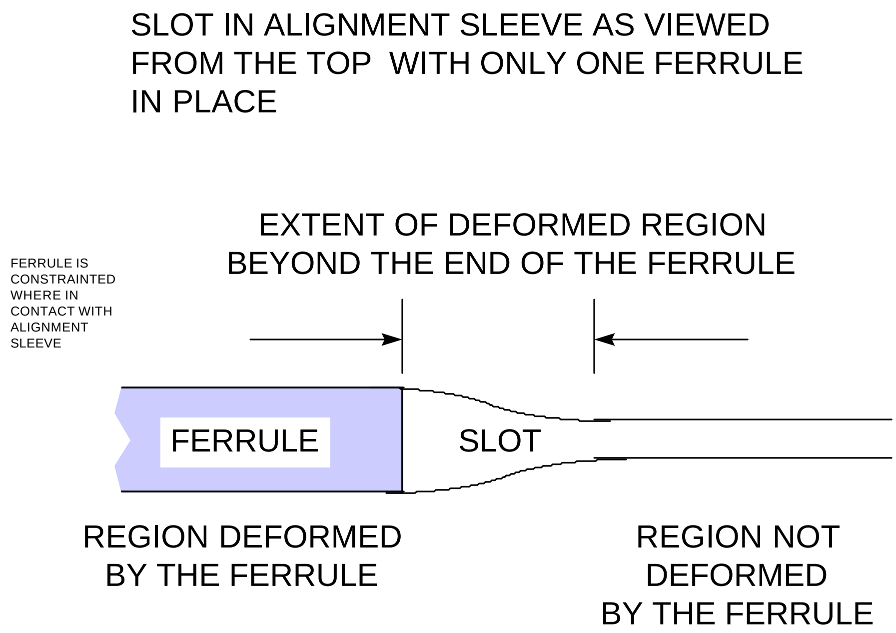


Figure 13 - Deformation of the sleeve slot in the axial direction

If the two ferrules are exactly the same size and the hole in the alignment sleeve is perfectly uniform along the entire length of the sleeve then there will be the same level of interference fit all along the alignment sleeve on both sides. In this case there is no need to be concerned about goldenness between the alignment sleeve and the ferrules.

For the more realistic case where the ferrules are not exactly the same size the larger ferrule will expand the slot more than the smaller ferrule. In this case Figure 14 shows the critical role the extent of the deformation region has in determining the alignment tolerances at the ferrule to ferrule interface.

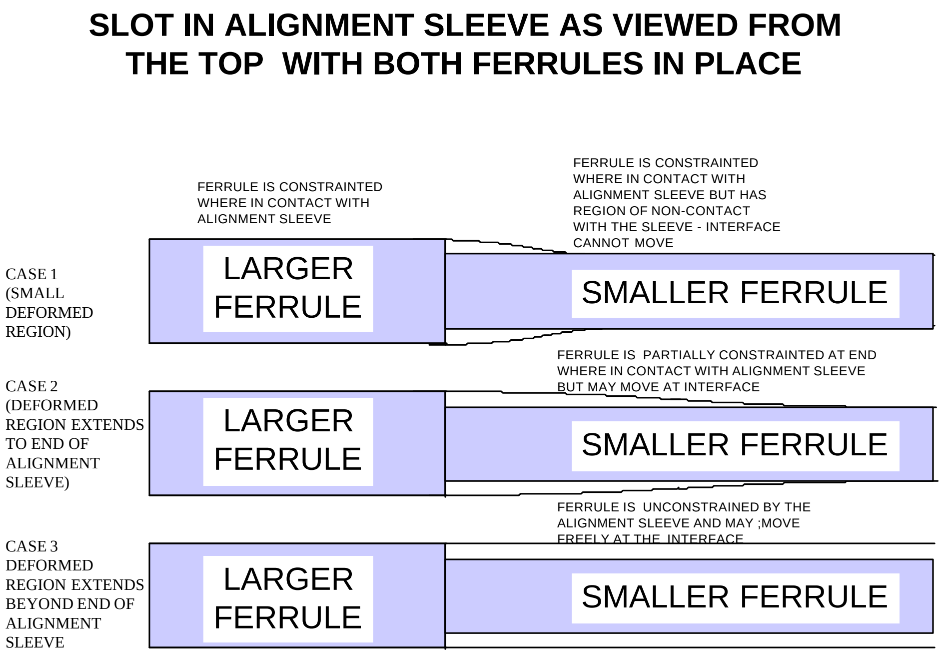


Figure 14 - Three slot deformation cases

Present practice in the industry uses a test involving the pull force required to separate two ferrules out of an alignment sleeve. This test can be used to indicate the relative alignment sleeve dimensions with respect to the ferrule dimensions. Using ferrules at the smallest specified diameter produces the smallest interference force. An acceptance criteria of a minimum extraction force with nominal ferrules can be used as an acceptance criteria for alignment sleeves.

While mechanical simulations on the alignment as an elastic member could be used to model the extent of the deformed region of the alignment sleeve, data from actual measurements of sleeves that had a ferrule inserted into only one side may also be used. Such data is shown in Figure 15.

The test ferrule had a diameter (by a ring gauge test) of 2.499 +-0.0005 mm. This is the highest grade ferrule obtainable and is very near the nominal. With the ferrule inserted approximately 5 mm into the sleeve the slot in the sleeve varied in width according to the data in Figure 15:

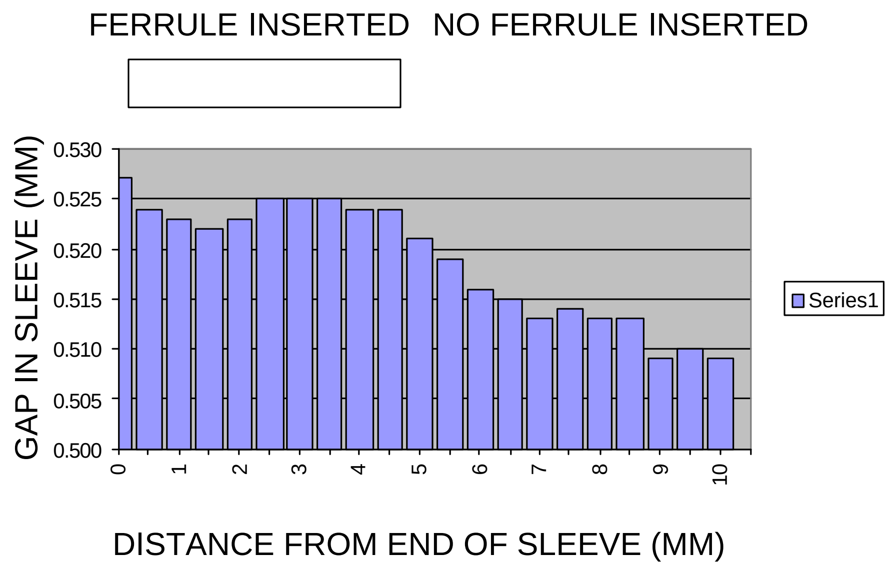


Figure 15 - Experimental slot deformation data

This data clearly shows that the sleeve returns to the unstressed gap (approximately 0.51mm) within a few mm of the end of the ferrule and with approximately 1.5 mm of unstressed gap. If a smaller ferrule were to be inserted into the open end the interference fit would be much larger than 1.5 mm and would be close to the top case shown in Figure 14. The FUT would therefore have interference fit guidance from the sleeve for both angular and axial positioning during the test.

The question of the mechanism for accommodating the interference in transceivers remains unanswered. The use of slotted alignment sleeves is not common in transceivers. It appears that cable assemblies and transceivers are different in these respects yet there is no distinction in the commonly executed testing processes between whether a cable assembly is used for alignment sleeve applications with another cable assembly or is connected to a transceiver.

The golden connector with the golden alignment sleeve needs to be such that compensation of IUT properties does not occur. Exactly how to accomplish this feature in specifying these golden components is now easier after the results of the slot deformation extent test. Assuming that the data presented in Figure 15 applies generally to all alignment sleeves the goldenness properties are related only to the geometry of the test fixture ferrule and should not be affected by the details of the insertion process provided excessive non axial force is not applied.

5.10.2.4 Guide pin types (GP)

Those connector schemes that use guide pins need separate detailed consideration. Guide pin schemes are used with parallel fiber constructions.

The following conditions describe goldenness for GP types:

- Maximum material condition (MMC)* for both guide pins and guide pin holes
- Position of the fiber hole center with respect to the guide pin/hole is true
- Ferrule face is truly perpendicular to the guide pin/hole axis
- Ferrule face radius of curvature is maximized (both major and minor face axes)

*all material is present in the part that is allowed within the tolerances. For example, the largest pin diameter and the smallest hole diameter is the MMC.

5.10.2.5 V grove types (VG)

Connector schemes that use V grooves, for example the SG, are significantly different in many respects from the AS and GP types. Some of the considerations for the VG involve the dimensions of the buffer layer and mechanical spring properties of the fiber since there is no ferrule. Golden connector properties for the VG types are not presently addressed in this document.

All measurements described in this document are still useable for VG types but it is left to the implementer to determine how to define goldenness.

5.10.2.6 Summary of golden connector properties

Table 1 and Table 2 contain a summary of the golden connector properties for AS and GP types.

Table 1 - Golden connector property summary - AS types

Parameter	Desired condition in the golden test fixture	effect on performance
test fixture ferrule face apex	apex of ferrule at average center of ferrule	makes FUT appear better
test fixture ferrule diameter	midpoint of the tolerance	makes FUT appear better
test fixture ferrule OD/ID concentricity	concentric outer and inner	makes FUT appear better
test fixture ferrule OD and ID circularity	perfectly circular	makes FUT appear better
alignment sleeve inside average diameter	midpoint of the tolerance	makes FUT appear better
alignment sleeve circularity	perfectly circular	makes FUT appear better
transceiver alignment sleeve	midpoint of the tolerance	makes FUT appear better
apex offset (fiber center displacement from ferrule center)	minimized	makes FUT appear better
end face radius	at least 25 mm	maximizes the effect of interface particles on the FUT
interface angle (determined by apex offset tangent plane and the fiber axis tangent plane)	minimized	makes FUT appear better
fiber undercut	maximum allowed	makes FUT appear worse
Surface finish on fiber	best possible	makes FUT appear better
surface contamination	as clean as possible	makes FUT appear better

Table 2 - Golden connector property summary - GP types

Parameter	Condition in the golden test fixture	effect on performance
test fixture ferrule face apex	apex of ferrule at average center of ferrule major and minor axes	makes FUT appear better
test fixture ferrule guide pin hole diameter	maximum material condition	makes FUT appear better
test fixture ferrule guide pin hole circularity	perfectly circular	makes FUT appear better
test fixture ferrule guide pin diameter	maximum material condition	makes FUT appear better
transceiver guide pin diameter	maximum material condition	makes FUT appear better
transceiver guide pin circularity	perfectly circular	makes FUT appear better
test fixture ferrule apex offset (fiber center displacement from ferrule center)	minimized	makes FUT appear better
test fixture ferrule end face radii	>1000 mm major axis >100 mm minor axis	maximizes the effect of interface particles on the IUT
interface angle (determined by apex offset tangent plane and the fiber axis tangent plane)	minimized	makes FUT appear better
fiber undercut	maximum allowed	makes IUT appear worse
surface finish on fiber	best possible	makes IUT appear better
surface contamination	as clean as possible	makes IUT appear better

5.10.3 Physical extent of text fixtures

The test fixture for optical cable assemblies may include a length of optical fiber.

5.11 Cladding Modes

Cladding modes refers to optical energy transported through the transparent non-core part of the fiber. Normally cladding modes quickly lose their energy by absorption in the buffer layer and from other loss mechanisms.

The subject of cladding modes has been particularly problematic to specify.

There are three cases where cladding modes may be important to the link operation: (a) inaccurate measurement of launch conditions, (b) excessive reflections in short cable assemblies and (c) optical attenuator calibration .

In all cases the issue is that the optical energy transported through the cladding layer is affecting the performance of the optical component.

It appears that the cladding mode performance will need to be a level 1 test or a stress condition added to the reflection or signal degradation test requirements.

Short cable assemblies with significant cladding mode propagation deliver more optical power than actually is available for longer distance propagation. This effectively overstates the launch power of transmitters and needs to be eliminated.

The second issue with cladding modes is related to excessive reflection (return loss) in short cable assemblies. This can cause degradation of the launched signal under certain laser operating and design conditions. There is presently no material specifically relating to this issue available for this document but it has been anecdotally reported to be significant for some lasers.

The effect of cladding modes on optical attenuators is considered in Annex A.

6. Level 1 tests

6.1 Signal degradation

6.1.1 Overview

During the transmission, degradation is expected from a number of causes such as attenuation, dispersion, ISI, and cross talk. In order to capture the entire behavior of the optical signal degradation an optical eye pattern comparison scheme is used. Signal degradation is measured at the end of a simulated link (which may not be the direct output of the FUT).

This is an optical eye pattern comparison test where launched optical signals into the FUT having minimum allowed amplitude and maximum allowed jitter for transmitters are transferred through the FUT and an attached dispersive reference fiber (DRF) cable assembly. The output signal shall not lose amplitude or increase jitter beyond the allowed specification for the FUT.

The FUT_{NOT} transmitter has asynchronous worst case signals (maximum amplitude) present during the testing. The signals from the FUT_{NOT} transmitter consist of data patterns with both a run length of at least 5 and run length of 1 – e.g. the K28.5 pattern or individually programmed patterns. Asynchronous signals are required to ensure that all time points in the signal under test are impacted by the cross talk noise. Real applications almost always operate with either end under different timing control which produces asynchronous noise at the receiver.

Mechanical stresses near the connector and angular displacements of the fiber are applied during testing. A specified number of turns around a specified diameter round mandrel is required for the FUT while executing the test to simulate the effects of minimum bend radius in actual installations. The number of turns and mandrel diameters depend on the requirements for different IUT designs and applications. This test includes effects of attenuation, cross talk, dispersion, jitter, fiber bandwidth, and launched signal coupling into the fiber.

There are five launch conditions that shall be used:
(a) overfilled per TIA/EIA-455-54
(b) restricted per TIA/EIA-455-204 [23 micron]
(c) (c,d,e) three different offset single mode launches. The offset shall be 0, 7.5 and 15 micron from the fiber center. Note that TIA/EIA-455-204 uses a 23.5 micron fiber to “filter” the overfilled launch condition described in TIA/EIA-

455-54. This automatically prevents excessive power launched into the center of the FUT which could cause DMD.

Note: the single mode launch depends on the wavelength: 9 micron for 1300 nm, 4.5 micron for 850 nm.

If it is known that the FUT will not be used for any of the launch conditions specified above then that launch condition is not required but the FUT shall be identified as not qualified for the launch condition eliminated.

Any DRF used shall meet the requirements of the link application under all launch conditions expected in service as well as meeting the requirements specified in 7.2.

This test requires a modulated optical signal at a specific center wavelength. Signals are measured with an optical oscilloscope that has a known linear detector.

Properties of the launch signal are scaled to the following worst case conditions:

- Minimum allowed OMA (optical modulation amplitude) - related to average launched power
- Maximum allowed jitter
- All rise/fall times between 0 and max allowed
- 2**7-1 data pattern

Receiver side instrumentation is specified to collect all the light coming out of the FUT and a derating is applied to account for this special collection.

An eye pattern test scheme is used for both amplitude and bandwidth properties of the FUT and is suitable for use in very high integrity applications because there is no known mechanism for producing Gaussian jitter in passive optical transmissions. This allows use of commercially available optical oscilloscopes to make the measurement.

There are three major planks in the strategy for this test:

- Use linearity and superposition as much as possible to simulate the worst case input signals
- Use linearity and superposition as much as possible to simulate the allowed output mask
- Account for the portion of the link budget that is expected to be consumed by the FUT as a result of the FUT length.

The test ideally consists of applying the most degraded allowed transmitter output signal to the FUT and verifying that the signal out of the FUT does not violate the specified output.

For purposes of this test it is assumed that only two properties of the transmitted signal are important: the vertical eye opening (amplitude) and the horizontal eye opening (jitter). If the actual applied signal does not match the allowed transmit eye mask in other areas no further attempts will be made to make a more perfect fit. The procedure for simulating a worst case signal is:

1. Using an available signal from a real source the reported amplitude for the eye opening is adjusted using software compensation such that it appears that the minimum allowed transmit eye opening is being applied. This same amplitude scale and scaling factor is used to record the received eye.

2. The difference between the actual jitter in the transmitted signal and the maximum allowed jitter is used to adjust the receive eye mask by an equal amount in the

opposite direction (making the receive mask wider and therefore more difficult to achieve). This procedure is shown in Figure 16 for the case where the minimum jitter margin exists near optical receiver threshold. The minimum jitter margin anywhere in the transmit mask is the value added to the receiver mask. Jitter in the transmit signal is transmitted unattenuated to the receiver across the FUT - superposition applies.

Also shown in Figure 16 is an alignment mask that is useful for positioning the receiver mask along the time axis. This alignment mask is created by positioning its zero crossing at the center of the population of transmit signals. This center of population is revealed by the peak of the histogram of the zero crossing signals. If multiple peaks are detected then the mean of the histogram is considered the center of the population.

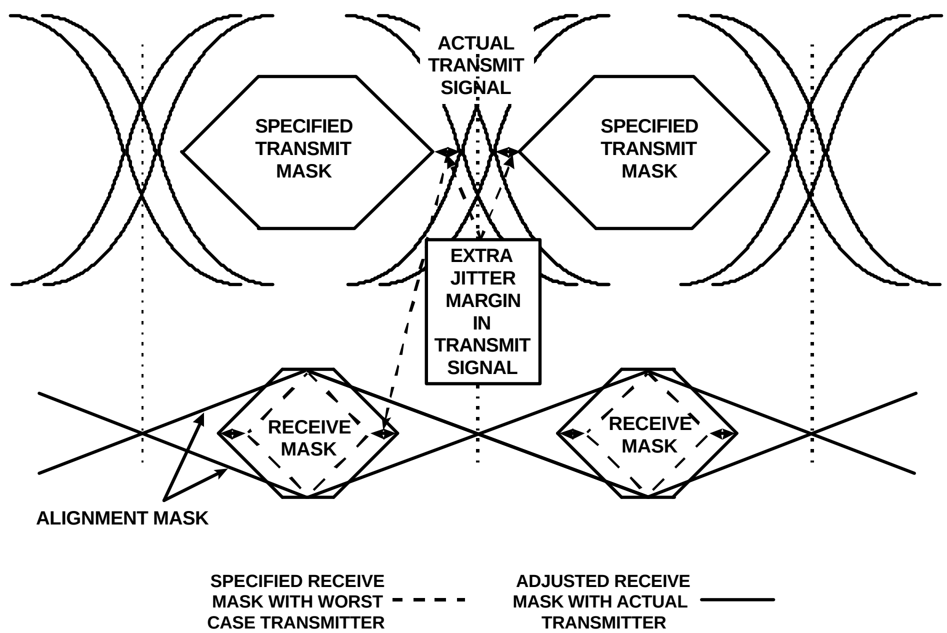


Figure 16 - Compensation for real transmitter jitter (example 1)

The longest link length specified for the application is L_{link}. Allocation of the portion of the link due to the FUT is based on the fraction of L_{link} occupied by the FUT less the effects attributable to the connectors not associated with the FUT.

Example: Longest link length is 300 meters. 1.5 dB total connector loss (3 mated pairs). (allowance of 0.5 dB for the FUT connectors) 0.3 UI for link jitter. Power budget for cable plant is 5 dB (includes the connectors).

Assume FUT is 50 meters long.

Modified budget for FUT:

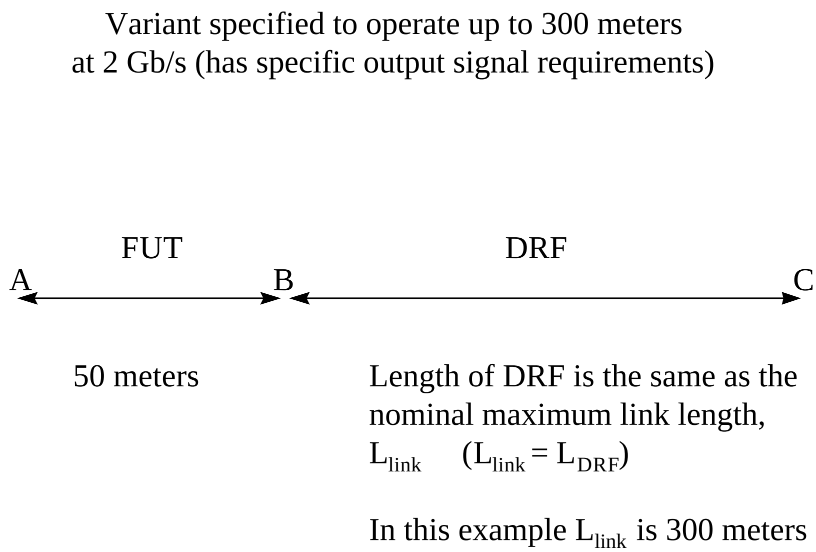


Figure 17 - Use of the DRF in the signal degradation measurement

Pick link variant length: DRF = 300 meters

At least two DRF's, qualified per 7.2 shall be used such that:

- The DMD distribution across the core has significant modal dispersion at the center of the fiber
- The DMD distribution across the core has significant modal dispersion beyond the 18 micron radius.

The characterization of the DRF's used for the measurement shall be supplied with the signal degradation results.

Create reference signal at C for each launch condition:

E.G. for worst case RML (23 micron) launch into B using a 23 micron fiber. Use 156 uw OMA at B, PRBS 2^7-1.
Measure output eye at C with optical scope: calculate OMA, calculate vertical eye opening (OMA), calculate horizontal eye opening (UI) (eye 1). This is the reference signal for the RML launch ultimately to be used at A with the FUT.

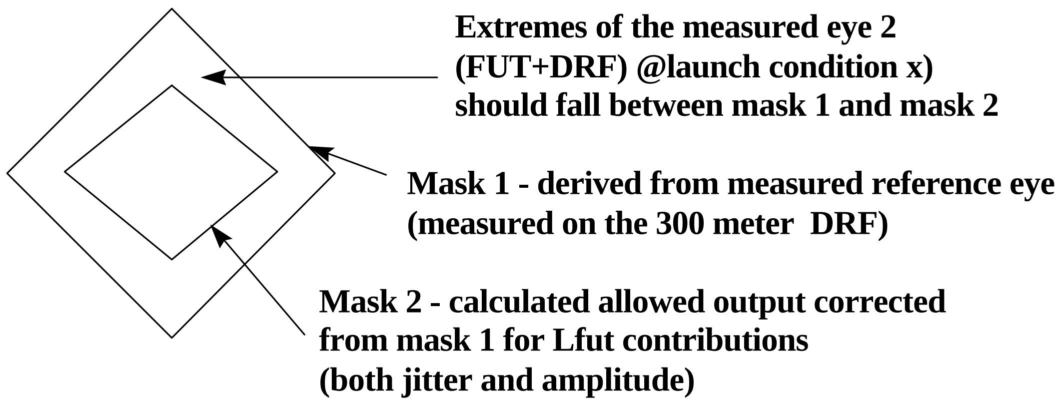
Put FUT in, launch worst case RML (23 micron) into A. Use 156 uw OMA at A, PRBS 2^7-1.
Measure output eye at C with optical scope: calculate OMA, calculate vertical eye opening (OMA), calculate horizontal eye opening (UI) (eye 2).

Adjust the receive mask at C to the portion of link budget allocated for the FUT (decrease the size of eye 1 mask by Lfut/Llink * TJ) where TJ is specified maximum jitter into the optical receiver per the application specification

Eye 2 mask jitter part is the adjusted eye 1 mask per above.

Adjust the output mask amplitude to reflect the actual transmitted signal as measured in eye 1 relative to the allowed worst case.

Total eye 2 mask is that with both amplitude and jitter adjusted.



Steps to create mask 2

Reduce the mask 1 width by the portion of link budget allocated for the FUT (decrease the width of mask 1 by $Lf_{ut}/(L_{link}+L_{fut}) * TJ$)

Reduce the mask 1 height by the portion of the link budget allocated for the FUT (decrease the height of mask 1 by Lfut/(Llink+Lfut) * TJ

TJ is specified maximum jitter into the optical receiver per the application specification

Figure 18 - Relation between mask 1 and mask 2

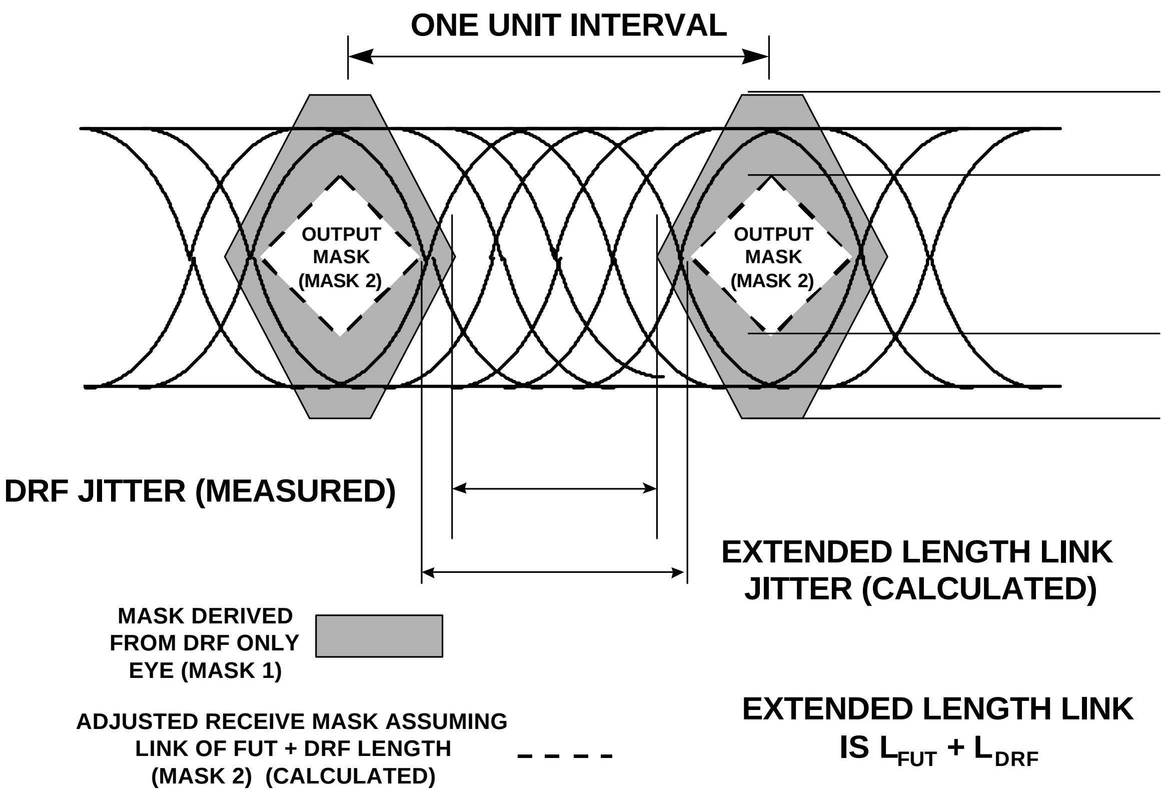


Figure 19 - Adjusted output mask

The adjusted output mask is calculated from the formula:

Jitter that would be measured if the DRF had the length of the extended link = (DRF jitter meas){(L_{FUT} + L_{DRF})/L_{DRF}}

If the eye with the FUT + DRF encroaches into the output mask then the FUT is contributing more than its share to the output jitter. It is possible that the FUT + DRF will produce less jitter than the DRF alone because the launch condition out of the FUT is better suited to the DRF than the launch condition used to establish the DRF jitter.

The physical DRF may not be the worst case possible for that style and may not exactly match other similar DRF’s. In order to accommodate these cases the extended length jitter may be modified by a multiplicative constant not defined in this document.

The DRF and launch condition that produces the worst performance with the FUT shall be used for the measurement of signal degradation. The measurement shall account for the additional connector and DRF losses when extracting the FUT’s contribution to the output amplitude.

6.1.2 Measurement test fixtures and measurement equipment

Figure 20 shows the custom cable assemblies that comprise the test fixture and the positioning of the source and measurement instruments.

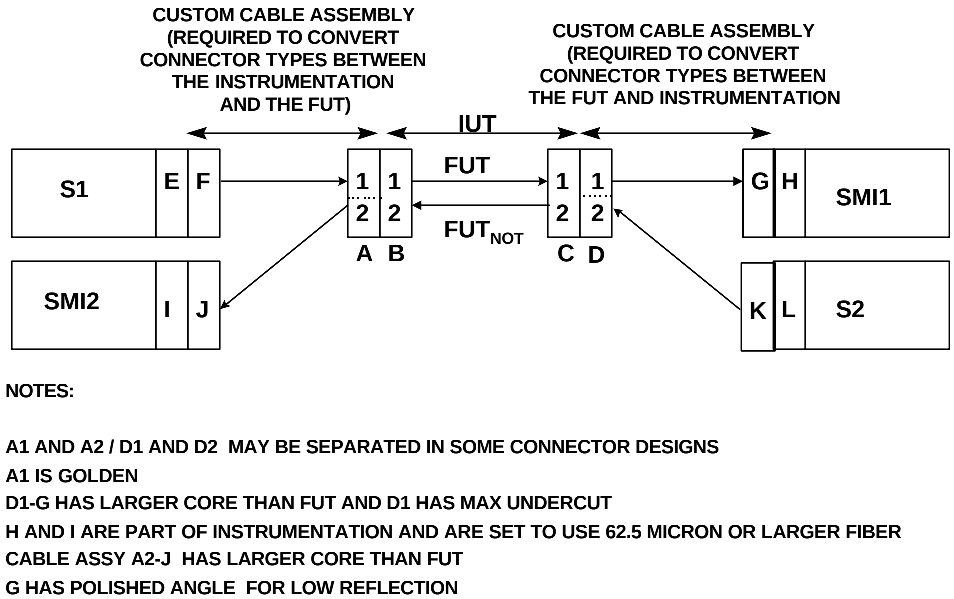


Figure 20 - Test fixture and instrumentation locations

The source side cable assembly is shown in more detail in Figure 21.

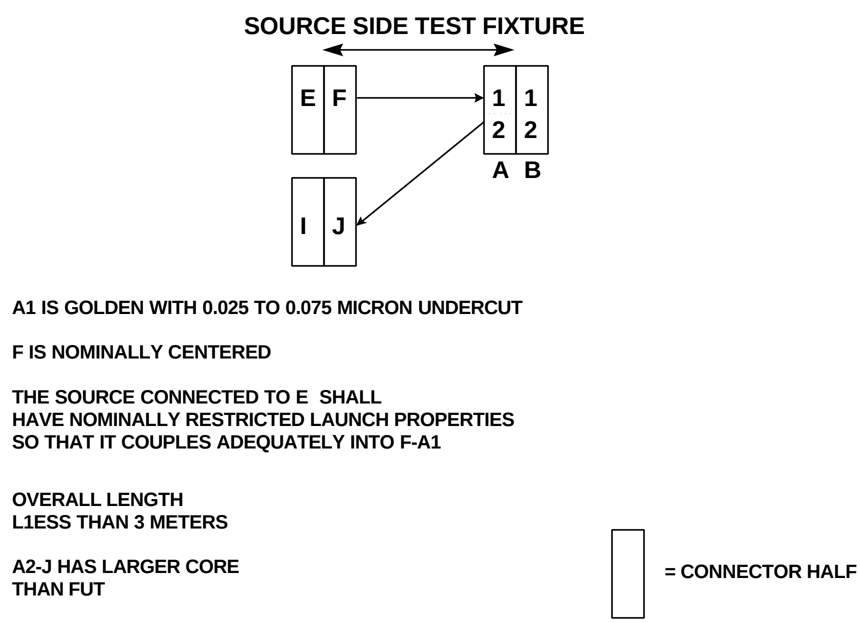


Figure 21 - Source side test fixture for signal degradation tests

F to A1 is one of the following:

- a 9 micron fiber with special provision in A1 to allow positioning of the fiber axis to the following positions center of the connector optical axis: 7.5 microns off center, 15 microns off center (three separate fixtures or adjustable A1)

- a 23 micron centered core
- a core that matches the FUT

Figure 22 shows the receiver side test fixture.

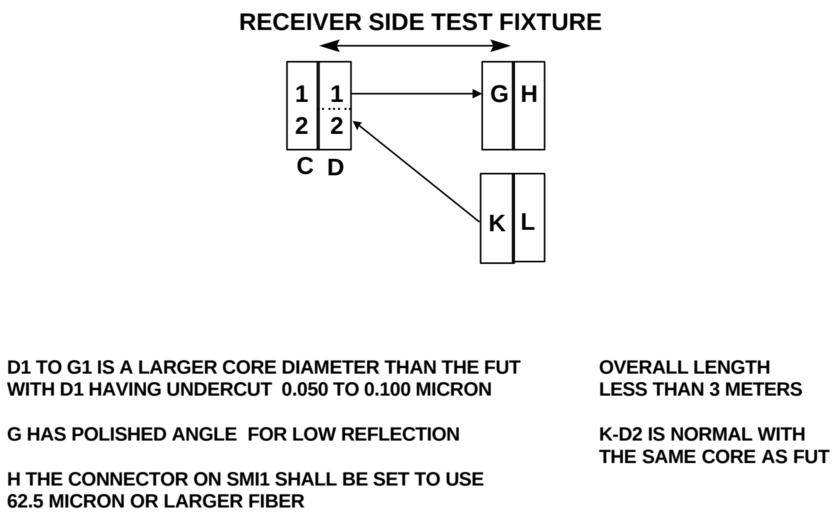


Figure 22 - Receiver side test fixture for signal degradation tests

Measurement equipment consists of two signal sources, S1 and S2, and a sampling optical oscilloscope.

S1 is an optical source that has the following properties:

- Has an optical output with the wavelength to be used
- Has the ability to deliver required data patterns
- Can operate at the data rate of interest
- Can deliver at least -3dBm average power
- Is limited to eye safe levels for the conditions being used for the measurement

S2 is an optical source that has the following properties:

- Has an optical output with the wavelength to be used
- Has the ability to deliver required data patterns
- Can operate at the data rate of interest
- Can deliver at least 80% of the maximum legal power for the application of interest
- Is limited to eye safe levels for the conditions being used for the measurement
- S2 uses a different timing reference from S1

SMI1 and SMI2 are sampling oscilloscopes with optical inputs.

The data patterns used shall have a mixture of run lengths ranging from 1 to 5 in order to produce significant ISI and shall be d.c. balanced within a digit.

One repeating 32 bit data pattern that is acceptable is:
11000001010011111010110000010101.

Another is 2^7-1.

A dispersive reference fiber (DRF) is used between the FUT and SMI1 to ensure that the bandwidth degradation is developed across the DRF.

6.1.3 Calibration procedure

The highest signal level used is from S2 and that level is set by the maximum allowed launch power (presently 0dBm in FC-PI). The calibration of this level is not critical and can be done by using simple power meters or by direct connection to SMI1 or SMI2.

The signal level from S1 is affected by the use of the 9 micron fiber in the source side test fixture and must be calibrated using the procedure described in this sub-clause.

6.1.3.1 Calibration configuration for S1

A special calibration configuration is required for S1 as shown in Figure 23.

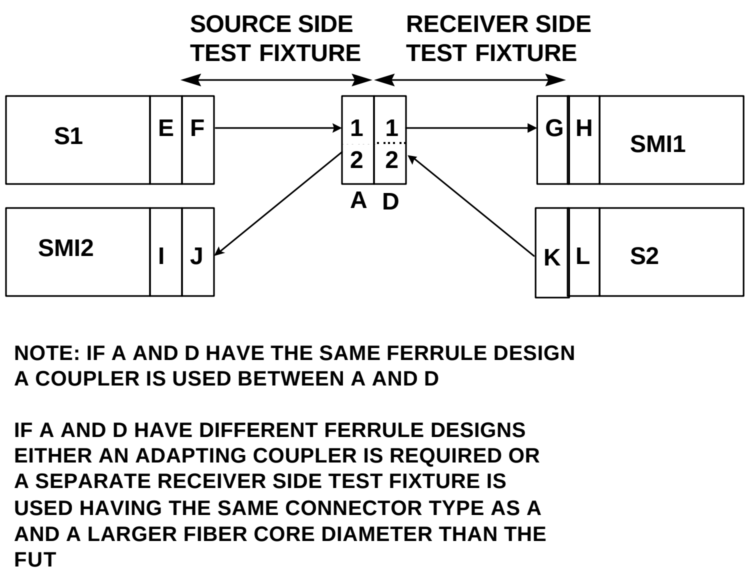


Figure 23 - S1 calibration configuration

Calibration is done by creating the configuration shown in Figure 23 and adjusting the amplitude of the signal to the minimum allowed optical modulation amplitude (OMA) for the application. The peak and minimum values used to determine the OMA shall use the average value over the center 30% of the bit time.

If attenuators are required to adjust this amplitude then these attenuators shall remain in the test configuration as part of the test fixture.

The timing reference for SMI1 shall be taken from S1.

6.1.3.2 Calibration for S2

The calibration procedure for S2 uses the same signal measurement instrument as for S1. Using the data pattern chosen set the power level of S2 to at least 80% of the maximum allowed for the application.

6.1.4 Testing procedure

The five tests required for every multimode FUT are specified in Table 3. Single mode FUT's require only test lead "C".

Table 3 - Test conditions for signal degradation

S1 TEST LEAD	NOMINAL CORE SIZE	NOMINAL OFFSET	S1
A*	MATCH FUT CORE	ZERO	OVERFILLED FOR FUT CORE
B	23 MICRON	ZERO	23 MICRON COUPLED
C*	9 MICRON	ZERO	9 MICRON COUPLED
D	9 MICRON	7.5	9 MICRON COUPLED
E	9 MICRON	15	9 MICRON COUPLED
* most likely to produce high jitter for MM fiber			

Every test is executed the same way except with the conditions indicated in Table 3 set according to the test being done. The separable IUT is connected between the test fixtures shown in Figure 20 and Figure 22 and the resulting eye diagram is recorded and compared to the modified receive signal mask. Any intrusion into the mask constitutes a failure. The allowed receive mask is the same for all tests.

Notice that the trigger for SMI1 must come from the S1 trigger output.

Mechanical stresses near both connectors that are likely to produce worst case signal degradation are applied during the measurement. The details of these stresses shall be determined by applying the full range of allowed stresses to both connectors during the data acquisition. If a set of stresses are found to be common for maximum impact then restricting the range of stresses is allowed.

Angular displacements of the fiber shall also be applied during testing by using a specified number of turns around a specified diameter round mandrel. The number of turns and mandrel diameters depend on the application.

6.1.5 Acceptable ranges

The acceptable ranges are shown in Annex A.

6.2 Reflections (return loss)

An ideal connector system will exactly match the index of refraction and core sizes at all time points associated with the connector (that is, be the same as the fiber as much as possible). Reflections are produced when part of the incident optical signal is returned back toward the source at imperfections in the fiber or at an optical interface surface in the cable assembly.

For purposes of HSOI cable assemblies, reflections are measured by the average optical power presented back to the optical source. The optical signal activity and launched power level are not important since the optical transmission system is linear in amplitude. Signal activity may be anywhere from d.c. to the full data rate of the link and may have any intensity consistent with the capabilities of the instrumentation.

A pulse technique is also possible for isolating the near end connector in long cable assemblies where the pulse reflected from the far end is ignored by virtue of the time required for the far end reflection to return to the source.

Rifocs makes some equipment that is capable doing pulsed average power measurements. Model 687RL is capable of doing MM 850 and model 685RL is used for MM 1300 nm testing. SM versions are also available for 1300 and 1550 nm.

The reflections test is done on each end of the IUT separately and the results are reported separately. The highest reflection is reported as the property of the IUT. A special low loss golden connector, connector G in Figure 24, is used and the requirements are derated to account for the condition in service where the IUT is not connected to a golden connector.

The reflection from the I connector is eliminated either by shutting off the signal to the I connector using mandrel wrap methods or by using an index matching fluid on the I connector. The signal returned by reflections therefore consists of the signal reflected from the GH connector and the signal reflected from the fiber in the FUT. The alignment of the fiber cores is not critical due to the small reflection energy coming from the fiber.

6.2.1 Test fixture and measurement equipment

6.2.1.1 Test fixture and measurement set up

Figure 24 shows the test configuration for the optical reflection tests.

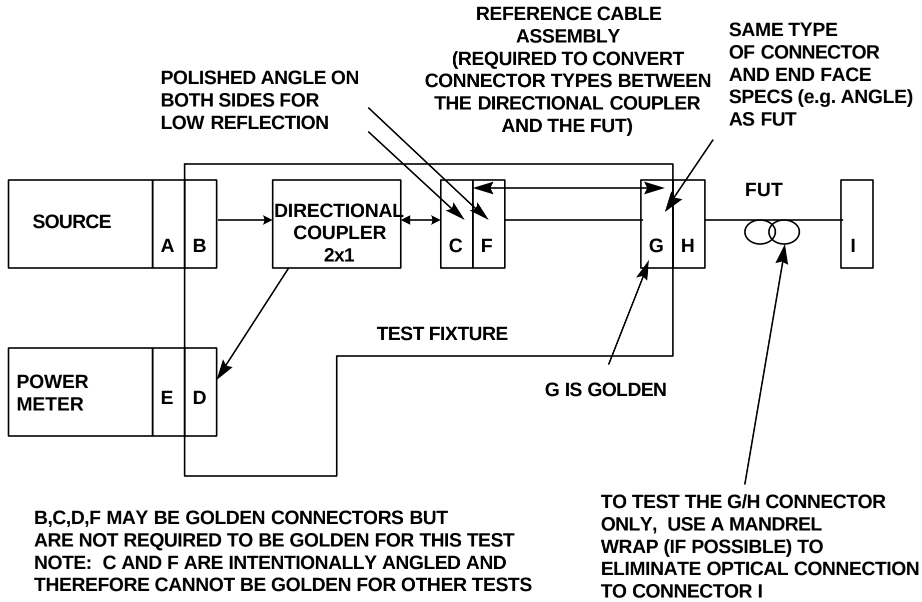


Figure 24 - Test configuration for optical reflections

6.2.1.2 Measurement equipment and special components

The measurement equipment consists of an optical source and a power meter. Equipment is available that integrates both functions into a single unit. Suitable sources are JDS Model RX-1070 (integrated with power meter), Exfo Model IQ-2600 (integrated with power meter), HP Model 8457 (integrated with power meter).

Also required is index matching fluid or gel to be used as part of the calibration process. [Jose to supply specs.]

A special reference cable assembly approximately 3 meters long is required with the special angled connectors for connector F and with G matching the IUT connector style.

The polished angles in connectors C and F in Figure 24 shall be matched within 0.1 degree between 8 and 10 degrees.

6.2.2 Calibration and verification procedure

6.2.2.1 Instrument calibration

Calibrate the power meter according to its manufacturer’s specifications.

6.2.2.2 Test fixture verification

With no IUT attached to connector G, the launch power is adjusted such that the power meter reads -20dB. This is the maximum reflection possible and is the value expected from the glass/air interface.

Connector G is validated as golden by mechanical inspection.

6.2.3 Testing procedure

Connect the IUT to connector G, wrap the IUT around a mandrel until no further decrease in reflection power is noted upon further wrapping. Record the power meter reading to yield the optical reflection parameter for that direction of the IUT.

Reverse the IUT and repeat the process above.

Record the larger of the two measurements.

This result was obtained by using the golden connector (with maximum allowed undercut) and the golden connector assures that the highest possible reflection measurement is reported. No further adjustment to the recorded value needs to be made for this test.

6.2.4 Acceptable ranges

No specific acceptable ranges are defined in this document. However, high performance cable assemblies are reported to have reflection intensity significantly less than -26dB.

6.3 Cladding mode transmission/reflection

6.3.1 Overview

This level 1 test is executed using a grossly offset launch into cladding only and measuring the optical power out the far end. If little transmission is detected then no significant cladding mode reflection is likely. There is no separate measurement for cladding mode reflections. The FUT fails if more than 1% of the launched power is detected in the transmission mode. If this test is passed then even very short cable assemblies are acceptable. Failure of this requirement is unlikely and routine testing would normally not be required with present fiber technology.

6.3.2 Measurement test fixtures and measurement equipment

6.3.2.1 Measurement set up

The measurement setup shown in Figure 25 shall be used.

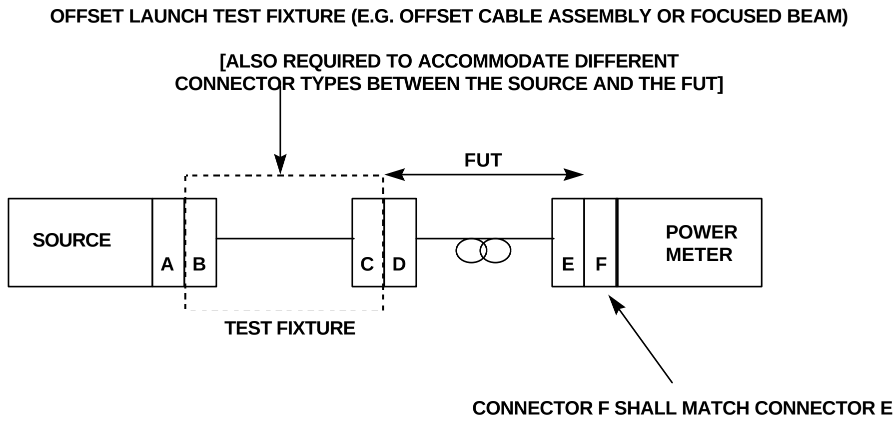


Figure 25 - Measurement setup

6.3.2.2 Measurement equipment and special components

The measurement equipment consists of an optical source and a power meter. Equipment is available that integrates both functions into a single unit. Suitable sources are JDS Model RX-1070 (integrated with power meter), Exfo Model IQ-2600 (integrated with power meter), HP Model 8457 (integrated with power meter).

The offset test fixture referred to in Figure 25 consists of an offset cable assembly approximately 3 meters long or a focused lens scheme. This is required to launch optical power into only the cladding of the FUT. Concepts for these test fixtures are shown in Figure 26.

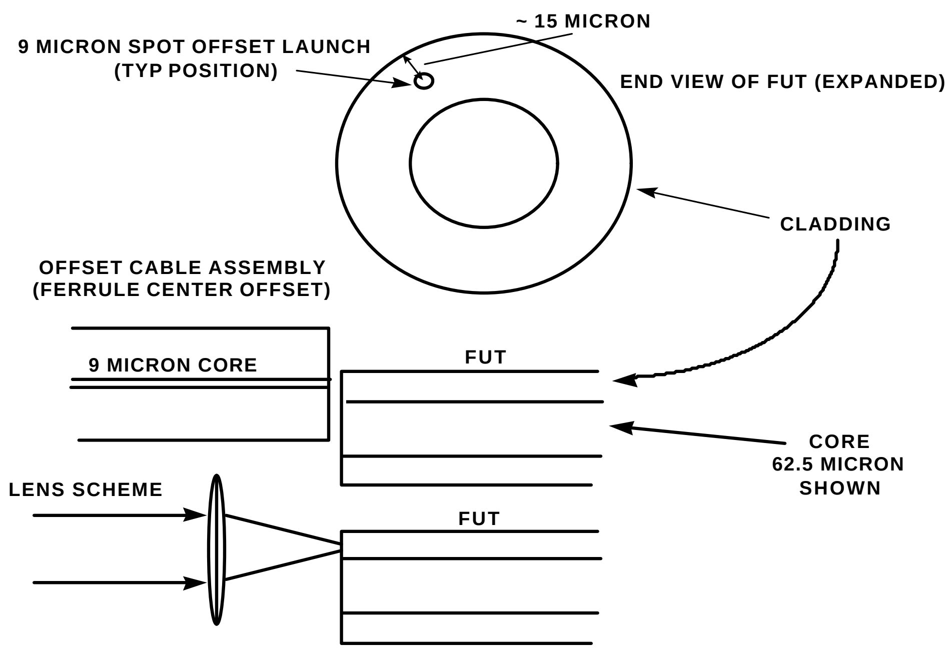


Figure 26 - Offset test fixture concepts

The launch shall be nominally 9 micron diameter spot centered approximately 15 microns from the outer cladding edge.

6.3.3 Calibration procedure

Set the optical source output to near the full scale sensitivity level of the power meter if practical. Connect the power meter to the optical source and record the power level.

6.3.4 Testing procedure

With the optical source set as specified in 6.3.3 set up the configuration shown in Figure 25 and record the reading on the power meter. Calculate the difference between this reading and the output power level of the optical source.

6.3.5 Acceptable ranges

The difference between the power meter readings in dB shall be greater than 20 dB. If reading in microwatts the ratio shall be less than 1%.

6.4 Near end cross talk, NEXT, (Quiescent noise)

6.4.1 Overview

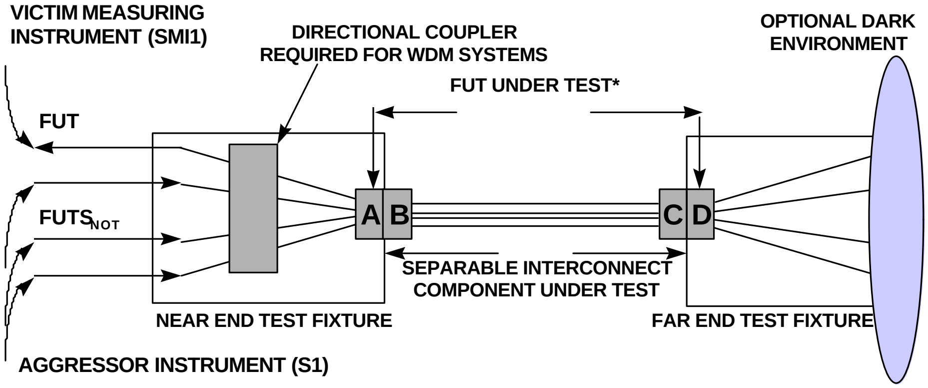
The NEXT is the amplitude of the signal at the FUT_{NOT} receiver (adjacent to the FUT transmitter) when no signal is driven into the FUT_{NOT} receiver from the FUT_{NOT} transmitter. The signals from the FUT transmitter are individual isolated pulses that have the maximum permitted amplitude. With present technology, it is believed that cable assemblies are unlikely to fail this requirement and routine testing is normally not required.

In order to avoid reflected and ambient light coupled into the far end of the FUT from being measured as cross talk the far end may be placed in a dark environment.

6.4.2 Measurement test fixtures and measurement equipment

6.4.2.1 Measurement set up and test fixtures

The measurement set up and test fixtures for NEXT is shown in Figure 27.



A = PERMANENTLY MOUNTED CONNECTOR ON THE TEST FIXTURE
B, C = PART OF THE FUT
D = TERMINATION

LINES SHOWN ARE EITHER INDIVIDUAL FIBERS IN A PARALLEL OPTICS SYSTEM OR INDIVIDUAL COLORS IN A SINGLE FIBER FOR A WDM SYSTEM

*NOTE THAT THE FUT INCLUDES THE MATING CONNECTOR ON BOTH ENDS SINCE OPTICAL CROSS TALK MAY ORIGINATE AT THE CONNECTOR INTERFACE

Figure 27 - Measurement set up and test fixtures for NEXT

The contribution to NEXT from mating interface portion of connector half “A” in Figure 27 is not part of the test fixture but rather is an intrinsic part of the measurement of the performance of the FUT. This is caused by the fact that one primary conduit for coupling optical energy between fibers is via the cavity formed by the A/B and C/D interfaces.

An ideal method should calibrate the contributions from ideal A/B and C/D interfaces. However, the complexity of implementation is assumed to be unjustified for this test. The assumption is that the A/B and C/D contributions are grossly detected by the methods specified.

Note:

> This is somewhat similar to the copper measurement requirements where it is necessary to include the mated connector A/B as part of the IUT. The electrical behavior of unmated copper connector halves is very different from the mated pair due to the physical placement of key connector parts changing when the connector is mated. Further, the means for attaching one copper connector half to the board can be an important part of the overall performance. In the optical case, there is no interface between the fiber and the board and the fiber is not significantly changed when the connector halves are mated.

6.4.2.2 Measurement equipment

The measurement equipment consists of an optical source and a power meter. Equipment is available that integrates both functions into a single unit. Suitable sources are JDS Model RX-1070 (integrated with power meter), Exfo Model IQ-2600 (integrated with power meter), HP Model 8457 (integrated with power meter).

6.4.3 Calibration procedure

Calibration consists of ensuring that the test fixtures and measurement equipment are not the cause of the measured cross talk.

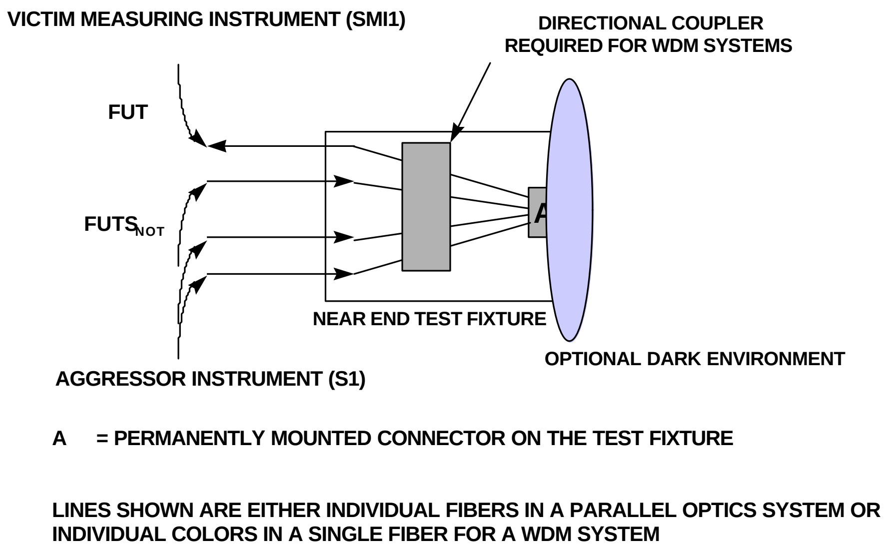


Figure 28 - Calibration system for near end test fixture

Launch 0 dBm into all $FUTS_{NOT}$, (either simultaneously or in smaller groups) measure the power out of the FUT connection. The sum of the powers measured on SMI1 in Figure 28 with all $FUTS_{NOT}$ excited shall not exceed -50 dBm. It may be necessary to place connector A in a dark environment to eliminate the effect of reflections and ambient light. Similar requirements apply to the far end test fixture.

6.4.4 Testing procedure

Apply 0 dBm to all aggressors using the set up shown in Figure 27 and measure the power out of the FUT on SMI1. The aggressors may be excited simultaneously or in smaller groups with the cross talk result on the same victim FUT added.

6.4.5 Acceptable ranges

Acceptable values in this document are less than - 30 dBm for all victum FUTS with all other $FUTS_{NOT}$ excited with 0 dBm aggressor launch power.

6.5 Propagation time and propagation time skew

6.5.1 Overview

The propagation time is the time required for the midpoint of a signal transition to propagate between a physical input and physical output measurement point. The propagation time skew is the difference in the time required for the midpoint of the signal transition to simultaneously propagate down two nominally identical paths between an input and output measurement point. Propagation time skew applies to wave division multiplexing and parallel fiber applications only. The propagation time skew for different modes within the same multimode fiber is part of the bandwidth reduction of the fiber and is not explicitly considered as skew in this document.

Skew shall be reported only on the specific lengths of interest because skew may not scale with length. Many mechanisms that cause skew, such as different propagation velocities for different colors, are expected to produce linear length contributions if the properties of the fiber are constant over the entire length of the link. There is no apriori assumption of uniformity of properties over length in this document.

For long cable plants and for parallel constructions where the skew may scale with length, several hundred ns of skew is possible.

By carefully examining the output pulses from two fibers in a parallel fiber system or two colors in a WDM system it may be possible to determine the cause(s) of the propagation time skew. Figure 29 illustrates how different mechanisms can produce propagation time skew at the midpoint of the signal transition at the receiver.

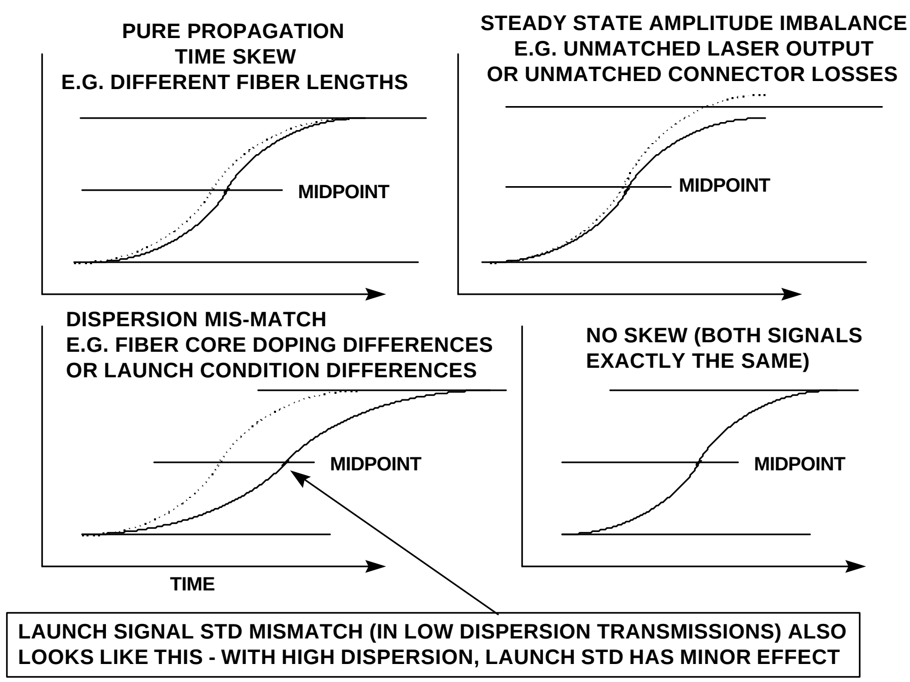


Figure 29 - Examples of received pulses on two fibers or colors

The path length propagation time skew can be corrected by a simple time translation. The skew caused by steady state amplitude differences can be corrected by a simple gain adjustment on one fiber or one color. The dispersion mismatch or the launch STD mismatch, on the other hand, will not be corrected by either a time translation or a gain adjustment.

The effects caused by the launched signal amplitude or STD may be coming from the connectors at the transmit or receive end - not from the transmitter itself.

Examination of the structure of the received pulses can provide primary clues to aid in the diagnosis of the cause of fiber to fiber or color to color skew.

Requirements are placed on matching the amplitudes used for each path in the measurement due to the importance of amplitude on skew. Since the connectors may contribute to the skew golden connectors are required on the measurement test fixtures.

6.5.2 Measurement test fixtures and measurement equipment

6.5.2.1 Measurement set up and test fixtures

The measurement set up and test fixtures are shown in Figure 30.

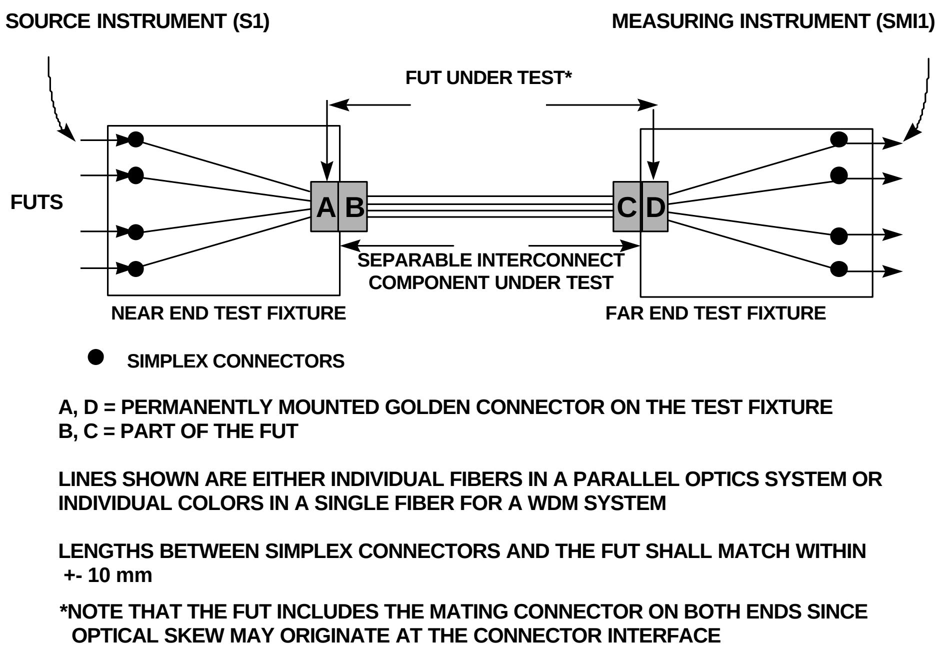


Figure 30 - Measurement set up and test fixtures

If connectors A and D are golden the test fixtures may be the same as those used for NEXT.

6.5.2.2 Measurement equipment

Measurement equipment consists of a signal source S1 and a sampling optical oscilloscope (SMI1).

S1 is an optical source that has the following properties:

- Has an optical output with the wavelength to be used
- Has the ability to deliver launch pulses with STD of less than 50 ps
- Can deliver at least -3dBm average power
- Is limited to eye safe levels for the conditions being used for the measurement

SMI1 is a sampling oscilloscope with optical inputs.

6.5.3 Calibration procedure

The test fixture shown in Figure 31 shall be used for this procdure.

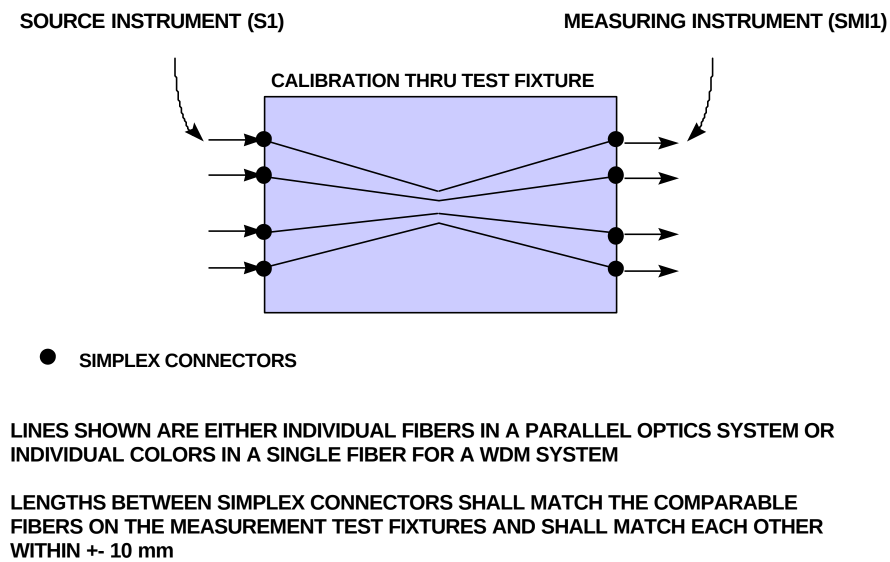


Figure 31 - Calibration test fixture

Each path through the calibration test fixture shall exhibit no more than 0.2 dB loss from S1 to SMI1 (power measurement) and the pulse amplitude measured for each path shall match within 2%.

6.5.4 Testing procedure

Connect the FUT as shown in Figure 30 and measure the time between the midpoints of the launched and received pulses for each path. This is the propagation time for that path. The difference between the shortest and longest propagation times measured for all paths is the maximum skew.

6.5.5 Acceptable ranges

The skew performance is defined by the requirements of the application derated to account for the effects of the golden connectors in the measurement test fixtures.

7. Level 2 measurements

7.1 Signal transition duration

The purpose of this measurement is to determine the time required for a signal transition that is reproducible between different measurement equipment.

The measurement is defined such that there are no user variables. The base data rate of the signals under consideration must be known.

7.1.1 Test fixture and measurement equipment

This measurement applies to whatever physical point is of interest. Since this is a level 2 measurement its purpose is to aid in diagnosing and characterizing systems and measurements and there is no specific test fixture required.

The equipment is a sampling optical oscilloscope that can provide the scales required for the time and amplitude axes.

7.1.2 Calibration procedure

The only calibration required is that needed for the basic instrument. Use the manufacturers procedure.

7.1.3 Measurement procedure

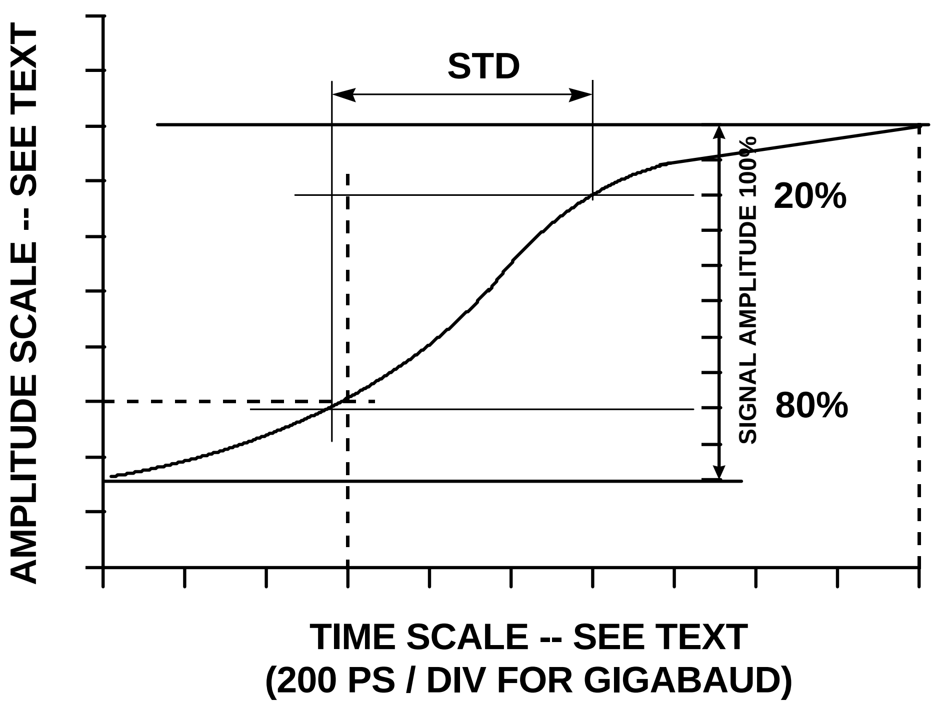


Figure 32 - Signal transition duration calibration

Assuming a rising edge, set up the display on the oscilloscope as shown in Figure 32.

This display has the following properties:

- The span of the time scale on the display is approximately twice the nominal bit or half cycle period for the data rate being used and is specified in Table 4. Ten divisions are used on the time axis.
- The vertical axis is set at 15% of the expected pulse amplitude per division (for example 75 mV for a 500 mV pulse).
- Move the displayed curve to the right such that the flat portion of the curve [flat for at least three time divisions] passes through the first graticule (division) from the bottom.
- Set the horizontal position such that the displayed curve passes through the third graticule on the time axis and the third graticule on the vertical axis
- Use the measure function on the oscilloscope (if available) to find the peak to peak signal amplitude of the displayed portion of the trace as shown in Figure 32. This amplitude may also be read directly off the display. This signal amplitude of the displayed trace may or may not accurately represent the asymptotic signal levels that may exist at times not displayed.
- The signal transition duration (STD) is the time between the 20% and 80% values of the displayed signal amplitude

Table 4 - Scale to be used for STD calibrations

Bit rate * (Mbits/s)	Time axis scale (ps/div)
1062.5	200
1250	200
1600	100
2125	100
2500	100
3200 (3187,3125)	50
4250	50
5000	50
10000	20
12800	20

For a falling edge signal the STD measurement is the same as for the rising edge with the following changes: the flat portion is set at the 9th graticule, the curve passes through the third vertical and the seventh horizontal graticules.

7.2 Dispersive reference fiber performance

Dispersive reference fibers (DRF) shall meet the requirements specified in this clause.

Figure 33 shows an example of a DMD trace set that is used as the basis for selecting DRF’s. This trace set is acquired by following the TIA/EIA specifications for DMD in TIA/EIA-455-220. The trace set is created by launching a ps pulse (typically around 50 ps) from a single mode fiber (at the wavelength of interest) into the DRF at a precisely known radial position and observing the pulse that exits the DRF. This pulse is observed on an optical oscilloscope without using any filtering.

A family of exit pulses is created by recording a trace at each incremental position by using the same oscilloscope trigger for each. The position of the center of the launch fiber core is moved in 1 micron increments until the edge of the core is reached.

The width of the input pulse shall be accounted for as described below.

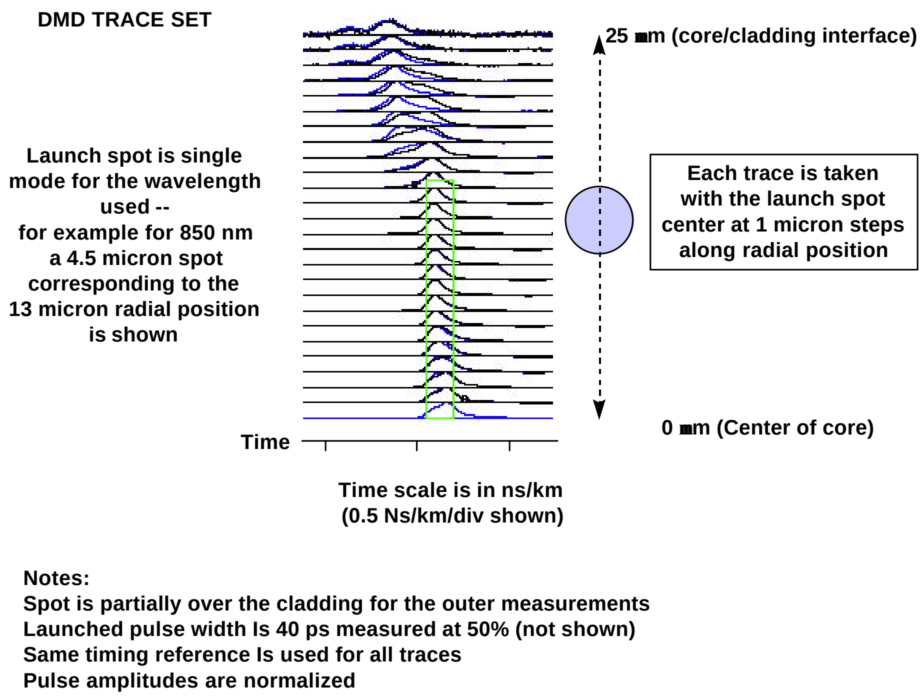


Figure 33 - Definition of DMD trace set

Figure 34 shows the relative size of cores used for launch conditions described in this document (except that 62.5 micron is not shown) and examples of DMD traces that may exist in 50 micron fiber. The DMD trace sets below the core center have been artificially created by mirroring through the horizontal axis to give a better visual comparison to the actual core sizes.

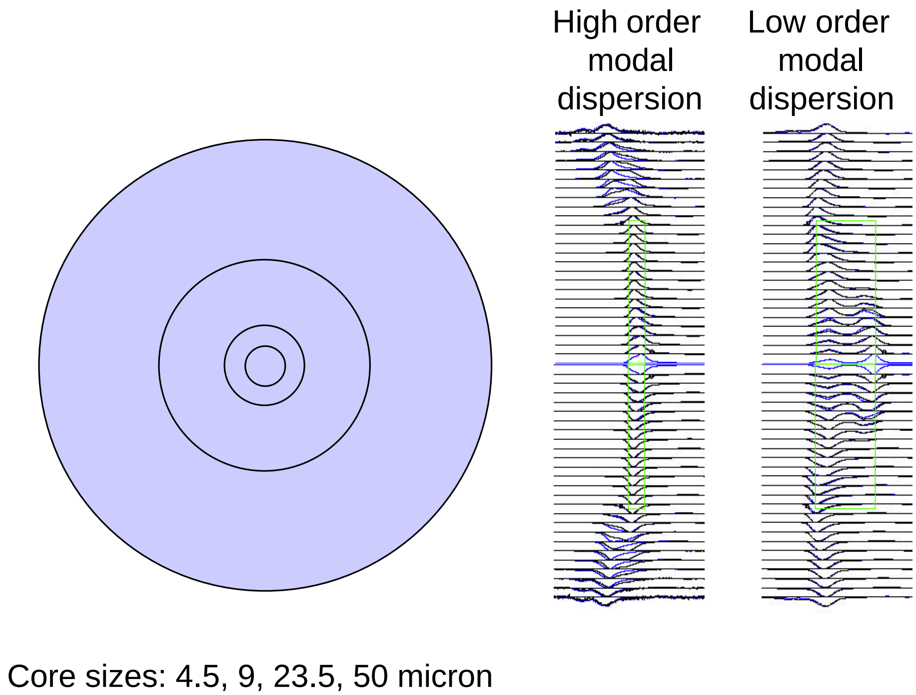


Figure 34 - Size comparisons and example DMD trace sets for 50 um core

Figure 35 shows the requirements for selecting the low order DRF and the high order DRF.

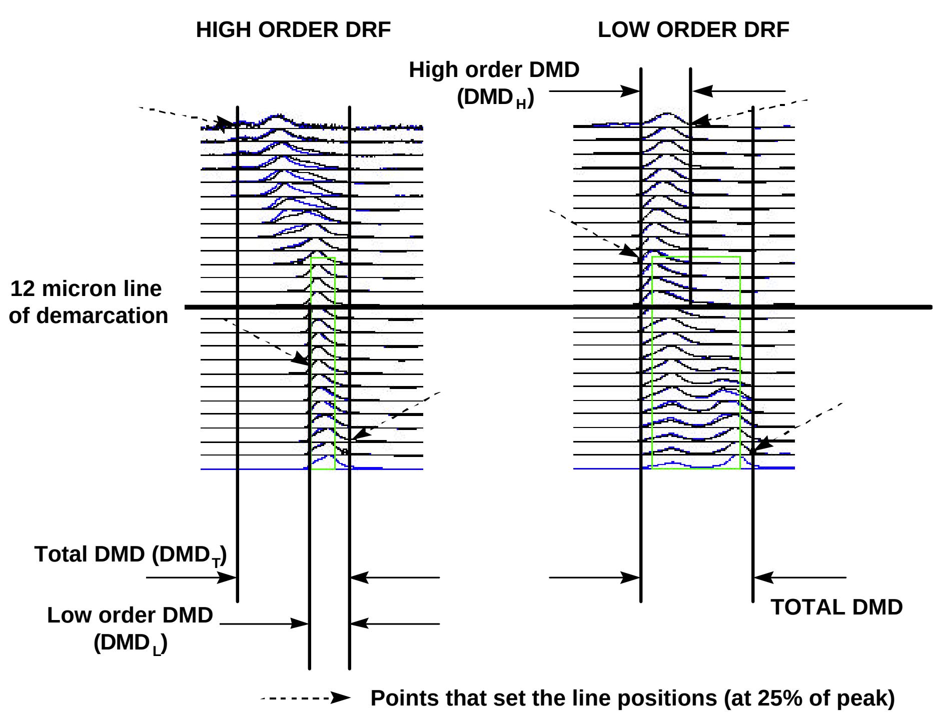


Figure 35 - DRF selection criteria

The 25% point is used to define the leading and trailing edges within each trace. The extreme leading and trailing edge position of any trace defines the total DMD. A line of demarcation at the 12 micron radial position separates the high and low order modes.

For the high order DRF, the extreme edge positions for the traces at or below the 12 micron line of demarcation is used to define the low order DMD. Similarly, for the low order DRF, the extreme edge positions for the traces at or above the 12 micron line of demarcation is used to define the high order DMD.

For the high order DRF the following conditions shall be satisfied:

(DMD_L - input pulse width)/(DMD_T - input pulse width) < 0.5

For the low order DRF the following conditions shall be satisfied:

(DMD_H - input pulse width)/(DMD_T - input pulse width) < 0.5

8. ANNEX A - Calibration of optical attenuators

[needs extensive editing]
Following is a letter provided by Amphenol for a plug style attenuator. This letter describes the cladding mode problem in short fiber sections. Even though this specifically addresses an attenuator, the issue is relevant to standard single mode cable (from which the attenuator is made). This is related to optical power being transmitted into a detector, not return loss.

AMPHENOL PLUG ATTENUATOR TESTING

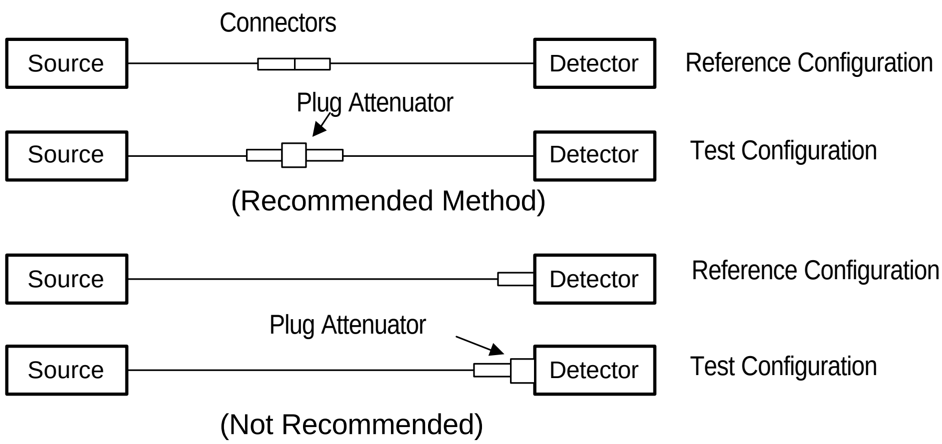
The Amphenol plug style attenuator is designed to be placed between two optical patch cords at some point in a fiber optic link, generally close to the detector. The optical signal is attenuated by scattering a fixed amount of light into the cladding, which is then dissipated in a short section of the fiber in the patch cord following the attenuator (approximately 5 inches). In general, high-speed detectors used in typical fiber optic telecommunication systems are small and must be pigtailed to an input connector located on the receiver. Therefore, even if an attenuator is plugged directly into the optical receiver, there is still a section of fiber to dissipate any light scattered into the cladding, thereby preventing the light from striking the detector.

The insertion loss (IL) of an Amphenol plug attenuator is measured by placing it between two test patch cords (see Figure 1). One patch cord is interfaced to the laser source and the other patch cord provides a link to the detector. The input power level is determined by first connecting the two patch cords together and recording the power (reference power). The patch cords are then separated and reconnected with the plug attenuator placed between them. The power level with the attenuator in place is measured and compared with the reference power to get the IL of the device. This measurement technique is used because it most closely simulates the configuration in which the attenuator will be used in an actual telecommunications system and follows the steps outlined in Bellcore GR-910-CORE, Section 5.2.1 “Generic Requirements for Fiber Optic Attenuators” .

A second method that could be used to test plug attenuators does not simulate actual telecommunications systems and could give erroneous results. In the single input patch cord method (see Figure 2), the reference power is determined by placing the output connector of the patch cord interfaced to the laser source directly into a large area detector (the second patch cord is not used). The output connector is removed from the detector and inserted into the attenuator, which is then placed into the detector. The attenuated power compared with the reference power defines the attenuator’s IL.

This technique looks similar to the two patch cord technique, but actually gives erroneous results because there is no fiber to dissipate the light that has been scattered into the cladding by the plug attenuator. The light scattered into the cladding reaches the detector and gives an abnormally high but incorrect power reading. This will translate into an incorrect low IL reading for the attenuator. The error magnitude is not predictable and could exceed 30% in some cases.

Amphenol plug attenuators are always tested using the two patch cord technique because this is the configuration that most closely represents that of high-speed digital systems. Experiments have shown that 5 inches of fiber between the output of the plug attenuator and the detector is adequate to dissipate the cladding light. The IL of an Amphenol plug attenuator cannot be guaranteed if the device is not tested with this minimum length of fiber between the attenuator and the detector.



• **Figure 36 - Measurement configurations**

Plug attenuator theory and testing.

Amphenol plug attenuators along with plug attenuators in general, have a number of unique characteristics inherent to the plug design that must be accounted for when using the attenuators in a fiber optic system or testing for specification compliance. The in-line attenuator, while manufactured by using a similar process, does not exhibit the same characteristics for reasons, which will be discussed below.

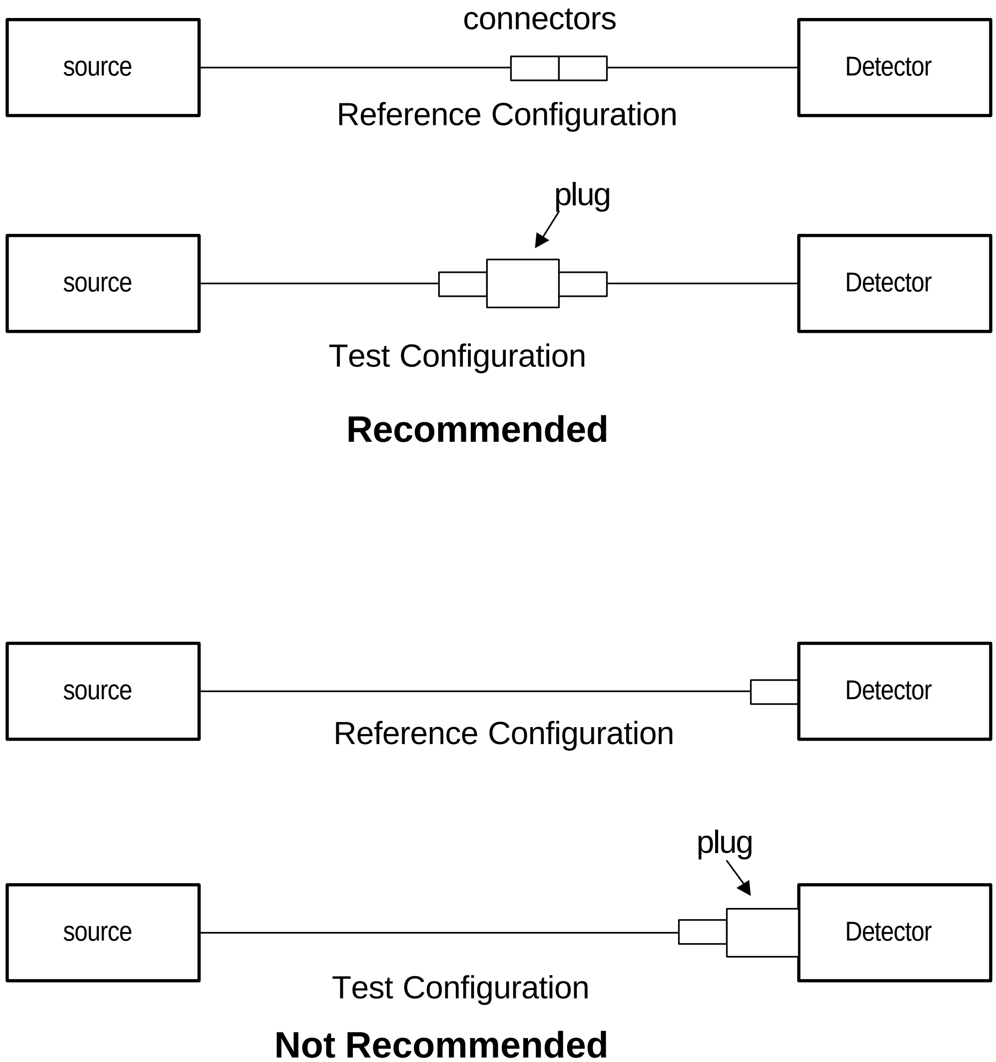
Virtually all fixed attenuators induce loss by one of three methods. The first method incorporates a short section of very high loss fiber within the unit to absorb the excess energy. The second method couples the light out of the optical fiber and passes it through a bulk optic attenuating device, such as a partly silvered mirror, and then couples it back into a second section of fiber. The third method places a fiber optic junction into the optical path within the unit that scatters the light into the cladding where it is dissipated within the next 5 inches of fiber. All three techniques lead to the same result (the reduction of the optical signal) but behave somewhat differently under varying test or operating conditions

The insertion loss (IL) of an attenuator is generally measured by placing it between two test patch cords (see figure 1). One patch cord is interfaced to the laser source and the other patch cord provides a link to the detector. The input power level is determined by connecting the two patch cords together and recording the input power. The patch cords are then separated and reconnected with the attenuator placed between them. The power level with the attenuator in place is measured and compared with the original input level to get the IL of the device. This technique will give accurate results for all attenuator types, including those that scatter to obtain the loss, because any light scattered into the cladding by the device will be dissipated before it reaches the detector.

Attenuators may also be tested by using a single input patch cord (see figure 2). The input power for this test situation is determined by placing the output connector of the patch cord interfaced to the laser source directly into the detector (the second patch cord is not used). The output connector is removed from the detector and inserted into the attenuator that is then placed into the detector. The attenuated power compared with the input power defines the attenuator’s IL. If the detector is actually pigtailed to a connector then the result will be identical to the result calculated using two patch cords. However, if the input connector is placed directly in front of the detector (no pigtail) the results may be different depending on the plug design as discussed above.

Attenuators that scatter even a small amount of light into the cladding within the plug body exhibit a lower loss when measured using a single input patch cord if the detector is not pigtailed to the detector input connector. If the detector is not pigtailed, light scattered into the cladding will reach the detector and give an abnormally high but incorrect power reading. This translates into an incorrect low insertion loss reading for the plug. Units that attenuate by utilizing a high loss fiber section or a bulk optic system are generally affected less by the measurement configuration because only a small percentage of the light is scattered into the cladding within the plug body. Units that scatter a higher percentage of light into the cladding, such as the FOP design, exhibit a much greater measurement dependent variation. This variation is quite variable and not predictable and could exceed 30% in some cases.

FOP plug attenuators are always tested using the two patch cord technique because this is the configuration that most closely represents that of a high-speed digital system where a small area detector is pigtailed to the input connector. This configuration is shown in the top of Figure 37. Experiments have shown that 5 inches of fiber between the output of the plug and the detector is all that is required to dissipate the cladding light. The IL of an Amphenol plug attenuator cannot be guaranteed if the device is tested as shown in the bottom of Figure 37 without this minimum length of fiber between the attenuator and the detector



- **Figure 37 - Attenuator test configurations**

9. Annex B - Modeling of HSOI

Modeling documented in textbooks may include some of the following features:

- axial misalignment
- angular misalignment
- separation of the interfaces
- surface roughness

These testbook treatments may be used to establish a crude starting point for estimating the effects of “goldenness” of the test fixture. Several important issues may not be covered in these simple models however:

- non uniform distribution of modes due to launch conditions or index profiling
- practical means for determining input parameters (axial misalignment etc.)
- wear on the re-used connector

- reproducibility on repeated mating and demating (see additional discussion below)

Modeling is now viewed to be valuable for the following:

- to establish the additional performance required during the testing process since golden hardware is being used on the test fixture side
- to determine what kind of statistical distribution should be assumed if one decides to distribute some tolerances across the entire link instead of using a worst case component paradigm.

The issue of repeatability on repeated mating / demating may prove to be especially challenging for effective modeling. The reasons for the lack of repeatability fall into three types:

- The physical location of the mating interface is different
- The physical condition of the mating interface is different
- Stability of the test environment

The physical location variable falls into two sub-types:

- The final physical location is determined by the mating process and remains fixed once mating is completed
- The actual physical location is determined by external forces on the mated connector pair and changes if the external forces change

If the physical location is determined only by the mating process such as exact angle of entry, small change in force direction each time, intensity of mating force applied, or wear then this will require special insertion (and possibly removal) requirements to remove the insertion variables. A series of controlled insertion conditions that covers all the likely insertion modes will be needed to establish the worst case performance.

In the case where the location of the mating optical interface can be affected by applying external forces (such as when the optical end faces are not in intimate contact and also possibly even when they are in intimate contact but are forced to move anyway by the external forces) one may apply external forces in different directions and intensities to determine the worst case performance.

In order to use the modeling to determine how much to derate the test requirements it may be necessary to somehow determine how much movement was produced by the worst case force/mating process condition.

Given the potential complexities intrinsic in managing reproducibility an alternate approach may be needed.

The physical condition of the interface may be different because:

- Significant time elapsed between the testing events and one or both sides of the mating interface became contaminated in the interim.
- Physical damage occurred while the connector was unmated
- The force on the mating interface is different because of stiction in movable parts or differences in the retention performance

Both the near term physical condition stability and the extended time stability are important. However, it is the near term stability that is the most important to HSOI because that is intimately involved with the testing process itself. The extended time stability is more associated with the storage, handling and cleaning processes of the IUT.

Therefore, as long as the IUT and the test fixture remain undamaged and do not become contaminated between test system calibration events there should be no need for the HSOI effort to consider different physical conditions.

Similar comments apply to the stability of the test environment (calibration should handle any environmental or equipment drift instabilities that occur over extended periods). A requirement of the testing process is that no significant short term test environment instabilities exist.

The following areas for modeling are noted:

Coupled area loss due to axial offset (attenuation / signal degradation)

Effect of force applied to the optical interface on the contact area

Effect of actual optical geometry of the connectors on reflections and attenuation

Effect of actual launched light patterns into the fiber of the interconnect

Effects of bending and stress on the fiber itself

Effects of contamination and scratches on the surface of the interface

10. Annex C - EIA-455 documents

Document Number	Title	Description
EIA-455-00d0B	Test Procedure for Fiber Optic Fibers, Cables, Transducers, Sensors, Connecting and Terminating Devices, and other Fiber Optic Components	This document, together with its addenda, provides uniform test procedures for testing the fiber optic components intended for, or forming a part of, optical communications and data transmission systems. Neither this document, nor its addenda, provide procedures designed for testing fiber optic systems. For test procedures for fiber optic systems or subsystems, refer to the TIA/EIA-526 series of documents. The test procedures included in the addenda to this document are designed to satisfy the broadest possible industry requirements; in general, special test methods are not included.
EIA-455-001B	Cable Flexing for Fiber Optic Interconnecting Devices	This test is intended to determine the ability of fiber optic interconnecting devices, device interfaces, and strain relief to withstand bending and flexing stresses resulting from loads as might be experienced during installation and service conditions.
EIA-45-006B	Cable Retention Test Procedure for Fiber Optic Cable Interconnecting Devices	The intent of this test is to mechanically stress the interconnecting-device-to-fiber-optic-cable-joint in tension. The results of this test provide an indication as to the relative strength of the cable-to-interconnecting device joint and may also indicate degradation resulting from prior environmental exposure.
EIA-455-011B	Vibration Test Procedure for Fiber Optic Components and Cables	The intent of this test is to determine the effects of vibration within the sinusoidal and random vibration environments that may be encountered during the life of the fiber optic component. The procedure is applicable to all types of fiber, cable or cable assemblies, and fiber optic devices including connectors, splices, passive branching devices (couplers), etc.

Document Number	Title	Description
EIA-455-013A	Visual and Mechanical Inspection of Fiber Optic Components, Devices, and Assemblies	This test method is intended to provide the basic criteria for visual and mechanical inspection of fiber optic component parts and assemblies. Additionally, it provides the infrastructure for use with other FOTPs and associated Generic, Sectional, or Detail Specifications that may detail explicit requirements for reported information and acceptance criteria. This test method may be used at any stage, or at event milestones, of the qualification or quality conformance inspection test sequence as a “stand alone” test or for pre/post exposure examinations.
EIA-455-020A	Measurement of Change in Optical Transmittance	The intent of this procedure is to provide uniform methods for monitoring and measuring the change in optical transmittance of fiber optic circuits or paths of various configurations. This FOTP may be referenced by a Detail Specification or similar document , but the procedure is usually applied to a passive optical device undergoing other testing as described in another procedure, hereafter called “the primary FOTP,” which may invoke its use. Typical applications include evaluating effects of environmental or mechanical stresses on interconnecting devices, fiber or cable.
EIA-455-022B	Ambient Light Susceptibility of Fiber Optic Components	Describes a method to establish the susceptibility of components such as cabled fibers, interconnecting devices, splices, or couplers to ambient light. Test conditions simulate expected conditions of use and is unlikely to produce failing results for any fiber optic cable with a black or other opaque-colored jacket. Cable failures may occur with transparent or translucent jackets.
EIA-455-030B	Frequency Domain Measurement of Multimode Optical Fiber Information Transmission Capacity	This procedure describes the method of determining the information transmission capacity of multimode optical fibers having glass cores. The baseband frequency response is measured directly in the frequency domain by determining the fiber response to a sinusoidally modulated light source. Another EIA/TIA test procedure, OFSTP-1, describes a field version of this measurement.
EIA-455-034A	Interconnection Device Insertion Loss Test	This procedure defines methods by which the optical insertion loss of a complete fiber optic interconnection can be measured.

Document Number	Title	Description
EIA-455-042A	Optical Crosstalk in Fiber Optic Components	The intent of this test procedure is to determine the crosstalk ratio between any two optical paths in a cable, connectorized cable, slice or similar device. In addition, the device’s contribution to the crosstalk in a system may be determined. The effectiveness of the material surrounding the optical conducting device in restricting light paths to other elements may also be measured. However, note that the test methods of FOTP-180 should be used to measure crosstalk in fiber optic couplers (branching devices) and in similar devices of this class.
EIA-455-043	Output Near-Field Radiation Pattern Measurement of Optical Waveguide Fibers	This Standard was adopted and approved for DoD use on February 14, 1986.
EIA-455-045B	Microscopic Method for Measuring Fiber Geometry of Optical Waveguide Fibers	This method is intended to provide ways to measure five fiber-geometry parameters: 1). Core Diameter, 2). Core Noncircularity, 3). Cladding Diameter, 4). Cladding Noncircularity and 5). Core/Cladding Concentricity Error. These parameters are often used in characterizing the intrinsic joint loss that may be expected when two optical fibers are joined together, either by means of fusion or a mechanical connection. Note: In general, this method does not have sufficient accuracy and reproducibility for measurement of core diameter, except for Classes Ic, Iia, and Iib step-index fibers.
EIA-455-047B	Output Far-Field Radiation Pattern Measurement	This procedure describes three methods by which the angular radiant intensity (far field) distribution from an optical fiber can be measured. Methods A and B are angular scans of the far field pattern; Method C is a scan of the spatial transform of the angular intensity pattern.
EIA-455-048B	Measurement of Optical Fiber Cladding Diameter Using Laser-Based Instruments	This test procedure is used to measure the cladding (outside) diameter of an optical fiber drawing process prior to the application of the protective buffer coating(s). It is also used off-line as a quality inspection method. In this application, it is normally used instead of FOTP-45. Control of the cladding diameter is required to assure the performance of the fiber in cabling, connectorization and splicing. Uniformity of the cladding diameter along the length is also required.

Document Number	Title	Description
EIA-455-050B	Light Launch Conditions of Long-Length Graded-Index Optical Fiber Spectral Attenuation Measurements	This standard establishes the light launch conditions for Class Ia fiber attenuation measurements. Primary uses include FOTP46, FOT53, and FOT61. Either of two methods is allowed. Method A uses overfilled launch conditions along with a mandrel wrap mode filter. Method B uses restricted launch conditions created by beam optics. Values obtained by Methods A and B may not exactly agree, and care must be used when comparing them.
EIA-455-051A	Pulse Distortion Measurement of Multimode Glass Optical Fiber Information Capacity	This procedure defines the time domain method for measuring the information transmission capacity of EIA-4920000-A Class I (glass core, glass clad) optical fibers. Various methods of reporting the results are described in the appendices, but the results shall be expressed in terms of the -3 dB (optical power) frequency unless otherwise specified by the Detail Specification. Note: This test method is commonly used in factories. It generally requires the use of extensive computational equipment. However, commercial equipment employing this technique exists. Refer to FOTP-30 for a comparable field test method.
EIA-455-053A	Attenuation by Substitution Measurement for Multimode Graded-Index Optical Fibers or Fiber Assemblies Used in Long-Length Communications Systems	This test method describes a procedure for measuring the attenuation of graded-index, multimode optical fibers or fiber assemblies by the substitution technique. This test is intended to produce a value for fiber loss representative of its performance in a typical long length (^{3} 1 km) communications system.
EIA-455-054B	Mode Scrambler Requirements for Overfilled Launching Conditions to Multimode Fibers	This procedure describes light launch conditions to the test fiber for the purpose of achieving a uniform overfilled launch with a laser diode or other light source. While FOTP54 can be used to establish overfilled launching conditions for the measurement of various fiber parameters, it is principally used in conjunction with FOTP30 or FOTP51 for measuring information-carrying capacity. Light launch conditions are established through the use of a mode scrambler. The mode scrambler is positioned between the light source and test fiber to produce a radiation distribution overfilling the test fiber core and numerical aperture, irrespective of the spatial radiation properties of the light source.

Document Number	Title	Description
EIA-455-057B	Preparation and Examination of Optical Fiber Endface for Testing Purposes	This procedure provides guidelines for acceptable optical fiber endface appearance and defines the techniques which are commonly employed to obtain such appearance. This procedure is intended to promote uniformity in fiber end preparation quality for testing and for optical signal transmission. This FOTP is not intended to require examination of every fiber end, nor is it intended to establish firm requirements (which are normally established by Detail Specifications), and is made available only to provide guidelines for various levels of end quality that may be called out in Detail Specifications or in other FOTPs. Lastly, the intent of this method shall not be confused with the intent of FOTP-179, which is concerned primarily with the comparison of relative results.
EIA-455-059	Measurement of Fiber Point Defects Using an OTDR	This procedure describes the use of an optical time-domain reflectometer (OTDR) to measure the positions, losses, and character of point defects along an optical fiber or fiber cable. It is intended for quality control and acceptance testing. This procedure may not be necessary or appropriate for installation and maintenance purposes.
EIA-455-060	Measurement of Fiber or Cable Length Using an OTDR	This procedure describes the use of an optical time-domain reflectometer (OTDR) to measure the length of an optical fiber or fiber cable. It is intended for quality control and acceptance testing. The procedure may not be necessary or appropriate for installation and maintenance purposes.
EIA-455-061	Measurement of Fiber or Cable Attenuation Using an OTDR	This procedure describes the use of an optical time-domain reflectometer (OTDR) to indirectly measure the attenuation or the attenuation coefficient of an optical fiber or fiber cable. It is intended for quality control and acceptance testing. The procedure may not be necessary or appropriate for installation and maintenance purposes.
EIA-455-087B	Fiber Optic Cable Knot Test	Evaluates the effect of a sever bend in a fiber optic cable due to a knot using appropriate test procedures and parameters. Used to test any type of fiber optic cable.
EIA-455-088	Fiber Optic Cable Bend Test	The intent of this bend test is to determine the degree of cable degradation that will occur if the cable is statically bent around a corner of a given radius. Cables that are most likely to be subject to this type of bend in actual installation are building-entrance cables, flexible cables and buried service type cables.

Document Number	Title	Description
EIA-455-095	Absolute Optical Power Test for Optical Fibers and Cables	This procedure describes a method for determining the total optical power emanating from an optical fiber. This procedure may be used for, but is not limited to, measuring the attenuation of the fiber or cable, the loss of terminating devices or methods, the amount of optical power coupled into the fiber by a source, or the optical power at the system receiver.
EIA-455-107-A	Determination of Component Reflectance or Link/System Return Loss Using a Loss Test Set	The intent of this procedure is to determine the ratio of optical power reflected by a component or an assembly to the optical power incident upon a port of a component when that component or assembly is introduced into a link or system. This ratio is termed “Return Loss.”
EIA-455-132	Measurement of the Effective Area of Single-Mode Optical Fiber	This standard is intended to document the methods for measuring the effective area (Aeff) of single-mode fiber.
EIA-455-134	Measurement of Connector Ferrule Hole Inside Diameter	The intent of this procedure is to determine the inside diameter of the ferrule hole in an optical fiber connector ferrule.
EIA-455-135	Measurement of Connector Ferrule Inside and Outside Diameter Circular Runout	The intent of this procedure is to determine the circular runout of the ferrule hole in the end of an optical fiber connector ferrule relative to the ferrule outer surface.
EIA-455-164A	Single-Mode Fiber, Measurement of Mode Field Diameter by Far-Field Scanning	This test method describes the far-field method for measuring the mode field diameter, 2w0, of a single-mode fiber. This test procedure applies to both Class Iva and Class Ivb types of single-mode fiber operating near 1300 nm or 1550 nm.
EIA-455-165A	Mode-Field Diameter Measurement by Near-Field Scanning Technique	Describes the direct near-field method for measuring the mode-field diameter of the fundamental mode of a single-mode fiber, by measuring the near-field intensity distribution. Applies to Class Iva and Ivb types of single-mode fiber, produced in accordance with EIA-4920000-A, measured in both the 1300/1310 and 1550 nm wavelength ranges.
EIA-455-167A	Mode Field Diameter Measurement, Variable Aperture Method in the Far-Field	This document defines the method for determining the mode field diameter, 2w0, of a single-mode fiber by measuring the far field output distribution through a series of transmitting apertures of various size. This test applies to single-mode fibers, Classes Iva and Ivb (in accordance with EIA-4920000-A), for both the 1300 and 1550 nm wavelength ranges.

Document Number	Title	Description
EIA-455-171	Attenuation by Substitution Measurement for Short-Length Multimode Graded-Index and Single-Mode Optical Fiber Cable Assemblies	These test methods describe procedures for measuring the attenuation by substitution of short-length multimode graded-index and single-mode optical fiber cable assemblies. The cable assemblies have one or more fiber paths, with a connector on only one end with a pigtail on the other, or connectors on both ends of the cable that may be identical or different from each other. For multimode, the cables are usually less than 100 meters in length, but for single-mode, the length is unlimited. These tests are primarily evaluations of the connector loss since the fiber loss is usually only a small portion of the total loss. For those assemblies which are long enough for the fiber loss to be a significant portion of the total loss, the fiber loss will have to be taken into account when specifying limits for the measured loss.
EIA-455-191	Measurement of Mode Field Diameter of Single-Mode Optical Fiber	This standard documents the methods of measuring the mode field diameter (MFD) of single-mode fiber. The MFD represents a measure of the transverse extent of the electromagnetic field intensity of the mode in a fiber cross section and it is defined from the far-field intensity distribution, as a ratio of integrals known as the Petermann II definition.
EIA-455-203	Launched power distribution measurement for graded index MM fiber transmitters	Measurement of encircled flux
EIA-455-204	Measurement of bandwidth on MM fiber	Overfilled launch (one method) or RML (Restricted mode launch) (another method) with 23.5 micron launch condition. RME allows higher bandwidth performance from existing MM fiber.
EIA-455-220	DMD measurements	

11. Annex D - Measurement results, measurement type and instruments

The meanings of the terms **measurement result** (hereafter referred to simply as "measurement") measurement **type,** and **instrument** as used in this document are discussed in this annex.

The **type** of measurement is determined by the nature of the stimulus used in the measurement. If pulse stimulus is used then the measurement is time domain. If sinusoidal stimulus is used then the measurement is frequency domain. The form of the display of the output does not define the type of measurement.

A **measurement result** is the output of an instrument, as presented to the user, that is derived from the stimulus applied to (or through) the IUT. The instrument may execute calculations and conversions internally prior to presenting its output.

An **instrument** is the combination of associated hardware and software that is used to produce a measurement result. It is not required that all the components of an instrument be within the same enclosure.