SFF specifications are available at http://www.snia.org/sff/specifications
or ftp://ftp.seagate.com/sff

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:

Chairman SFF TA TWG
Email: SFF-Chair@snia.org

If you are interested in participating in the activities of the SFF TWG, the membership application can be found at:
http://www.snia.org/sff/join

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:
http://www.snia.org/feedback

READ EDITOR'S NOTES IN FRONT OF TABLE OF CONTENTS

SFF Committee

SFF - 8416 Specification for

Measurement and Performance Requirements for HPEI Bulk Cable

Rev 15.0 June 27, 2005

Secretariat: SFF Committee

Abstract: This specification defines the electrical measurement and performance requirements for high performance, point to point, bulk cable operating at speeds greater than 1 Gbaud = 1 Gb/s. This architecture is used in most applications requiring high speed serial and serial-parallel copper connections. Some representative applications of such interconnect are: Fibre Channel, Gigabit Ethernet, Infiniband, SAS, and SATA. Other applications for this general purpose specification are also possible. HPEI is an acronym for high performance electrical interconnect.

This specification provides a common specification for systems manufacturers, system integrators, and suppliers of magnetic disk drives. This is an internal working document of the SFF Committee, an industry ad hoc group.

This document 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 document.

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. If such hardware is supplied it must comply with this specification to achieve interoperability between suppliers.

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

POINTS OF CONTACT:

Bill Ham
HP
165 Dascomb Road
Andover, MA 01810
Ph: 978-828 9102 Fx: 978-470-0321
Email: Bill.Ham@HP.com

I. Dal Allan
Chairman SFF Committee
14426 Black Walnut Court
Saratoga CA 95070
Ph: 408-867-6630 Fx: 408-867-2115

EXPRESSION OF SUPPORT BY MANUFACTURERS

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

Amphenol
Dell
EMC
FCI
Foxconn
Hewlett Packard
Intel
Montrose/CDT
Samtec
Sun Microsystems

The following SFF member companies voted no on the technical content of this industry specification.

Compaq
Hitachi Cable
Madison Cable
Nexans

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

Adaptec
Agilent
Emulex
Eurologic
FCI/Berg
Fujitsu Compnts
Fujitsu CPA
Hitachi GST
IBM
Infineon
Intel
LSI Logic
Maxtor
Micrel
Molex
Seagate
Toshiba America
Tyco AMP
Unisys
Vitesse Semi
Xyratex

The user's attention is called to the possibility that implementation to this Specification may require use of an invention covered by patent rights. By distribution of this Specification, no position is taken with respect to the validity of this claim or of any patent rights in connection therewith. The patent holder has filed a statement of willingness to grant a license under these rights on reasonable and non-discriminatory terms and conditions to applicants desiring to obtain such a license.

If you are not a member of the SFF Committee, but you are interested in participating, the following principles have been reprinted here for your information.

PRINCIPLES OF THE SFF COMMITTEE

The SFF Committee is an ad hoc group formed to address storage industry needs in a prompt manner. When formed in 1990, the original goals were limited to defining de facto mechanical envelopes within which disk drives can be developed to fit compact computer and other small products.

Adopting a common industry size simplifies the integration of small drives (2 1/2" or less) into such systems. Board-board connectors carrying power and signals, and their position relative to the envelope are critical parameters in a product that has no cables to provide packaging leeway for the integrator.

In November 1992, the SFF Committee objectives were broadened to encompass other areas which needed similar attention, such as pinouts for interface applications, and form factor issues on larger disk drives. SFF is a forum for resolving industry issues that are either not addressed by the standards process or need an immediate solution.

Documents created by the SFF Committee are expected to be submitted to bodies such as EIA (Electronic Industries Association) or an ASC (Accredited Standards Committee). They may be accepted for separate standards, or incorporated into other standards activities.

The principles of operation for the SFF Committee are not unlike those of an accredited standards committee. There are 3 levels of participation:

- Attending the meetings is open to all, but taking part in discussions is limited to member companies, or those invited by member companies
- The minutes and copies of material which are discussed during meetings are distributed only to those who sign up to receive documentation.
- The individuals who represent member companies of the SFF Committee receive documentation and vote on issues that arise. Votes are not taken during meetings, only guidance on directions. All voting is by letter ballot, which ensures all members an equal opportunity to be heard.

Material presented at SFF Committee meetings becomes public domain. There are no restrictions on the open mailing of material presented at committee meetings. In order to reduce disagreements and misunderstandings, copies must be provided for all agenda items that are discussed. Copies of the material presented, or revisions if completed in time, are included in the documentation mailings.

The sites for SFF Committee meetings rotate based on which member companies volunteer to host the meetings. Meetings have typically been held during the ASC T10 weeks.

The funds received from the annual membership fees are placed in escrow, and are used to reimburse ENDL for the services to manage the SFF Committee.

If you are not receiving the documentation of SFF Committee activities or are interested in becoming a member, the following signup information is reprinted here for your information.

Membership includes voting privileges on SFF Specs under development.

CD_Access Electronic documentation contains:
- Minutes for the year-to-date plus all of last year
- Email traffic for the year-to-date plus all of last year
- The current revision of all the SFF Specifications, as well as any previous revisions distributed during the current year.

Meeting documentation contains:
- Minutes for the current meeting cycle.
- Copies of Specifications revised during the current meeting cycle.

Each electronic document mailing obsoletes the previous mailing of that year e.g. July replaces May. To build a complete set of archives of all SFF documentation, retain the last SFF CD_Access mailing of each year.

Name: ____________________________ Title: __________________________

Company: ____

Address: ____

____

Phone: ____________________________ Fax: ____________________________

Email: ____

Please register me with the SFF Committee for one year.

___	Voting Membership w/Electronic documentation	$ 2,160
___	Voting Membership w/Meeting documentation	$ 1,800
___	Non-voting Observer w/Electronic documentation	$ 660 U.S. $ 760 Overseas
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Check Payable to SFF Committee for $_________ is Enclosed

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SFF Committee
14426 Black Walnut Ct
Saratoga CA 95070

408-867-6630
408-867-2115Fx
endlcom@acm.org

Foreword

When 2 1/2" diameter disk drives were introduced, there was no commonality on external dimensions e.g. physical size, mounting locations, connector type, connector location, between vendors.

The first use of these disk drives was in specific applications such as laptop portable computers in which space was at a premium and time to market with the latest machine was an important factor. System integrators worked individually with vendors to develop the packaging. The result was wide diversity, and with space being such a major consideration in packaging, it was not possible to replace one vendor's drive with a competitive product.

The desire to reduce disk drive sizes to even smaller dimensions such as 1.8" and 1.3" made it likely that devices would become even more constrained in dimensions because of a possibility that such small devices could be inserted into a socket, not unlike the method of retaining semiconductor devices.

The problems faced by integrators, device suppliers, and component suppliers led to the formation of an industry ad hoc group to address the marketing and engineering considerations of the emerging new technology in disk drives. After two informal gatherings on the subject in the summer of 1990, the SFF Committee held its first meeting in August.

During the development of the form factor definitions, other activities were suggested because participants in the SFF Committee faced problems other than the physical form factors of disk drives. In November 1992, the members approved an expansion in charter to address any issues of general interest and concern to the storage industry. The SFF Committee became a forum for resolving industry issues that are either not addressed by the standards process or need an immediate solution.

At the same time, the principle was adopted of restricting the scope of an SFF project to a narrow area, so that the majority of documents would be small and the projects could be completed in a rapid timeframe. If proposals are made by a number of contributors, the participating members select the best concepts and uses them to develop specifications which address specific issues in emerging storage markets.

Those companies which have agreed to support a documented specification are identified in the first pages of each SFF Specification. Industry consensus is not an essential requirement to publish an SFF Specification because it is recognized that in an emerging product area, there is room for more than one approach. By making the documentation on competing proposals available, an integrator can examine the alternatives available and select the product that is felt to be most suitable.

Suggestions for improvement of this document will be welcome. They should be sent to the SFF Committee, 14426 Black Walnut Ct, Saratoga, CA 95070.

The development work on this specification was done by the SFF Committee, an industry group. The membership of the committee since its formation in 1990 has included a mix of companies which are leaders across the industry.

SFF Committee --

Measurement and Performance Requirements for HPEI Bulk Cable

1. Scope

This specification defines the terminology and physical requirements for specifying and enforcing through measurements the electrical performance requirements for bulk cable used in point to point HPEI (High Performance Electrical Interconnects). Such performance requirements are in addition to the mechanical and environmental requirements that may be specified elsewhere. The requirements for both shielded and unshielded bulk cable are included.

Point to point constructions are characterized by having a single connector on each end of the cable assembly or a concatenated series of cable assemblies and/or backplanes. Multi-drop constructions (constructions that have more than one connector attached to the same conductor in the same cable assembly) are specifically excluded from consideration in this specification although some value may be realized by applying the methodologies defined herein to multi-drop constructions. A separate effort has completed within the T10 INCITS committee working group to address multi-drop constructions and bulk cable used in multi-drop constructions. The resulting document is ‘Passive Interconnect Performance - PIP’ that is now a published standard.

Methods for extending the measurements specified for the documented point to point constructions to other constructions that use combinations of point to point constructions are also included.

These constructions may contain conductors that are not part of the HPEI paths but nevertheless may affect the performance of the HPEI conductors through coupling. Specification of the termination or grounding requirements for these coupled conductors is included in the measurement.

This is the second SFF specification that deals with the electrical performance of electrical interconnect. The first specification is SFF-8410 and a third is planned as a follow on, SFF-8415.

- SFF-8410 was originally published in March 2000 and is focused mainly on passive duplex constructions.
- SFF-8415 extends the focus of SFF - 8410 to the serial/parallel constructions and introduces new methodologies that are better suited to higher speed operation.

In the HPEI applications area existing specifications in standards have been found to be inadequate to produce the same results between independent measurements of the same parameters on the same hardware. Requirements are frequently called out with no reference to the methods required to verify the performance relating to the requirements. This specification significantly improves on this condition by defining measurement specifications that include enough detail to allow the performance specifications to be used effectively. Until such time as standards include such detail this specification can serve as the specification for the measurement methodology.

The numerical performance requirements for specific technologies are formally set by the standards that apply. It is the intent of this SFF specification to provide the measurement methodology that should be used to verify these performance parameters. Please refer to the relevant standard for the most current numerical requirements. In the absence of any standardized performance requirements one may use the suggested values presented in the "acceptable values" clauses of the respective measurement specifications.

This specification includes the requirements for constructions where one signal is traveling away from the transmitter at the same time another signal that is asynchronous to the data pattern is being received by a receiver on the same end of the cable assembly as the transmitter.

The performance requirements in this specification do NOT include the effects of connectors, board mounting, shield attachment to bulkheads, and other parts of the connection that are required to make a complete link. Only those features that are contributed by the unconnectorized bulk cable are included. For bulk cable, both shielded and unshielded, effects of the surrounding environment may contribute significantly to the performance of the bulk cable. In order to attain a transportable measurement methodology requirements for the environment during the measurement are included for unshielded bulk cable measurements. One may need to adjust the acceptable performance values for specific applications if the environment in service is different from that used during the measurements.

The HPEI bulk cable measurement procedures break down into two key levels:

(1) those that are used to verify that the required performance for the desired signals is being delivered to the receiving end while being a "good neighbor" and not exporting more than specified intensities of undesirable signals to other parts of the system or environment

(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 or being a good neighbor

Most attention is paid to the level 1 requirements. The level 2 measurements are described or referenced but measurement details are mostly not provided and no performance limits are suggested or referenced.

The SFF Committee was formed in August, 1990 to broaden the applications for storage devices, and is an ad hoc industry group of companies representing system integrators, peripheral suppliers, and component suppliers.

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 many SFF Specifications.

- X3.131R-1994	SCSI-2 Small Computer System Interface
- X3.253-1995	SPI (SCSI-3 Parallel Interface)
- X3.302-xxxx	SPI-2 (SCSI-3 Parallel Interface -2)
- X3.277-1996	SCSI-3 Fast 20
- asd;LAKJ	PIP (Passive Interconnect Performance)
- X3.221-1995	ATA (AT Attachment) and subsequent extensions
- EIA PN-3651	Detail Specification for Trapezoidal Connector 0.50" Pitch used with Single Connector Attach -2.
- X3.230-1994	FC-PH (Fibre Channel Physical Interface) and subsequent extensions FC-PH-3, FC-PI, FC-PI-2, FC-PI-3 and FC-PI-4
- 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). As the copyright on such documents is retained by the author, the INF or 'i' specifications cannot be freely copied for distribution.
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 28, 2005
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
SFF-8025	0.7	SFF Committee Specification Categories
INF-8028i	E	- Errata to SFF-8020 Rev 2.5
SFF-8029	E	- Errata to SFF-8020 Rev 1.2
SFF-8030	2.0	SFF Committee Charter
SFF-8031		Named Representatives of SFF Committee Members
SFF-8032	1.6	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	4.7	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	0.2	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	E	Emailing drawings over the SFF Reflector
SFF-8062		Rolling Calendar of SSWGs and Plenaries
SFF-8064		Unshielded HD Cable/Board Connector System
SFF-8065	C	40-pin SCA-2 Connector w/High Voltage
SFF-8066	C	80-pin SCA-2 Connector w/High Voltage
SFF-8067	3.4	40-pin SCA-2 Connector w/Bidirectional ESI
INF-8068i	E	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	C	XFP-E
SFF-8079	1.7	SFP Rate and Application Selection
SFF-8080	E	ATAPI for CD-Recordable Media
SFF-8082	5.1	Labeling of Ports and Cable Assemblies
SFF-8084	0.2	0.8mm SFP Card Edge Connector Dimensioning
SFF-8085	0.9	100 Mbs Small Formfactor Transceivers
SFF-8086	1.2	Compact Multilane Series: Common Elements
SFF-8087	1.3	Compact Multilane Series: Unshielded
SFF-8088	1.2	Compact Multilane Series: Shielded
SFF-8089	1.3	SFP Rate and Application Codes
INF-8090i	6.09	ATAPI for Multimedia Devices (Mt Fuji5)
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-8122		1.8" (60x70mm) w/SCA-2 Connector
SFF-8120	2.6	1.8" drive form factor (78x54mm)
SFF-8123	C	1.8" (60x70mm) w/Serial Attachment Connector
SFF-8124	0.2	Memory Form Factor Disk Drive Connections
SFF-8131		40mmx50mm Form Factor
SFF-8200e	1.1	2 1/2" drive form factors (all of 82xx family)
SFF-8201	2.4	2 1/2" drive form factor dimensions
SFF-8212e	1.2	2 1/2" drive w/SFF-8001 44-pin ATA Connector
SFF-8221	C	Pre-Aligned 2.5" Drive >10mm Form Factor

SFF-8222	2.1	2.5" Drive w/SCA-2 Connector
SFF-8223	2.4	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	1.4	3 1/2" drive w/Serial Attachment Connector
SFF-8332e	E	3 1/2" drive w/80-pin SFF-8015 SCA Connector
SFF-8337e	E	3 1/2" drive w/SCA-2 Connector
SFF-8342e	1.3	3 1/2" drive w/Serial Unitized Connector
INF-8350i	E	3 1/2" Packaged Drives
SFF-8400	C	VHDCI (Very High Density Cable Interconnect)
SFF-8401		Optical Transceiver for Short-Reach Appcns
SFF-8410	16.1	High Speed Serial Testing for Copper Links
INF-8411	1.0	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	15.0	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	0.5	Dual Row HSSDC-2 Shielded Connections
SFF-8425	1.4	Single Voltage 12V Drives
SFF-8426		HSSDC Double Width
SFF-8429	1.1	Signal Specification Architecture for HSS Links
SFF-8430	4.1	MT-RJ Duplex Optical Connections
SFF-8431		SFP+
SFF-8441	14.1	VHDCI Shielded Configurations
SFF-8448	0.4	SAS Sideband Utilization
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-8454		SCA-2 Enhanced HSS
SFF-8460	1.2	HSS Backplane Design Guidelines
SFF-8464	C	Improved MM HSS Optical Link Performance
SFF-8470	2.9	Multilane Copper Connector
SFF-8471	C	ZFP Multilane Copper Connector
SFF-8472	9.5	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	1.8	Unshielded Dual Port Serial Attachment Connector
SFF-8483	C	External Serial Attachment Connector
SFF-8484	1.6	Multilane Unshielded Serial Attachment Connector
SFF-8485	0.5	Serial GPIO (General Purpose Input/Output) Bus
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	1.4	5 1/4" drive w/Serial Attachment Connector
SFF-8551	3.2	5 1/4" CD Drives form factor
SFF-8552	1.1	5 1/4" 9.5mm/12.7mm Optical Drive Form Factor
SFF-8572	C	5 1/4" Tape form factor
SFF-8610	C	SDX (Storage Device Architecture)
SFF-8617		SAS Transition cables

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

Document subscribers and members are automatically updated every two months with the latest specifications. Specifications are available by FTP 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.

3. Editor's notes:

This revision incorporates editorial input through the May 18, 2005 HPEI SSWG. This revision is being used for a publication ballot.

TABLE OF CONTENTS

4. Introduction

This document contains methodologies for measuring the electrical performance of high speed serial copper bulk cable and backplanes without connectors. It is intended specifically to be used in conjunction in the following applications:

> 1,2, 4, 8, 16, 10 GFC, 1, 10 GBE, 4x InfiniBand, SAS, SATA, XAUI, 12x InfiniBand backplane, FC backplane, XAUI backplane and other HPEI applications for bulk cable and passive backplanes as they develop.

These measurements may also be useful for other high speed copper interconnects such as SCSI and IDE.

Although the specifications specifically document the measurements required for a single transmit and a single receive path in a single duplex bulk cable the methods are directly extensible to parallel implementations that use multiple high speed paths. Methods for extending the documented tests for multiple paths constructions are also outlined.

This document should be treated as a new specification available to aid in implementing the measurements required to meet the requirements in various published standards.

The methods described herein may be more stringent than some common industry practice due to lack of complete specification of measurement methods in the published standards. 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 (including the bulk cable performance contribution to the overall cable assembly performance), 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, for example, it is known that the receivers used in this application are more sensitive than required by the standard. However, taking this same cable assembly into an open, unbounded application may cause link failures because less sensitive, but still compliant, receivers happen to be on the attached ports.

5. Definitions and abbreviations

5.1 Definitions

Some terms used in this document require careful definition as specified in this section.

Characteristic impedance:

IEC definition:

A quantity defined for a mode of propagation at a given frequency in a specific uniform transmission line or uniform wave guide by any of the three following relations:

$\mathbf{Z} = \mathbf{S}/|\mathbf{I}|^2 \quad \mathbf{Z} = |\mathbf{V}|^2/\mathbf{S} \quad \mathbf{Z} = \mathbf{V}/\mathbf{I}$

where **Z** is the complex characteristic impedance, **S** the complex power and **V** and **I** are the values, usually complex, respectively of a voltage and a current conventionally defined for each type of mode by analogy with transmission line equations.

For a parallel-wire transmission line, **V** and **I** can be uniquely defined and the three equations are consistent. If the transmission line is lossless, the characteristic impedance is real.

IEEE definition:

The ratio of the complex voltage between the conductors to the complex current on the conductors taken at a common reference plane for a single transverse electromagnetic (TEM) propagating wave.

Use in this document:

The IEC definition is not used because this definition reports the characteristic impedance only for uniform conditions. Real transmission lines have impedance properties that are more complicated.

The IEEE definition is not used because the IEEE definition is open to interpretation due to the common reference plane not being defined (point in time/space or a ground plane?), the assumptions of uniformity not being stated, and the TEM wave not being distinguishable between a single sinusoidal wave and a pulse edge wave.

For real transmission lines (that have some non-uniformity) the characteristic value is defined in the context of the measurement method. Therefore this document does not use the term characteristic impedance. When impedance properties are described the term used is ‘transmission line impedance’ or the measurement method defines the meaning.

Common mode (Zcm): The impedance to ground seen when testing into a pair of lines shorted together at the source. In general, Zcm is the parallel combination of Zoe1 and Zoe2, i.e., (Zoe1*Zoe2)/(Zoe1+Zoe2)

Differential (Zdiff): The impedance between the lines of a pair of lines with each line driven by equal and opposite polarity signals with respect to ground. Zdiff = Zoo1 + Zoo2.

Even Mode (Zoe): the impedance to ground of one line of a differential pair of lines when the other line is driven with the same polarity and equal amplitude. Each line of the pair has a different value for even mode impedance, Zoe1 and Zoe2, (except for perfectly balanced pairs).

In-pair propagation time skew: the difference between propagation time of + signal and the - signal at the midpoint of the transition over the same nominal path. This definition is optimized for use by digital receivers, does not consider the skew of the specific frequencies in the signal and is not equivalent to the sine wave response. Equivalent to the term ‘within pair skew’.

Odd Mode (Zoo): the impedance to ground of one line of a differential pair of lines when the other line is driven with opposite polarity and equal amplitude. Each line of the pair has a different value for odd mode impedance, Zoo1 and Zoo2, (except for perfectly balanced pairs).

Pair to pair skew: the difference between propagation time of the zero volts level for the differential signal of two pairs. (The differential zero crossing is the mid point of the differential signal transition). This definition is optimized for use by digital receivers, does not consider the skew at specific frequencies, and is not equivalent to sine wave response.

Propagation delay: See propagation time

Propagation time: the time required for a specific part of a signal to travel a specific distance along the path of the line. For in-pair skew measurements the midpoint of the transition is the applicable part of the signal and for pair to pair measurements the differential zero volts level is the applicable part of the signal. - Equivalent to propagation delay.

Single ended Zo: The impedance to ground for a single line which is not coupled to an adjacent line.

Transmission line impedance: The same as characteristic impedance

5.2 Abbreviations

BCUT:	Bulk Cable Under Test
CJTPAT:	Compliant Jitter Tolerance PATtern
CMPT:	Common Mode Power Transfer
EMI:	ElectroMagnetic Interference
EMR:	ElectroMagnetic Radiation
HPEI:	High Performance Electrical Interconnect
HSS:	High Speed Serial
IL:	Insertion Loss
ISI:	InterSymbol Interference
NA:	Network Analyzer (scalar)
PRBS:	Pseudo Random Bit Sequence
S21:	Scattering parameter 21 for single ended insertion loss
SCC21:	Scattering parameter 21 for Common mode to Common mode (common mode insertion loss)
SCD21:	Scattering parameter 21 for Differential to Common mode conversion
SDD21:	Scattering parameter 21 for Differential to Differential insertion loss
STD:	Signal Transition Duration (rise/fall time)
TDNA:	Time Domain Network Analyzer (vector)
TDR:	Time Domain Reflectometry
TDT:	Time Domain Transmission
TDW:	Time Domain Waveform
VNA:	Vector Network Analyzer (frequency domain)

6. General requirements

The boundary where high speed testing (as opposed to low speed testing) becomes necessary is not sharp and this document does not attempt to define the boundary. The signals of interest in this document range from 1.0 to >10 Gbits/sec with rise times from approximately 20 to 100 ps. Testing techniques for HPEI bulk cable in this speed range lack good standardization and measurement methods. This deficiency leads to unintended incompatibilities between suppliers and users. Although the specifications in this document are written around 100 ohm balanced transmission, the methods are readily adaptable to other transmission line impedance levels such as the 110 ohm used by 1394.

The bulk cable requirements specified in this document do not attempt to anticipate all the possible effects that can occur to the performance as a result of connector attachment, of placing connectors on boards, and of mating the finished assembly to a shielded bulkhead. Except for the electromagnetic compatibility tests, all tests apply to both shielded and unshielded constructions. The test fixturing for measuring the performance of bulk cable is considered directly in this document.

All measurements are intended to apply to all constructions of bulk cable except where specifically noted.

The general requirements for HPEI bulk cable are to meet the defined limits for performance in the following areas:

- S21 (insertion loss, attenuation)
- Jitter contributed by the bulk cable (low population data patterns plus isolated pulses)
- Transmission line impedance
- Crosstalk
- EMI (external interconnect applications, shielded versions only*)
- Signal propagation time
- Signal pair to signal pair propagation time skew
- Within pair skew
- Mode conversion (differential to common mode)

* unless the application requires specially balanced launch signals in which case unshielded versions could be considered e.g. Cat 5 types with EMR methods

The performance requirements apply over a defined range of frequencies.

The set of measurement methodologies specified offer the ability to specify performance requirements for bulk cable over a large range of applications. The pass/fail criteria is expected to depend on the details of the application in terms of the data patterns that are used, transceiver signal requirements, and other properties.

There is no guarantee that bulk cable that meets the performance requirements will produce cable assemblies or backplanes that meet the overall port to port signal requirements. The properties of the connectors, the connector to bulk cable termination, the properties of the data patterns used in the system, and system noise all contribute to the cable assembly performance. It is the responsibility of the cable assembly and overall system designer to produce compliant signals at the interoperability points.

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

One risk comes from inadequately characterizing the launched signals used in the measurements. If launched signals used during the measurement are degraded more than that allowed then the bulk cable will be called on to cause less degradation to produce the minimum specified output. The use of excessively degraded launched signals places unfair burden on the bulk cable. Conversely, if the launched signals are better than allowed, the bulk cable may cause more degradation than allowed for the bulk cable but still deliver specified outputs. This condition permits defective bulk cable to be measured as good bulk cable. The way to avoid these risks is to execute an adequate characterization of the launched signals and to compensate in the measurement requirements for the amount of excess goodness or badness in the launched signals. Figure 1 illustrates this general scheme.

Another risk derives from the fact that some parameters in launched signals related to balance, common mode levels, and crosstalk can be corrected by bulk cable that introduces degradation (or compensation) of equal and opposite sign and phase. If this happens it gives a false sense of goodness since launched signals from other sources may have the parameters degraded in the same sense as the bulk cable with a nominal resulting doubling in the negative effects at the output.

In general, if the polarity of connection of the bulk cable to the launched signals is reversed then the polarity of the degradation in the bulk cable is also reversed (for those parameters that are sensitive to polarity, like balance and near end crosstalk). Therefore the second risk can be managed by performing a second test with reversed connections but changing nothing else.

In order to avoid this risk one must take two measurements: (1) with the + signal of the transmitter connected to the + line of the PUT and the - signal of the transmitter connected to the - line of the PUT and (2) with the + signal of the transmitter connected to the - line of the PUT and the - signal of the transmitter connected to the + line of the PUT. Figure 2 illustrates this scheme.

Summarizing, the combination of real launched signal properties and bulk cable properties causes additional burden on the measurement process. The compensation for real launched signals is likely to be a one time cost for the same transmitter. The polarity reversal, however, requires that two independent measurements be executed because one cannot be sure which sense of degradation is present in the bulk cable under test.

During the calibration processes for the measurements 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 bulk cable is concerned. Said differently, if the launched signals are better than allowed (as is usually the case) then the requirements on the output 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 output signal range is broadened.

This process eliminates a major problem with creating calibrated degraded high frequency signals, uses the linear property of copper bulk cable to good advantage, and allows the properties of the bulk cable to be fairly and accurately measured.

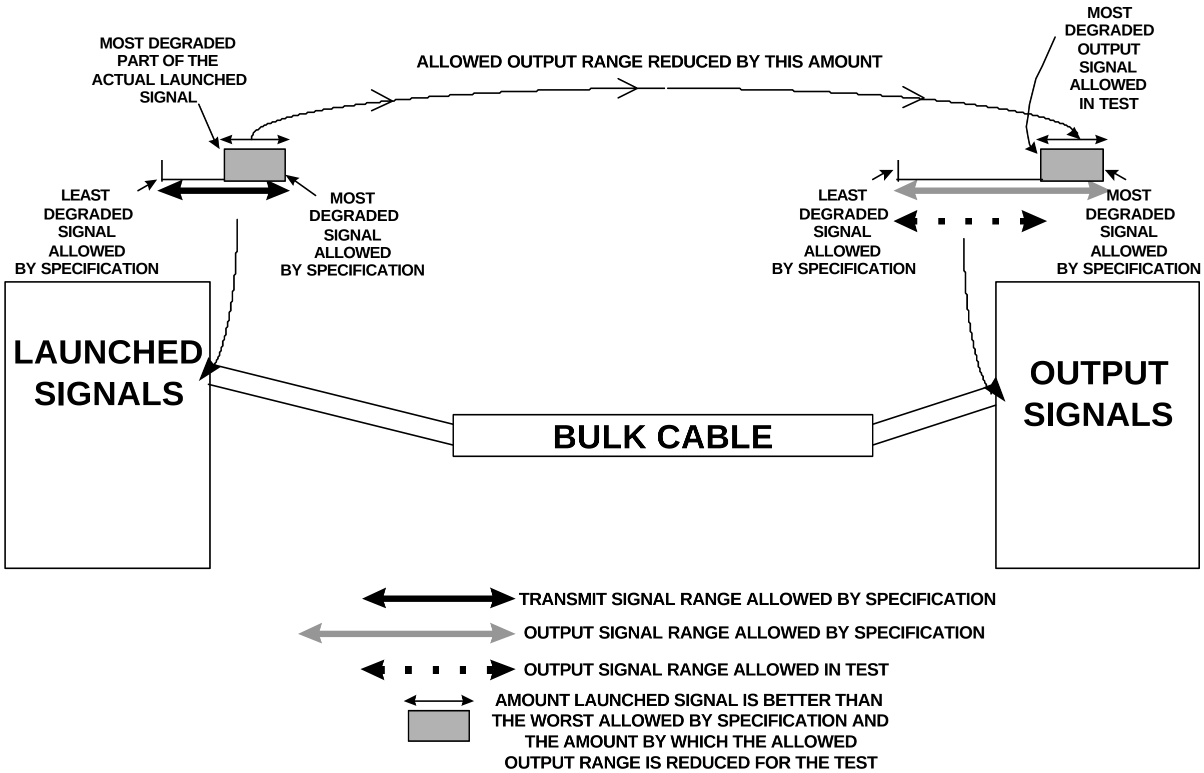


Figure 1 - Range compensation strategy (if needed)

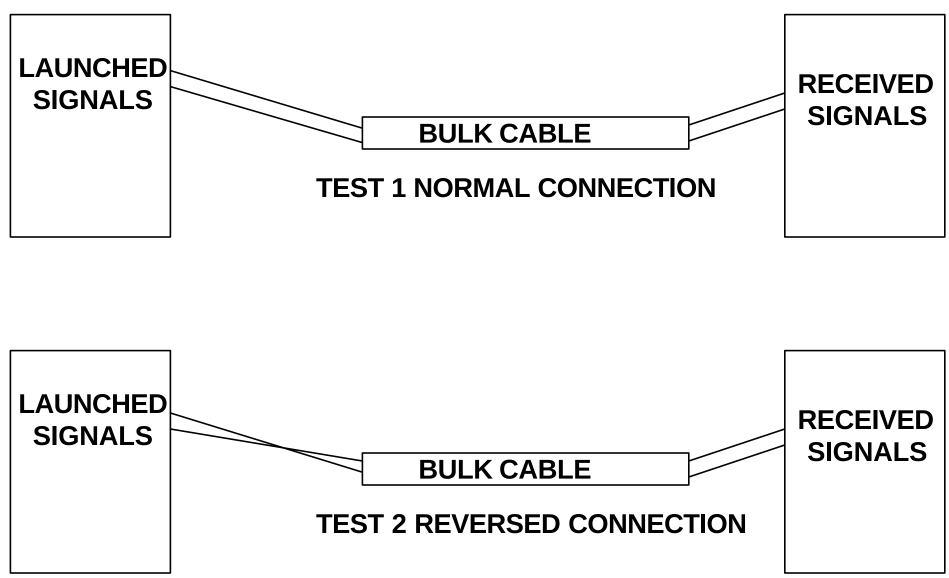


Figure 2 - Degradation sense compensation / detection

7. Framework for HSS testing

7.1 Area of applicability

This section specifies the framework used for the high frequency performance requirements and test methods to be used for measurement and verification of properties of the bulk cable. These requirements apply to the minimally disturbed (by the attachment to the test fixture) bulk cable and to the electrical neighborhood of the point of attachment to the test fixture. See section 7.3.

7.2 HSS test levels

7.2.1 Overview of tests, measurements and levels

The terms “test” and “measurement” are closely related and are frequently used interchangeably in common parlance. The distinction between these two terms in this document is that the concept of a measurement is the pure act of obtaining a valid result without judgment on whether the result represents a good performance or a bad performance while the concept of a test requires a valid measurement process and definition of pass-fail limits. The distinction between test and measurement is formally made in this clause but may not always be rigorously applied in this document because the distinction is a fine one and not likely to cause misinterpretation or errors.

The test/measurement distinction also applies in a more important way when the pass/fail limits are different for different applications. The approach used in this document considers that all the procedures are described purely as measurements. Whether a procedure is also a test in this document depends on whether a valid standard exists that specifies acceptable values. Only in the cases where (1) no valid standard exists or (2) where the measurement process required to enforce the standard is not specified adequately should this document be treated as a test specification. In these two cases this document should be used as both a way to create performance requirements where none now exist and as a way to specify measurement processes where none are adequately specified.

Regardless of where the pass-fail limits are specified, two broad levels of measurements (tests) are described: level 1 and level 2. Level 1 measurements are intended to be used as tests while level 2 measurements are intended to be used as characterization and diagnostic tools. For simplicity we may choose to use the term “measurement” for both levels.

More details of the level 1 and level 2 measurement are given in clauses 7.2.2, 7.2.3, and 7.2.4.

7.2.2 Level 1 measurement definition

Level 1 measurements are those that are suitable for use as compliance or qualification tests. Specific applications may require only some of the level 1 measurements described in this document. Compliance limits are defined by the application requirements, not this document.

7.2.3 Level 2 measurement definition

Level 2 measurements are intended for diagnosis and characterization of the BCUT performance.

7.2.4 Relationship between level 1 and level 2 measurement

The specific measurements used for the two levels is specified in detail in later sections. By separating the measuring requirements into the two different levels, laboratory 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 measurements need be used to verify an bulk cable for sale or use by both the supplier and the user. The level 2 measurements are available to the bulk cable designer and manufacturer to more efficiently create designs and manufacturing processes that produce good bulk cable. Figure 3 shows a graphical relationship between the two levels of measurement.

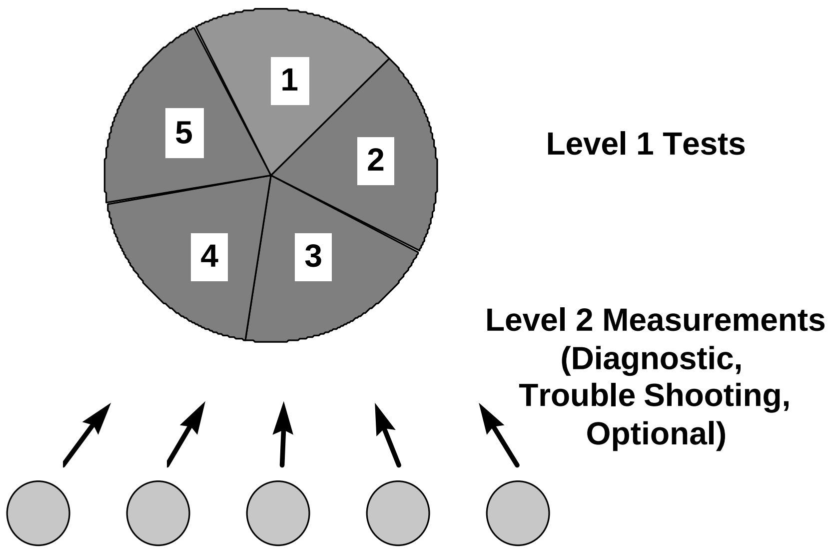


Figure 3 - Two levels of measurement for HSS bulk cable

7.3 Electrical Neighborhood

The electrical neighborhood is defined as being those physical electrically conducting structures that have the following properties:

- Not part of the bulk cable
- Attached to a bulk cable conductor through a signal path in the measurement environment
- Any part of the signal path during the measurement that affects the measurement (excluding a 1-2% allowance for multiple reflections)

For time domain reflectometry the electrical neighborhood extends up to the distance occupied by three times the rise or fall lengths from the connection to the test fixture. The largest rise or fall length (rise time or fall time times the propagation velocity) is for the slowest signal under consideration. Examples of properties that may affect the measurement are transmission line impedance mismatches and discontinuities. From this point forward the terms “rise time” and “fall time” have been replaced in this document by the more general term “signal transition duration” or “STD”.

For other measurements the electrical neighborhood may extend far beyond the test fixture. Examples of extended electrical neighborhoods are attenuation or crosstalk measurements that are affected by the far end termination and bulk cable impedance far away from test fixture attachment point.

two types of electrical neighborhood are defined:

- Close proximity (within three STD lengths of the attachment point)
- Extended: not close proximity

For example, for a 200 ps (0.2 ns) STD and a bulk cable with a propagation velocity of 6 cm/ns the close proximity electrical neighborhood would be all the electrical paths within 0.2 x 6 x 3= 3.6 cm from the attachment point. Notice that the slower signals dominate the extent of the close proximity electrical neighborhood but the faster signals that stress the electrical performance the most have a smaller electrical neighborhood.

Features within the close proximity electrical neighborhood may act as if they were part of the BCUT itself as far as contribution to the overall performance of the bulk cable is concerned. For measurements not requiring high accuracy, smaller close proximity electrical neighborhoods may be allowed.

PCB features such as vias, corners in PCB traces, and pads for board mounting applications all typically fall within the close proximity electrical neighborhood for board mounting applications. Dressing of wire paths near the connector termination, the termination contacts, and metallic strain relief parts typically fall within the close proximity electrical neighborhood in wire termination applications.

Some examples of close proximity electrical neighborhood features that may apply are shown in Figure 4.

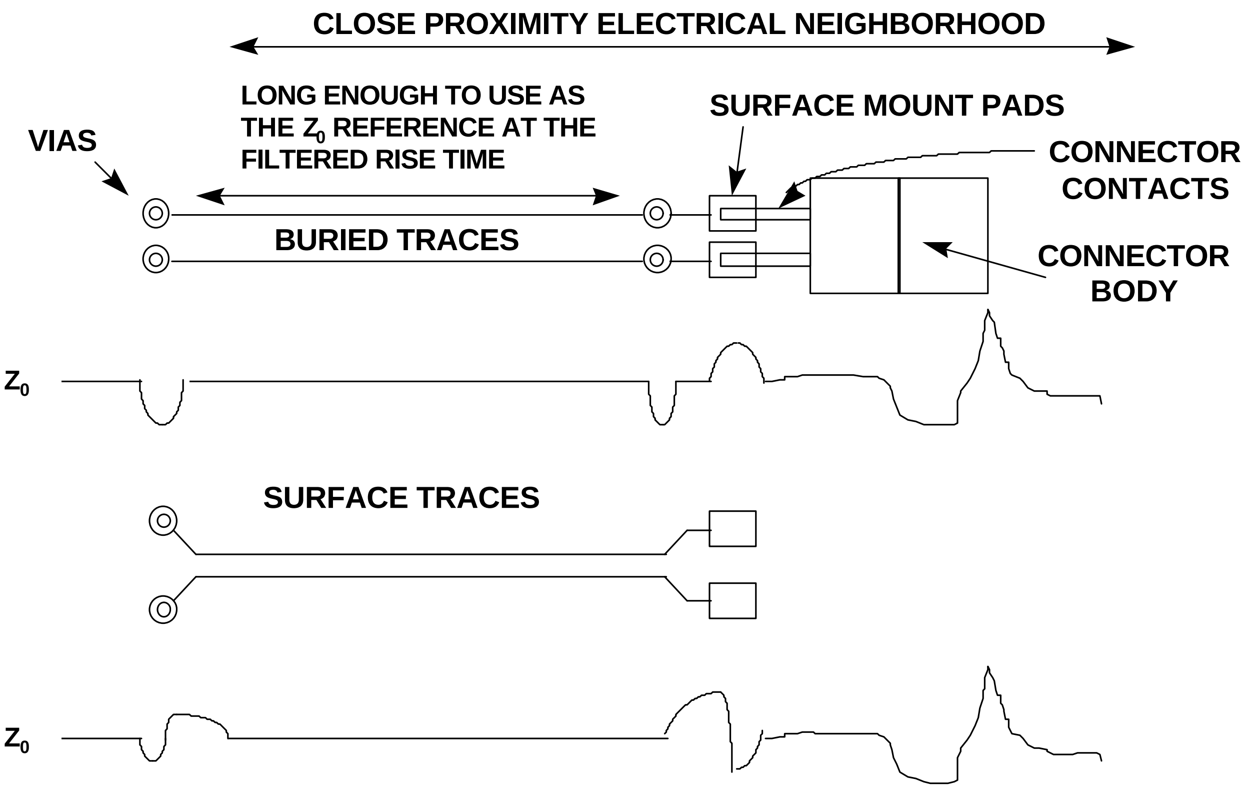


Figure 4 - Some key design areas for pcb features

Close proximity electrical neighborhoods find their greatest application in the use of time domain reflectometry (TDR) and in the behavior of connectors used as media or transmission line termination elements.

Figure 5 shows an example of a TDR measurement on the same sample with different STD’s. The effect of the discontinuities appears larger when shorter STD’s are used. It is very important to make measurements using STD’s over the entire allowed range. For the shortest allowed STD the maximum amplitude of effects of the discontinuities are revealed. For the longest allowed STD the maximum extent of the close proximity electrical neighborhood is shown.

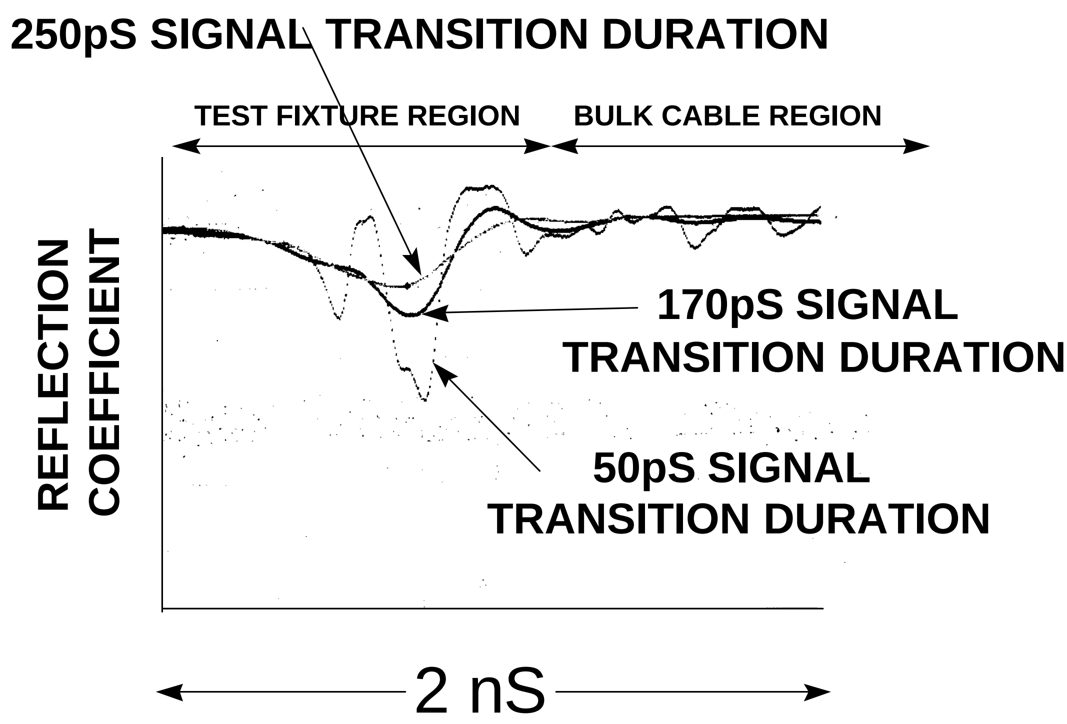


Figure 5 - TDR data in a typical HPEI bulk cable

7.4 Scaling with lengths issues

It is tempting to assume that one may pick any length of bulk cable to measure as long as there is enough signal to get about 10 dB above the noise floor of the measurement. This simplification of linearity with length is very risky due to several mechanisms that can exist in bulk cable. Details of these risks follow.

The following mechanisms may cause measurement results that do not scale with sample length:

- Within pair skew measured at the midpoint of the signal transition
- Pair to pair skew
- Insertion loss, near end crosstalk, and SDD11 in the presence of periodic structures
- Differential to common mode conversion
- Bulk cable contributed jitter

The skew mechanisms can result from a statistical distribution along the length of the sample of the features that cause the skew.

The periodic structures have impacts that depend strongly on the actual number of periodic disturbances that exist in the sample and on the magnitude of the disturbances. Examples of periodic disturbances are lay of the twists and periodic extrusion variation during dielectric application to the wire. For all periodic effects a longer sample produces a greater effect.

Mode conversion tends to occur at points in the construction where imbalance exist and such points may be statistically distributed along the length of the sample.

The following mechanisms generally scale with sample length:

- Insertion loss (in dB) where there is no significant periodic structure

- Propagation time

It may happen that certain suppliers of bulk cable guarantee that specific properties such as propagation time skew scale with length. However, if such scaling can be predicted and guaranteed then a key clue to eliminate the cause exists. Guaranteeing linearity with cable length for properties that involve interaction between different conductors or insulators is essentially an advertisement that some predictable differences between pairs or within a pair exists.

It is required that some knowledge of the maximum application length be available in order to do an effective assessment of the quality of the bulk cable. This document requires sample lengths for bulk cable performance measurements that approximate the expected maximum in the application for measurement of properties that may not scale with length. See also 8.2.2.

7.5 Relationship between applications and test conditions

Table 1 lists the relationship between applications, defined as transports and speeds, in terms of sample length and data pattern requirements for the bulk cable measurement. The lengths stated in Table 1 are those expected when using the anticipated largest wire that is compatible with the connectors. If smaller wires are used (with resulting shorter maximum length) or if other application lengths are known, then the maximum length expected in the application shall be used for the measurement of bulk cable performance.

Note that encoding scheme used forces different data patterns. See FC-MJSQ for more details concerning the issues when using scrambling and other non 8b10b encoding schemes.

Table 1 - Map of required test conditions

Transport	Data rate per signal Gb/s	Encoding	Transmitter or receiver compensation required	Compliance interconnect	Data patt	Nominal max length (meters)
Single stream FC	1.0625	8b10b	none	no	2^7-1	30
Single stream FC	2.125	8b10b	none	no	2^7-1	15
Single stream FC	4.25	8b10b	none	yes	2^7-1	7
4 lane copper FC	3.1875 (10G nominal)	8b10b	none	yes	2^7-1	10
4 lane copper GE CX-4	3.125 - 10G nominal	scrambled 8b10b	receiver equalization	yes	40x Ibit*	15
4 lane 10GBASE-T	1.0	10 level multilevel probable	receiver signal conditioning	?	TBD	100
Single stream IB	2.5	scrambled 8b10b	none	no	40x Ibit*	17
4 lane IB	2.5	scrambled 8b10b	none	no	40x Ibit*	10
4 lane IB	5.0	scrambled 8b10b	none	no	40x Ibit*	5
4 lane IB	10.0	scrambled 8b10b	?	no	40x Ibit*	5
12 lane IB	2.5	scrambled 8b10b	none	no	40x Ibit*	10
12 lane IB	5.0	scrambled 8b10b	none	no	40x Ibit*	5
12 lane IB	10.0	scrambled 8b10b	?	no	40x Ibit*	5
SAS (single stream)	1.5	scrambled 8b10b	none	yes	40x Ibit*	10
SAS (single stream)	3.0	scrambled 8b10b	transmitter	yes	40x Ibit*	10
SAS (single stream)	6.0	scrambled 8b10b	transmitter + receiver	yes	40x Ibit*	10
SATA internal	1.5	scrambled 8b10b	none	yes	40x Ibit*	1
SATA internal	3.0	scrambled 8b10b	none	yes	40x Ibit*	1
SATA-2 external	1.5	scrambled 8b10b	none	yes	40x Ibit*	10
SATA-2 external	3.0	scrambled 8b10b	none	yes	40x Ibit*	10
* 40x Ibit means a balanced pattern with isolated bits in a 40 to 1 ratio. Balance in this context means the number of ‘1’s’ and the number of ‘0’s’ are equal. The specified pattern is: 40 ‘1’s’, single ‘0’, 40 ‘1’s’, 40 ‘0’s’ single ‘1’, 40 ‘0’s’, repeat. This pattern may <u>not</u> be substituted with less stressful patterns such as: 2^7-1, 2^{15}-1, 2^{31}-1, CJPAT, CJTPAT, K28.5, idle primitives.						

For the bulk cable contributed jitter requirements, additional allowance is required to account for mechanisms that are not present during the measurement. See 7.6.5 for more detail.

7.6 Definition of HPEI bulk cable electrical performance parameters

7.6.1 Overview

Clause 7.6 gives more detail concerning the performance parameters requirements.

7.6.2 Definition of PUT and PUT_{NOT}

HPEI bulk cable has two basic parts: (1) the pair transporting the signal path under test and (2) the other pairs transporting other signals, that is, the pairs that are NOT under test but may be providing significant interactions with pair under test. The pair that is under test is called the “pair under test” or the PUT. The pair(s) that is not under test is called the “pair(s) not under test” or the PUT_{NOT}.

The PUT and the PUT_{NOT}‘s each have an associated transmitter and receiver. Figure 6 illustrates an example relationship for a simple HPEI bulk cable.

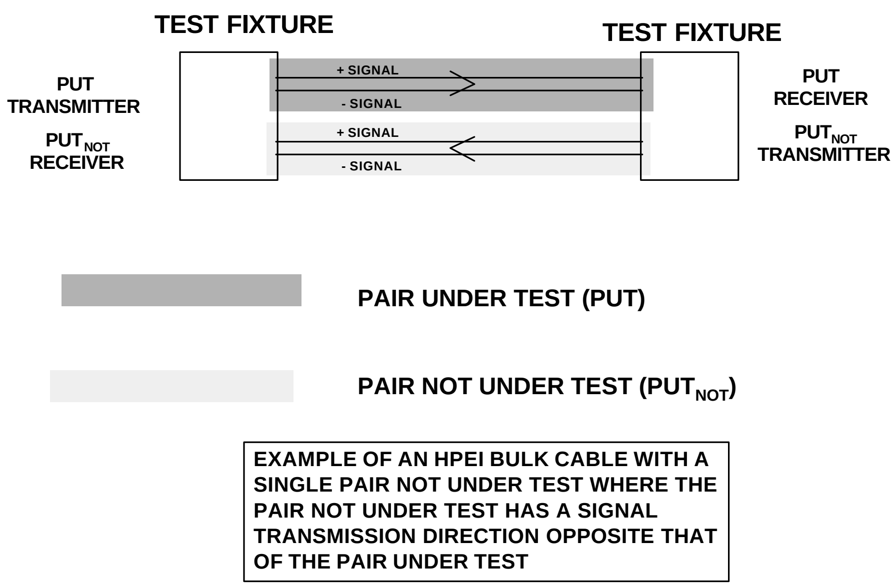


Figure 6 - Terminology for bulk cable under test (BCUT)

Figure 7 shows the conventions and abbreviations used for signals and instruments for the same example construction shown in Figure 6.

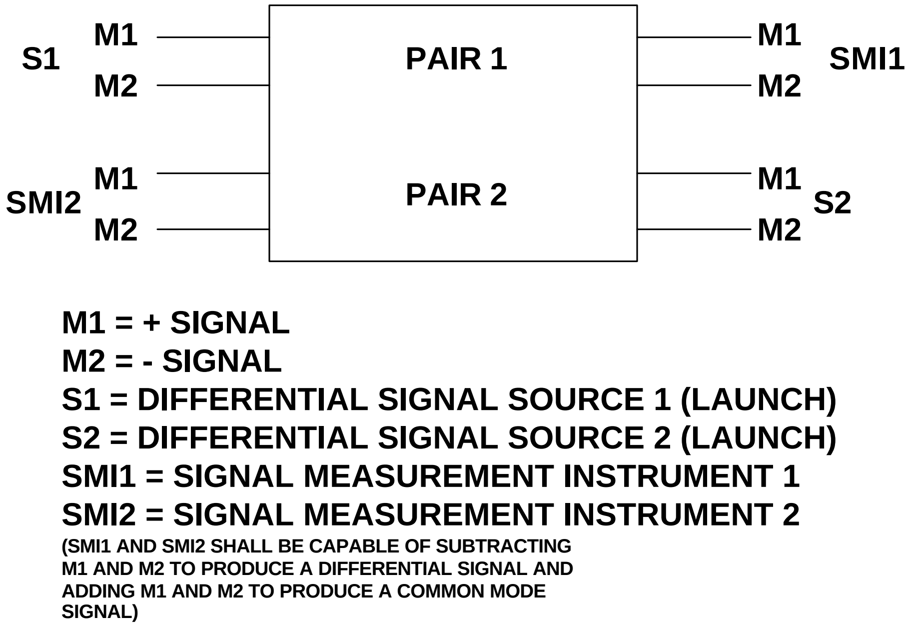


Figure 7 - Definition of abbreviations used for signals and instruments

7.6.3 Definition of S parameter naming conventions

Figure 8 shows the connections that would be made to a four port vector network analyzer (VNA) for measuring S parameters on a four single ended port ‘black box’ device. VNA’s recognize incident signals denoted by the ‘A’ subscript and reflected signals from the same port denoted by the ‘B’ subscript.

All the measurements specified in this document relate to differential signal pairs. It requires all four VNA ports to measure the properties of two differential ports. VNA ports are all single ended and the differential and common mode properties for differential ports are calculated internal to the VNA.

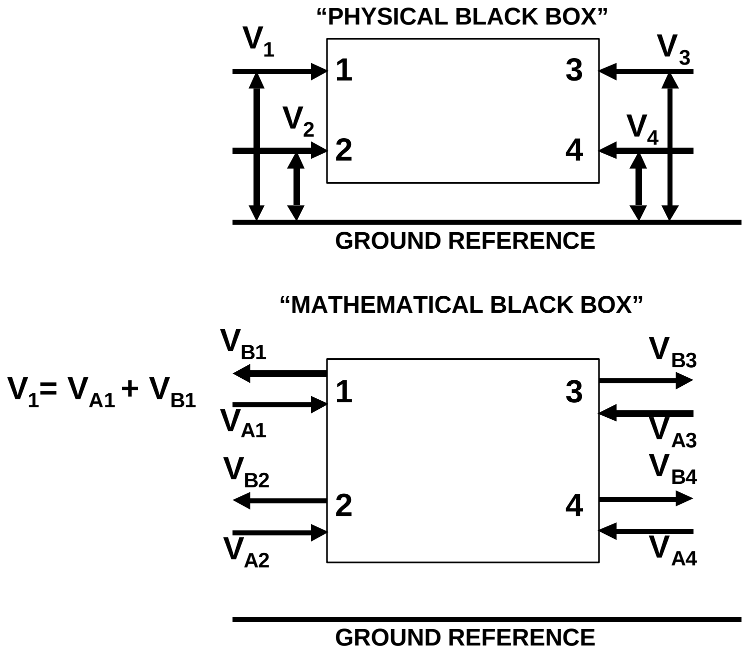
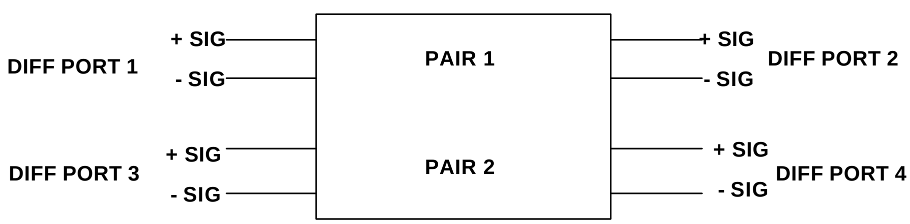


Figure 8 - Architecture of a 4 port VNA measurement

Figure 9 shows the definition of the differential ports and the differential S parameters that may be acquired from a two pair BCUT. Since the VNA has only four single ended ports only two differential ports may be measured at one time. Physical reconfiguration is required to access all the differential S parameters listed in Figure 9.



SDD11 = DIFFERENTIAL RETURN LOSS FROM DIFF PORT 1
SDD22 = DIFFERENTIAL RETURN LOSS FROM DIFF PORT 2
SDD33 = DIFFERENTIAL RETURN LOSS FROM DIFF PORT 3
SDD44 = DIFFERENTIAL RETURN LOSS FROM DIFF PORT 4
SDD21 = DIFFERENTIAL INSERTION LOSS AT DIFF PORT 2 FROM DIFF PORT 1
SDD31 = DIFFERENTIAL NEAR END CROSS TALK AT DIFF PORT 3 FROM DIFF PORT 1
SDD41 = DIFFERENTIAL FAR END CROSS TALK AT DIFF PORT 4 FROM DIFF PORT 1
SDD42 = DIFFERENTIAL NEAR END CROSS TALK AT DIFF PORT 4 FROM DIFF PORT 2
SDD43 = DIFFERENTIAL INSERTION LOSS AT DIFF PORT 4 FROM DIFF PORT 3
SDD32 = DIFFERENTIAL FAR END CROSS TALK AT DIFF PORT 3 FROM DIFF PORT 2
SDD31 = DIFFERENTIAL NEAR END CROSS TALK AT DIFF PORT 3 FROM DIFF PORT 1
SDD12 = DIFFERENTIAL INSERTION LOSS AT DIFF PORT 1 FROM DIFF PORT 2
SDD13 = DIFFERENTIAL NEAR END CROSS TALK AT DIFF PORT 1 FROM DIFF PORT 3
SDD14 = DIFFERENTIAL FAR END CROSS TALK AT DIFF PORT 1 FROM DIFF PORT 4
SDD23 = DIFFERENTIAL FAR END CROSS TALK AT DIFF PORT 2 FROM DIFF PORT 3
SDD24 = DIFFERENTIAL NEAR END CROSS TALK AT DIFF PORT 2 FROM DIFF PORT 4

Figure 9 - Definition of differential S parameters

Figure 10 shows all the possible configurations for a two pair BCUT. Note that termination is required on all differential ports that are not connected to the VNA.

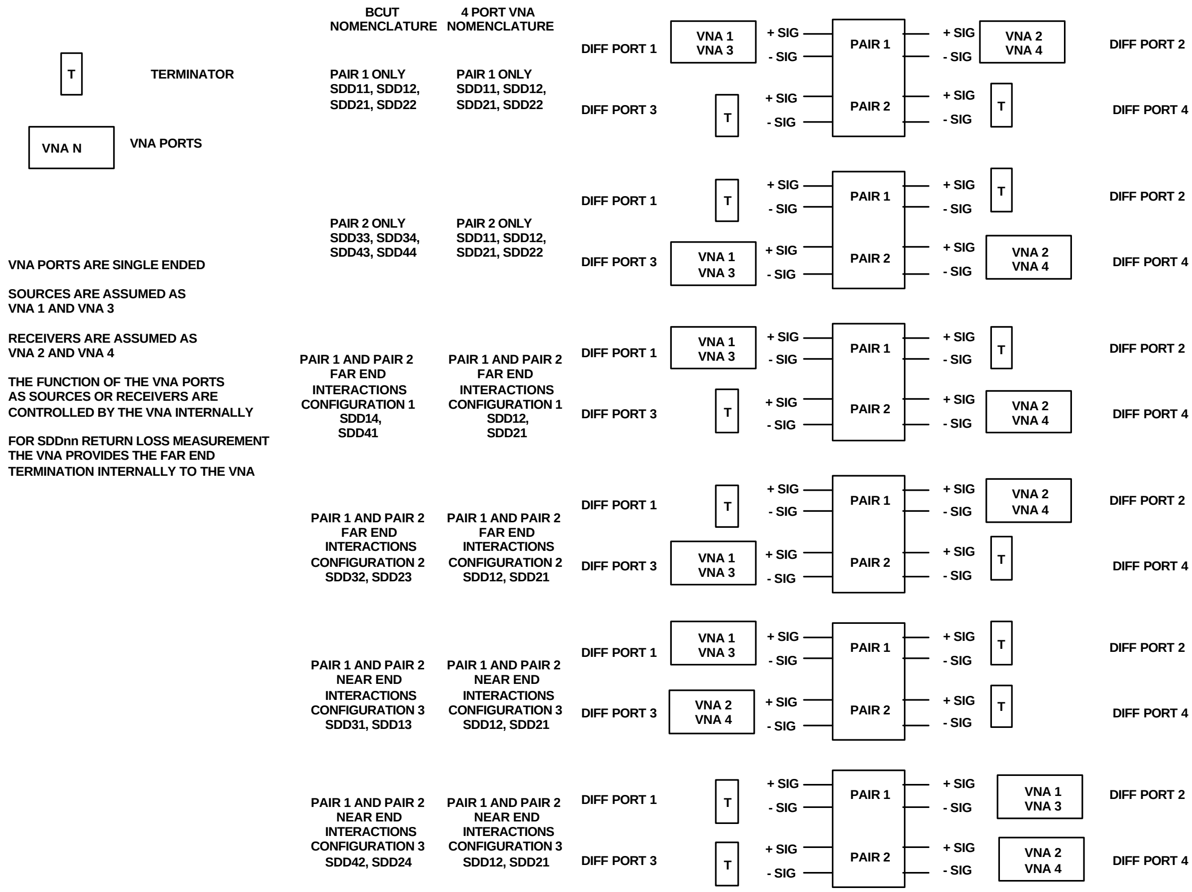


Figure 10 - Possible configurations for differential S parameter measurements

Although the above figures show the connections for a VNA the same information may be obtained by using a TDR/TDT measurement to acquire a time domain waveform. The waveforms may then be converted to S parameters using a suitable software package.

7.6.4 Stimulus and response forms

The following 4 x 4 matrix shows all differential, common, and mode conversion S parameters that are possible from a differential two port (single ended 4 port).

In the first matrix the differential only portions are shown in larger font. In the second matrix the common mode only portions are shown in larger font. In the third matrix the mode conversion responses are shown in larger font. Transmission responses acquired via TDT and reflection responses acquired via TDR are noted. Mapping the time domain measurements to the frequency domain S parameter space is shown for all cases.

Three types of measurement are defined: return loss, insertion loss and mode conversion.
Return loss uses TDR methods. Insertion loss and mode conversion uses TDT methods.

For differential measurements differential stimulus signals are used with differential response measurements. For common mode measurements common mode stimulus signals are used with common mode response measurements. For mode conversion measurements differential stimulus with common mode response or common mode stimulus with differential response is used. This set of relationships is mapped in Figure 11.

Differential TDR stimulus, differential response

$$\begin{bmatrix} S_{DD11} \text{ « } TDR_{DD11} & S_{DD12} \text{ « } TDT_{DD12} & S_{DC11} \text{ « } TDR_{DC11} & S_{DC12} \text{ « } TDT_{DC12} \\ S_{DD21} \text{ « } TDT_{DD21} & S_{DD22} \text{ « } TDR_{DD22} & S_{DC21} \text{ « } TDR_{DC21} & S_{DC22} \text{ « } TDR_{DC22} \\ S_{CD11} \text{ « } TDR_{CD11} & S_{CD12} \text{ « } TDT_{CD12} & S_{CC11} \text{ « } TDR_{CC11} & S_{CC12} \text{ « } TDT_{CC12} \\ S_{CD21} \text{ « } TDT_{CD21} & S_{CD22} \text{ « } TDT_{CD22} & S_{CC21} \text{ « } TDT_{CC21} & S_{CC22} \text{ « } TDR_{CC22} \end{bmatrix}$$

Common mode TDR stimulus, common mode response

$$\begin{bmatrix} S_{DD11} \text{ « } TDR_{DD11} & S_{DD12} \text{ « } TDT_{DD12} & S_{DC11} \text{ « } TDR_{DC11} & S_{DC12} \text{ « } TDT_{DC12} \\ S_{DD21} \text{ « } TDT_{DD21} & S_{DD22} \text{ « } TDR_{DD22} & S_{DC21} \text{ « } TDR_{DC21} & S_{DC22} \text{ « } TDR_{DC22} \\ S_{CD11} \text{ « } TDR_{CD11} & S_{CD12} \text{ « } TDT_{CD12} & S_{CC11} \text{ « } TDR_{CC11} & S_{CC12} \text{ « } TDT_{CC12} \\ S_{CD21} \text{ « } TDT_{CD21} & S_{CD22} \text{ « } TDT_{CD22} & S_{CC21} \text{ « } TDT_{CC21} & S_{CC22} \text{ « } TDR_{CC22} \end{bmatrix}$$

Mixed mode

$$\begin{bmatrix} S_{DD11} \text{ « } TDR_{DD11} & S_{DD12} \text{ « } TDT_{DD12} & S_{DC11} \text{ « } TDR_{DC11} & S_{DC12} \text{ « } TDT_{DC12} \\ S_{DD21} \text{ « } TDT_{DD21} & S_{DD22} \text{ « } TDR_{DD22} & S_{DC21} \text{ « } TDT_{DC21} & S_{DC22} \text{ « } TDR_{DC22} \\ S_{CD11} \text{ « } TDR_{CD11} & S_{CD12} \text{ « } TDT_{CD12} & S_{CC11} \text{ « } TDR_{CC11} & S_{CC12} \text{ « } TDT_{CC12} \\ S_{CD21} \text{ « } TDT_{CD21} & S_{CD22} \text{ « } TDR_{CD22} & S_{CC21} \text{ « } TDT_{CC21} & S_{CC22} \text{ « } TDR_{CC22} \end{bmatrix}$$

Figure 11- Mapping of frequency domain and time domain parameters

7.6.5 Definition of level 1 electrical performance parameters

The measurements in the following list are the level 1 measurements for HPEI bulk cable.

a) Transmission line impedance (Z_0) (time domain (local))

b) Propagation time and propagation time skew (time domain @ 50% point, differential, TDT - using lengths appropriate for the application)

c) Propagation time skew between + and - signals

d) S21 (insertion loss, attenuation within pair - frequency domain - assumed to scale with length within measurement error)

e) Time domain near end and far end crosstalk (any aggressor to any victim)

f) Bulk cable contributed jitter (eye test at 0 differential volts crossing using a data pattern appropriate for the application as defined in this document) [Note that the bulk cable contributed jitter specified via this method is only part of the entire jitter budget.]

g) Mode conversion within pair (frequency domain) (does not scale with length - standard lengths appropriate for the bulk cable design (e.g. 5, 10 and 30 meters for 24 AWG 150 ohm) or the specified application length(s))

h) EMI (EMR and CMPT)

Figure 12 summarizes the level 1 measurement types for HPEI bulk cable.

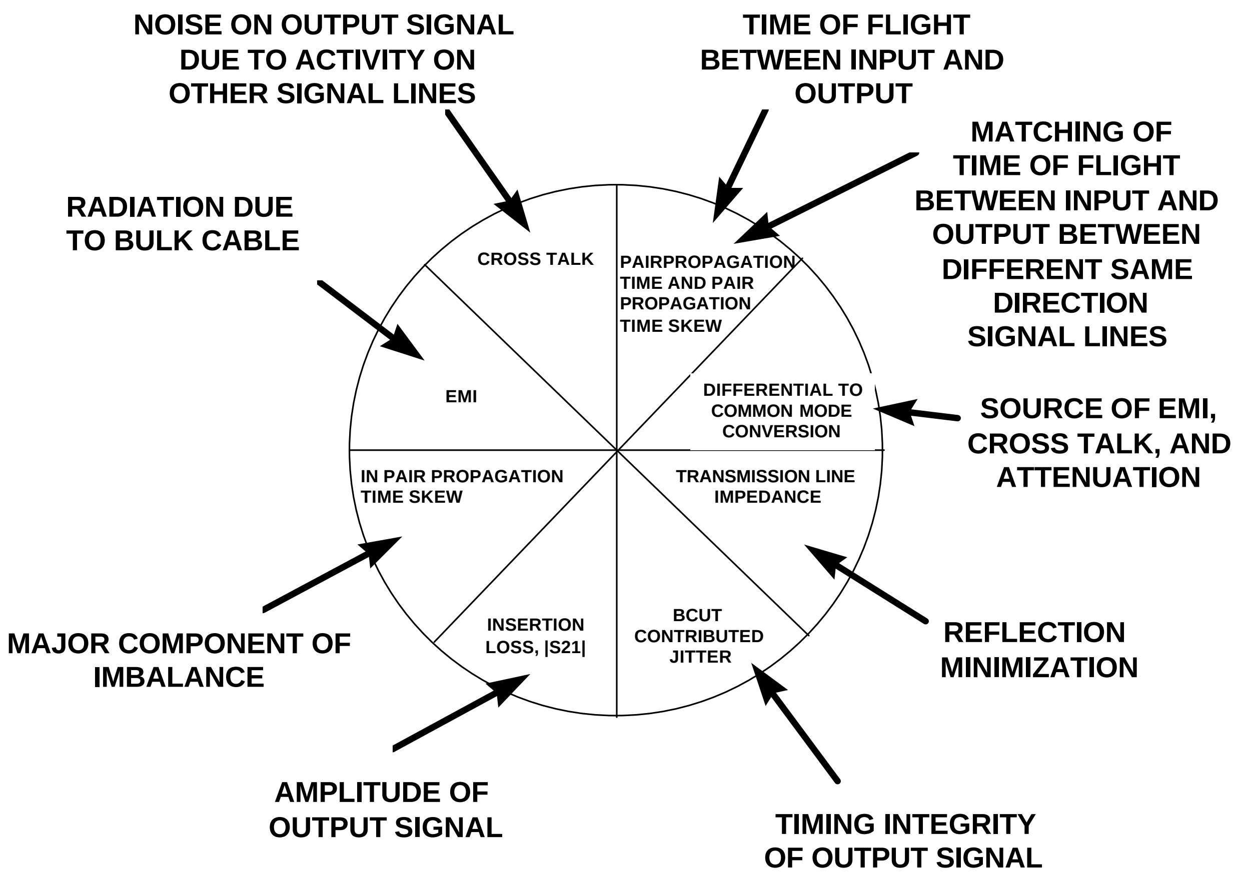


Figure 12 - Level 1 tests

Another level of detail is described below for the nine level 1 measurements defined:

1. **Transmission line impedance (Z_0)** time domain (local measurement): differential impedance (each side of the signal driven) versus distance at a signal transition duration specified for the application. Basic information captured may be direct

impedance or reflection coefficient which is subsequently converted into impedance.

2. **Propagation time:** propagation time is the time required for the midpoint of a differential signal edge to propagate between an input and output measurement point. This measurement is included as a level 1 because a maximum latency in the cable plant is assumed in some link protocols.

3. **Pair to pair propagation time skew:** the difference in the time required for the midpoint of differential signal edges (assumed to be the zero volts crossing point) to simultaneously propagate in the same direction down two nominally identical pairs in the BCUT between an input and output measurement point. Pair to pair propagation time skew is a primary result of physical differences in pair construction including pair length. The measurement method includes skew due to mismatched losses (that results in mismatched signal edge STD) as well as that due to path length and ground reference differences between pairs. This measurement is not expected to be important for most HPEI applications because the receivers on different pairs use independent clock and data recovery for each pair.

4. **In-pair signal propagation time skew (time domain):** the maximum magnitude of the difference between the propagation time of the midpoint of the signal transition between the + and - signal at the receive end. In-pair propagation time skew is a primary result of physically unbalanced construction and of launched signal skew. The measurement method includes skew due to mismatched losses (mismatched STD on the single ended + and - signal edges) as well as that due to path length differences. This measurement is included because it is often a bulk cable performance requirement in purchase specifications even though this property is only one contributor to common mode creation.

5. **Insertion loss (SDD21 / attenuation):** differential signal amplitude loss over the spectrum from 50 MHz to 3x the fundamental frequencies of the data rates.

   For example the frequency range would be:

   > for 2.125 Gb/s with a 1.0625 GHz fundamental frequency the requirement applies up to 1.0625 GHz x 3 = 3.1875 GHz.

   The factor of 3 is determined from the spectral content of a pseudo random run length encoded NRZ data pattern (where the significant energy content is below 3 times the fundamental frequency - the third harmonic energy is included at this frequency). The 50 MHz is derived from the fundamental frequency of the longest pulse in a 64/66 encoded signal operating at 10 GBaud or the fundamental frequency of the longest pulse in an 8b10b encoded signal operating at 1 GBaud.

   SDD21 data output shall have a specified minimum frequency increment between data points (that affects the minimum number of discrete data points, see 8.3.1.3) acquired with an IF bandwidth of 300 Hz.

   Comparison to a maximum loss mask function is expected to determine compliance. For example a mask boundary defined by $af^{1/2} + bf + c$ could be used for uniform copper conductors. Other conductor types and specific requirements of the application may use different functional forms. This document does not define this maximum loss mask. In the above equation the coefficients ‘a’, ‘b’, and ‘c’ are determined by the application.

6. **Swept frequency differential to common mode conversion:** required to limit causes of EMI and crosstalk issues. A VNA is required to execute this test. It is expected that the BCUT is in a physical position during the measurement that is similar to that expected in service in the system. Swept frequency (possibly acquired via time domain methods) is required because the frequency content is important is assessing the aggressiveness of the common mode created.

7. **Time domain near end and far end crosstalk:** the near end measurement is taken at the same end of this BCUT as the aggressor source. The far end measurement is taken at the far end. A single signal transition is launched into a PUT_{NOT} while recording the crosstalk signal impressed in the PUT (either near end or far end). This

measurement may be useful for determining the physical parts of the BCUT where more intense sources of coupling exist. The peak excursion over the entire length of the BCUT is recorded as the crosstalk. Resonant effects and periodic disturbance effects that may be observed in a swept frequency measurement are controlled via the insertion loss tests.

8. **Bulk cable contributed jitter:** eye pattern measured at zero volts nominal (receiver switching threshold) using a specified data pattern. The differential signal from the PUT transmitter (the difference of the +signal and the - signal) having a known amount of jitter is launched into the PUT and the jitter observed at the far end into a laboratory quality termination is recorded. The bulk cable contributed jitter is the difference between the known launched jitter and the observed jitter. Bulk cable contributed jitter measured per this method is significantly less than that allowed for the link and a derating process is required to account for: (a) crosstalk generated in the bulk cable, (b) crosstalk generated in the cable assembly connector, (c) noise coupled into the bulk cable, (d) response of the link receiver to data pattern changes, and (e) reflections caused by link termination. However, if the application requires compensation for the BCUT insertion loss frequency dependence in the link then the allowed bulk cable contributed jitter budget may be increased by the amount of jitter removed by the compensation. Application specific data patterns are required. Different data encoding schemes (e.g. 8b10b, scrambling) require different data patterns.

9. **EMI (CMPT and EMR):**
   Overall shielded versions - all conductors driven purely common mode. CMPT (common mode power transfer) methods and EMR (Electromagnetic radiation) methods apply.
   Unshielded versions all conductors driven differentially. EMR and current clamp methods apply.
   The measurements for bulk cable are similar to those specified in SFF-8410 for cable assemblies with differences in the shield attachment to test fixture requirements and signal launch conditions.

7.6.6 Definition of level 2 electrical performance parameters

The measurements in the following list are the level 2 measurements for HPEI bulk cable. Notice that many of these measurements are available as a result of measuring the full S parameter set on the BCUT.

1. Swept frequency differential return loss
2. Common mode impedance (Z_{CM}) (time domain (local)):
3. Parameter extraction via VNA
4. Attenuation to far end crosstalk ratio (frequency domain)
5. Differential to common mode conversion (eye-like test at 0 differential crossing using appropriate data pattern)
6. Amplitude imbalance between the + and - signals
7. Signal transition duration
8. Group propagation time dispersion
9. Far end crosstalk, FEXT, (swept frequency)
10. Near end crosstalk, NEXT, (Quiescent noise)(swept frequency)
11. Full eye diagram signal degradation (time domain)

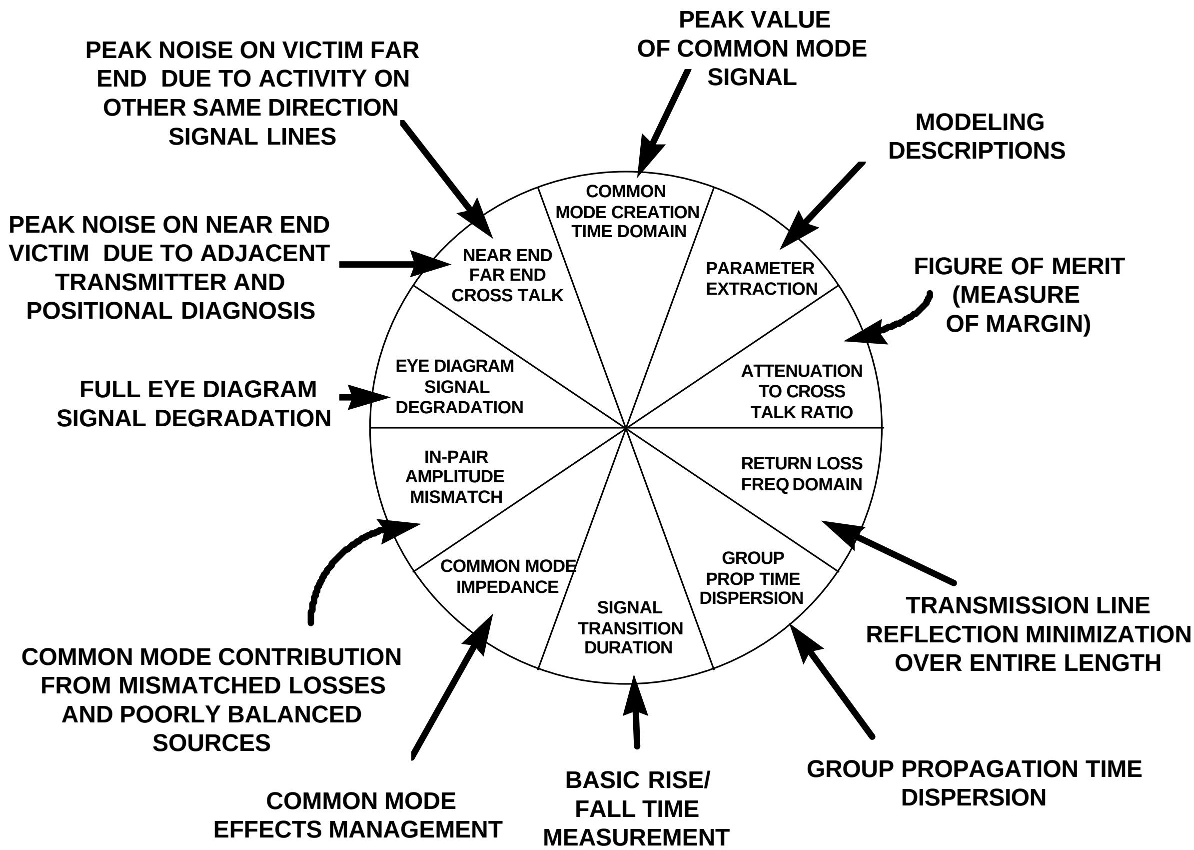


Figure 13 - Level 2 measurements

Another level of detail is described below for the eleven level 2 electrical performance parameters defined:

1. **Return loss, Snn:** (Frequency domain measurement of S11 or S22 either differential or common mode driven): Notable BCUT structural features that may affect this measurement are periodic with length (such as foil wrap pitch or lay lengths of pairs). Test fixture contributions may dominate the results for BCUT's that meet the level 1 impedance requirements unless these contributions are removed via calibration. BCUT's that do not meet level 1 impedance requirements are likely to have large return losses.

2. **Common mode impedance ,(Z_{CM})** (time domain (local)): impedance of the pair with respect to ground versus distance at a signal transition duration specified for the application. There are two ways to approach the measurement of Z_{CM} (1) short both lines of the pair and measure the shorted combination as if it were a single line and (2) drive both lines independently with signal having the same amplitude and phase (and at exactly the same time) and measure the impedance of each line with respect to ground. In the second approach the common mode impedance is the parallel combination of the individual impedances measured. Basic information captured may be direct impedance or reflection coefficient which is subsequently converted into impedance.

3. **Parameter extraction via VNA**

   This measurement is intended for determining the circuit modeling values that should be used for the IUT such as:

   - capacitance
   - inductance

- various circuit elements for specific designs.

4. **Attenuation to crosstalk ratio (frequency domain):** This measurement is an indication of the overall quality of the BCUT. It is formed by taking the ratio of insertion loss (attenuation) to the far end crosstalk at all frequencies in the range examined.

5. **Differential to common mode conversion:** eye-like test at 0 differential crossing using 2^7-1 data pattern. Transmitted signals with minimum common mode content are transported across the BCUT and the common mode content in the received signal (+ signal + - signal)is measured. During the transmission differential to common mode conversion may occur. This measurement is useful for recording the peak value of the common mode created.

6. **Amplitude difference between the + signal and - signal (time domain):** the maximum magnitude of the difference between the peak amplitudes on the + signal and - signal lines at any point in time. This measurement is useful for diagnosing the source of common mode creation.

7. **Signal transition duration (rise / fall time):** the time required for a differential 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 determines the induced common mode levels, the EMI, the impedance profile, quiescent noise and intersymbol interference

8. **Group propagation time analysis:** The basic data is phase vs frequency for a given sample. The expected behavior for a frequency independent dielectric is a first order equation of the form: Phase = group delay x (f) + constant. If group delay is not constant with frequency a straight line is not observed. The constant term may also represent other important information. If the constant is not zero one will not observe doubling of phase with doubling of frequency. Consult standard references for further details. This analysis may aid in determining the causes of ISI.

9. **Far end crosstalk (swept frequency):** This is a basic SDD21 measurement where the output port is on the victim line and the input port is on the opposite end of the BCUT is the aggressor. Assigning optimum pass fail limits is problematic but the measurement may be a valuable diagnostic tool.

10. **Near end crosstalk, NEXT, (Quiescent noise)(swept frequency):** This is a basic SDD21 measurement where the output port is on the victim line and the input port is on the same end of the BCUT is the aggressor. Assigning optimum pass fail limits is problematic but the measurement may be a valuable diagnostic tool.

11. **Full eye diagram signal degradation (time domain):** The signal coming from the BCUT when a worst case launched signal is applied. Traditional eye mask methodology is used. This measurement integrates all the effects of the signal transmission into a single result.

7.7 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 bulk cable under test (IUT)
- Calibration procedures to account for the effect of fixturing and instrumentation
- 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.

7.8 Definition of the bulk cable under test (BCUT)

The bulk cable under test (BCUT) is between the prepared ends that are attached to the test fixture at TP1 and TP2 as shown in Figure 14. The prepared ends on each side of the BCUT and the electrical features within the electrical neighborhood for each side of TP1 and TP2 on the test fixture may affect the measurement and are explicitly included in the measurement specification.

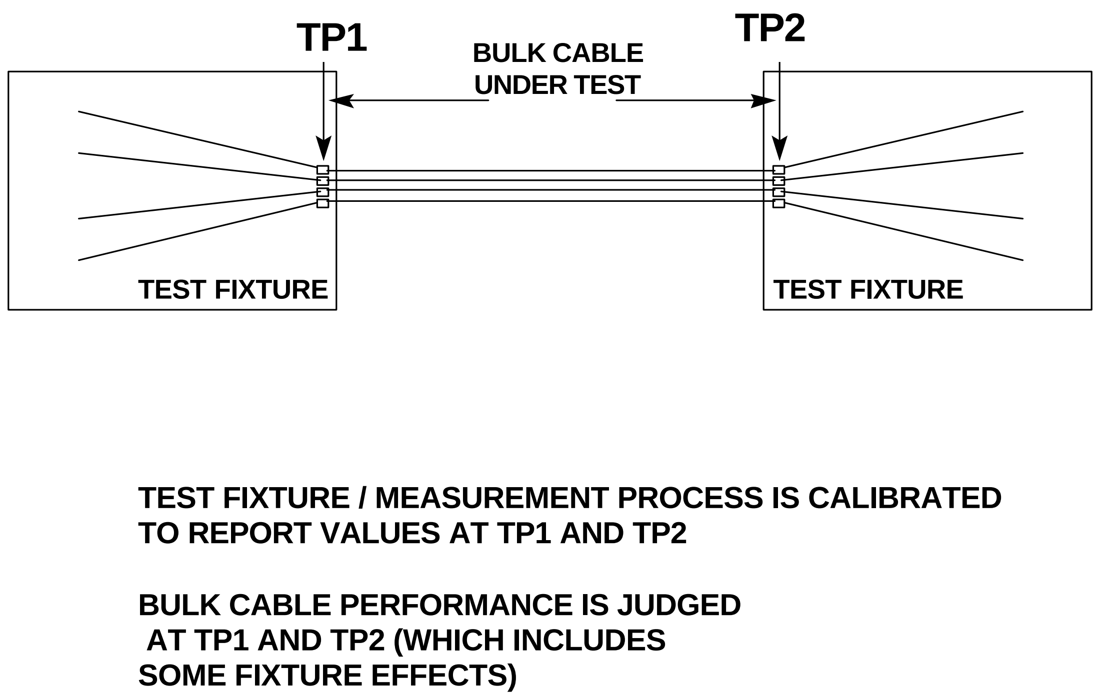


Figure 14 - Definition of the bulk cable under test

This definition of the BCUT test allows electrical performance specification outside the context of a specific application for shielded designs. For unshielded bulk cable designs the details of the application may affect the performance in service and specific conditions for the measurement are specified such that some relationship to common applications exists. Good agreement between measurement results in different laboratories is expected when using the same measurement conditions. If the bulk cable performs adequately according to the measurements specified in this document then it should be suitable for use in HPEI cable assemblies.

Meeting the requirements of the application using the methodologies defined in this document guarantees that the bulk cable contribution to system performance is controlled to within application specified limits and that bulk cable from different sources could be used interchangeably in that application. Meeting these bulk cable requirements does not guarantee that the cable assembly is adequate since significant contributions may come from wire termination, connector, and other electrical neighborhood features.

7.9 Transmission line termination during BCUT measurements

Transmission line terminations consist of differential and common mode. Both the transmitter and receiver ends have specified transmission line terminations. The value of the terminations are determined by the applications and can seriously affect the measurement results.

In this document the differential impedance is specified for the BCUT as a level 1 test but the common mode impedance is only indirectly specified through the common mode impedance required for the common mode termination used during the measurements. The BCUT common mode impedance measurement method is specified as a level 2 measurement.

For many measurements the differential and common mode termination impedances should match the application nominal values. However, for S parameter measurements, all ports are terminated in 50 ohms to ground. TDT measurements described in this document also require termination into the measurement system's 50 ohms to ground. TDR measurements require that the PUT be open circuited at far end.

7.10 Special considerations for test fixtures and testing

Using the definition of the BCUT in section 7.8 the parts of the test fixture within the electrical neighborhood are part of the BCUT performance measurement even though they remain as part of the test fixtures when the BCUT is removed. The test fixtures are typically used many times when testing different BCUT's (see Figure 14). The parts of the test fixtures that affect the measurement are termed the "stationary" parts of the BCUT measurement.

The contribution of the stationary parts to the measured result may not be small. The stationary parts could compensate for or exacerbate degradation caused by the BCUT proper. It is generally expected that different BCUT's will cause different test results. What may be less obvious is that the same BCUT may yield different results with different test fixtures that have different stationary parts. In both cases the differences in the test results exist even if identical instrumentation and calibration processes are used.

Therefore:

- Differences in the BCUT test results from different laboratories are to be expected unless the same identical test fixtures and the same BCUT's are tested together.

- If the stationary parts of the BCUT measurement compensate for the properties of the BCUT then it is to be expected that other laboratories testing the same BCUT may find that the BCUT fails (since their stationary parts may not deliver the same level of compensation).

- If the stationary parts of the BCUT measurement exacerbate the degradation in the BCUT to the extreme allowed without allowing the BCUT measurement to indicate a failure then a more conservative total BCUT performance test results and it becomes less likely that testing with different test fixtures will indicate BCUT failures.

Suppliers of BCUT's should carefully understand the effects of the stationary parts of the BCUT measurement so that unintentional compensation of BCUT properties parts is not occurring.

Although the stationary parts of the BCUT measurement are attached to the test fixture they are not formally part of the test fixture (even though it may appear so in a casual observation since they are attached). Anything within the electrical neighborhood of the BCUT is also considered formally part of the BCUT performance.

For some measurements the details of cable positioning (coiling, bending, proximity to metal surfaces, etc.) may affect the results. This document assumes that special positioning to achieve favorable results is not practiced. Positioning and stresses during testing should not exceed specified application performance limits for bend radius, tensile stress, twist, impressed external noise and the like. Details of positioning and stressing during measurement shall be specified.

7.11 Extensions to parallel - serial constructions

7.11.1 Overview

Section 7.11 describes how to extend the tests described in this document to constructions beyond the simple duplex. Such constructions are useful for example when one needs higher bandwidth without sacrificing length. Using more paths carrying information may appear to be easier than using a single path because data rate increase on a single path is increases the frequency with associated increased losses. Such reasons may prove to be false in the overall picture, however, because of the intrinsic increased cost for more conductors, more transmitters, more panel space and so forth.

Other possible reasons for more complex constructions include needing additional independent control paths and needing some paths to be bi-directional. When the basic transmission on a single path is unidirectional serial and there are multiple paths following the same physical routing (for example multiple twin-axes in the same overall jacket) the construction is termed parallel - serial (p-s) in this document.

Several transports, including SAS, Infiniband, and PCI express for example, presently specify p-s constructions.

The extensions described here apply only to point to point applications (that may or may not contain equalizers or active circuits in the path for most tests).

In general one uses superposition along with worse case alignments and polarities (to avoid cancellations) to deal with the more complex structures. A generalized p-s construction is shown in Figure 15. The Sn is a source for the nth path while the SMIn is the signal measurement instrument corresponding to the nth source.

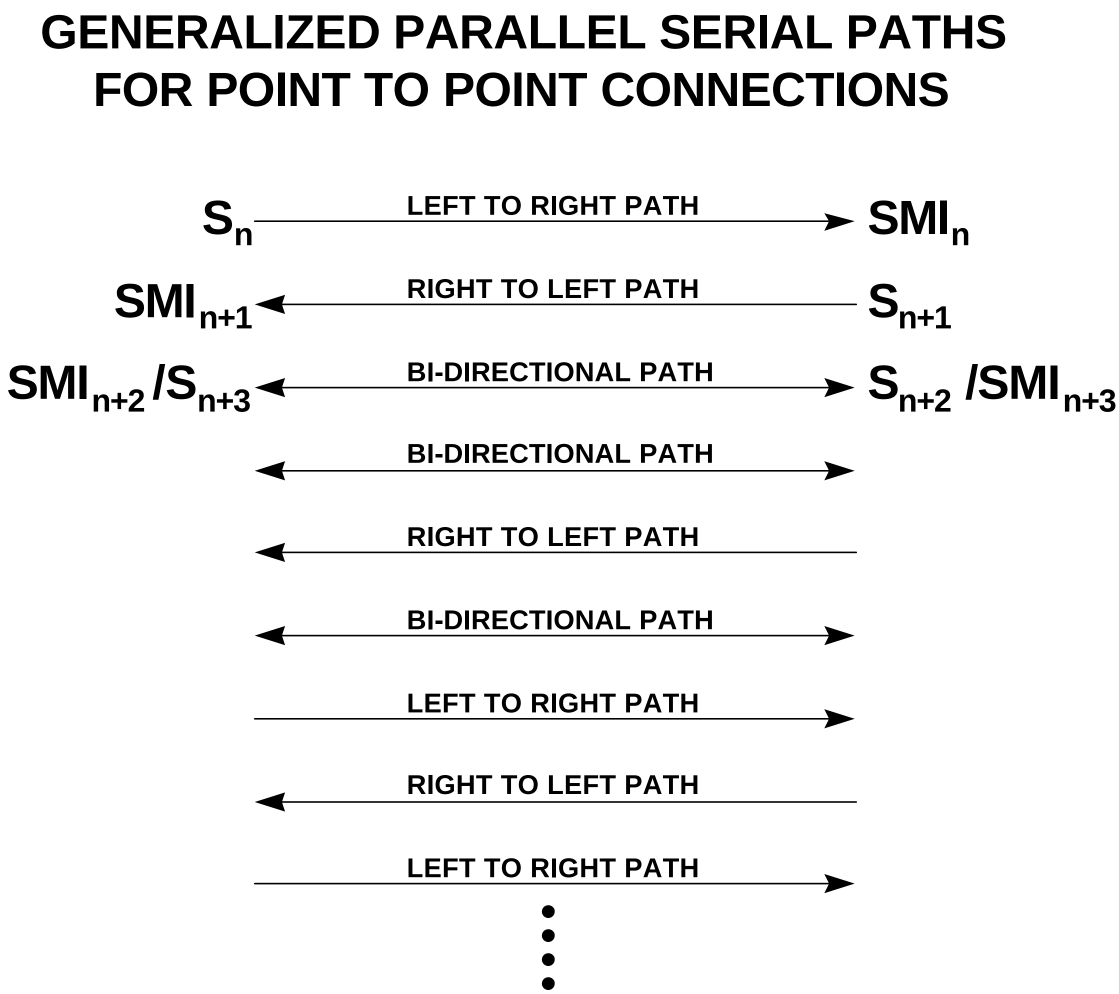


Figure 15 - Sources and instruments for a general p-s construction

The level 1 tests for duplex BCUT applications have counterparts in p-s constructions. Some of these are briefly considered separately.

7.11.2 Transmission line impedance for p-s constructions

The transmission line impedance test is exactly the same as for a duplex BCUT. Each path in the p-s construction is measured separately and uses the same test procedures described in this document.

7.11.3 Propagation time and propagation time skew for p-s constructions

Each pair for propagation time and pair to pair propagation time skew or each leg of a differential pair is measured the same way for p-s constructions as for duplex constructions. The pair to pair skew is recorded as the maximum difference between any pair whose signals are propagating in the same direction. See 8.2.3.2.

7.11.4 SDD21 (insertion loss)for p-s constructions

This measurement is essentially the same as for duplex assemblies. Additional termination is required on the unmeasured pairs.

7.11.5 Time domain near end and far end crosstalk for p-s constructions

7.11.5.1 Near end crosstalk for p-s constructions

Near end crosstalk for p-s constructions is determined by sequentially applying differential aggressor pulses on every near end pair except the victim pair and recording the peak crosstalk contribution from each aggressor pair on the victim pair. The absolute value of the results are then added to produce the total peak crosstalk on the victim line pair. The process is repeated for every victim pair in the p-s construction.

The measurement conditions are identical to the duplex case described in this document with suitable modifications to the test fixtures to accommodate the p-s constructions.

This extension methodology was originally developed for use on parallel SCSI cables and produces a conservative (i.e. more stringent) test on the BCUT than actually exists in service. However, since there is no correlation assumed (either time or signal level) between the aggressor signals and the victim signals in this measurement the resulting noise measurement (calculation) approximates the worst possible condition.

Note: for bi-directional pairs two measurements are required.

7.11.5.2 Far end crosstalk for p-s constructions

Far end crosstalk for p-s constructions is determined by sequentially applying differential aggressor pulses on every near end pair except the victim pair and recording the crosstalk contribution from each aggressor pair at the far end of the victim pair. The absolute value of the results are then added to produce the total crosstalk on the victim line pair. The process is repeated for every victim pair in the p-s construction.

The measurement conditions are identical to the duplex case described in this document with suitable modifications to the test fixtures to accommodate the p-s constructions.

Note: for bi-directional pairs two measurements are required.

7.11.6 Bulk cable contributed jitter for p-s constructions

Since bulk cable contributed jitter is defined as that resulting from mechanisms other than crosstalk each pair in the p-s construction is measured separately in the same manner as specified for duplex constructions.

7.11.7 Mode conversion within pair for p-s constructions

The mode conversion measurements follow exactly the same flow as described in 7.11.4 for the insertion loss measurements except using the mode conversion methodology instead of the insertion loss methodology.

7.11.8 EMI (CMPT and EMR) for p-s constructions

The CMPT test applies to p-s constructions essentially without modification. The EMR test requires that the excitation be set up to simulate actual signals on all paths simultaneously but is otherwise identical to the duplex case.

7.11.9 Summary of extensions to p-s constructions

With simple modifications to the measurement process and test fixtures a very broad array of complex p-s constructions can be tested using the basic procedures described in this document for duplex constructions. It is not practical to attempt to detail every possible p-s construction but the formula for constructing these details are contained herein.

7.12 Sample preparation

7.12.1 Overview

Samples shall be prepared according to the requirements in this clause. If specific measurements require special consideration, these are defined in the details for the relevant measurements.

There are many different constructions for HPEI bulk cable. Some key features are:

- Construction of the differential signal element (DSE)
    - ◊ Case 1: unshielded twisted pair
    - ◊ Case 2: shielded twisted pair
    - ◊ Case 3: shielded parallel pair (e.g. twinax)
    - ◊ Case 4: shielded quad
- Number of pairs or quads in the cable
- Presence of a shield around the bundle of all the pairs or quads in the cable
    - ◊ Case 1: individual pairs or quads are shielded*
    - ◊ Case 2: individual pairs or quads are not shielded
- Presence of a jacket when there is no overall shield and no individual pair or quad shield - if either shielding systems is present the jacket is irrelevant
- Presence of buffer layer/insulating layers between the overall shield and the inner pairs or quads

*the overall shield in this case is intended for chassis/frame ground for EMI containment – sample preparation of this overall shield is important only for EMI measurements

Shielded differential signal elements (DSE) come in at least three variants:

1. Each pair has a drain wire + foil facing in (most common)
2. Each pair wrapped with foil facing in (no drain) - the foil is intended to float
3. Pairs wrapped with foil facing out (contacts other internal foil shield)
    - ◊ Case 1: no drain wire
    - ◊ Case 2: drain wire for the bundle

A general rule is if there is a drain wire or if the foil is facing out a means for grounding the shield shall be provided on both ends during the measurement.

Sample preparation shall isolate the measurement to the electrical neighborhood relevant to differential signal element under test.

The electrical neighborhood is generally bounded by the nearest shield that encloses the DSE or by the materials that electrically couple to the DSE. For example, for a shielded twinax is bounded by its own shield. A four unshielded twisted pair cable with an overall shield is bounded by the overall shield. A four unshielded twisted pair cable with no overall shield is bounded by the overall jacket and the placement of the cable with respect to external grounds. This document details only the most common constructions expected for HPEI applications.

7.12.2 General requirements

Materials outside the electrical neighborhood may be removed as required from either or both ends. For example, for an 8 shielded parallel pair cable having an overall shield and overall jacket; remove the jacket and overall shield as required to provide access to the desired pairs. Typically removing this material 75 to 100 mm from the ends is adequate.

Within the electrical neighborhood remove as little material as possible because such removals disturb the physical construction and affect the measurement results. Different measurements require different levels of sensitivity to this requirement. For example, insertion loss measurements on long length samples are less sensitive to the disturbed region length compared to local impedance measurements.

Requirements of the specific measurement determine the length of the allowable disturbance. This allowable length determines the sample preparation and test fixture design requirements. Test fixturing and sample preparation are critical for some measurements.

The attachment scheme of the DSE to the test fixture and the design of the test fixture are intimately related. Soldering and clamping are the commonly used schemes.

Parts of the BCUT that are not part of the electrical neighborhood of the DSE should be moved as far as possible from the test fixture during the measurement.

In measurements where grounding of the shield is required, it may be less disruptive to clamp the foil or braid than to attach the drain wire (if a drain wire exists). Whichever scheme produces the least disruption to the sample is preferred.

7.12.3 Sample preparation examples

This clause provides two detailed examples for sample preparation.

Example 1:

Single shielded quad with foil under outer braid shield

[For this construction the foil defines the boundary of the electrical neighborhood. For convenience, a pigtail from the braid is being used to attach the foil to the test fixture. A clamping method for foil shield contact might be less disruptive but is not described in this example.]

- Cut sample to length as required by the measurement (e.g. x.xx m +/- 0.025 m)
- Remove jacket material for approximately 1.5 outside cable diameters from the end to be measured (e.g. 10 mm)
- Braid shield: fold back in 360º circle over cut back jacket and form a pigtail (to be used as an attachment for the foil shield if required by the measurement)
- Foil shield and buffer (if any): cut off to 4 mm max from the end
- Remove 2.0 mm of dielectric from the PUT wires (e.g. @ 12 and 6 O’clock)
- Push the remaining two wires (e.g. @ 3 and 9 O’clock) to the side (out of the way)
- Similar preparation at the other end may be required depending on the measurement

Example 2:

Shielded twisted pair within a cable having 8 shielded twisted pairs each pair with foil-in and drain wire under this foil. All pair shields are isolated from outer shields. The outer shield is foil under braid.

[For this construction each pair’s foil defines the boundary of the electrical neighborhood for that pair. The pair’s shield is grounded if required using the drain wire.]

- Cut sample length to the required length (e.g. xx.x m +/- 0.025 m)
- Remove approximately 10.0 cm of outer jacket and outer shield (foil and braid) from one end
- Trim filler (if present)
- Remove 2.5 mm max of the PUT shield being careful not to damage the drain wire
- Remove 1.5 mm of dielectric from the PUT wires
- The exposed PUT drain wire is used to provide shield ground if required by the specific test
- Shielded pairs not under test should be moved out of the way - it does not matter whether the shields of these other pairs are grounded or floating since they are not in the electrical neighborhood for the PUT.
- Similar preparation at the other end may be required depending on the measurement

8. Level 1 tests

8.1 Transmission line impedance (local measurement)

8.1.1 Overview

The transmission line impedance is a plot of characteristic or transmission line impedance as recorded by a time domain reflectometer. This is a mapping of the impedance versus time of the reflected signal. The physical position within the BCUT may be determined when one knows the velocity of propagation or by other means such as a local physical perturbation (e.g. pinching). Transmission line impedance is specified as one of the elements required to manage signal reflections in the link. The transmission line impedance is the average impedance within a small specific position range.

This transmission line impedance test is intended to be used on bulk cable that has nominally uniform construction along its length. An example of non-uniform construction is ‘twisted and flat’. It is also expected that the BCUT is designed and manufactured to be uniform. This uniformity allows the STD for this measurement to be loosely specified compared to that required for a cable assembly where non-uniformity is intrinsic with connectors and its terminations (see SFF-8410 6.1.2.3). However, STD is important for bulk cable because the disturbances from the test fixtures are affected by STD and extending the measurement far from the BCUT attachment point introduces errors due to wire losses. This measurement is a compromise between conductor attenuation errors and the STD used for the measurement.

The measurement shall be performed using a signal transition duration that allows the measured waveform to settle within 0.5 ns (displayed) of the BCUT attachment point. Typically STD = 100 ps or less at the BCUT interface satisfies this requirement. STD calibration methods use the measured STD at the TDR from an open circuit test fixture with the recognition that the measured STD is typically greater than existing at the BCUT interface. A measured STD of 100 ps is used to ensure that the STD at the BCUT interface is 100 ps or less.

The requirements apply in a specified 0.5 to 1.0 ns time window. Pass-fail criteria are based on exceeding the limits anywhere in this time window. The impedance of the sample is recorded as the mean of the population in the time window.

Differential TDR heads provide dual channel complementary single ended signals. These signals are equal amplitude and equal STD transitions in opposite directions to produce a single differential transition between the two channels.

These TDR signals are different from that driven from most functional HSS transmitters. Functional HSS transmitters drive the + signal high and the - signal low or the + signal low and the - signal high -- they do not dwell at a single signal level. The calibration for the transmission line impedance measurements may be somewhat different than that required for other measurements in this document that require controlled signal transition duration.

Two methods are described: Precision Airline and Precision Resistor. Both yield results that are within acceptable accuracy for the applications of interest to SFF-8416. The measurement accuracy is expected to be better than ± 0.5 ohm for both methods.

Caution: The sample should be shorted to a grounded conductive surface prior to connecting to the measurement setup in order to eliminate any static charge that can damage the TDR sampling heads.

8.1.2 Sample preparation

Samples shall be prepared according to 7.12 with the following properties:

Only one ends needs to be prepared. Preparation of both ends is allowed (if sample is to be used for other measurements that require both ends to be prepared). Sample length is not critical as long as it is at least 1 meter. For most common constructions shields may be left floating or may be grounded with no expected effect on measurement results. However, for some constructions such as two discrete coax used as a differential pair, the shields should be grounded. Sensitivity to shield grounding should be verified for each construction. The test report shall indicate whether the shield is grounded or floating.

Every effort should be made to keep the end preparation (i.e. disturbed region caused by shield and dielectric removal) to less than 2.5 mm.

Ends of the pairs not being measured should be moved away from the test fixture TP1 by at least 2.5 mm.

The far end shall be left open.

8.1.3 Test fixture and sample attachment

8.1.3.1 Overview

Figure 16 shows the test fixtures and sample attachment for the transmission line impedance profile tests. The test is calibrated to measure performance at TP1.

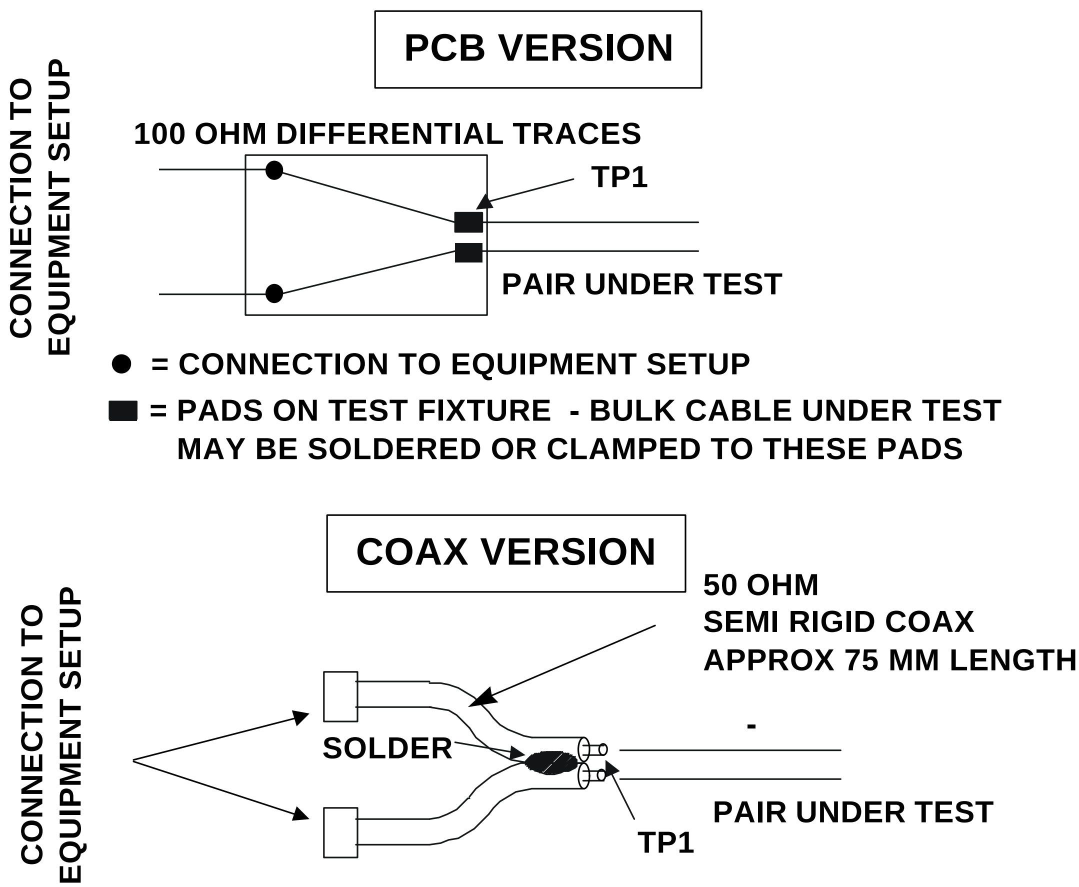


Figure 16 - Test configuration for transmission line impedance

The test fixture may be constructed of semi rigid coax, precision coax, microstrip PCB, or stripline PCB. The open circuit STD at TP1 shall be such that the signal settles prior to reaching the 0.5 ns point from TP1 with the BCUT attached.

8.1.3.2 Test fixture verification

Test fixture impedance verification is done by design. For the semi rigid coax fixture the coax manufacturer's specification shall indicate nominal 50 ohms. For the PCB test fixture the designed impedance based on trace width, dielectric material and ground plane separation shall be 50 ± 5 ohms. Measurement verification is not required for impedance of the fixture. The overall fixture including the connection to the equipment set up shall be verified as described in Figure 17.

8.1.4 Measurement equipment

8.1.4.1 Overview

Equipment such as the Tektronix TDS 8000 or Tektronix 11801 with TDR sampling heads or equivalent shall be used. This equipment has features such as software filters to simulate the effects of different STD's, auto readout of cursor positions, and conversion between reflection coefficient and transmission line impedance.

8.1.4.2 Equipment accessories

The following accessories are required to connect the measurement equipment to the BCUT:

- Two matched length instrumentation quality SMA cable assemblies or equivalent (length chosen shall meet the STD requirements)
- A differential test fixture (see Figure 16).

8.1.4.3 Instrument calibration

The vertical scale calibration for the instrument is included in the calibration for the measurement set up. The time calibration shall be traceable to NIST and is not further specified in this document.

8.1.5 Equipment setup

Figure 17 shows the equipment setup and test fixture attachment for both impedance measurement methods.

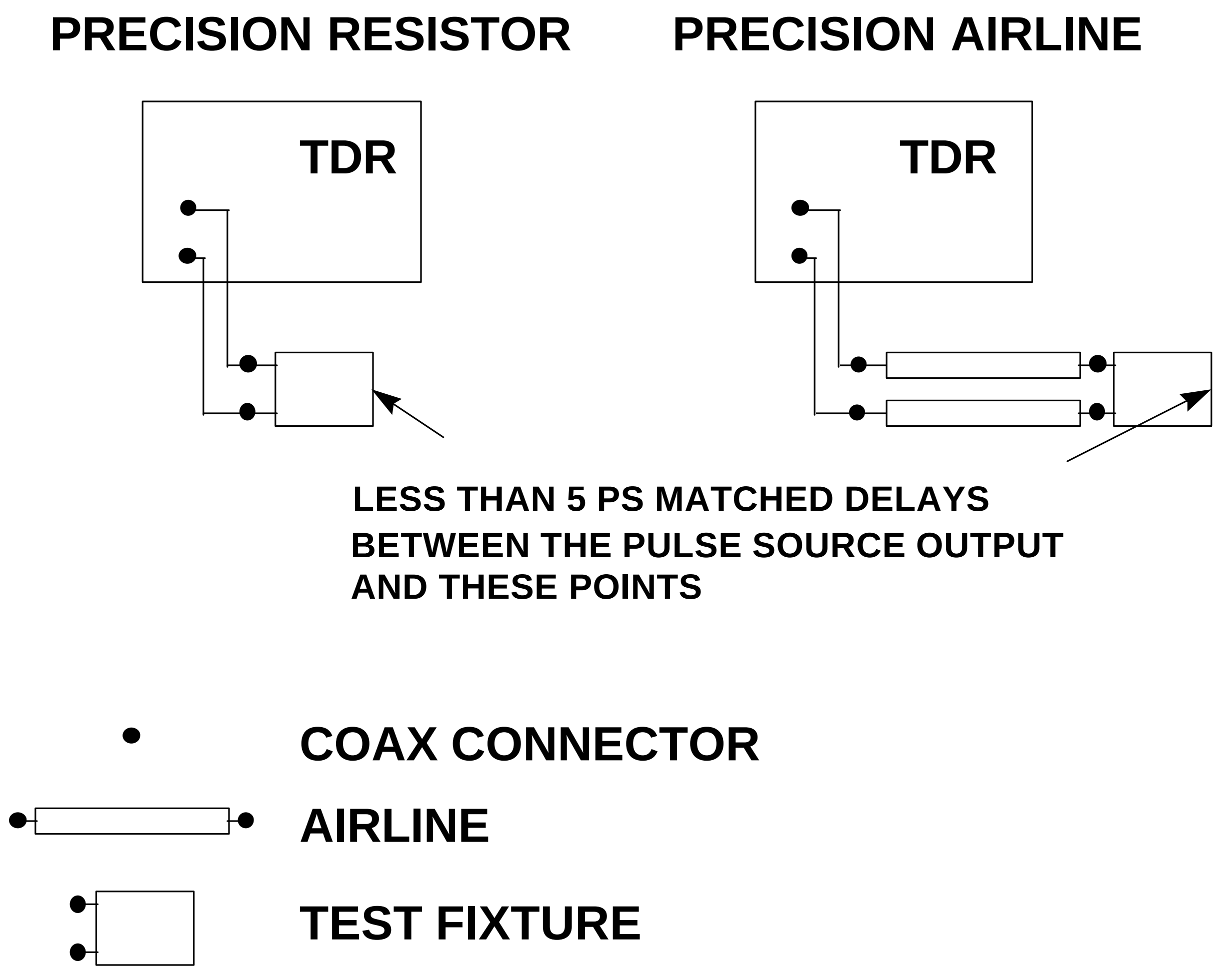


Figure 17 - Equipment setup with test fixtures attached

Activate the TDR channels. **Diff TDR Preset** may be used to automate the setup for differential TDR for the following functions:

Turn on both channels of the TDR Sampling Head
Turn on both step generators
Invert polarity on one step generator
Auto set the scales for both traces
Turn on internal baseline correction
Change the vertical scaling from Volts to rho
Select internal clock trigger

Note: If an internal baseline correction is supplied within the instrument it does not affect the procedures in this document whether used or not.

Define a calculated waveform that represents the differential TDR signal as the difference between the + signal and the - signal.

Specific instruments may not include all these functions. Consult the documentation for the instrument being used to determine which apply.

Note:
Baseline shift is caused by imperfect attempts of the AC coupled sampling systems to restore the DC component lost by the AC coupling. These DC components are affected by the resistance to ground in the BCUT. Baseline shift may introduce a significant error into impedance measurements made by the precision resistor method and must be taken into account for precise measurements.

Baseline shift correction is not important for precision airline methods described in this document.
The procedure for manual baseline shift correction for the precision resistor method is included in this document.

8.1.6 Test setup calibration

8.1.6.1 Overview

The test setup consists of the equipment setup shown in Figure 17 with the test fixture shown in Figure 16 but without the PUT attached to the test fixture. The de-skew and STD calibrations are done at TP1 with no PUT attached.

8.1.6.2 De-skew

The following procedure outlines the steps necessary to de-skew the signal source.

1. Set instrument to differential TDR mode. Two traces are displayed, one going positive, the other going negative.
2. With the test fixture attached to the TDR outputs (with no BCUT attached), adjust the time-base until the rising edge and the falling edge are approximately as shown in Figure 18. (200 ps/div recommended).
3. Define a trace that is Positive_pulse + Negative_pulse. Because the two pulses are equal amplitude but opposite polarity, the resultant display is flat, except for the region where the edges are skewed. See Figure 18.
4. Adjust the delay between Positive_pulse and Negative_pulse so that the calculated trace is as flat as possible in the rise-time / fall-time region.

The de-skew procedure is complete. Do not disturb the fixture.

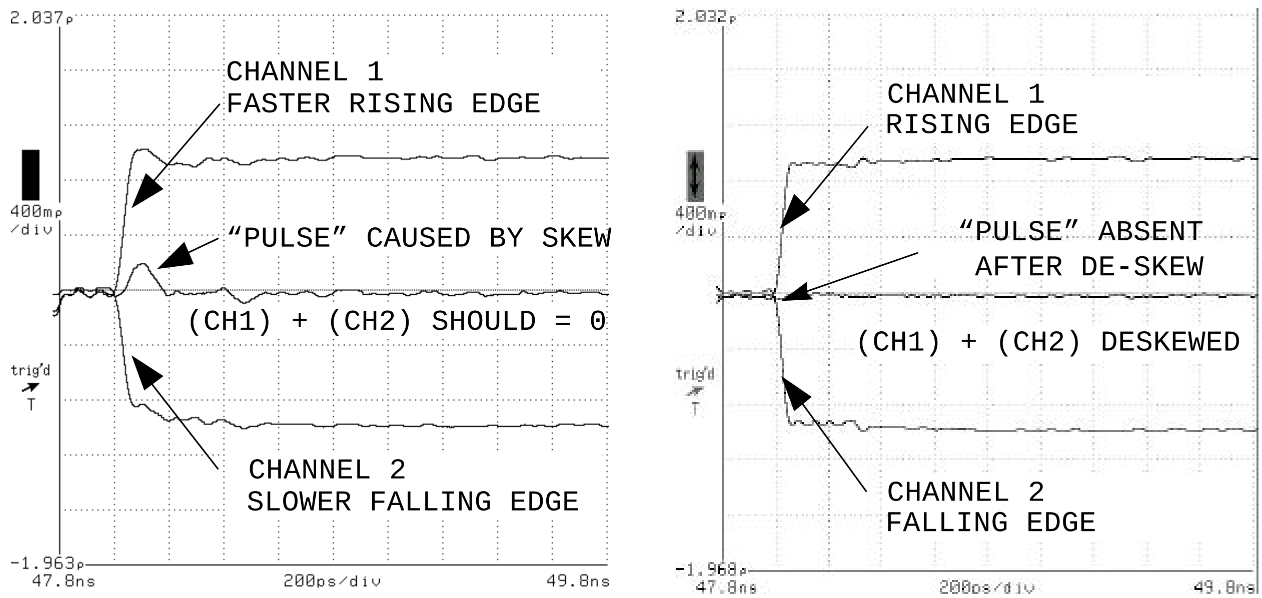


Figure 18 - TDR launch de-skew

8.1.6.3 Differential signal transition duration calibration

This calibration ensures that the proper signal transition time is being presented to the BCUT.

The setup for this calibration is shown in Figure 17 with the pair under test removed (i.e. an open circuit at TP1). Apply a differential pulse from the TDR and observe the resulting waveform using the scales shown in Figure 19. Verify that the STD is less than or equal to 100 ps using the following procedure:

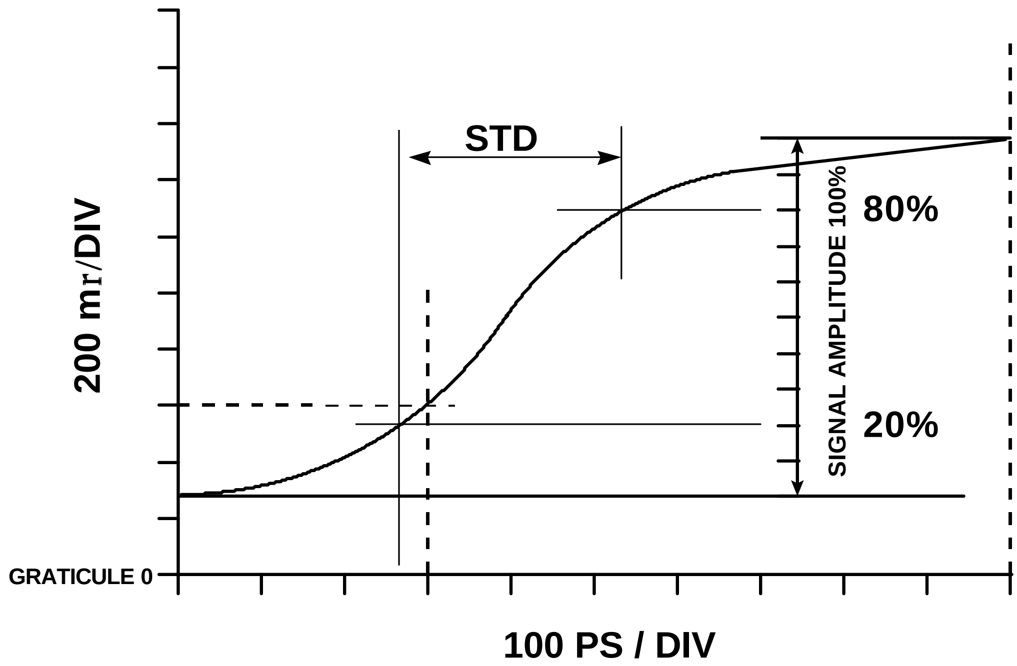


Figure 19 - Signal transition duration and amplitude calibration

1. Move the displayed curve to the right until a clearly defined flat portion is observed on the lower left portion of the trace.
2. Adjust the vertical position such that the flat portion of the curve (flat for at least three time divisions) passes through the first graticule from the bottom.
3. Position the trace horizontally such that it passes through the third vertical and third horizontal graticule using the scales shown in Figure 19.
4. Locate the 0% and 100% levels where the trace passes through the 0 and 10 horizontal divisions respectively as shown and measure the difference between the 0 and 100% levels.
5. Calculate/measure the 20% and 80% levels.
6. Calculate the STD as the difference in time between the points where the 20% and 80% levels occur as shown.

8.1.7 Precision resistor method

8.1.7.1 Overview of the precision resistor method

This procedure defines the method of measuring the transmission line impedance of a BCUT using precision microwave chip resistors. The calibration is performed at the point of BCUT attachment by using the precision resistors in place of the BCUT. A TDR instrument (see 8.1.4) is used in a balanced (differential) mode to send a step into the sample and monitor the reflections.

This method has the following properties:

- Calibrated at the launch point of the BCUT
- A flat trace exists in calibration when the resistor is attached
- Contact resistance effects (typically < 0.1 Ohm) are not easily calibratable
- Digital ohm meters may be used to verify the resistor value and its stability over time

- Cost of resistors is low enough to use in a disposable mode
- Precision resistors values may be chosen to be close to the nominal impedance of the BCUT (this scheme is the one documented in this clause)
- For better accuracy, resistor values that are close to but above and below the expected BCUT impedance may be used to produce a calibrated scale

8.1.7.2 Calibration and verification procedure

8.1.7.2.1 Overview

The calibration for impedance is done using a chip resistor method where the chip resistor is attached in place of the pair under test on the test fixture. The chip resistor method accounts for all test fixture effects since it occupies the same physical position in the test set up as the PUT.

Impedance measurements of samples that are terminated at the far end into a terminating resistor (typically 100 ohms) are slightly different than measurement of the same sample when the far end is open circuit. Figure 20 shows two traces recorded from the same 100 Ohm shielded pair. One trace was taken with the pair’s far end terminated with a 100 Ohm resistor. The other trace was taken with the pair’s far end open circuited. The vertical difference between the traces is frequently called ‘baseline shift’.

Baseline shift is caused by imperfect attempts of the AC coupled sampling systems to restore the DC component lost by the AC coupling. Baseline shift introduces an error into impedance measurements and must be taken into account for precise measurements.

For bulk cable measurement it is physically difficult to terminate the far end therefore an open circuit method is preferred. However, the chip resistor calibration method terminates the test setup and causes baseline shift relative to the unterminated sample. Therefore, baseline shift is expected when using unterminated samples with chip resistor calibration. The calibration procedure in this section accounts for the baseline shift as well as instrument vertical scale factor error.

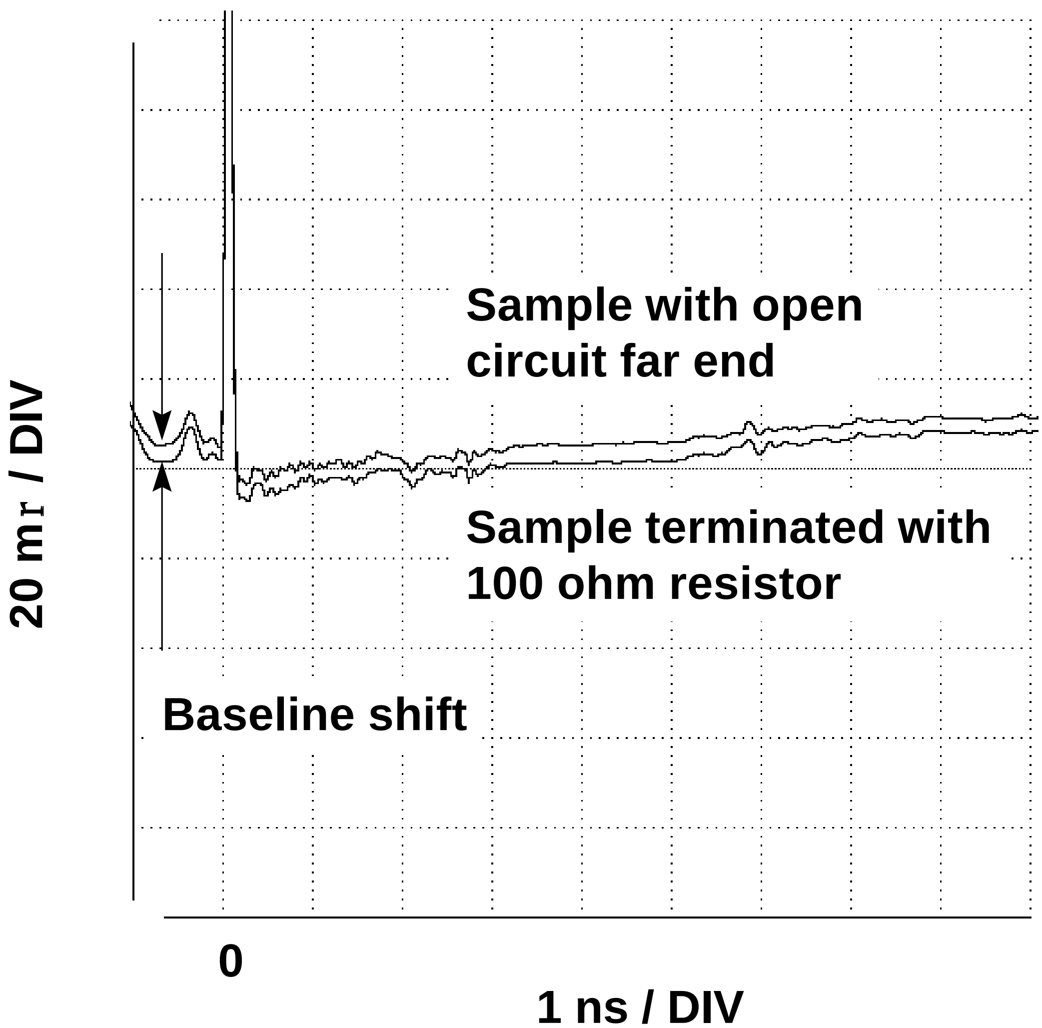


Figure 20 - Baseline shift example

Using this method it is permissible to measure samples that are terminated at the far end but in that case there is no baseline shift to correct. Measurements at points B and C in Figure 24 will be the same except for noise.

8.1.7.2.2 Chip resistor

The chip resistor shall be a low inductance type intended for microwave applications.

Figure 21 shows the effect of not using low inductance resistors.

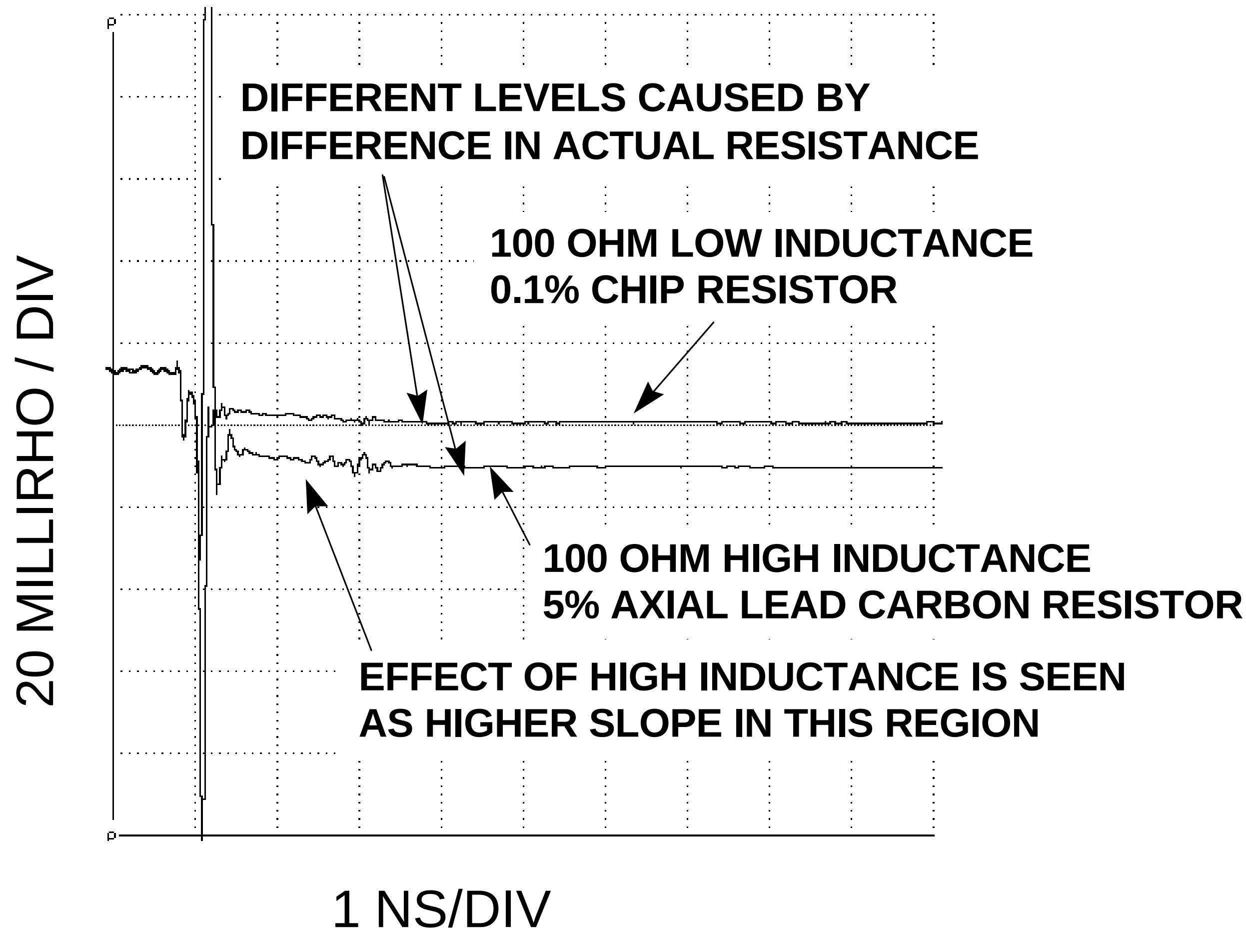


Figure 21 - Comparison of resistor types

The resistor described in this procedure is 100 ± 0.1% ohms because most HPEI bulk cable is expected to be nominally 100 ohms differential. This same procedure applies for other nominal impedances by choosing chip resistors that closely match the expected nominal impedance.

8.1.7.2.3 Calibration process

The test setup has already been de-skewed and the STD verified.

Using the test set up shown in Figure 16 attach the chip resistor to TP1 of the test fixture (soldering for the semi rigid type and gentle clamping for the PCB type).

1. Using the scales shown in Figure 22 display the TDR trace for the chip resistor. This trace contains two reference impedances (test fixture’s measured impedance value B, and chip resistor region’s measured impedance value A).
2. Using the TDR’s built in measuring function measure the average impedance in region A, impedance value A and measure the impedance value at point B, impedance value B. (Region A begins at 0.5 ns from TP1 and ends at 1.0 ns from TP1.)
3. Remove the resistor and display the TDR trace for the open circuit at TP1.
4. Using cursors, measure the impedance value at point C (taken in the fixture region at the same time settings as the point B measurement).

5. The known value of the chip resistor, value R (from 4 wire measurements or the NIST traceable value from the manufacturer of the resistor), the average impedance in Region A, and the impedances at points B and C constitute the calibration parameter set.

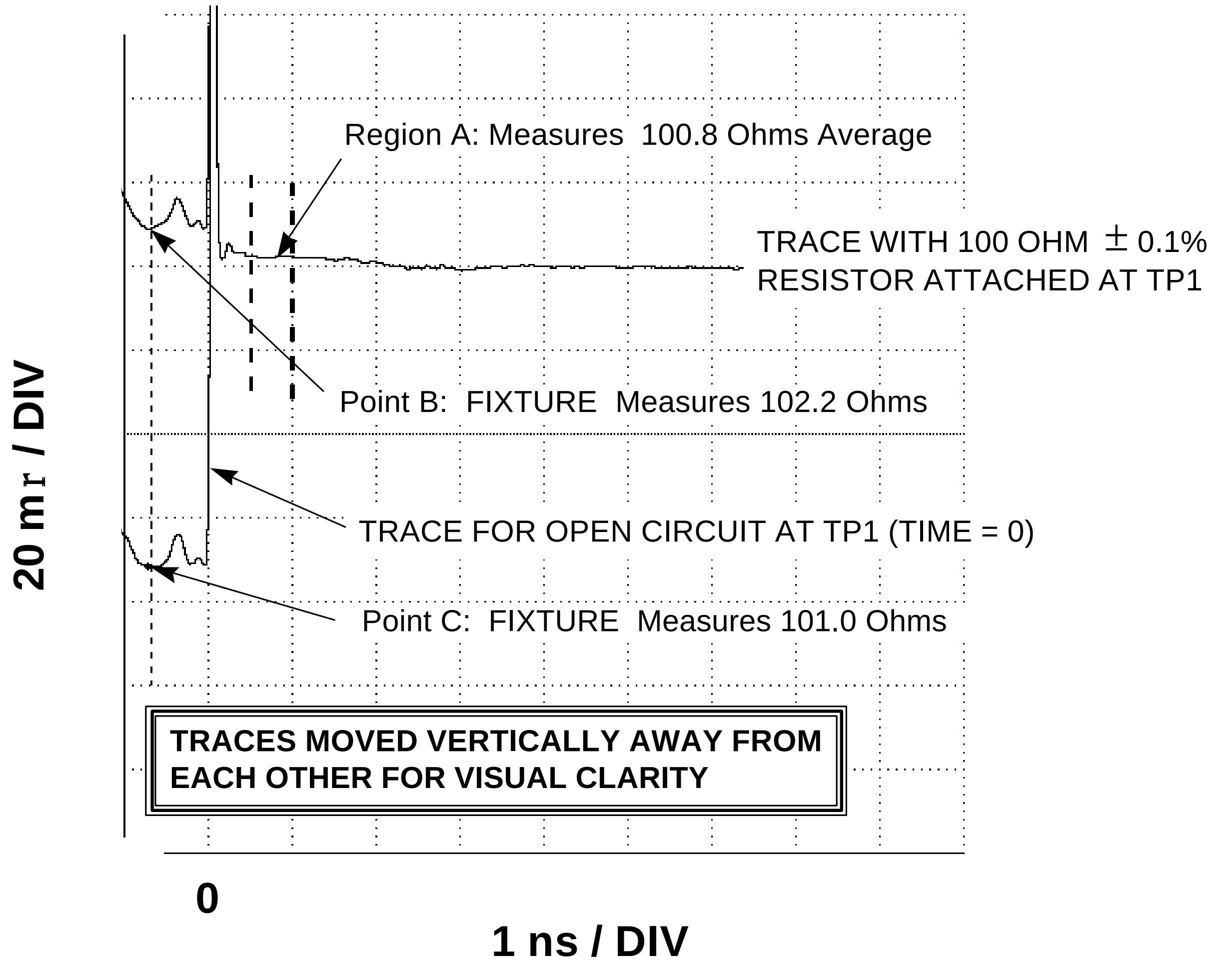


Figure 22 - Baseline and scale calibration example

8.1.7.3 Testing procedure

Figure 23 and Figure 24 illustrate the relationship between the calibration plots and the measurement condition.

Figure 23 shows a composite display with the BCUT connected to the test fixture at TP1 and the resistor calibration trace.

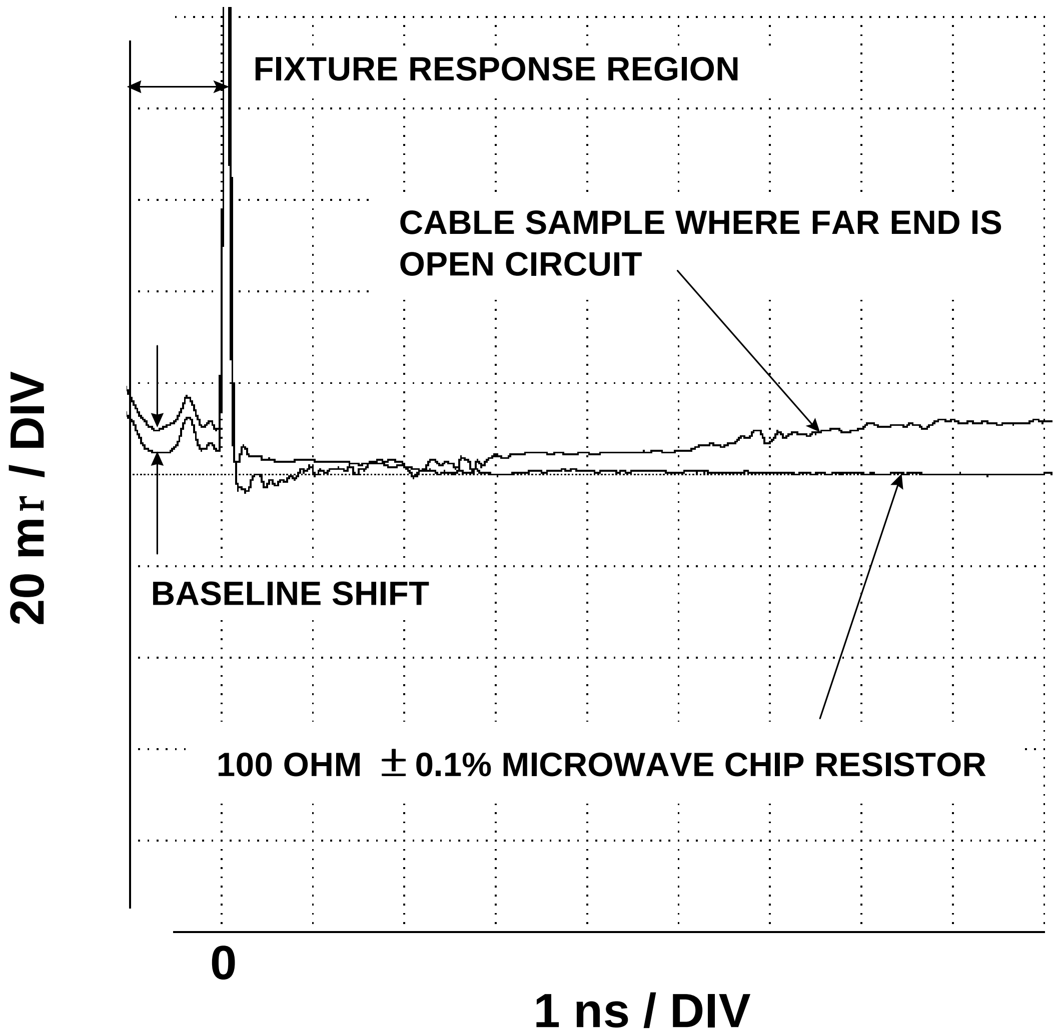


Figure 23 - Example without repositioned traces

Figure 23 shows the traces as recorded without repositioning.

Figure 24 shows the same traces separately for clarity. Figure 24 also shows the location of the points where measurements were previously recorded during calibration.

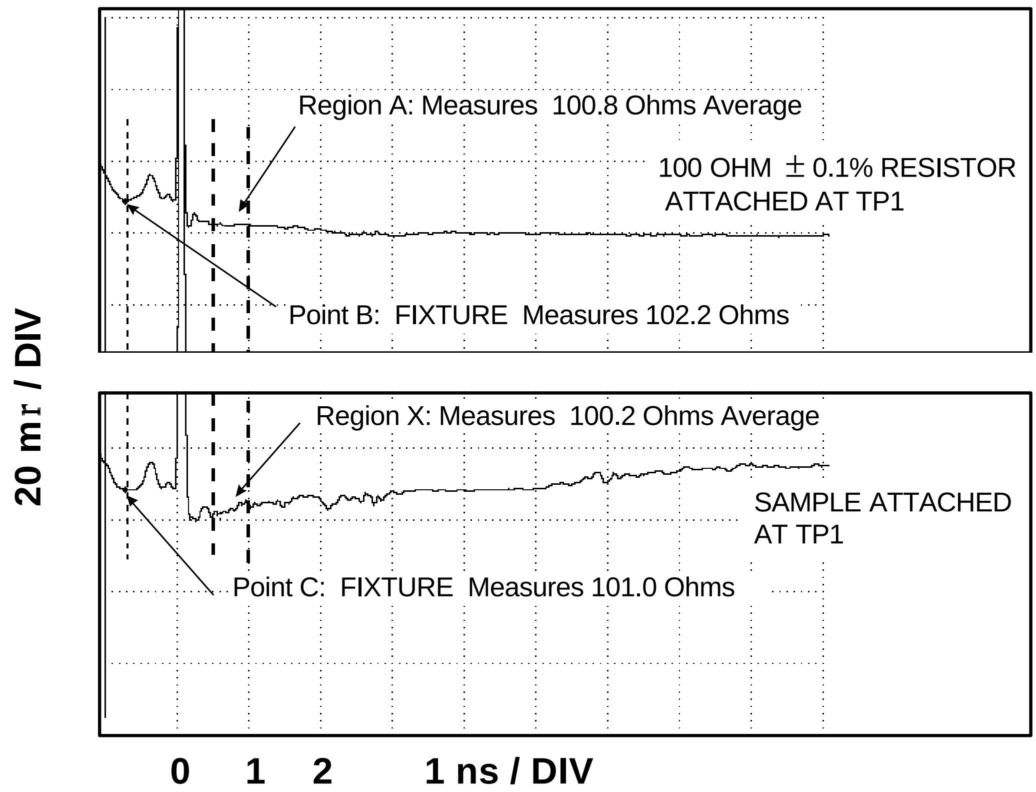


Figure 24 - Example with traces repositioned for clarity

Measurement procedure:

1. Connect the BCUT to the test fixture and display the trace as shown in Figure 24.

2. Place the cursors at the 0.5 and 1.0 ns positions. Measure the average impedance on the BCUT trace in the range between the cursors, region “X”.

3. Calculate the corrected impedance using the equation below. The method is illustrated in the example that follows which is based on the numbers shown in Figure 24 (all values in Ohms):

```
CORRECTED IMPEDANCE = (X - C) + (B - A) + R
                    = (99.57 - 101.0) + (102.2 - 100.8) + 100
                    = 99.97
```

The steps detailed below are summarized in the above equation:

MEASURE THE REFERENCE RESISTOR (already done during calibration):
Region A = 100 (assigned value)
Region A measures 100.8
Region A error = +0.8

DETERMINE FIXTURE IMPEDANCE:
Point B measures 102.2
Point B = 102.2 - (Region A error) = 101.4

DETERMINE ERROR CAUSED BY BASELINE SHIFT:
Measurement includes baseline shift because sample is not terminated at far end.
Point C = Point B = 101.4
Point C measures 101.0

Point C error = (- 0.4)

DETERMINE CORRECTED SAMPLE IMPEDANCE IN REGION X
Region X measures 0.4 Ohms less than the actual value. This error may be used to correct subsequent measurements.
Region X measures 99.57
Region X = 99.57 - (Point C error)
= 99.57 - (- 0.4)
= 99.97

8.1.8 Precision airline method

8.1.8.1 Overview of the precision airline method

This procedure defines the method of measuring the transmission line impedance of a BCUT using two 20 cm 50 Ohm reference airlines in combination with a TDR instrument (see 8.1.4) used in a balanced (differential) mode to send a step into the sample and monitor the reflections.

This method has the following properties:

- The airline is directly NIST traceable
- The transmission line impedance of the airline may be calculated from the geometry of the airline
- A flat trace exists in calibration
- Baseline shift effects caused by termination or shorting of the far end of the BCUT occur in both the BCUT and the airline portions of the trace - no baseline shift errors exist if the measurement is made relative to the airline
- Airline is ahead of the BCUT in the measurement and the reflection at the end of the airline affects the BCUT measurement
- Cost is generally higher than the resistor method
- Mechanical shock to the airline (e.g. accidental dropping) may cause loss of calibration
- Precision airlines may be available only in a few impedance values

There are two cases that apply to airline methods:

(1) where the BCUT is close to the impedance of the airline and the airline is used as the reference
(2) where the impedance of the BCUT is significantly different from the impedance of the airline and a calibration is required at the end of the airline.

In case 1 scale factor and offset errors are low. In Case 2 scale and offset errors increase and the accuracy degrades. According to some equipment manufacturers the scale and offset is expected to be up to ± 3% of the impedance difference. For example, for a 105 Ohm BCUT and a 100 Ohm airline the expected error is up to ± 3% of 5 Ohms or ± 0.15 Ohm.

An arbitrary division between case 1 and case 2 at the error level of ± 0.3 Ohm is made for editorial convenience. If accuracy better than 0.3 Ohm is required at the 100 ohm level or if the BCUT differs from the airline by more than 10% correction of the up to ± 3% error is attempted by a separate calibration as described in 8.1.8.4.2.

Actual scale and offset error values should be obtained from the measurement equipment manufacturers.

8.1.8.2 Precision airline

Two 50 Ohm precision airlines traceable to NIST shall be used. The length of the airlines, when combined with the matched test leads and fixtures of the measurement system (see 8.1.4.2), shall be such that the required STD or faster is delivered to the BCUT.

8.1.8.3 Calibration and setup procedure

The calibration for impedance is done using a precision airline where the precision airline is placed in front of the BCUT in the measurement setup.

- Assume the airline is calibrated for impedance
- Verify the STD at the point of attachment of the BCUT as specified in 8.1.6.3
- Note the time position at the end of the test fixture (where the BCUT is attached)

The BCUT is in place during the following operations:

- Adjust the vertical scale to 20 milli rho / division
- Adjust the horizontal scale to 1 ns / div
- Adjust the horizontal position such that the precision airline portion of the trace is near the left of the display screen

8.1.8.4 Testing procedure

8.1.8.4.1 Case 1 (within 10% of airline)

Place one cursor at the approximate center of the airline.
Place the second cursor at any time position between 0.5 and 1.0 ns positions from the fixture end where the value of impedance is the average of the trace between 0.5 and 1.0 ns. The average may be determined automatically or manually. Calculate the impedance as:

$Z_{corrected} = Y + A - X$

where:

A = calibrated value of airline
X = measurement of airline at center by TDR
Y = value reported by cursor 2 (average Z between 0.5 and 1.0 ns)

For example if A = 100, X = 102 and Y = 105, the correction is -2 ohms and $Z_{corrected} = 105 - 2 = 103$ ohms.

If A is 50 or 100 ohms most instruments allow the center of the airline to be set as zero rho by placing both cursors at the center of the precision airline and pressing the **Set Zero Rho** soft key. In these cases $Z_{corrected}$ is reported directly by the cursor 2 measurement.

Figure 25 shows an example of a precision airline measurement where the time scale is shown as 0.5 ns/div for clarity.

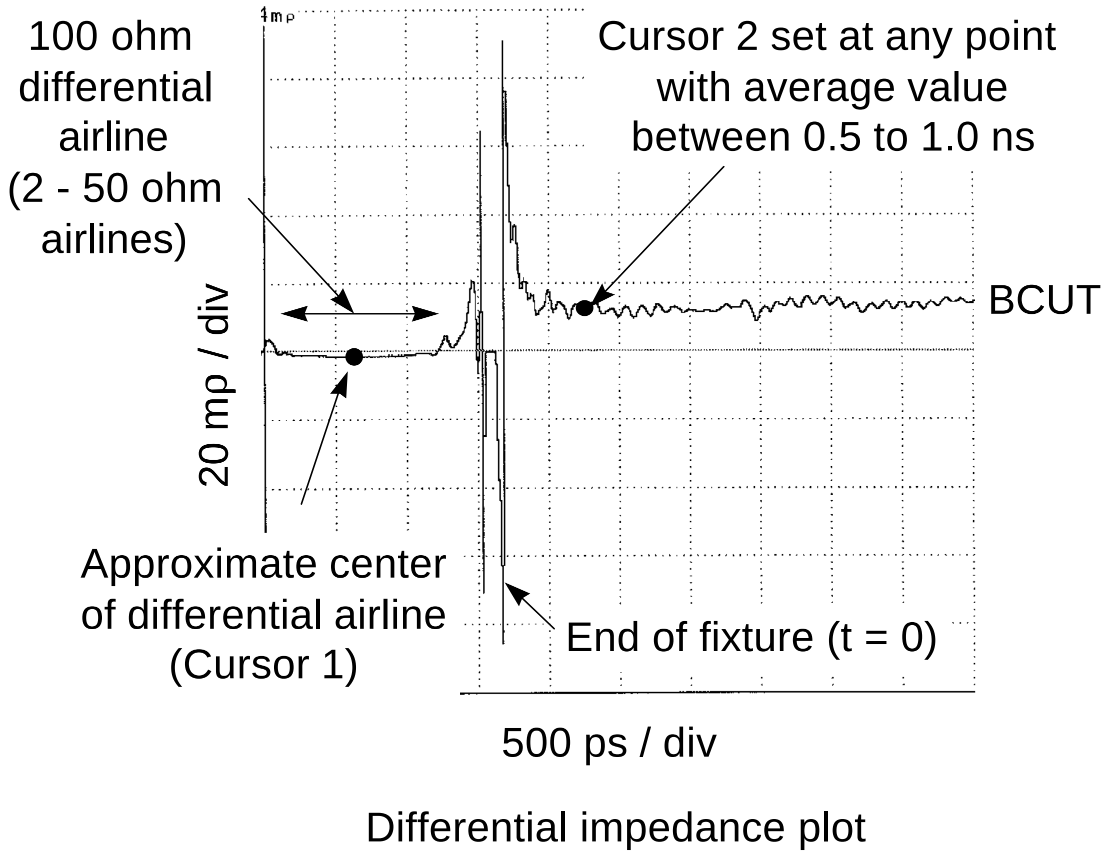


Figure 25 - Airline measurement example

8.1.8.4.2 Case 2 (more than 10% difference between BCUT and airline)

Use the same process as defined in 8.1.8.4.1.

The scale and offset error is corrected by placing a known sample (e.g., a known BCUT, another airline, or a resistor) in place of the BCUT and comparing to the known value of the measurement system airline at the point closest to the pulse source. This process yields a scale factor correction that may be applied to BCUT’s whose impedance is in the neighborhood of the calibration condition.

This process assumes that the calibration remains stable over the time period of interest.

8.1.9 Acceptable ranges

Acceptable ranges are defined in the applicable standards provided that the procedures defined in this document are used to acquire the data.

8.2 Propagation time and propagation time skew

8.2.1 Overview

Propagation time refers to the time required for a specific part of a signal to travel a specific distance along the path of the line. For in-pair skew measurements the midpoint of the transition is the applicable part of the signal and for pair to pair measurements the differential zero volts level is the applicable part of the signal. All skew measurements are TDT where the skew recorded is at the receive end of the BCUT under calibrated launch conditions.

The propagation time skew is the difference between the applicable parts of the signal over the same nominal path.

Only the differential propagation time is of interest for the propagation time requirements.

There are two propagation time skews of interest for this document:

- The in-pair skew is between the + signal and the - signal for the same pair
- The pair to pair skew is between pairs whose signals propagate in the same direction.

In-pair propagation time skew is one major contributor to imbalance.

The impact of skew may be considered in relation to the STD for the signal of interest. Signals with long STD’s show a large skew sensitivity to small differences in the signal level matching even though the common mode voltage produced is very small. Nevertheless, specifications are written around skew alone and this procedure removes the signal level effects as much as practical.

The method used to remove the signal level effects is to specify the voltage level to be used for measurement of skew timing values independent of the actual 100% voltage for the signal. The same signal level value is used for both legs in the same skew measurement but the signal level value may change for different BCUT’s.

For example, if a the + signal had 250.4 mV and the - signal had 249.5 mV a value of 125.0 mV could be chosen as the value to be used for the timing measurements. The 125.0 value was chosen as approximately half of either signal and the skew recorded is not significantly affected by small changes in the chosen signal level value.

On the other hand, if the actual 100% values were to be used a skew error could result. The + signal would be measured at 125.2mV and the - signal would be measured at 124.75. The difference in measurement signal level would be 0.45 mV. In a signal with a 16.7 ps/mV slope near the 50% region the 0.45 mV difference would appear as 16.7*0.45 = 7.5 ps skew.

Note that there are presently no requirements in this document on which pair is attached to which connector pin for parallel constructions. All pairs in the BCUT shall be considered for in-pair propagation time skew requirements unless specific application pin out requirements are known.

Signals are launched differentially in all measurements to avoid possible effects due to anisotropic dielectrics in real constructions.

The intrinsic noise floor for time domain measurements with present technology is dependent on the details of the methodologies. The best performance achievable is limited by cursor placement to approximately ± 2 ps. Other factors such as equipment drift, temperature drift, scaling factors used, accuracy of determining midpoint and calibration accuracy also are important. The actual aggregate practical error for the best time domain methods is around ± 5 ps.

For the protocols listed in Table 1 propagation time skew between pairs is required at the data word level not at the bit level. This provides significant relief to the pair to pair propagation time skew requirements (hundreds of ps) compared to systems that use a separate timing signal that must align at the bit level (such as parallel SCSI).

For applications that require very accurate pair to pair propagation time skew specification methods are known that are based on phase matching between pairs to achieve very accurate propagation time skew. Phase matching using a single ended launch condition and VNA measurements schemes is a popular method. Sophisticated analysis is required to include the anisotropic dielectric effects. The measurement accuracy of typical instrumentation is 2 degree phase error (50 GHz is present state of the art with 6, 20 and 26.5 being most popular). At 20 GHz the 2 degree phase error is equivalent to ± 3 ps. This method is treated as being beyond the scope of this document but will be addressed at the cable assembly level in SFF-8415.

Single pulse methods are used for all measurements of propagation time and propagation time skew. It is important that the repetition rate of the pulses not be too high. High repetition rates may not allow enough time for the BCUT to reach steady state and forces the measurement to a different part of the signal transition. High repetition rates typically report less skew. Ten propagation times between pulse edges is the minimum time used for these tests. All times are recorded at the midpoint of the received pulses. In all measurements in this section averaging may be used. The term “single pulse” refers to the time average of a series of widely spaced but repeating pulses.

The STD of the launched signal into the BCUT shall be less than 70 ps as viewed at the TDR head.

Annexes A and B discuss more details concerning the general concepts of measuring and interpreting within pair skew.

8.2.2 Distribution of skew along the length of the sample

Conventional practice in the past has assumed that skew scales with sample length. In other words a 20 meter part would have twice the skew of a 10 meter part. Extensive research into this assumption has yielded the conclusion that linearity with length should NOT be assumed. See Annex C for some details. The basic reason for this conclusion is that the mechanisms that cause skew may be statistically distributed along the length. Some constructions may have a significant linear component to the skew. In this case a statistical distribution may be added to the linear component. Skew is not specified in time/unit length in this document. Users should be wary of any skew specifications given in time/unit length with the implicit expectation that distributions that are proportional to length exist. If the measured skew is very small then distribution details may not be important.

The figure below shows a contrived local propagation velocity distribution that has the same overall average velocity for each line but has fairly large local variations at different positions along the cable.

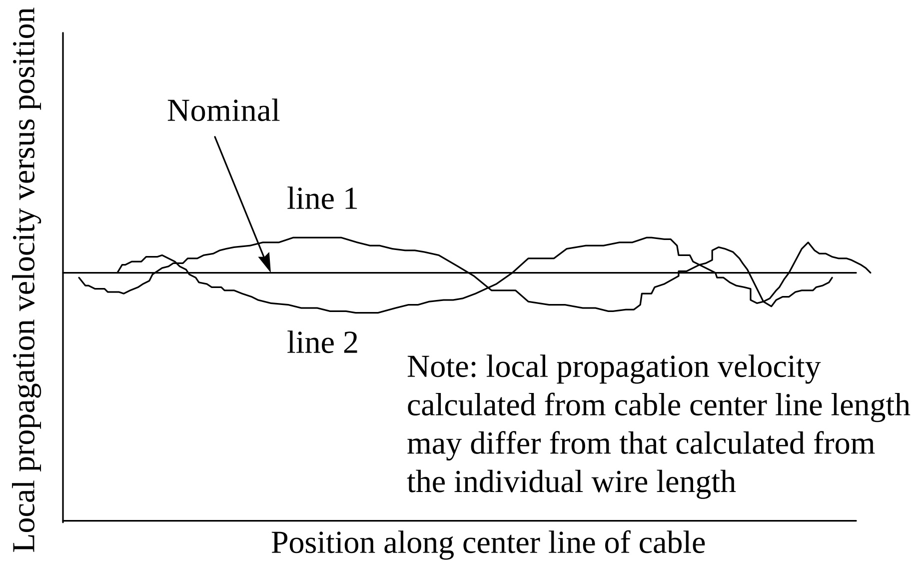


Figure 26 - Hypothetical propagation velocity distribution along the length of a sample

This document assumes that both in-pair and pair to pair skew may have a statistical distribution along the length. The statistical distribution is not expected to be the same because the mechanisms that cause in-pair skew and pair to pair skew are different.

This effect causes different requirements for how a supplier of bulk cable can specify skew content. For cable assembly applications addressed in SFF-8410 and SFF-8415 skew is a level 2 measurement that applies only to the cable assembly - there is no need to consider any length variations since the length is that of the cable assembly. For bulk cable applications, however, the following is required:

> Bulk cable shall not exceed an absolute skew number for any section of cable from 3 to 30 meters in length. The details of how to enforce this requirement over an entire reel of cable are left to the manufacturer.
>
> Using this approach, conformance to the skew requirement for bulk cable shall be done using the application length if known. Alternatively, sample lengths of 3, 10, 20, and 30 meters may be used.

Attenuation of the sample measured shall not exceed the noise floor of the instrumentation at the maximum measurement frequency. Typical noise floors may be in the neighborhood of 30dB.

The amount of skew that is tolerable changes with the application but is the same for all lengths. In other words the skew requirement is an absolute number of nanoseconds not normalized to length and the same requirement applies for all lengths.

Some related points are:

- When the in-pair skew is equal to 1/2f, complete loss of differential signal occurs.

- When the in-pair skew exceeds approximately 1/4 of the signal rise time (measured at the output of the BCUT) significant imbalance occurs.

- As the signal travels down the line it loses rise speed and the 1/4 rise time number increases. Therefore there is a relationship between the loss and the skew. More in-pair skew is tolerable in a high loss cable.

- In a system with real data, some finite differential signal will still be seen even if the skew causes loss of signal at the fundamental bit rate - this occurs because data patterns with run length longer that a single bit time exceed the skew and allow the differential signal to develop.

8.2.3 Basic measurement approaches

8.2.3.1 In-pair propagation time skew

The basic approach to the in-pair skew measurement:

> Simultaneous opposite polarity pulses are launched at low repetition rate (slower than ten round trip times) on the + signal and the - signal. The time required for the midpoint of each pulse to reach the other end of the bulk cable is measured. The difference between these times is the skew.

Note that sense reversal is required to ensure that compensating degradation is not occurring. The sense that reports the worst skew shall be used.

8.2.3.2 Pair to pair propagation time skew

Figure 27 shows the concept of pair propagation time and pair to pair propagation time skew.

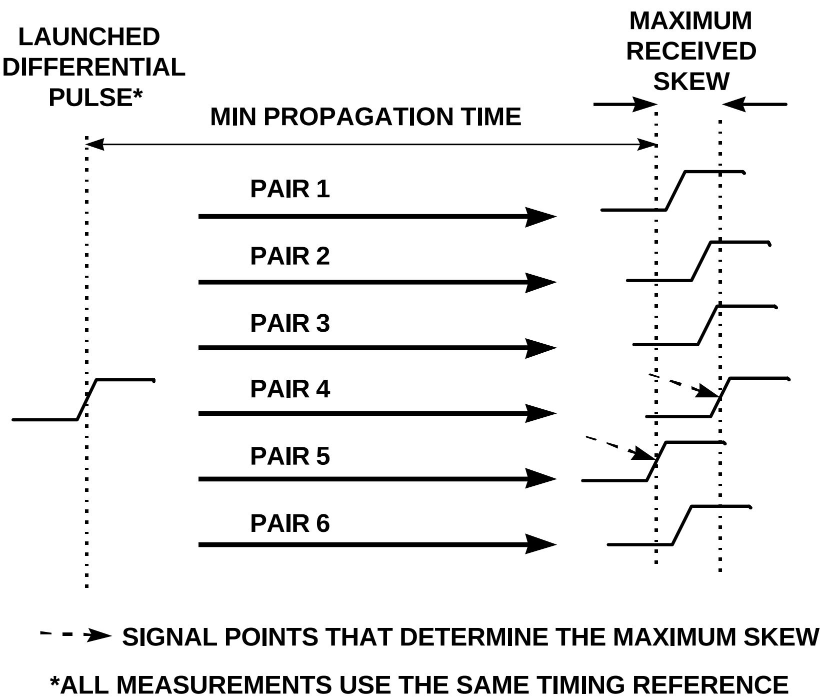


Figure 27 - Pair to pair propagation time and skew

The basic approach to the pair propagation time and the pair to pair propagation time measurements:

> Single differential pulses are launched on the each pair, usually one pair at a time. The time difference between the midpoint of the launched pulse and the mid point of the received pulse at the other end of the BCUT is measured. The repetition rate for the pulses shall be slower than ten one way propagation times.

8.2.4 Test fixture and sample attachment

The test fixture and sample attachment shall be as described in 8.1.3.

8.2.5 Measurement equipment

8.2.5.1 Overview

Equipment such as the Tektronix TDS 8000 or Tektronix 11801 with TDR sampling heads or equivalent shall be used. This equipment has features such as auto readout of propagation time and allows automatic or manual placement of bottom line and top line references (0% and 100% respectively).

8.2.5.2 Instrument calibration

The vertical scale calibration for the instrument is included in the calibration for the measurement set up. The time calibration shall be traceable to NIST and is not further specified in this document.

8.2.6 Calibration procedure

8.2.6.1 Overview

Low skew fixtures + test lead cables are desirable. If the test fixtures + test leads have negligible skew for the application then no further calibration is required.

If the skew in the test fixtures + test leads needs to be accounted for the following procedure is used:

- The launch signal is adjusted to have zero skew by observing the reflected pulses from an open circuit at TP1 through the combination of launch test fixture + test leads. To achieve the zero skew launch condition the observed reflected signal is adjusted to display half the skew measured under the open circuit condition.

- To account for the skew in the receive test fixture + test leads the measurement of the BCUT skew is taken first with one polarity of BCUT attachment to the receive side test fixture and again with the other polarity. No other measurement conditions shall be changed. The algebraic average of these two skew measurements is recorded as the skew of the BCUT. If the skew of the receive side test fixture + test leads is known then the skew of the BCUT may be calculated from a single measurement by subtracting the known test fixture + test lead skew from the skew measured with both test fixtures, leads, and BCUT in place.

8.2.6.2 Launch signal calibration

8.2.6.2.1 Overview

The measurement setup including the launch side test fixture + test lead cables measures the **round trip** propagation time as measured at the pulse source (TDR head).

This calibration procedure guarantees that the skew launched into the BCUT at TP1 is equal to and opposite in polarity to the skew in the test fixture + test lead cables between TP1 and the differential pulse source. The skew from the test fixture + test lead cables is identical in both directions because the same test fixture is used for both transmit and receive in the TDR method used.

The launch calibration configuration shown in Figure 28 is used. Open circuit is shown but short circuit may also be used.

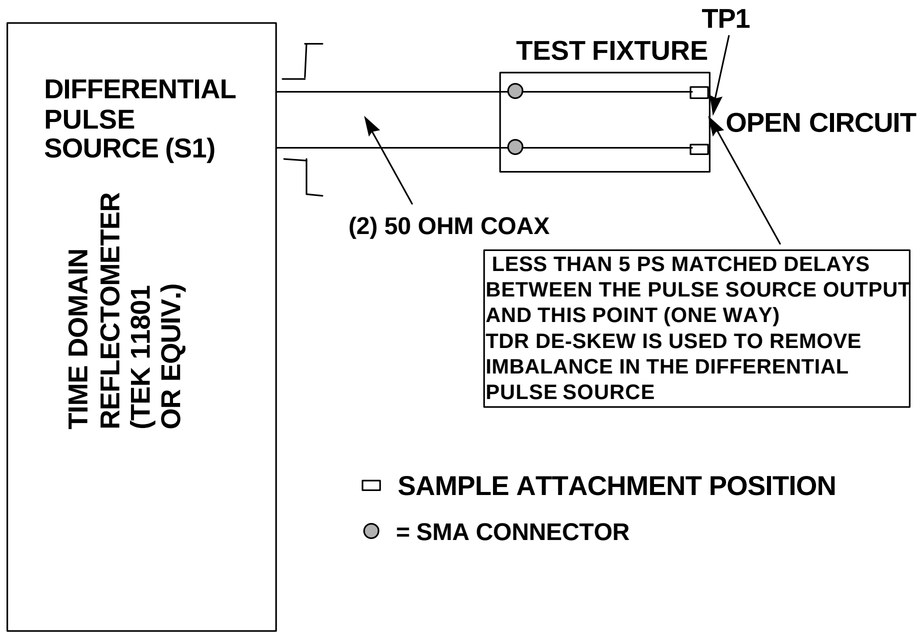


Figure 28 - Launch calibration at
TP1 for propagation time tests

The following process outlines calibration by an example. Mismatched test leads + test fixtures are purposefully used.

8.2.6.2.2 TDR head deskew (Step 1)

To deskew the TDR head nothing is attached to TDR head. TDR head is open circuit on both channels in the figures in this sub clause.

Preset instrument for differential TDR. Two traces will be displayed, one pulse positive, other negative.

Measure the skew from M1 (positive edge) to M2 (negative edge). Figure 29 shows that M2 edge is 4.49 ns AFTER M1 edge.

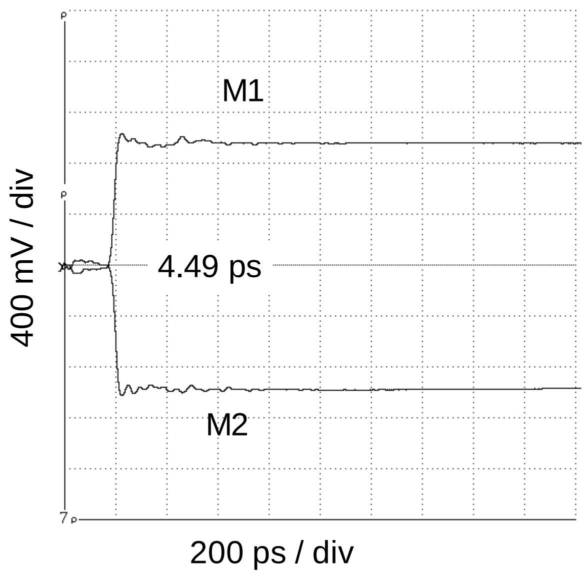


Figure 29 - TDR head nothing attached before head deskew

Adjust TDR delta delay to deskew open circuited TDR head. This is best done iteratively. Figure 30 shows the open circuit skew after this step. For this example, the two edges are coincident to 0.51 ps.

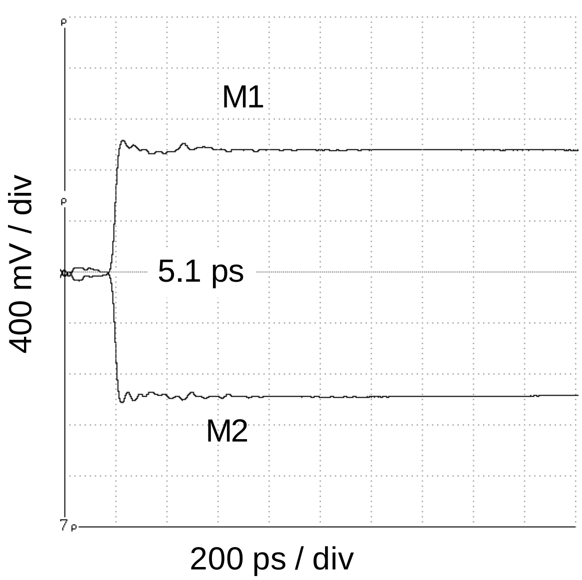


Figure 30 - TDR head with nothing attached after head deskew

8.2.6.2.3 Determine skew of test fixture + test leads (Step 2)

The transmit test leads + test fixture is attached to the deskewed TDR head. In the figures following, the test leads + test fixture are purposefully mismatched to a extreme degree (much more than expected in actual practice) to illustrate the procedures.

Figure 31 shows the round trip skew measured through the test leads + test fixture.

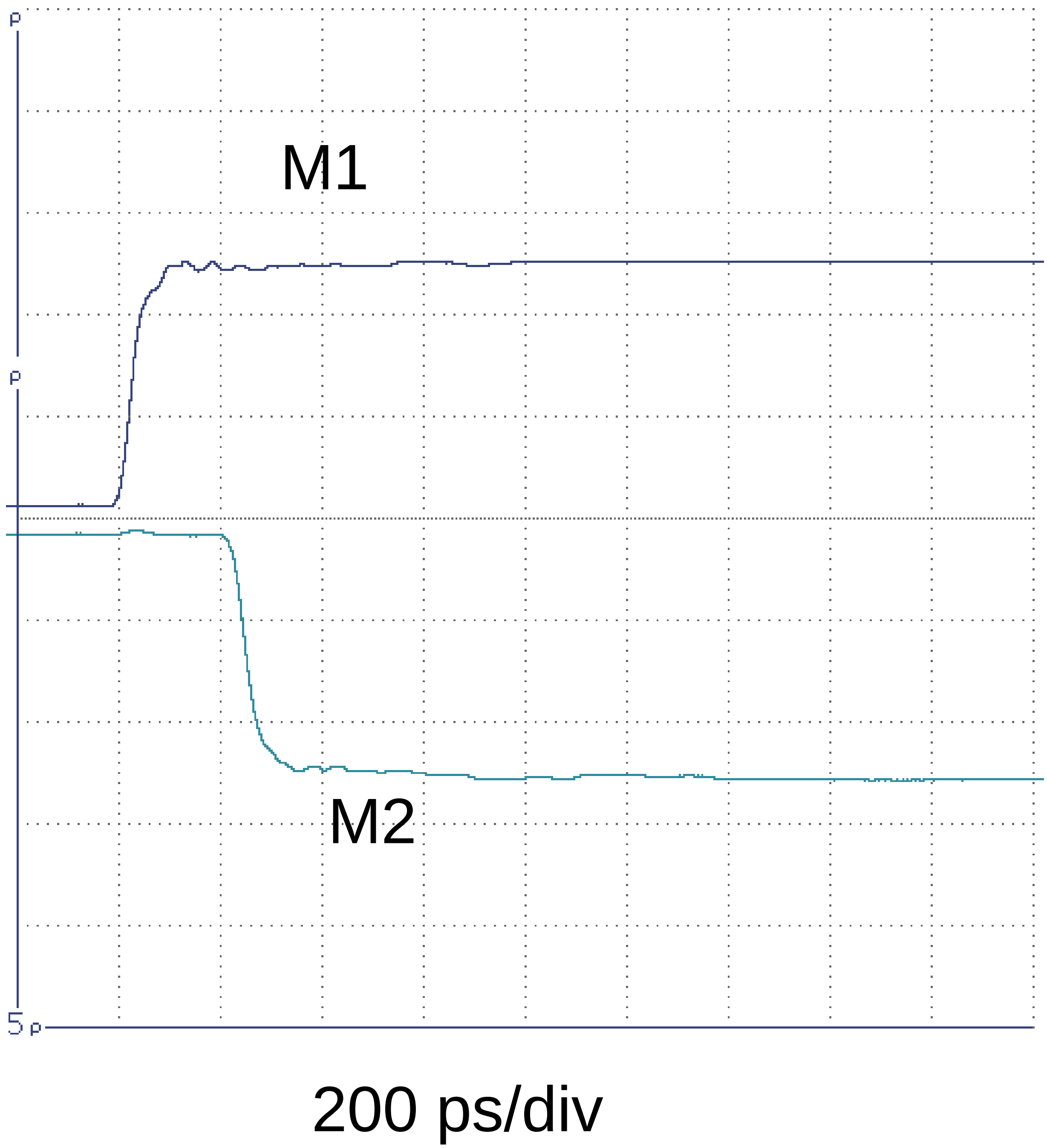


Figure 31 - Round trip TDR skew measurement

Figure 31 indicates a round trip skew of 225.87 ps. The path on M2 is actually 112.94 ps “longer” than the path on M1 for a one way trip.

8.2.6.2.4 Deskew the launch signal (Step 3)

Iteratively adjust Δ delay until the skew is half of the value recorded in step 2 (about 112.94 ps after M1 edge in the example shown in Figure 32).

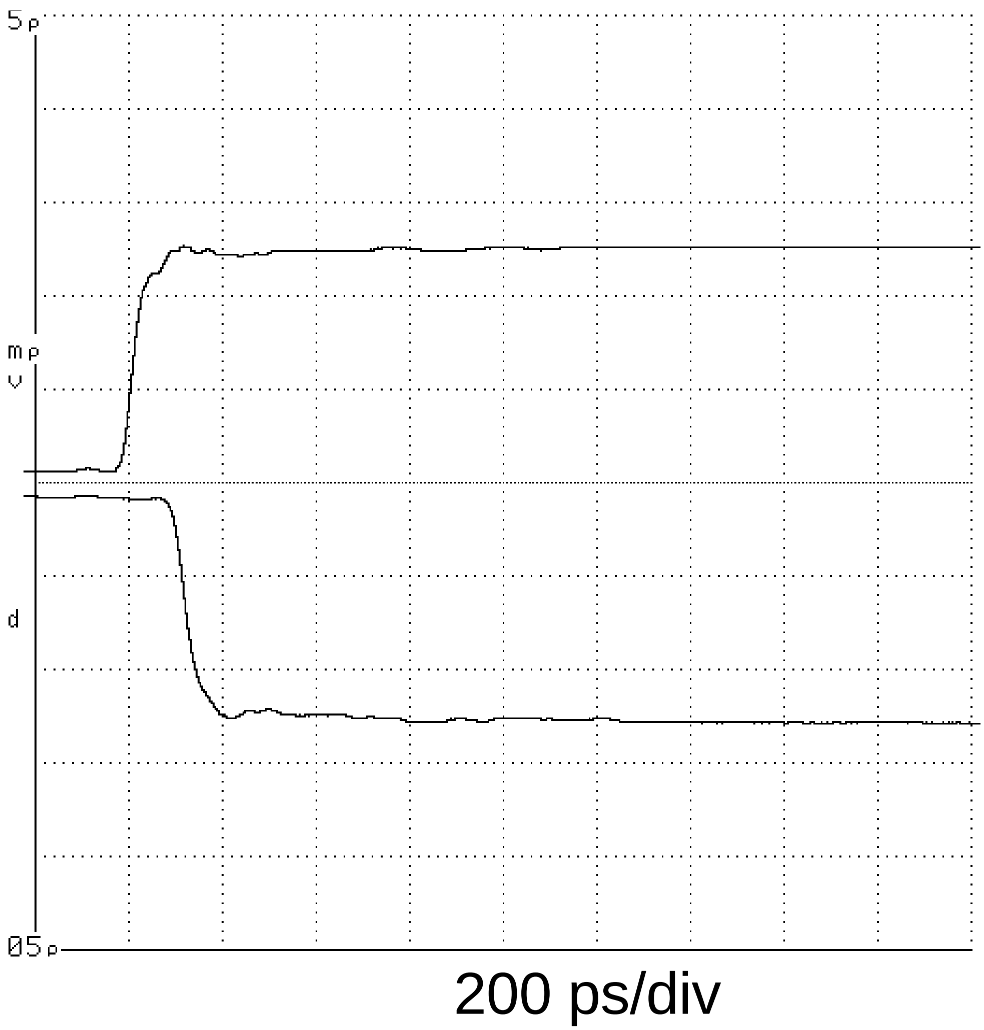


Figure 32 - Reflected skew at TDR head after deskew (112.94 ps skew shown)

8.2.6.3 Total test system propagation time and skew measurement setup

Figure 33 shows the setup for the total test system skew measurement.

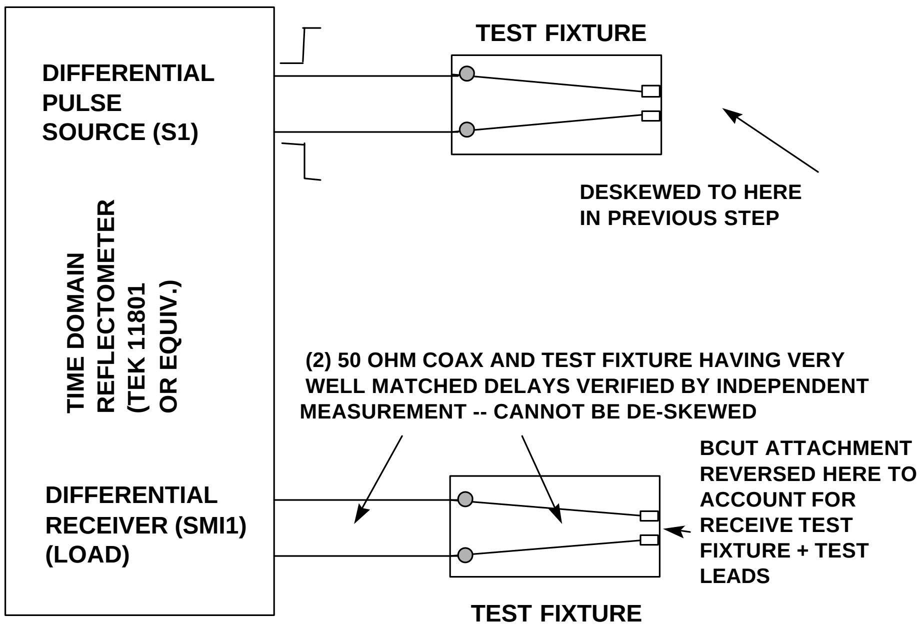


Figure 33 - Total test system skew measurement setup

For propagation time measurement setup calibration use the same setup as shown in Figure 33 with an additional ‘zero length’ interconnect between the two test fixtures as shown in Figure 34:

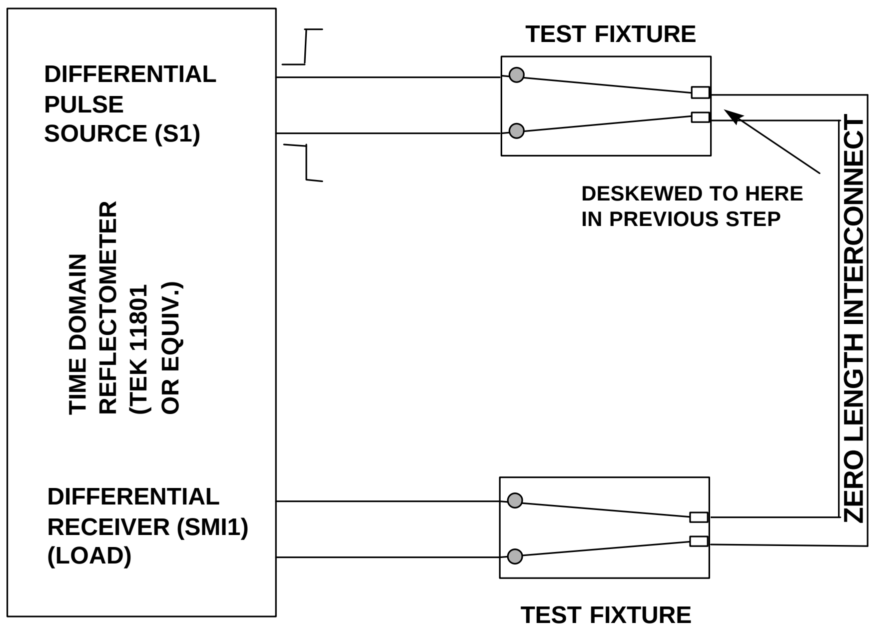


Figure 34 - Configuration for the propagation time calibration

1. To approximate a zero length interconnect use solder, clamps, or extremely short cable. (The coaxes going from lower fixture to the measurement instrument in Figure 34 shall be extremely well matched for delay - see Figure 33.
2. Measure the instrument timing of the 50% crossing of the measured differential pulse through the measurement setup and record for use in propagation time measurements to correct for the measurement setup. (The user may prefer to store this trace instead of recording the crossing time.)

Do not disturb fixtures from step 2 above. The calibration and verification procedure is complete.

8.2.7 Testing procedure

8.2.7.1 Test set up

Using the test fixtures described in section 8.2.4 connected as shown in Figure 34 with the BCUT in place of the zero length interconnect apply the same pulses from S1 that were used during the calibration process.

8.2.7.2 Within-pair propagation time skew measurement

This procedure assumes that the + signal and the - signal amplitudes are approximately the same. The + signal is used to determine the exact measurement conditions. The vertical zero reference is established internally in the TDR for both the measurement and the launched signals. This zero reference is not affected by the display position settings. Only automatic measurements of voltage (including manually set cursor methods if used) are allowed for this measurement process.

1. Display the + signal trace and adjust the horizontal scale such that a clearly defined square wave is observed at the BCUT output.

2. Measure the peak to peak voltage for the square wave, $V+_{PP}$. Calculate $0.5*V+_{PP}$.

3. Record the time where the magnitude of the + signal crosses the $0.5*V+_{PP}$ signal level. Adjust horizontal scales as necessary to achieve the required accuracy

4. Using the same scales display the - signal trace

5. Record the time where the magnitude of the - signal crosses the $0.5*V+_{PP}$ signal level

6. Subtract the recorded time of the - signal crossing from the recorded time of the + signal crossing. Store this result as "polarity A skew," keeping track of the sign.

7. Reverse the polarity of the attachment of the BCUT to the receive test fixture (change nothing else in the set-up, i.e., do not reverse the polarity of the receive test fixture attachment to the test system).

8. Record the time where the magnitude of the - signal crosses the $0.5*V+_{PP}$ signal level. Use the same scales established in step 3 above.

9. Using the same scales display the - signal trace

10. Record the time where the magnitude of the - signal crosses the $0.5*V+_{PP}$ signal level

11. Subtract the recorded time of the - signal crossing from the recorded time of the + signal crossing. Store this result as "polarity B skew," keeping track of the sign.

12. The BCUT skew is recorded as polarity A skew minus polarity B skew divided by 2. (the signs of the polarity A and polarity B skews must be maintained in this equation).

13. If the value of receive test leads + test fixture skew is known for the STD of the signal exiting from the BCUT a correction may be used. The BCUT skew is the recorded time where the magnitude of the + signal crosses the $0.5*V+_{PP}$ signal level minus the receive test lead + test fixture skew (keeping track of the signs). The receive test fixture value may be algebraically added to the polarity A or polarity B skew and achieve the same result as step 12.

Additional diagnostic information:

To evaluate the causes for the observed data note that if the received traces cannot be made coincident by a simple time translation then effects other than pure propagation time are operating.

Figure 35 shows three kinds of imbalance and some example causes that may be experienced in real systems.

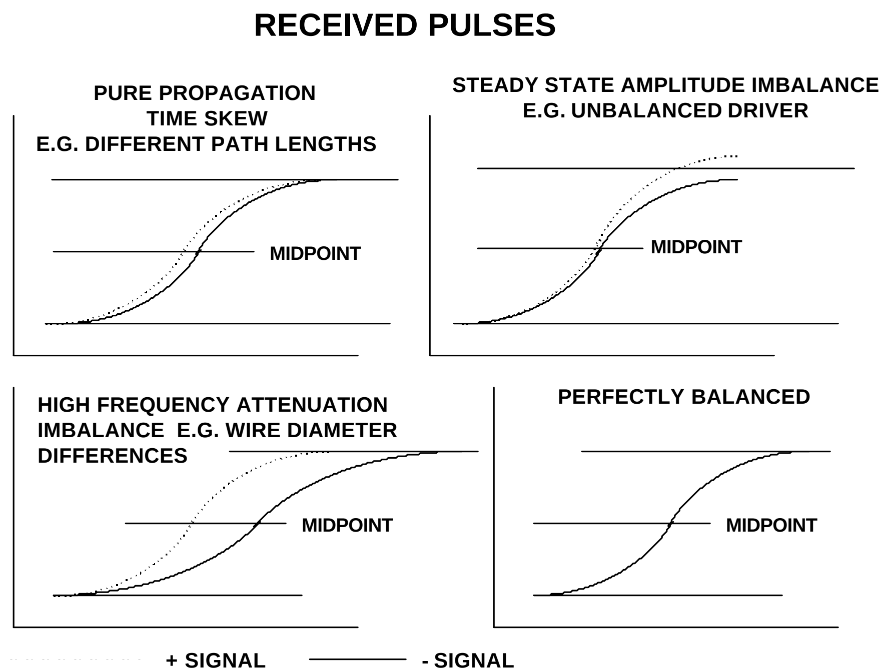


Figure 35 - Examples of received pulses

The path length propagation time skew imbalance can be corrected by a simple time translation. The steady state amplitude imbalance can be corrected by a simple gain adjustment. The high frequency attenuation,. on the other hand, will not be corrected by either a time translation or a gain adjustment.

Examination of the structure of the received pulses can provide primary diagnosis of the cause of imbalance.

8.2.7.3 Propagation time

1. Use the recorded 50% time or the stored trace done in 8.2.6.3.

2. The non-adjusted propagation time including that of the test fixture and instrumentation is the time position of the average of the zero crossing points of the + signal and - signal pulses measured in the within-pair measurement above, relative to the recorded time.

3. The recorded BCUT propagation time is found by subtracting the recorded 50% time from the measured non-adjusted propagation time for each pair.

8.2.8 Acceptable ranges

Propagation time and skew acceptable ranges are defined in the relevant standard.

8.3 Insertion loss (SDD21, SCC21)

8.3.1 Overview

8.3.1.1 Basic theory

Insertion loss is commonly used almost interchangeably with the term ‘attenuation’ and this document uses only the insertion loss term for simplicity. The inverse of insertion loss is gain.

There are three types of insertion loss of interest: differential (SDD21), common mode (SCC21) and single ended (S21). All three types are available from the same measurement. Distinction between types is made only where needed for clarity.

Attenuation, however, can only be measured directly with an ideal test system that is perfectly matched to the balanced transmission line to be tested. In a practical test system, the quantity that is actually measured is insertion loss. Insertion loss is comprised of a component due to the attenuation of the balanced transmission line, a component due to the mismatch loss at the input or near end side of the transmission line and a component due to the mismatch loss at the output or far end side of the transmission line.

Insertion loss of interest in this document is the signal amplitude loss over the spectrum from 50 MHz to 3x the fundamental frequencies of the data rates.

For example the frequency range would be:

> for 2.125 Gb/s with a 1.0625 GHz fundamental frequency the requirement applies up to 1.0625 GHz x 3 = 3.1875 GHz.

The factor of 3 is determined from the spectral content of a pseudo random run length encoded NRZ data pattern (where the significant energy content is below 3 times the fundamental frequency - the third harmonic energy is included at this frequency). The 50 MHz is derived from the fundamental frequency of the longest pulse in a 64/66 encoded signal operating at 10 Gbaud or the fundamental frequency of the longest pulse in an 8b10b encoded signal operating at 1 GBaud.

Comparison to a maximum loss mask function is expected to determine compliance. This document does not define this maximum loss mask. This mask could be defined, for example, by $af^{1/2} + bf + c$ for uniform copper conductors. The ‘c’ term may be required to account for impedance differences between the BCUT and the test system. Other conductor types and specific requirements of the application may use different functional forms. In the above equation the coefficients ‘a’, ‘b’, and ‘c’ are determined by the application.

Insertion loss data output shall have a specified maximum frequency increment between data points (that affects the minimum number of discrete data points, see 8.3.1.3) acquired with an IF bandwidth of 300 Hz.

Properties of suckouts in the measured data are defined.

Insertion loss is calculated from the ratio of output voltage signal level to input voltage signal level through the PUT and is a measure of the losses experienced when transmitting a signal through the bulk cable. Higher insertion loss means less signal at the output or equivalently a gain of less than unity. A sinusoidal signal is used to eliminate the need for complex descriptions of real pulses and square or trapezoidal signals in terms of Fourier components. A complete insertion loss specification requires examining all frequencies of interest to the application.

A spectral description is recommended. The basic formula for insertion loss in decibels is:

Insertion loss (dB) = 20 $\log_{10}$ (input signal voltage / output signal voltage).

Note that this formula gives the insertion loss as a positive number since the ratio of the input signal to the output signal is greater than unity. Sometimes insertion loss is casually reported as a negative number when the gain is really the intended mathematical statement. In any case, the **magnitude** is the same for gain, insertion loss and attenuation. The following formula expresses gain in decibels.

Gain (dB) = 20 $\log_{10}$ (output signal voltage / input signal voltage)

Since the ratio of the input signal to the output signal is greater than unity the gain is a negative number.

If the output and input signals are measured in power instead of voltage then the multiplier in the above equations is 10 instead of 20.

This document requires that insertion loss be expressed as a positive number unless there is active gain in the path from active circuits.

Therefore a typical insertion loss plot has the form shown in Figure 36.

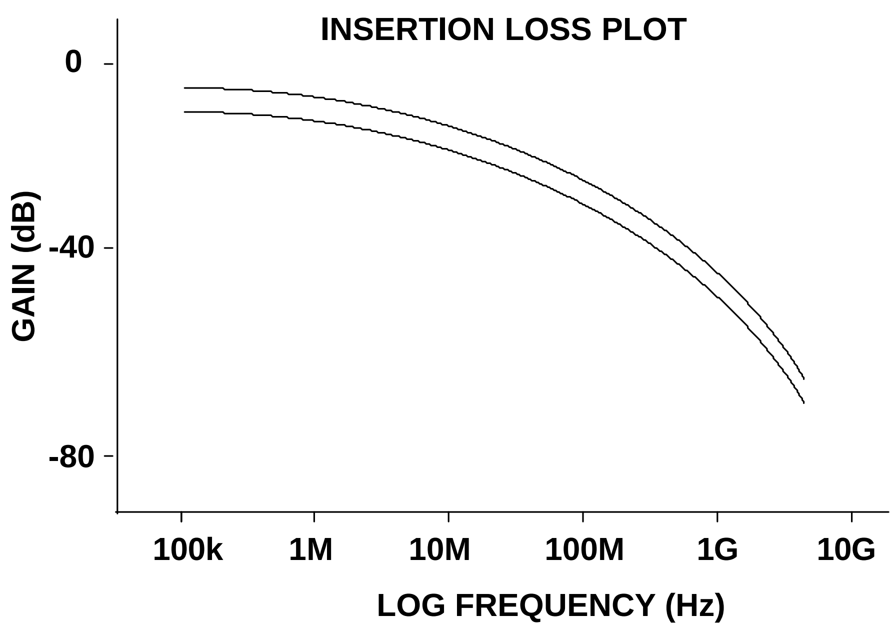


Figure 36 - Usual form of insertion loss plots

Insertion loss is a measurement of the reactive and dissipative losses in the differential signal on a balanced transmission line.

Dissipative losses include series resistive loss of the conductors (copper) and the shunt loss due to the dissipation factor of the dielectric covering the conductors. At higher frequencies, the conductor loss increases due to skin effect. Skin effect is where the current become increasing confined in the outer “skin” of the conductor as the frequency increases. This effectively reduces the conductor area available for current flow. The insertion loss for a given balanced transmission line is affected by the conductor metal composition and size and the composition, uniformity, and thickness of the dielectric that surrounds the conductors.

Reactive losses include radiation (crosstalk and EMI) and mode conversion.

There is a mismatch loss component at any interface where the transmission line impedance is not perfectly matched on both sides of the interface. The amount of mismatch loss that is experienced at each interface is :

Mismatch Loss (dB) = $(- 10 \text{ LOG}_{10} (1 - | \Gamma |^2))$ dB (where Γ is the reflection coefficient between the BCUT and the termination)

Balanced transmission lines are also susceptible to measurement errors when measuring high values of attenuation (>50 dB) due to radiated energy coupling into the transmission line. The largest source of this error is due to direct coupling of the near end side of the test system to the far end side of the test system. This coupled signal will combine with the test signal passing through the transmission line under test and cause a significant ripple error in the insertion loss measurements at the higher frequencies where the attenuation of the transmission line under test is the largest.

Historically the test instrument’s single ended interface required a coupling device called a balun to connect the differential BCUT to the test equipment. At the high frequencies required to measure HPEI bulk cable balun performance is inadequate so a balunless scheme is required.

There are two balunless schemes defined:

One uses a 4 port vector network analyzer with appropriate software support. Vector network analyzers are required because the phase information is needed to convert the single ended raw VNA measurements to differential and common mode results.

The other scheme uses a time domain measurement with subsequent data processing to produce the insertion loss over frequency.

8.3.1.2 Sample length considerations

The most fundamental consideration is adequate length to characterize a reel of bulk cable. Insertion loss is assumed to scale with sample length. To minimize measurement uncertainty the sample length should be such that the insertion loss at the maximum frequency of interest is at least 30 dB for VNA measurements and 20 dB for TDNA measurements. (TDNA allows better removal of test fixture effects). The measurement environment (test fixture, instruments, environmental noise) has a noise floor. The maximum insertion loss in the frequency range of interest should remain at least 10 dB above this noise floor. (TDNA noise floors are typically -50 dB, VNA noise floors are typically -80 dB).

This requirement assures that all important properties including periodic disturbances are represented in the sample.

8.3.1.3 Maximum frequency increment

The maximum frequency increment suggested is 7.5 MHz for frequency ranges up to 12 GHz. This is sufficient resolution that the important peaks and valleys in the insertion loss frequency range are unlikely to be missed while minimizing the data acquisition time. It may be useful to use a frequency increment of 5 MHz so that round numbers exist in the measurements. This makes it easier to match the actual frequency points specified by the mask.

In the case of wide frequency ranges the number of points required to meet the 7.5 MHz maximum frequency increment requirement may exceed the instrument’s capability in a single sweep. In this case the sweep may be broken up into multiple measurements at smaller frequency ranges to cover the entire range required.

The minimum number of data points is calculated from the minimum frequency increment and the frequency range required. Since the quotient needs to be a whole number slight adjustment of the actual frequency range or the actual number of points may be required.

For example, for a typical frequency range of 3 GHz the minimum number of points is 3000/7.5 + 1 = 401 using the 7.5 MHz increment.

The number of points may be reduced in production applications if it can be established that the magnitude of the suckouts that exist are visible with at least 8 points in each suckout at the reduced number of points.

Isolated points (points not clearly connected to the main population in the vicinity of the frequency of interest by at least 10% of the local expected insertion loss) should be considered as possible under sampled suckouts. Insertion loss in the vicinity of isolated points should be remeasured with sufficient resolution to capture at least 8 points in the suspected suckout.

8.3.1.4 IF bandwidth requirements

IF bandwidth affects the frequency sweep rate, the noise level at the set point frequency, and the measurement accuracy.

Wide IF bandwidth allows faster frequency sweep rates - faster overall measurement throughput. If the IF bandwidth is too wide then the measurement error increases because the received frequency is not synchronized with the transmitted frequency due to transit time through the long sample. The wide IF bandwidth allows the actual frequency measured to be different from the stated frequency. Wide IF bandwidth also has the effect of including noise from inappropriate frequencies in the IF band. This causes the system noise floor to rise (e.g. from -60 dB to -55 dB).

The time to perform the frequency sweep increases more or less in direct proportion to the IF bandwidth. If the IF bandwidth is too narrow good measurement accuracy results but time may be wasted.

A good starting point for IF bandwidth is 100 Hz. It is suggested that results be recorded at 100 Hz and wider (e.g. 300 Hz, 500 Hz). The highest IF bandwidth that does not show measurement accuracy reduction should be used.

For the same accuracy, long samples require narrow IF bandwidth, short samples allow wide IF bandwidth. If the sample length is changed the IF bandwidth should be rechecked.

8.3.1.5 Suckout

A suckout is a sharp reduction of the magnitude of the insertion loss for a relatively narrow group of frequencies within the BCUT’s overall frequency response.

Common causes of suckouts are spatially periodic disturbances along the length of the cable in the cable construction and resonance conditions.

Examples of spatially periodic disturbances include spirally wrapped drain wires, spiral shields, periodic fluctuations in dielectric extrusion processes, and wheels/bearings with flat or sticking portions that damage wires or dielectrics during the wheel/bearing rotation.

Resonances are usually caused by mismatched impedances that cause multiple round trip reflections.

Suckouts are characterized by center frequency, height and width at half height as shown in Figure 37.

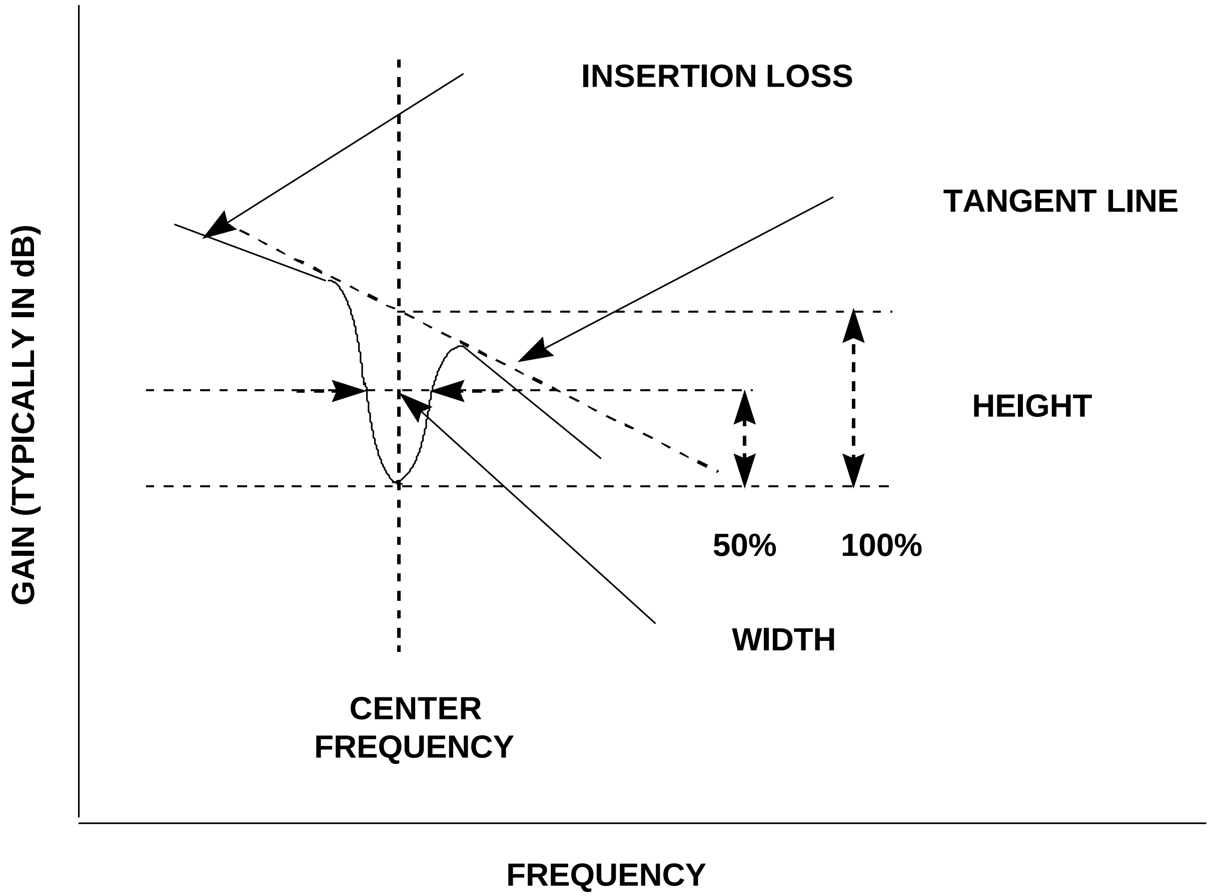


Figure 37 - Definition of suckout properties

8.3.2 Measurement test fixture and measurement equipment

8.3.2.1 Test fixture

A test fixture with even and odd mode impedance of 50 ohms shall be used to match the conditions needed during calibration where 50 ohms is assumed for both even and odd modes. This requirement can be met using semi rigid coax as shown in Figure 38. PCB versions meeting this requirement are not shown in this document.

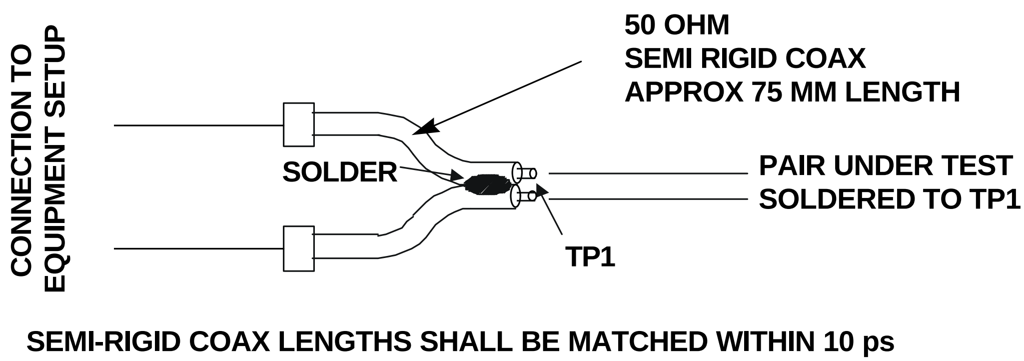


Figure 38 - Measurement system set up for insertion loss

Two measurement test fixtures are required: one for the source end and one for the sink end.

Also impedance through the BCUT attachment area shall be carefully controlled to avoid local cavity effects and resonances in the measurement caused by the measurement process. The requirement of at least 20 dB insertion loss at the highest frequency of interest reduces the impact of the highest frequency resonance conditions.

Considerations for designing this area of the measurement system include:

- maximum frequency of interest
- length of the BCUT
- overall length of the test fixture + cable
- length of the BCUT attachment region

If suckouts are experienced in the insertion loss measurement of the BCUT, the test fixture and measurement system should be checked for its contribution to these suckouts.

A suggested method for checking the measurement system is to use semi rigid coax as a BCUT. Two equal lengths of semi rigid coax with the shields soldered together at each end and of length that produces approximately 20 dB insertion loss at the highest frequency of interest is recommended. With this idealized BCUT, changes in the test fixture, attachment scheme, etc. are made until the performance of the measurement set up is reduced to acceptable levels.

Acceptable levels are when the peak to peak variations from the second degree curve fit are small compared to the suckout observed.

Another useful tool to identify suckout sources from the test fixture is return loss measurements into the test fixture. If the test fixture is producing the suckout then a suckout should be also observed in the return loss measurement.

8.3.2.2 Measurement equipment

8.3.2.2.1 Overview

Two types of measurement equipment are specified: frequency domain network analyzers and time domain network analyzers. Frequency domain network analyzers are often referred to as vector network analyzers (VNA). Time domain network analyzers are often referred to as TDNA. TDNA's are capable of producing frequency domain vector outputs and VNA's are capable of producing time domain outputs (with suitable software processing). Typical TDNA equipment consists of TDT/TDR's with associated software.

8.3.2.2.2 Frequency domain analyzers

A four port vector network analyzer specified for use over the desired frequency range is required.

> The VNA instrument uses 4 single ended ports with internal mathematical processing to calculate "true" differential and common mode responses (see 7.6.3), assuming that superposition applies which is the case for the linear bulk cables of interest in this document.

The VNA shall be capable of meeting the frequency increment and associated minimum data point requirements in 8.3.1.3.

An example of suitable measurement equipment up to 20 GHz is an Agilent 8720ES VNA with an N4418A s parameter test set.

8.3.2.2.3 Time domain analyzers

A four TDR channel instrument having suitable STD to cover the specified frequency range is required.

> The instrument uses four single ended channels to produce two differential channels. A true differential or common mode signal may be produced if both single ended channels associated with the differential channel are switching simultaneously. Internal mathematical processing is used to display the differential or common mode signals.

The frequency domain output required for SDD21 is produced by processing the waveforms measured with suitable software.

An example of a TDNA measurement equipment set is a Tektronix 11801, Tektronix TDS 8000 or Agilent 86100 digital sampling oscilloscope with TDA IConnect modeling software.

8.3.3 Calibration procedure

The basic instruments are assumed to be calibrated according to the manufacturers recommendations before executing the procedures described in this section. This calibration is done up to the SMA connections to the test fixtures and it typically called the reference plane as shown in Figure 39.

A special "through" test fixture is used for the calibration process for VNA or TDNA that consists of two connected test fixtures as shown in Figure 39. It is important that the discontinuity at the sample attach point be in the through test fixture. This allows resonances and reflections caused by the test fixture to be somewhat calibrated out and not be included in the actual BCUT performance. The resonances experienced with the through connect fixture in the sample attachment area with the VNA method are not expected to be the same as with the BCUT attached because the resonant conditions are grossly different. This difference comes from additional ‘cavities’ and different lengths of the ‘cavities’. This difference is not accounted for in the VNA measurement process.

The TDNA calibration allows calibration to the tip of the test fixture wire and is not affected by the ‘cavity’ effects.

In either case the requirement for a minimum insertion loss at the highest frequency of interest mitigates these test fixture errors to a large degree.

In all cases the calibration configuration should look as much as possible like the configuration to be used for the BCUT measurements.

The constructions shown in Figure 39 and Figure 40 show an open region near the BCUT attachment point. This open construction allows the E fields in this region to extend far away from the fixture and allows more variability between the calibration configuration and the measurement configuration. Additional control may be achieved by extending the shields over the center conductor. Examination of a Smith chart of the test fixture can aid in determining if the additional shielding is needed.

A well performing through text fixture has a Smith Chart trace that centers on 50 ohms and stays close to 50 Ohms at all frequencies below the maximum frequency.

A well performing open test fixture has a Smith Chart trace that follows the outer circumference of the chart (rho =1). At some frequency the trace will begin to encroach on the center of the chart and this provides an indication of the threshold frequency.

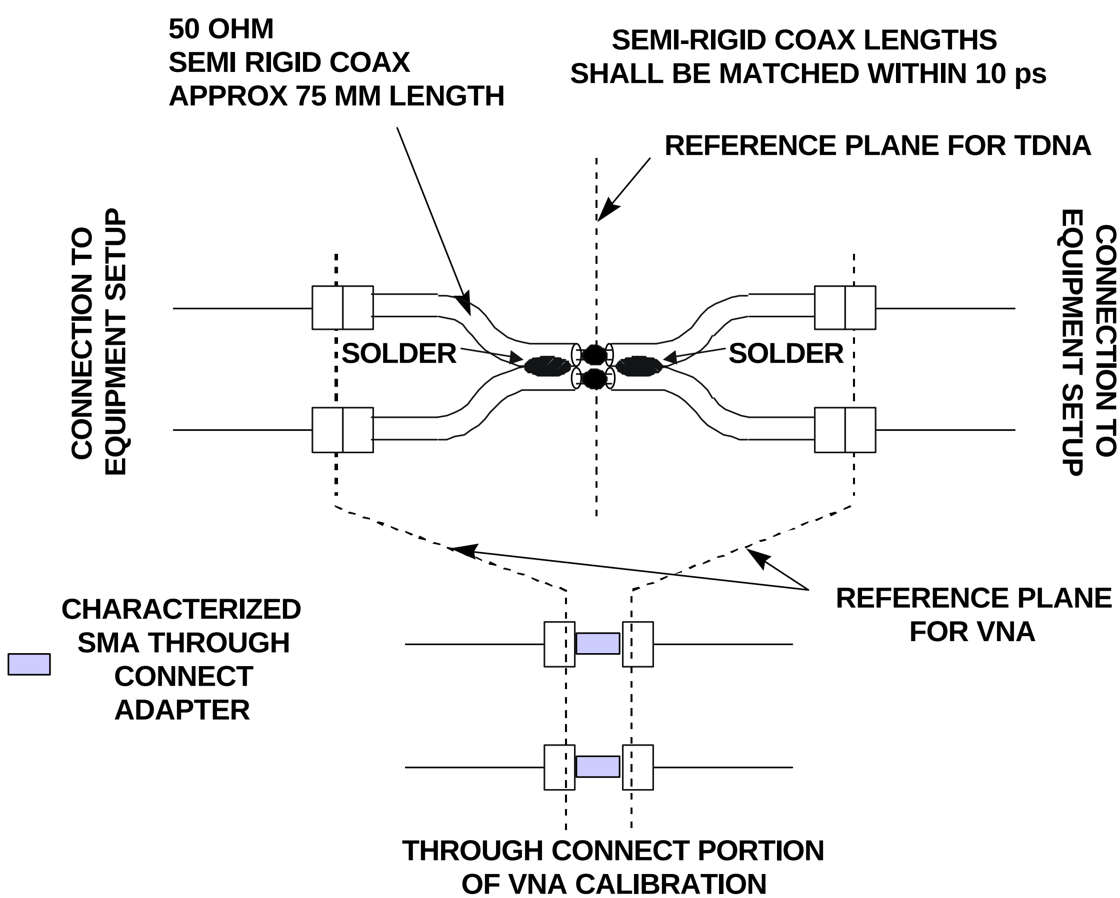


Figure 39 - Calibration through connect test fixture for VNA or TDNA

For the TDNA scheme a optional TDR mode calibration may be used as shown in Figure 40.

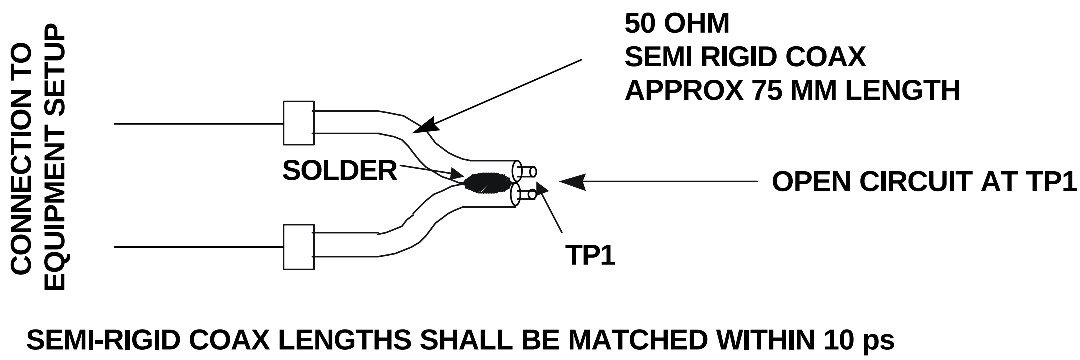


Figure 40 - TDNA calibration setup using TDR mode

For TDNA measurement a reference waveform is recorded using the conditions in either Figure 39 or Figure 40. The STD for this recorded waveform shall be faster than 50 ps for frequencies up to 10 GHz.

For a more complete calibration standard shorts and loads may be used at TP1 in addition to the open shown in Figure 40.

8.3.4 Testing procedure

8.3.4.1 VNA (Vector network analyzer)

Set up the conditions in the upper part of Figure 39 and measure the insertion loss of the through connect test fixture.

Connect the BCUT to the test fixtures shown in Figure 38 and measure the insertion loss of the BCUT + test fixture.

Obtain the BCUT insertion loss by subtracting the through connection measurement from the BCUT + test fixture measurement using vector methods.

8.3.4.2 TDNA (Time domain network analyzer)

8.3.4.2.1 Overview

The basic process is to acquire a calibrated reference waveform that is launched into the BCUT and to acquire the waveform after transmission through the BCUT (and associated test fixtures) as shown in Figure 41. These two waveforms provide the input to an S parameter computation algorithm.

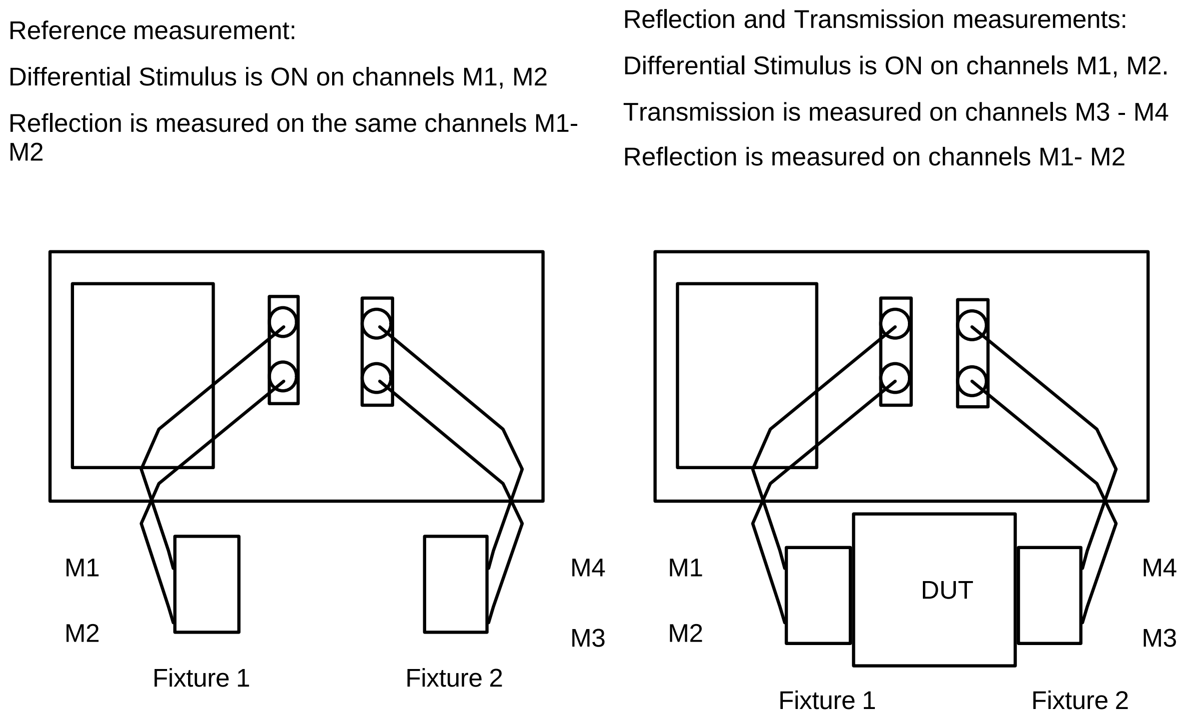


Figure 41 - Waveform measurement configurations

Figure 42 shows the reference and transmitted waveforms using a though test fixture measurement.

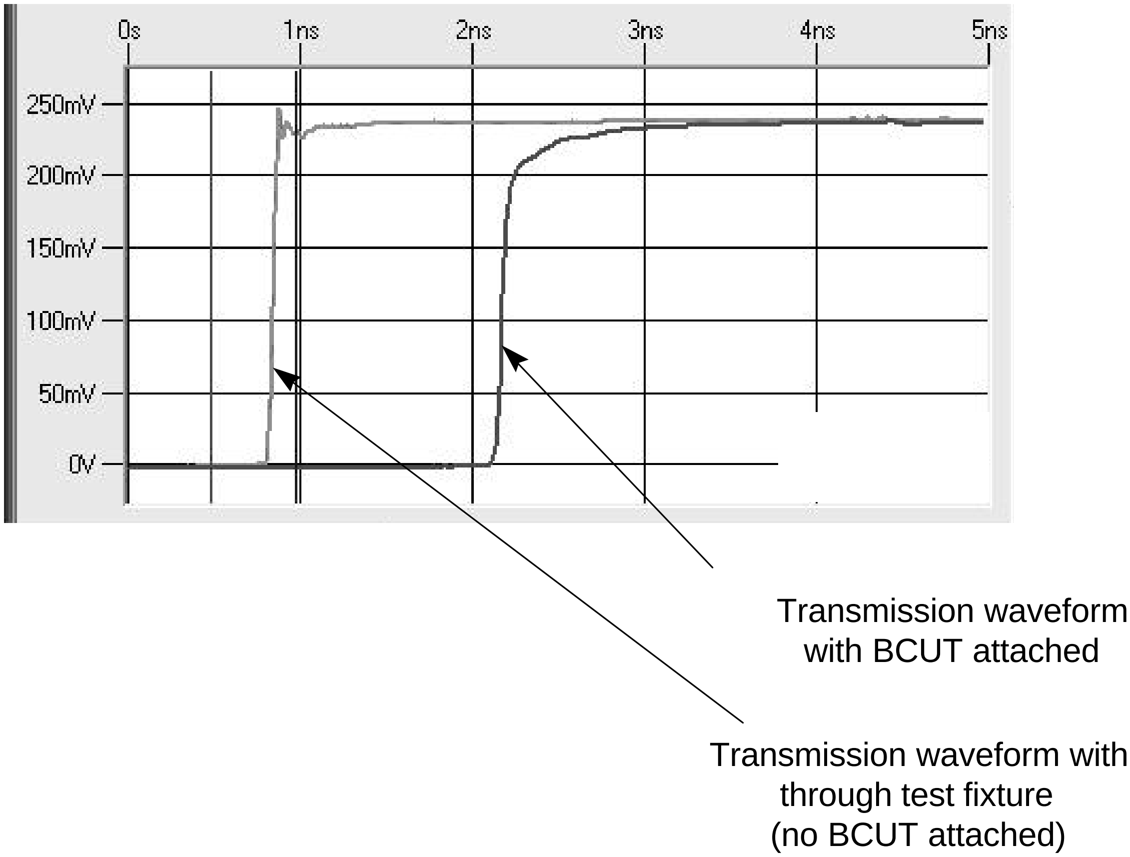


Figure 42 - Example of using the reflection calibration method

When using the open test fixture method the waveform transition corresponding to the interface from the sampling head to the instrumentation leads must be windowed out as shown in Figure 43. When looking at an open reference waveform, one sees essentially a two-step staircase. The first step in the staircase must be windowed out as shown in Figure 43, and the measurement must be zoomed in on the BCUT. The reflection waveform is effectively the same as the launched signal into the BCUT.

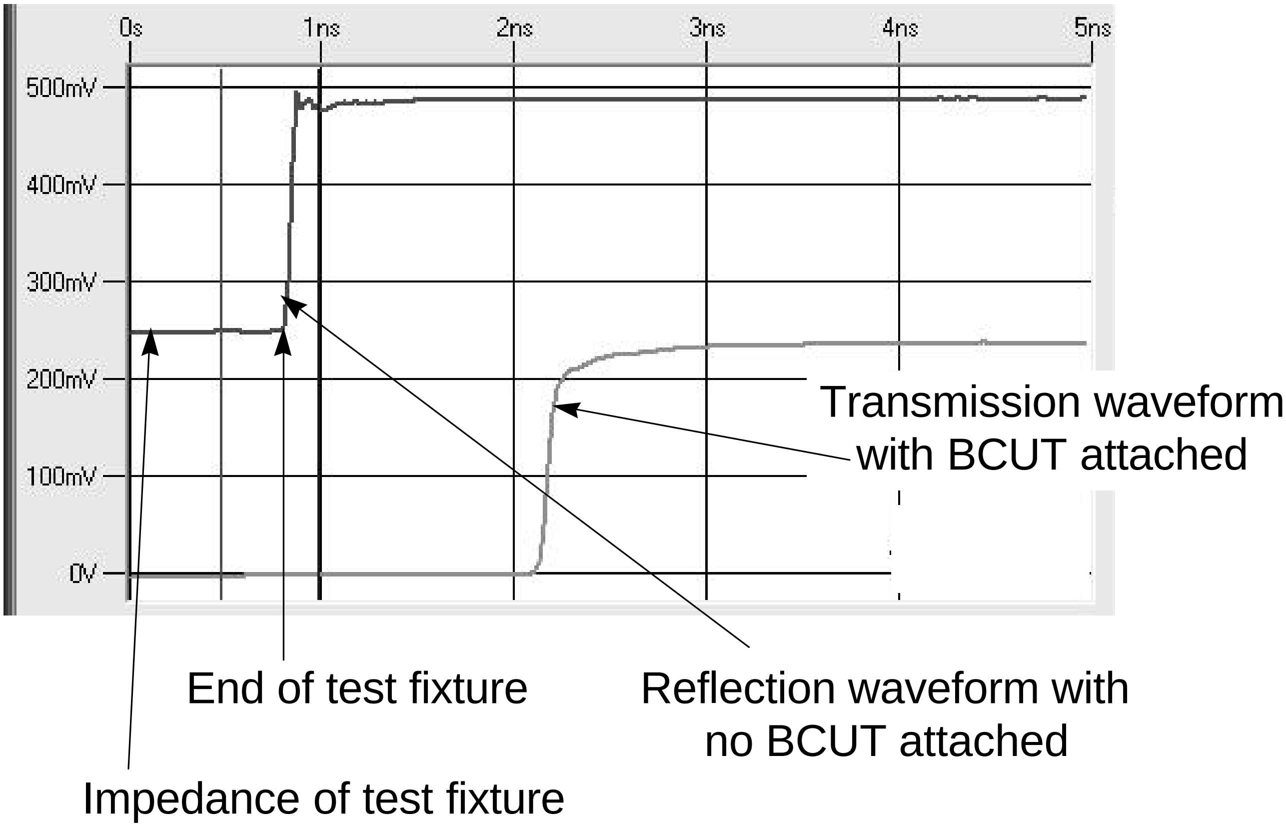


Figure 43 - Example of using the reflection calibration method

When dealing with differential measurements the deskew methods described in 8.2 shall be used for calibration of the launch signal. Additional calibration procedures may further increase the accuracy.

For differential, common mode and mode conversion S-parameters the same general process is used.

For differential waveforms, the oscilloscope must have the + signal and the - signal switching in opposite direction. For common mode waveforms, the oscilloscope must have the + signal and the - signal switching in the same direction. For differential response, subtract the two response channels; for common mode response, add the two channels.

Waveforms used in the S-parameter computation must be acquired with 50-Ohm cables and fixtures connected to all BCUT measurement ports, thus ensuring a 50-Ohm termination at all BCUT measurement ports. BCUT’s whose nominal impedance is different from 100 Ohms differential may be used with exactly the same test set up.

Connect the BCUT to the test fixtures shown in Figure 38.

8.3.4.2.2 Set acquisition window and number of data points

The acquisition window is required to ensure that the DUT waveform settles to the same DC level as the reference waveform by the end of window. In addition, a sufficient number of data points is required in the oscilloscope acquisition window to ensure that the desired upper frequency content is captured. However, excessively long windows reduce the dynamic range.

All the required waveforms are captured without changing the timebase on the TDR oscilloscope.

In addition, the length of acquisition window, t_{window} and the number of points in the acquisition window, N, are particularly critical for analyzing long interconnects such as cables. The upper frequency limit, f_{upper}, of the measurement is determined by

$$f_{upper} = \frac{1}{2t_{step}} = \frac{N}{2t_{window}}$$

and

$$\boldsymbol{f_{step} = \frac{1}{t_{window}}}$$

t_{step} is the time step of the scope, f_{step} is the frequency interval in the calculated S parameter plot. To get S-parameter data to the desired upper frequency the number of points and window length are adjusted as required. To get the desired frequency step, the window length needs to be long enough. When working with long cables, it is generally a good idea to keep the number of points at the maximum number allowed for a given instrument. The window length is adjusted to include all the waveform details associated with the BCUT and to include the D.C. level after the transients. Consistent with these constraints keep the window as short as possible in order to maximize the effective power.

Furthermore, to increase (i.e. change) the dynamic range, DR of the measurements, it is important to keep number of averages and number of points to the maximum, as the equation below indicates:

$$\mathbf{DR}(N, N_{avg}) = \mathbf{DR}(N_0, N_{avg0}) \times \sqrt{\frac{N}{N_0}} \times \sqrt{\frac{N_{avg}}{N_{avg_0}}}$$

where N_0 is the number of points before the change, N_{avg} is the ‘number of averages’ setting on the instrument, and $N_{avg\ 0}$ is the number of averages setting used before the change. Make sure to use lots of averages in your instrument. 128 averages gives an extra 20 dB of dynamic range; use at least that many if the instrument averages quickly.

8.3.4.2.3 S-parameter calculation

The scattering parameter measurement results are computed from the reference and transmitted time domain waveforms using software contained within the instrument. The details of these computations are not specified in this document.

8.3.4.2.4 Sample data output

Figure 44 shows an example of differential insertion loss magnitude and phase obtained from a TDNA method.

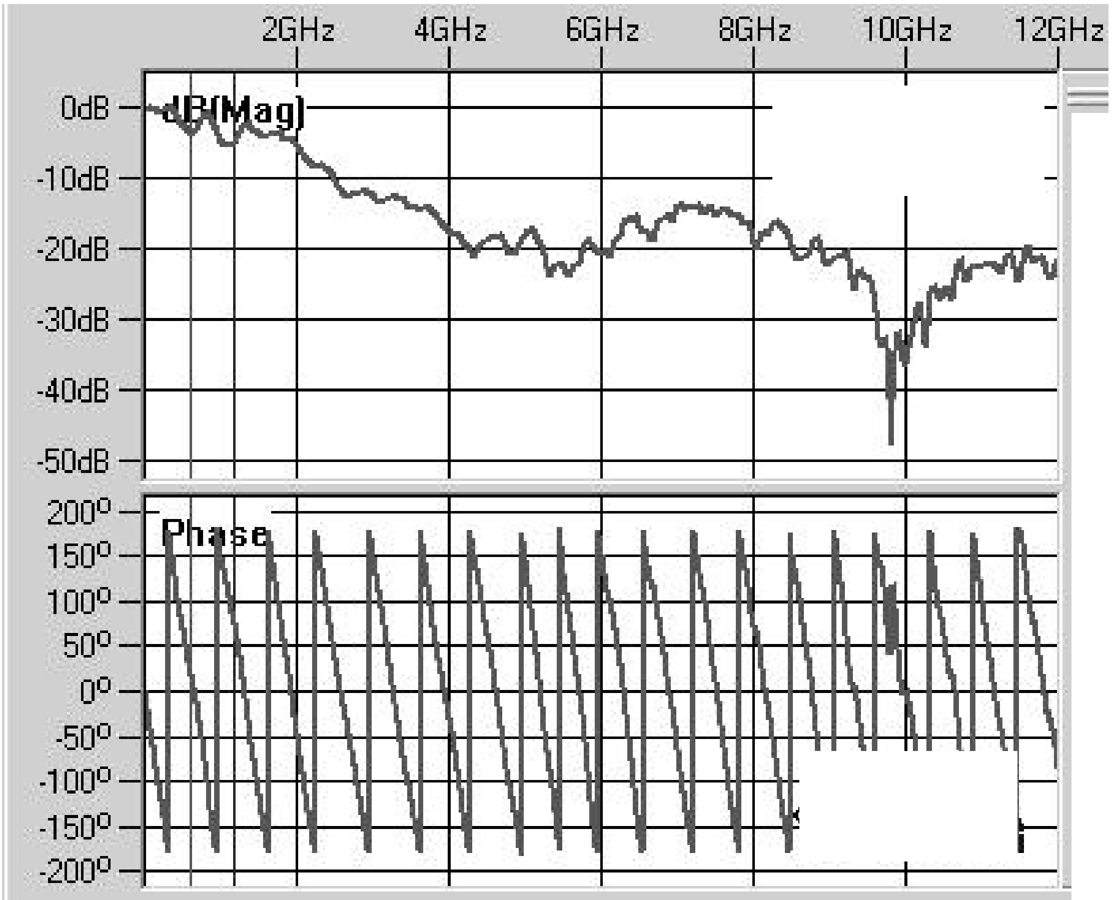


Figure 44 - Sample differential insertion loss data output

8.3.5 Acceptable ranges

Insertion loss acceptable ranges are defined in the relevant standard.

8.4 Differential to common mode conversion (SCD21)

Differential to common mode conversion is treated as if it were the insertion loss between a differential launch and a common mode output. Level 2 measurement of common mode to differential conversion is also available from this measurement.

All the requirements specified in 8.3 are the same as for the differential insertion loss except that the receiver is set to measure the sum of the + signal and the - signal instead of the difference.

8.5 Creation of BCUT eye diagrams via simulation

Eye diagrams may be created from S parameter measurement as shown in Figure 45 and Figure 46.

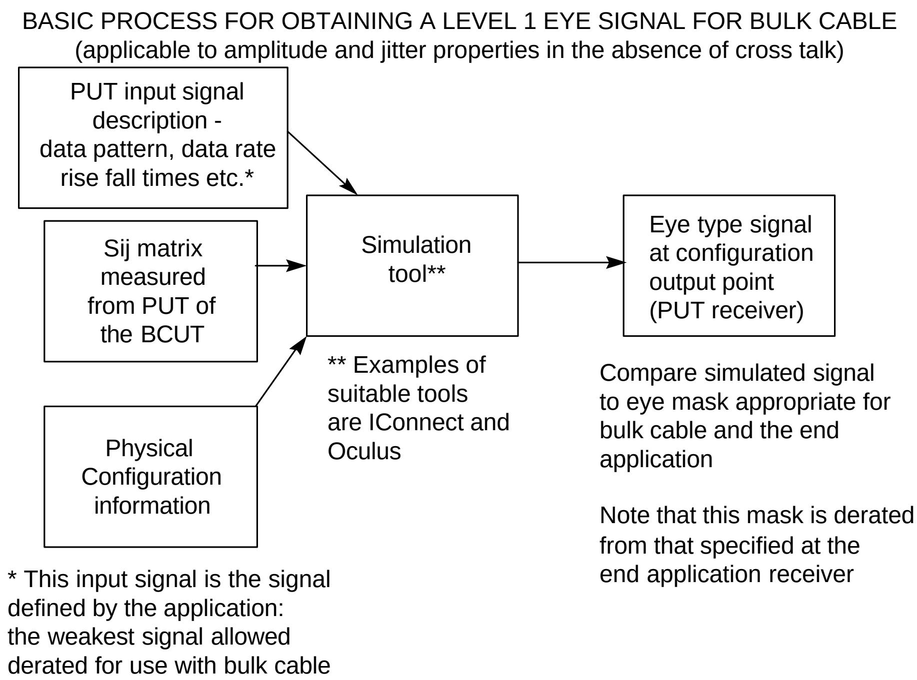


Figure 45 - BCUT eye diagrams with no crosstalk

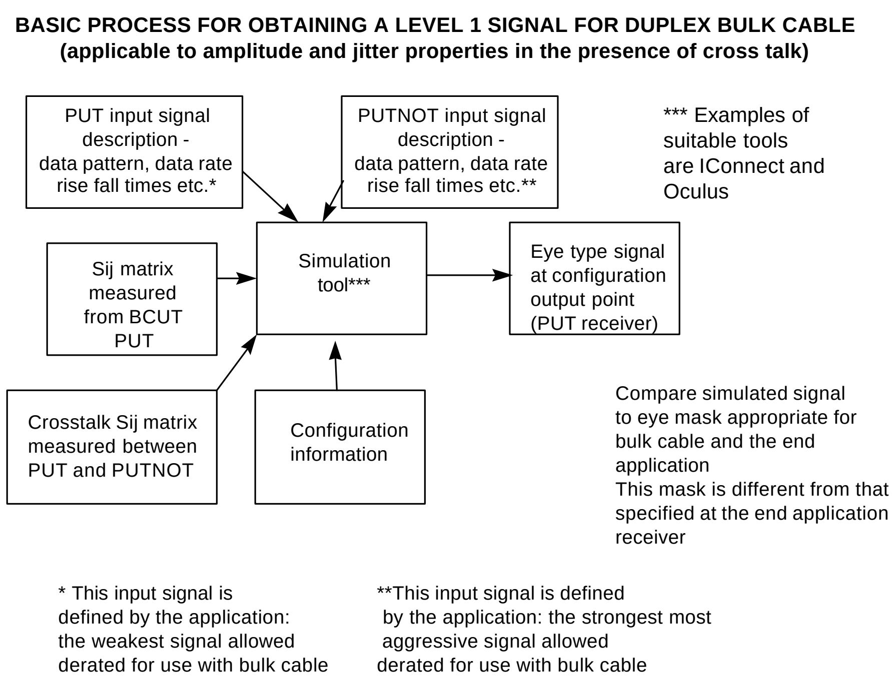


Figure 46 - Duplex BCUT eye diagrams with crosstalk

8.6 Crosstalk (near end and far end)

8.6.1 Introduction

Bulk cable is generally not a significant source of pair to pair crosstalk compared to interconnect assemblies. Therefore this measurement is not specified as rigorously as other measurements. Acceptable quality BCUT's should exhibit less than 1% pair to pair crosstalk. See applicable standards for actual required values.

Crosstalk is a result of unbalanced constructions and/or unbalanced propagating signals. The unbalanced propagating signals may be caused either by an unbalanced launched signal or by mode conversion during propagation from a balanced launch signal. If caused by mode conversion during propagation the resulting crosstalk is attributable to the BCUT. Crosstalk caused by unbalanced launch signals is also attributable to the BCUT for levels of unbalance allowed by the application for launch signals.

This measurement is limited to a single option: the single applied pulse method. In this method pulses with maximum differential amplitude, maximum allowed imbalance, maximum and minimum STD signal are applied to the BCUT on the aggressor pair and the signal induced on the victim pair is measured. In this test both pairs are under test. There are no signals applied to the victim pair for this test. It is necessary to reverse the polarity of the aggressor signal to ensure that balance compensation is not occurring.

Single pulse tests eliminate the effects of resonance, are deterministic in the causes of the induced noise (due to the mapping of the time and space as in the TDR tests), and produce the worst case results for non periodic localized disruptions. Resonant effects and periodic disturbance effects that may be observed in a swept frequency measurement are controlled via the insertion loss measurements.

The aggressor pulses are of the same type used for the impedance profile test: start with single ended signals: + signal at +/- 250 mV and the - signal at -/+ 250 mV. The + signal and - signal pulses initiate in opposite directions to form a collapsing differential aggressor pulse ending at differential zero.

The use of actual worst case data patterns on the aggressor lines has been extensively debated and considered. This is the natural excitation that is initially considered. Extensive testing has shown that resonance conditions and effects of test fixtures can severely distort the measured results when using real data patterns. Sometimes these effects improve the crosstalk performance and other times they exacerbate it. It is very difficult to diagnose the intensity and cause of resonance and fixture effects when using a real data pattern. The single pulse (with maximum allowed imbalance in the signals) eliminates these effects and gives a worst case result that can be attributed to as much of the system as desired.

Another important point is the value of the recorded disturbance in the victim line. Should the peak, peak to peak or some other feature of the induced noise be used? This document requires that the differential peak value of the induced noise at a time position within the IUT electrical neighborhood be used.

This requirement may appear contrary to logic that says the maximum disturbance occurs with the maximum signal swing and that occurs with a peak to peak measurement. The reason that the peak measurement is the important parameter is that receivers measure the differential signal from a differential zero position. Even if the intensity of the crosstalk signal is greater with a peak to peak measurement the receiver will only be affected by that portion that deviates from the zero differential level (i.e the peak level).

Since the crosstalk is a linear function of amplitude it is not required that the actual aggressor signal be the maximum differential amplitude. A scaling technique is used to compensate for equipment that is not capable of launching maximum amplitude signals. (This is another reason why the time domain pulse technique is desirable.)

Although crosstalk is generally more intense with shorter STD aggressor signals, both the maximum and minimum STD signals are required to be used. This is to cover the case where a physical imbalance may extend over longer distances and therefore could yield a more intense crosstalk with longer STD aggressor signals.

Effectively the aggressor pulse injects noise into the victim line as the aggressor pulse travels down the aggressor line. Therefore the measured victim noise signal is a direct map of the intensity of the coupling between the aggressor line and the victim line at different points along the path. It is generally found that the BCUT attachment region to the test fixture is responsible for the most intense coupling. This is a localized coupling that produces a victim line noise pulse with a width approximately twice the electrical length of the coupling region.

In the case where the BCUT attachment region is producing the most intense coupling, the victim line noise pulse returns to near zero as the aggressor pulse passes into the undisturbed BCUT. In the case where the BCUT itself has significant coupling, the noise pulse on the victim line persists for a time equal to approximately twice the electrical length of the coupling region (i.e., twice the length of the BCUT for uniform coupling). The factor of two arises because it takes one time for the aggressor pulse to travel and an equal time for the victim line to propagate the resulting noise pulse back to the receiver.

If the victim line noise pulse does not return to near zero after passing the connector/termination region that is a clear indication of high coupling within the BCUT itself.

If there are significant non-uniformities in the coupling within the BCUT these are revealed by victim line noise pulses well away from the BCUT attachment point.

This crosstalk test is used to specify a performance requirement but is also exceptionally useful to diagnose the causes of the crosstalk in all forms.

It is critical that construction related balance between the conductors of the pairs be maintained during the measurement through the sample attachment region. Failure to maintain this balance causes the signal to become unbalanced and compromises accuracy.

Some constructions, notably shielded quad, have severe difficulty in maintaining this balance requirement without using balanced connectors appropriately designed for use with the bulk cable. See Figure 47.

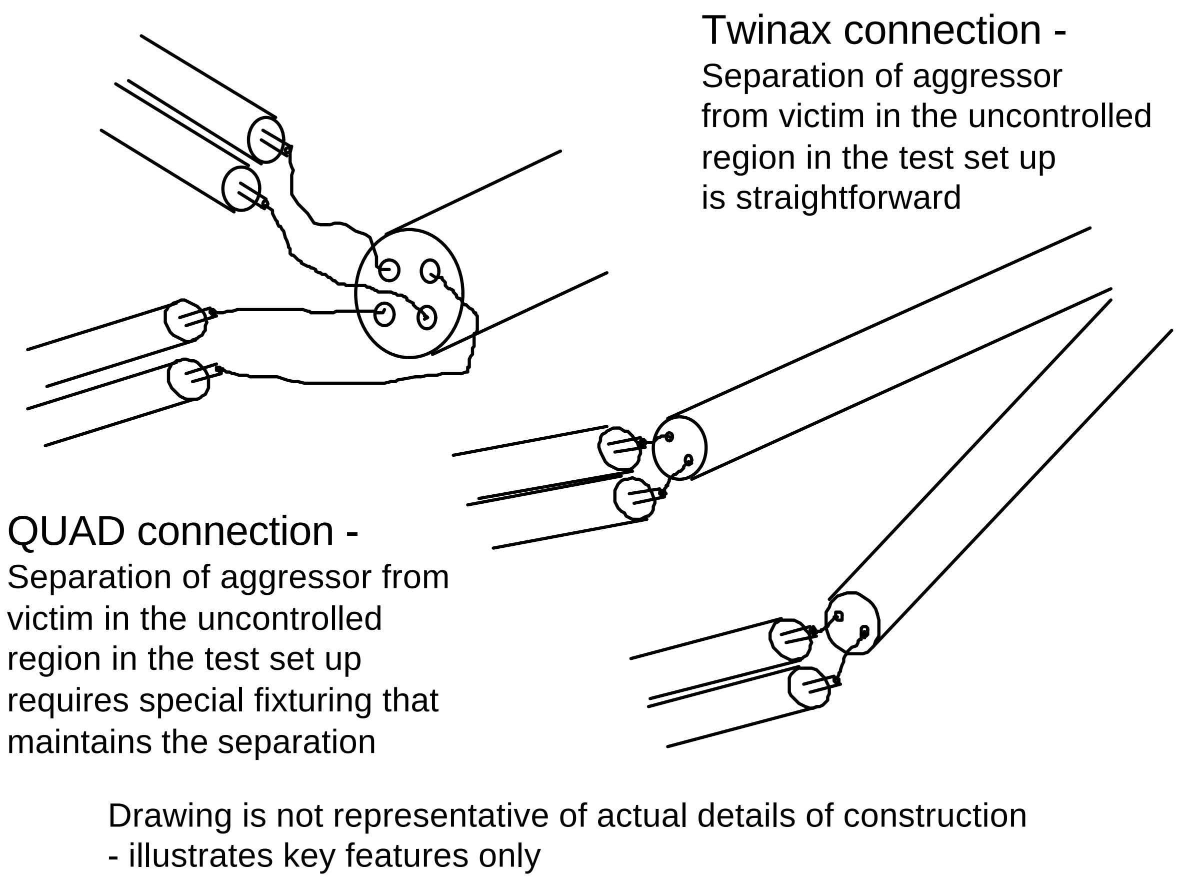


Figure 47- Illustration of different constructions

Figure 48 shows schematically how one may build a lower crosstalk test fixture and associated BCUT connection for QUAD constructions.

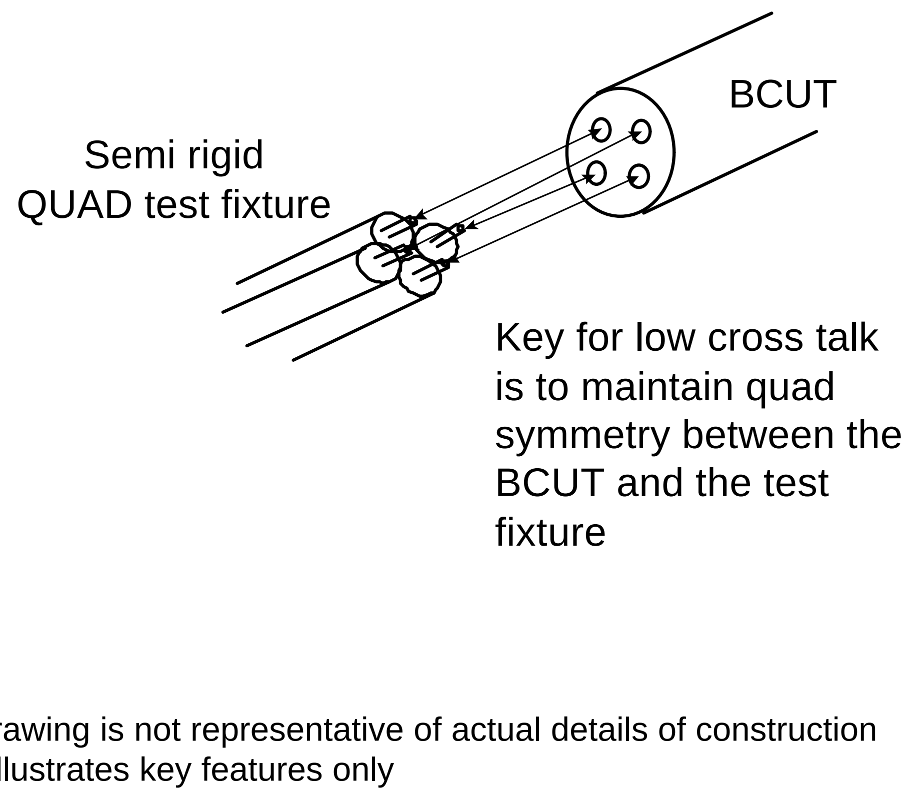


Figure 48 - Schematic of a lower crosstalk suitable QUAD test fixture

In a practical test set up the measured crosstalk is likely to come mostly from the test fixtures and sample attachments. This effect makes the time domain attractive for near end measurements because time domain measurements can account for the test fixtures better than frequency domain. For far end measurements a single pulse is expected but that pulse lies on top of the pulse from the test fixture. Time domain is still used for the far end measurement but the fixture contribution is not separated from the total result. This behooves the use of high quality fixtures.

The near end measurement is taken at the same end of the BCUT as the aggressor source The BCUT crosstalk is measured at a time position after the test fixture disturbance has dissipated.

The far end is the same as the near end except the measurement is taken at the end of the BCUT opposite the aggressor source.

Only single pair aggressor activity is required due to the overall requirement for very low crosstalk.

8.6.2 Test fixtures and measurement equipment

The semi rigid test fixtures used for insertion loss measurements in 8.3 are suitable for crosstalk measurements on non-quad constructions. Another example of a test fixture that may be used for non-quad constructions is shown in Figure 49. This test fixture does not require solder attachment.

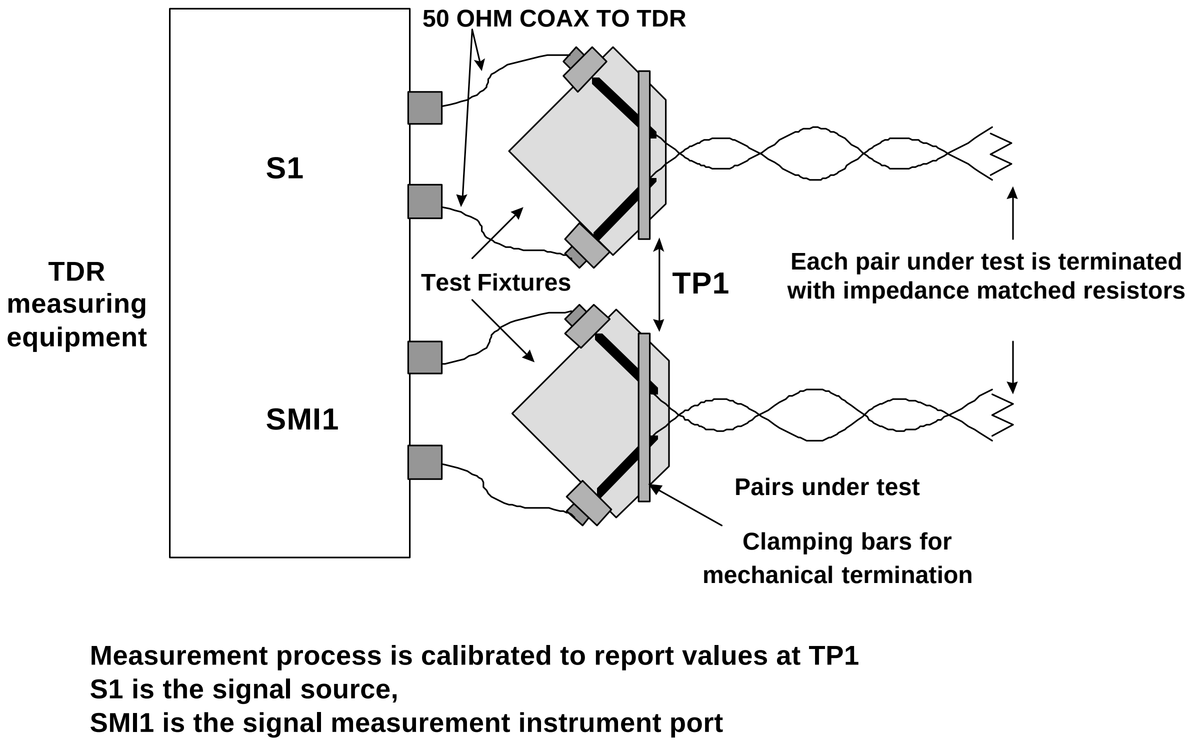


Figure 49 - Basic measurement setup including non-quad test fixtures

For quad constructions use a test fixture designed using the principles illustrated in Figure 48.

The measurement equipment is the same as for the propagation time measurement in 8.2.5.

8.6.3 Calibration procedure

8.6.3.1 Time reference

The time reference calibration is done using the same test fixture and nearly the same procedure as for the TDR tests in section 8.1 (using a short in place of the IUT for reference time calibration).

Noting the time position of the short establishes a reference time for determining the parts of the tests configuration that are causing the crosstalk.

8.6.3.2 STD and aggressor amplitude calibration

The STD calibration is done using a through fixture identical to that used for the insertion loss measurement tests. See Figure 39.

Using the test fixture shown in Figure 39 apply a differential pulse from S1 (the signal source for the aggressor signal) as large as possible within the capabilities of S1 (if the amplitude is adjustable on S1 otherwise use the default pulse from S1) and measure the received differential pulse at SMI1 (the measurement instrument attached to to the other side of the through test fixture.

Adjust the scales as described in Figure 50 and Table 2. Move the displayed curve to the right until a clearly defined flat portion is observed on the lower left portion of the trace. Adjust the vertical position such that the flat portion of the curve (flat for at least three time divisions) passes through the first graticule from the bottom. Position the trace horizontally such that it passes through the third vertical and

third horizontal graticule. Set S1 to the required STD by using software filtering or hardware filters. Record the amplitude as described in Figure 50.
To reduce error it is recommended to use the maximum number of data points available (highest horizontal resolution) in the instrument.

Retain all the settings for reuse in the measurement.

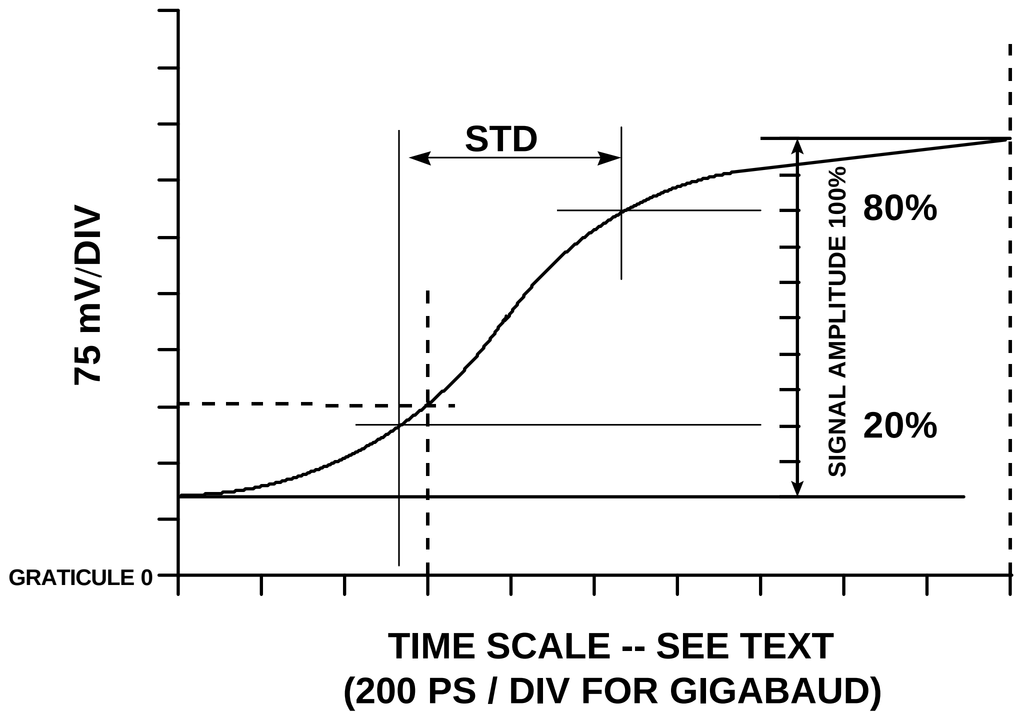


Figure 50 - Signal transition duration and amplitude calibration

Table 2 - 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	100
4250	50
5000	50
6000 and up	50

8.6.3.3 Aggressor signal imbalance calibration

To calibrate the imbalance in the aggressor signal use again the test fixture in Figure 39. Set SMI1 to measure sum of the + signal and - signal. Using the same signal settings as used for the STD and amplitude calibration adjust phase trimmers or use different length of cable for the + signal and - signal such that the launch imbalance (M1+M2) is approximately 25% of the differential peak established in the amplitude calibration or to the maximum allowed imbalance in the launch signal specified for the application.

Record the exact settings used for the minimum STD conditions as these are reused when doing the actual measurement.

8.6.3.4 Test fixture crosstalk verification

A second calibration fixture configuration is used to verify that the fixture set used is not causing excessive crosstalk. This fixture set is identical to that described in Figure 39 but with 100 ohm resistors or the application value added instead of shorts and both the S1 and SMI1 fixtures in place as it would be in an actual measurement. The second calibration setup is shown in Figure 51 where both test fixtures are shown integrated into a single configuration as will exist during the measurement.

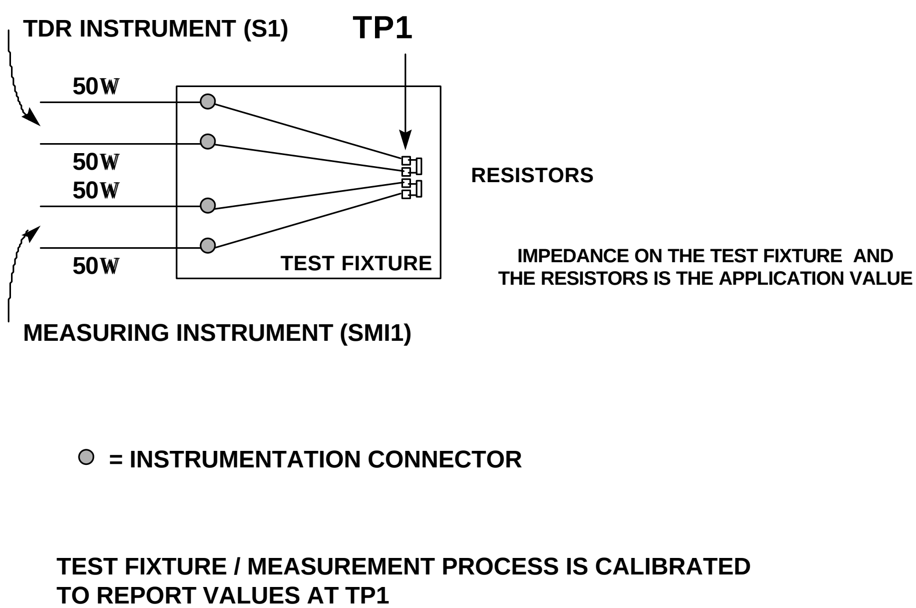


Figure 51 - Calibration system for NEXT

Use the calibrated S1 signal created in the previous steps with the test fixture in Figure 51 measure the crosstalk produced at SMI1.

The maximum allowed crosstalk in the victim pair in this calibration condition is 1% for both the longer and shorter STD aggressor signals.

8.6.4 Measurement procedure

8.6.4.1 Near End

Using the test setup shown in Figure 52 apply the calibrated aggressor pulse for the minimum STD to the aggressor line, S1, and measure the induced noise on the victim line at SMI1. The value of the aggressor signal amplitude as determined by the STD calibration used in the test shall be reported along with the crosstalk noise results even if scaling is used. This is required to evaluate the effects of the noise floor for BCUT’s with small crosstalk.

Repeat the test exactly except with the polarity of the leads to S1 reversed. Repeat with maximum STD using both polarities for S1.

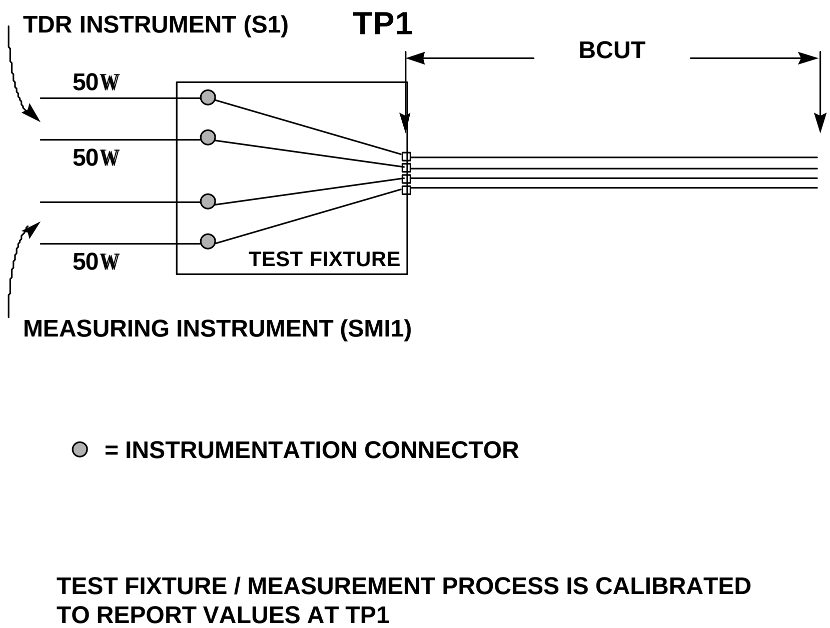


Figure 52 - Test configuration for NEXT

Note the largest peak (i.e., largest deviation from zero differential) on the victim line at a time position farther from S1 than the time position of the short determined in the calibration. This largest peak from either polarity is the value of the induced signal for that STD. Note that a peak to peak value is NOT used. Both the absolute value of the induced signal peak and its percentage with respect to the amplitude of the aggressor signal are recorded.

Figure 53 shows an example of a complete near end measurement.

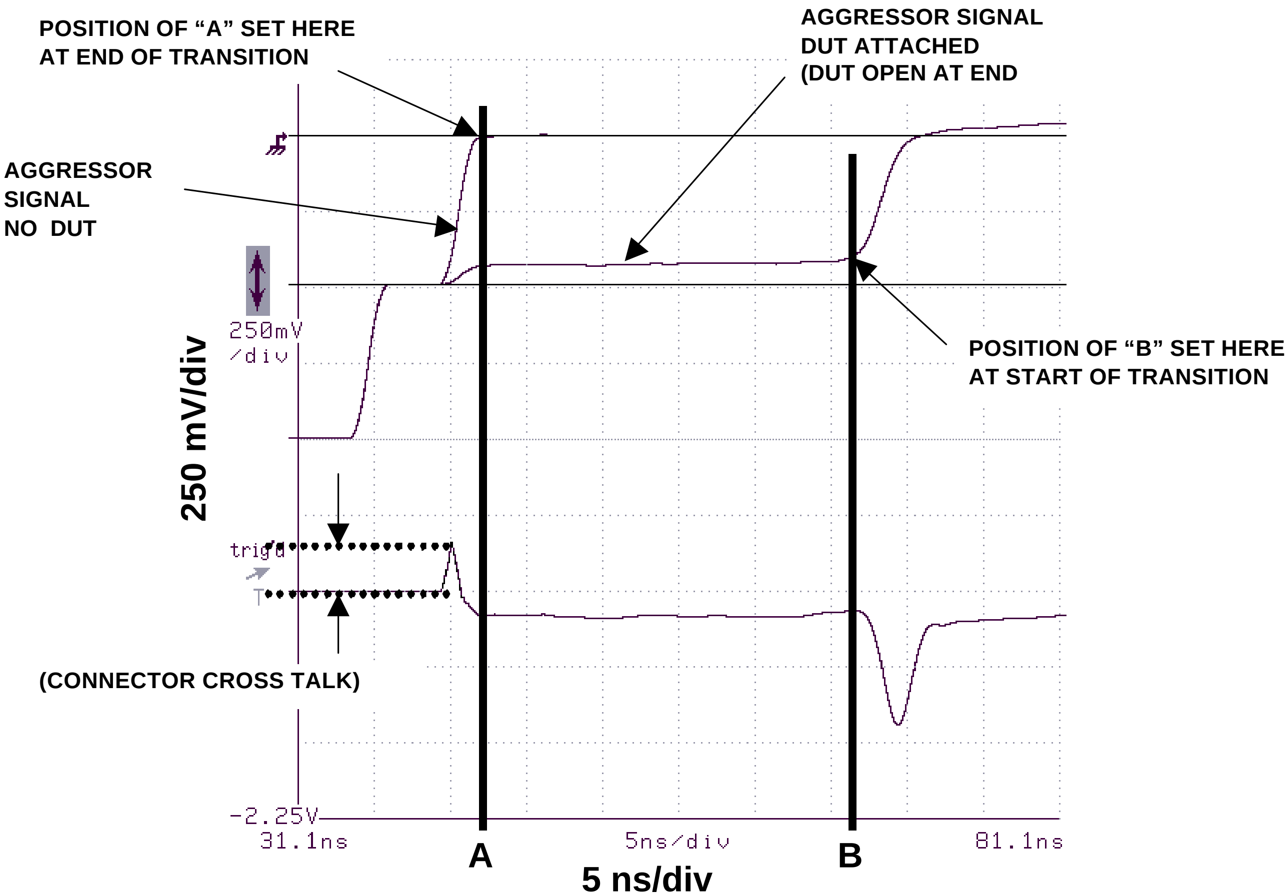


Figure 53 - Near end crosstalk measurement

Vertical line "A" is defined by using only a test fixture with an open circuit load (no BCUT attached). Vertical line "A" represents the end of the test fixture and the beginning of the BCUT.

Crosstalk in the region to the left of vertical line "A" is dominated by fixture crosstalk (or in an interconnect assembly by connector and connector attachment crosstalk).

Vertical line "B" is defined by connecting a BCUT to the test fixture with an open circuit on the end of the BCUT. Vertical line "B" represents the end of the BCUT.

Crosstalk in the region to the right of vertical line "B" is dominated by multiple reflections bouncing between the open circuit impedance and the fixture impedance.

Crosstalk in the region between vertical lines "A" and "B" is dominated by the BCUT.

Recommended details: Aggressor signal scale, 250 mV/div. Victim signal scale, 50 mV/div. Use averaging for capturing crosstalk waveform on victim pair.

Another example is shown in Figure 54.

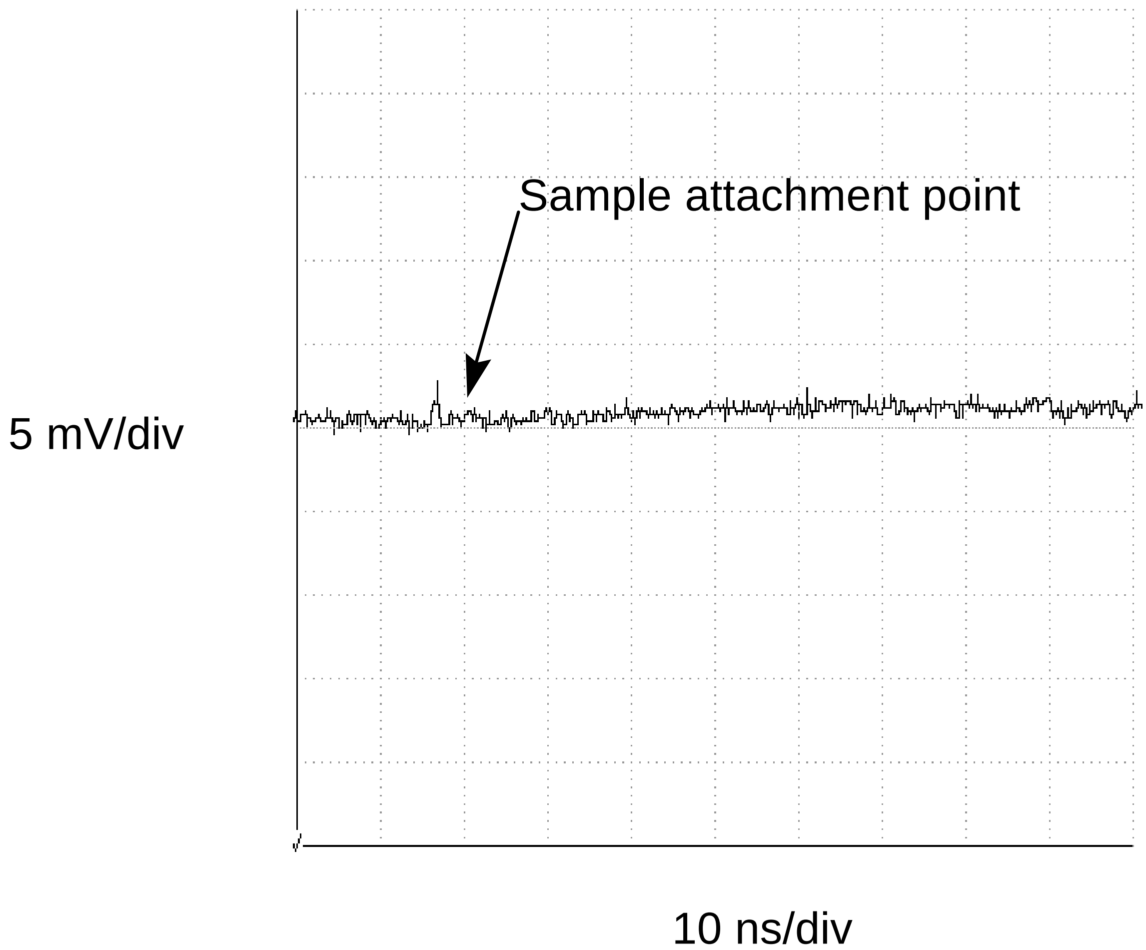


Figure 54 - Example of a NEXT measurement for a low crosstalk BCUT

The absolute value crosstalk is scaled to account for the actual amplitude of the aggressor signal. For example if the actual aggressor signal is 500 mV peak and the maximum allowed aggressor signal is 1000 mV then the measured absolute crosstalk result would be multiplied by 2.0.

The percentage result does not need to be scaled.

8.6.4.2 Far end

Execute the measurement as for NEXT except attach the far end of the victim pair to SMI1.

8.6.5 Acceptable ranges

Acceptable ranges are defined in the relevant standards.

The amplitude of the signal on the victim line should return to a level significantly lower than observed in the connector/termination region within a few STD’s of the mating interface. If this is not observed it is an indication of serious degradation in the BCUT. Other measurements, notably mode conversion, will detect this degradation as a failure so the observation of the high BCUT coupling is not a direct reason for failing the crosstalk test.

8.7 Bulk cable contributed jitter

Bulk cable contributed jitter (eye test at 0 differential crossing using a data pattern appropriate for the application as defined in this document, a derating scheme is required to match the bulk cable jitter measured via this method to the overall link jitter budget)

The measured jitter comes at three points: at the launch instrument, at the test fixture calibration, and at the end of the BCUT.

Experience has shown that short constructions can have significant jitter due to local resonances and reflections. This is similar in some ways to the noise at the center of the launch eye for signal degradation measurements for bulk cable as described in SFF-8410. Excessive jitter measured during test fixture calibration that is not present when the BCUT is being measured effectively makes the BCUT appear better than it should. Another way of looking at this is that the launch source appears to have more jitter than it actually has during the BCUT measurement.

The bulk cable contributed jitter is the difference between the observed peak to peak jitter at the BCUT output and the peak to peak jitter in the launch source. Any jitter contributed by the test fixtures is considered part of the BCUT performance.

Test fixtures with suckouts may produce falsely good results in the BCUT test. To mitigate this possibility data rates at 10% above and below the application data rate shall also be measured. Bulk cable intended for multiple applications where the data rate is different require repeating this measurement at all applicable data rates.

The jitter from the launch source can be accurately measured using instrumentation quality cables and is generally very low.

The jitter distributions expected for bulk cable do not include uncorrelated crosstalk because of the very low crosstalk expected in bulk cable.

The jitter distributions also do not contain any significant Gaussian content since the launch source with very low total jitter is the only source for producing Gaussian jitter in the measurement. The absence of Gaussian jitter allows a simple observation of the peak to peak value of the observed jitter distribution to be the only property that needs to be captured. Taking the difference of the peak to peak properties does not require the convolution normally required when calculating the difference between two different jitter distributions.

BCUT contributed jitter is expected to increase monotonically with increasing length. Simulations on typical BCUT's show that the length dependence is not linear, exponential, or any simple power function yet the dependence is smooth. This behavior prevents any simple scaling of BCUT contributed jitter with length.

The BCUT contributed jitter is also independent of the STD in the launch signal for rapid STD's (less than approximately 0.15 UI). The longest allowed STD causes the greatest BCUT contributed jitter condition in most cases.

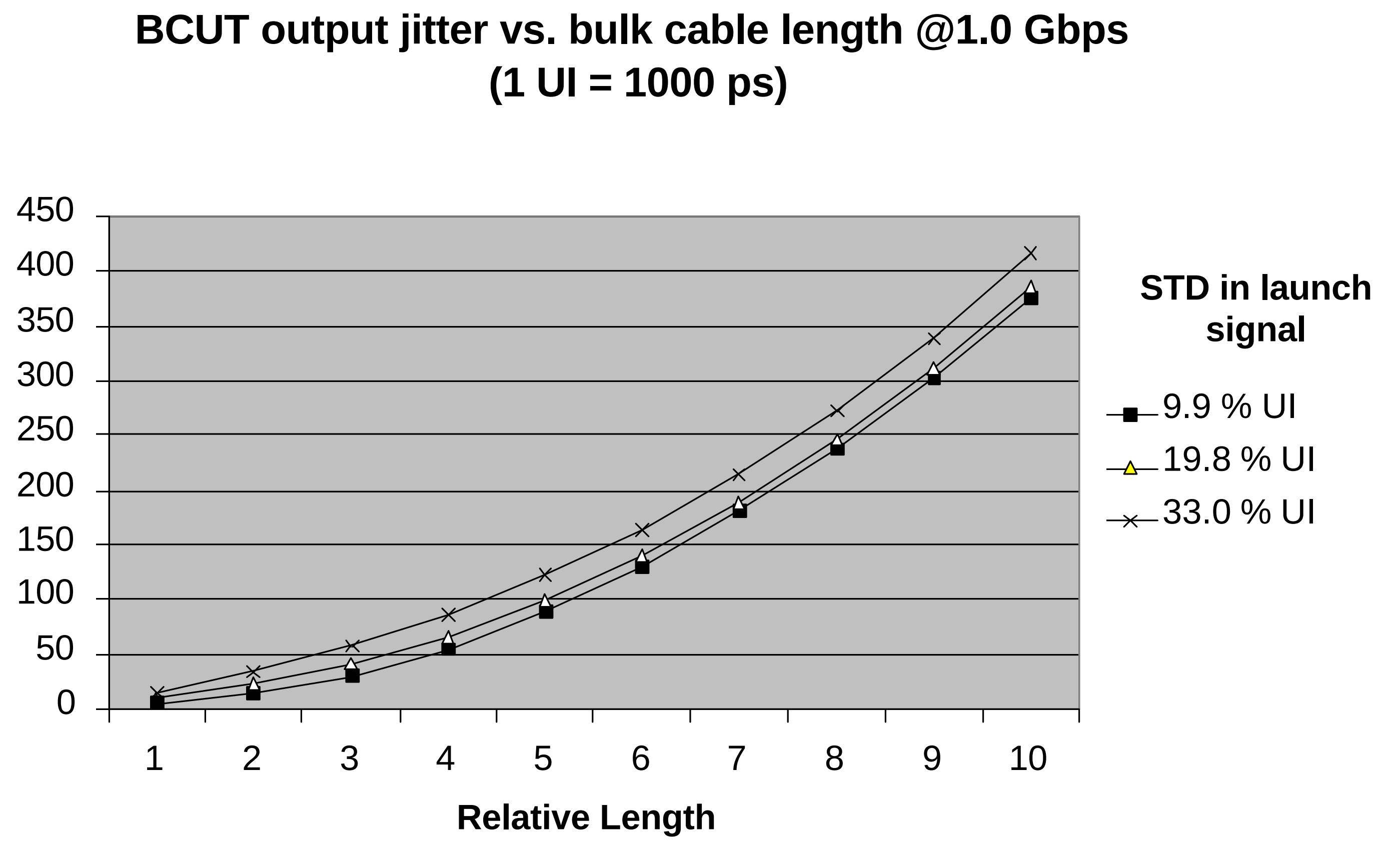


Figure 55 - BCUT contributed jitter dependence on length and STD at 1.0 Gbps

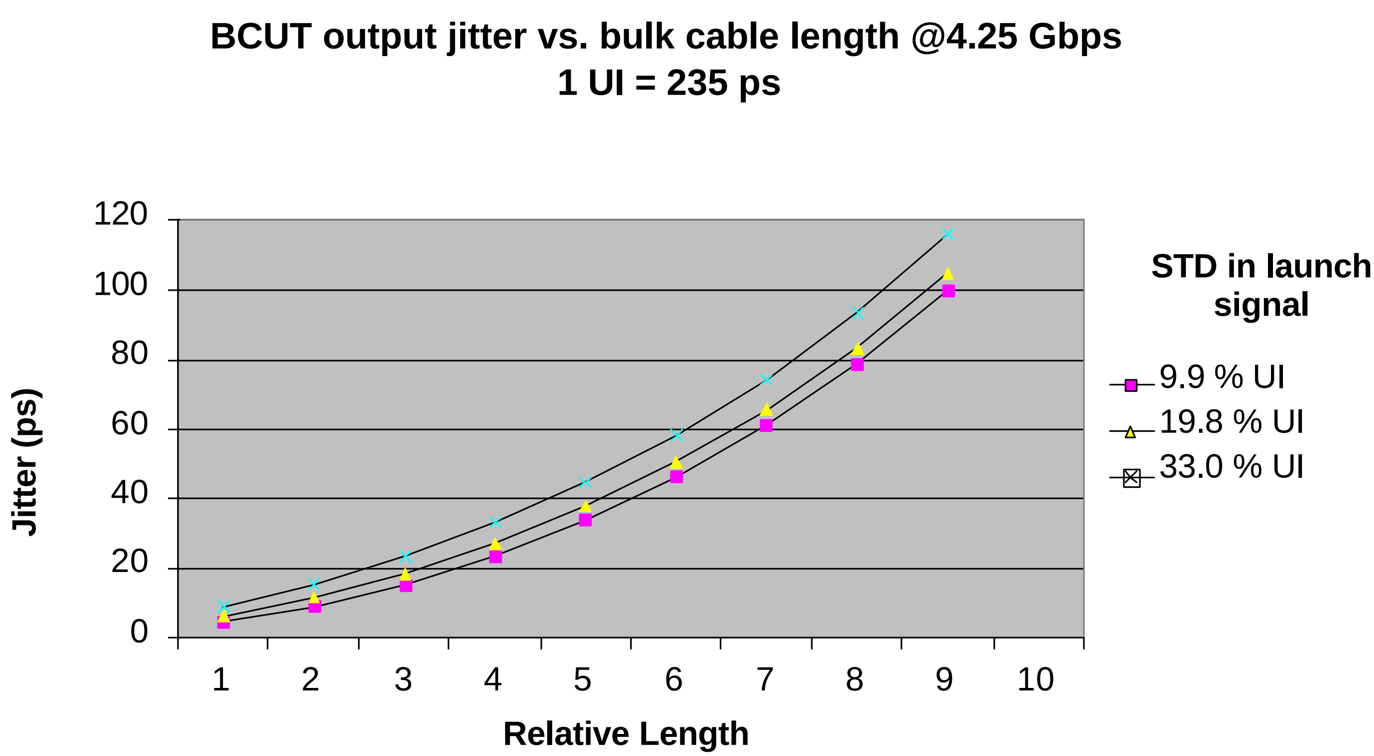


Figure 56 - BCUT contributed jitter dependence on length and STD at 1.0 Gbps

The measurement using a hardware data pattern generator requires that a hardware filter be used between the pattern generator and the BCUT transmit test fixture. This keeps the test fixture related reflections to a minimum and ensures that software algorithms that operate only on the signals displayed are not used to generate the required STD.

Measurements using the software based pattern generator method use the pattern specified by the simulation tool with the appropriate STD and data pattern specified for the application.

Also shown in Figure 57 is a timing reference for both sides of the eye that is needed to position the signals along the time axis so that the signals have the specified relationship with the position of the mask. This timing reference is created by finding the mean of the population of the transmit signals at the zero differential voltage crossing points.

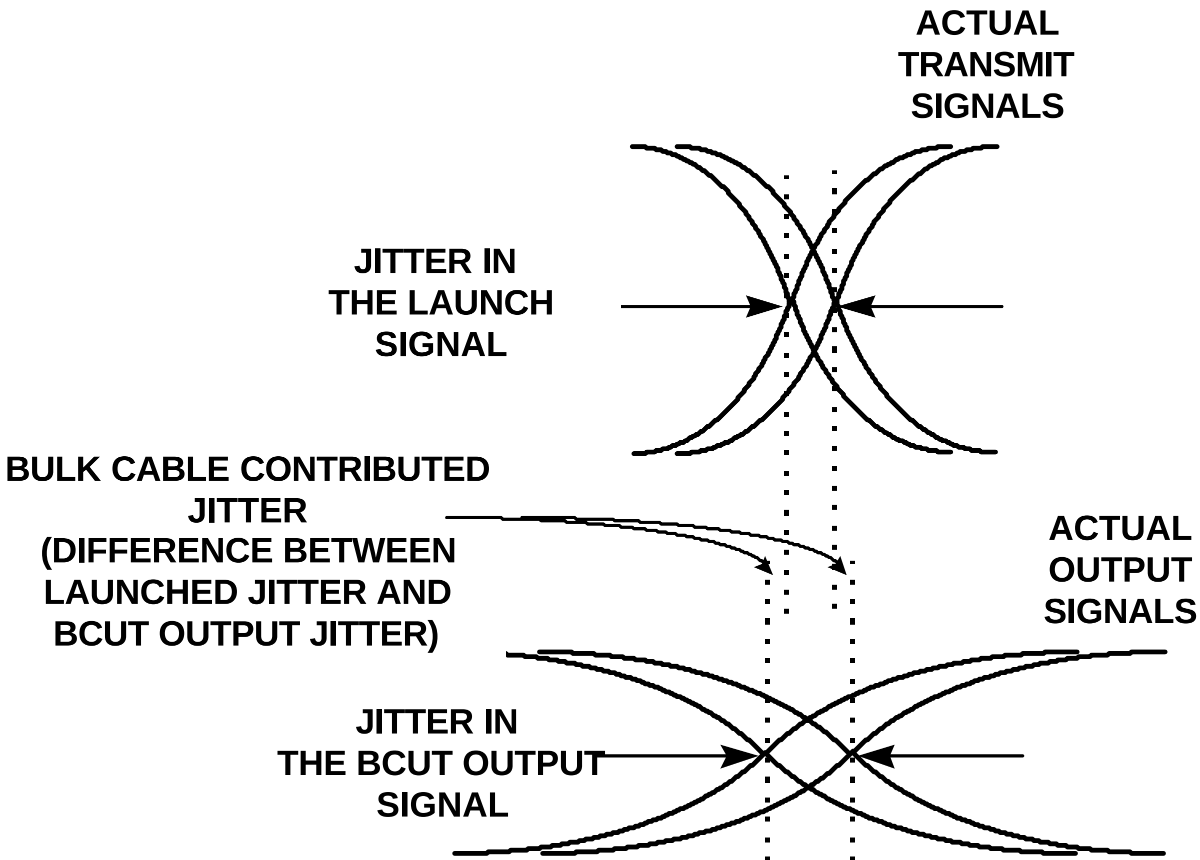


Figure 57 - Compensation for launch source + test lead jitter

8.7.1 Measurement test fixtures and measurement equipment

8.7.1.1 Overview

Test fixtures are the same as for insertion loss measurements described in 8.3.2. Measurement equipment depends on the method used. Two methods are described that should yield equivalent results.

8.7.1.2 Measurement equipment

8.7.1.2.1 Software based pattern generator method

Equipment required includes TDR/TDT or insertion loss measurement equipment as described in 8.3.2.2.

8.7.1.2.2 Hardware based pattern generator method

The following equipment is required:

- Hardware pattern generator capable of delivering pseudo random data patterns of the type appropriate for the encoding and data rate used in the application. For example, 8b10b encoding should use 2^7-1 and 64b66b encoding should use 2^{31}-1 (actually should use even longer but that is not very practical).
- Hardware filters for each leg of the differential signal that are capable of producing the longest allowed STD for the application.
- Good quality equivalent time sampling oscilloscope

8.7.2 Calibration procedure

8.7.2.1 Calibration test fixture

An optional calibration test fixture may be used as shown in Figure 39.

8.7.2.2 Calibration for S1 and signal measurement instrument

The following procedure assumes that the signal measurement instrument needs input signals less than 800 mV differential pp.

Using the calibration test fixture in Figure 39:

1. Select in-line attenuators such that the differential pp output of S1 measured through the calibration test fixture is 800 mV max differential pp
2. Select hardware filters and/or connecting cables attached to the output of S1 to produce the maximum STD values (slowest allowed edges) allowed for the application
3. With the filters / cables in place for the maximum STD value verify that the STD is that expected
4. If STD is not that expected or the amplitude does not satisfy step 1, repeat steps 2 and 3 until the desired STD and amplitude is achieved
5. Remove the test fixture and connect the test leads to the output of the in line attenuators
6. Measure jitter from the launch source + test leads (see Figure 57) and record

8.7.3 Measurement procedure

8.7.3.1 Hardware pattern generator method

Use S1 calibrated as described in 8.7.2.2 and running a PRBS data pattern and data rate appropriate for the application connect the BCUT to the test fixtures and measure the output jitter as shown in Figure 57.

Subtract the launch source jitter from the BCUT output jitter. This result is the BCUT contributed jitter at the nominal data rate.

Repeat the measurement at data rate 10% above and 10% below the nominal data rate.

The largest BCUT contributed jitter at any of the three frequencies is reported as the BCUT contributed jitter.

8.7.3.2 Software pattern generator method

Capture the S21 for the BCUT as described in 8.3. Use this result with a suitable simulation package to calculate the BCUT contributed jitter.

Use the PRBS data pattern appropriate for the encoding used in the application. The launch source shall be set to the maximum STD (slowest edge rate). The source impedance shall exactly match the application reference impedance for the BCUT. (The reference impedance is the nominal impedance without a tolerance.)

Since there is no jitter in the launch source or from the test fixtures (except as contained in the captured S21) the BCUT contributed jitter at the nominal data rate is that measured.

Repeat the measurement at data rate 10% above and 10% below the nominal data rate.

The largest BCUT contributed jitter at any of the three frequencies is reported as the BCUT contributed jitter.

8.7.4 Acceptable ranges

No acceptable ranges for BCUT contributed jitter are defined in this document.

8.8 EMI (EMR and CMPT)

8.8.1 Introduction

This section describes measurements for EMI related performance for shielded bulk cable. These methods are adapted from similar methods specified in SFF-8410 for shielded cable assemblies.

EMI is a measure of the intensity of electromagnetic energy exported from the BCUT. The frequency range covered by EMI is affected by at least three factors:

- FCC requires that EMI be measured between 30 MHz and five times the fundamental frequency highest of any data rate or clock in the system. For example, the frequency range for a 10 Gb/s serial data rate (5 GHz fundamental) is 30 MHz to approximately 25 GHz.

- Capabilities of commonly available practical instrumentation is limited to 20 GHz

- The expected frequency range where significant EMI is likely to exist in actual systems is not known. For fundamental frequencies of 2.5 GHz, for example, energy has been reported up to 12.5 GHz. Since the frequency range based on this consideration is not known it cannot be used as a criteria for specifying the EMR measurements

Two options are specified for determining the electromagnetic compatibility of HPEI BCUT's: (1) electromagnetic radiation (EMR) and (2) common mode power transfer (CMPT).

A significant difference between this document and SFF-8410 is the frequency response of presently available current clamps required for the CMPT method is not sufficient for level 1 HPEI usage. The EMR measurements are therefore the primary level 1 methods for bulk cable EMI performance.

Questions have been raised concerning the use of common mode launch instead of differential mode launch for the EMR measurement as specified in SFF-8410. The questions usually have their root in the thought that common mode launch may not represent the use condition and may place additional unnecessary burden on the performance requirements for the BCUT.

For **shielded** constructions the EMI performance is designed to be primarily determined by the outer/overall shield. The level 1 measurements are therefore designed to validate the performance of the shield. Real systems can couple significant common mode energy into the BCUT. Even if the BCUT is perfectly balanced it may still carry significant common mode energy when excited by these common mode signals. For these reasons a common mode launch is used for shielded BCUT constructions.

For **unshielded** applications the coupled common mode issue is the same as for shielded constructions but there is no shield to contain the EMI. The EMR measurement is therefore not useful for characterizing EMI because EMI control must be implemented in the overall system design by limiting the common mode energy that can couple onto the cable. Therefore no EMI measurements are specified in this document for unshielded constructions.

Both the CMPT and EMR measurements are included in this section for convenience. A summary of the measurements described follows:

Level 1 measurements:

- Shield effectiveness using EMR methods with common mode launch. The difference in EMR between shield on and shield off is a measure of shield effectiveness. The shield off measurement may use a reference sample of the same construction instead of removing the shield from the BCUT. Some inaccuracy is expected due to difficulty of removing the shield without disturbing the BCUT geometry or the reference sample not being identical to the BCUT.

Level 2 measurements:

- CMPT using BCUT's with shield on and using calibrated common mode launch. This method is limited by the frequency response of the current clamp. This measurement is described in detail in this document.
- Shield effectiveness using CMPT methods using BCUT's with shield on and BCUT's with shield off. The difference in CMPT results between shield on and shield off is a measure of the shield effectiveness
- EMR using BCUT's with shield on and using calibrated common mode launch. There are issues with accurate calibration but this method is non destructive and requires no reference sample.

A typical EMR test chamber may cost more than the CMPT setup. Data acquisition times for EMR measurements are much longer than the CMPT measurements. That notwithstanding, the CMPT measurements specified in this document should be used only for level 2 purposes. See however, 8.8.2 for possible alternative methods that may be less expensive.

The EMI measurements are intended to apply to all constructions of BCUT including those with distributed and integral equalizers.

8.8.2 Methods from other documents

There are a number of IEC documents that relate to EMI performance of bulk cable. Those that have been identified to date are listed below with comment concerning the utility of the document for HPEI applications. Note especially 4 and 6 as these appear suitable alternatives for level 1 use for HPEI applications.

1. IEC 62153-4-2_46A_560e_FDIS_screening_and_coupling_attenuation_injection_clamp_method.pdf [describes signal injection up to 1 GHz, detects internal differential signals created, requires baluns - only good up to 2G, current injection clamps also limited to 2G]

2. Coupling_attenuation_triaxial_setup_01.pdf [describes signal injection, draft document - not referenceable, use of ferrites limit frequency to lower than required values

3. IEC 62153-4-5_46A_586e_CD_screening_or_coupling_attenuation_absorbing_clamp_method.pdf [describes a measurement similar to the CMPT but without the stovepipe, uses differential launch for balanced constructions, ferrite frequency limits]

4. IEC 62153-4-4_46A_581e_CD_shielded_screening_attenuation.pdf [improved version of 2 above, looks like a good way to do CMPT without ferrites + appears suitable for level 1 use]

5. IEC_46_107_PAS____IEC_PAS.pdf [a draft document of 2 above - do not use]

6. EN_50289_1_6_March_2002.pdf [Cenelec version of 4 above - appears suitable for level 1 use]

A method applicable for measuring the performance of unshielded BCUT’s based on S parameters and software conversions may be found in: ANSI/TIA/EIA-568-B.2-1 - yyyy. Balanced twisted pair cabling components - Addendum 1 transmission performance specifications for 4-pair 100 Ohm Cat 6 cabling.

8.8.3 Electromagnetic radiation (EMR)

Electromagnetic radiation testing is executed by using an antenna and the BCUT together in a large chamber (known as a reverberation chamber) with metallic walls and a means to modify the fields in the chamber (mode stirring). The BCUT in this measurement consists of the complete bulk cable and the associated bulkhead attachments. Each end of the BCUT shield (if any) is connected to fixtures mounted on the walls of the chamber with provision for the internal BCUT conductors to penetrate through the wall. Common mode (single ended) transmitters are attached to the BCUT outside the chamber and apply maximum amplitude common mode signals to the BCUT. The transmitters are attached in a manner that emulates the direction of the signal for each respective pair in the BCUT.

Any changes to the geometry of the shield within the EMR chamber (at the fixture attachment or by excessive bending, for example) may compromise the accuracy of the EMR measurement.

The EMR of the BCUT is the difference between the radiation measured with the BCUT and excitation in place and an identical test from an unshielded reference sample. The reference cable may be created by stripping the outer shield off the BCUT or may be a separate sample of the same length (within 5 mm) and be of the same construction as the BCUT.

The significant difference between this specification and Method 3008 of MIL-STD-1344 is that in this technique the BCUT is driven and the energy emitted from the sample is measured. Method 3008 drives the reverberation chamber and measure the energy received in the sample.

Under these conditions and using a mode stirrer in the chamber the antenna detects all the radiation emanating from the BCUT.

Related Documents:

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.

8.8.3.1 Test fixture and measurement equipment

8.8.3.1.1 Measurement equipment

The following equipment is required to execute this test:

Reverberation chamber – a shielded enclosure fitted with a mode stirrer. The mode stirrer is a rotating vane generally under computer control. A shielded enclosure of 20’ x 10’ x 12’ can be used optimally down to 200 MHz and possibly as low as 50 MHz. The lower frequency limit is determined by the size and specific properties of the chamber with larger chambers generally having lower frequency limits. Generally good performance at 50 MHz indicates good performance at 30 MHz.

Signal Generator – the signal generator should have roughly 0 to 10 dBm output power capability and controllable via an external interface bus. Frequency range should be 50 MHz or less to the upper limits established in 8.8.1.

Power Amplifier – measuring very well shielded BCUT’s may require a 1-watt power amplifier with a frequency range of 50 MHz or less to the upper limits established in 8.8.1.

Antennae – appropriate sense antennae for the applicable frequency range to measure the field from the BCUT with a typical frequency range of 50 MHz to the upper limits established in 8.8.1.

Pre-amplifier – broad band low noise pre-amplifier is useful in measuring well shielded BCUT’s. Typical specifications are a gain of 40 dB and a frequency range of 50 MHz or less to the upper limits established in 8.8.1.

Spectrum analyzer – the analyzer should be instrument bus configurable and have a frequency range of 50 MHz or less to the upper limits established in 8.8.1.

PC controller – A PC with a stable operating system and software for instrument control is ideal. The PC is also required to perform motor control for the rotating vane.

8.8.3.1.2 Test fixture

Test fixture preparation can be involved, as it requires machining a brass plate with a pre-defined cutout for the BCUT shield and conductors. The shield connection to panel interface can be a significant leakage mechanism.

Figure 58 shows a diagram of a typical fixture. Termination resistors are soldered to the appropriate conductors of the BCUT as shown in Figure 59.

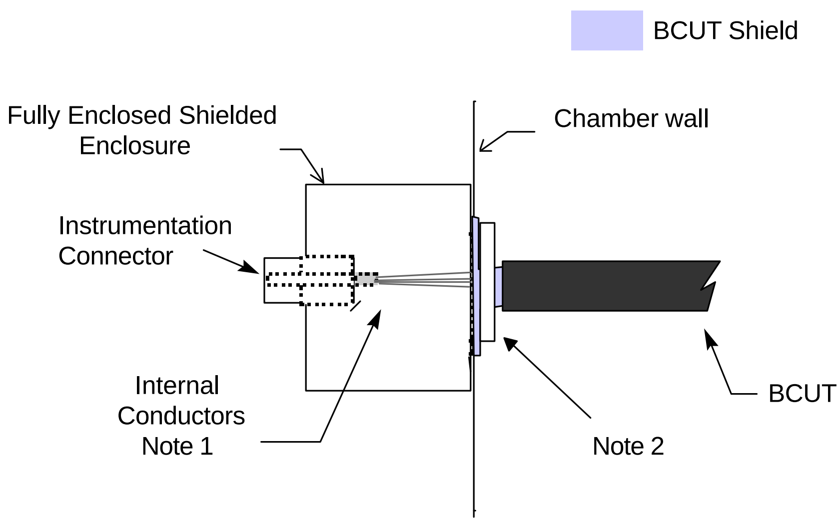


Figure 58 - Diagram showing typical receptacle fixturing

Notes:

1. All internal conductors are connected together and attached to center pin of the coaxial connector. The distance from the coaxial connector to the bulkhead should be kept as short as possible.

2. A 360 degree connection of the BCUT shield and the end cap of the pipe is required. Use of a washer, gasketing or soldering to insure there are no openings from the adapter enclosure to the testing area is recommended.

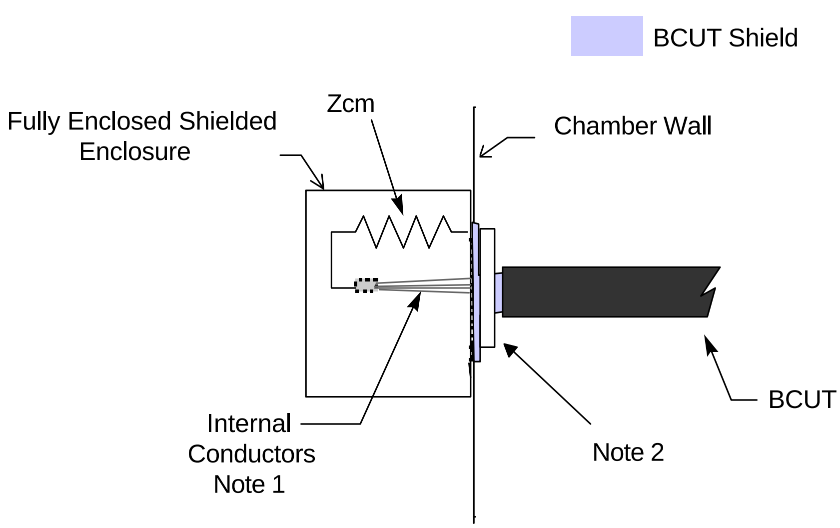


Figure 59 - Far end common mode termination

8.8.3.1.3 Zcm determination procedure

Using a TDR, measure and record the single ended transmission line impedance of the BCUT to be tested. This is easily accomplished using the test fixture in Figure 58. This single ended impedance is measured with the internal conductors shorted together and the shield of the BCUT connected to ground. This measurement determines the value of Zcm shown in Figure 59 for the BCUT terminator.

8.8.3.2 Test setup

The test setup is shown in Figure 60. The BCUT fixturing is mounted to the wall of the chamber.

The main concern is that fields from the signal excitation path may couple to the input of the pre-amplifier giving a falsely high reading. For this reason the signal generator is attached to the instrumentation connector on the test fixture with at least double braid coax. The coaxial feed from the receive antenna to the pre-amp should use a similar well shielded cable.

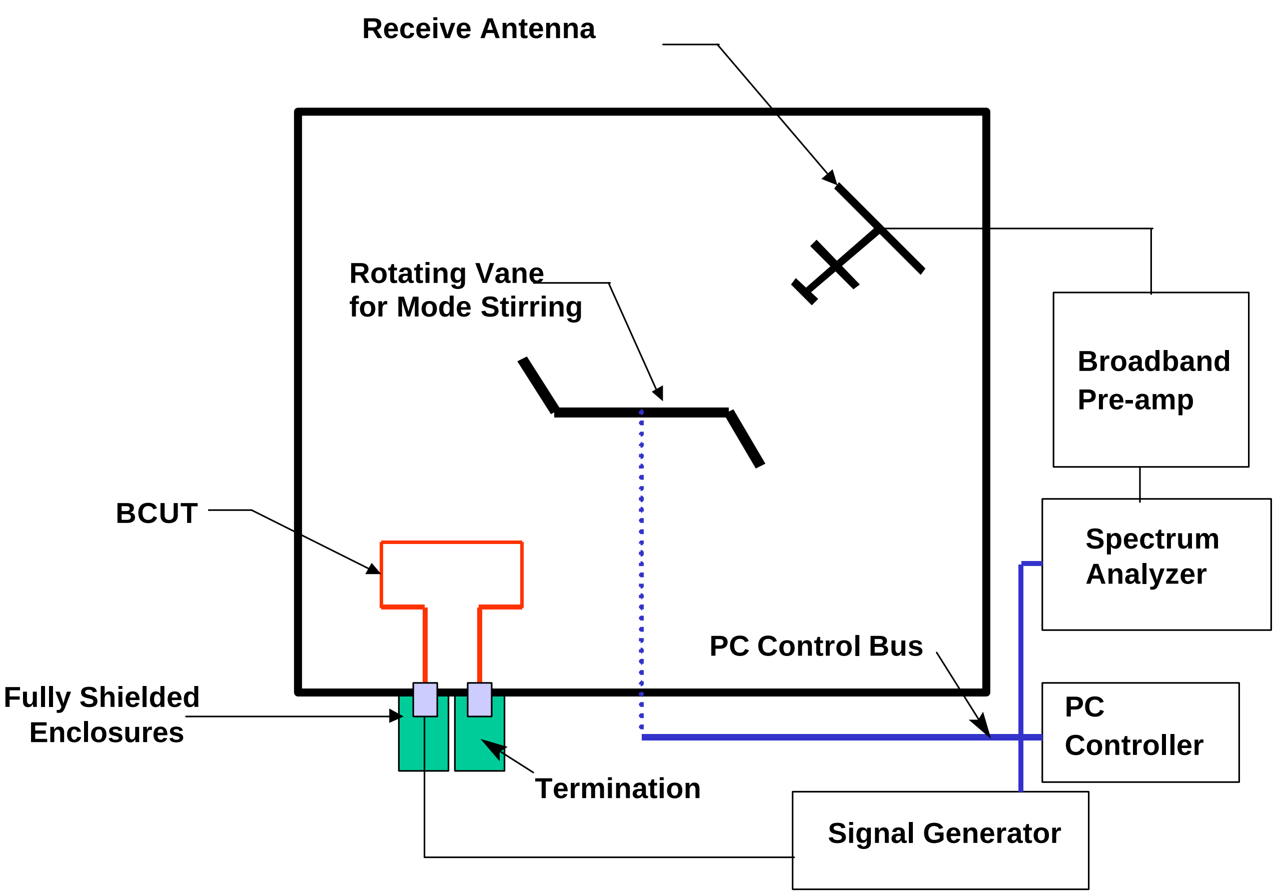


Figure 60 - Typical test setup

It is recommended that prior to any testing of BCUT samples that several ambient measurements be performed to verify that the received signal are indeed due to radiation from the BCUT. Tests with no BCUT installed and tests with the BCUT installed but not excited are useful checks.

The placement and routing of the BCUT is not critical but should extend into the mode stir chamber at least 3 feet. If the BCUT is very close to the wall of the mode stir chamber, fields from the BCUT tend not to couple to the interior volume of the mode stir chamber.

8.8.3.3 Calibration procedure

There are situations where the BCUT must be used to create the reference sample (for example if only one sample exists). In this case the calibration procedure may be performed after performing the BCUT measurement. The procedures described below assumes that a separate reference sample exists.

For each test the following procedure is used to create a reference scan that calibrates the test setup:

In all cases the signals are common mode sinusoids.

Put the unshielded reference cable in place of the BCUT in Figure 60.

The signal generator is set to an initial frequency (50 MHz) and radiated emission level is recorded. The signal generator is then incremented to the next frequency and the radiated emission level is again recorded. These emission levels are recorded in logarithmic space (dBm). This process is continued until the entire frequency range of 50 MHz to the upper limits established in 8.8.1 is covered. Linear frequency sweeps or logarithmic frequency sweeps are commonly used.

The rotating vane of the mode stir chamber is moved in 18 degree increments and the radiated emission level is recorded at each vane position. An 18 degree increment equates to 20 positions where radiated emission levels are recorded for all frequencies. More rotating vane positions could be used at the expense of longer test duration.

For each frequency, the peak radiated emission level found in a complete sweep of the vane positions is recorded. This set of peak emission level vs. frequency is the calibration.

If more convenient the vane position may be held constant while the frequency is swept.

8.8.3.4 Testing procedure

Remove the reference cable and attach the BCUT to the test fixture using the same physical routing as used for the reference cable.

Record measurements of the BCUT emissions in exactly the same way as was used for the calibration that measured the emissions from the reference cable.

The shield effectiveness is the BCUT emissions (in dB) minus the reference calibration emissions (in dB) at each frequency.

8.8.3.5 Acceptable levels

No acceptance levels are defined in this document.

8.8.4 Commom mode power transfer (CMPT)

Common mode power transfer (previously known as transfer impedance or shield effectiveness) applies to external shielded cables. When cables are attached to a system, they can add to the overall radiated emissions of the system. This additional radiation, is due in part, to the amount of energy transferred to the outside of the cable shield from inside the EMI enclosure. How much energy a particular cable allows to escape the enclosure can be determined by measuring the “CMPT” of the system.

Common mode power transfer is the power transferred from signals inside a shielded bulk cable to the shield outside of the bulk cable. Within the context of a specific test condition, one may assume linearity between the intensity of the signal inside the shield to that transferred to the outside.

The CMPT measurement produces direct stress on the shielding system by using unbalanced driven signals. The CMPT captures energy placed on the shield by the test fixture system and by leakage through the shield between the test fixture and the current clamp. The EMR test measures the radiation pattern from the entire shield. Depending on the details of the construction of the BCUT and the source of leakage one may not always get close agreement between the CMPT and EMR tests.

8.8.4.1 Test fixture and measurement equipment.

Test equipment needed:

Spectrum Analyzer	HP 8595E or equivalent
Signal Generator	HP 8657B or equivalent
Signal Amplifier	HP 8447D or equivalent
Absorbing / Current Clamp	Rhode and Schwarz MDS-21
Test Bed and Adapters	

The test bed consists of a 6” inch diameter flue pipe, whose seam has been separated to make a 7” diameter slotted flue pipe. Seven inch end caps are used at either end. The slot opening in the side of the pipe is used for inserting and removing cable assemblies under test. This slot opening could have a hinged cover if there is excessive RF noise in the test environment.

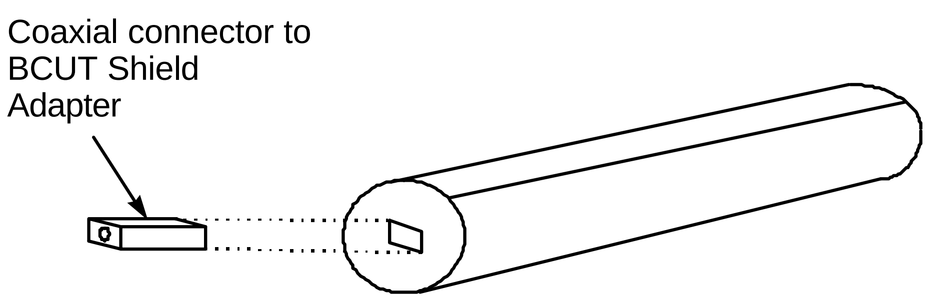


Figure 61 - General view of BCUT adapter (test fixture) and “stovepipe”

The test bed needs an adapter to bring the signal from the signal generator to the BCUT.

The bulkhead connection of the adapter is a solid connection through 360 degrees between the face of the adapter and the test bed enclosure.

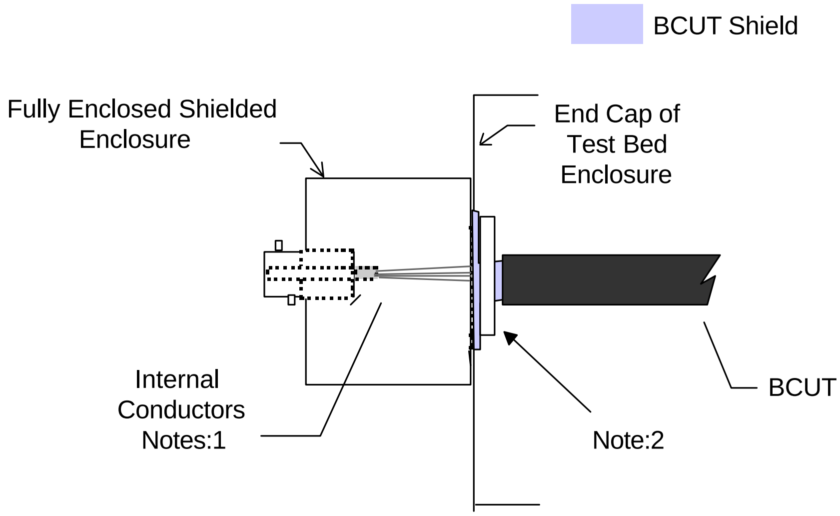


Figure 62 - Test fixture for individual cable assemblies

Notes:

1. All internal conductors are connected together and attached to center pin of the coaxial connector. The distance from the coaxial connector to the bulkhead should be kept as short as possible.

2. A 360 degree connection of the BCUT shield and the end cap of the pipe is required. Use of a washer, gasketing or soldering to insure there are no openings from the adapter enclosure to the testing area is recommended.

The BCUT is terminated on the far end with the circuit shown in Figure 63.

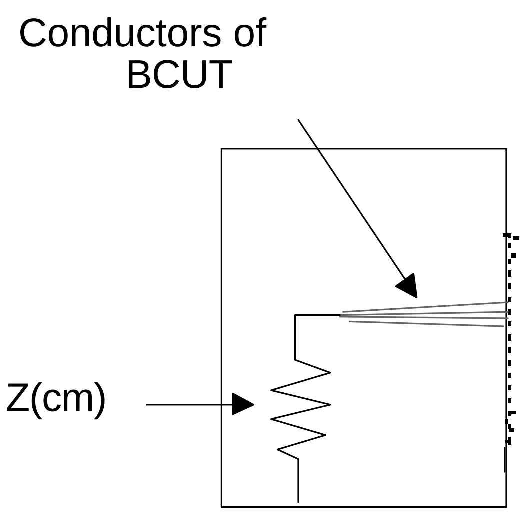


Figure 63 - BCUT terminator

8.8.4.2 Calibration procedure

Using a TDR, measure and record the single ended transmission line impedance of the BCUT to be tested. This is easily accomplished using the test fixture in Figure 63. This single ended impedance is measured with the internal conductors shorted together and the shield of the BCUT connected to ground. This measurement determines the value of Zcm shown in **Error! Reference source not found.** for the BCUT terminator.

The internal common-mode current is established by inserting the BCUT in to the stove pipe (measurement fixture) and absorbing / current clamp as shown in **Error! Reference source not found.**, connecting the RF output of the signal generator and the input of the spectrum analyzer to the 'T' connection of the test fixture for the BCUT. The measurement indicates the current that exists on the shield of the BCUT between the test fixture and the center of the current clamp, in the MDS-21. The center of the current clamp should be placed as far away as possible from the test fixture. The far end of the BCUT is terminated in its transmission line impedance, Zcm, with the BCUT terminator.

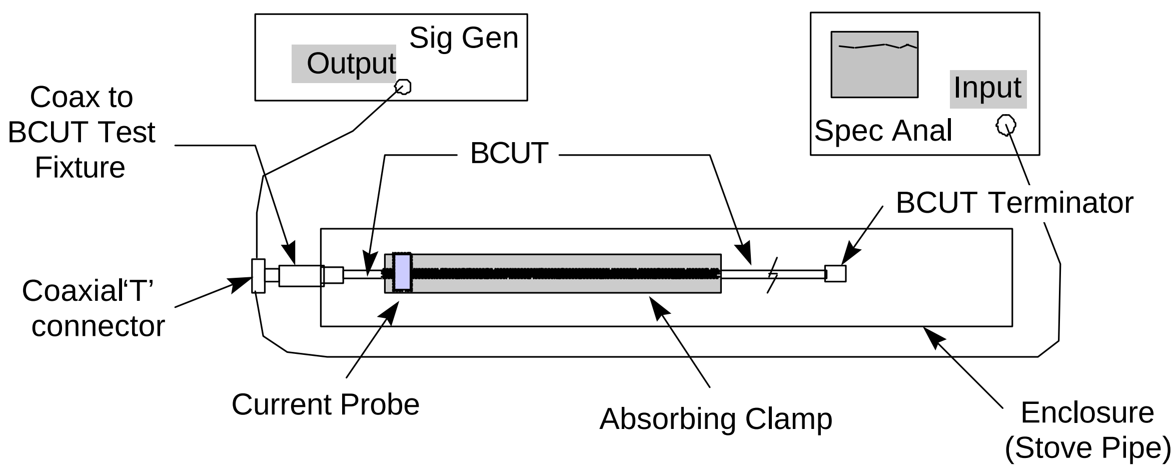


Figure 64 - Calibration configuration

Set the signal generator's RF output to 0 dBm and sweep from 100 MHz to 1 GHz or the highest frequency required. Record this output with the spectrum analyzer in dBm as Pin to be used in the final CMPT calculation. Pin should be between 0 and -10 dBm.

8.8.4.3 Testing procedure

Pout, the power generated on the outside of the cable as a result of the common mode power transfer function is measured and recorded. The common mode power transfer, CMPT, is derived from Pin and Pout.

CMPT = Pout - Pin

Pout is measured using the setup as shown in Figure 65. The only differences in the two setups is that the input of the spectrum analyzer is connected to the output of the amplifier, the current clamp is connected to the input of the amplifier and the spectrum analyzer 'T' connection is replaced with a 50 Ohm terminator. Leave the signal generator set to 0 dBm and sweep from 100 MHz through 1 GHz or the highest frequency required. The spectrum analyzer records the external power, Pout.

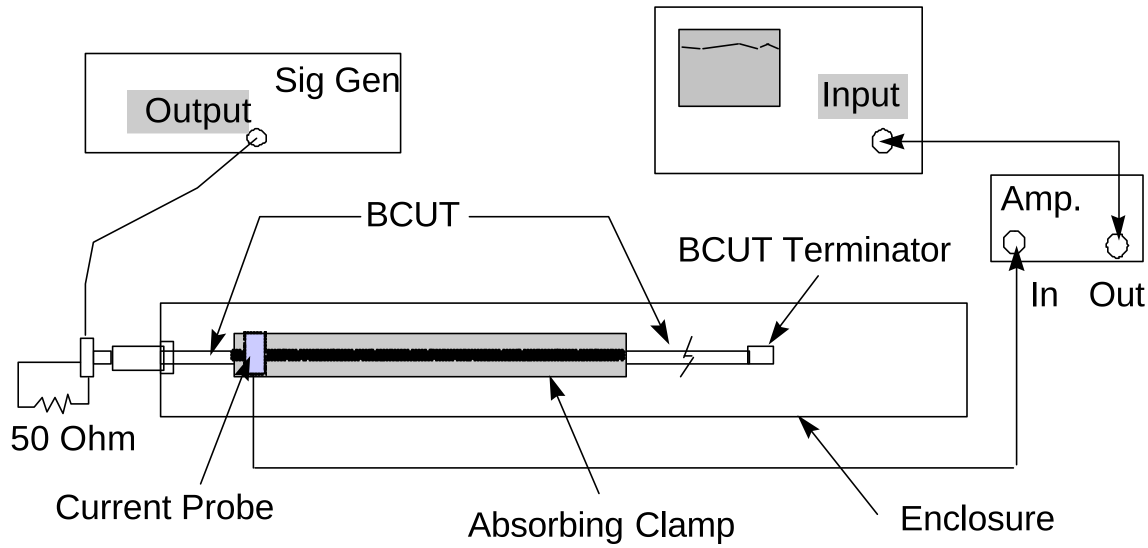


Figure 65 - Measurement configuration

A sample spectrum analyzer display is shown in Figure 66 and the calculated CMPT is shown in Figure 67.

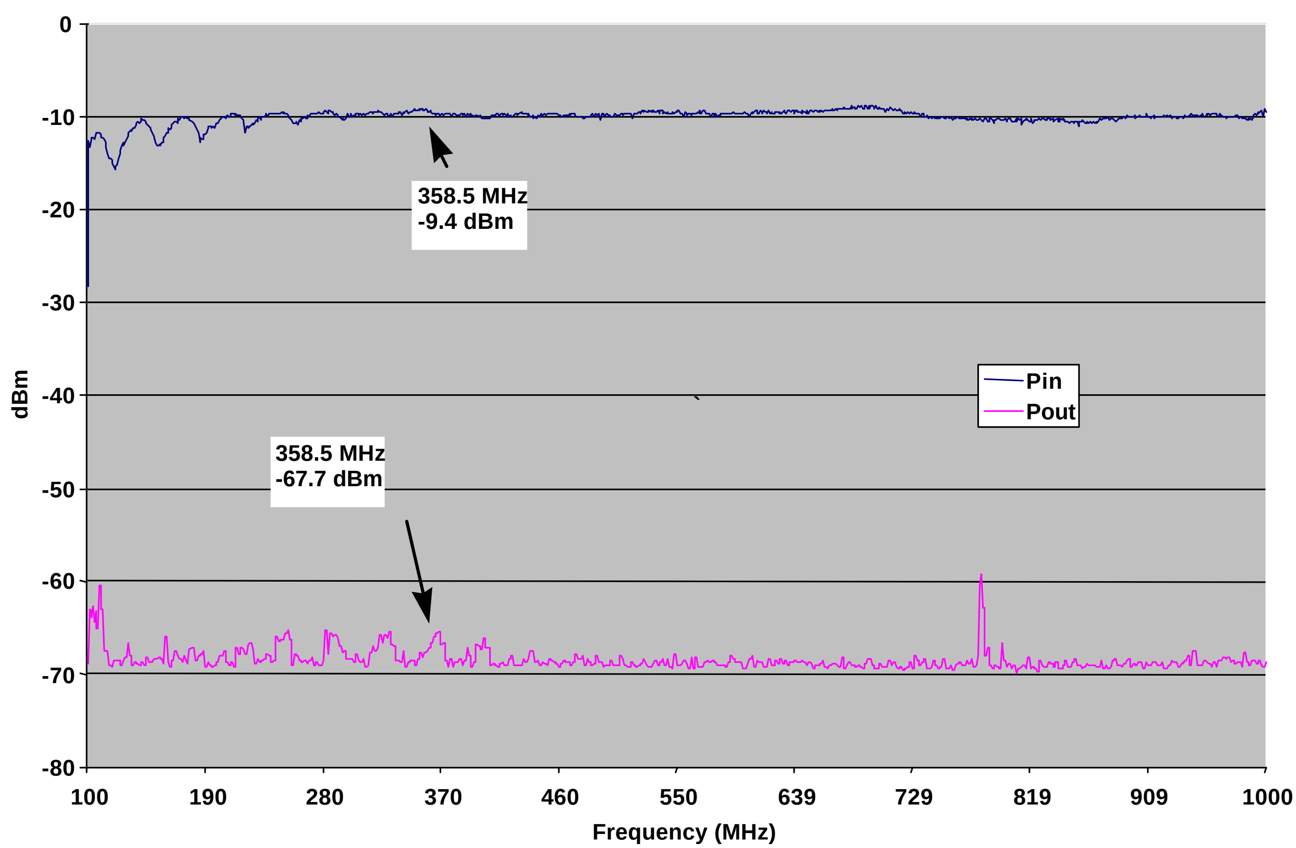


Figure 66 - Pin and Pout example

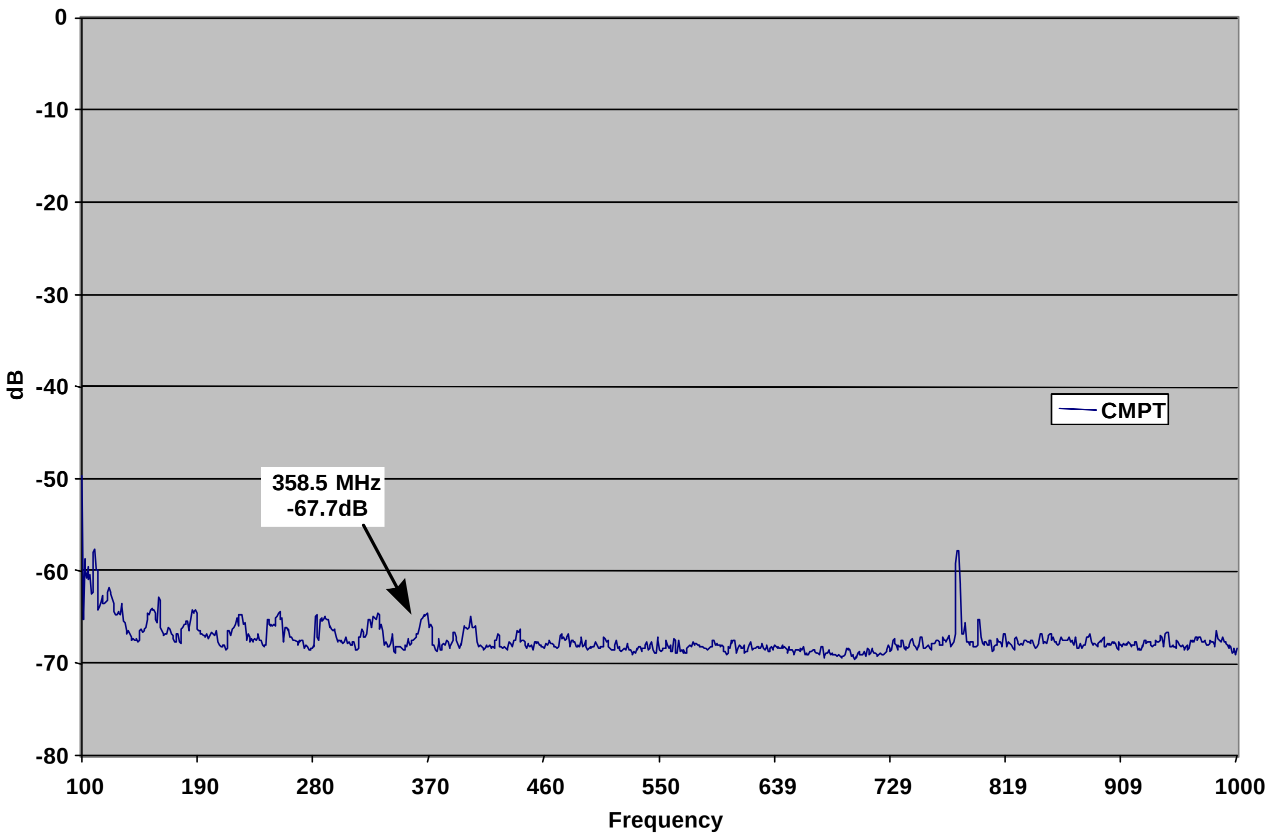


Figure 67 - CMPT calculated using Pin and Pout

At each frequency the common mode power transfer is calculated from the following equation:

CMPT = (Pout – Amplifier gain + Insertion Loss) - Pin

For example, in Figure 66 at 358.5 MHz Pout is -67.7 dB and Pin is -9.4 dB:

CMPT = (-67.7dBm -26dB + 17dB) – (-9.4dBm) = -67.7dB

where Pin is the input signal that was established on the calibration procedure. Pout is the value displayed on the spectrum analyzer measured with the current probe. Insertion loss is provided by the clamp manufacturer and may be different at each frequency. Amplifier gain is from the inline amplifier, if used, and also may vary with frequency.

8.8.4.4 Acceptable Ranges

The intent of the test affects the acceptable range. If the bulkhead attachment is not well sealed and is part of the test then the range specified below does not apply. If the intent is to measure the cable assembly and it’s mating connector then across the frequency range of 100 MHz to 1 GHz a recommended acceptable CMPT is less than -40 dB.

The CMPT measurement is unique to this document and SFF-8410 at the moment.

Annex A - Comparison of within pair skew measurement methods

(Contributed by Greg Vaupotic, Principal Engineer, Amphenol Spectra Strip)

A.1 Measured within-pair delay skew, results dependent on method

A.1.1 Preface

This annex compares three different methods that might be considered for making within pair skew measurements. The method defined in the body of this document is not affected by this Annex.

Measured in-pair delay-skew is highly dependent on test conditions. Conflicting test results abound when similar samples are tested by differing methods. This is because we rarely measure frequency dependent intrinsic propagation delay defined as:

$$[(R_{series} + j\omega L)/(G_{shunt} + j\omega C)]^{1/2}.$$

What we do measure, and often but erroneously call "delay", is really intrinsic propagation delay plus some portion of risetime. But risetime is intensely dependent on sample length and the overall measurement is dependent on details of the test conditions as will be shown in this Annex.

Recommendations are presented after surveying test results taken from one sample, showing skew and 10-90% risetimes under a wide variety of test conditions.

The sample used for the measurements reported in this annex is 15 meters long, 100 Ω, shielded parallel pair with 30 AWG conductors.

A.1.2 Setup 1 (Bit Error Rate Tester (BERT) and oscilloscope)

A continuous square-wave source set to various bit-rates (frequencies) feeding a digital oscilloscope. Adjustable delay lines were used to adjust the delays of the two signal paths (data and inverted-data) to equality.

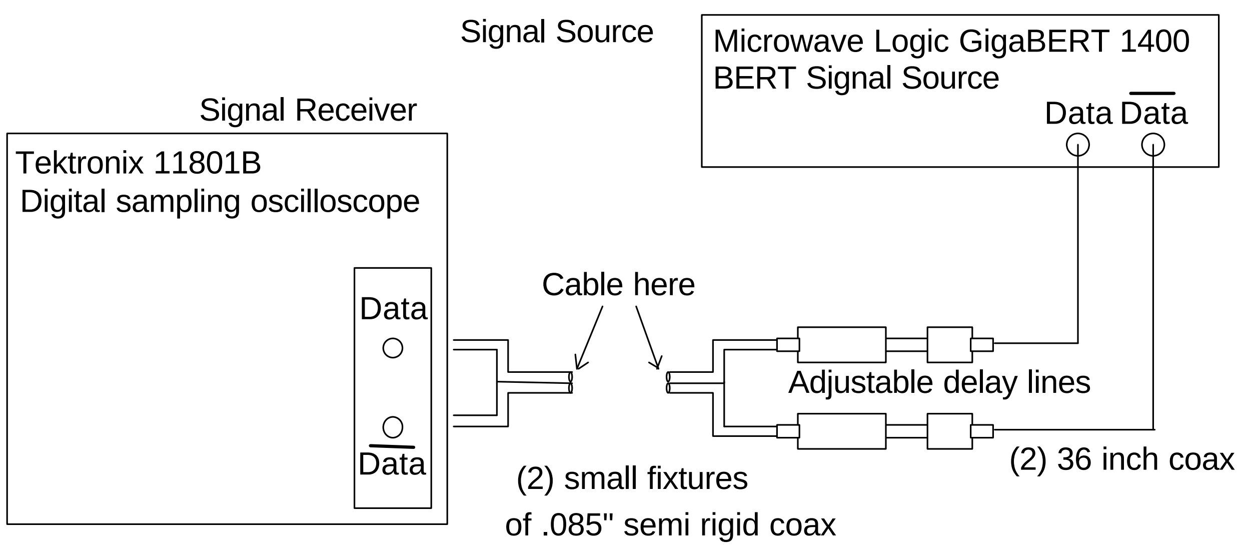


Figure A.1 - Measurement setup 1

Skew (at 50%, that closely approximates where the + signal and - signal "cross") and risetime were measured at 500, 400, 300, 200, 150, and 100 Mb/sec (symmetric square waves at the following frequencies: 250, 200, 150, 100, and 75 MHz).

A.1.3 Setup 2 (time domain thru):

A digital oscilloscope was set to have zero skew at TDR signal launch. Skew was measured through the fixtures and was approximately 1 picosecond.

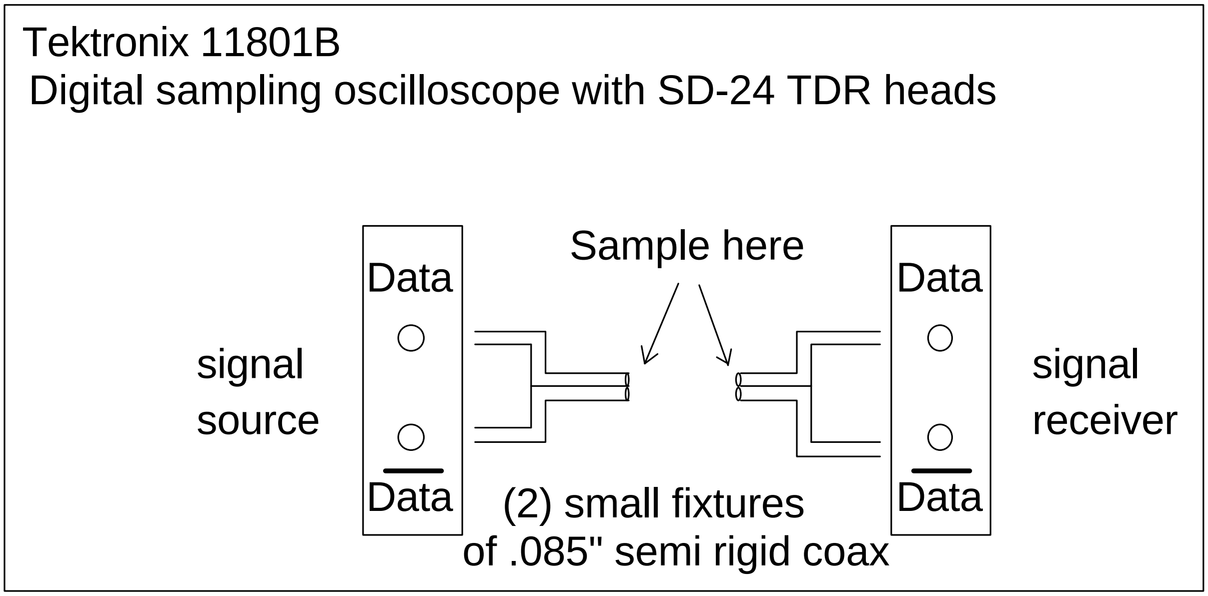


Figure A.2 - Measurement setup 2

The time base was set at 5120 points for maximum resolution, and averaging was set to 256 samples to reduce noise effects.

Skew was measured using the **50% - 50% Time Domain Thru Method** (at 50% of the rising and falling edges of the received waveform). The time base was set at 10, 20, and 50 ns per division to show effects of time base setting on measured skew and risetime.

Last, measurements were made on the undisturbed setup and undisturbed sample using the **Delta Voltage Time Domain Thru Method** where one cursor was manually set on the output baseline and the other cursor was adjusted to 50, 100, and 110 millivolts away from the baseline.

A.2 Results:

Method: BERT and oscilloscope
Using oscilloscope software to find "baseline" and "topline":

Bit Rate Mb	Frequency MHz	Skew picoseconds	"Risetime" 10-90% nanoseconds
500	250	- 13.7	1.32
400	200	- 3.2	1.58
300	150	+ 10.7	1.95
200	100	+ 12.7	2.57
150	75	- 10.3	3.25
100	50	+ 29.3	4.22

Method: BERT and oscilloscope
Manually setting the "baseline" and "topline":
Observe, compared to above, values change, but signs remain the same

Bit Rate Mb	Frequency MHz	Skew picoseconds	"Risetime" 10-90% nanoseconds
500	250	- 17.1	1.33
400	200	- 11.5	1.61
300	150	+ 2.11	2.00
200	100	+ 6.26	2.62
150	75	- 5.7	3.23
100	50	+ 33.8	4.23

Method: 50% - 50% TDT (Time Domain Thru)

Time Base setting ns / division	Skew picoseconds	"Risetime" 10-90% nanoseconds
10	+ 117.3	24.4
20	+ 91.2	38.9
50	+ 100.1	57.9

Method: D Voltage TDT (Time Domain Thru)

	Delta Voltage for measurement	Skew picoseconds	"Risetime" 10-90% nanoseconds
	± 50 mv	+ 10	---
	± 100 mv	+ 40	---
about 50% >>>	± 110 mv	+ 80	---

A.3 Observations

Note that the measured skew from the **BERT and Oscilloscope Method** is extremely variable and even changes sign depending on frequency (one leg may be faster at one square wave frequency but the same leg may be slower at a different frequency).

Note the relative uniformity of the **50% - 50% TDT Method** data, where large changes in time base setting resulted in relatively small changes in measured skew. *Note also* *that the measured skew is always greater than skew seen with high frequency square waves.*

Note that the **D Voltage TDT Method**, particularly at ± 100 mv, gives a skew measurement that is about the same as the worst BERT data. This might only be true for about 15 meters at similar wire size. Different sample lengths and wire sizes might have different Δ voltages that would reflect end-use.

A.4 Recommendation

The **50% - 50% TDT Method** gives data that might minimize unpleasant surprises in the end use. The **D Voltage TDT Method**, *when D volts is skillfully chosen on a case-by-case basis*, might give results approximately equal to end-use while easing the cable producers burden by not overstating skew. The **D Voltage TDT Method** might be dangerous if casually applied to a broad range of products.

Annex B - Effects of within pair skew on insertion loss (asymptotic behavior vs frequency)

(Contributed by Greg Vaupotic, Principal Engineer, Amphenol Spectra Strip)

B.1 Background

Allegedly, within-pair skew causes suckouts to be present in measured insertion loss. The frequency of skew related suckouts may be calculated using the following equation:

$$\mathrm{Freq} = \frac{1+2n}{2(\mathrm{Skew})} \quad \text{for } n = 0,1,....$$

Several shielded parallel pair cable samples were examined to study these predicted suckouts. No suckouts were observed when measuring these cables even though purposely induced skew was known to be present in the construction. The experimental observations appear to contradict the predictions thereby providing motivation to further investigate.

Presented data confirms the equation, but only when launch skew exists. Launch skew is a condition where the drive signals are mismatched in time. If one wire of the pair is driven before the other wire, then a launch skew condition exists.

Finally, a curious effect is noted, where insertion loss degradation of high-skew pairs appears to stabilize at high frequencies.

B.2 Acknowledgement

Dean Vermeersch, Tyco Electronics, provided valuable insight concerning launch skew.

B.3 The samples

Three samples were measured:

1) A single shielded parallel pair having low within-pair skew.

2) A single shielded parallel pair, “identical” to above, only deliberately designed for very high skew.

3) A round nineteen pair cable, 15 meter length, containing shielded parallel pairs having both very good and very bad skew.

B.4 Results - launch skew

Figure B1 demonstrates the effect of launch skew. A low-skew measurement setup was modified by inserting adapters into the signal path going to one wire of the low-skew pair, while the other wire was driven without the adapters. The drive signal therefore had 162 ps launch skew. The equation predicts a suckout at 3.09 GHz (and odd harmonics). The first suckout is confirmed for launch skew.

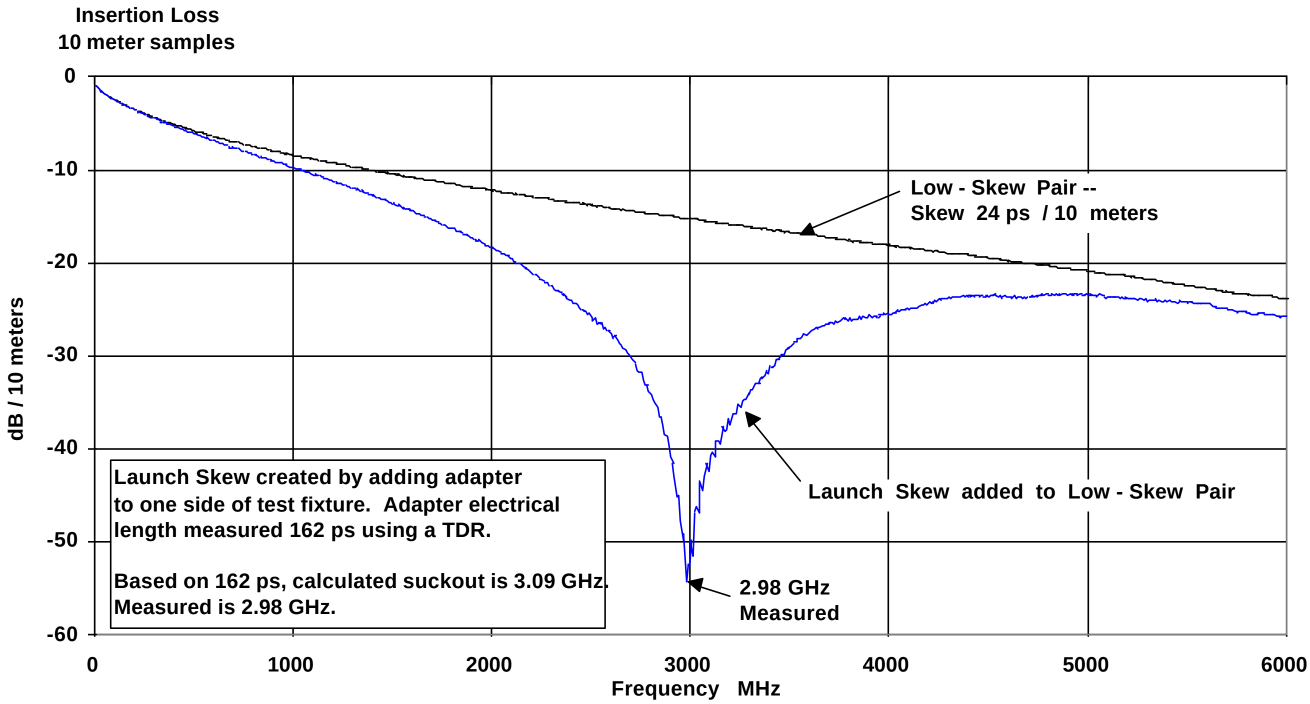


Figure B1 - Low-skew pair vs. low-skew pair with added 162 ps launch skew

B.5 Results - low-skew pair and high-skew pair

If within-pair skew caused suckouts, the high-skew pair would have shown a suckout at about 1.48 GHz, based on the above equation. There is no evidence of such a suckout in Figure B2 where results from such a sample are shown.

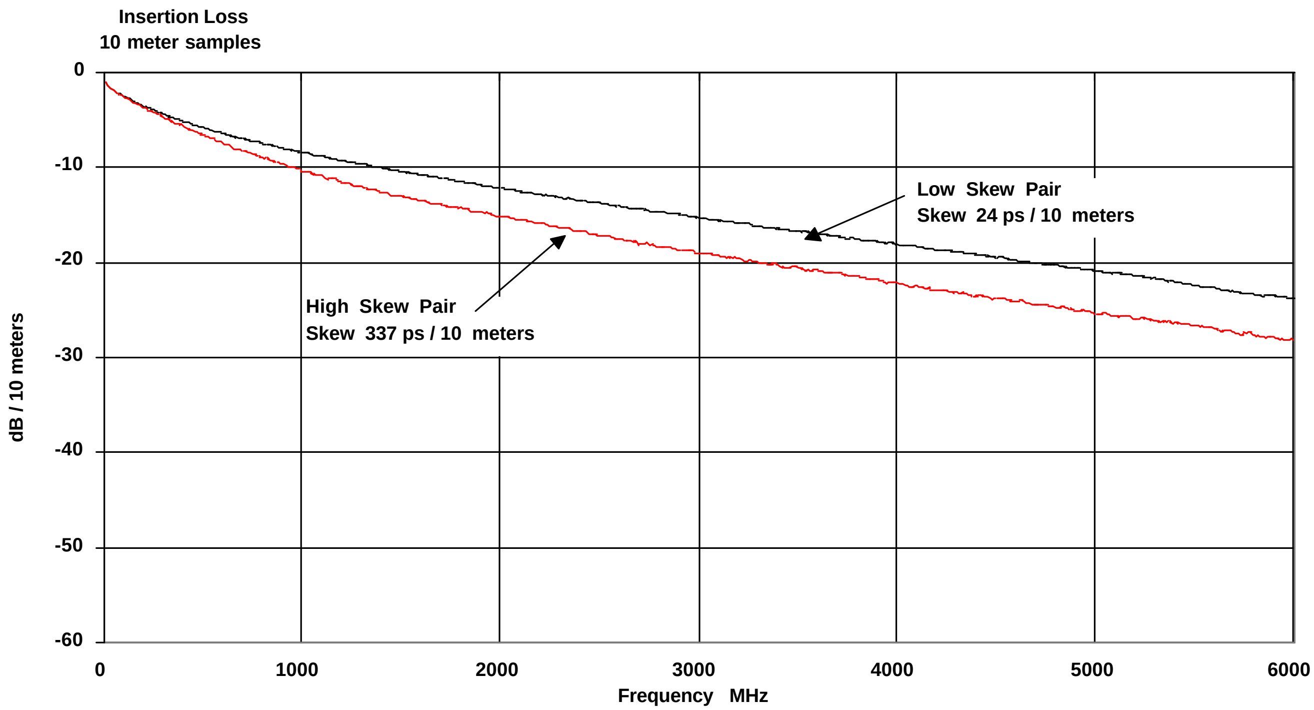


Figure B2 - Low skew pair vs. high skew pair

B,6 Results - 19 Pair Cable

If within-pair skew caused suckouts, the pair having 264 ps skew would have shown a suckout at about 1.89 GHz. Lower skew pairs would have higher frequency suckouts. Again, no suckouts are present in the results from such a sample as shown in Figure B3.

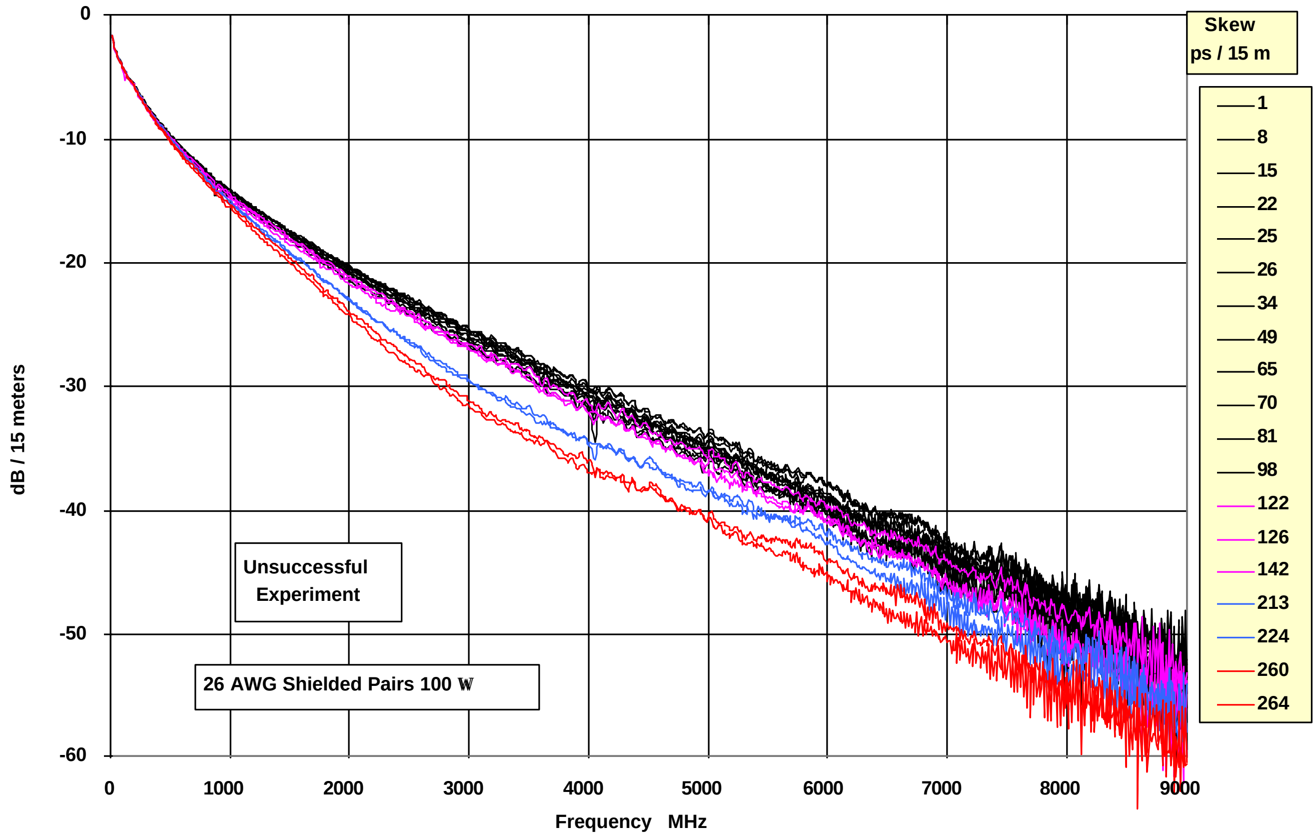


Figure B3 - Insertion loss - 19 pairs, 15 meter sample

B.7 Curious effect

Figure B3 shows insertion loss for high-skew pairs rapidly diverging from loss of low-skew pairs up to about 3 GHz. But, at frequencies higher than 3 GHz the difference in loss diverges much less rapidly.

Figure B4 shows the loss of the seven worst pairs with respect to the lowest loss seen in the entire 19 pair data-set. Excess loss is calculated as follows:

Excess Loss = (Measured loss of a pair) – (Minimum measured loss from entire data set)

The four highest skew pairs show rapidly increasing loss to 3 GHz. At higher frequencies the excess loss becomes almost “flat”.

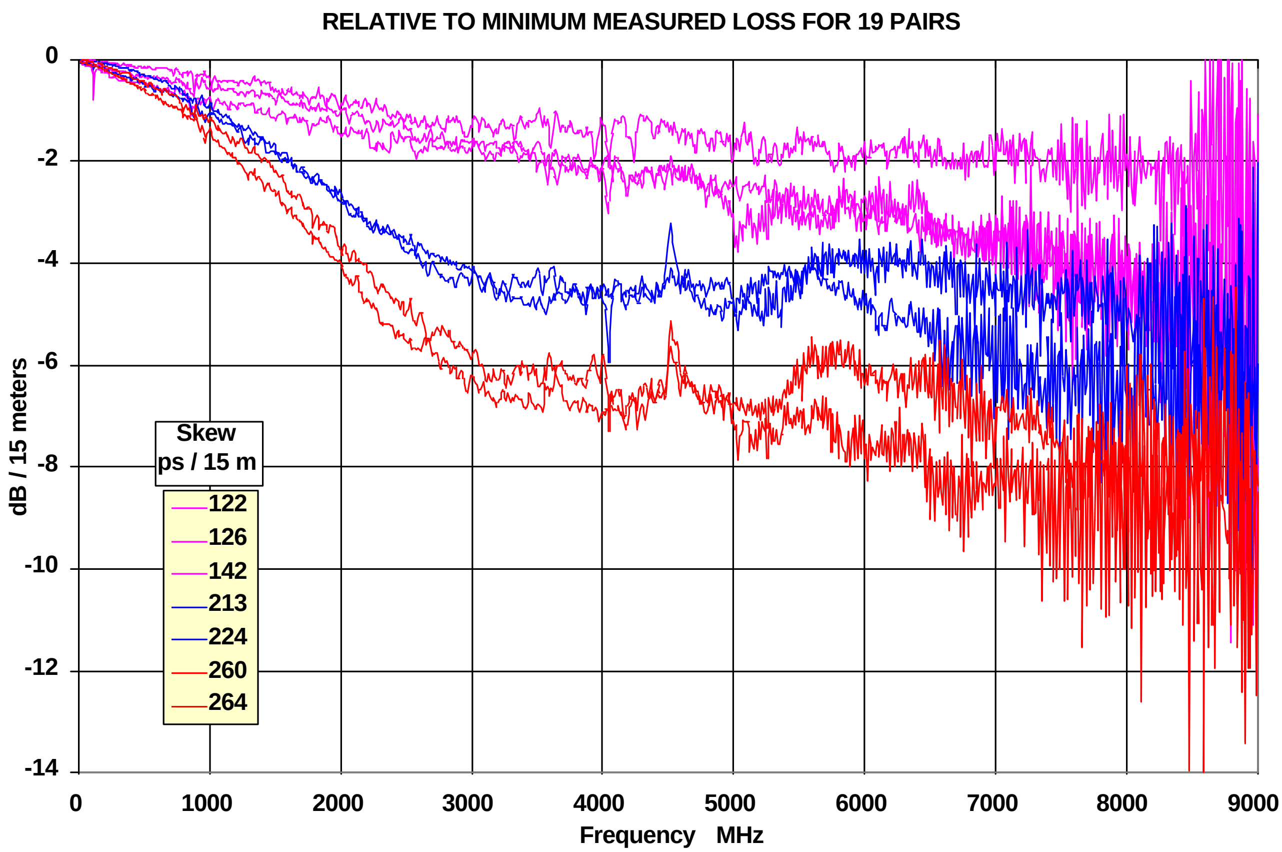


Figure B4 - "Excess" insertion loss - several pairs, 15 meter sample

Below, the best pair and the worst pair from figure B4 (122 and 264 ps skew) are examined from a phase-shift perspective. Assuming the excess loss is caused exclusively by skew induced phase shift, that shift can be calculated as follows:

Output signals (volts): Vpos = 0.5 Vneg = -0.5 (cosθ) θ = phase shift

Differential output: Vdiff = Vpos – Vneg = (0.5 – (-0.5(cosθ)) = 0.5 (1+cosθ)

Differential input (θ = 0): Vin = 0.5 (1+cos0) = 0.5 (1+1) = 1

Excess Loss: $$\mathrm{dB} = 20\log\left(\frac{V_{OUT}}{V_{IN}}\right) = 20\log\left(\frac{0.5\,(1+\cos(q))}{1}\right)$$

then $$q = \operatorname{acos}\left(2\,(10^{\frac{\mathrm{dB}}{20}} - 1)\right)$$

Figure B5 shows the phase shift required to produce the measured “excess” insertion loss according to the equation above.

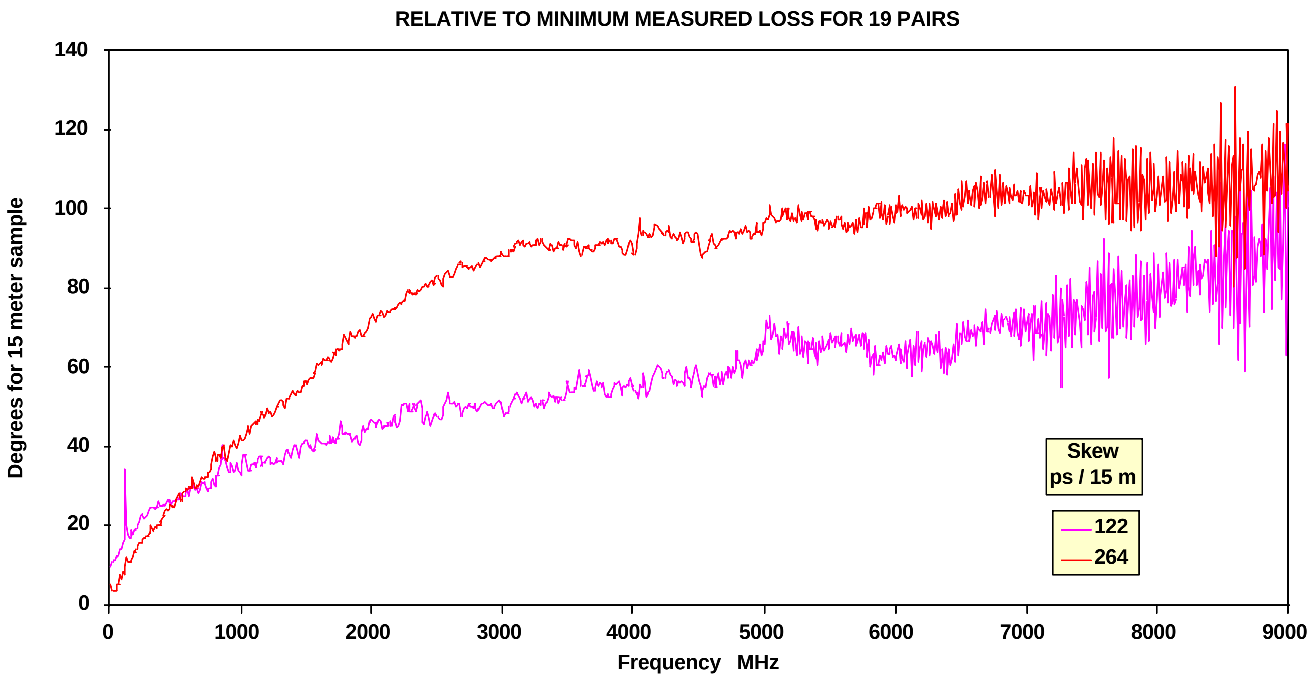


Figure B5 - Phase shift required to account for "excess" insertion loss - selected pairs, 15 meter sample

The phase shift of the worst pair (264 ps / 15 meters) rises rapidly to 3 GHz, then rises very slowly between 3 GHz and 9 GHz. The author of this annex would not have predicted this result.

B.8 Implied maximum skew

Figure B6 shows the implied skew as derived from assuming that the insertion loss is caused by within pair skew. The implied skew is calculated from the phase shift via the following equation.

Implied skew = (phase shift)(period/360) = (phase shift)/(360 * Frequency)

The data shown in Figure B6 did not come from the same sample as shown in Figure B5 and is used for illustration of principle.

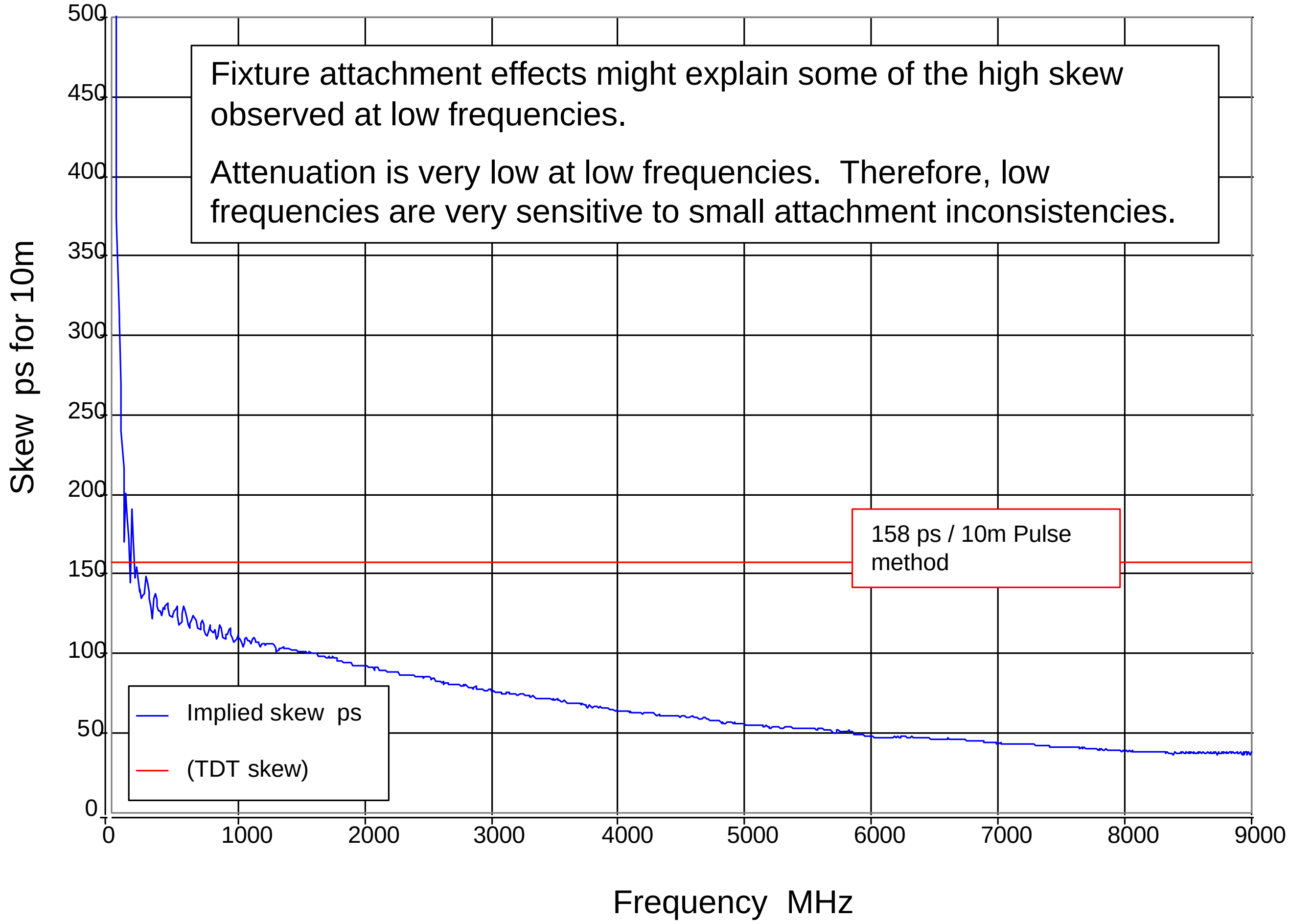


Figure B6 - Skew vs. frequency for 10m sample

B.7 Comments

1. The author of this annex used Ansoft's 2D electromagnetic simulator to model a high-skew pair and a low-skew pair. The modeled attenuation of the low-skew pair adequately matched previously shown data. The modeled attenuation of the high-skew pair was much lower than measured data. Perhaps 3D simulation might be more accurate.
2. Only shielded parallel pairs were measured. Other types of pairs might conceivably show skew related suckouts, although this seems unlikely.

Annex C - Progressive cut down in-pair skew, risetime, and insertion loss measurements

C.1 Overview

This annex presents data concerning the distribution of in pair skew, signal transition duration (risetime), and insertion loss along the length of samples of bulk cable. In order to eliminate sample to sample variations the same samples were measured and then cut to shorter lengths that were then remeasured. The measured results indicate the performance at the length measured. If properties scale with length then one expects to see properties be linearly related to the length. It is also possible that a non linear or at least monotonic relationship could exist. This annex explores measured distributions in typical shielded pair constructions.

C.2 First sample set

C.2.1 Overview

In sub clause C.2 two 'identical' pairs were created, one having low skew, the other having designed-in skew. In subclause C.5 there was no prescreening used.

Skew and risetime of these pairs were measured at the following lengths: 1, 2, 4, 8, 16, and 32 meters. Insertion loss was measured at 2, 4, 8, 16, and 32 meters.

C.2.2 Within-pair skew

Pairs were measured using the TDT method, with data taken at the 50% point of the signal transitions.

	Data	Data	Calculated	Calculated
Length meters	Low skew pair ps for total length of sample	High skew pair ps for total length of sample	Low skew pair ps / meter of sample length	High skew pair ps / meter of sample length
1	- 1.07	- 16.02	- 1.1	- 16.0
2	- 9.49	- 31.8	- 4.8	- 15.9
4	- 14.04	- 141.5	- 3.5	- 35.4
8	- 48.6	- 288.8	- 6.1	- 36.1
16	- 94	- 643	- 5.9	- 40.2
32	+ 94 *	- 1520	+ 2.9 *	- 47.5

Observation: Calculated skew clearly shows that skew does not scale with sample length when measured using the TDT method at 50% points.

* The 32 meter low skew data may have been recorded incorrectly. Unfortunately, this datum can not be confirmed as the samples were destroyed as part of the experiment.

C.2.3 Risetime (10-90%) at far end of sample

Risetime was recorded from the differential signal at the end of the samples as shown in the table below.

The TDT method for measuring propagation delay, hence skew, does not really measure intrinsic (real) propagation delay. TDT measures intrinsic delay plus risetime to the 50% point of the signal transition in the data shown here.

$$\text{"Delay"}_{\text{TDT } 50\%\text{–}50\%} = \text{Delay}_{\text{REAL}} + \text{Risetime}_{0\%\text{–}50\%}$$

Length meters	Low skew pair risetime ns	High skew pair risetime ns
0 (fixture)	.091	.091
1	.201	.209
2	.453	.442
4	.897	.935
8	2.503	3.415
16	12.57	13.78
32	40.88	42.71

Because risetime changes dramatically with sample length a major component of skew is the matching of risetimes between the + signal and the - signal of the pair. If the only skew is that caused by risetime differences and the risetime for both the + signal and the - signal is distributed along the sample length by the same (non linear)formula except with a small difference in the formula parameters between the + signal and the - signal then the resulting skew would not scale linearly with length. The skew in this case would have a monotonic relationship to the length however.

The risetime matching between the + signal and - signal may have a statistical relationship to the length as would the risetime dominated skew.

Figure C1 and C2 show respectively the risetime data plotted as a function of length and as normalized to the sample length.

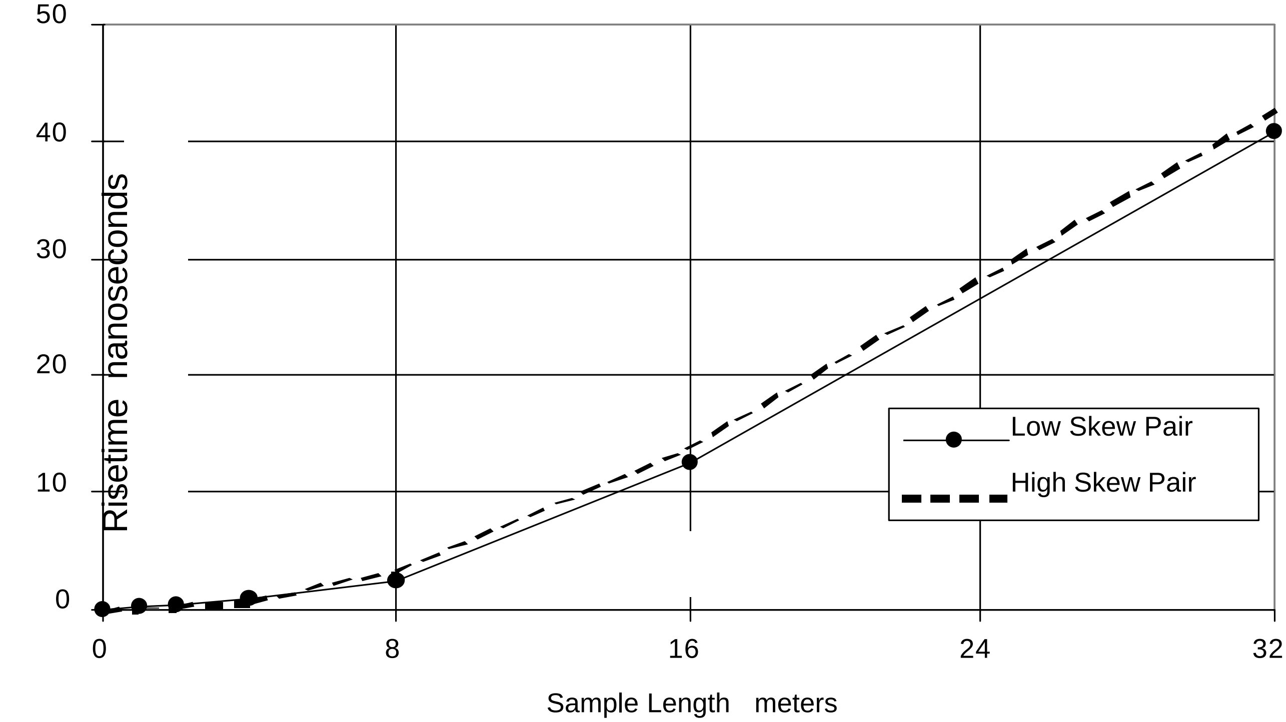


Figure C1 - TDT differential risetime vs sample length

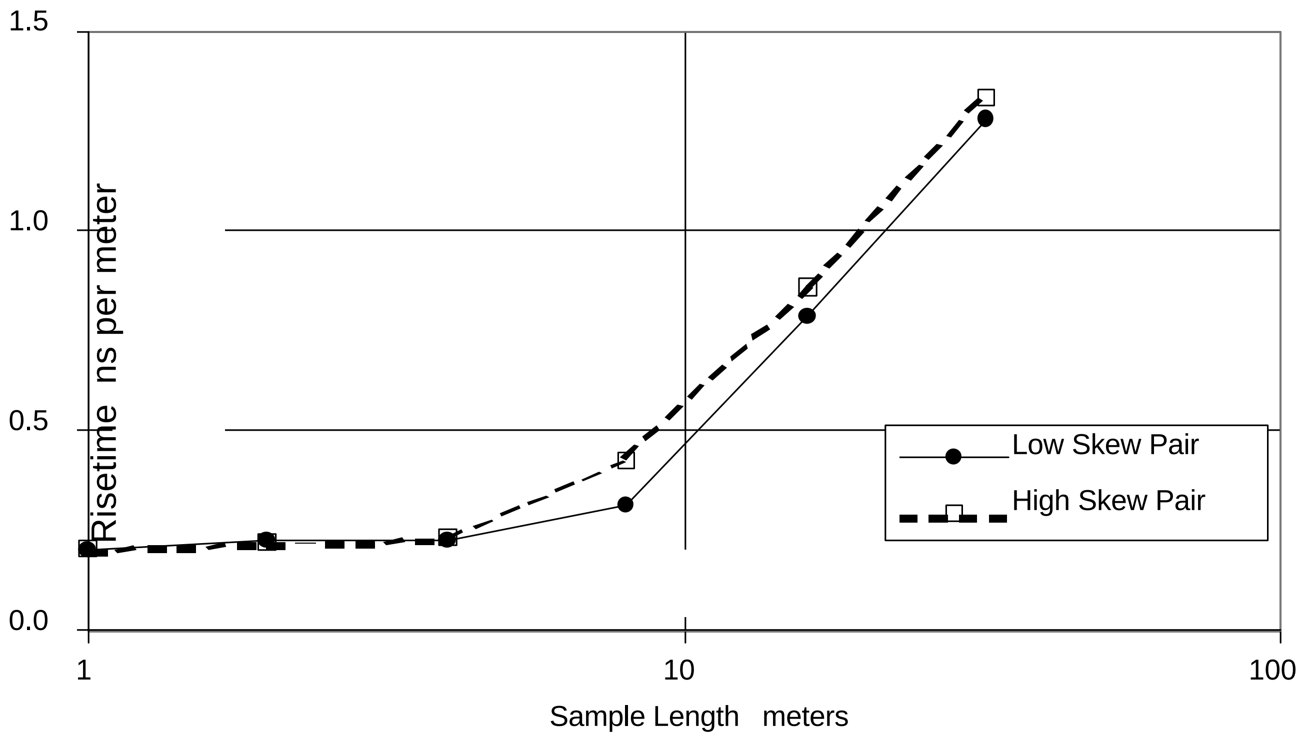


Figure C2 - Differential risetime normalized to length

C.2.4 Insertion loss

Insertion loss for the same sample set was measured using a 4-port network analyzer (Agilent E8358A with ATN-4111D test set) as shown in Figure C3.

Observe the absence of skew-induced suckouts. Also, for all measured lengths, the high skew pair's insertion loss is significantly greater than that of the low skew pair.

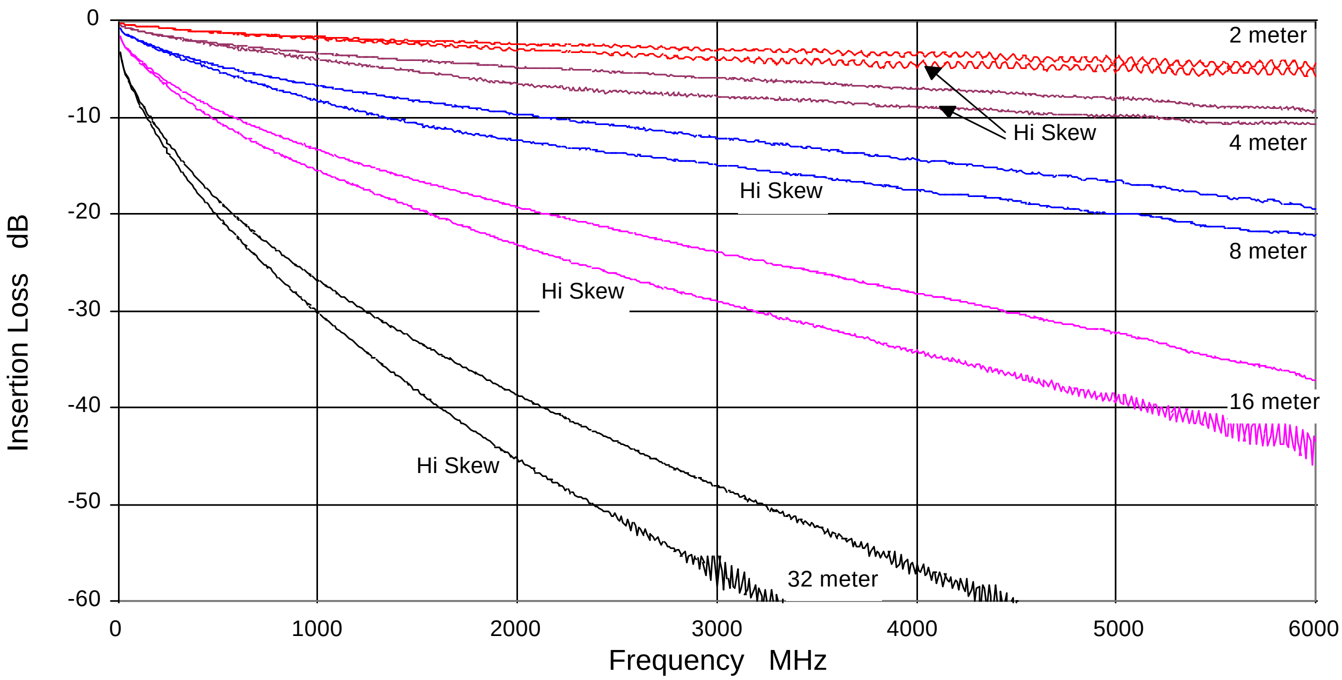


Figure C3 - Insertion loss for the high skew pair and the low skew pair

C.5 Second sample set

The data in this sub clause was acquired on bulk samples provided by Madison Cable. There was no identified prescreening used for these samples and they may or may not represent properties of shipping Madison Cable products. The data is provided as examples of behavior that can exist in real bulk cables.

The following table contains the raw data on within pair skew. Within pair skew is calculated as TD2 - TD1.

Mad. P/N: DOSDK00038 – Sample A 08SDK00002 Spec# Mad 12360 :4Pr Twisted Pr							
		-	-	-	-	-	-
				(ps/32m)			**(ps/16m)**
		TD1	TD2	Skew	TD1	TD2	Skew
Black-Red		155.7659	155.9136	147.7	77.9326	77.7292	-203.4
Green-White		154.5159	154.7292	213.3	77.0576	77.1508	93.2
Orange-Blue		153.5159	153.7292	213.3	76.7384	76.5573	181.1
Brown-Yellow		153.7373	153.7292	-8.1	76.9326	76.8125	-120.1
		-	-	-	-	-	-
				(ps/8m)			**(ps/4m)**
		TD1	TD2	Skew	TD1	TD2	Skew
Black-Red		38.1244	38.1240	-0.4	18.9896	18.9505	-39.1
Green-White		37.7838	37.7649	-18.9	18.7833	18.7852	1.9
Orange-Blue		37.5635	37.5345	-2.9	18.7131	18.7041	-0.9
Brown-Yellow		37.6837	37.6537	-30.0	18.7407	18.7220	-18.7
		-	-	-	-	-	-
				(ps/2m)			**(ps/m)**
		TD1	TD2	Skew	TD1	TD2	Skew
Black-Red		9.3975	9.3792	-18.3	4.6405	4.6201	-20.4
Green-White		9.2370	9.2191	-17.9	4.5159	4.5030	-12.9
Orange-Blue		9.2224	9.2041	-18.3	4.5496	4.5487	-0.9
Brown-Yellow		9.2451	9.2462	1.1	4.5496	4.5487	-0.9
Mad. P/N: DOSDK00038 - Sample B 04KB200001 Spec# Mad 100-5509 :Parallel Pr W/Drain							
		-	-	-	-	-	-
				(ps/32m)			**(ps/16m)**
		TD1	TD2	Skew	TD1	TD2	Skew
#1		154.2659	154.2292	-36.7	74.4881	74.4792	-8.9
#2		154.2659	153.9792	286.7	74.3425	74.4930	150.5
		-	-	-	-	-	-
				(ps/8m)			**(ps/4m)**
		TD1	TD2	Skew	TD1	TD2	Skew
#1		36.2053	36.1488	-56.5	17.9624	17.9463	-16.1
#2		36.1302	36.1054	-24.8	17.9322	17.9376	5.4
		-	-	-	-	-	-
				(ps/2m)			**(ps/m)**
		TD1	TD2	Skew	TD1	TD2	Skew
#1		8.9115	8.9054	-6.1	4.4055	4.4016	-3.9
#2		8.8606	8.8758	15.2	4.4142	4.4132	-1.0
Mad. P/N: DOSDK00038 - Sample C 04KD200001 Spec# Mad 100-4376 :Parallel Pr W/O Drain							
		-	-	-	-	-	-
				(ps/32m)			**(ps/16m)**
		TD1	TD2	Skew	TD1	TD2	Skew
#1		135.4395	135.5655	126.0	68.2163	68.2640	47.7
#2		135.7545	135.9330	178.5	68.3488	68.4442	95.4
		-	-	-	-	-	-
				(ps/8m)			**(ps/4m)**
		TD1	TD2	Skew	TD1	TD2	Skew
#1		33.3606	33.3866	26.0	16.6413	16.6361	-5.2
#2		33.4516	33.4594	7.8	16.6972	16.6751	-22.1
		-	-	-	-	-	-
				(ps/2m)			**(ps/m)**
		TD1	TD2	Skew	TD1	TD2	Skew

#1		8.2557	8.2485	-7.2	4.0905	4.0613	-29.2
#2		8.2732	8.2804	7.2	4.0908	4.0761	-14.7

The same data shown in the table above is reproduced in the table below for ease of comparison.

Summary of skew (ps) for cut down samples of length indicated

Sample length (m)	32	16	8	4	2	1
Sample A						
Black-Red	147.7	-203.4	-0.4	-39.1	-18.3	-20.4
Green-White	213.3	93.2	-18.9	1.9	-17.9	-12.9
Orange-Blue	213.3	181.1	-2.9	-0.9	-18.3	-0.9
Brown-Yellow	-8.1	-120.1	-30.0	-18.7	1.1	-0.9
Sample B						
Pair #1	-36.7	-8.9	-56.5	-16.1	-6.1	-3.9
Pair #2	286.7	150.5	-24.8	5.4	15.2	-1.0
Sample C						
Pair #1	126.0	47.7	26.0	-5.2	-7.2	-29.2
Pair #2	178.5	95.4	7.8	-22.1	7.2	-14.7

C.6 Summary and conclusions

It is very clear that the within pair skew does not scale with length for these samples (except for a few isolated cases where there is the false appearance between neighboring lengths that a linear relationship exists). There is a relationship between the largest skew measurements being in the general set of samples with the longer lengths but this relationship is not even monotonic within the same pair. Examination of the data clearly shows a significant 'statistical' content and validates the position in this document that within pair skew is not considered to be predictable from sample lengths other that those intended for use in the application.

It is recommended that specifications use total skew for the application length and avoid using a skew per unit length format.

If a linear, monotonic, or any other predictable relationship with length for within pair skew is found for a particular set of samples or for a specific product from a specific supplier then these samples/products contain systematic causes for the within pair skew that are removable (in principle) by identifying the causes and eliminating them from the manufacturing process.

Annex D - Measurement methodology dependent bias in within pair skew

(Contributed by Greg Vaupotic, Principal Engineer, Amphenol Spectra Strip)

D.1 Overview

Within pair skew measurement methodology can contribute significant bias or shift to the results. This annex compares three methods for measuring testing within pair skew in long balanced-pair cables.

The superiority of the "Alternate Top-Line" method of measuring within-pair skew compared to two other commonly specified methods is demonstrated. All three methods are described and an assumption is stated. Data are presented which appear to validate the assumption. Data shows that the methods differ greatly in capability.

(Comment: It is well known that a cable's skew in the lab can be quite different compared to skew in the system. Laboratory skew is, however, a good figure of merit even if not a perfect predictor.)

D.2 Details of measurement methodologies used

D.2.1 50%-50% TDT IEEE Method:

A differential signal is launched into the near end of a balanced pair, the far end is terminated into a proper load, and the signal at the load is examined, typically with a digital sampling oscilloscope (e.g.: Tektronix 11801 series). This method requires the oscilloscope to "find" the 0% and 100% locations on the received waveforms. But, *long cables* exhibit "dribble-up", where the time taken to achieve 100% is exceptionally long. In fact, this dribble-up time is so long that the oscilloscope performs in an inconsistent manner, yielding inconsistent results.

D.2.2 Crossing method:

A differential signal is launched into the near end of a balanced pair, the far end is open circuit (floating). The signal is reflected by the open circuit at the far end, and returns to the launch-point where the skew is measured. The round-trip skew is said to equal twice the one-way skew. The delays are determined by examining when the reflected signal crosses through some pre-defined voltage levels (e.g.: "true" signal going through + 100 mv, "complement signal going through - 100 mv). This method provides better data than the IEEE method, but the Crossing method's accuracy is limited by inconsistencies in the test instrument. For example, the "true" and "complement" pulses launched into the pair are NOT perfectly equal, and the amplifiers that examine the reflected signal do not have equal gain or equal offset. The Crossing method, although having limited accuracy, has a strong virtue compared to the other methods under discussion: only one end of the cable must be "prepared" for test. This reduces testing labor-cost, and makes the method appropriate where accessing both ends of the cable is otherwise impractical (e.g.: in-process tests during assembly operations).

D.2.3 50%-50% TDT alternate topline method:

This method is almost the same as the IEEE method. The problem of locating the vague 100% point is resolved by finding the highest value on the oscilloscope screen, then defining 100% to be 90% of this highest value. Experience (and data) indicates that this modification to the IEEE method greatly improves consistency.

D.3 Assumption

If within-pair skew is measured with one leg going to "true", then by flipping the pair so the measurement is on the same leg going to "complement", one should find the measurement results to be equal and opposite if all else in the measurement remains unchanged (i.e., perfect). For example, if skew measures +25 ps on a 10 meter pair before the flip the skew should measure -25 ps on the same 10 meter pair after the flip.

If the assumption is true, or nearly true, then totaling the skews measured from a 22 pair cable with the skews measured from the same cable "flipped" should equal zero. If the sum of flipped and non-flipped is not zero, then the test has a bias, or built-in error. Bias is usually instrument and setup dependent. The producer's test setup has one bias, the customer's has a different bias, so disagreements are frequent when producer and customer measure the same sample.

D.4 Measurement results

Figure D1 shows three graphs, with data taken from one 22 pair cable having 20 meter length.

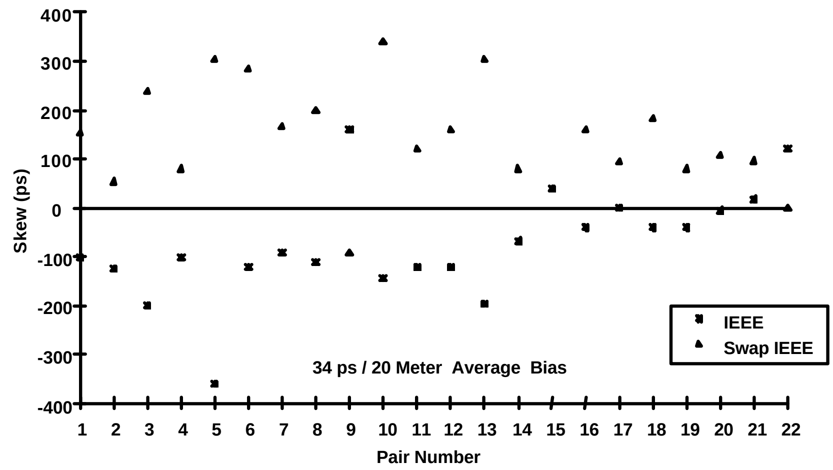
The top graph (IEEE method) shows very wide data scatter, showing a 34 ps / 20 meter bias.

The middle graph ("crossing" method with reflected pulse) shows much less scatter and is therefore a better test -- *but Crossing method still shows a very significant 31 ps / 20 meter bias.*

The bottom graph (Alternate Top-line method) shows almost mirror images comparing swap to non-swap data. The bias is only -2 ps / 20 meters, in this case about 93% less bias than the "crossing" method.

D.5 Conclusion

The IEEE method should not be specified for long cables (those having significant dribble-up). The crossing method might advantageously be specified where only one end of the cable is available to test, or for economy where producer and customer agree that tolerances are generous enough to allow a reduced capability test. The alternate-topline method should be specified for long cables having demanding tolerances.



Tek 11801's
default
IEEE Method
TDT

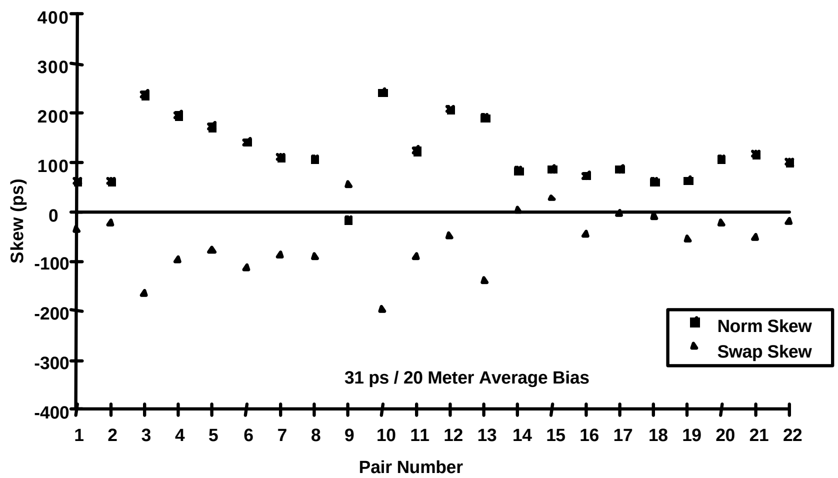
512 points

32 average

?50 mv / div

?20 ns / div

(using Window)



Cray's method
225 mr crossing
reflected

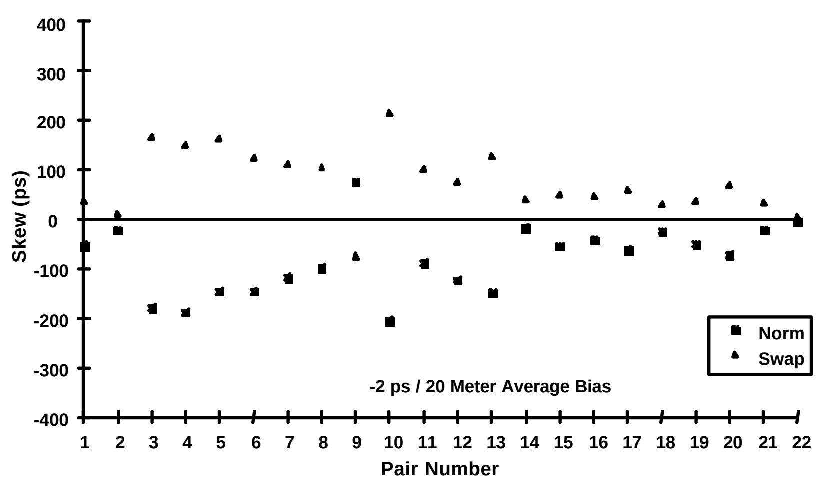
512 points

128 average

80 mr / div

0.5 ns / div

M3 & M4 on Main



Tek 11801's
Alternate Method
TDT

512 points

32 average

50 mv / div

20 ns / div

M3 & M4 on Main

Figure D1 - Within-pair skew, ps per 20 meter length, three methods compared