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

PLEASE READ EDITOR'S NOTES IN FRONT OF TABLE OF CONTENTS

SFF Committee

SFF-8415 Specification for

HPEI Measurement Methodology and Signal Integrity Requirements

Rev 8.2   July 18, 2005

September 2011: Development of this specification had stalled when the editor retired. The membership believes the content still has merit and should not be Expired so it was balloted for Publication as Rev 8.2

Secretariat: SFF Committee

Abstract: This specification defines the electrical and performance requirements for HPEI (High Performance Electrical Interconnect), point to point, copper cable assemblies and associated system connections operating at high speeds greater than 1 Gbaud. This architecture is used in most applications requiring high speed serial and serial-parallel copper connections. Some representative applications of such interconnects are Fibre Channel, Gigabit Ethernet, and Infiniband. Other applications for this general-purpose specification are also possible

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

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

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

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

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EXPRESSION OF SUPPORT BY MANUFACTURERS

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

> ENDL
> Foxconn
> Hewlett Packard
> Hitachi Cable
> ICT-Lanto
> Sandisk
> Siemon
> Toshiba America

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

> Dell Computer
> EMC
> FCI
> Finisar
> Fujitsu CPA
> Hitachi GST
> IBM
> Intel
> JDS Uniphase
> Molex
> NetApp
> Picolight
> Seagate
> TE Connectivity
> Unisys
> Yamaichi

Foreword

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

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 and system integrators worked individually with vendors to develop the packaging. The result was wide diversity, and incompatibility.

The problems faced by integrators, device suppliers, and component suppliers led to the formation of the SFF Committee as an industry ad hoc group to address the marketing and engineering considerations of the emerging new technology.

During the development of the form factor definitions, other activities were suggested because participants in the SFF Committee faced more problems than the physical form factors of disk drives. In November 1992, the charter was expanded 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.

  Those companies which have agreed to support a 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.

SFF Committee meetings are held during T10 weeks (see www.t10.org), and Specific Subject Working Groups are held at the convenience of the participants. Material presented at SFF Committee meetings becomes public domain, and there are no restrictions on the open mailing of material presented at committee meetings.

Most of the specifications developed by the SFF Committee have either been incorporated into standards or adopted as standards by EIA (Electronic Industries Association), ANSI (American National Standards Institute) and IEC (International Electrotechnical Commission).

If you are interested in participating or wish to follow the activities of the SFF Committee, the signup for membership and/or documentation can be found at:

                www.sffcommittee.com/ie/join.html

The complete list of SFF Specifications which have been completed or are currently being worked on by the SFF Committee can be found at:

                ftp://ftp.seagate.com/sff/SFF-8000.TXT

If you wish to know more about the SFF Committee, the principles which guide the activities can be found at:

                ftp://ftp.seagate.com/sff/SFF-8032.TXT

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

SFF Committee --

HSS Interconnect Attributes

1. Scope

This specification defines the terminology and physical requirements for specifying and enforcing through measurements the electrical performance requirements for point to point High Performance Electrical Interconnect (HPEI). Such performance requirements are in addition to the mechanical and environmental requirements that may be specified elsewhere. The requirements for both shielded and unshielded connections 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. Multidrop 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 document although some value may be realized by applying the methodologies defined herein to multidrop constructions. A separate effort is underway within the T10 NCITS Passive Interconnect Performance (PIP) working group to address multidrop constructions.

The specifications specifically document the measurements required for three representative "profile" constructions which include:

  - one transmit and one receive path in a single shielded cable assembly (duplex)
  - four serial paths in each direction in a single cable assembly
  - one transmit and one receive path in a single unshielded backplane (duplex)

Requirements for extending the measurements specified for the documented profiles to other constructions are also included.

This is the second SFF specification that deals with the electrical performance of electrical interconnects, the other is SFF-8410. SFF-8410 is focused only on passive duplex constructions.

In the high performance electrical interconnect applications area existing specifications in standards documents 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 document significantly improves on this conditions by defining measurement specifications that include enough detail to allow the performance specifications to be used effectively. Until such time as standards documents include such detail this document can serve as the specification for the measurement methodology.

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

This document includes the requirements for constructions where one signal is traveling away from the transmitter at the same time another uncorrelated signal is being received by a neighboring receiver on the same end of the cable assembly as the transmitter. The test conditions required for this application are somewhat unique - especially with respect to the effects of the signals on parts of the link that are not directly under test.

The performance requirements include the effects of connectors, board mounting, shield attachment to bulkheads, and all the parts of the connection that are required to make a complete link. These requirements apply directly to several connectors

specified mechanically in other SFF documents. The HSSDC, HSSDC-2, HSSDB9, 40 position SCA-2 and any other connector type used in an HPEI cable assembly or backplane is directly affected. These connectors are desirable in GBE, FC-AL, FC-SW, 1394, SSA, and Infiniband systems where high speed serial copper technology is used.

The HPEI measurement procedures break down into two key levels:

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

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

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

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

1.1 Description of Clauses

Clause 1 contains the Scope and Purpose.
Clause 2 contains Referenced and Related Standards and SFF Specifications.
Clause 3 contains the General Description.

2. References

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

2.1 Industry Documents

   EDITOR'S NOTE: More references need to be added.

The following interface standards are relevant to this Specification.

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

2.2 SFF Specifications

There are several projects active within the SFF Committee. The complete list of specifications which have been completed or are still being worked on are listed in the specification at ftp://ftp.seagate.com/sff/SFF-8000.TXT

2.3 Sources

Those who join the SFF Committee as an Observer or Member receive electronic copies of the minutes and SFF specifications (http://www.sffcommittee.com/ie/join.html).

Copies of ANSI standards may be purchased from the InterNational Committee for Information Technology Standards (http://www.techstreet.com/incitsgate.tmpl).

Editor's notes:

This document may contain information that is a hold over from the 8410 document.

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SFF Committee --

HPEI Measurement Methodology and Signal Integrity Requirements

1. Introduction

This document contains specifications for validating the electrical performance of high speed serial copper interconnects. It is intended specifically to be used in conjunction with the HSSDC, HSSDB9, HSSDC-2, Fujitsu 10 GFC, 4x Infiniband, SpeedPak I/0 (12x Infiniband), SCA-2, 2mm-HM and other connector families used in a high performance serial and serial/parallel applications. These tests may also be useful for other high speed copper interconnects such as SCSI and IDE. SFF-8415 is one of the family of SFF documents.

Although the specifications specifically document the testing required for a single transmit and a single receive path in a single cable assembly the methods are directly extensible to parallel implementations that use multiple high speed paths. Requirements for extending the documented tests for multiple paths constructions are also contained.

This document should be treated as a new specification relating to implementing the testing 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 testing methods in the published standards.

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

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

In real systems, opportunities for trading off margins between transmitter, cable assemblies, and receivers commonly exist. Therefore it may be possible to qualify a cable assembly for use in specific bounded applications where the cable assembly does not meet the stringent requirements described herein because, 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 FC ports.

2. 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 GBaud to several GBaud with rise times from approximately 20 to 100 ps. Testing techniques for HPEI interconnect in this speed range lack good standardization and methods. This deficiency leads to unintended incompatibilities between suppliers and users. Further, the specific conditions existing when an HPEI connection is required are explicitly addressed. This document is not a general specification for testing all high speed copper interconnect but rather is aimed at the architectures used in Fibre Channel, Gigabit Ethernet, Infiniband, 1394, and the like. Although the specifications are written around 100 and 150 ohm balanced transmission the methods are readily adaptable to other transmission line impedance levels such as the 110 ohm used by 1394.

It is assumed that a completed cable assembly (media with connectors on both ends) constitutes the primary interconnect component of interest. This does not mean that

the bulk cable is not important in producing good interconnect but rather means that the focus of this document includes all the effects of adding connectors, 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 testing raw media is not considered directly in this document.

All tests except the impedance profile are intended to apply to all constructions of cable assembly including those with equalizers and those with known non uniformities such as intermediate connection points.

The general requirements are:

- for a launched signal with the most degraded allowed parameters to traverse the interconnect without further degrading beyond the allowed input specifications for the receiver

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

- to behave like a matched transmission line for devices and other cable assemblies attached to the ends

The received signal and exported noise are influenced both by the properties of the launched signals and by the degradations occurring during the transmission process. The goal is to deliver adequate signal quality to the receiver and to not export excessive noise under the worst allowed cases. This means that both the properties of the launched signals and the properties of the interconnect must be considered in the testing processes.

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

One risk comes from inadequately characterizing the launched signals used in the tests. Since the properties of the signals at the receiver are the only properties that matter to an operating system, the standards only consider the final result at the receiver. If launched signals used during the test are degraded more than that allowed then the interconnect will be called on to cause less degradation so that the result at the receiver will still be within specification. The use of excessively degraded launched signals places unfair burden on the interconnect. Conversely, if the launched signals are better than allowed, the interconnect may cause more degradation than allowed for the interconnect but still deliver compliant signals to the receiver. This condition permits defective interconnect to be measured as good interconnect. The way to avoid these risks is to execute an adequate characterization of the launched signals and to compensate in the test requirements for the amount of excess goodness or badness in the launched signals. Figure 1 illustrates this general scheme.

Another risk derives from the fact that some parameters in launched signals can be corrected by interconnect that introduces degradation of equal and opposite sign. If this happens it gives a false sense of goodness since launched signals from other transmitters may have the parameters degraded in the same sense as the interconnect with a resulting doubling in the negative effects at the receiver.

In general, if the polarity of connection of the interconnect to the launched signals is reversed then the polarity of the degradation in the interconnect is also reversed (for those parameters that are sensitive to polarity, like balance degradation and near end cross talk). 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 interconnect properties causes additional burden on the testing 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 tests be executed because one cannot be sure which sense of degradation is present in the interconnect under test.

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

This process eliminates a major problem with creating calibrated degraded high frequency signals, uses the linear property of copper interconnect to good advantage, and allows the properties of the interconnect to be fairly and accurately measured.
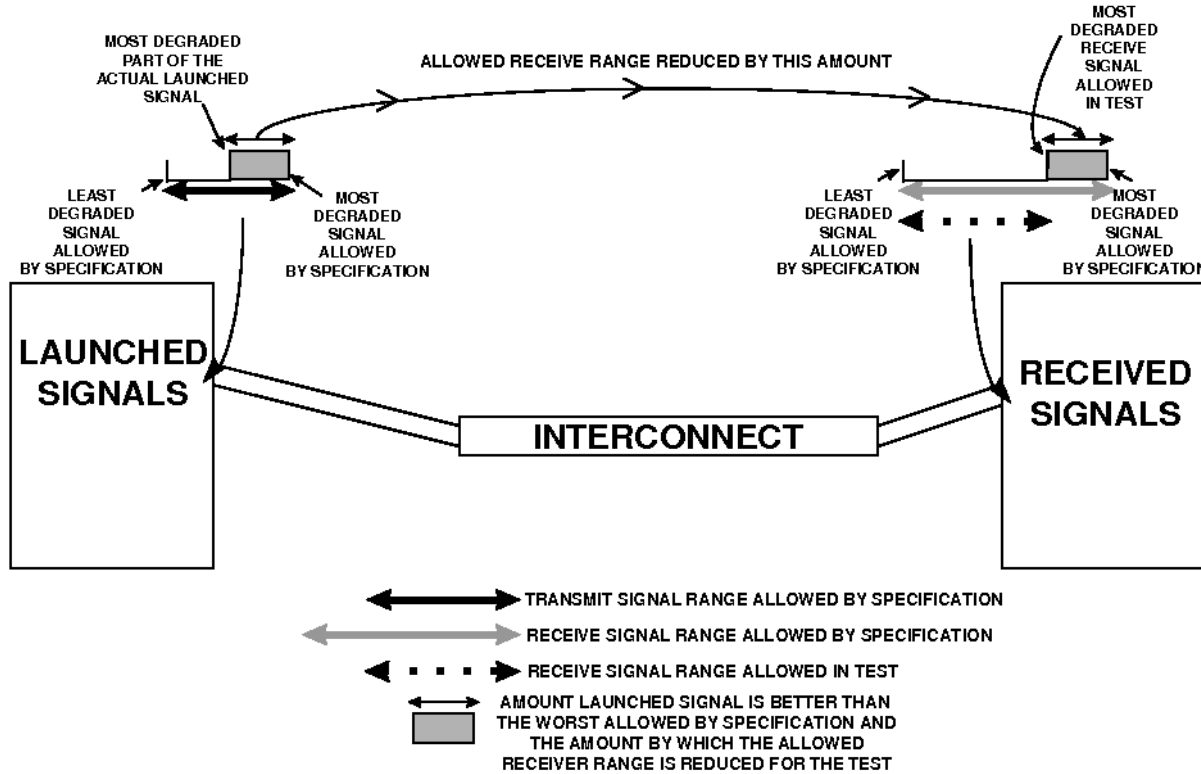
Figure 1 - Range compensation strategy
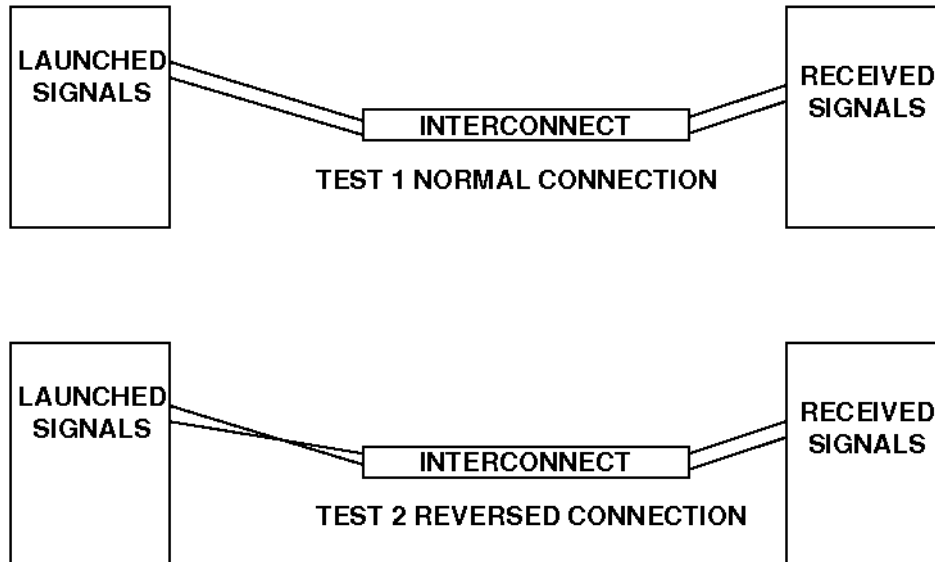
Figure 2 - Degradation sense compensation / detection

3. Framework for HSS testing

3.1 Overview

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 interconnect. These requirements apply to the physical connector and to its electrical neighborhood. See section 3.6. Since the connector does not exist alone in a serial link the electrical properties of (1) the wire (or other conductor) termination to the connector contact and (2) any other non-uniformities within the electrical neighborhood of the connector are intrinsic parts of the performance of the connector and its associated interconnect. The electrical performance requirements are on the finished cable assembly, board, the mated partner to the connector and whatever exists within the electrical neighborhood of the physical connector. Tests that are used to measure the high frequency performance properties are termed HSS tests.

3.2 HSS test levels

3.2.1 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 3.2.2,
3.2.3, and **Error! Reference source not found.**.

3.2.2 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.

3.2.3 Level 2 measurement definition

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

3.3 Applicability to specific connectors

This document contains electrical testing requirements for HSS copper interconnect
applications relating to the HSSDC and HSSDB9 connectors. The test methods could
also be applied to the SCA-2 40 position connector and other legacy connectors.
While these legacy connectors formally have the same performance requirements in the
standards as the HSSDC and HSSDB9 (since they are used in the same kind of link) this
specification is not attempting to place new requirements on legacy connectors. If
an interconnect containing an SCA-2 connector, for example, were to meet the
requirements in this specification the connector could be considered an HSSSCA-2.

It is assumed that the connectors will be used in a duplex connection where one pair
of balanced signal lines is propagating a high speed differential signal through the
connector in one direction and another pair of balanced signal lines is propagating
an asynchronous (to the first signal) differential signal through the connector in
the opposite direction. Other connectors that may be defined in future
specifications when used in a duplex signal application may also be subject to the
requirements in this document

Many of the test philosophies and methods documented herein may be applied, with
minor modification, to other physical interconnect variants such as unbalanced copper
cables, balanced copper backplanes, single mode optical links and multimode optical
links. This document is intended to provide the foundation for developing specific
test procedures for all high speed serial interconnects.

3.4 Basic measurement issues - Oculus / VNA / TRL /

[This subject was only briefly discussed in this meeting and small modifications were
made to the content below. This section will be retained until the relevant parts
can be moved into the SFF-8415 document. There was a significant change of position
at this meeting in terms of using the VNA as a level 1 test. By adding a requirement
that cross talk be low the single differential channel VNA can yield a good result.
By restricting the S21 suckout intensity to low levels (3dB??) the results of the
time domain eye diagram test may be validated. Therefore the VNA for both cross talk
and S21 is now considered a requirement for level 1 testing - contrary to the words
listed below.]

Bill went thru another brief pass at the vector network analyzer (VNA) concepts, potential uses, and limitations. One goal of this discussion was to determine whether the HPEI group should seriously consider VNA based measurement techniques for level 1 testing.

Dana had previously presented data comparing different Baluns with calculated results using vector network analyzers. It was clearly shown that the effects of the baluns can severely distort the results of an attenuation test. The data shown used proprietary software but similar software is available from ATN. This data shown was attached to previous minutes.

There was an extended discussion concerning whether vector network analysis is suitable for level 1 performance testing. The primary discussion considers two basic trade offs:

(1) poor performance of test fixtures, which may include baluns
(2) poor ability of VNA's to capture the entire suite of signal and balance
    degradation that occurs during real signal transmission.

Since cross talk can be a major component of signal degradation, no scheme that does not adequately consider cross talk can be considered as a level 1 performance test.

On the other hand any measurement scheme that does not give reasonably accurate results also cannot be considered for level 1 or level 2 testing in the first place.

In principal, VNA's can do a good job of extracting performance parameters in multiple specific test configurations and by using these extracted parameters as input for an excellent signal simulation tool the real signal degradation may be revealed.

A further major benefit of using the parameter extraction / signal simulation method is that the signal degradation for the IUT can be revealed for any arbitrary launched signal: special signal generators having exactly the right properties are not needed.

The main factors impeding the use of the VNA approach for level 1 testing are:

   I.   maturity level for the parameter extraction methods and results
   II.   lack of a complete suite of test configurations for ensuring that the cross
         talk effects are adequately captured
   III. lack of good specifications on how to construct the models for the IUT
   IV.   lack of good modeling based specification methods for the launched signals
   V.   unknown simulation time and tools for executing the final signal simulation
   VI.   general lack of confidence in any modeled results across a broad spectrum of
         the industry.
   VII. lack of calibration kits that allow moving the reference plane onto the
         surface mount provisions of the receptacle on the test fixture board (rather
         than at the 3.5 mm/SMA connector reference plane). (These connectors are good
         up to 26.5GHz presently available for VNA instruments)

Therefore, without exception, the HPEI SSWG rejected the use of VNA based approaches for SFF-8415 as a level 1 test. It was recommended that a section be added to SFF-8415 that discusses the VNA approach, outlines exactly what is needed to use it for level 1 testing in future documents, and possibly how to use it for some level 2 applications (e.g. primary attenuation).

This position forces continued emphasis on passive test fixture connection to eye diagram instrumentation for level 1 signal degradation measurements in SFF-8415. This may limit the upper frequency that can be accurately addressed - especially for measurements that use baluns.

3.5 Time vs frequency domain measurements

The meaning of the terms "measurement", "measurement type", "instrument detector type", and "stimulus type" is discussed in this section. The following represents the consensus of the group.

The instrument detector type is determined by whether a detector tuned to a frequency is used or not. If a tuned detector is used the instrument detector type is frequency domain, if not, it is a time domain.

The nature of the stimulus used in the measurement contains both frequency and time domain properties and is determined by the name of the waveforms used - it is not classified as either time domain or frequency domain.

A measurement is the output presented to the user by an instrument as a result of the stimulus applied to a physical part and the reaction of the instrument detector. Note that there may be significant processing of the response within the instrument after the detector and before presentation to the user.

Note that if anything is changed from the conditions used to achieve the original measurement that this is no longer a measurement. Examples of things that could change are different resistive loads and different data patterns or other stimuli.

Unless a physical part, a physical stimulus, and a detecting instrument are all present then the activity is not a measurement.

All outputs created by not using physical parts or physical stimulus are considered simulations in this document.

Some methods combine measurements with simulations and/or models to produce measurement based simulations.

It is up to the user to clearly define the boundaries of the instrument.

There is no benefit from defining the term "measurement type". This term will not be used in this document.

3.6 Electrical Neighborhood

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

- not part of the physical connector
- attached to a connector termination contact through a signal path
- any part of the signal path 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 a physical connector part. 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 physical connector. Examples of extended electrical neighborhoods are attenuation or cross talk measurements that are affected by the far end termination and media impedance far away from the connectors.

two types of electrical neighborhood are defined:

- close proximity (within three STD lengths of the physical connector)
- extended: not close proximity

For example, for a 200 ps (0.2 ns) STD and a media 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 closest physical connector part. 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 will have a smaller electrical neighborhood.

Features within the close proximity electrical neighborhood may act as if they were part of the connector itself as far as contribution to the overall performance of the interconnect is concerned. 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 3.
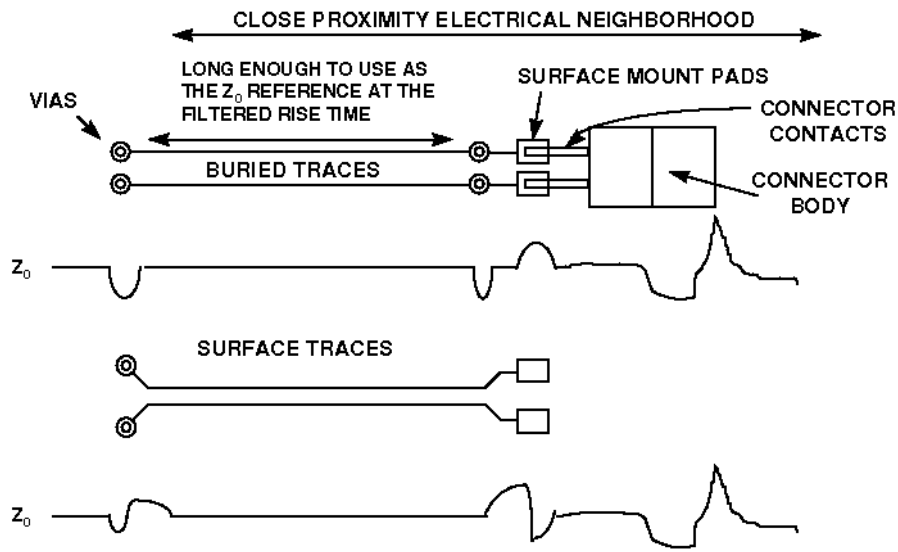
Figure 3 - Some key design areas for pcb features

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 4 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.
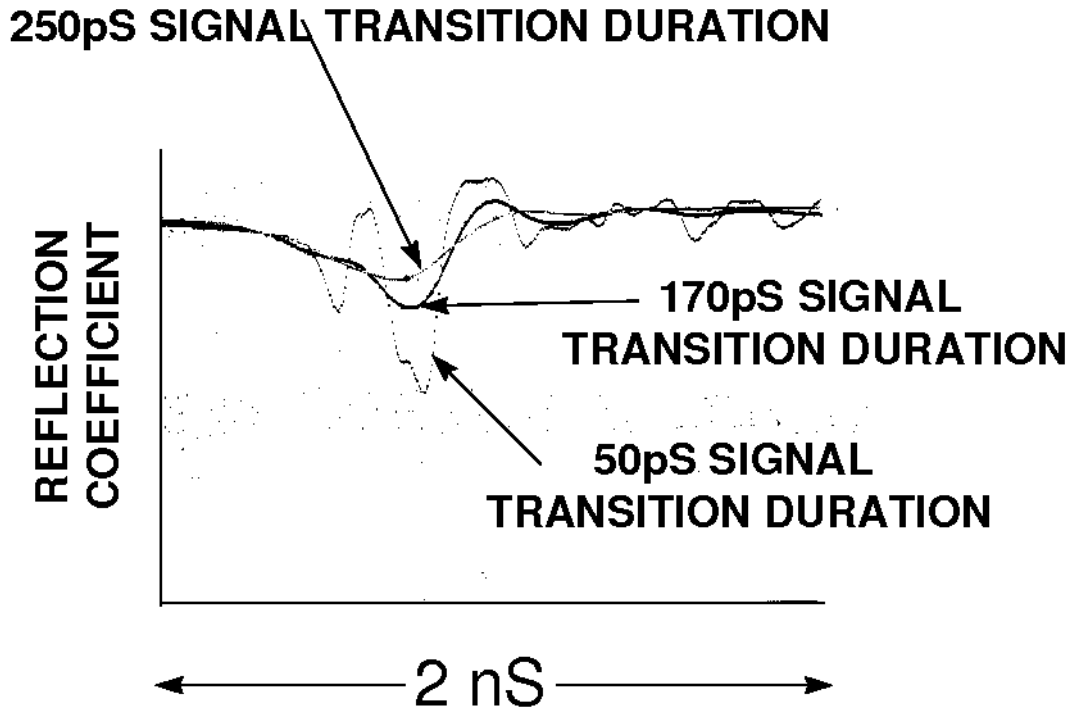
Figure 4 - TDR data in a typical HSS cable assembly

3.7 Definition of level 1 HSS electrical performance parameters

This section gives more detail concerning the level 1 performance requirements.

3.7.1 Definition of PUT and PUT$_{NOT}$

Duplex cable assemblies have two basic parts: (1) the half of the duplex containing the signal path under test and (2) the other half of the duplex containing the half NOT under test. The part that is under test is called the "pair under test" or the PUT. The part that is not under test is called the "pair not under test" or the PUT$_{NOT}$.

The PUT and the PUT$_{NOT}$ each have an associated transmitter and receiver. Figure 5 illustrates the relationships.
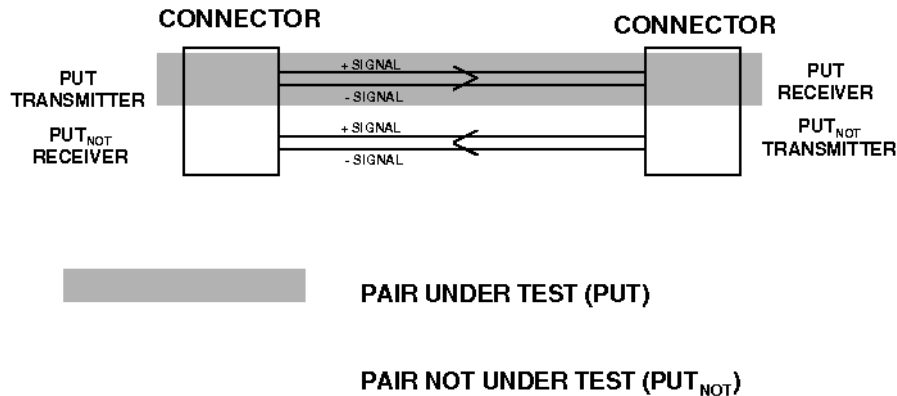
Figure 5 - Terminology for duplex interconnect under test

Figure 6 shows the conventions and abbreviations used for signals and instruments.
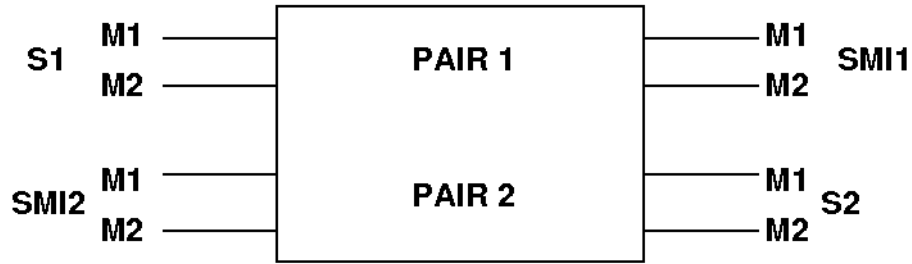
M1 = + SIGNAL
M2 = - SIGNAL
S1 = DIFFERENTIAL SIGNAL SOURCE 1 (LAUNCH)
S2 = DIFFERENTIAL SIGNAL SOURCE 2 (LAUNCH)
SMI1 = SIGNAL MEASUREMENT INSTRUMENT 1
SMI2 = SIGNAL MEASUREMENT INSTRUMENT 2
(SMI1 AND SMI2 SHALL BE CAPABLE OF SUBTRACTING
M1 AND M2 TO PRODUCE A DIFFERENTIAL SIGNAL AND
ADDING M1 AND M2 TO PRODUCE A COMMON MODE
SIGNAL)

Figure 6 - Definition of abbreviations used for signals and instruments

3.8 Time domain waveform measurements

The idea here is to eliminate the test fixture effects by using a full time domain waveform measurement (TDW) to calibrate the thru fixture and to acquire the data. Oculus or IConnect® is then used to recreate the time domain eye with the appropriate data pattern. Agreement between the recreated measurements that included the text fixture and the raw time domain data has been demonstrated to be quite good (within measurement error around 1%).

This is only useful with simplex measurements at the moment, however, multiline methods are in development at atSpeed and TDA systems.

The term "vector time domain" has been used in some earlier SFF presentations. This term is now replaced by the term "**time domain waveform, TDW**" to describe measurements where the entire waveform is used in deriving the results. The term "scalar" is not used anymore. When a thru fixture / IUT + test fixture on each end methodology is used the terminology is "**fixture calibrated TDW**"

The STD of the launch signal (TDW) has no effect on the extracted transfer function in the frequency range where the frequency content is common. STD's with lower frequency content do not reveal the S21 properties at the higher frequencies.

The performance of the IUT with specific data patterns is simulated using specific requirements for the application.

The architecture of the measurement involves acquiring five different TDW results

```
                    ┌─────────────────────┐
   S1   M1 ─────────┤                     ├───── M1  SMI1
   SMI3 M2 ─────────┤      PAIR 1         ├───── M2  S4
                    │      (PUT)          │
                    │                     │
   SMI2 M1 ─────────┤      PAIR 2         ├───── M1
   S3   M2 ─────────┤      (PUT_NOT)      ├───── M2   S2
                    └─────────────────────┘
```
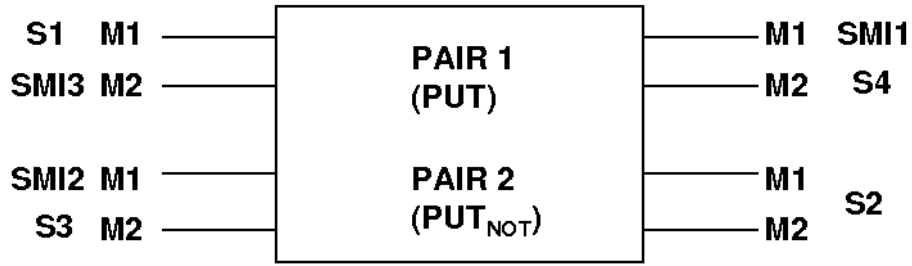
M1 = + SIGNAL
M2 = - SIGNAL
SX = DIFFERENTIAL SIGNAL SOURCE X (LAUNCH)
SMIX = SIGNAL MEASUREMENT INSTRUMENT X
(SMIX2 SHALL BE CAPABLE OF SUBTRACTING
M1 AND M2 TO PRODUCE A DIFFERENTIAL SIGNAL AND
ADDING M1 AND M2 TO PRODUCE A COMMON MODE
SIGNAL)

The first step is to characterize the thru test fixture (TTF). The following measurements are done on the TTF:

S1 to TTF to SMI1 (Sij especially S21)
S2 to TTF to SMI1 (Sij especially S21 Next)
S3 to TTF to SMI1 (Sij especially S21 Fext)
S1 to TTF to SMI3 (Sij especially S11)
S4 to TTF to SMI1 (Sij especially S22)

The IUT is inserted and the same set of data is acquired.

The set of data from the TTF calibration and the IUT constitutes all the physical measurements required.

Using this data and the appropriate software tools an S parameter matrix can be created. This matrix is used to calculate the differential and common mode performance. The data pattern of interest is applied to the S-parameter matrix to produce an eye diagram output that includes the cross talk noise content from PUT_{NOT}.

This methodology is not quite released from the tool suppliers (cross talk not yet included) and needs to be validated. However, it promises to become a valid methodology and is treated in this document as suitable for level 1 tests.

3.8.1 Definition of level 1 electrical performance parameters

There are seven level 1 electrical performance measurements defined:

1. **Signal degradation: - differential signal transmission degradation test**

    Four options are described as summarized in the following table:

	Physical eye diagram measurement based	Simulated eye diagram from measured S parameters
Integral cross talk	1.1 With simultaneous asynchronous physical aggressor signals	1.3 Multiline simulation including aggressor sources and cross talk terms
Separate cross talk	1.2 Three separate steps: (1) eye diagram without aggressors (2) stand alone cross talk (3) combination of eye diagram and cross talk to form composite eye	1.4 Multiple single line simulations: (1) where no cross talk is present and (2) where cross talk is simulated as a single line. Results are post processed to form a single composite eye

The required S-parameter suite includes:

- Swept frequency return loss (SDD11, SDD22) for PUT.
- Swept frequency common mode return loss (SCC11, SCC22) for PUT, for differential constructions only.

Swept frequency insertion loss (SDD21) suite between PUT and PUTNOT's – includes aggressor/victim insertion loss functions.

If transmitters are allowed to use compensation then that compensation shall be emulated in the measurements over the allowed range of parameters for the transmitter device. Use of "golden PLL" timing references for output signal measurements are optional.

Both swept frequency S21 tests and swept frequency near and far end cross talk tests are required to ensure that the results are robust.

2. Swept frequency differential return loss (SDD11, SDD22)

3. Swept frequency Common Mode Return Loss (SCC11, SCC22), for differential constructions only.

4. **Cross Talk (near and far end).**
   Further discussion needed on frequency domain versus time domain testing. Dean Vermeersch will submit proposed test procedure. requires that the power sum of cross talk from all aggressors be limited to less than -22 dB across the frequency range up to the data rate fundamental. Meeting this requirement and the previous requirement guarantees that the eye diagram will change by no more than a few percent due to small differences between the measurement conditions and the service conditions.

5. **Electromagnetic compatibility (EMC):**
   the energy that may be coupled to the world external to the IUT shield. Two methods for measuring this performance requirement are available: (1) Common mode power transfer, CMPT, (formerly known as "transfer impedance" or shield effectiveness) and (2) Electromagnetic radiation.

6. Propagation time and propagation time skew (pair-to-pair, for multi-pair applications only)

7. Differential to common mode conversion.

Pie chart needs work???
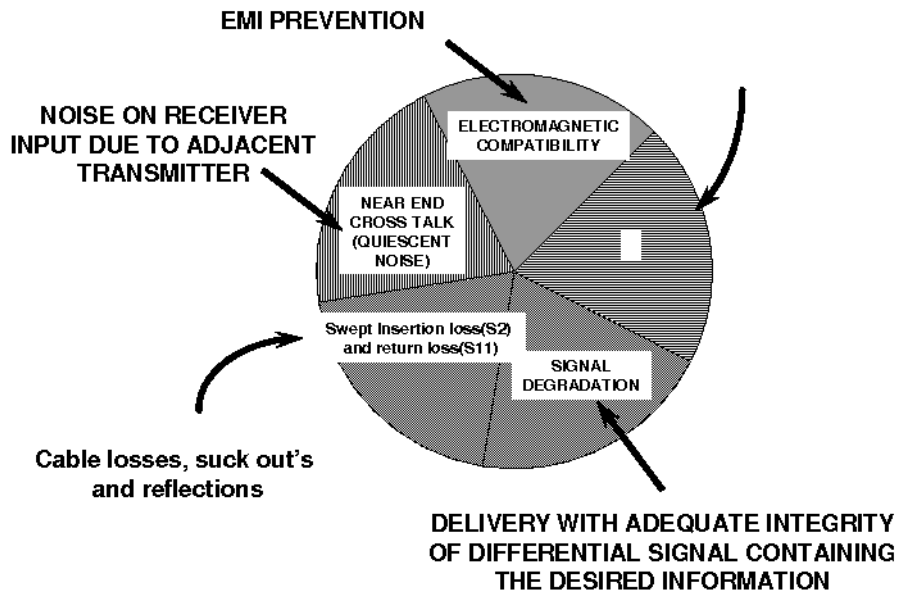
Figure 7 - Level 1 tests
[this figure needs to be modified]

3.9 Definition of level 2 HSS electrical performance parameters

Level 2 measurements:

1   Eye pattern with no cross talk aggressors.
2   Group propagation time dispersion. Does this mean phase dispersion?
3   Impedance profile
4   Cross talk using alternate method from cross talk test in level 1.
5   Amplitude imbalance between the + signal and – signal.
6   Within pair skew.
7   Swept frequency insertion loss (S21) – no suckouts measured from the departure
    from an eyeball curve fit up to a frequency of 2.5 times the fundamental
    frequency of the basic signal. The frequency of the suckout is defined as the
    lowest frequency where the 3dB departure from the eyeball curve fit occurs. This
    test is needed to ensure that the signal degradation test is robust. Meeting
    this requirement and the following requirement guarantees that the eye diagram
    will change by no more than a few percent due to small differences between the
    measurement conditions and the service conditions. [details are likely to change
    based on current round robin work]

Eight level 2 electrical performance parameters are defined below.

1. **Amplitude imbalance between the + signal and - signal:**
    the maximum magnitude of the difference between the peak amplitudes on the +
    signal and – signal lines at any point in time.

2. **Group propagation time dispersion**
    – also called group delay dispersion or phase dispersion – also known as the
    phase content for S21 – diagnostic method for addressing ISI issues

3. **Impedance profile:**
    Z_0 (differential) reflection coefficient versus distance at minimum signal
    transition duration for the application – measures the ability of the interconnect
    to function within specifications as a transmission line in the electrical
    neighborhood of the connector by the use of time domain reflectometry. Also

includes requirements on the transmission line outside the electrical neighborhood of the connector in the cable media through the use of differential reflection coefficient with suitable modifications.

4. **Cross talk component of signal degradation:**
The effect of asynchronous signals on PUT$_{NOT}$ on the signals in the PUT. Cross talk generally degrades signal quality including increased jitter and amplitude parameters on the differential eye pattern. Three different approaches are described: individual pulses, eye diagram with broad spectral data pattern, and swept sinusoidal.

5. **Swept frequency differential to common mode conversion**
- required to ensure adequate EMI performance from unshielded constructions. A TDNA or VNA is required to execute this test. It is expected that the IUT is in the position in the system that will be used in service when this test is executed.
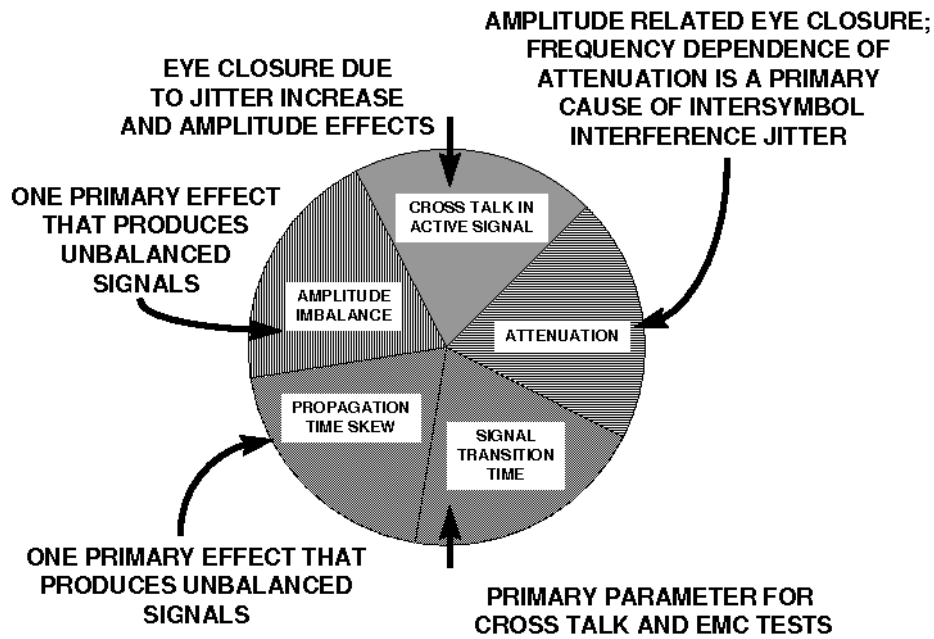
Figure 8 - Level 2 tests

3.10 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 interconnect under test (IUT)
- calibration procedures to account for the effect of fixturing
- applied stimuli and measured responses that contain the results of the HSS test

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 will usually be different for the different tests.

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

3.11 Definition of the HSS interconnect under test (IUT)

The interconnect under test (IUT) is always at least a mated connector pair (for example connectors A and B in Figure 9), the terminations for each side of the mated connector, and the electrical features within the electrical neighborhood for each side of the mated connector. In some cases the interconnect under test is a completed cable assembly having a specific length, the mated connectors on each end and the electrical features within the electrical neighborhood of each end.

TP1   PHYSICAL INTERCONNECT   TP2
           UNDER TEST

(GAMMA T PER FC-PI)

A B   C D

SEPARABLE INTERCONNECT
COMPONENT UNDER TEST

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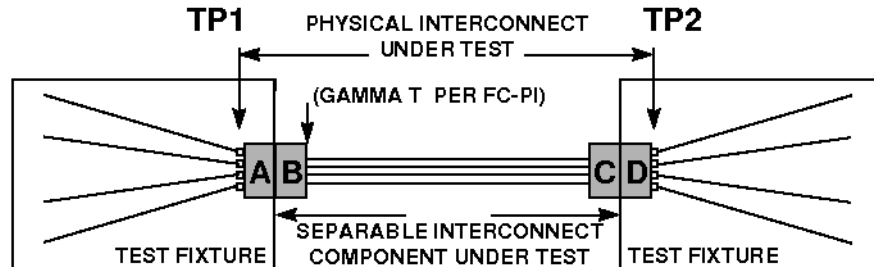
A, D = PERMANENTLY MOUNTED CONNECTOR ON THE TEST FIXTURE
B, C = PART OF THE SEPARABLE INTERCONNECT UNDER TEST

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

SEPARABLE INTERCONNECT PERFORMANCE IS JUDGED BY ITS PERFORMANCE
AT TP1 AND TP2 (WHICH INCLUDES THE EFFECTS OF CONNECTORS A AND D)

NOTE: FOR THE INTERCONNECT ASSEMBLY, IT IS RECOMMENDED THAT
SPECIFICATIONS FOR SIGNALS AT GAMMA T BE APPLIED AT TP1 AND NOT
AT THE POSITION INDICATED IN FC-PI FOR GAMMA T (THIS PRACTICE EFFECTIVELY
INCLUDES THE LOSSES IN THE A/B PAIR TWICE - ONCE FOR THE TRANSMITTER
AND AGAIN FOR THE INTERCONNECT ASSEMBLY. THIS ELIMINATES THE POSSIBLITY
IN FC-PI OF AN INTERCONNECT SUPPLIER DISCOUNTING THE PERFORMANCE OF
THE A/B PORTION OF THE INTERCONNECT)

Figure 9 - Definition of the interconnect under test

This definition of the interconnect under test does not allow electrical performance specification of a connector outside the context of a specific application. Some tests, such as impedance profile may allow visibility of the contribution of the connector while other tests will show only the net effect of the complete interconnect system under test without directly offering visibility to the contribution of the connector. If the interconnect system performs adequately according to the tests in this document then the connectors or other pieces of the interconnect system are adequate.

3.12 Special considerations for test fixtures

Using the definition of the IUT in section 3.11 parts of the total IUT remains attached to the test fixtures and are typically used many times when testing different removable parts of the IUT (see Figure 9). The "A" and "D" halves of the mated connectors are permanently attached and are termed the "stationary" parts of the IUT.

This definition for the IUT is necessary in order to measure the performance of the total connection but it has several consequences that may not be obvious.

The contribution of the stationary parts of the IUT to the measured result for the total IUT may not be small. The stationary parts could compensate for or exacerbate degradations caused by the removable parts of the IUT. It is generally expected that different removable parts of the IUT will cause different total IUT test results. What may be less obvious is that IUT's with the same removable part but with different test fixtures with different stationary parts may also yield different

results. In both cases the differences in the IUT test results exist even if
identical instrumentation and calibration processes are used.

Therefore:

- Differences in the IUT test results from different laboratories are to be expected
  unless the same total IUT (both the same stationary and the same removable parts)
  are tested together

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

- If the stationary parts of the IUT exacerbate the degradation in the removable
  parts to the extreme allowed without allowing the total IUT to fail then a more
  conservative total IUT test results and it becomes unlikely that testing with
  different stationary IUT parts will show failures in the total IUT

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

Although the stationary parts of the IUT 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 stationary parts of the IUT is also formally part of the IUT and not part of the
test fixture.

Test system rise time, Dean V.

[retained until transfer to the document]

Dean went through several approaches to the issue of rise time at different points in
the test system. This issue is becoming very important.

Dean to supply presentation in electronic format.

3.13 Extensions to parallel - serial constructions

This section 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 and more paths carrying
information is easier than a single path because clock rate increase on a single path
is not desirable. Other possible reasons include needing additional independent
control paths and needing some paths to be bi-directional. When the basic
transmission on a single path is serial unidirectional 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 new transports, including FC, are considering using p-s constructions because
the problems facing increasing the data rate on a single path are greater than the
problems of introducing multiple paths.

The extensions described here apply only to point to point applications (which may or
may not contain equalizers or active circuits in the path for most tests).
Specifically, multidrop constructions are not considered.

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 10. The Sn is a source for the nth path while the SMIn is the signal
measurement instrument corresponding to the nth source.

GENERALIZED PARALLEL SERIAL PATHS
FOR POINT TO POINT CONNECTIONS

S_n ——— LEFT TO RIGHT PATH ——→ SMI_n

SMI_{n+1} ←——— RIGHT TO LEFT PATH ——— S_{n+1}

SMI_{n+2}/S_{n+3} ←——— BI-DIRECTIONAL PATH ——→ S_{n+2}/SMI_{n+3}

←——— BI-DIRECTIONAL PATH ——→

←——— RIGHT TO LEFT PATH ———

←——— BI-DIRECTIONAL PATH ——→

——— LEFT TO RIGHT PATH ——→

←——— RIGHT TO LEFT PATH ———

——— LEFT TO RIGHT PATH ——→
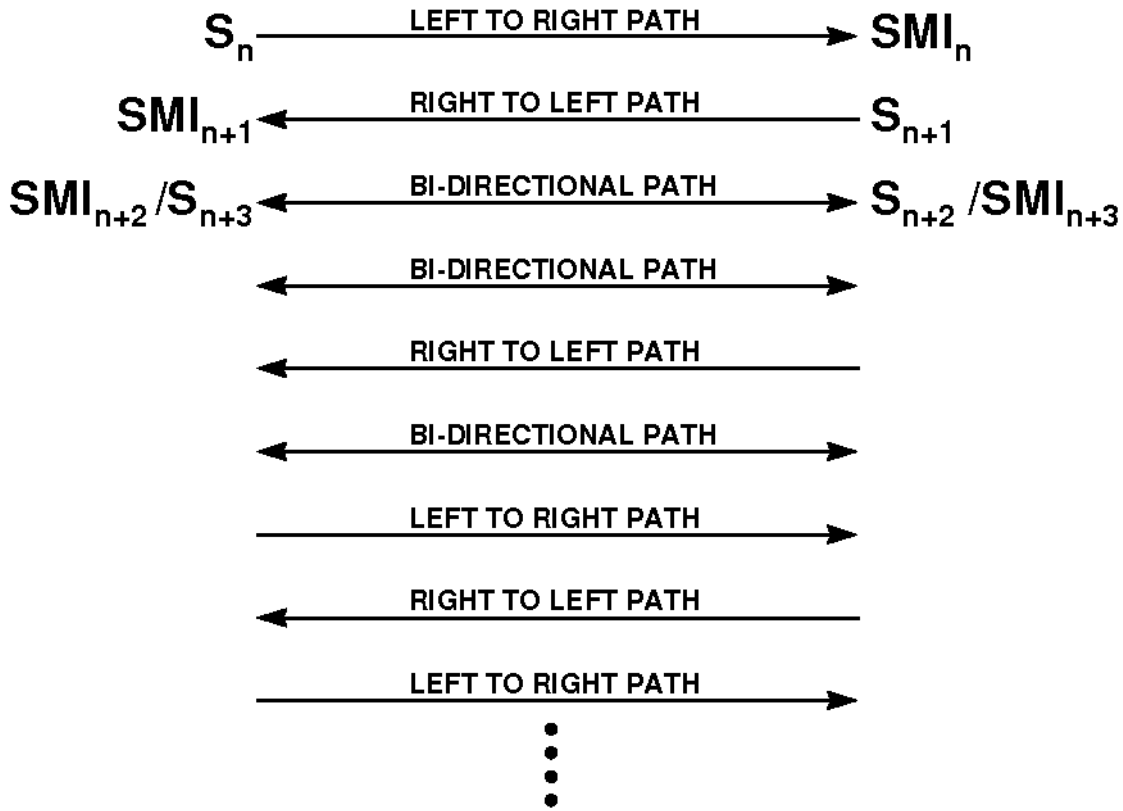
Figure 10 - Sources and instruments for a general p-s construction

The five level 1 tests for duplex assemblies each have a counterpart in p-s constructions. Each will be briefly considered separately.

3.13.1 Impedance profile for p-s constructions

The impedance profile test is exactly the same as for a duplex PUT. Each path in the p-s construction is measured separately and uses the same test procedures described in this document.
Taken over by S21 and S11

3.13.2 Signal degradation for p-s constructions

This test is essentially the same as for duplex assemblies except that additional second sources may be required for all the PUT_{NOT}'s and a test fixture suitable for the p-s construction is needed. Note that there may be second sources on the same side of the IUT as the primary source.

A general feature of p-s constructions is that one does not need to use second sources for the paths that are not coupling significantly to the PUT. However, until proven otherwise, ALL PUT_{NOT}'s shall have worst case signals applied. Unfortunately there is no simple way to use superposition for this test (unlike the cross talk test described below) so all second sources shall be on at the same time the PUT is being tested.

All the second sources on the same side may be derived from the same clock source as would be normal in a real application and may be distributed to several PUT$_{NOT}$'s from the same second source. Many times the second sources on the same side as the Sn will be derived from the same clock source as the Sn and Sn may also be used as a second source in this case. It is up to the user to determine the requirements of the transport protocol and to structure the test accordingly.

For the bi-directional case where each direction is used at different times by the transport protocol the path must be tested separately in each direction. There is at least one implementation used in Ethernet where the launched signal simultaneously contains the received signal and signal processing is used to subtract the transmitted signal so that the received signal may be revealed. This document does not describe how to test simultaneous bi-directional transmissions.

A complete test of a p-s construction is therefore a combination of tests where each PUT is separately tested. For example, a p-s construction containing 4 left to right, 4 right to left, and 2 bi-directional paths a total of 4+4+2x2=12 tests are needed.

3.13.3 Balance degradation for p-s constructions

The balance degradation tests follow exactly the same flow as described in 3.13.2 for the signal degradation except using the balance degradation methodology instead of the signal degradation methodology.

3.13.4 EMC 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.

3.13.5 Near end cross talk for p-s constructions

Near end cross talk for p-s constructions is determined by sequentially applying aggressor pulses on every path except the victim path and recording the cross talk contribution from each aggressor path. The absolute value of the results are then added to produce to total cross talk on that victim line. The test 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 does produce a conservative (i.e. more stringent) test on the IUT than actually exists in service. However, since there is no correlation assumed (either time or amplitude) between the aggressor signal and the service signals in this test the resulting noise measurement (calculation) is the worst possible condition and there cannot be a more intense cross talk in service than revealed by this test.

The process is repeated for every victim line in the p-s construction.

Note that for bi-directional paths that two tests are required.

Will depend on the NEXT method picked.

3.13.6 Summary of extensions to p-s constructions

With simple modifications to the test 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.

3.14 Data pattern considerations

3.14.1 Effective data patterns - lonely bit issues, Greg Vaupotic

Greg Vaupotic reviewed his earlier data that showed significant effects from the lonely bit. A lively discussion ensued with the following results:

There are three possible issues:

- Data acquisition time may not be adequate for detecting the worst case event
- The calibration of the system for the PRBS measurement and with the lonely bit need to be validated
- The conditions present during the lonely bit response NEVER occurs in the PRBS pattern regardless of how long data acquisition persists.

There was no definite conclusion at this meeting and further discussion is needed.

Greg to send the data presented.

3.15 Behavioral considerations rarely encountered below 1 GHz

3.15.1 Effects of periodic structures

Some examples: foil wrap period, cable lay period, shield braid spikes, flat spots on rollers, printing on external jackets, periodic via placement on PCB, periodic slots in ground planes, designed in structures such as connector placements in multidrop constructions.
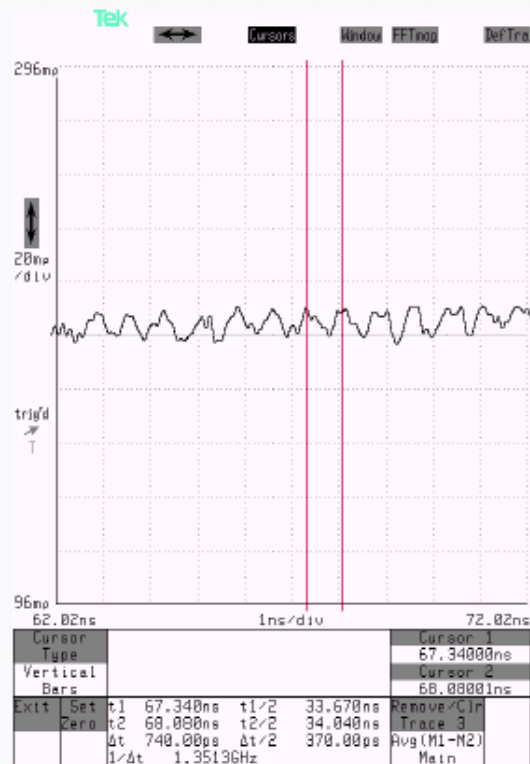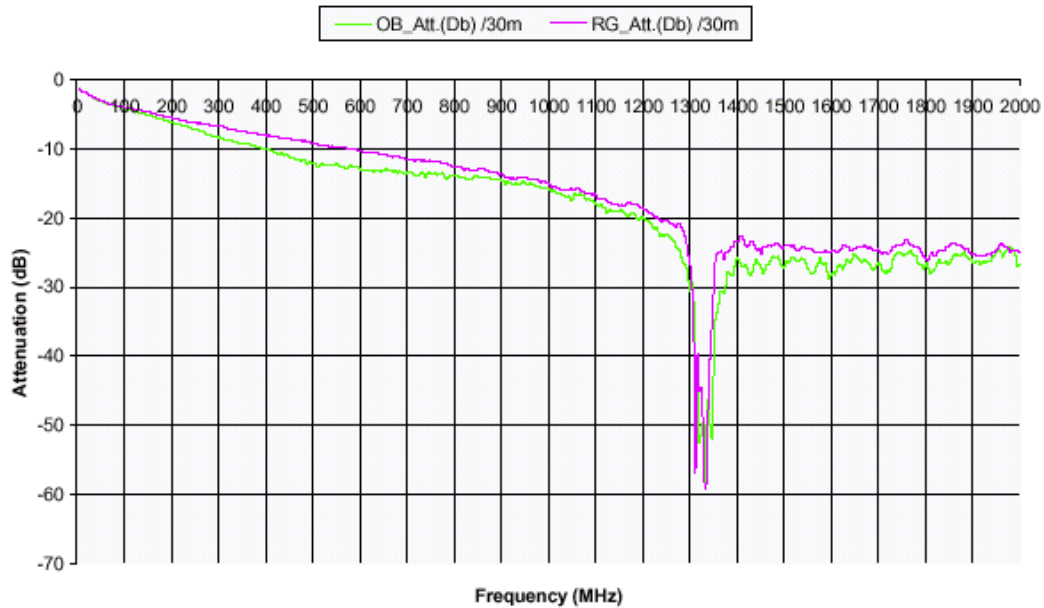
3.15.2 Interactions between in-pair propagation time skew and attenuation

3.15.3 Suckouts due to launch signal skew

3.15.4 Higher order waveguide mode excitation

Usually initiated by some kind of signal interference or physical disturbance. Exceeding the cutoff frequency for the lowest modes.

3.15.5 Differential to common mode conversion

3.15.6 Dielectric frequency response

3.16 Evaluating HPEI performance when precompensation and/or receiver compensation is expected

  – add material from T11 presentation.

3.16.1 Timing reference issues

Add material relating to golden PLL

3.17 PCB considerations

3.17.1 Relationship between cable and PCB geometries

24 & 30AWG solid vs 5 & 10 mil 1 oz copper

**DRAWN APPROXIMATELY
TO SCALE
HIGH FREQUENCY
CURRENTS FLOW
MAINLY ON THE SURFACE***

30 AWG copper
24 AWG copper

**CONSIDERING THE
SURFACE AREA ONLY,
A 0.5 METER 5 MIL PCB
TRACE HAS THE
SAME LOSS AS A
6 METER 24 AWG WIRE**

1 oz copper 10 mil
PCB trace

1 oz copper 5 mil
PCB trace
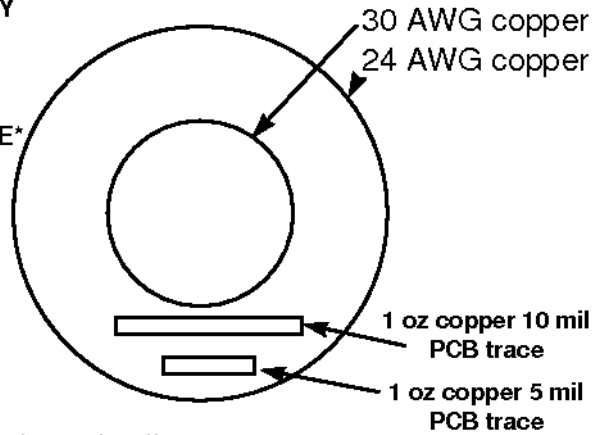
@1GHz copper skin depth ~0.1 mil

*PCB has rough surfaces both sides due to
electroplating process and surface of substrate
(most current flows on the substrate side normally)
PCB dielectric losses are high

3.18 Map of the HSS parameters

Table 1 shows the map of the HSS performance parameters

Table 1 - Map of the HSS testing requirements

Parameter	Test fixture and measurement equipment description	Calibration procedure	Test procedure	Acceptable ranges
Insertuon Loss (s21) and Return Loss (s11)	Section 4.1.1	Section 4.1.2	Section 4.1.6	SECTION 4.1.7
signal degradation	Section 4.2.1	Section 4.2.2	Section 4.2.3	section 4.2.4
	SECTION 4.3.1	SECTION 4.3.2	SECTION 4.3.3	section 4.3.4
EMC CMPT EMR	Section 4.4.1.1 SECTION 4.4.2.1	Section 4.4.1.2 section 4.4.2.2	Section 4.4.1.3 section 4.4.2.3	SECTION 4.4.1.4
near end cross talk	section 4.5.1	section 4.5.2	section 4.5.3	SECTION 4.5.4
Attenuation	Section 5.1.1	Section 5.1.2	Section 5.1.3	NA
propagation time Skew	Section 5.2.1	Section 5.2.2	Section 5.2.3	NA
amplitude imbalance	section 5.3.1	section 5.3.2	section 5.3.3	NA
signal transition duration	Section 5.4.1	Section 5.4.2	Section 5.4.3	NA
Cross talk component of signal degradation	Section 5.5.3.1	Section 5.5.3.2	Section 5.5.3.3	NA
Common mode conversion				

4. Level 1 tests

4.1 Swept frequency SDD11 and SDD21

This test can be done with TDVNA or VNA. Equipment such as Tektronix TDS/CSA 8000 with appropriate software can be used to extract the S21 and S11 from the time domain data.

4.1.1 Test fixture and measurement

4.1.1.1 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 11.

Insert test fixture figure here Fig 39 from 8416 plus new pcb one

Figure 11 Test Fixtures

Two measurement test fixtures are required: one for the source end and one for the sink end. Also impedance through the cable assembly attachment area shall be carefully controlled to avoid local cavity effects and resonances in the measurement caused by the measurement process.

Considerations for designing this area of the measurement system include:
- .maximum frequency of interest
- length of the cable assembly
- overall length of the test fixture + cable

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.
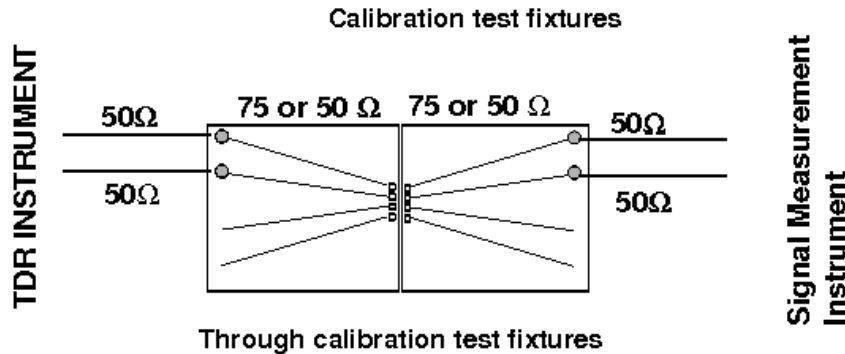
The construction of the SMA to mating connector path should be the same physical properties and electrical length as that of the connectorized test fixtures.

Figure 12 - Test configuration for Swept frequency S21 and S11.

The test fixture may be constructed of semi rigid coax, precision coax, microstrip PCB, or stripline PCB. The test fixture must contain the entire close proximity electrical neighborhood on the side of the connector near the instrumentation and have a section where there are no non uniformities such as vias.

4.1.1.2 TDVNA Measurement equipment

4.1.1.2.1 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.

4.1.1.2.1.1 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 5.6.3), 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 ????
An example of suitable measurement equipment up to 20 GHz is an Agilent 8720ES VNA with an N4418A s parameter test set.

4.1.1.2.1.2 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.

4.1.2 Calibration and verification 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 ????

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 40. 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 40 and Figure 41 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 ?? – 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 ??.

50 OHM
SEMI RIGID COAX
APPROX 75 MM LENGTH
SEMI-RIGID COAX LENGTHS
SHALL BE MATCHED WITHIN 10 ps
SOLDER
CONNECTION TO
EQUIPMENT SETUP
SOLDER CONNECTION TO
EQUIPMENT SETUP
CHARACTERIZED
SMA THROUGH
CONNECT
ADAPTER
THROUGH CONNECT PORTION
OF VNA CALIBRATION
REFERENCE PLANE
FOR VNA
REFERENCE PLANE FOR TDNA

Figure for TDNA fixture goes here

For TDNA measurement a reference waveform is recorded using the conditions in either Figure ?? or Figure ??. 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 41.

4.1.3 Testing Procedure

4.1.4

4.1.5

4.1.5.1 Test fixture verification

Connect the 50 cables to the test fixture and record the value when the trace is in the uniform portion of the test fixture. The other end can be open or have a cable assembly attached. This establishes the effects of the reflection from the 50 to the 75 discontinuity between the test fixture and the 50 cable. If the differential impedance in the uniform portion of the trace is 150 ± 10 then the test fixture is satisfactory. This measurement should be independent of the TDR filter setting (signal transition duration) over the range of the measurement.

4.1.5.2 Differential signal transition duration calibration
Will we need this if we have no impedance profile test.

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

A special test fixture is required for this calibration. Progressing from left to right the test fixture is exactly like the test fixture in Figure 12 up to the TP1 point and continues as a mirror image through TP1 as illustrated in Figure 13. Previous versions of this calibration procedure used a reflected pulse measured at the source, S1, that required an electrical short at TP1 using the test fixture shown in Figure 12. The previous method has been found to be prone to serious error due to the effects of reflections within the test fixture. These reflections can be a very significant part of the measured signal at the TDR head (position S1 in Figure 13). However, when using the transmitted signal through TP1 in a thru connection sense as shown in Figure 13 the effects of the reflections in the test fixture are second order. The signal measured at SMI1 accurately represents the signal presented to the IUT at TP1.
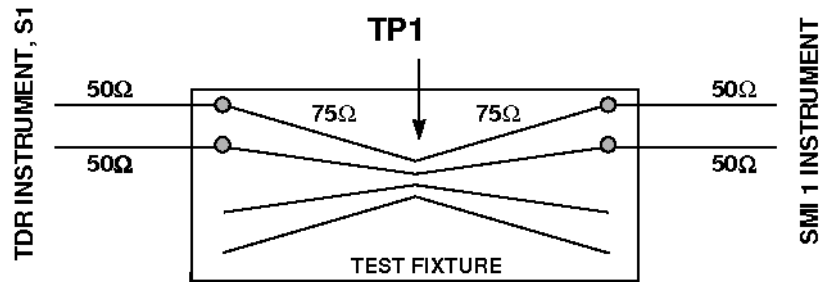
= CONNECTOR BETWEEN 50 AND 75 OHM SECTIONS

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

Figure 13 - Test fixture for STD calibration

Using the test fixture and configuration shown in Figure 13 apply a differential pulse from S1 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. Most practical TDR instruments present the signal resulting at SMI1 as a rising differential pulse.

To calibrate the STD for the rising pulse edge set up the display on the SMI1 as shown in Figure 14. The following procedure results in a calibrated STD:

- The span of the time scale on the display is approximately twice the nominal bit period for the data rate being used. Ten divisions are used on the time axis. Specifically Table 2 shows the time scales to use.

- Set the vertical axis divisions at 15% of the expected pulse amplitude (e.g., 75 mV per division for a 500 mV pulse).
- Move the displayed curve to the right and adjust the vertical position such that the flat portion of the curve (flat for at least three time divisions) passes through the first graticule (division) from the bottom.
- Set the horizontal position such that the displayed curve passes through the third graticule on the time axis and the third graticule on the vertical axis.
- Use the measure function on SMI1 to find the peak to peak signal amplitude of the displayed portion of the trace as shown in Figure 14. This amplitude may also be read directly off the display. This signal amplitude of the displayed trace may or may not accurately represent the asymptotic signal levels that may exist at times not displayed.
- The signal transition duration (STD) is the time between the 20% and 80% values of the displayed signal amplitude.

Table 2 - Scales required for STD calibrations

Bit rate * (Mbits/s)	Time axis scale (ps/div)
1062.5	200
1250	200
1600	100
2125	100
2500	100
3200 (3.125, 3.1875)	50
4250	50
5000	50
6000	40
10000	20
12800 (12500, 12750)	20
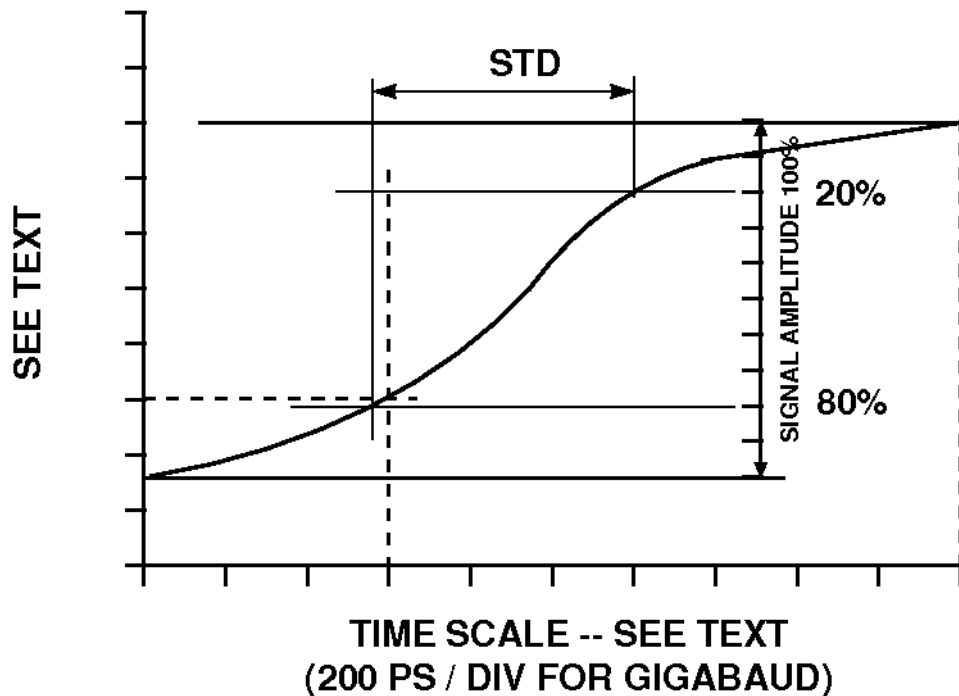
Figure 14 - Signal transition duration calibration

It may be found with some practical test fixtures that the extreme level is not found at the 10th graticule. An example of such a trace is shown in Figure 15 (for a falling pulse example) where a reflection causes the lowest level to be at approximately the 8th horizontal graticule instead of at the 10th graticule. Using automatic features of some instruments will cause the reflection to be used to set the level. If the peaks are not at the 0 and 10th horizontal graticules then an extrapolation should be used to determine the peak level as shown in Figure 15. It is important that this step not be avoided because the STD can be seriously affected if the signal edge rolls off slowly near one or both ends of the transition region.

TIME SCALE -- SEE TEXT
(200 PS / DIV FOR GIGABAUD)
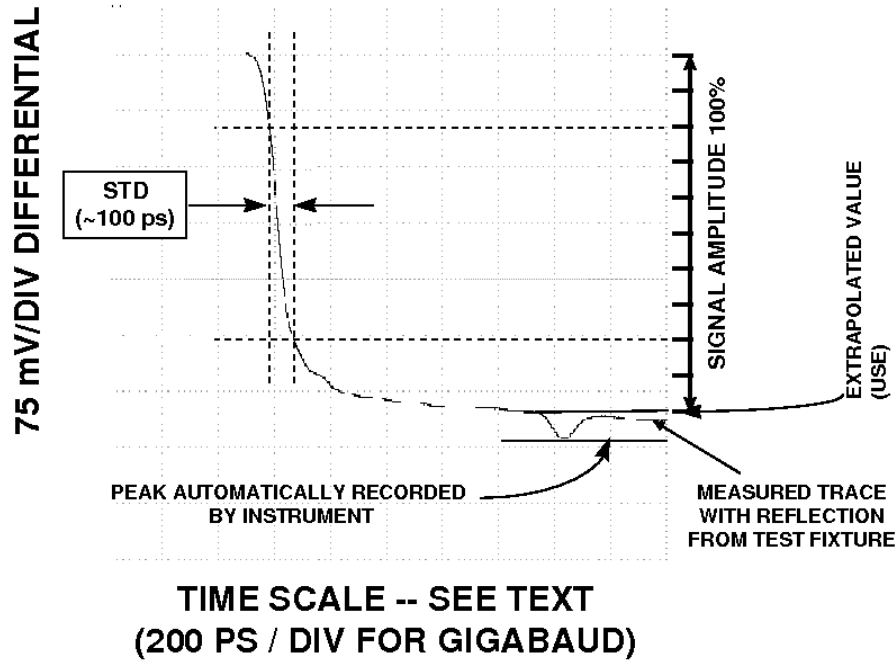
Figure 15 - Setting amplitude for STD with degraded test fixture

Adjust the filter function on SMI1 so that the desired STD is displayed. Note that there will usually be two values of STD required: one for each extreme of the specification. For gigabit FC the extremes are 100 ps to 385 ps. The value of the filter setting required to achieve these STD conditions should be used during the impedance profile measurement

Retain all the settings for reuse in the measurement.

4.1.6 Testing procedure

4.1.6.1 Impedance profile in connector region

Connect the separable interconnect under test to the test fixture receptacle connector, terminate the separable interconnect under test with its nominal transmission line impedance (passive) and record the TDR trace using the method described below. Figgure 17 shows the TDR display setup to use for this measurement.
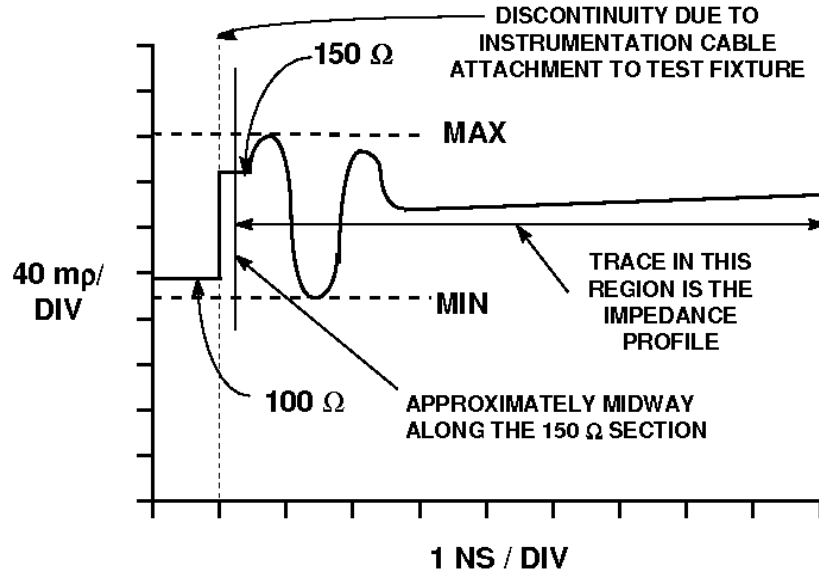
Figure 16 - Transmission line impedance profile measurements

- Set the time scale to 1 ns /div (total time axis span of 10 ns).
- Set the vertical scale (m) to 40 m /div
- Adjust the vertical position to approximately center the trace on the display
- Adjust the horizontal position such that the discontinuity between the instrumentation cables and the test fixture is on the first division. (It may be necessary to disconnect the instrumentation cables from the test fixture and disable the filter to find this time position - if disconnected, reconnect the cables and re-enable the filter)
- Set the TDR cursor to read ohms
- Use the cursor to measure the minimum and maximum values in ohms near the left side of the trace that shows the disturbances from the connector

Execute the test with both extremes of transition time allowed (e.g. 100 ps and 385 ps for Gigabit FC) using the above method to record the trace. Note: a separate calibration and verification should have been done at these STD extremes. Different test fixtures may be required to accommodate the three STD length requirement for the uniform 150   region.

4.1.6.2 Impedance profile in the media region

Using the same setup as for section 4.1.6.1 execute the following:

150 Ω

DISCONTINUITY WITH SEPARABLE
PART OF IUT REMOVED

**40 mρ/
DIV**

100 Ω

TRACE IN THIS
REGION IS THE
MEDIA IMPEDANCE
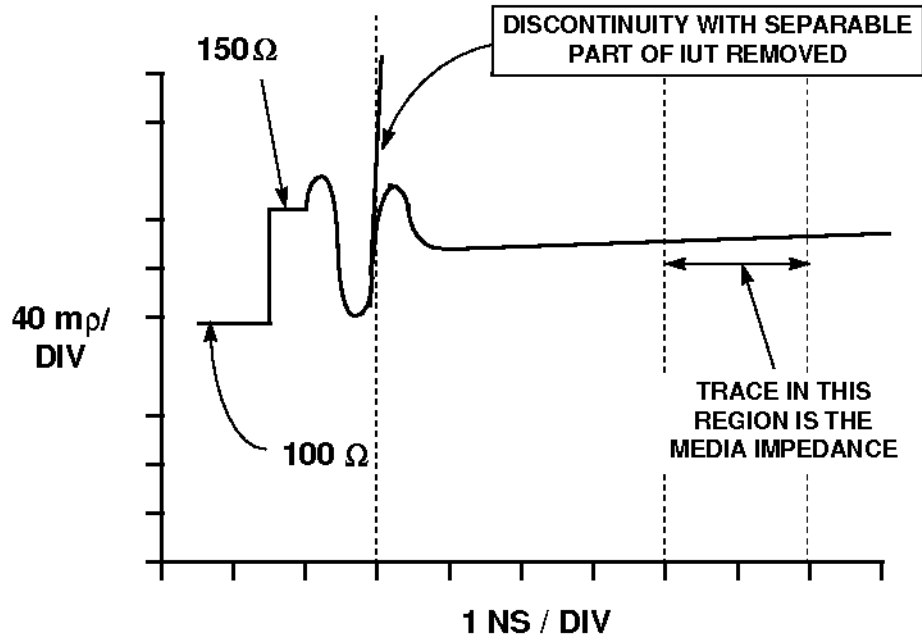
1 NS / DIV

Figure 17 - Media impedance measurement

- Set the time scale to 1 ns /div (total time axis span of 10 ns).
- Set the vertical scale (m) to 40 m /div
- Adjust the vertical position to approximately center the trace on the display
- Disconnect the separable part of the IUT and adjust the horizontal position such that the discontinuity at the open produced is on the third division. (Pick any convenient part of the discontinuity signal to use to set this position).
- Set the TDR cursor to read ohms
- Record the min, max and average of the trace between 7th and 9th divisions displayed (4 to 6 ns from the IUT separation point). (see
- Figure 17).

The media impedance measurement contains a small error caused by losses in the wire which increases the measured value slightly.

4.1.7 Acceptable ranges

The trace within the close proximity electrical neighborhood should be within in the range shown in Table 6 in Annex A for all signal transition times allowed for the application. If an exception window is allowed where the values may be outside the nominal range for a period of time it is noted in the table.

The FC standards allow a 800 ps exception window (see Annex A) for this test. The FC standard is applied to constructions beyond cable assemblies, for example GBIC's, and does not distinguish between the details of the applications. The SFF HSS group recommends that a reduced exception window be allowed for duplex copper cable assemblies. The requirements recommended are a window of no more than 300 ps with impedance between 90 and 190 ohms in the window (this is a reduction in the exception window width of 500 ps). This 300 ps exception window applies for full speed and double speed applications.

4.2 Signal degradation

Jan 25, 2005

Proposal: Use a TCTF to determine the S1 input amplitude necessary to achieve the desired FC output of 310mV. There after that amplitude number is used in place of the 1.1V input value used today. This motley crew will have to make a few TCTFs to determine this amplitude value. Volunteers are being solicited to do this work. Dave Chapman, Amphenol, has volunteered to manage this endeavor.
Then we should be able to use this test pretty much as we have here today.

There are three major planks in the strategy for this test:
- Use linearity and superposition as much as possible to simulate the worst case input signals
- Use linearity and superposition as much as possible to simulate the allowed output mask
- Ensure that the activity on PUT_{NOT} is close to the most extreme allowed

The test ideally consists of applying the most degraded allowed transmitter output signal to the PUT and verifying that the signal into the receiver (out of the PUT) does not violate the specified receiver mask. The main technical challenges are to actually produce the worst case legal signal into the interconnect and to not violate the requirements of the signal levels available to/from real test instruments.

For purposes of this test it is assumed that only two properties of the transmitted signal are important: the vertical eye opening (amplitude) and the horizontal eye opening (jitter). How do you do the jitter through the TCTF????? If the actual applied signal does not match the allowed transmit eye mask in other areas no further attempts are made to make a more perfect fit. The procedure for simulating a worst case signal is:
Jan 25 2005
1. Using an available signal from a real source (while transmitting a 2**7-1, K28.5 or other data pattern with run lengths of at least 5 max and 1 min and frequency within 1% of the nominal data rate) the reported amplitude for the eye opening is adjusted using software compensation such that it appears that the minimum allowed transmit eye opening is being applied. This same amplitude scale and scaling factor is used to record the received eye.

2. The difference between the actual jitter in the transmitted signal and the maximum allowed jitter is used to adjust the receive eye mask by an equal amount in the opposite direction (making the receive mask wider and therefore more difficult to achieve). This procedure is shown in Figure 18. The minimum jitter margin in the transmit mask is the value added to the receiver mask. Jitter in the transmit signal is transmitted unattenuated to the receiver across the PUT - superposition applies.

Also shown in Figure 18 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.
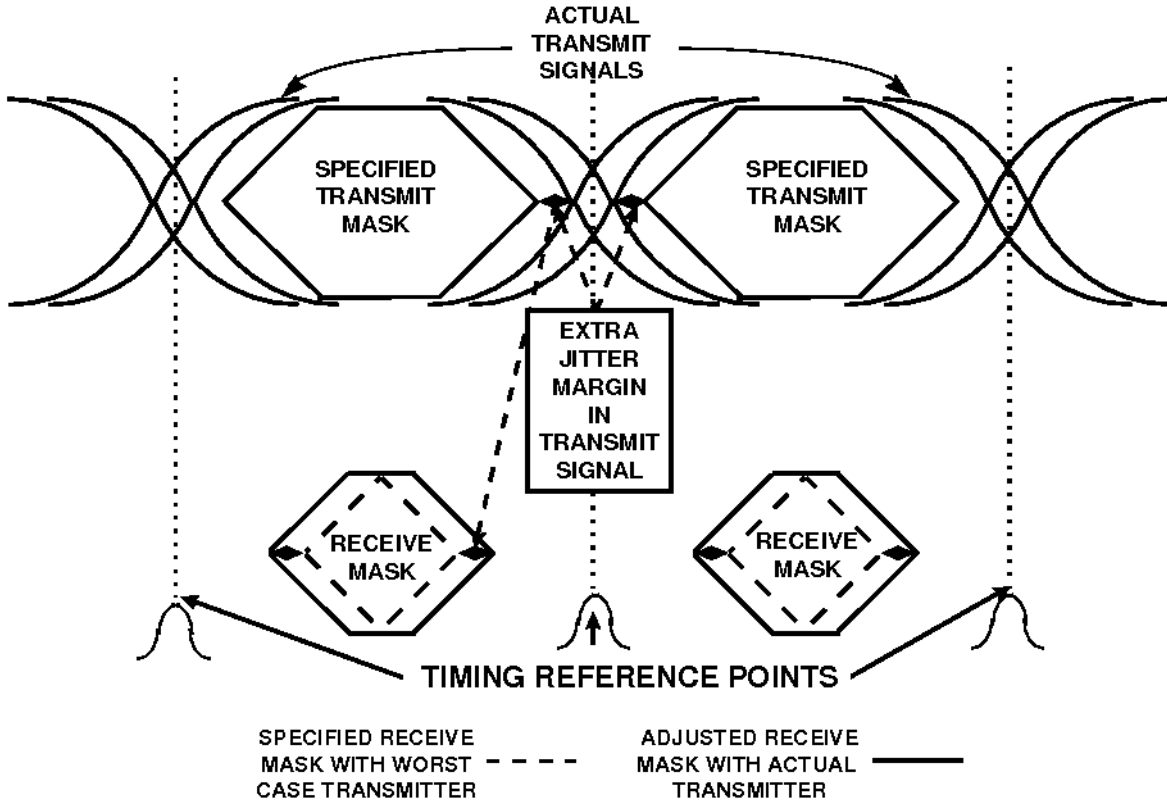
Figure 18 - Compensation for real transmitter jitter

The signal degradation test is intended to apply to all constructions of cable assembly including those with equalizers and those with known non uniformities such as intermediate connection points. It is basically a four port test requirement that does not specify the internal construction of the cable assembly.

4.2.1 Measurement test fixtures and measurement equipment

Figure 19 shows the source side measurement test fixture.
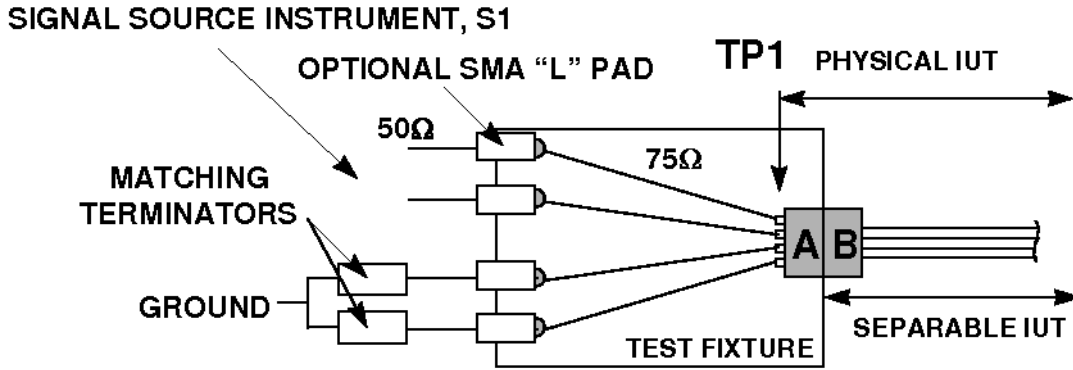
A   = PERMANENTLY MOUNTED CONNECTOR ON THE TEST FIXTURE
B   = PART OF THE SEPARABLE INTERCONNECT UNDER TEST
)   = 75 SMA CONNECTOR

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

Figure 19 - Source side measurement test fixture for signal degradation test

Figure 20 shows the receiver side test fixture.
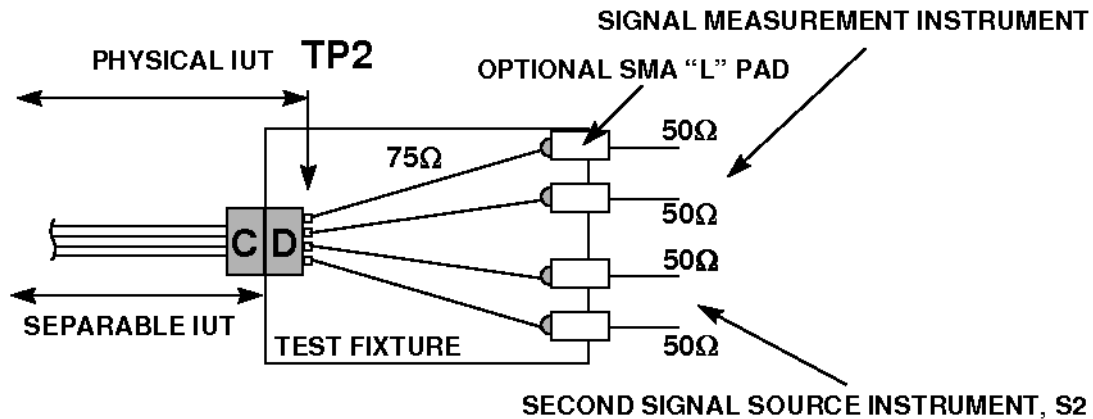
C   = PERMANENTLY MOUNTED CONNECTOR ON THE TEST FIXTURE
D   = PART OF THE SEPARABLE INTERCONNECT UNDER TEST
●   = 75 SMA CONNECTOR

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

Figure 20 - Receiver side measurement test fixture for signal degradation tests

Measurement equipment consists of two signal sources, S1 and S2, and a sampling oscilloscope. The Tektronix Gigabert or equivalent is used for S1. This instrument delivers a differential signal containing any of several data patterns. Both the + signal and the – signal are 50 output impedance. High quality 50 coaxial cables are used to attach all instruments to the test fixture.

A sampling oscilloscope such as the Tektronix 11801 or equivalent is used for the signal measurement instrument. S2 is a source that has the following properties:

•   Differential outputs, 50   each side

- No correlation to the signal driving the PUT (cannot be derived from the same timing source)
- Maximum amplitude allowed from a transmitter (2.0 volt p-p differential for full speed FC)
- Minimum allowed signal transition duration (100 ps for full speed FC)
- Maximum allowed unbalance (can be produced by using different path lengths for the + signal and the - signal between the signal source and the untested line, phase trimmers are another method for adjusting the imbalance)
- Signal is similar to a normal active data transmission: data is present with a run length of at least 5 max and 1 min, frequency within 1% of the nominal data rate. Lower Baud signals are not allowed for this signal due to balance dependence on frequency effects.

This signal can be generated by readily available sources (e.g. HP 8133) with some special purposefully unbalanced interconnect between the source and the PUT_{NOT}.

One repeating data pattern that is acceptable is: 1100000101001111101011000001010101.

4.2.2 Calibration procedure

The highest signal level used is from S2 and that level will determine the scaling factor needed for signal measurement instruments that cannot accept real signals as large as the specified maximum for S2. For the case of full speed FC the amplitude of S2 is set to 2.0V differential pp. Since the maximum voltage level that can be applied to some common signal measurement instruments is around 800 mV pp one must scale the actual signals so that the input levels stay within the capabilities of the instruments.
In a procedure using the TCTF, scaling may still be necessary but not as drastically. Because at 2.125GHz, the loss on the TCTF is just 6dB, while the TCTF need for cal will be no more then the TCTF described, you won't have quite 6dB. The maximum allowable amplitude for S2 in 4Gb FC is 1600mVolts, half or 6dB yields 800 mV. If the equipment allows upto 500 mV per channel scaling may not be needed at all.
It is further important to do the calibration in a way that has the fine adjustments done by instruments that are capable of fine tuning the amplitude of the signals. Some common S1 sources do not have adjustable output signal levels so the fine adjustment must come from the signal measurement instrument and the S2 source.

Because of the limited adjustability of S1 the calibration of S1 and the signal measurement instrument will therefore be done before the calibration of S2. However, since the same signal measurement instrument is used to calibrate both S1 and S2 the compliance range of the signal measurement instrument for S2 must be considered when calibrating S1. The same settings on the signal measurement instrument as determined in the calibration of S1 is used in the calibration of S2. This may force S1 to have a coarse adjustment in its output level to approximately half the amplitude it would normally use. For the case of 4Gb full speed FC S1 needs to appear to be approximately 1.1 V 310mV differential pp across the end of the TCTF If the signal measurement instrument can handle no more than 800 mV the actual S1 output must be reduced to approximately 400 mV differential pp. This coarse adjustment may be accomplished though the use of in-line attenuators (around 9dB).
Again if the equipment used can handle the 500mV mentioned above for S2 then scaling is not need.
This allows an S2 actual output of slightly less than 800 mV to appear as 2.0 V. When the signal measurement instrument is calibrated the 400 mV output appears as 1.1V and an 800 mV output appears as 2.2V. Note that the exact values of the S1 actual output are not critical - the fine tuning will take place in the software scale adjustments of the signal measurement instrument.

4.2.2.1 Calibration test fixture

A special calibration test fixture is required as shown in Figure 21. This test fixture is exactly the same on each side as the measurement test fixtures up to the mounting pads/holes for the connectors. No mounting pads/holes exist on the

calibration test fixture. This fixture is intended to determine the effects of the actual measurement test fixtures.
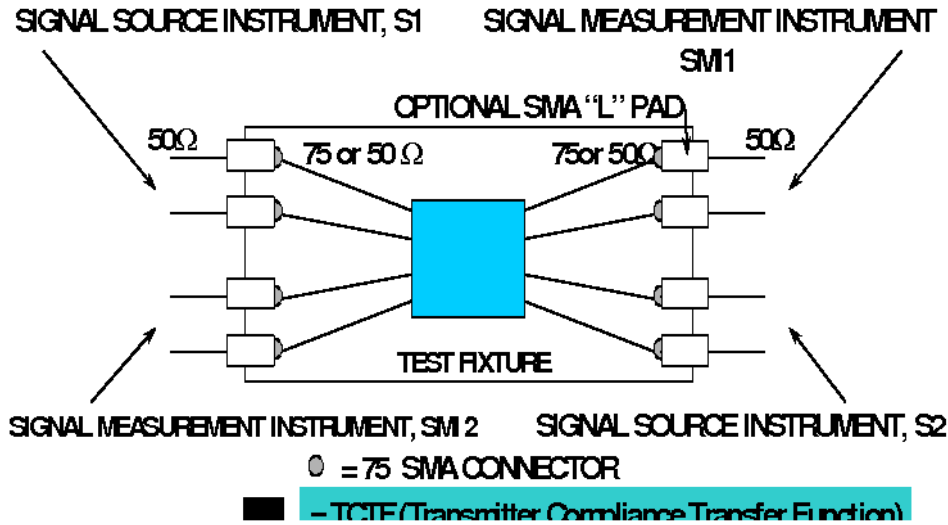
Figure 21 - Calibration test fixture

It is possible to use the top traces for both S1 and S2 calibration if the fixture used for the tests is identical for both the PUT and the PUT$_{NOT}$.

4.2.2.2 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 21 with S2 disconnected:

1. Select in-line attenuators such that the differential pp output of S1 measured through the calibration test fixture is near but less than 400 mV differential pp at the time representing the closest approach to the top and bottom of the (vertically scaled) transmit mask
2. Select hardware filters and/or connecting cables attached to the output of S1 to produce the minimum STD values allowed for the application as indicated on the signal measurement instrument
3. With the filters / cables in place for the minimum 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. Adjust signal measurement instrument scale using the internal software of the instrument to report the minimum acceptable differential pp amplitude at the closest approach to the top and bottom of the(vertically scaled) transmit mask (See Figure 22)** (e.g. 1.1V pp for full speed FC)
6. Measure jitter (see Figure 18) and record
7. Subtract the measured jitter in the actual transmit signal from the maximum specified jitter allowed for transmitters (see Figure 18)
8. Create a test mask for the received signal using the method shown in Figure 18
9. Record all the settings and hardware needed to create steps 5,6, and 7 as the calibration conditions for the minimum STD tests
10. Repeat steps 1 thru 9 with the maximum STD values allowed for the application
If a TCTF is used where is the STD determined?????4Gb FC only calls out a minimum rise/fall time.
If the minimum allowed STD is not achievable (due to losses in L pads, test fixtures and cables) then use the lowest possible STD. NO allowance is made in the acceptable ranges due to inability to achieve minimum STD.

** The transmitted signals measured may contain high frequency noise due to resonances and reflections within the test fixture (especially if the matching "L" pads are not used). Figure 22 shows a representation of a well behaved launched signal that contains HF noise. Other launch signals may show more separation between the rails and the transitions, as shown in Figure 23. Regardless of whether there is a separation or not in all cases all the "dots" shown above or below the horizontal parts of the transmit eye mask are considered in taking the averages.

In Figure 22 and Figure 23 the adjustment on the signals was done graphically for purposes of illustration by keeping the mask exactly the same size and scaling the signals in the vertical direction only. Unfortunately, since there is no practical way to separate the signal from the graticules, this scheme also scales the graticules along with the signals. The amplitudes of the adjusted signals should be related to the size of the graticules before the adjustment in upper part of the figures. The graticules in the lower parts of the figures should be ignored. The absolute scale in the figures is the same for everything except the lower graticules.
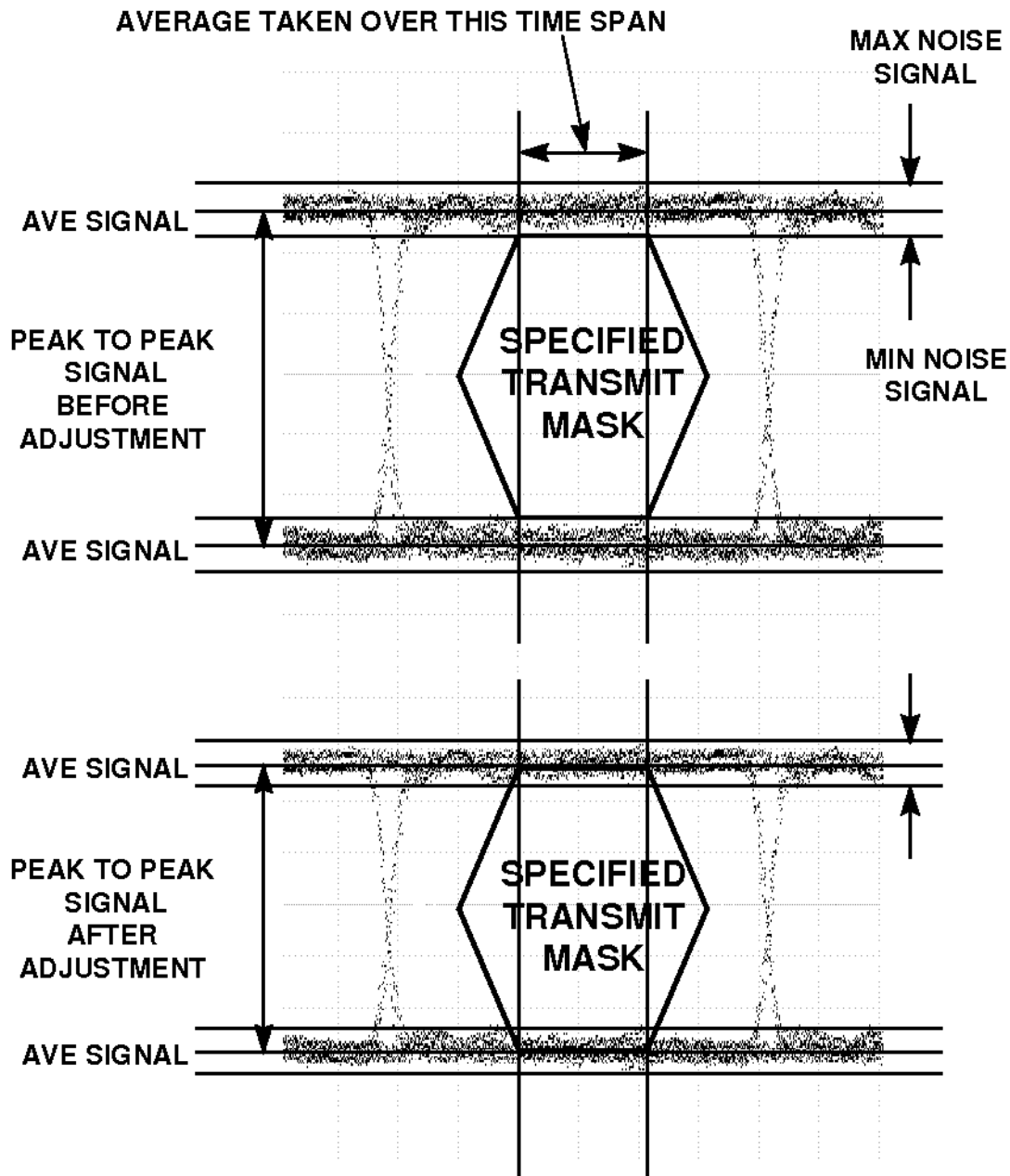
Figure 22 - Adjustment of launch amplitude (example 1)
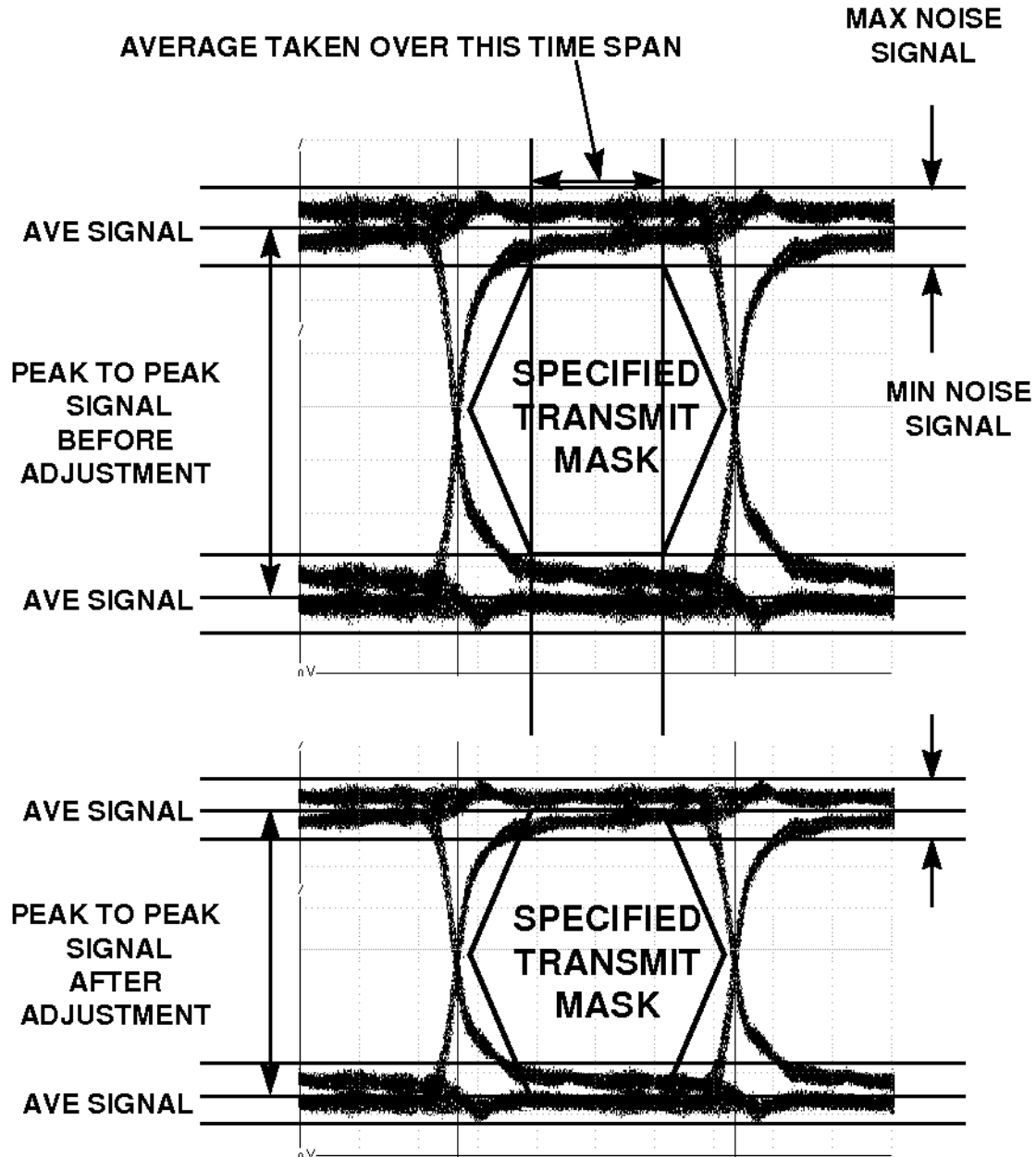
Figure 23 - Adjustment of launch amplitude (example 2

It is in general not possible to determine from examination of the eye whether the amplitude broadening is caused by very high frequency noise or by signals more closely related to the basic data pattern. Since these very high frequency signals will not propagate very far into the interconnect and will not reach the receiver they are not really part of the launched signal for purposes of this test. However, the presence of the very high frequency noise can seriously affect the measurement of the launched signal amplitude and needs to be limited and accounted for.

There are two requirements relating to launched signals containing significant broadening of the eye pattern bands:

- the peak to peak launched signal amplitude shall be measured from the mean of the vertical population between the closest approach points at the top and bottom of the transmit mask (see upper part of Figure 22 and Figure 23)

- the test fixture and test environment shall be designed and built such that the peak to peak amplitude noise in the signal (see upper part of Figure 22 and Figure 23 max noise signal - min noise signal) between the closest approach points at the

top and bottom of the transmit mask is no more than 20% of the peak to peak average.

The mean or average of the vertical population in the specified time band shall be calculated using the averaging function of the instrument.

Failing to follow these requirements may allow a bad test fixture and/or environment to launch higher amplitude signals than intended and effectively gives the IUT a larger signal degradation budget than intended. The received eye opening is larger without the adjustments for HF noise than it would be with a HF noise-free launched signal with the same amplitude.

Note that the amplitude of the signal for purposes of this test does NOT occur at the center of the eye unless that happens to coincide with the point of closest approach to the top and bottom of the transmit eye mask. This is particularly evident when there is some slope to the transitioning signals while over the flat part of the mask as shown in Figure 23. In these cases the amplitude is determined significantly from the signal not in the center of the mask.

For a signal of the type shown in Figure 22 note that the visible edge of the measured eye after adjustment penetrates into the transmit mask area by an amount equal to half the peak to peak local noise on the signal as shown in the lower part of Figure 22.

For a signal of the type shown in Figure 23 note that the visible edge of the measured eye after adjustment penetrates into the transmit mask area more at the left end of the flats of the mask and has greater penetration than for the signals shown in Figure 22.

The lower part of Figure 22 and Figure 23 illustrates the way a properly adjusted launch signal should appear.

The better the quality of the test fixture the more launched signal amplitude is available for the IUT. Said differently, poor quality test fixtures place more burden on the IUT to deliver the signals to the receiver.

4.2.2.3 Calibration for S2

The calibration procedure for S2 uses the same signal measurement instrument as for S1. This is required to maintain the same scale factors for all measurements. The data pattern described in section 4.2.1 shall be used on S2.

Using the calibration test fixture in Figure 21 with S1 disconnected and the signal measurement instrument used and calibrated in 4.2.2.2 attached to the output of PUT_{NOT}:

1. Select hardware filters and/or connecting cables attached to the output of S2 to produce the minimum STD values allowed for the application as indicated on the signal measurement instrument
2. With the filters / cables in place for the minimum STD value verify that the STD is that expected
3. If STD is not that expected repeat steps 1 and 2 until the desired STD is achieved
4. Adjust the output of S2 such that the maximum allowed differential peak to peak amplitude is indicated (note the actual signal is less due to the calibration process) (this indicated amplitude is 2.0V for full speed FC) - the peak to peak amplitude for this adjustment is the maximum local average signal recorded anywhere in the eye (see Figure 22 for definition of amplitude)
5. Using the same settings and conditions produced in step 4, set the signal measurement instrument to add the + signal and the - signals
6. If needed, add lengths of cable or phase trimmers to either the + signal or - signal cable from S2 to the calibration test fixture until the signal measurement instrument indicates the maximum peak amplitude allowed for imbalance (see section 4.3 for definition of imbalance - 12.5% of differential peak to peak signal amplitude, i.e. 250 mV for a 2.0 V p-p launched signal is the maximum allowed

   launch imbalance in this document) if the launch imbalance exceeds the allowed
   levels without adding extra lengths of cable or phase trimmers then S2 must be
   adjusted so that it does not deliver more imbalance than allowed)
7. Record all the settings and hardware selections needed to satisfy steps 4 and 6

The S2 calibration does not need to be done for the maximum allowed STD or minimum
allowed amplitude.

4.2.3 Testing procedure

Use S1 calibrated as described in 4.2.2.2 and running a data pattern with a run
length of at least 5 max and 1 min such as 2**7-1 or K28.5 with a bit rate within 1%
of the nominal data rate. Use S2 calibrated and running a data pattern as described
in 4.2.2.3. The bit rate for S2 shall be supplied from a timing source different
from that used for S1.

The eye pattern on SMI1 is recorded as the result of the signal degradation test.

There are four specific measurements required for each PUT in the IUT. Table 3 shows
the matrix.

Table 3 - Test conditions for signal degradation

Polarity of S2	normal (see Figure 2)	reversed (see Figure 2)
STD for S1		
minimum	Test 1	Test 2
maximum	Test 3	Test 4

Every measurement is executed the same way except with the conditions indicated in
Table 3 set according to the measurement being done. The separable IUT is connected
between the test fixtures shown in Figure 19 and Figure 20 and the resulting eye
diagram is recorded and compared to the modified receive signal mask.

Data acquisition should be continued long enough to ensure that all the noise from
the PUT_{NOT} has a chance to experience the worst case interaction with the PUT signals.
This time can be determined by running some test cases for extended times and backing
off until good confidence is felt at the data acquisition times to be used for the
tests.

Any intrusion into the mask constitutes a failure. The allowed receive mask is the
same for all tests.

Notice that the trigger for SMI1 must come from the S1 trigger output and that the
polarity reversals for S2 must be done between S2 and the IUT.

4.2.4 Acceptable ranges

The acceptable ranges for full speed FC are shown in Annex A.

4.3 Differential to common mode conversion

Replaced with Common mode conversion???

The balance degradation test uses the same strategy to produce the worst case input
signals as is used for the signal degradation test (section 4.2) except that the

maximum input differential amplitude from both S1 and S2 is applied and there is no jitter component specified.

Balance is generally associated with the difference between the slopes of the + signal and the - signal at the same point in time along the line. However, when the STD is known, as in this test, one may use the peak instantaneous sum of the + signal, M1, and the - signal, M2, to approximately define the imbalance. The peak sum divided by the STD is the difference in the average slopes of the + signal and the - signal. This method avoids needing to use single ended differentiators and allows the use of the same signal measurement instrument that is used to make the signal degradation measurements. This not only simplifies the test but also reduces the cost of the equipment.

Figure 24 shows a simple example of two balanced single ended signals within a differential pair and imbalanced single ended signals caused by a time skew on the M1 line.
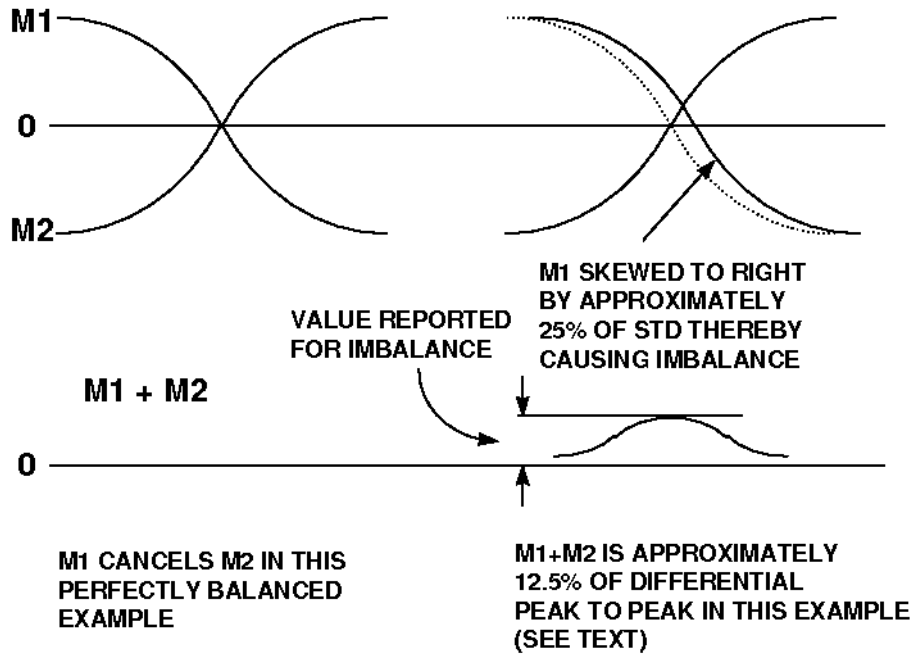
Figure 24 - Example of imbalance measurement

The imbalance is recorded as the peak value of M1 + M2 minus the average of all M1 + M2 data sampled and is reported in mV peak. The imbalance reported may be referred to the peak to peak launched differential signal amplitude regardless of the point in the PUT where the measurement is taken. For a 2.0 mV peak to peak launched differential signal a 12.5% imbalance is 2000 mV x 0.125 = 250 mV.

In Figure 24, if the peak value of M1 and M2 is 0.5V the peak differential voltage is 1.0V and the peak to peak differential voltage is 2.0 V. The peak sum of M1 +M2 (the imbalance) is shown as approximately half of the peak of M1 or M2 and is approximately 250 mV. Therefore, the imbalance shown in Figure 24 is approximately 12.5%.

Since the maximum imbalance is the only feature of interest only the minimum STD is used for both S1 and S2.

The possibility of an unbalanced transmitted signal compensating for an unbalanced (in the other direction) connector/cable was noted in section 2. Therefore it is important to make this test with all four permutations of S1 and S2 polarity connections.

The reported imbalance for the IUT is the imbalance measured at the receiver less that present in the transmit signal.

The balance degradation test is intended to apply to all constructions of cable assembly including those with equalizers and those with known non uniformities such as intermediate connection points. It is basically a four port test requirement that does not specify the internal construction of the cable assembly.

4.3.1 Test fixture and measurement equipment

The same test fixture and measurement equipment is used as for the signal degradation tests. See Figure 19 and Figure 20.

4.3.2 Calibration procedures

4.3.2.1 Calibration for S1 and SMI1

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 21 with S2 disconnected:

1. Select in-line attenuators such that the differential pp output of S1 measured through the calibration test fixture is near but less than 750 mV differential pp as defined in Figure 22.
2. Select hardware filters and/or connecting cables attached to the output of S1 to produce the minimum STD values allowed for the application as indicated on the SMI1
3. With the filters / cables in place for the minimum STD value verify that the STD is that expected on SMI1 (the procedures in section 5.4 shall be used to measure the STD)
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. Adjust signal measurement instrument scale using the internal software of the instrument to report the maximum acceptable differential pp amplitude anywhere in the display (e.g. 2.0V pp for full speed FC)
6. Under the conditions of step 5 set SMI1 to display the sum of the + signal and the - signal using a horizontal scale that displays at least 30 bit times. Record the display pattern
7. Determine the average level of the displayed pattern (this average should be close to zero)
8. Measure the peak deviation from the average level (see Figure 26) and record - this is the launched imbalance in the S1 signal
9. Record all the settings and hardware needed to create the conditions in step 5 for future use

If the minimum allowed STD is not achievable (due to losses in L pads, test fixtures and cables) then use the lowest possible STD. NO allowance is made in the acceptable ranges due to inability to achieve minimum STD.

An example of the launched imbalance is shown in Figure 25. This example does not use the correct horizontal scale for this bit rate. Note that high frequency noise is blurring the signal.
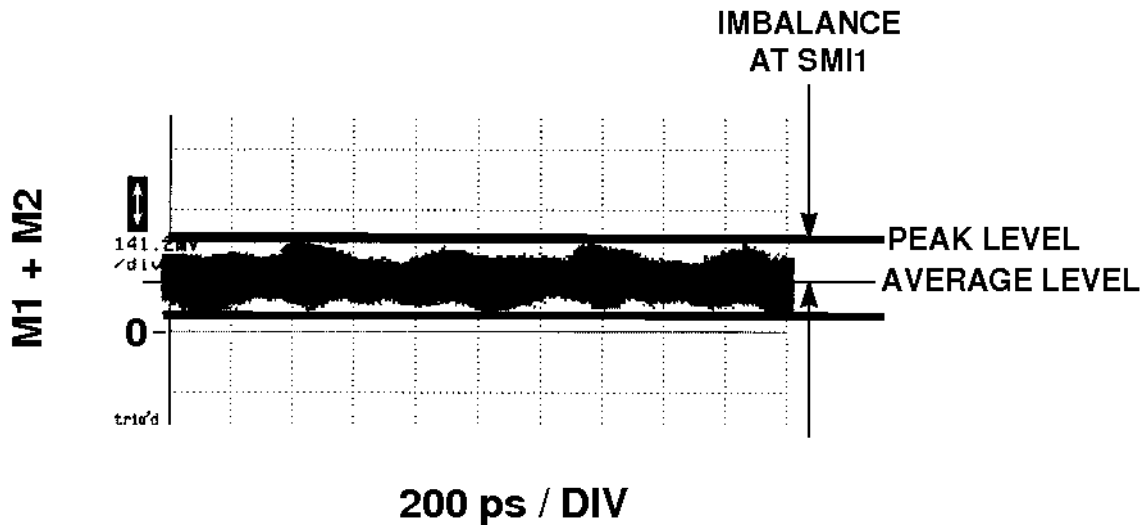
Figure 25 - Launched signal imbalance example

4.3.2.2 Calibration for S2

The calibration procedure for S2 uses the same signal measurement instrument as for S1. This is required to maintain the same scale factors for all measurements. The data pattern described in section 4.2.1 shall be used on S2.

Using the calibration test fixture in Figure 21 with S1 disconnected and using the same signal measurement instrument as was used and calibrated in 4.2.2.2 attached to the output of PUT$_{NOT}$ as SMI2:

1. Select hardware filters and/or connecting cables attached to the output of S2 to produce the minimum STD values allowed for the application as indicated on the signal measurement instrument
2. With the filters / cables in place for the minimum STD value verify that the STD measured on SMI2 is that expected using the steps described in section 5.4
3. If STD is not that expected repeat steps 1 and 2 until the desired STD is achieved
4. Adjust the output of S2 such that the maximum allowed differential peak to peak amplitude is indicated on SMI2 (note the actual signal is less due to the calibration process) (this indicated amplitude is 2.0V for full speed FC)
5. Using the same settings and conditions produced in step 4, set SMI2 add the + signal and the - signals
6. If needed, add lengths of cable or phase trimmers to either the + signal or - signal cable from S2 to the calibration test fixture until SMI2 indicates the maximum peak amplitude allowed for imbalance (this maximum is 12.5% of peak to peak differential launched voltage for this document) -- if the measured imbalance exceeds 12.5% of peak to peak differential launched amplitude without adding extra lengths of cable then S2 must be adjusted so that it does not deliver more than 12.5% imbalance)
7. Record all the settings and hardware selections needed to satisfy steps 4 and 6

The S2 calibration does not need to be done for the maximum allowed STD or minimum allowed amplitude.

4.3.3 Testing procedure

Use S1 calibrated as described in 4.3.2.1 and running a data pattern with a run length of at least 5 max and 1 min such as 2**7-1 or K28.5 with a bit rate within 1% of the nominal data rate. Use S2 calibrated and running a data pattern as described

in 4.3.2.2. The bit rate for S2 shall be supplied from a timing source different from that used for S1.

Using a horizontal scale such that at least 30 bit times are displayed the pattern displayed on SMI1 is recorded as the result of the balance degradation test.

There are four specific tests required for every PUT. Table 4 shows the matrix.

Table 4 - Test conditions for balance degradation

Polarity of S2	normal (see Figure 2)	reversed (see Figure 2)
Polarity of S1		
normal (see Figure 2)	Test 1	Test 2
reversed (see Figure 2)	Test 3	Test 4

Every test is executed the same way except with the conditions indicated in Table 1 set according to the test being done. The separable IUT is connected between the test fixtures shown in Figure 19 and Figure 20 and the resulting signal pattern from the sum of the + signal and the - signal is recorded. The average value of the pattern is the reference level and will account for any D.C. content. D.C. content shifts the entire pattern up or down. The imbalance is intrinsically an A.C. effect and shall be calculated as the difference from the average level of the measured signal. For signals with no D.C. content this average level is zero. Figure 26 shows an example of an imbalance output test where no d.c. content exists and the average level is therefore zero. The horizontal scale does not meet the 30 bit time requirement but is expanded to show some detail.
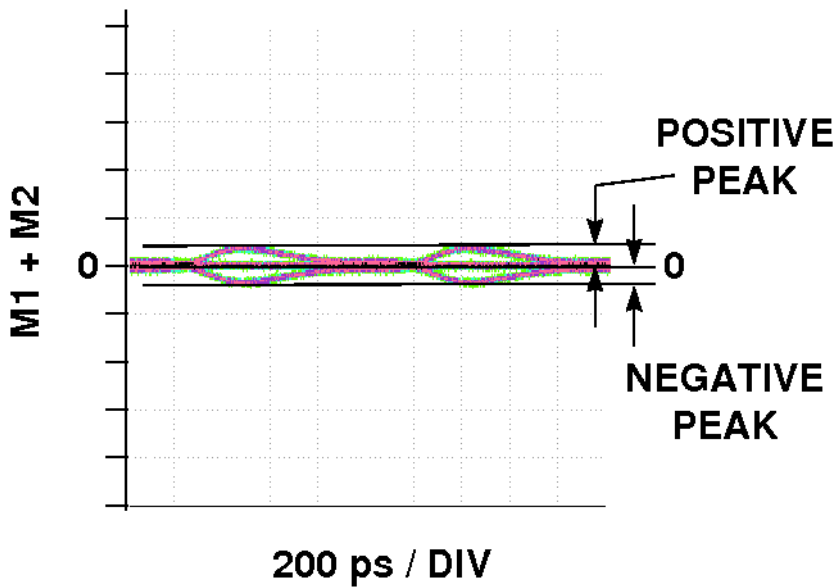
Figure 26 - Example of an imbalance output measurement

If SMI1 is not balanced, that is if the same signal applied to both M1 and M2 does not yield exactly the same value on both M1 and M2, then the balance measurement will be shifted in the same way as if there were common mode D. C. content in the signals.

An example of a received imbalance display with D. C. content (or unbalanced channels on SMI1) and many bit times is shown in Figure 27.
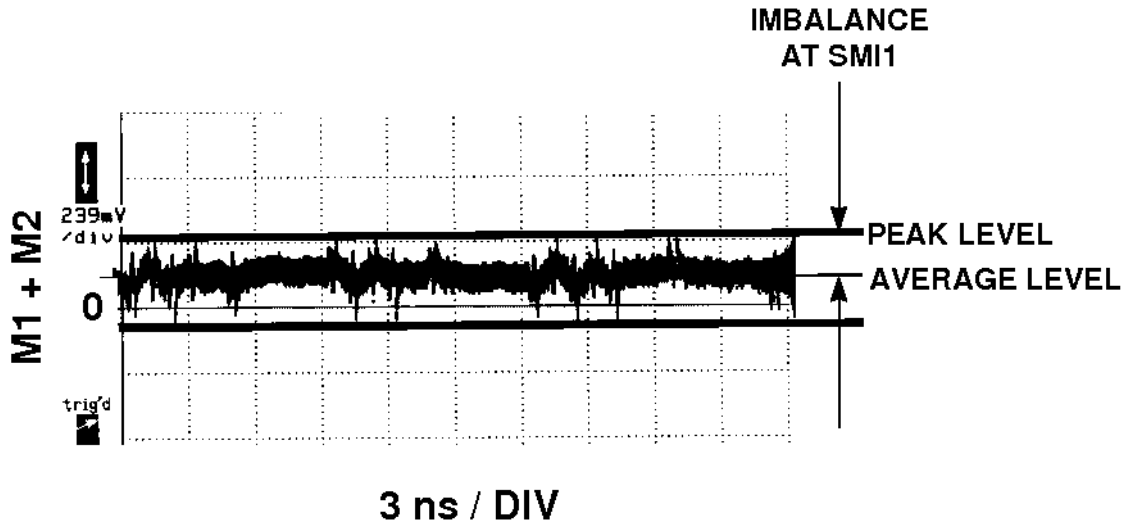
Figure 27 - Imbalance output with d. c. content

This the output through the IUT using the source shown in Figure 25 but with time and amplitude scales significantly different from that used for Figure 25.

Note that the imbalance display in Figure 27 has quasi-periodic features that probably indicate the difference between the S1 timing source and the S2 timing source.

The maximum difference from the average level noted from any of the four tests is the imbalance in the received signal. In Figure 26 the imbalance is the positive peak less the average level (zero). Since the negative peak is the same magnitude as the positive peak the same imbalance result is obtained using the negative peak.

To obtain the imbalance added by the IUT subtract the value of the launched imbalance determined during the S1 calibration described in section 4.3.2.1.

IMBALANCE CREATED BY IUT, mV = (RECEIVED IMBALANCE, mV) - (LAUNCHED IMBALANCE, mV)

The recorded imbalance shall be given in percentage of the peak to peak launched differential signal.

RECORDED IMBALANCE FOR IUT =   IMBALANCE CREATED BY IUT, mV
                                 LAUNCHED P-P DIFFERENTIAL SIGNAL, mV

Notice that the trigger for SMI1 must come from the S1 trigger output and that the polarity reversals must be done between S1 and the IUT and S2 and the IUT.

4.3.4 Acceptable ranges

For this document the maximum allowed launch imbalance (peak) is 12.5% of the differential peak to peak launched signal and the maximum added imbalance (peak) by the IUT is 12.5% of the differential peak to peak launched signal for a total of 25% of differential peak to peak launched signal in the received signal. These values are based partly on the skew specifications in the FC standard for launched signals and partly on the measured performance of known good cable assemblies.

4.4 Electromagnetic compatibility (EMC)

EMC is a measure of the intensity of electromagnetic energy exported from the IUT. Although these tests can be applied to any IUT they are generally applicable only to shielded external types.

Two options are specified for determining the electromagnetic compatibility of HSS cable assemblies: (1) common mode power transfer (CMPT) and (2) electromagnetic radiation (EMR). Either or both may be used.

The launched signals are nominally unbalanced for both the EMR test and in the CMPT test. The EMR test measures radiated emissions while the CMPT test uses an absorbing clamp to measure the current on the shield of the IUT. The cost of the test environment is vastly larger for the EMR than for the CMPT test due to the requirement of a special mode stir chamber. A typical EMR test chamber may cost up to several hundred thousand dollars including the building. The cost of the CMPT test environment is typically thousands of dollars, mostly for the measurement equipment. The upper frequency in the CMPT method is limited by the ability of the absorbing clamp to respond. Typical upper limits are a few GHz. The upper frequency limit of the EMR method is determined by the state of the art of EMC compliance equipment.

Data acquisition times for EMR tests are much longer than the CMPT tests

Both options have the ability to reliably specify and measure EMC performance requirements on HSS cable assemblies and associated bulkhead attachments.

The EMC tests are intended to apply to all constructions of cable assembly including those with equalizers and those with known non uniformities such as intermediate connection points.

4.4.1 Commom mode power transfer ratio (CMPTR)

Common mode power transfer (previously known as transfer impedance or shield effectiveness) applies to external shielded cables and the associated attachments to enclosures. 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 and connection system will allow to escape the enclosure can be determined by measuring the "CMPT" of the system.

Common mode power transfer is the power transfer from signals inside a shielded interconnect to the shield outside of the interconnect. 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 test produces direct stress on the shielding system by using unbalanced driven signals. By contrast the EMR test (section 4.4.2) uses a nominally balanced driven signal scheme that does not produce this additional stress on the shielding system. Another difference is the CMPT captures energy placed on the shield by the connector system and by leakage through the shield between the connector and the current clamp. The EMR test measures the radiation pattern from the entire shield and both connectors. Depending on the details of the construction of the IUT and the source of leakage one may not always get close agreement between the CMPT and EMR tests for these reasons.

4.4.1.1 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 units under test fall generally into two categories: (1) cable assemblies and (2)
bulkhead to cable assembly connectorization.

The test bed for both categories, 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.
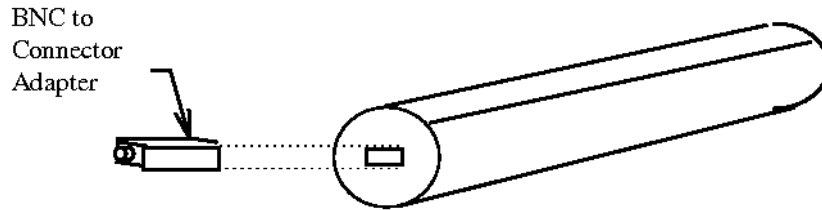
Figure 28 - General view of IUT adapter (test fixture) and "stovepipe"

The test bed needs a adapter to bring the signal from the signal generator to the
IUT. The construction of this adapter is different for each of the following two
testing categories.

The first test category, used for testing only individual cable assemblies, the
bulkhead connection on the adapter is a solid connection through 360 degrees between
the face of the connector and the bulkhead.

For the second category, used for testing the complete bulkhead connection with the
cable assembly mated as it exists in service, the bulkhead connector is attached in
the adapter just as it would be in normal service. For example a PCI bracket may be
used on the adapter to simulate a PC option card connection.
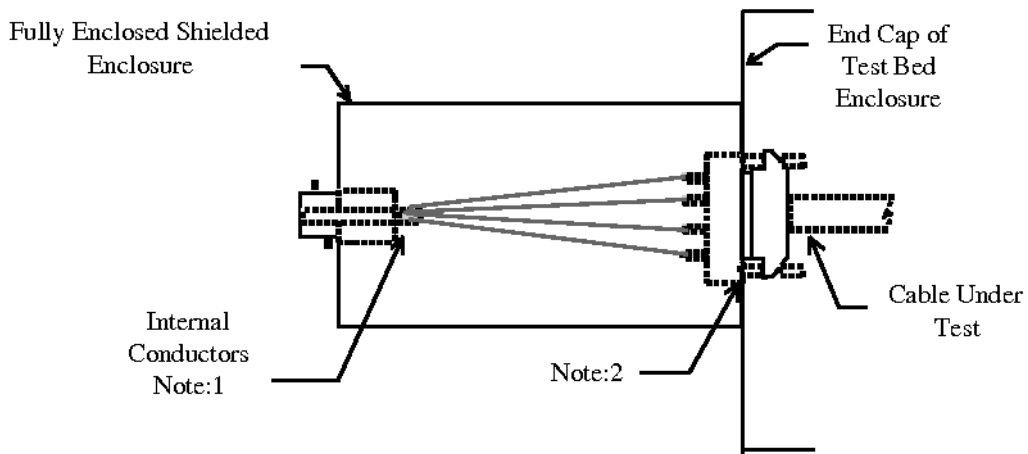
Figure 29 - Test fixture for individual cable assemblies

Notes:

1. All internal connector contacts bused together and attached to center pin of BNC connector.

2. For the first testing category a 360 degree connection between the connector housing and the end cap of the pipe is required. Use gasketing or soldering to insure there are no openings from the adapter enclosure to the testing area.

3. The connector shown is capable of being hard mounted on the bulkhead and can accept wire termination on the test fixture side

4. For connectors that get their mechanical support from being mounted on a PCB the test fixture will use a PCB instead of wires as shown in Figure 30 – only the PCB feature shown in Figure 30 applies to this test fixture

5. The distance from the BNC connector to the bulkhead should be kept as short as possible

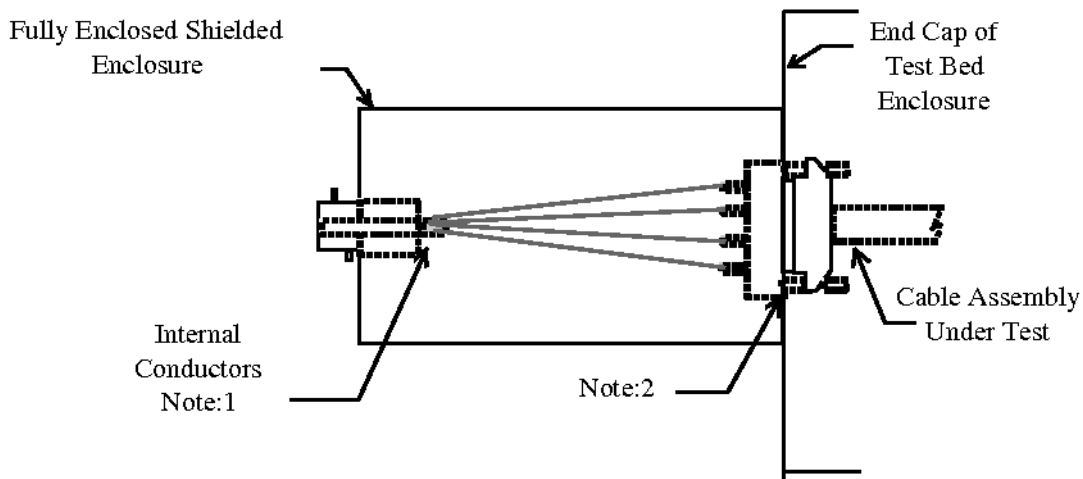In the case of the HSSDC connector system, for example, a PCB may have to be used in the adapter box because not all of the HSSDC bulkhead connector variations use hardware to hold the connector to the bulkhead. Some connector variants rely on a pressure fit or some kind of spring contact.

Figure 30 - Test fixture for complete bulkhead interface testing

Notes:

1. All internal connector contacts bused together and attached to center pin of BNC connector.

2. The bulkhead interface is created in the fixture in the same way as it would be in normal service

3. The connector shown requires mounting on a PCB for mechanical support

4. The distance from the BNC connector to the bulkhead should be kept as short as possible

The IUT is terminated on the far end with the circuit shown in Figure 31, Figure 32 and Figure 33. The resistor in Figure 31 is terminated to the metal enclosure and the metal enclosure is connected to the connector's metal shield.
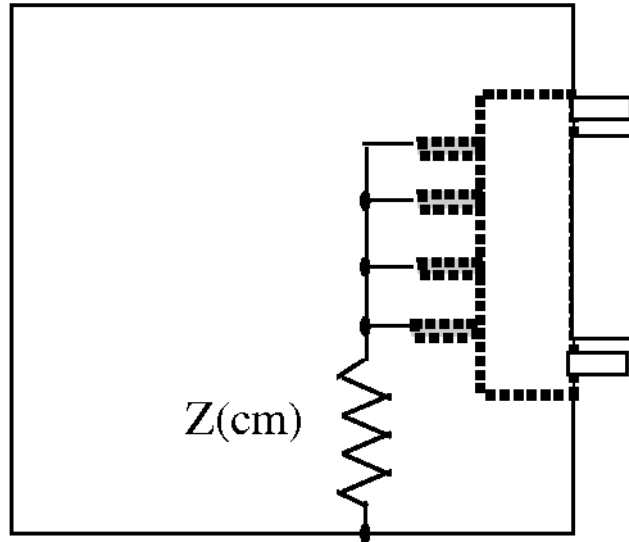
Figure 31 - IUT terminator

4.4.1.2 Calibration procedure

Using a TDR, measure and record the single ended characteristic impedance of the
cable assembly to be tested. This singled ended characteristic impedance is measured
with the four internal conductors shorted together and the shield of the cable
connected to ground. This is easily accomplished using either test fixture in Figure
29 or Figure 30. This is the Zcm shown in Figure 31 for the IUT terminator.

The internal common-mode current is established by inserting the IUT in to the stove
pipe (measurement fixture) and absorbing / current clamp as shown in
Figure 32, 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 IUT. The center
of the current clamp, in the MDS-21, is placed 10 cm away from the end of the test
bed enclosure. The far end of the IUT is terminated in its characteristic impedance,
Zcm, with the IUT terminator.
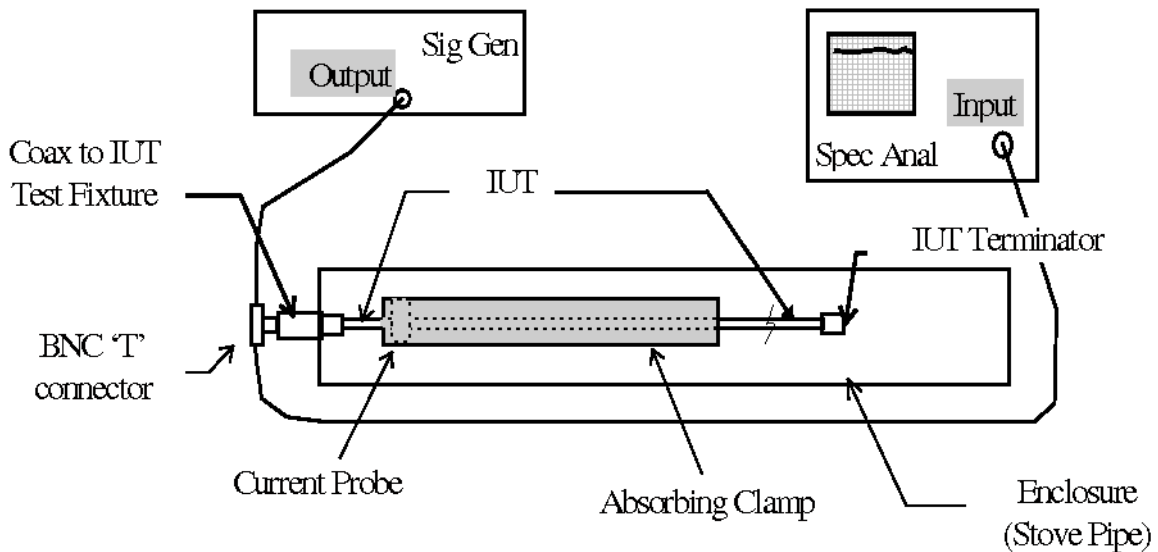
Figure 32 - Calibration configuration

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.

4.4.1.3 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 33. 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.
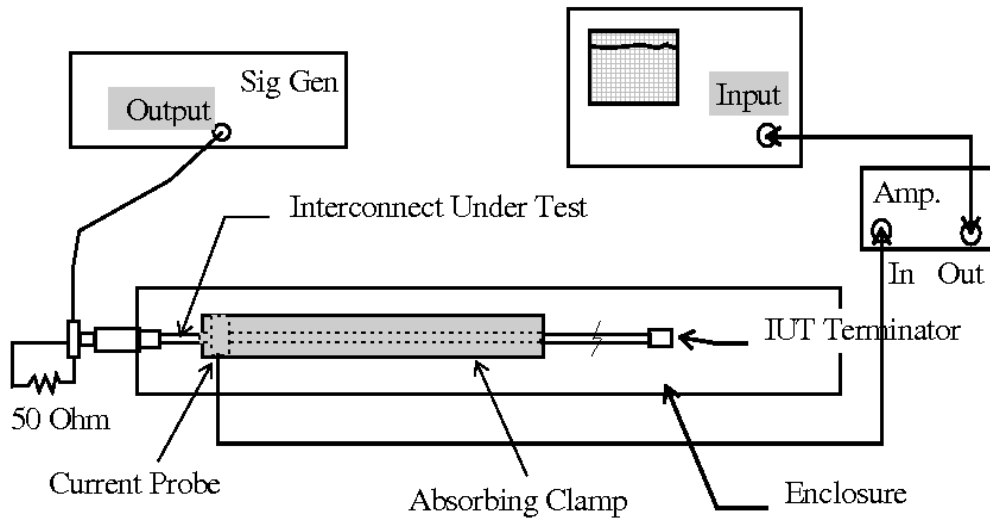
Figure 33 - Measurement configuration

A sample spectrum analyzer display is shown in Figure 34 and the calculated CMPT is shown in Figure 35.
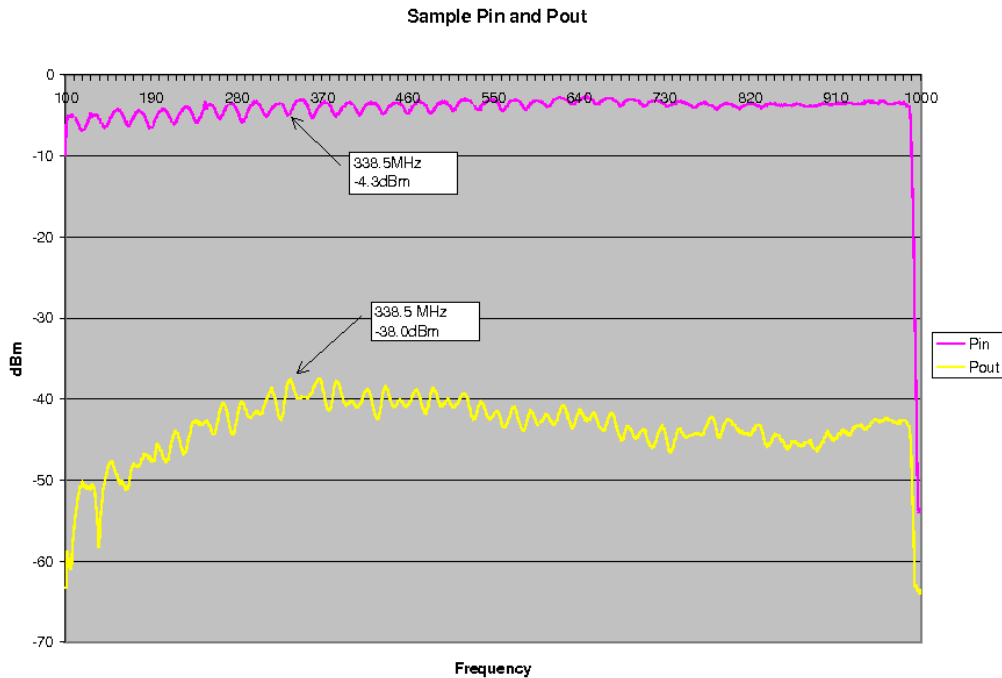
Figure 34 - Pin and Pout example

Figure 35 - CMPT calculated using Pin and Pout in

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 35 at 338.5 MHz Pout is -38.0 dB, amplified gain is 26 dB, insertion loss is 17 dB, and Pin is -4.3 dB:

CMPT = (-38.0 dBm - 26 dB + 17 dB) - (-4.3 dBm) = -42.7 dB

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 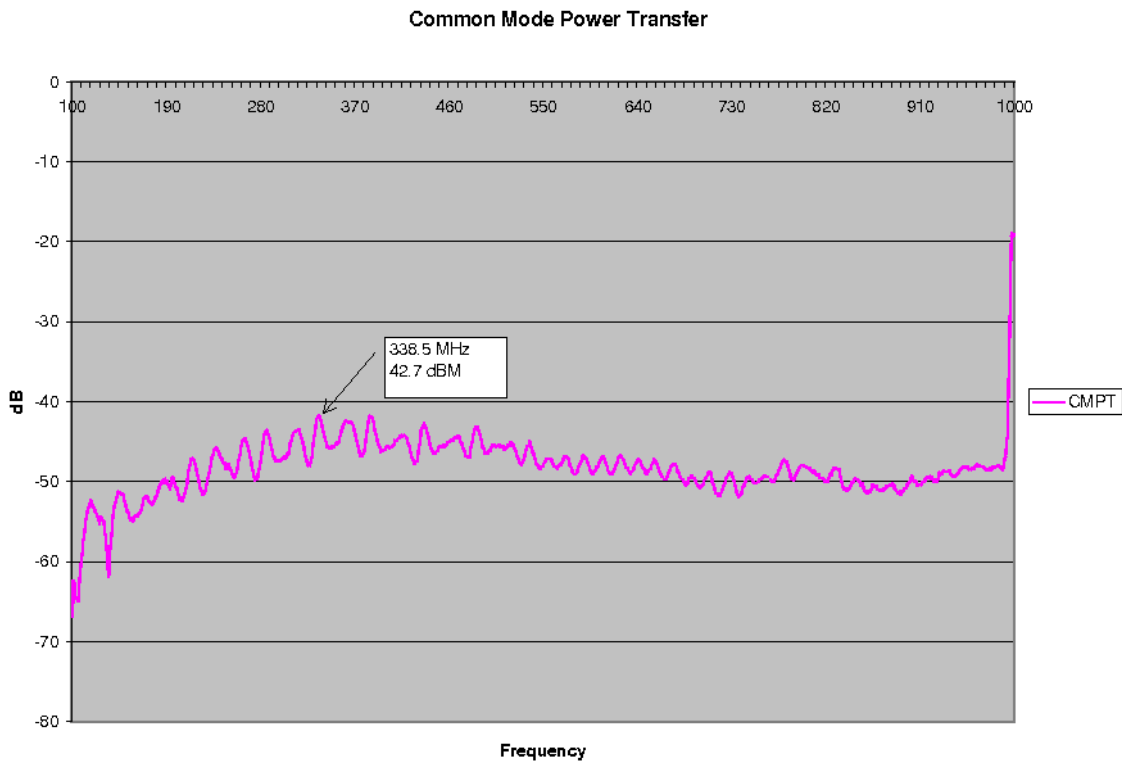current probe. Insertion loss is provided by the clamp manufacturer and may be different at each frequency. Amplifier gain is from the inline amplifier, if used, and also may vary with frequency.

4.4.1.4 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 its mating connector then across the frequency range of 100 MHz to 1 GHz a recommended acceptable CMPT is less than -40 dB.

The CMPT requirement is unique to this document at the moment.

4.4.2 Common mode radiated power ratio (CMRPR) [Using mode stir chamber]

Electromagnetic radiation testing is executed by using an antenna and the IUT 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 IUT in this test consists of the complete duplex cable assembly and the associated bulkhead attachments. Each end of the IUT is connected to connectors mounted on and penetrating through the walls of the chamber. Differential transmitters for both halves of the IUT are attached outside the chamber and apply maximum amplitude signals with minimum STD and maximum allowed imbalance to the IUT.

The EMR of the IUT is the difference between the radiation measured with the IUT and excitation in place and an identical test from a reference sample. An unshielded reference cable is required. The reference cable should have the outer shield stripped off and it should be of the same length as the cable under test within 5mm.

The significant difference between this specification and Method 3008 of MIL-STD-1344 is that in this technique the cable assembly 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. By driving the cable assembly, differential signal excitation methods can be used which is representative of the intended application of the cable assembly.

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

Notice that the signals applied in this test are much less likely to cause EMI than the CMPT tests because a nominally balanced signal is used in this test. In the CMPT test the conductors are all connected together to produce the worst possible (least balanced) case for producing EMI.

Evidence exists that shows that the EMR and CMPT tests both produce equivalent results for measuring balanced duplex copper interconnect.

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.

4.4.2.1 Test fixture and measurement equipment

4.4.2.1.1 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 down to 200 MHz, possibly as low as 50 MHz.

Signal Generator - the signal generator should have roughly 0 to 10 dBm output power capability and controllable via an external interface bus. Bandwidth should be 50 MHz or less to at least 1 GHz.

Power Amplifier - measuring very well shielded cable assemblies may require a 1-watt power amplifier with a bandwidth of 50 MHz or less to at least 1 GHz.

Differential Coupler - required for differential excitation of the cable assembly and should have a bandwidth of 50 MHz or less to at least 1 GHz.

Log periodic antenna - a sense antenna to measure the field from the cable assembly with a typical bandwidth of 200 MHz to at least 1 GHz

Biconnical antenna - a sense antenna to measure the field from the cable assembly with a typical bandwidth of 50 MHz or less to at least 200 MHz

Pre-amplifier - broad band low noise pre-amplifier is useful in measuring well shielded cable assemblies. Typical specifications are a gain of 40 dB and a bandwidth of 50 MHz or less to at least 1 GHz.

Spectrum analyzer - the analyzer should be instrument bus configurable and have a bandwidth of 50 MHz or less to at least 1 GHz.

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

Data pattern generator - a data pattern generator is useful to evaluate cable assemblies using the exact data sequence the cable assemblies are expected to transport. The generator should support data rates of 200 MB/s to at least 1.4 GB/s.

See Figure 37 for examples of specific test equipment.

4.4.2.1.2
EMI data up to 6 GHz, Dean

[retained until transfer to the document]

Dean showed EMR data from his mode stirred chamber up to 6 GHz. He used his VNA as the receiver since it could go to the higher frequency and the usual spectrum analyzers cannot go this high. The vector network analyzer supplied the source signal as well as measured the response from the antenna. This is a novel use for a VNA and may help to mitigate the cost for these instruments.

This data showed no particular concerns but many features are not yet understood.

Dean to supply the data for the records.

Dean to supply the test setup details for the EMI measurements using VNA.

4.4.2.1.3 Test fixture

Test fixture preparation can be involved, as it requires machining a brass plate with a pre-defined cutout for the connector receptacle. The connector receptacle to panel interface can be a significant leakage mechanism so installing the connector receptacle correctly is required for credible results.

Figure 36 shows a diagram of a typical fixture. The 3"x4" brass plate has 2 machined openings for the connector receptacle to penetrate through. The receptacles are mounted to a PCB substrate using the receptacle board mount features. The center conductor of RG402 semi rigid cabling is connected to the appropriate pins of the receptacle. The outer shield is soldered to the surface ground plane PCB material for referencing and mechanical stability. Termination resistors are soldered to the appropriate pins of the receptacle. Right angle brackets mount the PCB to the wallplate. Care must be taken to ensure that the electrical length of the semi-rigid feed is identical so that source induced skew is minimized in the differential excitation.
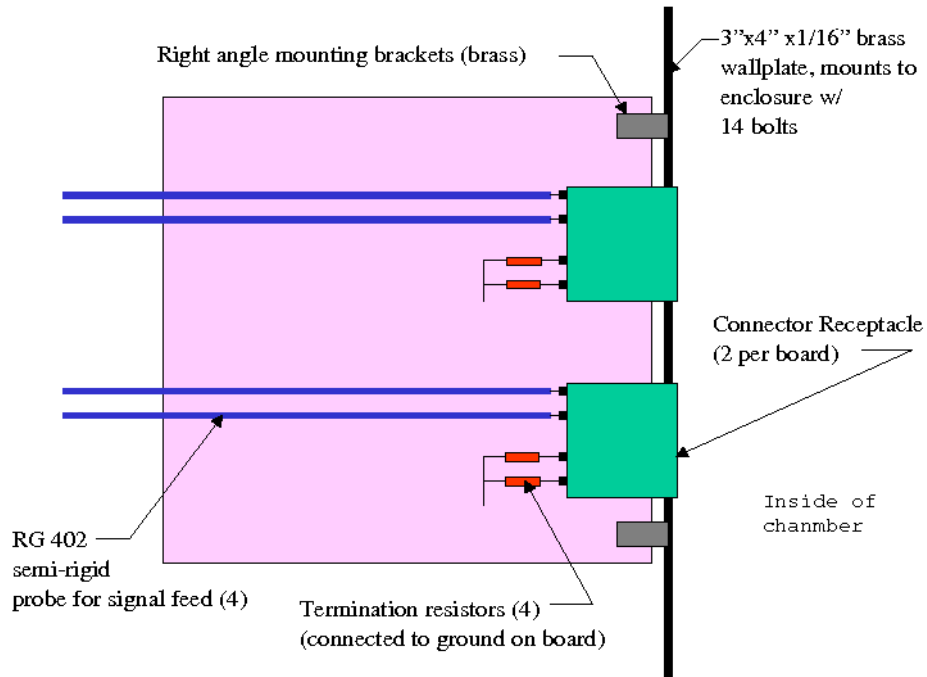
Figure 36 - Diagram showing typical receptacle fixturing

4.4.2.2 Calibration and verification procedure

The calibration process uses the same test setup and equipment as during the test of the IUT but with different excitation and samples attached.

4.4.2.2.1 Test setup

The test setup is shown in Figgure 38. The connector receptacle fixturing is mounted to a bulkhead panel cutout in the MSC. The signal generator should be attached to the hybrid coupler with at least double braid coax (RG223 or equivalent). The electrical path length for differential excitation from the hybrid coupler to the receptacle needs to be well matched and consistent from test to test. It is recommended that semi-rigid coax be used for these connections.

The coaxial feed from the receive antenna to the pre-amp should use a well shielded cable. Ethernet thicknet trunk cable (double braid, double foil) has been used successfully. The main concern is that fields from the signal excitation path will couple to the input of the pre-amplifier.

Figure 37 - Typical test setup

4.4.2.2.2 Calibration procedure

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

The placement and routing of the IUT is not critical but should extend into the MSC at least 3 feet. If the cable is very close to the wall of the MSC, fields from the cable assembly tend not to couple to the interior volume of the MSC.
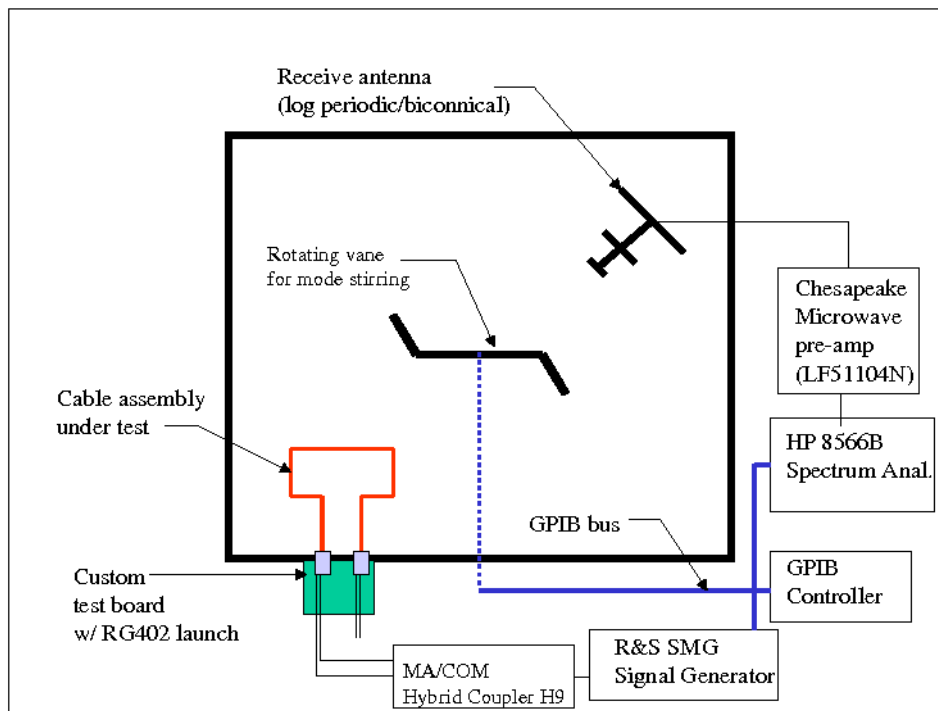
Put the unshielded reference cable in place of the IUT in Figure 41.

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

In all cases the signals are pure differential sinusoids with maximum allowed imbalance (25% of differential peak) and maximum allowed amplitude (2.0 v pp for FC).

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 at least 1 GHZ is covered. Linear frequency sweeps or logarithmic frequency sweeps are commonly used.

The rotating vane of the MSC is then moved 18 degrees and the process of recording the radiated emission level at each frequency is repeated. 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.

A 2-dimensional matrix of radiated emission measurements is created. For each frequency, the radiated emission level must be averaged over the 20+ rotating vane positions. This is accomplished by converting the levels from logarithmic space (dBm) to linear space (mW), summing the 20 values for each position and dividing the sum by the number of vane rotations (20+). This single value is then converted back to logarithmic space. This process is repeated for each frequency.

4.4.2.3 Testing procedure

Attach the IUT to the test fixture using the same physical routing as used for the reference cable.

Take a test spectrum scan as described in section 4.4.2.2.2

The shielding effectiveness is computed as the difference between the reference and the IUT at every frequency.

The reference cable should be excited in the same manner as the IUT i.e. with the same signal intensity and launched imbalance at every frequency.

Documentation: The final documentation should include the test results, description of cable assembly tested, source power level setting and source induced skew (if any).

4.4.2.4 Acceptable levels

No acceptable levels have yet been identified for this test.

4.5 Near end cross talk (quiescent noise)

May need update with area under the curve information

This test 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 IUT on one pair and the signal induced on

the neighboring pair is measured. In this test both pairs are under test. The pair with the applied pulse is the aggressor pair and the pair with the induced noise is the victim pair. There are no signals coming into the victim pair from the remote transmitter for this test.

Single pulse tests eliminate the effects of resonance, are very 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. It is necessary to reverse the polarity of the aggressor signal to ensure that balance compensation is not occurring.

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 cross talk 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. For example, if connector termination techniques are causing the cross talk then that can be revealed by examining the time points associated with the termination points.

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 cross talk 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 cross talk 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 pulse technique is desirable.)

Although cross talk 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 cross talk 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 connector itself and the termination of the media to the connector are 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 connector and termination are producing the most intense coupling, the victim line noise pulse returns to near zero as the aggressor pulse passes into the undisturbed media. In the case where the media 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. 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
media itself. Wiring of lines in the media to the wrong connector contact positions
is one possible mechanism that can inadvertently produce much higher coupling than
intended.

If there are significant non-uniformities in the coupling within the media these will
be revealed by victim line noise pulses well away from the connectors.

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

The near end cross talk test is intended to apply to all constructions of cable
assembly including those with equalizers and those with known non uniformities such
as intermediate connection points.

4.5.1 Test fixture and measurement equipment

The same basic test fixture is used as for the impedance profile tests. See Figure
12.

The measurement equipment is also the same as for the impedance profile tests except
that a separate receiving head is used for SMI1.

The length and properties of the 50 ohm leads connecting the aggressor signal and the
victim measurement instrument to the test fixture should be the same (except as
needed to induce imbalance).

4.5.2 Calibration procedure

The time reference calibration is done using the same test fixture and nearly the
same procedure as for the TDR tests in section 4.1.1 (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 cross talk.

The STD calibration is done using a through fixture identical to that used for the
signal degradation tests except that the lower traces are not used. See Figure 40.
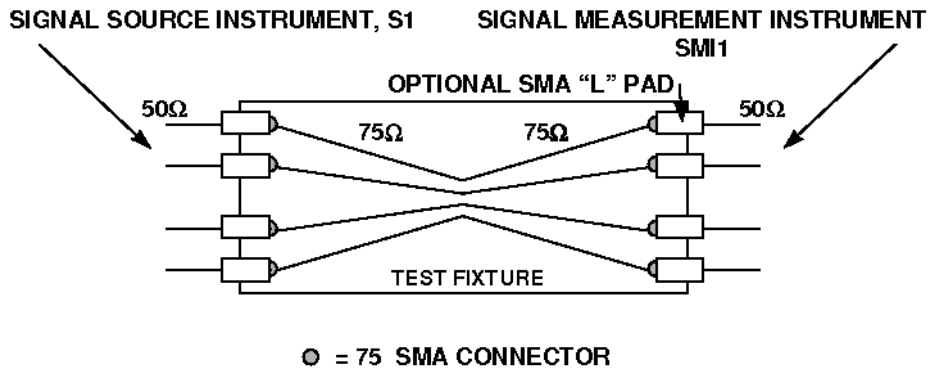
Figure 38 - Amplitude calibration test fixture

Using the test fixture shown in Figure 38 apply a differential pulse from S1 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. 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 using the scales shown in Figure 39. Set S1 to the required STD by using software filtering or hardware filters. Record the amplitude as described in Figure 41.

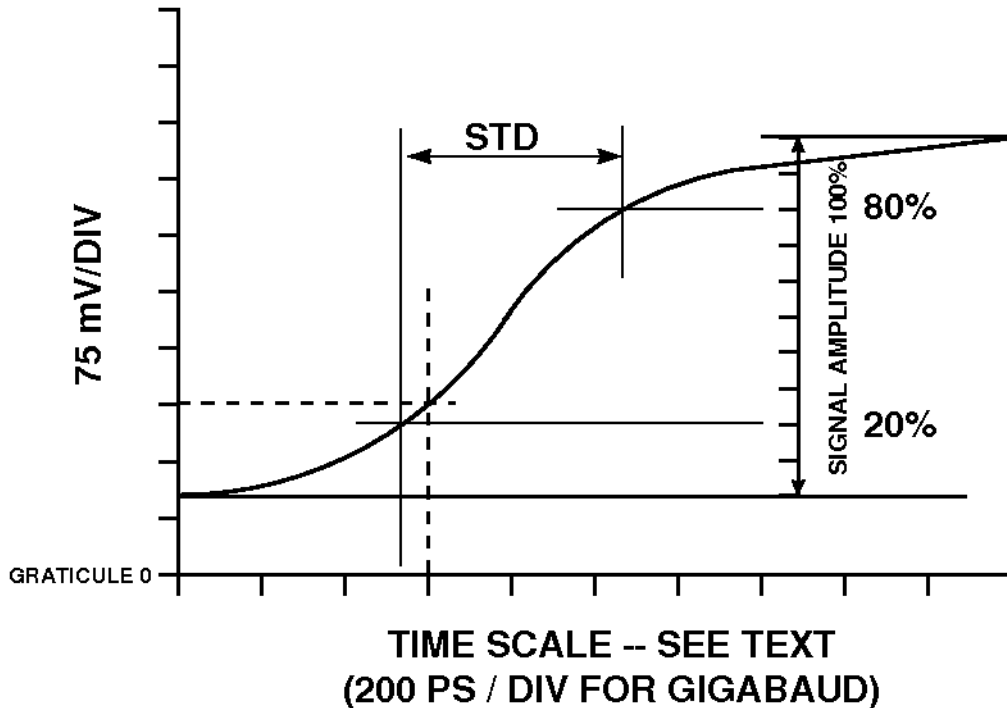Retain all the settings for reuse in the measurement.

Figure 39 - Signal transition duration and amplitude calibration

To calibrate the imbalance in the aggressor signal use again the test fixture in Figure 38. 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.

Note the exact settings used for both the minimum and maximum STD conditions as these are reused when doing the actual measurement.

A second calibration fixture configuration is used to verify that the fixture is not causing excessive cross talk. This second fixture is identical to that described in section 4.1.1 but with 150 ohm resistors added instead of shorts. The second calibration setup is shown in Figure 40.
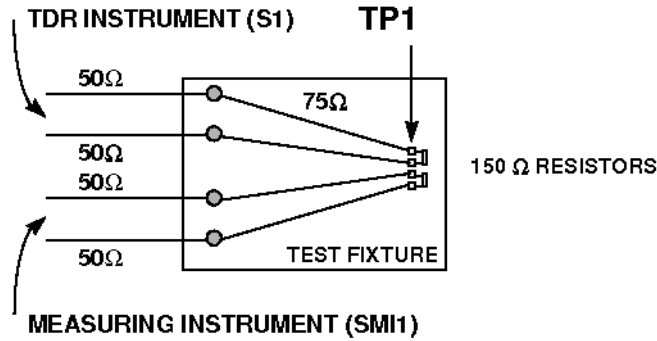
**TEST FIXTURE / MEASUREMENT PROCESS IS CALIBRATED
TO REPORT VALUES AT TP1**

Figure 40 - Calibration system for NEXT

Use the calibrated S1 signal created in the previous steps with the test fixture in Figure 40 measure the cross talk produced.

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

4.5.3 Testing procedure

Using the test setup shown in Figure 41 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 cross talk noise results even if scaling is used. This is required to evaluate the effects of the noise floor for IUT's with small cross talk.

Repeat the test exactly except with the polarity of the leads to S1 reversed.

A   = PERMANENTLY MOUNTED CONNECTOR ON THE TEST FIXTURE
B, C = PART OF THE SEPARABLE INTERCONNECT UNDER TEST
D   = TERMINATION
⊙   = CONNECTOR BETWEEN 50 AND 75 OHM SECTIONS

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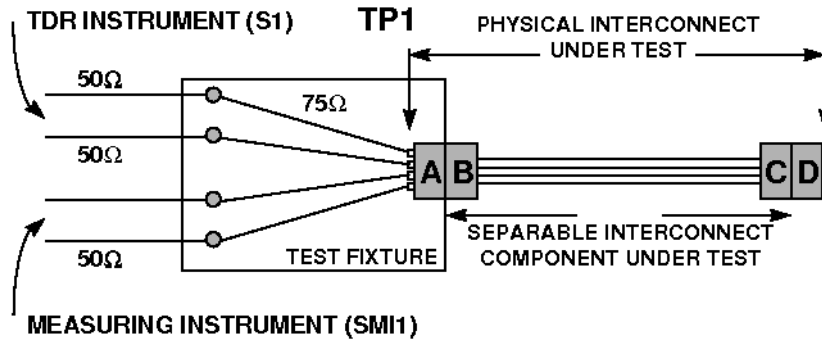TO REPORT VALUES AT TP1

Figure 41 - 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 percentag
e with respect to the amplitude of the aggressor signal are recorded.
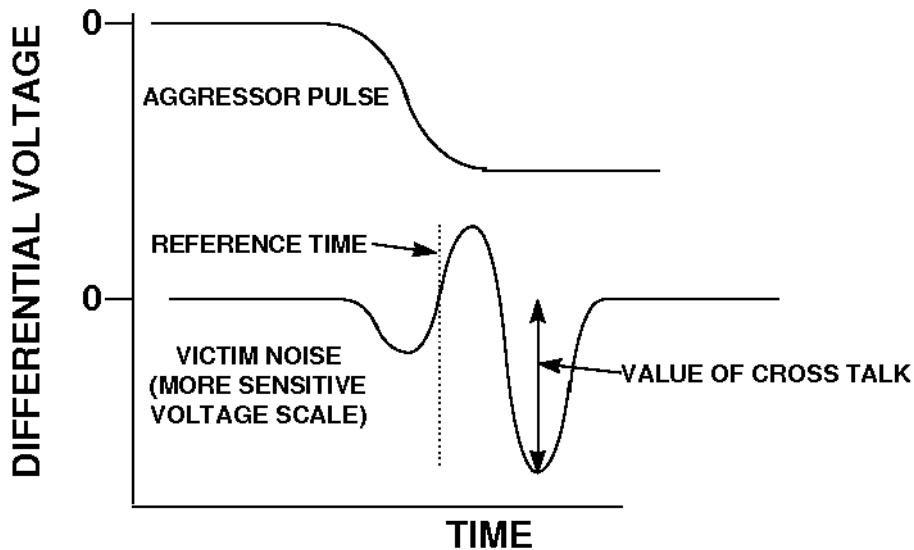
Figure 42 - Example of cross talk measurement

Repeat the tests for both polarity of lead attachment to S1 with the maximum STD
aggressor signal.

The absolute value cross talk 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 cross talk
result would be multiplied by 2.0.

The percentage result does not need to be scaled.

4.5.4 Acceptable ranges

Acceptable values in this document for FC are less than 3%. No number or test procedure has been established in the formal 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 IUT. Other tests, notably balance degradation, will detect this degradation as a failure so the observation of the high media coupling is not a direct reason for failing the cross talk test.

5. Level 2 tests

5.1 Attenuation

Attenuation 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 interconnect. Higher attenuation 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 trapeziodal signals in terms of Fourier components. A complete attenuation specification requires examining all frequencies of interest to the application. A spectral description is recommended. The basic formula for attenuation in decibels is:

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

Note that this formula gives the attenuation as a positive number since the argument of the log is greater than unity. Sometimes attenuation 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 both gain and attenuation. The following formula expresses gain in decibels.

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

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.

Since the argument of the log is less than unity the gain is a negative number.

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

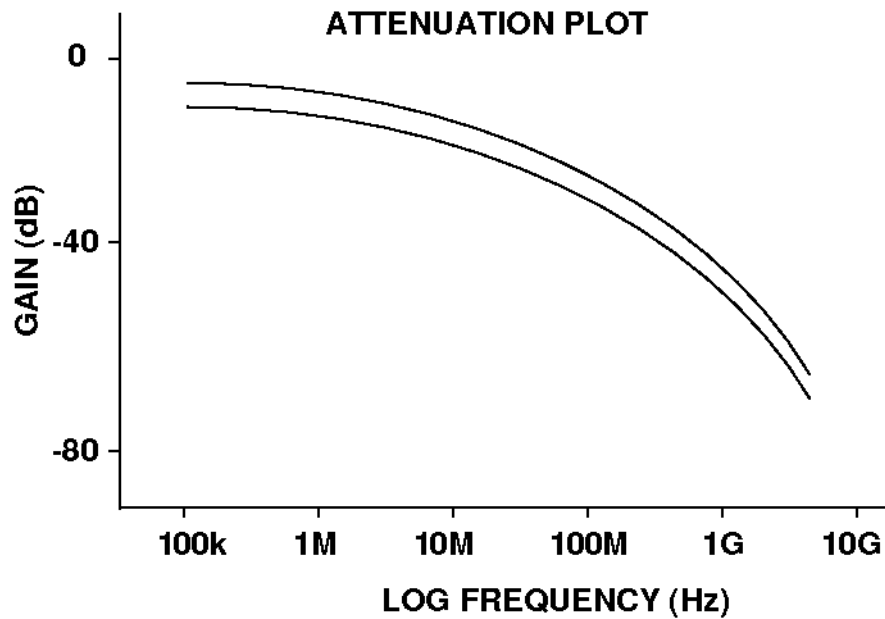Therefore a typical attenuation plot has the form shown in Figure 43.

ATTENUATION PLOT

Figure 43 - Form of attenuation plots

Attenuation is a measurement of the dissipative losses on a balanced transmission line. The series resistive loss of the conductors (copper) and the shunt loss due to the dissipation factor of the dielectric covering the conductors dominate these losses. 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 attenuation 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.

Attenuation 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.

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) = $(- 10 \, LOG_{10} \, (1 - |\,_\Gamma\,|^2 \,))$ dB

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.

Since the test instruments are single ended and the IUT is balanced a coupling device called a balun is required to connect the IUT to the test equipment.

Balun Selection. The impedance on the primary side of the balun must match the impedance of the test equipment, normally a network analyzer. The impedance on the secondary side of the balun must be matched as closely as possible to the nominal

impedance of the IUT in the balanced state to minimize reflections. If reflections
are present they will skew the data by introducing a mismatch loss ripple component.

Figure 44 shows the effect of different baluns on a very long cable (approximately
300 meters). There are no reflections visible because they are attenuated to
insignificant levels by the long length. Another very important benefit to using
long cables for these tests is the elimination of resonance effects for the same
reason that reflections are not a problem. The main effect of using relatively
seriously mismatched baluns on very long cables is a small error in the attenuation
reported (less than 1 dB in the example shown).

tbd

Figure 44 - Effect of balun selection on measured attenuation for very long cables

Sample Length.   The optimum sample length is such that there is at least ~ 1db of
one way attenuation at the lowest frequency of interest. This will guarantee that
there is at least 2 dB of additional loss experienced by that portion of the test
signal that reflects from the far end.

This will reduce the uncertainty caused by multiple reflections due to the far end
and will result in acceptable resolution / ripple. The resulting measurements is
accurate and repeatable. If a sample is used that yields an attenuation of less than
1dB the mismatch ripple from the near end combined with the mismatch ripple from the
far end can approach the same or greater magnitude than the attenuation at the lowest
frequency. For example in the unmatched balun case:

Case 1 :
Near End Balun Z = 100 Ohm
Far End Balun Z = 100 Ohm
Nominal Balanced Cable Z = 150 Ohm
Balanced Cable loss at lowest test frequency = 0.5 dB = 0.94406

In case 1 there is only 0.5dB attenuation in the presence of a ripple that will add
anywhere from 0.354 dB to 0.6972dB of measurement error as shown in Figure 45.

FREQUENCY MHz

Figure 45 - Effects of mismatched baluns in a short IUT

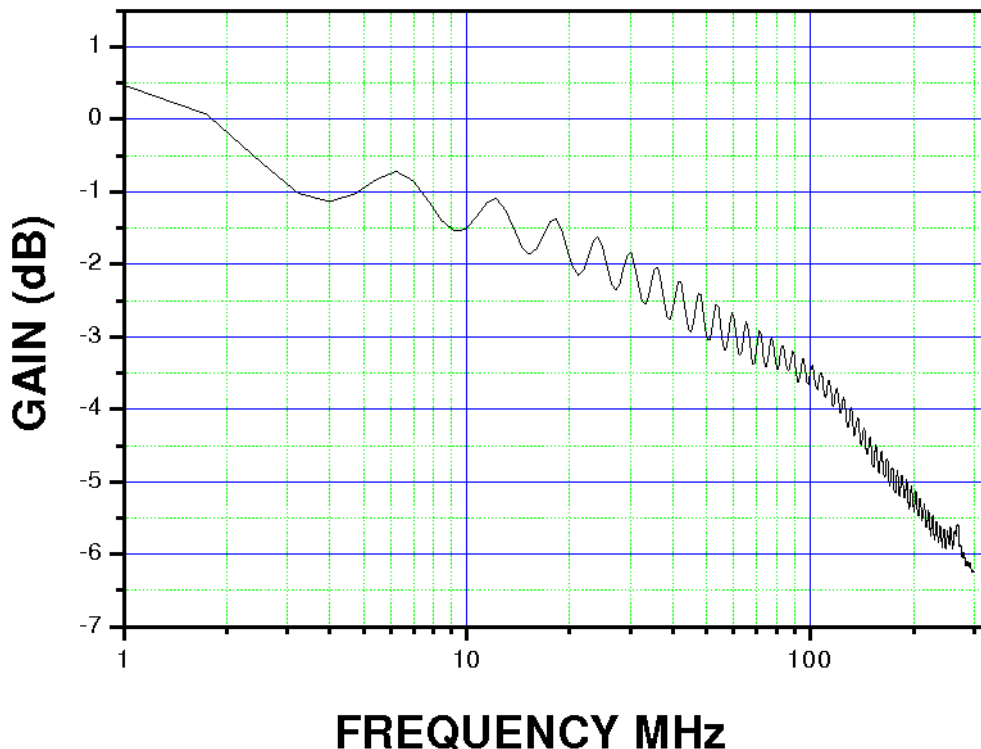For the matched case otherwise identical to case 1:

Case 2 :

Near End Balun Z = 150 Ohm
Far End Balun Z = 150 Ohm
Nominal Balanced Cable Z = 150 Ohm
Balanced Cable loss at lowest test frequency = .5 dB = .94406

The insertion loss equals the desired attenuation result and there is no ripple to cause measurement uncertainty as shown in Figure 46.
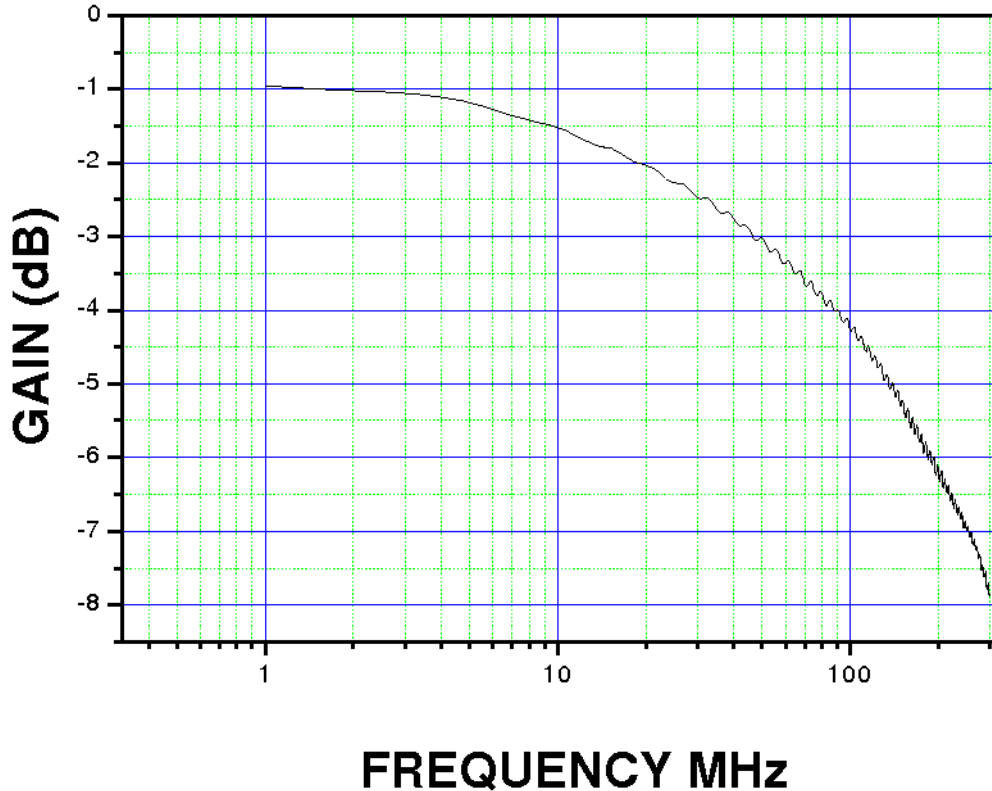

Figure 46 - Effect of matched baluns on a short sample

Finally, for the case of at least 6 dB of low frequency attenuation the results are achieved without requiring a closely matched balun:

Case 3 :

Near End Balun Z = 100 Ohm
Far End Balun Z = 100 Ohm
Nominal Balanced Cable Z = 150 Ohm
Balanced Cable loss at lowest test frequency ~ 6 dB

Under a mismatched condition, the insertion loss equals the attenuation plus the mismatch loss at the near end and at the far end. However, in this case, there is sufficient attenuation in the cable at the lowest frequency to make multiple reflections inconsequential, so there is no ripple component of measurement uncertainty. The mismatch loss error is still present, but it is ~ 0.3 dB out of a measured insertion loss of ~ 6 dB.

Figure 47 - Effects of mismatched baluns with 6 dB LF attenuation

Note: The use of an attenuator for measuring shorter lengths is not acceptable because there is still mismatch loss uncertainty due to the fact that the attenuator
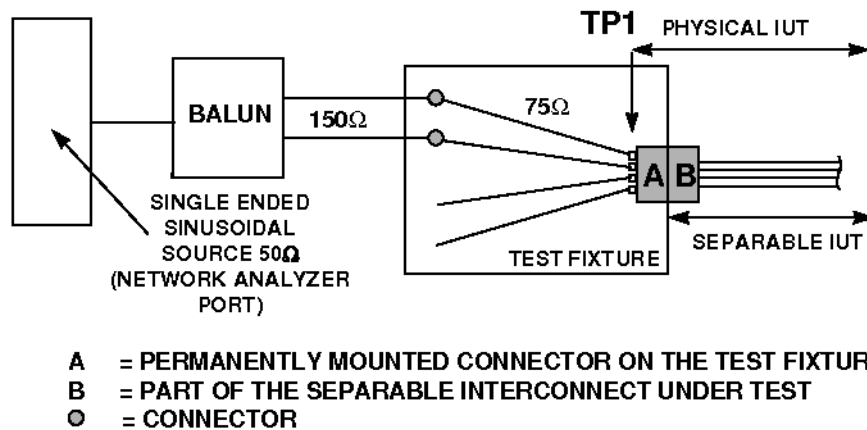
  GAIN (dB)

*does not have any better match than the far end test port. Also an additional
uncertainty is introduced because a small value (cable attenuation) is being
subtracted from a large value, (attenuator attenuation). There are also dynamic
range issues for the instrumentation.*

5.1.1 Measurement test fixture and measurement equipment

An instrument capable of supplying a sinusoidal signal is used as the signal source
and an instrument capable of detecting the amplitude of a sinusoidal signal is used
as the signal sink. Two measurement test fixtures are required: one for the source
end and one for the sink end. Since most source and sink instruments capable of
using variable frequency sinusoidal signals are single ended, a balun [Picosecond
Pulse Labs] or a hybrid [Picosecond Pulse Labs, Minicircuits] may be used between the
instruments and the test fixtures. If a source or sink is used that is capable of
sourcing or sinking differential signals then no balun is required for the
differential source or sink.

Equipment Required: Network Analyzer (HP 87xx Series)

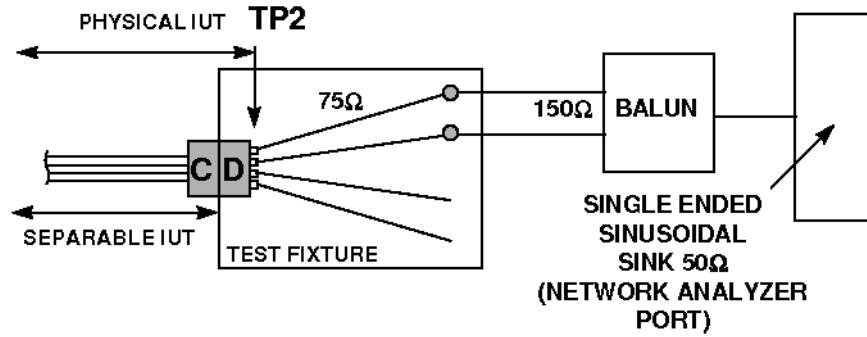A test fixture having 75 single ended paths for each signal line is used for the
measurement as shown in Figure 48 and Figure 49 an calibrated as shown in Figure 50.
This test fixture may be exactly the same as used for the impedance profile tests in
section 4.1.

Figure 48 - Source-end test fixture for attenuation tests

The balun shown in Figure 49 is 50 Ohm single ended to 150 Ohm
differential.

PHYSICAL IUT **TP2**

75Ω   150Ω **BALUN**

**SINGLE ENDED
SINUSOIDAL
SINK 50Ω
(NETWORK ANALYZER
PORT)**

SEPARABLE IUT   **TEST FIXTURE**

A = PERMANENTLY MOUNTED CONNECTOR ON THE TEST FIXTURE
B = PART OF THE SEPARABLE INTERCONNECT UNDER TEST
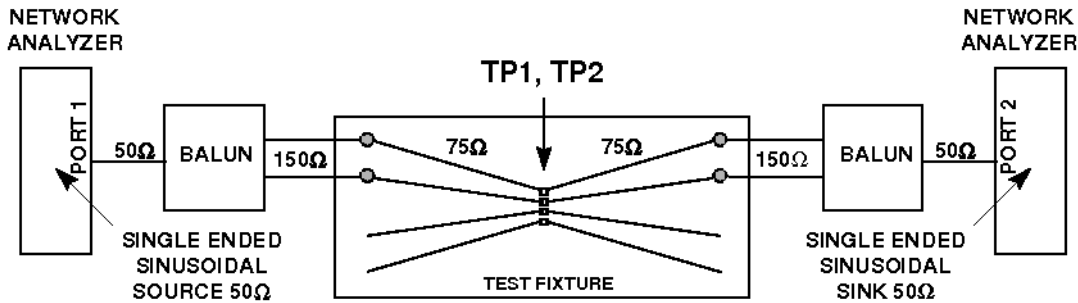**◎** = CONNECTOR

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

Figure 49 - Sink end test fixture for attenuation tests

The separable IUT is connected between the source and sink test fixtures.

5.1.2 Calibration procedure

A special "through" test fixture is used for the signal calibration process which is exactly like the test fixture in Figure 48 and Figure 49 except that there are no IUT connectors (A, D). See Figure 50.

NETWORK
ANALYZER

TP1, TP2

NETWORK
ANALYZER

PORT 1   50Ω **BALUN** 150Ω   75Ω   75Ω   150Ω **BALUN** 50Ω   PORT 2

SINGLE ENDED
SINUSOIDAL
SOURCE 50Ω   **TEST FIXTURE**   SINGLE ENDED
SINUSOIDAL
SINK 50Ω

◎ = CONNECTOR

**TEST FIXTURE / MEASUREMENT PROCESS IS CALIBRATED
TO REPORT VALUES AT IUT CONNECTION POINT (TP1, TP2)**

Figure 50 - Calibration configuration for attenuation tests

Using the instructions from the network analyzer perform a calibration scan over the frequency of interest.

5.1.3 Testing procedure

Connect the IUT to the test fixtures shown in Figure 48 and Figure 49 (including the board mounted connectors).

Using the instructions from the network analyzer perform an attenuation scan over the frequency range of interest. The instrument automatically accounts for the attenuation found in the calibration scan.

It is important to either separate or shield the baluns from each other when measuring long cable samples. When the attenuation of the cable exceeds ~50 dB or the frequency is above approximately 150 MHz, potential direct coupling from the near end to the far end balun will create an increasingly large ripple in the attenuation measurement that can cause a significant amount of measurement uncertainty.

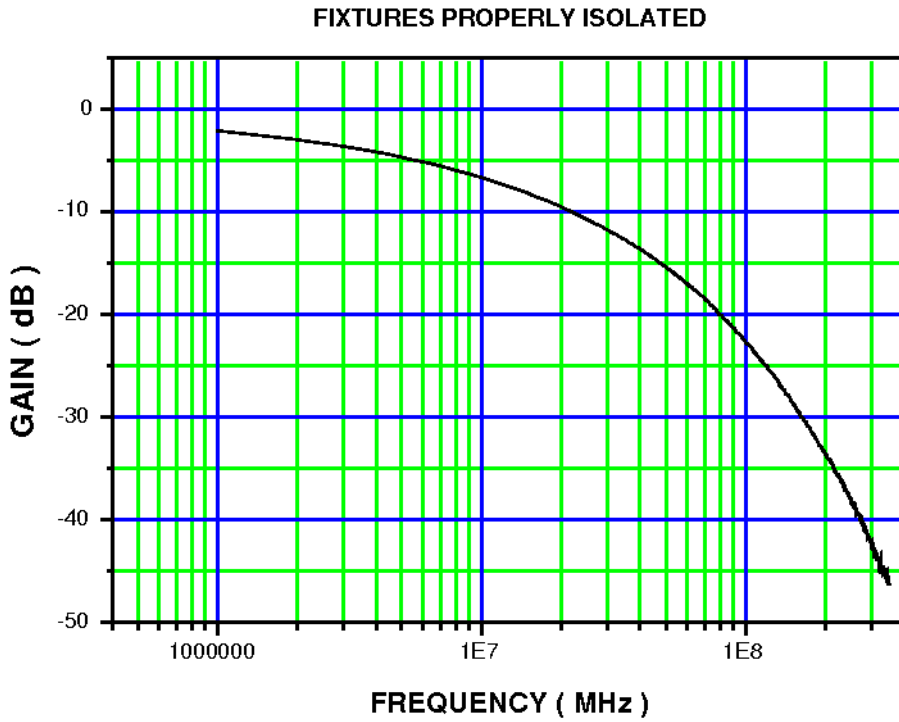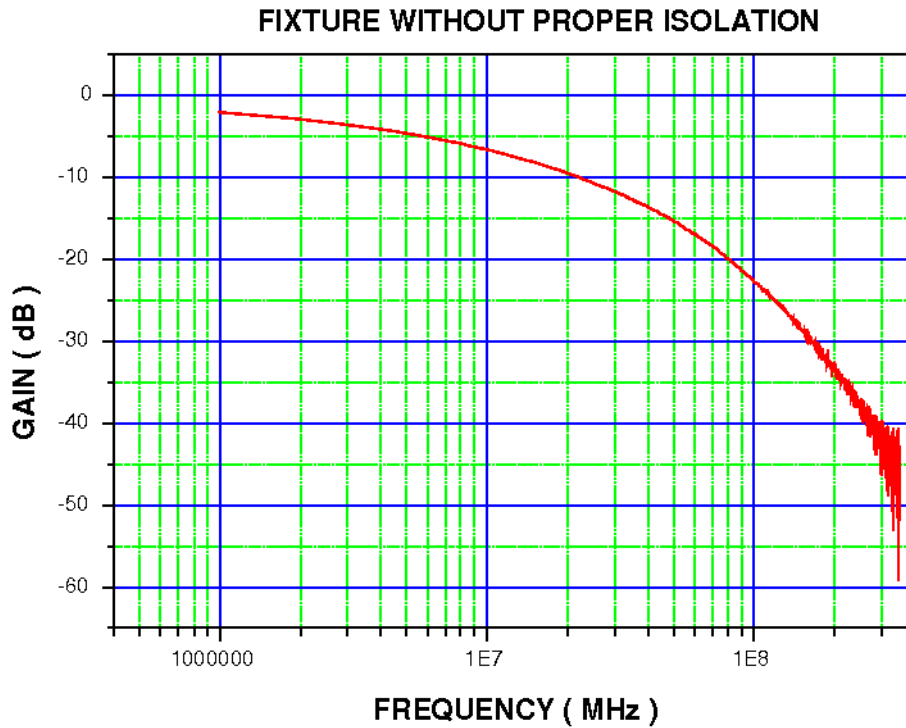Figure 51 and Figure 52 show the effects of balun isolation.

FIXTURES PROPERLY ISOLATED

Figure 51 - Attenuation scan with proper balun isolation

FIXTURE WITHOUT PROPER ISOLATION

Figure 52 - Attenuation scan without good balun isolation

5.1.4 Acceptable ranges

Since attenuation is a level 2 test there are no acceptable ranges defined in this document.

5.2 Propagation time and propagation time skew

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. The propagation time skew is the difference between the propagation times for the + signal and the - signal over the same nominal path.

Since the only skew of interest for this document is between the + signal and the - signal the measurements are all single ended.

Propagation time skew is one major contributor to imbalance.

There are two basic approaches to this measurement:

(1) single pulses are simultaneously launched on the + signal and the - signal. The time required for the midpoint of each to reach the other end of the interconnect is measured.

(2) a repeating clock like data pattern is launched differentially onto the + signal and - signal at one end and the points where the + signal and - signal cross each other and respectively cross the d.c. common mode point (normally zero) are noted at the other end.

These methods are nearly identical in principle but the former method may be easier to use since there is only one pulse propagating while with a repeating pattern one must figure out which received edge goes with the respective transmit edge. The equipment needed is also different for the S1. Only the first method is documented in detail in this document.

This test is a close relative to the amplitude imbalance test described in section 5.3 and the same equipment and test fixtures may be used for both purposes.

5.2.1 Test fixture and measurement equipment

The same thru connection test fixture and measurement test fixtures as described in section 4.2 are used. There is no requirement for a second source for these tests.

The equipment consists of a Tektronix 11801 with SD24 heads or equivalent.

5.2.2 Calibration procedure

The calibration configuration shown in Figure 53 is used.
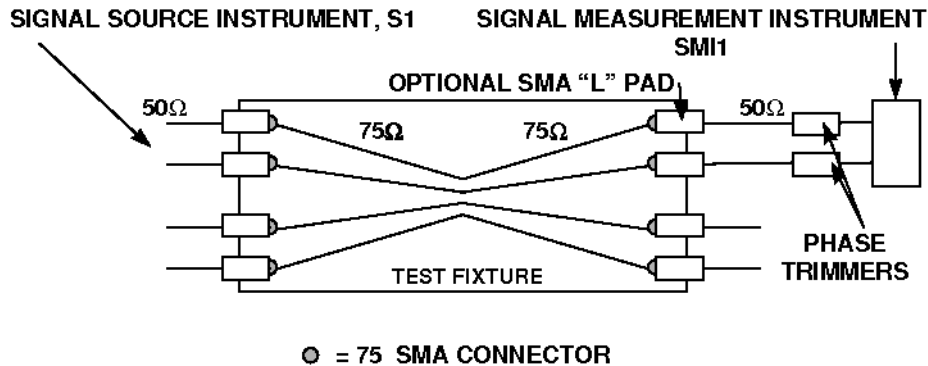
Figure 53 - Calibration configuration for propagation time tests

A differential pulse signal is applied from S1 through the test fixture as shown in Figure 53. The trigger output from S1 is used to trigger SMI1. SMI1 is adjusted such that M1 and M2 are displayed on exactly the same scales but with the polarity reversed on one or the other. This will produce two nearly identical pulses overlaid on each other. The zero level is set the same for both channels.

Adjust the phase trimmers such that the midpoints of the M1 and M2 traces are coincident on SMI1. This will produce identical M1 and M2 traces if the causes of imbalance are purely due to propagation time skew. If the traces are not substantially coincident go to section 5.3 for further discussion of the causes. The test equipment and fixtures should produce substantially coincident traces for use with this test.

Figure 54 - Use of phase trimmers for calibration

If the traces are not coincident then amplitude imbalance is at least part of the imbalance in the received signal.

This calibration process effectively takes all the propagation time skew and other sources of equipment and test fixture imbalance out of the measurement process. There is some propagation time required to traverse the instrumentation cables and test fixture and this needs to be accounted for in the propagation time measurement.

Note the time position of the midpoint of the received pulses. During the testing procedure this time is subtracted from the measured propagation time since exactly the same trigger is used for SMI1.

In all measurements in this section averaging shall be used in SMI1 to eliminate the effects of jitter. The term "single pulse" refers to the time average of a series of widely spaced but repeating pulses.

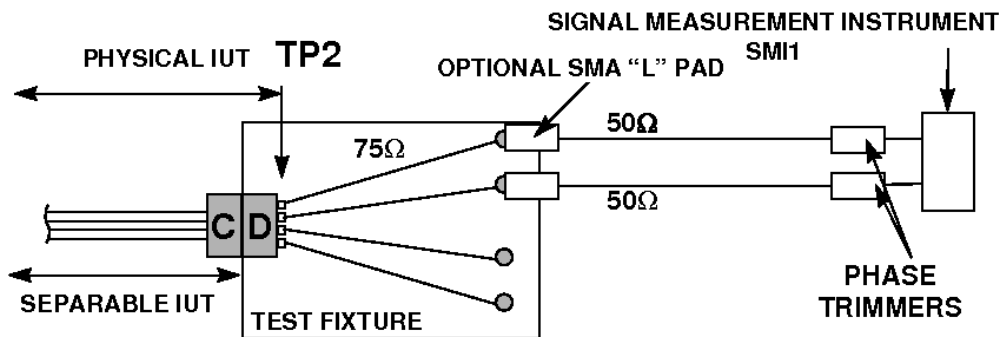### 5.2.3 Testing procedure

Using the test fixtures described in section 4.2.1 connected as shown in Figure 55 and Figure 56 apply the same pulses from S1 that were used during the calibration process.
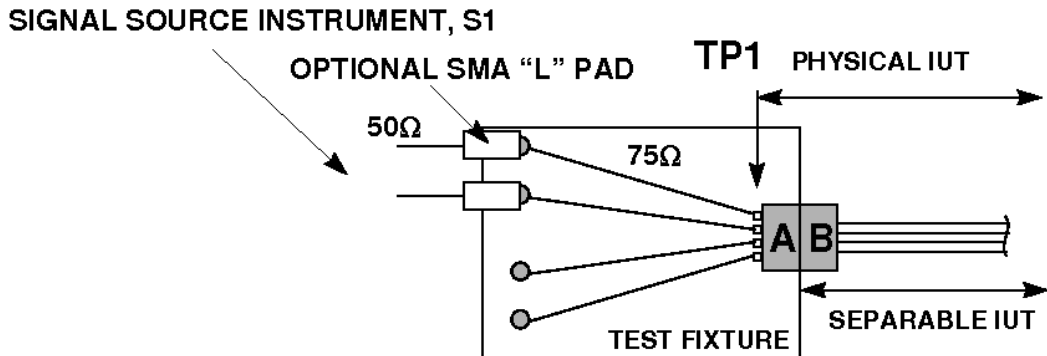
SIGNAL SOURCE INSTRUMENT, S1

OPTIONAL SMA "L" PAD

TP1   PHYSICAL IUT

50Ω

75Ω

A B

SEPARABLE IUT

TEST FIXTURE

A   = PERMANENTLY MOUNTED CONNECTOR ON THE TEST FIXTURE
B   = PART OF THE SEPARABLE INTERCONNECT UNDER TEST
◎   = 75 Ω SMA CONNECTOR

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

Figure 55 - Source side measurement test fixture configuration for propagation time

PHYSICAL IUT   TP2

SIGNAL MEASUREMENT INSTRUMENT
SMI1

OPTIONAL SMA "L" PAD

50Ω

75Ω

50Ω

C D

PHASE
TRIMMERS

SEPARABLE IUT

TEST FIXTURE

C   = PERMANENTLY MOUNTED CONNECTOR ON THE TEST FIXTURE
D   = PART OF THE SEPARABLE INTERCONNECT UNDER TEST
◎   = 75 SMA CONNECTOR

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

Figure 56 - Receiver side measurement test fixture for propagation time tests

Record the results in exactly the same manner as used for adjusting the phase trimmers in the calibration section. The time difference between the midpoints of the received pulses is the propagation time skew and the time position of the average of the midpoints of the pulses is the propagation time (including that of the test fixture and instrumentation). Subtract the time position noted during the calibration to attain the propagation time of the IUT.

Note that if the received traces cannot be made coincident by a simple time translation then effects other than pure propagation time are operating. See section 5.3.

5.2.4 Acceptable ranges

Since propagation time and propagation time skew are level 2 tests there are no acceptable ranges defined in this document.

5.3 Amplitude imbalance between the + signal and - signal

Amplitude imbalance is that not caused by propagation time skew. The test for amplitude imbalance is inability to make the traces match by a simple time translation. See section 5.2.

Figure 57 shows three kinds of imbalance and some example causes that may be experienced in real systems.
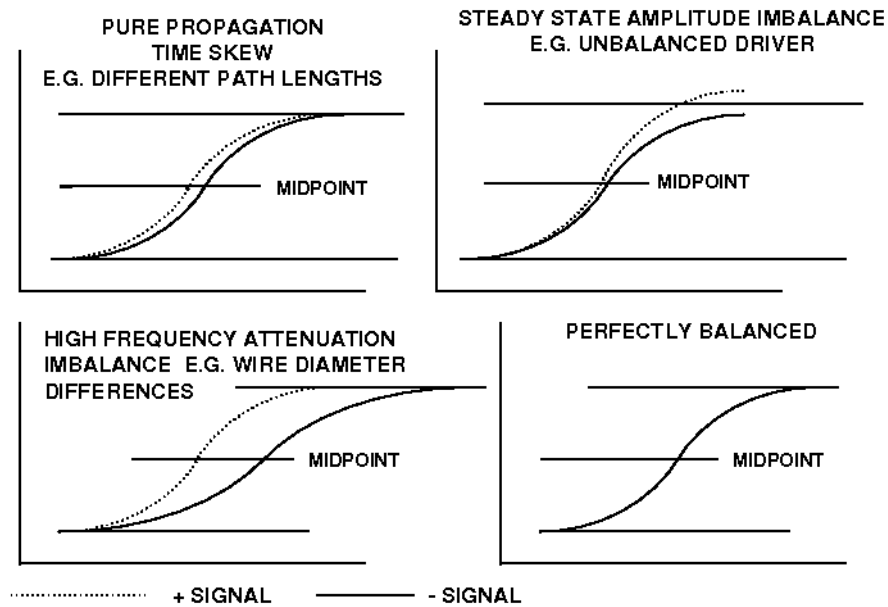
Figure 57 - Examples of received pulses

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.

5.3.1 Test fixture and measurement equipment

The test fixtures and equipment are exactly the same as used for the propagation time tests in section 5.2.1.

5.3.2 Calibration procedure

The calibration procedure is exactly the same as for the propagation time tests in section 5.2.2. Note that it is necessary to remove any significant imbalance in the test equipment and test fixtures before proceeding.

5.3.3 Testing procedure

Connect the IUT and perform the tests exactly as described for the propagation time tests in section 5.2.3.

5.3.4 Acceptable ranges

Since amplitude imbalance is a level 2 test there are no acceptable ranges defined in this document.

5.4 Signal transition duration

This level 2 test is very similar to the level 1 STD calibrations described for the impedance profile tests in section 4.1 except that it is done on actual signals from a driver instead of using a TDR source. The main difference is that the driver source does not start with the single ended signals at zero but rather is always driving a logical "zero" or a logical "one". The purpose of this test is to measure a signal transition duration that is reproducible between different measurement equipment and to allow calibration of S2 sources.

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

5.4.1 Test fixture and measurement equipment

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

The equipment is a sampling oscilloscope, such as the Tektronix 11801 that can provide the scales required for the time and voltage axes.

5.4.2 Calibration procedure

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

5.4.3 Testing procedure

This same process applies for differential and single ended measurements.

In some applications there is a non zero average signal level even when when using perfectly symmetrical (clock like) or d. c. balanced coded data patterns (e.g. 8b10b) for the single ended signals. The single ended signals are always referenced to this average level for the STD test. This section assumes that the average level is zero. If the average level is not zero then the actual average level is used for the center of the display. One may determine the average level by adding the + signal and the – signal, taking the average to remove high frequency common mode (imbalance) content and dividing the average by two.

Assuming a falling edge, set up the display on the TDR as shown in Figure 14. This display has the following properties:

- The span of the time scale on the display is approximately twice the nominal bit or half cycle period for the data rate being used. Ten divisions are used on the time axis. Specifically Table 5 shows the time scales to use.
- The vertical axis is set at 100 mV per division with the zero level set at the fifth division from the bottom (see Figure 14).
- Set the horizontal position such that the displayed curve passes through the third division on the time axis and the seventh division on the vertical axis
- Use the peak to peak function on the oscilloscope (if available) to find the signal amplitude of the displayed portion of the trace as shown in Figure 14. This amplitude may also be read directly off the display. This signal amplitude of the displayed trace may or may not accurately represent the asymptotic signal levels that may exist at times not displayed. If the signal amplitude is such that the minimum value exceeds ±500 mV change the vertical scale to 200 mV/div and repeat this and the immediately preceding steps.
- The signal transition duration (STD) is the time between the 20% and 80% values of the displayed signal amplitude

Table 5 - Scale to be used for STD calibrations

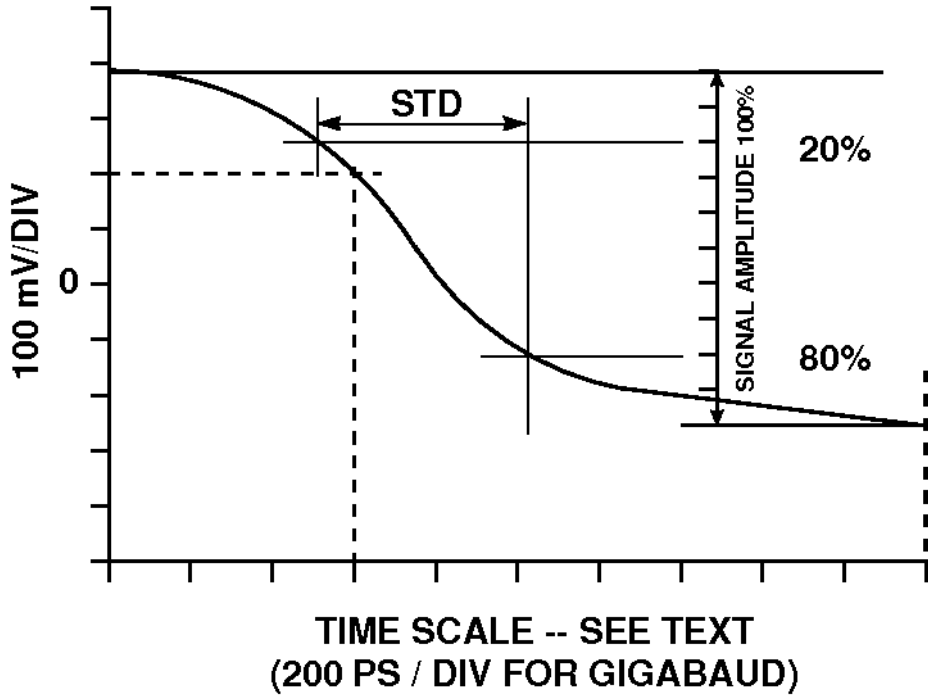| Bit rate * (Mbits/s)	Time axis scale (ps/div)
20 ST	5000
40 ST	2500
40 DT	5000
80 ST	1250
80 DT	2500
100 DT	2000
200 DT	1000
400 DT	500
800 DT	250
1062.5	200
1250	200
1600	100
2125	100
2500	100
3200	50
4250	50
5000	50
* ST = single transition clocking DT = double transition clocking	

Figure 58 - Signal transition duration measurement

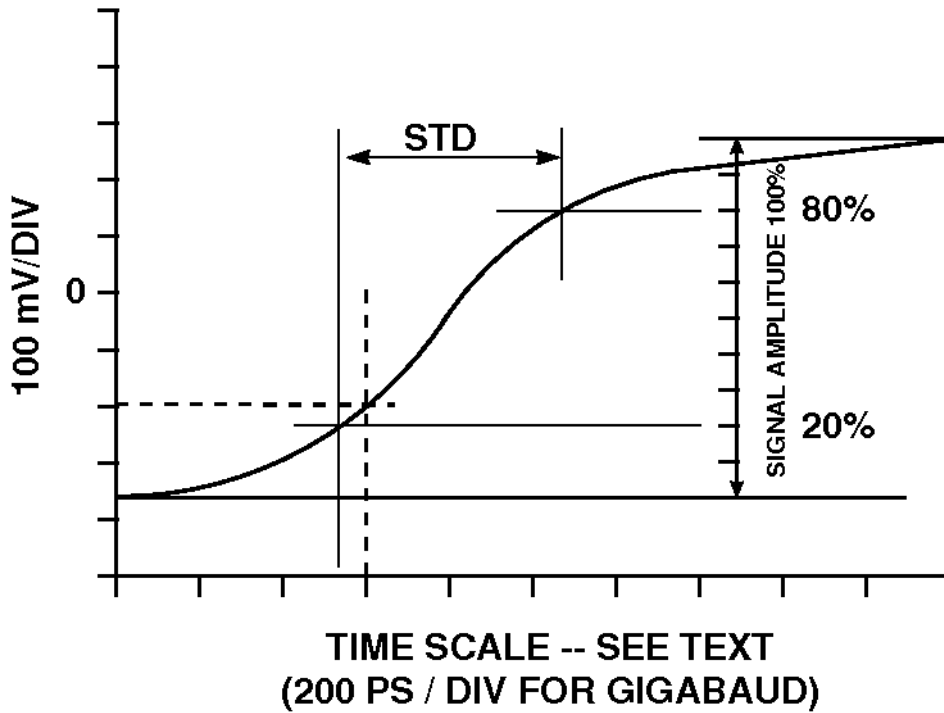For a rising edge signal the STD measurement is the same as for the falling edge with the changes noted in Figure 59.

Figure 59 - Signal transition duration calibration

5.4.4 Acceptable ranges

Since this is a level 2 test there are no acceptable ranges defined.

5.5 Cross talk component of signal degradation

Cross talk provides one source of asynchronous noise that degrades both the amplitude and jitter of the PUT signals. This section describes three methods that can be used to diagnose and characterize cross talk noise:

1. Noting effect of removal of second source on the signal degradation
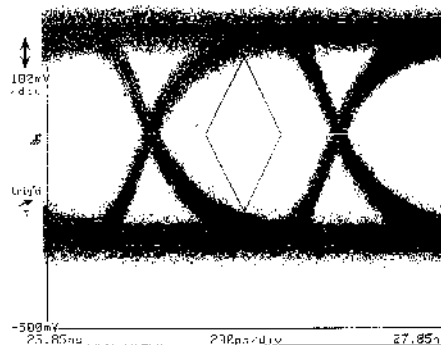
2. Single pulse

3. Sinusoidal

Each of these is a separate test type and each yields different information. It may be desirable to use more than one technique on the same IUT.


5.5.1 Removal of second source

This test is identical to that described under sections 4.2 and 4.3 except that the second source is removed and the resulting eye pattern or signal display is compared to that measured with the second source turned on. The difference between the two measurements provides a quantitative measure of the cross talk.

This technique has at least two significant drawbacks: (1) the results may be seriously affected by resonant conditions in the IUT and/or the test fixtures and (2) it is not possible to determine which part of the IUT/test fixture is the primary contributor to the cross talk.

SIGNAL DEGRADATION TEST WITH SECOND SOURCE ACTIVE (SAMPLE A -NORMAL)

SIGNAL DEGRADATION TEST WITH SECOND SOURCE ACTIVE (SAMPLE B - HIGH CROSS TALK)
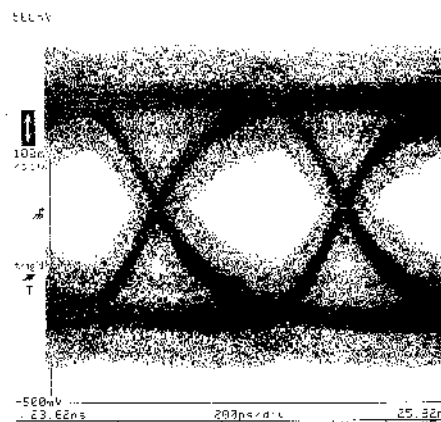
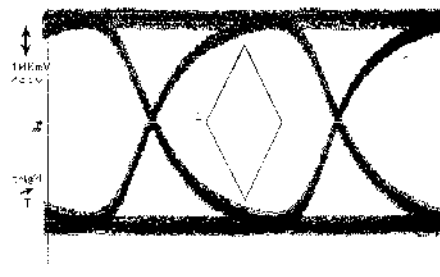# SIGNAL DEGRADATION TEST WITH SECOND SOURCE OFF -- NO CROSS TALK

Figure 60 - Cross talk effects on signal degradation test results

5.5.2 Single pulse

This method is exactly the same as that described in 4.5. The parts of the test fixture/IUT that are responsible for the cross talk are identifiable by noting the time position where the cross talk occurs.
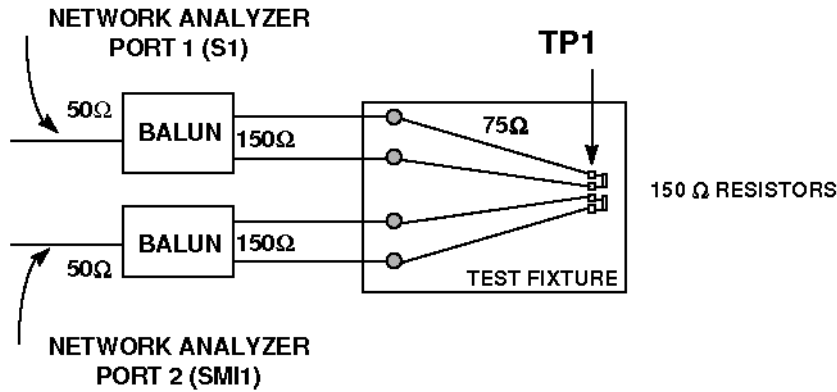
5.5.3 Sinusoidal

This test is very similar to the attenuation tests described in section 5.1 except that the signal on the victim line is measured rather than the signal from the far end of the IUT. A frequency scan is made over the entire range of interest.

This test is of interest because it can expose cross talk effects that have their origin well away from the connectors and because the effects of resonances can be seen.

5.5.3.1 Test fixture and measurement equipment

The test fixtures used for the NEXT tests in section 4.5 and the test equipment and baluns described in section 5.1.1 are used for this test .

5.5.3.2 Calibration procedure

○ = CONNECTOR

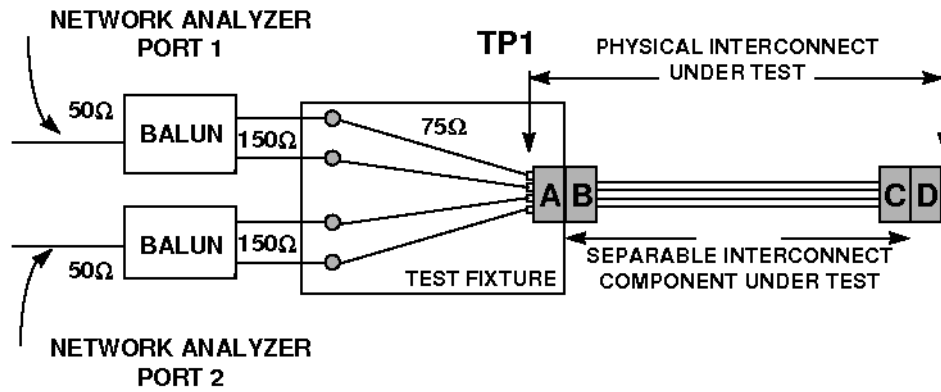TEST FIXTURE / MEASUREMENT PROCESS IS CALIBRATED
TO REPORT VALUES AT TP1

Figure 61 - Calibration configuration for sinusoidal cross talk

Using the instructions from the network analyzer manufacturer run a calibration scan on the configuration shown in Figure 61.

5.5.3.3 Testing procedure

Using the instructions from the network analyzer manufacturer run a test scan on the configuration shown in Figure 62.

Figure 62 - Test configuration for sinusoidal near end cross talk tests

Subtract the calibration scan from the test scan to reveal the cross talk performance of the IUT.

The cautions concerning cross coupling between the baluns described in section 5.1.3 apply to these tests as well.

5.5.3.4 Acceptable ranges

Since this is a level 2 test there are no acceptable ranges defined.

6. ANNEX A Acceptable ranges

6.1 Impedance profile

Table 6 lists some of the known requirements for impedance profile parameters.

Table 6 - Allowed ranges for impedance profile

Application	Allowed values in close proximity electrical neighborhood	Exception windows	Signal transition duration ranges (ps)	Media
Full speed FC	150 ±30	800 ps *	100 to 385	150 ±10
Double speed FC	150 ±30	800 ps *	75 to 200	150 ±10
GBE				
1394				
SSA				
NGIO				
Future I/O				
* This SFF document recommends a 300 ps exception window for cable assemblies (see 4.1.7)				

6.2 Signal degradation

The acceptable ranges are specified by eye diagrams for the respective technologies. The allowed ranges for full speed FC are given in Figure 63, Figure 64, Figure 65 and Figure 66. Note that these are not the allowed test ranges for the receive signals per the test procedures defined in this document. The allowed test ranges much be modified to account for launch test signals that are better than the worst case allowed. Refer to earlier sections for a detailed discussion.

Ranges for other technologies will be added as they become available.
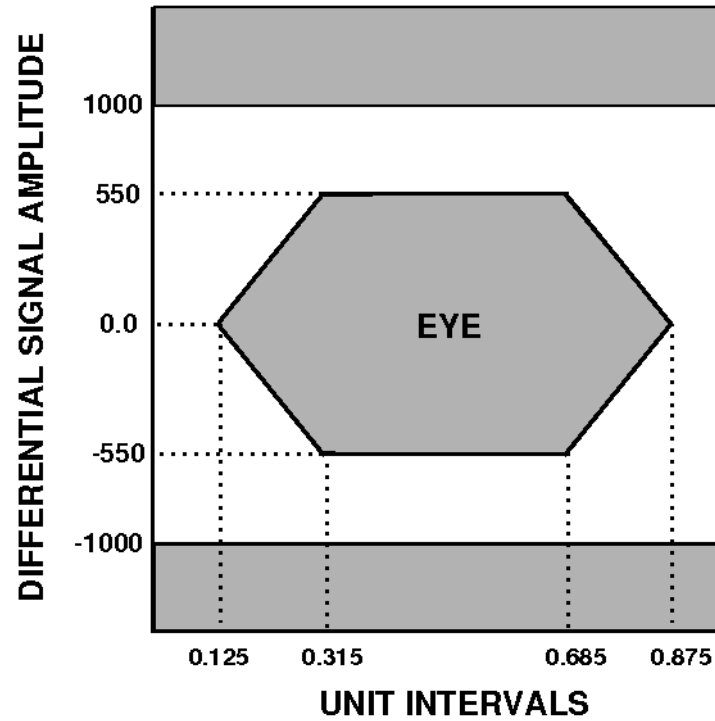
Figure 63 - Specified transmit mask for full speed FC external
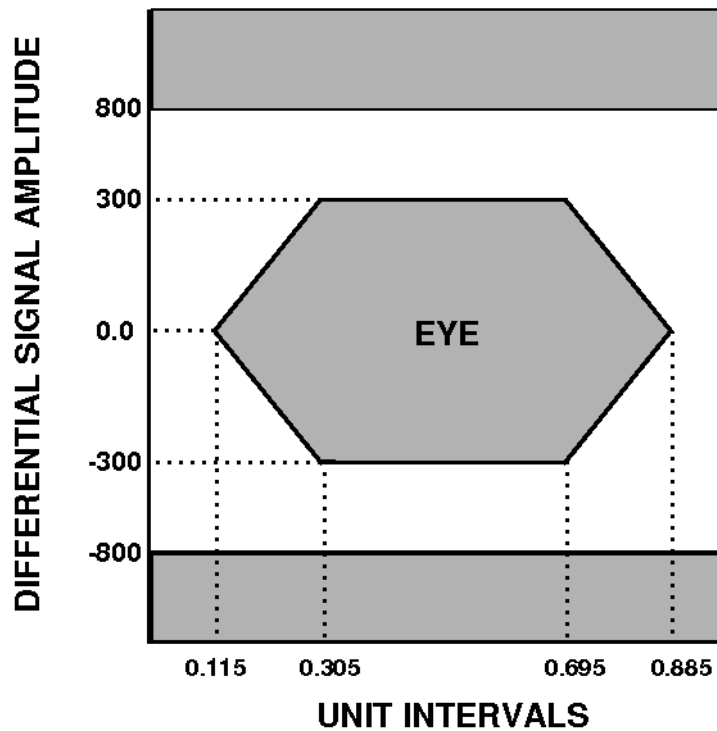
Figure 64 - Specified transmit mask for full speed FC internal
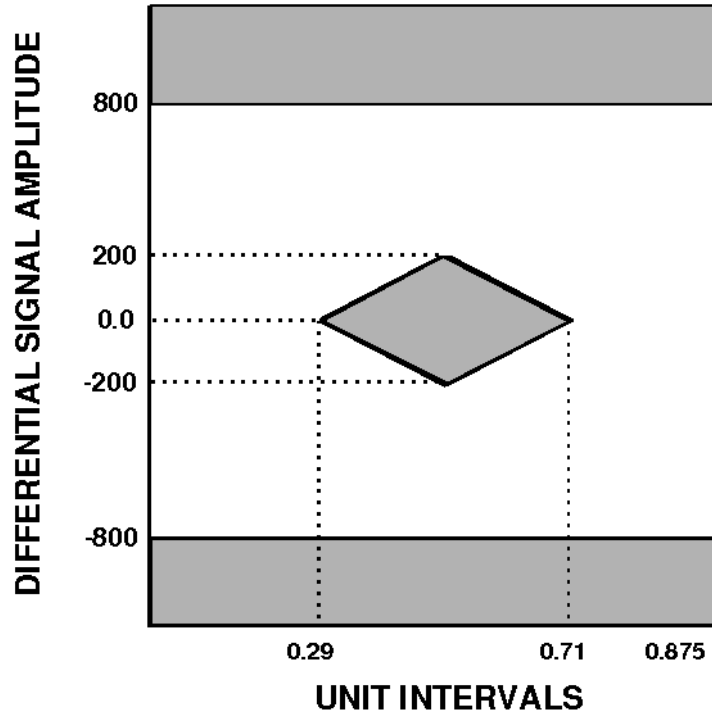
Figure 65 - Specified receive mask for full speed FC external
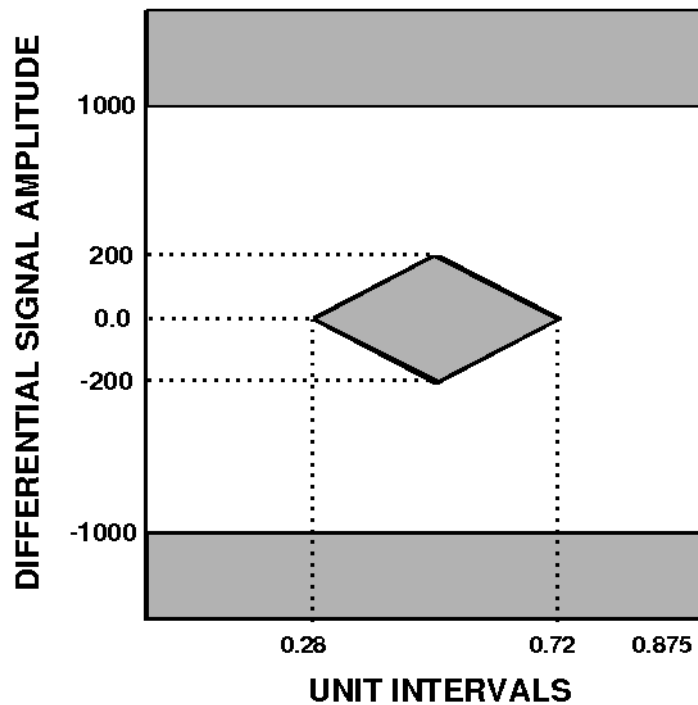
Figure 66 - Specified receive mask for full speed FC internal

6.3 Balance degradation

Acceptable values for balance degradation are presently only directly defined in this
document. Some standards documents note a line to line skew requirement (which only
accounts for one component of balance degradation and is nearly never present alone).
For example the latest FC standards allow a full 200 ps skew at the receiver - this
value is much larger than is appropriate for a balanced signal. With a 200 ps skew

there is almost no balance present in the signals since the rise and falls times are
of the same magnitude.

6.4 EMC

Acceptable values for EMC are presently only defined in this document.

6.5 NEXT (Quiescent noise)

Acceptable values for NEXT are proposed for FC at 3% max but have not been accepted
by the standard.

7. Annex B Skew vs length

7.1 Background

Skew versus length: Dean Vermeersch, Tyco/AMP

The present thinking is that the skew is statistically distributed long the length of
the cable and that the concept of linearity with length is not valid. [Secy note:
This is consistent with several observations in real cable where linearity with
length was not observed and the data that shows that skewed launched signals DO NOT
self compensate as once postulated.]

This understanding will clearly require a new specification methodology for skew that
is not based on a per unit length number.

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.

Local propagation velocity versus position

Nominal

line 1

line 2

Note: local propagation velocity
calculated from cable center line length
may differ from that calculated from
the individual wire length

position along center line of cable
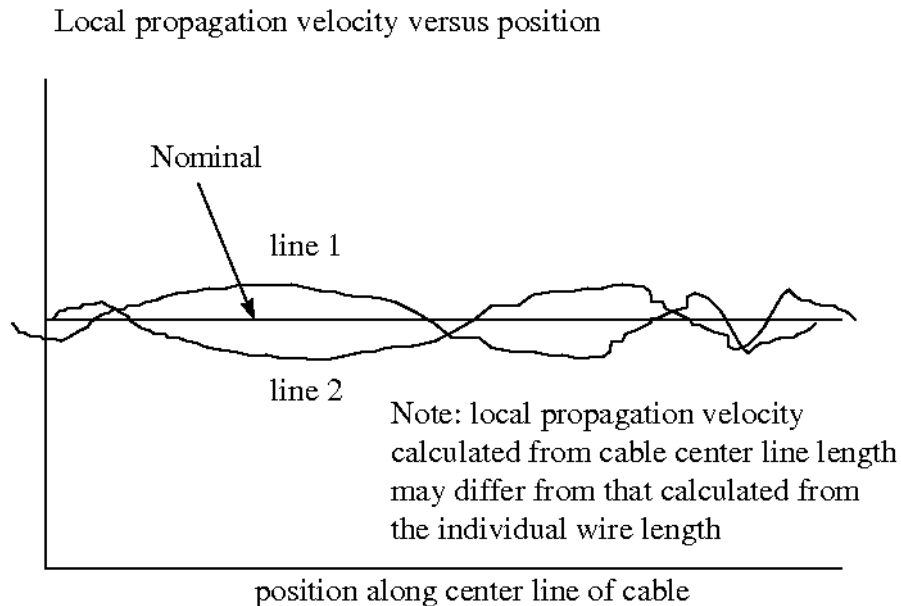
The issue is centered around how a supplier of bulk cable can specify skew content. For cable assembly applications skew is a level 2 measurement that applies only to the cable assembly - there is no need to consider any length variations.

The approach suggested for bulk cable suppliers was that the bulk cable shall not exceed an absolute skew number for any section of cable from 1 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 following lengths:

(Note that the skew requirement is an absolute number of nanoseconds not normalized to length and the same requirement applies for all lengths)

The lengths specified for bulk cable shall be: 1, 5, 10, 30 meters. Attenuation shall not exceed the noise floor of the instrumentation at the maximum measurement frequency. Typical noise floors may be in the neighborhood of 30dB (e.g. when using hybrid mixers).

The amount of skew that is tolerable changes with the application but is the same for all lengths. A couple of key points mentioned were:

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

- When the skew exceeds approximately ¼ of the signal rise time, serious loss of balance occurs.

- As the signal travels down the line it loses rise speed and the ¼ rise time number increases. Therefore there is a relationship between the loss and the tolerable skew. More in-pair skew is tolerable in a high loss cable.

- In a system with real data some 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.

This skew specification methodology will be incorporated into SFF-8416 - the bulk media performance specification.

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

Two 'identical' pairs were created, one having low skew, the other having designed-in skew.

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.

Within-Pair Skew
Pairs were measured using the ubiquitous TDR method, with data taken at the 50% points.

	Data	Data	Calculated	Calculated
Length meters	Low Skew Pair ps / length	High Skew Pair ps / length	Low Skew Pair ps / meter	High Skew Pair ps / meter
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.

Risetime (10-90%) at Far End of Sample
Risetime was recorded from the differential signal at the end of the samples.

The TDT method for measuring propagation delay, hence skew, does not really measure delay. TDT measures delay plus risetime to the 50% points (typically).

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

Because risetime changes dramatically with sample length, we should not be surprised that skew does not scale with length.

Length meters	Low Skew Pair ns	High Skew Pair 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
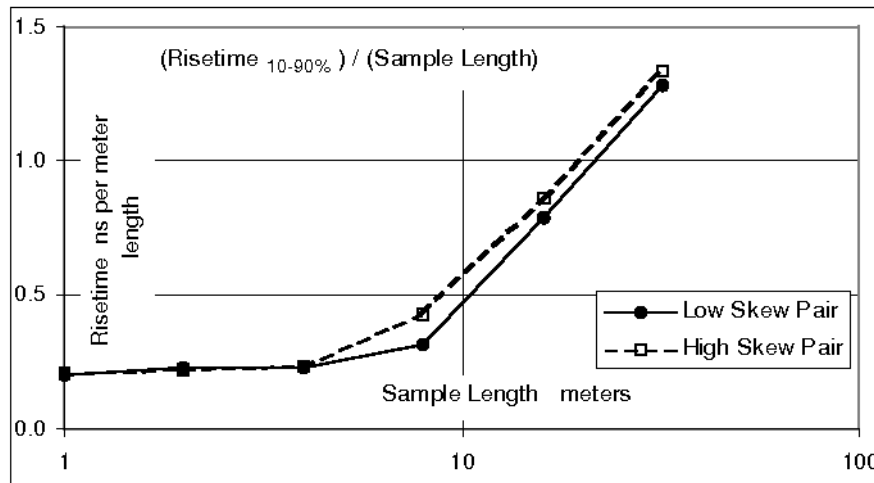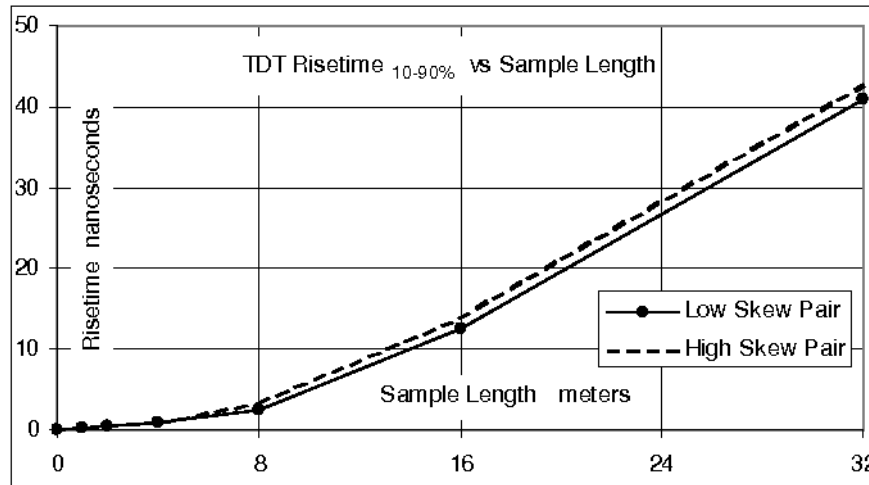
Insertion Loss

Insertion loss was measured using a 4-port network analyzer (Agilent E8358A with ATN-4111D test set).

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

Insertion Loss for Good Pair and Bad Pair -- dB / sample length
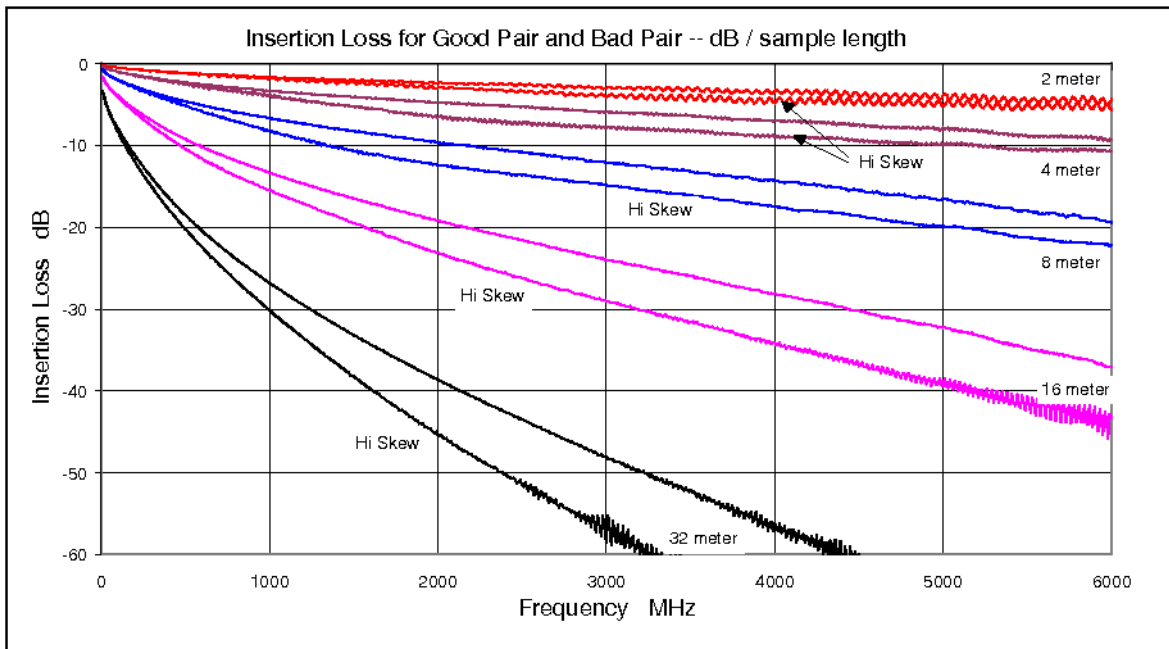
Madison provided the following data:

Mad. P/N: DOSDK00038	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	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	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

8. Annex C - Insertion loss specifications

This topic relates to the relationship between the amplitude of complete signals in the form of eye patterns or other time domain signal measurements and the purely sinusoid signal required for true insertion loss.

Insertion loss specifications should be strictly limited to purely sinusoidal signals.

Performance specifications may be effective thru the use of time domain techniques such as eye diagrams. However, the problem comes when one attempts to use time domain (non-sinusoidal) measurements to calculate an insertion loss and then impose the insertion loss as a requirement on the interconnect. That process is not valid. Ham noted that taking a ratio of the amplitude of signals that do not have precisely scalable waveshapes is like taking a ratio of apples and oranges and claiming that the result is dimensionless.

Another basic problem is that a single point insertion loss is inadequate for specifying any interconnect.

In order to emphasize the last point above Madison, Hitachi, Gore, and Tensolite agreed to show attenuation (insertion loss) plots that demonstrate "suck out". The purpose of this is to educate the larger community that simplistic square root of f attenuation performance may not be valid.

Dean drew the following figures for discussion.
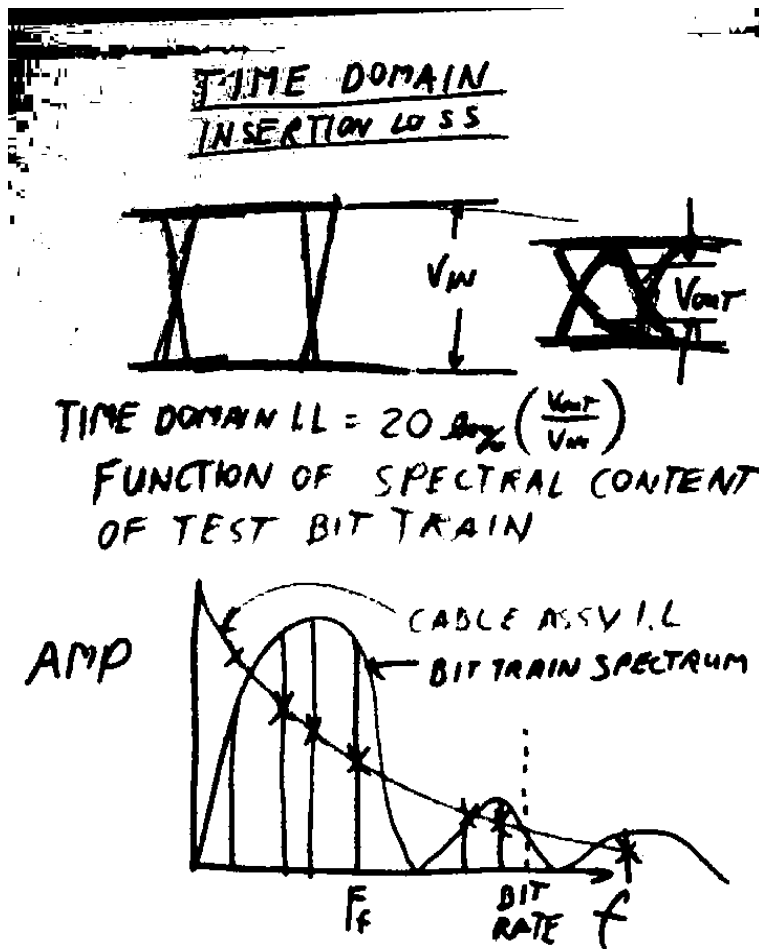
FREQUENCY DOMAIN

INSERTION LOSS
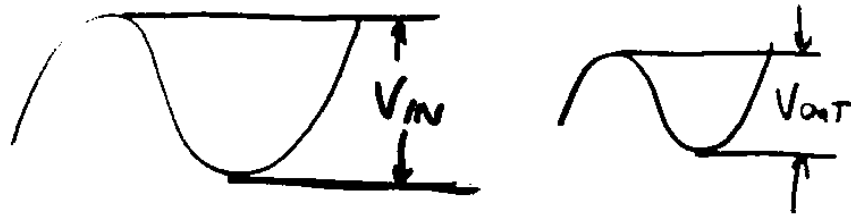
$$\text{FREQUENCY DOMAIN } I.L = 20 \log_{10}\left(\frac{V_{OUT}}{V_{IN}}\right)$$

The above figure illustrates another way to arrive at the conclusion that insertion loss cannot be effectively expressed as a ratio of the amplitude of signals that are not sinusoidal. The concept of time domain insertion loss is bogus.