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

**This specification was developed by the SFF Committee prior to it becoming the SFF TA (Technology Affiliate) TWG (Technical Working Group) of SNIA (Storage Networking Industry Association).**

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

POINTS OF CONTACT:


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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

SFF Committee documentation may be purchased in electronic form.
SFF specifications are available at ftp://ftp.seagate.com/sff

SFF Committee

**SFF-8461**

Specification for

# SFP+ Active Cable Specifications and Alternate Test Methods

Rev 0.2 May 6, 2015

SSWG (Specific Subject Work Group) development of this specification ended because the editor could no longer participate.

The members decided that this specification should be Published because, although incomplete, the content herein is of value.

Secretariat: SFF Committee

Abstract: This specification defines SFP+ active cabling for SFF-8431 linear and limiting host. This specifications also defines alternate cable test methods based on S-parameters.

This specification provides a common reference for systems manufacturers, system integrators, and suppliers. 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 connector in this specification does not assure that the specific component is actually available from connector suppliers. If such a connector is supplied it must comply with this specification to achieve interoperability between suppliers.

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.

| | |
|---|---|
| All Best | QLogic |
| Broadcom | Seagate |
| Cinch | Shenzhen |
| EMC | Sumitomo |
| ETRI | Sun Microsystems |
| Foxconn | TE Connectivity |
| HGST | Volex |
| Oclaro | |

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

| | |
|---|---|
| Amphenol | Luxtera |

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

| | |
|---|---|
| Applied Micro | Luxshare-ICT |
| Dell Computer | Molex |
| FCI | NetApp |
| Finisar | Sandisk |
| Hewlett Packard | Toshiba |
| JDS Uniphase | |

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

**Change History**

Rev 0.1 - First draft 8/21/2009
Rev 0.2 - Re-formatted to current style
- Contents of Appendix A provided by Broadcom

**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.

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SFF Committee --

# SFP+ Active Cable Specifications and Alternate Test Methods

## 1. Scope

This specification defines cabling solutions compatible with SFP+ linear or limiting host for 10.3125 GBd operation based on "SFI" as defined in and.

This specifications also defines an alternative passive cable test method based on cable S-parameters. The S-parameters method provides parameters for cable VMA loss, VCR, dWDP, and Vcm.

SFP+ active and passive cable assemblies are hot pluggable and are powered by individual power connections for the transmitter (VccT) and the receiver (VccR). Multiple modules can share a single 3.3 V power supply with individual filtering for each VccT and VccR.

### 1.1 Application Specific Criteria

The SFP+ cable assemblies compatible with SFI could be active-active, active-passive, passive-active, or passive-passive implementations and may support one or more of the applications listed in Table 1. SFP+ cable assemblies are either compatible with host supporting linear modules or a host supporting limiting module.

## 2. References

### 2.1 Industry Documents

- ******* FC-PI-4 Fibre Channel - Physical Interface-4
- ******* 10GFC Fibre Channel - 10 Gigabit
- ******* FC-MJSQ Methodologies for Jitter and Signal Quality Specifications FC INCITS Project 1316-DT Rev 14.1, June 5, 2005
- IEEE 802.3 - IEEE Standard 802.3, Relevant 10 Gigabit Ethernet clauses are 49, 10GBASE-R LAN PHY; 50, 10GBASE-W WAN PHY; 52, 10 Gigabit Ethernet serial PMDs; and 68, 10GBASE-LRM)
- OIF CEI Optical Internetworking Forum - Implementation Agreement # OIF-CEI-02.0 Common Electrical I/O (CEI)
- INF-8074i SFP (Small Formfactor Pluggable) 1 Gb/s Transceiver
- INF-8077i XFP 1X 10 Gb/s Pluggable Module
- SFF-8079 SFP Rate and Application Selection
- SFF-8083 SFP+ 1X 10 Gb/s Pluggable Transceiver Solution (SFP10)
- SFF-8089 SFP Rate and Application Codes
- SFF-8418 SFP+ 10 Gb/s Electrical Interface
- SFF-8419 SFP+ Low Speed Electrical Interface
- SFF-8431 Specifications for Enhanced Small Form Factor Pluggable Module SFP+
- SFF-8432 SFP+ Module and Cage
- SFF-8472 Diagnostic Monitoring Interface for Optical Transceivers

### 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).

## 2.4 Conventions

The dimensioning conventions are described in ANSI-Y14.5M, Geometric Dimensioning and Tolerancing. All dimensions are in millimeters, which are the controlling dimensional units (if inches are supplied, they are for guidance only).

The ISO convention of numbering is used i.e., the thousands and higher multiples are separated by a space and a period is used as the decimal point. This is equivalent to the English/American convention of a comma and a period.

| American | French | ISO |
|---|---|---|
| 0.6 | 0,6 | 0.6 |
| 1,000 | 1 000 | 1 000 |
| 1,323,462.9 | 1 323 462,9 | 1 323 462.9 |

## 2.5 Definitions

| Abbrev | Description |
|---|---|
| 64B/66B | Data encoded with 64B/66B encoder as defined by the IEEE Std. 802.3 CL 49. |
| BER | Bit Error Ratio |
| CDR | Clock and Data Recovery |
| CRU | Clock Recovery Unit |
| dB | Decibel. 10*log10(ratio of power quantities). Powers can be electrical or optical. Conventional usage. See also dBe and dBo. |
| dBe | Specific case of dB where signals are electrical. 10*log10(ratio of electrical power quantities). 20*log10(ratio of voltage quantities) can be used if reference impedances are equal. |
| dBm | Decibel (relative to 1 mW) |
| dBo | Decibel optical (1 time dBo= 2 time dBe). Specific case of dB where the signals are in optical power. 10*log10(ratio of optical power quantities). Also; in certain cases with electrical signals relating to linear optical modules; where it is expected that electrical voltage is in proportion to optical power; 10*log10(ratio of voltage quantities). |
| DCD | Duty Cycle Distortion |
| DDPWS | Data Dependent Pulse Width Shrinkage |
| DDJ | Data Dependent Jitter |
| dRN | Difference of Relative noise see Appendix D |
| DUT | Device Under Test |
| dWDP | Difference of the Waveform Distortion Penalty of an optical receiver |
| dWDPc | Difference of the Waveform Distortion Penalty of an electrical cable assembly |
| EMC | ElectroMagnetic Compatibility |
| EMI | ElectroMagnetic Interference |
| FC | Fibre Channel |
| h | hexadecimal notation |
| HCB | Host Compliance Board |
| IEEE | Institute of Electrical and Electronics Engineers |
| ITU-T | ITU Telecommunication Standardization Sector |
| Gbit | Gigabit = 10e9 bits |
| GBd | Gigabaud |
| J2 | 99% Jitter |
| LRM | IEEE 802.3 CL68 Physical Layer Specifications for 10Gb/s using 10GBASE-R encoding and long wavelength optics for multimode fiber |
| MCB | Module Compliance Board |
| OMA | Optical Modulation Amplitude |
| PCB | Printed Circuit Board |

| | |
|---|---|
| PRBS9 | Pseudo-Random Bit Sequence 2e9-1 |
| PRBS31 | Pseudo-Random Bit Sequence 2e31-1 |
| Qsq | Qsq a measure of SNR (see IEEE 802.3.68.6.7) |
| RI | Random Interference |
| RMS | Root Mean Square |
| RN | Relative Noise |
| Rx | Receiver |
| Rx_LOS | Loss of Signal same as defined in FC PI-4 and the inverse of signal detect (SD) in 802.3 |
| RSS | Root Sum of Squares |
| SD | Signal Detect |
| SerDes | Serializer/Deserializer |
| SFI | SFP+ high speed serial electrical interface |
| SNR | Signal-to-Noise Ratio |
| VccT | Module positive power supply rail for the transmitter |
| VccR | Module positive power supply rail for the receiver |
| VMA | voltage Modulation Amplitude |
| Tx | Transmitter |
| TWDP | Transmitter Waveform Distortion Penalty for an optical transmitter |
| TWDPc | Transmitter Waveform Distortion Penalty of a host transmitter supporting an electrical cable assembly |
| UI | Unit Interval = 1 symbol period |
| UJ | Uncorrelated Jitter |
| WDP | Waveform Distortion Penalty |
| WDPc | Waveform Distortion Penalty for an electrical cable assembly |

# 3. General Description

## 3.1 SFP+ Supported Standards

The SFF-8461 cable assembly may comply with any combination of the standards shown in Table 1, and may be suitable for other or future standards. This specification does not preclude operation at other signalling rates that are not listed in this table, such as 2.125 GBd for 2GFC, or 4.25 GBd for 4GFC.

**TABLE 1 SFP+ STANDARD COMPLIANCE**

| Standard | Signal-ing Rate (Gbd) | High Speed Serial Inter-face | High Speed Serial Test Method | Low Speed Elec-trical Defi-nitions and Test Methods | Manage-ment | Mechan-ical/ Conn-ector |
|---|---|---|---|---|---|---|
| IEEE 802.3 Clause 38 or Clause 59 (1 Gb/s Ethernet) | 1.25 | SFF-8418 Appx F | | SFF-8419 | SFF-8431 Sctn 4 SFF-8472, SFF-8079, SFF-8089 | SFF-8432 SFF-8083 |
| 8 GFC | 8.5 | FC-PI-4 | FC-PI-4 | """" | """" | """" |
| 10GSFP+Cu | 10.3125 | SFF-8431 Sctn 3 Appx E | SFF-8431 Appx D and E | """" | """" | """" |
| 10GSFP+Ac | 10.3125 | Sctn 2 and SFF-8431 Sctn 3 Appx E | """" | """" | """" | """" |
| IEEE 802.3 CL 52 (10 Gb/s Ethernet LAN PHY) | 10.3125 | SFF-8431 Sctn 3 | Appx D | """" | """" | """" |
| IEEE 802.3 CL 52 (10 Gb/s Ethernet WAN PHY) | 9.95328 | """" | """" | """" | """" | """" |
| IEEE 802.3 CL 68 (LRM) | 10.3125 | """" | """" | """" | """" | """" |
| 10 GFC | 10.51875 | """" | """" | """" | """" | """" |
| 10GBASE-R (IEEE 802.3 CL 49) Encapsulated in G.709 ODU-2 Frame (FEC) | 11.10 | """" | """" | """" | """" | """" |

## 3.2 ESD

The active and passive cable assemblies SFI contacts (High Speed Contacts) shall withstand 1000 V electrostatic discharge based on Human Body Model per JEDEC JESD22-A114-B.

The active and passive cable assemblies contacts with exception of the SFI contacts (High Speed Contacts) shall withstand 2 kV electrostatic discharge based on Human Body Model per JEDEC JESD22-A114-B.

The active and passive cable assemblies shall meet ESD requirements given in EN61000-4-2, criterion B test specification such that units are subjected to 15 kV air discharges during operation and 8 kV direct contact discharges to the case.

# 4. Active Cabling Specifications

## 4.1 Introduction

High speed cabling specifications are based on SFI signalling as defined in SFF-8431 supporting either a limiting or linear host. Active cable assemblies may be used to provide operation over longer or thinner cables than achievable with direct attach copper assemblies. This section defines electrical specification and compliance testing methodology for such assemblies.

## 4.2 Cable Applications Reference Model

A compliant active cable assembly is designated as 10GSFP+ACA and it can be identified by reading the memory map of SFF-8472.

The compliance points for SFP+ Active Cables(10GSFP+ACA) are the same as host compliance test points in 3.3.1 and the module compliance test points in 3.3.2 of SFF-8431.

All SFI test equipment must have 50 Ohms single ended impedance on all test ports.

Tx_Disable contacts in the module for cable assembly with active transmitter shall enable or disable the transmitter. For a passive assembly it shall be pulled to VccT with a 4.7 kO to 10 kO. The RX_LOS contact in the module for a cable assembly with active receiver shall be connected to the receiver IC loss of signal. A passive cable assembly RX_LOS contact shall be pulled low in the module. Direct connection of RX_LOS to VeeR is allowed for a cable assembly with passive receiver.

This specification does not assume transmit pre-emphasis beyond the level defined in SFF-8431.

Warning: 10GSFP+Cu can only be used on systems with common grounds. Connecting systems with different ground potential with SFP+ direct attach cable results in a short and may cause damage.

## 4.3 10GSFP+AC Direct Attach Construction

10GSFP+ACA SFP+ active cable assemblies could be copper or optical, providing either a linear or a limiting output. While particular implementations are not specified by this standard, it is expected that SFP+ Active Cables operate with either linear or limiting hosts as defined in section X.2.

An example of active cable assembly with active transmitter is shown below. The cable assembly shown has an active transmitter and active receiver. Other implementation possibilities are active-passive and passive-active. The cable assembly shall incorporate DC blocking capacitors with at least 4.3 V rating between any signal commissioning IC and the SFP+ edge card connector (SFP+ edge card connector contacts are defined in SFF-8431*** 8418/8419?). The DC blocking capacitor shall have high pass pole of between 20 kHz and 100 kHz. For a copper cable assembly, the drain wire is connected to VeeT and to VeeR and the cable shield directly connects the module A and B cases.

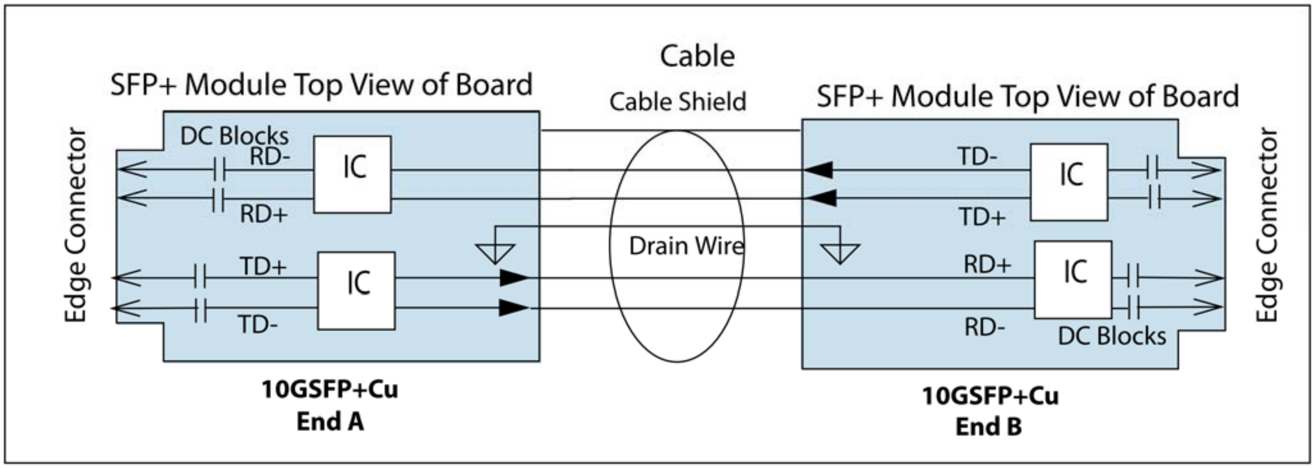


FIGURE 1 10GSFP+ACA DIRECT ATTACH BLOCK DIAGRAM

## 4.4 SFP+ Active Cable High-speed Electrical Specification

This section defines the high-speed electrical specification for implementations with limiting or linear outputs. Active Cables designed to operate with limiting hosts are broadly defined as Type I, while Active Cables designed to operate with linear Hosts are broadly defined as Type II. The test setup for both Type I and Type II Active Cables is shown below.

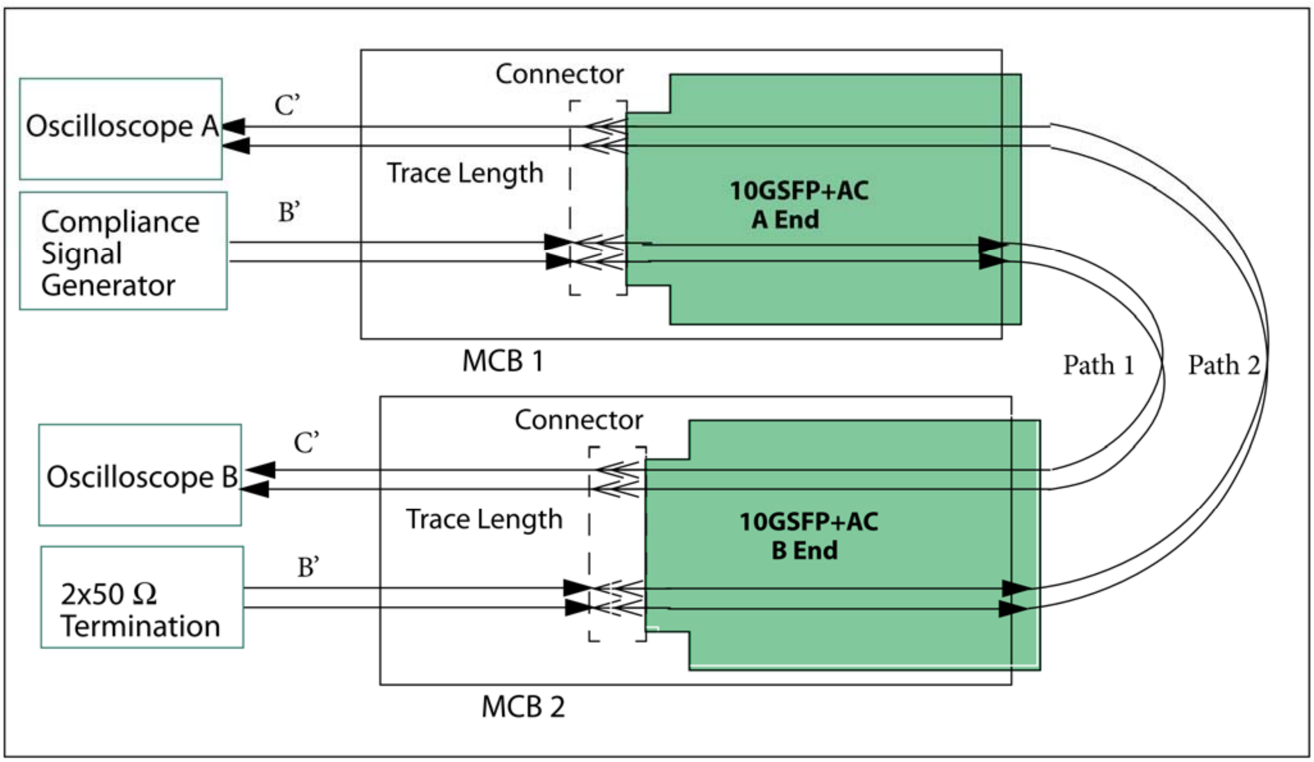


FIGURE 2 ACTIVE CABLE ASSEMBLY TEST SETUP

## 4.5 2.5 SFP+ Active Cables Type I (for operation with a limiting host)

SFP+ Active Cable's Type I are assemblies that operate with the SFP+ limiting hosts defined in Section 3 of SFF-8431****. Specifically, the active cable input must satisfy the SFP+ module transmitter input specifications at B' in Table 16 of SFF-8431**** and tolerance specifications at B" in Table 17 of SFF- 8431****. The active cable output must satisfy the SFP+ Limiting Module Receiver Output Electrical Specifications at C' in Table 18 of SFF-8431and the SFP+ Limiting Module Receiver Output Jitter and Eye Mask Specifications Table 19 of SFF-8431. These output specifications must be met with worst case input allowed by Table 16 and Table 17 of SFF-8431****.

### 4.6 SFP+ Active Cables Type II

SFP+ Active Cables Type II are cables that operate with the linear hosts defined in Section 3 of SFF-8431. To ensure this, SFP+ Active Cables Type II must comply with the following specifications. The active cable input must satisfy the SFP+ module transmitter input specifications at B' in Table 16 of SFF-8431 and tolerance specifications at B" in Table 17 of SFF-8431. The output at C' of Active Cables Type II must satisfy the requirements of SFF-8431 Table 18. In addition, it must meet the following specifications.

**TABLE 2 ACTIVE CABLE TYPE II OUTPUT SPECIFICATIONS AT C'**

| Parameters - C' | Symbol | Conditions | RN | | RNmax |
|---|---|---|---|---|---|
| | | | m | b | |
| Relative Noise with post-cursor stressor | RN | See 3 and D14.1 in SFF-8431 | -0.01 | 0.12 | 0.083 |
| **Parameters - C'** | **Symbol** | **Conditions** | **Min** | **Max** | **Unit** |
| Waveform Distortion Penalty | WDP | See 4 and 5 | | 10 | dBe |
| Differential Voltage Modulation Amplitude For LRM | VMA | See D.7 in SFF-8431 | 180 | 600 | mV |
| Differential peak to peak voltage | Vpk-pk | See D.14.3 in SFF-8431 | | 600 | mV |

## 5. S-Parameters Test Method For 10GSFP+CU

S-Parameters test method is an alternate method of calculating 10GSFP+Cu cable parameters for passive cable assembly. The advantage of the S-parameters method is that it can give consistent results without requiring extensive adjustment to the SerDes driver. This method gives equivalent result to direct measurement of cable dWDP, VMA loss, and VCR per definition of SFF-8431 Appendix E.4.

### 5.1 S-Parameters Test Method Procedure

The following test procedure is required in order to calculate the cable parameters as defined in SFF-8431 table 37.

S-Parameter Test Method Matlab code, Appendix A, reads the three S- parameters s4p files in order to calculate the cable parameters dWDP, VMA loss, and VCR.

### 5.1.1 Measure S-parameters for MCB-HCB from point B" to B

The 4-ports S-parameters for the MCB-HCB response from B" to B is measured with a Vector Network Analyzer, see below. The MCB-HCB 4-ports S-parameters are used for S-Parameter Test Method Matlab code calibration, see Appendix A.

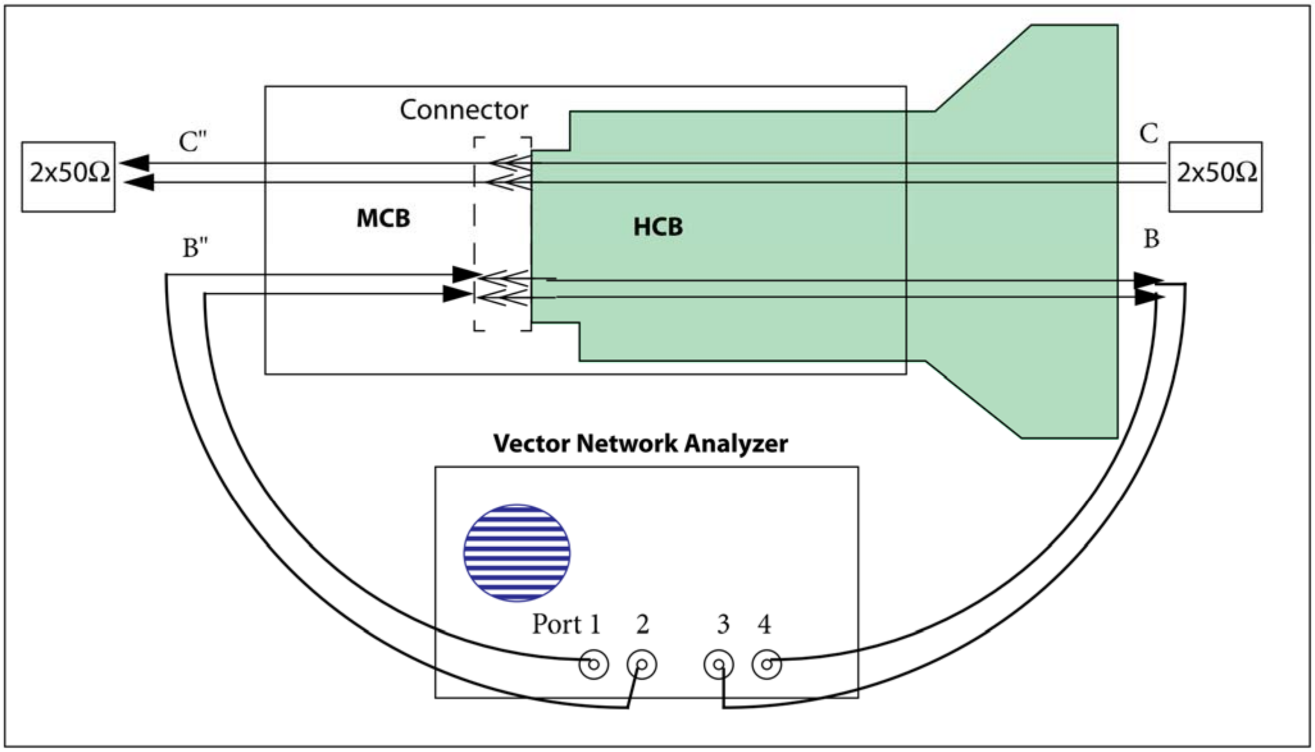


**FIGURE 3 MCB-HCB S-PARAMETERS TEST SETUP**

### 5.1.2 Measure the s4p for Through S-parameters for Cable End 1 to Cable End 2

Cable S-Parameters through Measurement setup is shown below. The through measurement setup shown is for cable end B to cable end A with the response measured B' to C'. The procedure is then repeated to measure cable through response from end A to end B.

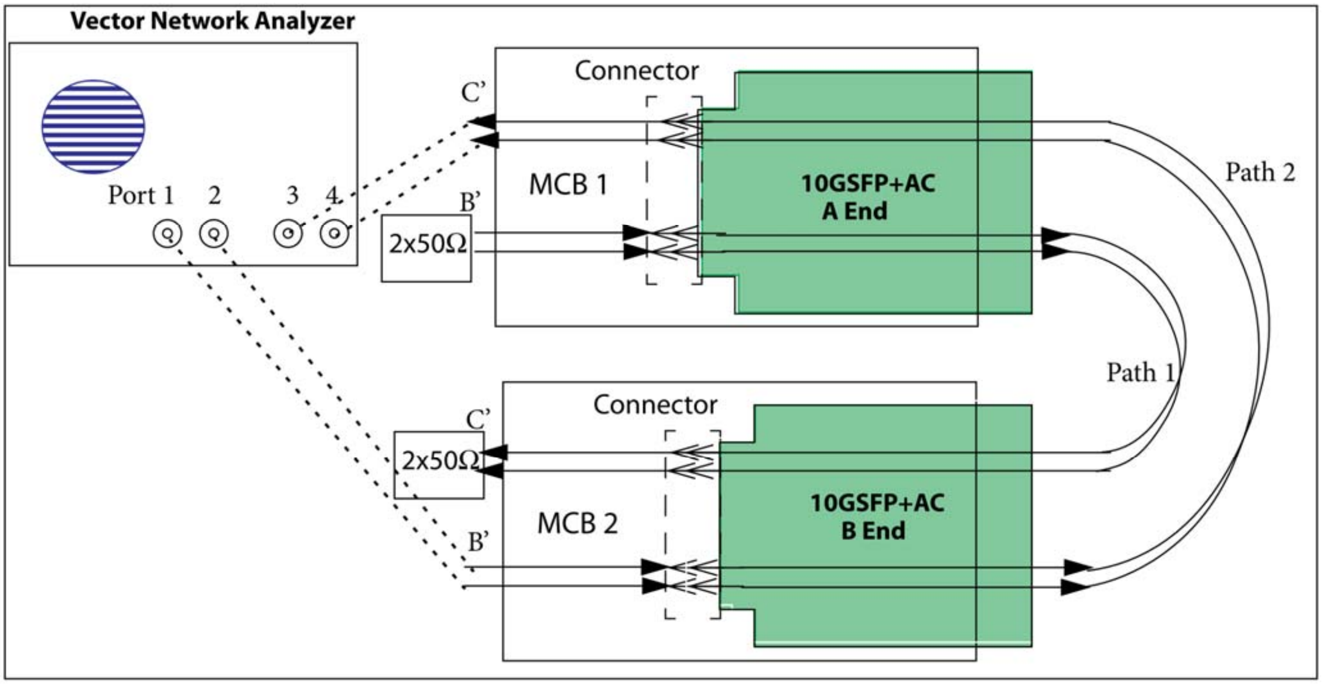


**FIGURE 4 CABLE S-PARAMETERS THROUGH TEST SETUP**

### 5.1.3 Measure the s4p for Crosstalk S-parameters for Cable End under Test

Cable S-parameters crosstalk measurements setup is shown below. The crosstalk measurement setup shown is for the cable end B measured from B' to C'. The procedure is then repeated to measure cable crosstalk for the other end.

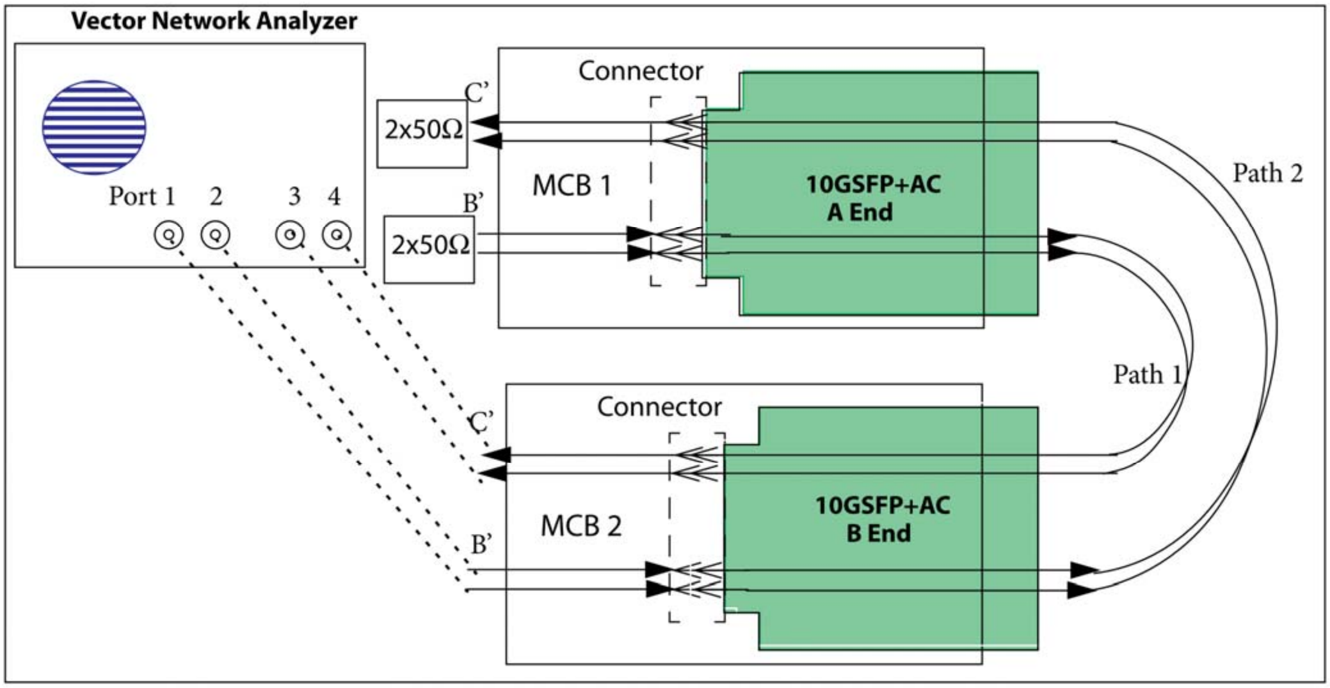


FIGURE 5 CABLE S-PARAMETERS CROSSTALK MEASUREMENT

## A. MATLAB Code for S-Parameters Method

```
%%%%%%%%%% MATLAB (R) Code for sWDP Computation from cable s-parameters%%%%%%%
%%% The materials for Appendix A (Matlab Code for S-Parameters Method) is
%reprinted with permission from Broadcom Corp., (C)  2015 Broadcom
%Corporation.  The implementation of Appendix A may be covered by various
%Broadcom patents and other intellectual property rights in various
%jurisdictions worldwide, which requires a license from Broadcom Corp.
%Redistribution of any portion of Appendix A (Matlab Code for
%S-Parameters Method) is only permitted with the express written
%permission of Broadcom Corporation.
%%%
%% Revision 1.00 - Release to SFF-8461
%% Based on original TWDP methodology described in IEEE Std 802.3aq(TM)-2006

function [cable_sWDP, vma_loss, VCR] = sWDP(thrufilename,xtlkfilename)
%function [cable_sWDP, vma_loss, VCR] = sWDP(thrufilename,xtlkfilename)
%% Example calling syntax:
%% [cable_sWDP, vma_loss, VCR] =
sWDP('SFP_Golden8.5m_Thru_End1TX_End2RX.s4p','SFP_Golden8.5m_NEXT_End2TX_End2RX.s4p
');
%% Output: "VMA Loss = 4.68 dB, Cable sWDP = 6.58dB, VCR = 33.06 dB"

% Read in Reference package model
pkgs = s4p2sdd('10GSFP_PKG_Port12.s4p');
% Read in Cable s-parameters
cblthrus = s4p2sdd(thrufilename);
cblxtlks = s4p2sdd(xtlkfilename);

% Read in prbs bit sequence
bitseq = load('prbs9_950.txt').';

% Parameter values
vma_ref = 0.9243; %VMA of MCB-HCB board
cwdp_ref = 2.14; %CWDP of MCB-HCB board
VMAmin_mv = 300;

Vp_thru = 1; % launch voltage of thru Tx
Tr_2080_thru = 19.4e-12; % rise time of thru Tx
Tf_2080_thru = 19.4e-12; % fall time of thru Tx

Vp_xtlk = 0.7; % launch voltage of xltk Tx
Tr_2080_xtlk = 24e-12; % rise time of xtlk Tx
Tf_2080_xtlk = 24e-12; % fall time of xtlk Tx

% specify required resolution and range
fsym = 10.3125e9; % symbol rate
osr = 16; % oversampling rate
nsym = 511; % don't change this

% secondary variables
fsim = osr*fsym;
fdelta = fsym/nsym; % resolution of frequency points;
fvec = [0:fdelta:fsim/2];
tsim = 1/fsim;
tsym = 1/fsym;
nwin = 2*(length(fvec)-1);

% extrapolate all data out in frequency
```

```
pkgs3 = interp_s3(pkgs,fvec);
cblthrus3 = interp_s3(cblthrus,fvec);
cblxtlks3 = interp_s3(cblxtlks,fvec);

% concatenate package and cable TF
pkgpluscbl = smul(pkgs3.s,cblthrus3.s);
% concatenate package and xtlk TF
pkgplusxtk = smul(pkgs3.s,cblxtlks3.s);

% get TF of pkg + cable
pkgpluscbl_tf = squeeze(pkgpluscbl(2,1,:)).';
pkgpluscbl_tf(1) = abs(pkgpluscbl_tf(2));
pkgpluscbl_fd = [pkgpluscbl_tf conj(fliplr(pkgpluscbl_tf(2:length(pkgpluscbl_tf)-
1)))];

% get TF of pkg + xtlk
pkgplusxtk_tf = squeeze(pkgplusxtk(2,1,:)).';
pkgplusxtk_tf(1) = abs(pkgplusxtk_tf(2));
pkgplusxtk_fd = [pkgplusxtk_tf conj(fliplr(pkgplusxtk_tf(2:length(pkgplusxtk_tf)-
1)))];

% Source bit wfm
wfm_bit = reshape([bitseq;zeros(osr-1,length(bitseq))],1,osr*length(bitseq));

% create pulse shape at source TP0 point
Tr_thru = Tr_2080_thru/0.6;
Tf_thru = Tf_2080_thru/0.6;
tp0_pulse_thru = [(Vp_thru/Tr_thru)*[0:tsim:Tr_thru] ...
           Vp_thru*ones(1,round((tsym-Tr_thru/2-Tf_thru/2)*fsim)-1) ...
           Vp_thru-(Vp_thru/Tf_thru)*[0:tsim:Tf_thru]];
tp0_pulse_thru = [tp0_pulse_thru zeros(1,nwin-length(tp0_pulse_thru))];

% Create waveform at TP0 (driver output)
wfm_tp0_thru = real(ifft(fft(wfm_bit).*fft(tp0_pulse_thru)));
% Create waveform at TP3 (at cable output)
wfm_tp3_thru = real(ifft(fft(wfm_bit).*fft(tp0_pulse_thru).*pkgpluscbl_fd));

% Realign waveform with bit sequence for cwdp computation
xc = xcorr(wfm_tp0_thru,wfm_tp3_thru,nwin/2,'unbiased');
wfm_tp3 = circshift(wfm_tp3_thru.',find(xc==max(xc))-nwin/2).';

% Write out waveform to file, since SFF8431 code expects to read a file
filename='wfm_tp3.dat';
fid=fopen(filename,'w');
fprintf(fid,'%e\n',wfm_tp3);
fclose(fid);

% Use standard code to compute CWDP
[cwdp,vma3] = SFF8431xWDPr1_4(filename,14,5,fsym/1e9,'Copper_WDP');

% Compute Crosstalk
% create crosstalk waveforms
Tr_xtlk = Tr_2080_xtlk/0.6;
Tf_xtlk = Tf_2080_xtlk/0.6;
tp0_pulse_xtlk = [(Vp_xtlk/Tr_xtlk)*[0:tsim:Tr_xtlk] ...
           Vp_xtlk*ones(1,round((tsym-Tr_xtlk/2-Tf_xtlk/2)*fsim)-1) ...
           Vp_xtlk-(Vp_xtlk/Tf_xtlk)*[0:tsim:Tf_xtlk]];

% Create Crosstalk waveform at TP3 point
```

```
tp0_pulse_xtlk = [tp0_pulse_xtlk zeros(1,nwin-length(tp0_pulse_xtlk))];
wfm_tp0_xtlk = real(ifft(fft(wfm_bit).*fft(tp0_pulse_xtlk)));
wfm_tp3_xtlk = real(ifft(fft(wfm_bit).*fft(tp0_pulse_xtlk).*pkgplusxtk_fd));

% Compute crosstalk RMS
xtlk_rms_mv = sqrt(var(wfm_tp3_xtlk))*1e3; % RMS value in mV

%Compute finale metrics
vma_loss = -20*log10(vma3/vma_ref);
cable_sWDP = cwdp - cwdp_ref;
C = 0.3*10^-(2*vma_loss/20);
VCR = 20*log10(VMAmin_mv/(2*xtlk_rms_mv*(1+C))) - vma_loss;

fprintf(1,'VMA Loss = %.2f dB, Cable sWDP = %.2fdB, VCR = %.2f
dB\n',vma_loss,cable_sWDP,VCR);

%%%%% End of Main Code %%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Read .s4p file
% File should have port ordering (1,2)<=> (3,4),
% and data should be in mag(dB)/phase form
function sdd3 = s4p2sdd(filename);

fid = fopen(filename,'r');

% strip off header lines, defined as starting with either '!' or '#'
nhdr=0;
loc=0;
firstchar='!';
while (strcmp(firstchar,'!') | strcmp(firstchar,'#'))
  header = strtrim(fgets(fid));
  if isempty(header)
    header='!';
  end
  firstchar=header(1);
  nhdr = nhdr+1;
  locprev=loc;
  loc=ftell(fid);
  if strcmp(firstchar,'#')
    formattxt = header;
  end
end
fseek(fid,locprev-loc,'cof');
nhdr = nhdr-1;

% Each row of data has 33 elements, reshape into a matrix
data = fscanf(fid,'%e',[33,inf]);
fclose(fid);

f = data(1,:);
for idx=1:4
  for jdx=1:4
    mag = 10.^(data(8*(idx-1)+2*(jdx-1)+2,:)/20);
    phs = data(8*(idx-1)+2*(jdx-1)+3,:)*pi/180;
    smm(idx,jdx,:) = mag.*(cos(phs) + j*sin(phs));
  end
end
```

```
% Convert single ended data to differential data
sdd(1,1,:) = 0.5*(smm(1,1,:) + smm(2,2,:) - smm(1,2,:) - smm(2,1,:));
sdd(1,2,:) = 0.5*(smm(1,3,:) + smm(2,4,:) - smm(1,4,:) - smm(2,3,:));
sdd(2,1,:) = 0.5*(smm(3,1,:) + smm(4,2,:) - smm(3,2,:) - smm(4,1,:));
sdd(2,2,:) = 0.5*(smm(3,3,:) + smm(4,4,:) - smm(3,4,:) - smm(4,3,:));

s11 = squeeze(sdd(1,1,:));
s12 = squeeze(sdd(1,2,:));
s21 = squeeze(sdd(2,1,:));
s22 = squeeze(sdd(2,2,:));
% create s3 struct to output
sdd3.f = f;
sdd3.s(1,1,:) = s11;
sdd3.s(1,2,:) = s12;
sdd3.s(2,1,:) = s21;
sdd3.s(2,2,:) = s22;

function s3 = interp_s3(a,fn,extrapval)

if ~(exist('extrapval', 'var') && isstruct(extrapval))
    extrapval = struct('rl', 1-eps(max(abs(a.s(:)))), 'il', eps(max(abs(a.s(:)))));
end

for i=1:2
    for k=1:2
        if (i == k)
            mag = interp1(a.f(:), squeeze(abs(a.s(i,k,:))),fn(:), 'linear',
extrapval.rl);
            ang = interp1(a.f, squeeze(unwrap(angle(a.s(i,k,:)))),fn(:),
'linear',extrapval.rl);
        else
            mag = interp1(a.f(:), squeeze(abs(a.s(i,k,:))),fn(:), 'linear',
extrapval.il);
            ang = interp1(a.f, squeeze(unwrap(angle(a.s(i,k,:)))),fn(:),
'linear',extrapval.il);
        end
        s3.s(i,k,:) = mag'.*exp(j*ang');
    end
end
s3.f = fn;

function s = t2s(t);

s(1,1,:) = t(2,1,:)./t(1,1,:);
s(1,2,:) = t(2,2,:)-((t(2,1,:).*t(1,2,:))./t(1,1,:));
s(2,1,:) = 1./t(1,1,:);
s(2,2,:) = -t(1,2,:)./t(1,1,:);

function t = s2t(s);

t(1,1,:) = 1./s(2,1,:);
t(1,2,:) = -s(2,2,:)./s(2,1,:);
t(2,1,:) = s(1,1,:)./s(2,1,:);
t(2,2,:) = s(1,2,:)-((s(1,1,:).*s(2,2,:))./s(2,1,:));

function sprod = smul(sa, sb);

ta = s2t(sa);
tb = s2t(sb);
```

```
tprod = tmul(ta,tb);
sprod = t2s(tprod);

function tprod = tmul(ta, tb);

tprod(1,1,:) = ta(1,1,:).*tb(1,1,:) + ta(1,2,:).*tb(2,1,:);
tprod(1,2,:) = ta(1,1,:).*tb(1,2,:) + ta(1,2,:).*tb(2,2,:);
tprod(2,1,:) = ta(2,1,:).*tb(1,1,:) + ta(2,2,:).*tb(2,1,:);
tprod(2,2,:) = ta(2,1,:).*tb(1,2,:) + ta(2,2,:).*tb(2,2,:);
```