Application Note

MECT Series
Final Inch® Designs in SFP+ Applications

Revision Date: August 20, 2009

Developed in conjunction with
Teraspeed Consulting Group LLC

Series: MECT-110-01-X-D-RA1
Standard: SFP+

Abstract

The SFP+ specification SFF-8431 Revision 3.2 defines the electrical interfaces and test specification between the SFP+ module and a host board for operation up to 11.1 Gbps. As with any modern high speed PCB design, the performance of an actual SFP+ interconnect is highly dependent upon the implementation. This paper demonstrates the use of the Samtec MECT connector in SFP+ compliant designs, utilizing advanced modeling and simulation methodology. SFP+ standard Host and Module compliance board channels are modeled and simulated, along with the MECT connector, for performance validation and application compliance.

Applicable Documents and Specifications

SFF-8431 – Specifications for Enhanced Small Form Factor Pluggable Module "SFP+", Revision 3.2, 12th of November 2008

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Introduction

From SFF-8431:

> "The SFP+ specification defines the electrical interfaces and their test methods between the SFP+ module and host board for operation up to 11.1 Gbps. The high speed electrical interface between the host and SFP+ module is called "SFI". SFI simplifies the module and leverages host based transmit pre-emphasis and host based receive equalization to overcome PCB and external media impairments. SFI typically operates with one connector at the module interface and up to about 200 mm of improved FR4 material or 150 mm of standard FR4 ...."

Samtec has developed the MECT connector for use in Small Form Factor Pluggable (SFP and SFP+ applications, at differential serial data rates up to 11.1 Gbps. In this application note, we will show the modeling and simulation methodology necessary to verify operation of the MECT connector in the SFP+ environment.

Connector Modeling

Full wave 3-dimensional connector modeling was performed on the Samtec MECT connector, utilizing CST Microwave Studios time domain solver. Fully mated and deflected 3D CAD models of the connector were imported into the tool, along with models of the module and host PCB interface regions. Metal and dielectric structures were modeled with frequency dependent losses, from 5 MHz to 20 GHz. Figure 1 and Figure 2 show the modeled structure, including connector, model and host PCB interfaces.

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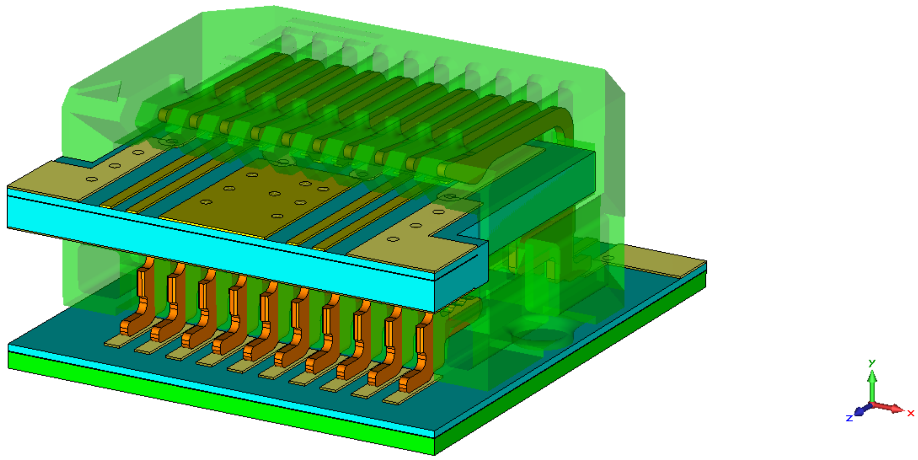

Figure 1 – MECT connector with mated host and module printed circuit boards.

(Module edge card side view)

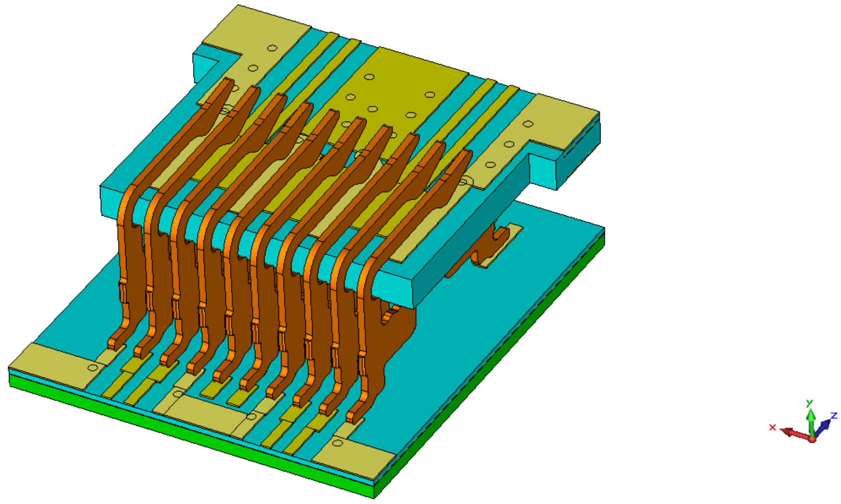

Figure 2 – MECT connector with mated host and module printed circuit boards.

(Host PCB side view)

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A Touchstone© 8-port S-parameter model of the Tx and Rx differential paths was extracted from the connector structure. This model has been de-embedded to the far edge of the connector pads, away from the MECT connector. This model is available directly from Samtec for use in simulations.

Connector solder pads on the host PCB side (Module compliance board in SFF terminology), have been reduced in size as specified in SFF-8431- Section 3.5:

> "The solder pads for the high speed traces in the SFF-8431Module Compliance Board are 1.1x0.4 mm to improve high frequency performance instead of 2.0x0.5mmas defined in the SFF-8083 for improved manufacturability. Tradeoff between host performance and manufacturability are left to the host designer."

In addition, to improve high frequency performance, solder and edge finger pads on the Host and Module side PCB, have additional adjacent plane relief, as shown in Figures 3 and 4.

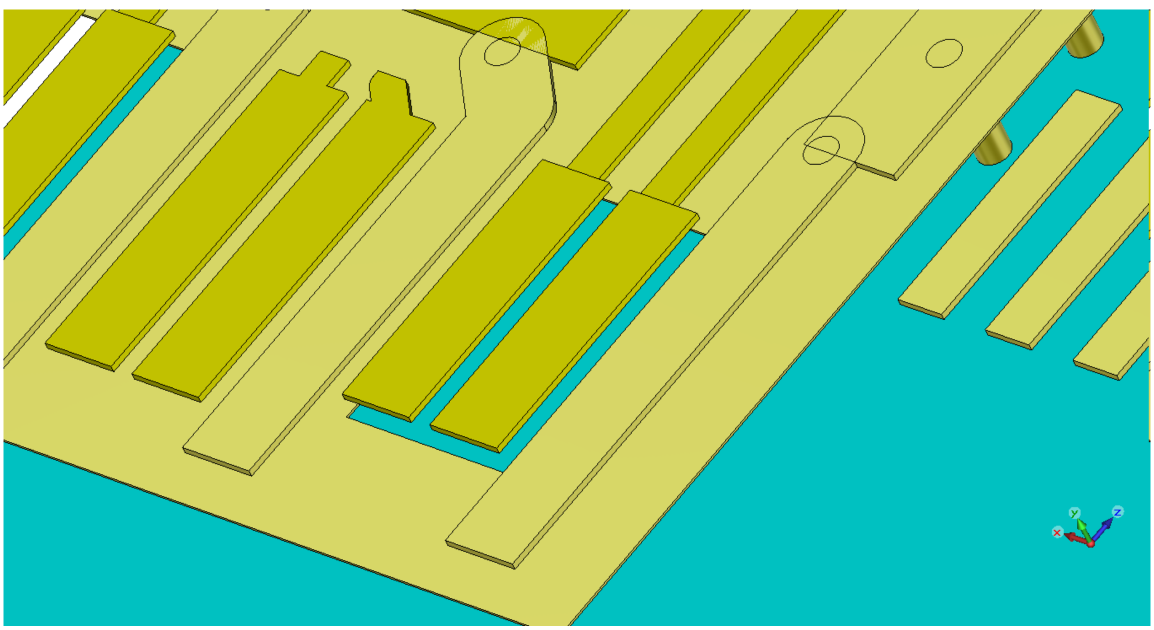

Figure 3 – MECT connector with module plane relief

(Rectangle dimensioned to open plane directly underneath both pads)

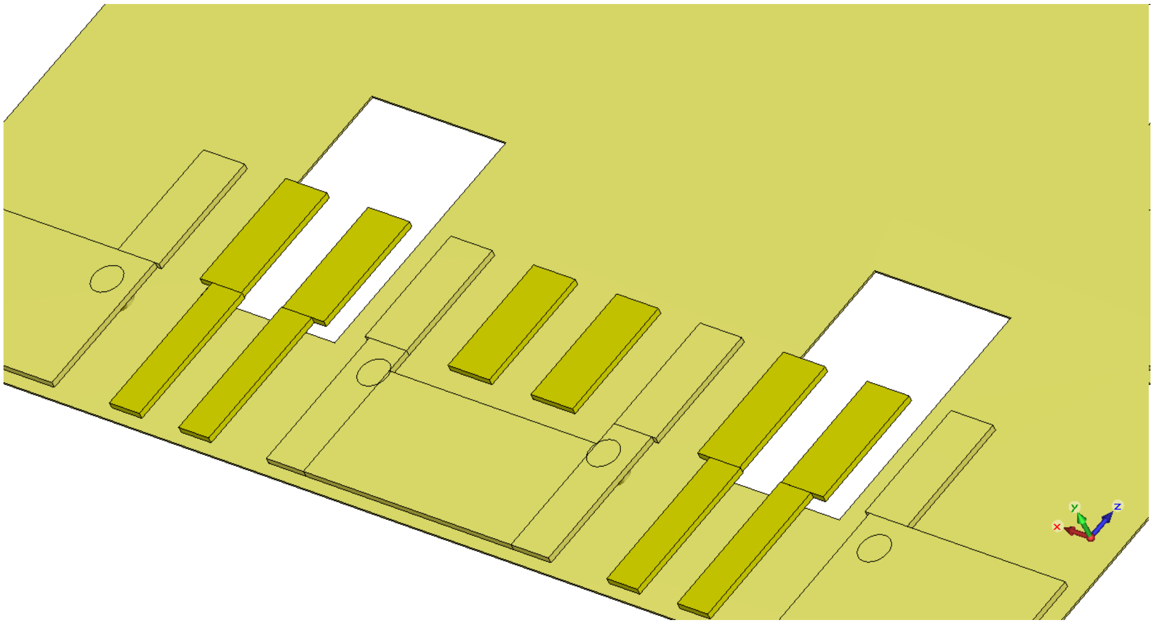

Figure 4 – MECT connector with host PCB plane relief

Connector-only performance

SFF-8431, section A.2 provides guidance for SFP+ channel transfer characteristics. In Figure 5, the differential insertion loss transfer characteristics of the MECT connector alone are shown from 3D modeling and simulation.

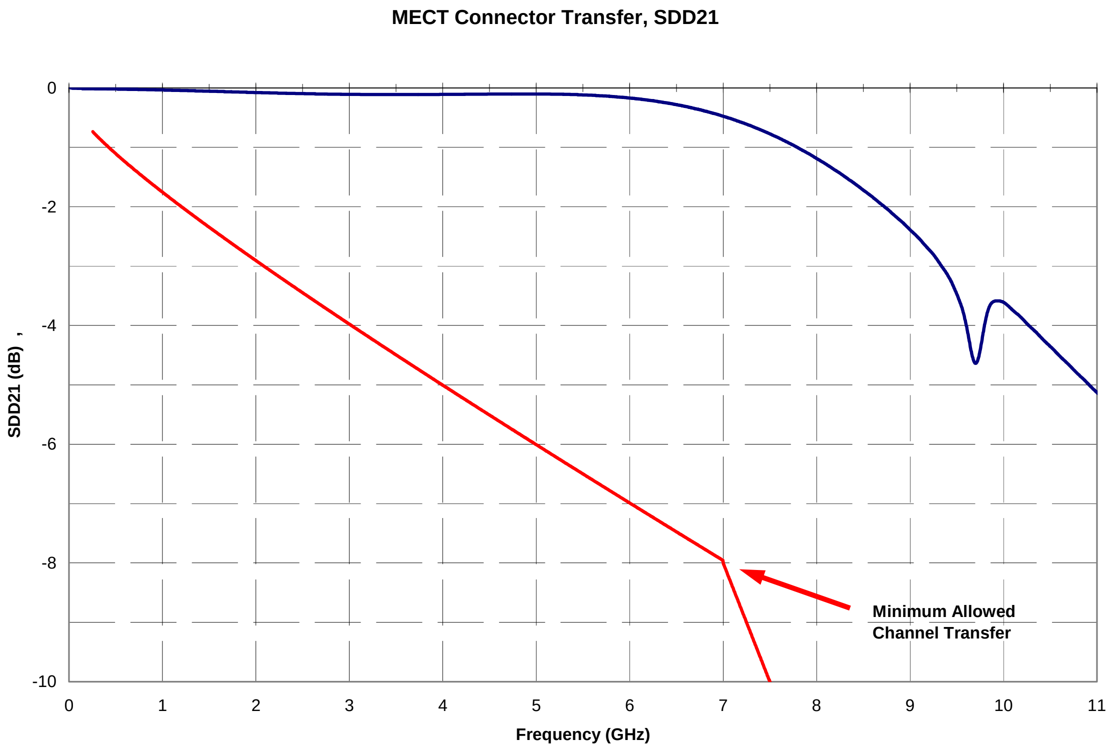

Figure 5 – Connector Insertion Loss

From SFF-8431:

> "The minimum channel transfer SDD21 (maximum loss) mask contour is given by:
>
> SDD21(dB) = –0.55 × f from 0.01 GHz to 0.25 GHz
> SDD21(dB) = (– 0.108 – 0.845 × sqrt(f) – 0.802 × f) f from 0.25 GHz to 7 GHz
> SDD21(dB) = 20 – 4 × f from 7 GHz to 8 GHz
> SDD21(dB) ≥ –16 from 8 GHz to 11.1 GHz"

It can be seen that the MECT connector meets the SFP+ requirements.

SFF-8431, section A.3 provides guidance for SFP+ channel ripple characteristics. In Figure 6 the insertion loss ripple from a fitted characteristic for the MECT connector alone is shown from 3D modeling and simulation.

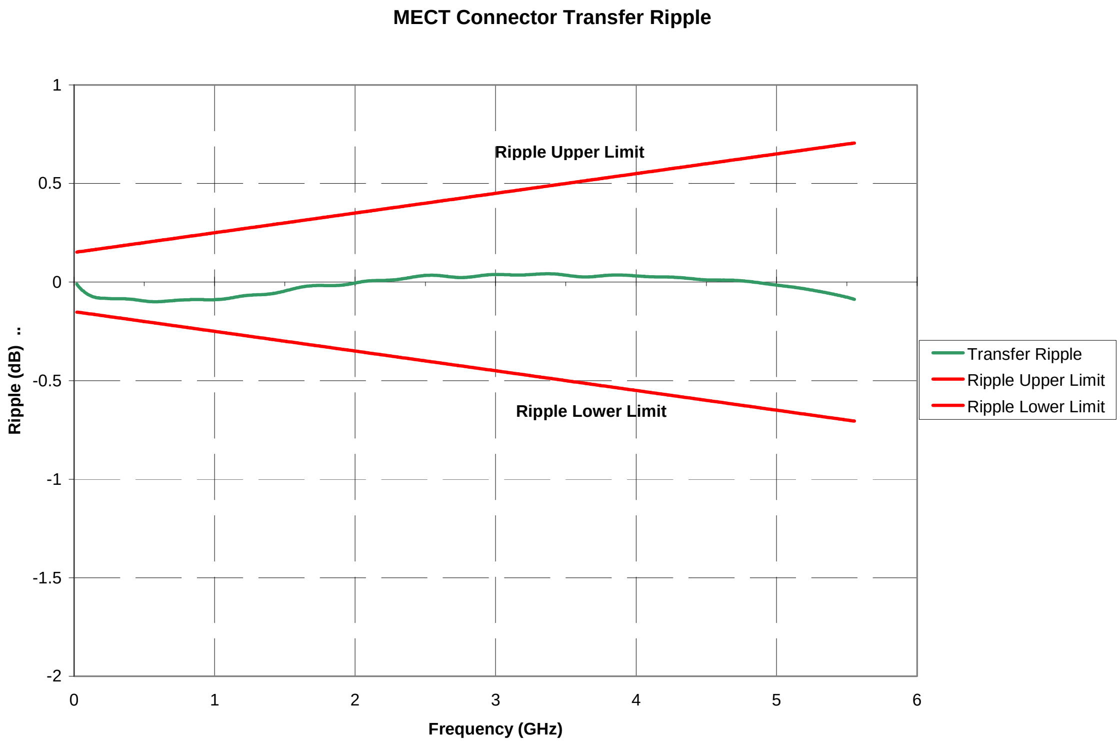

Figure 6 – Connector Transfer Ripple

The MECT connector meets the requirements for channel ripple response.

Compliance Application Reference Board Performance

Section C of the SFF-8431 specification defines normative specifications for the defined application reference boards. Two of the application reference boards, the Host Compliance Board (HCB) and the Module Compliance Board (MCB), are modeled and used for MECT compliance simulations. An HCB inserts into the edge card module side of the SFP+ (MECT) connector, and is used to perform host system compliance measurements and testing. A MECT connector is soldered to the MCB, to provide module compliance measurement and test access. SFF-8431 section 3 defines all of the tests possible with these compliance boards, in various configurations. For our tests, the HCB and MCB are shown mated in Figure 7.

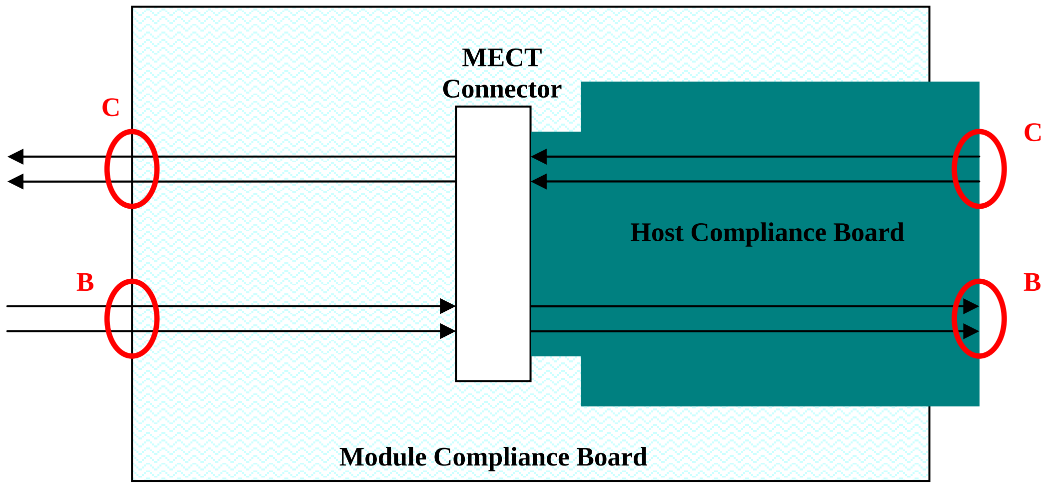

Figure 7 – SFP+ Host and Module Compliance Boards

The Host Compliance Board is based upon stack-up and Gerber design files available through the SFF Committee. The board stack-up is defined in SFF-8431 section C.2.1 as follows, and shown in Figure 8:

> "Host Compliance Board stack-up shown in Figure 36 is on six metal layers Rogers RO4350B© / FR4-6 material. The board is compliant with requirements of SFF-8432 and SFF-8083. SFP signals are routed on signal layer 1, low speed signals and controls are routed on signal layer 6."

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1. Top Layer	Signal	17 µm/0.5 oz Copper platted to 1 oz min+ 1.25 µm Nickel + 2.5 µm Gold
0.168 mm / 6.6 mils Rogers RO4350B		
2. Layer	Vee	34 µm/1 oz Copper
0.14 mm / 5.5 mils FR4-6		
3. Layer	Signal 1	17 µm/0.5 oz Copper
0.178 mm / 7 mils FR4-6		
4. Layer	Signal 2	17 µm /0.5 oz Copper
0.14 mm / 5.5 mils FR4-6		
5. Layer	Power	34 µm/1 oz Copper
0.168 mm / 6.6 mils Rogers RO4350B		
6. Bottom Layer	Signal	17 µm/0.5 oz Copper platted to 1 oz min + 1.25 µm Nickel + 0.25 µm Gold

Figure 8 - Host Compliance Board stack-up

The Module Compliance Board is based upon stack-up and Gerber design files available through the SFF Committee. The board stack-up is defined in SFF-8431 section C.3.1 as follows, and shown in Figure 9:

> "Module Compliance Board stack-up shown in Figure 38 is based on a laminate of Rogers RO4350B/ FR4-6 with ten metal layers. SFI signals are routed on signal layer 1, low speed signals and controls are routed on signal layers 8 and 10."

1. Top Layer	Signal	17 µm/0.5 oz Copper + 1.25 µm Nickel + 2.5 µm Gold
0.168 mm / 6.6 mils Rogers RO4350B		
2. Layer	Vee	17 µm /0.5 oz Copper
0.382 mm / 15 mils FR4-6		
3. Layer	Vee	34 µm/1 oz Copper
0.076 mm / 3 mils FR-4		
4. Layer	VccR	34 µm/1 oz Copper
0.076 mm / 3 mils FR4-6		
5. Layer	Vee	34 µm /1 oz Copper
0.076 mm / 3 mils FR4-6		
6. Layer	VccT	34 µm /1 oz Copper
0.076 mm / 3 mils FR4-6		
7. Layer	Vee	34 µm/1 oz Copper
0.076 mm / 3 mils FR4-6		
8. Layer	Signal	34 µm/1 oz Copper
0.382 mm / 15 mils FR4-6		
9. Layer	Vee	17 µm/ 0.5 oz Copper
0.168 mm / 6.6 mils Rogers RO 4350B		
10. Bottom Layer	Signal	17 µm Cu / 0.5 oz Copper+ 1.25 µm Nickel + 0.25 µm Gold

Figure 9 - Module Compliance Board stack-up

Differential Insertion Loss

When these boards are mated, SFF-8431, Section C.4 provides guidance regarding the total insertion loss from input to output.

"The maximum and the minimum values of SDD21 or SDD12 looking into either the Module Compliance Board or Host Compliance Board are ...:

$SDDxx(dB)min \geq -0.012 - 0.694 \times sqrt(f) - 0.127 \times f$ for $0.01 \text{ GHz} \leq f \leq 5.5 \text{ GHz}$
$SDDxx(dB)min \leq 0.75 - 0.65 \times f$ for $5.5 \text{ GHz} \leq f \leq 11.1 \text{ GHz}$
$SDDxx(dB)max \geq (0.0915 - 0.549 \times sqrt(f) - 0.101 \times f)$ for $0.01 \text{ GHz} \leq f \leq 11.1 \text{ GHz}$"

HCB to MCB differential insertion loss compliance for the MECT connector SFP+ modeling and simulation environment is shown in Figure 10.

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Standard: SFP+

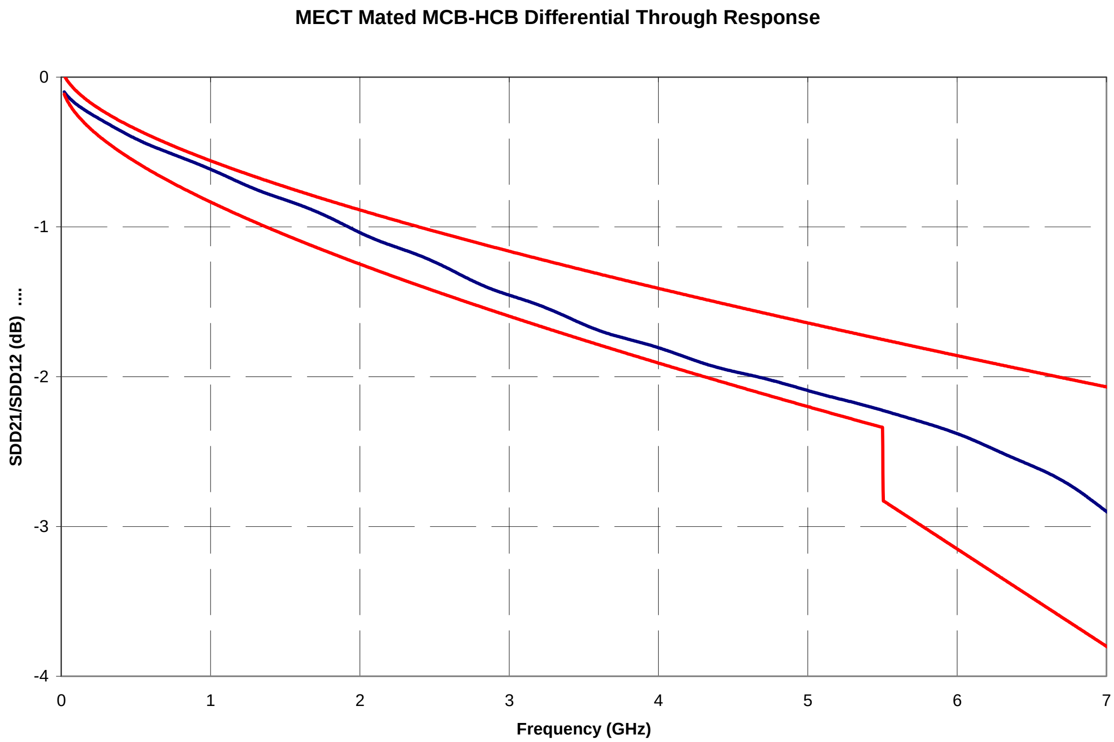

Figure 10 - MECT Differential Through Compliance

The modeled HCB and MCB compliance cards meet the loss requirements of a SFP+ channel.

Differential to Common Mode Conversion

Differential SFF-8431, Section C.4 provides guidance regarding the differential to common mode conversion compliance

> "The maximum values of Differential to Common Mode Response SCD21 and SCD12 looking into either the Module Compliance Board or Host Compliance Board are...:
>
> SCDxx(dB) $\leq -30 + 2.91 \times f$, from 0.01 to 5.5 GHz
> SCDxx(dB) ≤ -14, from 5.5 to 15 GHz."

HCB to MCB differential to common mode response for the MECT connector SFP+ modeling and simulation environment is shown in Figure 11.

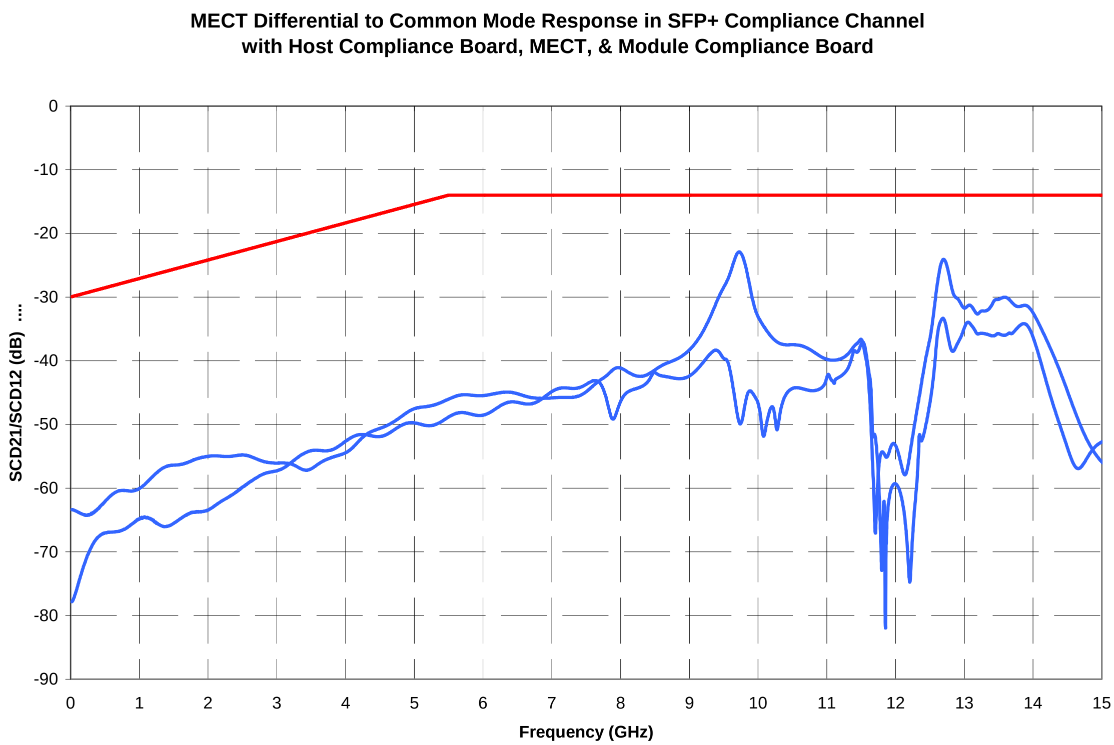

Figure 11 – MECT Differential to Common Mode Compliance

The modeled HCB and MCB compliance cards, with MECT connector, meet the differential to common mode conversion compliance of an SFP+ channel.

Common Mode Return Loss

SFF-8431, Section C.4 provides guidance regarding the common mode return loss compliance

"The maximum values of SCC11 or SCC22 looking into either the Module Compliance Board or Host Compliance Board are...:

$SCCxx(dB) \leq -12 + 2.8 \times f$, from 0.01 to 2.5 GHz
$SCCxx(dB) \leq -5.2 + 0.08 \times f$, from 2.5 to 15 GHz."

HCB to MCB common mode return loss compliance for the MECT connector SFP+ modeling and simulation environment is shown in Figure 12.

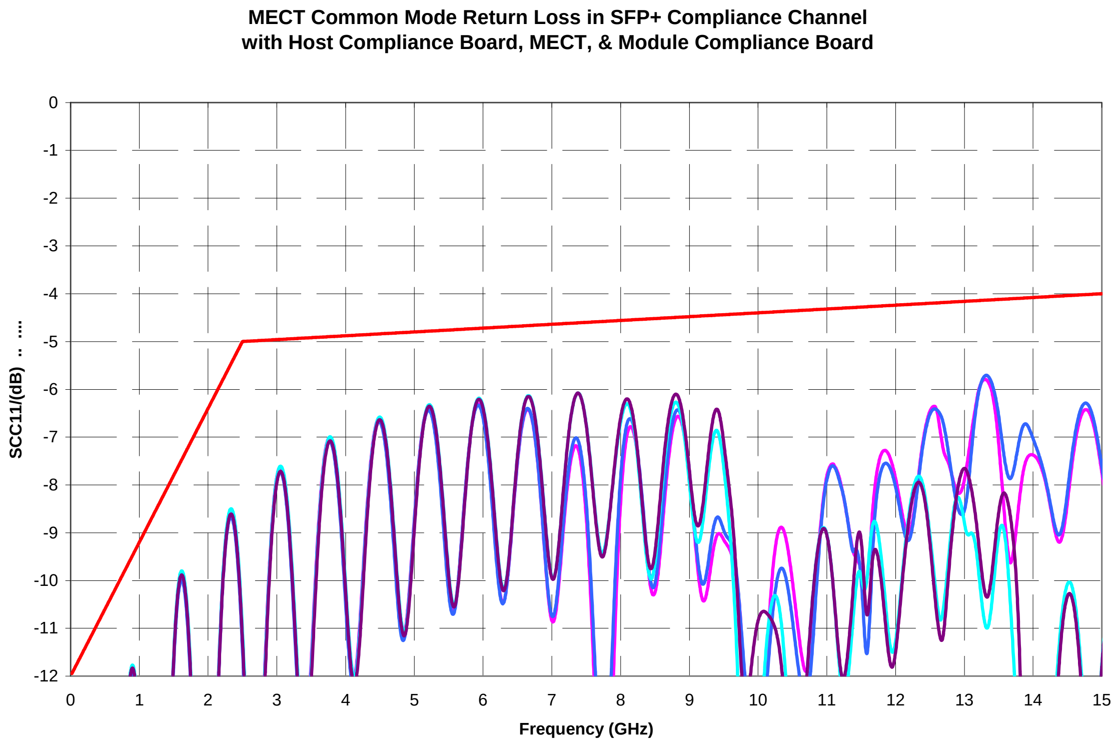

Figure 12 – MECT Common Mode Return Loss Compliance

The modeled HCB and MCB compliance cards, with MECT connector, meet the differential return loss compliance of an SFP+ channel.

Near End Crosstalk (NEXT)

SFF-8431, Section C.4 provides guidance regarding NEXT compliance

> "The integrated differential NEXT from MCB Port 1 to MCB Port 2 for the mated Module Compliance Board and the Host Compliance Board is..."
>
> NEXT(dB) ≤ -50 f, from 0.01 to 4 GHz
> NEXT(dB) $\leq -70 + 5 \times f$, from 4 to 8 GHz
> NEXT(dB) ≤ -30 f, from 8 to 15 GHz "

HCB to MCB NEXT compliance for the MECT connector SFP+ modeling and simulation environment is shown in Figure 13.

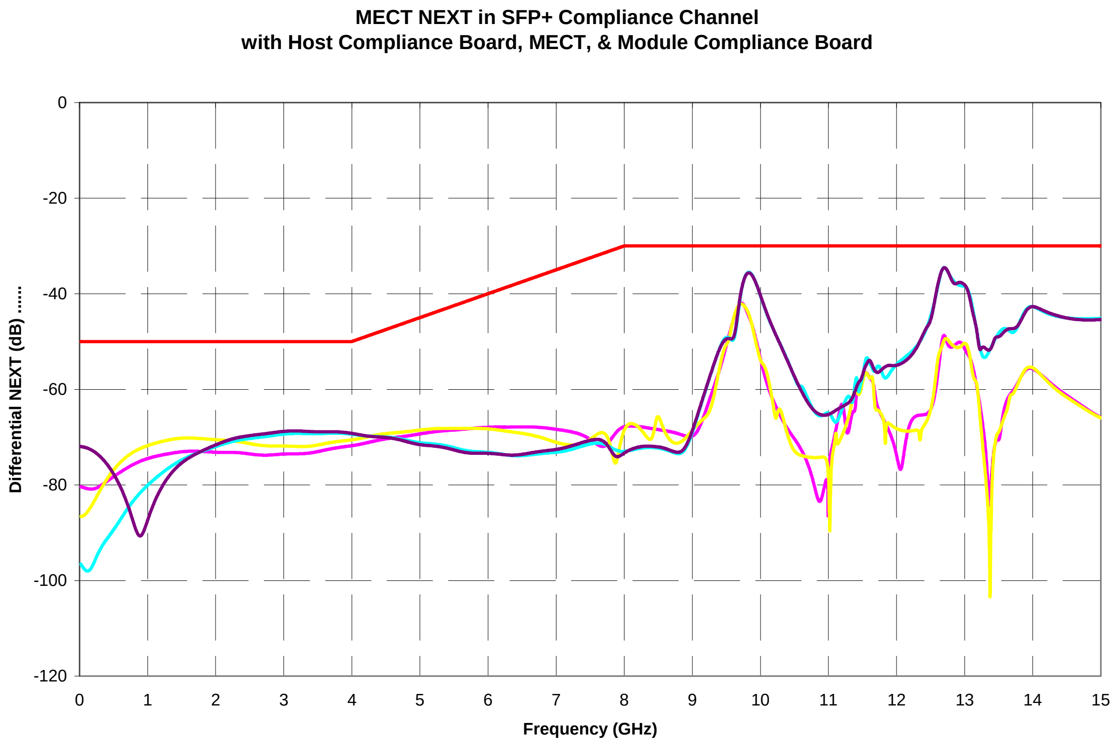

Figure 13 – MECT NEXT Compliance

The modeled HCB and MCB compliance cards, with MECT connector, meet the NEXT compliance of an SFP+ channel.

SFP+ Channel Host Board Simulations

In most SFP+ applications, an application host board is designed to use available Modules. In SFF-8431, section 1.2, the supported module standards are defined.

> "An SFP+ module 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 lower signaling rates not listed in this table, such as 1.25 GBd for IEEE Gigabit Ethernet, 2.125 GBd for 2GFC, or 4.25 GBd for 4GFC."

<table>
<tr><th>Standard</th><th>signalling Rate (GBd)</th><th>High Speed Serial Interface</th><th>High Speed Serial Test Method</th><th>Low Speed Electrical Definitions</th><th>Low Speed Test Methods</th><th>Management</th><th>Mechanical/ Connector</th></tr>
<tr><td>8 GFC</td><td>8.5</td><td>FC-PI-4</td><td>FC-PI-4</td><td rowspan="7">Chapter 2</td><td rowspan="7">Appendix D</td><td rowspan="7">Chapter 4
SFF-8472,
SFF-8079,
SFF-8089</td><td rowspan="7">SFF-8432
SFF-8083</td></tr>
<tr><td>10GSFP+Cu</td><td>10.3125</td><td>Appendix E</td><td>Appendix E</td></tr>
<tr><td>IEEE 802.3 CL 52 (10 Gb/s Ethernet LAN PHY)</td><td>10.3125</td><td rowspan="5">Chapter 3</td><td rowspan="5">Appendix D</td></tr>
<tr><td>IEEE 802.3 CL 52 (10 Gb/s Ethernet WAN PHY)</td><td>9.95328</td></tr>
<tr><td>IEEE 802.3 CL 68 (LRM)</td><td>10.3125</td></tr>
<tr><td>10 GFC</td><td>10.51875</td></tr>
<tr><td>10GBASE-R (IEEE 802.3 CL 49) Encapsu-lated in G.709 ODU-2 Frame (FEC)</td><td>11.10</td></tr>
</table>

Table 1 - SFP+ Standard Compliance

The designer of an SFP+ application host board must meet specific recommended design specifications. In order to do this, guidance for maximum trace length for common and advanced PCB materials is provided in SFF-8431, section 1.3.

> "The SFI channel may be implemented with either microstrip or stripline structures.
> Example host board designs with typical PCB trace reaches are shown in Table 2."

Type	Material	Trace Width (mm)	Loss Tangent	Copper Thickness (oz) see 1	Copper Thickness (µm)	Trace Length (mm)
Microstrip	FR4-6/8	0.3	0.022	1	35	200
	Nelco 4000-13	0.3	0.016	1	35	300
Stripline	FR4-6/8	0.125	0.022	0.5	17.5	150
	Nelco 4000-13	0.125	0.016	0.5	17.5	200

1. Copper (oz) is defined as an ounce of copper over one square foot of laminate.

Table 2 - Host Board Achievable Trace Length

Simulation of an SFP+ compliant channel with the MECT connector were performed using 200 mm of FR4 Microstrip trace, as defined above, and combined with a simulation model of the MECT connector and Module Compliance Board. SFF-8431, section A provides guidance for designers of SFP+ compliant channels:

> "The purpose of the recommended SFI channel is to provide guidelines for host designers. The recommended SFI host channel consists of PCB traces, vias, and the 20 position enhanced connector defined by SFF-8083. The PCB traces are recommended to meet 100 ±10Ωdifferential impedance with nominal 7% differential coupling.
>
> SFI channel S-parameters are defined from ASIC transmitter pads to Host Compliance Board output at B and from Host Compliance Board input at C to ASIC input pads. "

The SFP+ compliant channel differential insertion loss is defined in SFF- 8431, section A.2.

> "The minimum channel transfer SDD21 (maximum loss) mask contour is given by:.
>
> SDD21(dB) = –0.55 f from 0.01 GHz to 0.25 GHz
> SDD21(dB) = (– 0.108 – 0.845 × sqrt(f)– 0.802 × f) f from 0.25 GHz to 7 GHz
> SDD21(dB) = 20 – 4 × f f from 7 GHz to 8 GHz
> SDD21(dB) ≥ –16 f from 8 GHz to 11.1 GHz
>
> where f is the frequency in GHz.
>
> The SFI channel maximum transfer is given by:
>
> SDD21(dB) = 0 f from 0.25 GHz to 1.0 GHz
> SDD21(dB) = 0.5 × (1 – f) f from 1 GHz to 7 GHz
> SDD21(dB) = –3 f from 7 GHz to 11.1 GHz
>
> where f is the frequency in GHz."

SFP+ channel insertion loss compliance for the MECT connector SFP+ modeling and simulation environment with Module Compliance Board, MECT connector and 200 mm of FR4 differential Microstrip trace is shown in Figure 14.

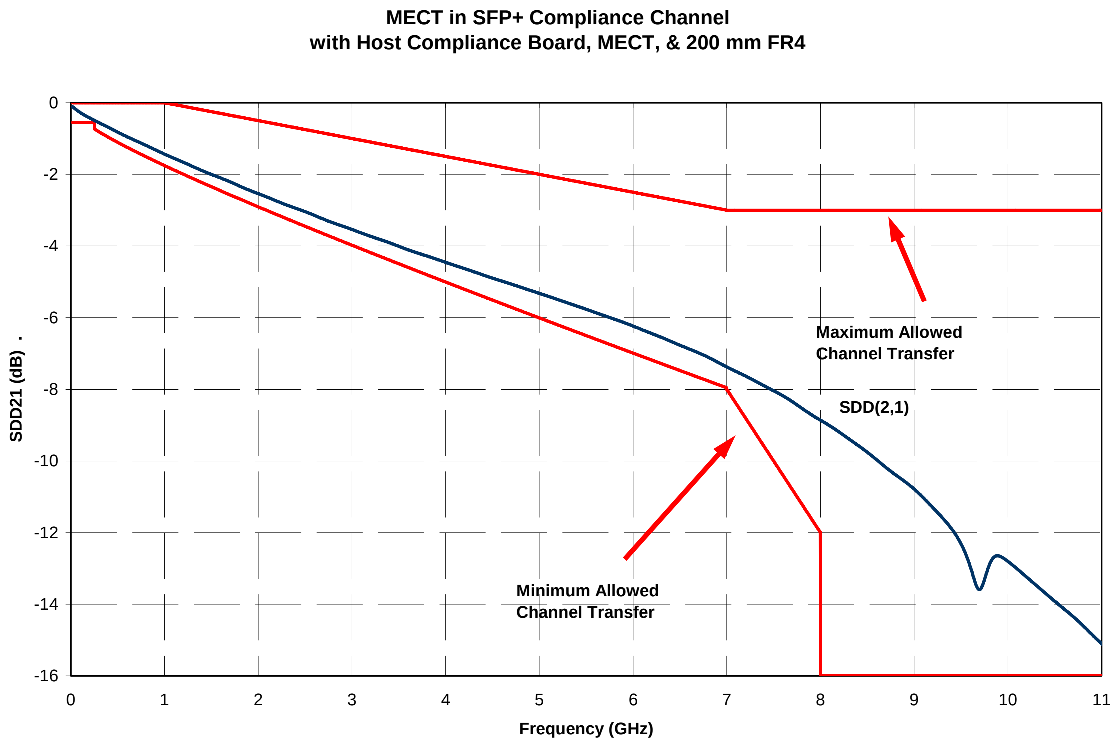

Figure 14 – MECT Insertion Loss Compliance

The SFP+ compliant channel differential return loss is defined in SFF- 8431, section A.3.

> "The reflection coefficients, SDD11 and SDD22, of the SFI channel are recommended to meet the following equations:
>
> SDDxx(dB) ≤ –14.5 f from 0.01 to 5 GHz
> SDDxx dB ≤ - 23.25 – 8.75 x (f/5), from 5 to 11.1 GHz
>
> where variable f (frequency) is in GHz and SDDxx is either SDD11 or SDD22."

SFP+ channel return loss compliance for the MECT connector SFP+ modeling and simulation environment with Module Compliance Board, MECT connector, and 200 mm of FR4 differential Microstrip trace is shown in Figure 15.

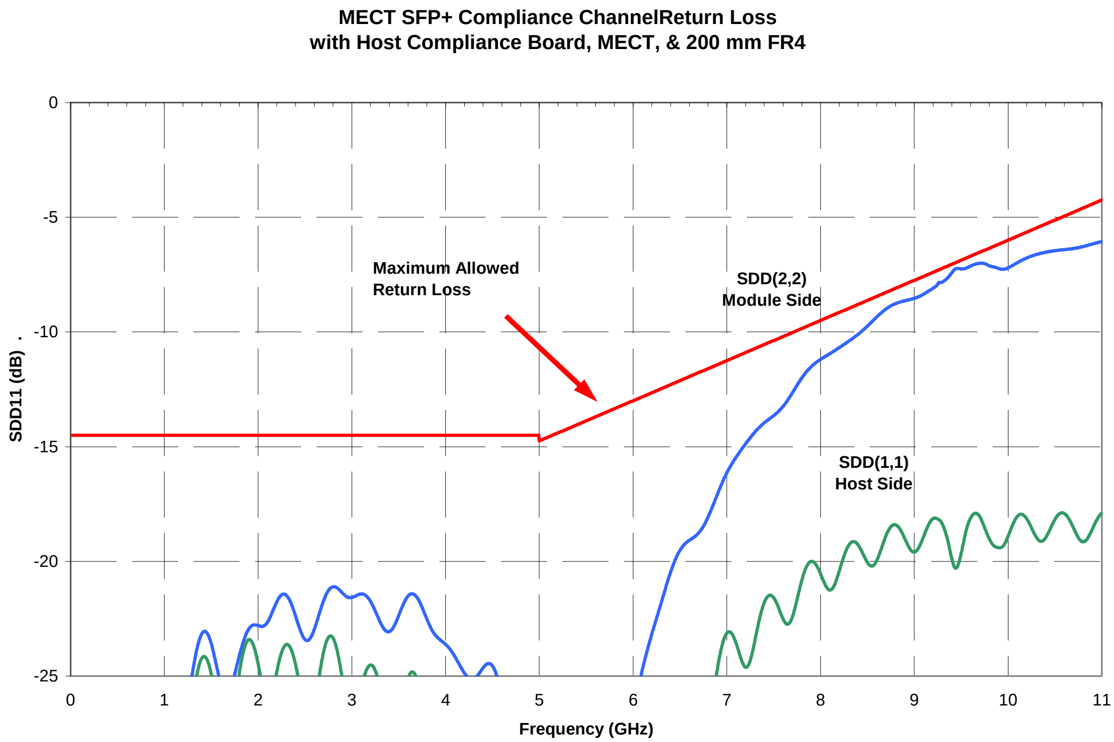

Figure 15 – MECT Return Loss Compliance

Figures 14 and 15 show that the MECT connector meets the SFP+ compliance specs. SFF-8431, section 3.5.2, defines the transmitter output requirements necessary to provide a faithful channel. These requirements are measured with the transmitter driving from the host application board, through the SFP+ connector (MECT) and into a Host Compliance Board, as we have modeled for insertion loss and return loss compliance. The specifications for are defined in SFF-8431, Table 12 and figure 19, as shown in Table 3 and Figure 15 below.

Parameters- B	*Symbol*	*Conditions*	*Min*	*Target Value*	*Max*	*Units*
Crosstalk Source Rise/Fall time (20% to 80%)	Tr, Tf	See 1, 2, D.6 and Figure 16		34		ps
Crosstalk Source Amplitude (p-p differential)		See 1, 2, D.7 and Figure 16		1000		mV
Signal Rise/Fall time (20% to 80%)	Tr, Tf	See D.6	34			ps
Total Jitter	TJ	See D.5			0.28	UI(p-p)
Data Dependent Jitter	DDJ	See D.3			0.1	UI(p-p)
Data Dependent Pulse Width Shrinkage	DDPWS				0.055	UI (p-p)
Uncorrelated Jitter	UJ	See 3 and D.4			0.023	UI (RMS)
Transmitter Qsq	Qsq	D.8	50			
Parameters- B	*Symbol*	*Conditions*	*Value*			*Units*
Eye Mask	X1	Mask hit ratio of 5×10^{-5}, See D.2 and Figure 19	0.12			UI
Eye Mask	X2		0.33			UI
Eye Mask	Y1		95			mV
Eye Mask	Y2		350			mV

1. Measured at C" with Host Compliance Board and Module Compliance Board pair.
2. Since the minimum module output transition time is faster than the crosstalk transition time the amplitude of crosstalk source is increased to achieve the same slew rate.
3. It is not possible to have the maximum UJ and meet the TJ specifications if the Uj is all Gaussian.

Table 3 - Host Transmitter Eye Mask Specifications

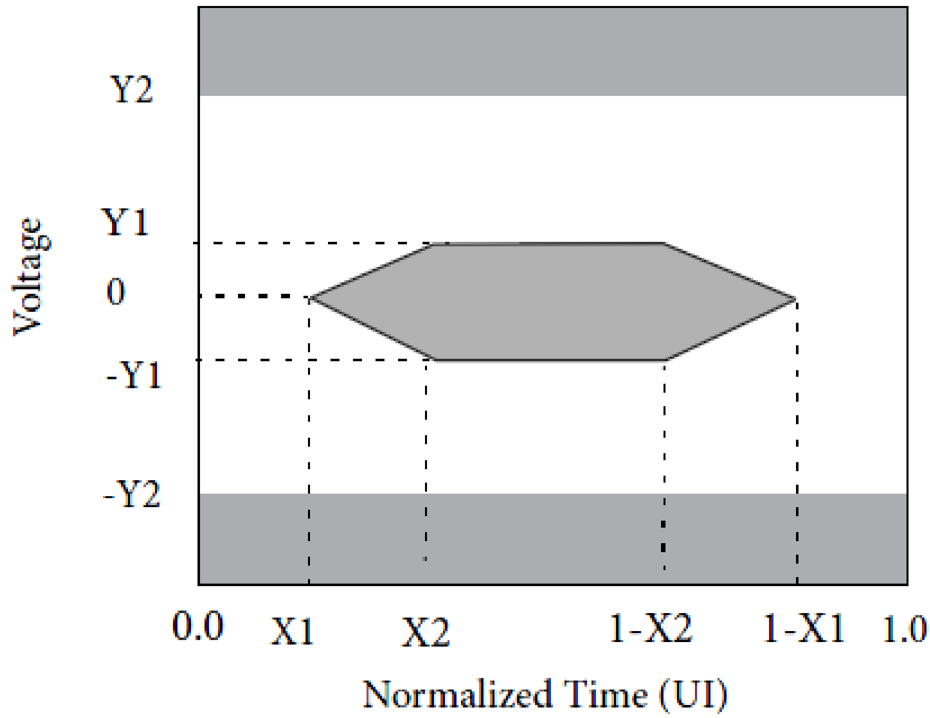

Figure 15 - Host Transmitter Eye Mask

Simulation of the channel was performed with a PRBS-9 source, filtered and adjusted to a 20%/80% rise and fall time of 24 ps, and maximum voltage swing (Y2,-Y2) of +/- 350 mV.

Figure 16 shows a simulation of the channel with the MECT connector, Module Compliance Board and Host Compliance Boards, as a baseline, exhibiting the connector performance at 11.1 Gbps. Additive deterministic jitter for this configuration is 4.4 ps (0.05 UI). This simulation utilizes Rogers 4350B material for all traces in the channel.

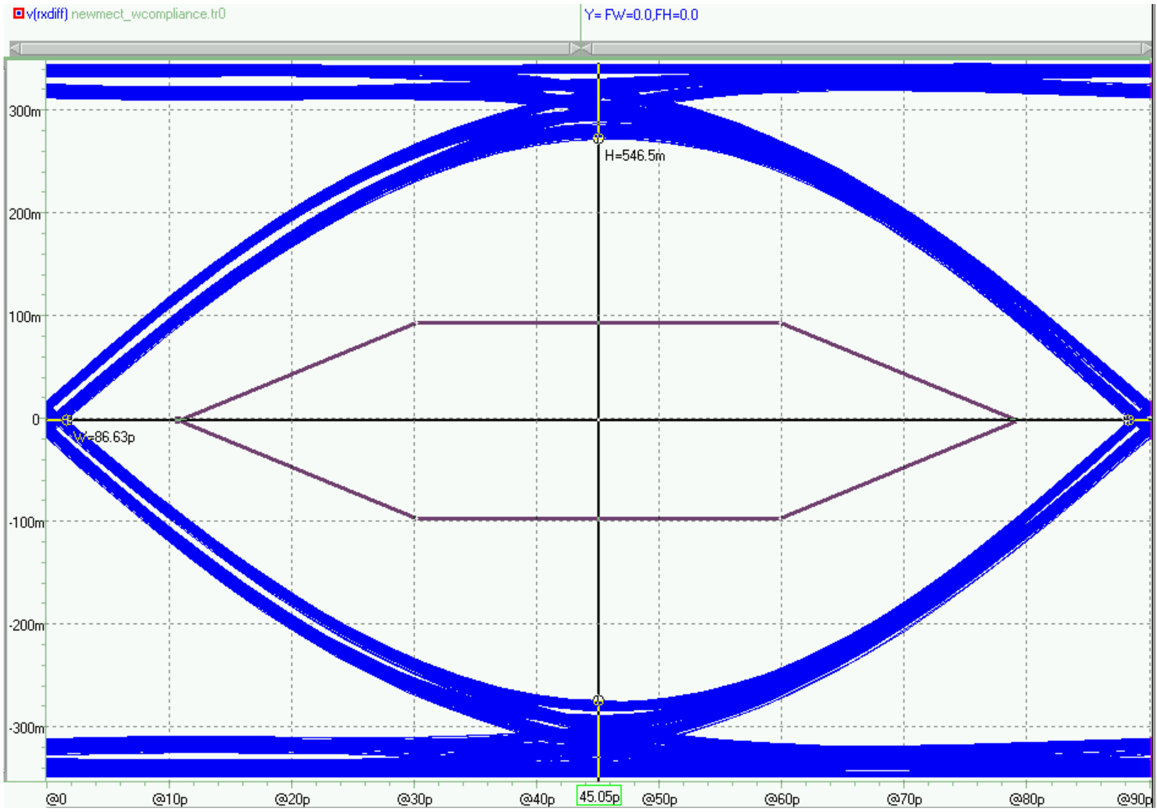

Figure 16 – 11.1 Gbps PRBS 9 eye of MECT connector SFP+ Host Compliance Board with Module Compliance Board

(3.5 ps deterministic jitter, 546 mV differential eye height)

Figure 17 shows a short host FR4 channel, 35 mm long, with the MECT connector and Host Compliance Board at 11.1 Gbps. This is indicative of short channels where the driving SERDES is placed extremely close to the SFP+ module connector. Performance is essentially unchanged when compared to the previous results with the application compliance boards.

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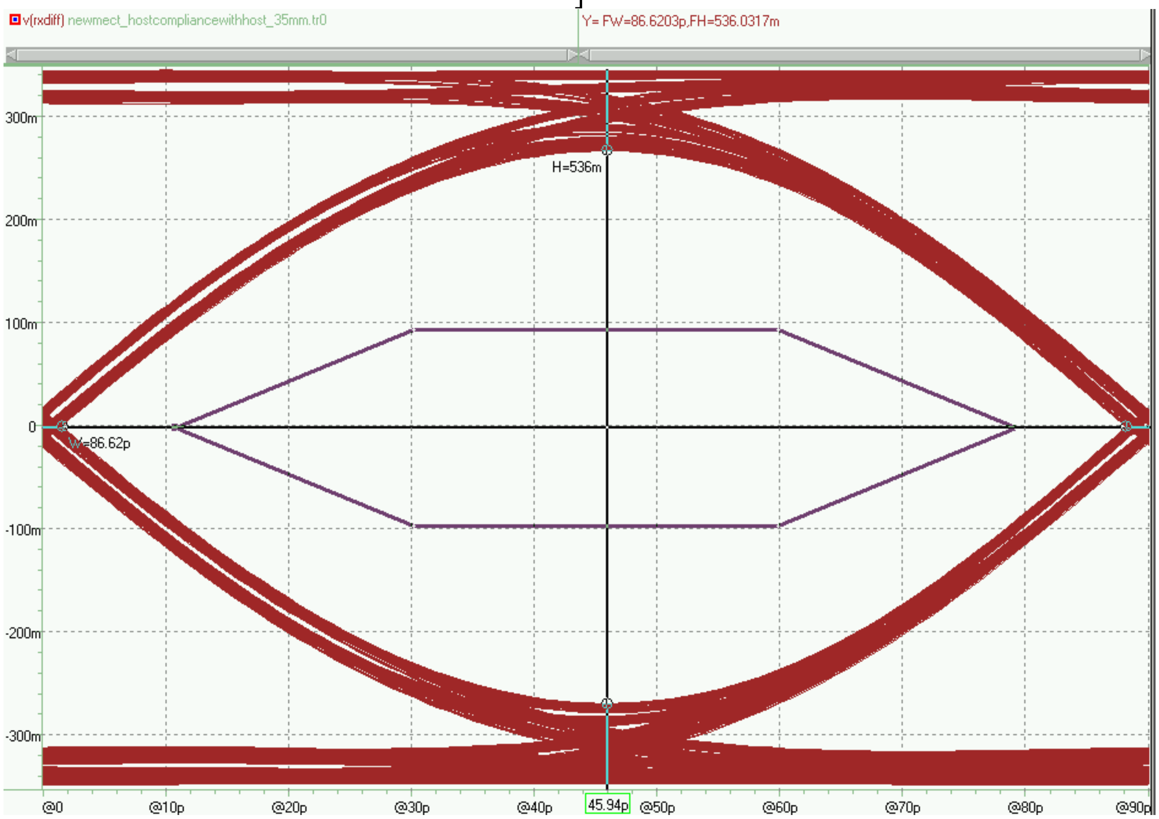

Figure 17 – 11.1 Gbps PRBS 9 eye of MECT connector SFP+ Host Compliance Board with 35 mm of Host FR4 trace

(3.5 ps deterministic jitter, 536 mV differential eye height)

Figures 18 and 19 show a long 200 mm FR4 host channel simulation at 11.1 Gbps. Figure 18 uses a PRBS 9 source pattern, while in Figure 19 a PRBS 15 pattern is used to show the impact of long run length patterns. In both cases, the received eye is well-behaved and has margin with respect to the compliance eye mask.

The MECT connector shows eye performance that is well within the SFP+ specification requirements.

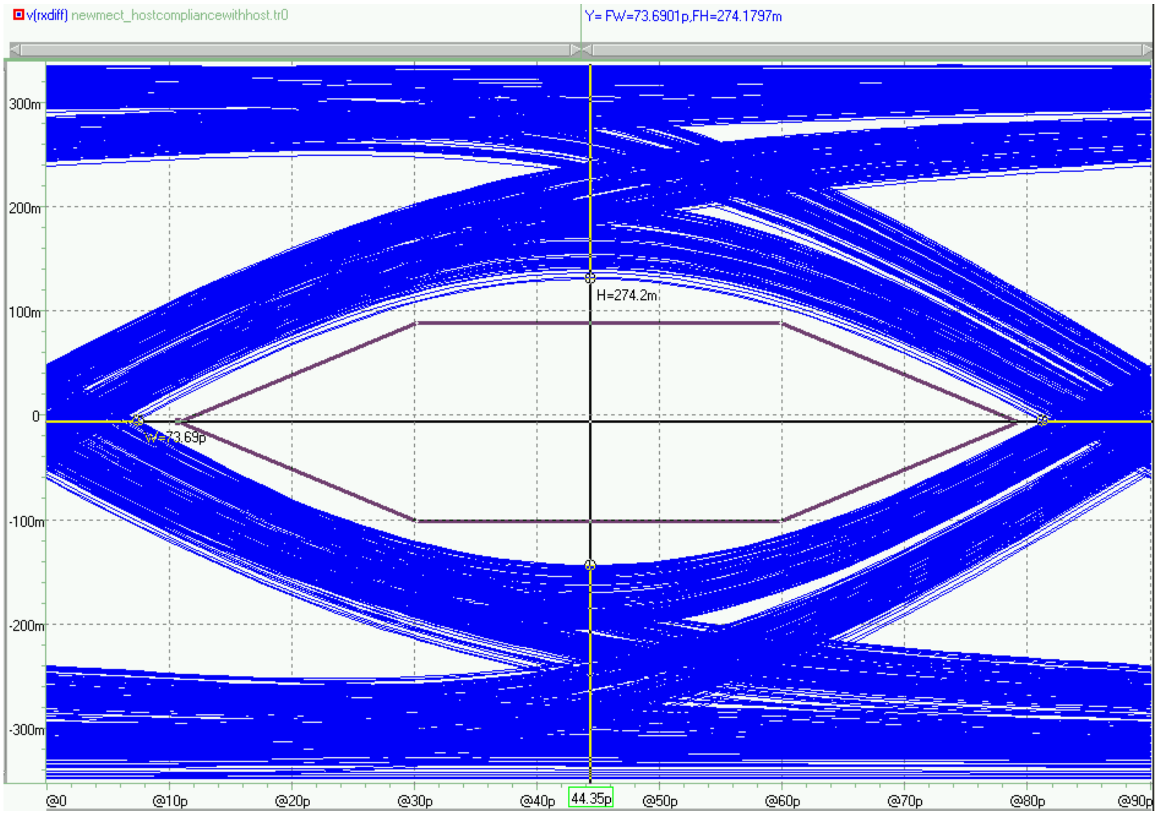

Figure 18 – 11.1 Gbps PRBS 9 eye of MECT connector SFP+ Host Compliance Board with 200 mm of host FR4 trace

(16.4 ps deterministic jitter, 274.2 mV differential eye height)

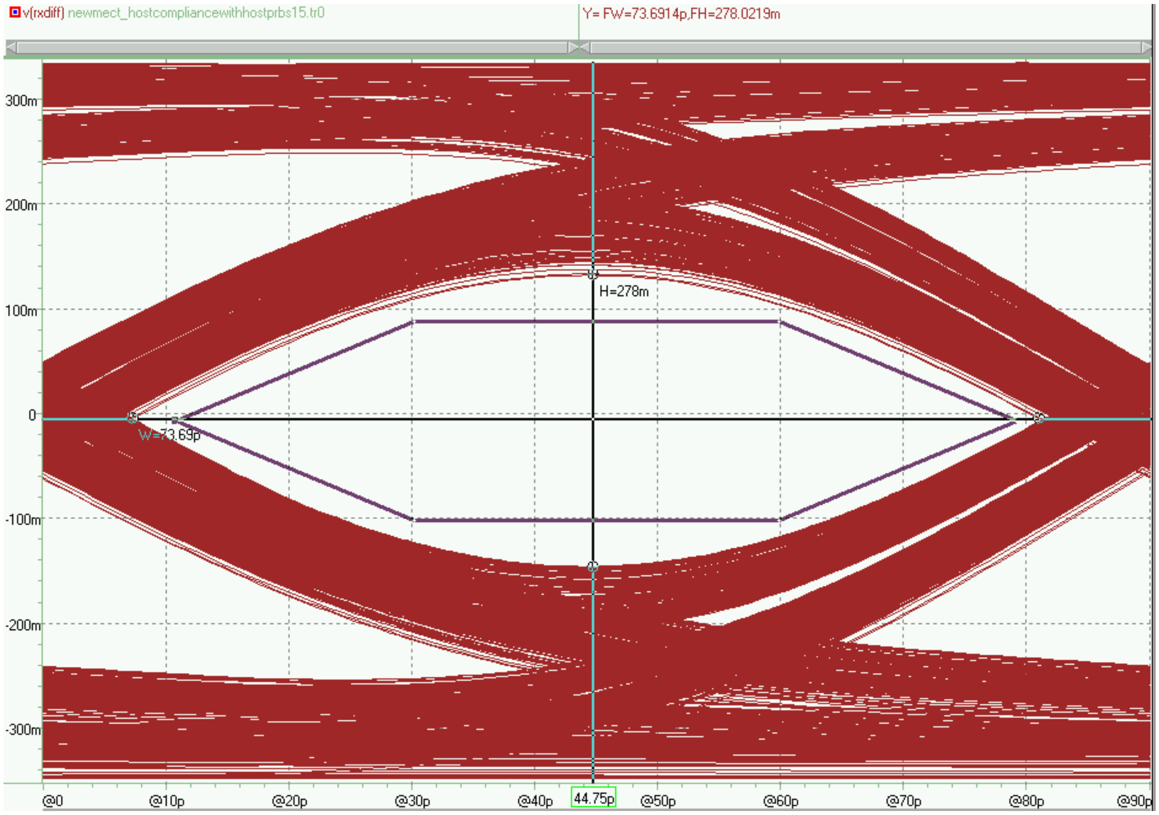

Figure 19 – 11.1 Gbps PRBS 1 eye of MECT connector SFP+ Host Compliance Board with 200 mm of host FR4 trace

(16.4 ps deterministic jitter, 278 mV differential eye height)