Implementation Agreement for Common Analog Coherent Optics (ACO) Electrical I/O

IA # OIF-COM-ACO-1.0

May 31, 2018

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ABSTRACT: This contribution is the baseline text for the Common Analog Coherent Optics (ACO) Electrical I/O implementation agreement as approved at the Q3-2017 technical meeting. The project was approved at the Q4 technical meeting, November 2016 (Auckland, New Zealand). OIF2016.407.03 is the original project start document for this project.

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List of Figures

List of Tables

1 Document Revision History

Table 1 provides the OIF-COM-ACO-1.0 IA document revision history.

Document	Date	Revisions/Comments
OIF-COM-ACO-1.0	May 31, 2018	Initial Release

Table 1: IA Document Revision History

2 Reference Documents

2.1 Normative References

[1] OIF-CFP2-ACO-01.0 - Implementation Agreement for CFP2-Analogue Coherent Optics Module (January 2016)

[2] OIF-HBPMQ-TX-01.0 - Implementation Agreement for High Bandwidth Integrated Polarization Multiplexed Quadrature Modulators (January, 2017).

[3] OIF-DPC-MRX-02.0 - Implementation Agreement for Micro Intradyne Coherent Receivers

[4] OIF-microITLA-01.1 – Implementation Agreement for Micro Integrable Tunable Laser Assembly (July 2015)

[5] OIF-ITLA-MSA-01.3 - Integrable Tunable Laser Assembly Multi Source Agreement (July 2015)

[6] OIF-CEI-03.1 - Common Electrical I/O (CEI) - Electrical and Jitter Interoperability agreements for 6G+ bps, 11G+ bps, 25G+ bps I/O (February 2014)

3 Introduction

Faceplate density of optical IO is a key metric for routing, switching and line-side transport applications. The industry experience is that this faceplate density is maximized when high power electronics are removed from optical modules [e.g. CFP → CFP2 → CFP4 → QSFP28 for 100GbE client modules.]

Faceplate density improvements can be realized for line-side optical transport by placing coherent DSP engines on the Host board and the E-to-O conversion functions within a module of chosen form factor. This density improvement can also be potentially realized using an on-board optic (OBO). This architecture for line cards, that broadly separates optical and electronic DSP functions, offers the following additional benefits:

- Margin stacking of the coherent DSP engine in the supply chain is removed.
- Coherent DSP engine development is decoupled from the electro-optics development, which is beneficial since they have different supply chains and development cadences. This decoupling also enables specialization within the supply chain and reduces duplication of development efforts.
- Optimal cooling of the optical and electronic DSP functions is possible, enabling higher performance line-side applications. Shared heat sinking between low temperature optics and high temperature electronics is avoided and there is no inefficient “box”-in-“box” thermal stacking:
    - A Host board coherent DSP engine can have a permanently attached full slot height heat sink with excellent thermal interface conductivity. The DSP engine can operate with high junction temperatures.
    - A faceplate pluggable module has limited space available for a riding heat sink and the interface thermal conductivity is limited by both the maximum spring force that can be applied to the module and the module surface roughness. A pluggable module is best suited to relatively low power E-to-O conversion functionality.
- The dominant coherent modem Bill of Material (BOM) cost along with the main contributors to reliability FITs (Failures in Time) become hot-pluggable with the use of a COM-ACO compliant module. This addresses the problem of the modem first-in install cost in multi-port line cards. It also allows the selection of the best-fit COM-ACO module for each system application at the time of deployment (price/performance/power/etc.)

A host with DSP and a module each compliant to the Common ACO (COM-ACO) Electrical I/O Implementation Agreement may be known as a COM-ACO host and COM-ACO module, respectively. A COM-ACO module can contain all the required functions to perform bi-directional dual polarization coherent optical signaling over a pair of single mode optical fibers. Support of multi-carrier applications is an implementation choice by making use of more than one Common ACO electrical I/O.

4 COM-ACO Module Functions

In this Section an overview is provided on the functions contained within the COM-ACO module to provide E-to-O and O-to-E conversions for dual polarization (DP) coherent optical signaling. The high-level block diagram for the COM-ACO module is given in Figure 1. The diagram shows the possibility of having multiple channel support in a COM-ACO module. For specification definition purposes, the following sections will focus on signal channel COM-ACO, in which 4 high-speed diff pairs will be presented on both transmit and receive sides. Class 2 specification for CFP2-ACO in Ref. [1] is used as the baseline for the COM-ACO definitions.

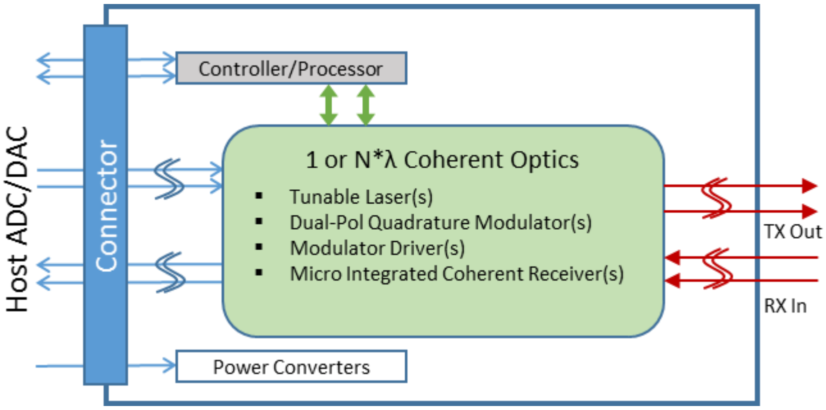

Figure 1 COM-ACO Module High Level Block Diagram

4.1 Laser Sources (Tx and Rx LO)

The COM-ACO module may contain a single laser source whose optical power is shared between the transmit signal and LO functions, or it may contain multiple laser sources if multiple channels are supported. The laser source(s) may be integrated with other electro-optics such as the PMQ modulator [2] or the ICR [3], or be stand-alone components such as might be derived from the Ref. [4, 5] μITLA. The number of channels supported in a single COM-ACO module will depend on the technology available to the manufacturer along with design trade-offs such as module form factor, module power dissipation or the physical space available.

The laser source(s) will require a narrow optical linewidth that is consistent with operation of coherent optical systems. Lorentzian components of the laser source(s) are expected to be below 500 kHz linewidth.

The channelization of the laser sources is expected to vary by application, with the most demanding applications requiring compatibility with arbitrary wavelength channel grids having a 6.25 GHz channel spacing.

4.2 Integrated Polarization Multiplexed Quadrature Mach-Zehnder Modulator (PMQ Modulator)

The PMQ modulator impresses the optical phase modulation onto the Tx CW source output. Electrical drive signals are provided from four modulator RF drivers and may be differential or single-ended, depending on the material and/or design of the optical modulators.

The modulator comprises X and Y polarization paths which are orthogonally polarization multiplexed prior to coupling into the single mode fiber output. Power in the two polarization paths may be balanced by the action of variable optical attenuator (VOA) or semiconductor amplifier (SOA) functions. Prior to launch into the output fiber the total power shall be controlled by a shutter, variable optical attenuator (VOA), or optical amplifier (SOA or EDFA) using associated tap monitoring photodiodes.

The individual Mach-Zehnder (MZ) modulator elements have electrodes that allow the phase imbalance between their arms to be adjusted to maintain optimum system performance over life, wavelength and temperature. Control is facilitated using various in-line and complimentary optical tap monitoring points. It is expected that all control for bias and imbalance of the MZ elements will be controlled by the module itself, or via the management interface.

4.3 Intradyne Coherent Receiver (ICR)

The ICR function may be a stand-alone function within the COM-ACO module or it may be physically integrated with other functions such as a PMQ modulator. The Ref. [3] ICR µICR is an example implementation for this function. The Rx optical input signal may be monitored and controlled by optical photodiode tap and VOA functions before or after the polarization de-multiplexing occurs within the ICR.

The ICR function shall provide Rx optical input polarization de-multiplexing, LO splitting, and 90-degree mixer hybrids feeding eight photodiodes in 4 balanced pairs. Four differential transimpedance amplifiers (TIAs) shall amplify the received X and Y polarization quadrature signals (XI,XQ,YI,YQ) and AC couple them to the COM-ACO module connector Rx differential signal pairs for return to the Host.

The TIAs in the ICR function enable multiple signal monitors and control methods. The most notable TIA control choice is between an automatic or manual gain control operating mode (AGC or MGC). The TIAs may also facilitate a bandwidth equalization function and provide various input signal strength and/or output level monitors.

In the AGC operating mode there is RF output level adjust control available on the management interface and in the MGC operating mode an external signal is used to control the gain of each differential amplifier. The MGC external gain control can be provided via management interface registers.

4.4 MZ Modulator RF Drivers

The MZ modulator RF drivers amplify the signals from the Host that are delivered across the module transmit-side connector interface. They drive the optical MZ modulators at a chosen fraction of 2×Vpi, dependent on the COM-ACO module operating modulation format.

RF drivers are likely to be one of the more highly power dissipative components within the COM-ACO module, so they require appropriate heatsinking for long-term operation.

The RF drivers may be controlled from the management interface registers and/or their output drive level may be actively controlled. To assist with accurate drive level control the driver function may include output side RF detectors which return mean or peak signal levels.

RF drivers shall provide a linear drive transfer characteristic in order to deliver the COM-ACO modules operating at linear regimes.

4.5 Monitoring and Control

Monitoring and control are key parts of the functionality in the COM-ACO module. The electronics within the module must process the various monitoring signals and make them available over the management interface. Requirements for the monitoring and control functions include the following:

- Maintain stable total output power.
- Adjust output power to match the use situation.
- Shutter Tx output power during tuning and set up operations.
- Monitor or adjust modulation depth to suit modulation type.
- Maintain modulator imbalance and bias point over time, temperature and wavelength.
- Control receiver optical signal level.

- Adjust receiver output voltage swing.
- Indicate received signal strength
- Alarm on LOS

Optional monitoring and control functions include the following:

- Balance X and Y polarization optical powers.
- Adjust receiver bandwidth or peaking function for separate 45Gbaud and 64Gbaud implementations.
- Tx to Rx loopback for calibration and debugging purposes

5 COM-ACO Tx and Rx RF Electrical Interfaces

5.1 Introduction

The Tx and Rx RF interfaces on the ACO connector are AC-coupled. RF signals must be carried differentially across the COM-ACO connector interface to achieve acceptable levels of crosstalk. The Host is therefore agnostic to the PMQ modulator RF drive design (differential or series push-pull). The COM-ACO RF electrical interface requirements **do not** limit modulator technology choices.

5.2 Tx and Rx Electrical Interface Specification Compliance Points

Reference test fixtures, called “Compliance Boards,” are used to access the electrical specification parameters. The interface specification compliance points are identified in Figure 2 are defined as per Ref [6] OIF-CEI-03.1 Section 13.3.1,

> *“The output of the Host Compliance Board (HCB[1]) provides access to the host-to-module electrical signal (host electrical output) defined at TP1a. Additional module electrical input specifications, for host-to-module communication, are defined at TP1, the input of the Module Compliance Board (MCB[2]). The output of the Module Compliance Board (MCB) provides access to the module to host electrical signal (module electrical output) defined at TP4. Additional host electrical input specifications, for module-to-host communication, are defined at TP4a, the input of the Host Compliance Board (HCB).”*

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[1] HCB: Host Compliance Board (represents Module side, tests Host compliance)

[2] MCB: Module Compliance Board (represents Host side, tests Module compliance)

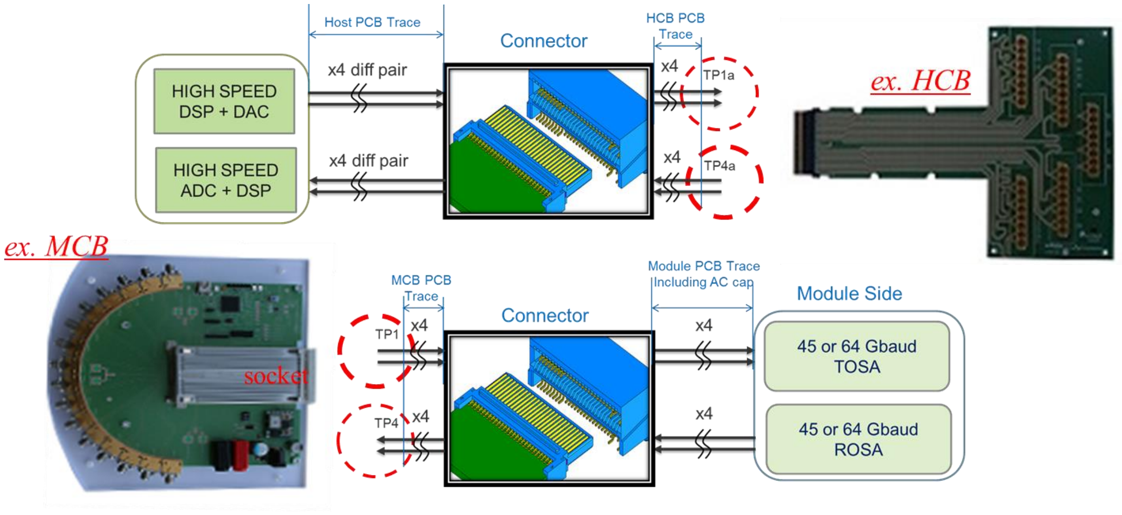

Figure 2: Tx and Rx Electrical Interface Compliance Points. The Provided HCB and MCB Implementation Pictures are *Informative* Examples Only.

5.3 Compliance Board Suppliers and Example Part Numbers

TBD

5.4 Compliance Board S Parameter Requirements

Use of compliance boards for testing is assumed for the electrical interface specifications given in Section 5.5.

The mated compliance boards used to measure the COM-ACO compliant Module and Host should conform to the S parameter requirements of Annex B (Section 8), with the individual reference MCB and HCB compliance board PCB traces in the mated pair conforming to the differential insertion loss equations provided by Annex A (Section 7).

If compliance boards do not meet the specified S-parameters in Annex A then test results shall be corrected for the difference. The mated MCB-HCB compliance boards S-parameters provided in Annex B are defined between the reference planes of the RF coax connectors.

5.5 RF Electrical Interface Specifications

5.5.1 Tx RF Interface Specifications

The Tx RF interface electrical specifications for 45Gbaud and 64Gbaud COM-ACO with a *Module controlled* PMQ transmitter are given in Table 2.

ID	Parameter	Conditions	Test Point	Min	Max	Units
TE.010	**Differential Voltage from Host**	Differential output voltage from Host measured at the TP1a compliance point and at 1.0GHz[3]. The voltage must include the effects of equalization required to compensate the Host and the module portion of the TE030 channel. Compensation is defined as the wave shaping required to obtain the desired system performance when carrying traffic. It is assumed the COM-ACO module will also support sufficient phase modulation to achieve the Host defined module performance (optical power, linearity, power dissipation, etc.).	TP1a	200	450	mVppd
TE.020	**Tx Modulator Driver Linearity**	Parameter is *not measurable at the module level.* It is evaluated in a test fixture representative of the application environment and at output voltage levels representative of in service operating conditions. Test frequencies are 2GHz, 5GHz, and 10GHz. THD = sqrt(V2^2 + V3^2 + … + Vinf^2)/V1.	NA		5	% THD
TE.030	**Tx EO S21 Magnitude Mask**	Normalized Tx EO MAG(S21) compliance mask measured from TP1 to Tx Out. Inner MZ modulator operating at quadrature and under small signal conditions (i.e. RF drive ≤ 0.3Vπ). MAG(S21) is normalized to 1GHz.	TP1	Normalized OE MAG(S21) Mask: in Figure 3 for 45Gbaud and Figure 4 for 64Gbaud		dBe
TE.040	**Tx EO Group Delay Variation**	Group Delay Variation Magnitude from 1GHz to 0.5*Baud Rate GHz with 1GHz span smoothing. TP1 to Tx Out.	TP1	0	20ps: 45Gbaud; 15ps: 64Gbaud	ps
TE.050	**Electrical Return Loss**	Electrical Return Loss at the TP1a and TP1 compliance points. This is a differential specification. 1MHz < f ≤ 0.5*Baud Rate GHz 0.5*Baud Rate GHz < f ≤ 0.75*Baud Rate GHz 0.75*Baud Rate GHz < f < Baud Rate GHz	TP1a TP1	10 8 6		dBe dBe dBe
TE.060	**Low corner cutoff frequency**	-3dBe low corner cutoff frequency. AC coupled. TP1 to Tx Out. S21 is normalized at 1GHz.	TP1		1000	kHz
TE.070	**IQ Timing Skew**	Time difference[4] up to 0.5*Baud Rate GHz of the Q channel relative to the I channel within a polarization. The time for a channel is defined as the mean of P and N. Includes TE090. TP1 to Tx Out.[5]	TP1	-5	+5	ps
TE.080	**XY Timing Skew**	Time difference[4] up to 0.5*Baud Rate GHz of the Y polarization relative to the X polarization, defined as (XI+XQ)/2 - (YI+YQ)/2, where the time for an individual I or Q channel is the mean of P and N. Includes TE090. TP1 to Tx Out.[5]	TP1	-8	+8	ps
TE.090	**Skew Variation**	Temporal variation up to 0.5*Baud Rate GHz among any two channels due to module temperature, wavelength, amplifier gain, and aging[4]. TP1 to Tx Out. Time for channel defined as mean of P and N.[6]	TP1	-1	1	ps

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[3] A square wave data pattern that is as close to 1.0 GHz as can be achieved at the operating symbol rate is acceptable, e.g., 16 ones and 16 zeros at 32 GBaud NRZ. The amplitude is defined as the difference between the two primary peaks in a vertical histogram that encompasses a full cycle of the 1.0 GHz waveform. The transmitter must be otherwise in a mode that includes all skew, de-emphasis, spectral shaping, and other operational settings and functions.

[4] Time can be calculated using the Electrical Delay (ED) method outlined in TxC305 in Ref. [1]. <Deviation from linear phase (DLP) is obtained by removing the electrical delay (ED) in seconds from the unwrapped phase □□ $ED = -AVG\left(\frac{1}{360}\frac{\partial\phi}{\partial f}\right)$ for 1GHz ≤ f ≤ 16GHz, and then DLP is given by DLP = ϕ + 360 * f * ED. The DLP specification frequency range is 1MHz-20GHz. TP1 to Tx Out.>

[5] A wider range is allowed if calibration data is stored in the module.

[6] Specified values do not include any measurement inaccuracy, which itself might be as large as +/-1 ps in practical measurements.

TE.100	**PN Intrapair Timing Skew**	Informative: Time difference[4] up to 0.5*Baud Rate GHz between any P and N pair over the module operating temperature and life. TP1 to RF driver input. Applies only to modules using RF drivers with a differential input stage.	TP1		1	ps

Table 2: 45Gbaud and 64Gbaud COM-ACO Module Tx RF Interface Electrical Specifications

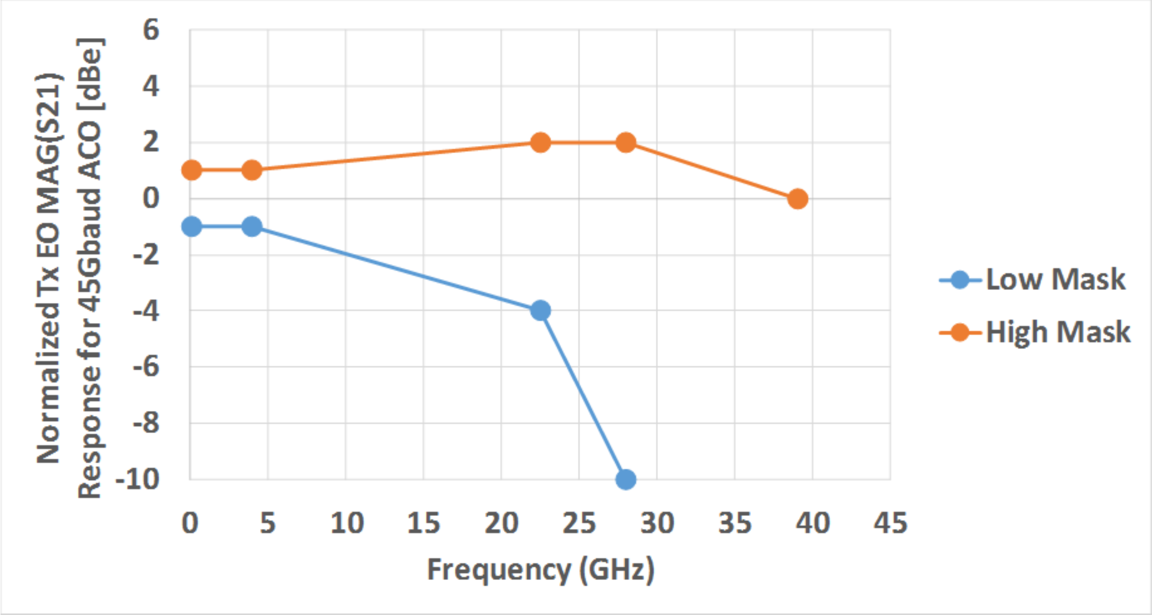

Figure 3: Normalized Tx OE CG MAG(S21) Compliance Mask for 45Gbaud ACO.

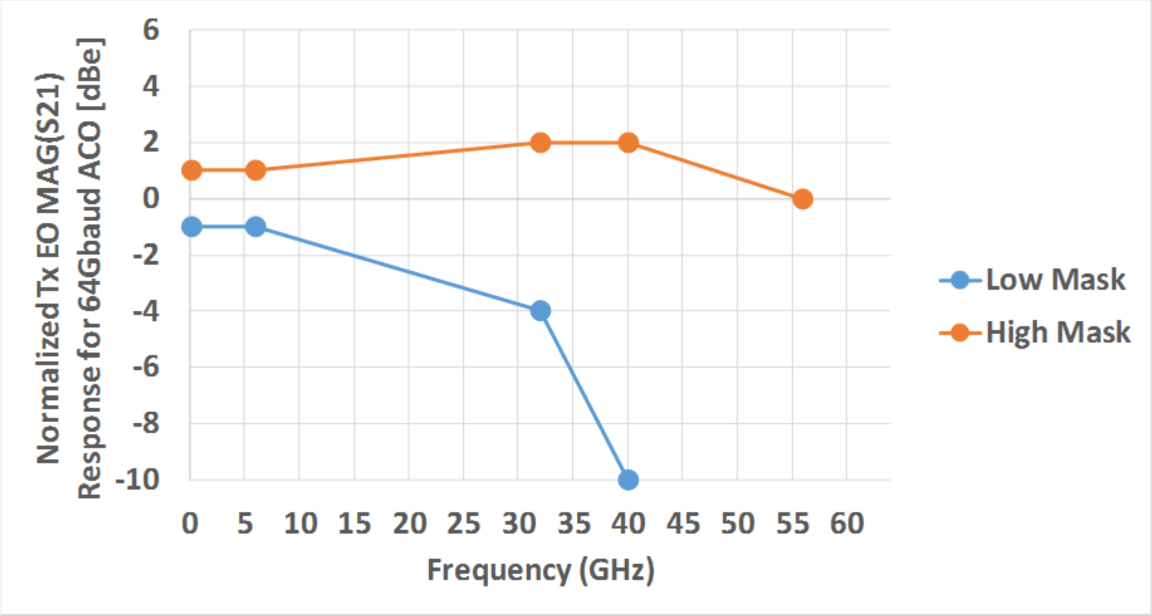

Figure 4: Normalized Tx OE CG MAG(S21) Compliance Mask for 64Gbaud ACO.

5.5.2 Rx RF Interface Electrical Specifications

The Rx RF interface electrical specifications for 45Gbaud and 64Gbaud COM-ACO module are given in Table 3.

Table 3 makes use of the following related parameter definitions: CG is the Rx OE Conversion Gain for a channel expressed in $\frac{V}{\sqrt{W}}$, $VOUT(t)$ is the *differential* electrical output AC signal for a channel from the COM-ACO receiver, $\sqrt{P_{SIG}}$ is the mean power of the COM-ACO input optical signal that beats with the LO, and $\cos\big(\theta(t)\big)$ is the received channel phase modulated AC signal. The parameters are related for a channel by the following:

$$VOUT(t) = CG \cdot \sqrt{P_{SIG}} \cdot \cos\big(\theta(t)\big).$$

In Table 3 CGmin and CGmax are the minimum and maximum OE Conversion Gains for an Rx channel in the COM-ACO, agreed between the vendor and user. For a given CGmin and CGmax there is a corresponding range of values for the TIA GC voltage used in specifications RE.080-RE.100.

ID	Parameter	Conditions	Test Point	Min	Max	Units
RE.010	**Differential Output Voltage Range (VOUT)**	Differential output voltage (VOUT) dynamic range at the TP4 compliance point and at 1GHz with the Rx electrical output not in shutdown. The necessary Rx In power will be provided for the agreed upon CGmin and CGmax. The dynamic range is controlled by the Host, which for CFP MIS is register BB8C (MGC) or register BBCC (AGC).	TP4	300	700	mVppd
RE.020	**Rx Channel Output Total Harmonic Distortion (THD)**	Rx channel output total harmonic distortion (THD) = sqrt(V2^2 + V3^2 + … + Vinf^2) / V1. Measured from Rx In to the TP4 compliance point and at 1GHz over the full range of differential output voltage VOUT in RE.010: VOUT ≤ 400 mVppd 400mVppd < VOUT ≤ 1000 mVppd	TP4		2.5 4	% %
RE.030	**Rx OE CG S21 Magnitude Mask**	Compliance mask for the normalized Rx OE Conversion Gain MAG(S21) response, measured from Rx In to TP4, over the CG range CGmin ≤ CG ≤ CGmax. CG MAG(S21) is normalized to 1GHz.	TP4	Normalized OE MAG(S21) Mask: in Figure 5Figure 3 for 45Gbaud and Figure 6 for 64Gbaud		dBe
RE.040	**Rx OE CG S21 Magnitude Response, Variation over CG**	Allowed variation in the CG MAG(S21) response determined in RE.030, relative to the midpoint CG response, over the CG range CGmin ≤ CG ≤ CGmax: f < 0.5*Baud Rate GHz 0.5*Baud Rate ≤ f ≤ 0.6*Baud Rate GHz	TP4	-1.5 -3.0	+1.5 +3.0	dBe dBe
RE.050	**OE S21 Deviation from Linear Phase**	Deviation from linear phase (DLP) is obtained by removing the electrical delay (ED) in seconds from the unwrapped phase ϕ: $ED = -AVG\left(\frac{1}{360}\frac{\partial\phi}{\partial f}\right)$ for 1GHz ≤ f ≤ 0.5*Baud Rate GHz, and then DLP is given by DLP = ϕ + 360 * f * ED. The DLP specification applies over the CG range CGmin ≤ CG ≤ CGmax, and for the frequency range from 0-20GHz. This parameter is acknowledged to be *difficult to measure at the module level.* ICR only verification testing acceptable.	TP4	-40	40	Degrees

RE.060	**Differential Electrical Return Loss**	Differential electrical return loss at the TP4 and TP4a compliance points: 100kHz < f ≤ 0.5*Baud Rate GHz 0.5*Baud Rate GHz < f ≤ 0.75*Baud Rate GHz 0.75*Baud Rate GHz < f ≤ Baud Rate GHz	TP4 TP4a	10 8 6		dBe dBe dBe
RE.070	**Low corner cutoff frequency**	3dB low corner cutoff frequency. AC coupled. Rx In to TP4. CG MAG(S21) is normalized to 1GHz.	TP4	10	1000	kHz
RE.080	**IQ Timing Skew**	Time difference of the Q channel relative to the I channel within a polarization[7]. Rx In to TP4. The time for a channel is defined as the mean of P and N. Applies for TIA GC_I = TIA GC_Q, over the TIA GC range, and at start of life and room temperature. The time difference could be extracted from the Beat Frequency skew measurement method[8].	TP4	-3	+3	ps
RE.090	**XY Timing Skew**	Time difference of the Y polarization relative to the X polarization[7]. Rx In to TP4. The time for a polarization is defined as (XI+XQ)/2 - (YI+YQ)/2 where the time for an individual I or Q channel is the mean of P and N. Applies for TIA GC_XI = TIA GC_XQ = TIA GC_YI = TIA GC_YQ, over the TIA GC range, and at start of life and room temperature. Time difference could be extracted from the Beat Frequency Skew measurement method5,[8].	TP4	-8	+8	ps
RE.100	**Channel Timing Variation with GC**	Temporal variation of a channel over the TIA GC range. Rx In to TP4. Time for channel defined as mean of P and N.[6]	TP4	-1	+1	ps
RE.110	**IQ Skew Variation**	Deviation of IQ Timing Skew (RE.080) from the SOL room temperature value, over the module operating temperature range and life.[6]	TP4	-1	+1	ps
RE.120	**XY Skew Variation**	Deviation of XY Timing Skew (RE.090) from the SOL room temperature value, over the module operating temperature range and life.[6]	TP4	-1	+1	ps
RE.130	**P/N Intrapair Timing Skew**	Informative: Time difference between any P and N pair over the module operating temperature and life. Rx In to TP4. Applies over the CG range CGmin ≤ CG ≤ CGmax.	TP4		1	ps
RE.140	**Tx to Rx Crosstalk**	Rx electrical noise power is computed by integrating the 0.2-20GHz Rx RF output power spectrum on an ESA including the tones. Rx electrical noise power is measured with no light on the Rx In, for CG = CGmax, *with and without* PRBS-11 signals on the 4 Tx RF inputs [uncorrelated to each other.] The Tx to Rx Crosstalk is defined as $10\cdot\log_{10}$(((Rx electrical noise power:Tx On) - (Rx electrical noise power:Tx Off)) / (Rx electrical noise power:Tx Off)).	TP4		20	dB

Table 3: 45Gbaud and 64Gbaud COM-ACO Module Rx RF Interface Electrical Specifications

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[7] If Rx channel skew data is provided with the COM-ACO module, then increased *IQ Timing Skew* might be tolerated (Host specific.)

[8] The Beat Frequency skew measurement method is defined in Appendix II.

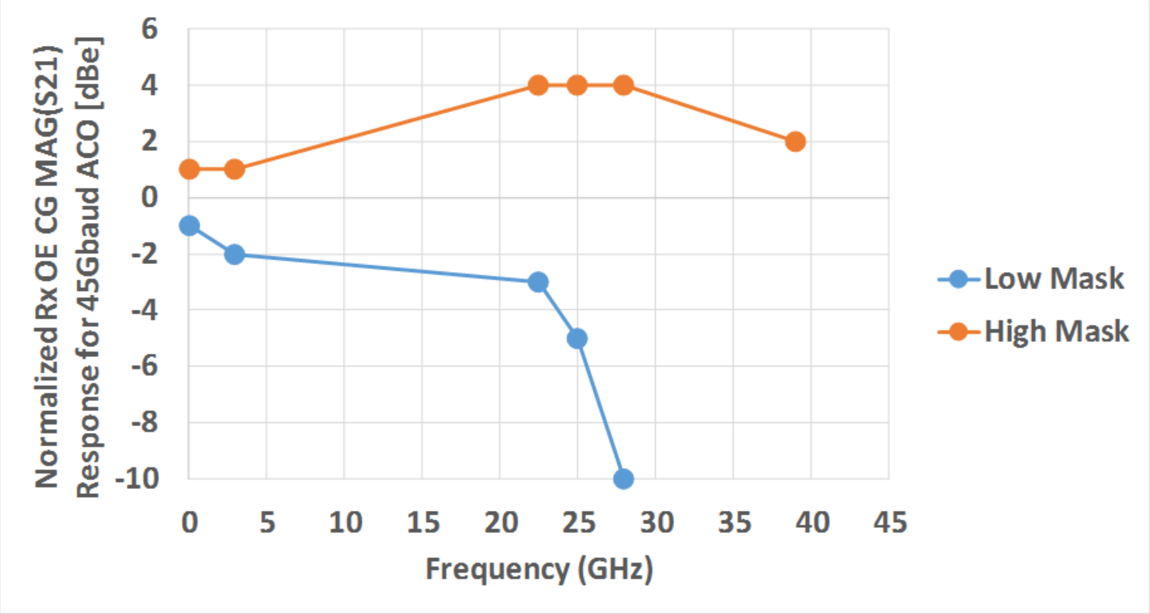

Figure 5: Normalized Rx OE CG MAG(S21) Compliance Mask for 45Gbaud ACO.

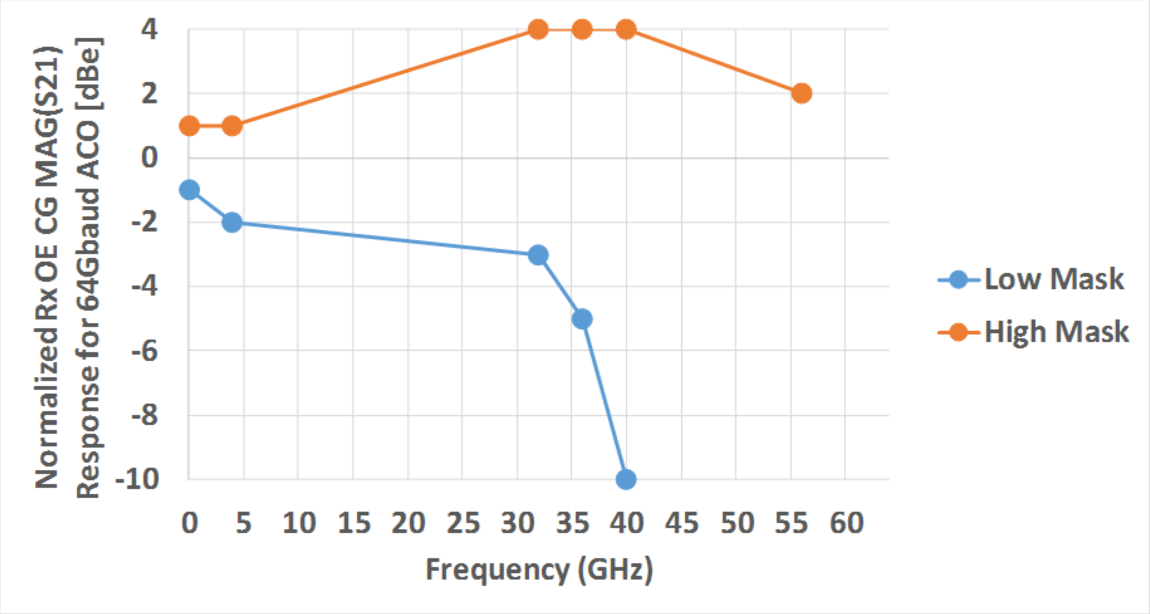

Figure 6: Normalized Rx OE CG MAG(S21) Compliance Mask for 64Gbaud ACO.

6 Glossary

Table 4 presents definitions for acronyms used in this IA.

Term	Definition	Term	Definition
ADC	Analog to Digital Converter	**MIS**	Management Interface Specification
AGC	Automatic Gain Control	**MSA**	Multiple Supplier Agreement
ASE	Amplified Spontaneous Emission	**MZ**	Mach-Zehnder
BOM	Bill of Materials	**OSP**	Organic Solderability Preservatives (PCB finish)
COM-ACO	Common Analog Coherent Optics Electrical I/O	**p/n**	The complementary electrical outputs for each channel are labeled p and n, see Section **Error! Reference source not found.**.
CG	Rx OE Conversion Gain	**PBS**	Polarization Beam Splitter
CMRR	Common Mode Rejection Ratio	**PCB**	Printed Circuit Board
CTE	Coefficient of Thermal Expansion	**PD**	Photodiode
DAC	Digital to Analog Converter	**PDL**	Polarization Dependent Loss
dB	10*log$_{10}$(x)	**PER**	Polarization Extinction Ratio
dBe	20*log$_{10}$(x)	**PLC**	Planar Lightwave Circuit
DLP	Deviation from Linear Phase	**PMF**	Polarization Maintaining Fiber
DP	Dual Polarization	**PMQ**	Integrated Polarization Multiplexed Quadrature Mach-Zehnder Modulator
DSP	Digital Signal Processing	**PP/RMS**	Peak-to-Peak to RMS Ratio
ED	Electrical Delay	**PRBS**	Pseudo-Random Bit Sequence
EOL	End of Life	**Psig**	Mean power of the COM-ACO Module Rx input that will beat with the LO
ESA	Electrical Spectrum Analyzer	**QPSK**	Quadrature Phase Shift Keying
E-to-O	Electrical to Optical	**REFCLK**	Reference Clock
FAWS	Fault and Warning System	**RMS**	Root Mean Square
FIT	Failures in Time	**Rx**	Receiver
GC	Gain Control (usually in reference to TIA)	**SMF**	Single Mode Fiber
GSSG	Differential RF Line [GND-Sig-Sig-GND]	**SOA**	Semiconductor Optical Amplifier
HCB	Host Compliance Board	**SOL**	Start of Life
I / Q	Mutually orthogonal phase channels in each polarization as defined in Section 8.3.	**TBD**	To Be Determined
IA	Implementation Agreement	**TDL**	Temperature Dependent Loss
ICR	Intradyne Coherent Receiver	**TE**	Transverse Electric Polarization (electric vector of incident wave parallel to the boundary plane)
IL	Insertion Loss	**TEC**	Thermoelectric cooler
InP	Indium Phosphide	**THD**	Total Harmonic Distortion
IO	Input Output	**TIA**	Transimpedance Amplifier
LO	Local Oscillator [Optical Source]	**Tx**	Transmitter
LVCMOS	Low Voltage CMOS	**V1**	V1 is the rms voltage of the fundamental frequency
MCB	Module Compliance Board	**V2**	V2 is the rms voltage of the 2nd harmonic
MCLK	Monitor Clock	**VGA**	Variable Gain Amplifier
MDIO	Management Data Input/Output	**VOA**	Variable Optical Attenuator
ME	Modulation Efficiency	**VOUT**	Differential Output Voltage from Rx at TP4
MGC	Manual Gain Control	**X / Y Pol.**	Pair of mutually orthogonal polarizations of any orientation
mils	Thousandths of an inch	**xQAM**	

Table 4: Glossary

7 Annex A: HCB and MCB Differential Insertion Losses

Individual MCB and HCB test traces of matching length and geometry to the signal traces between the Host connector and RF ports should conform to the differential insertion losses provided by Equations 1 and 2 for 45Gbaud application and Equations 3 and 4 for 64Gbaud application. Plots are shown in Figure 7 and Figure 8**.** *These specifications are defined between the reference planes of the RF coax connectors on the test trace with the S-parameter magnitudes in dBe and f (frequency) in GHz.*

$MCB\ SDD21 = -0.05 - 0.038 \cdot \sqrt{f} - 0.0175 \cdot f\ dB,\ 0.001 < f < 45\ (1)$

$HCB\ SDD21 = 2.5\ x\ (-0.05 - 0.038 \cdot \sqrt{f} - 0.0175 \cdot f)\ dB,\ 0.001 < f < 45\ (2)$

$MCB\ SDD21 = -0.05 - 0.0275 \cdot \sqrt{f} - 0.0128 \cdot f\ dB,\ 0.001 < f < 64\ (3)$

$\mathrm{HCB\ SDD21} = 2.5\ \mathrm{x}\ (-0.05 - 0.0275 \cdot \sqrt{\mathrm{f}} - 0.0128 \cdot \mathrm{f})\ \mathrm{dB},\ 0.001 < \mathrm{f} < 64\ (4)$

As per Section 5.4, observed differences from Equations 1 and 2 on actual MCBs and HCBs can be applied as corrections to measurements that use them.

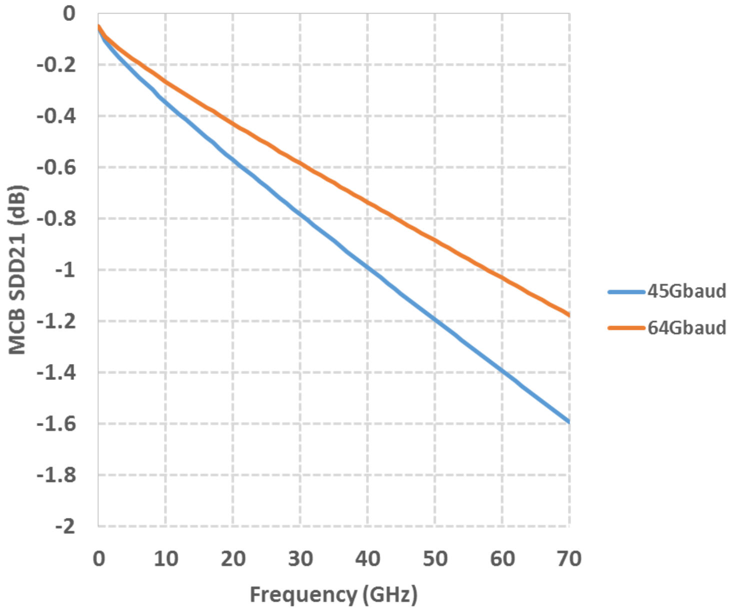

Figure 7: Reference Differential Insertion Losses for the PCB Traces on Two Module Compliance Boards [MCB SDD21]

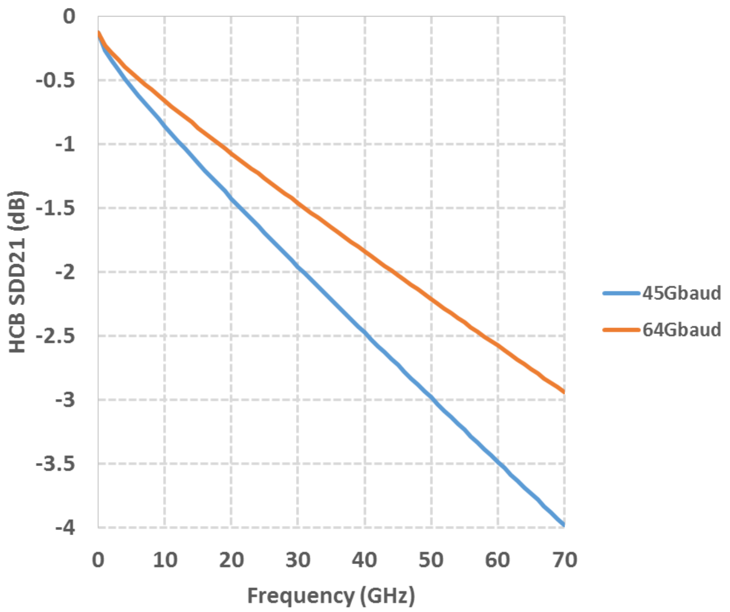

Figure 8: Reference Differential Insertion Losses for the PCB Traces on a Host Compliance Board [HCB SDD21]

8 Annex B: Mated HCB and MCB S-Parameters

The specifications given for the mated HCB and MCB shall be verified in both directions, except for the differential insertion loss that can be measured in either direction. In the equations provided here the S-parameter magnitudes are in dBe and f (frequency) is in GHz. *The mated MCB-HCB specifications are defined between the reference planes of the RF coax connectors on the MCB and HCB.*

The differential return loss of the mated HCB and MCB pair: TBD

The differential to common mode conversion for a mated HCB and MCB pair: TBD

The mode conversion return loss for a mated HCB and MCB pair: TBD

The maximum differential insertion loss for a mated HCB and MCB pair (45Gbaud) are given in Equation 5, 6 and 7. The minimum differential insertion loss for a mated HCB and MCB is given in Equation 8. The preliminary differential insertion loss for a mated HCB and MCB pair are plotted in Figure 9.

$$\text{Mated HCB-MCB SDD21, SDD12} > -0.087-0.29*\mathrm{sqrt}(f)-0.162*f,\ 0.001 < f < 22.5\quad(5)$$
$$\text{Mated HCB-MCB SDD21, SDD12} > 4-0.4*f,\ 22.5 < f < 45\quad(6)$$
$$\text{Mated HCB-MCB SDD21, SDD12} > 15.5-0.65*f,\ 45 < f < 70\quad(7)$$
$$\text{Mated HCB-MCB SDD21, SDD12} < -0.003-0.122*\mathrm{sqrt}(f)-0.062*f,\ 0.001 < f < 70\quad(8)$$

The maximum differential insertion loss for a mated HCB and MCB pair (64Gbaud) are given in Equation 9, 10 and 11. The minimum differential insertion loss for a mated HCB and MCB is given in Equation 12. The preliminary differential insertion loss for a mated HCB and MCB pair are plotted in Figure 10.

*Mated HCB-MCB SDD21, SDD12 > -0.087-0.225*sqrt(f)-0.116*f, 0.001 < f < 32 (9)*
*Mated HCB-MCB SDD21, SDD12 > 5.6-0.33*f, 32 < f < 50 (10)*
*Mated HCB-MCB SDD21, SDD12 > 25.2-0.72*f, 50 < f < 70 (11)*
*Mated HCB-MCB SDD21, SDD12 < -0.003-0.122*sqrt(f)-0.062*f, 0.001 < f < 70 (12)*

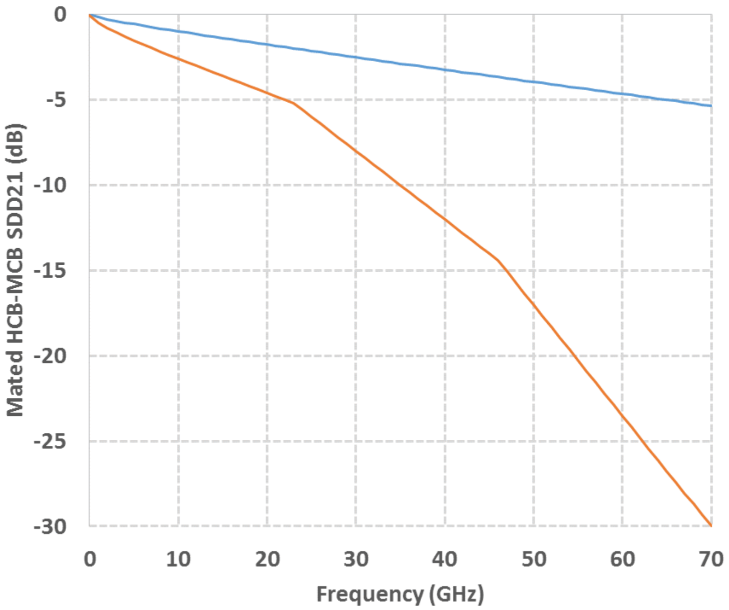

Figure 9: Mated HCB-MCB SDD21, SDD12 (45Gbaud)

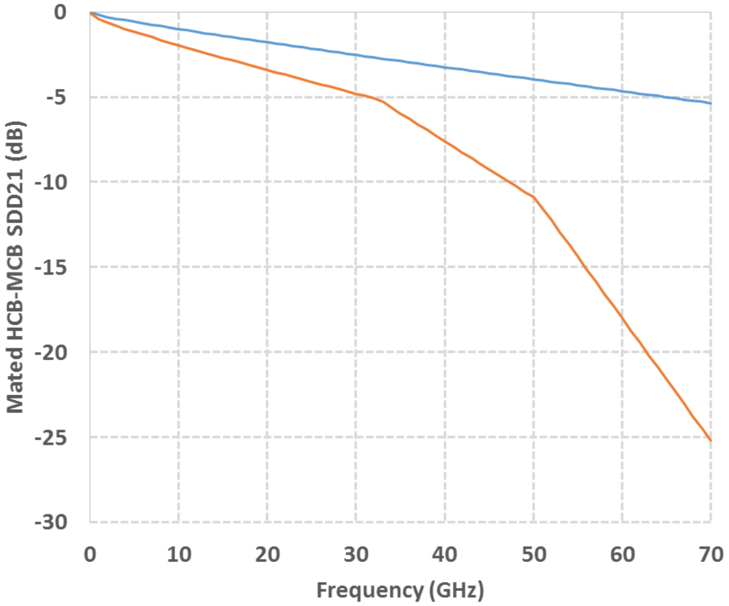

Figure 10: Mated HCB-MCB SDD21, SDD12 (64Gbaud)

9 Appendix I: Electrical Connector S-Parameters *(Informative)*

Figure 11 and **Figure 12** provide informative reference data for typical mated COM-ACO connectors (Courtesy of Yamaichi).

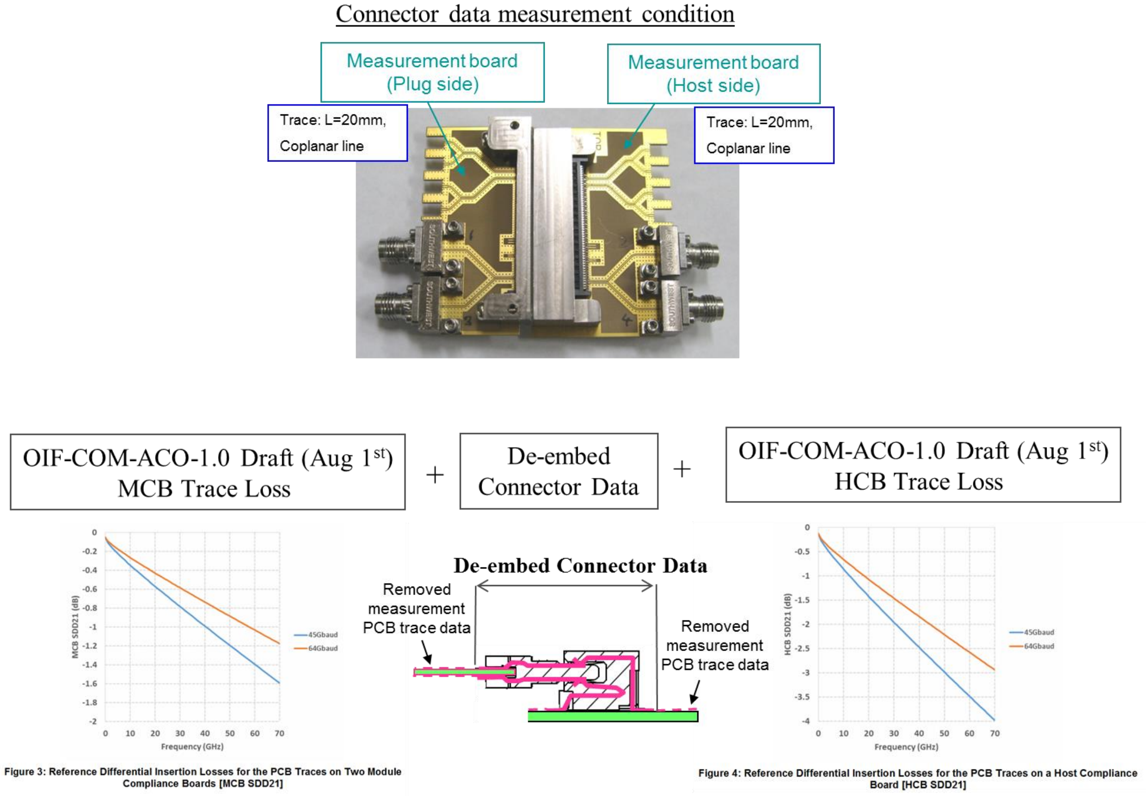

Figure 3: Reference Differential Insertion Losses for the PCB Traces on Two Module Compliance Boards [MCB SDD21]

Figure 4: Reference Differential Insertion Losses for the PCB Traces on a Host Compliance Board [HCB SDD21]

Figure 11: Mated COM-ACO Connector SI Performance Measurement Conditions

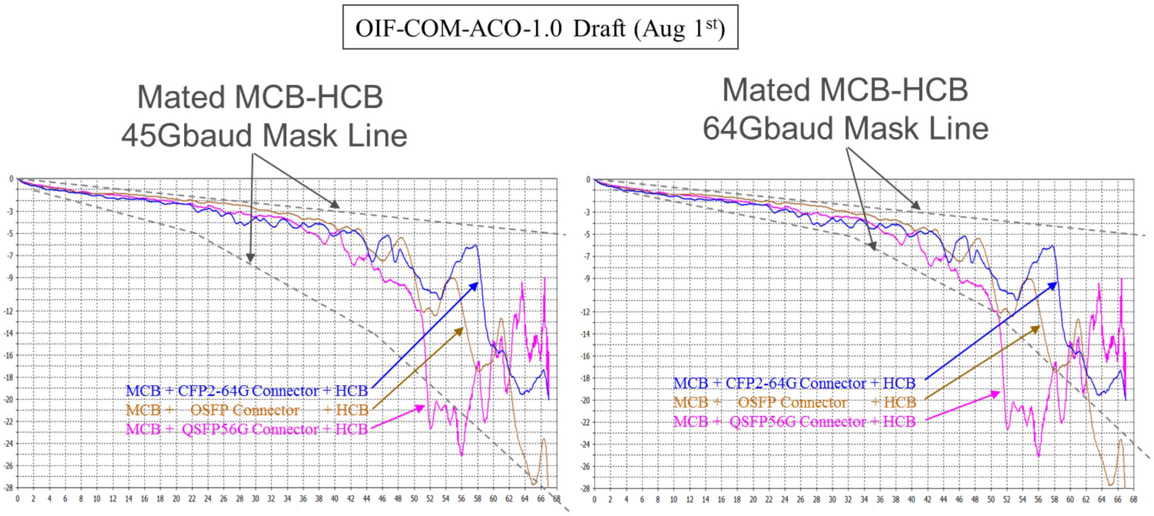

Figure 12: Typical Mated COM-ACO Connector SI Performance

10 Appendix II: Beat Frequency Skew Measurement Method (Informative)

Two un-modulated narrow line width CW laser sources (one is the LO in the ACO, the other is an optical Rx input signal to the ACO) are used in the Beat Frequency skew measurement method. The frequency offset between the two laser sources creates an ICR output beat signal from which the phase delay between XI, XQ, YI and YQ can be determined at the set offset frequency. This measurement is repeated with various offset frequencies to obtain enough accuracy for a line fit, typically between 1.0 GHz and 5.0 GHz, and with a frequency step size small enough to resolve big skews, typically 0.1 GHz. The slope of the fitted line determines the skew between the tributaries.

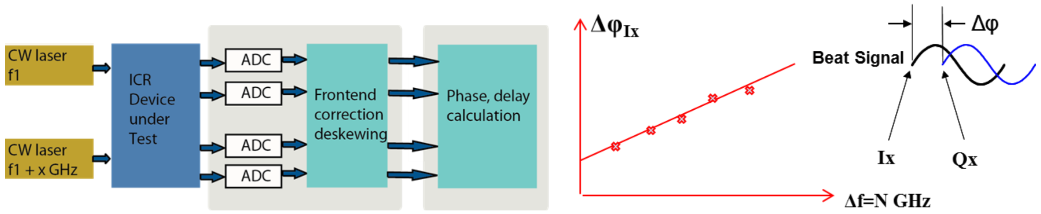

Figure 13: Beat Frequency Skew Measurement Method

11 Open Issues / Current Work Items

12 List of Companies Belonging to OIF when Document was Approved

Acacia Communications

ADVA Optical Networking

Alibaba

Amphenol Corp.

Anritsu

Arista Networks

Barefoot Networks

Broadcom Limited

Cavium

CenturyLink

China Telecom Global Limited

Ciena Corporation

Cisco Systems

Coriant

Corning

Credo Semiconductor (HK) LTD

Dell

Elenion Technologies, LLC

Epson Electronics America, Inc.

eSilicon Corporation

Fiberhome Technologies Group

Finisar Corporation

Foxconn Interconnect Technology, Ltd.

Fujikura

Fujitsu

Furukawa Electric Japan

Gigamon Inc.

Global Foundries

Google

Hewlett Packard Enterprise (HPE)

Hitachi

Huawei Technologies Co., Ltd.

IBM Corporation

Infinera

Inphi

Integrated Device Technology

Intel

Invecas, Inc.

IPG Photonics Corporation

JCRFO

Juniper Networks

Kaiam

Kandou Bus

KDDI Research, Inc.

Keysight Technologies, Inc.

Lumentum

MACOM Technology Solutions

Marvell Semiconductor, Inc.

Maxim Integrated Inc.

MaxLinear Inc.

MediaTek

Mellanox Technologies

Microsemi Inc.

Microsoft Corporation

Mitsubishi Electric Corporation

Molex

Multilane SAL Offshore

NEC Corporation

NeoPhotonics

Nokia

NTT Corporation

O-Net Communications (HK) Limited

Oclaro

Orange

PETRA

Precise-ITC, Inc.

Qorvo

Ranovus

Rianta Solutions, Inc.

Rockley Photonics

Rosenberger Hochfrequenztechnik GmbH & Co. KG

Roshmere

Samsung

Samtec Inc.

Semtech

SiFotonics Technologies Co., Ltd.

Silab Tech Private Ltd.

Sino-Telecom Technology Co., Inc.

SK Telecom

SM Optics S.r.l.

Socionext Inc.

Spirent Communications

Sumitomo Electric Industries

Sumitomo Osaka Cement

Synopsys, Inc.

TE Connectivity

Tektronix

Teledyne LeCroy

Telefonica I + D

TELUS Communications, Inc.

UNH InterOperability Laboratory (UNH-IOL)

Verizon

Viavi Solutions Deutschland GmbH

Xelic

Xilinx

Yamaichi Electronics Ltd.

ZTE Corporation