54. Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-CX4

54.1 Overview

This clause specifies the 10GBASE-CX4 PMD (including MDI) and the baseband medium. In order to form a complete Physical Layer, the PMD shall be integrated with the appropriate physical sublayers (see Table 54–1) and with the management functions which are accessible through the Management Interface defined in Clause 45, all of which are hereby incorporated by reference.

Table 54–1—10GBASE-CX4 PMD type and associated physical layer clauses

Associated Clause	10GBASE-CX4
46—RS and	Required
XGMII[a]	Optional
47—XGXS and XAUI	Optional
48—10GBASE-X PCS/PMA	Required
49—10GBASE-R PCS	n/a
50—10GBASE-W WIS	n/a

[a]The XGMII is an optional interface. However, if the XGMII is not implemented, a conforming implementation must behave functionally as though the RS and XGMII were present.

Figure 54–1 shows the relationship of the PMD and MDI sublayers to the ISO/IEC (IEEE) OSI reference model.

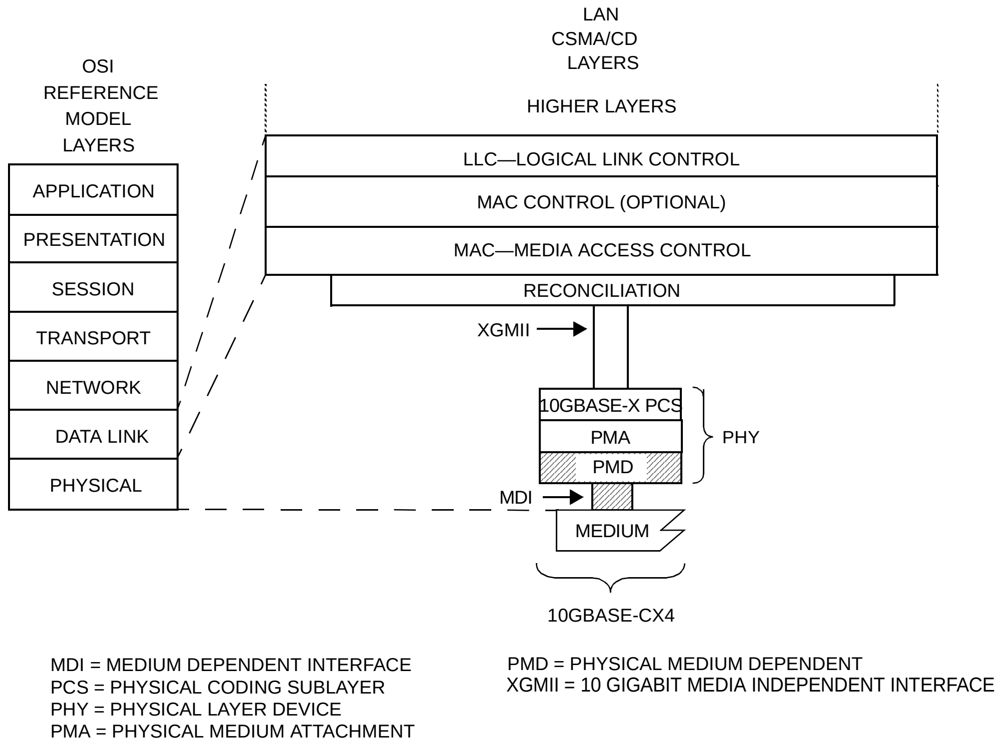


Figure 54–1—10GBASE-CX4 PMD relationship to the ISO/IEC Open Systems Interconnection (OSI) reference model and the IEEE 802.3 CSMA/CD LAN model

54.1.1 Physical Medium Dependent (PMD) service interface

This subclause specifies the services provided by the 10GBASE-CX4 PMD. The service interface for this PMD is described in an abstract manner and do not imply any particular implementation. The PMD Service Interface supports the exchange of encoded data between peer PMA entities. The PMD translates the encoded data to and from signals suitable for the specified medium.

The following PMD service primitives are defined:

PMD_UNITDATA.request

PMD_UNITDATA.indicate

PMD_SIGNAL.indicate

54.1.2 PMD_UNITDATA.request

This primitive defines the transfer of data (in the form of encoded 8B/10B characters) from the PMA to the PMD.

54.1.2.1 Semantics of the service primitive

PMD_UNITDATA.request (tx_bit <0:3>)

The data conveyed by PMD_UNITDATA.request is a continuous sequence of four parallel code-group streams, one stream for each lane. The tx_bit <0:3> correspond to the bits in the tx_lane<0:3> bit streams. Each bit in the tx_bit parameter can take one of two values: ONE or ZERO.

54.1.2.2 When generated

The PMA continuously sends four parallel code-group streams to the PMD at a nominal signaling speed of 3.125 GBaud.

54.1.2.3 Effect of Receipt

Upon receipt of this primitive, the PMD converts the specified stream of bits into the appropriate signals on the MDI.

54.1.3 PMD_UNITDATA.indicate

This primitive defines the transfer of data (in the form of encoded 8B/10B characters) from the PMD to the PMA.

54.1.3.1 Semantics of the service primitive

PMD_UNITDATA.indicate (rx_bit <0:3>)

The data conveyed by PMD_UNITDATA.indicate is a continuous sequence of four parallel encoded bit streams. The rx_bit<0:3> correspond to the bits in the rx_lane<0:3> bit streams. Each bit in the rx_bit parameter can take one of two values: ONE or ZERO.

54.1.3.2 When generated

The PMD continuously sends stream of bits to the PMA corresponding to the signals received from the MDI.

54.1.3.3 Effect of receipt

The effect of receipt of this primitive by the client is unspecified by the PMD sublayer.

54.1.4 PMD_SIGNAL.indicate

This primitive is generated by the PMD to indicate the status of the signals being received from the MDI.

54.1.4.1 Semantics of the service primitive

PMD_SIGNAL.indicate (SIGNAL_DETECT)

The SIGNAL_DETECT parameter can take on one of two values: OK or FAIL. When SIGNAL_DETECT = FAIL, rx_bit is undefined, but consequent actions based on PMD_UNITDATA.indicate, where necessary, interpret rx_bit as a logic ZERO.

NOTE—SIGNAL_DETECT = OK does not guarantee that rx_bit is known to be good. It is possible for a poor quality link to provide sufficient power for a SIGNAL_DETECT = OK indication and still not meet the 10^{-12} BER objective.

54.1.4.2 When generated

The PMD generates this primitive to indicate a change in the value of SIGNAL_DETECT.

54.1.4.3 Effect of receipt

The effect of receipt of this primitive by the client is unspecified by the PMD sublayer.

54.2 PCS and PMA functionality

The 10GBASE-CX4 PCS and PMA shall conform to the PCS and PMA defined in clause 48 unless otherwise noted herein.

54.3 Input / Output mapping

The 10GBASE-CX4 shall have the XAUI lane, as shown in Figure 47-2, to MDI connector pin mapping depicted in Table 54–2.

Table 54–2—XAUI lane to MDI connector pin mapping

XAUI Rx lane	MDI Connector pin	XAUI Tx lane	MDI Connector pin
DL0<p>	S1	SL0<p>	S16
DL0<n>	S2	SL0<n>	S15
DL1<p>	S3	SL1<p>	S14
DL1<n>	S4	SL1<n>	S13
DL2<p>	S5	SL2<p>	S12
DL2<n>	S6	SL2<n>	S11
DL3<p>	S7	SL3<p>	S10
DL3<n>	S8	SL3<n>	S9

54.4 Delay constraints

Predictable operation of the MAC Control PAUSE operation (Clause 31, Annex 31B) demands that there be an upper bound on the propagation delays through the network. This implies that MAC, MAC Control sublayer, and PHY implementers must conform to certain delay maxima, and that network planners and administrators conform to constraints regarding the cable topology and concatenation of devices.

The sum of transmit and receive delay contributed by the 10GBASE-CX4 PMD shall be no more than 512 BT (including 15 meters of cable).

54.5 PMD MDIO function mapping

The optional MDIO capability described in Clause 45 defines several variables that provide control and status information for and about the PMD. Mapping of MDIO control variables to PMD control variables is shown in Table 54–3. Mapping of MDIO status variables to PMD status variables is shown in Table 54–4.

Table 54–3—MDIO/PMD control variable mapping

MDIO control variable	PMA/PMD register name	Register/ bit number	PMD control variable
Reset	Control register 1	1.0.15	PMD_reset
Global transmit disable	Control register 1	1.9.0	Global_PMD_transmit_disable
Transmit disable 3	Transmit disable register	1.9.4	PMD_transmit_disable_3
Transmit disable 2	Transmit disable register	1.9.3	PMD_transmit_disable_2
Transmit disable 1	Transmit disable register	1.9.2	PMD_transmit_disable_1
Transmit disable 0	Transmit disable register	1.9.1	PMD_transmit_disable_0

Table 54–4—MDIO/PMD status variable mapping

MDIO status variable	PMA/PMD register name	Register/ bit number	PMD status variable
Local fault	Status register 1	1.1.7	PMD_fault
Transmit fault	Status register 2	1.8.11	PMD_transmit_fault
Receive fault	Status register 2	1.8.10	PMD_receive_fault
Global PMD signal detect	Receive signal detect register	1.10.0	Global_PMD_signal_detect
PMD signal detect 3	Receive signal detect register	1.10.4	PMD_signal_detect_3
PMD signal detect 2	Receive signal detect register	1.10.3	PMD_signal_detect_2
PMD signal detect 1	Receive signal detect register	1.10.2	PMD_signal_detect_1
PMD signal detect 0	Receive signal detect register	1.10.1	PMD_signal_detect_0

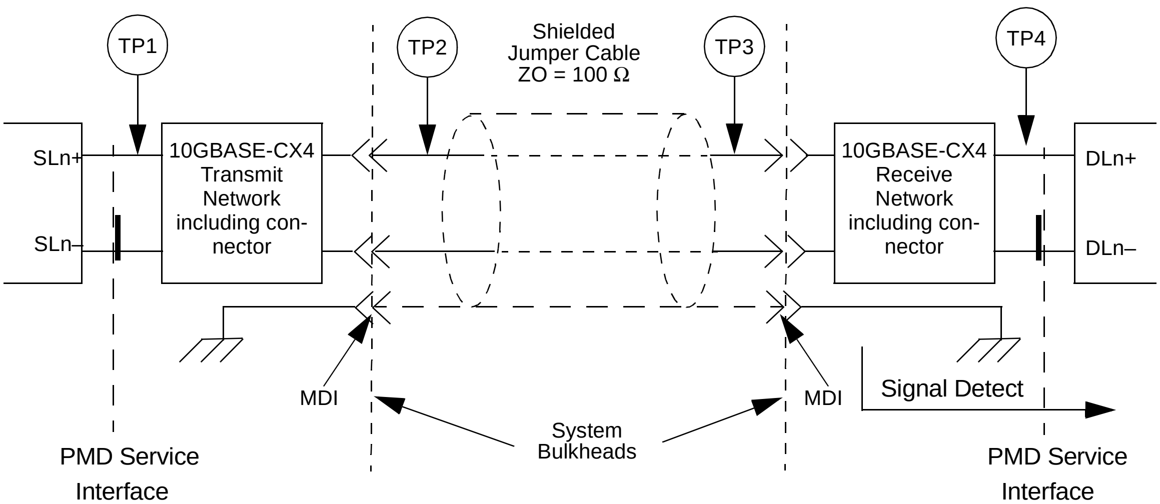
54.6 PMD functional specifications

The 10GBASE-CX4 PMD performs the Transmit and Receive functions which convey data between the PMD service interface and the MDI plus various management functions if the optional MDIO is implemented.

54.6.1 PMD block diagram

The PMD block diagram is shown in Figure 54–2. For purposes of system conformance, the PMD sublayer is standardized at the points described in this subclause. The electrical transmit signal is defined at the output end of the connector (TP2) at the MDI. Unless specified otherwise, all transmitter measurements and tests defined in 54.7.3 are made at TP2. The electrical receive signal is defined at the output of the cabling connector (TP3) at the MDI. Unless specified otherwise, all receiver measurements and tests defined in 54.7.4 are made at TP3.

Figure 54–2—10GBASE-CX4 link (half link is shown)



NOTE—Jumper cable assembly shielding is attached to the system chassis via the connector shroud.

SLn+ and SLn- are the positive and negative sides of the transmit differential signal pair and DLn+ and DLn- are the positive and negative sides of the receive differential signal pair for Lane n (n = 0, 1, 2, 3)

TP1 <0:3> and TP4 <0:3> are informative reference points that may be useful to implementers for testing components (these test points will not typically be testable in an implemented system).

54.6.2 PMD transmit function

The PMD Transmit function shall convert the four electronic bit streams requested by the PMD service interface message PMD_UNITDATA.request (tx_bit<0:3>) into four separate electrical signal streams. The four electrical signal streams shall then be delivered to the MDI, all according to the transmit electrical specifications in this clause. The higher output voltage of SLn+ minus SLn– (differential voltage) shall correspond to tx_bit = ONE.

54.6.3 PMD receive function

The PMD Receive function shall convert the four electrical signal streams from the MDI into four electronic bit streams for delivery to the PMD service interface using the message PMD_UNITDATA.indicate (rx_bit<0:3>), all according to the receive electrical specifications in this clause. The higher electrical voltage level in each signal stream shall correspond to a rx_bit = ONE.

The PMD shall convey the bits received from the PMD_UNITDATA.request(tx_bit<0:3>) service primitive to the PMD service interface using the message PMD_UNITDATA.indicate(rx_bit<0:3>), where rx_bit<0:3> = tx_bit<0:3>.

54.6.4 Global PMD signal detect function

The Global_PMD_signal_detect function shall report the state of SIGNAL_DETECT via the PMD service interface. The SIGNAL_DETECT parameter is signaled continuously, while the PMD_SIGNAL.indicate message is generated when a change in the value of SIGNAL_DETECT occurs.

SIGNAL_DETECT shall be a global indicator of the presence of electrical signals on all four lanes. The PMD receiver is not required to verify whether a compliant 10GBASE-CX4 signal is being received. This standard imposes no response time requirements on the generation of the SIGNAL_DETECT parameter.

Table 54–5—SIGNAL_DETECT value definition

Receive conditions	Receive Signal OK value
For any lane; Input electrical power ≤ TBD dBm	FAIL
For all lanes; [(Input_electrical power ≥ Receiver sensitivity (max) in OMA in Table 54–8) AND (compliant 10GBASE-CX4 signal input)]	OK
All other conditions	Unspecified

As an unavoidable consequence of the requirements for the setting of the SIGNAL_DETECT parameter, implementations must provide adequate margin between the input electrical power level at which the SIGNAL_DETECT parameter is set to OK, and the inherent noise level of the PMD due to crosstalk, power supply noise, etc.

Various implementations of the Signal Detect function are permitted by this standard, including implementations that generate the SIGNAL_DETECT parameter values in response to the amplitude of the modulation of the electrical signal and implementations that respond to the average electrical power of the modulated electrical signal.

54.6.5 PMD lane by lane signal detect function

Various implementations of the Signal Detect function are permitted by this standard. When the MDIO is implemented, each PMD_signal_detect_n, where n represents the lane number in the range 0:3, value shall be continuously set in response to the amplitude of the average electrical power of the modulated electrical signal on its associated lane, according to the requirements of Table 54–5.

54.6.6 PMD reset function

If the MDIO interface is implemented, and if PMD_reset is asserted, the PMD shall be reset as defined in 45.2.1.1.1.

54.6.7 Global PMD transmit disable function

The Global_PMD_transmit_disable function is optional and allows all of the electrical transmitters to be disabled.

a) When a Global_PMD_transmit_disable variable is set to ONE, this function shall turn off all of the electrical transmitters so that the each transmitter meets the requirements of the Absolute output voltage limits in Table 54–6.
b) If a PMD_fault is detected, then the PMD may set the Global_PMD_transmit_disable to ONE, turning off the electrical transmitter in each lane.

54.6.8 PMD lane by lane transmit disable function

The PMD_transmit_disable function is optional and allows the electrical transmitters in each lane to be selectively disabled.

a) When a PMD_transmit_disable_n variable is set to ONE, this function shall turn off the electrical transmitter associated with that variable so that the transmitter meets the requirements of the Absolute output voltage limits in Table 54–6.
b) If a PMD_fault is detected, then the PMD may set each PMD_transmit_disable_n to ONE, turning off the electrical transmitter in each lane.

If the optional PMD_lane_by_lane_transmit_disable function is not implemented in MDIO, an alternative method shall be provided to independently disable each transmit lane.

54.6.9 PMD fault function

If the MDIO is implemented, and the PMD has detected a local fault on any of the transmit or receive paths, the PMD shall set PMD_fault to ONE.

54.6.10 PMD transmit fault function (optional)

If the MDIO is implemented, and the PMD has detected a local fault on any transmit lane, the PMD shall set the PMD_transmit_fault variable to ONE.

54.6.11 PMD receive fault function (optional)

If the MDIO is implemented, and the PMD has detected a local fault on any receive lane, the PMD shall set the PMD_receive_fault variable to ONE.

54.7 PMD to MDI Electrical specifications for 10GBASE-CX4

54.7.1 Signal levels

The 10GBASE-CX4 MDI is a low swing AC coupled differential interface. AC coupling allows for interoperability between components operating from different supply voltages. Low swing differential signaling provides noise immunity and improved electromagnetic interference (EMI).

54.7.2 Signal paths

The 10GBASE-CX4 MDI signal paths are point-to-point connections. Each path corresponds to a 10GBASE-CX4 MDI lane and is comprised of two complementary signals making a balanced differential pair. There are four differential paths in each direction for a total of eight pairs, or sixteen connections. The signal paths are intended to operate up to approximately 15m over standard twinaxial cables as described in 54.8.

54.7.3 Driver characteristics

The 10GBASE-CX4 MDI driver characteristics are summarized in Table 54–6. The 10GBASE-CX4 MDI Baud shall be 3.125 GBaud ±100 ppm. The corresponding Baud period is nominally 320 ps.

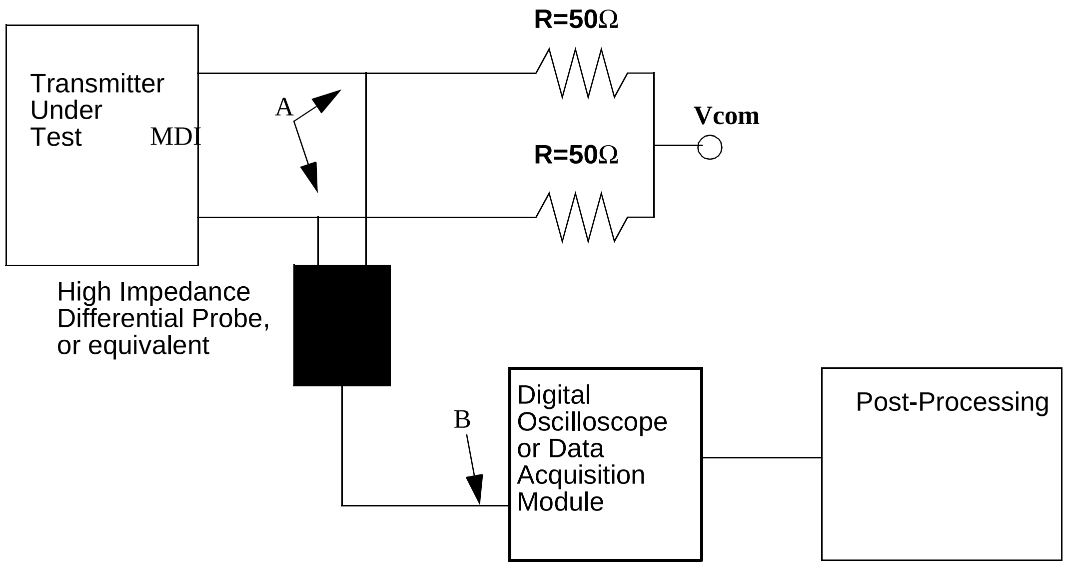
Table 54–6—Driver characteristics

Parameter	Value	Units
Baud rate tolerance	3.125 GBd ± 100 ppm	GBd ppm
Unit interval nominal	320	ps
Differential peak amplitude maximum minimum	 1600 800	 mV_{pp} mV_{pp}
Absolute output voltage limits maximum minimum	 2.3 –0.4	 V V
Differential output return loss minimum	TBD [See Equation (54.1)]	dB
Output jitter Near-end maximums Random jitter Deterministic jitter Total jitter	 ± 0.090 peak from the mean ± 0.085 peak from the mean ± 0.175 peak from the mean	 UI UI UI

54.7.3.1 Test Fixtures

The following fixture (illustrated by Figure 54–3), or its functional equivalent, shall be used for measuring the transmitter specifications described in 54.7.3. The transmitter uder test includes the driver, pcb traces, any AC coupling components and the MDI connector described in 54.9.1

Figure 54–3—Transmit Test Fixture



54.7.3.2 Load

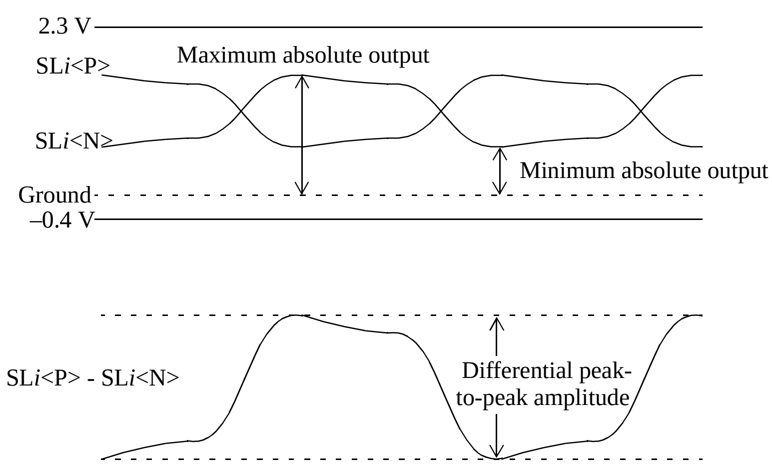
The load is 100 Ω ± 5% differential to 2.5 GHz for these measurements, unless otherwise noted.

54.7.3.3 Amplitude and swing

Driver differential output amplitude shall be less than 1600 $mV_{p\text{-}p}$. The minimum differential peak to peak output voltage shall be greater than 800 $mV_{p\text{-}p}$. DC-referenced logic levels are not defined since the receiver is AC coupled. Absolute driver output voltage shall be between –0.4 V and 2.3 V with respect to ground. See Figure 54–4 for an illustration of absolute driver output voltage limits and definition of differential peak-to-peak amplitude.

Figure 54–4—Driver output voltage limits and definitions

[SL*i*<P> and SL*i*<N> are the positive and negative sides of the differential signal pair for Lane *i* (*i* = 0, 1, 2, 3)]



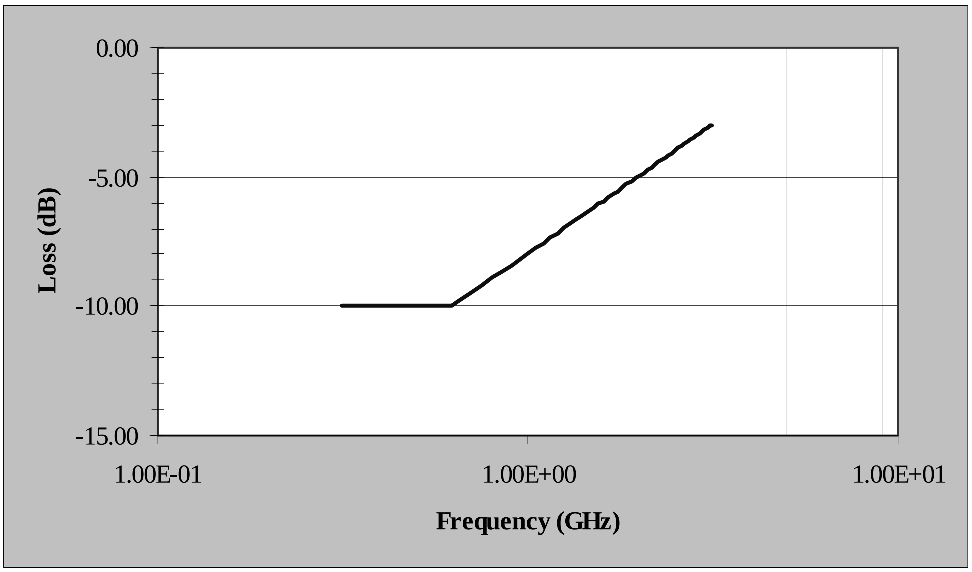
54.7.3.4 Output impedance

For frequencies from 312.5 MHz to 3.125 GHz, the differential return loss of the driver shall exceed Equation 54.1. Differential return loss includes contributions from on-chip circuitry, chip packaging, and any off-chip components related to the driver. This output impedance requirement applies to all valid output levels. The reference impedance for differential return loss measurements is 100 Ω.

s_{11} = –10 dB for 312.5 MHz < Freq (f) < 625 MHz, and Eq. (54.1)

–10 + 10log(f/625) dB for 625 MHz <= Freq (f) = < 3.125 GHz Eq. (54.2)

Figure 54–5—Tx differential output return loss



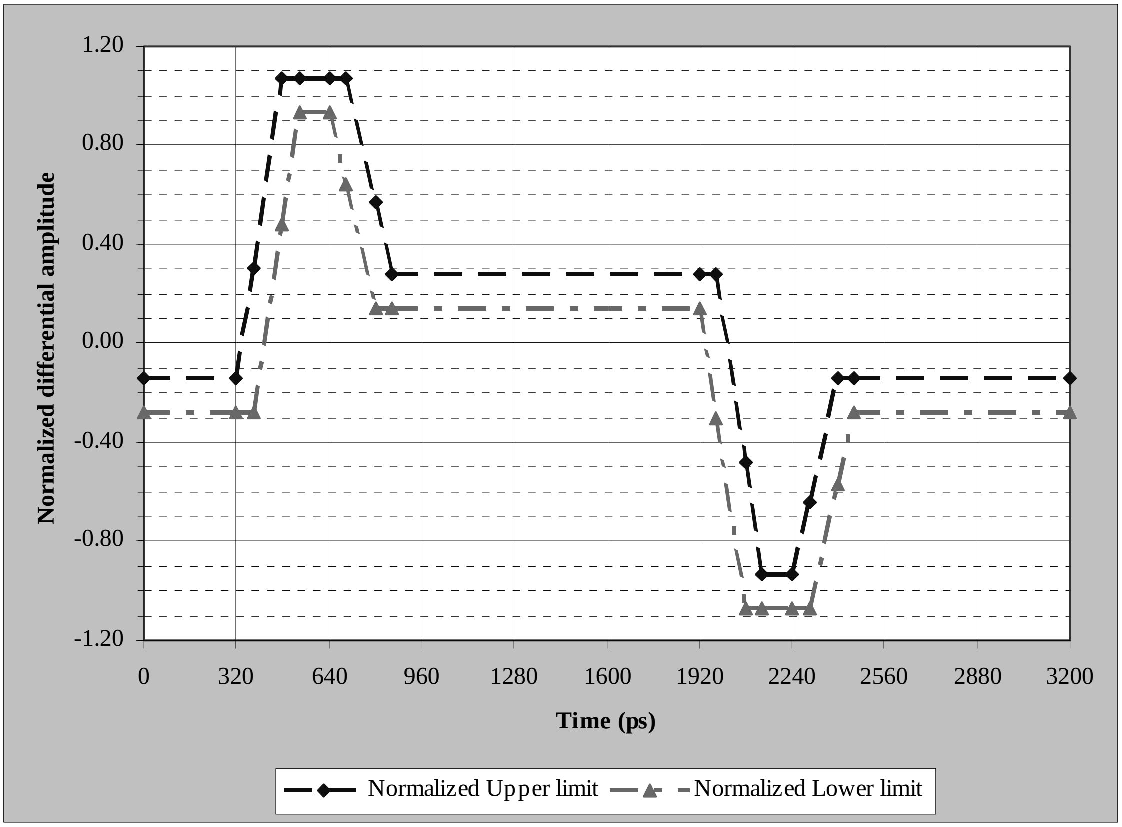
54.7.3.5 Transition time

Differential transition times between 60 and 130 ps are recommended, as measured between the 20% and 80% levels. Shorter transitions may result in excessive high-frequency components and increase EMI and crosstalk. The upper recommended limit of 130 ps corresponds to a sine wave at half the Baud rate.

54.7.3.6 Differential output template

The differential output template shall be tested using the low frequency test pattern specified in Annex 48A.2. The waveform is normalized by dividing the waveform by the peak value of the waveform. The differential voltage waveform shall lie within the time domain template defined in Figure 54–6 and the piecewise linear interpolation between the points in Table 54–7. These measurements are to be made for each pair while observing the differential signal output at the MDI using the transmitter test fixture. The waveforms may be shifted in time as appropriate to fit within the template.

Figure 54–6—Normalized transmit template as measured at MDI using Figure 54–3



NOTE—The transmit template is not intended to address electromagnetic radiation limits.

Table 54–7—Normalized time domain voltage template

Time, ps	Normalized transmit time domain template, upper limit	Normalized transmit time domain template, lower limit	Time, ps	Normalized transmit time domain template, upper limit	Normalized transmit time domain template, lower limit
0	-0.142	-0.282	1920	0.282	0.142
320	-0.142	-0.282	1978	0.282	-0.304
378	0.304	-0.282	2078	-0.483	-1.070
478	1.070	0.483	2137	-0.930	-1.070
537	1.070	0.930	2240	-0.930	-1.070
640	1.070	0.930	2298	-0.640	-1.070
698	1.070	0.640	2398	-0.142	-0572
798	0.572	0.142	2457	-0.142	-0.282
857	0.282	0.142	3200	-0.142	-0.282

NOTE—The ASCII for Table 54–7 is available from http://www.ieee802.org/3/publication/index.html. (NOTE: NEED correct url)

54.7.3.7 Transmit jitter

The driver shall satisfy the near-end jitter requirements with a maximum total jitter of ± 0.175 UI peak from the mean, a maximum deterministic component of ± 0.085 UI peak from the mean and a random component of ± 0.09 UI peak from the mean. Note that these values assume symmetrical jitter distributions about the mean. If a distribution is not symmetrical, its peak-to-peak total jitter value must be less than these total jitter values to claim compliance. Jitter specifications include all but 10^{-12} of the jitter population.

54.7.4 Receiver characteristics

Receiver characteristics are summarized in Table 54–8 and detailed in the following subclauses.

Table 54–8—Receiver characteristics

Parameter	Value	Units
Bit error ratio	10^{-12}	bps
Baud rate tolerance	3.125 ±100	GBd ppm
Unit interval (UI) nominal	320	ps
Receiver coupling	AC	
Differential input amplitude sensitivity maximum	 100 1600	 mVpp mVpp
Return loss[a] differential common mode	 10 6	 dB dB

[a]Relative to 100 Ω differential and 25 Ω common mode. See 54.7.4.5 for input impedance details.

54.7.4.1 Bit error ratio

The receiver shall operate with a BER of better than 10^{-12} in the presence of a compliant transmit signal, as defined in 54.7.3, and a compliant channel as defined in 54.8.

54.7.4.2 Baud rate tolerance

A 10GBASE-CX4 receiver shall tollerate a baud rate of 3.125GBd ±100 ppm.

54.7.4.3 AC coupling

The 10GBASE-CX4 receiver shall be AC coupled to the cable assembly to allow for maximum interoperability between various 10 Gbps components. AC coupling is considered to be part of the receiver for the purposes of this specification unless explicitly stated otherwise. It should be noted that there may be various methods for AC coupling in actual implementations.

54.7.4.4 Input signal amplitude

10GBASE-CX4 receivers shall have a minimum differential input amplitude sensitivity of 100mVpp and accept differential input signal amplitudes produced by compliant transmitters connected without attenuation to the receiver. Note that this may be larger than the 1600 mV_{pp} differential maximum of 54.7.3.3 due to actual driver and receiver input impedances. The minimum input amplitude is defined by the transmit driver, the channel and the actual receiver input impedance. Note that the transmit driver is defined using a well controlled load impedance. The minimum signal amplitude into an actual receiver may vary from the minimum height due to the actual receiver input impedance. Since the 10GBASE-CX4 receiver is AC coupled, the absolute voltage levels with respect to the receiver ground are dependent on the receiver implementation.

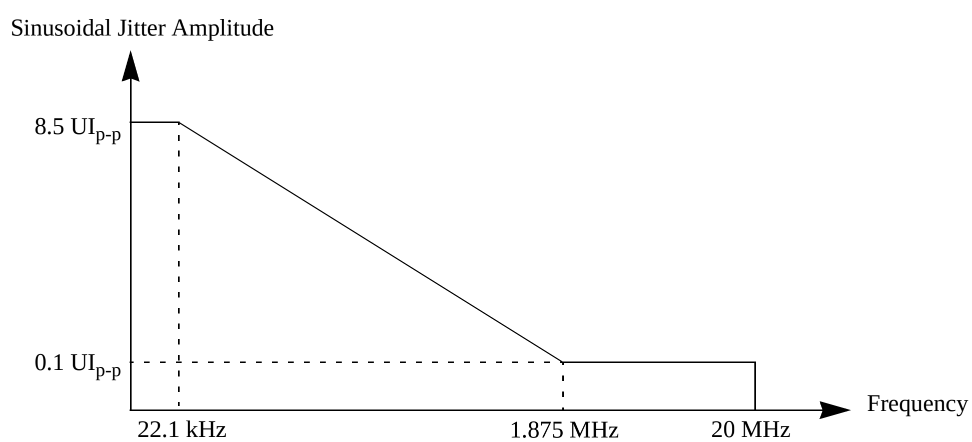
54.7.4.5 Input impedance

Receiver input impedance shall result in a differential return loss better than 10 dB and a common mode return loss better than 6 dB from 100 MHz to 2.5 GHz. This includes contributions from on-chip circuitry, the chip package and any off-chip components related to the receiver. AC coupling components are included in this requirement. The reference impedance for return loss measurements is 100 Ω for differential return loss and 25 Ω for common mode return loss.

54.7.4.6 Jitter tolerance

The total jitter is composed of three components: deterministic jitter, random jitter, and an additional sinusoidal jitter. Deterministic jitter tolerance shall be at least 0.37 UI_{p-p} not including any jitter due to ISI. Random jitter tolerance shall be at least 0.18 UI_{p-p}. Tolerance to the sum of deterministic and random jitter shall be at least 0.55 UI_{p-p}. The 10GBASE-CX4 receivers shall tolerate an additional sinusoidal jitter with any frequency and amplitude defined by the mask of Figure 54–7. This additional component is intended to ensure margin for low-frequency jitter, wander, noise, crosstalk and other variable system effects. Jitter specifications include all but 10^{-12} of the jitter population. Jitter tolerance test requirements are specified in 54.10.1.

Figure 54–7—Single-tone sinusoidal jitter mask



54.8 Cable assembly characteristics

The 10GBASE-CX4 is primarily intended as a point-to-point interface of up to approximately 15 m between integrated circuits using controlled impedance cables. Loss and jitter budgets are presented in Table 54–9.

Table 54–9—Informative 10GBASE-CX4 loss and jitter budget

	Loss (dB)	Total jitter (UI_{p-p})[a]	Random jitter (UI_{p-p})[a]	Deterministic jitter (UI_{p-p})[ab]
Driver & package	0	0.35	0.18	0.17
PCB & connector	TBD	0.20		0.20
Cable Assembly	19.4	0.20		0.20
Other[c]	TBD	0.10		0.10
Total	TBD	0.65	0.18	0.47

[a]Jitter specifications include all but 10^{-12} of the jitter population.
[b]All bounded jitter not including jitter from ISI.
[c]Includes such effects as crosstalk, noise, and interaction between jitter and eye height.

Table 54–10—Normative cable assembly differential characteristics

Description	Value	Unit
Characteristic Impedance @ TP2/TP3[a]	100 ± 10	Ω
Insertion loss at 1.5625 GHz (max.)	19.42	dB
Return loss at 1.5625 GHz (max.)	TBD	dB
Minimum NEXT loss @ Tr = 60 ps (max)	28	dB
Minimum MDNEXT loss @ Tr = 60 ps (max)	TBD	dB
Minimum FEXT loss @ Tr = 60 ps (max)	26	dB
Minimum MDFEXT loss @ Tr = 60 ps (max)	TBD	dB
Round-trip delay (max)[b]	256	BT

[a]The link impedance measurement identifies the impedance mismatches present in the cable assembly when terminated in its characteristic impedance. This measurement includes mated connectors at both ends of the Jumper cable assembly (points TP2 and TP3). The impedance for the jumper cable assembly, shall be recorded 4.0 ns following the reference location determined by an open connector at TP2 and TP3.
[b]Used in Clause 42. This delay is a budgetary requirement of the upper layers. It is easily met by the jumper cable delay characteristics in this clause.

54.8.1 Characteristic impedance

The recommended differential characteristic impedance of circuit board trace pairs and the cable assembly is 100 Ω ± 10% from 100 MHz to 2.5 GHz.

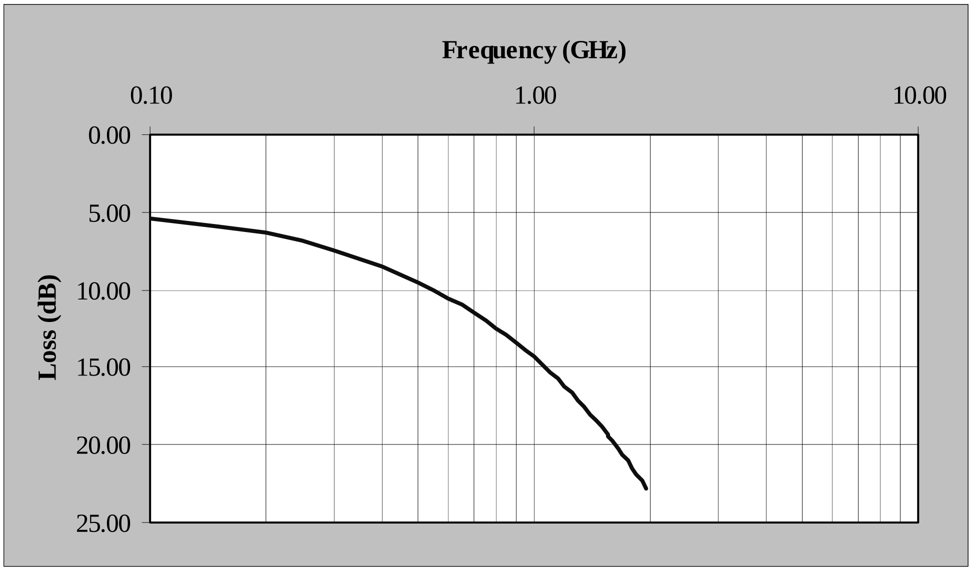
54.8.2 Cable assembly insertion loss

The insertion loss, in dB, of each pair of the 10GBASE-CX4 cable assembly shall be:

$$InsertionLoss(f) \le (2.25\times10^{-4} \cdot \sqrt{f}) + (6.08\times10^{-9} \cdot f) + \left(\frac{2.08\times10^{4}}{\sqrt{f}}\right) + 0.5 \quad \text{Eq. (54.3)}$$

for all frequencies from 100 MHz to 2 GHz. This includes the attenuation of the differential cabling pairs, and the assembly connector. The cable assembly insertion loss shall not deviate by more than 10% from equation 54.3.

Figure 54–8—Cable assembly insertion loss



54.8.3 Cable assembly insertion loss deviation

The insertion loss, in dB, of each pair of the 10GBASE-CX4 cable assembly shall not deviate more than 10% from a best fit to an equation of the form:

$$InsertionLoss(f) = (a \cdot \sqrt{f}) + (b \cdot f) + \left(\frac{c}{\sqrt{f}}\right) + d \quad \text{Eq. (54.4)}$$

54.8.4 Cable assembly return loss

The return loss, in dB, of each pair of the 10GBASE-CX4 cable assembly shall be:

$$ReturnLoss(f) \le \quad \text{Eq. (54.5)}$$

for all frequencies from 100 MHz to 2 GHz. This includes the attenuation of the differential cabling pairs, and the assembly connector.

54.8.4.1 Multiple Disturber Near-End Crosstalk (MDNEXT)

In order to limit the crosstalk at the near end of a link segment, the differential pair-to-pair Near-End Crosstalk (NEXT) loss between the any of the four transmit channels and any of the four recieve channels is specified to meet the bit error rate objective specified in 54.7.4.1. The NEXT loss between any transmit and receive channel of a link segment shall be at least

$$NEXT(f) \leq \quad \text{Eq. (54.6)}$$

where f is the frequency over the range of 100 MHz to 2 GHz.

Since four transmit and four recieve channels are used to transfer data between PMDs, the NEXT that is coupled into a receive channel will be from the four transmit channels. To ensure the total NEXT coupled into a receive channel is limited, multiple disturber NEXT loss is specified as the power sum of the individual NEXT losses.

The Power Sum loss between a receive channel and the four transmit channels shall be at least

$$MDNEXT(f) \leq \quad \text{Eq. (54.7)}$$

where *f* is the frequency over the range of 100 MHz to 2 GHz.

NOTE—The above equations approximates the NEXT loss specification at discrete frequencies for <**NOTE**: put cable reference here>.

54.8.4.2 Multiple Disturber Far-End Crosstalk (MDFEXT)

In order to limit the crosstalk at the far end of a link segment, the differential pair-to-pair Far-End Crosstalk (FEXT) loss between any transmit channel and any of he three remaining transmit channels is specified to meet the bit error rate objective specified in 54.7.4.1. The FEXT loss for any transmit channel of a link segment shall be at least

$$FEXT(f) \leq \quad \text{Eq. (54.8)}$$

where f is the frequency over the range of 100 MHz to 2 GHz.

Since four transmit channels are used to transfer data between PMDs, the FEXT that is coupled into a transmit channel will be from the three remaining transmit channels. To ensure the total FEXT coupled into a transmit channel is limited, multiple disturber FEXT loss is specified as the power sum of the individual FEXT losses.

The Power Sum loss between a transmit channel and the three remaining transmit channel shall be at least

$$MDFEXT(f) \leq \qquad \text{Eq. (54.9)}$$

where f is the frequency over the range of 100 MHz to 2 GHz.

NOTE—The above equations approximates the FEXT loss specification at discrete frequencies for <**NOTE**: put cable reference here>.

54.8.5 Shielding

The cable assembly shall provide class 2 or better shielding in accordance with IEC 61196-1.

54.9 MDI specification

This sub-clause defines the Media Dependent Interface (MDI). The 10GBASE-CX4 PMD of 54.7 is coupled to the cable assembly of 54.8 by the media dependent interface (MDI).

54.9.1 MDI connectors

Connectors meeting the requirements of 54.9.1 shall be used as the mechanical interface between the PMD of 54.7 and the jumper cable assembly of 54.8. The plug connector shall be used on the jumper cable assembly and the receptacle on the PHY.

54.9.1.1 Connector specification

The connector for the cable assemblies shall be the <**NOTE**: short description here> with the mechanical mating interface defined by IEC <**NOTE**: IEC reference number here?>, having pinouts matching those in Table 54–2, and the signal quality and electrical requirements of 54.7 and 54.8.

Figure 54–9—Plug bird without slot

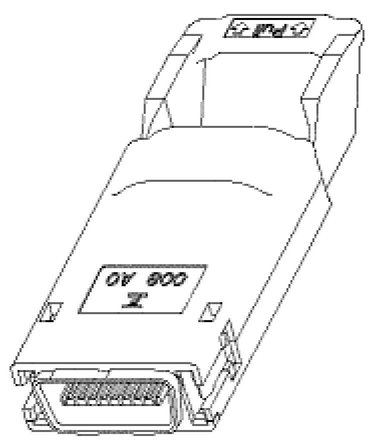


Figure 54–10—Jack bird without slot

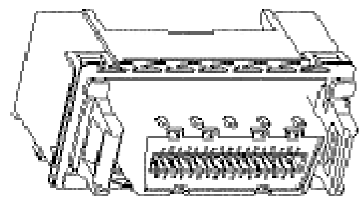


Figure 54–11—Plug bird with key

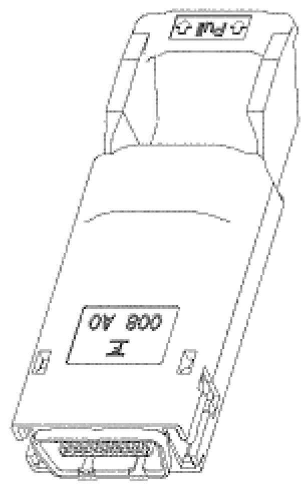
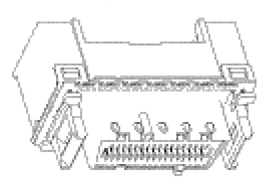


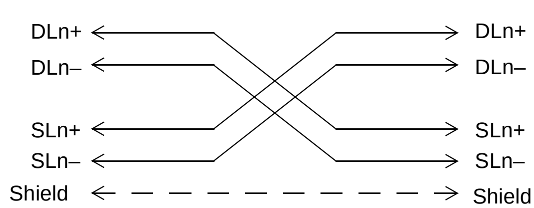
Figure 54–12—Jack bird with key



54.9.2 Crossover function

The default jumper cable assembly shall be wired in a crossover fashion as shown in Figure 54–13, with each of the four pairs being attached to the transmitter contacts at one end and the receiver contacts at the other end.

Figure 54–13—Cable wiring



54.10 Electrical measurement requirements

54.10.1 Jitter test requirements

For the purpose of jitter measurement, the effect of a single-pole high pass filter with a 3 dB point at 1.875 MHz is applied to the jitter. The data pattern for jitter measurements is the CJPAT pattern defined in Annex 48A. All four lanes of the 10GBASE-CX4 transciever are active in both directions, and opposite ends of the link use asynchronous clocks. Jitter is measured with AC coupling and at 0 volts differential. Jitter measurement for the transmitter (or for calibration of a jitter tolerance setup) shall be performed with a test procedure resulting in a BER bathtub curve such as that described in Annex 48B.

54.10.1.1 Transmit jitter

Transmit jitter is measured at the MDI output when terminated into the load specified in 54.7.3.2.

54.10.1.2 Jitter tolerance

Jitter tolerance is measured at the receiver using a jitter tolerance test signal. This signal is obtained by first producing the required sum of deterministic and random jitter defined in 54.7.4.6 and then adjusting the signal amplitude until the data eye contacts the 6 points of the driver's template shown in Figure TBD and Table TBD. Note that for this to occur, the test signal must have vertical waveform symmetry about the average value and have horizontal symmetry (including jitter) about the mean of the zero crossing. If these symmetries are not achieved, then some portions of the test signal will encroach into the template and provide overstress of the receiver, and/or some points of the template may not be contacted, resulting in understress of the receiver. Eye template measurement requirements are given inTBD. Random jitter is calibrated using a high pass filter with a low-frequency corner of 20 MHz and 20 dB/decade rolloff below this. The required sinusoidal jitter specified in 54.7.4.6 is then added to the signal and the far-end load is replaced by the receiver being tested.

54.11 Environmental specifications

All equipment subject to this clause shall conform to the requirements of 14.7 and applicable sections of ISO/IEC 11801: 1995.

54.12 Protocol Implementation Conformance Statement (PICS) proforma for Clause 54., Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-CX4[1]

54.12.1 Introduction

The supplier of a protocol implementation that is claimed to conform to IEEE Std 802.3ak-2003, Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-CX4, shall complete the following Protocol Implementation Conformance Statement (PICS) proforma. A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

54.12.2 Identification

54.12.2.1 Implementation identification

Supplier[1]	
Contact point for enquiries about the PICS[1]	
Implementation Name(s) and Version(s)[1,3]	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)[2]	
NOTES 1—Required for all implementations. 2—May be completed as appropriate in meeting the requirements for the identification. 3—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

54.12.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3aj-2003, Clause 54., Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-CX4
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3ae-2002.)	

Date of Statement	

54.12.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
LX4	10GBASE-CX4 PMD	54.1		O/1	Yes [ ] No [ ]
TP1	Standardized reference point TP1 exposed and available for testing	54.6.1	This point may be made available for use by implementers to certify component conformance	O	Yes [ ] No [ ]
TP4	Standardized reference point TP4 exposed and available for testing	54.6.1	This point may be made available for use by implementers to certify component conformance	O	Yes [ ] No [ ]
DC	Delay constraints	54.4	Device conforms to delay constraints	M	Yes [ ]
*MD	MDIO capability	54.5	Registers and interface supported	O	Yes [ ] No [ ]

54.12.4 PICS proforma tables for 10GBASE-CX4 and baseband medium

54.12.4.1 PMD Functional specifications

Item	Feature	Sub clause	Value/Comment	Status	Support
FN1	Integration with 10GBASE-X PCS and PMA and management functions	54.1		M	Yes [ ]
FN2	Transmit function	54.6.2	Convey bits requested by PMD_UNITDATA.request() to the MDI	M	Yes [ ]
FN3	delivery to the MDI	54.6.2	Supplies electrical signal streams for delivery to the MDI	M	Yes [ ]
FN4	Mapping between electrical signal and logical signal for transmitter	54.6.2	Higher electrical power is a one	M	Yes [ ]
FN5	Receive function	54.6.3	Convey bits received from the MDI to PMD_UNITDATA.indicate(rx_bit<0:3>)	M	Yes [ ]
FN6	Conversion of four electrical signals to four electrical signals	54.6.3	Converts the four electrical signal streams into four electrical bit streams for delivery to the PMD service	M	Yes [ ]
FN7	Mapping between electrical signal and logical signal for receiver	54.6.3	Higher electrical power is a one	M	Yes [ ]
FN8	Receive function behavior	54.6.3	Conveys bits from PMD service primitive to the PMD service interface	M	Yes [ ]
FN9	Global Signal Detect function	54.6.4	Report to the PMD service interface the message PMD_SIGNAL.indicate(SIGNAL_DETECT)	M	Yes [ ]
FN10	Global Signal Detect behavior	54.6.4	SIGNAL_DETECT is a global indicator of the presence of electrical signals on all four lanes	M	Yes [ ]
FN11	Lane-by-Lane Signal Detect function	54.6.5	Sets PMD_signal_detect_n values on a lane-by-lane basis per requirements of Table 54–5	MD:O	Yes [ ] No [ ] N/A [ ]
FN12	PMD_reset function	54.6.6	Resets the PMD sublayer	MD:O	Yes [ ] No [ ] N/A [ ]

54.12.4.2 PMD to MDI electrical specifications for 10GBASE-CX4

Item	Feature	Subclause	Value/Comment	Status	Support
PMS1	XAUI lane to MDI lane assignment	54.3	Device supports connector pin assignments in Table 54–2	M	Yes [ ] N/A [ ]
PMS2	Transmitter meets specifications in Table 54–6	54.7.3	Per measurement techniques in 54.10	M	Yes [ ] N/A [ ]
PMS3	Receiver meets specifications in Table 54–8	54.7.4	Per measurement techniques in 54.10	M	Yes [ ] N/A [ ]

54.12.4.3 Management functions

Item	Feature	Subclause	Value/Comment	Status	Support
MR1	Management register set	54.5		MD:M	Yes [ ] N/A [ ]
MR2	Global transmit disable function	54.6.7	Disables all of the electrical transmitters with the Global_PMD_transmit_disable variable	MD:O	Yes [ ] No [ ] N/A [ ]
MR3	PMD_lane_by_lane_transmit_disable function	54.6.8	Disables the electrical transmitter on the lane associated with the PMD_transmit_disable_n variable	MD:O	Yes [ ] No [ ] N/A [ ]
MR4	PMD_lane_by_lane_transmit_disable	54.6.8	Disables each electrical transmitter independently if FN12 = NO	O	Yes [ ] No [ ]
MR5	PMD_fault function	54.6.9	Sets PMD_fault to a logical 1 if any local fault is detected	MD:O	Yes [ ] No [ ] N/A [ ]
MR6	PMD_transmit_fault function	54.6.10	Sets PMD_transmit_fault_n to a logical 1 if a local fault is detected on the transmit path x	MD:O	Yes [ ] No [ ] N/A [ ]
MR7	PMD_receive_fault function	54.6.11	Sets PMD_receive_fault_x to a logical 1 if a local fault is detected on the receive path x	MD:O	Yes [ ] No [ ] N/A [ ]

54.12.4.4 Jitter specifications

Item	Feature	Subclause	Value/Comment	Status	Support
JS1	Transmit jitter	54.10	Meet BER “bathtub curve” specifications	M	Yes [ ]
JS2	Channel transmit jitter		As described in steps a) through c) in	M	Yes [ ]
JS4	Receive jitter		BER less than 10^{-12}	M	Yes [ ]
JS5	Receive jitter		Meets requirements of the receiver input jitter mask	M	Yes [ ]
JS6	Receive jitter		Uniform spectral content over the measurement frequency range of 18.75kHz to 1.5GHz	M	Yes [ ]
JS7	Receive jitter		Using a Clock Recovery Unit	M	Yes [ ]
JS8	Receive jitter		Using a low-frequency corner of less than or equal to 1.875MHz and a slope of 20dB/decade	M	Yes [ ]
JS9	Receive jitter		Using fourth-order Bessel-Thomson filter	M	Yes [ ]
JS10	Receive jitter		Meets the requirements of	M	Yes [ ]
JS11	Receive jitter		Sinusoidal jitter added to the test signal in compliance with	M	Yes [ ]

54.12.4.5 electrical measurement requirements

Item	Feature	Subclause	Value/Comment	Status	Support
OM1	Length of patch cord used for measurements		2 to 5 m	M	Yes [ ]
OM2	Wavelength ranges		Wavelengths fall within ranges specified in, and under modulated conditions using valid 10GBASE-X signals	M	Yes [ ]
OM3	electrical power measurements		Per TIA/EIA-455-95	M	Yes [ ]
OM4	Source spectral window measurements		Individually measured per test setup in , with all other channels below –30 dBm	M	Yes [ ]
OM5	Source spectral window measurements		Under modulated conditions using valid 10GBASE-X signals	M	Yes [ ]
OM6	Extinction ratio measurements		Per ANSI/TIA/EIA-526-4A	M	Yes [ ]
OM7	OMA measurements		Each channel tested individually per methodology defined in 52.9.5	M	Yes [ ]
OM8	$RIN_{12}OMA$		Each channel tested individually per methodology defined in 52.9.6		Yes [ ]
OM9	Transmit eye		Per ANSI/TIA/EIA-526-4A (OFSTP-4)	M	Yes [ ]
OM10	Transmit eye mask measurement conditions		Using fourth-order Bessel-Thomson filter	M	Yes [ ]
OM11	Transmit eye mask measurement conditions		Using a Clock Recovery Unit to trigger the scope	M	Yes [ ]
OM12	Transmit eye mask measurement conditions		Using a low-frequency corner of less than or equal to 1.875MHz and a slope of 20dB/decade	M	Yes [ ]
OM13	Transmit rise/fall characteristics conditions		Waveforms conform to mask in , measured from 20% to 80%, using a patch cord	M	Yes [ ]
OM14	Transmit rise/fall characteristics conditions		Removed mask conforming filter mathematically	M	Yes [ ]
OM15	Transmit rise/fall characteristics conditions		Mask filters use a fourth-order Bessel-Thomson filter	M	Yes [ ]
OM16	Receive sensitivity measurement conditions		Using conformance test at TP3 and meeting conditions specified in	M	Yes [ ]
OM17	Transmit jitter conformance measurement conditions		Using a fourth-order Bessel-Thomson filter for single-mode fiber	M	Yes [ ]

Item	Feature	Subclause	Value/Comment	Status	Support
OM18	Transmit jitter conformance measurement conditions		Using a fourth-order Bessel-Thomson filter followed by a transversal filter with 2 equal amplitude paths with a differential delay of 157ps for multimode fiber	M	Yes [ ]
OM19	Transmit jitter conformance measurement conditions		Using a low-frequency corner of less than or equal to 1.875MHz and a slope of 20dB/decade	M	Yes [ ]
OM20	Transmit jitter conformance measurement conditions		Measured at the average value of the overall waveform	M	Yes [ ]
OM21	Transmit jitter conformance measurement conditions		Asynchronous data flowing in all four electrical receiver channels	M	Yes [ ]
OM22	Transmit jitter conformance measurement conditions		Meets requirements listed in	M	Yes [ ]
OM23	Transmit jitter conformance measurement conditions		For single-mode fiber; compliant with dispersion at least as negative as the “minimum dispersion” and at least as positive as the “maximum dispersion”	M	Yes [ ]
OM24	Transmit jitter conformance measurement conditions		Achieved using ITU-T G.652 fiber	M	Yes [ ]
OM25	Transmit jitter conformance measurement conditions		Using the linear regime of the single-mode fiber	M	Yes [ ]
OM26	Transmit jitter conformance measurement conditions		Provide an electrical back reflection specified in	M	Yes [ ]
OM27	Transmit jitter conformance measurement conditions		Back reflection adjusted to create the greatest RIN	M	Yes [ ]
OM28	Transmit jitter conformance measurement conditions		For multimode fiber, back reflection set to –12dB	M	Yes [ ]
OM29	Transmit jitter conformance measurement conditions		Using a low-frequency corner of less than or equal to 1.875MHz and a slope of 20dB/decade	M	Yes [ ]
OM30	Receiver sensitivity		Meet the specifications in	M	Yes [ ]
OM31	Stressed receiver conformance conditions		Asynchronous data flowing out of the electrical transmitter of the system under test	M	Yes [ ]
OM32	Stressed receiver conformance conditions		Data is consistent with normal signal properties and content	M	Yes [ ]
OM33	Stressed receiver conformance conditions		Using a Clock Recovery Unit meeting the requirements of	M	Yes [ ]
OM34	Stressed receiver conformance conditions		Calibrated at the average value of the overall electrical waveform	M	Yes [ ]

Item	Feature	Subclause	Value/Comment	Status	Support
OM35	Stressed receiver conformance conditions		Using a Clock Recovery Unit meeting the requirements of	M	Yes [ ]
OM36	Receiver 3dB electrical upper cutoff frequency		Performed on each channel independently using a laser source with its output wave-length within the specified wavelength range of the chan-nel to be tested	M	Yes [ ]
OM37	Receiver 3dB electrical upper cutoff frequency		As described in steps a) through e) of	M	Yes [ ]
OM38	Compliance test signal at TP3		Meets the requirements of	M	Yes [ ]
OM39	Compliance test signal at TP3		DJ eye closure no less than 14ps	M	Yes [ ]
OM40	Compliance test signal at TP3		Vertical eye-closure penalty meets requirements of	M	Yes [ ] N/A [ ]
OM41	Compliance test signal at TP3		Bandwidth of photodetector > 2.34GHz, and couple through fourth-order Bessel-Thomson filter	M	Yes [ ]
OM42	Receiver WDM conformance conditions		As described in steps a) through f) of	M	Yes [ ]
OM43	General safety		Conform to IEC-60950: 1991	M	Yes [ ]
OM44	Laser safety		Class 1	M	Yes [ ]
OM45	Compliance with all require-ments over the life of the product			M	Yes [ ]
OM46	Compliance with applicable local and national codes for the limitation of electromagnetic interference			M	Yes [ ]

54.12.4.6 Characteristics of the fiber optic cabling

Item	Feature	Subclause	Value/Comment	Status	Support
LI1	Fiber optic cabling		Meets specifications in	INS:M	Yes [ ] N/A [ ]
LI4	MDI		IEC 61753-1-1 and IEC 61753-3-2	M	Yes [ ]