O-band Optical Specifications for 800GBASE-LR1

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Supporters

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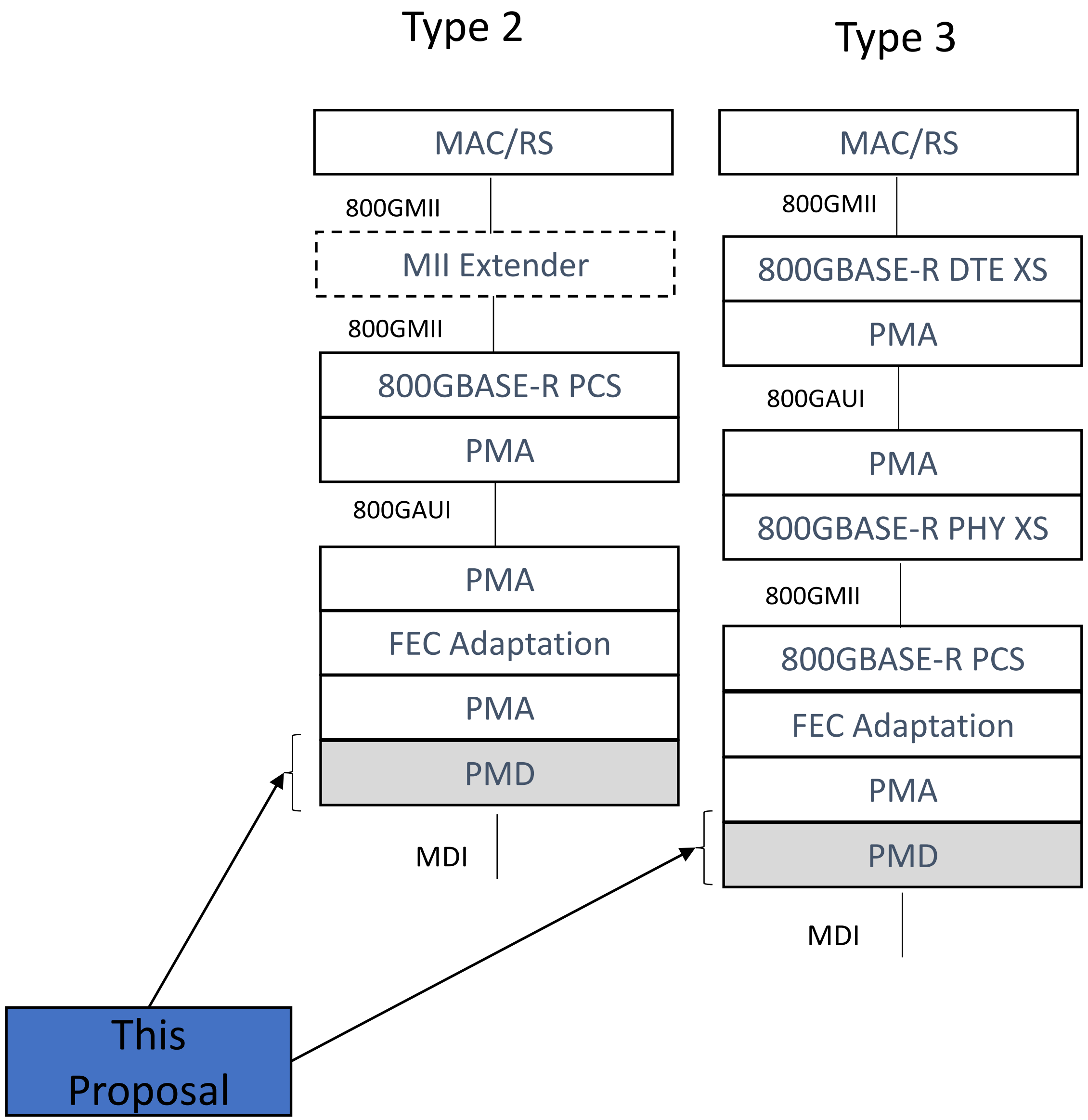
- Ernest Muhigana - Lumentum

This proposal

- Provides optical specifications for an 800GBASE-LR1 PHY to support 10km objective using single wavelength coherent modulation in the O-band
- Topics covered in this presentation
    - Channel Specifications
    - TX Laser Specifications
    - RX Optical Specifications
    - TX Optical Specifications



O-band considerations

- DSP design can benefit from lower chromatic dispersion in O-band
  - Enables low latency, low power, time domain implementations
  - C-band would require frequency domain implementations to achieve low power. This negates some of the low latency benefits.
  - Future increases in symbol rates will make this comparison worse for C-band.
  - Fiber loss in C-band can be lower. However, this does not provide enough relaxation if end-users care about the overall channel loss.
- O-band can leverage lasers developed for IMDD

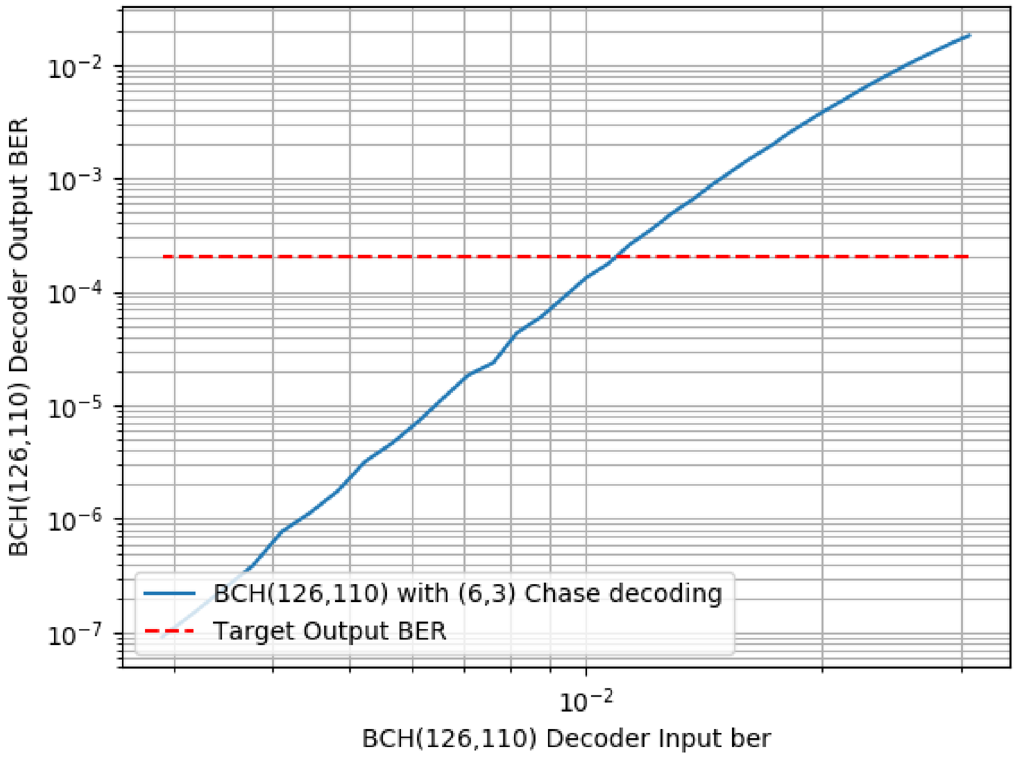
O-band is the better choice for 800GBASE-LR1 from viewpoints of low power, low latency and future backwards compatibility

PMD Baseline Requirements

- Support single-wavelength 800G coherent line interface
- Support FLR targets when processed according to the adopted logic baseline (kota_3dj_01a_2307) consistent with adopted DER0 target for AUIs within a PHY
- Support requirements which are unique to single-wavelength coherent interfaces (such as burst error tolerance, unequal bit error rates, laser phase noise tolerance, ability to recover carrier offset etc.)

BER Requirements

- FLR target for complete PHY interface including the electrical interfaces for 64 octet frames with min IPG: 6.2×10^{-11}
  - DER0 of 2.67×10^{-5} (BER= 4×10^{-5} with precoding ON) was previously adopted as total allocation for AUIs within a PHY for 200G/lane electrical interfaces
  - Therefore, BER target for the FEC/PMA/PMD sublayers after decoding the adopted BCH inner code is **2×10^{-4}**
  - BER target at the input of the BCH inner code is 1×10^{-2}



Fiber Optic Cabling (Channel) Characteristics

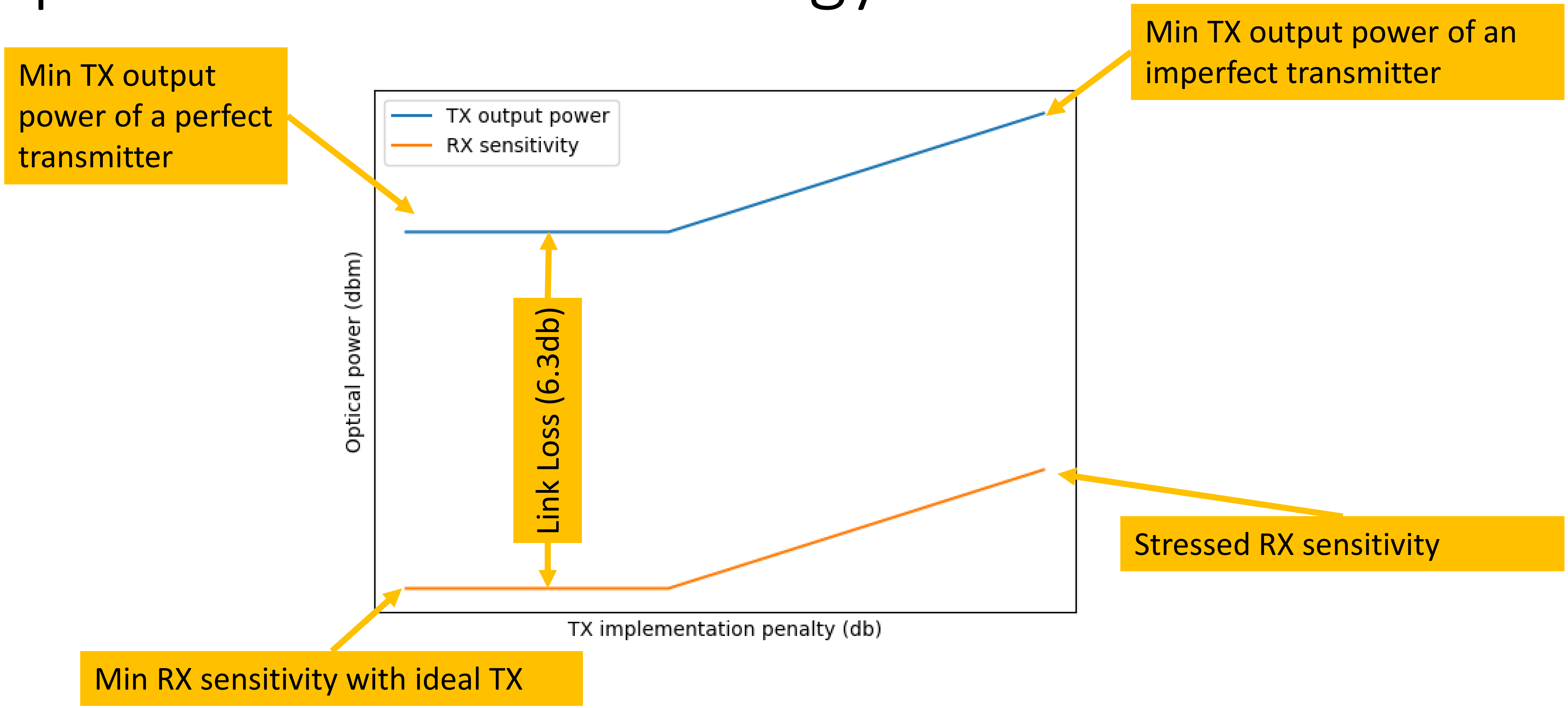
Description	800GBASE-LR1	Unit
Operating Distance (max)	10	km
Channel Insertion Loss (max)	6.3	dB
Channel Insertion Loss (min)	0	dB
Positive Dispersion (max)	10	ps/nm
Negative Dispersion (min)	-12	ps/nm
DGD (max)	5	ps
Optical Return Loss (min)	22	dB

Based on prior clauses (100GBASE-LR4, 25GBASE-LR, 50GBASE-LR, 200GBASE-LR4) for 10km objective

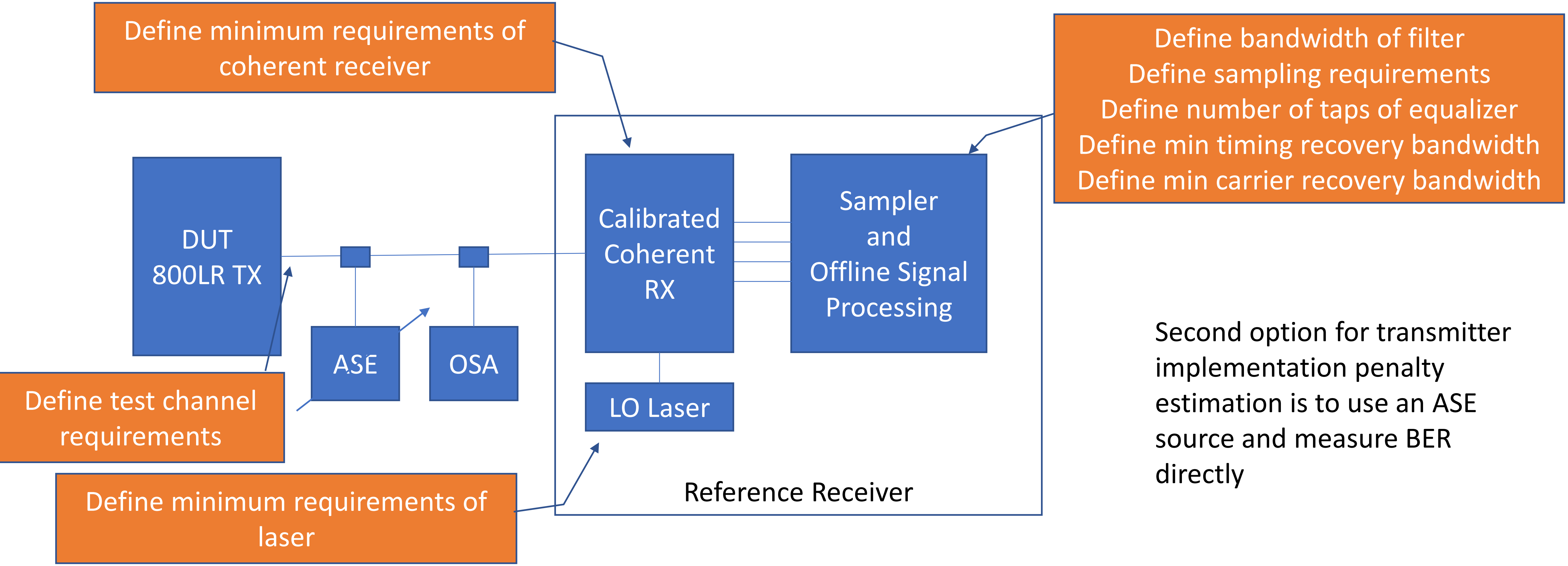
Based on a center frequency of 1311nm and ITU-T G.652D limits

200GBASE-LR4 (Clause 122) uses 8ps. However, 400G-LR4-10 MSA uses 5ps

Specification Methodology



Possible setup to measure TX Q-metric



Second option for transmitter implementation penalty estimation is to use an ASE source and measure BER directly

Transmit Characteristics

Description	800GBASE-LR1	Unit
Signaling rate	123.6364±50ppm	GHz
Modulation Format	DP-QAM16	
Operating Frequency (absolute accuracy)	228833±10	GHz
~~Laser Frequency EOL drift relative to BOL (max)~~ Laser Relative Frequency tracking accuracy (max)	±0.5	GHz
Laser linewidth (max)	1	MHz
Rate of laser frequency change (max) (100ns averaging)	1	THz/s
Side-mode suppression ratio (SMSR) (min)	30	dB
Laser RIN (max)	-145	dBc/Hz

1311nm to match nominal frequency of multiple prior clauses (e.g. 200GBASE-LR4) near the center of the zero-dispersion window

Laser absolute accuracy of ±10GHz to enable use of low cost lasers (for e.g., DFB lasers with TEC in non-hermetically sealed packaging). Propose that modules independently adjust laser frequency at link startup ~~and stop the adjustments once the frequencies are accurate within a dead zone~~ to specified accuracy relative to far-end transmit laser

~~Laser frequency drift limit of ±5GHz at end-of-life (EOL) relative to beginning-of-life (BOL) frequency~~
Modules which share laser between TX and RX will need to adjust the laser if the relative frequency drifts beyond a dead zone. An example algorithm to be provided in future contribution.

Receive Characteristics

Description	800GBASE-LR1	Unit
Signaling rate	123.6364±50ppm	GHz
Modulation Format	DP-QAM16	
Operating Frequency (absolute accuracy)	228833±10	GHz
LO frequency offset after linkup (max)	±0.5	GHz

Module may adjust transmit laser frequency during linkup and as needed during lifetime of the link to reduce the relative LO frequency offset to below a dead zone.

Laser Frequency Accuracy

Option A: ±3GHz each laser

- Requires etalon or wave-locker in laser which adds cost
- Simplifies design of DSP and modules

Option B: ±10GHz at startup

- Enables use of lasers without wave-locker
- DFB laser with TEC in a non-hermetically sealed package for lowest cost
- Propose that modules independently adjust laser frequency at startup ~~and stop once the frequencies are accurate within a dead zone~~ to achieve a target relative accuracy. Further adjustments during life of the link may be needed to accommodate laser frequency drift. This allows designers the flexibility to have either separate lasers for TX and RX or share a single laser.

Receive Characteristics (contd)

Description	800GBASE-LR1	Unit
Damage Threshold input power	TBD	dBm
Total average receive power (max)	-6.7	dBm
Receiver reflectance (max)	TBD (-26?)	dB
Receiver sensitivity (min) for TXQ<1.4dB for 1.4dB<TXQ<3.4dB	 -18 -19.4 + TXQ	 dBm dBm
Stressed receiver sensitivity, each lane (min)	-16	dBm
Dispersion tolerance (min)	15	ps/nm
SOP rate of change tolerance (min)	5	krad/s

Defining minimum receive optical power per lane (XI/XQ/YI/YQ). This power can be calculated by measuring the total receive power and measuring TX power imbalances using an OMA or a receiver

Minimum receive power per lane is defined based on the transmitter Q-penalty metric. Transmitter Q-penalty is the penalty (in dB) incurred by a transmitter at a reference receiver (TBD)

Proposal for State of Polarization (SOP) tracking

- 400ZR specification for receiver SOP tracking is 50krad/s.
- Unfortunately, the data on polarization changes is sparse
- Most data points to slow changes in SOP. The few extremely fast transients significantly exceed 50krad/s
- Our experience is that 50krad/s requires loops to run fast and contributes non-negligible power to the overall DSP
- A factor of 10 reduction to 5krad/s would help to slow these loops and reduce power. The data suggests there would not be a significant increase in outages from this reduction in tracking speed.

Proposing a value of 5krad/s for SOP tracking

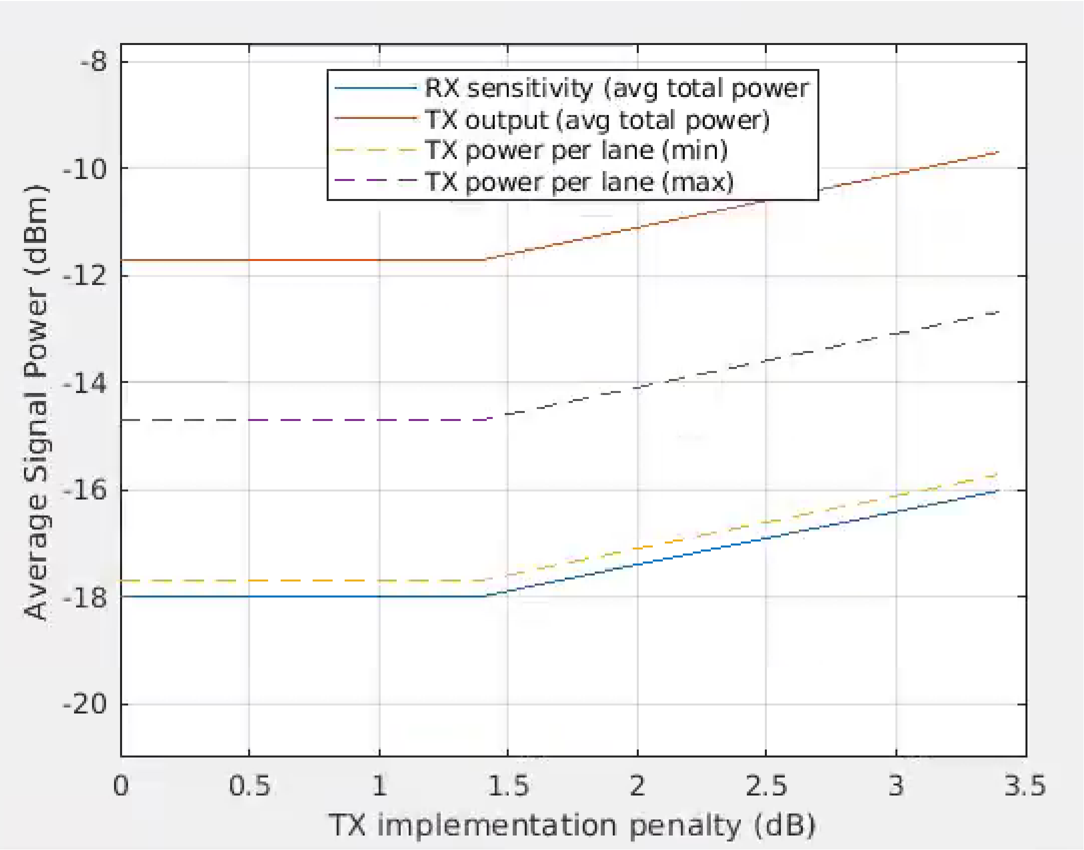
Transmit Characteristics (contd)

Description	**800GBASE-LR1**	**Unit**
Total average launch power (max)	-6.7	dBm
Average launch power, each lane (max)	-12.7	dBm
Average launch power, each lane (min) for TXQ<1.4dB for 1.4dB<TXQ<3.4dB	 -17.7 -19.1 + TXQ	 dBm dBm
Difference in average launch power between lanes (max)	TBD	dB
Transmit Q-penalty (max)	3.4	dB
Transmit in-band OSNR (min)	35	dB
Average launch power of OFF transmitter (max)	TBD (-16?)	dBm
Optical return loss tolerance	TBD (15.6?)	dB
Transmitter reflectance	TBD (-26?)	dB

Defining minimum transmit optical power per lane (XI/XQ/YI/YQ). This power can be calculated by measuring the total power and measuring lane power imbalances using an OMA or a receiver

Following IMDD/PAM4 methodology. Defining a TXQ metric for a transmitter. Minimum transmit power of a lane is a function of the TXQ for that lane

TX and RX optical signal powers



- Example 1: TX with perfect equalization and bandwidth (TXQ=0dB)
  - TX power (min): -11.7dBm
  - RX power (min): -18dBm
- Example 2: TX with imperfect equalization/bandwidth (TXQ=3.4dB)
  - TX power (min): -9.7dBm
  - RX power (min): -16dBm
- Example 3: TX with imperfect equalization/bandwidth (TXQ=3.4dB) and 3dB X-Y power imbalance
  - TX power (min): -7.9dBm
  - RX power (min): -14.2dBm

Transmit Characteristics (impairments)

Description	800GBASE-LR1	Unit
TX random jitter (max) assuming 3MHz high-pass filter	0.015	UIrms
TX bounded jitter (max) assuming 3MHz high-pass filter	0.03	UIpp
I-Q phase error (max)	±5	deg
X-Y Skew (max)	5	ps
I-Q Skew (max)	0.75	ps
DC I-Q offset (max)	-26	dB
I-Q power imbalance (max)	1	dB
X-Y power imbalance (max)	1.5	dB

Relaxed X-Y skew to reduce module calibration requirements

Same specification as 400GBASE-ZR. Increase in symbol rate implies a relaxation in the specification. This assumes receive-side compensation[§]

[§] C. R. S. Fludger and T. Kupfer, "Transmitter Impairment Mitigation and Monitoring for High Baud-Rate, High Order Modulation Systems," ECOC 2016; 42nd European Conference on Optical Communication, Dusseldorf, Germany, 2016, pp. 1-3.

Summary

- Proposing O-band for 800GBASE-LR1
- Specification methodology follows PAM4 through the use of a transmit Q-metric (TXQ)
- Proposed starting point of specifications to be further refined

Thank you!

Backup

SOP tracking spec for 800LR

- 800ZR spec is 50krad/s derived from 400ZR specification
- 800LR DSP can benefit from a lower spec. For e.g., slower tracking requirements can save power from adaptive loops which do not need to run at full speed
- How much polarization tracking is “enough”?
  - Polarization changes are the result of stress on fiber or vibrations from normal events (for e.g., fans or temperature changes) or infrequent events (e.g., a person or a tool striking the fiber during maintenance).
  - Ideally, this data should be derived from datacenter deployments over sufficient time to estimate polarization rotation speeds and calculate outage probabilities
  - Some previously published measurements on following slides

Measurements on an 1800km terrestrial link

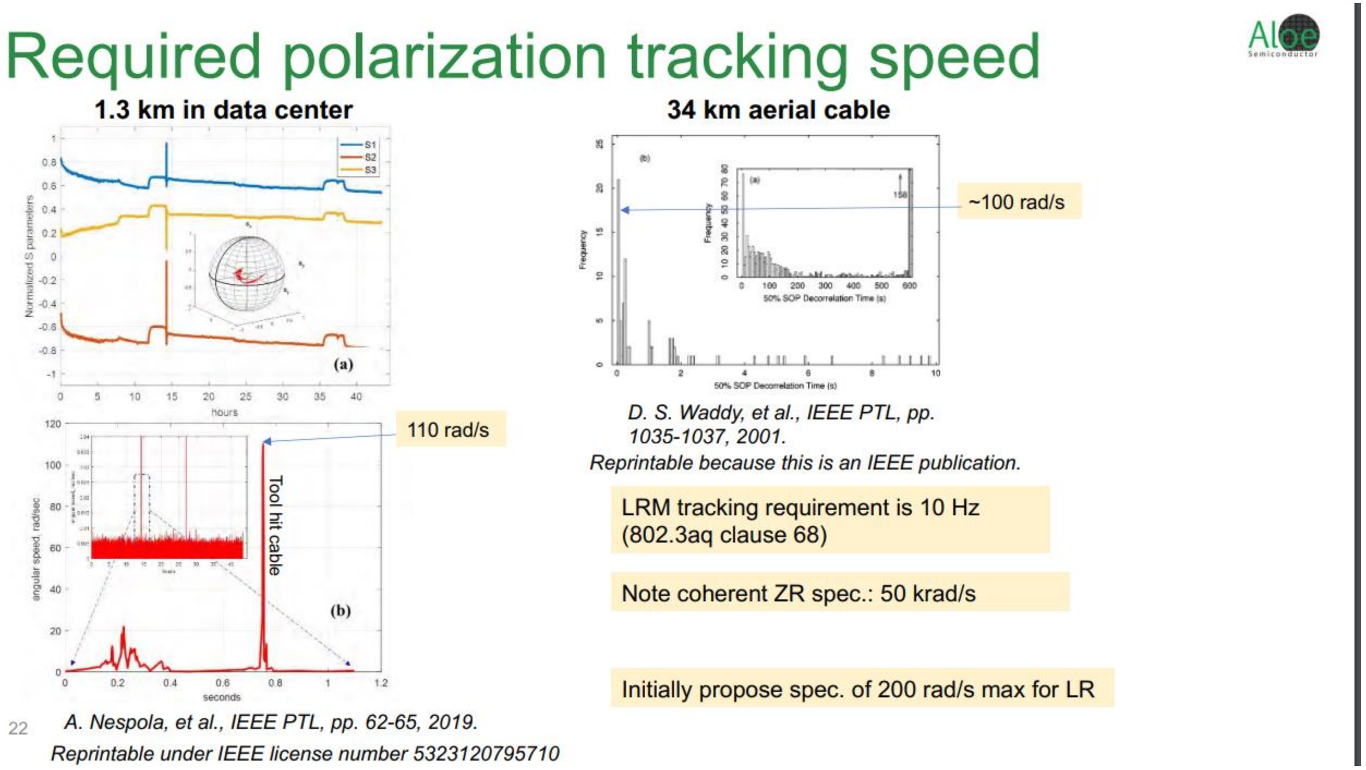
L. E. Nelson, M. Birk, S. L. Woodward and P. Magill, "Field measurements of polarization transients on a long-haul terrestrial link," IEEE Photonic Society 24th Annual Meeting, Arlington, VA, USA, 2011, pp. 833-834, doi: 10.1109/PHO.2011.6110816.

- Recorded 515 transients over 79 days on an 1800km link in the AT&T network
- Some transients recorded with 5kHz sampling; others recorded at 50kHz
- 1 transient measured at 50kHz sampling exceeded the measurement limit of 78krad/s
- 3 additional transients measured at 5kHz sampling exceeded measurement limit of 7.8krad/s
- 8 of the remaining 511 transients were between 175rad/s – 790rad/s
- Rest of the transients were under 175rad/s

Measurements in a datacenter

A. Nespola et al., "Proof of Concept of Polarization-Multiplexed PAM Using a Compact Si-Ph Device," in IEEE Photonics Technology Letters, vol. 31, no. 1, pp. 62-65, 1 Jan.1, 2019, doi: 10.1109/LPT.2018.2882888.

- Measurements made on installed cable in a datacenter of length ~1280m by looping back signal over 10 fibers in the cable and SOP monitored over 48hrs
- A couple of transient events were detected corresponding to a peak of 110rad/s and the timing matched a manual maintenance procedure when the fiber was hit by a tool



C. Doerr et. al. “Proposal for 800G-LR4 Optical PMD Based on DP-PAM4”, P802.3df contribution, https://www.ieee802.org/3/df/public/22_0609/doerr_3df_01a_220609.pdf

Arguing for a 200rad/s for 800G 10km application

Other References

- 40km fiber along a train route
  - *Peter Barcik and Petr Munster, "Measurement of slow and fast polarization transients on a fiber-optic testbed," Opt. Express 28, 15250-15257 (2020)*
  - Largest SOP transients (upto 3.6krad/s) recorded when the trains passed bridges where the buried cable was routed in a tray on the bridge
- Controlled test with a hammer
  - *J. E. Simsarian and P. J. Winzer, "Shake before break: Per-span fiber sensing with in-line polarization monitoring," 2017 Optical Fiber Communications Conference and Exhibition (OFC), Los Angeles, CA, USA, 2017, pp. 1-3.*
  - Test used a robotic hammer to strike an optical fiber
  - Measured transients less than 4krad/s
- Measurement of fast changes in DCF spools
  - P. M. Krummirich and K. Kotten, "Extremely fast (microsecond timescale) polarization changes in high speed long haul WDM transmission systems," Optical Fiber Communication Conference, 2004. OFC 2004, Los Angeles, CA, USA, 2004, pp. 3 pp. vol.2-.
  - This paper examined effects of mechanical disturbances such as dropping spools of fiber on table, hitting the cage with the fiber spool or hitting the fiber with various mechanical tools
  - Spools of standard mode fiber showed polarization changes on the order of 6krad/s
  - Spools of DCF showed polarizations changes as high as 280krad/s!