Proposal for 400GE Optical PMDs for SMF Objectives based on 4 x 100G DMT

David Lewis, Sacha Corbeil, Beck Mason

Summary

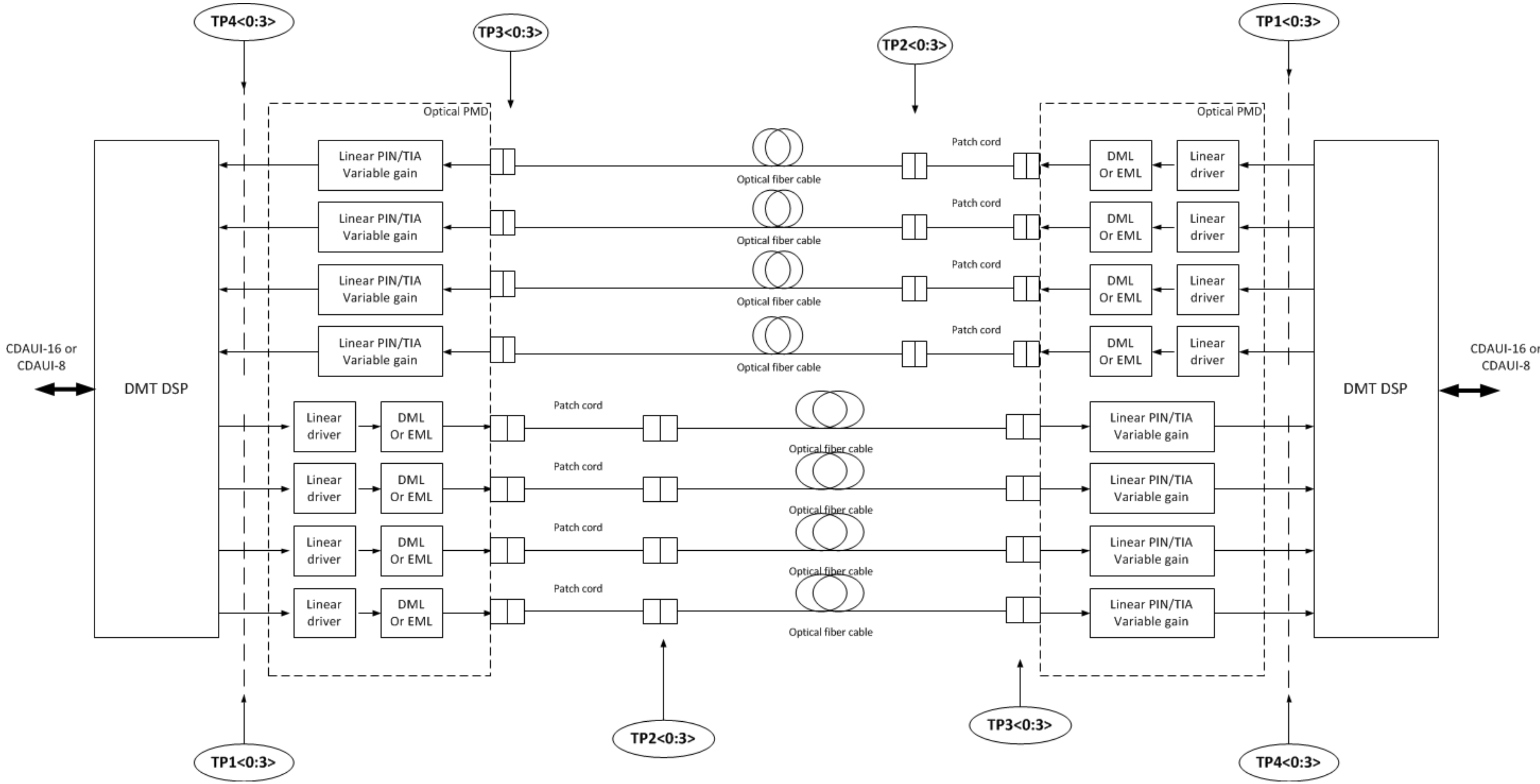
- 10km objectives (400GBASE-LR4) covered in takahara_3bs_01_1114

- This presentation provides the baseline proposals for
  - 500 m reach on parallel SMF (400GBASE-PSM4)
  - 2 km reach on duplex SMF (400GBASE-FR4)

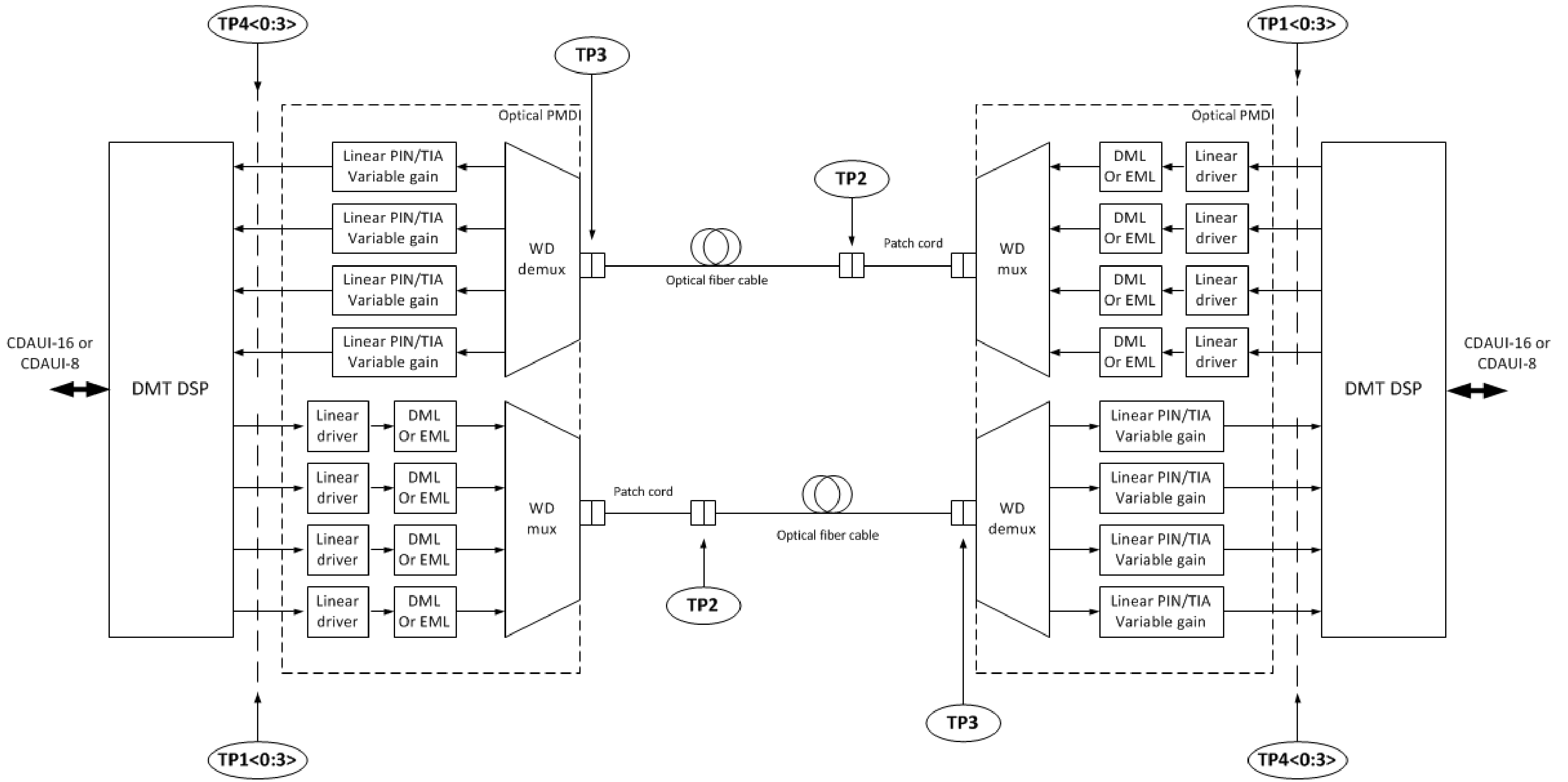
Supporters and Contributors

- Hisaya Sakamoto, Fujitsu Optical Components
- Hideki Isono, Fujitsu Optical Components
- Tomoo Takahara, Fujitsu Optical Components
- Toshiki Tanaka, Fujitsu
- Brian Tiepen, Adva Optical
- Moonsoo Park, OE-Solution
- YK Park, OE-Solution
- Ian Dedic, Fujitsu Semiconductor
- Patricia Bower, Fujitsu Semiconductor
- Bernd Nebendahl, Keysight Technologies
- Rolf Steiner, Keysight Technologies

PMD Block Diagram – for Parallel SMF (500 m reach)



PMD Block Diagram – for Duplex SMF (2 and 10 km reach)



JDSU

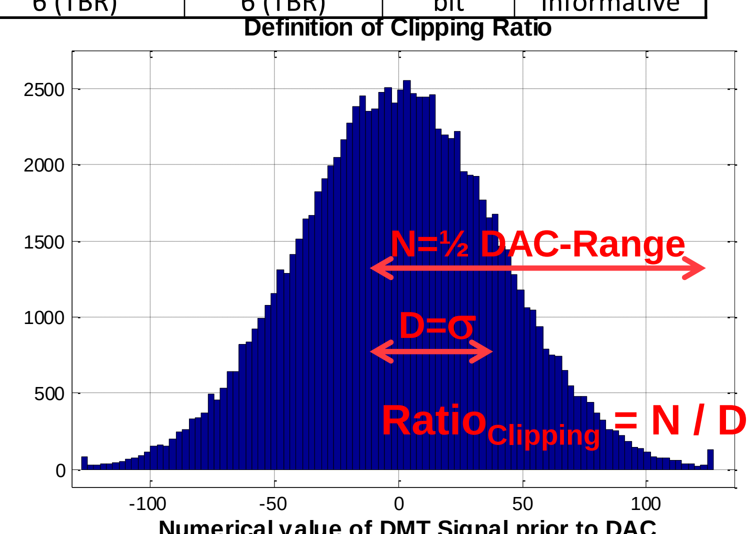
Transmitter Optical Specifications at TP2

Description	400GBASE-PSM4	400GBASE-FR4	400GBASE-LR4	Unit	Note
Input signaling rate, each lane (range)	103.125 +/-100 ppm			Gb/s	
Output signaling rate, each lane (range)	116.015625 +/-100 ppm			Gb/s	
Lane wavelengths (range)	1260 - 1355	1294.53 to 1296.59 1299.02 to 1301.09 1303.54 to 1305.63 1308.09 to 1310.19		nm	
Average launch power, each lane (max)	1.5	4.0	TBD	dBm	
Average launch power, each lane (min)	-1.5	1.0	2.8	dBm	
Dispersion and MPI penalties, each lane (max)	1.0	1.0	1.0	dB	
RIN, each lane, average (max)	-145	-145	-148	dB/Hz	
Optical return loss tolerance (max)	20	20		dB	
Transmitter reflectance (max)	-26	-26	-26	dB	
Optical modulation index			0.45		
Clipping Ratio (of numerical transmit data)	3.16	3.16	3.16		Tolerance TBD*
Cascaded Tx 3 dB electrical upper cutoff frequency (min)	15	15	15	GHz	Informative
Total harmonic distortion (max)	2	2	2	%	TBR
Effective number of bits for DAC	6 (TBR)	6 (TBR)	6 (TBR)	bit	Informative

- **Additional notes & definitions**

* **Clipping Ratio**: Defined here as the ratio to be maintained, by design, at the numerical generation of data at the transmitter, (i.e. prior to conversion to a voltage).

$$\text{Ratio}_{\text{Clipping}} = \frac{Range_{DAC}}{2\cdot\sigma_{Data}} = \frac{2^{\#bits}}{2\cdot\sigma_{Data}} = \frac{2^{(\#bits-1)}}{\sigma_{Data}}$$



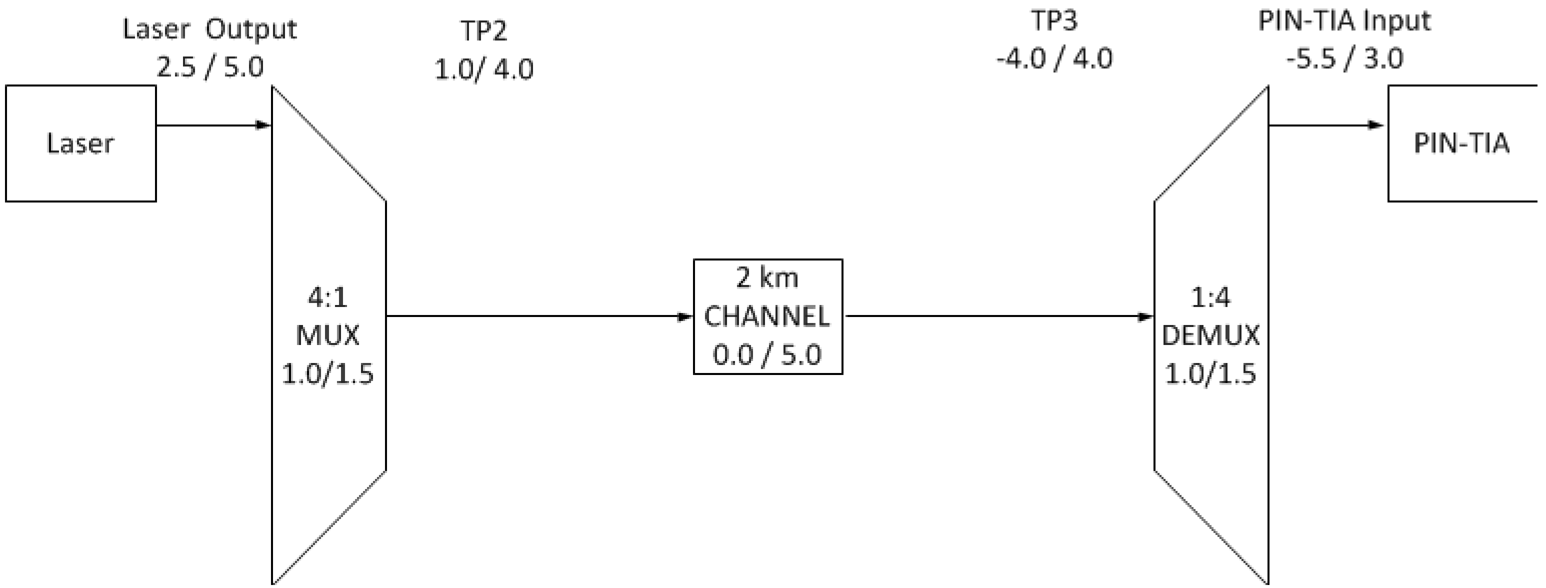
Receiver Optical Specifications at TP3

Description	400GBASE-PSM4	400GBASE-FR4	400GBASE-LR4	Unit	Note
Input signaling rate, each lane (range)	116.015625 +/-100 ppm			Gb/s	
Output signaling rate, each lane (range)	103.125 +/-100 ppm			Gb/s	
Lane wavelengths (range)	1260 - 1355	1294.53 to 1296.59 1299.02 to 1301.09 1303.54 to 1305.63 1308.09 to 1310.19		nm	
Damage threshold (min)	5.0	7.0		dBm	
Average receive power, each lane (max)	1.5	4.0		dBm	
Average receive power, each lane (min)	-5.5	-4.0	-5.0	dBm	*
Receiver reflectance (max)	-26			dB	
Receiver sensitivity (max)	-6.5	-5		dBm	**
Reference BER	3.3e-3				FEC threshold
Cascaded Rx 3dB electrical upper cutoff frequency (min)	15			GHz	informative
Total harmonic distortion, per component	2 (TBR)			%	informative
Effective number of bits for ADC	5.5 (TBR)			bit	informative

* Measured over fiber with worst-case transmission penalties included at reference BER.
** Measured in back-to-back condition (no dispersion), with typical Tx, at reference BER.

Optical Link Budgets

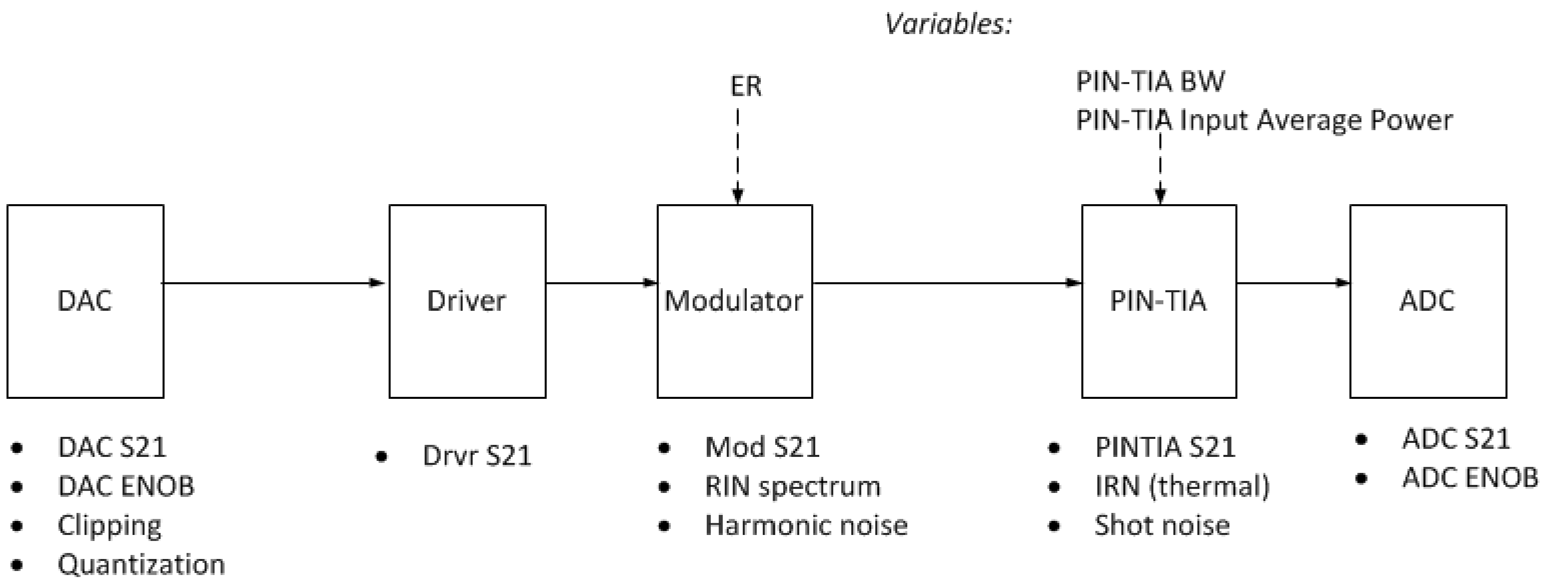
Description	400GBASE-PSM4	400GBASE-FR4	400GBASE-LR4	Unit	Note
Power budget at maximum TDP	5	6	7.8	dB	
Operating distance	500	2000	10000	m	
Channel insertion loss	4	5	6.3	dB	
Allocation for penalties	1	1	1.5	dB	
Additional insertion loss allowed	0	0	0	dB	



Min / Max average power in dBm for 2 km case

Reach Objective Feasibility

- The proposed reach objectives were verified in terms of sensitivity performance through noise modeling.
- The noise model takes into account the frequency response of all components in the transmission-chain, as well as noise contributions, and develops an SNR spectrum and DMT BER prediction.
- SNR spectrum and BER predictions correlate well with existing hardware measurements using both a DMT test-chip, as well as earlier DAC/ADC DMT implementations.



SNR Model Factors

Reach Objective Feasibility

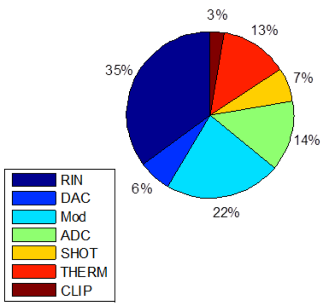
- Using the parameters specified in the table shown here, the proposed Average receive power range (per lane) was swept for each reach proposal (500m, 2km, 10km).
  - The range was exceeded by 1dB at both extremes to understand the margin.
- Rx PIN-TIA bandwidth was first approximated as a 4th order Bessel (swept over 3dB bandwidths from 17 to 24GHz), then using a target PIN-TIA with 20 GHz bandwidth and peaking near 17 GHz.
  - All modeled TIAs used the IRN profiles shown in following slides.
- For each Rx power, the Tx amplitude was also swept (characterized by extinction ratio at 8 GHz), to characterize the parameter space.

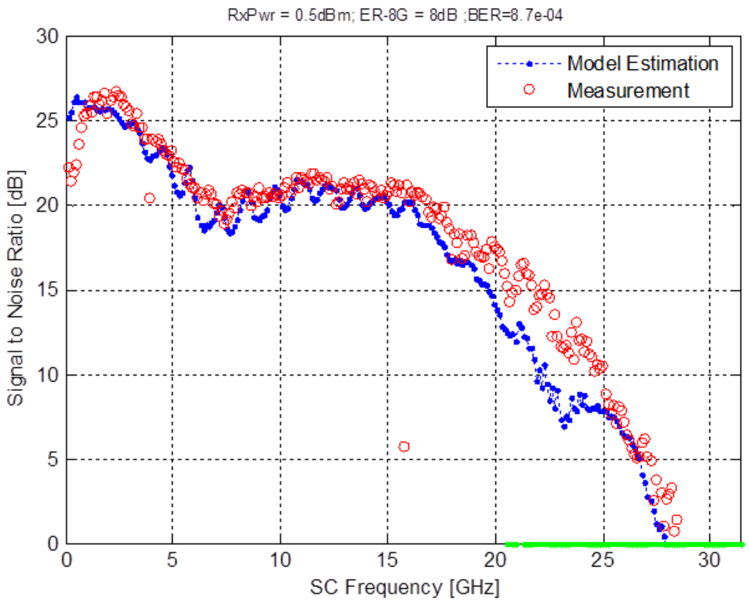
Parameter Values for following Results	
Parameter	**Value**
Data Rate	116 Gb/s
Sampling Rate	58 GS/s
Cyclic Prefix	16 samples
Clipping Ratio	3.16
Laser RIN, average	-145 dB/Hz
Input Referred Noise	Variable with Gain. < 12pA at high gain
DAC Bandwidth	14.5 GHz
Driver Bandwidth	28 GHz
Modulator BW	InP MZM, 27 GHz
PIN-TIA BW	Variable
ADC Bandwidth	19.3 GHz

Measured SNR data with 1310 EML

- Off-the-shelf 100G-LR4 1310nm Transmitter
- Actual measured SNR and BER results used to calibrate the DMT system model

Hardware	28nm DAC/ADC
Samp-Rate	63 GS/s
Data-Rate	116 Gb/s
Source	EML-TOSA DFB
Modulator	EML-TOSA EA
Ext-Ratio (8GHz)	Estimated at 8dB
Receiver	Disco R409
Rx Pwr	0.5 dBm
Meas BER	4.6e-4



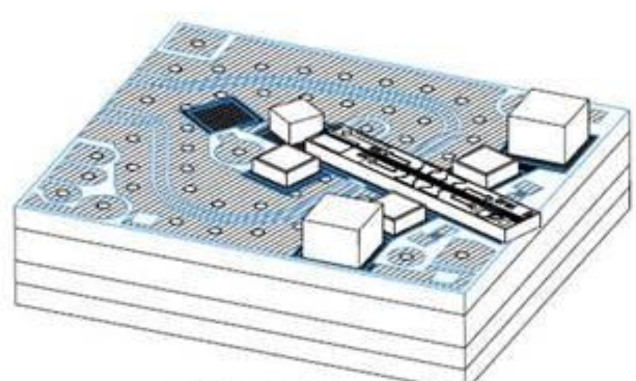


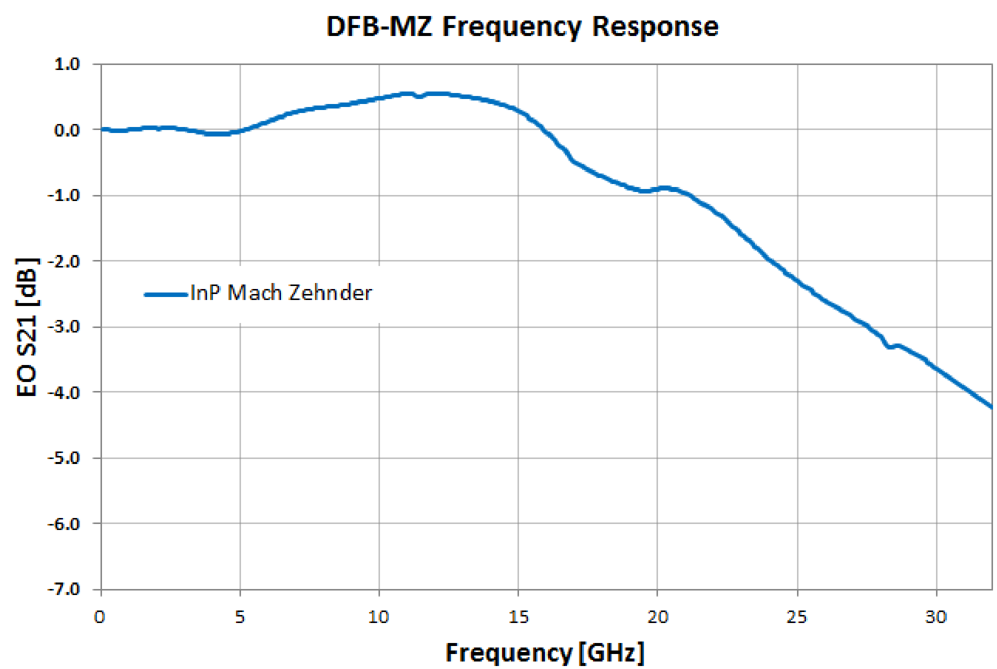
- Predicted SNR shows close agreement with measured SNR.
- Worst noise contributor is laser RIN, fol’d by harmonics from EA Modulator non-linearity then ADC & thermal
  - Integrated RIN of this device is -145 with a peak at -138 dB/Hz
  - Dip seen ~7GHz is due to RIN peak.

JDSU

Tx Used for Modeling: DFB-MZ

- We have demonstrated live-traffic 100G/λ DMT transmission using directly modulated 25G DFB lasers, EMLs, and MZMs
  - Traffic and BER performance were shown to be stable over >12 hour test
  - BER as low as 4E-5 demonstrated with MZM in a back-to-back configuration
  - Work showed that any of the three transmitter types could be used in the DMT application
- For the noise modeling in this proposal we have used an InP DFB-MZM frequency response and EO transfer function.

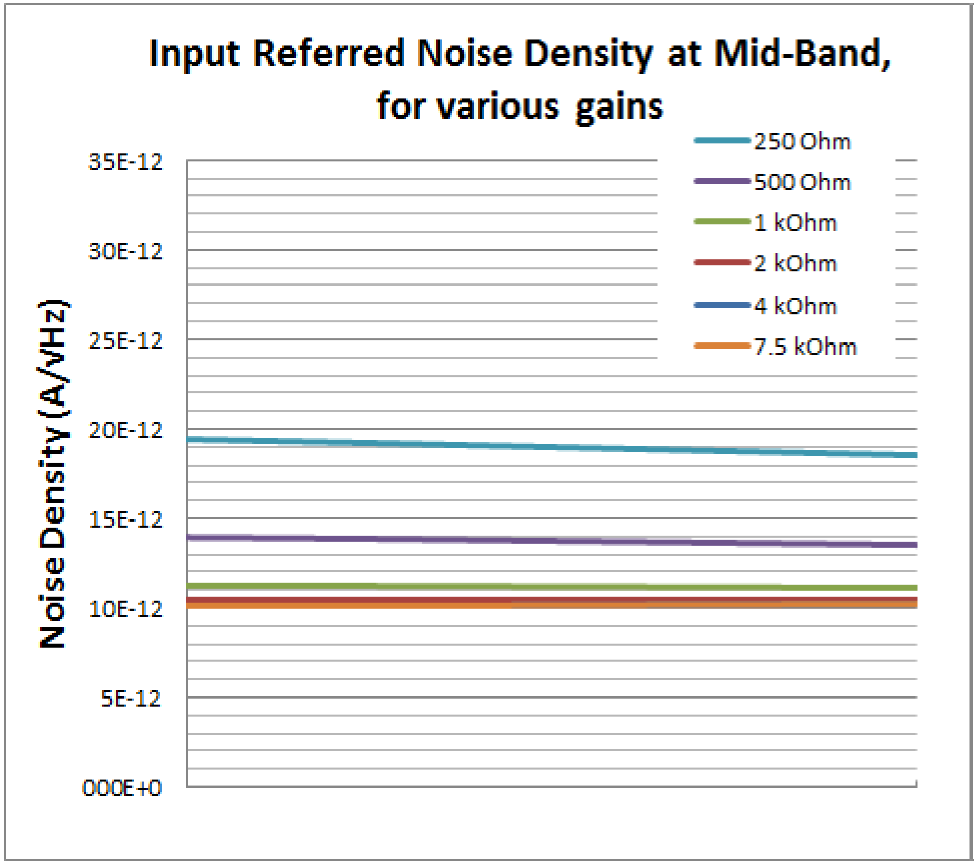


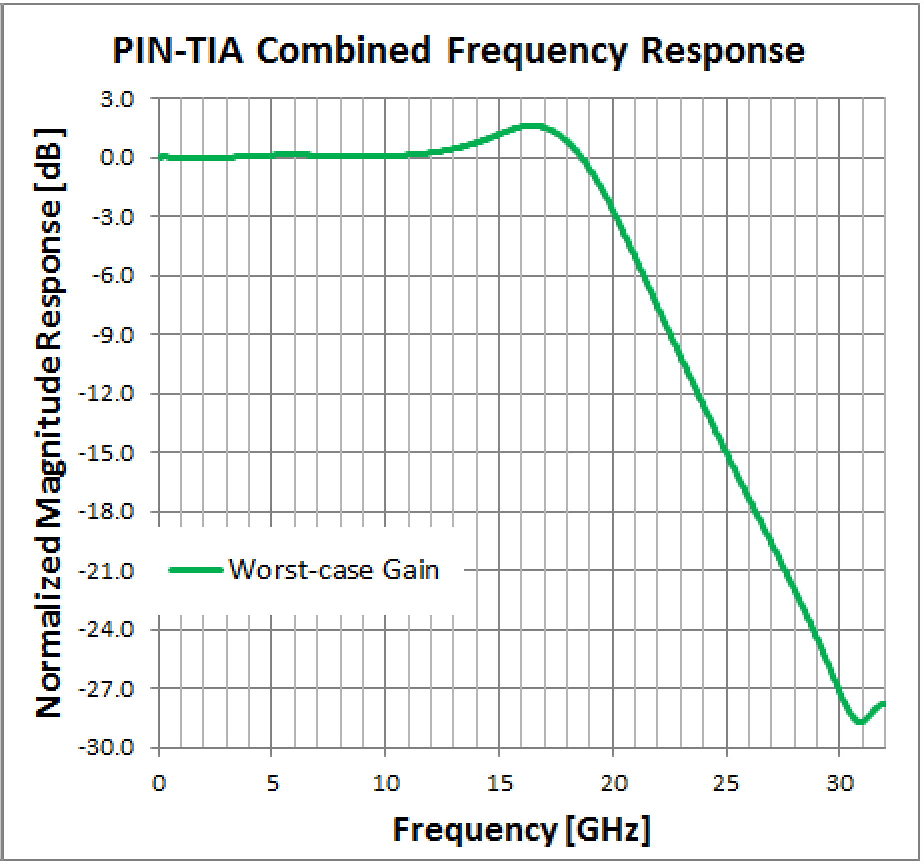


JDSU

Rx: PIN-TIA

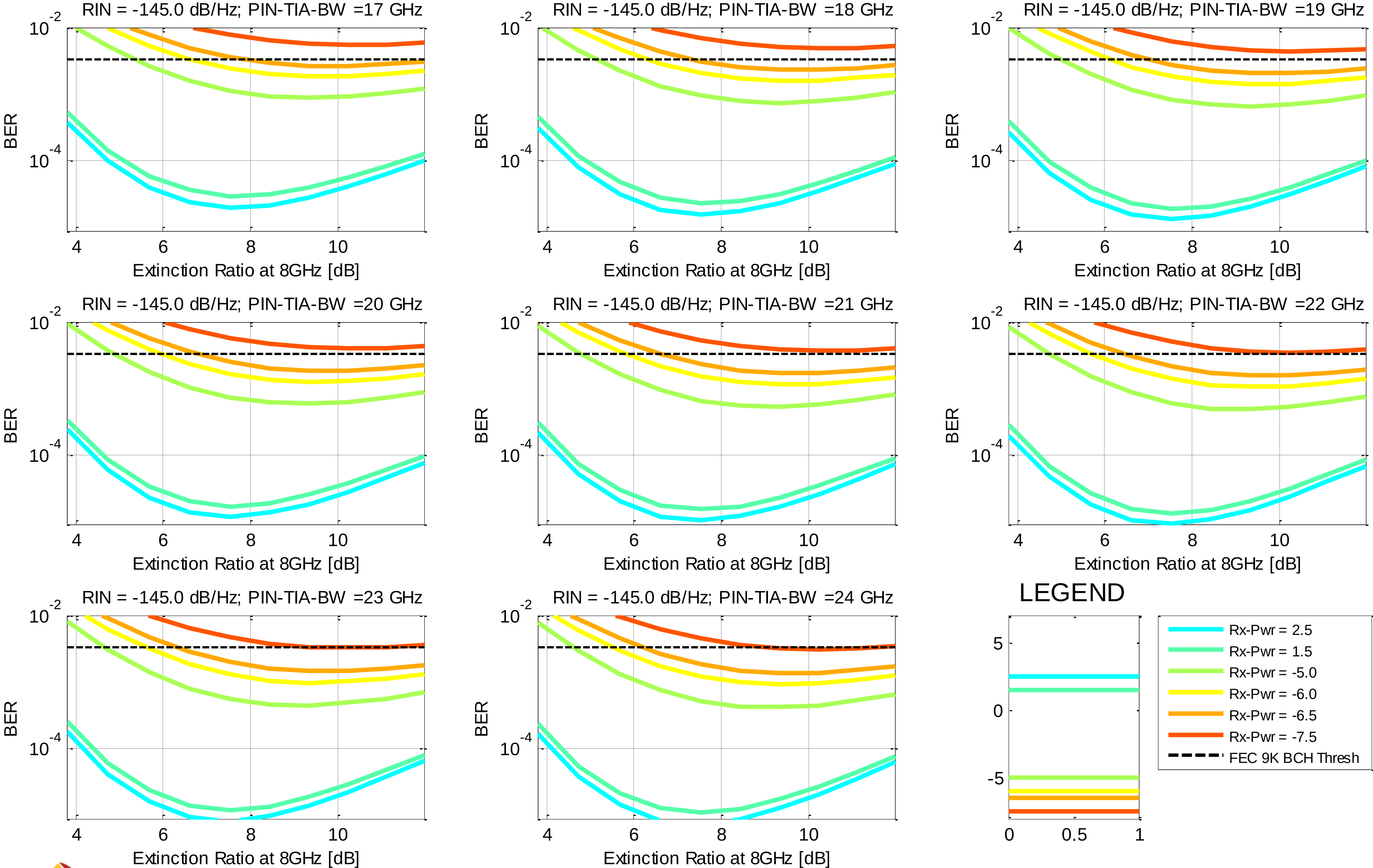
- One improvement required to enable DMT and other higher-order modulation formats for 400GE is lower IRN (*tipper_3bs_01a_0914*)
- TIA with IRN < 12pA/√Hz for gain > 1 kΩ is possible, and has been used in following results.





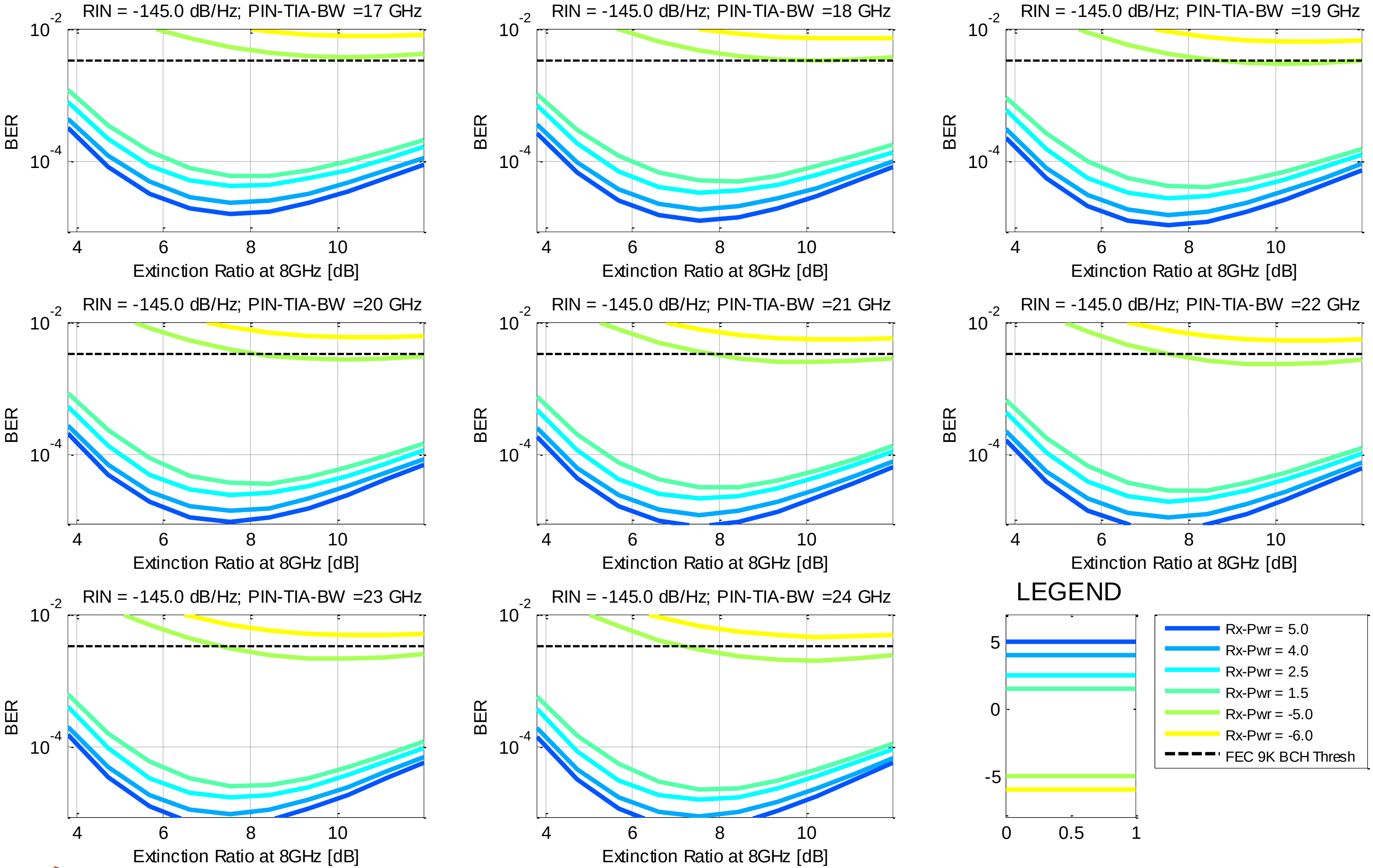
** Information in above charts courtesy of Semtech.*

500 m Feasibility



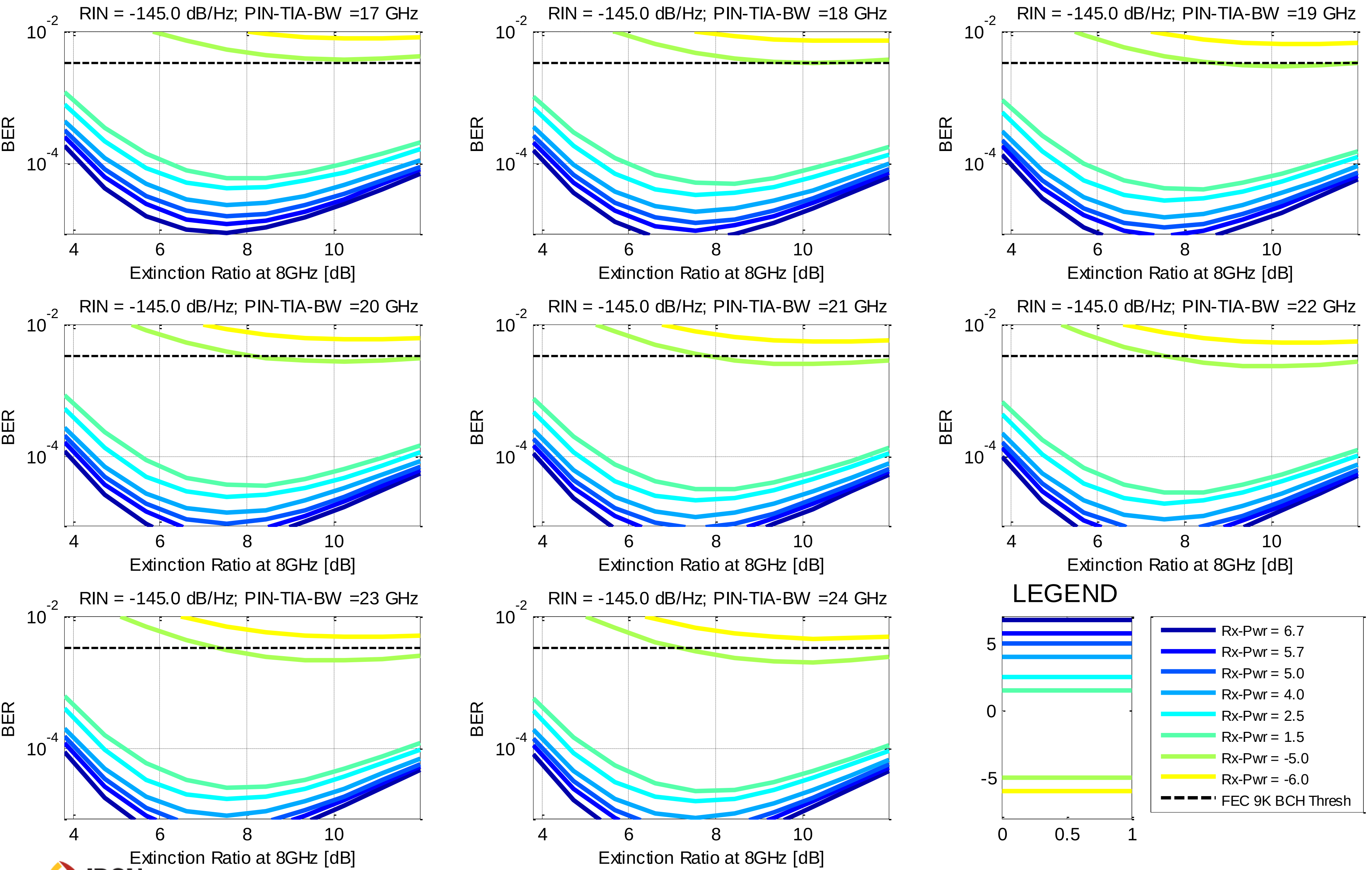
JDSU

2 km Feasibility



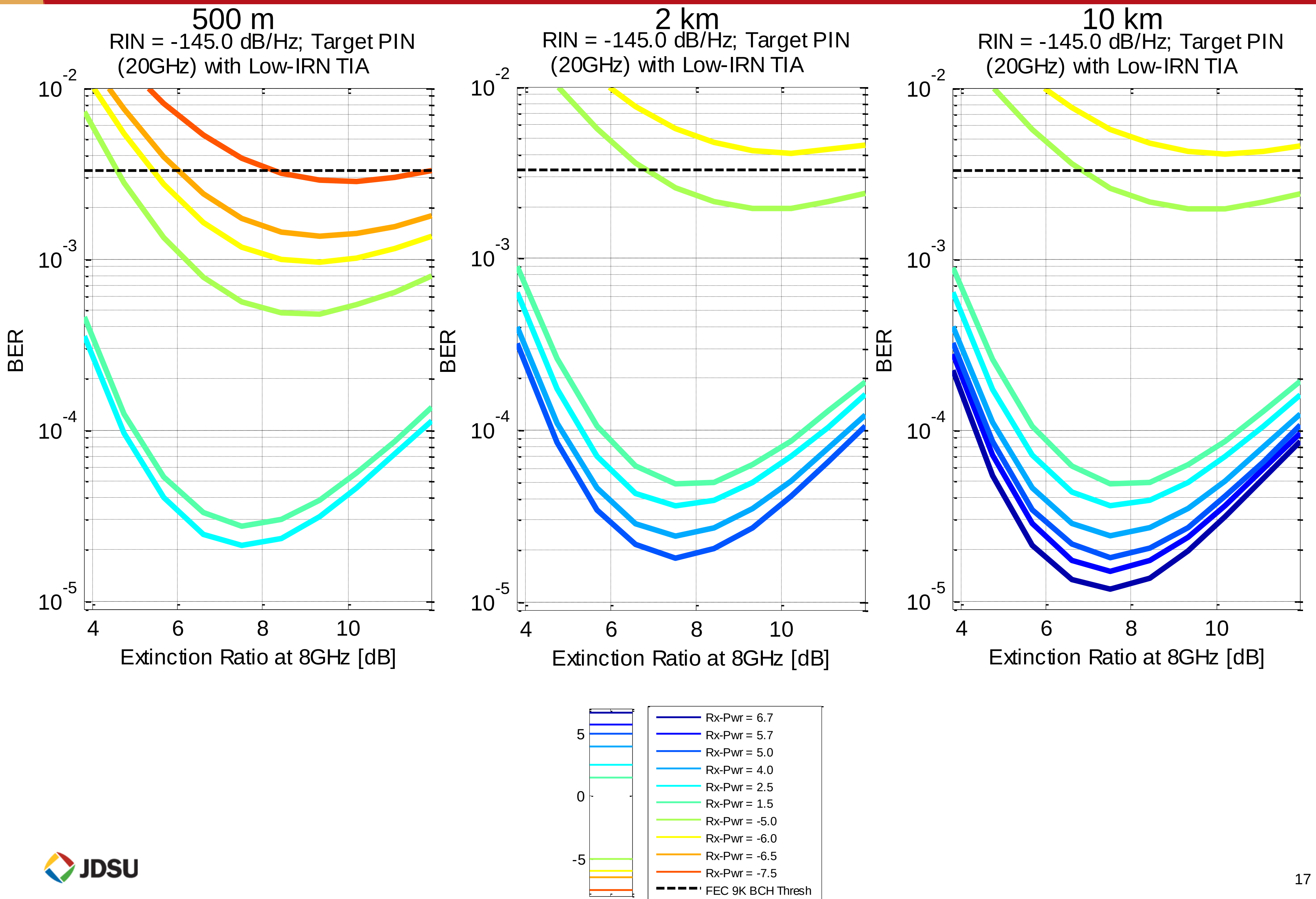
JDSU

10 km Feasibility



JDSU

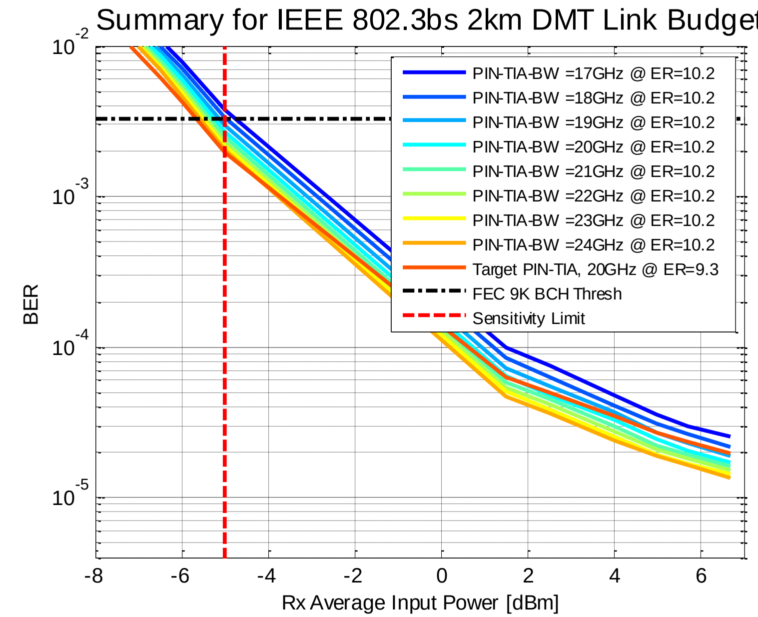
Target Receiver

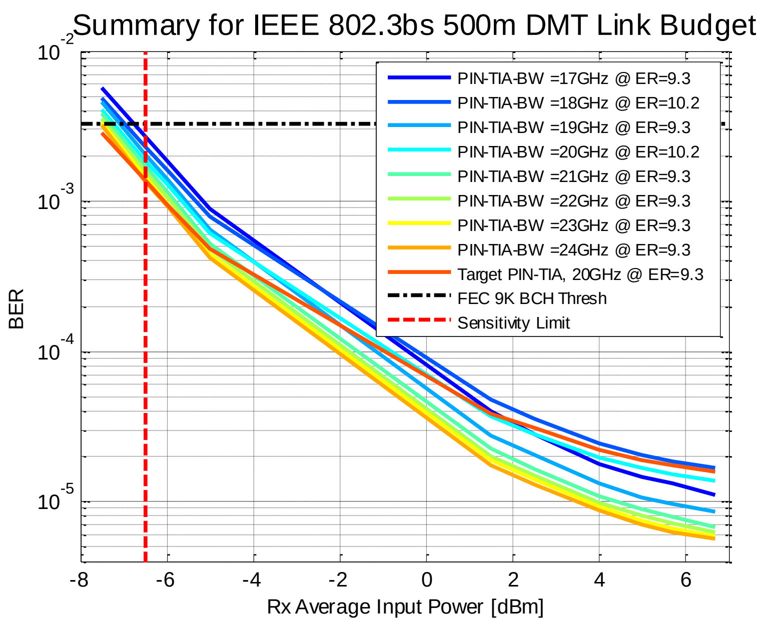


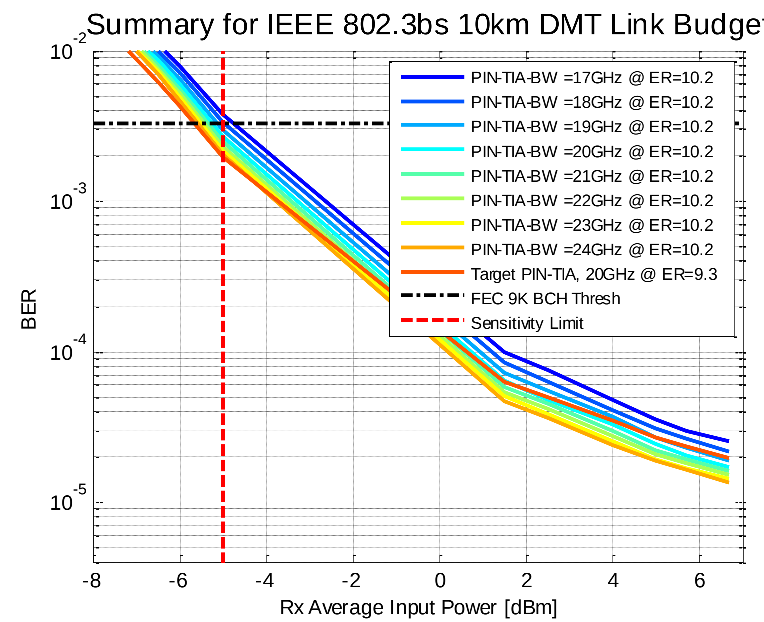
JDSU

Feasibility Summary

- Executive summary of results:
  - With PIN-TIA bandwidth >= 19 GHz, including the target PIN-TIA, and selecting the proper transmitter amplitude, the receiver sensitivity level can *always* be achieved below the FEC threshold for each of the reach objectives.
  - DMT is viable for the receive power ranges proposed for each reach objective (500 m, 2 km, 10 km)







JDSU

Conclusion

- Proposed baselines for 500 m SMF and 2 km SMF based on 4 x 100 Gb/s DMT
- Noise and bandwidth models developed and verified by comparison to live-traffic experiments with several different transmitter types
- Real receiver bandwidth and noise models at different gain settings used in verification analyses
- Modeling supports the proposed link budgets