Big Ticket Items for DMT

Sacha Corbeil, Ying Jiang, David Lewis, Brandon Collings

IEEE 802.3bs Task Force March 10th, 2015

Supporters

- Hisaya Sakamoto, Fujitsu Optical Components
- Hideki Isono, Fujitsu Optical Components
- Tomoo Takahara, Fujitsu Ltd.
- Toshiki Tanaka, Fujitsu Ltd.
- Martin Bouda, Fujitsu US
- Moonsoo Park, OE-Solution
- Bongsin Kwark, OE-Solution
- Ian Dedic, Socionext
- Markus Weber, Socionext
- Richard Castell, Socionext
- Michael Kaushke, Socionext
- Brian Teipen, Adva
- Sven Krueger, H&S Cube Optics
- Paul Brooks, JDSU T&M

Outline

- Big Ticket item overview/checklist
- Introduction and Purpose
- Proposed modifications to 10km DMT proposal
- Chromatic Dispersion Tolerance
- Cost and Power Comparison
- Summary
- Next Steps

Big Ticket Item Overview and Checklist

- Proposals
  - takahara_3bs_01_1114 (DMT)
  - corbeil_3bs_01_0115 (DMT)
- Actions

Evaluate Coupling between electrical and optical interfaces	➢ **update by May interim**
RX Technical feasibility	➢ **this presentation (simulations)** ➢ **by May interim (measurements)**
Dispersion penalty worst case	➢ **tanaka_01_0215_smf & here (simulations)** ➢ **more measurements by May interim**
TDP MPI	➢ **this presentation (simulations)** ➢ **tanaka_3bs_01a_0115 (measurements)**
RX sensitivity	➢ **this presentation (simulations)** ➢ **by May interim (measurements)**
Optical loss budget model	➢ **update at May interim**
Interoperability	➢ **update at May interim**

JDSU

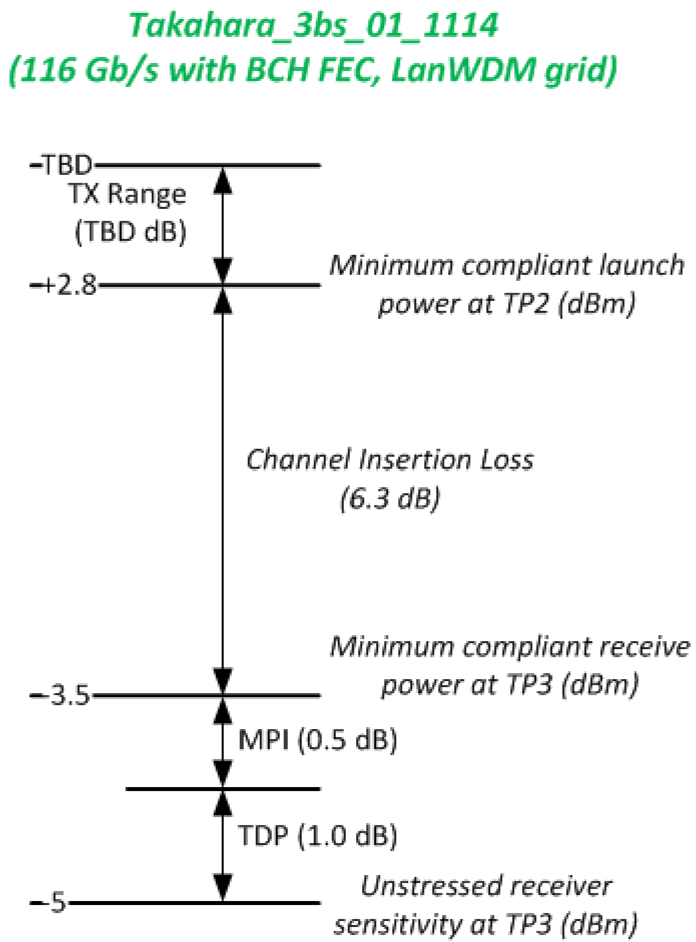
Proposed Modifications to 10km DMT proposal

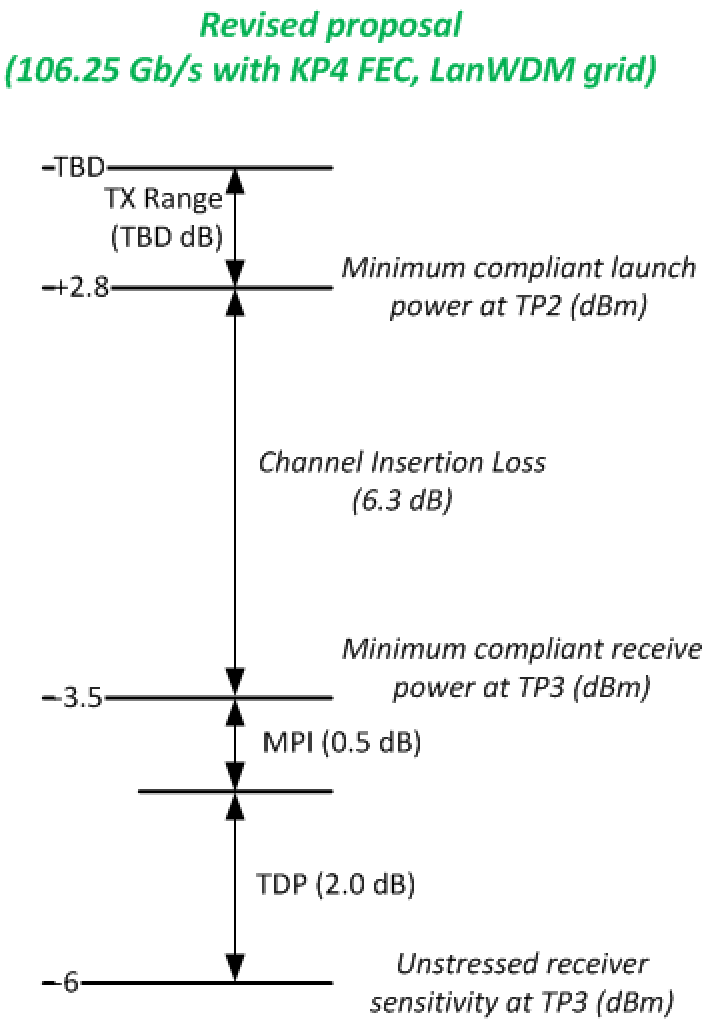
- Based on DMT link simulations at 106.25 Gb/s rate and max BER of 2E-4 we conclude that it is feasible to drop the BCH FEC and rely on host implemented KP4 FEC
  - Increase minimum cascaded Tx and Rx bandwidths from 15 to 20 GHz
  - Unstressed Rx sensitivity from -5 to -6 dBm (informative)
  - TDP from 1.0 to 2.0 dB
  - Minimum average power at receiver = -3.5 dBm (equivalent to stressed sensitivity)

- Propose to stay with LanWDM grid for now, but the penalties of moving to CWDM are low
  - Plan to work on this and report back at future task force meeting
  - Our goal is to move to the CWDM grid for lowest power and cost

- The following slides present the basis for these proposed changes

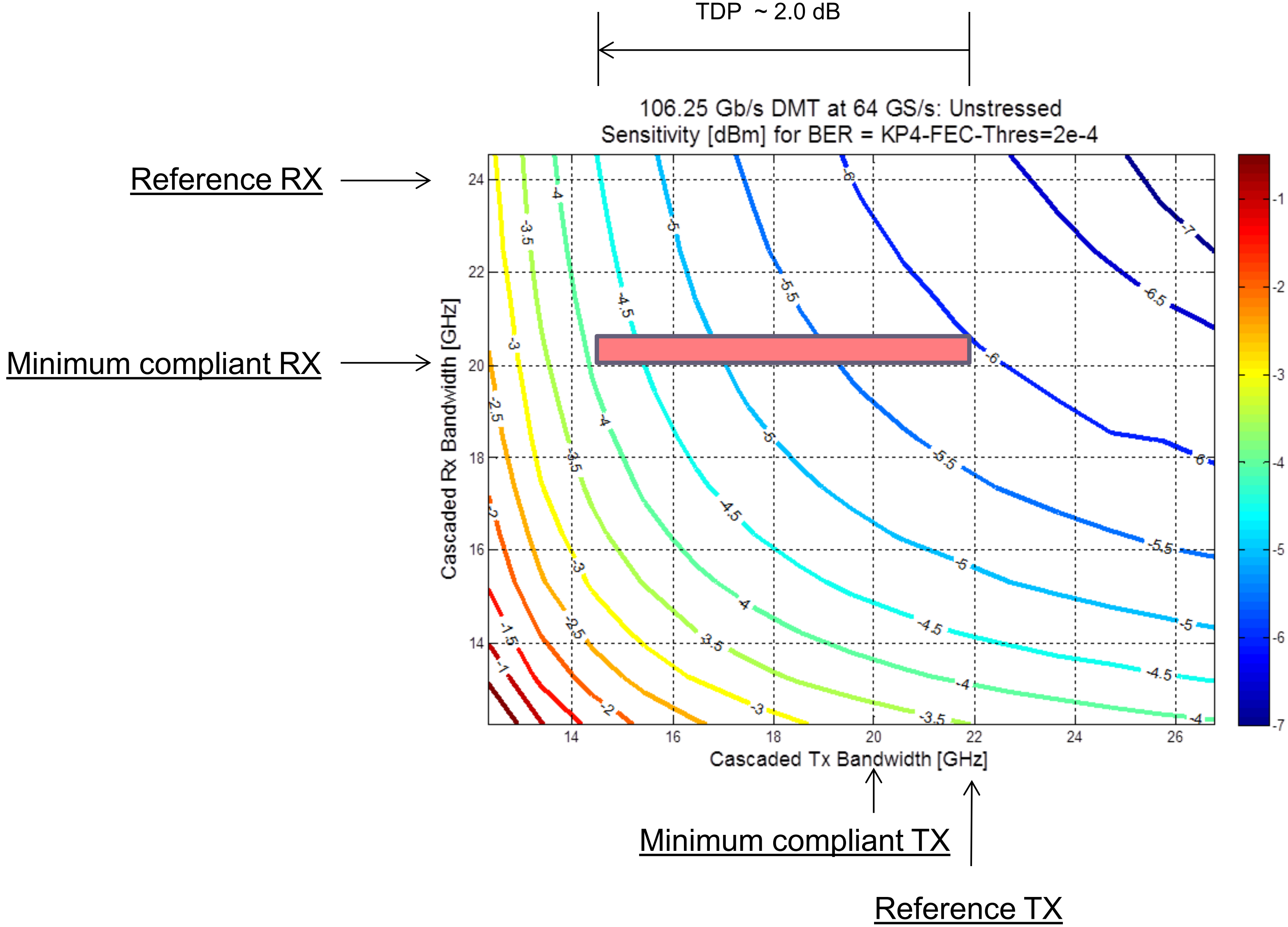
Changes to Link Power Budget





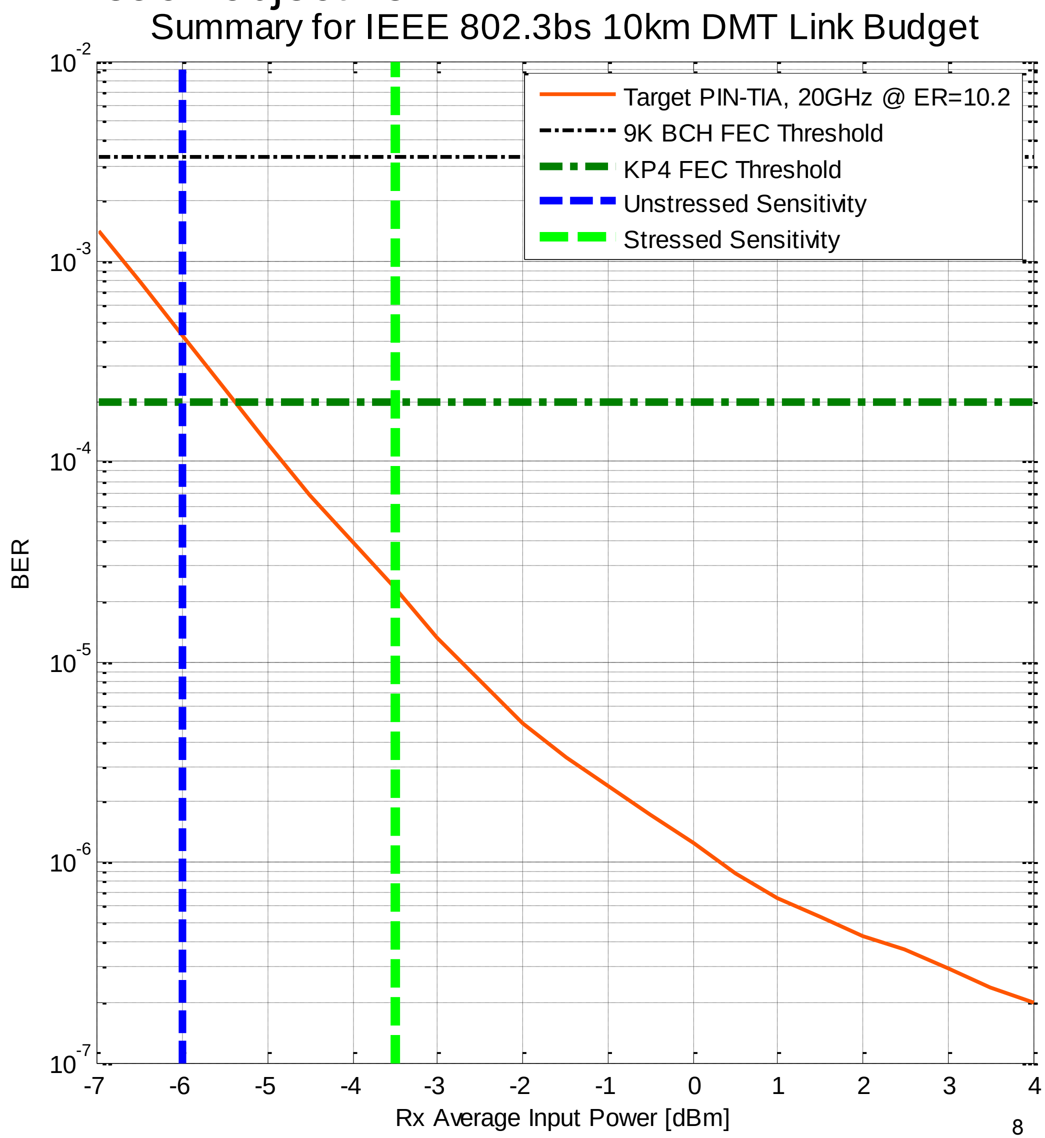
- Increase of cascaded Tx BW from 15 to 20GHz allows for lower unstressed sensitivity – and a higher TDP value

Illustration of Sensitivity and TDP derivation



KP4 for DMT – Feasibility Study

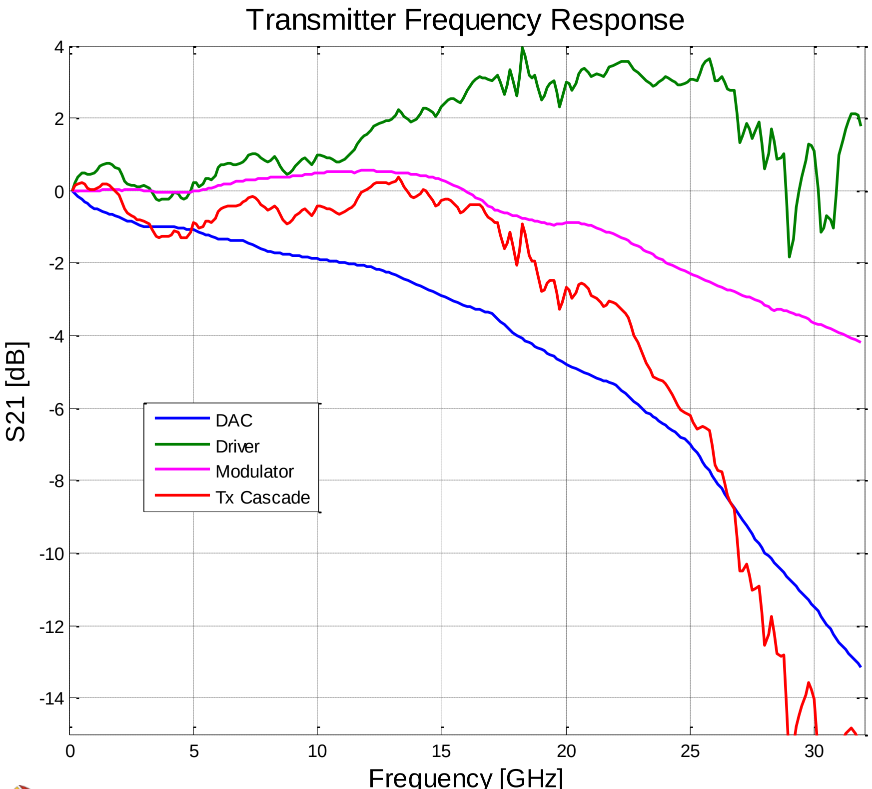
- Using same realistic component parameters as for Nov'14 proposal, we demonstrate feasibility over the 10 km reach objective.
  - OMA corresponds to optimal for performance at sensitivity. Approximately 10 dB at 2 GHz.
- RIN: 1310 DFB
  - Integrated (average) -145 dB/Hz,
  - Peak ~ -138 dB/Hz near 7 GHz
- Low IRN PIN-TIA
  - 12-15 pA/√Hz at High Gain
- DMT Specifics:
  - Clipping Ratio of 3.16 (peak/RMS)
  - Cyclic-Prefix of 8
  - Sample-Rate of 64 GS/s
  - 256 sub-carriers

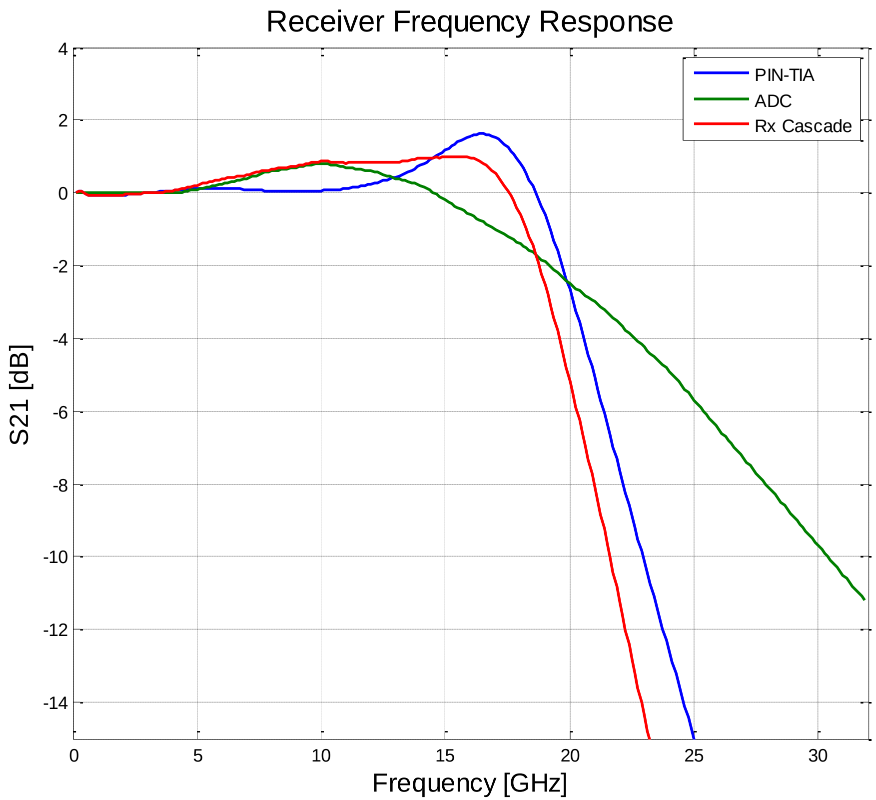


JDSU

KP4 for DMT – Feasibility Study - Conditions

- Data-Rate = 106.25 Gb/s, Sample-Rate = 64 GS/s
  - DAC ~15.5 GHz 3dB BW
  - Peaking Driver to compensate for bandwidth of DAC
  - Modulator is InPh MZ with High-Vpi, ~27 GHz Bandwidth,
  - ADC ~21 GHz 3dB BW
  - Some Peaking in PIN TIA and ADC



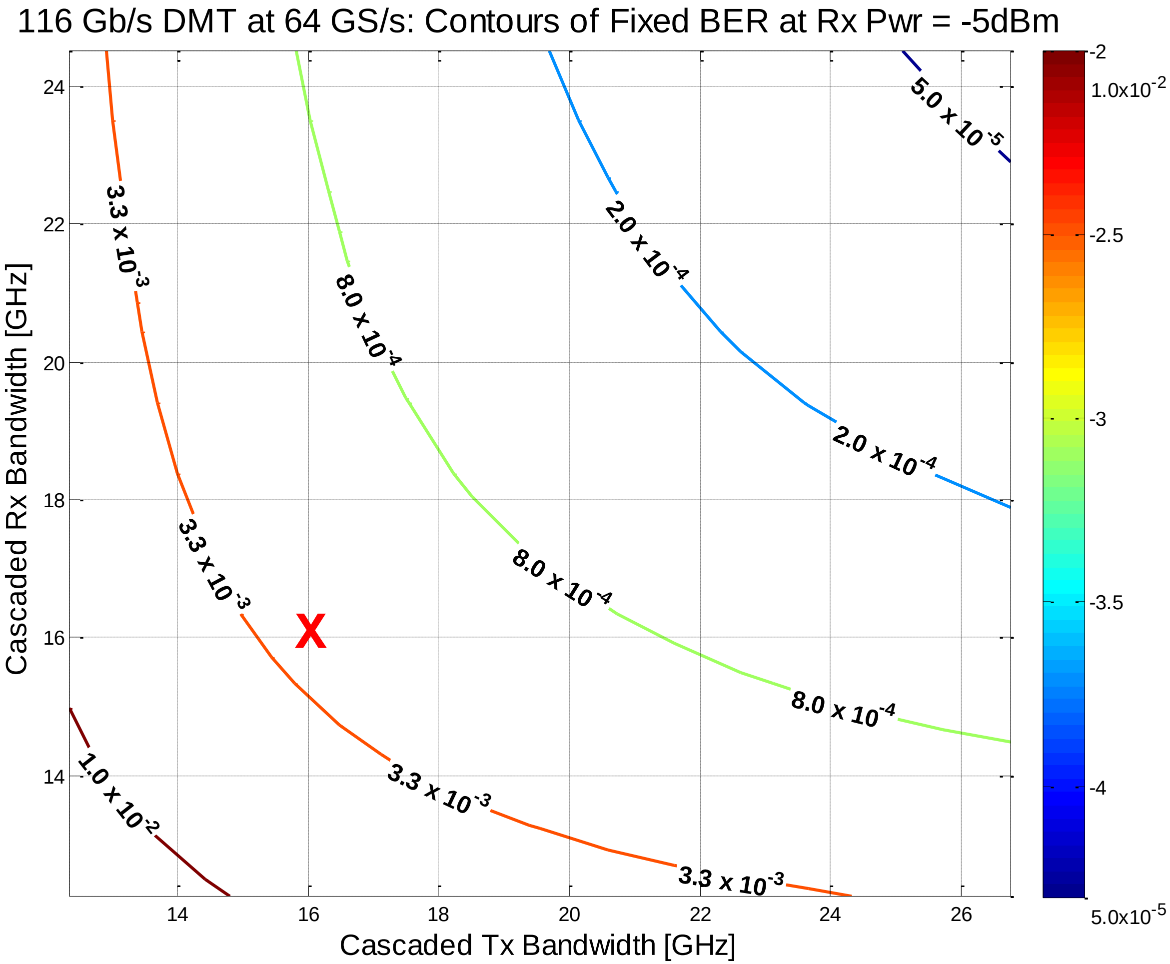


JDSU

KP4 Feasibility Study – Simulated BER contours at 116 Gb/s

- Initial DMT research led us to requiring a high coding gain FEC, pushing the line-rate to 116 Gb/s due to overhead required to maintain low latency
- We projected cascaded Tx & Rx Bandwidth each of ~15 GHz, placing us near the red **X**.

  - Contours shown on this plot use ideal 4th order Bessel responses to mimic DAC, Driver, Modulator, ADC and PIN-TIA.
  - All three Tx components are kept equal in bandwidth in order to give desired cascaded bandwidth
  - Ditto for both Rx components.
  - Noise sources (RIN and IRN) same as in previous slides.

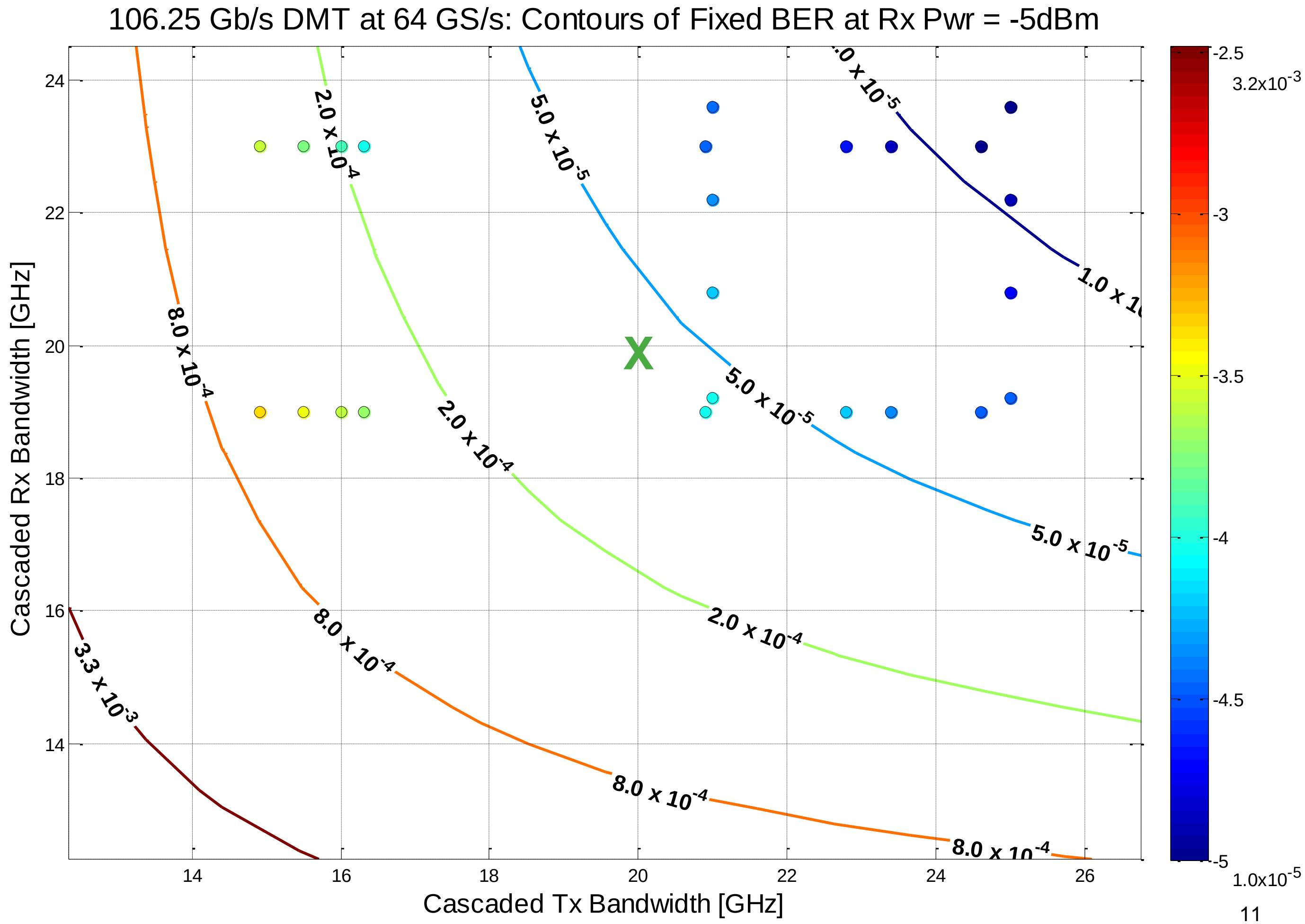


JDSU

KP4 Feasibility Study– Simulated BER contours at 106.25 Gb/s

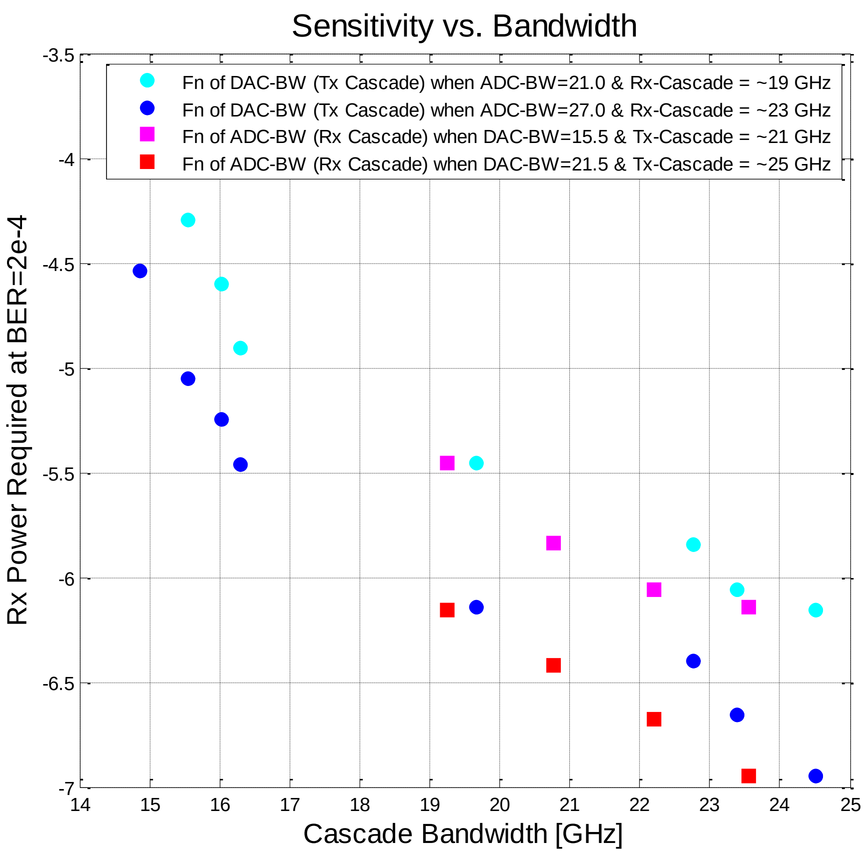
- Lower line-rate of KP4 (106.25 Gb/s) helps in achieving better performance with same components.
- Component availability in 2018 will yield higher bandwidth, placing us closer to the Green **X**.

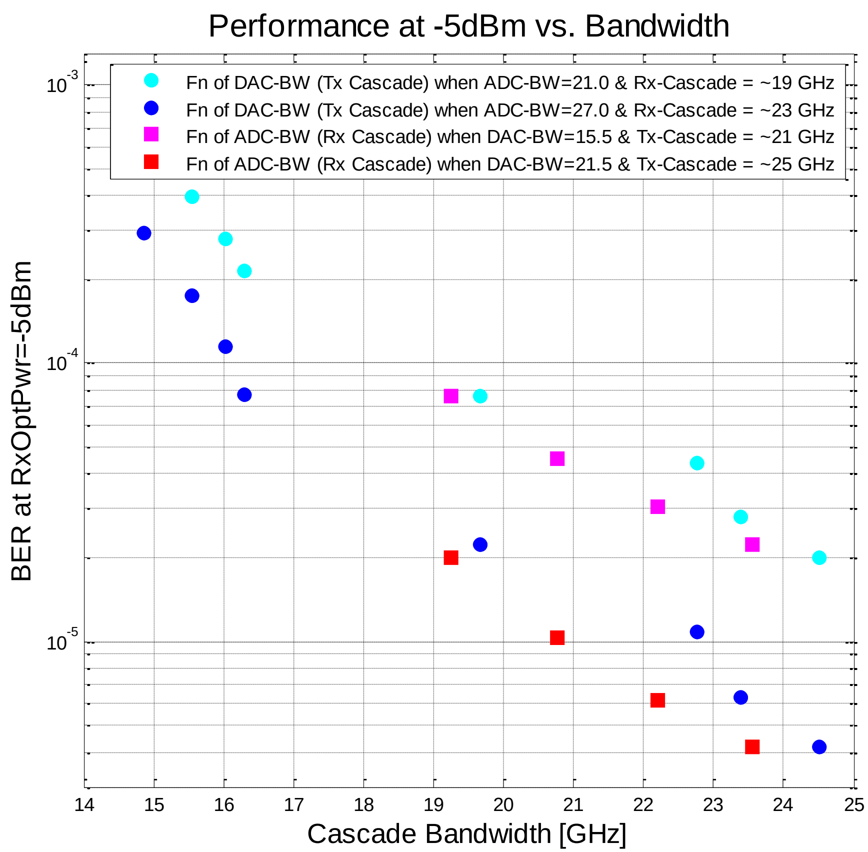
- Data points (colored circles shows noise model simulations based on more realistic data, still using the Tx cascade 3dB BW as a figure of merit.
- BER information is in color-coding: good match with generic component contour predictions.



JDSU

KP4 Feasibility Study– Simulated BER Dependence on Tx and Rx Bandwidth





JDSU

Proposed DMT PMA Functional Specifications

- DMT Detail Table for each λ of 400GbE
  - adapted from takahara_3bs_01_1114.pdf

Description	Symbol	Value	Unit	Note
100G per λ Bit-Rate	B_R	106.250	Gb/s	Assumes KP4 FEC on 100G
Sample Rate	F_S	63.947	GS/s	
Number of Subcarriers	N_{FFT} / 2	256		Nominal ,and related to FFT size: only 253 data-carrying subcarriers
Subcarrier spacing [MHz]	ΔF	124.896	MHz	
Lowest subcarrier (#1)	F_{sc001}	124.896	MHz	
Highest subcarrier (#255)	F_{sc255}	31.848	GHz	
Cyclic Prefix Length	N_{CP}	8	samples	
# Samples/DMT – symbol	$N_{FFT} + N_{CP}$	520	samples	
Symbol Rate [MHz]	$F_F = F_S / (N_{FFT} + N_{CP})$	122.975	MHz	
# Bits / DMT Symbol	$b_F = B_R / F_F$	864	bits	
Frame Synchronization Pilot Tone subcarriers		65, 66	TBC	
	F_{sc065}	8.118	GHz	
	F_{sc066}	8.243	GHz	
Additional FEC overhead		0	%	No FEC added in this proposal

- ASIC Related parameters:

Latency Target	225	ns

JDSU

Chromatic Dispersion: Propagation Simulations of DMT Tolerance

- DMT Specifics
  - Clipping Ratio of 3.16 (peak/RMS)
  - Cyclic-Prefix of 8
  - Sample-Rate of 64 GS/s
  - 256 sub-carriers
- Laser RIN
  - Integrated (average) -145 dB/Hz
- PIN-TIA
  - 15 pA/√Hz at High Gain
- Transmitter and Receiver bw
  - The transmitter and receiver bandwidth are represented by a single 4th order Bessel filter

Note that there is a difference between these propagation simulations and the noise-model results from slides 7-12.

Propagation simulations use conventional fiber propagation models (VPI) and a DMT front end and back end to transmit and receive a DMT signal

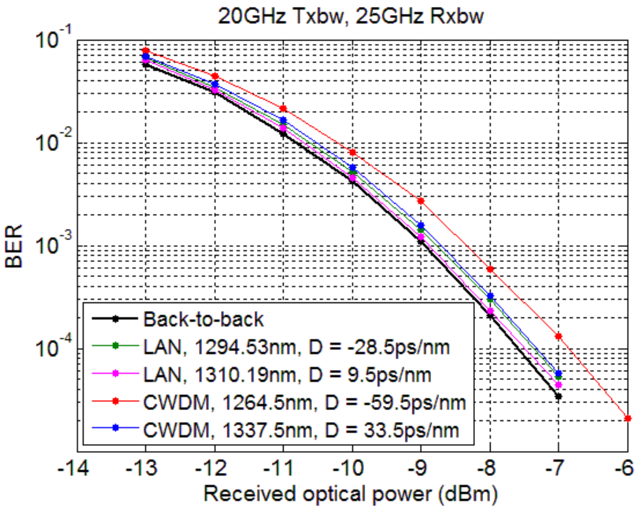
Noise model (Model) uses forward frequency responses and noise spectra to estimate the BER performance of each subcarrier.

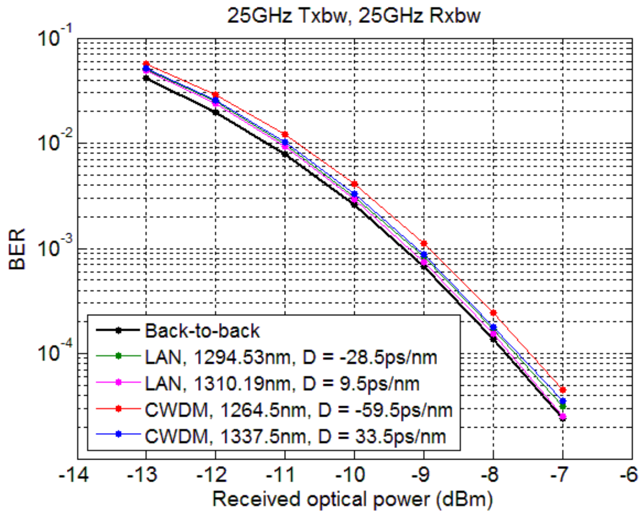
There are Rx power discrepancies between the two, because the component models used in the propagation simulations are not as refined and detailed as in the noise model.

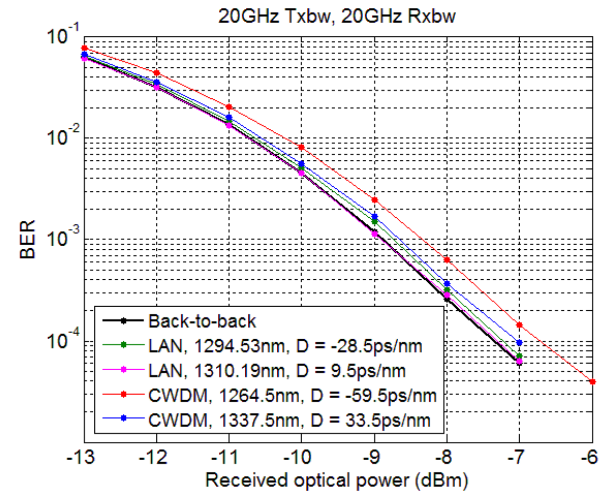
Our expectation is that the penalty trends derived from the propagation simulation results should hold despite the discrepancy.

Chromatic Dispersion: Simulated BER vs Power, varying Tx BW

- Penalty with 20 GHz Tx BW is < 1.0 dB for CWDM grid over 10 km
- With 25 GHz Tx, penalty is reduced to < 0.5 dB
- These simulated penalties are well below the proposed TDP value of 2.0 dB
- CD tolerance is low enough to consider the CWDM grid for 10km SMF

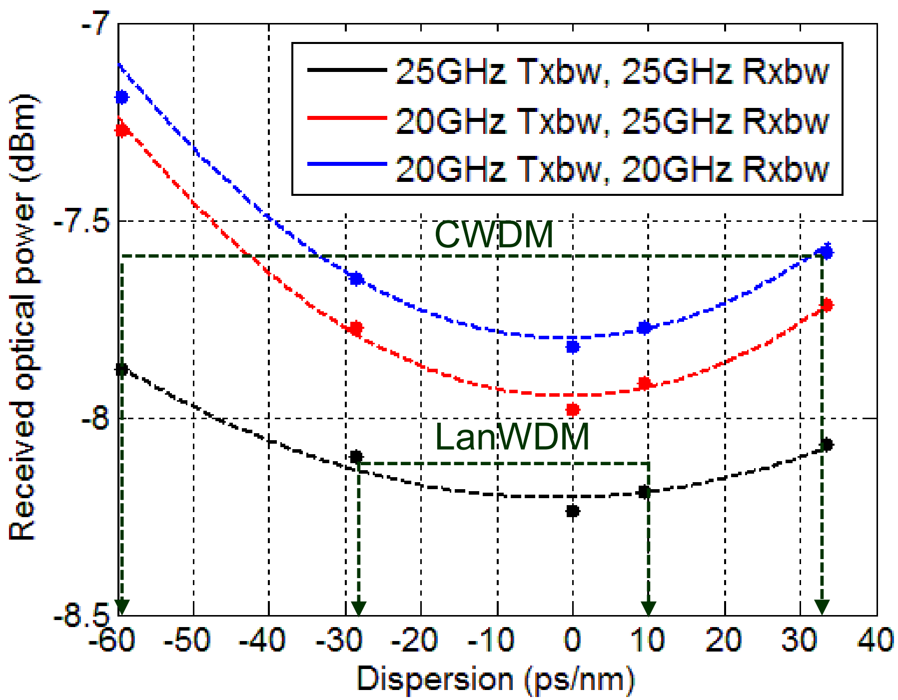


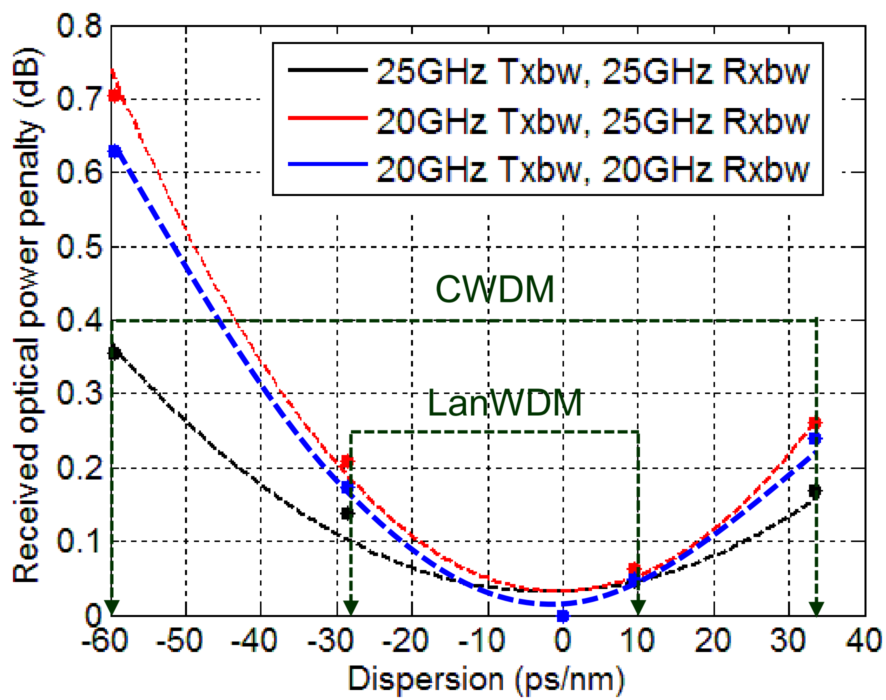




Chromatic Dispersion:
Simulated combined penalty for Tx BW and Dispersion

- Penalty < 0.2 dB over 10 km with LanWDM grid
- Penalty < 0.4 dB for 10 km, CWDM grid, 25GHz Tx BW, 25GHz Rx BW
- Penalty < 0.8 dB for 10 km, CWDM grid, 20GHz Tx BW, 25 GHz Rx BW
- Penalty < 0.7 dB for 10 km, CWDM grid, 20GHz Tx BW, 20 GHz Rx BW
- Measurements planned by May interim meeting





JDSU

Estimated Module Power Consumption – 10km proposals

		2km (1)	2km (2)	Estimated 10km	Comments on 10km column
8x50G-NRZ LanWDM_8	TX	3.4	6.1	4.3	40GHz cooled EML, 0dBm at TP2, limiting driver x 8
	RX	0.9	2.4	2.2	40GHz PD- limiting TIA x 8
	DSP/CDR	1.2	2.0	3.8	Ref (1). Average electrical I/O and 50Gb/s CDRs
	Other	3.4	0.4	0.5	
	Total	8.9	10.9	10.8	
8x50G-PAM4 LanWDM_8	TX	3.1	6.0	4.5	30GHz cooled EML, 1dBm at TP2, limiting driver x 8
	RX	0.8	1.6	2.2	30GHz PD-linear TIA x 8
	DSP/CDR	1.6	4.8	4.2	Ref (1). Average electrical I/O plus PAM4 decoder.
	Other	3.4	0.4	0.5	
	Total	8.8	12.8	11.3	
4x100G-PAM4 CWDM_4	TX	2.1	2.9		
	RX	0.6	1.4		
	DSP/CDR	1.2	4.2		
	Other	3.4	0.3		
	Total	7.2	8.8		
4x100G-DMT LanWDM_4	TX			2.3	25GHz cooled DML, 4dBm at TP2, linear driver x 4
	RX			1.1	25GHz PD-linear TIA x 4
	DSP/CDR			7.2	100G DMT DSP without FEC x 4
	Other			0.5	
	Total			11.1	
4x100G-DMT CWDM_4	TX			2.0	25GHz uncooled DML, 4dBm at TP2, linear driver x 4
	RX			1.1	25GHz PD-linear TIA x 4
	DSP/CDR			7.2	400G DMT DSP without FEC x 1
	Other			0.5	
	Total			10.8	

(1) welch_3bs_02a_0115
(2) rao_3bs_01a_0115

Conclusion is that 4x100G DMT is at parity with 8x50G approaches

Estimated Module Relative Costs – 10km proposals

		DMT	PAM4	NRZ
		4x100G	8x50G	8x50G
TX	Optical MUX	1	1.2	1.2
	DML/EML	1	2	2.5
	Driver	1	2	2.5
RX	Optical Demux	1	1.2	1.2
	PD Array	1	1.5	1.5
	TIA Array	1	1.5	2
IC	DSP	1	-	-
	PAM/EncDec	-	1	-
	CDAUI Interface	-	-	1

- TX and RX for 4x100G is always the lowest cost due to:
  - 4-wide versus 8-wide
  - Similar bandwidth to 8x50G PAM4 but ~50% bandwidth of 8x50G NRZ
- Total IC/non-optics cost for high volume modules tends to < 25% of total cost *
  - Not able to estimate relative cost for ICs at this time

** Based on experience at 10G/40G/100G pluggable modules*

JDSU

Summary

- We propose to eliminate the BCH requirement and rely on KP4 FEC as for other proposals
- The cascaded Tx and Rx bandwidths required (20 GHz) can be demonstrated now and is reasonable for volume production as 400GE starts to be implemented
- CD penalty low and allows CWDM
- Cost and power is advantageous for WDM and even better for CWDM
  - Using CWDM grid allows for reuse of 100G CWDM devices which are already ramping towards high volume

Next Steps - BTIs

- Evaluate Coupling between electrical and optical interfaces
  - ➢ **update by May interim**
- RX Technical feasibility
  - ➢ **by May interim (measurements)**
- Dispersion penalty worst case
  - ➢ **more measurements by May interim**
- TDP. MPI
  - ➢ **tanaka_3bs_01a_0115 (measurements)**
- RX sensitivity
  - ➢ **by May interim (measurements)**
- Optical loss budget model
  - ➢ **update at May interim**
- Interoperability
  - ➢ **update at May interim**

Thank You