Super-PON Link Budget Analysis

IEEE P802.3cs, May 2019

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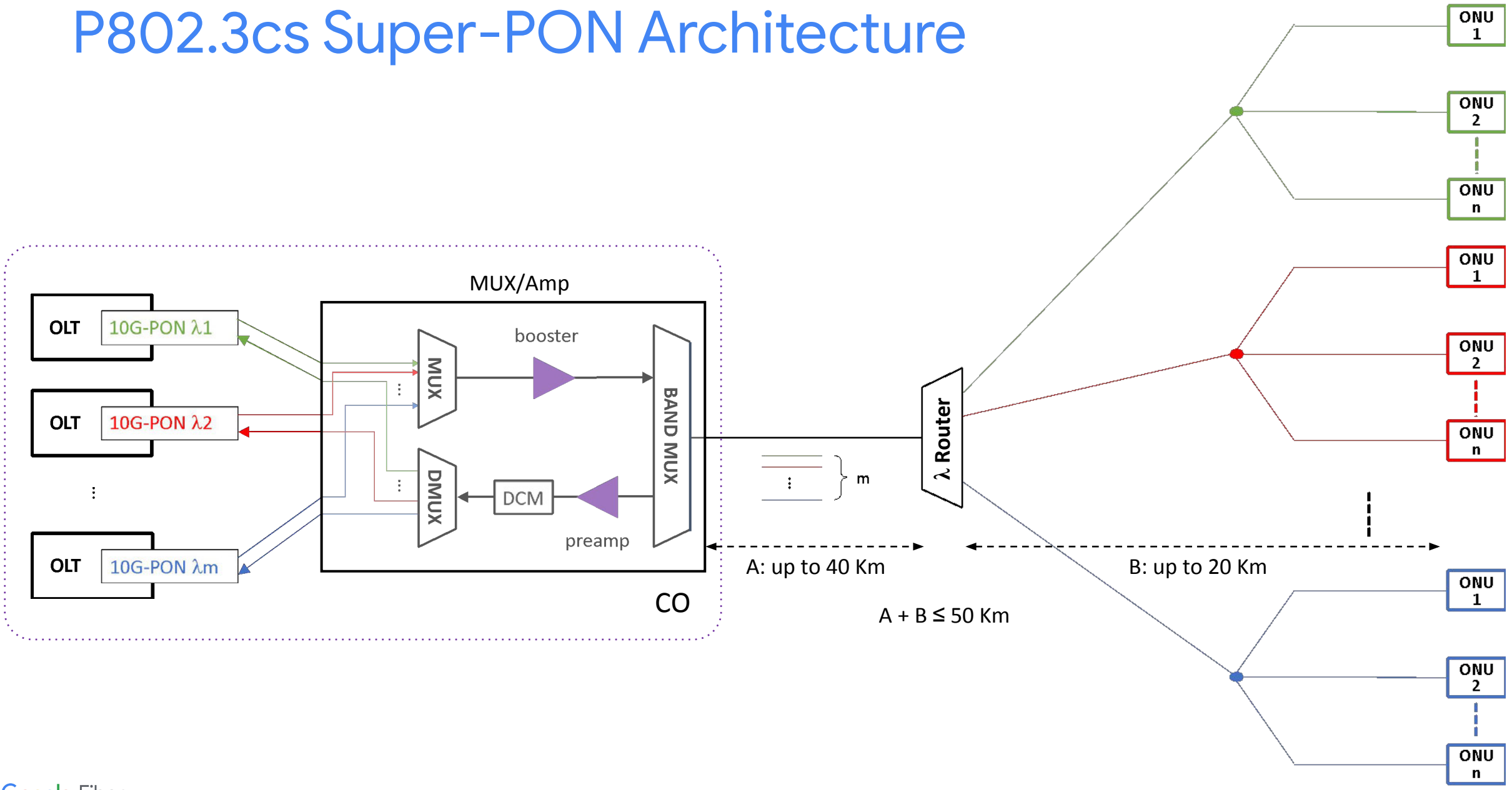
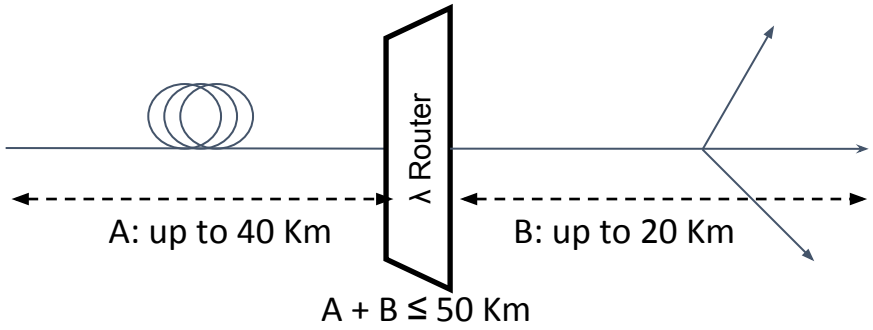
Google Fiber

P802.3cs Super-PON Architecture



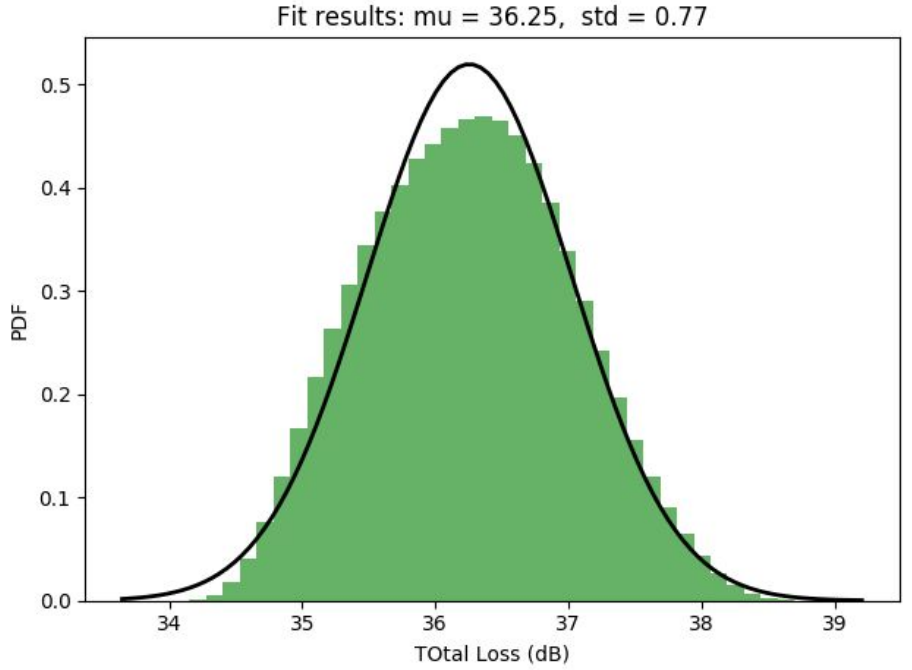
ODN Components



Loss budget (Worst case)		
Components	Loss Max (dB)	Comment
50km Fiber	12	0.24dB/km
λ Router	6.6	4 to 6.6
1x64	21.5	
Total	40.1	

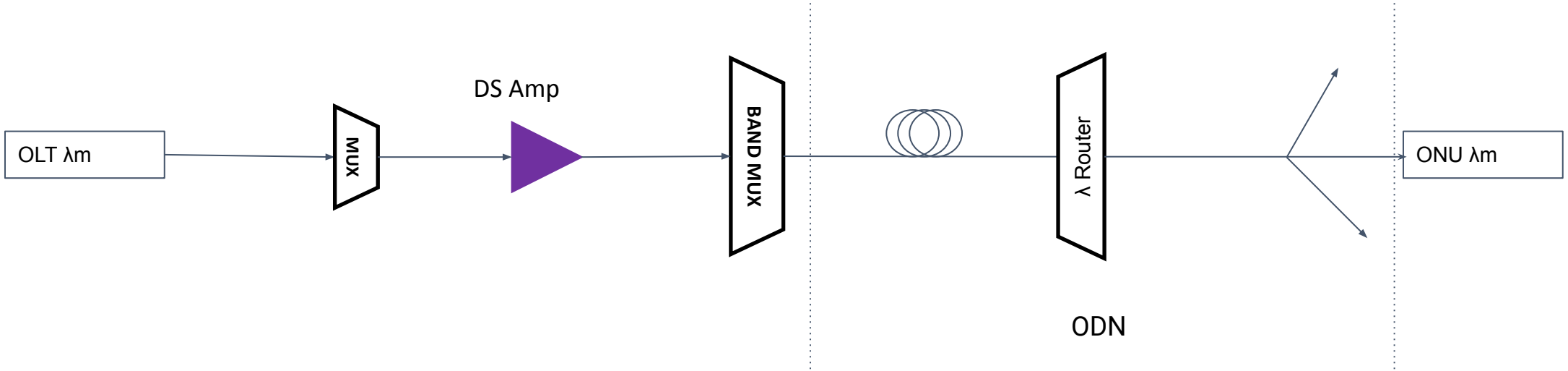
Statistical model: ODN Loss

- Assume the loss values of optical components have a truncated gamma distribution
- We simulated the statistical distribution of our ODN loss
- The average+3*sigma value is 38.56 dB
- Given extra 2.5dB to connector loss and optical impairment etc., we use 41 dB as the maximum loss value of the ODN



Components	Ave.	Min	Max	Comments
Fiber loss (dB/km)	0.2	0.18	0.22	
λ Router		4.5	6.6	Used a uniform distribution model
Fiber Splicing	0.04	0.02	0.1	one splice every 5km
1:64 splitter	20.5	19.5	21.5	

Downstream Components



- Since we are using boost amplifiers, the TX power of OLT optics is not critical
- OLT Tx laser chip can be fixed-wavelength EML
- If we assume the ONU RX sensitivity is -29 dBm, the per-channel launch power after band mux should be larger than 12 dBm
- The total power after band mux > 12 * 10*log10(16)=24 dBm

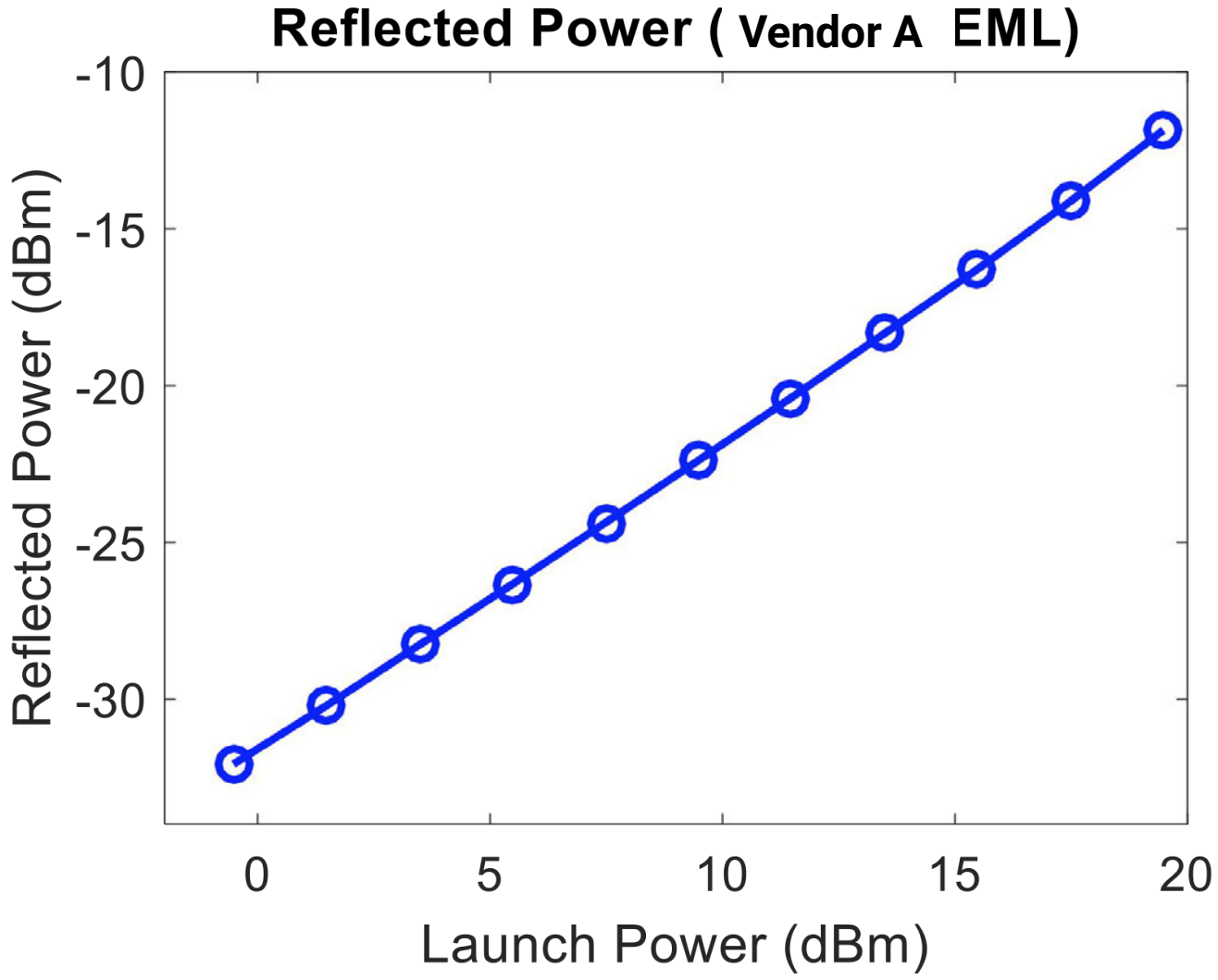
- It is possible to achieve this output power while keeping the cost of the DS amp reasonable
  - Dispersion and fiber nonlinearities appear to be manageable

10G EML Dispersion Penalty

- VPI simulation shows the TDP at different chirp factors
- With boost amplifier, the requirement of output power of downstream EML laser is greatly relaxed
- We can afford to bias the EM section to a large negative voltage so that the chirp factor goes to negative regime while keeping the cost of the laser chip low

Chirp Factor	TDP (50km)
-0.5	<0
0	0.6
0.5	2.5

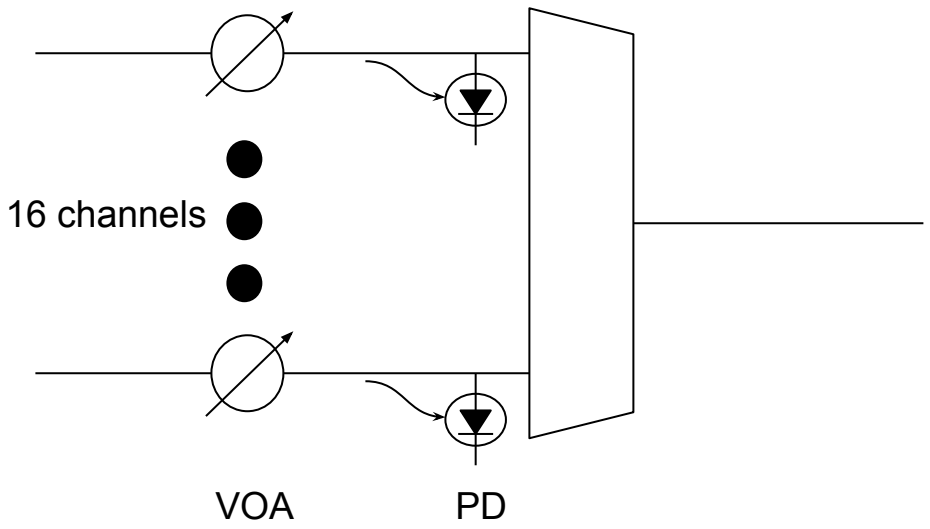
10G EML Reflected Power vs Launch Power



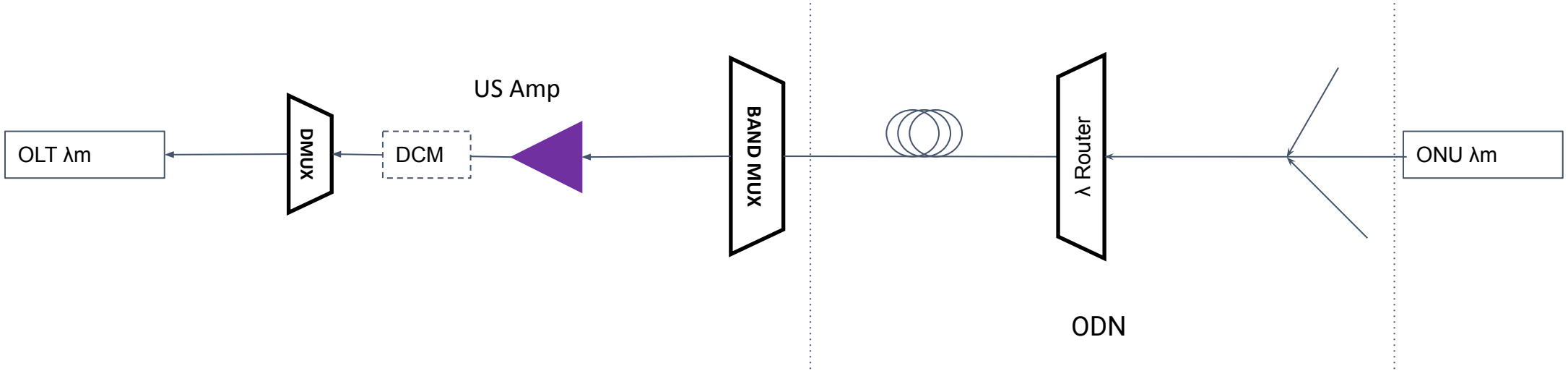
Reflected power linearly up to launch power of 20 dBm, no onset of SBS backscattering observed

Using VMUX to balance per-channel launch power

- It is possible to use VMUX to balance per-channel launch power
- By doing this, we can:
  - Relax the maximum power requirement of DS amplifier
  - Relax the TX power range spec of the OLT optics



Upstream (10G)



Two solutions are possible for the tunable ONU transmitter:

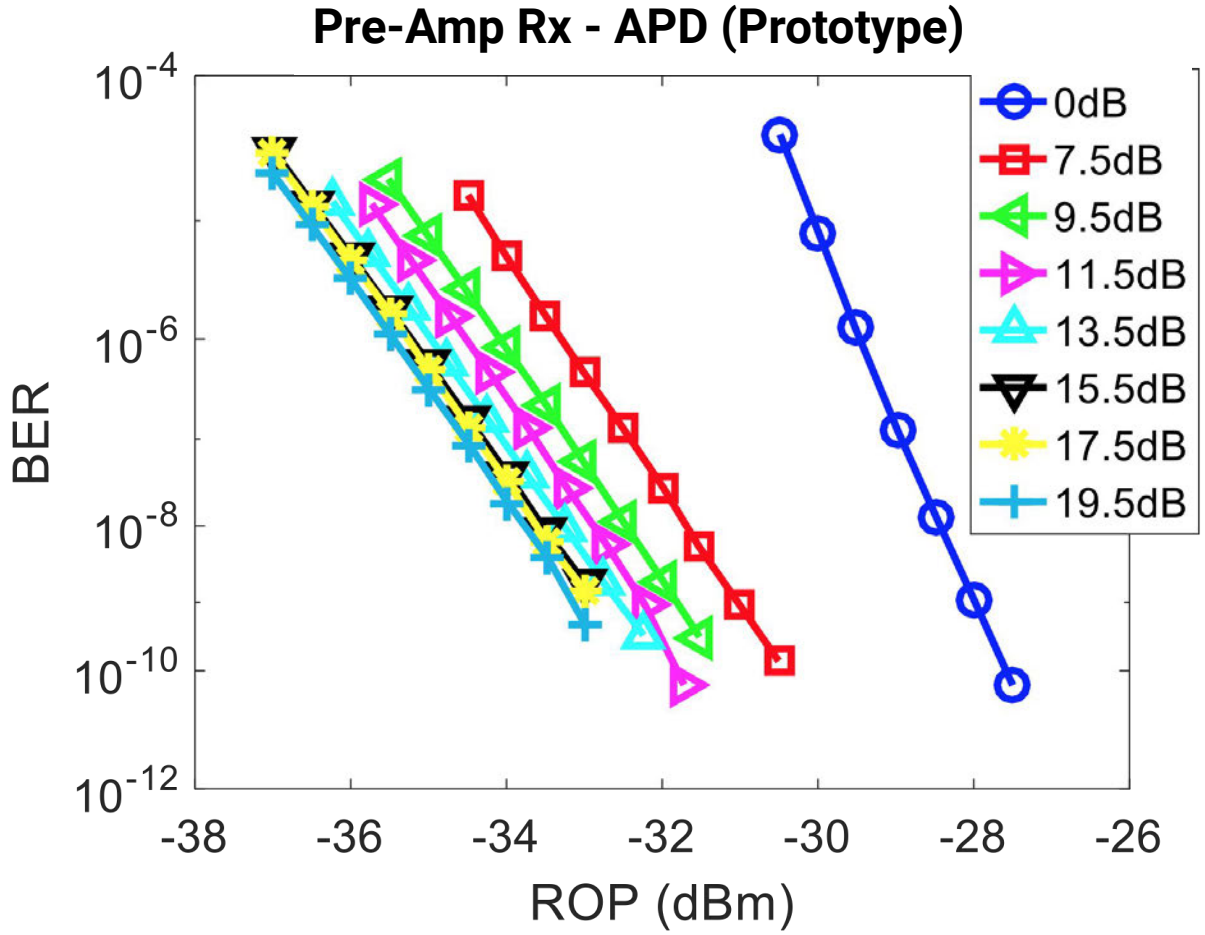
- Tunable EML chip (Gain section + Grating + Electrical Absorber)
  - May not need dispersion compensation, but higher cost
- Tunable DML chip (Grating + Gain section)
  - Need dispersion compensation, but overall cost is low

Performance: EML + pre-amp (10G)

Early samples shows we can achieve RX sensitivity -38dBm at BER=1e-4

- measured at the input of pre-amp
- ER=8.5dB

Need at least 3 dBm output power from ONU TX



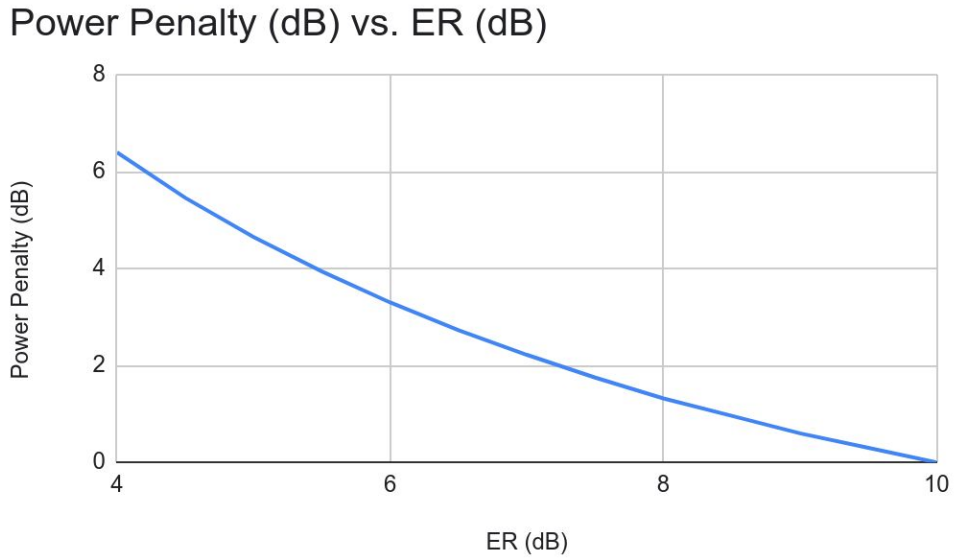
DML or EML for the upstream?

- DML is more cost effective
  - With large adiabatic chirp and DCM, we can achieve 50km transmission
  - See http://www.ieee802.org/3/SUPER_PON/public/201809/DBR_Lasers.pdf
- But DML has smaller ER
  - Usually 4.5 to 6.5dB

Penalty of limited ER: ASE noise dominated case

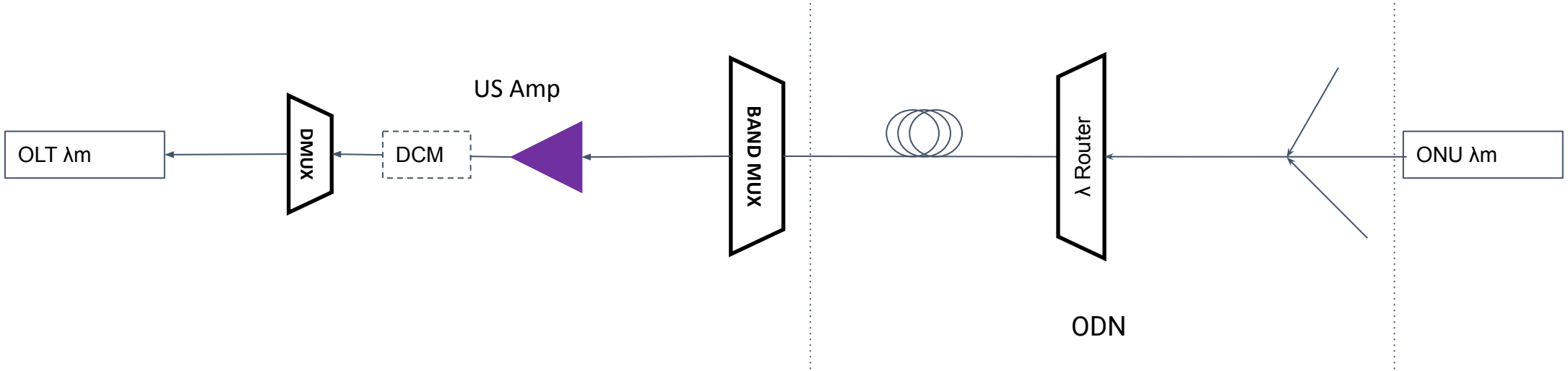
- Q is not only related to OMI (P1-P0)
- The zero-level power contributes to noise too.
- Figure shows power penalty at Q=6 (1e-9)

ER (dB)	Power Penalty (dB)
10	0
9.5	0.3
9	0.6
8.5	0.96
8	1.32
7.5	1.75
7	2.22
6.5	2.73
6	3.3
5.5	3.94
5	4.65
4.5	5.46
4	6.4



$$Q = \frac{I_1 - I_0}{\sigma_1 + \sigma_0} \propto \frac{P_1 - P_0}{\sqrt{P_1} + \sqrt{P_0}} \propto \sqrt{2P_{ave}} \frac{\sqrt{ER} - 1}{\sqrt{ER + 1}}$$

Upstream (2.5G)



Tunable DML chip should be used for 2.5Gbps ONU transmitter.

- Tunable DML chip (Grating + Gain section)
  - DCM is not needed for 2.5Gbps operations
  - Presence of a DCM does not impair 2.5Gbps operations

Transmission Power Requirements

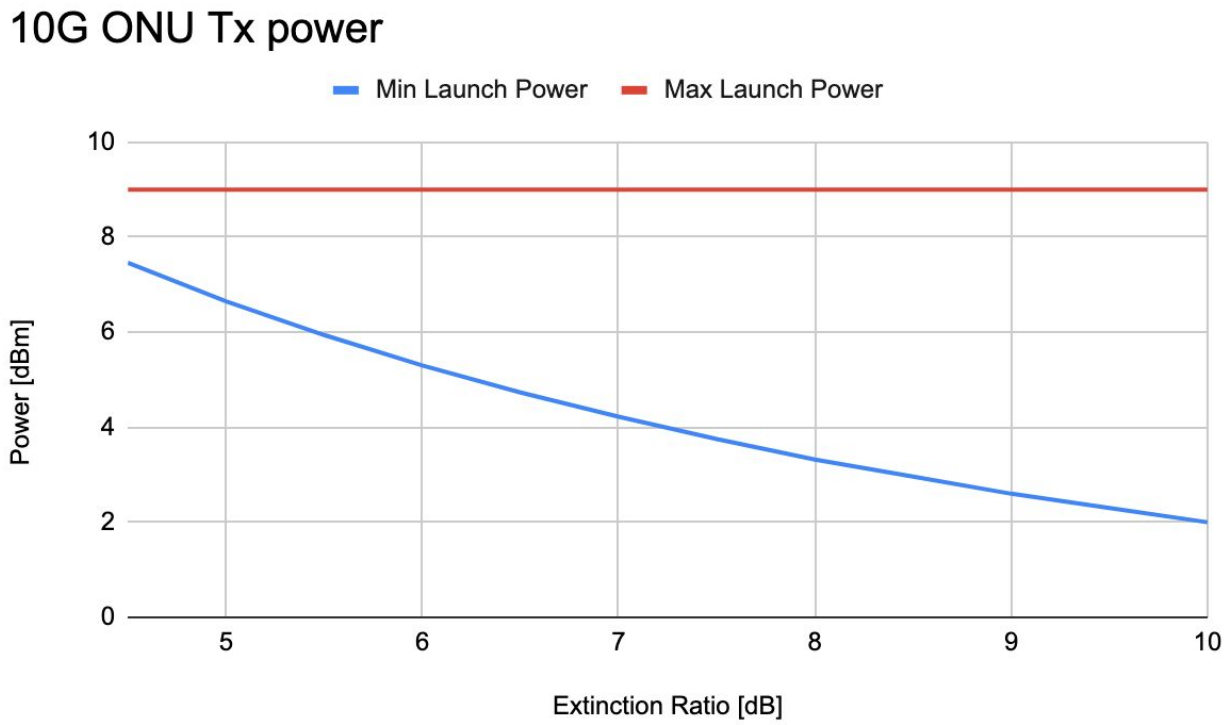


Figure 1

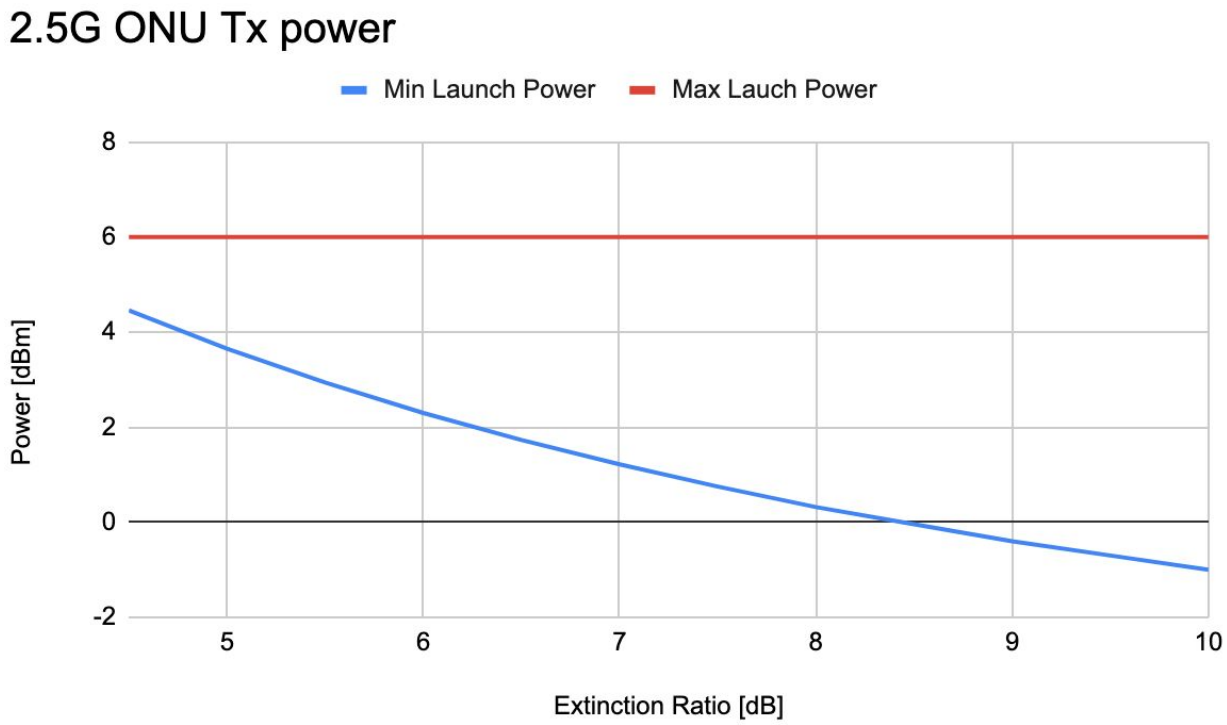
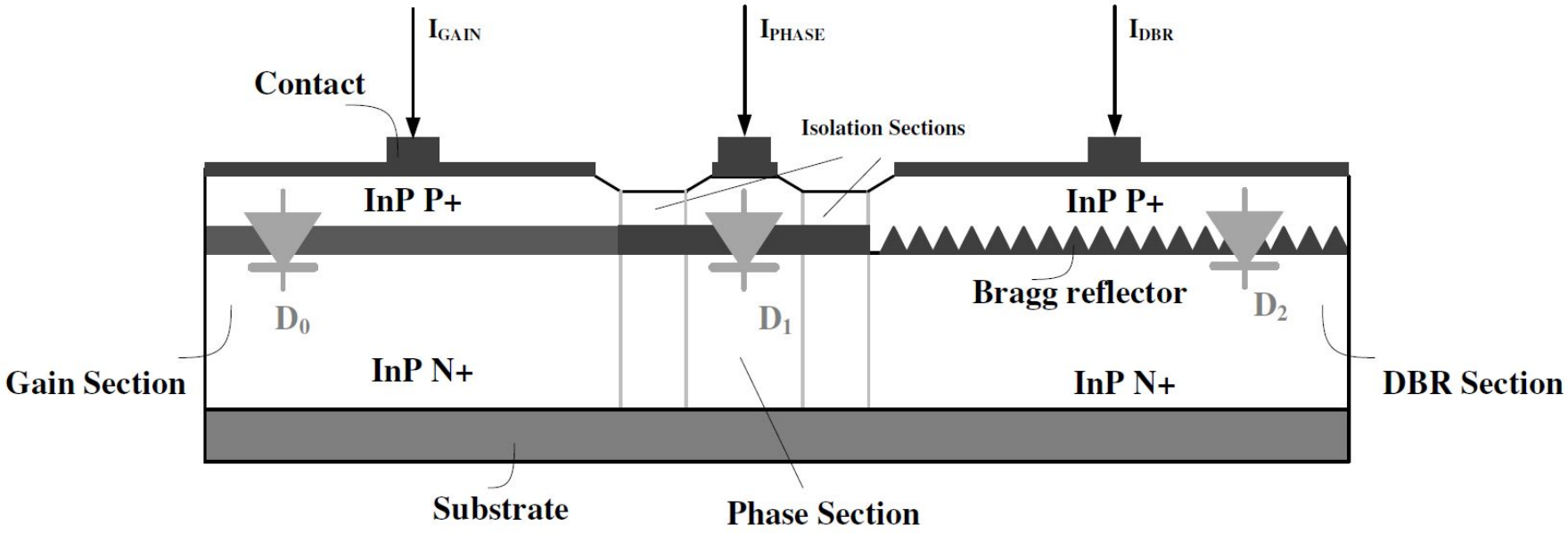


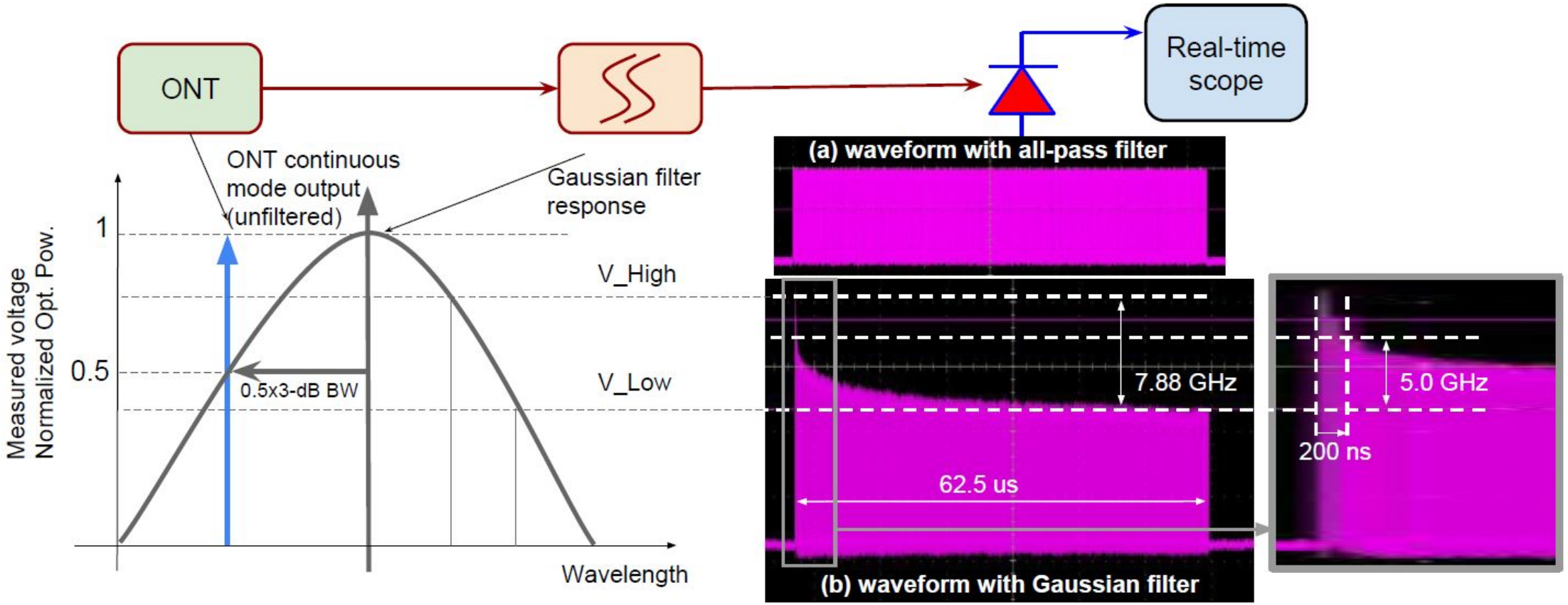
Figure 2

Example Implementation of Tunable DML



- Lights exits from the gain section
- Wavelength tuning achieved by changing DBR current and TEC temperature
- Output power can reach +5dBm at 50 mA bias

Wavelength drift during the burst



Wavelength drift measurement for Gain-switching method at 1.25 Gb/s

Conclusion

- Downstream link budget:
  - Assuming a reasonable ONU receiver sensitivity the link budget can be closed with a high-power booster EDFA
  - DCM is not needed with EML chirpless or negatively chirped transmitters

- Upstream link budget:
  - A possible solution to close the link is a tunable DML transmitter coupled with a DCM in the MUX/Amp module
  - Another possible solution is using a tunable EML transmitter
    - DCM may still be needed also for EML

OLT Transmit Characteristics

Parameter	10Gb/s	Unit
Side-mode suppression ratio (SMSR) (min)	35	dB
Average launch power (max)	2	dBm
Average launch power (min)	-3	dBm
Average launch power of OFF transmitter (max)	-39	dBm
Extinction ratio (min)	8.2	dB
$RIN_{15}OMA$ (max)	-120	dB/Hz
Transmitter and dispersion penalty (TDP) @ 0 to 1000 ps/nm residual CD	0*	dB
Optical return loss tolerance (max)	15	dB
Transmitter reflectance (max)	-10	dB
Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3}	{0.25, 0.4, 0.45, 0.25, 0.28, 0.4}	UI
* A negative chirp transmitter is assumed, which results in a negative dispersion penalty in the positive dispersion region.		

ONU Receive Characteristics

Parameter	10Gb/s	Unit
Bit error ratio (max)	10^{-3}	
Average receive power (max)	-8	dBm
Damage Threshold	-2	dBm
Receiver sensitivity (max)	-29	dBm
Receiver reflectance (max)	-12	dB
Signal detect threshold (min)	-44	dBm
Stressed receiver sensitivity (max)	-29	dBm

ONU Transmit Characteristics

Parameter	10Gb/s	2.5Gb/s	Unit
Side-mode suppression ratio (SMSR) (min)*	38	38	dB
Average launch power (max)	see figure 1	see figure 2	dBm
Average launch power (min)	see figure 1	see figure 2	dBm
Transmitter and dispersion penalty (TDP) @ -450 ps/nm residual CD @ +450 ps/nm residual CD @ +900 ps/nm residual CD	 1 1 N/A	 0.5 0.5 0.5	dB
Average launch power of OFF transmitter (max)	-45	-45	dBm
Extinction ratio (min)	see figure 1	see figure 2	dB
$RIN_{15}OMA$ (max)	-128	-128	dB/Hz
Optical return loss tolerance (max)	15	15	dB
Transmitter reflectance (max)	-10	-10	dB
Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3}	{0.25, 0.4, 0.45, 0.25, 0.28, 0.4}		UI
Turn-on time (max)	128		ns
Turn-off time (max)	128		ns
* It is assumed the SMSR is measured with only the DC laser bias (no data modulation).			

OLT Receive Characteristics

Parameter	10Gb/s	2.5Gb/s	Unit
Bit error ratio (max)	10^{-3}		
Average receive power (max)	-6	-6	dBm
Damage Threshold	-5	-5	dBm
Receiver sensitivity (max)	-28	-30	dBm
Receiver reflectance (max)	-12	-12	dB
Signal detect threshold (min)	-45	-45	dBm
Stressed receiver sensitivity (max)	-27	-29.5	dBm

Thank you