Reducing input dynamic range of SOA-preamplifier for 100G-EPON upstream

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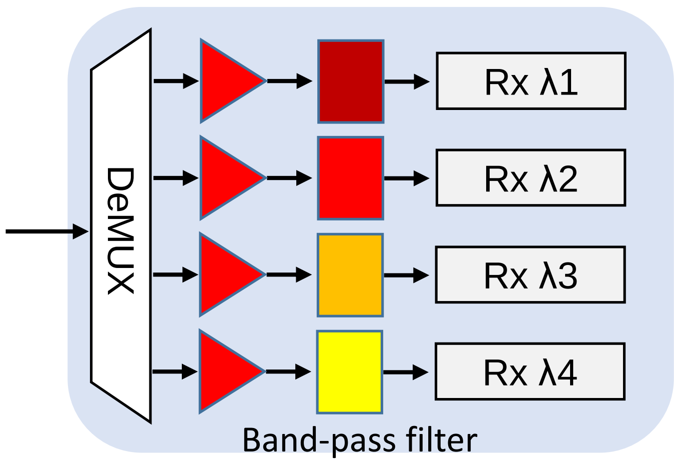
Motivation

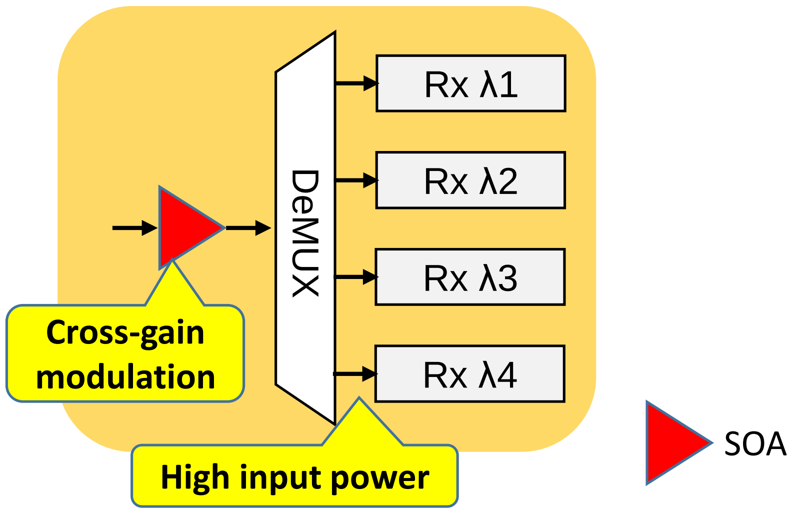
- 100G-EPON OLT must use a preamplifier to overcome additional losses of optical components to configure WDM channels transmission.
- A semiconductor optical amplifier (SOA) is an excellent candidate for compensating the additional losses considering their size, cost, and especially their flexibility in operating wavelength.
- In the previous meetings, some contributions reported feasibility of SOA as a preamplifier for upstream signals.
  - http://www.ieee802.org/3/ca/public/meeting_archive/2017/03/liudekun_3ca_1_0317.pdf
  - http://www.ieee802.org/3/ca/public/meeting_archive/2017/03/yang_3ca_1_0317.pdf
  - http://www.ieee802.org/3/ca/public/meeting_archive/2017/05/lee_3ca_1_0517.pdf
  - http://www.ieee802.org/3/ca/public/meeting_archive/2017/05/liudekun_3ca_1_0517.pdf
- Two issues were raised in the previous contributions.
  - Damage of OLT Rx due to a high output power of SOA
  - BER performance degradation due to cross-gain modulation
- In this contribution, we discuss about the issues and solutions.

Pre-amplifier configurations with SOAs

Case A: SOA for single λ

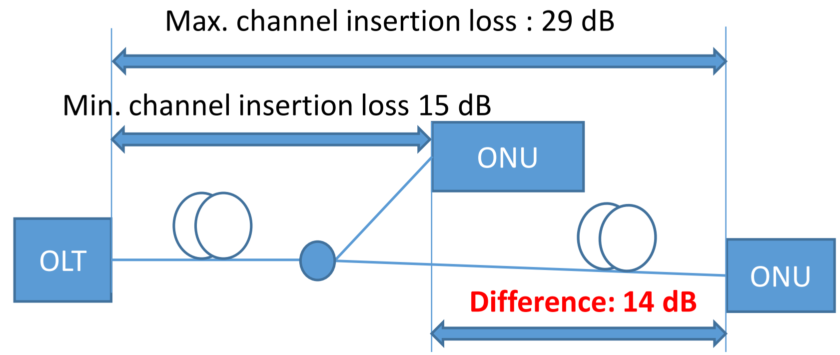


Case B: SOA for multi-λ



- SOAs can be applied to the OLT for amplifying a single upstream signal (case A) or multiplexed WDM upstream signals (Case B).
- Case A is not useful because it has a complex configuration and needs many SOAs and band-pass filters with various passbands.
- Case B is simple and cost effective. However, BER performance degradation due to cross-gain modulation and a damage of OLT receiver are considerations if an input dynamic range of SOA is wide.

19-dB input dynamic range of SOA



IEEE Std 802.3av

Table 75–1—Power budgets

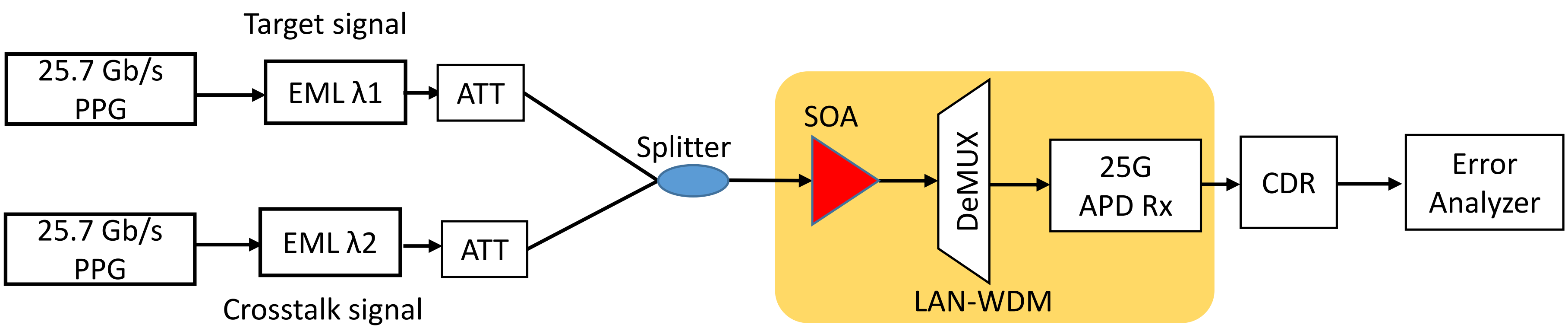
Description	Low Power Budget		Medium Power Budget		High Power Budget		Units
	PRX10	PR10	PRX20	PR20	PRX30	PR30	
Number of fibers	1						–
Nominal downstream line rate	10.3125						GBd
Nominal upstream line rate	1.25	10.3125	1.25	10.3125	1.25	10.3125	GBd
Nominal downstream wavelength	1577						nm
Downstream wavelength tolerance	–2, +3						nm
Nominal upstream wavelength	1310	1270	1310	1270	1310	1270	nm
Upstream wavelength tolerance	±50	±10	±50	±10	±50	±10	nm
Maximum reach[a]	≥10		≥20		≥20		km
Maximum channel insertion loss	20		24		29		dB
Minimum channel insertion loss	5		10		15		dB

Table 75–8—PR type ONU PMD transmit characteristics

Description	10GBASE –PR–U1	10GBASE –PR–U3	Unit
Signaling speed (range)	10.3125 ± 100 ppm	10.3125 ± 100 ppm	GBd
Wavelength (range)	1260 to 1280	1260 to 1280	nm
Side Mode Suppression Ratio (min)[a]	30	30	dB
Average launch power (max)	4	9	dBm
Average launch power (min)[b]	–1	4	dBm
Average launch power of OFF transmitter (max)	–45	–45	dBm
Extinction ratio (min)	6	6	dB

- 802.3av defined 14-dB difference of channel insertion loss between the max. channel insertion loss (29 dB) and the min. channel insertion loss (15 dB) to support flexible deployment on PON.
- 10G EPON ONU PMD transmit defined 5-dB difference of upstream signal power between the max. average launch power and the min. average launch power.
- If 100G EPON would have same specifications with 10G EPON then the input dynamic range of SOA must be 19 dB.

Experiment setup



- To test cross-gain modulation, 2 x 25 Gb/s NRZ signals in O-band and 25 Gb/s APD receiver were used.
  - Target signal (λ1): 1295 nm, NRZ, PRBS 2^{31}-1, ER: 8 dB
  - Crosstalk signal (λ2): 1309 nm, NRZ, PRBS 2^{31}-1, ER: 8 dB
- A saturation output power of SOA was over +11 dBm at 120 mA of operating current.
  - The SOA includes optical isolators inside so that noise figure performance is better than the SOA without installing isolators.

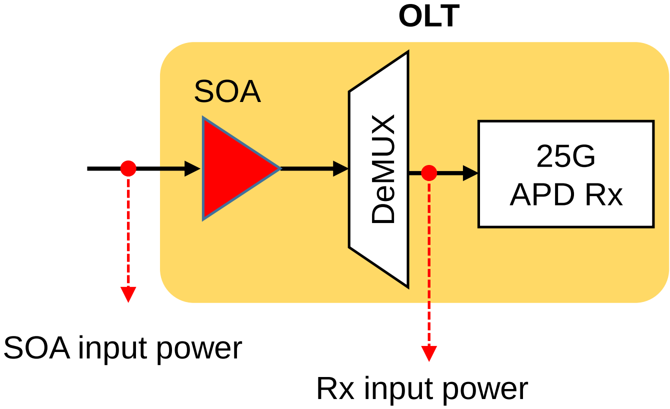
BER performance w or w/o crosstalk signal

Target signal power (dBm)	Dynamic range (dB)	Crosstalk signal power (dBm)	Measured BER of target signal		Optimized SOA current (mA)
			w/o crosstalk	w crosstalk	
-29	19	-10	1×10^{-3}	1.5×10^{-3}	28
-30	19	-11	1×10^{-3}	1.9×10^{-3}	33
-31	19	-12	1×10^{-3}	2.0×10^{-3}	50

- We set the input power of SOA from -29 dBm to -31 dBm considering the channel insertion loss (29 dB) and the addition loss of WDM MUX and other optics (~ 5 dB).
  - ➢ We assume that the minimum output power of ONU Tx is +3 dBm ~ + 5 dBm
- To have $10^{-3}$of BER, we optimized an operating current of SOA for each case without a crosstalk signal. The operating current of SOA had to be increased as the power of target signal was decreased.
- When the crosstalk signal was added, the case of smallest signal power (-31 dBm) showed worst BER performance even the power of crosstalk signal was small. This is because of saturation induced cross-gain modulation in SOA with the high gain (~20 dB) of SOA
- -29 dBm of SOA input power would be good considering a low operating current of SOA and low crosstalk because of a low gain of SOA.

Damage of OLT Rx

Min. SOA input power (dBm)	Dynamic range (dB)	Max. SOA input power (dBm)	Max. Rx input power (dBm)
-29	14	-15	-5.5
-29	15	-14	-4.5
-29	16	-13	-3.6
-29	19	-10	-1



Operating current of SOA: 28 mA

- A max. Rx input power was -1 dBm when the input dynamic range of SOA was 19 dB. The OLT receiver will be damaged by -1 dBm of received power.
- IEEE 802.3av defines -5 dBm of damage threshold power for 10G upstream in PR30 power budget.
- If 100G EPON has a similar specification of the damage threshold power for the 25G upstream with the specification of 10G EPON, the maximum SOA input power must be around -14 dBm.
- It means that the input dynamic range of SOA should be reduced from 19 dB to 15 dB.

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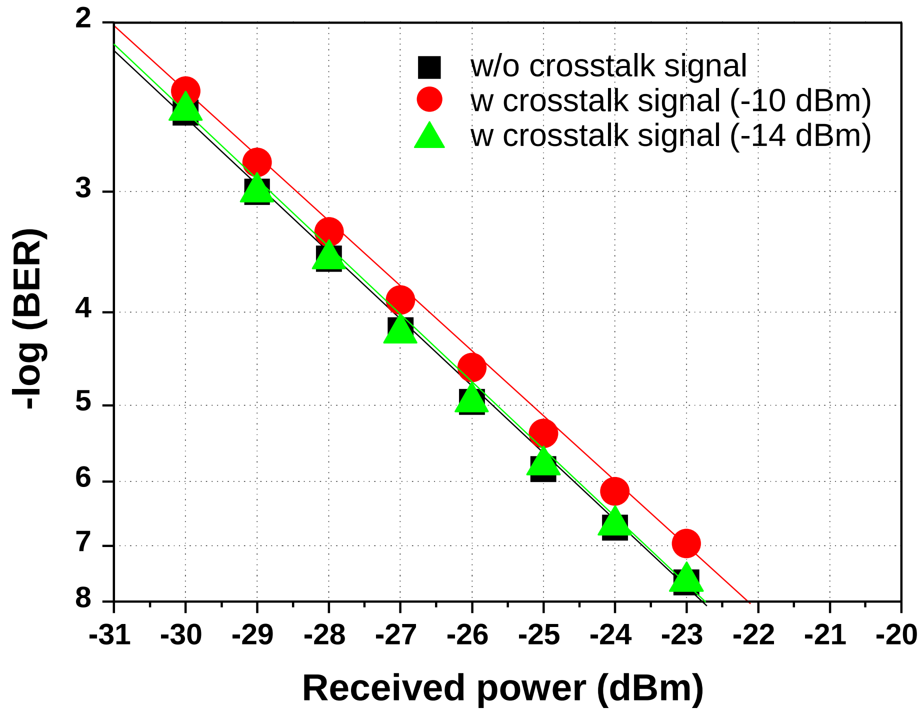
BER performance



- In the case of 19-dB input dynamic range, 0.5 dB of power penalty was observed at BER 10^{-3} with -10 dBm of crosstalk signal.
- But, no power penalty was observed with -14 dBm of crosstalk signal (15-dB input dynamic range).
- So, reducing the input dynamic range of SOA will be very useful to mitigate the cross-gain modulation induced power penalty and the damage of OLT Rx, also.

How to reduce input dynamic range

- Two approaches are possible to reduce the input dynamic range of SOA.
  1) Reducing the output power range of ONU Tx
  2) Using the output power levelling of ONU Tx
  ✓ ITU-T NG-PON2 specified 6-dB power levelling to mitigate a crosstalk problem

Examples of method

	Reducing output power range of ONU Tx	Using power levelling of ONU Tx	Consideration
Method 1	1 dB (10G EPON: 5 dB)	none	Reducing a yield of DFB LD
Method 2	none	4 dB (NG-PON2: 6 dB)	Difficult to have upstream BER performance (ER, Jitter…), constantly
Method 3	100G EPON: 3 dB (10G EPON: 5 dB)	100G EPON: 2 dB (NG-PON2: 6 dB)	

Conclusions

- The SOA preamplifier is good to extend a sensitivity of 100 G EPON OLT Rx.
- To mitigate cross-gain modulation induced power penalty, the SOA has to operate in low signal gain regime.
- Even the gain of SOA is low, 19 dB of wide input dynamic range of the SOA brings degradation of BER performance and damage to the 25G APD Rx.
- To solve both problems, the input dynamic range of SOA should be reduced. Some methods are applicable.
  - Method A: Reducing the output power range of ONU Tx
  - Method B: Applying power levelling of ONU Tx
  - Combination method