Semiconductor optical amplifier-based dual-rate multi-band OLT receiver for 1G/10G coexistence

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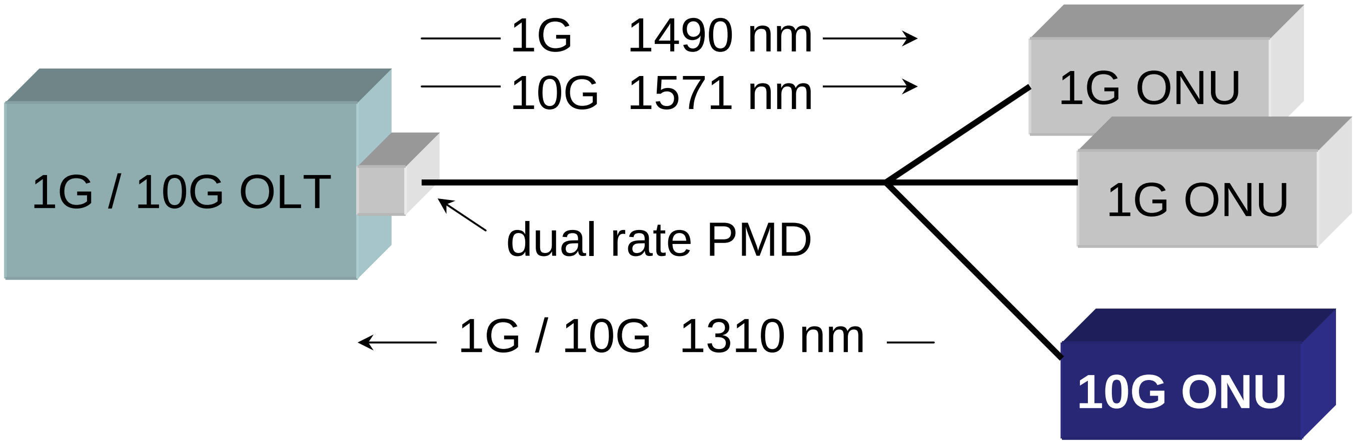
Coexistence: TDMA upstream



1310 nm 10G/1G TDMA in upstream

Constraints

(1) Existing OSP has 29 dB link budget
(2) Legacy 1G upstream receiver must have -30 dBm sensitivity at BER = 10^{-12} (no FEC)
(3) Legacy1G upstream wavelength specification is 1260 – 1360 nm

APD solution

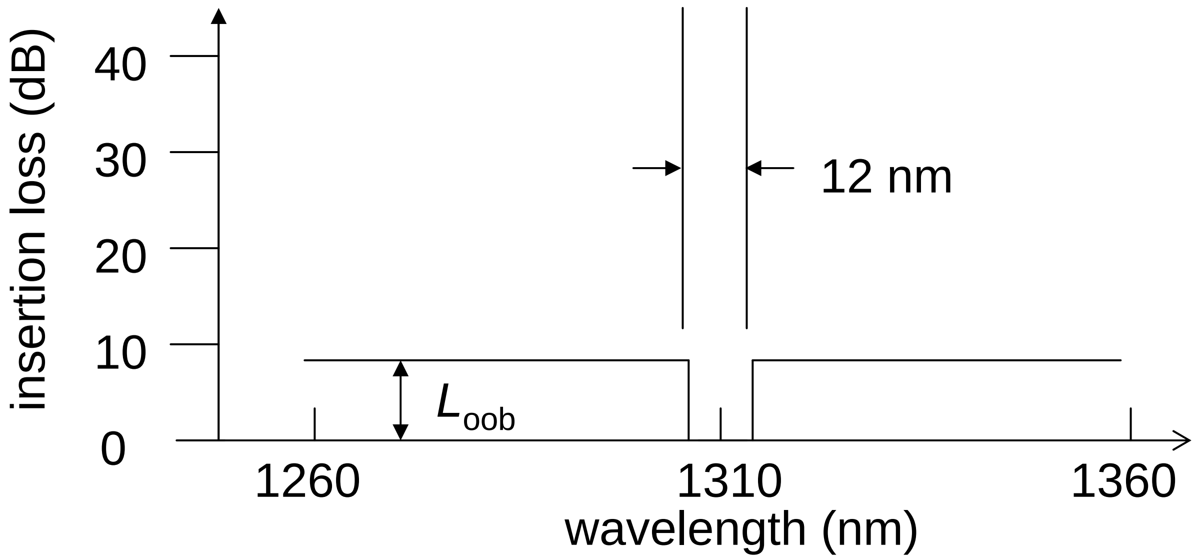
- Use APD as a dual rate receiver
- Problems

1. Sensitivity at 10G is -22 – -23 dBm. Must use higher power transmitter in 10G ONU.
2. Dual rate receiver penalty: Receiver’s 1G sensitivity suffers significantly unless “smart” TIA is implemented.
3. -30 dBm sensitivity at 1G is unlikely.

SOA solution

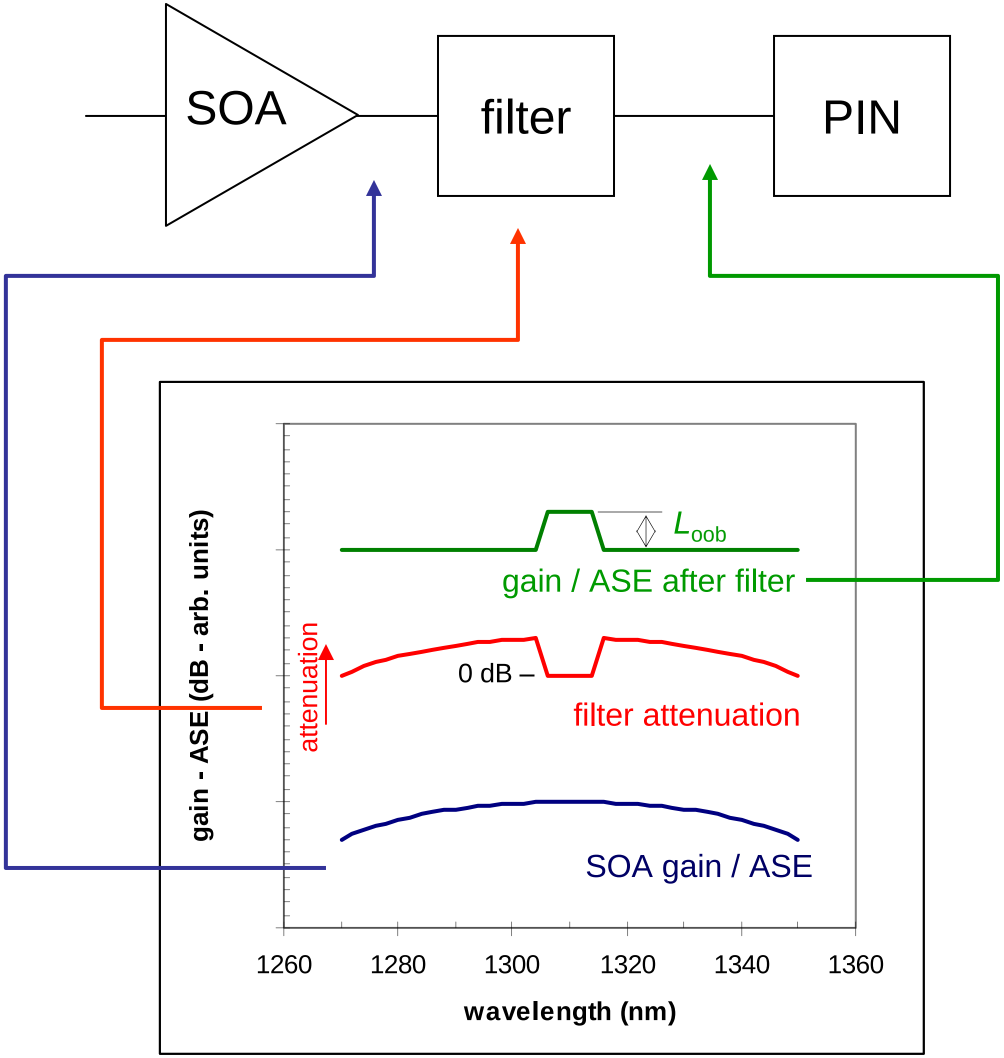
- SOA not considered early on due to incompatibility of noise blocking filter and legacy wavelength specification.
- Since last meeting we have proposed a “soft” filter solution.
  - Eliminates dual rate receiver penalty (noise is RIN-limited, not thermal)
  - Better overall performance than APD solution.
  - May enable single PMD for all classes of 10G ONUs.
- This presentation outlines SOA solution, addresses criticisms, and gives experimental results.

SOA solution



Adjust out of band loss (L_{oob}) of filter such that receiver sensitivity at 1G meets -30 dBm over whole band, while 10G in-band in sensitivity is still good.

Filter design

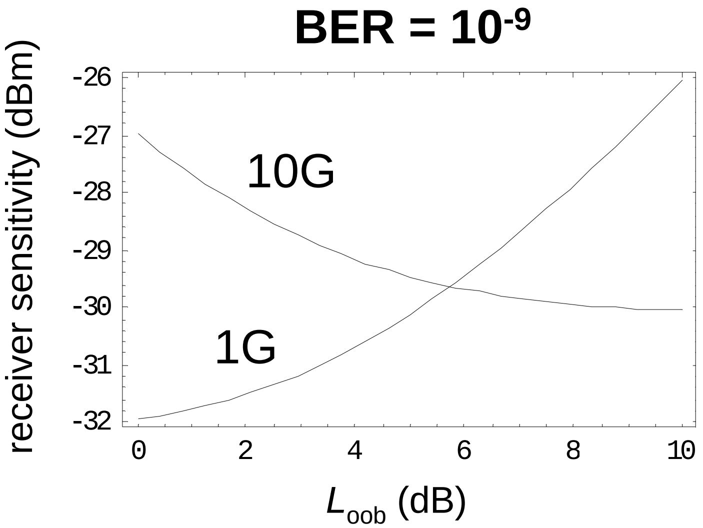


Non-uniform gain

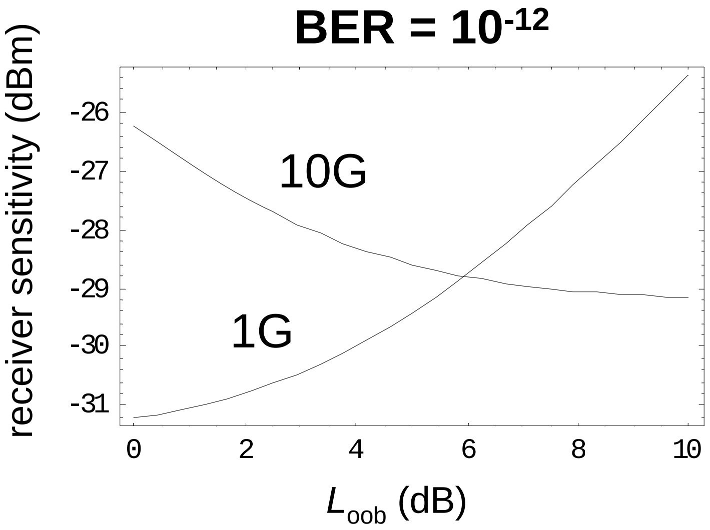
- A typical SOA has a 3 dB gain bandwidth of ~ 80 nm.
- I propose addressing this in two ways.
  - Gain flattening filter
  - Design of SOA chip for broader gain

- In the analysis that follows I assume a 80 nm (3 dB) gain profile. This can be generalized to wider gain profiles.

Modeling – Results



BER = 10^{-9}



BER = 10^{-12}

With G = 20 dB one sees that the 1G receiver sensitivity increases as the 10G falls with increasing L_{oob}

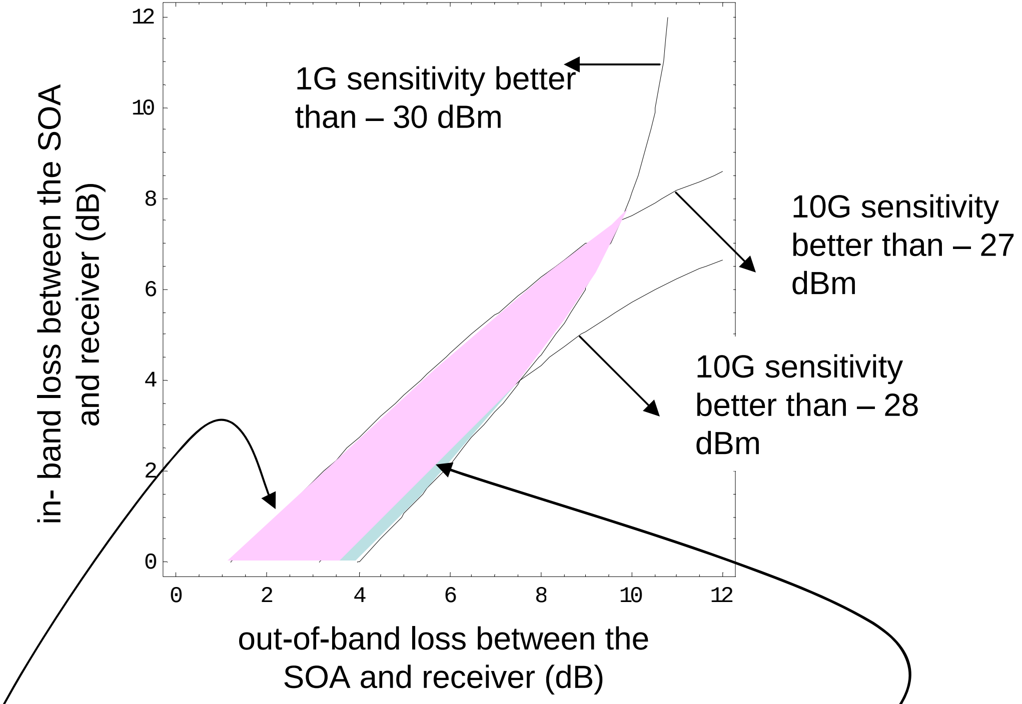
According to calculation, -30 dBm (1G) and -28 dBm (10G) are possible at L_{oob} = 4 at 10^{-12} BER

20 dB of gain may cause issues with receiver sensitivity. I address this next.

The calculations on this page are corrected versions of calculations sent to study group email reflector on 10 May 2007

Design flexibility

SOA gain = 20 dB (flat) BER = 10^{-12}



10 G sensitivity better than – 28 dBm
and
1 G sensitivity better than – 30 dBm

10 G sensitivity better than – 27
and
1 G sensitivity better than – 30 dBm

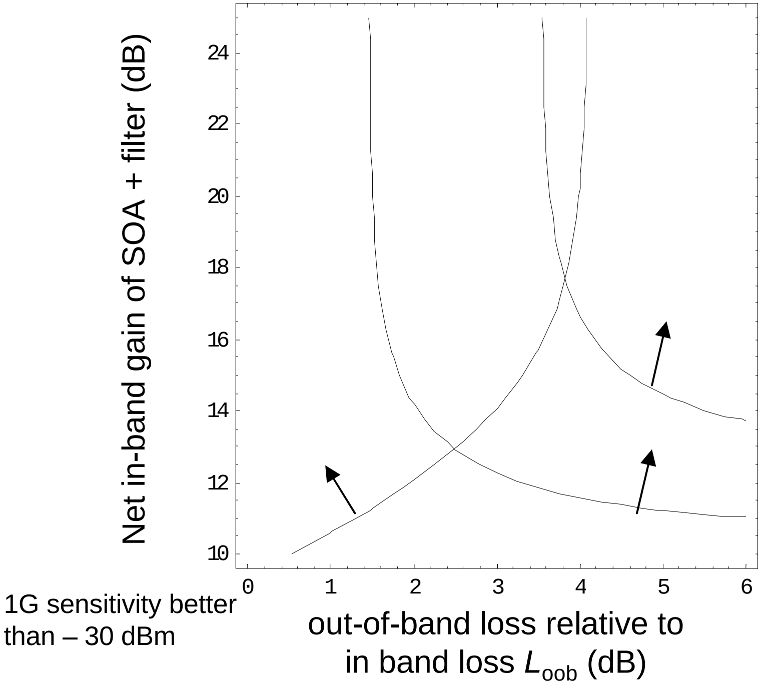
One has freedom to vary the filter design (and/or SOA gain) to achieve target specifications – including dynamic range.

For example by using filter with an in-band attenuation of 6 dB, and an out-of-band attenuation of 8 dB one can operate with wider dynamic range.

One achieves the exact same result with a lower gain SOA (14 dB) and a filter with L_{oob} = 2 dB, L_{ib} = 0 dB

The calculations on this page are corrected versions of calculations sent to study group email reflector on 10 May 2007

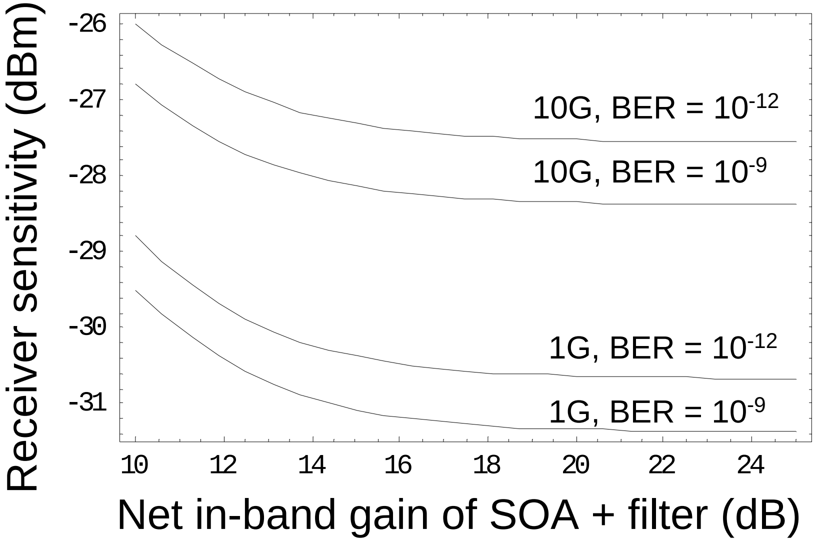
Gain / loss dependence



10G sensitivity better than – 28 dBm

10G sensitivity better than – 27 dBm

L_{oob} fixed at 2..5 dB



Dynamic range

- Consider using a filter with 14 dB (net) of in-band gain. In this case the receiver sensitivity is -27 dB or better. At this point the input power to the PIN will be -13 dBm.
- On the low input power (to the SOA) side range is limited by
  - P_{sat} of SOA
    - As long as $P_{in} < P_{sat}$(1dB) there will be no penalty. (see http://www.ieee802.org/3/av/public/2007_03/3av_0703_stefanov_1.pdf)
    - P_{sat} > 5 dBm is easily achieved in SOAs.
  - PIN saturation
    - A typical PIN will remain (optically) linear up to at least P_{in} = 2 dBm.
  - Electronic (RF amplifier) saturation.
    - A typical PIN receiver module can work up to from < -25 dBm to ~ 0 dBm. An optimized electronic design may allow operation from –15 dBm to beyond 0 dBm. Commercial 10G receivers are available with +3 dBm saturation.

Summary: Dynamic range of 15 dB (18 dB) can be easily achieved at 10G (1G) , more study required for > 15 dB (18 dB) dynamic range.

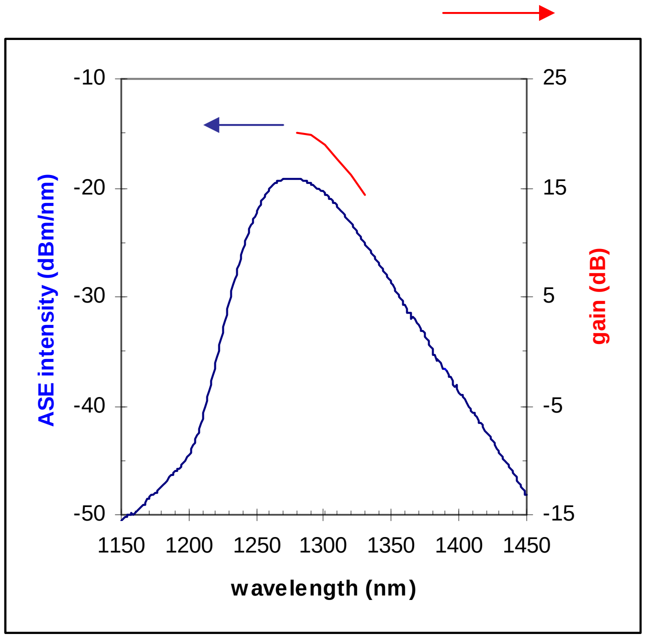
SOA gain

- An SOA with a gain less than 20 dB can satisfy needs of insertion loss, gain flattening, excess filter loss, and polarization dependant gain (PDG, below)
    - Net in-band gain required is modest ~ 15 dB
    - For optimal operation one wants to operate at the lowest gain to achieve maximum dynamic range.
    - PDG within ±0.5 dB is readily achieved in an SOA over 100 nm. This will increase the gain budget by 0.5 dB and reduce the dynamic range by 0.5 dB.
    - At constant current SOA gain can be specified to decrease by 1 dB at end-of-life. Simple electronics (no additional optics are needed) can maintain SOA in constant gain mode.

SOA vs. APD solution

- An SOA with a soft filter will provide several dB better sensitivity at 10G and 1G than an APD solution.
- There is significant design margin to exceed the APD solution.
- Areas for more study:
  - Achieving dynamic range > 18 dB at 1G and > 15 dB at 10G.
  - Architecture: Integrated vs. discrete solution, and costs implications.
  - Soft filter fabrication

SOA experiments

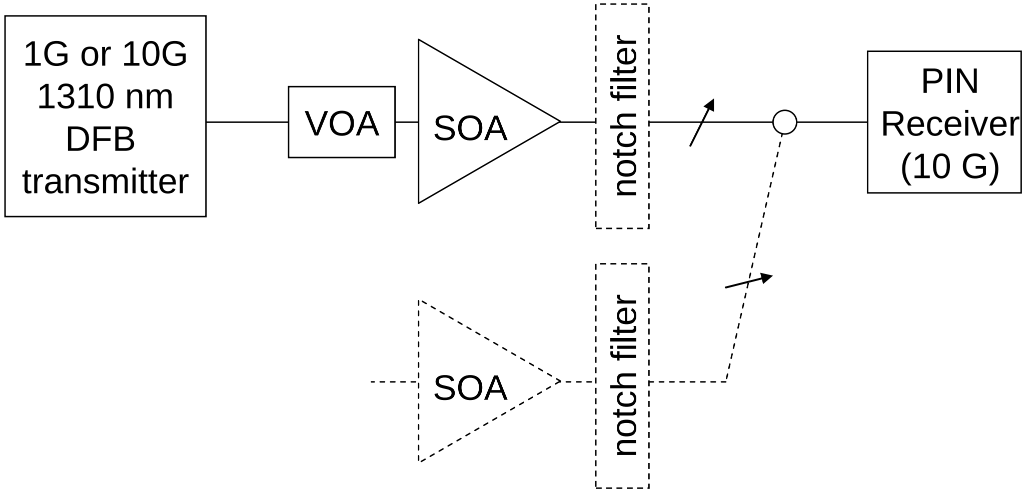


SOA used for experiments was manufactured by Alphion Corporation.

SOA had a 3-dB gain bandwidth of 52 dB, and a noise figure of < 6.5 dB.

SOAs with greater than 100 nm 3-dB bandwidth have been fabricated using standard techniques. (See for example, Iannone, Reichmann and Spiekman, OFC-2003, ThQ3 for a 140 nm SOA)

Experiment


1G or 10G 1310 nm DFB transmitter

VOA

SOA

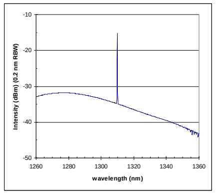
notch filter

PIN Receiver (10 G)

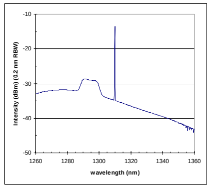
SOA

notch filter

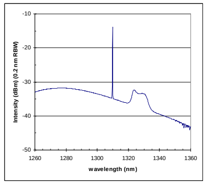
1G no filter



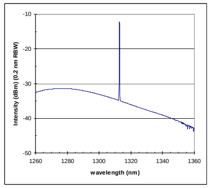
1G “soft” filter



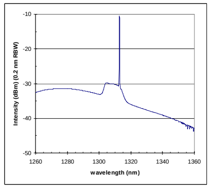
1G “soft” filter



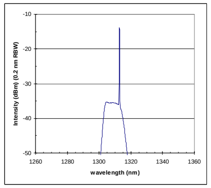
10G filter



10G “soft” filter



10G notch filter



1G transmitter

1309.8 nm DFB from a commercial GE-PON ONU transceiver
extinction ratio = 16 dB

10 G transmitter

1312.8 nm DFB from a commercial multi-protocol 10 Gb/s 10 km XFP transceiver
extinction ratio = 4.7 dB

Receiver

10 G SFP PIN from same package. Used for both 1G and 10G experiments.

Optical Filters

available in the 1288-1300, 1302-1314, and 1320 – 1232 (3dB bandwidth) bands.

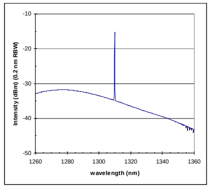
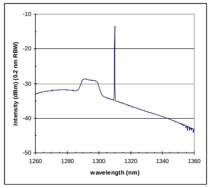
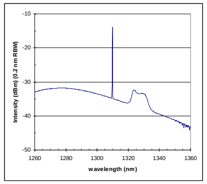
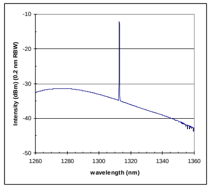
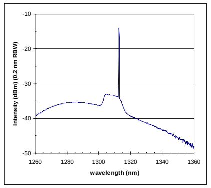
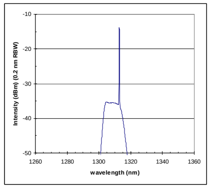
Creating the “soft” filter

The spectra were simulated combining the light from the SOA under test with a similar SOA without any input light. By doing this we could obtain arbitrary spectra of the SOA ASE with no filter, a “soft filter” and a notch filter.

The spectra of the output were measured at the PIN.

No gain flattening was available or used in experiments.

Experimental results and calculation

		Measurement (10^{-9} BER)	Calculation	Deviation
1G no filter		Ps = -25.6 dBm	Ps = -26.0 dBm	+ 0.4 dB
1G “soft” filter		Ps = -23.2 dBm	Ps = -24.9 dBm	+ 1.7 dB
1G “soft” filter		Ps = -24.2 dBm	Ps = -25.6 dBm	+ 1.2 dB
10G no filter		Ps = -21.0 dBm	Ps = -22.4 dBm	+ 1.4 dB
10G “soft” filter		Ps = -22.5 dBm	Ps = -24.4 dBm	+ 1.9 dB
10G notch filter		Ps = -26.6 dBm	Ps = -26.0 dBm	- 0.6 dB

Experiment: Discussion

- The receiver parameters were unknown, n = 0.85 mW/mA, and Be = 7 MHz were used (for both 1G and 10G) in calculations.
- The shape of the ASE were used to calculate the spontaneous-spontaneous beat noise.
- These experiments only validate that our calculations have a reasonable correlation with observation.
- Better extinction ratio transmitters (10 G), a gain flattening filter, and calibrated receivers are needed for further validation.

Summary

- SOA/PIN-solution performance exceeds APD solution, with significant design margin.

- Open issues
    - Receiver architecture, cost
    - Dynamic range exceeding 15 dB.
    - Gain flattening filter

- We should be looking at the big picture.
    - SOA/PIN eliminates the “multi-rate receiver penalty”.
    - SOA/PIN receiver at OLT may enable a single ONU PMD for all link budgets.

Alphion

Enabling the photonic future

Backup

Modeling - 1

Modeling noise and gain of SOAs is treated in (for example): F. Rühl and R. Ayre, “Explicit expressions for the receiver sensitivity and system penalties of optically preamplified direct-detection systems,” *IEEE Photon. Technol. Lett.*, vol. 5, pp. 358–361, Mar. 1993.

Assumptions:

$h\nu$ = -155.3 dBm / sec (at 1310 nm)
η= 0.85 A/W (at 1310 nm)
i_{th} = 18 pA/$\sqrt{}$Hz
B_e (1G) = 0.70 (1.25 Gb/s) = 0.875 GHz
B_e (10G) = 0.70 (10 Gb/s) = 7.0 GHz
SOA noise figure = 7 dB
Transmitter extinction ratio = 10 dB

optical noise spectral density
= ½ $h\nu$ NF (G-1) B_o = .0066 mW/nm
(for G = 20)

If notch width = 12 nm,
then the total ASE optical noise power =
(0.078 + 0.45 x $10^{-(Loob/10)}$) mW

where L_{oob} = out-of-band loss of filter (λ < 1304 nm, λ > 1316 nm)

Modeling-2

Standard techniques are used.

Shot noise is always there since ASE remains constant.

$RIN_{SOA} = 2h\nu\ NF / P_{in}$ for $G>>1$

Since “B_o” $>> B_e$

ASE-ASE beat noise =

$\sigma_{sp\text{-}sp}^2 = \frac{1}{4} B_e (B_o^{ib}-B_e/2)\ \eta^2\ P_{Rx}^2\ RIN_{SOA}^2 + \frac{1}{4} B_e(B_o^{oob}-B_e/2)\ \eta^2\ P_{Rx}^2\ RIN_{SOA}^2\ \ 10^{-(Loob/5)}$ (in band signals)

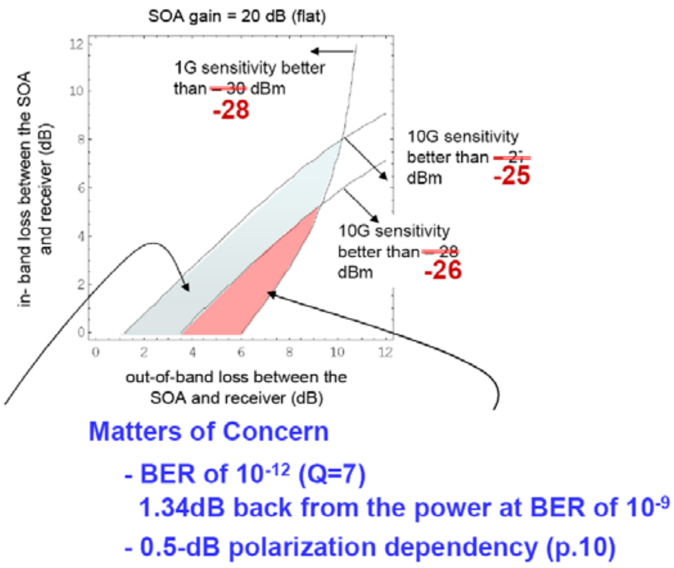
$\sigma_{sp\text{-}sp}^2 = \frac{1}{4} B_e (B_o^{ib}-B_e/2)\ \eta^2\ P_{Rx}^2\ RIN_{SOA}^2\ 10^{+(Loob/5)} + \frac{1}{4} B_e(B_o^{oob}-B_e/2)\ \eta^2\ P_{Rx}^2\ RIN_{SOA}^2$ (out of band signals)

Where $B_o^{ib} = 12$ nm; $B_o^{oob} = 68$ nm

Solve for $Q = 6$ for 10^{-9} BER or $Q = 7$ for 10^{-12} BER to get receiver sensitivity.

Addressing Concerns

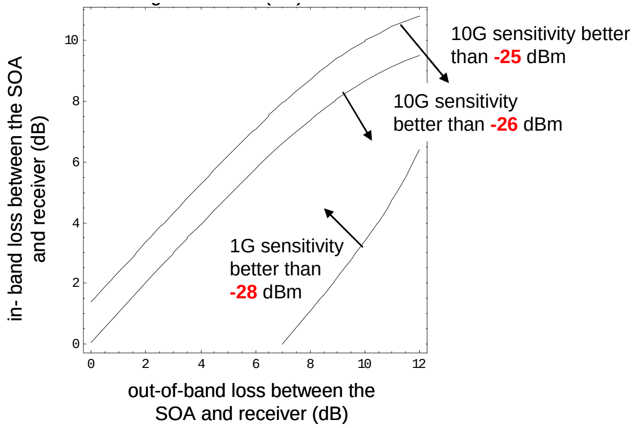
From reflector email (Hamano-san, 24 May 2007)



Matters of Concern

- BER of 10^{-12} (Q=7)
  1.34dB back from the power at BER of 10^{-9}
- 0.5-dB polarization dependency (p.10)

SOA GAIN = 19.5 dB (flat) BER = 10^{-12}



Accounted by polarization sensitivity by decreasing gain by decreasing gain by 0.5 dB, recalculated for 10^{-12} BER Readjusted calculation gives wider operating range than predicted at left.