

SOA preamp performance: theoretical modeling

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Receiver Model for SOA+Filter+PIN / APD

- Analytical Rx model for SOA+filter+PIN and APD (modified from “G. Agrawal, fiber-optic communication systems”)
- Different noise contributions included
 - Shot noise (signal , SOA-ASE (both polarization), dark current)
 - Thermal noise of TIA and electronic amplifier noise
 - APD: excess noise from multiplication process
 - SOA: signal-ASE and ASE-ASE beat noise
- Extinction ratio of signal is 6dB
- SOA: power independent and time independent small-signal gain and noise figure
- APD: fixed multiplication factor and excess noise
- Rectangular-shaped filters with insertion loss
- TIA and electronic amplifier noise for PIN and APD receivers assumed to be identical for all receiver types
- TIA and Si/Ge APD ($M=12$, $F_{\text{excess}} = 3.22$) modeled according to SiFotonics contributions [pan_3ca_1_0916.pdf](#)
- BER calculated including all noise contributions

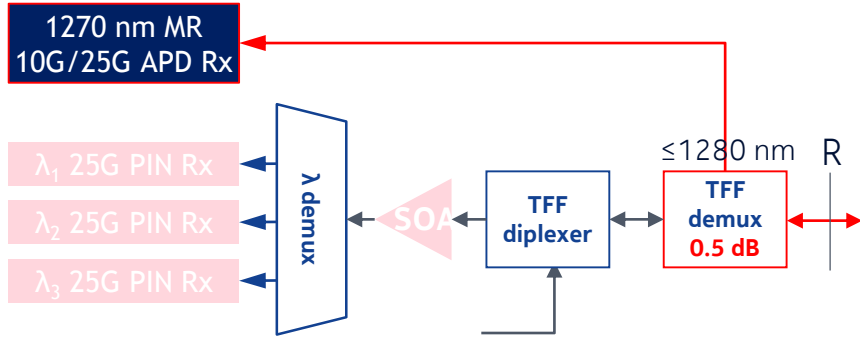
Parameter for Receiver Model for SOA+Filter+PIN / APD

Parameter	Value
APD/PIN Quantum Efficiency	0.7
Signal Wavelength	1270nm
Noise Factor of Electrical Amplifier	2
Load Resistor of TIA	150Ω
Electrical Bandwidth	18.75GHz for 25Gbit/s operation
SOA Gain	17dB
Device Temperature	300K
Dark Current	60nA
BER Threshold	1E-3
Si/Ge and InAlAs APD Multiplication Factor M	12
Si/Ge APD Excess Noise Factor F_{excess} @ M = 12	3.22 (according to SiFotonics, see pan_3ca_1_0916.pdf)
InAlAs APD Excess Noise Factor F_{excess} @ M = 12	5.69
Extinction Ratio at Rx	6dB

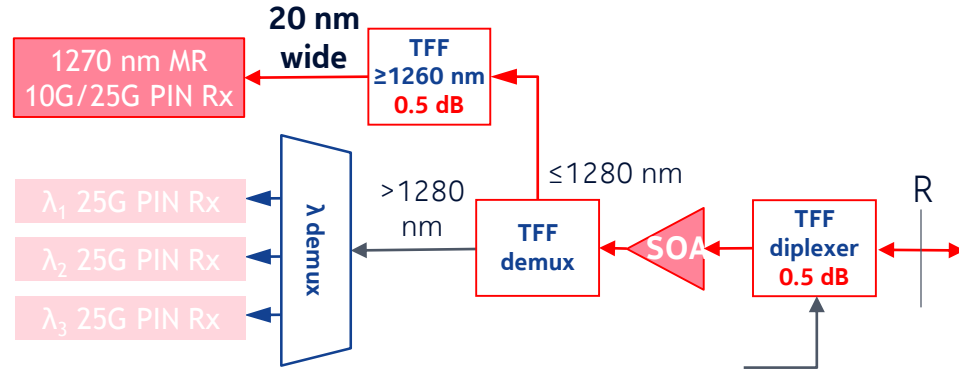
4x25G OLT receiver sensitivity: TDM co-existence, λ_0

How much receiver sensitivity benefit (measured at R) does the SOA+PIN implementation bring relative to the APD?

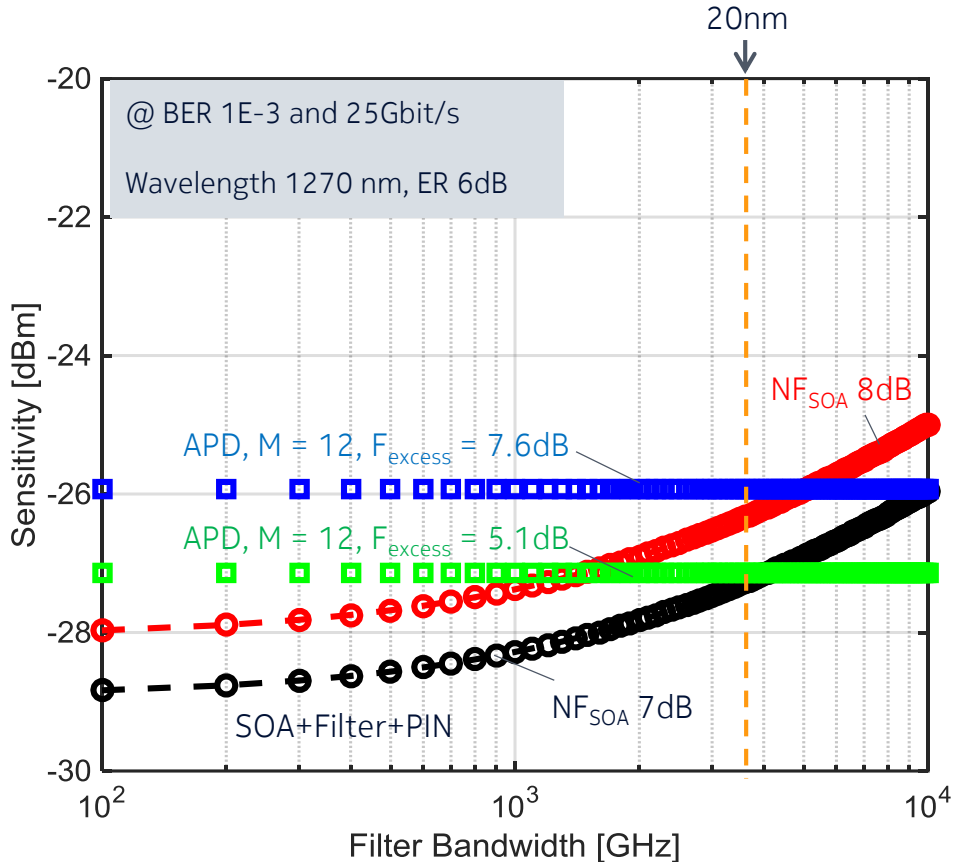
APD receiver



SOA+PIN receiver



4x25G OLT receiver sensitivity: TDM co-existence, λ_0 -- Results



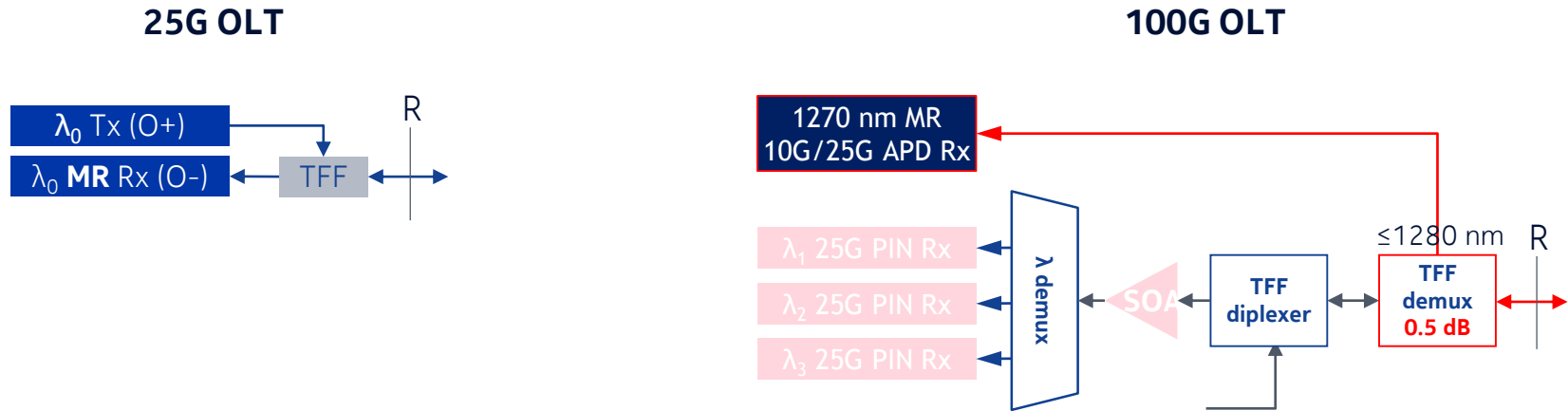
- Rx-filter loss included
- 20nm optical filter bandwidth in SOA-based Rx
- SOA noise figure of 7dB and 8dB
- Si/Ge APD: $M = 12$ and $F_{\text{excess}} = 3.22$ (5.1dB)
- InAlAs APD: $M = 12$ and $F_{\text{excess}} = 5.69$ (7.6dB)
- No margins included for aging, etc...

SOA / PIN Advantage @ 20nm

NF = 7dB	$F = 7.6\text{dB} \rightarrow 1.3\text{dB}$
	$F = 5.1\text{dB} \rightarrow 0.1\text{dB}$
NF = 8dB	$F = 7.6\text{dB} \rightarrow 0.4\text{dB}$
	$F = 5.1\text{dB} \rightarrow -0.8\text{dB}$

4x25G OLT receiver sensitivity: TDM co-existence, λ_0 discussion

- The 100G OLT receiver, for TDM co-existence, can be designed such that the λ_0 APD receiver filter loss is minimized to be the same as for single wavelength 25G OLT BOSA (one TFF):

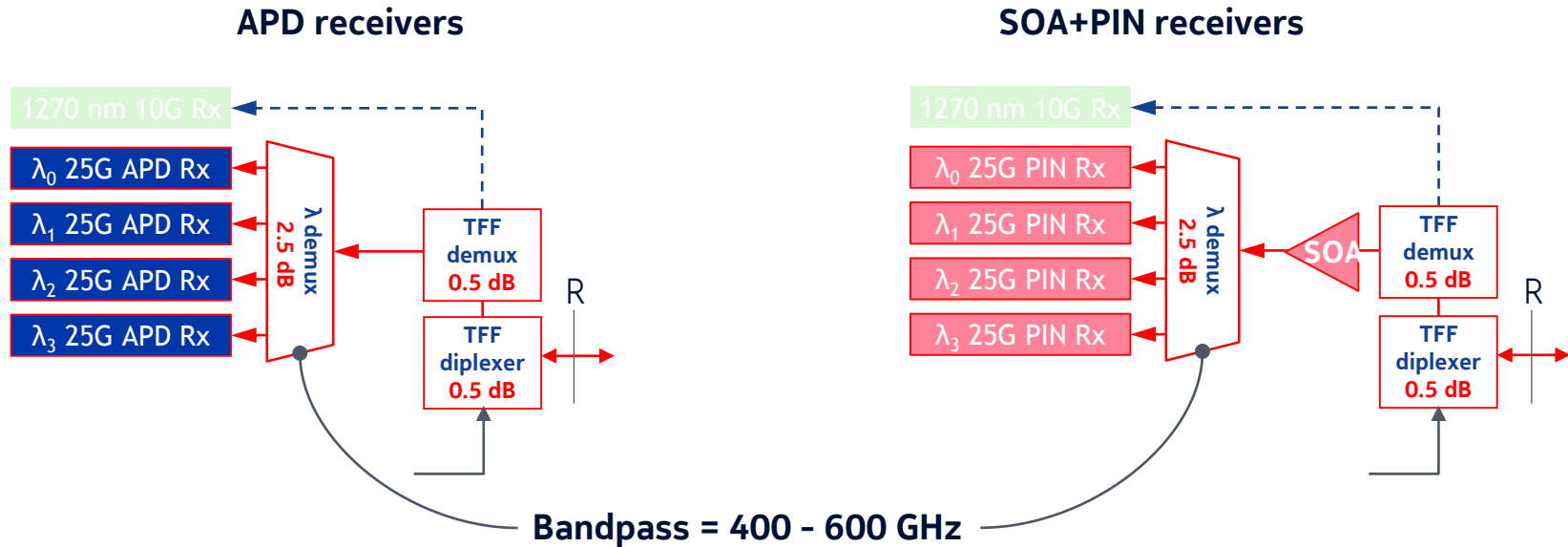


- In this case APD and SOA+PIN (with 20 nm ASE filter) receivers provide about the same performance for λ_0 receiver sensitivity

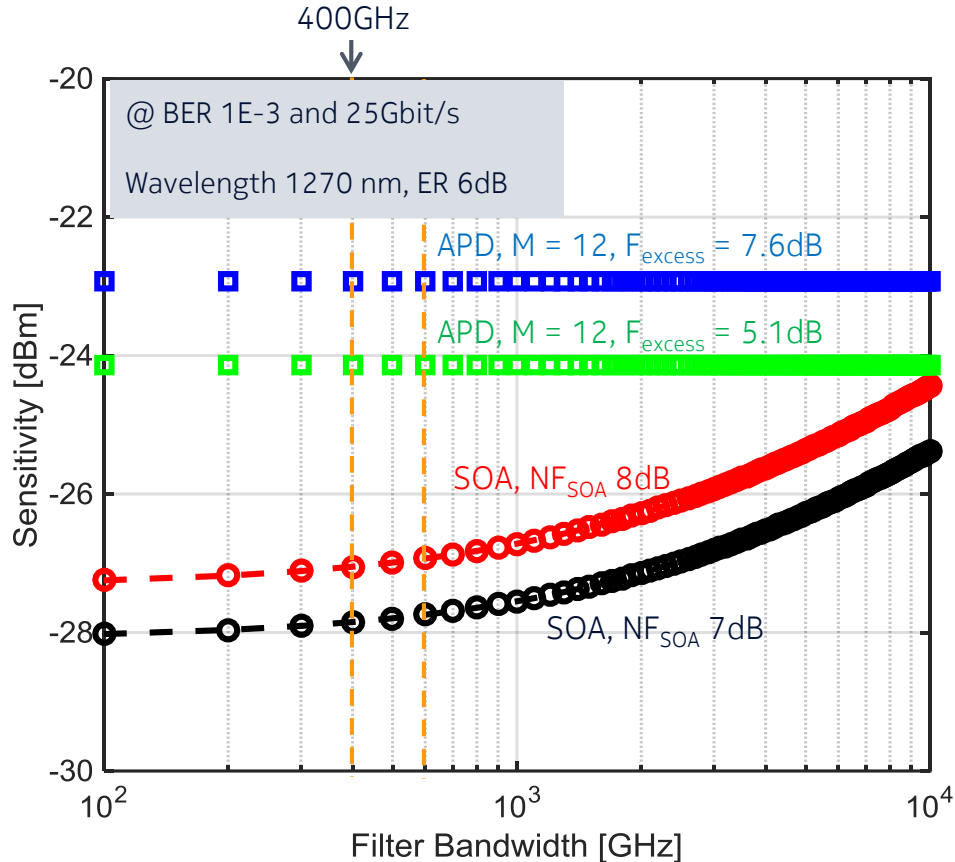
4x25G OLT receiver sensitivity: ...λ3

How much receiver sensitivity benefit (measured at R) does the SOA→demux→PIN implementation bring relative to the APD?

WDM co-existence case shown



4x25G OLT receiver sensitivity: ...λ3-- Results



- Rx-filter loss included
- 400GHz optical filter bandwidth in SOA-based Rx
- SOA noise figure of 7dB and 8dB
- Si/Ge APD: $M = 12$ and $F_{\text{excess}} = 3.22$ (5.1dB)
- InAlAs APD: $M = 12$ and $F_{\text{excess}} = 5.69$ (7.6dB)
- No margins included for aging, etc...

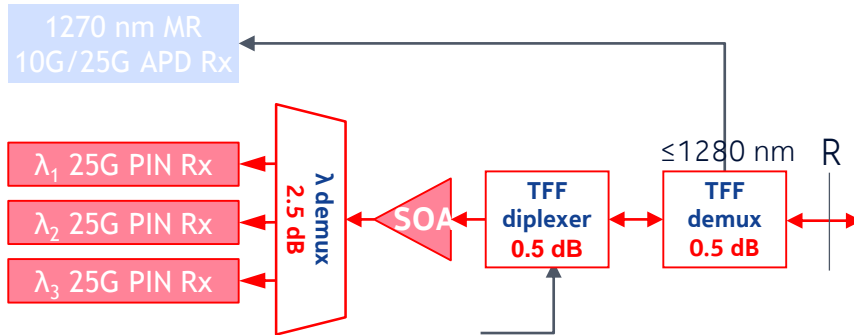
SOA / PIN Advantage @ 400GHz

NF = 7dB	F = 7.6dB → 4.9dB
	F = 5.1dB → 3.7dB
NF = 8dB	F = 7.6dB → 4.1dB
	F = 5.1dB → 2.9dB

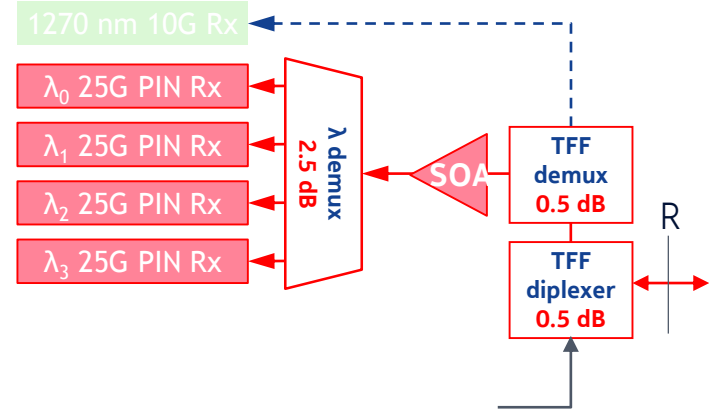
4x25G OLT receiver sensitivity: ...λ3-- discussion

- Vs. an APD receiver, the SOA→demux→PIN receiver with 400-600 GHz ASE filter provides appreciable sensitivity benefit, between ~ 3-5 dB.
- Therefore this confirms expectations that SOA preamps will be used in 100G OLTs.
- The same SOA→demux→PIN performance also applies to $\lambda_1 - \lambda_3$ for the TDM co-existence case:

TDM co-existence



WDM co-existence



NOKIA

Backup

Equations - BER

$$\text{BER} = \frac{1}{4} \left(\text{erfc} \left(\frac{i_1 (1-r)}{2\sqrt{2}\sigma_1} \right) + \text{erfc} \left(\frac{i_1 (1-r)}{2\sqrt{2}\sigma_0} \right) \right)$$

- Gaussian probability density function at the decision circuit voltage at the sampling times for bit 1 and bit 0 assumed
- r is inverse extinction ratio: i_0 / i_1 (i_x expectation of photocurrent for a received one $x = 1$ and zero $x = 0$)
- σ_x with $x = 1$ and 0 is standard deviation of zero and one
- Decision threshold is set to $(i_1 + i_0) / 2$
- Equal probabilities of logical 0 and 1 $\rightarrow 0.5$

Equations - APD

- Signal photocurrent
$$i_1 = \frac{2\bar{i}_{in}}{(1+r)} \quad \bar{i}_{in} = M_0 S (FL_1 \cdot FL_2) \bar{P}_{in}$$

- \bar{P}_{in} is average optical input power, M_0 APD multiplication factor, S responsivity, FL_1, FL_2 loss of Rx-filters, i_{in} resulting average photocurrent

- Standard deviation

$$\sigma_x = \sqrt{\sigma_{\text{shot},x}^2 + \sigma_{\text{TIA}}^2}$$

Shot noise Thermal noise and electrical amplifier noise

$$\sigma_{\text{shot},x} = \sqrt{2eSM_0^2 F_{\text{excess}} (FL_1 \cdot FL_2) P_{x,in} B_e + 2eI_{\text{dark}} B_e}, P_{1,in} = 2\bar{P}_{in} / (1+r), P_{0,in} = 2\bar{P}_{in} / (1+(1/r))$$

- e elementary charge, F_{excess} excess noise factor of APD, $P_{x,in}$ optical power of the zero and one level, B_e electrical bandwidth of the receiver, I_{dark} dark current

$$\sigma_{\text{TIA}} = \sqrt{\frac{4kTB_e F_{\text{TIA}}}{R}}$$

- k Boltzmann constant, T chip temperature, F_{TIA} noise factor of electrical amplifier, R load resistor of TIA

Equations – SOA+Filter+PIN

- Signal photocurrent
$$i_1 = \frac{2\bar{i}_{in}}{(1+r)} \quad \bar{i}_{in} = S(FL_1 \cdot \bar{P}_{in})(FL_2 \cdot G_{SOA})$$

G_{SOA} is SOA gain

- Standard deviation
$$\sigma_x = \sqrt{\sigma_{S-ASE,x}^2 + \sigma_{ASE-ASE}^2 + \sigma_{shot',x}^2 + \sigma_{TIA}^2}$$

- Shot noise:

$$\sigma_{shot',x} = \sqrt{2eS(FL_2 \cdot G_{SOA})(FL_1 \cdot P_{x,in})B_e + 4eS(FL_2 \cdot (G_{SOA} - 1))n_{sp}w_oB_oB_e + 2eI_{dark}B_e}$$

n_{sp} : Inversion factor, w_o minimum noise spectral power density in one polarization added by OA,
 B_o optical filter bandwidth

- Signal-ASE beat noise:

$$\sigma_{S-ASE,x} = \sqrt{4S(FL_2 \cdot G_{SOA})(FL_1 \cdot P_{x,in})S(FL_2 \cdot (G_{SOA} - 1))n_{sp}w_oB_e}$$

- ASE-ASE beat noise:

$$\sigma_{ASE-ASE} = \sqrt{4S^2((FL_2 \cdot (G_{SOA} - 1))^2)w_o^2n_{sp}^2(B_o - (\frac{B_e}{2}))B_e}$$