SOA-PIN performance

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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_{excess} = 3.22) modeled according to SiFotonics contributions pan_3ca_1_0916.pdf
- BER calculated including all noise contributions

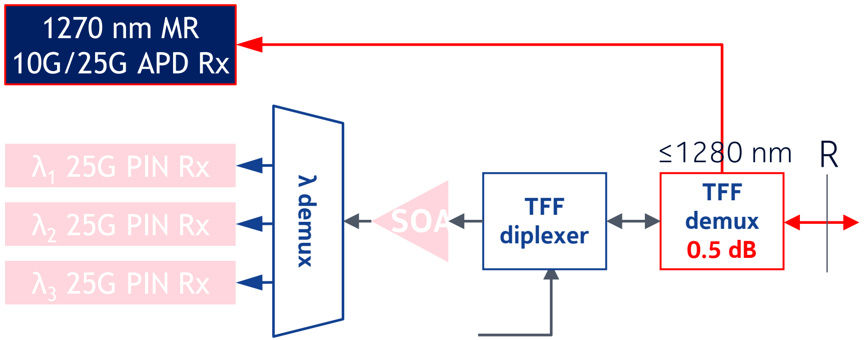
Parameter for Receiver Model for SOA+Filter+PIN / APD

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, λ0

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

APD receiver



1270 nm MR
10G/25G APD Rx

λ_1 25G PIN Rx

λ_2 25G PIN Rx

λ_3 25G PIN Rx

λ demux

SOA

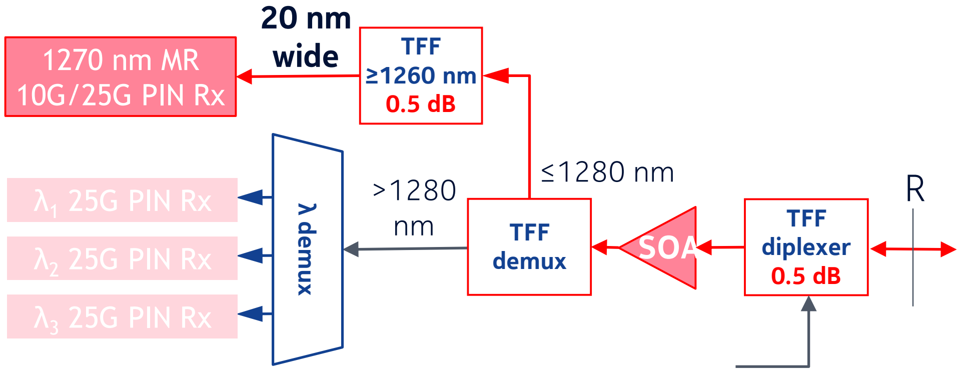
TFF diplexer

≤1280 nm

TFF demux
0.5 dB

R

SOA+PIN receiver



1270 nm MR
10G/25G PIN Rx

20 nm wide

TFF
≥1260 nm
0.5 dB

λ_1 25G PIN Rx

λ_2 25G PIN Rx

λ_3 25G PIN Rx

λ demux

>1280 nm

≤1280 nm

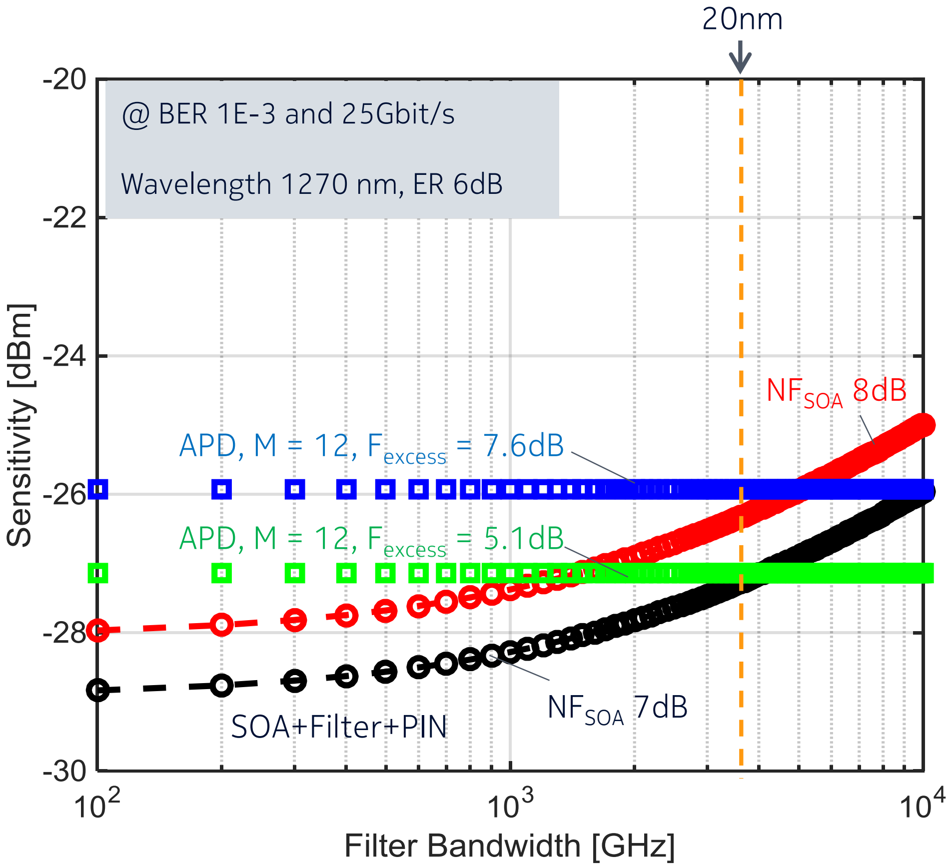
TFF demux

SOA

TFF diplexer
0.5 dB

R

4x25G OLT receiver sensitivity: TDM co-existence, λ0-- 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_{excess} = 3.22 (5.1dB)
- InAlAs APD: M = 12 and F_{excess} = 5.69 (7.6dB)
- No margins included for aging, etc…

SOA / PIN Advantage @ 20nm	
NF = 7dB	F = 7.6dB → 1.3dB
	F = 5.1dB → 0.1dB
NF = 8dB	F = 7.6dB → 0.4dB
	F = 5.1dB → -0.8dB

4x25G OLT receiver sensitivity: TDM co-existence, λ0-- discussion

- The 100G OLT receiver, for TDM co-existence, can be designed such that the λ0 APD receiver filter loss is minimal (same as for single wavelength 25G OLT BOSA).
- In this case, vs. an APD receiver, the SOA+PIN receiver design with 20 nm ASE filter does not provide appreciable benefit for λ0 receiver sensitivity
- Therefore it can be expected that an APD receiver would be used for the λ0 receiver

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

APD receivers

SOA+PIN receivers

1270 nm 10G Rx

λ_0 25G APD Rx

λ_1 25G APD Rx

λ_2 25G APD Rx

λ_3 25G APD Rx

λ demux 2.5 dB

TFF demux 0.5 dB

TFF diplexer 0.5 dB

R

1270 nm 10G Rx

λ_0 25G PIN Rx

λ_1 25G PIN Rx

λ_2 25G PIN Rx

λ_3 25G PIN Rx

λ demux 2.5 dB

SOA

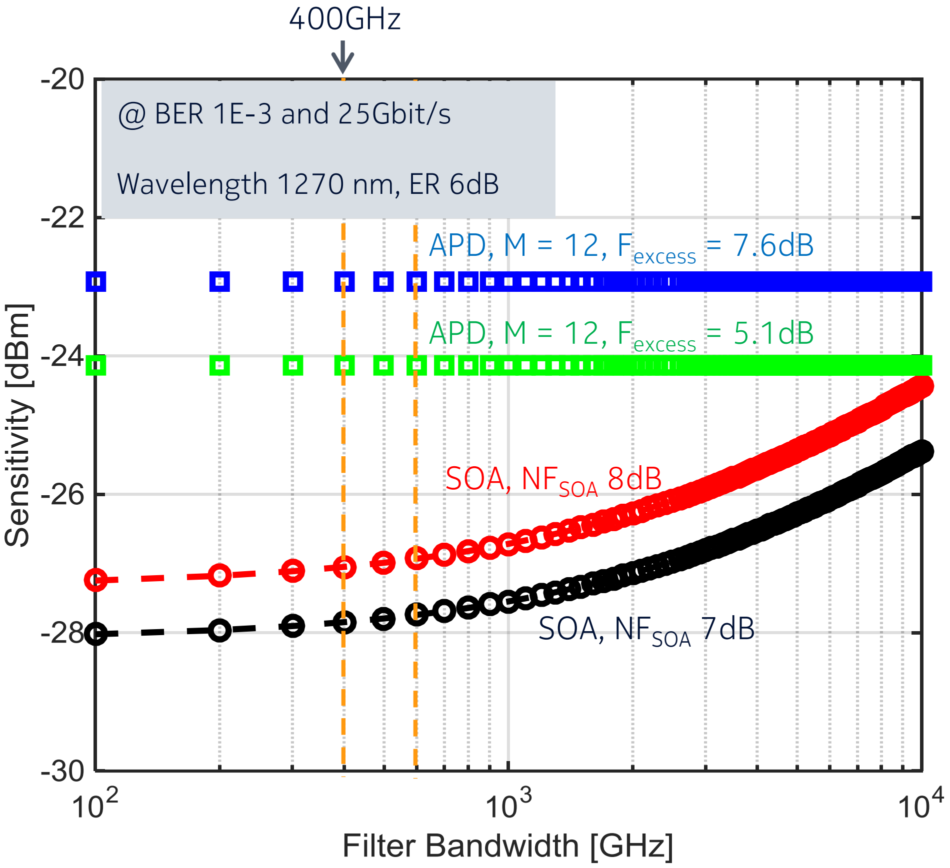
TFF demux 0.5 dB

TFF diplexer 0.5 dB

R

Bandpass = 400 - 600 GHz

4x25G OLT receiver sensitivity: …λ3-- Results



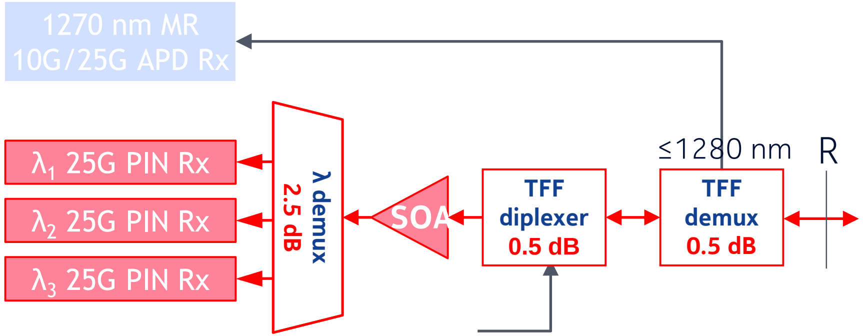
- Rx-filter loss included
- 400GHz optical filter bandwidth in SOA-based Rx
- SOA noise figure of 7dB and 8dB
- Si/Ge APD: M = 12 and F_{excess} = 3.22 (5.1dB)
- InAlAs APD: M = 12 and F_{excess} = 5.69 (7.6dB)
- No margins included for aging, etc…

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

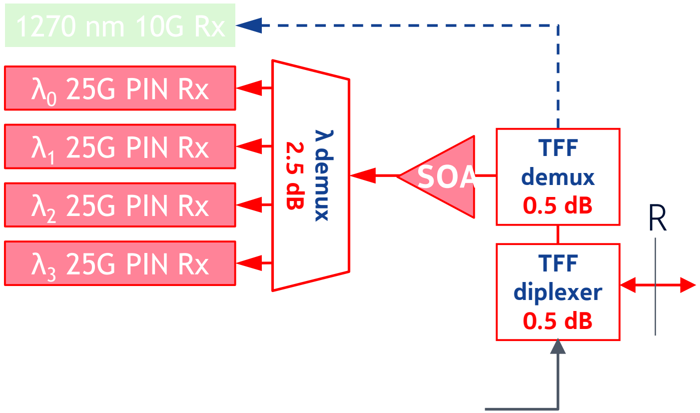
4x25G OLT receiver sensitivity: …λ3-- discussion

- 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 λ_1 - λ_3 for the TDM co-existence case:

TDM co-existence



WDM co-existence



Backup

Equations - BER

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

- 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 → 0.5

Equations - APD

- Signal photocurrent

$$i_1 = \frac{2\bar{i}_{\text{in}}}{(1+r)} \qquad \bar{i}_{\text{in}} = M_0 S\left(FL_1 \cdot FL_2\right)\bar{P}_{\text{in}}$$

- 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

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

- 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

$$i_1 = \frac{2\bar{i}_{\text{in}}}{(1+r)} \qquad \bar{i}_{\text{in}} = S\left(FL_1 \cdot \bar{P}_{\text{in}}\right)\left(FL_2 \cdot G_{\text{SOA}}\right)$$

G_{SOA} is SOA gain

- Standard deviation

$$\sigma_x = \sqrt{\sigma^2_{\text{S-ASE, x}} + \sigma^2_{\text{ASE-ASE}} + \sigma^2_{\text{shot}',\text{x}} + \sigma^2_{\text{TIA}}}$$

- Shot noise:

$$\sigma_{\text{shot}',\text{x}} = \sqrt{2eS(FL_2 \cdot G_{\text{SOA}})(FL_1 \cdot P_{\text{x,in}})B_{\text{e}} + 4eS(FL_2 \cdot (G_{\text{SOA}} - 1))\,\text{n}_{sp}\text{w}_o\text{B}_o\text{B}_e + 2eI_{\text{dark}}B_{\text{e}}}$$

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:

$$\sigma_{\text{S-ASE,x}} = \sqrt{4S(FL_2 \cdot G_{\text{SOA}})(FL_1 \cdot P_{\text{x,in}})\text{S}(FL_2 \cdot (G_{\text{SOA}} - 1))\,\text{n}_{sp}\, w_o B_{\text{e}}}$$

- ASE-ASE beat noise:

$$\sigma_{\text{ASE-ASE}} = \sqrt{4S^2((FL_2 \cdot (G_{\text{SOA}} - 1))^2)\,\text{w}_o^2\text{n}_{sp}^2(\text{B}_o - (\frac{B_e}{2}))\,\text{B}_e}$$