On the technical feasibility of 800G LR4

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Introduction

This presentation is following up on a previous presentation, kuschnerov_3df_01_220222, provided to the TF in February 2022.

• IM-DD is a candidate solution to satisfy .df SMF objectives at 200G/lane up to 10km.

• A high sensitivity receiver is desirable for 10km, not only to compensate the extra 2.3 dB channel insertion loss in 10km, but also to mitigate the penalties discussed in rodes_3df_01a_220329, yu_3df_01a_220329.

• This presentation provides updated results on the technical feasibility of 200G/lane PAM4 at 10km, including system performance verification, and link budget analysis.

Previous Results

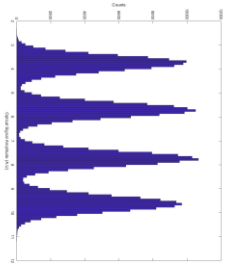
Our previous presentation, kuschnerov_3df_01_220222, has shown analysis of 200 Gb/s optical feasibility within 2km

- The demonstration of 224Gb/s PAM4 transmission for 2km WDM link budget with EML based technology.
- Measurements using optical amplification (PDFA) at the Rx was shown without optical filter.
- The link budget and FWM & CD penalty at longer reach was not fully analyzed yet.

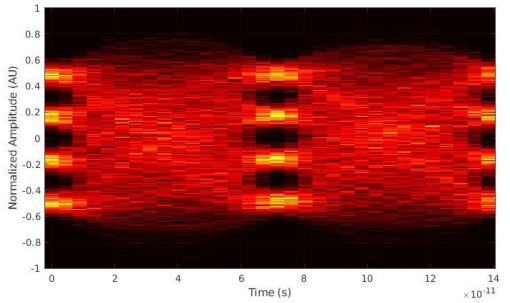
Measurements Setup

- The DAC, EML based TOSA and PD are identical to what was demonstrated in kuschnerov_3df_01_220222.
- In order to boost the sensitivity and to evaluate the benefit from optical amplification, the SOA (instead of PDFA) was deployed in this work,.
- The optical filter before the PD is a free-space coupled flat top optical filter with -3dB optical bandwidth ~2nm. The fiber-to-fiber insertion loss of the tunable filter is 3dB.
- The LA after the PD is a linear amplifier with 11 dB gain and a bandwidth larger than 60GHz.
- The received optical power (ROP) is measured before the SOA.

Equalized Histogram



Received Optical Signal with FFE EQ



ER is estimated to be 4.1 dB from equalized eye-diagram

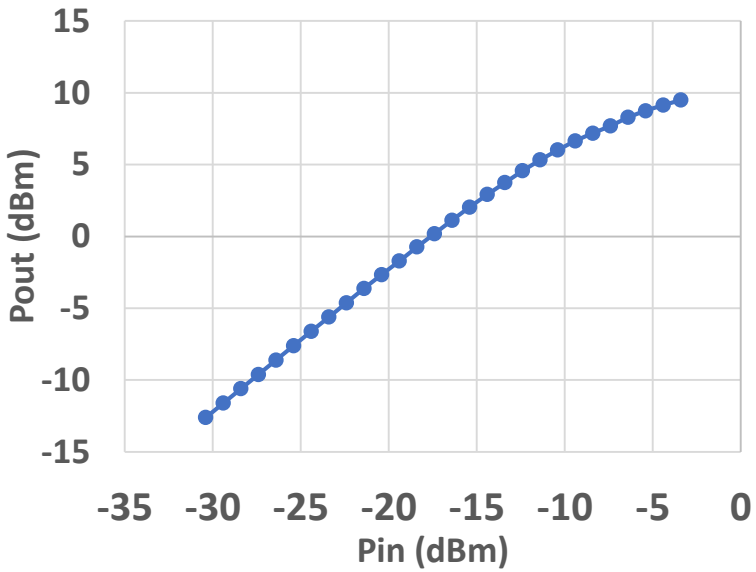
SOA characteristics

- The SOA has a wide dynamic range with gain of >16 dB.
- The noise figure of the SOA at this pumping level is 6 dB, with the following assessment equation [1]:

$$NF = \frac{1}{G} + \frac{P_{ASE}}{h\nu \times G \times \Delta\nu}$$

Where G is the SOA gain, P_{ASE} is the integrated ASE power, hν is the photon energy of the amplified signal and Δν is the OSA resolution.

SOA output power vs. input power



[1]. IEC61290-3-1 'Optical amplifiers - Test methods - Part 3-1: Noise figure parameters - Optical spectrum analyzer method' (2003-08)

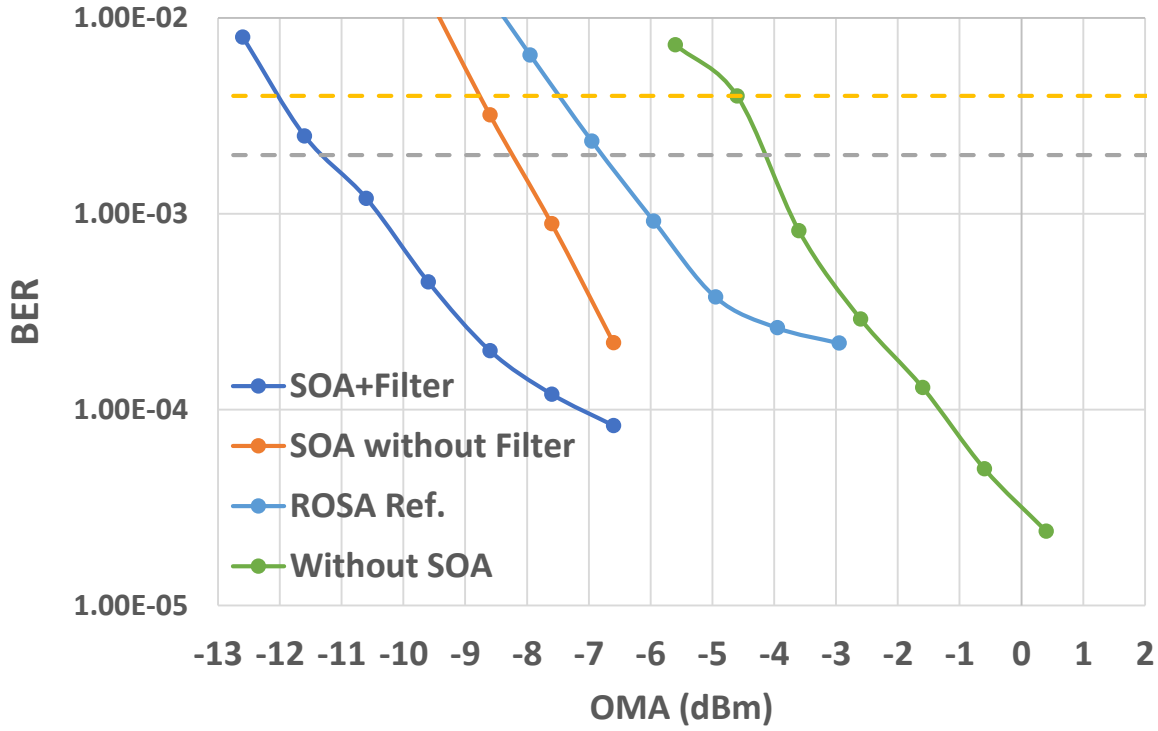
TOSA+SOA+PD results

- 41 tap FFE + Post Filter + MLSE is utilized to improve performance due to bandwidth limitation and RF cabling (DAC->TOSA, PD->DSO)
- FEC is still under discussion, and is assumed in the range between 2e-3 and 4e-3.
- Rx sensitivity:
  - OMA=-11.6 dBm (ROP=-11.0 dBm) @ 2e-3
  - OMA=-12.1 dBm (ROP=-11.5 dBm) @ 4e-3
- The Q factor of PAM4 before linear amplifier could be estimated as :

$$Q \propto \frac{OMA * Resposivity}{3 * 2 * Input\ noise}$$

Dominant at sensitivity point

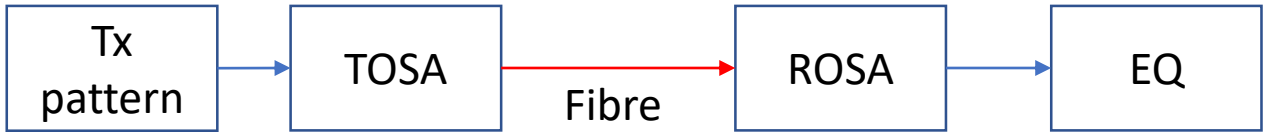
- The enhancement of receiver responsivity over noise in SOA+Filter+PIN scheme explains the improvement of sensitivity.
- The SOA+Filter+Pin+TIA should provide even better performance, which is under investigation.



	SOA+PIN+LA with filter	SOA+PIN+LA w/o filter	PIN+LA	ROSA
Responsivity (A/W)	8.7	17.5	0.4	0.5
Noise density of receiver (pA/sqrt(Hz)	27	120	21	17

Note: Input noise of current system is estimated from noise floor measurement in DSO

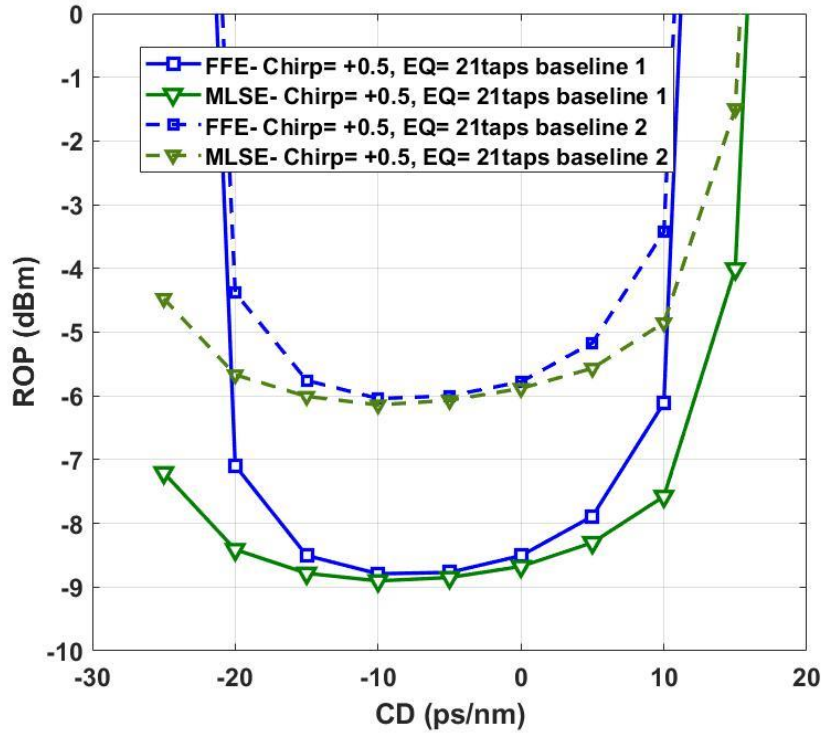
Link Budget Analysis - Dispersion



- The chromatic dispersion is added in the simulation based on model in [2].
- The simulation is based on the following baselines of the components.

Items	Baseline 1	Baseline 2
BW of TOSA	60 GHz	60 GHz
RIN	-145 dB/Hz	-145 dB/Hz
Responsivity	0.75 A/W	0.5 A/W
Input noise of ROSA	15 pA/sqrt(Hz)	17 pA/sqrt(Hz)
BW of ROSA	55 GHz	55 GHz

- Dispersion penalty < 1 dB could be achieved with proper designed of wavelength grid around zero dispersion region and Tx chirp.



Simulation results: Dispersion penalty with receiver parameters. Results from Baseline 1 were shown in rodes_3df_01a_220329

[2]: Fiber-Optic Communication Systems 4th Edition by G. Agrawal

Link Budget Analysis – Four-Wave mixing

- The potential link budget penalty of FWM in PAM4 transmission was comprehensively discussed in Johnson_3df_optx_01_220414.

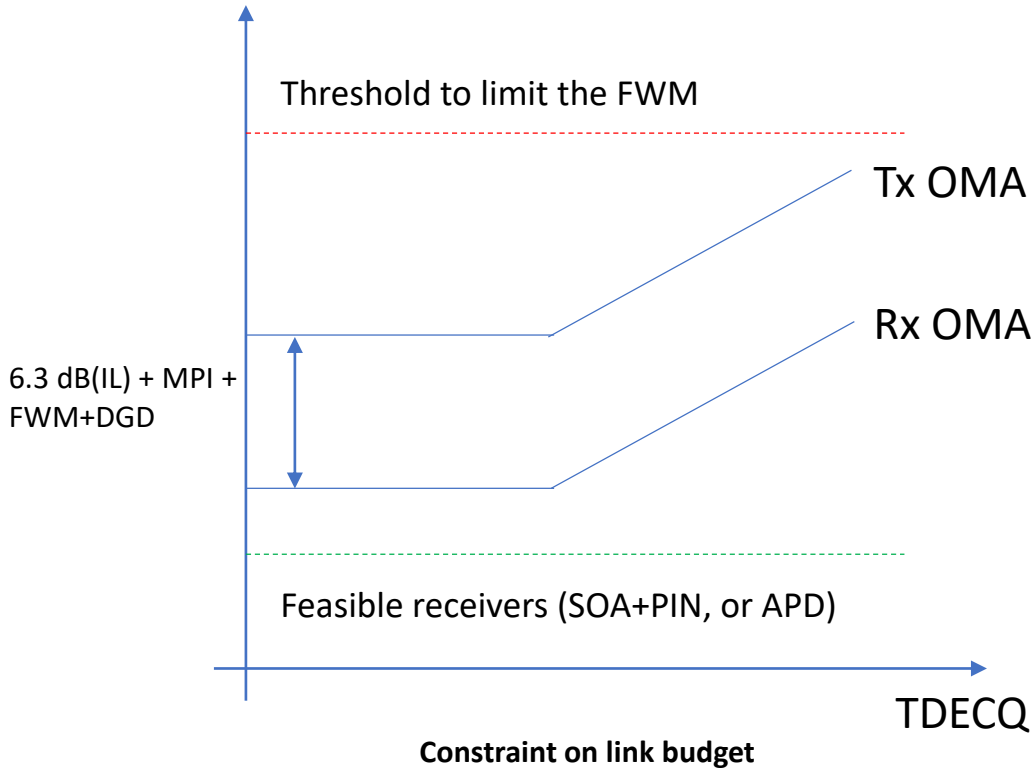
- Three major effective ways of mitigating FWM are:
  - reducing fiber launching power (rodes_3df_01a_220329, yu_3df_01a_220329)
  - uneven channel spacing (rodes_3df_01a_220329)
  - polarization interleaving (rodes_3df_01a_220329, yu_3df_01a_220329, Johnson_3df_optx_01_220414), 1 dB FWM penalty @ 1dBm launch power with KP4 FEC,

- The PMD would further mitigate the worst case penalty.

Link Budget Analysis - Summary

- The link budget decomposition is constrained by max launch power threshold (due to FWM), feasible receiver sensitivity, and CD, FWM, MPI penalties
- Consider a sensitivity of -11.6 dBm OMA (-11.0 ROP with 4 dB ER) demonstrated in this work.
- The FWM penalty with different FEC level would be very useful.
- An example of preliminary link budget consideration is shown below, where Tx OMA =0.4 dBm (1 dBm AOP with 4 dB ER)
- A preliminary required link budget of 11.5 dB is suggested as a starting point for further discussion.

Items	800G LR4	400G FR4	400G LR4-6
Link budget achieved (dB)	12	-	-
Channel insertion loss (dB)	6.3	4	5
Allocation for penalties (for maximum TDECQ, MPI, DGD, FWM) (dB)	4.2+1	3.8	4.2
Additional insertion loss allowed (dB)	0	0	1.3
Total link budget required for Max. TDECQ (dB)	11.5	7.8	10.5



Constraint on link budget

1 dB allocation penalties to account for additional penalty like FWM

Conclusions

- A sensitivity of -11 dBm has been demonstrated for 4x200G IM-DD solution, with feasible components.
- Investigation on SOA+PIN+TIA is undergoing to further improve the receiver sensitivity.
- With lower launch power, the FWM related penalty could be mitigated. The 10km-link budget seems feasible with IM-DD solution based on the result in this work.
- Further investigations are required to quantify the FWM penalty at different FEC levels, and to quantify other fiber impairments.

Thank You