FWM and zero dispersion wavelength analysis for 800G LR4

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Supporters

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- Rangchen (Ryan) Yu, SiFotonics
- Frank Chang, Source Photonics

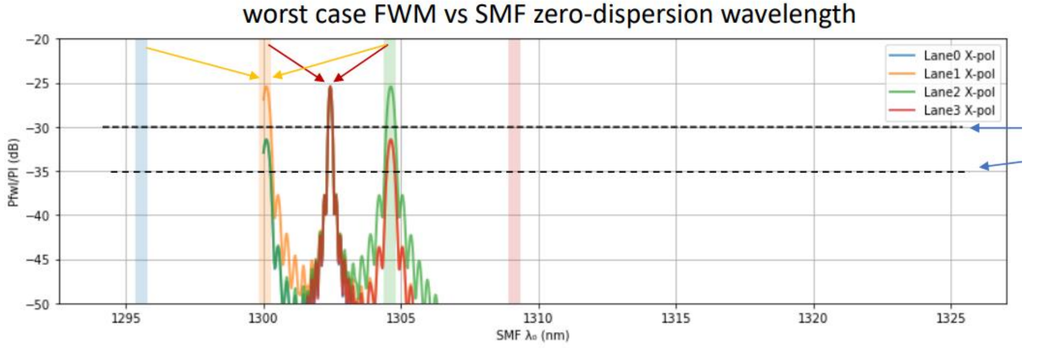
800G LR4 and four wave mixing (FWM)

- **Motivation**: Further advance the 800G LR4 baseline discussion as outlined in rodes_3df_01a_2211
- FWM modelling and penalties have been covered prior in johnson_3ca_1_0716 , johnson_3df_optx_01_220414, rodes_3df_01b_221012
- FWM refined modelling & management techniques in the context of the 800G LR4:
  - Unequal vs. equal channel spacing (rodes_3df_01a_220329)
  - Polarization interleaving (liu_3df_01b_2207)
  - Higher sensitivity receivers (APD: yu_3df_01a_2203239 , SOA-PIN: lin_3df_01_220609)
  - Use of statistical approach to fiber ZDW calculation (cole_3df_01a_2211, parsons_3df_01a_2211)
  - Modelling realistic fiber and transceiver parameter probabilities (rodes_3df_01a_2211)
  - Assuming typical deployment case of segmented fiber with varying ZDW (johnson_3df_optx_01_220414)
- **Note**: Current 800G LR4 baseline by [rodes_3df_01a_2211] derives the channel penalties based on improved channel modelling (ZDW, OMA, PMD, ER), but does not use interleaved polarizations (XYYX) for FWM management

FWM: Four wave mixing
ZDW: Zero dispersion wavelength
PMD: Polarization mode dispersion
DGD: Differential group delay
ER: Extinction ratio
OMA: Optical modulation amplitude

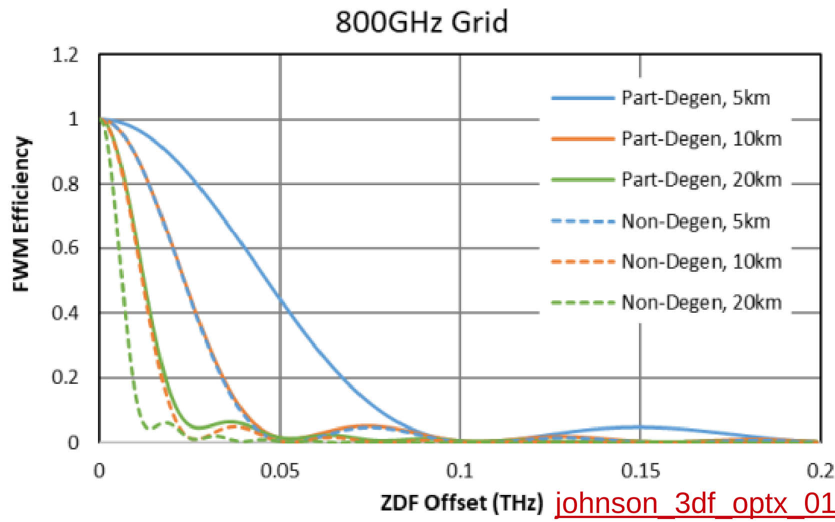
800G LR 4 system impact of FWM vs. ZDW

- rodes_3df_01b_221012 demonstrated that for a given 4-lambda grid only 3 limited spectral regions can experience FWM with a varying ZDW
- johnson_3df_optx_01_220414 has quantified a more general FWM bandwidth
- Here, we would like to evaluate the FWM bandwidth on the system level for 800G LR4
- Standard LAN-WDM grid used for analysis (1295.56nm, 1300.06nm, 1304.59nm, 1309.14nm)
- ZDW is swept from 1300nm till 1324nm (not implying any probability distribution of the ZDW)



LAN-WDM has potential FWM problem if the fiber has zero-dispersion lambdas: 1300.1nm , 1302.4nm and 1304.6nm

rodes_3df_01b_221012.pdf



johnson_3df_optx_01_220414

Channel modelling

- Advanced link modelling for FWM requires a joint analysis with DGD/PMD incl. a statistical assessment of outage probabilities
- DGD/PMD specifications for 200G/lane PAM4 were analyzed in kuschnerov_3df_01b_221012 and kuschnerov_3df_01a_2211
- So far there was no final conclusion on whether we could reduce DGD/PMD specs
- For our FWM assessment, we will use a numerical nonlinear fiber simulation with a FFE+MLSE reference receiver
- We will use **worst case channel conditions** (XXXX polarization alignment and no PMD) to avoid an exhaustive statistical evaluation based on preliminary PMD specifications

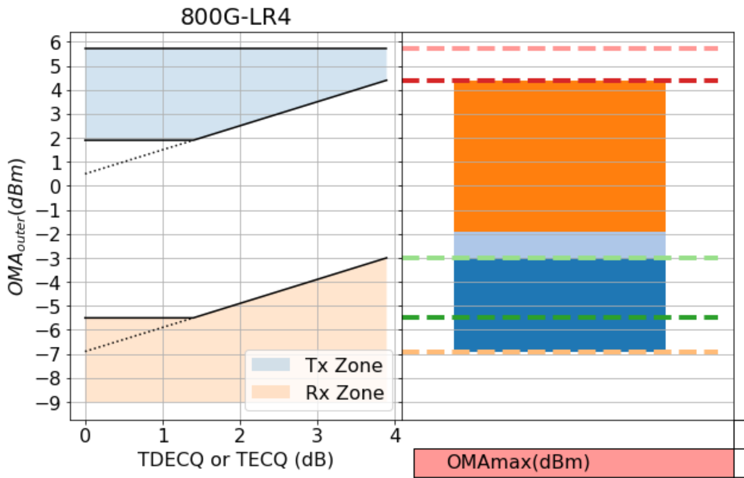
Modelling the 800G LR4 link budget

- As discussed on the email reflector in Dec 2022, the latest 800G LR4 IMDD specification proposal (rodes_3df_01a_2211) should have an increased Tx outer OMA per lane of 5.7dBm (up from 5.0dBm) to accommodate a higher transmitter headroom delta of 1.3dB at max TDECQ
- It would require further contributions to define the corresponding Tx average optical power (AOP) value
- For the time being, we will assume a Tx AOP of 5.5dBm (as per last baseline) + Δ1dB to cover any excess headroom in future discussions

Latest 800G LR4 link budget

Parameter	Proposal LR4	Unit
Power budget (for maximum TDECQ)	11.3	dB
Operating Distance	10	km
Channel insertion loss	6.3	dB
Maximum discrete reflectance	-35	dB
Allocation for penalties (for maximum TDECQ) *	5	dB

*DGD=0.7dB and MPI= 0.4dB , kuschnerov_3df_01b_221012, kuschnerov_3df_02a_221012

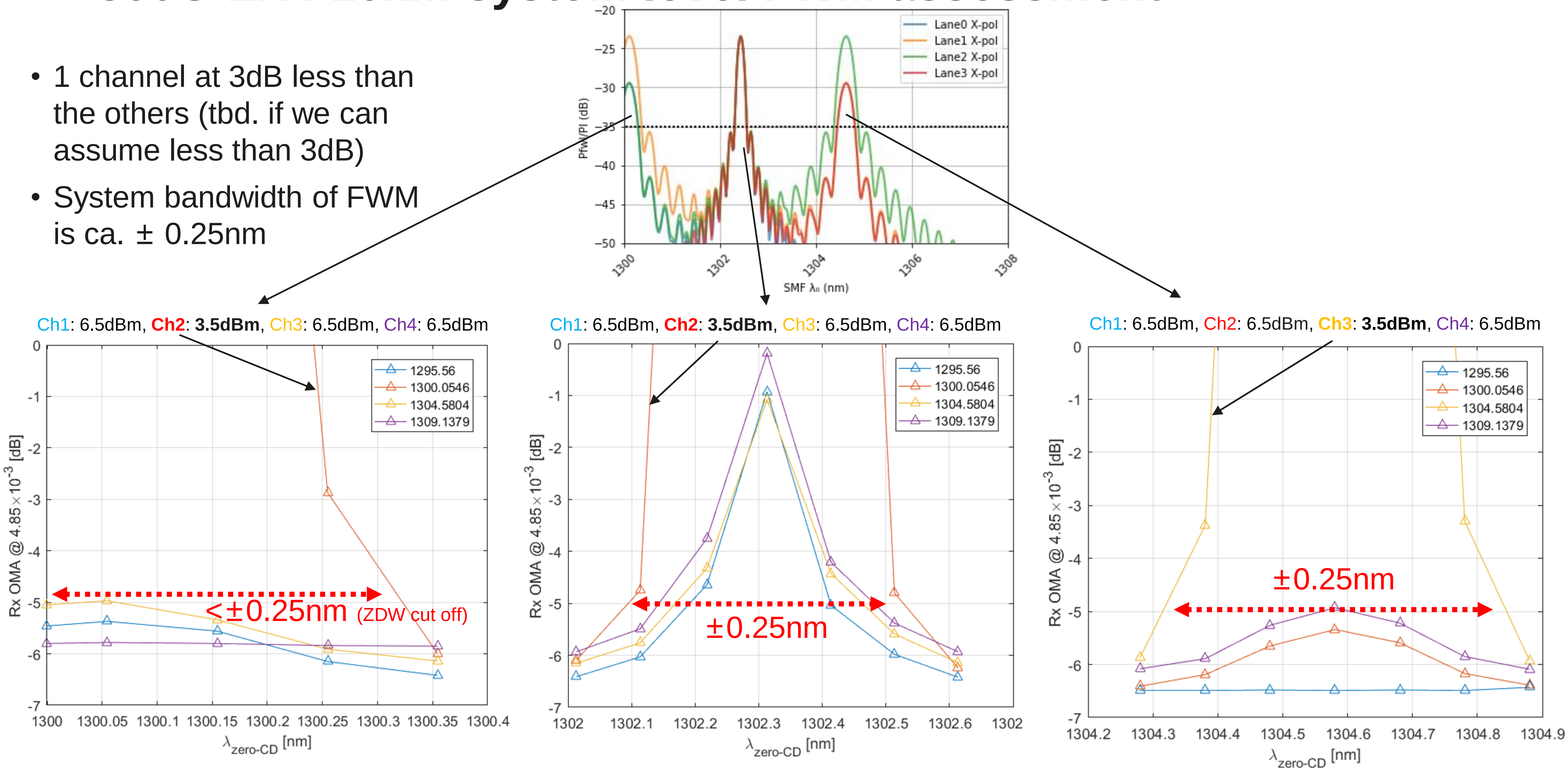


Improved Tx headroom Δ1.3dB

	800G-LR4
OMAmax(dBm)	5.7
OMA-TDECQ(dBm)	0.5
OMAmin@TDECQmax(dBm)	4.4
SRS(dBm)	-3.0
Rx Sens (TECQ <= 1.4dB)	-5.5
RSnominal(dBm)	-6.9
OpticalLossBudget	6.3
AdditionalPenalties	1.1
TDECQmax	3.9
PowerBudget	11.3

800G LR4 10km system level FWM assessment

- 1 channel at 3dB less than the others (tbd. if we can assume less than 3dB)
- System bandwidth of FWM is ca. ± 0.25nm



FWM management options

Statistical channel modelling

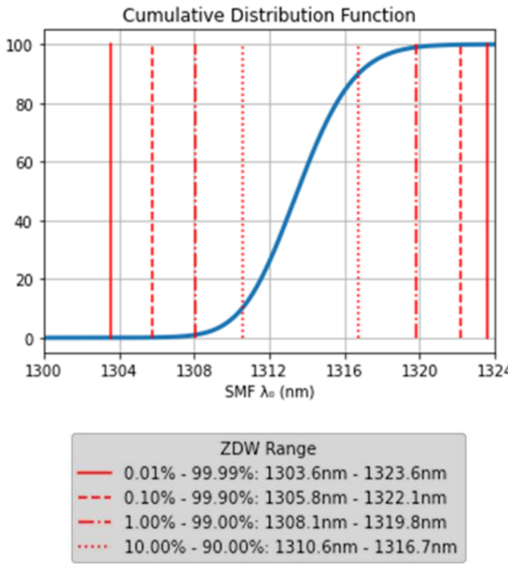
- The current 800G LR4 baseline manages FWM by statistical use of fiber parameters as proposed in parsons_3df_01a_2211.pdf or cole_3df_01a_2211 which effectively reduces (or even eliminates) the impact from the spectral ranges where FWM can cause a penalty for the analyzed grid

FWM management by design

- In addition, FWM could be eliminated by design with these adaptations:
  a) The (low probability) FWM regions could be avoided using straight-forward engineering solutions enabling a limited TEC tunability of ±0.25nm (±2.5ºC) and a few different working points of the transmitters
  b) Definition of an offset grid outside of the FWM region, where the slightly larger CD could be managed by chirp optimization
- FWM management by design would not require any statistical modelling of fiber parameters and could take the min/max definition of current ZDW/PMD specs as is

Note:

According to cole_3df_01a_2211 analyzing 4 major fiber manufactures, fibers having a ZDW in the range, relevant for potentially creating FWM for 800G LR4 on the proposed LAN-WDM grid, have a probability of ca. 5e-4



Conclusions

- The original 800G LR4 baseline introduced updated channel modelling and effectively manages FWM (rodes_3df_01b_221012)
  - Statistical modelling of ZDW shows that the impact of FWM is negligible
  - It doesn’t recommend a particular polarization alignment of the transmitter signals
  - Modelling and penalty assessment of CD, PMD, FWM, MPI was effectively demonstrated both in simulations and measurements and is included in the link budget
- In addition, we have demonstrated additional ways to manage FWM for 800G LR4 by design
- 800G LR4 is a crucial building block for 1.6T FR8 / LR8
  - As a next step, we intend to extend the discussion of grid selection, CD and FWM management and link budgeting to 8x200G
  - The availability of advanced receivers (e.g. SOA+PIN) will help to facilitate the scalability of 200G/lane technology to 8 lane interfaces

Thank you.