Four wave mixing in 100GBASE BR40 wavelength plan

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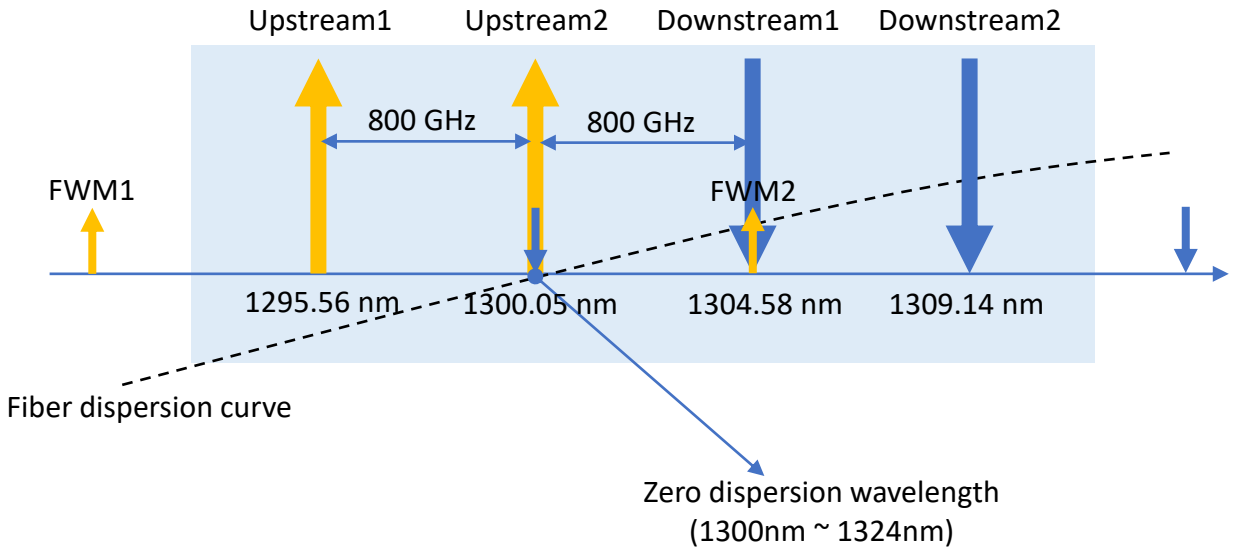
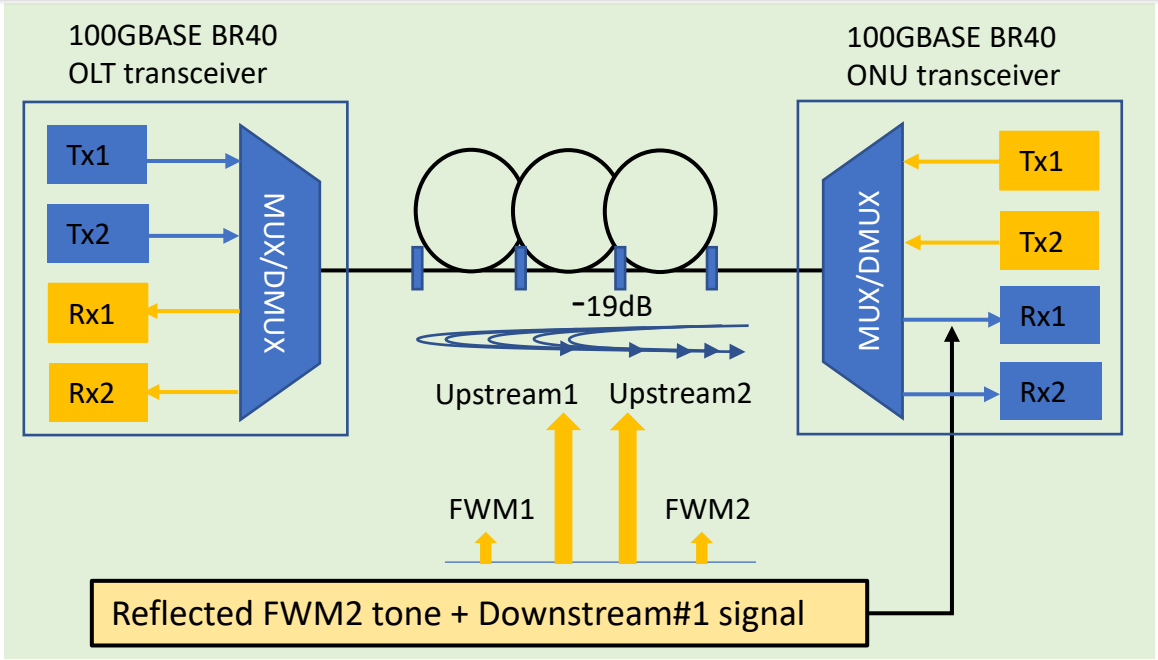
Introduction

- During the last meeting, a proposal was made to use a 2 x 50 Gb/s PAM4 modulation format for the 100GBASE BR40 application. This proposal takes advantage of the 800 GHz channel spacing in the LWDM range, which allows for the use of widely available LWDM optical components, resulting in cost and implementation benefits.
- However, one consideration is that the LWDM wavelength is situated across the zero-dispersion wavelengths, which can lead to Four-Wave Mixing (FWM) effects on four channels. For example, FWM tones generated by two upstream or downstream signals can be reflected in the optical link and received by the transceiver's receiver along with the downstream or upstream signals. This reflected FWM tone can act as signal noise, affecting the received signal quality.
- In this contribution, an analysis of FWM crosstalk and its impact will be provided.

Reflected FWM tone

- Each pair of uplink and downlink signals has been sequentially allocated to LWDM wavelengths.
- Second upstream signal can coincide with the finer zero-dispersion frequency at 1300 nm
- Given the channel spacing configured at 800 GHz, the frequency of the FWM2 tone matches the wavelength of the first downstream signal at 1304.58 nm.
- Due to reflections in the link, the reflected FWM2 can be inputted to Rx1 of the ONU transceiver. According to the 802.3cp standard, maximum reflectance value of the channel should not exceed -19 dB at a single point.





Four wave mixing product

FWM induced output power

$$P_{ijk} = \left(\frac{D_{ijk}}{3}\gamma L_e\right) P_i P_j P_k \, e^{-\alpha L}\eta$$

γ: nonlinear coefficient
D_{ijk}: 3 for two tone product, 6 for three tone product
L_e: fiber effective length
P_{ijk}: input peak power of channels

$$\text{efficiency } (\eta) = \frac{\alpha^2}{\alpha^2+\Delta\beta^2}\left(1+\frac{4e^{-\alpha L}sin^2(\Delta\beta/2)}{(1-e^{-\alpha L})^2}\right)$$

α: fiber loss
$\Delta\beta$: difference of propagation constants

$$\Delta\beta \propto \lambda^2/c\,(\Delta f)^2 D(\lambda)$$

FWM

- increases with P^2
- decreases as 4th power of channel spacing
- decreases quadratically with dispersion

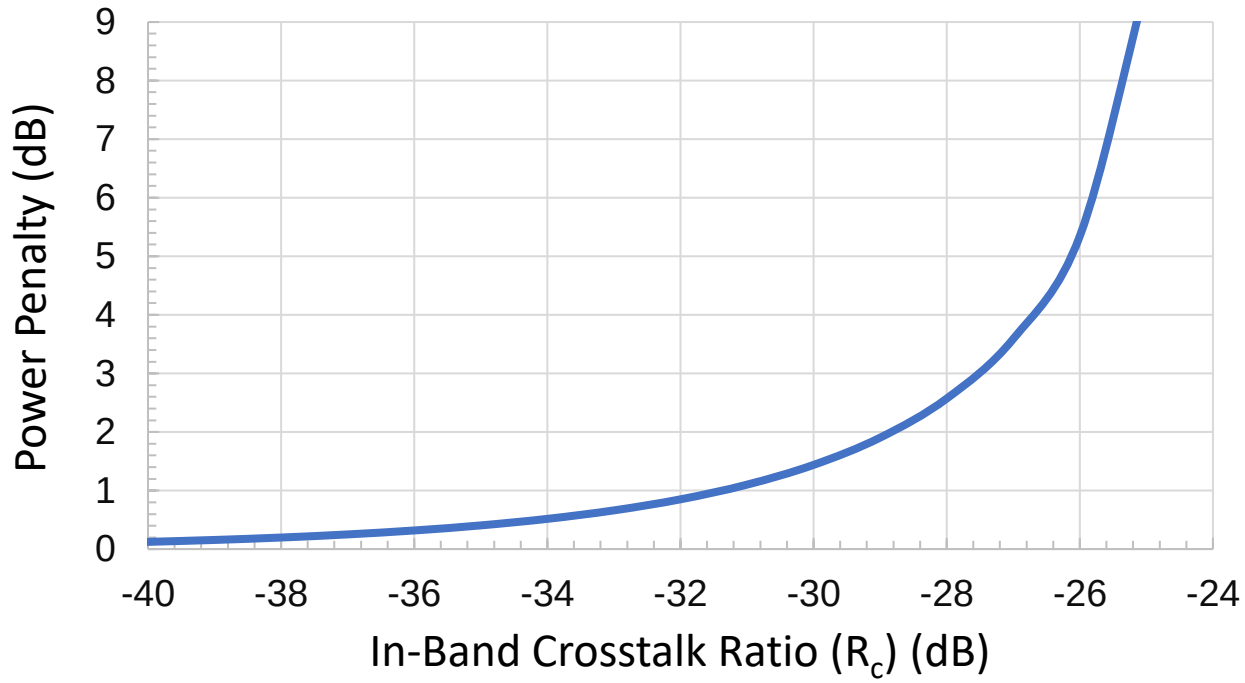
Ref., https://grouper.ieee.org/groups/802/3/ca/public/meeting_archive/2016/07/chung_3ca_1a_0716.pdf
"Analytical Investigation of FWM for O-band Multi-Channel Transmission"

Power penalty of PAM4 signal

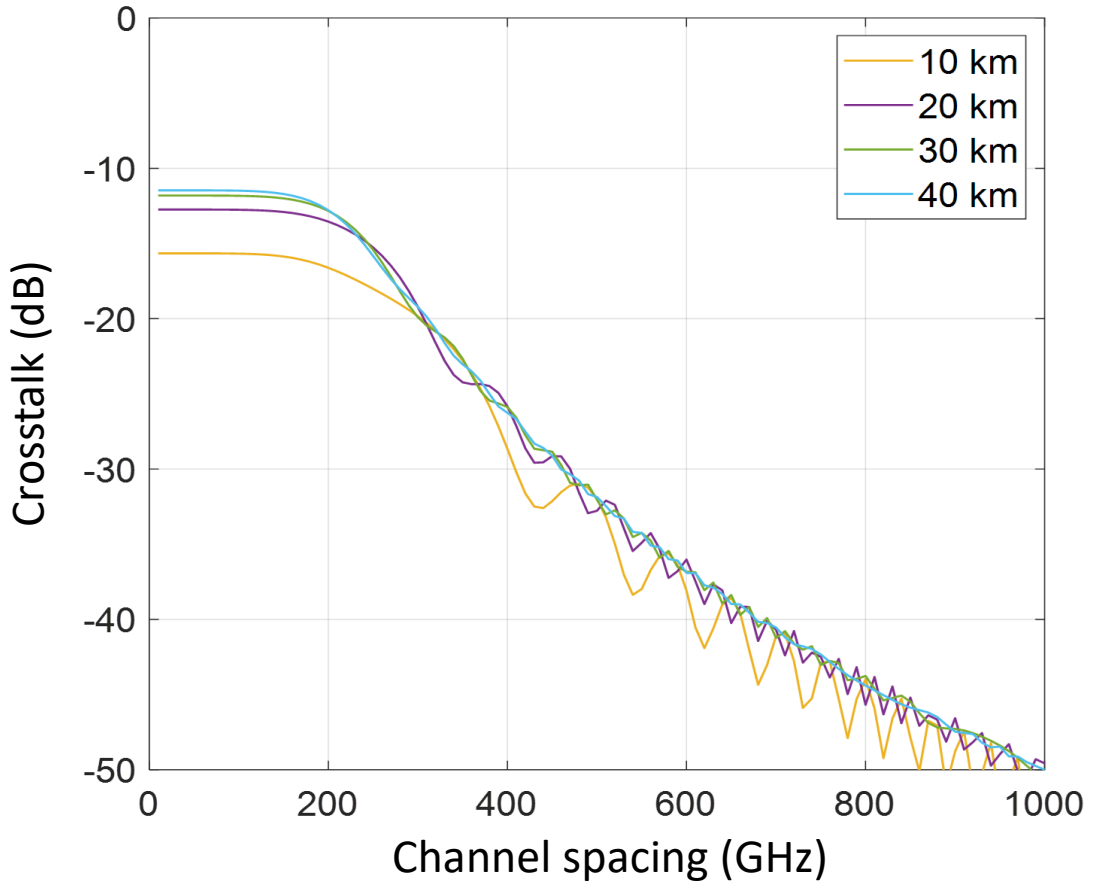
$$Penalty_{PAM4}(dB) = -10\log[1 - \frac{47}{6}R_cQ^2]$$

R_c: the average optical power ratio of each crosstalk component to the signal
Q: Q-factor (6 for BER of 1e-9, 3.1 for BER of 1e-3)

Ref., Chul Han Kim, "In-band crosstalk-induced power penalties in various signal modulation formats," Optical letters, Vol.44, No. 24, 2019



FWM crosstalk: O-band (zero dispersion wavelength)



λ = 1300 nm
P = 8 dBm/ch
α = 0.4 dB/km
$dD/d\lambda$= 0.08 ps/km/nm^2
D = 0 ps/nm/km

- A crosstalk between the signal and FWM tone is -44 dB after 10 km. The crosstalk is saturated at -43 dB even the length of fiber is increased because effective fiber length is around 10 km.
- Crosstalk due to FWM is negligible, even considering the maximum reflectivity of 19 dB on an optical link.

Summary

- In a zero dispersion region with an 800 GHz channel spacing, the FWM effect is insignificant. The FWM tones generated by the two signals are weak, resulting in negligible penalties caused by the reflected FWM tones from the fiber.
- Therefore, when considering a 100GBASE BR40 wavelength plan that utilizes 2 x 50 Gb/s wavelengths in both directions, there are no issues regarding FWM.
- A proposed BR40 wavelength plan is provided in the table below:

	Upstream #1	Upstream #2	Downstream #1	Downstream #2
Center wavelength	1295.56nm	1300.05nm	1304.58nm	1309.14nm
Wavelength range	+/- 1nm	+/- 1nm	+/- 1nm	+/- 1nm