Suppression of Four-Wave-Mixing (FWM) for 100G-EPON

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The Problem at Hand

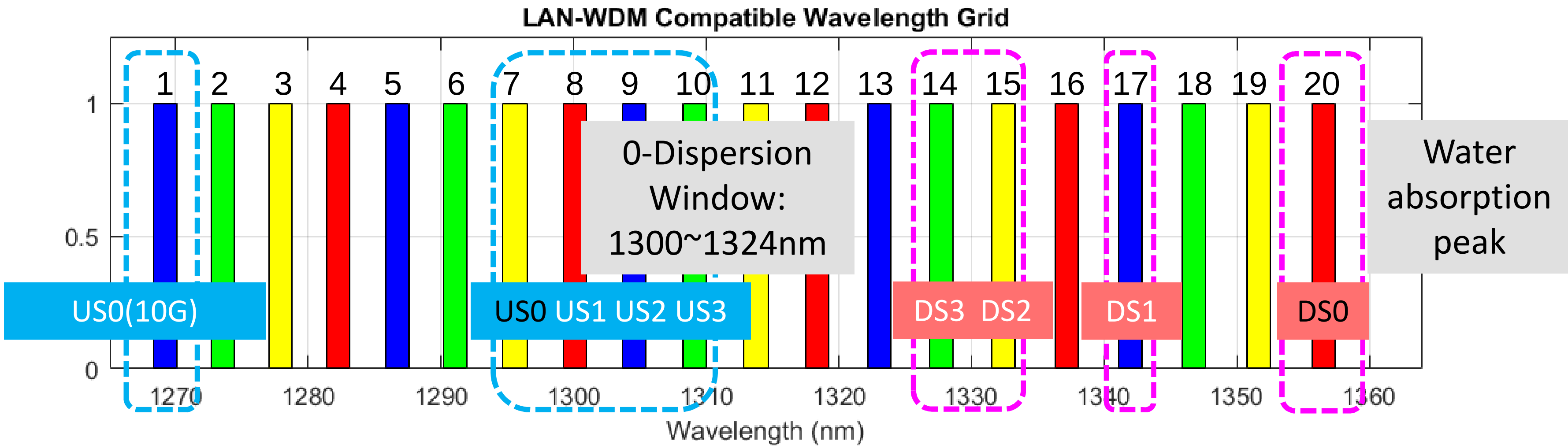
When defining the wavelength plan for 100G-EPON, it is needed to minimize four-wave-mixing (FWM) induced transmission penalty.

One option is to avoid any wavelength channels to be located in the zero-dispersion window, which can be as wide as 1300nm~1324nm. This option limits the available spectrum in the O-band and may increase the system cost.

Another option is to suppress FWM via judicious polarization control. We provide an analysis of how polarization control may be used to substantially suppress the FWM in this contribution.

100G-EPON Wavelengths: Plan A1*

– LAN-WDM Fully Reused & GPON Co-Existence



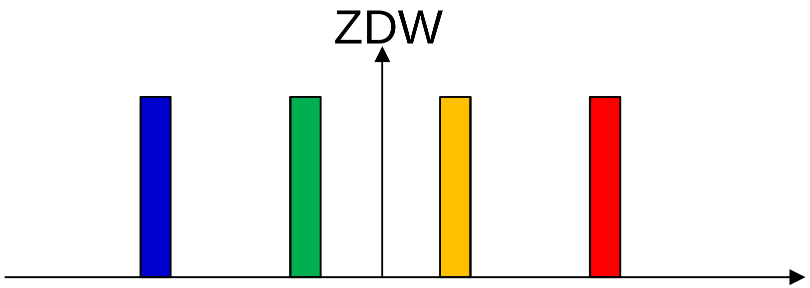
- ✓ US0-3 fully reuse the four wavelengths of LAN-WDM (L0-3) ➔sharing the industry chain
- ✓ US0 and DS0 coexist with GPON via WDM
- ✓ US0 and DS0 have >45nm gap ➔allowing for low-cost focused-beam diplexers [1]
- ✓ DS0 and DS1 have >12.4nm gap ➔allowing for low-cost focused-beam 25G BPF [2]
- ? FWM penalty among the US channels ➔ FWM-suppression is needed

* Please refer to another contribution entitled “liuxiang_3ca_2_0517_Unified Wavelength Plan for 100G-EPON” .

[1] Funada_3ca_1_0117; [2] johnson_3ca_2_0117

FWM Case (1): ZDW is in the middle of four channels – Theoretical Analysis

- The FWM is the worst when the zero-dispersion wavelength (ZDW) is in the middle of four wavelength channels.



For non-degenerated FWM crosstalk, we have:

$$|E_{FWM}/E|=(2\gamma)\cdot(2P_{avg})\cdot L_{eff}$$

Using γ=1.8/W/km, P_{avg}=8dBm=6.3mW, L_{eff}=10.6km (20km with 0.31dB/km loss), we have

$$|E_{FWM}/E|=3.6\cdot 12.6E\text{-}3\cdot 10.6=0.48$$

➔ Eye diagram would be completely closed ➔Large penalty & error floor, which is in reasonable agreement with the simulation results (shown in the next slide).

If P_{avg}=4dBm, we have:

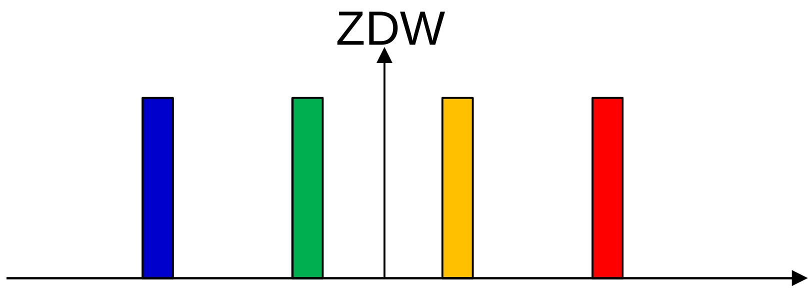
$$|E_{FWM}/E|=3.6\cdot 5E\text{-}3\cdot 10.6=0.2.$$

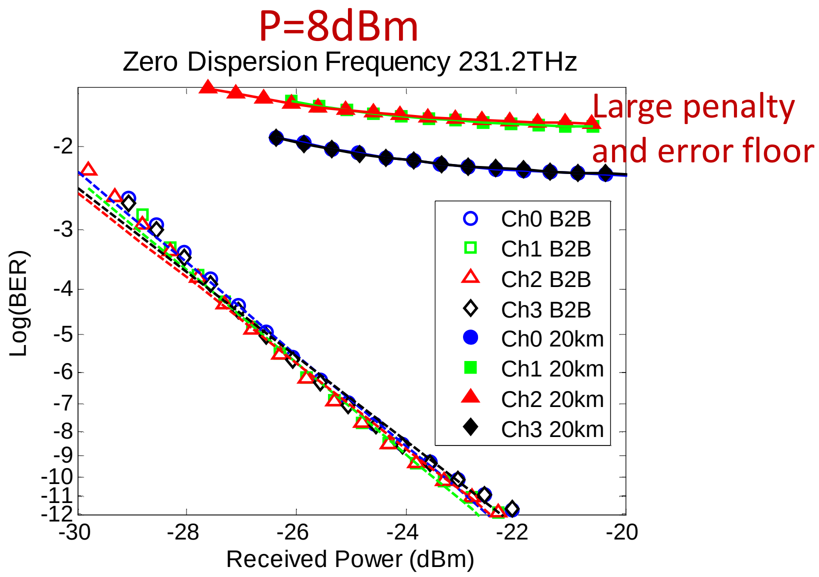
The worst-case power penalty at low BER level (e.g., BER~1E-5) would thus be:

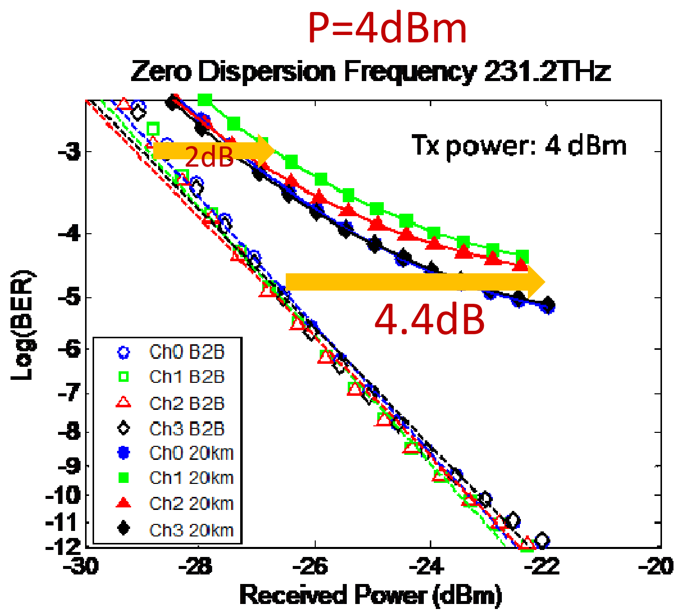
$$20\cdot\log_{10}(1-2|E_{FWM}/E|)= 4.4\ \text{dB},$$

which is again in reasonable agreement with the simulation results.

FWM Case (1): ZDW is in the middle of four channels
– Simulation Results

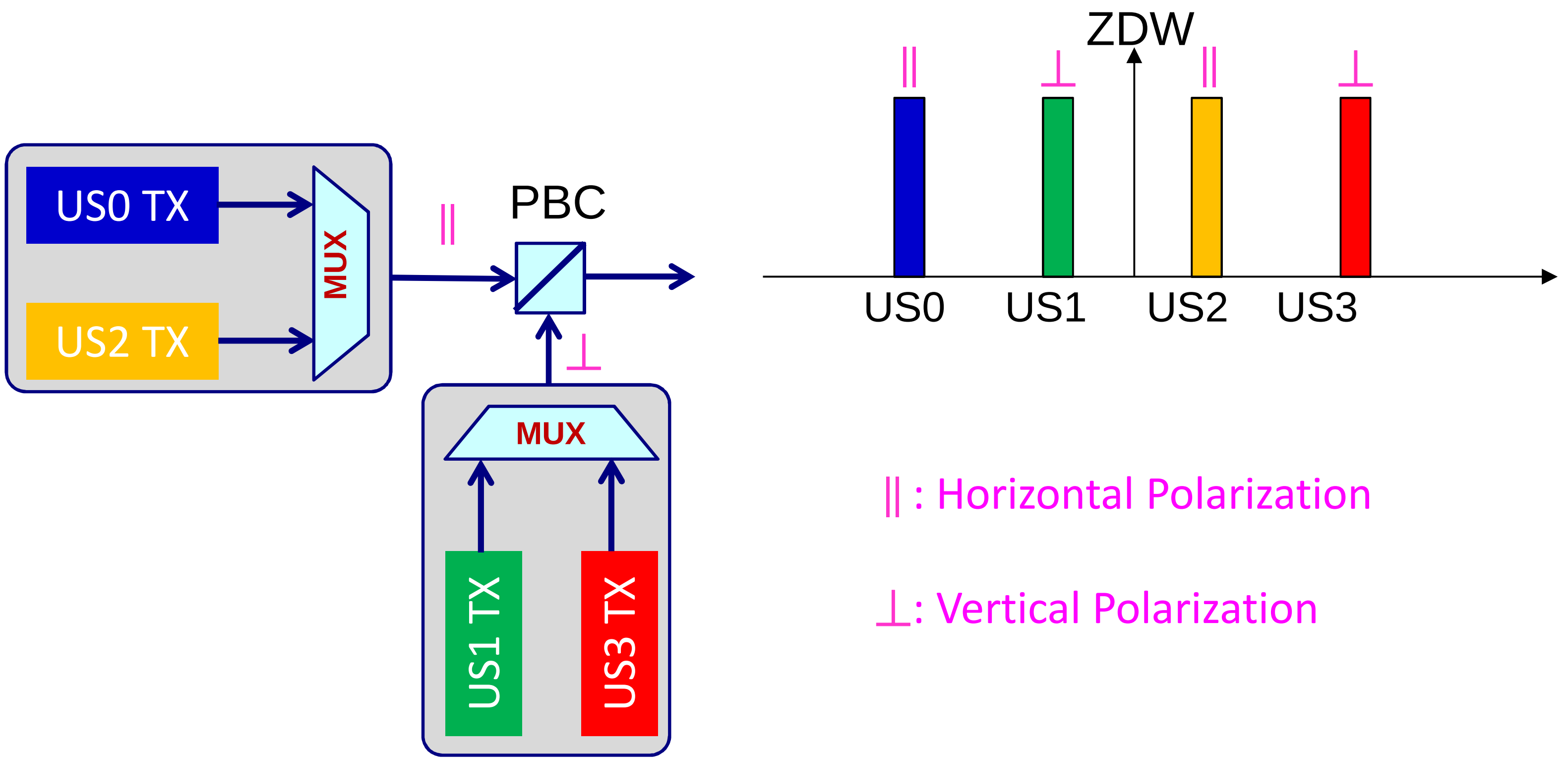






The simulation results are in reasonable agreement with the theoretical analysis.

FWM Case (1): ZDW is in the middle of four channels
- FWM suppression via alternating polarization among channels



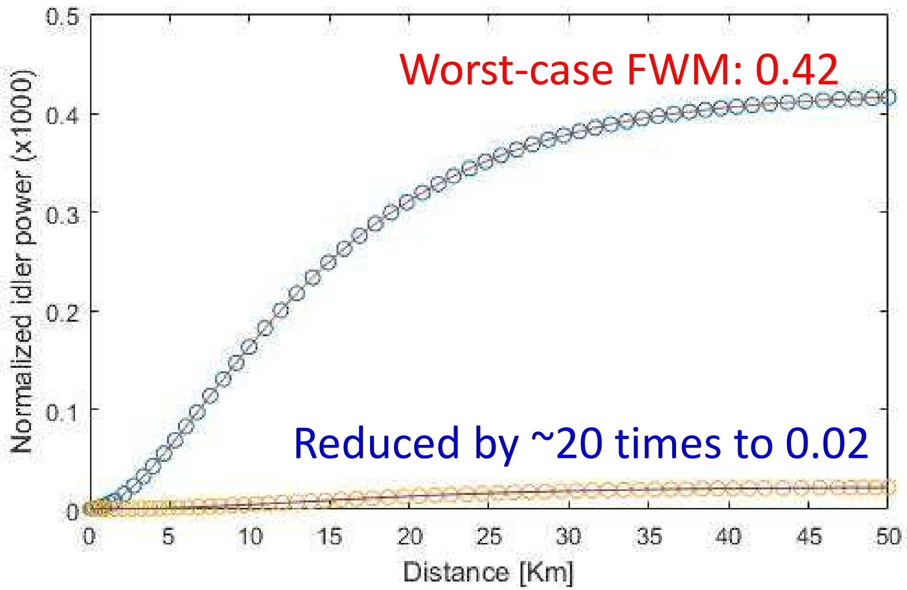
MUX: WDM multiplexer

PBC: Polarization beam combiner (typically loss: ~0.4dB [1])

[1] http://agiltron.com/PDFs/PM%20combiner-splitter.pdf

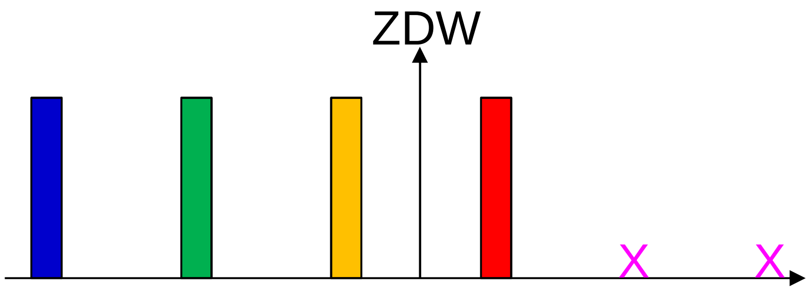
Analytical and numerical results for FWM

- For idler generation, $P_3 << P_1$ and P_2, in which case
- $$\frac{P_3(z)}{P_1(0)} = \frac{\gamma^2 e^{-\alpha z}}{\alpha - \alpha_r}\left[\frac{1-e^{-(\alpha+\alpha_r)z}}{\alpha+\alpha_r} - \frac{1-e^{-2\alpha z}}{2\alpha}\right] + \frac{\gamma^2 e_{21} e^{-\alpha z}}{\alpha-\alpha_r+\alpha_s}\left[\frac{1-e^{-(\alpha+\alpha_r)z}}{\alpha+\alpha_r} - \frac{1-e^{-(2\alpha+\alpha_s)z}}{2\alpha+\alpha_s}\right]$$



- Simulation confirms that the alternating polarization alignment substantially suppresses FWM, even in the presence of moderate polarization-mode dispersion (PMD).

FWM Case (2): ZDW is in the middle of 2 edge channels



For non-degenerated FWM crosstalk due to signal power depletion, we have:

$$|E_{FWM}/E|=[(2\gamma)\cdot(2P_{avg})\cdot L_{eff}]^2/2$$

Using γ=1.8/W/km, P_{avg}=6dBm=4mW, L_{eff}=10.6km (20km with 0.31dB/km loss), we have

$$|E_{FWM}/E|= 3 \cdot(3.6\cdot 8E\text{-}3\cdot 10.6)^2/2=0.094$$

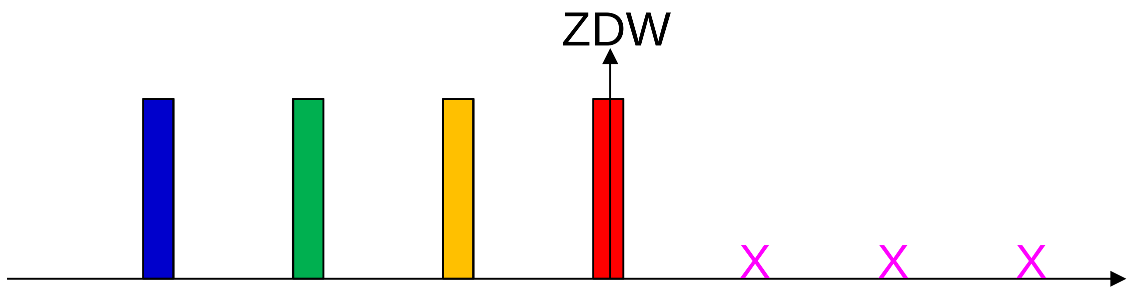
The worst-case power penalty at low BER level (e.g., BER~1E-5) would thus be:

$$20\cdot\log_{10}(1- 2|E_{FWM}/E|)= 1.7\text{ dB}.$$

At BER=1E-3, the worst-case power penalty is expected to be <1dB, which may be acceptable.

To reduce the FWM penalty, the 4^{th} (US3) channel can be made to be orthogonal to the rest 3 channels, in which case the FWM coefficient (γ) is reduced by about 3. Thus, the power penalty becomes <0.2 dB, which is negligible.

FWM Case (3): ZDW is in the middle of 1 edge channel



There are 3 degenerated FWM crosstalk terms due to power transfer, we have:

$$|E_{FWM}/E|=3\cdot[(\gamma)\cdot(2P_{avg})\cdot L_{eff}]^2/2$$

Using γ=1.8/W/km, P_{avg}=6dBm=4mW, L_{eff}=10.6km (20km with 0.31dB/km loss), we have

$$|E_{FWM}/E|=3\cdot(1.8\cdot 8E\text{-}3\cdot 10.6)^2/2=0.035$$

The worst-case power penalty at low BER level (e.g., BER~1E-5) would thus be:

$$20\cdot\log_{10}(1-2|E_{FWM}/E|)=0.63\text{ dB},$$

which may be acceptably small. At BER=1E-3, the worst-case power penalty is expected to be <0.3dB.

To reduce the FWM penalty, the 4th (US3) channel can be made to be orthogonal to the rest 3 channels, in which case the FWM coefficient (γ) is reduced by at least 3. Thus, the power penalty becomes <0.07 dB, which is negligible.

Options

- The P802.3ca standard specifies that there is at most one wavelength channel inside the zero-dispersion window of the SSMF fiber (1300nm~1324nm).

- In the case where one or more wavelength channels are inside the zero-dispersion window, the FWM-suppressing polarization control is applied.

Thank you

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