Available O Band WDM Spectra for 100G EPON

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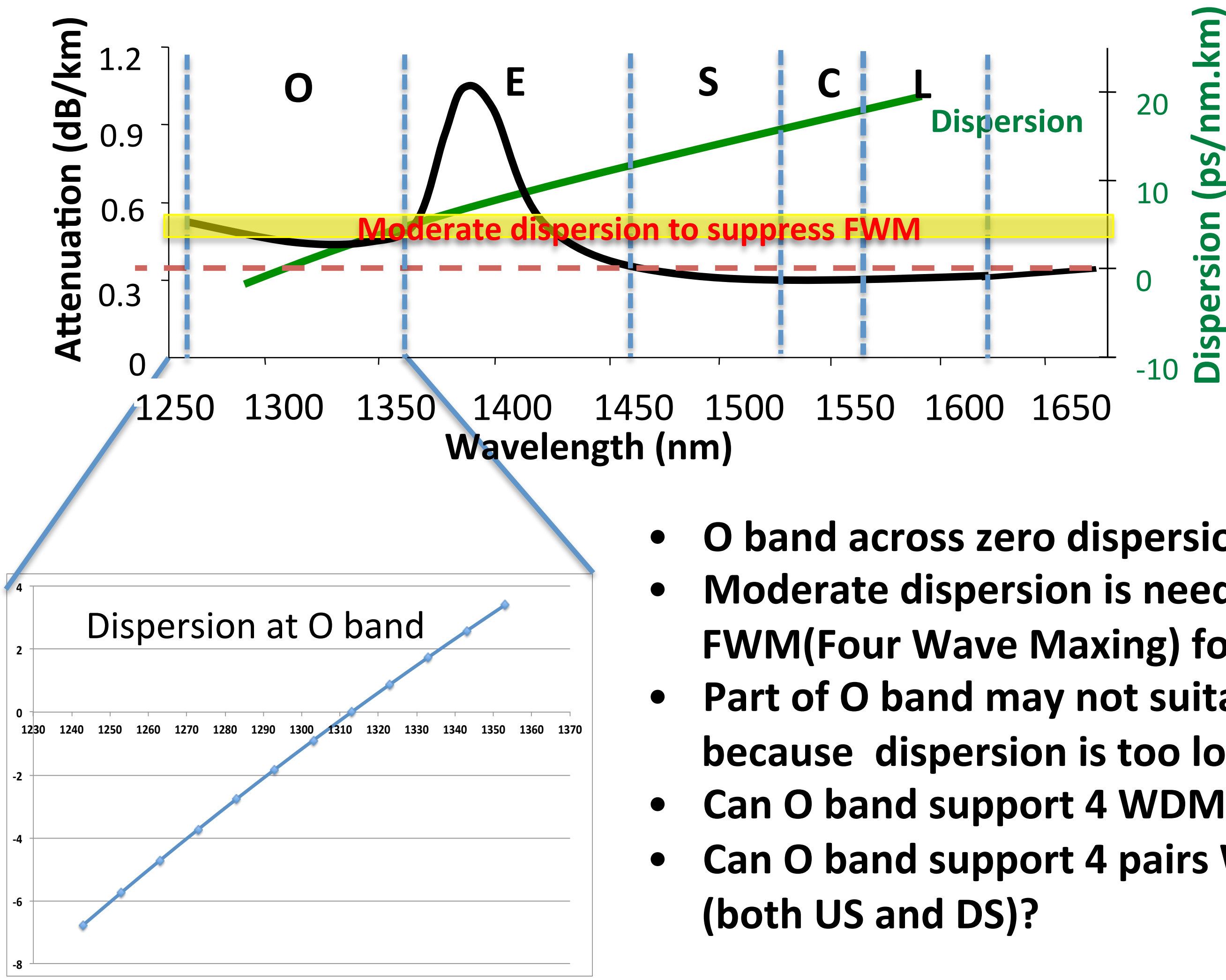
Outline

- FWM and Dispersion
- Zero dispersion zone
- FWM efficiency
- O band wavelength resources for WDM

Background

- Wavelength plans have been discussed in several interim and plenary meetings
- All O band and/or partial O band wavelength plans have been discussed since study group
- Impacts of FWM in O band have been discussed
- However, the distributions of zero dispersion and the consequences have not been brought up and have not been discussed
- The consequences of zero dispersion slop have not been discussed
- The contribution address the zero dispersion distribution and slop in SMF and their impacts on the available wavelength resources in O band for WDM

O* Band and WDM

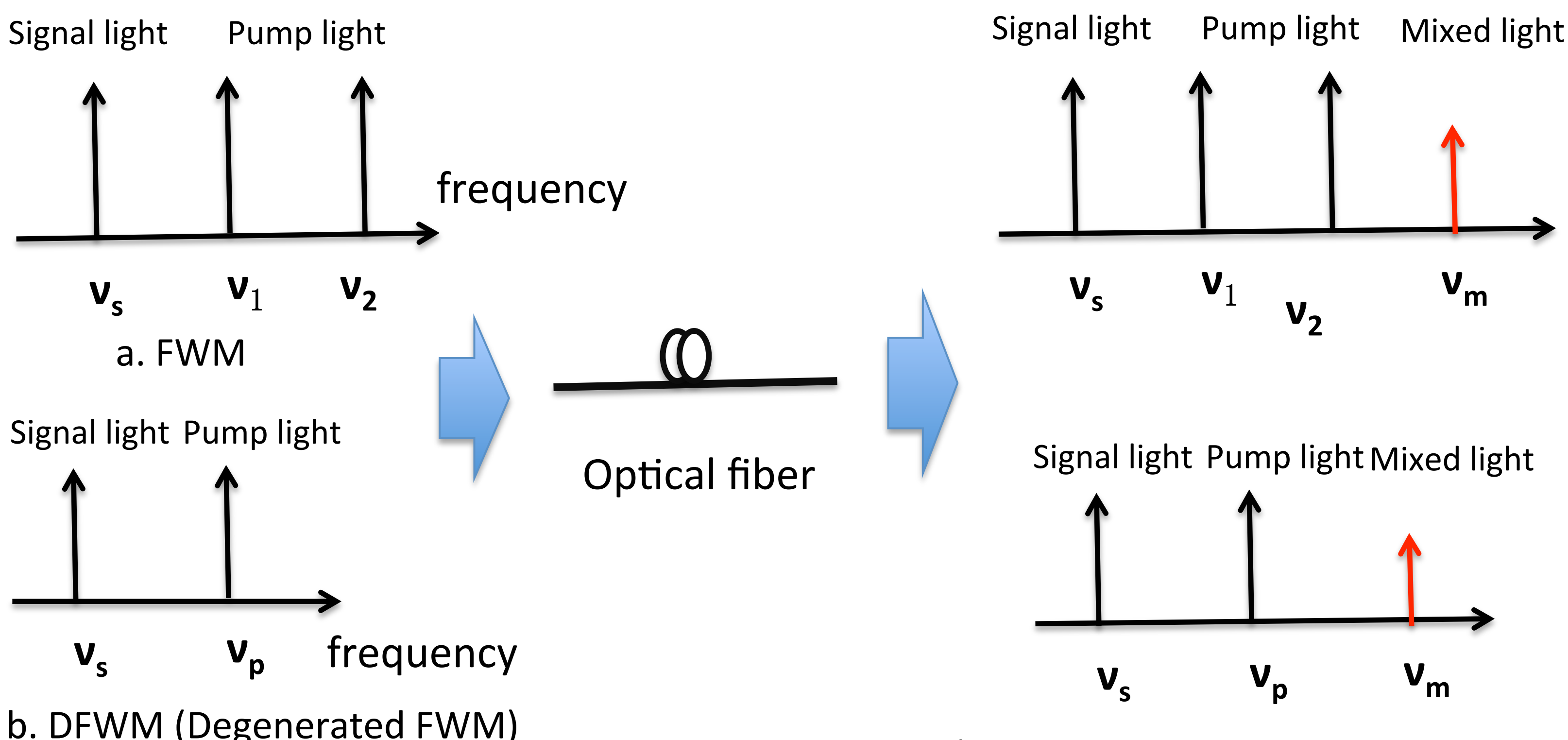


- **O band across zero dispersion zone**
- **Moderate dispersion is needed to suppress FWM(Four Wave Maxing) for WDM**
- **Part of O band may not suitable for WDM because dispersion is too low**
- **Can O band support 4 WDM channels (US)?**
- **Can O band support 4 pairs WDM channels (both US and DS)?**

* O band is normally defined as from 1250nm -1360 nm

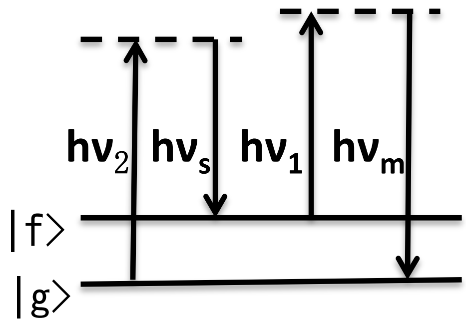
Four Wave Mixing

- FWM is a nonlinear effect which is linked to 3rd electric susceptibility in optical fiber.
- In a WDM system, FWM manifests as an optical signal interest with two pump signals (other optical signals), creating a new optical signal that falls into the frequency band of information carrying signals.



Four Wave Mixing and Dispersion (1)

Frequency match condition (energy conversation)



$\nu_m = \nu_1 + \nu_2 - \nu_s$ (FWM)

$\nu_m = 2\nu_p - \nu_s$ (DFWM)

Phase match condition (momentum conversation)

$\beta_m = \beta_1 + \beta_2 - \beta_s$ (FWM); $\beta_m = 2\beta_p - \beta_s$ (DFWM).

Where β is the imaginary part of propagation constant (phase constant).

If phase is mismatch, then

$$\Delta\beta = \beta_m - 2\beta_p + \beta_s = \frac{8\pi\nu_p^2}{c} D(\nu_p)(\nu_p - \nu_s) \qquad \text{(DFWM)}$$

$$\Delta\beta = \frac{2\pi\lambda^2}{c}\,\Delta\nu_{ik}\,\Delta\nu_{jk}\,\left(D + \frac{\lambda^2}{2c}(\Delta\nu_{ik} + \Delta\nu_{jk})\frac{dD}{d\lambda}\right) \qquad \text{(FWM)}$$

Four Wave Mixing and Dispersion (2)

where $D(\nu_p)$ is the dispersion at pump frequency. $\Delta\nu_{mn} = |\nu_m - \nu_n|, mn = i, k, j$

FWM efficiency

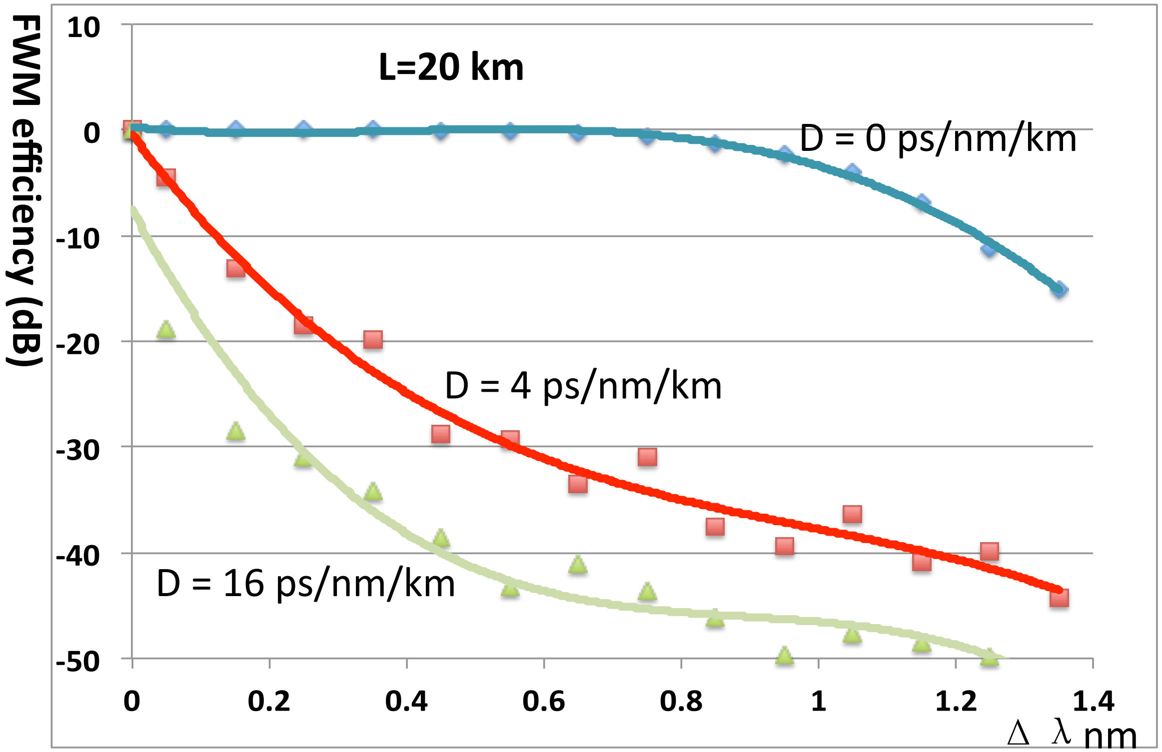
$$\eta = \left| \frac{1 - \exp[-(\alpha + i\Delta\beta)L}{(\alpha + i\Delta\beta)L} \right|^2$$

Where α is real part of propagation constant and β is the imaginary part propagation.

$$\eta = \begin{cases} 1, & \Delta\beta \rightarrow 0 \\ \sim 0, & \Delta\beta >> 1 \end{cases}$$

FWM efficiency η → 1 when Δβ →0; η → 0 when Δβ >>1.

FWM Efficiency



- Dispersion destroys phase matching condition and therefore suppress FWM
- Experiments and simulations show that dispersion ≥ 4ps/nm/km can effectively suppress FWM in a DWDM system

Wave Mixing and Dispersion (3)

Coherent length

$$L_{coh} = \frac{2\pi}{|\Delta\beta|}$$

To effectively produce FWM, fiber length L satisfies

$$L \leq L_{coh}$$

- When dispersion approaches to zero, $\Delta\beta \rightarrow 0$, $L_{coh} \rightarrow \infty$
- $L \leq L_{coh}$ is satisfied for any fiber length
- Zero dispersion region needs absolutely to be avoided if FWM is unwanted
- FWM is used for other purposes such as wavelength converge, produce entangled photon pairs , etc.

Zero dispersion of SMF

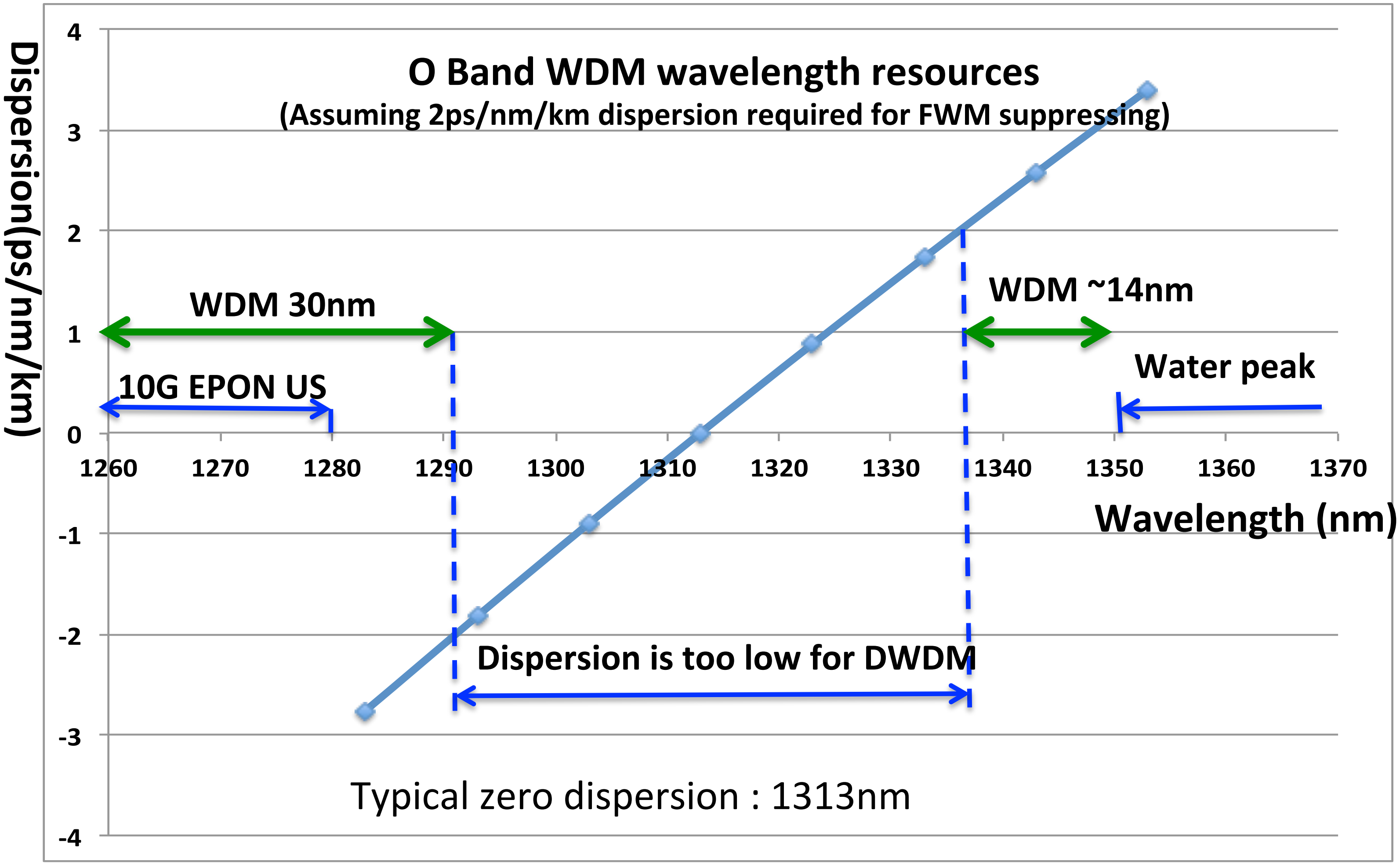
The dispersion of SMF28e and SMF28 can be expressed as

$$D(\lambda) \simeq \frac{S_0}{4}\left(\lambda - \frac{\lambda_0^4}{\lambda^3}\right) \text{(ps/nm/km)}$$

S_0 – Zero dispersion slop ≤ 0.089 ps/nm^2/km
λ_0 - Zero dispersion wavelength.
Typical value of λ_0: 1313nm. Range: 1302nm ≤ λ_0 ≤ 1322nm

- **The zero dispersion of SMF fibers have 20nm wide distributions**
- **We do not know precisely the zero dispersion wavelength of a randomly chosen SM optical fiber**
- **The existence of zero dispersion region of SMF impacts the availability of O band wavelength resources for WDM**

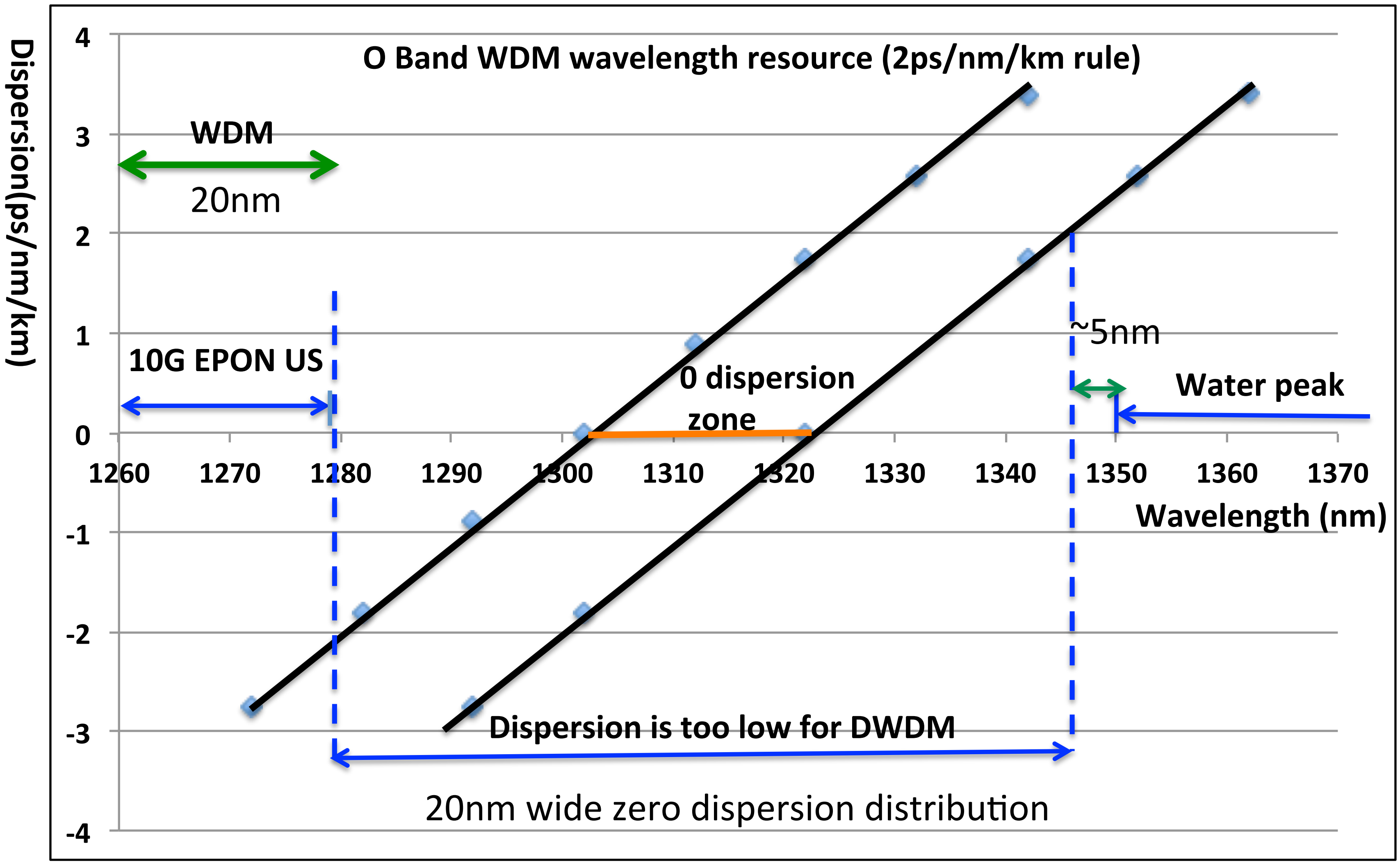
Available WDM resources – Typical Zero Dispersion (1)



Available WDM resources – Typical Zero Dispersion (2)

- The available WDM resource in O band depends on the system tolerance of FWM
- For typical WDM transmission on SMF, ≥ 4ps/nm/km dispersions are required to suppress FWM
- If we use 4ps/nm/km criteria, there is virtually no wavelength resources that exist for WDM in O band
- Considering we have fewer channels if only upstream channels are placed in O band, the dispersion requirement can be relaxed to 2ps/nm/km
- Under this condition, a 30 nm block(20 nm used by 10G EPON) from1260 nm to 1290 nm in negation dispersion region and a 14 nm from 1336 nm to 1350 nm in positive dispersion region are available for WDM

Available WDM resources – 20nm zero dispersion distribution (1)



Available WDM resources – 20nm zero dispersion distributions (2)

- Assuming relaxed dispersion requirement of 2ps/nm/km for FWM suppressing
- A 20 nm block (used by 10G EPON) from 1260 nm to 1290 nm in the negation dispersion region and ~5nm block from 1345 nm to 1350 nm in positive dispersion region are available for WDM
- Removing the 20 nm spectra occupied by 10G EPON, the available WDM wavelength resource is about 0 nm in negative dispersion region and about 5 nm in positive dispersion region.

O band wavelength resources for WDM

- Consider the 20nm wide distribution of zero dispersion in SMF
- Assume relaxing the dispersion requirement to 2ps/nm/km for FWM suppressing
- Assume WDM coexist with 10G EPON
- Only a ~5nm block from 1345nm to 1350nm in positive dispersion region is available for WDM
- The is not enough WDM resources to put all upstream channels in the O band using uncooled DFB lasers

Can we extend O Band to 1250 nm?

Cable cutoff Wavelength

Standard	Cable cutoff wavelength
ITU-T G.652A	Maximum 1260 nm
ITU-T G.652B	Maximum 1260nm
ITU-T G.652C	Maximum 1260 nm
ITU-T G.652C (operating in 1260nm)	Maximum 1250 nm
ITU-T G.652D	Maximum 1260 nm
ITU-T G.652D (operating in 1260nm)	Maximum 1250 nm
IEC-60793-2-50	Maximum 1260 nm

The answer is "only for some type of cable".

Conclusions

- **The 20nm wide distribution of zero dispersion and zero dispersion slop in SMF limits the O band spectra for WDM channels**
- **There is not enough WDM resources to put all upstream channels in O band using uncooled DFB lasers**
- **There is enough spectra in O band for a single pair of 25Gbps channels using uncooled DFB lasers for ONUs**

Thanks

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