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IEEE 802.3ca NGEPON Task Force:
Calculator for Four-Wave Mixing Products

Shawn M. Esser

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Presentation

- What this presentation does not do:
  - Indicate if Four-Wave Mixing is an issue for NGEPON
  - Quantify the impact of Four-Wave Mixing
  - Calculator does not determine the level/intensity of potential FWM products
- What this presentation does do:
  - High-level overview of FWM
  - Show calculator and graphing tool for wavelength locations of potential Partially Degenerate FWM products
  - Summarize of 100GBASE-LR4
  - Show calculator on few example wavelength plans

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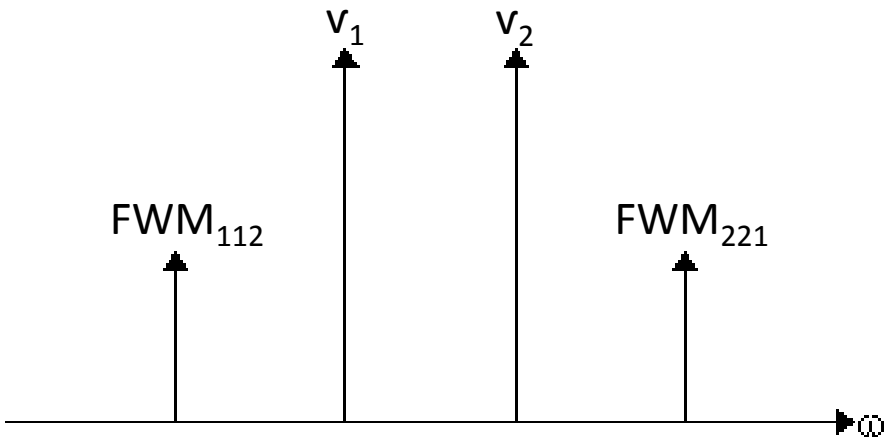
Four-Wave Mixing Overview

Four-Wave Mixing

- Four-wave mixing (FWM) occurs when two or more frequencies of light propagate through an optical fibre together. Provided a condition known as phase matching is satisfied, light is generated at new frequencies using optical power from the original signals.
- Products from four-wave mixing could be generated on the same wavelength as an optical signal carrying data, thus interfering with the data and increasing errors.

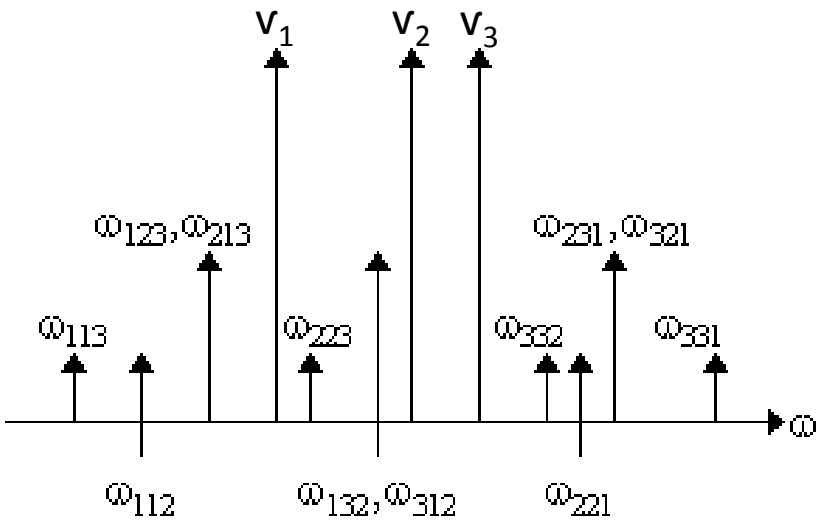
FWM: Partially Degenerate and Non-Degenerate cases

Partially Degenerate FWM



$$FWM_{112} = 2\nu_1 - \nu_2$$
$$FWM_{211} = 2\nu_2 - \nu_1$$

Non-Degenerate FWM



$$FWM_{ijk} = \nu_i + \nu_j - \nu_k$$

Figure from:
http://www.npl.co.uk/optical-radiation-photonics/optical-comms-and-data/products-and-services/four-wave-mixing-(fwm)

Parameters that impact Four-Wave Mixing

- Wavelength spacing (closer is worse)
- Average Optical Launch Power (higher is worse)
- Fiber distance (longer is worse)
- Chromatic dispersion of the fiber
- Polarization of the light signals

Sources

- “Four-Wave Mixing in an Optical Fiber in the Zero-Dispersion Wavelength Region”, Kyo Inoue, JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 10, NO. 11, NOVEMBER 1992
- “Four-Wave-Mixing-Induced Crosstalk and Distortion in Subcarrier-Multiplexed Lightwave Links: Theory and Measurement”, Mary R. Phillips, *Member, IEEE*, Kuang-Yi Wu, and F. X. Villarruel, *Member, OSA*, JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 26, NO. 15, AUGUST 1, 2008
- “Four-Wave Mixing (FWM)”, National Physical Laboratory | Hampton Road, Teddington, Middlesex

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Calculator for Degenerate Four-Wave Mixing Products

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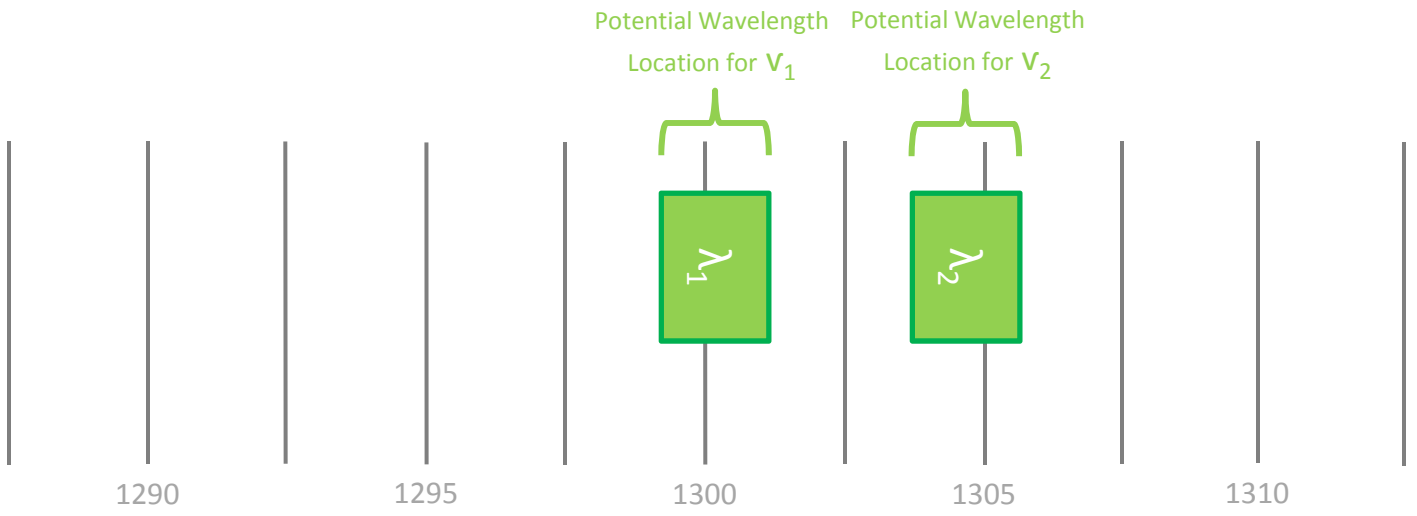
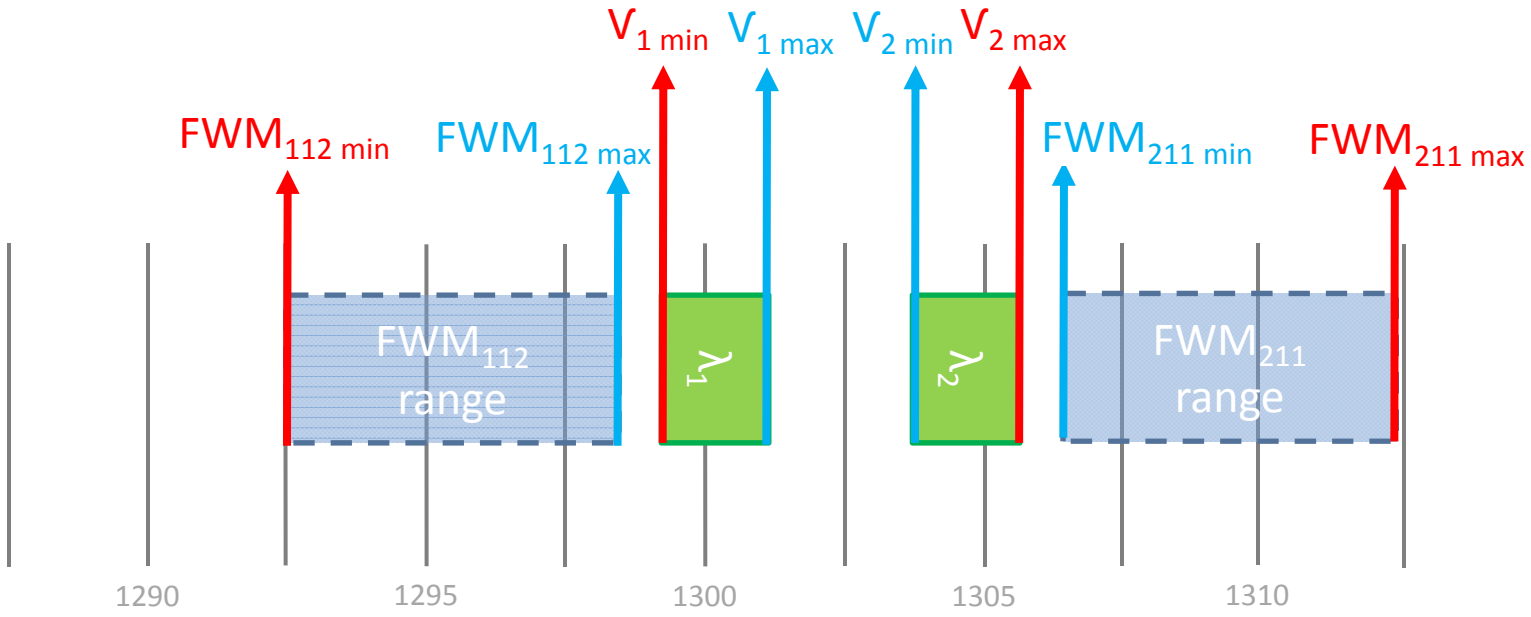
Theory of calculator of potential FWM products

- Assumes only partially degenerate FWM
  - FWM products generated from mixing only two optical signals
  - Formulas for location of potential FWM products:
    - $FWM_{112} = 2\nu_1 - \nu_2$
    - $FWM_{211} = 2\nu_2 - \nu_1$
  - Non-degenerate FWM calculations can be added later if needed
- Definition:
  - λ_1 is wavelength range where optical signal 1 with data (ν_1) can be located
  - λ_2 is wavelength range where optical signal 2 with data (ν_2) can be located



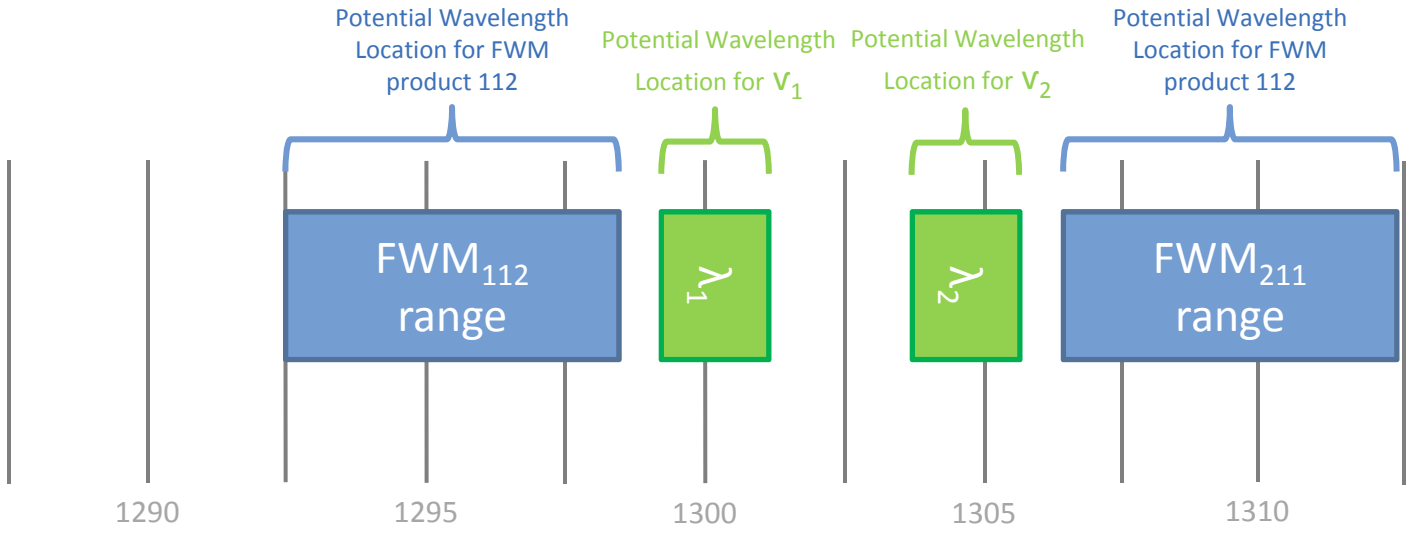
Calculation of wavelength range for FWM products

- Formulas for location of potential FWM products:
  - $FWM_{112\ min} = 2\nu_{1\ min} - \nu_{2\ max}$
  - $FWM_{112\ max} = 2\nu_{1\ max} - \nu_{2\ min}$
  - $FWM_{221\ min} = 2\nu_{2\ min} - \nu_{1\ max}$
  - $FWM_{211\ max} = 2\nu_{2\ max} - \nu_{1\ min}$

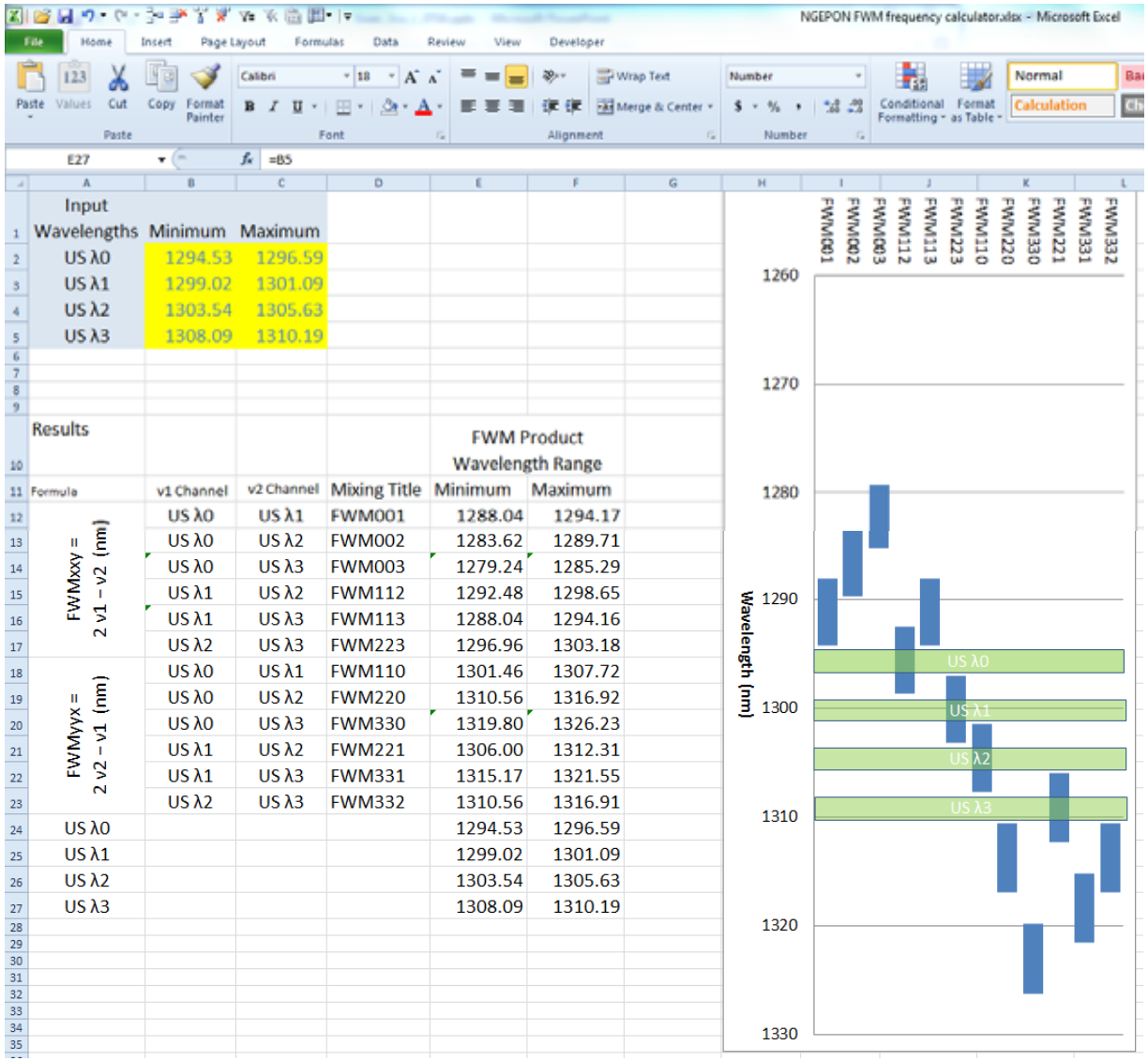


Output

- Repeat calculation for FWM wavelength ranges for all combinations of two:
  - λ_1 and λ_2
  - λ_1 and λ_3
  - λ_1 and λ_4
  - λ_2 and λ_3
  - λ_2 and λ_4
  - λ_3 and λ_4



Excel Spreadsheet Calculator



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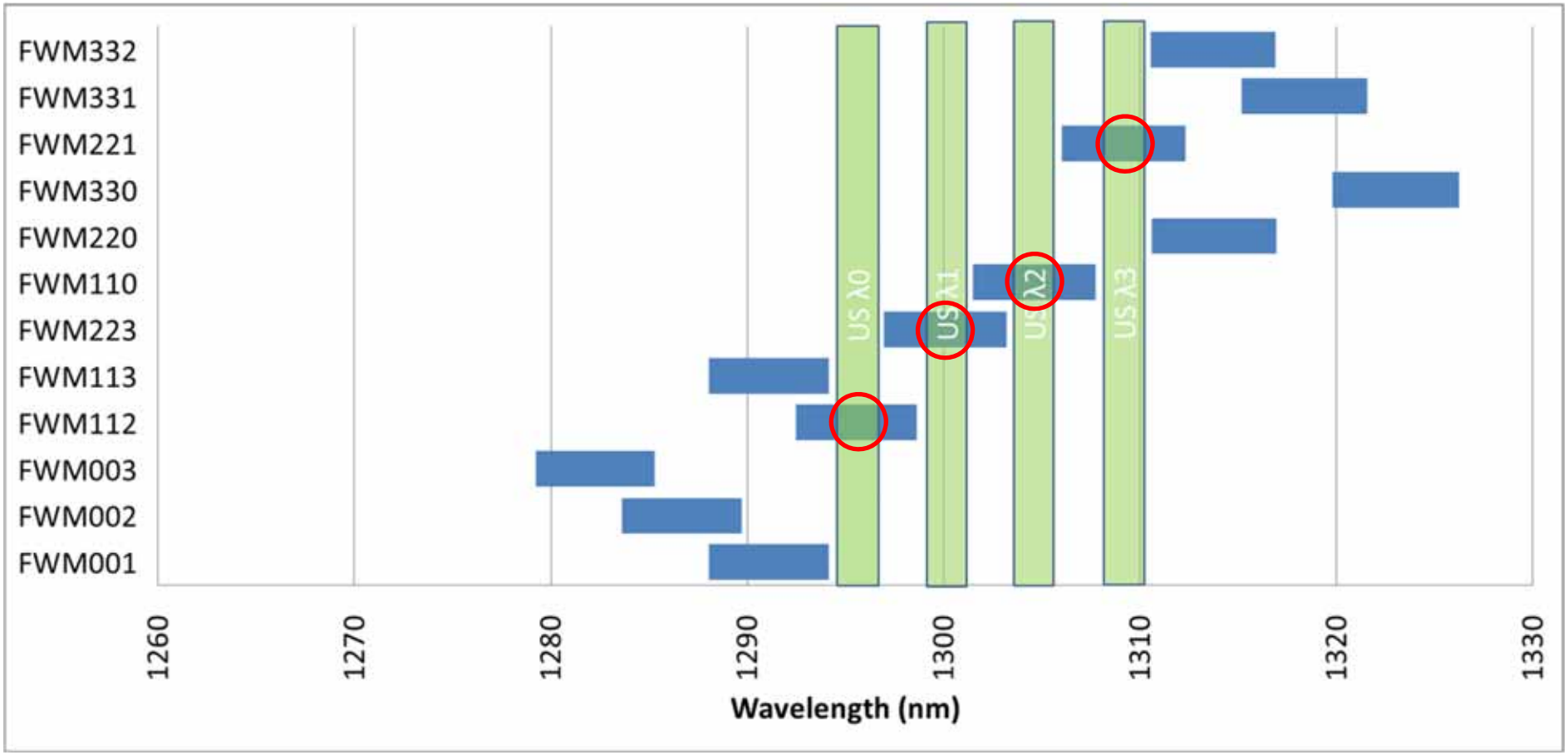
Examples with FWM Product calculator

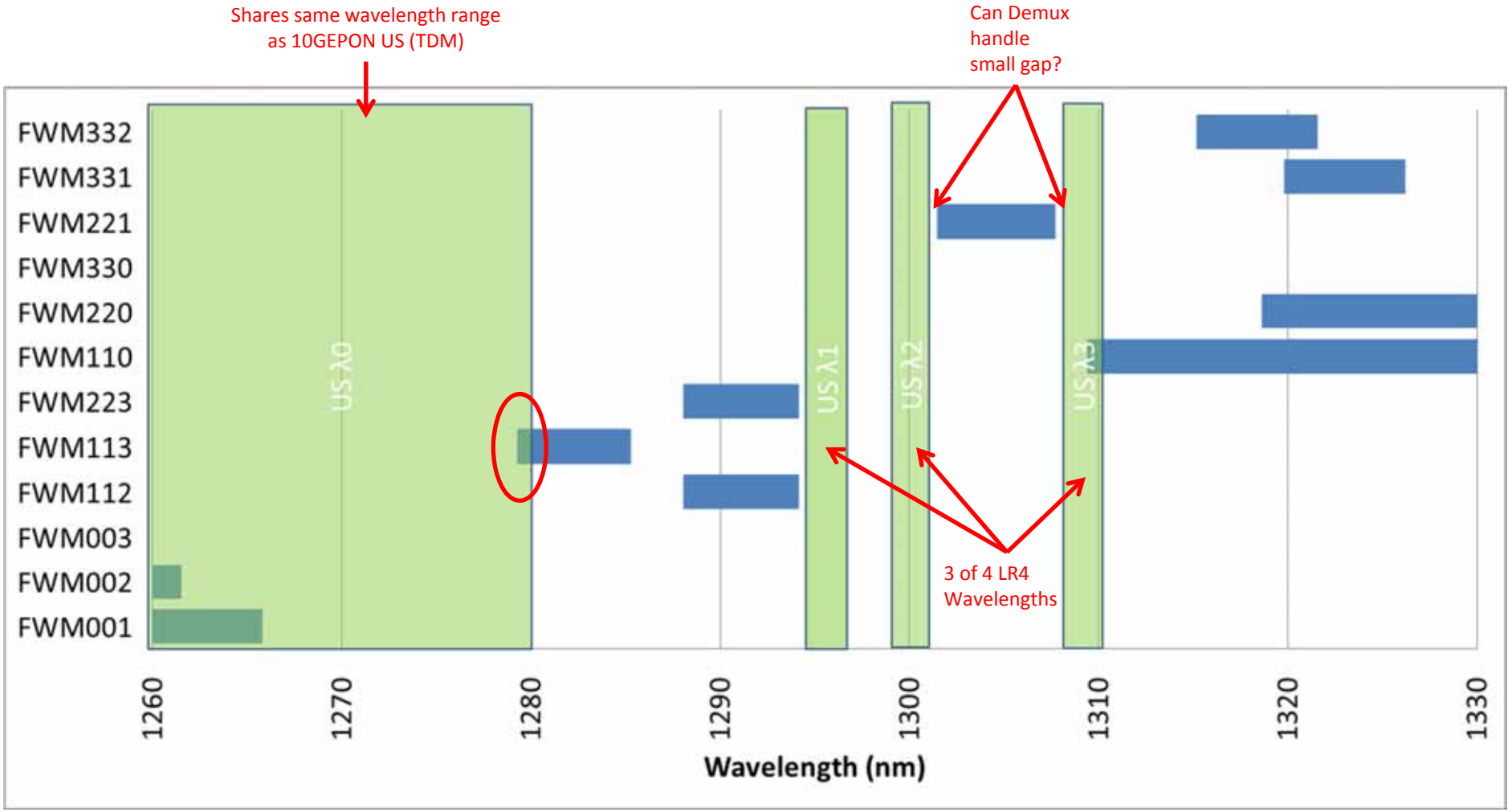
FWM Product Calculator: 100GBASE-LR4 Wavelength Plan



Wavelength Range for Potential FWM Product

Interference with US λ

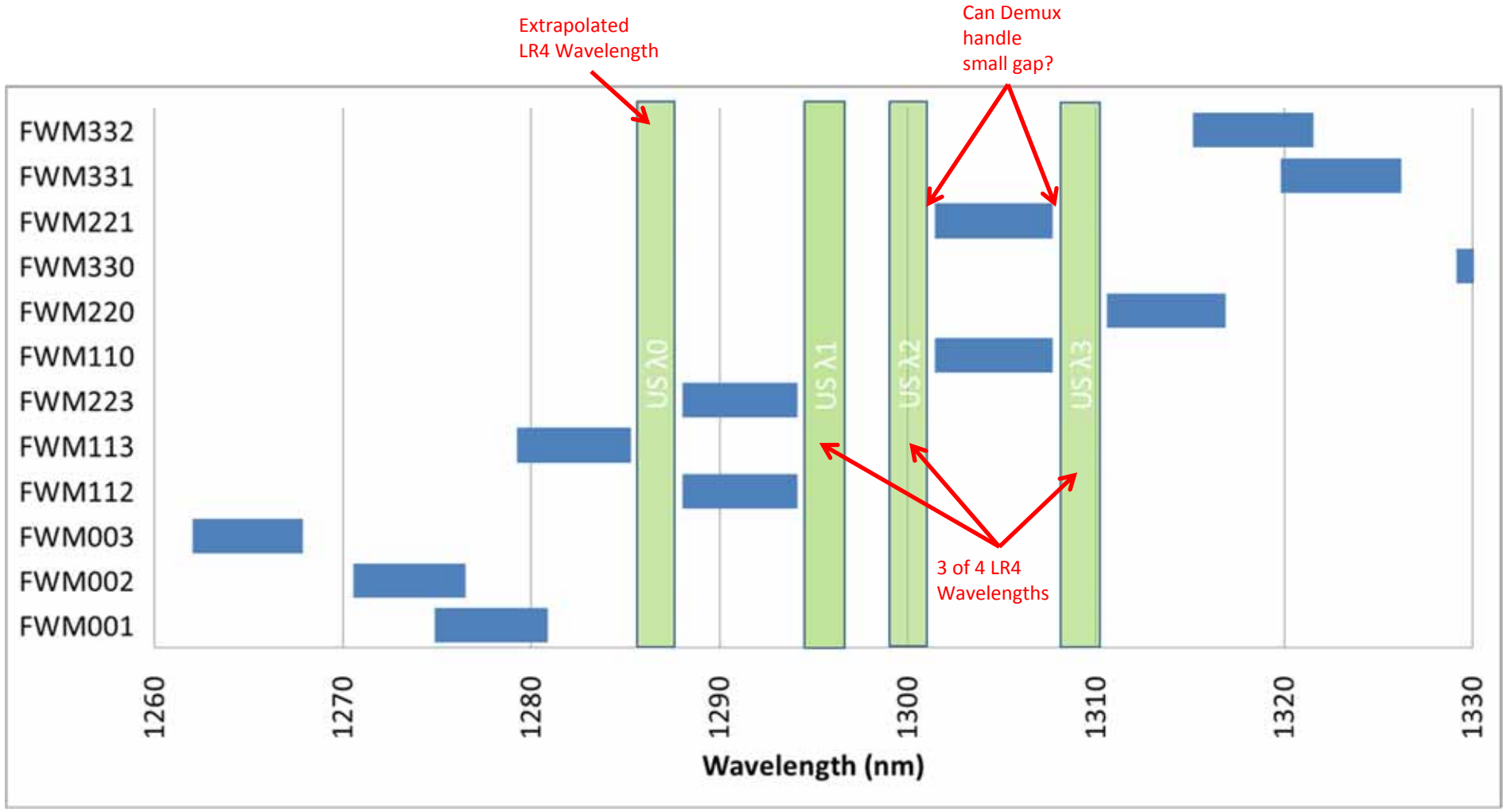
FWM Product Calculator: TDM 2.0 Upstream



Wavelength Range for Potential FWM Product

Interference with US λ

FWM Product Calculator: WDM 2.1 Upstream



Wavelength Range for Potential FWM Product

Interference with US λ