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

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Presentation

- ◆ **What this presentation does <u>not</u> 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

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.

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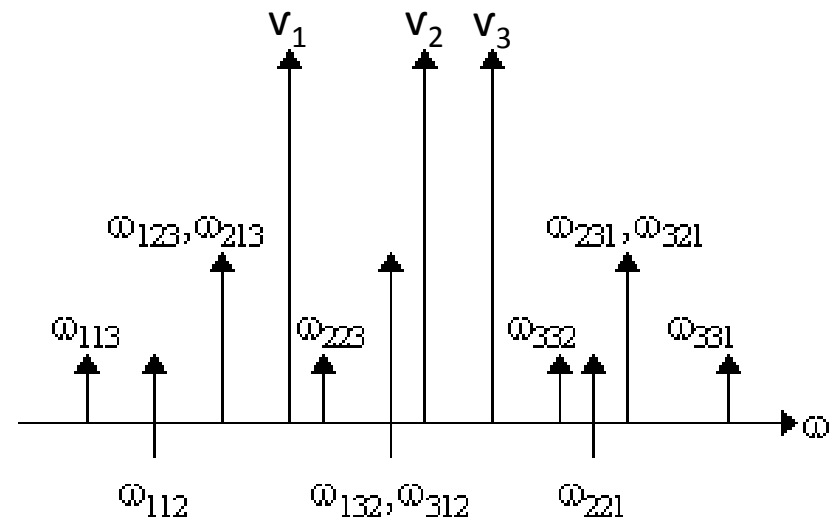# FWM: Partially Degenerate and Non-Degenerate cases

Partially Degenerate FWM
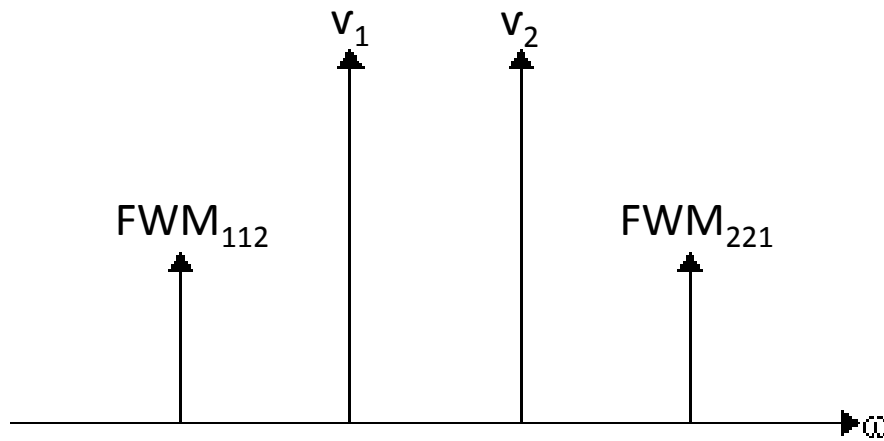
$$FWM_{112} = 2v_1 - v_2$$
$$FWM_{221} = 2v_2 - v_1$$

Non-Degenerate FWM

$$FWM_{ijk} = v_i + v_j - v_k$$

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

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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

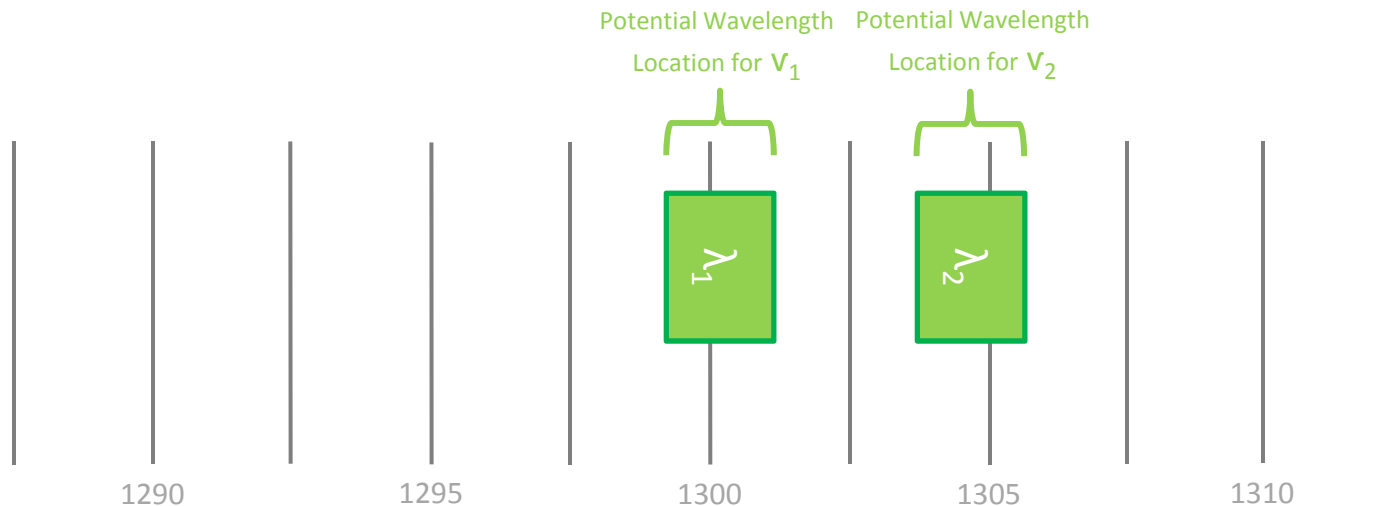# Calculator for Degenerate Four-Wave Mixing Products

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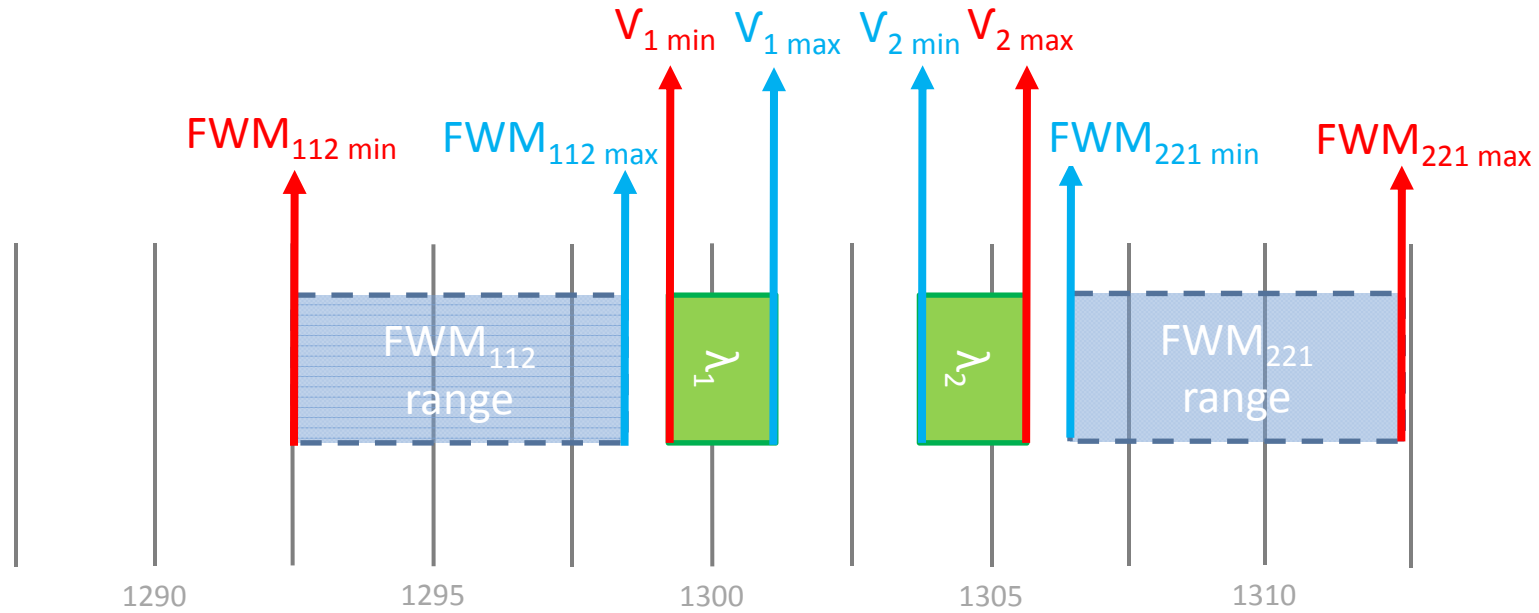# Theory of calculator of potential FWM products

- ◆ Assumes only partially degenerate FWM
  - ▪ FWM products generated from mixing only two optical signals
  - ▪ Formulas for location of potential FWM products:
    - • $FWM_{112} = 2\,v_1 - v_2$
    - • $FWM_{221} = 2\,v_2 - v_1$
  - ▪ Non-degenerate FWM calculations can be added later if needed
- ◆ Definition:
  - ▪ λ_1 is wavelength range where optical signal 1 with data (v_1) can be located
  - ▪ λ_2 is wavelength range where optical signal 2 with data (v_2) can be located

Potential Wavelength Location for V_1 Potential Wavelength Location for V_2

λ_1 λ_2

1290   1295   1300   1305   1310

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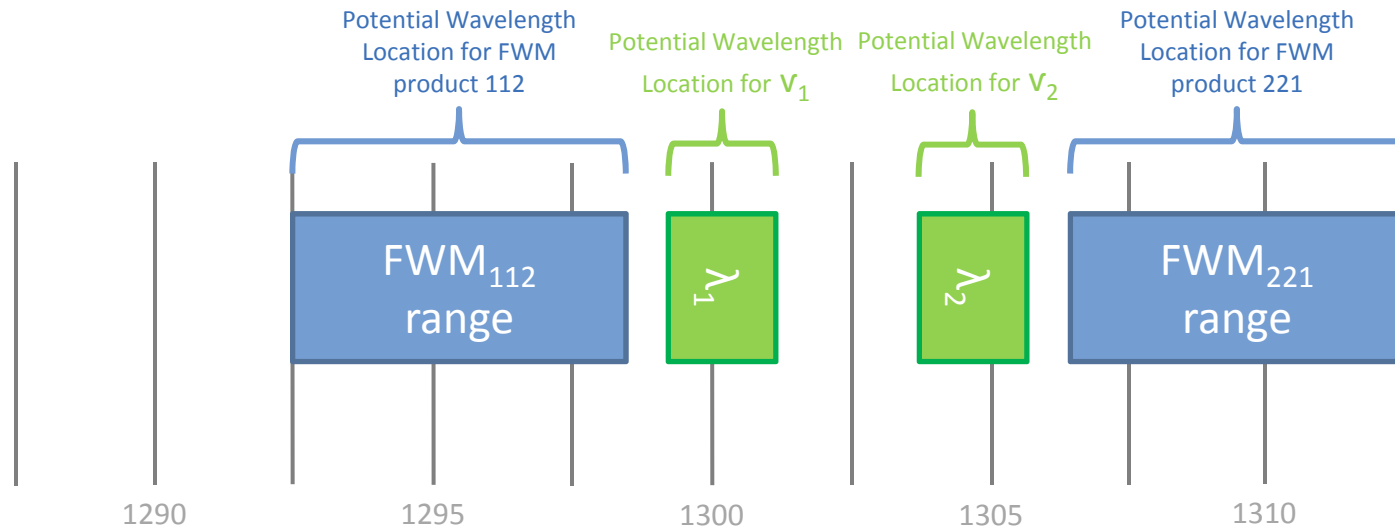# Calculation of wavelength range for FWM products

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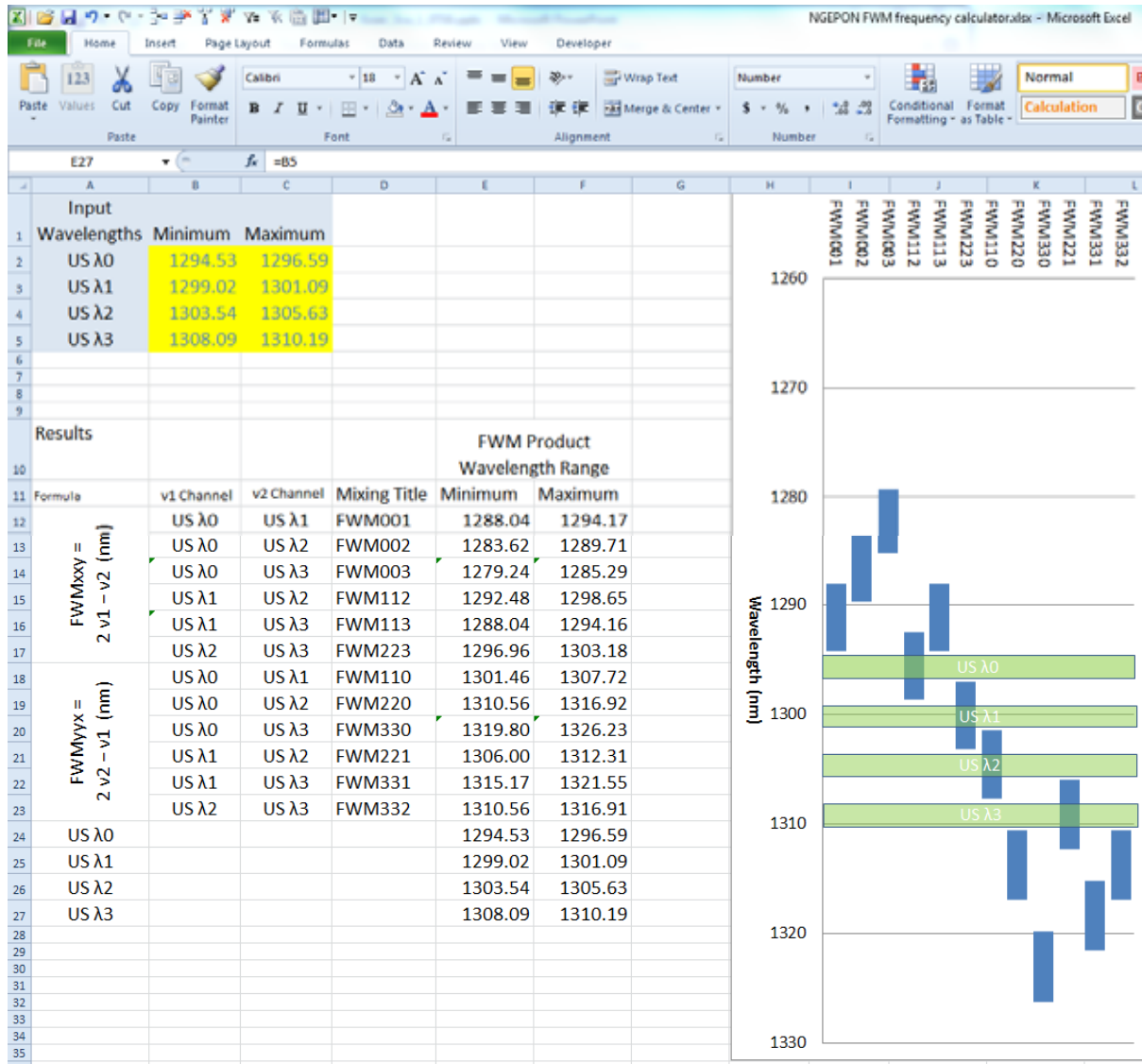 - $FWM_{221\ max} = 2\,v_{2\ max} - v_{1\ min}$

- 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

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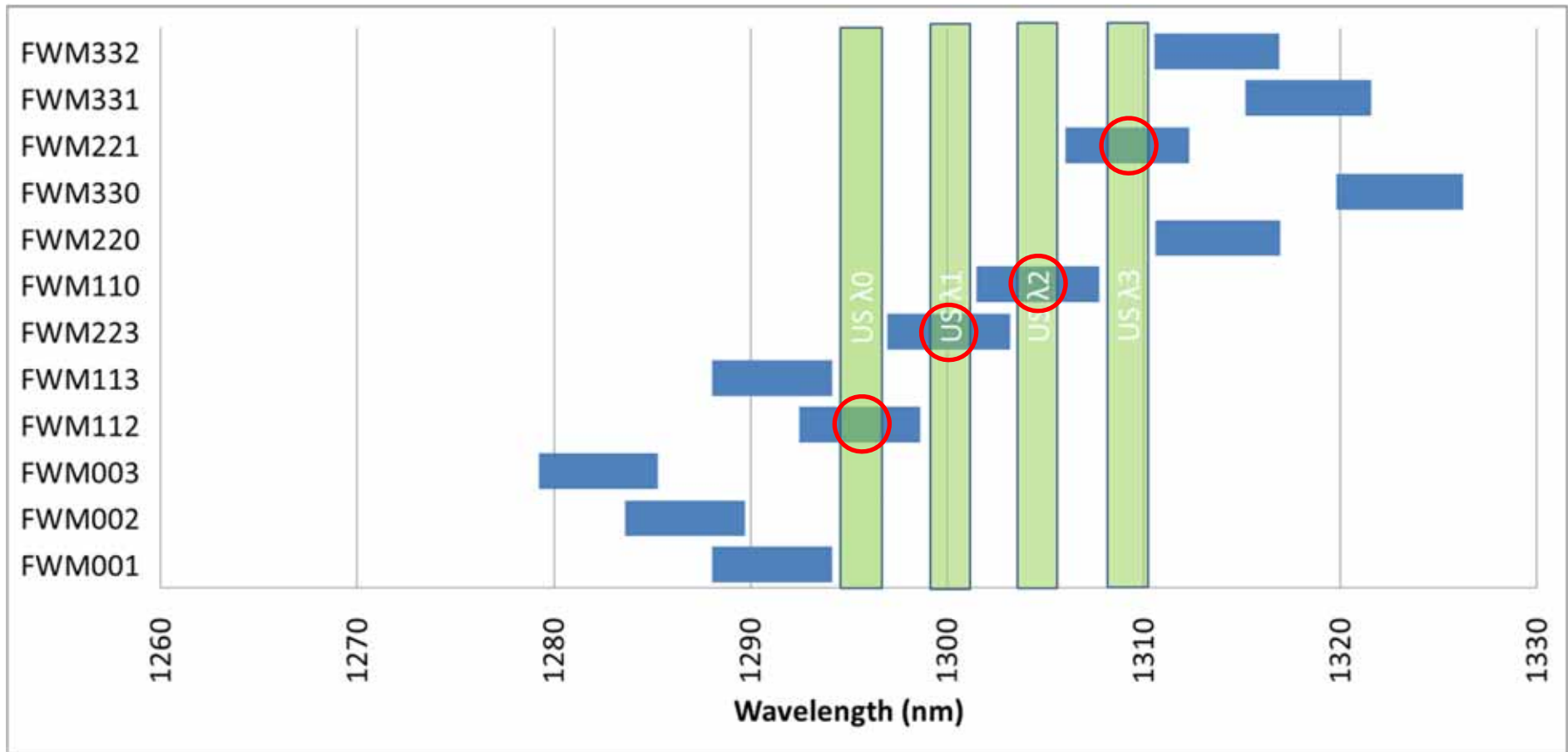# Excel Spreadsheet Calculator

Examples with FWM Product calculator

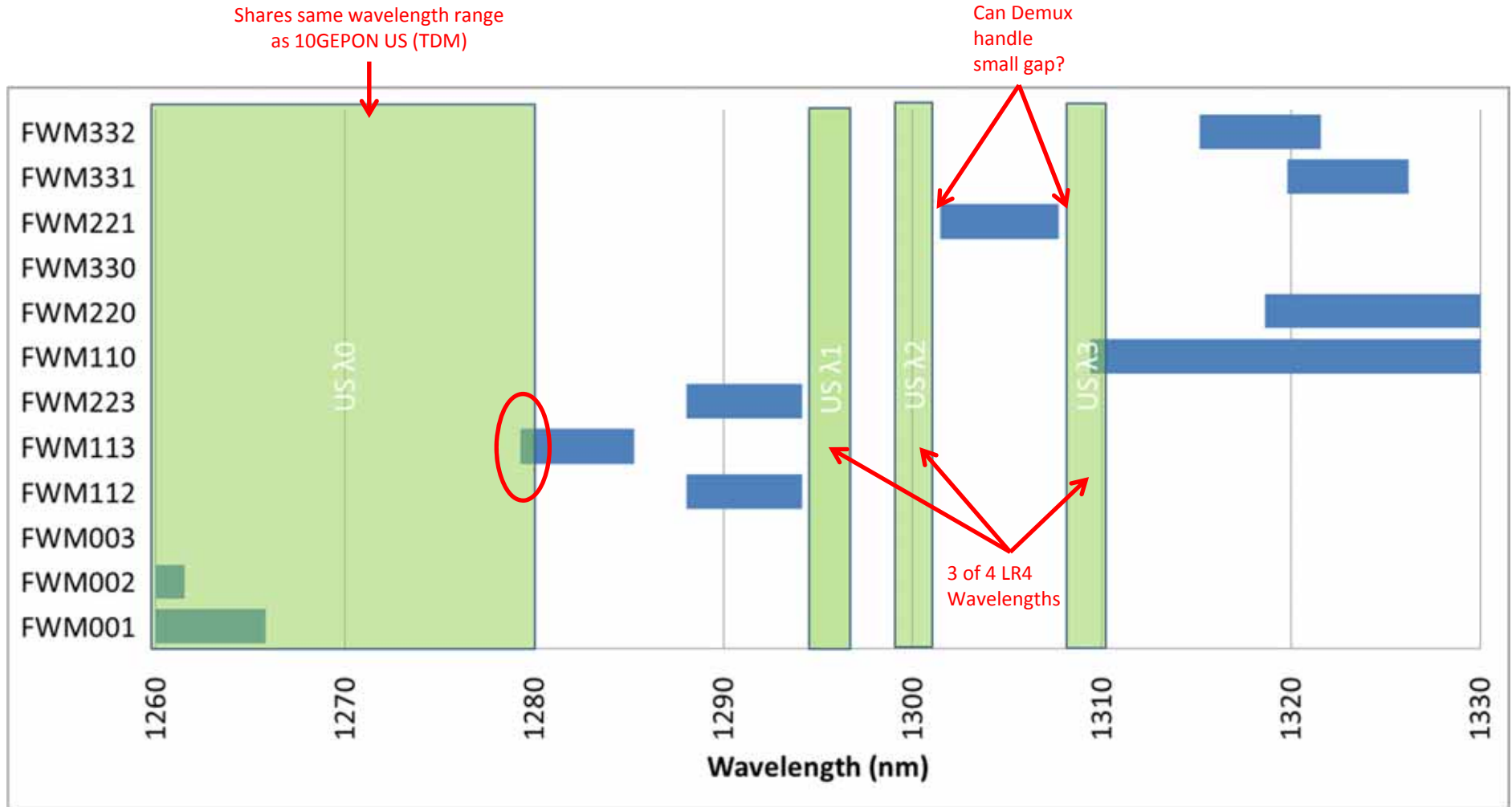**Wavelength Range for Potential FWM Product**   **Interference with US λ**
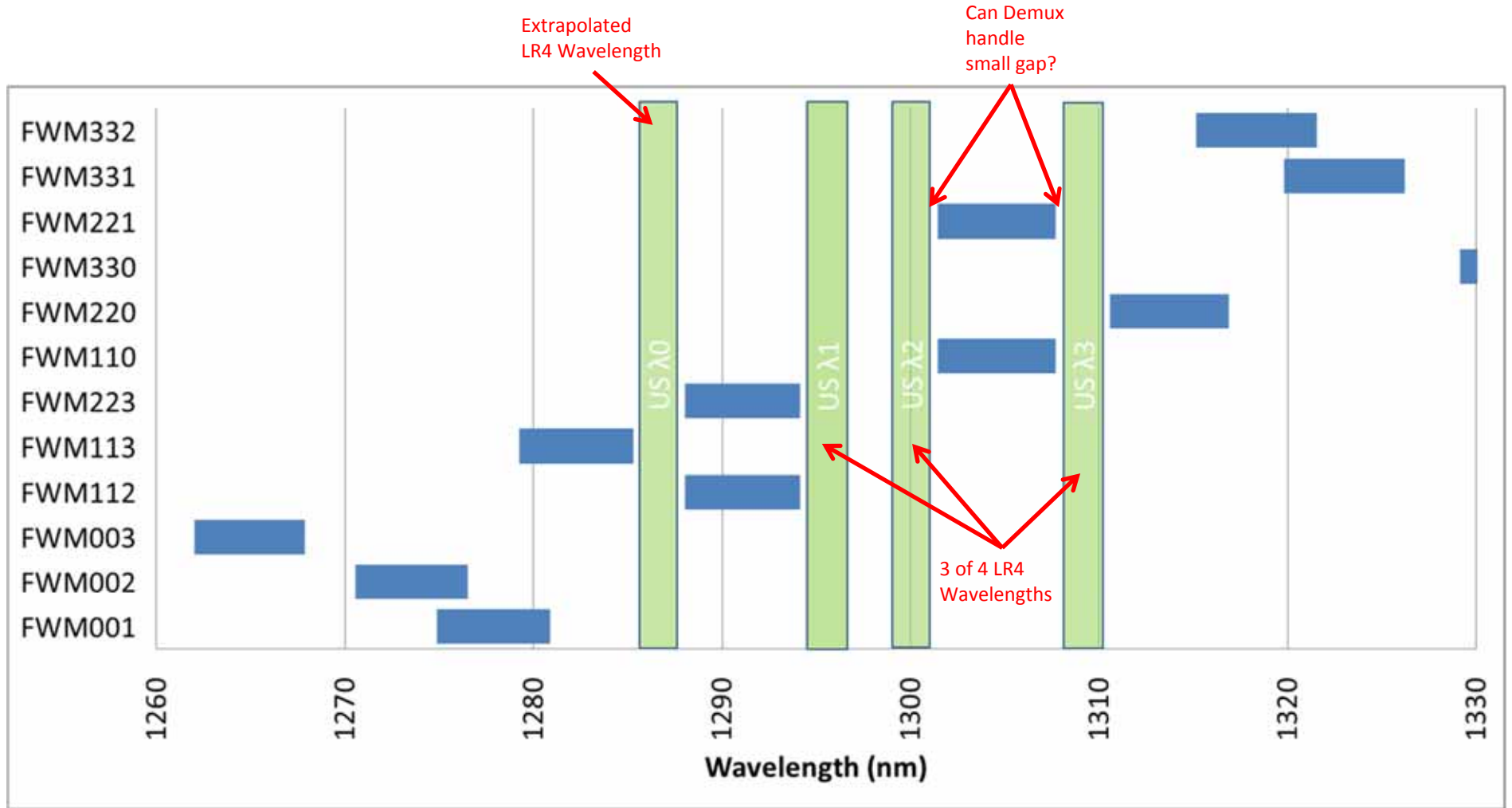
FWM Product Calculator: TDM 2.0 Upstream

FWM Product Calculator: WDM 2.1 Upstream