DWDM Link specifications for 75GHz spaced 400GBASE-ZR applications

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IEEE P802.3cw

Feb 1, 2021

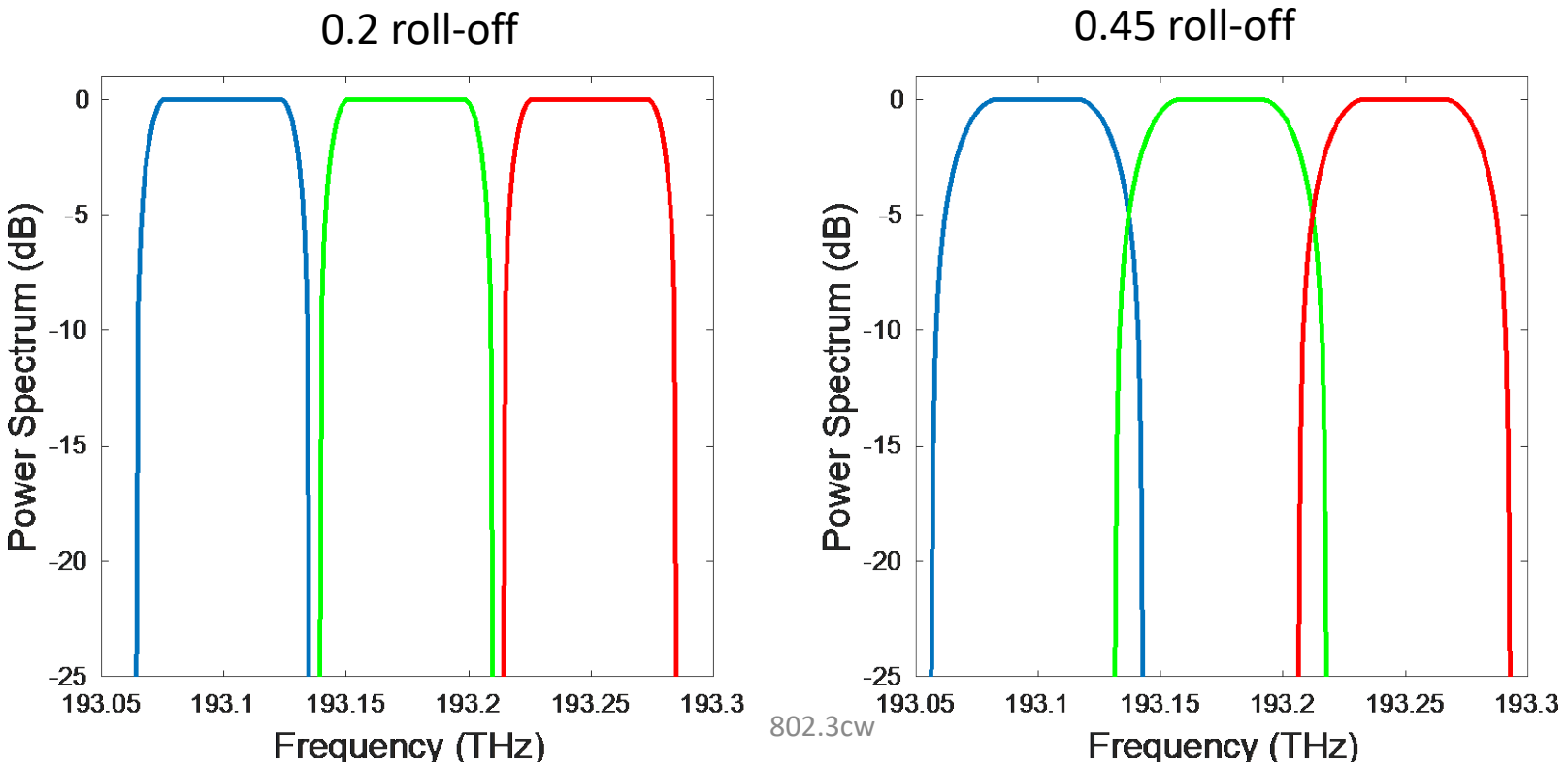
Background

- Defining the methodology for parameters to bound
  - Filtering penalty
  - Inter-channel Crosstalk
- Illustrations of transfer functions and methodology

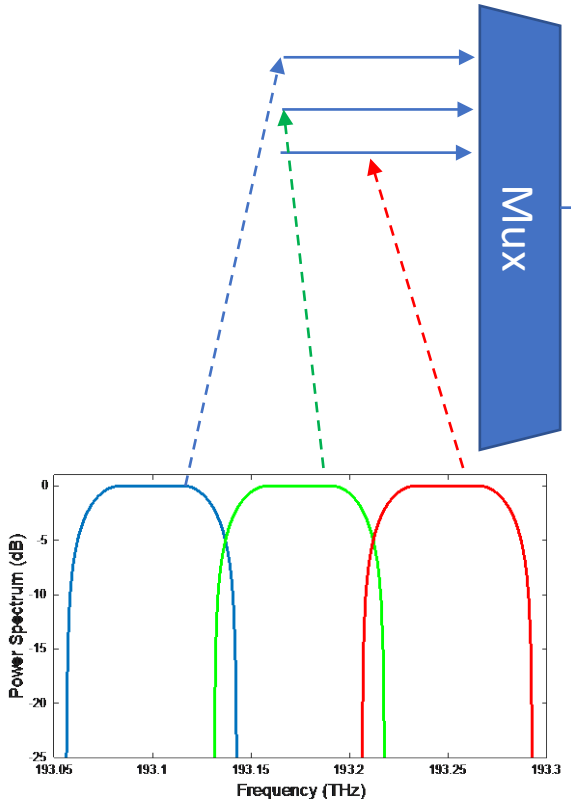
Note: The terms black link and DWDM link are used interchangeably in the following

400GBASE-ZR spectra

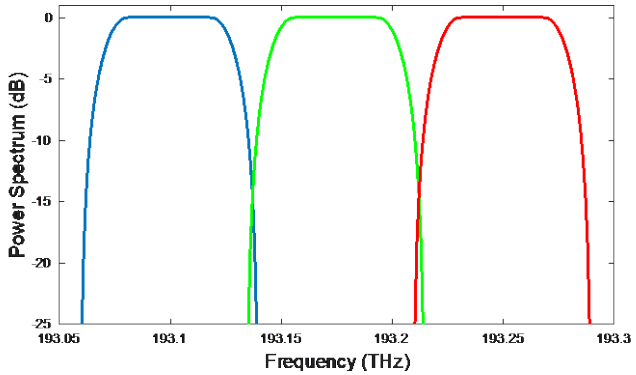
- 400GBASE-ZR is specifying ~60Gbaud channels with 75GHz spacing
- As opposed to 100GBASE-ZR, inter-channel crosstalk can result in a significant penalty.

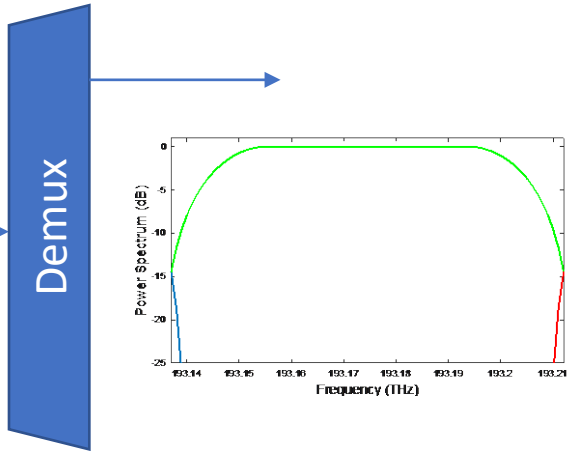


System View



The Mux Spectral shape can reduce the inter-channel crosstalk





Crosstalk Power Spectrum at Rx needs definition, both to calculate penalties and perform compliance measurements

Transmit spectra are shown together to illustrate overlap, but each channel is incident on one Mux port

Calculating Inter-channel Crosstalk Penalty

- Calculation of inter-channel crosstalk penalty requires information on more than the integrated crosstalk power – its spectral distribution is needed
  - With a proper weighting function, the integrated optical crosstalk penalty can be calculated.

- https://www.ieee802.org/3/cw/public/tf_interim/20_0528/maniloff_3cw_01_200528.pdf calculated the crosstalk distribution after Rx filtering matching the Tx spectrum, and applied an AWGN penalty based on this NSR term.

- https://www.ieee802.org/3/ct/public/20_09/kota_3cw_01_200921.pdf applied an optimal equalizer approach to the crosstalk for a variety of Tx shapes and link filters

- The specifics of how crosstalk is mapped into penalty is needed to finalize spectral masks.
- The methodology of how we specify the elements is needed to progress.
- 802.3cw will define an inter-channel crosstalk penalty, and ensure that the conditions are sufficiently well specified to allow Rx design & compliance measurements.
  - 1dB inter-channel crosstalk penalty is being used as an initial value

802.3cw definitions

- Key parameters (Tx, DWDM Link) should be independently specified & measurable
- Parameters should be sufficiently well defined to allow Rx design to meet spec requirements (i.e. inter-channel crosstalk penalty)
- Tx spectral mask of RRC with roll-off < 0.4 and a floor at -20 dB has been presented (details at https://www.ieee802.org/3/ct/public/20_11/way_cw_01b_201116.pdf)

- Tx spectra and black link passband are coupled through filtering penalty
- Tx spectra and adjacent channel isolation are coupled through inter-channel crosstalk penalty
- Definition of Tx spectral mask and a well-defined inter-channel filtering definition will bound inter-channel crosstalk, allowing penalty calculations
  - The final specs will be based on agreed-on penalty calculations

DWDM Link Spectral Characterization

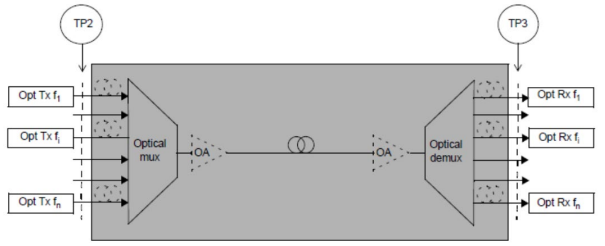
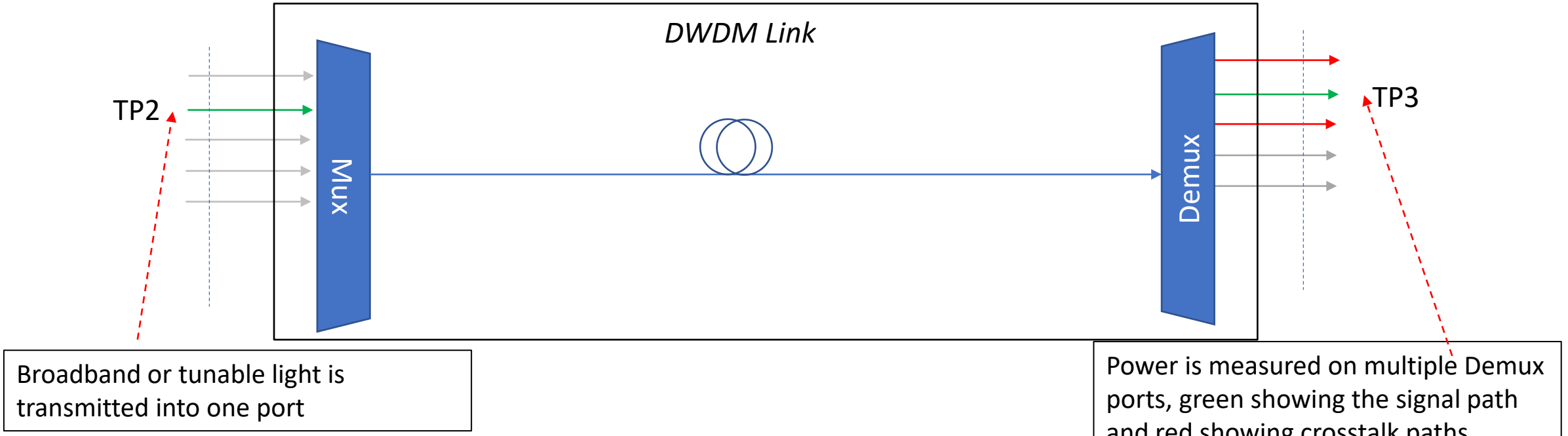


Figure 156–3—Example configuration of the black link approach

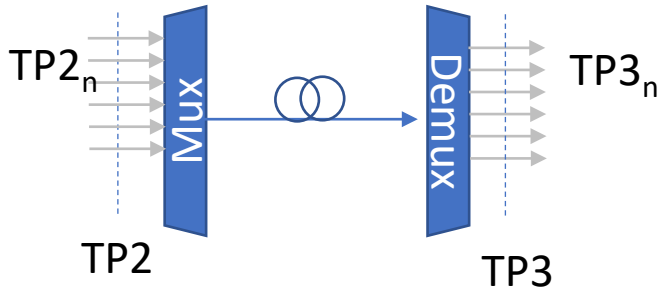


Spectral mask is defined and measured from Mux input (TP2) to Demux Output (TP3)

→ Measurement will cover both through channel and adjacent channels.

By specifying the Signal path and crosstalk path attenuation profiles, 802.3cw can provide the required information for the DWDM Link (Black Link) without specifying individual components

Definitions



- $TP2_n$ connects to Mux port n, corresponding to frequency f_n
- $TP3_n$ connects to Demux port n, corresponding to frequency f_n

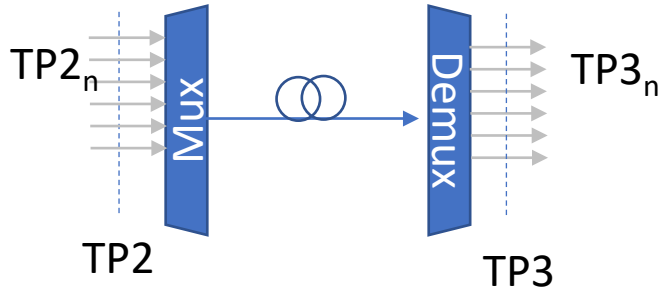
- $TP2_n$ → $TP3_n$ Signal Path through the DWDM Link (DWDM Channel)
- $TP2_n$ → $TP3_{n+1}$, Crosstalk paths to next higher channel frequency
- $TP2_n$ → $TP3_{n-1}$, Crosstalk paths to next lower channel frequency
  - TBD if we need to defined crosstalk more than n → n ± 1; assume no for now

- Transfer Functions $|H(f)|^2$ defined between TP2 & TP3 for signal and crosstalk
  - *Note: we are focused on the Mux/Demux at this point, but the transfer function may capture the full extent of the black link including amplifiers*

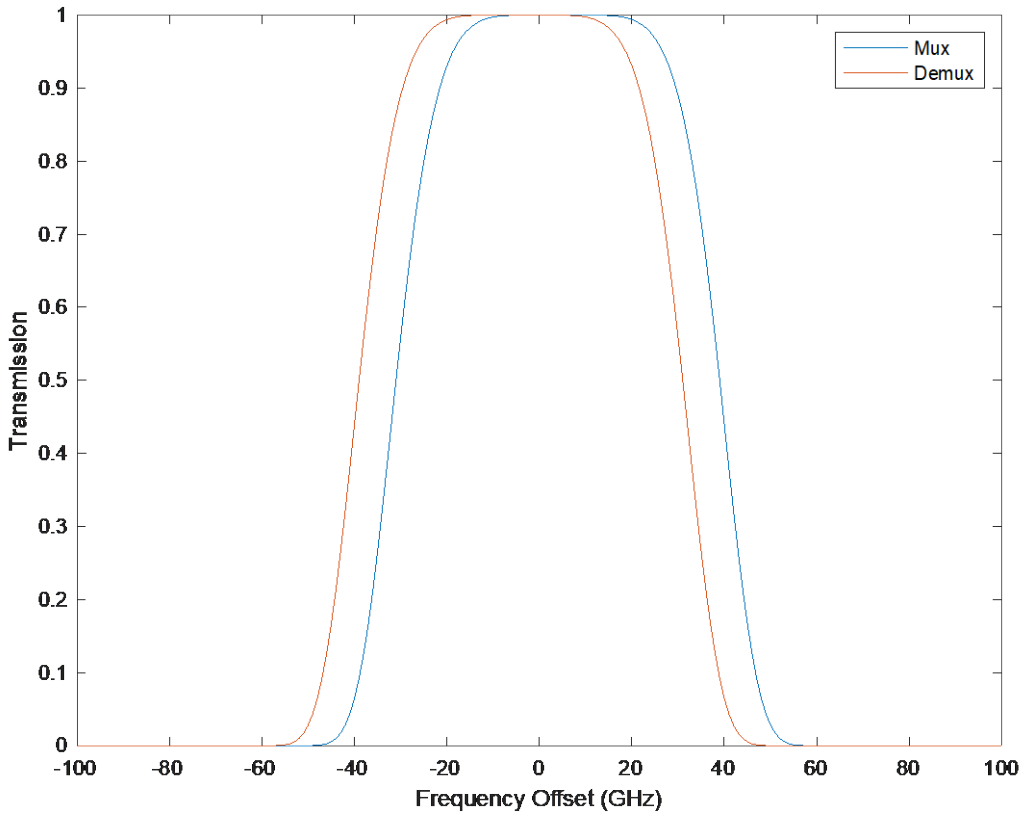
Suggested Parameters

- Tx Spectrum defined as RRC with roll-off ≤ 0.4
  - See: https://www.ieee802.org/3/ct/public/20_11/way_cw_01b_201116.pdf
  - Out of Band OSNR specified < X dB
  - Power variation of Tx channels needs to be included in crosstalk calculations
- Filter Parameters:
  - 3rd order SuperGaussian
  - Widths between 70 & 78 GHz
  - Center channel accuracy ± 4 GHz
  - Floor at =30dB attenuation (not added yet)
- The following figures illustrate spectral power transmitted assuming a lossless DWDM Link at $f = f_0$

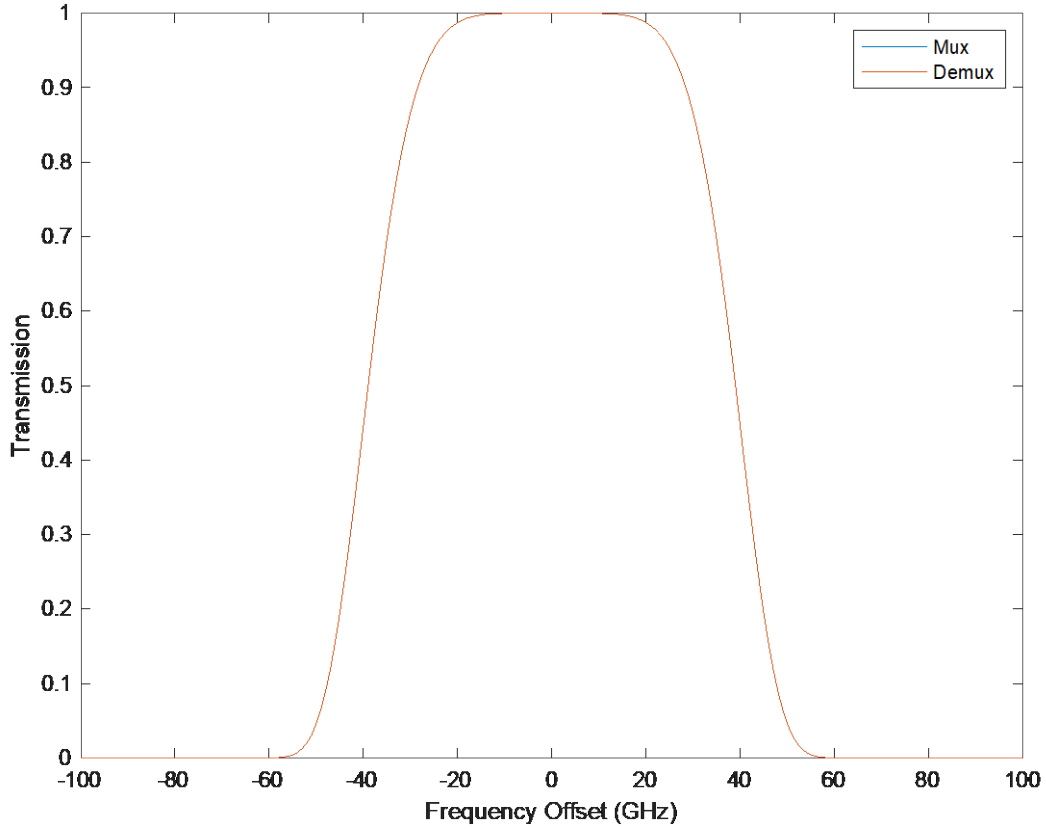
Intra Channel Illustration: $TP2_n$ to $TP3_n$



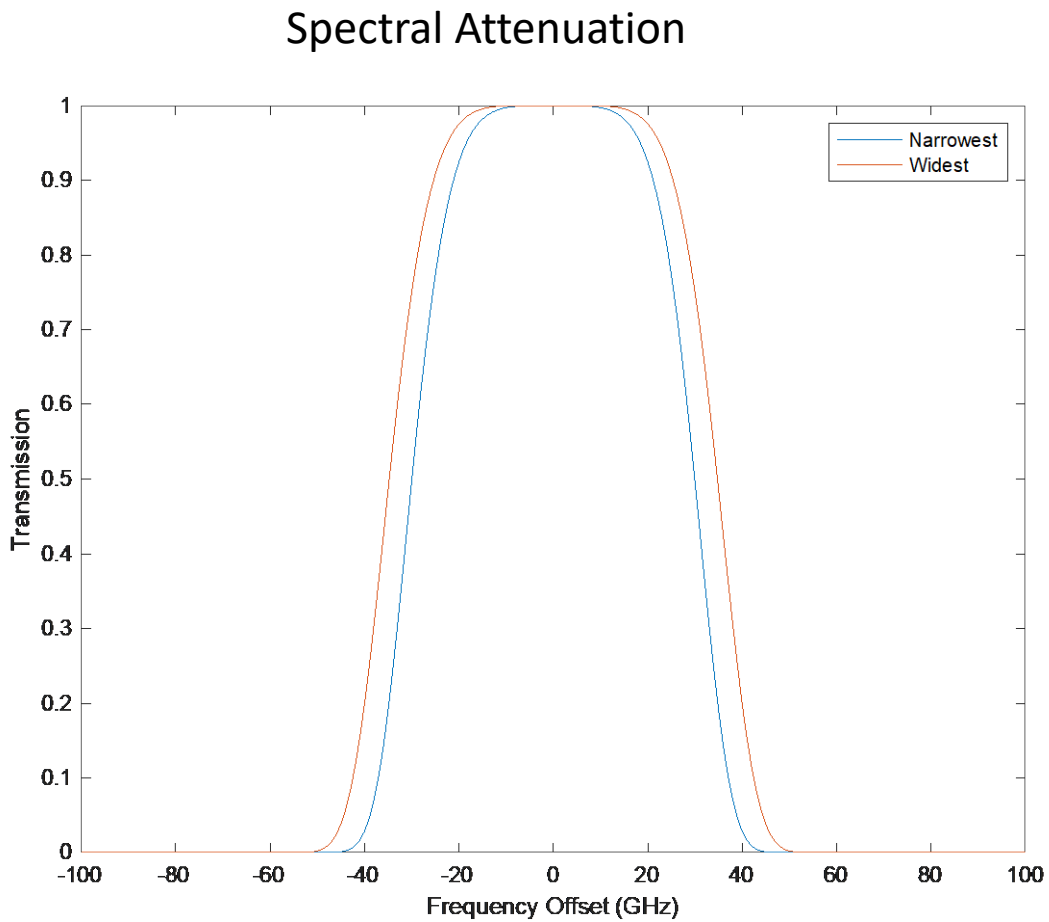
Narrowest filters, Max offset

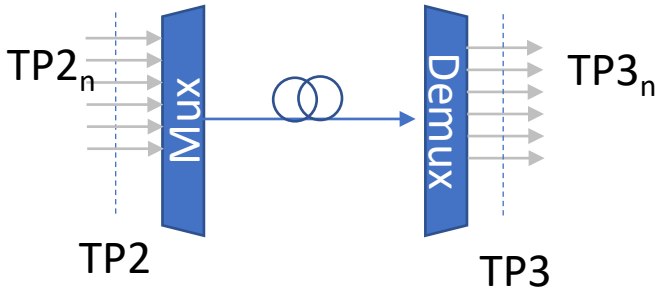


Widest Filters, min offset

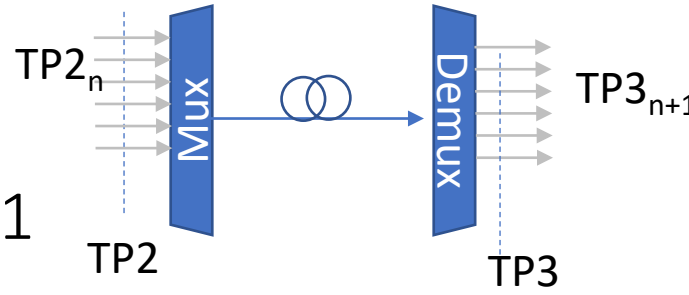


Intra Channel Illustration: $TP2_n$ to $TP3_n$

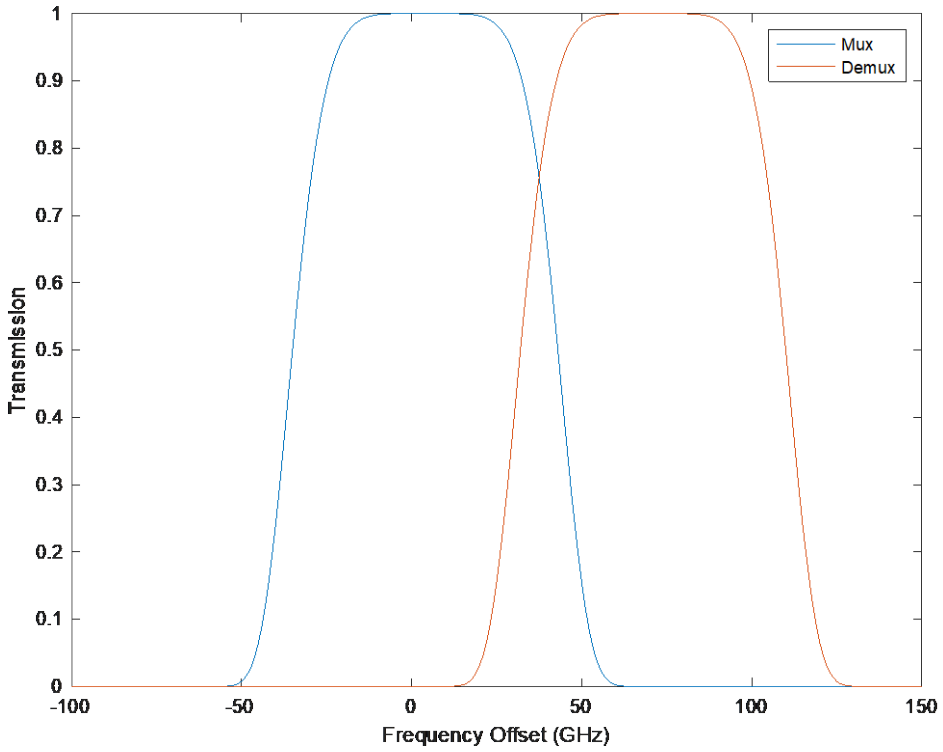




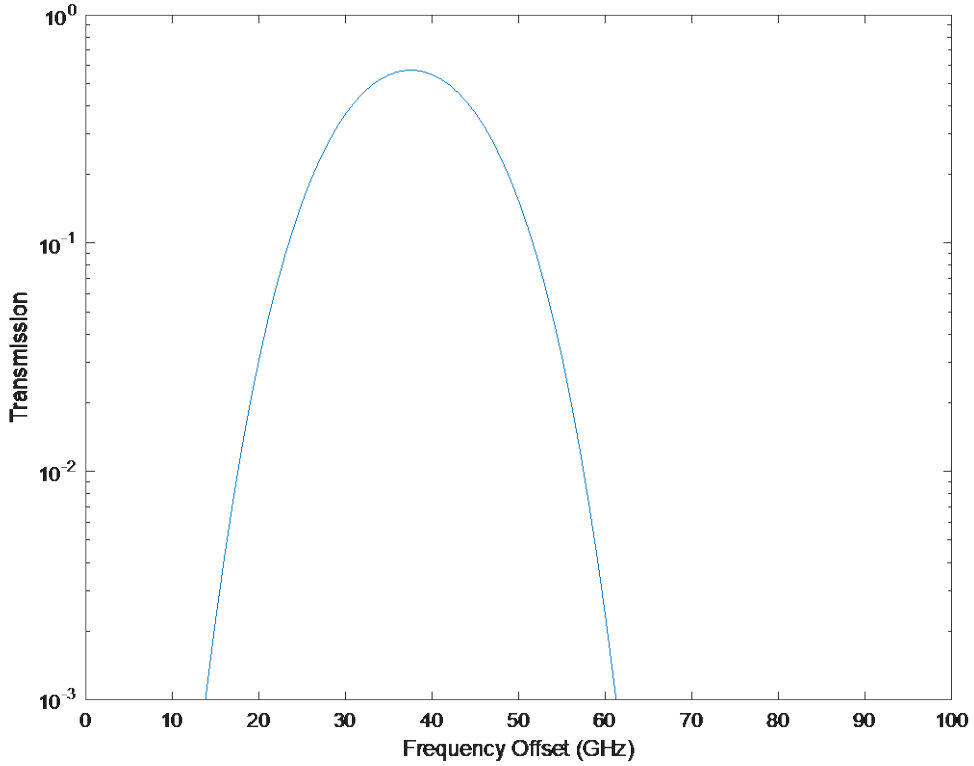
Inter-channel Illustration: $TP2_n$ to $TP3_{n+1}$



Widest Mux/Demux, worst case offset



Crosstalk passband



Transfer Functions

- For a symmetrical super-Gaussian filter, the transmission is:
  - $|H(f)|^2 = \exp[-\ln(2) * ((2(f-f_0)/B_0)^{2n})]$
    - B_o = Bandwidth
    - n = Filter Order Order
  - The overall transfer function will be based on two Super Gaussian filters representing the Mux and Demux:
    - $|H(f)|^2 = |H_M(f)|^2 \bullet |H_D(f)|^2$
  - Transfer functions to be defined based on B_0 and n.
  - Filter offsets need to be included in f_0
  - Starting Definition based on identical Mux & Demux filters
  - Minimum width for a signal channel also needs definition

Transfer function Definitions: Intra-channel

- Define a Transmission function for a 3rd order filter as previously
  - $T(f, B_0, f_0) = \exp[-\ln(2) * ((2(f-f_0)/B_0)^6)]$
  - floor of -30dB can be added
- Bounding our minimum and maximum B_0 between 70 GHz (B_{0Min}) & 78 GHz (B_{0Max}) as a starting point
  - A factor C is included to allow inclusion of channel gain, or other ripple effects if needed.

- For a channel centered at a frequency f_0, the DWDM Link transmission for $TP2_n$ to $TP3_n$ in GHz:
  - $T_{DWDMLink}(f) \geq C * \exp[-\ln(2) \bullet ((2(f- f_0 -4)/B_{0Min})^6)] \bullet \exp[-\ln(2) \bullet ((2(f- f_0 +4)/B_{0Min})^6)]$
  - $T_{DWDMLink}(f) \leq C * \exp[-\ln(2) \bullet ((2(f- f_0)/B_{0Max})^6)] \bullet \exp[-\ln(2) \bullet ((2(f- f_0)/B_{0Max})^6)]$

Transfer function Definitions (shorthand)

- For a channel centered at a frequency f_0, the DWDM link transmission for TP2n to TP3n
  - $T_{DWDMLink}(f) \geq C * T(f, B_{0Min}, f_0 - 4) \bullet T(f, B_{0Min}, f_0 + 4)$
  - $T_{DWDMLink}(f) \leq C * T(f, B_{0Max}, f_0) \bullet T(f, B_{0Max}, f_0)$

Transfer function Definitions: Interchannel

- For adjacent channels calculation of inter-channel crosstalk uses the same approach
- For a channel centered at a frequency f, the DWDM link transmission for $TP2_n$ to $TP3_{n+1}$
  - $T_{DWDMLink}(f) \leq C * T(f, B_{0Max}, f_0 + 4) \bullet T(f, B_{0Max}, f_0 + 71)$

- Note that this is the worst case inter-channel crosstalk from a single adjacent channel, and would not occur from both adjacent neighbors.

Summary

- Defining a Transmit spectral mask and Link transfer functions provides the information needed for 400GBASE-ZR filtering and crosstalk penalties
- A proposal for the Transmit Spectral mask has been presented previously
- The approach captured here can be used to define the DWDM Link (Black Link) spectral characteristics

Thanks!