400GBASE-ZR operation on 75GHz grid

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400GBASE-ZR
75GHz Grid operation Considerations - Agenda

- 400GBASE-ZR operation on 75GHz Grid
- Baseline OIF 400ZR IA compliant Optical Transceiver.
  - 100GHZ Grid analysis
  - 75GHz Grid analysis
- Penalty analysis
  - Due to Inter-channel crosstalk
  - Filtering
    - Filter Bandwidth
    - Filter Order
- Conclusions

Motivation and Executive Summary

- DCI demand for 75 GHz spacing is clear. See du_3ct_01b_0919
- This work explores the impact of 75 GHz spacing on xtalk between nearest neighbors
- Simulation used very conservative filter shapes but experimental work shows better performance possible. See way_3ct_02a_1119.pdf
- Simulation work shows 75 GHz spacing is feasible without additional power required for spectral shaping
  - OSNR penalty higher than desired but further analysis will identify ways to reduce
  - Opportunities include: more realistic filter shapes, modification to black link specs

Black Link Approach

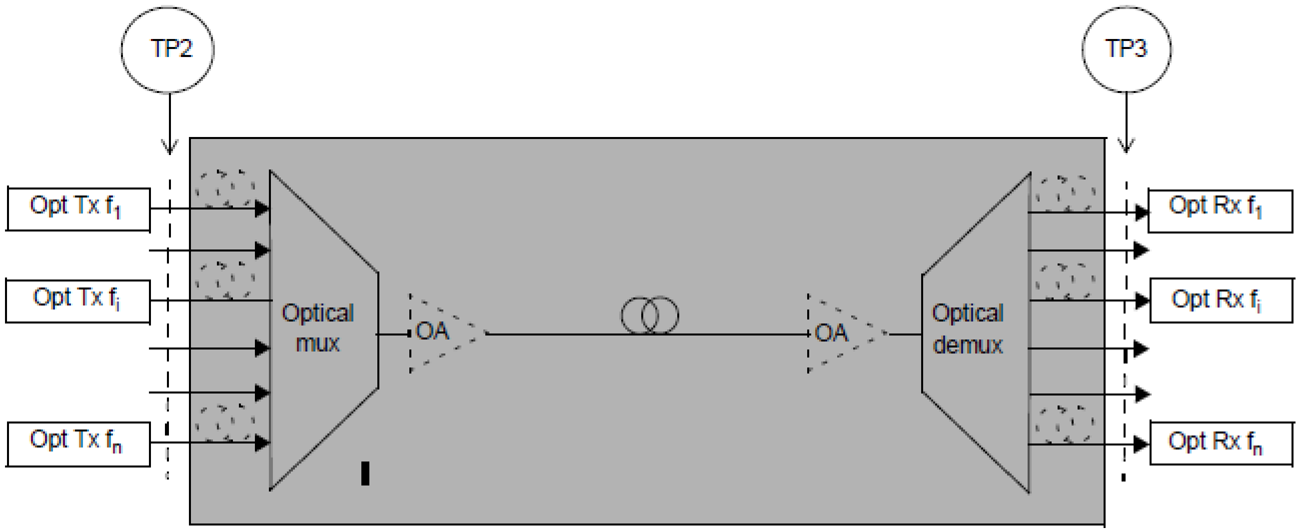


Figure 154–3—Example configuration of the black link approach

100GBASE-ZR (802.3ct) Transmit specification

Table 154–8—100GBASE-ZR transmit characteristics

Description	Value	Unit
Signaling rate (range)	27.9525 ± 20 ppm	GBd
Modulation format	DP-DQPSK	—
Minimum channel spacing	100	GHz
Average channel output power (max)	TBD	dBm
Average channel output power (min)	–8	dBm
Nominal center frequency	The frequency in Table 154–6 corresponding to the variable Tx_optical_frequency_index	THz
Spectral excursion (max)	±15	GHz
Side-mode suppression ratio (SMSR), (min)	30	dB
Laser linewidth (max)	1000	kHz
Offset between the carrier and the nominal center frequency (max)	1.8	GHz
Power difference between polarizations (max)	1.5	dB
Skew between the two polarizations (max)	TBD	ps
Error vector magnitude (max)	23	%
I-Q offset (max)	–25	dB
Transmitter OSNR(193.6) (min)	35	dB
Average launch power of OFF transmitter, each lane (max)	TBD	dBm
Optical return loss tolerance (max)	TBD	dB
Transmitter reflectance[a] (max)	TBD	dB

[a]Transmitter reflectance is defined looking into the transmitter.

400GBASE-ZR 16QAM DP-QPSK, 75GHz spacing

- Figure shows the optical spectrum post mux at the Tx.
  - 3 separate 400G ZR signals (RC 1.0) are multiplexed together with a spacing of 75GHz.

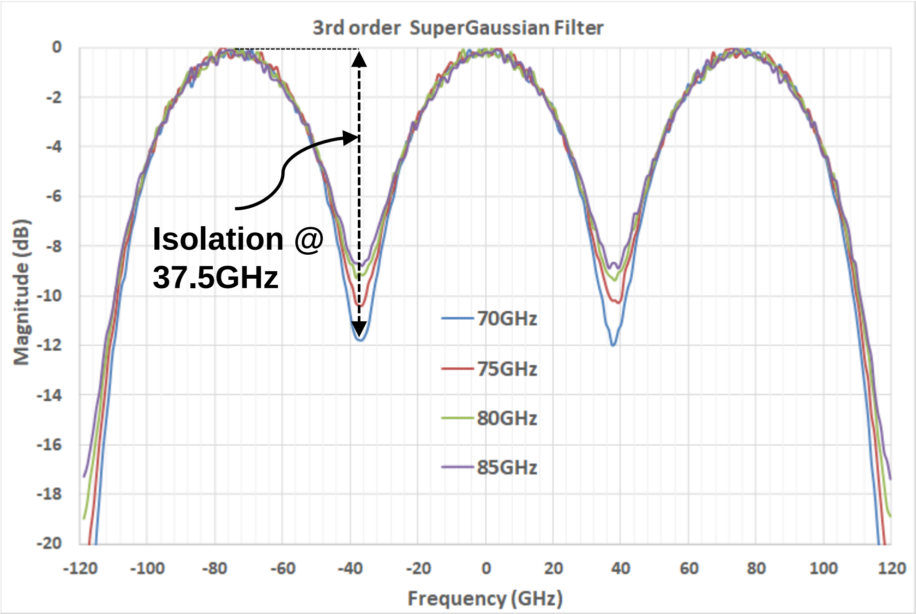
- Mux Filters are assumed to be 3rd order super-Gaussian filters.
  - There is no laser frequency offset or filter offset.

- Figure indicates that as the bandwidth of the filter is increased, the isolation between the channels decreases and hence the crosstalk increases.

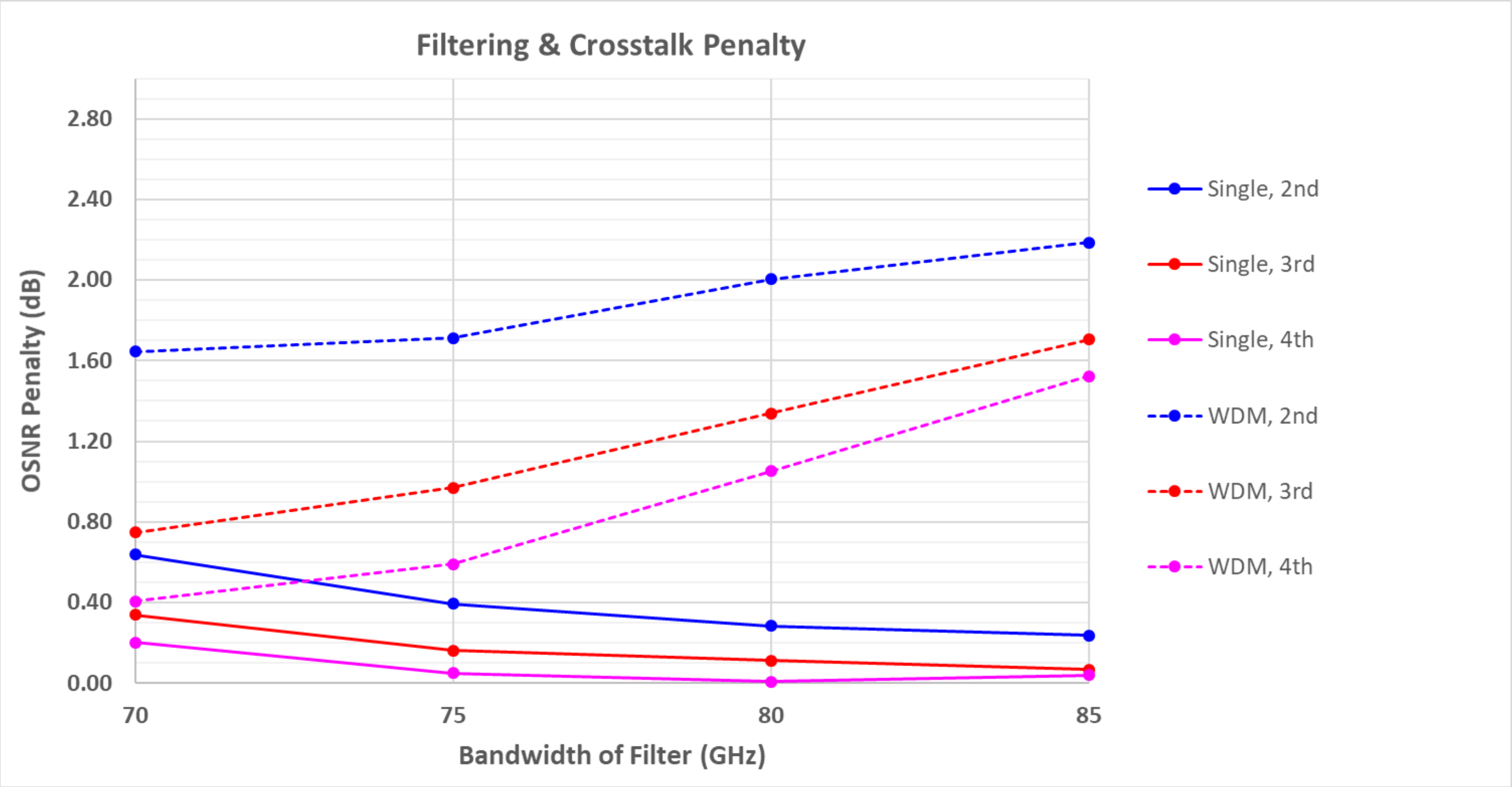
- As the bandwidth of the filters is decreased, the signal spectrum is filtered and thus increases the ISI.

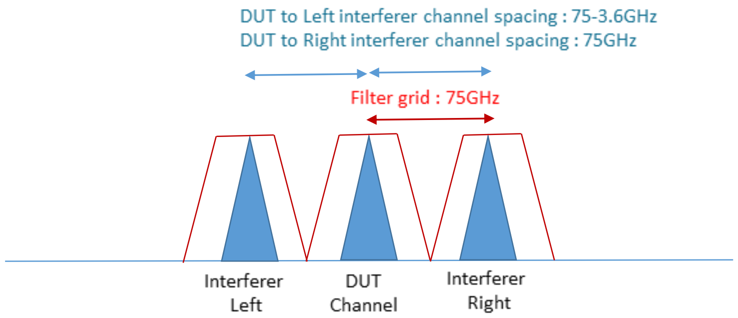
- Therefore an optimum bandwidth and order of the (AWG mux and demux) filters are required for better performance.

Optical spectra @ output of mux



Penalty due to crosstalk with Maximum Spectral Excursion; TX = RC 1.0; TX Offset = +/- 1.8GHz; Filter offset = 0 GHz



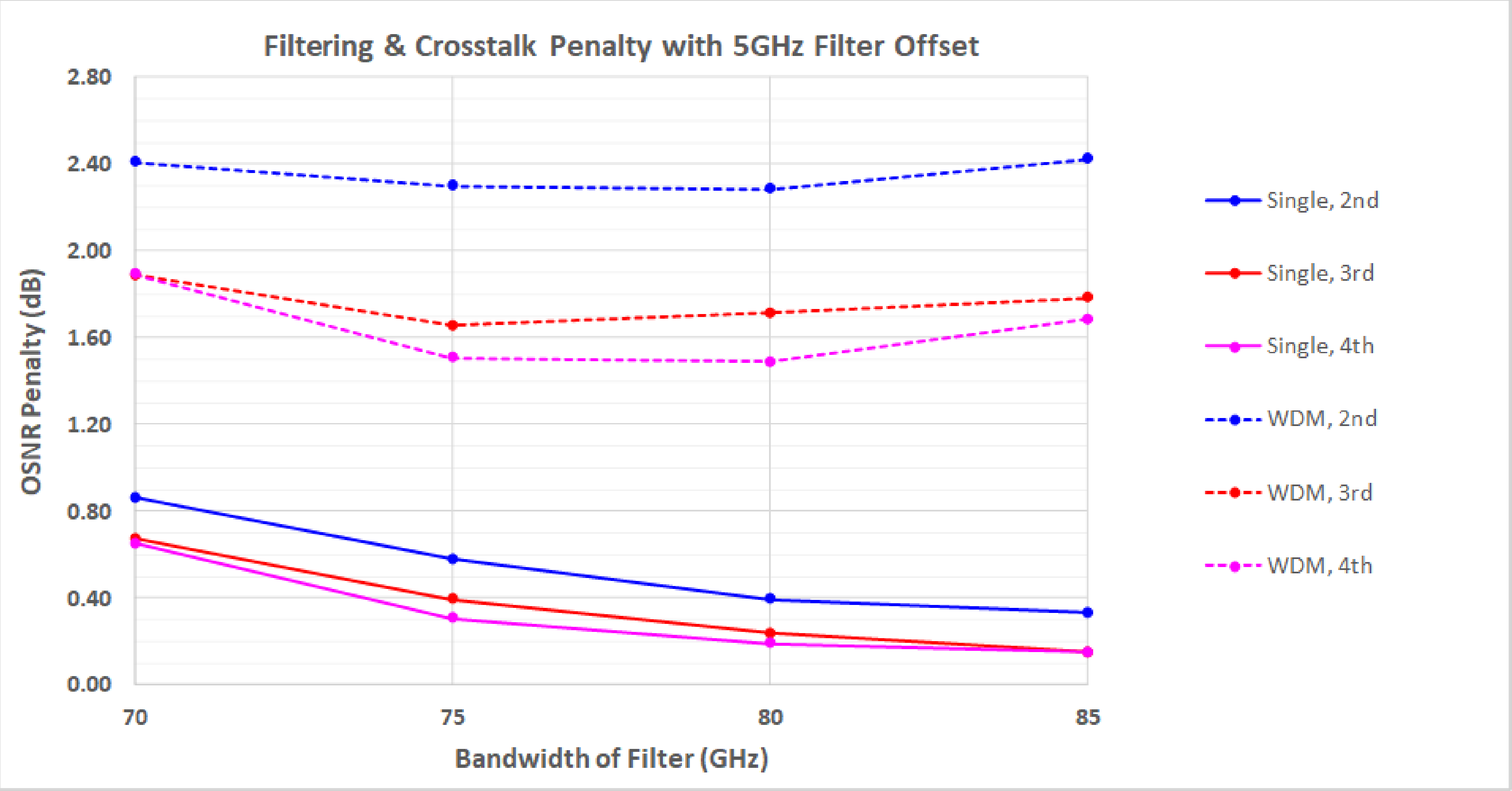


- Results shows that
  - Higher order filters are better.
  - It would be better to have a mux that has an order higher than 3.0.
  - Bandwidth of the filter should also be ~75GHz.
  - Filter polynomial:

$$H(f) = \exp\left(-0.3465736\left(\frac{2f}{BW}\right)^{2n}\right)$$

- Same filter is used both at Tx and Rx.
- Higher order filter shows higher isolation and hence better performance.
- No Filter Frequency offset is included.
- *BW* in the polynomial corresponds to the 3dB BW of the filter

Penalty due to filtering and Crosstalk with Maximum Spectral Excursion; TX = RC 1.0; Offset = +/- 1.8GHz; 5GHZ Filter offset



- The simulation methods are same as before. But the mux and demux filter are offset by 5GHz in the same direction.
- Elevated levels of penalties are seen due to the filter offset.
- If 3rd order mux and demux are chosen for AWG, ~2dB OSNR penalty may be seen compared to B-B with no ASE reduction.
- Received Optical power is -3dBm

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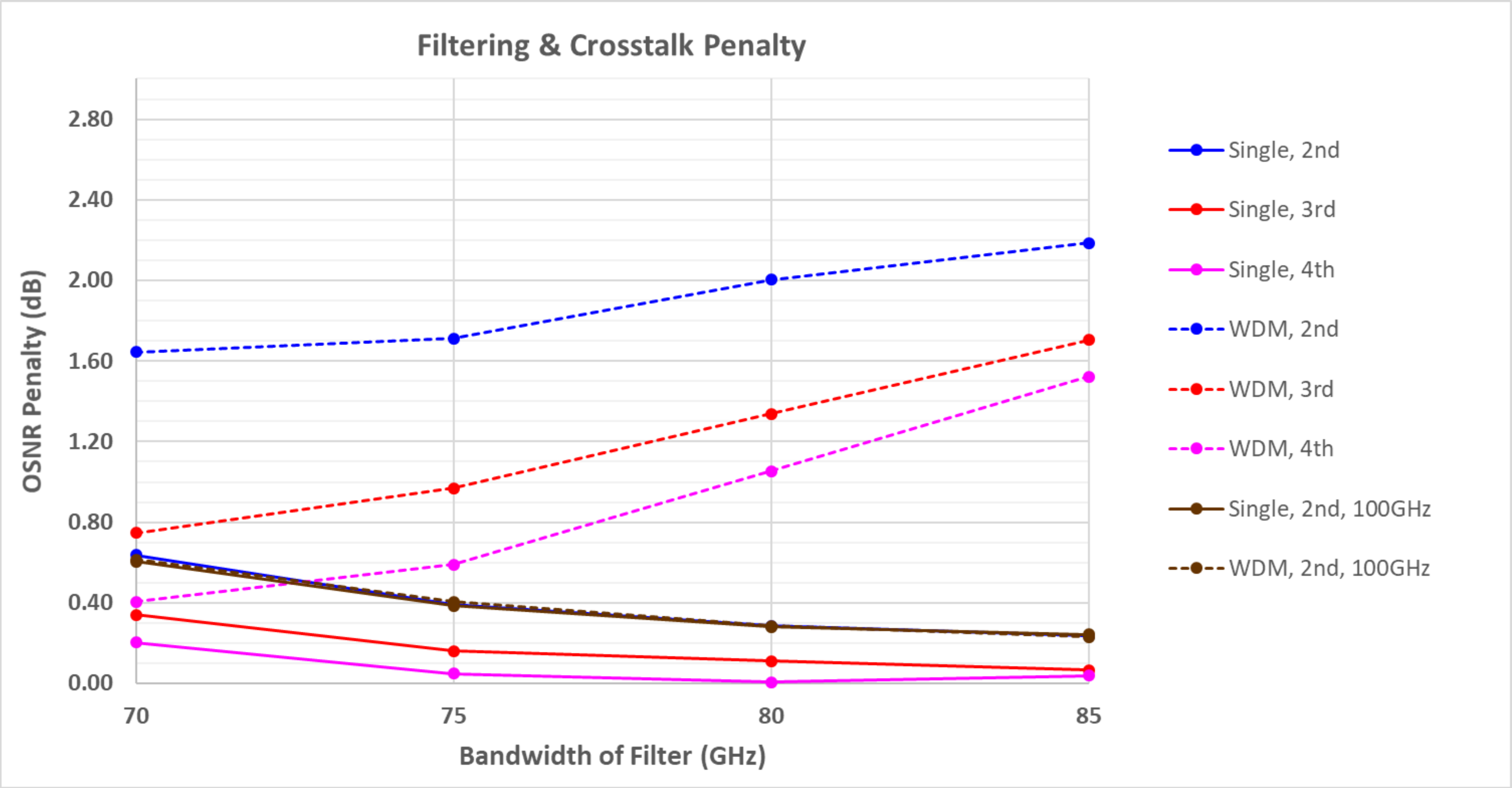
100GHz to 75GHz grid penalty comparison TX RC = 1.0



- Results show that there is no additional WDM crosstalk penalty when the channels are spaced at 100 GHz.
- Penalty is reduced with filtering (e.g. penalty @ 75GHz with 3rd order super Gaussian filter is ~1dB higher than same signal on 100GHz Grid).

Conclusions:

- OSNR Penalty for operating 400G 60 GBd 16QAM signal on 75 GHz Grid is primarily from xtalk due to proximity of neighbors.
- At 100GHz Grid spacing penalty due to xtalk penalty is not significant for DWDM vs. Single wavelength.
- A compliant OIF 400ZR Transceiver RC=1.0 with maximum spectral excursion, operating on 75GHZ grid in a DWDM application could see ~2dB OSNR Penalty over the same transceiver operating on 100GHz Grid due to inter-channel xtalk and ISI. Optimizing the filtering (order and BW) the penalty due to Xtalk and ISI can be reduced.
    - As modeled the OSNR penalty due to xtalk and ISI with 75GHz BW 3rd order Super Gaussian filter is .6dB higher than 100GHz grid baseline.
- Practical operation on 75 GHz is feasible. The following options require further discussion
    - Further analysis and input for AWG vendors on Filtering capabilities is required
    - Input from network operators on what penalty can be tolerated is required.

Proposed 400GBASE-ZR black link characteristics

Description	Value	Unit
Minimum channel spacing	75	GHz
Maximum channel inband ripple[d]	TBD (2.5)	dB
Maximum optical path penalty OSNR	TBD (3)	dB
Maximum (residual) chromatic dispersion	2000	ps/nm
Minimum (residual) chromatic dispersion	-200	ps/nm
Minimum optical return loss at TP2	24	dB
Maximum discrete reflectance between TP2 and TP3	-27	dB
Average Polarization Mode dispersion[a]	10	ps
Maximum polarization dependent loss[b]	2.0	dB
Maximum polarization rotation speed	50	krad/s
Maximum inter-channel crosstalk at TP3	TBD	dB
Maximum interferometric crosstalk at TP3	-35	dB
Nominal channel filter bandwidth	TBD	GHz
Maximum filter bandwidth offset	TBD	GHz
Minimum filter order	TBD	-

a). 10 ps of average PMD corresponds to max 33 ps of instantaneous DGD and max 500 ps^2 of SOPMD.
b). Does not include transmitter polarization imbalance.
c). Effective optical channel bandwidth (FWHM) due to DWDM optical filtering.
d). In-band IL ripple due to DWDM optical filtering.

Transmitter Optical Specifications

Description	Value	Unit
Signaling rate per polarization	59.84375	GBd
Minimum signaling rate offset	-100	ppm
Maximum signaling rate offset	100	ppm
Modulation format	DP-16QAM	-
Start channel frequency	191.375	THz
Stop channel frequency	196.1	THz
Nominal center frequency	The frequency defined in Table TBD corresponding to the variable Tx_optical_frequency_index	THz
Maximum offset between the carrier and the nominal center frequency	1.8	GHz
Maximum spectral excursion[a]	+/- 32	GHz
Minimum channel output power	-10	dBm
Maximum channel output power	-6	dBm

Transmitter Optical Specifications – Cont.

Description	Value	Unit
Maximum laser linewidth[a]	500	kHz
Average laser relative intensity noise[a]	-145	dB/Hz
Peak laser relative intensity noise[b]	-140	dB/Hz
Maximum power difference between X-Y polarizations	1.5	dB
Maximum skew between the X-Y polarizations	5	ps
Maximum Error Vector Magnitude	15.7	%
Maximum I-Q offset	-26	dB
Minimum transmitter Inband OSNR @ 193.7 THz	34	dB
Maximum output power with transmitter disabled	-20	dBm
Maximum output power during channel change	-20	dBm
Maximum transmitter reflectance[c]	-20	dB
Maximum transmitter back reflection tolerance[d]	-24	dB

a). Average over 0.2GHz < *f* < 10GHz.
b). Peak over 0.2GHz < *f* < 10GHz.
c). Optical power ratio of the reflected light of Tx output port back to fiber network vs. the external incident light into the Tx output port.
d). Maximum light power (relative in decibel w.r.t. Tx output) reflected back to transmitter while still meeting performance requirements.

Rx Optical Specs

Description	Value	Unit
Input Power Range (min)	-12	dBm
Input Power Range (max)	0	dBm
Frequency Offset Tolerance (min)[a]	± 1.8	GHz
OSNR Tolerance (min)[b]	26	dB
CD Tolerance (min) [c]	2000	ps/nm
DGD (max)[d]	33	ps
SOPMD (max)[d]	500	ps^2
Peak PDL Tolerance (min)[e]	3.5	dB
Change in SOP Tolerance (min)[f]	50	rad/ms
Optical Power Transient Tolerance (min)[g]	± 2	dB
Optical Return Loss (min)	20	dB
DWDM Transmission Penalty (max)[h]	0.5	dB

a). Rx must tolerate this amount of Tx frequency offset from the nominal ITU frequency grid based on 100 GHz channel spacing.
b). Minimum value of OSNR (referred to 0.1 nm noise bandwidth @ 193.6 THz) that can be tolerated while maintaining the maximum BER below the CFEC threshold. Must be met for a back-to-back measurement configuration at all input powers defined above.
c). Tolerance to chromatic dispersion with <0.5 dB OSNR penalty
d). Tolerance to max DGD and max SOPMD [according to 10ps mean PMD] with < 0.5 dB OSNR penalty and change in SOP < 1 rad/ms.
e). Peak PDL includes both transmitter polarization imbalance and link PDL. Tolerance to peak PDL with < 1.3 dB OSNR penalty. Tested with noise injected before PDL emulator and PSP < 1 rad/ms.
f). Tolerance to change in SOP with < 0.5 dB OSNR penalty.
g). Tolerance to change in input power with < 0.5 dB OSNR penalty.
h). OSNR penalty due to DWDM optical filtering effects [bandwidth and IL ripple], DWDM nonlinear transmission effects, and link reflections.

Optical Parameter Definitions

The Receiver Optical Signal-to-noise Ratio Tolerance

The receiver OSNR tolerance is defined as the minimum value of OSNR (referred to 0.1 nm @193.7 THz or 12.5 GHz) that can be tolerated while maintaining the maximum BER of the application. This must be met for all powers between the maximum and minimum mean input power with a transmitter with worst-case values of:

- Transmitter optical return loss,
- Receiver connector degradations
- Measurement tolerances

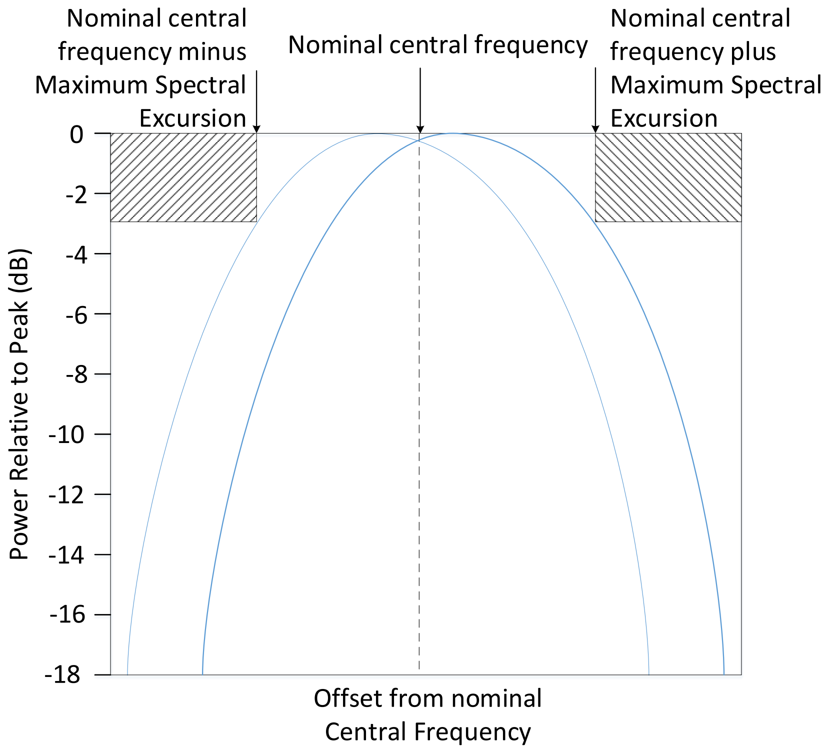
The receiver OSNR tolerance does not have to be met in the presence of chromatic dispersion, non-linear effects, reflections from the optical path, PMD, PDL or optical crosstalk. These effects are specified separately but contribute to total optical path OSNR penalty.

System integrators need to account for these path penalties when evaluating network performance.

Optical Parameter Definitions – Cont.

Spectral excursion

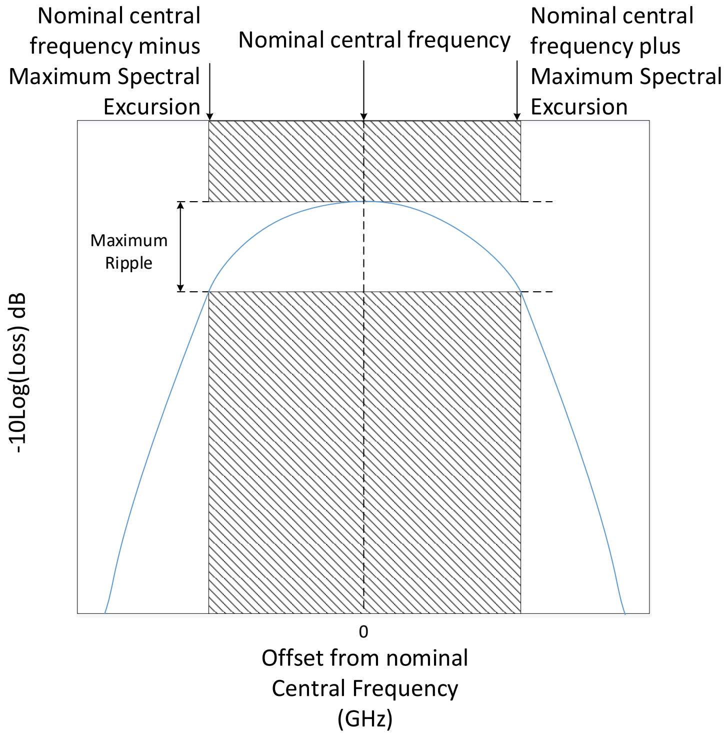
Spectral excursion is defined as the difference between the nominal central frequency of the channel and the -3dB points of the transmitter spectrum furthest from the nominal central frequency measured at point S_S. Including the laser frequency accuracy error value from the nominal center frequency.



Optical Parameter Definitions – Cont.

Ripple

Ripple is defined as the peak-to-peak difference in insertion loss between the input and output ports of the black link over that channel in the frequency (or wavelength) range of the channel +/- the maximum spectral excursion.



Optical Parameter Definitions – Cont.

Inter-channel crosstalk

Inter-channel crosstalk is defined as the ratio of total power in all of the disturbing channels to that in the wanted channel, where the wanted and disturbing channels are at different wavelengths.

Specifically, the isolation of the link shall be greater than the amount required to ensure that when any channel is operating at the minimum mean output power at point S_s and all of the others are at the maximum mean output power, then the inter-channel crosstalk at the corresponding point R_s is less than the maximum inter-channel crosstalk value.