75GHz-Spaced 400GBASE-ZR Analysis

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Supporters

- Ali Ghiasi, Ghiasi Quantum LLC
- Frank Chang, Source Photonics
- Gary Nicholl, Cisco
- Hideki Isono, Fujitsu Optical Components
- Ilya Lyubomirsky, Inphi
- Josef Berger, Inphi
- Liang Du, Google
- Mark Nowell, Cisco
- Mike Sluyski, Acacia Communications
- Rich Baca, Microsoft
- Tomas Maj, Inphi

Motivation

- Several cloud customers have expressed needs in 400GBASE-ZR operating over 75GHz grid which is aligned w/ broad market potential for IEEE
  - see http://www.ieee802.org/3/ct/public/19_09/du_3ct_01b_0919.pdf

- One of the main reasons for the split of 802.3ct PAR/CSD and the creation of 802.3cw is the lack of consensus on 400GBASE-ZR optical specs
  - see http://www.ieee802.org/3/ct/public/19_11/1119_3ct_open_report.pdf
  - see http://www.ieee802.org/3/ct/public/19_09/dambrosia_3ct_04_0919.pdf

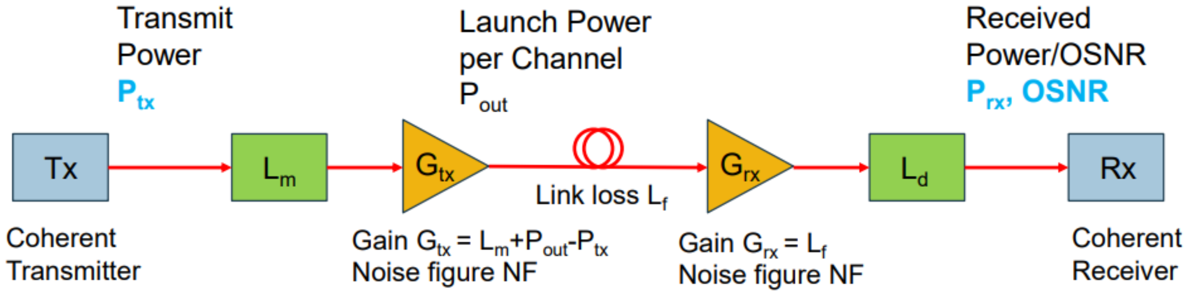
- Several technical presentations on 75GHz spacing analysis thus far
  - see http://www.ieee802.org/3/ct/public/19_11/way_3ct_02a_1119.pdf
  - see http://www.ieee802.org/3/ct/public/19_11/ogawa_3ct_01_1119.pdf
  - see http://www.ieee802.org/3/ct/public/19_09/deandrea_3ct_01a_0919.pdf
  - see http://www.ieee802.org/3/ct/public/20_01/sluyski_3ct_01_0120.pdf

Concerns Observed

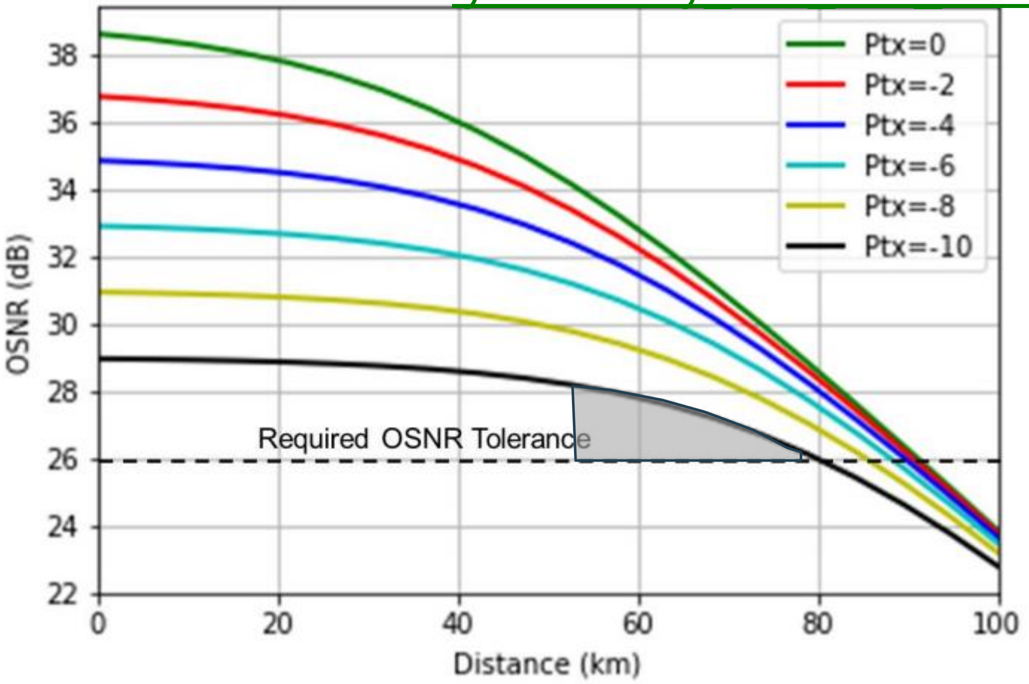
- Technical contributions thus far have shown a very wide range of MUX/DMUX filter bandwidth, shape, offset and isolation spec proposals
  - deandrea_3ct_01a_0919.pdf : 3dB bandwidth ranging from 70GHz to 95GHz
  - ogawa_3ct_01_1119.pdf: filter shape ranging from shallow Gaussian order to ‘rectangular’ sharp roll-offs
  - ogawa_3ct_01_1119.pdf: filter offset ranging from +/-2GHz to +/-5GHz
  - filter isolation lacks contribution (need correlation of inter-channel and interferometric crosstalk specs w/ MUX/DMUX isolation specs)
  - Lack of specific allocation of MUX/DMUX-induced ROSNR penalties

- One technical contribution proposes some metrics for transceiver specs – maybe challenging to measure
  - way_3ct_02a_1119.pdf : proposes a driver+modulator combo bandwidth metric – no direct access point to driver input in an 400GBASE-ZR small form factor optical transceiver.

System OSNR Margin



lyubomirsky_3cn_01a_1118.pdf



- In 802.3cn the worst case single-channel OSNR budget was shown to be ~3dB (lyubomirsky_3cn_01a_1118.pdf)
- OIF-compliant TX spectra in sluyski_3ct_01_0120.pdf shows a worst case cross-talk penalty of 2.5dB.
- Allowing a 2.5dB crosstalk penalty would reduce the application from 80km to <60km.
- Suggest allocating a penalty for crosstalk that better captures the broad market appeal.
  - Determine Tx operating window and MUX/DMUX specs based on crosstalk penalty allocation.

- P_{out} = 0 dBm
- L_m = 10 dB (patch panels, DWDM Mux, etc.)
- NF = 6 dB
- L_f = (0.25 dB/km) x distance
- G_{ripple} = 1 dB
- $OSNR_{penalties}$ = 2 dB

The Need for Coherent Tx Spectral Operating Window

- OIF Implementation Agreement (IA) for CFP2 Analogue Coherent Optics Module (IA # OIF-CFP2-ACO-01.0) specifies under transmitter RF interfaces section the normalized Tx EO magnitude response (S21 parameters) min and max values for a set of specific frequencies.

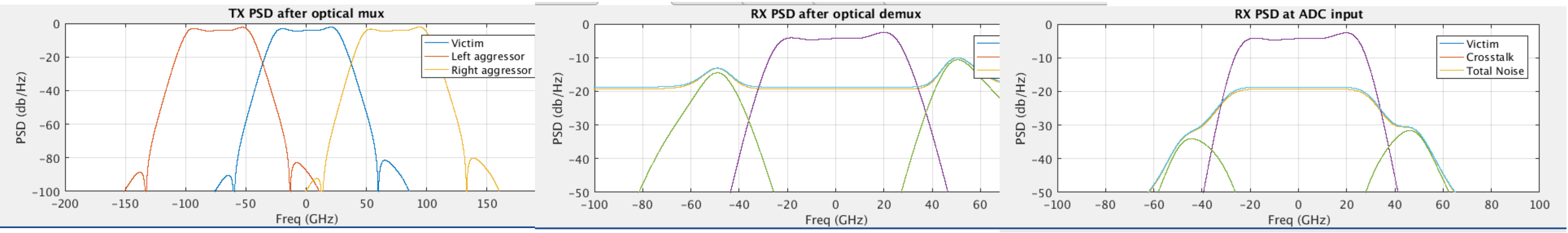
https://www.oiforum.com/wp-content/uploads/2019/01/OIF-CFP2-ACO-01.0.pdf

- OIF Implementation Agreement (IA) for the High Bandwidth Coherent Driver Modulator (HB-CDM) (IA # OIF-HB-CDM-01.0) specifies under RF Frequency Response section the EO S21 transfer function mask with lower and upper dB values for a set of frequencies.

https://www.oiforum.com/wp-content/uploads/2019/01/OIF-HB-CDM-01.0.pdf

Analysis on the Tx spectral operating window (1)

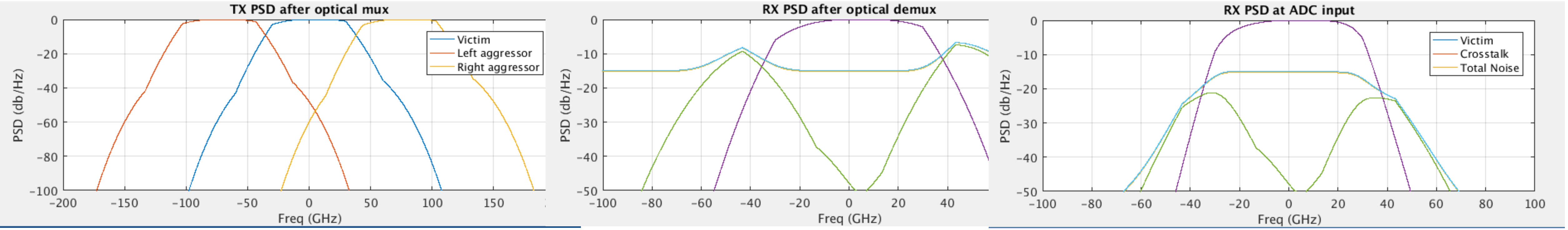
‘Narrower Tx spectra case’ with middle victim channel plus left/right aggressors with nominal 75GHz spacing, and nominal 75GHz MUX/DMUX filtering.



Spectral plots with three channels at various outputs (after optical MUX, after optical DMUX, at the ADC input), showing the dominating effect of ISI impairments with narrower Tx spectra scenario

Analysis on the Tx spectral operating window (2)

‘Wider Tx spectra case’ with middle victim channel plus left/right aggressors with nominal 75GHz spacing, and nominal 75GHz MUX/DMUX filtering.



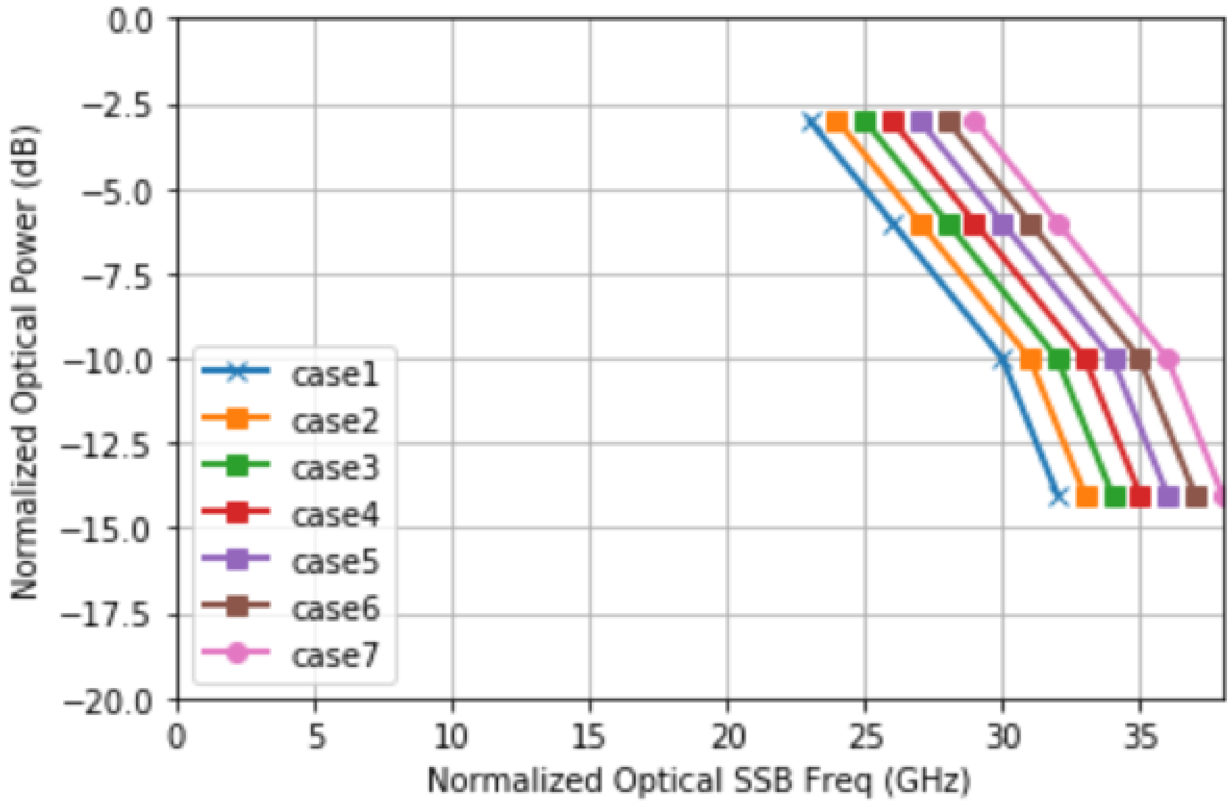
Spectral plots with three channels at various outputs (after optical MUX, after optical DMUX, at the ADC input), showing the dominating effect of crosstalk impairments with wider Tx spectra scenario

400G ZR Lab Set Up Conditions

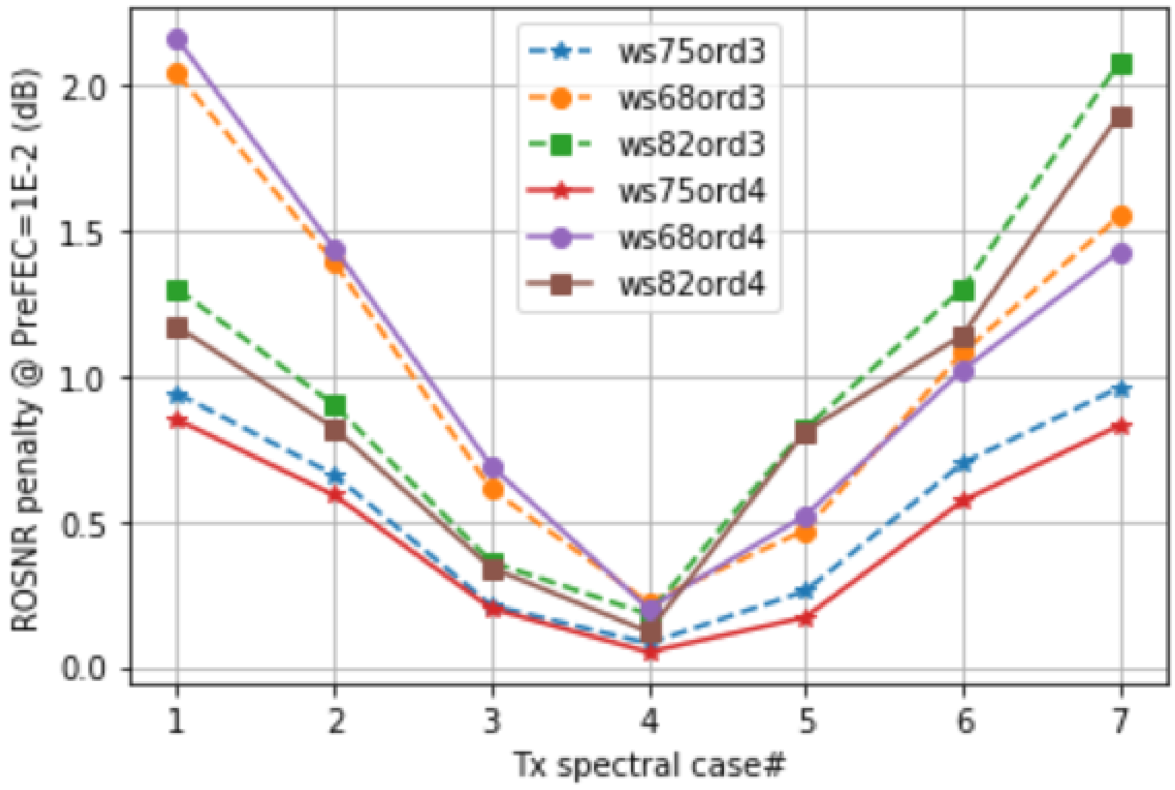
- One 400G ZR victim and One 400G aggressor nominally separated by 75GHz
- Victim laser skewed 1.8GHz from 75GHz on-grid (towards the aggressor)
- Aggressor laser skewed 1.8GHz from 75GHz on-grid (towards the victim)
- AWG MUX on the victim channel shifted 3GHz away from its on-grid (away from the victim laser skewed direction)
- AWG MUX on the aggressor channel shifted 3GHz away from its on-grid (same as the aggressor laser skewed direction)
- AWG DMUX on the victim channel shifted 3GHz away from its on-grid (same as the victim laser skewed direction)
- AWG DMUX on the aggressor channel shifted 3GHz away from its on-grid (same as the aggressor laser skewed direction)
- One shaping function (concatenated with the MUX/DMUX functions) is used right after the victim channel

400G ZR Lab Results

7 generated optically shaped transmitter spectra



ROSNR penalty as a function of the 7 generated cases



Tx Optical Specs I

Description	Value	Unit
Signaling rate, (range) per polarization	59.84375 +/-20ppm	GBd
Modulation Format	DP-16QAM	
Start Channel Frequency	191.3	THz
Stop Channel frequency	196.1	THz
Laser frequency accuracy	± 1.8	GHz
Laser line-width (max)[a]	500	kHz
Laser relative intensity noise (ave)[b]	-145	dB/Hz
Laser relative intensity noise (peak)[c]	-140	dB/Hz
Optical Output Power (max)	-6	dBm
Optical Output Power (min)	-10	dBm
Transmitter reflectance (min)[d]	-20	dB
Transmitter back reflection tolerance (min)[e]	-24	dB

a). Full Width Half Maximum (FWHM) high frequency component of the Tx laser phase noise.
b). Average over 0.2GHz < f < 10GHz.
c). Peak over 0.2GHz < f < 10GHz.
d). 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.
e). Maximum light power (relative in decibel w.r.t. Tx output) reflected back to transmitter while still meeting performance requirements.

Tx Optical Specs II

Description	Value	Unit
Transmitter polarization power imbalance	1.5	dB
In-band OSNR (min) per 0.1 nm[a]	34	dB
Out-of-band OSNR (min) per 0.1 nm[b]	23	dB
Total output power with transmitter disabled (min)	-20	dBm
Total output power during channel change (min)	-20	dBm
X-Y polarization skew	5	ps
I-Q DC offset	-26	dB
Error Vector Magnitude (max)[d]	TBD	%
Optical single side band spectral excursion (max)	TBD	{[dB], [GHz]}
Optical single side band spectral threshold (min)	TBD	{[dB], [GHz]}

a). Signal power over noise power in-band, measured with 12.5 GHz noise bandwidth.
b). Signal power over peak noise power in the whole frequency range, measured with 12.5 GHz noise bandwidth.
c). Ratio of unmodulated power to total signal power.
d). Some EVM proposals but test procedure still needs to be firmed up.

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
75GHz-induced DWDM crosstalk penalty (max)	TBD	dB

a). Rx must tolerate this amount of Tx frequency offset from the nominal ITU center frequency grid.
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 black link PDL. Tolerance to peak PDL with < 1.3 dB OSNR penalty. Tested with noise injected after 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.

400GBASE-ZR black link table (Option A)

Description	Value	Unit
Minimum channel spacing	75	GHz
Maximum channel inband ripple	2.5	dB
Maximum optical path penalty OSNR	4 (3)	dB
Maximum (residual) chromatic dispersion	2000	ps/nm
Minimum (residual) chromatic dispersion	0	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	-10	dB
Maximum interferometric crosstalk at TP3	-35	dB
Nominal channel filter bandwidth (min)	73	GHz
Nominal channel filter bandwidth (max)	77	GHz
Channel filter bandwidth offset (max)	+/- 2	GHz
Channel filter order – Super Gaussian (min)	3	-rd order

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.

400GBASE-ZR black link table (Option B)

Description	Value	Unit
Minimum channel spacing	75	GHz
Maximum channel inband ripple	2.5	dB
Maximum optical path penalty OSNR	5 (3)	dB
Maximum (residual) chromatic dispersion	2000	ps/nm
Minimum (residual) chromatic dispersion	0	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	-10	dB
Maximum interferometric crosstalk at TP3	-35	dB
Nominal channel filter bandwidth (min)	70	GHz
Nominal channel filter bandwidth (max)	80	GHz
Channel filter bandwidth offset (max)	+/- 2	GHz
Channel filter order – Super Gaussian (min)	3	-rd order

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.

Summary

- We have presented some analysis and data related to multichannel 400G ZR for 75GHz grid operation.
- Crosstalk penalty needs to be allocated for 75GHz operation.
- Tx spectral operating window (spectral threshold and spectral excursion enhancement) are proposed to be added to the Tx spec table.
- Channel filter characteristics are proposed to be added into the black link table for clarity. Two options are provided for consideration.