# Impacts of 75GHz Channel Spacing for 400GBASE-ZR: Interchannel Crosstalk/Minimum Excess Bandwidth

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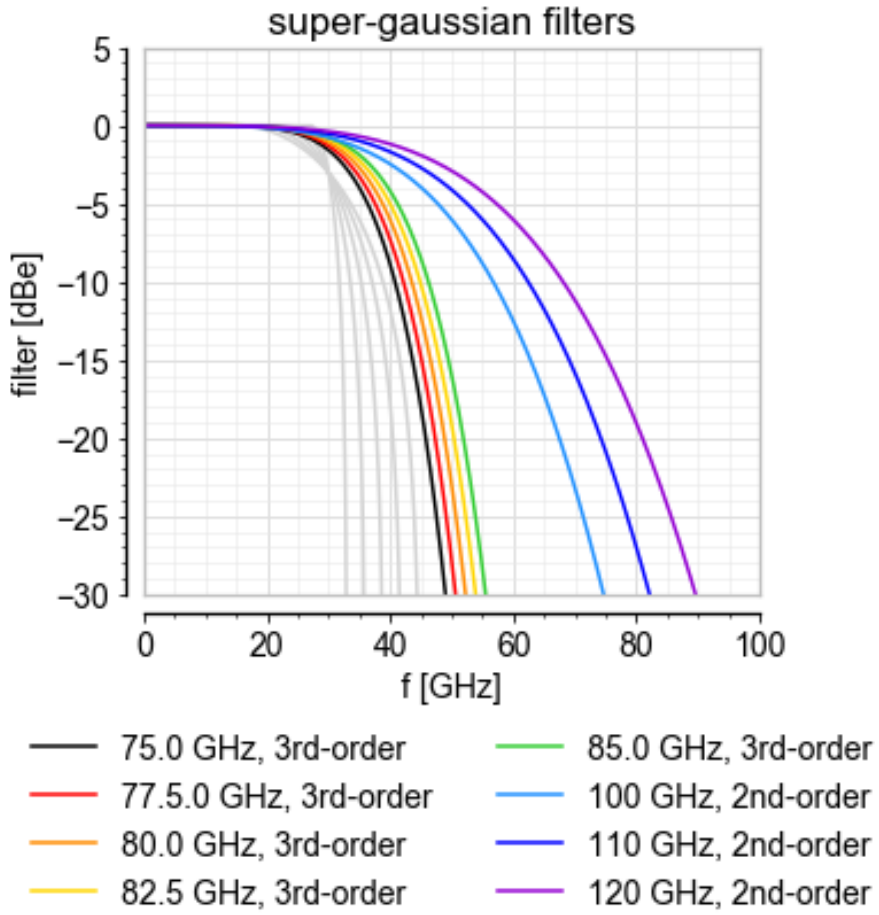
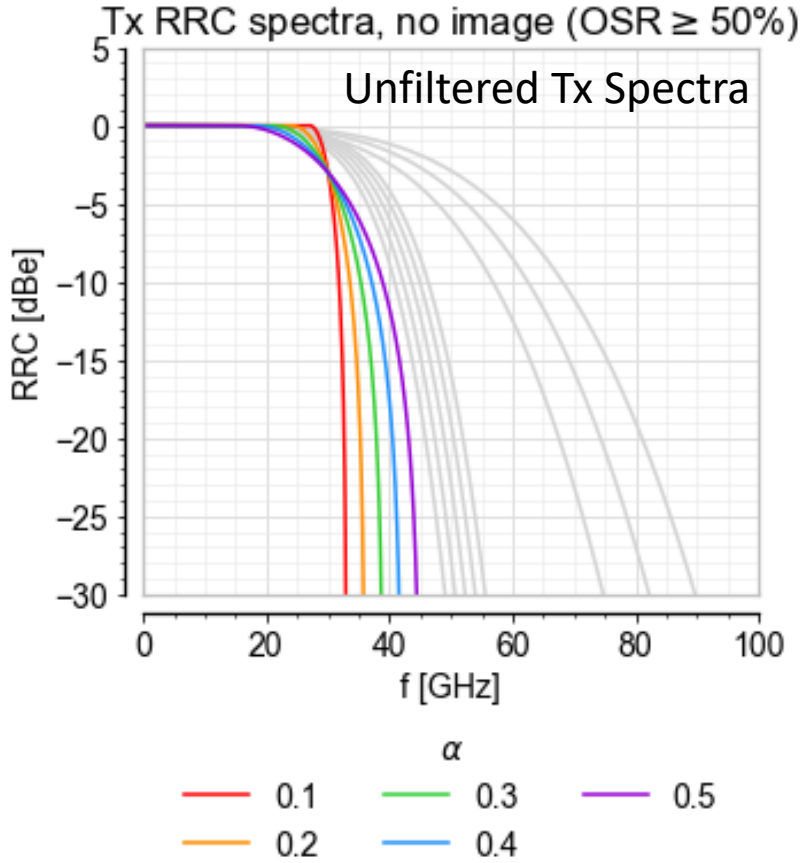
# Overview

- A simple model is applied to quantify interchannel crosstalk for 75GHz spaced 400GBASE-ZR channels
- Crosstalk and excess bandwidth are analyzed for 2$^{nd}$ and 3$^{rd}$ order super-Gaussian filters appropriate to this application
- Analysis is performed to show how this crosstalk can be modelled as an OSNR impairment

# Illustrative Toy Models: Mux/Demux Filters and Ideal RRC Tx Spectra

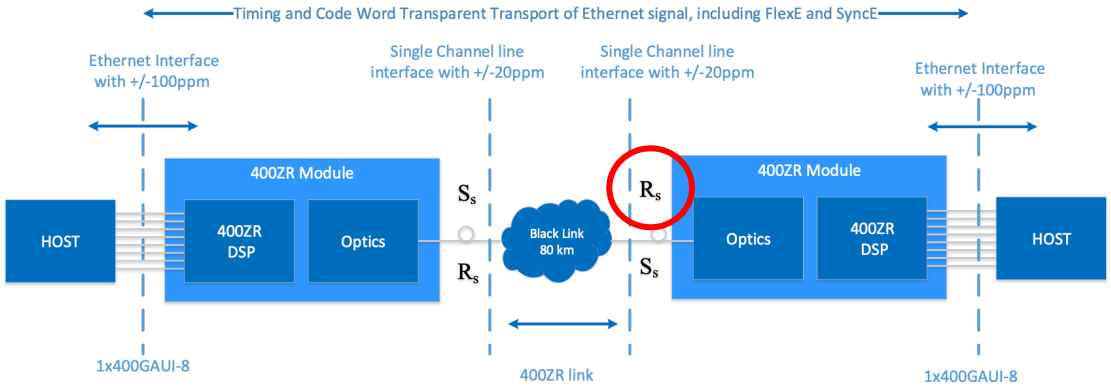


# Interchannel Crosstalk Definition in OIF 400ZR IA

$$X = 10\log_{10}\left(\frac{\int_{-f_{BW}/2}^{f_{BW}/2}\left(S_{left}(f)+S_{right}(f)\right)df}{\int_{-f_{BW}/2}^{f_{BW}/2}S_{centre}(f)df}\right)$$

- No receiver included in this crosstalk definition (at Rs)
- No need to consider non-adjacent crosstalk in a coherent system. ITU-T G.sup39 not applicable (direct detect reference)
- BW=Channel Spacing=75GHz. Integration window not explicitly defined anywhere?




From OIF published 400ZR IA:

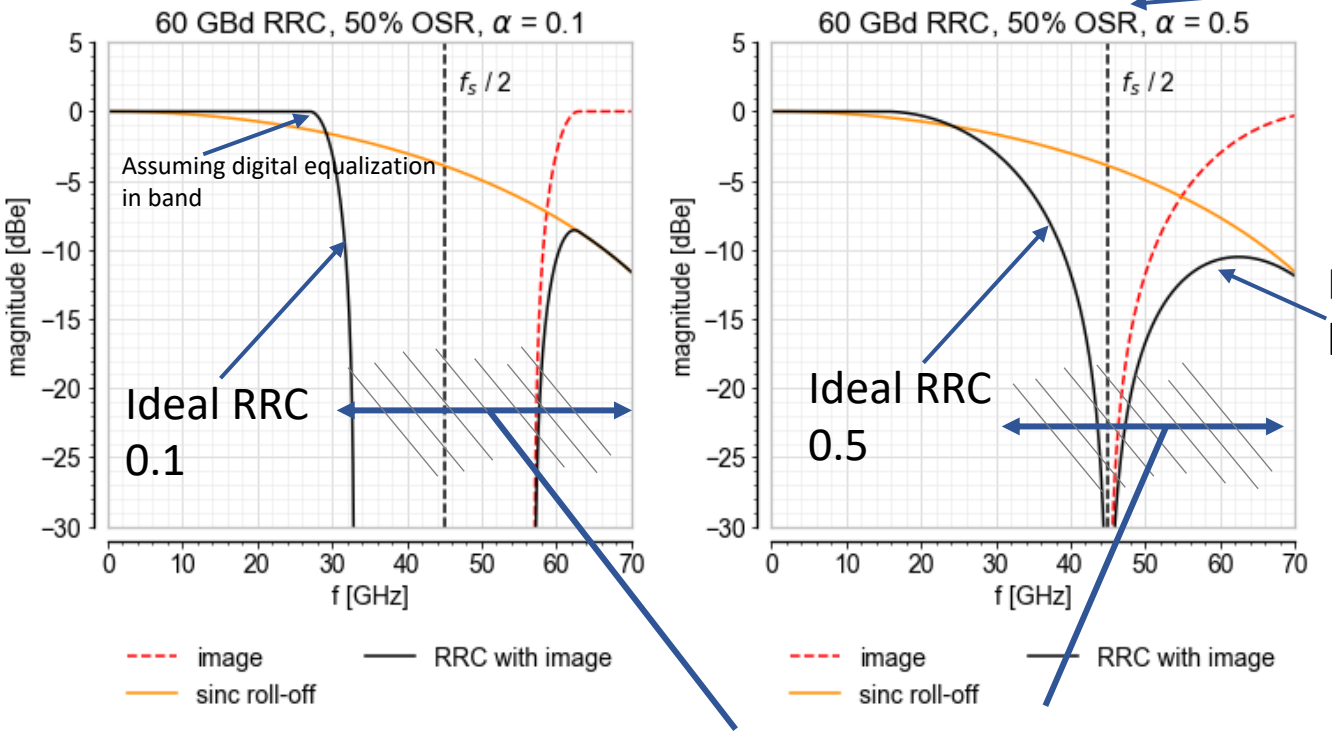
Inter-channel crosstalk is defined as the ratio of total power in all the disturbing channels to that in the wanted channel, where the wanted and disturbing channels are at different wavelengths.

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 Ss and all of the others are at the maximum mean output power, then the inter-channel crosstalk at the corresponding point Rs is less than the maximum inter-channel crosstalk value.

Ref. Clause 9.6 and Fig 9-17 in ITU-T G.sup39.

| | | | | | | |
|---|---|---|---|---|---|---|
| 13.1.180 | Inter-channel Crosstalk at $R_s$ | | | -8 | dB | (See definition 13.3.10)<br>Ref. Clause 9.6 and Fig 9-17 in ITU-T G.sup39. |

# Illustrative Tx Spectra: 1st Order Correction to an Ideal RRC– DAC Image with Non-Limiting EO Bandwidth





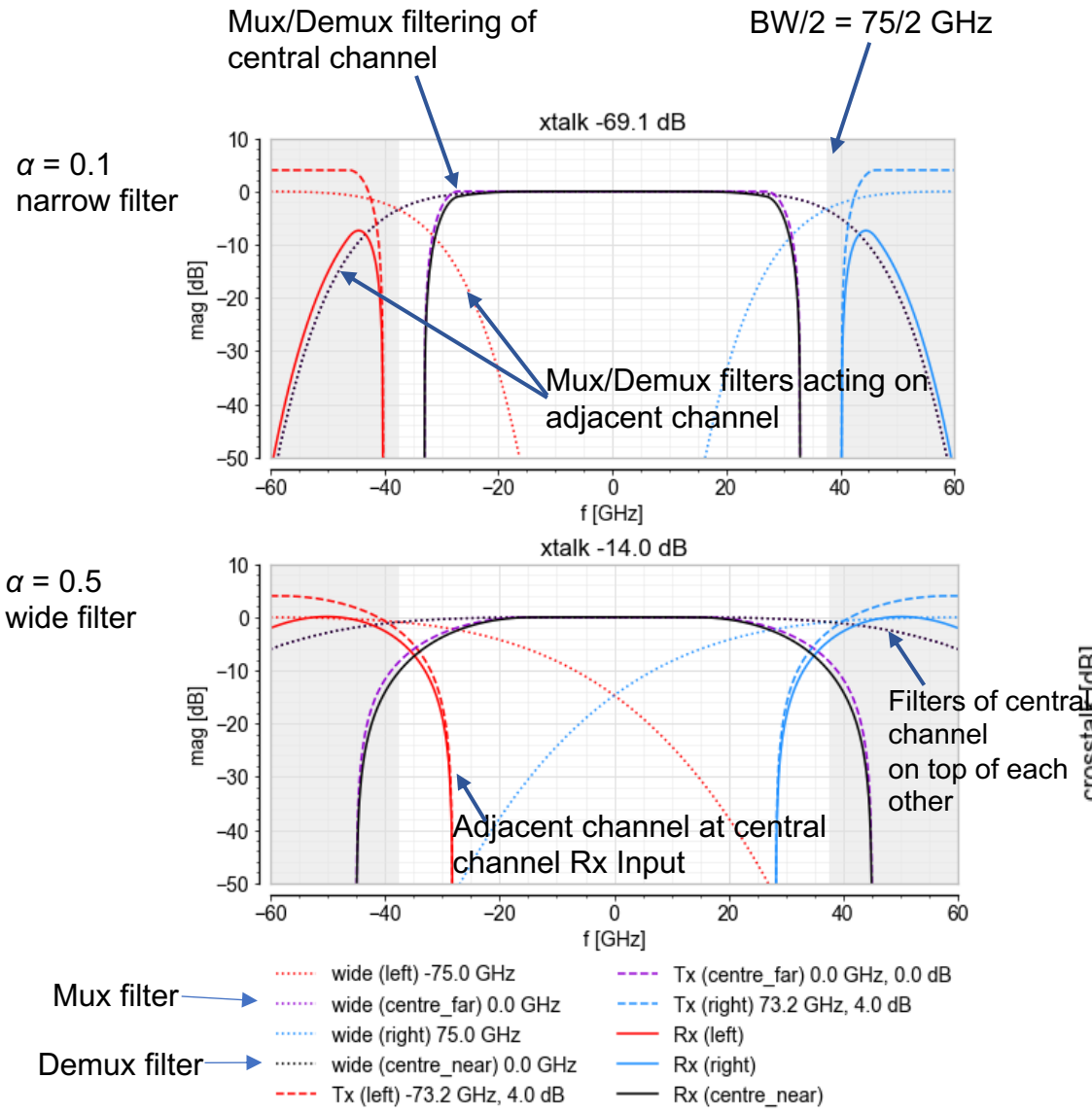


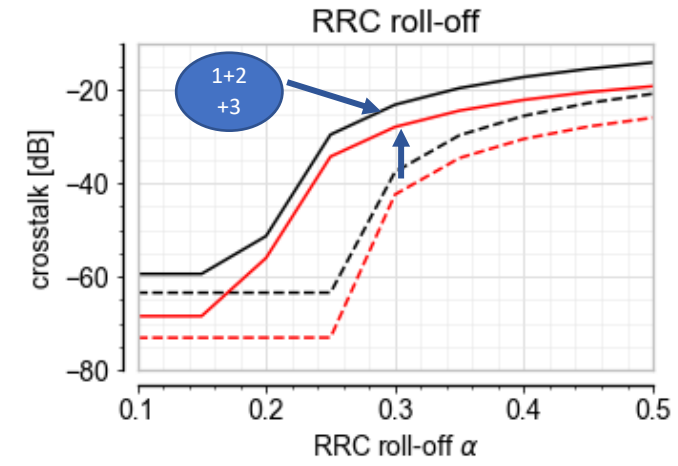
Over Sampling Ratio (OSR) is an implementation detail.
Illustration purposes only

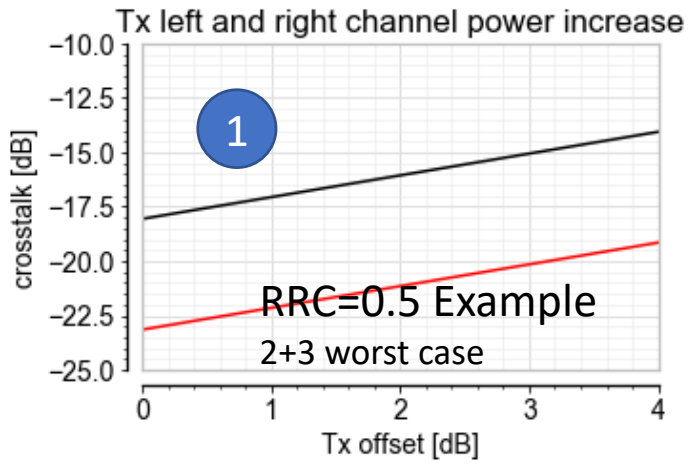
Finite BW of EO chain will attenuate the image beyond the shown DAC sinc roll-off

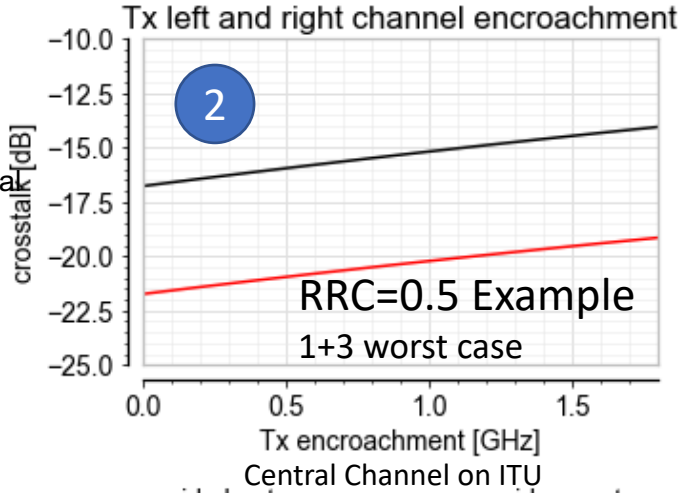
OOB integrated power metrics are required to determine the system penalty of Interchannel Crosstalk

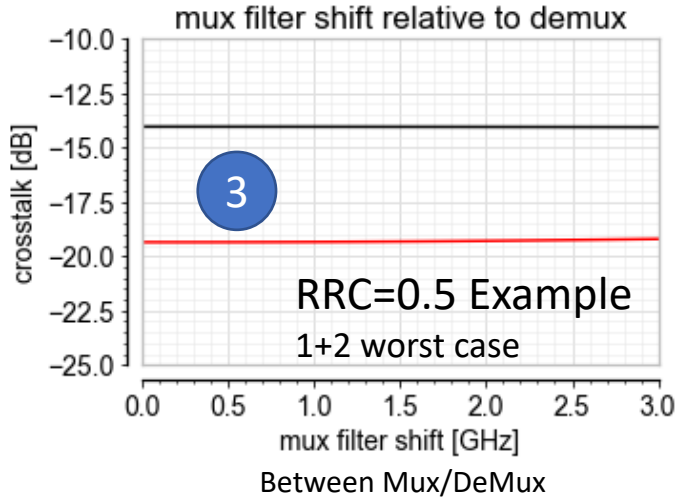
# Interchannel Crosstalk Calculation for Ideal RRC Tx Spectra (no Image)



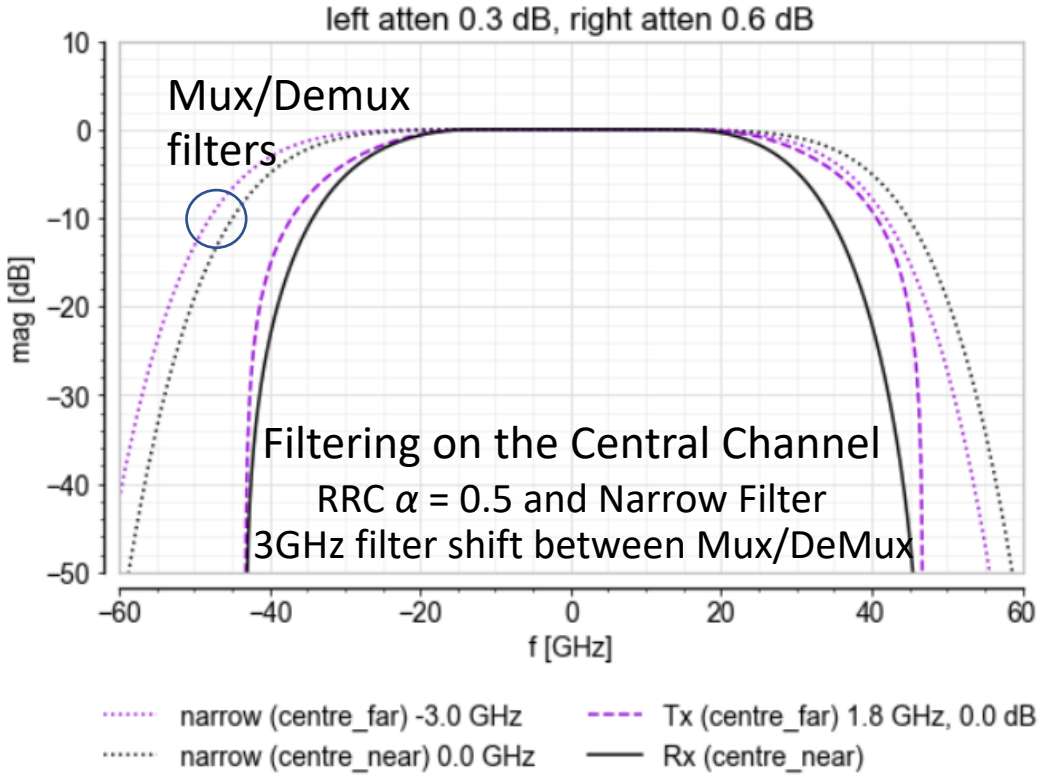



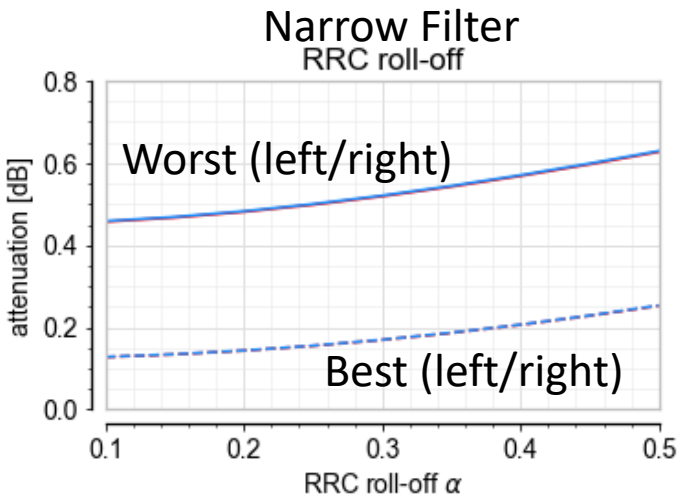



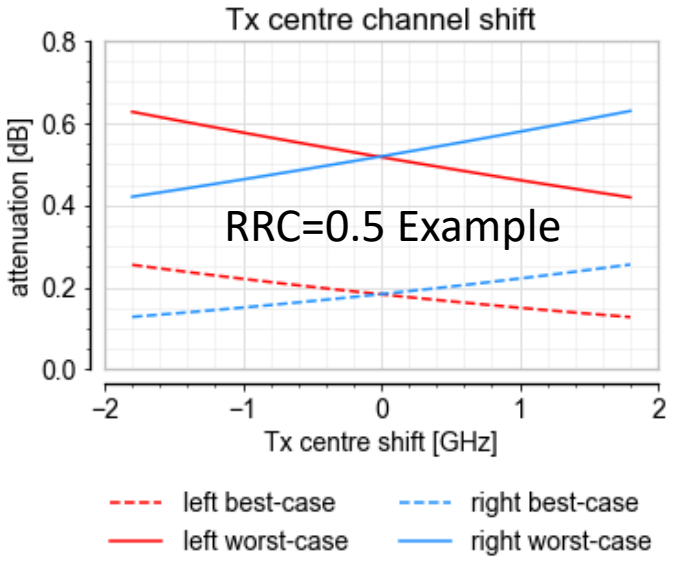
# Impact of Narrowing the Mux/Demux Filter on the Signal

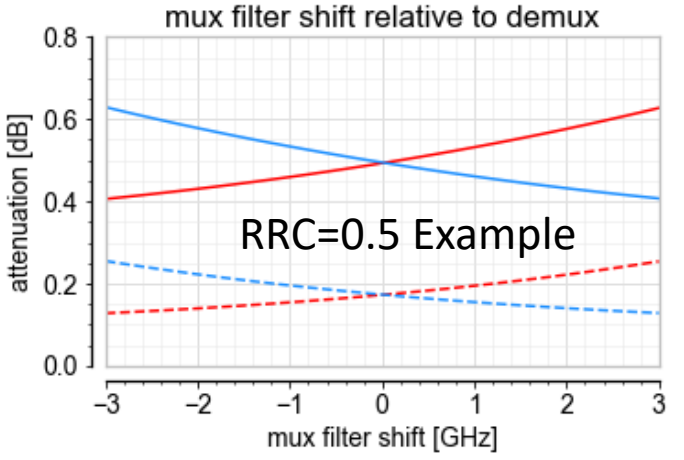
Central Channel Attenuation (dB) $= \begin{cases} 10\log_{10}\left(\frac{\int_{-\infty}^{0} S_{\mathrm{Tx,centre}}(f)\mathrm{d}f}{\int_{-\infty}^{0} S_{\mathrm{Rx,centre}}(f)\mathrm{d}f}\right) & \text{left} \\ 10\log_{10}\left(\frac{\int_{0}^{\infty} S_{\mathrm{Tx,centre}}(f)\mathrm{d}f}{\int_{0}^{\infty} S_{\mathrm{Rx,centre}}(f)\mathrm{d}f}\right) & \text{right} \end{cases}$




Filter Order > 3. Manufacturability concerns?



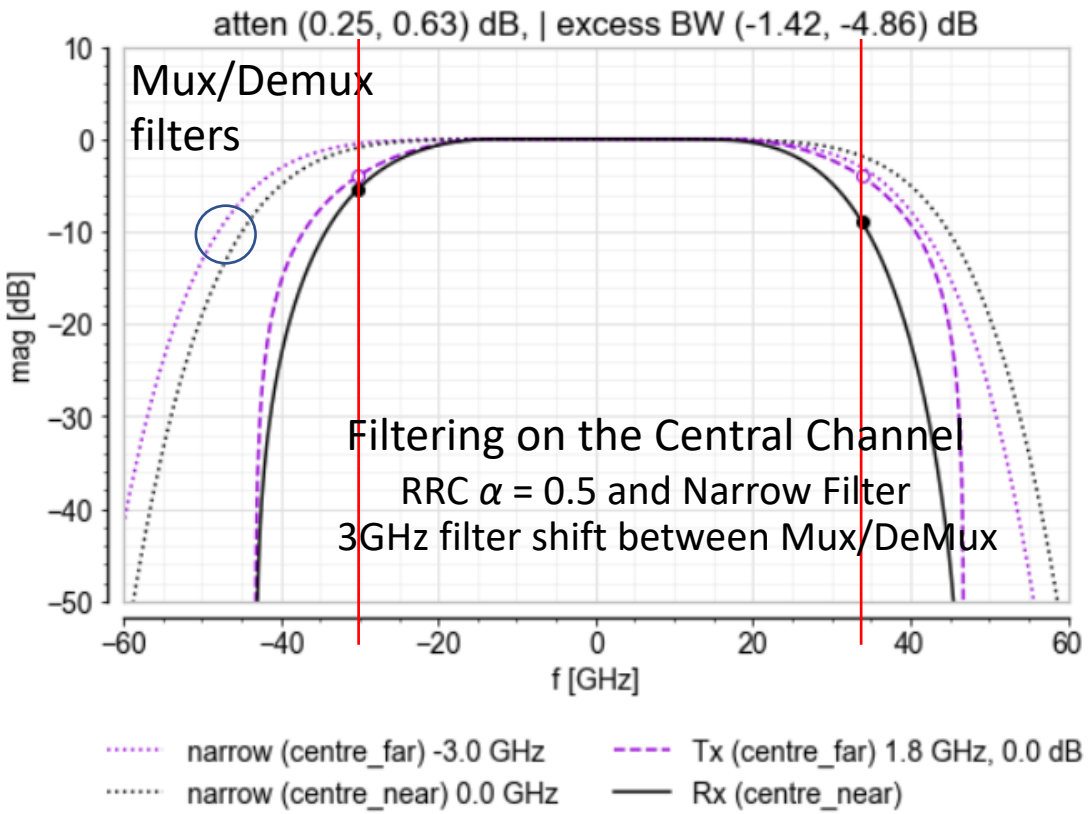




Between Mux/DeMux

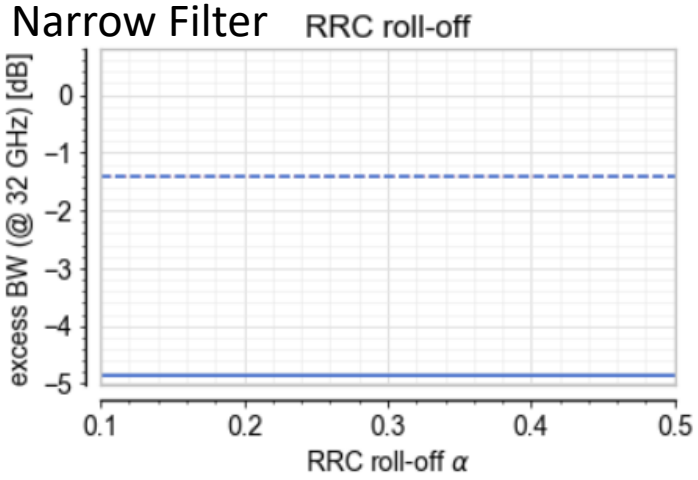
Frequency dependent attenuation of the central channel can cause some Intersymbol interference and in band noise enhancement. Requires sophisticated Receiver equalizer model (MMSE) to determine system penalty.

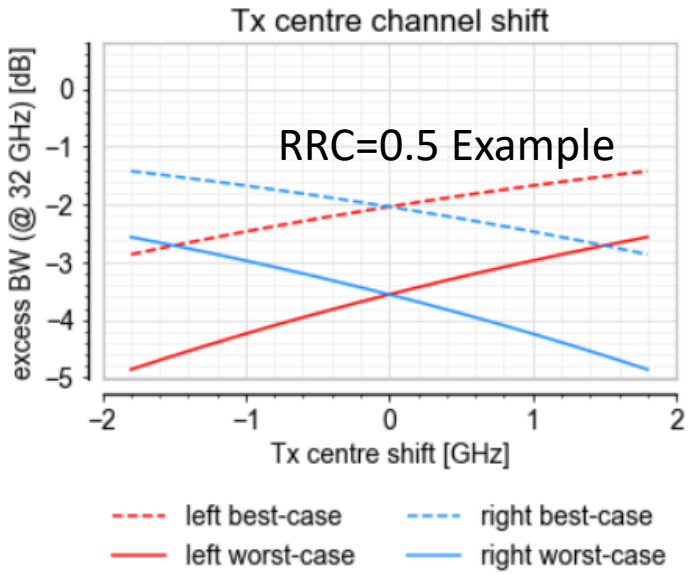
# Impact of Narrowing the Mux/Demux Filter on the Minimum Excess Bandwidth @ 32GHz

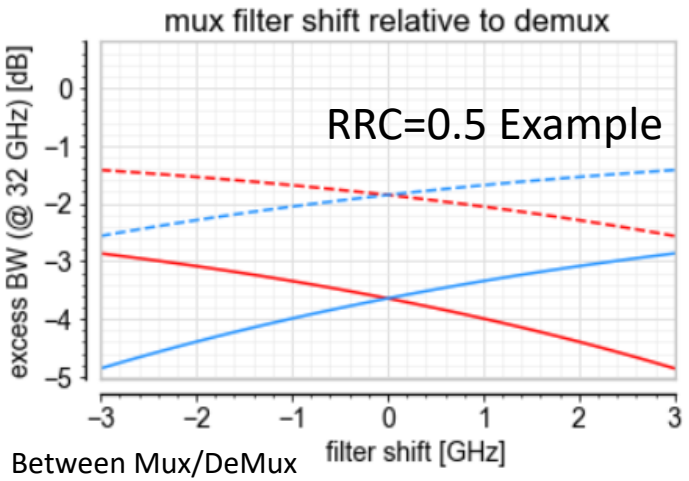



The interpolation frequencies are (-32 + 1.8 = -30.2, +32 + 1.8 = 33.8) GHz since minimum excess bandwidth is a baseband specification for clock recovery

Narrow Filter



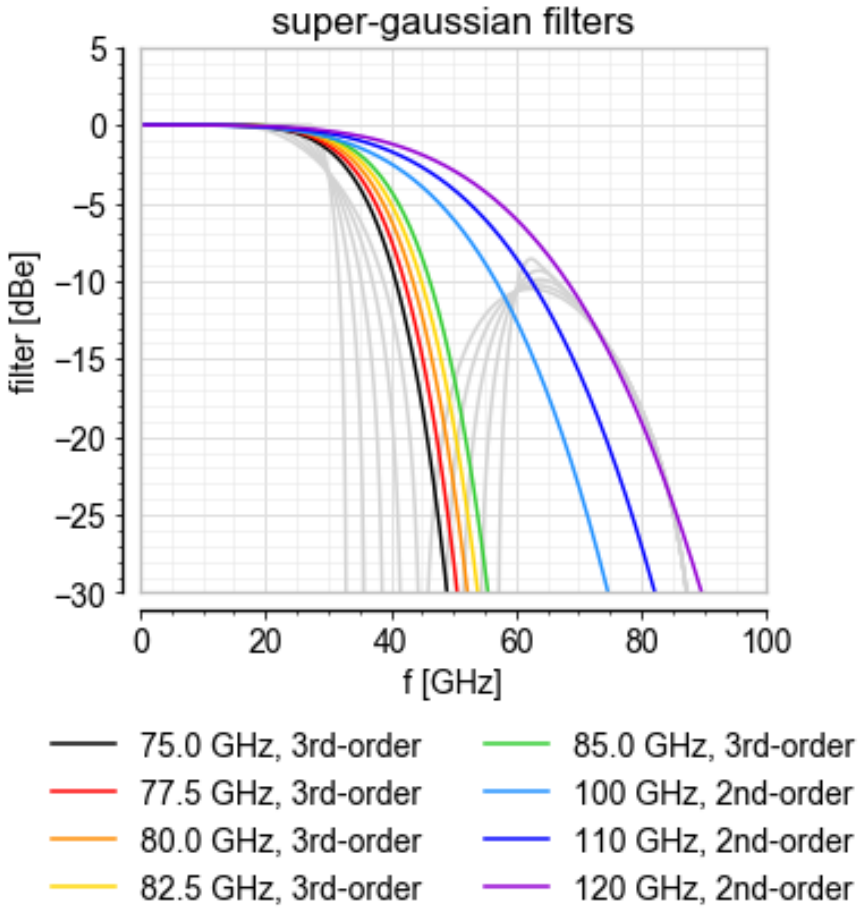



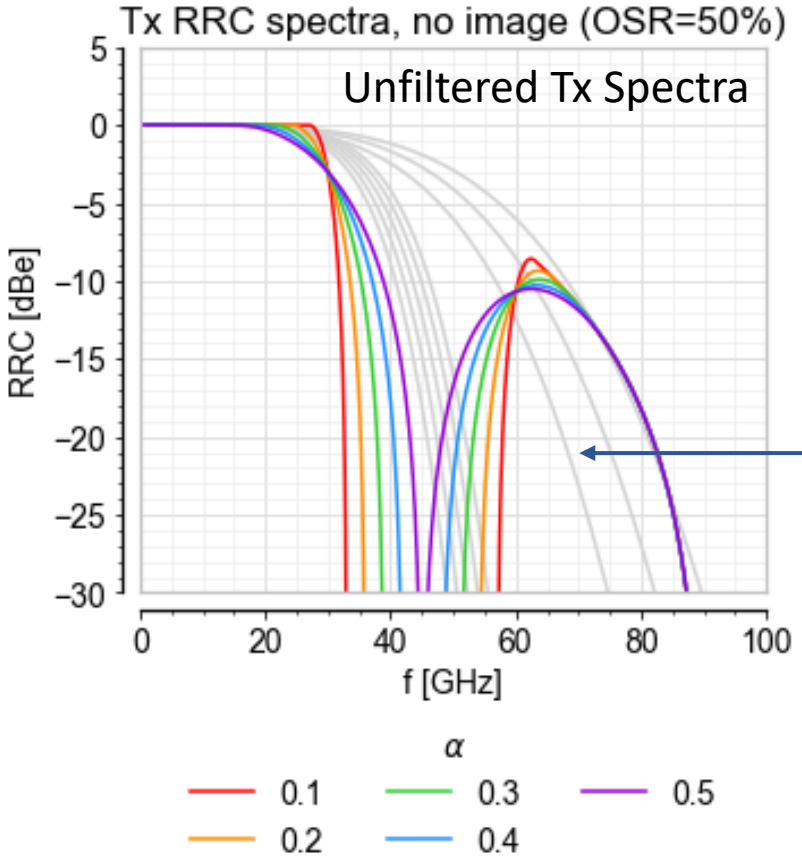

Between Mux/DeMux

Narrow filters will impact the Rx Minimum Excess BW at Rs.

For Discussion: The Rx Minimum Excess BW should account for the impact of 75GHz channel spacing and be specified explicitly at Rs.

# Illustrative Toy Models: Mux/Demux Filters and RRC Tx Spectra with DAC Image



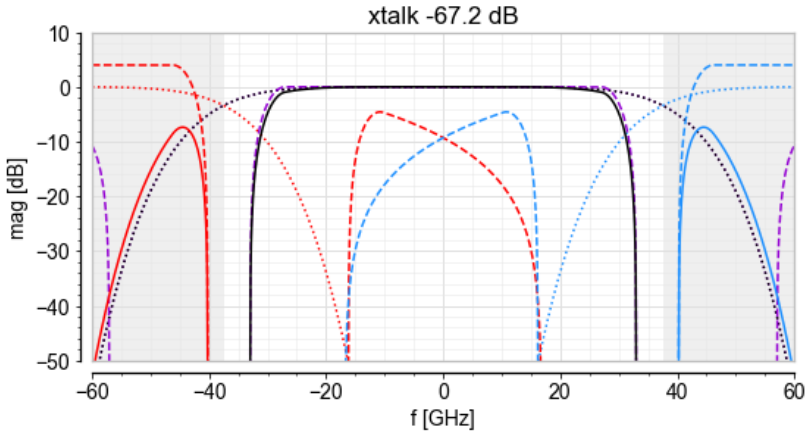




Recall Finite BW of EO chain will attenuate the image beyond the shown DAC sinc roll-off.

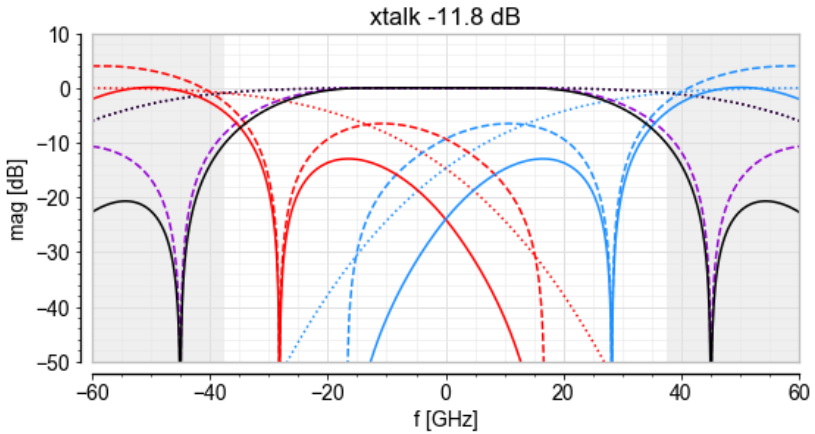
This toy model is usefully illustrative in upcoming calculations

# Interchannel Crosstalk Calculation for RRC Tx Spectra with DAC Image

$\alpha$ = 0.1
narrow filter



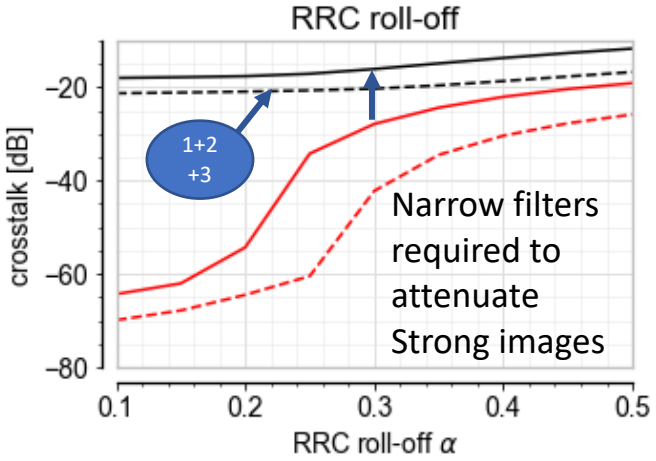

$\alpha$ = 0.5
wide filter

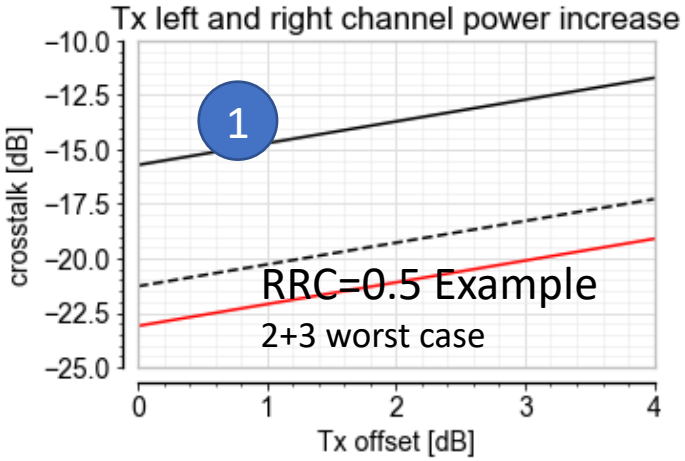


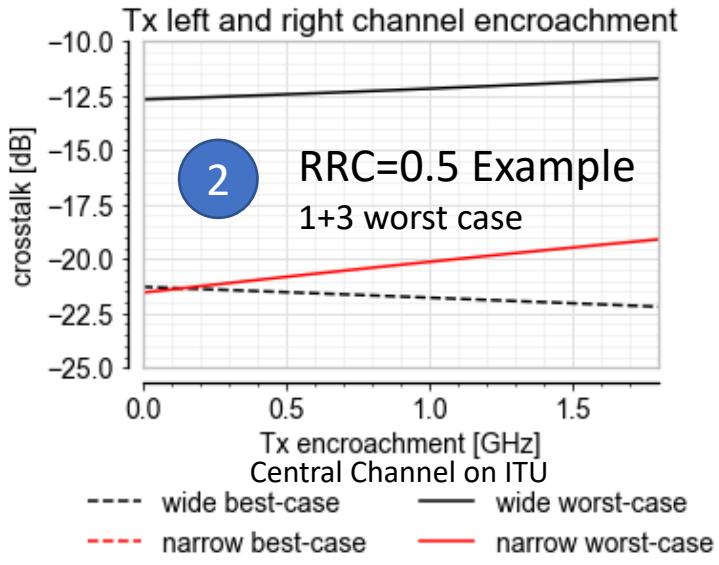

Mux filter

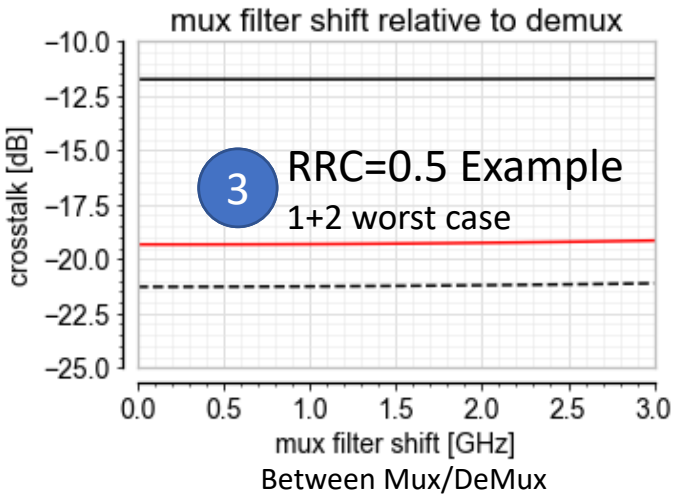
Demux filter

wide (left) -75.0 GHz
wide (centre_far) 0.0 GHz
wide (right) 75.0 GHz
wide (centre_near) 0.0 GHz
Tx (left) -73.2 GHz, 4.0 dB
Tx (centre_far) 0.0 GHz, 0.0 dB
Tx (right) 73.2 GHz, 4.0 dB
Rx (left)
Rx (right)
Rx (centre_near)



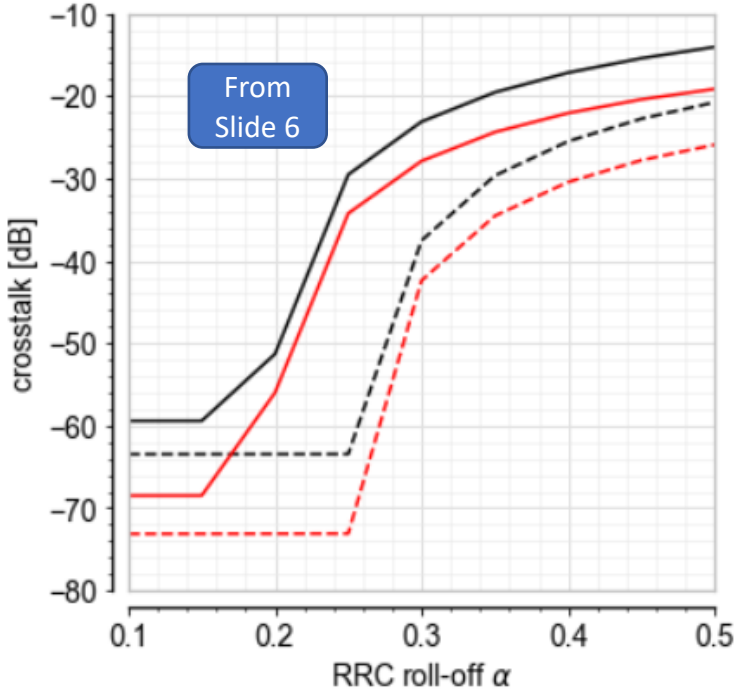



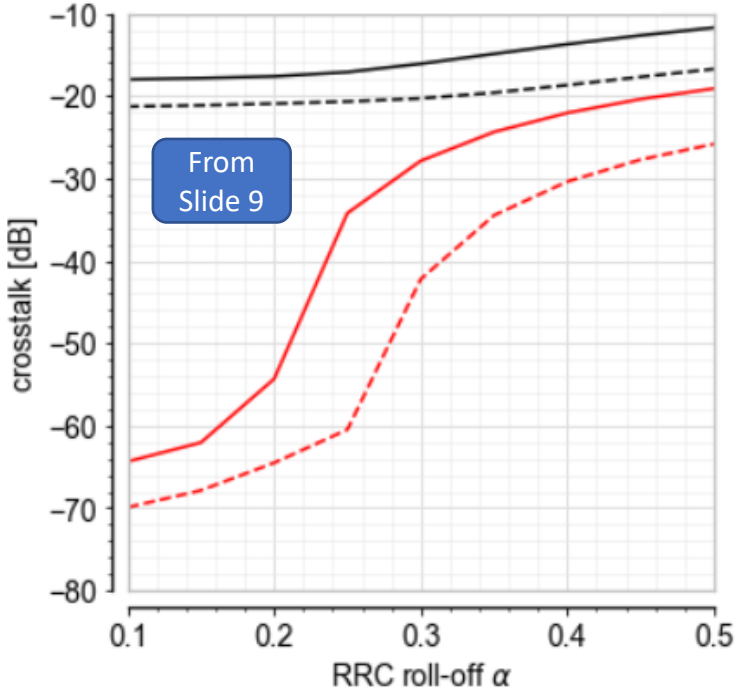
# Summary of Interchannel Crosstalk Calculations

$$X = 10\log_{10}\left(\frac{\int_{-f_{\mathrm{BW}}/2}^{f_{\mathrm{BW}}/2}\left(S_{\mathrm{left}}(f)+S_{\mathrm{right}}(f)\right)\mathrm{d}f}{\int_{-f_{\mathrm{BW}}/2}^{f_{\mathrm{BW}}/2}S_{\mathrm{centre}}(f)\mathrm{d}f}\right)$$

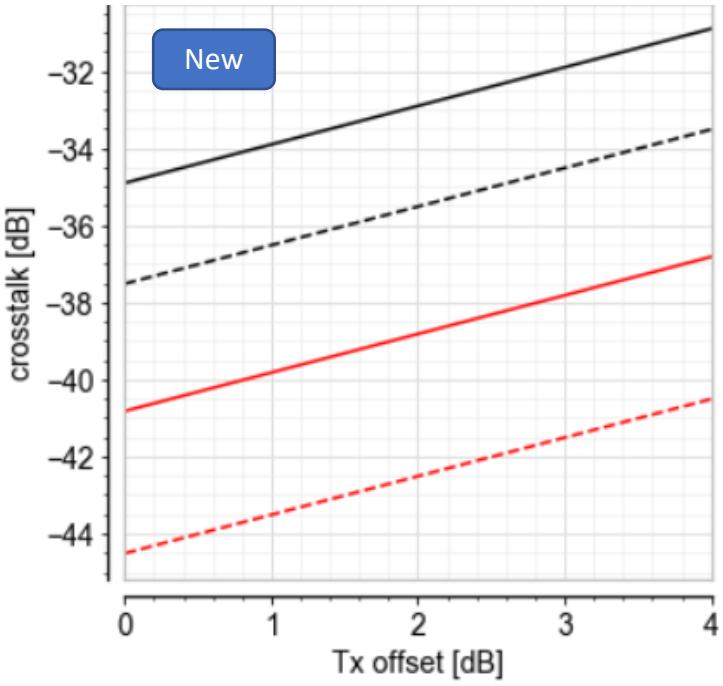
Ideal RRC

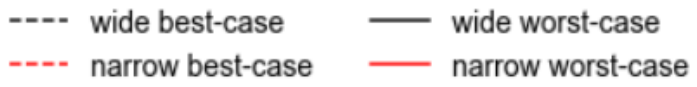



RRC with DAC Image




Realistic Tx and Filter Spectra



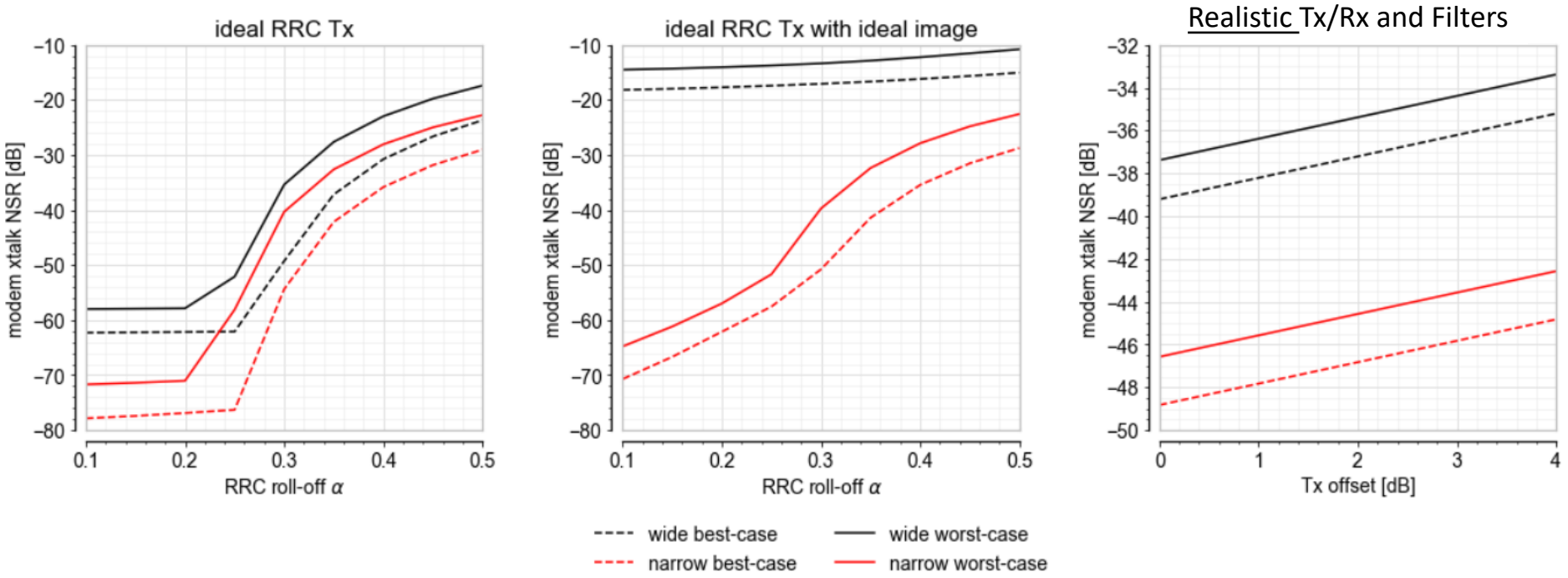



# From Interchannel Crosstalk to a System Link Budget Penalty?

- **Not Possible:** Link budget penalties cannot be defined without an Rx filter definition.
- *Modem Noise-to-Signal Ratio (NSR) Interchannel Crosstalk:* Include the Rx filter definition.
  - **Best Implementation:** Exactly the same RRC response at the Rx as present in the Tx (minimization of ISI.)
  - OIF has <u>not defined</u> the Tx spectrum as part of the IA. The best implementation is not available in multivendor interop
  - Do we define a reference Rx spectrum for a Modem NSR Interchannel Crosstalk calculation?
  - Note the existing optical *Interchannel Crosstalk* calculation is <u>not</u> a parameter in this Modem NSR Interchannel Crosstalk calculation.
  - Once the Rx filter is included in the concatenation the integration window should be extended to +/- the channel spacing

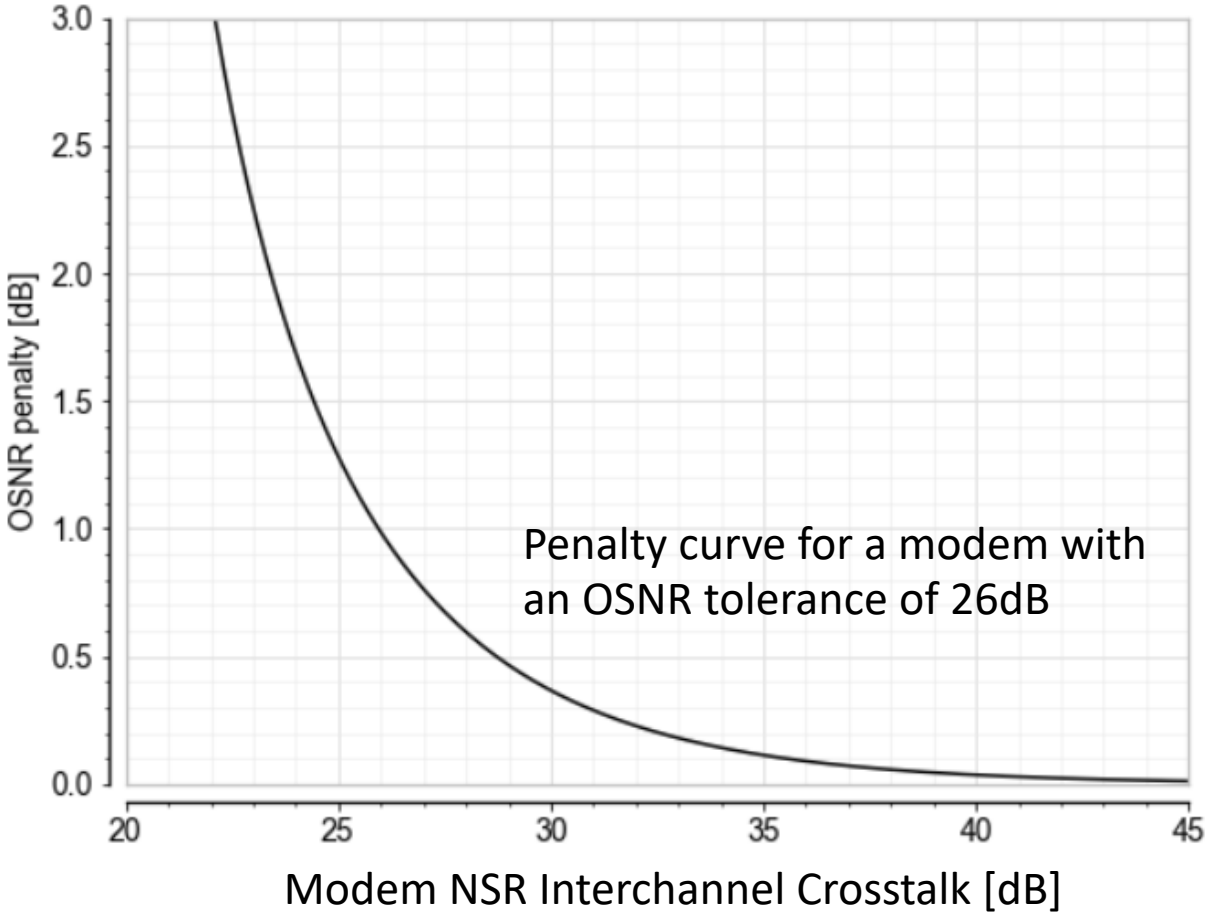
**Modem NSR Interchannel Crosstalk:** Illustrative calculations with the same RRC response at the Rx as present at the Tx

Calculations Require Spectra-**Not Min/Max Masks**

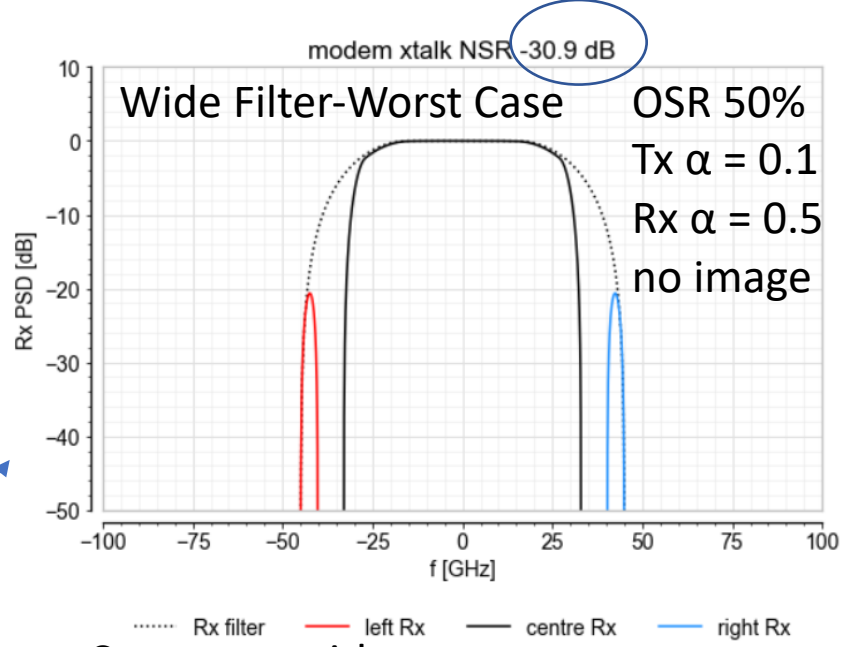


# OSNR Penalty Calculation

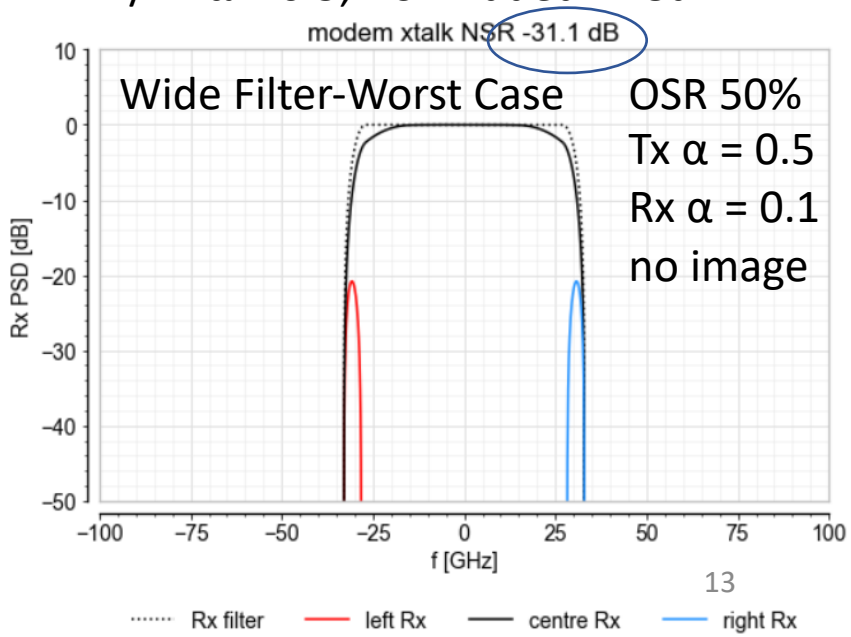
NSR Model for Modem Performance
-No clock recovery considerations, etc.




Same answer for Tx/Rx α inversion




Compares with:
Tx/Rx α = 0.1, NSR Added: -58dB
Tx/Rx α = 0.5, NSR Added: -18dB



# Conclusions

- The practical application of the current definition of Interchannel Crosstalk is unclear.
- A modem NSR Interchannel Crosstalk calculation can be mapped to a system penalty; however it requires the definition of a receiver.
- Tx/Rx spectra with RRC $\alpha \lesssim 0.3$ and realistic Tx/Rx spectra can produce negligible Interchannel Crosstalk penalty across a wide variety of Mux/Demux filter designs at 75GHz channel spacing:
  - It is not a given that a significant penalty should be assigned to Interchannel Crosstalk.
  - It is not a given that a narrow 3rd order Super-Gaussian Mux/Demux filter is required to have negligible 400ZR Interchannel Crosstalk system penalty.
- The OIF 400ZR IA minimum excess bandwidth specification currently assumes the impact of the line is negligible. This assumption is valid for 100GHz channel spacing; however, this may not be true at 75GHz channel spacing if higher order Super-Gaussian filters are considered.
  - We propose that we explicitly define the minimum excess bandwidth at Rs and that we explore adopting a minimum requirement reduced relative to the published OIF IA.