400GBASE-ZR Specification framework for 75G spacing

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Outline

- Specification framework for 75G spacing

Key Aspects of the Proposal

Optimal Eq SNR metric	• A rigorous metric that is backed by digital communication theory accounts for arbitrary signal and noise/crosstalk spectral shapes
Link Compliance Mask	• Defines the transfer function requirements for the optical mux and demux components
TX Center Ch Test	• Calculates a figure of merit which ensures a compliant TX spectrum will produce better receiver SNR than the RX compliance test setup
TX Crosstalk Test	• Calculates a figure of merit which ensures a compliant TX does not cause more crosstalk than the RX compliance setup
RX Compliance Test	• Defines a worst case setup specifying the minimum performance required from a compliant receiver

Optimal Eq SNR Metric

- Metric based on rigorous mathematical theory of the relationship between arbitrary signal spectrum, noise/crosstalk spectra and linear equalization
- Introduced in https://www.ieee802.org/3/ct/public/20_09/kota_3cw_01_200921.pdf and demonstrated good match between theory and simulation
- Easy to calculate from a measured signal spectrum
- Provides a way to calculate an upper bound on performance of unknown receiver implementations
- Also provides a way to calculate a lower bound on required receiver performance (using a suboptimal reference receiver structure) and therefore useful for deriving specifications

Channel Compliance Mask

- Defines requirements on the optical mux/demux used in a 400ZR link
  - Upper and lower mask provides allowable range for 3dB bandwidth and rolloff
  - Specification on maximum allowed variation of center frequency
- Defined to be independent of the transmitter and receiver implementations
- Compliance mask is derived from supergaussian filter shapes

TX Center Channel Test

- Derives a figure of merit on the entire transmit spectrum of the device under test
- This test ensures that a compliant transmitter will provide a minimum performance level at the receiver and robustness to crosstalk
- Input to the calculation is a capture of the signal spectrum of the transmitter under test using an OSA (optical spectral analyzer)
- Calculates the SNR after equalization guaranteed under worst case crosstalk and channel conditions at a reference receiver

TX Crosstalk Channel Test

- Derives a figure of merit on the entire transmit spectrum of device under test
- This test ensures that the crosstalk introduced by a compliant transmitter will be less than assumed by the receiver compliance test
- Input to the calculation is a capture of the signal spectrum of the transmitter under test using an OSA

Receiver Compliance Test

- Defines a worst case reference setup for receiver compliance
- Setup ensures worst case SNR and crosstalk conditions
- Requirement on receiver to operate in reference setup with specified margin

Details of the proposal

EqSnrMax: Definition

- Inputs:
  - Signal spectrum: $S_x(f)$ where f is the frequency and $S_x(f)$ is a power spectral density in linear units (for e.g. W/Hz or equivalent)
  - Noise/Crosstalk spectrum: $S_n(f)$ is a power spectral density in linear units
  - Symbol rate: F_{sym} ; The Symbol period is T_{sym}
- Output: "EqSnrMax" which represents the SNR obtained by an optimal linear equalizer for an optimal receiver structure

$$SNR(f) \triangleq \frac{S_x(f)}{S_n(f)}$$

$$SNR\_f(e^{j\omega T}) \triangleq \sum_l SNR\left(j\left(w - \frac{2\pi l}{T_{sym}}\right)\right)$$

$\langle \quad \rangle_H$ *is harmonic mean over* $[-\pi, \pi]$

$$\text{EqSnrMax} = \left\langle 1 + SNR\_f\left(e^{j\omega T}\right)\right\rangle_H$$

EqSnrMin: Definition

- Inputs:
  - Signal spectrum: $S_x(f)$ where f is the frequency and $S_x(f)$ is a power spectral density in linear units (for e.g. W/Hz or equivalent)
  - Noise/Crosstalk spectrum: $S_n(f)$ is a power spectral density in linear units
  - Reference Receiver suboptimal frontend: $H_{rx}(f)$ to be specified by members of the task force
  - Symbol rate: F_{sym} ; The Symbol period is T_{sym}
- Output: "EqSnrMin" which represents the SNR obtained by an optimal equalizer for a reference suboptimal receiver structure based on symbol-rate sampling

$$S_{x}\_f\left(e^{j\omega T}\right) \triangleq \sum_{l} S_x\left(j\left(w-\frac{2\pi l}{T_{sym}}\right)\right)\left|H_{rx}\left(j\left(w-\frac{2\pi l}{T_{sym}}\right)\right)\right|^2$$

$$S_{n}\_f\left(e^{j\omega T}\right) \triangleq \sum_{l} S_n\left(j\left(w-\frac{2\pi l}{T_{sym}}\right)\right)\left|H_{rx}\left(j\left(w-\frac{2\pi l}{T_{sym}}\right)\right)\right|^2$$

$$SNR\_f\left(e^{j\omega T}\right) \triangleq \frac{S_{x}\_f\left(e^{j\omega T}\right)}{S_{n}\_f\left(e^{j\omega T}\right)}$$

$\langle\quad\rangle_H$ *is harmonic mean over* $[-\pi,\pi]$

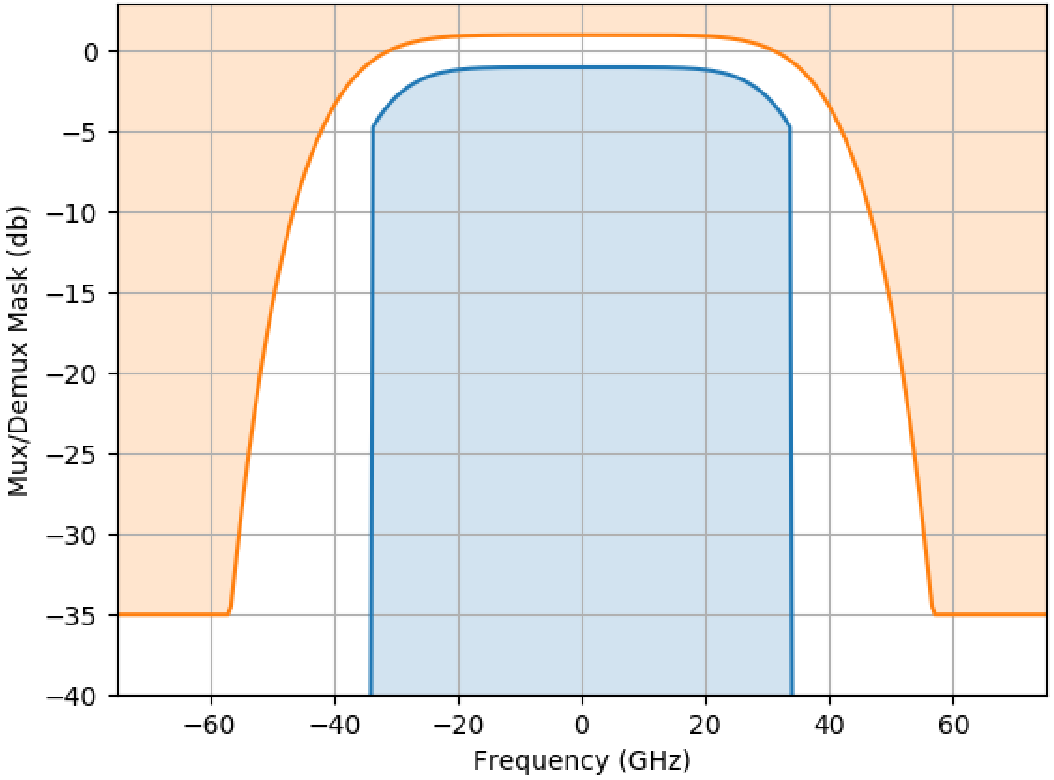
$$\text{EqSnrMin} = \left\langle 1 + SNR\_f\left(e^{j\omega T}\right)\right\rangle_H$$

Operating Margin: Definition

- Margin in dB is the difference between the SNR achieved after equalization and the minimum required SNR at the FEC decoder input
- FEC threshold SNR for CFEC is 13.6db
- Operating Margin = 10*log10(EqSNRMin) – 13.6

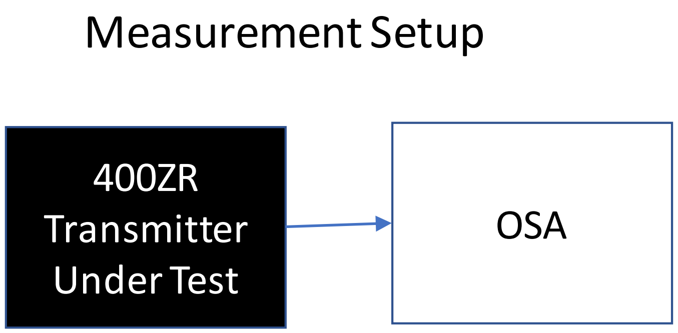
400ZR Link Compliance Mask

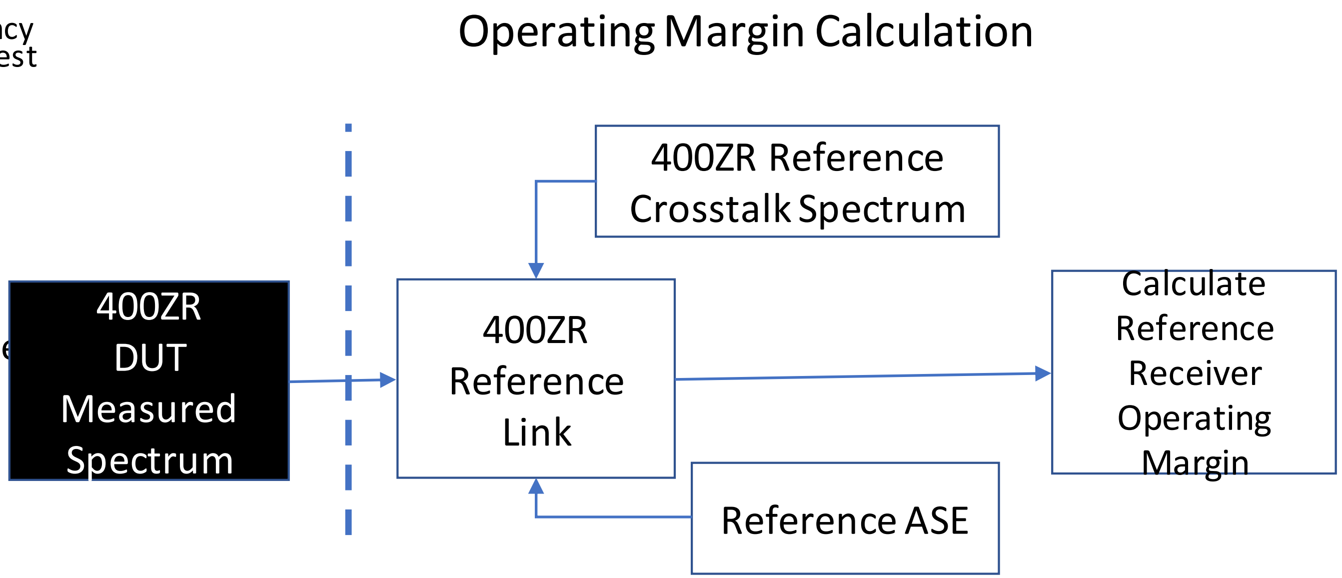
- Define an allowed compliance transmission mask for each channel
  - Use super-gaussian responses to select allowable range of links
- Define a reference link based on super-gaussian responses for TX and RX compliance tests
  - Nominal center frequency (ITU grid with 75G spacing or 0.6nm spacing)
  - Minimum order (for eg.. 3rd order)
  - Range of allowable 3db bandwidth (for e.g. 70G±4GHz)
  - Allowed variability of center frequency (for e.g. [-4,4]GHz)



400ZR TX Center Channel Compliance Test

- Measurement Setup: Transmitter under test connected to an optical spectrum analyzer (OSA) to capture the signal spectrum vs frequency
- Operating Margin Calculation:
  - Signal spectrum filtered with a reference optical mux and demux (3^{rd} order Supergaussian with 3db bandwidth of 74GHz) centered on channel under test
  - Crosstalk spectrum generated as a RRC with power 4db higher than transmitter under test
  - Crosstalk channels centered at 75GHz-1.8GHz (i.e. worst case laser offset) to the left and right of channel under test
  - Crosstalk channels filtered with reference mux for left and right channels (3^{rd} order Supergaussian with 70GHz+4GHz i.e max bandwidth variation) centered 75GHz-4GHz (i.e. max frequency variation of mux center frequency) closer to channel under test
  - Reference ASE 26db OSNR (flat spectrum vs frequency)
  - Reference demux (3^{rd} order supergaussian 70GHz+4GHz centered on channel under test)
  - Calculate EqSnrMin
  - Calculate Operating Margin
- Specification: Operating Margin > TBD (needs to exceed operating margin of reference setup used for RX compliance test)

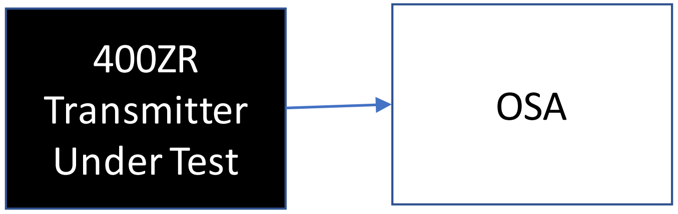




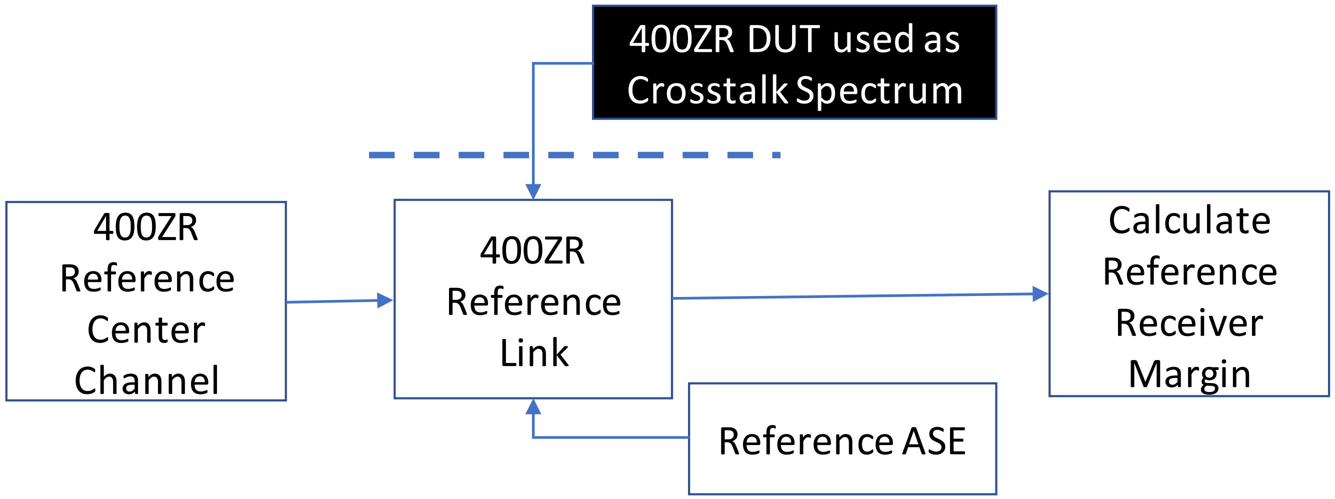
400ZR TX Crosstalk Channel Compliance Test

- Measurement Setup: Transmitter under test connected to an optical spectrum analyzer (OSA) to capture the signal spectrum vs frequency
- Operating Margin Calculation:
    - Reference transmitter used as center channel (RRC with power 4db below transmitter under test)
    - Center channel filtered with a reference optical mux and demux (3rd order Supergaussian with 3db bandwidth of 74GHz) centered on channel under test
    - Crosstalk spectrum from transmitter under test
    - Crosstalk channels centered at 75GHz-1.8GHz (i.e. worst case laser offset) to the left and right of channel under test
    - Crosstalk channels filtered with reference mux for left and right channels (3rd order Supergaussian with 70GHz+4GHz i.e max bandwidth variation) centered 75GHz-4GHz (i.e. max frequency variation of mux center frequency) closer to channel under test
    - Reference ASE 26db OSNR (flat spectrum vs frequency)
    - Reference demux (3rd order supergaussian 70GHz+4GHz centered on channel under test)
    - Calculate EqSnrMin
    - Calculate Operating Margin
- Specification: Operating Margin > TBD (needs to exceed operating margin of reference setup used for RX compliance test)

Measurement Setup



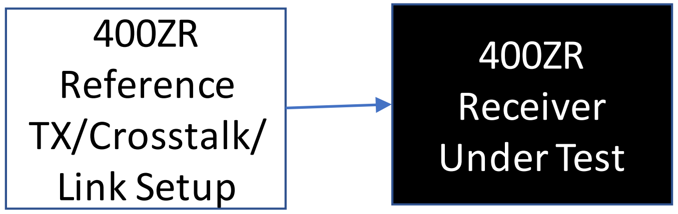
Receiver Margin Calculation



400ZR RX Compliance Test

- 400ZR Reference setup
  - Center channel using reference RRC spectrum at lowest allowed power
  - Crosstalk channels using RRC spectrum at highest allowed power with worst case laser offsets
  - Worst case setup for mux/demux bandwidths, frequency offset
  - Reference ASE
- RX under test needs to operate with positive Q-margin in reference setup

Measurement Setup



400ZR Reference Setup