# Coherent 100G and 400G PMD Layer WDM Considerations

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- PMD layer Add/Drop MUX Filter Technology
- 100/400G Nyquist Pulse shaping
- Amplified versus un-amplified links and reach
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# Objectives (Focus on DWDM)

- *50 Gb/s Ethernet*
- **Support a MAC data rate of 50 Gb/s***
- **Support a BER of better than or equal to 10^-12 at the MAC/PLS service interface (or the frame loss ratio equivalent) for 50 Gb/s***
- **Provide a physical layer specification which supports 50 Gb/s operation over at least 40 km of SMF***

- *100 Gb/s Ethernet*
- **Support a MAC data rate of 100 Gb/s ****
- **Support a BER of better than or equal to 10^-12 at the MAC/PLS service interface (or the frame loss ratio equivalent) for 100 Gb/s ****
- **Provide a physical layer specification supporting 100 Gb/s operation on a single wavelength capable of at least 80 km over a DWDM system. ****

- *200 Gb/s Ethernet*
- **Support a MAC data rate of 200 Gb/s ****
- **Support a BER of better than or equal to 10^-13 at the MAC/PLS service interface (or the frame loss ratio equivalent) for 200 Gb/s ****
- **Provide a physical layer specification supporting 200 Gb/s operation over four wavelengths capable of at least 40 km of SMF****

- **400 Gb/s Ethernet**
- **Support a MAC data rate of 400 Gb/s *****
- **Support a BER of better than or equal to 10^-13 at the MAC/PLS service interface (or the frame loss ratio equivalent) for 400 Gb/s *****
- **Provide a physical layer specification supporting 400 Gb/s operation over eight wavelengths capable of at least 40 km of SMF*****
- **Provide a physical layer specification supporting 400 Gb/s operation on a single wavelength capable of at least 80 km over a DWDM system. *****

# PMD layer Add/Drop MUX technology

- **Mux- De-Mux Technology**
  - Thin-film filters (TFFs)
  - Arrayed-waveguide gratings (AWG)
    - Thermal (use heaters to stabilize)
    - Athermal
    - Flat Top Filter shape
    - Gaussian Filter shape (lower loss)
  - Wavelength Selective Switch/Filters, programmable (WSS/F)
    - LCOS (Liquid Crystal on Silicon, reflective)
    - LC (Liquid Crystal, transmissive)
    - MEMS (Micro-Electro-Mechanical Systems)

# Add/Drop MUX Filter Shapes

- ## Flat Top AWG Filters
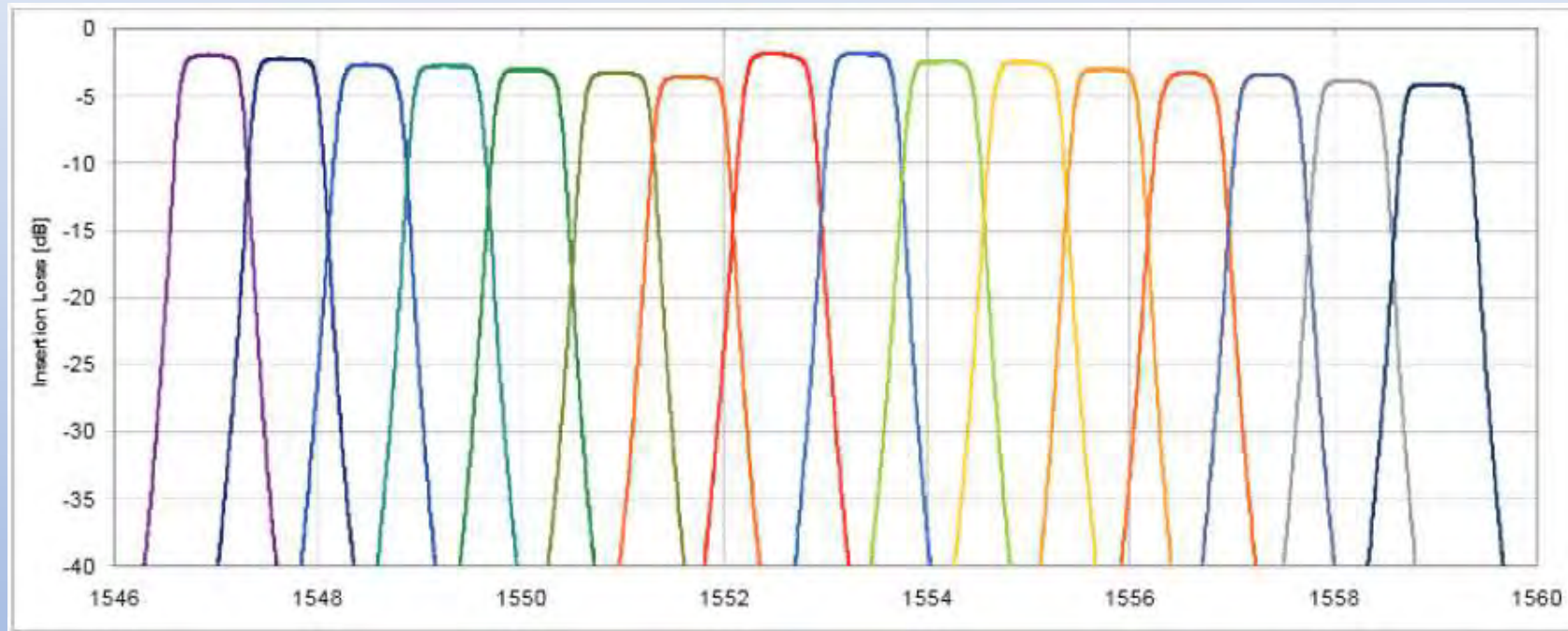  - ### These have slightly higher insertion loss versus Gaussian type



Figure 1, Typical Flat-top Filter

# Add/Drop MUX Filter Specs

- ITU(International Telecom Union) reference

- Filter center is specified per the ITU grid

- Passband, FWHM, from ITU center

- Passband may shift due to temperature or aging

- Passband minimum BW should be specified to guarantee transmitter compliance with any laser drift/offset over temperature and life
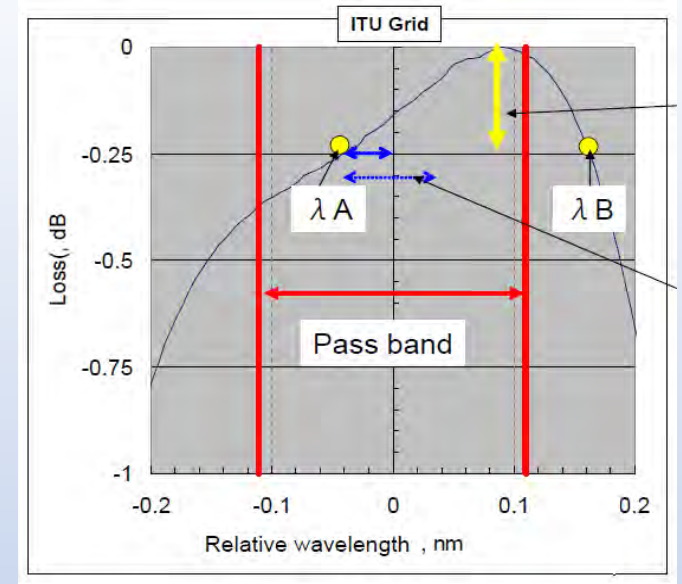


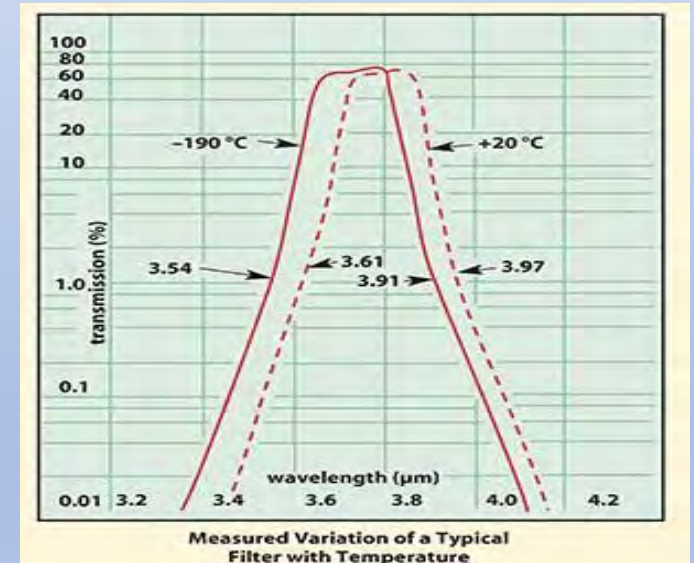Figure 2, Filter shift, temperature



Figure 3, Filter shift, temperature

# Multiple Vendor Add/Drop MUX  Specs

- 5 Vendors
- 100GHz Filters, 40 channels
- Channels available up to 48 @ 100 GHz
- Includes connectors (2x)

| Vendor | Typ Insertion Loss, dB | Max Insertion loss, dB | Uniformity dB | Passband Ripple, dB | Adjacent isolation, dB | PDL, dB | Passband BW, nm | Full BW 0.5 db (GHZ) | Full BW - 1 db (GHZ) |
|--------|------------------------|------------------------|---------------|---------------------|------------------------|---------|-----------------|----------------------|----------------------|
| A      | 3.5                    | 4.2                    | 2.0           | 0.5                 |                        | 0.25    | 0.22            | 27.0                 |                      |
| B      | 4.5                    | 5.5                    | 1.0           | 0.5                 | 23 /20                 | 0.50    | 0.40            | 50.0                 |                      |
| C-gaus |                        | 4.25                   | 1.0           | 1.5                 | 27.0                   | 0.50    | 0.20            |                      | 25.0                 |
| C-flat |                        | 5.5                    | 1.0           | 0.5                 | 27.0                   | 0.40    | 0.40            |                      | 50.0                 |
| D      |                        | 5.5                    | 1.0           | 0.5                 | 27.0                   | 0.50    | 0.25            | 31.0                 |                      |
| E      | 4.5                    | 6.5                    | 1.5           |                     | 20/ 17                 | 0.70    | 0.22            | 27.0                 |                      |

# 100G QPSK Coherent Transmitter

- Considering 7% FEC, the symbol rate selected as 28GBd

- Nyquist Filtering versus Bandwidth and roll-off for ideal transmitter(Full BW):

| QPSK | 0.2 roll-off | 0.5 roll-off | 1.0 roll-off |
|---|---|---|---|
| 0.5 dB BW | 24.0 GHz | 18.8 GHz | 11.8 GHz |
| 3 dB BW | 26.4 GHz | 24.0 GHz | 20.2 GHz |
| 20 dB BW | 32.4 GHz | 39.0 GHz | 44.8 GHz |



Roll-off = 0.2

Roll-off = 0.5
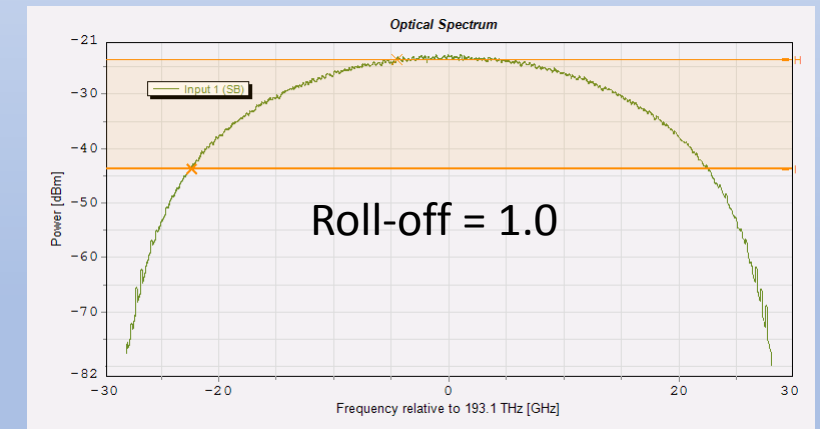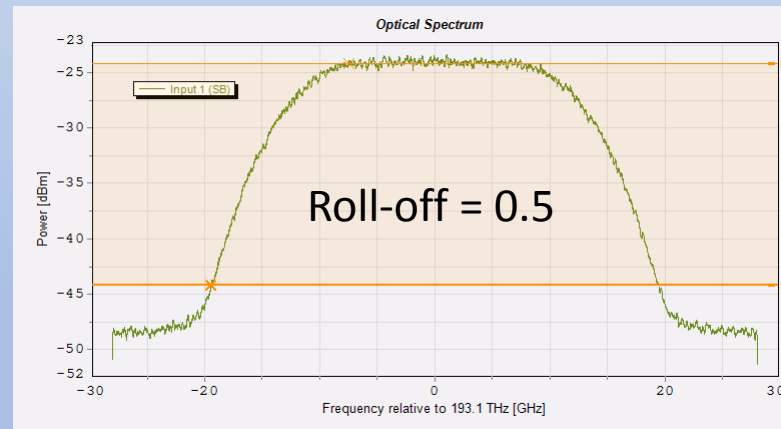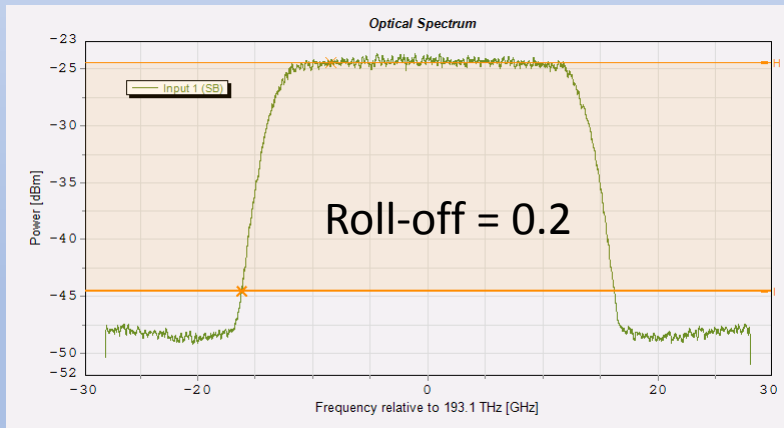
Roll-off = 1.0

# 400G 16 QAM Coherent Transmitter

- Considering 15% C-FEC or O-FEC, the symbol rate is selected as 60GBd

- Nyquist Filtering versus Bandwidth and roll-off for ideal transmitter (Full BW)

| QAM | 0.2 roll-off | 0.5 roll-off | 1.0 roll-off |
|---|---|---|---|
| 0.5 dB BW | 51.8 GHz | 42.6 GHz | 28.0 GHz |
| 3 dB BW | 55.0 GHz | 47.6 GHz | 40.4 GHz |
| 20 dB BW | 69.0 GHz | 81.8 GHz | 95.6 GHz |



Roll-off = 0.2



Roll-off = 0.5



Roll-off = 1.0
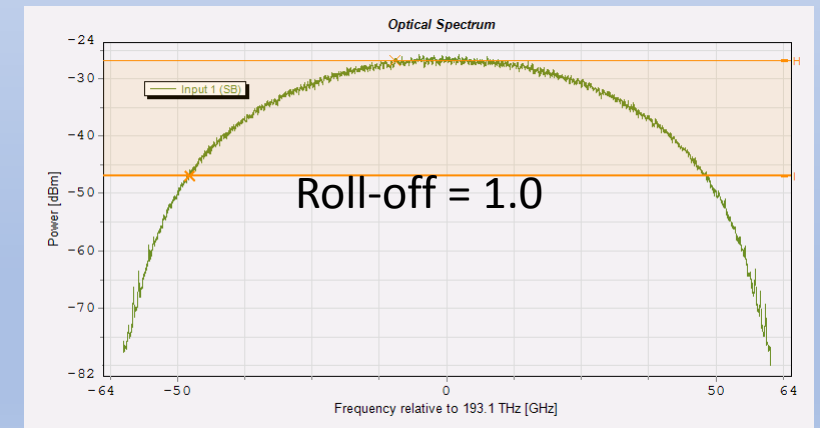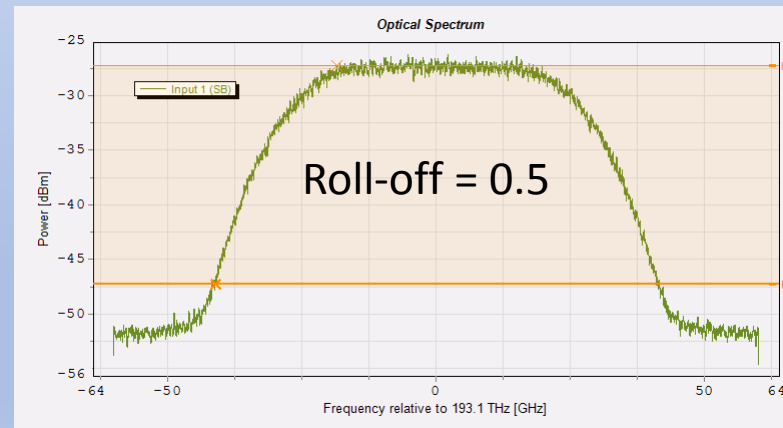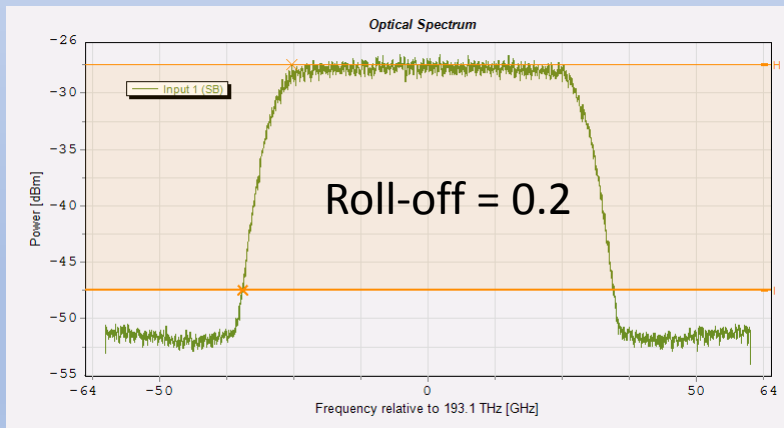
# Filter Specs for 100G versus 400G Coherent link

- Based on 400G Nyquist shaping, 50 GHz filters will not support this option
- Present Filter BW options deployed for Telecom are 50 and 100 GHz
- 100GHz are the highest quantity and lower relative cost based on volume
- 75 GHz Filters have been developed for the 400G for optimal channel count
- Propose a filter PMD "Mask" for compliance
  - Should we develop 2 masks for the filters?
  - Or shall we develop a single mask for 100 GHz?

# Filter Relative cost model comparison , Rack mount

- Rack mount AWG
  - Housing
  - AWG chip
  - Fiber Connector
  - Front panel couplers

| Filter Type | 100 GHz | 75 GHz | 50 GHz |
|---|---|---|---|
| Channel Count | 40 | 60 | 80 |
| AWG Chip | 1.0n | 1.3n | 1.4n |
| Housing | 1.0a | 1.0a | 1.0a |
| Duplex Coupler | 1.0x | 1.5x | 2x |
| Labor | 1.0v | 1.2v | 1.4v |
| Cost/Port | 1.5p | 1.2p | 1.0p |

# Add/Drop Mux comments

| QPSK | 0.2 roll-off | 0.5 roll-off | 1.0 roll-off |
|---|---|---|---|
| 0.5 dB BW | 24.0 GHz | 18.8 GHz | 11.8 GHz |
| 3 dB BW | 26.4 GHz | 24.0 GHz | 20.2 GHz |
| 20 dB BW | 32.4 GHz | 39.0 GHz | 44.8 GHz |

| QAM | 0.2 roll-off | 0.5 roll-off | 1.0 roll-off |
|---|---|---|---|
| 0.5 dB BW | 51.8 GHz | 42.6 GHz | 28.0 GHz |
| 3 dB BW | 55.0 GHz | 47.6 GHz | 40.4 GHz |
| 20 dB BW | 69.0 GHz | 81.8 GHz | 95.6 GHz |

- 50/75 and 100 GHZ filter options exist as options

- These three support the 100G Coherent Objective

- Only the 75 and 100 GHz filters support the 400G Objective

Does IEEE need to specify WDM channel count?

- If "Yes" then we will need analysis of Nyquist roll-off versus filter drift and Tx frequency accuracy for the 75 GHz option
- If "No" then 100 GHZ filters should be sufficient for both 100 G and 400G options, and a single PMD can be supported

Alternately, we can specify a PMD optical filter "Mask" to ensure 100G and 400G links and Transmit Nyquist compliance to cable plant, and push responsibility on compliance testing.

- This allows different options for channel count, filter BW and types

- Let the Market and Implementors decide.

# ITU-T Recommendation G.698.2 (11/09)

- Type 4 and 5 options for DWDM links
  - For single span, we might eliminate one amplifier or both amplifiers
  - Slight OSNR Penalty with amps
  - Amplified or un-amplified for 100G?
  - Impact on 80 km objective and cost

**Optical link types 4 and 5**

Type 4 — Example G.698.1 (Optical Tx → Optical Rx)

Type 5 — Example simplified G.698.2 (Optical Tx → Optical Rx)

4
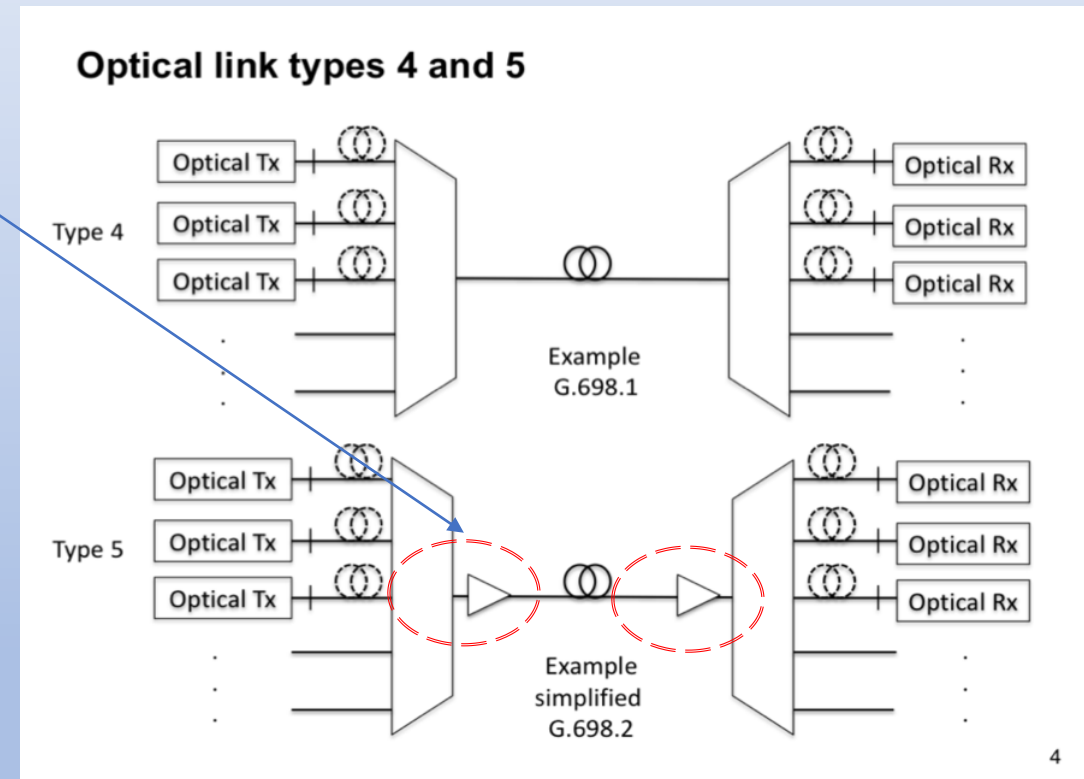
http://www.ieee802.org/3/B10K/public/18_01/anslow_b10k_01_0118.pdf

# 100G  Coherent Dynamic range
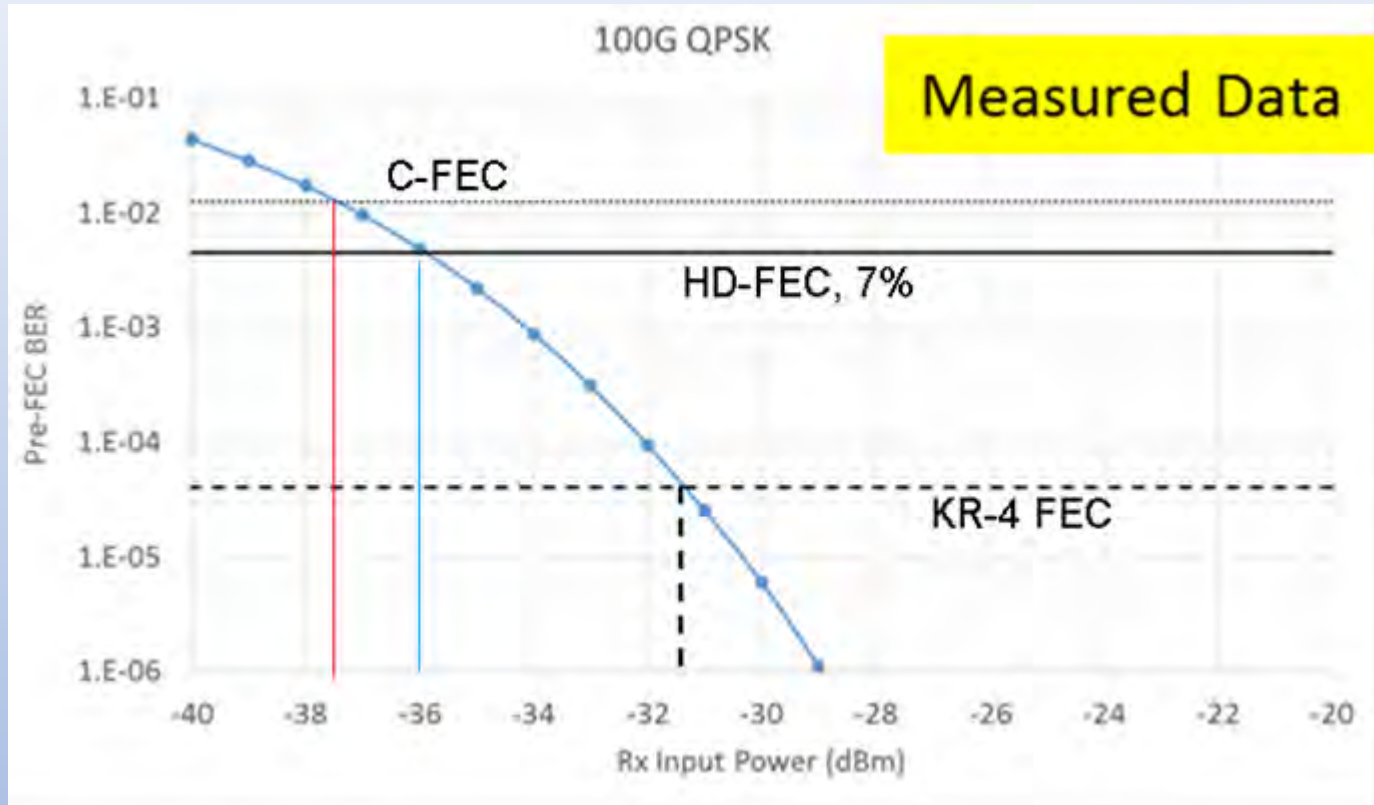


- Receiver Sensitivity Assumptions:
  - LO power = +10dBm
  - Rx PIC responsivity = 0.035A/W
  - 28Gbaud (D)QPSK → -31.5dBm
    - @ KR4 FEC limit
  - Back to Back
  - 40 dB OSNR

- Receiver Sensitivity/FEC
  - -31.5 dBm , KR-4 FEC
  - -36.0 dBm, HD-FEC-%
  - -37.5  dBm, C-FEC

# Link Analysis, Point Point-DWDM 100G Ref. Link

- No Amplifier: Link Budget = Pout – Lm - L$_f$ - L$_f$ -Ld Rxs
  - Pout = Optical transmit Power
  - Lm = Mux + Connector Loss
  - Lf = Fiber Loss
  - Ld = DeMux + Connector Loss
  - Rxs = Receiver Sensitivity
  - No EDFA's, minimal impact on OSNR Link Budget
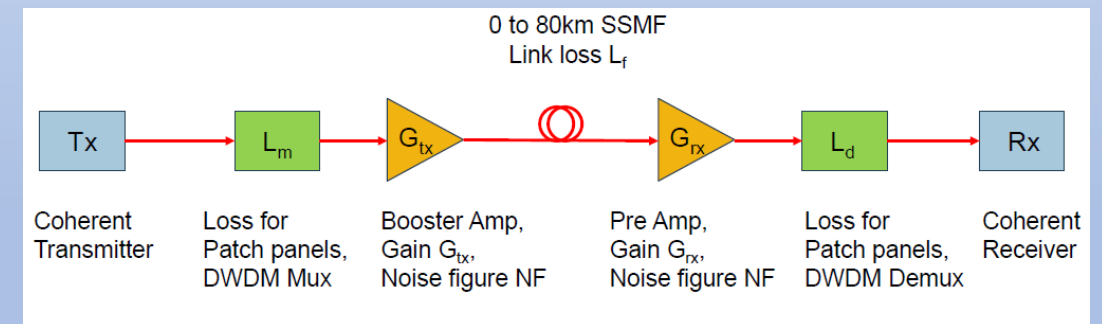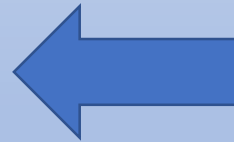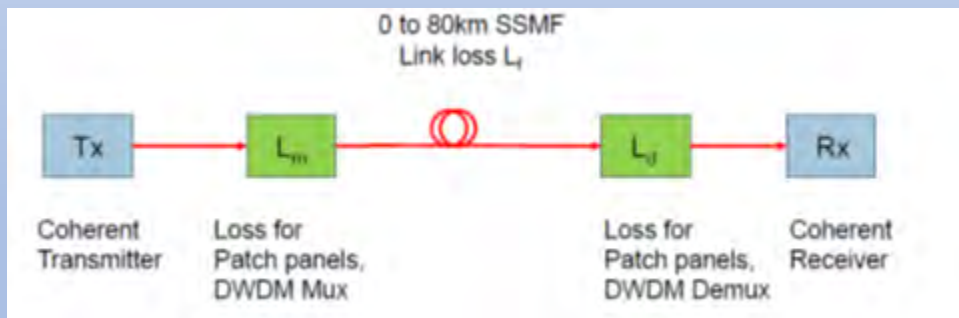
http://www.ieee802.org/3/cn/public/adhoc/18_1025/lyubomirsky_3cn_01_181025.pdf

# Link Analysis, Power Budget, 100G Coherent

- +1 dBm Launch Power
  - SOA
  - Micro Edfa
- 0.75 dB loss connectors/side (3x)
- 5 dB Filter loss, Mux and DeMux
- 0.25 dB/km loss
- Rx Sensitivity = -31.5
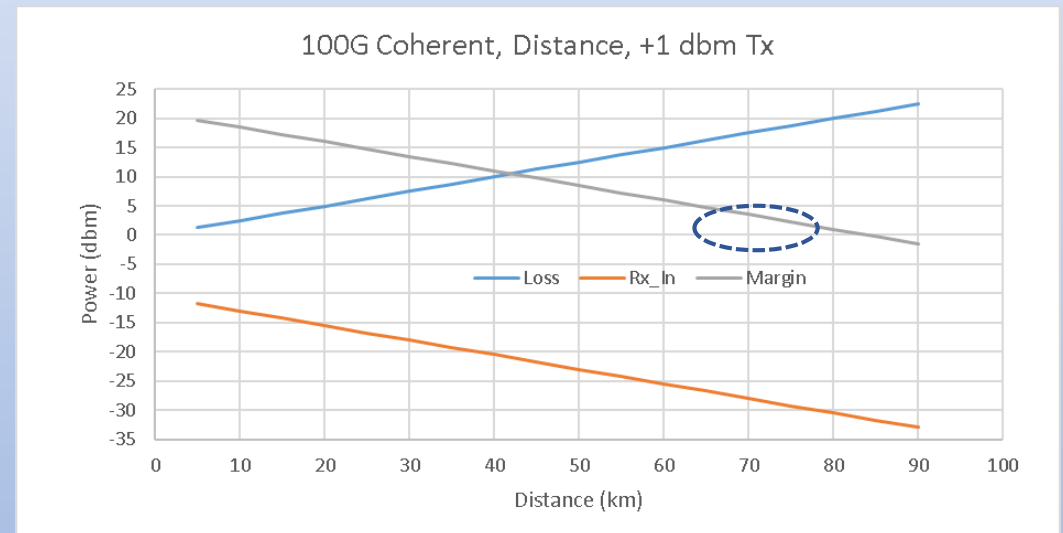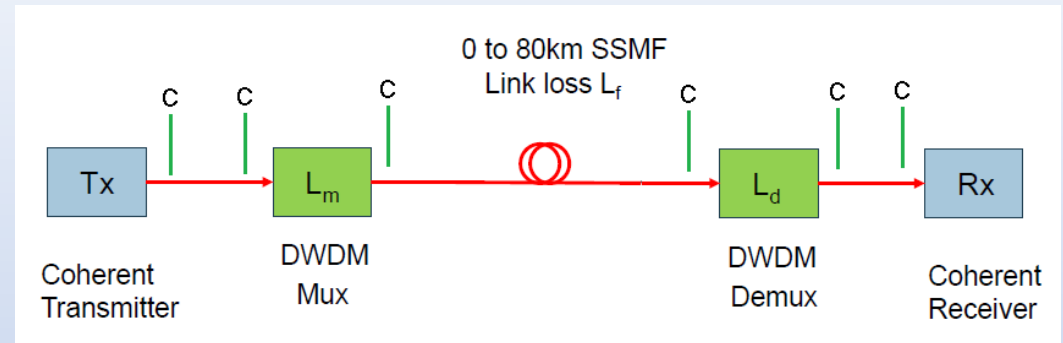


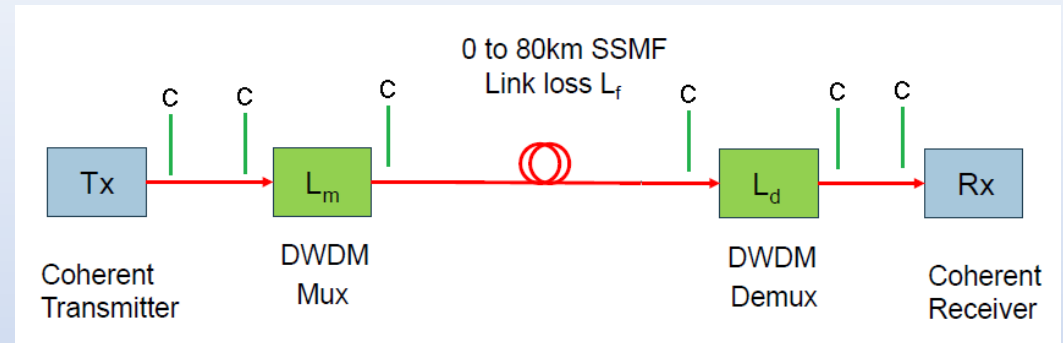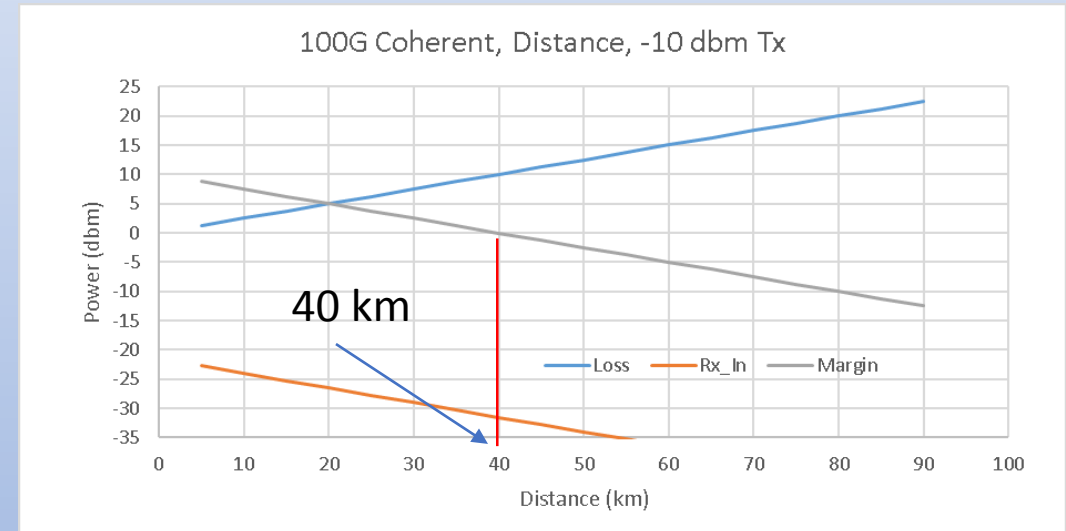| Tx_Power | connectors | Add Mux | Cable | Drop DeMux | connectors | Budget | Rx_In | Margin | Notes |
|----------|-----------|---------|-------|-----------|-----------|--------|-------|--------|-------|
| 1 | -0.75 | -5 | -10 | -5 | -0.75 | -32.5 | -20.5 | 11 | 40 km |
| 1 | -0.75 | -5 | -20 | -5 | -0.75 | -32.5 | -30.5 | 1 | 80 km |

# Link Analysis, Power Budget, 100G Coherent

- -8 dBm Launch Power

- 0.75 dB connectors/side

- 5 dB Filter, Mux and DeMux

- 0.25 dB/km

- Rx Sensitivity = -31.5

- Weighted average of survey results based on number of subscribers per operator
  - <30km: 69%
  - <40km: 88%
  - <60km: 94%
  - <80km: 98%
  - <120km: 100%

http://www.ieee802.org/3/B10K/public/18_05/schmitt_b10k_01a_0518.pdf





100G Coherent, Distance, -8 dbm Tx

48 km
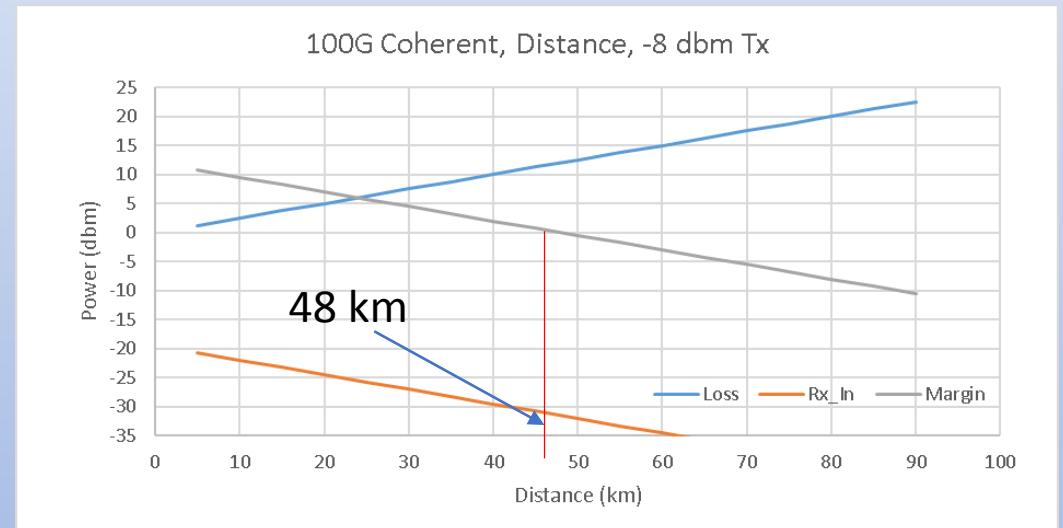
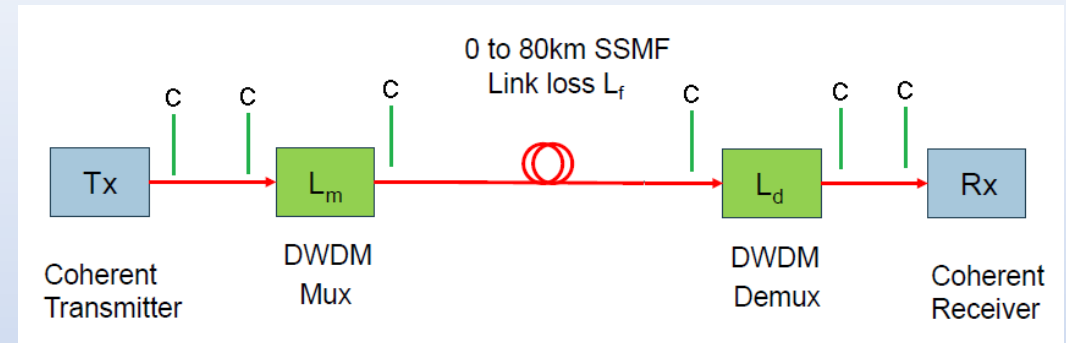| Tx_Power | connectors | Add Mux | Cable | Drop DeMux | connectors | Budget | Rx_In | Margin | Notes |
|----------|-----------|---------|-------|-----------|-----------|--------|-------|--------|-------|
| -8 | -0.75 | -5 | -10 | -5 | -0.75 | -23.5 | -29.5 | 2 | 40 km |
| -8 | -0.75 | -5 | -20 | -5 | -0.75 | -23.5 | -39.5 | -8 | 80 km |

# Link Analysis, Power Budget, 100G Coherent

- -10 dBm Launch Power
- 0.75 dB connectors/side
- 5 dB Filter, Mux and DeMux
- 0.25 dB/km
- Rx Sensitivity = -31.5



- Weighted average of survey results based on number of subscribers per operator
  - <30km: 69%
  - <40km: 88%
  - <60km: 94%
  - <80km: 98%
  - <120km: 100%

http://www.ieee802.org/3/B10K/public/18_05/schmitt_b10k_01a_0518.pdf



| Tx_Power | connectors | Add Mux | Cable | Drop DeMux | connectors | Budget | Rx_In | Margin | Notes |
|---|---|---|---|---|---|---|---|---|---|
| -10 | -0.75 | -5 | -10 | -5 | -0.75 | -21.5 | -31.5 | 0 | 40 km |
| -10 | -0.75 | -5 | -20 | -5 | -0.75 | -21.5 | -41.5 | -10 | 80 km |

# Link Analysis, Power Budget, 400G Coherent

- -5 dBm Launch Power
- 0.75 dB connectors/side
- 5 dB Filter, Mux and DeMux
- 0.25 dB/km
- OIF Rx Sens of -20 dBm (CFEC limit)



- Weighted average of survey results based on number of subscribers per operator
  - <30km: 69%
  - <40km: 88%
  - <60km: 94%
  - <80km: 98%
  - <120km: 100%

http://www.ieee802.org/3/B10K/public/18_05/schmitt_b10k_01a_0518.pdf



400G Coherent, Distance, -5 dbm Tx
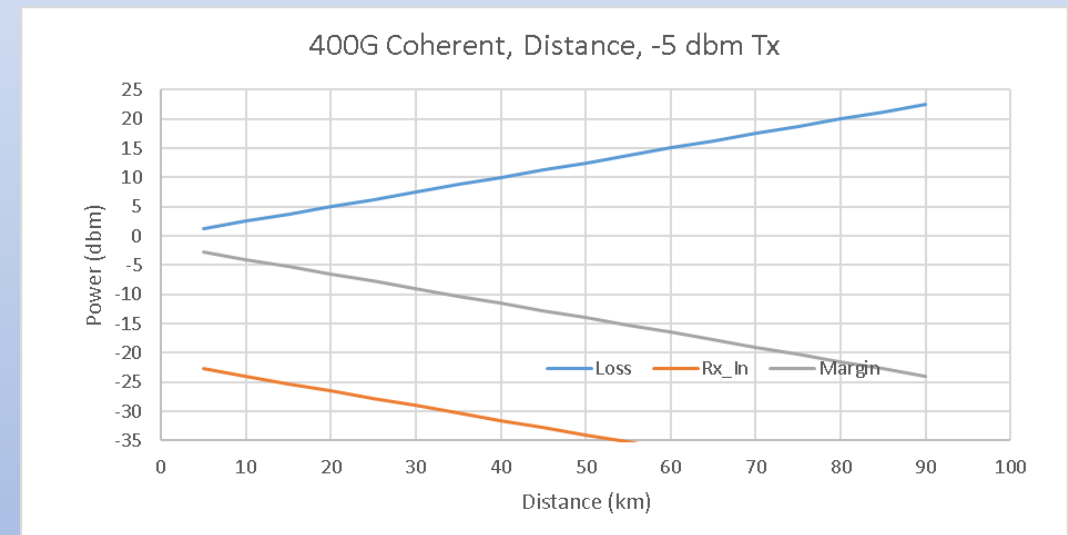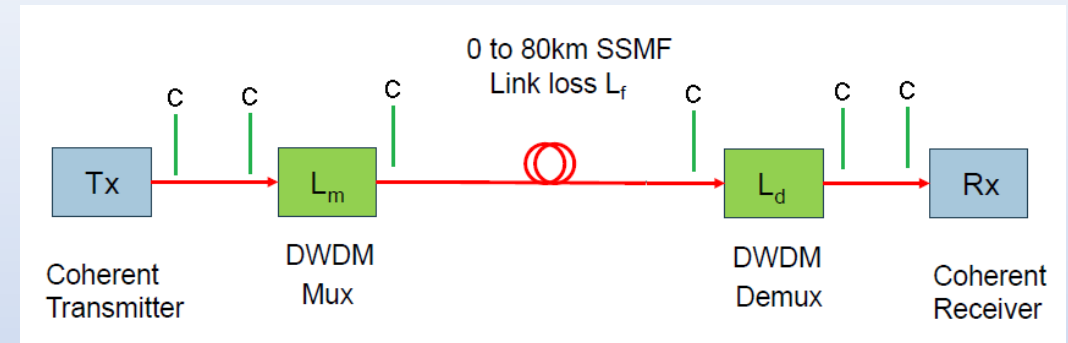
| Tx_Power | connectors | Add Mux | Cable | Drop DeMux | connectors | Budget | Rx_In | Margin | Notes |
|----------|-----------|---------|-------|------------|-----------|--------|-------|--------|-------|
| -5 | -0.75 | -5 | -10 | -5 | -0.75 | -15 | -26.5 | -6.5 | 40 km |
| -5 | -0.75 | -5 | -20 | -5 | -0.75 | -15 | -36.5 | -16.5 | 80 km |

# Pluggable EDFA and Micro EDFA

- Pluggable SFP+ EDFA available today, + 16 dBm output power
- Pluggable CFP2 available, and can support 21 dBm or higher
  - Uncooled pumps support power to 18 dBm
  - Cooled pumps to 22 dBm, based on CFP2 power dissipation
- Optical Amplifier can be realized in a transceiver
  - TO-can 980 pump
  - High bend radius erbium fiber
  - 980/1550 WDM
  - Integrated isolators
  - Enables Higher power SiP transmitters for cable plant  EDFA-less links
  - Also, hybrid designs, SiP and SOA

- WDM filters and cable plant can be deployed for 100G system, no external EDFA's
  - Pluggable amps can be added later to make up the loss for 400G

# Link Analysis, Power Budget, 100G Coherent

- -10 dBm Launch Power
- 0.75 dB connectors/side
- 5 dB Filter, Mux and DeMux
- 0.25 dB/km
- Single EDFA, Preamp
  - Pluggable amplifier (SFP+, CFP2)
  - 48 channel, with GFF (Gain Flattening Filter)
  - 80 km loss budget, add amplifier with gain = 18 dB
  - Link Budget = Pout – Lm - $L_f$ - $L_f$ + Pgain - Rxs
- Receiver Input
  - Pin(edfa) = Pout – Lc – Lm – Lf = -10 – 0.75 – 5 – 20 = -35.75 dBm
  - Pin(Rx ) = Pin(edfa) + Gain – Ld –Lc = -35.75+ 18 – 5 -0.75 = -23.5 dBm
- Optical Amplifier
  - Pout (amp)min= Pin(edfa) + Gain + 10* log (channel count)
  - Pout (amp)min = - 35.75 + 18 + 10 * log (48) = - 0.9 dBm (80 km)
  - Pout (amp)max = - 15.75 + 18 + 10 * log (48) = 19.0 dBm (0 km)
- Note: A lower total output amplifier can be used, gain saturates and constant output power mode as distance is decreased
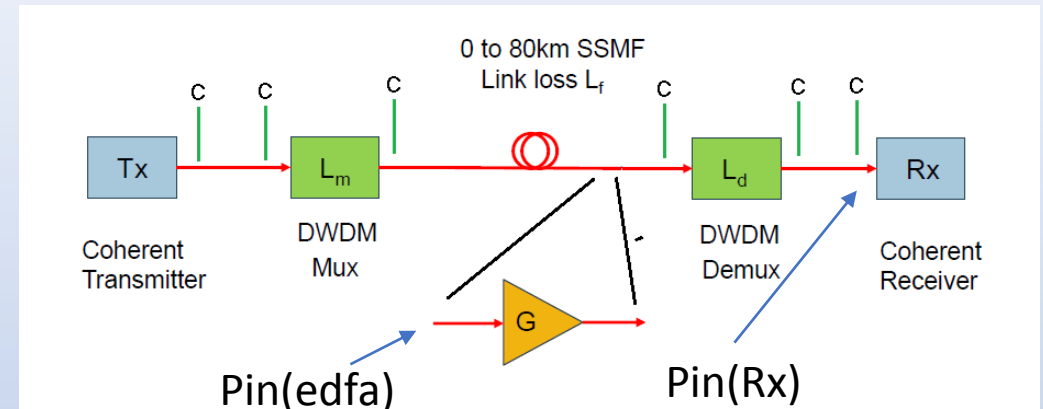
# 100G Coherent, OSNR Link Budget
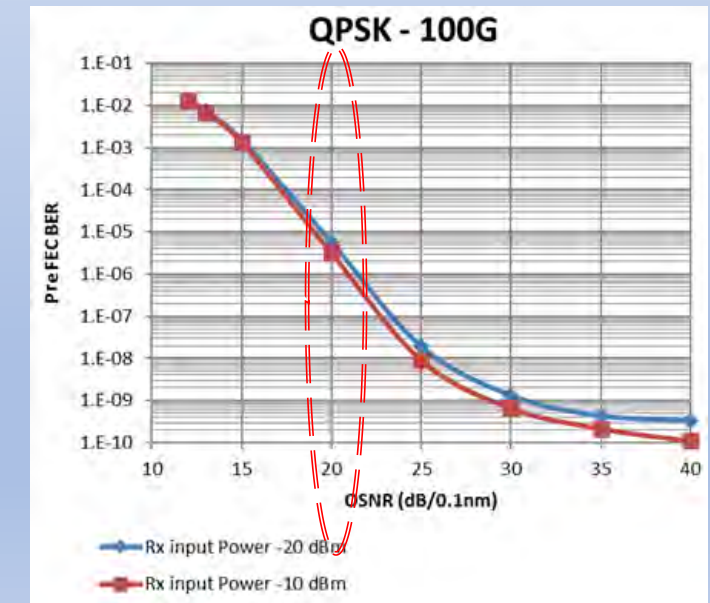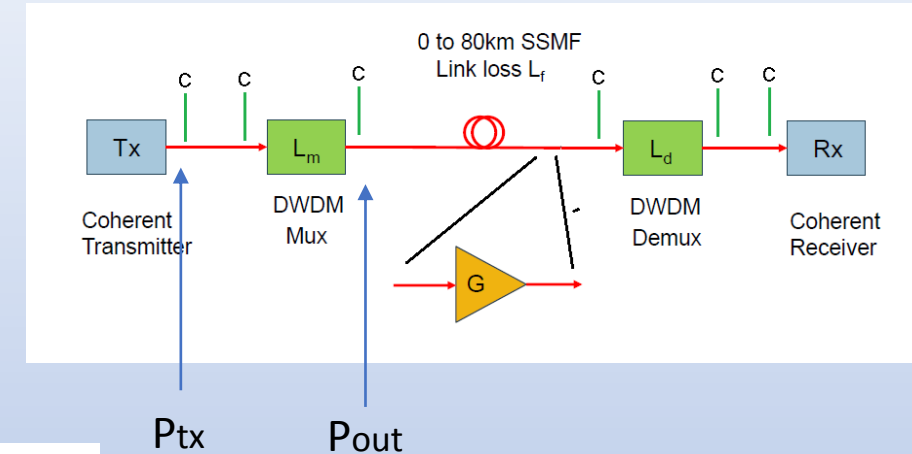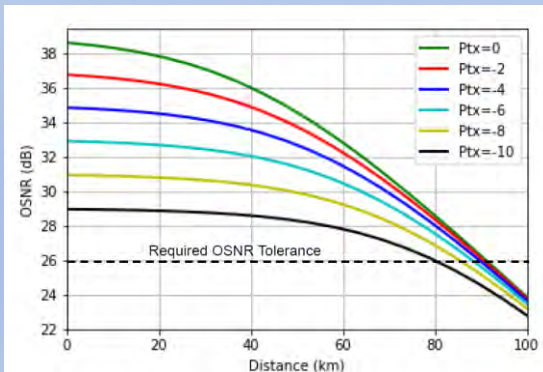
- -10 dBm Launch Power

$$OSNR_{dB} = 58 + P_{out} - L_f - NF - TX_{loss} - G_{ripple} - OSNR_{penalties}$$

$$TX_{loss} = 10Log\left(1 + \frac{10^{-\frac{L_f}{10}}10^{\frac{P_{out}}{10}}}{10^{-\frac{L_m}{10}}10^{\frac{P_{tx}}{10}}}\right)$$

http://www.ieee802.org/3/cn/public/adhoc/18_1025/lyubomirsky_3cn_01_181025.pdf

- OSNR $_{dB}$ = 58 + (-15.75) - 20 - 5 − 0.03 - 1 -2 = 14.22 dB

  Pout    Lfiber    NF    TXloss

# EDFA Noise Figure, Signal to Noise

*"Erbium doped Fiber Amplifiers", Emmanual Desurvire, 2002, Wiley and sons*

- Chapter 5, Amplifier Technology and Design for Terrestrial Transmission
  - WDM filters create high OSNR values for the transmitters
  - S/N remains constant over passive loss of fiber spans
  - EDFA's add broadband ASE noise, but post-filters creates narrowband S/N to the receiver



Narrowband  S/N
To receiver

Tx S/N
Narrowband = 45 dB

S/N= 45 dB
After fiber

BroadBand S/N
From amplifier
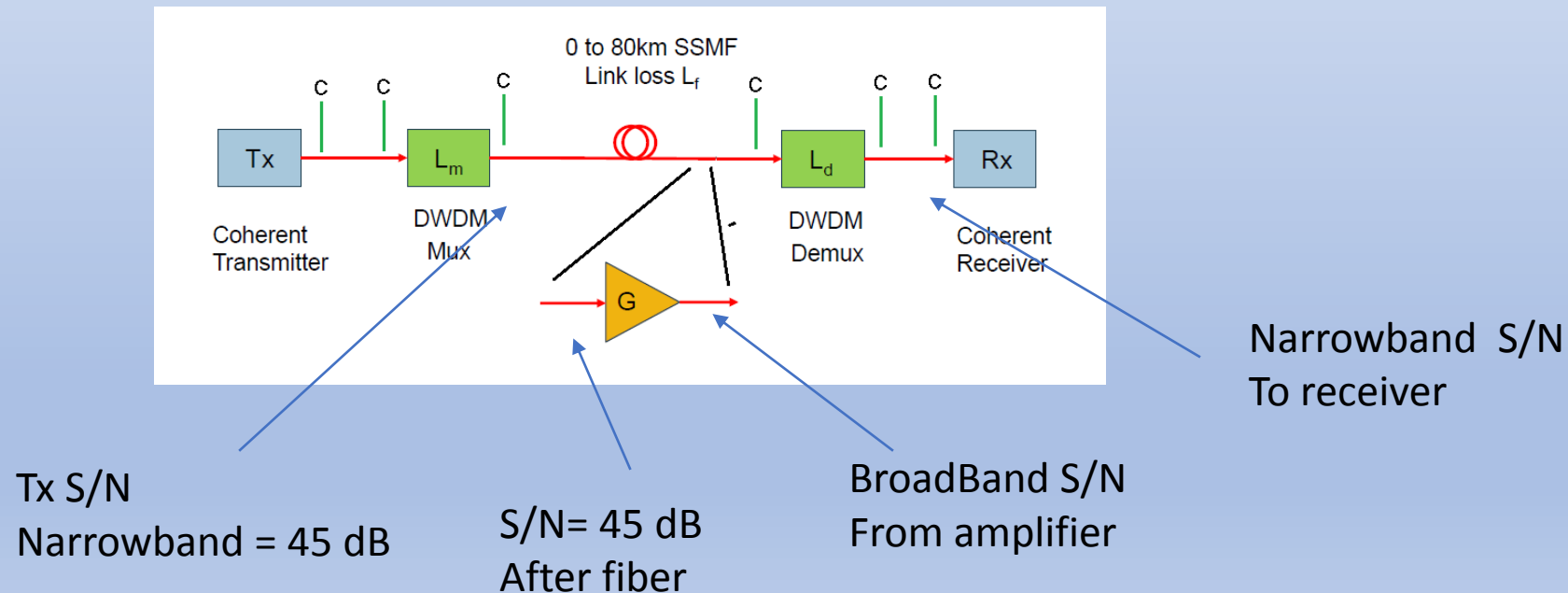
# EDFA Noise Figure, Signal to Noise Modelling
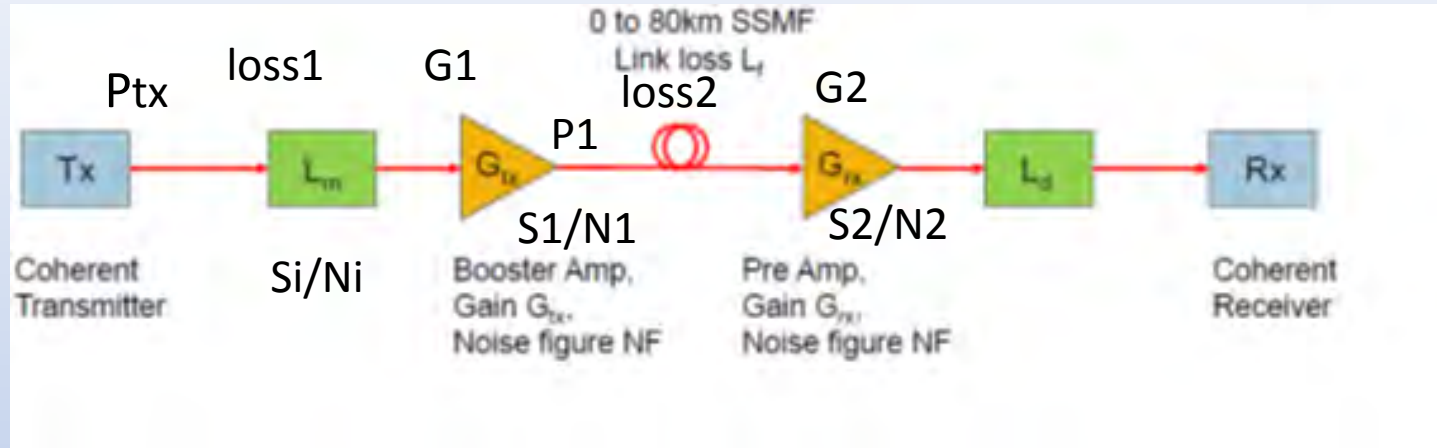


Equation 1: NF*Eff Span Loss (mW) = $10^{\frac{Ptx - Loss1}{10}} \times 10^{\frac{NF1}{10}}$

Equation 2: OSNR = $58 - 10 \times \log10$ ( Equation 1)

Equation 3: = $10^{\frac{P1 - Loss2}{10}} \times 10^{\frac{NF2}{10}}$

Equation 4: OSNR = $58 - 10 \times \log10$ ( Equation 1 + Equation 3)

# Signal to Noise Model

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---------|---------|---------|---------|---------|---------|
| Booster | -10.0 | 5.75 | 6.0 | 149.6 | **36.3** |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | **22.8** |

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---------|---------|---------|---------|---------|---------|
| No Booster | -10.0 | 5.75 | 0.0 | 37.6 | **42.3** |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | **22.9** |

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---------|---------|---------|---------|---------|---------|
| Booster | -8.0 | 5.75 | 6.0 | 94.4 | **38.3** |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | **22.9** |

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---------|---------|---------|---------|---------|---------|
| No Booster | -8.0 | 5.75 | 0.0 | 23.7 | **44.3** |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | **23.0** |

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---------|---------|---------|---------|---------|---------|
| Booster | 1.0 | 5.75 | 6.0 | 11.9 | **47.3** |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | **23.0** |

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---------|---------|---------|---------|---------|---------|
| No Booster | 1.0 | 5.75 | 0.0 | 3.0 | **53.3** |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | **23.0** |
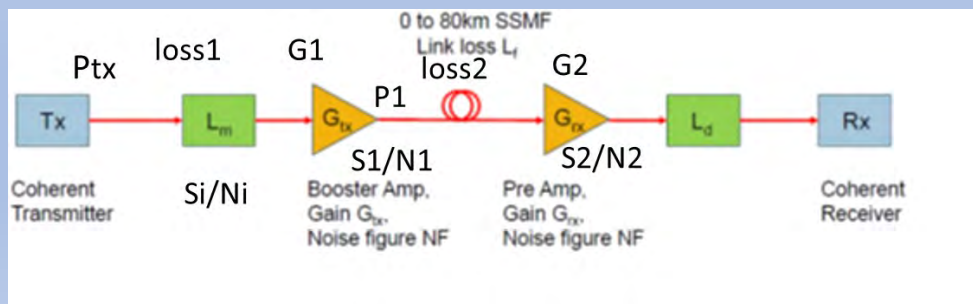
Too Optimistic



Equation 1: NF*Eff Span Loss (mW) $= 10^{\frac{Ptx - Loss1}{10}} \times 10^{\frac{NF1}{10}}$

Equation 2: OSNR $= 58 - 10 \times \log10 ( \text{Equation 1} )$

Equation 3: $= 10^{\frac{P1 - Loss2}{10}} \times 10^{\frac{NF2}{10}}$
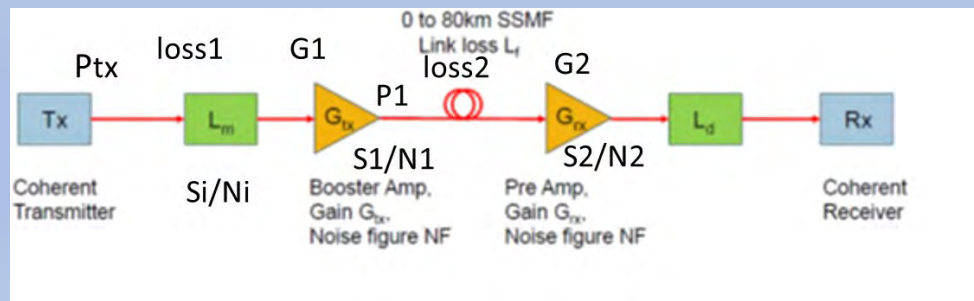
Equation 4: OSNR $= 58 - 10 \times \log10 ( \text{Equation 1} + \text{Equation 3} )$

# Signal to Noise Model (modified)

- Add transmitter OSNR:

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---|---|---|---|---|---|
| Transmitter | -10.0 | N/A | N/A | 20.0 | **45.0** |
| No Booster | -10.0 | 5.75 | 0.0 | 20.0 | **45.0** |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | **23.0** |

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---|---|---|---|---|---|
| Transmitter | -10.0 | N/A | N/A | 50.0 | **41.0** |
| No Booster | -10.0 | 5.75 | 0.0 | 50.0 | **41.0** |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | **22.9** |



Equation 1: NF*Eff Span Loss (mW) $= 10^{\frac{Ptx - Loss1}{10}} \times 10^{\frac{NF1}{10}}$

Equation 2: OSNR $= 58 - 10 \times \log 10\,(\text{Equation 1})$

Equation 3: $= 10^{\frac{P1 - Loss2}{10}} \times 10^{\frac{NF2}{10}}$

Equation 4: OSNR $= 58 - 10 \times \log 10\,(\text{Equation 1} + \text{Equation 3})$

# Signal to Noise Model, update

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---|---|---|---|---|---|
| Transmitter | -10.0 | N/A | N/A | 50.0 | 41.0 |
| Booster | -10.0 | 5.75 | 6.0 | 149.6 | 35.0 |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | 22.7 |

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---|---|---|---|---|---|
| Transmitter | -10.0 | N/A | N/A | 50.0 | 41.0 |
| No Booster | -10.0 | 5.75 | 0.0 | 50.0 | 41.0 |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | 22.9 |

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---|---|---|---|---|---|
| Transmitter | -8.0 | N/A | N/A | 50.0 | 41.0 |
| Booster | -8.0 | 5.75 | 6.0 | 94.4 | 36.4 |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | 22.8 |

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---|---|---|---|---|---|
| Transmitter | -8.0 | N/A | N/A | 50.0 | 41.0 |
| No Booster | -8.0 | 5.75 | 0.0 | 50.0 | 41.0 |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | 22.9 |

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---|---|---|---|---|---|
| Transmitter | 1.0 | N/A | N/A | 50.0 | 41.0 |
| Booster | 1.0 | 5.75 | 6.0 | 11.9 | 40.1 |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | 22.9 |

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---|---|---|---|---|---|
| Transmitter | 1.0 | N/A | N/A | 50.0 | 41.0 |
| No Booster | 1.0 | 5.75 | 0.0 | 50.0 | 41.0 |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | 22.9 |
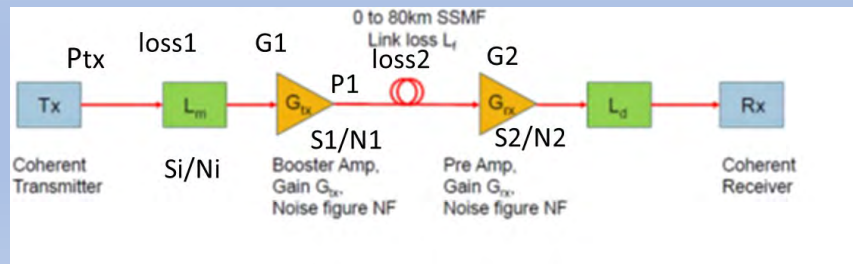


Equation 1: $\text{NF*Eff Span Loss (mW)} = 10^{\frac{Ptx - Loss1}{10}} \times 10^{\frac{NF1}{10}}$
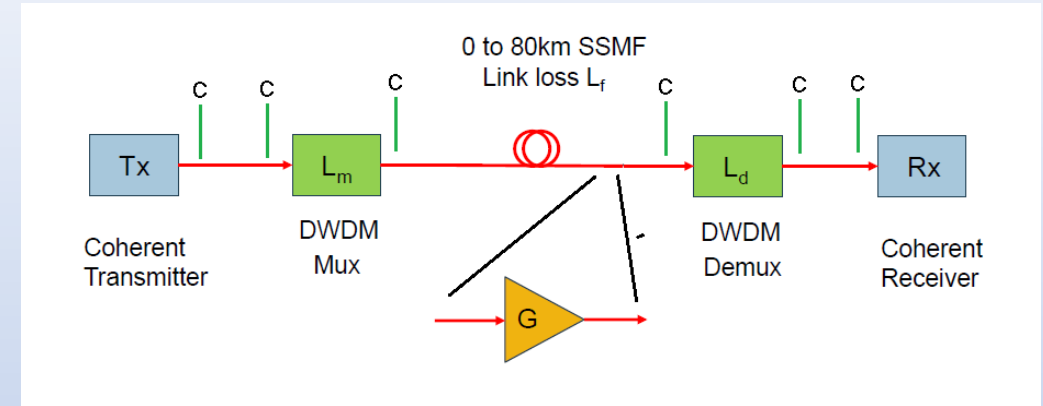
Equation 2: $OSNR = 58 - 10 \times \log_{10}(\text{Equation 1})$

Equation 3: $= 10^{\frac{P1 - Loss2}{10}} \times 10^{\frac{NF2}{10}}$

Equation 4: $OSNR = 58 - 10 \times \log_{10}(\text{Equation 1} + \text{Equation 3})$

# Link Analysis, Power Budget, 400G Coherent

- -5 dBm Launch Power
- 0.75 dB connectors/side
- 5 dB Filter, Mux and DeMux
- 0.25 dB/km
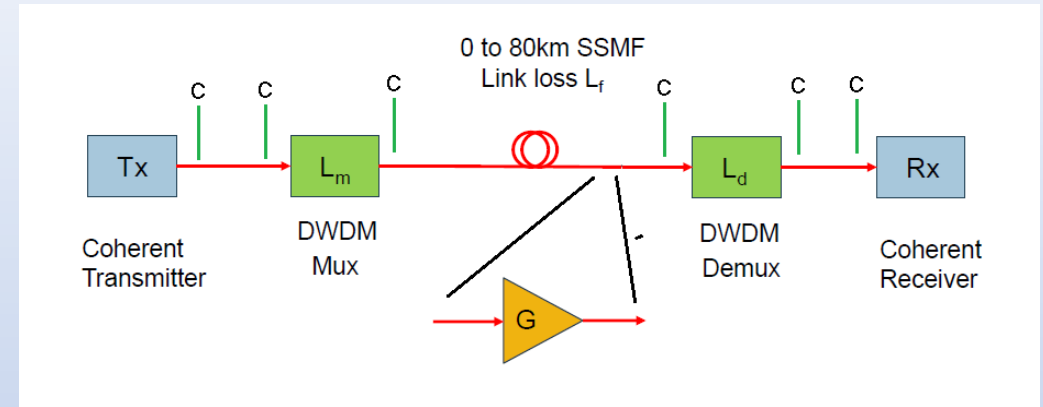- Single EDFA, Preamp
- Meets the 80 km objective





400G Coherent, Distance, -5 dbm Tx
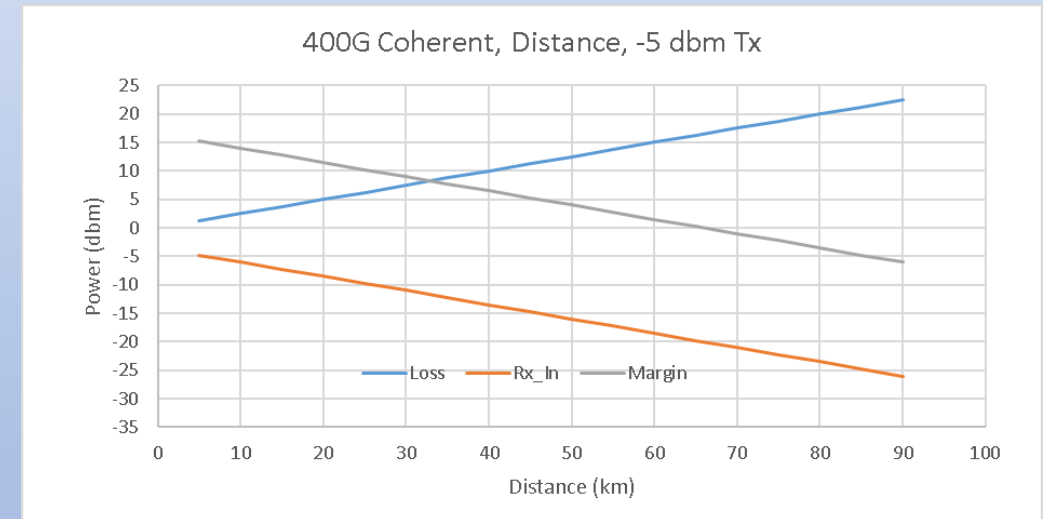
| Tx_Power | connectors | Add Mux | Cable | Drop DeMux | connectors | Budget | Amp Gain | Rx_In | Margin | Notes |
|----------|-----------|---------|-------|------------|-----------|--------|----------|-------|--------|-------|
| -5 | -0.75 | -5 | -10 | -5 | -0.75 | -15 | 18 | -8.5 | 11.5 | 40 km |
| -5 | -0.75 | -5 | -20 | -5 | -0.75 | -15 | 18 | -18.5 | 1.5 | 80 km |

# Link Analysis, Signal to Noise, 400G Coherent

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---|---|---|---|---|---|
| Transmitter | -5.0 | N/A | N/A | 50.0 | **41.0** |
| Booster | 0.0 | 5.75 | 6.0 | 15.0 | **39.9** |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | **22.9** |

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---|---|---|---|---|---|
| Transmitter | -5.0 | N/A | N/A | 50.0 | **41.0** |
| No Booster | 0.0 | 5.75 | 0.0 | 50.0 | **38.0** |
| Preamp | -10.0 | 20 | 5.0 | 3162.3 | **22.9** |



0 to 80km SSMF Link loss $L_f$

Coherent Transmitter — DWDM Mux — DWDM Demux — Coherent Receiver

**Change Pre-amp Output Power/ch:**

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---|---|---|---|---|---|
| Transmitter | -10.0 | N/A | N/A | 50.0 | **41.0** |
| No Booster | -5.0 | 5.75 | 0.0 | 50.0 | **41.0** |
| Preamp | -5.0 | 20 | 5.0 | 1000.0 | **27.8** |

| Section | Launch Power/Ch (dBm) | Loss Prior to Amp | Amplifier NF (dB) | NF*Eff Span Loss (mW) | OSNR (dB) |
|---|---|---|---|---|---|
| Transmitter | -10.0 | N/A | N/A | 50.0 | **41.0** |
| No Booster | -10.0 | 5.75 | 0.0 | 50.0 | **41.0** |
| Preamp | -3.0 | 20 | 5.0 | 631.0 | **29.7** |

**Power Budget, with pre-amplifier**

| Tx_Power | connectors | Add Mux | Cable | Rx_pre_in | Pre_Gain | Pre_out | Drop DeMux | connectors | Rx_in | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| -10 | -0.75 | -5 | -10 | -20.75 | 26 | 5.25 | -5 | -0.75 | -0.5 | 40 km |
| -10 | -0.75 | -5 | -20 | -30.75 | 26 | -4.75 | -5 | -0.75 | -10.5 | 80 km |

Pout (amp)min= Pin(edfa) + Gain + 10* log (channel count)

Pout (amp)min = - 30.75 + 26  + 10 * log (48) =  12 dBm (80 km)

# Wrap Up

- 100GHz fixed filters, sufficient for 100 and 400G PMD sub-layer
  - Sufficient margin for all Nyquist roll off in 100 and 400G objective
- 50 GHZ fixed filters will need further analysis for 400G, 80 km coherent objective
  - We could add Channel Filter compliance mask to cover the requirement
- 100G, 80 km Objective could be met without external amplified links:
  - Different FEC can allow no EDFA links for the 80 km objective
- 100G OSNR budget non-issue for the 100G Objective
- 400G, 80 km Objective could be met with single receive amplifier
- 400G OSNR budget could be met with a single preamplifier and no booster

# Future Study

- 100G/400G Coherent objective
  - Compliant channel filter masks
  - 80 km objective and amplifier/OSNR tradeoffs
  - Backup data on OSNR model of actual links
- Straw man Channel cable plant/filter model
  - Base line specification
  - Filter compliance testing
- Consensus Building
  - Power Budgets
  - Amplifier tradeoffs, transceivers and/or cable plants
  - OSNR model for 400G

# Backup Slides

- Theory and Measurement Techniques for the Noise Figure of Optical Amplifiers
- EDFA Design and simulations

# Amplifier Signal to Noise

"Theory and Measurement Techniques for the Noise Figure of Optical Amplifiers"

Baney, Gallion, Tucker, 1999, *Australian Photonics Cooperative Research Centre*
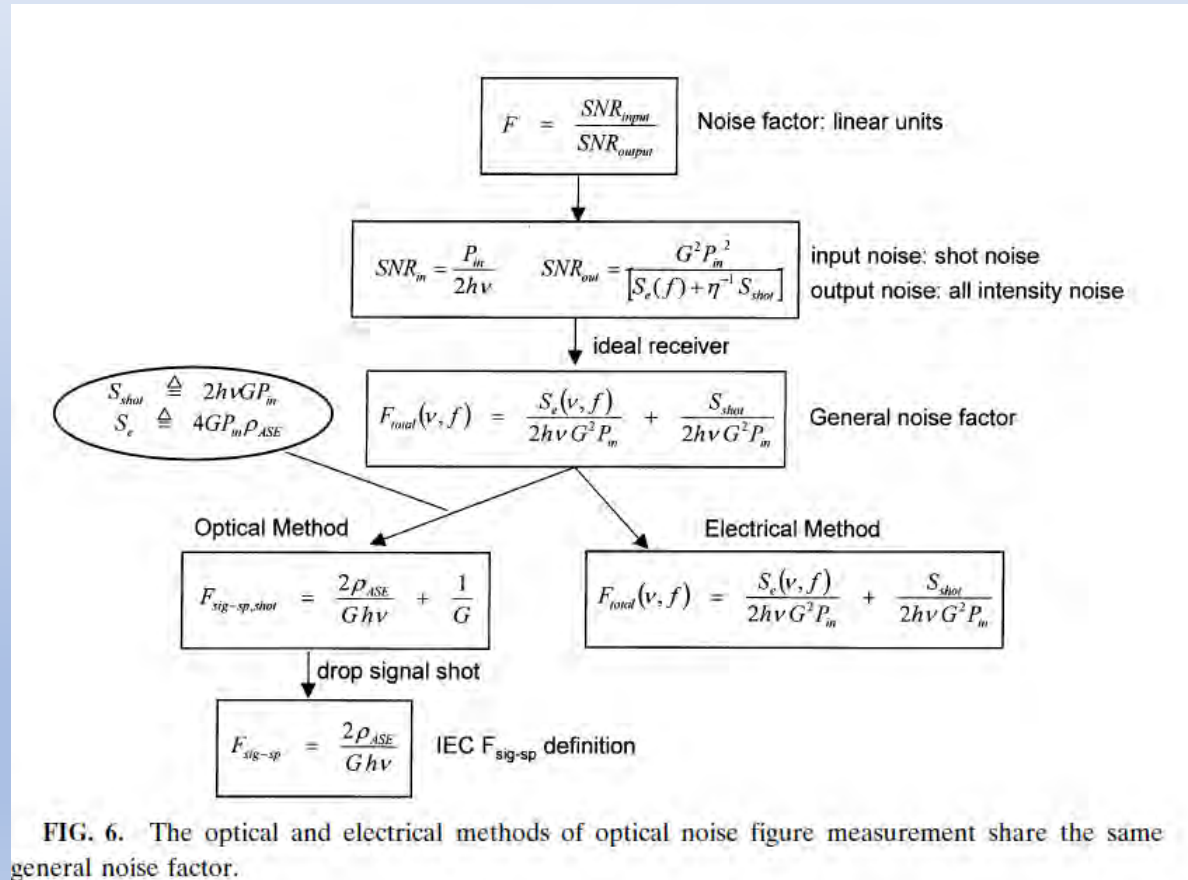


FIG. 6. The optical and electrical methods of optical noise figure measurement share the same general noise factor.

# EDFA design and saturation

- 48 channels
- -30 dBm/ch, -20dbm/ch, -10dbm/ch
- Constant pump current



EDFA Modelling Tool
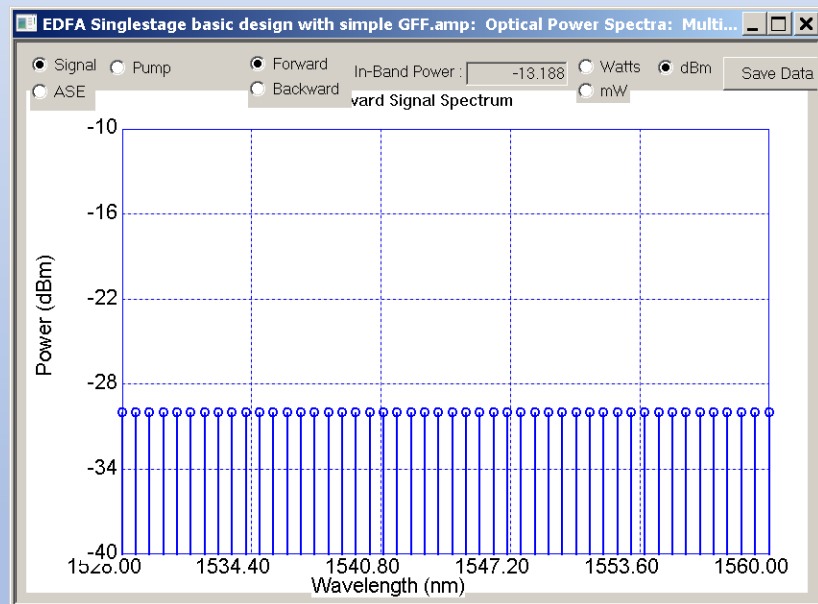


Input Power Spectrum

# EDFA design and saturation



Gain

Noise Figure

DeMux Pin

80 km

40 km

0 km
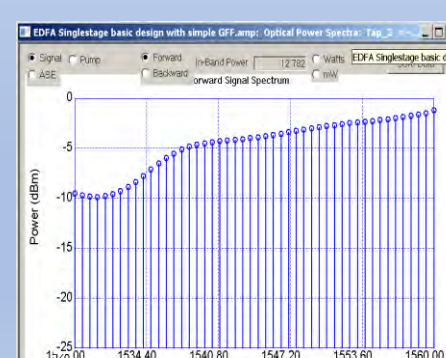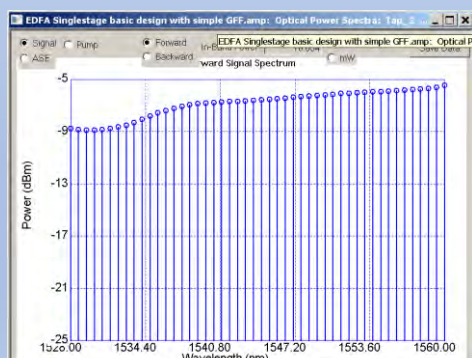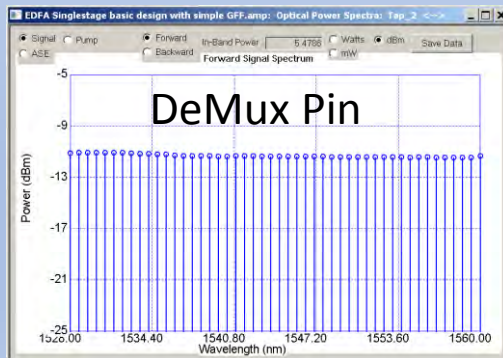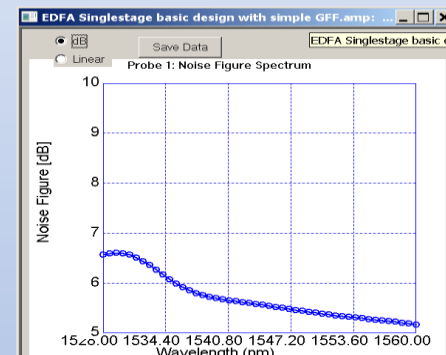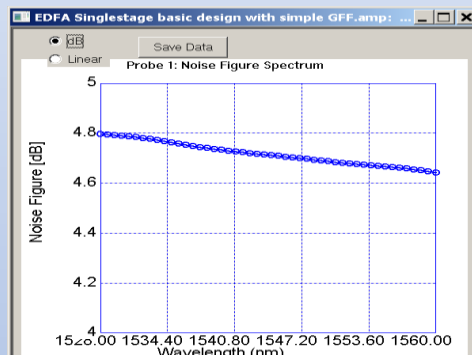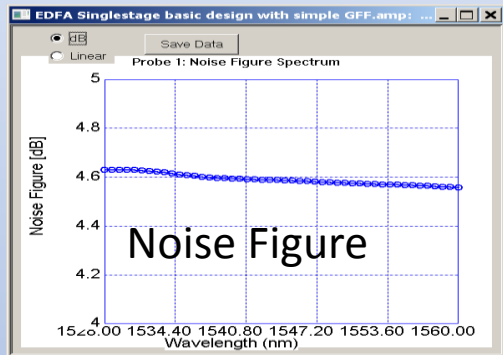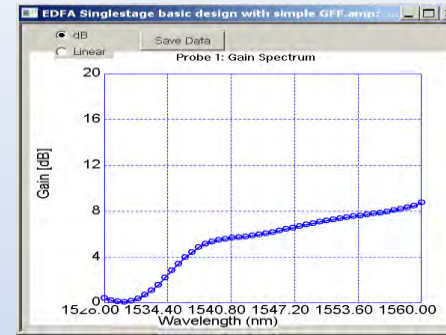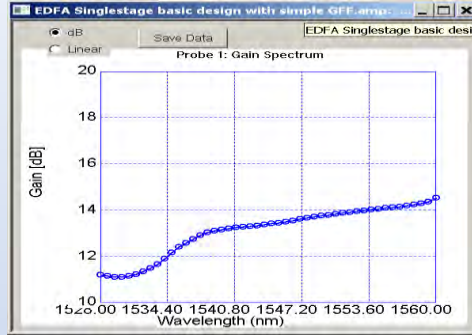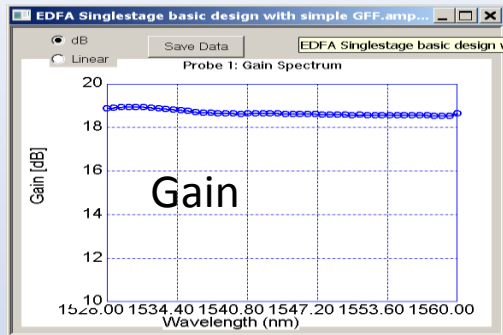
EDFA Model

Vary span length

DeMux Pin

**IEEE 802.3cn 50 Gb/s….. and DWDM Task Force**

**J. DeAndrea**