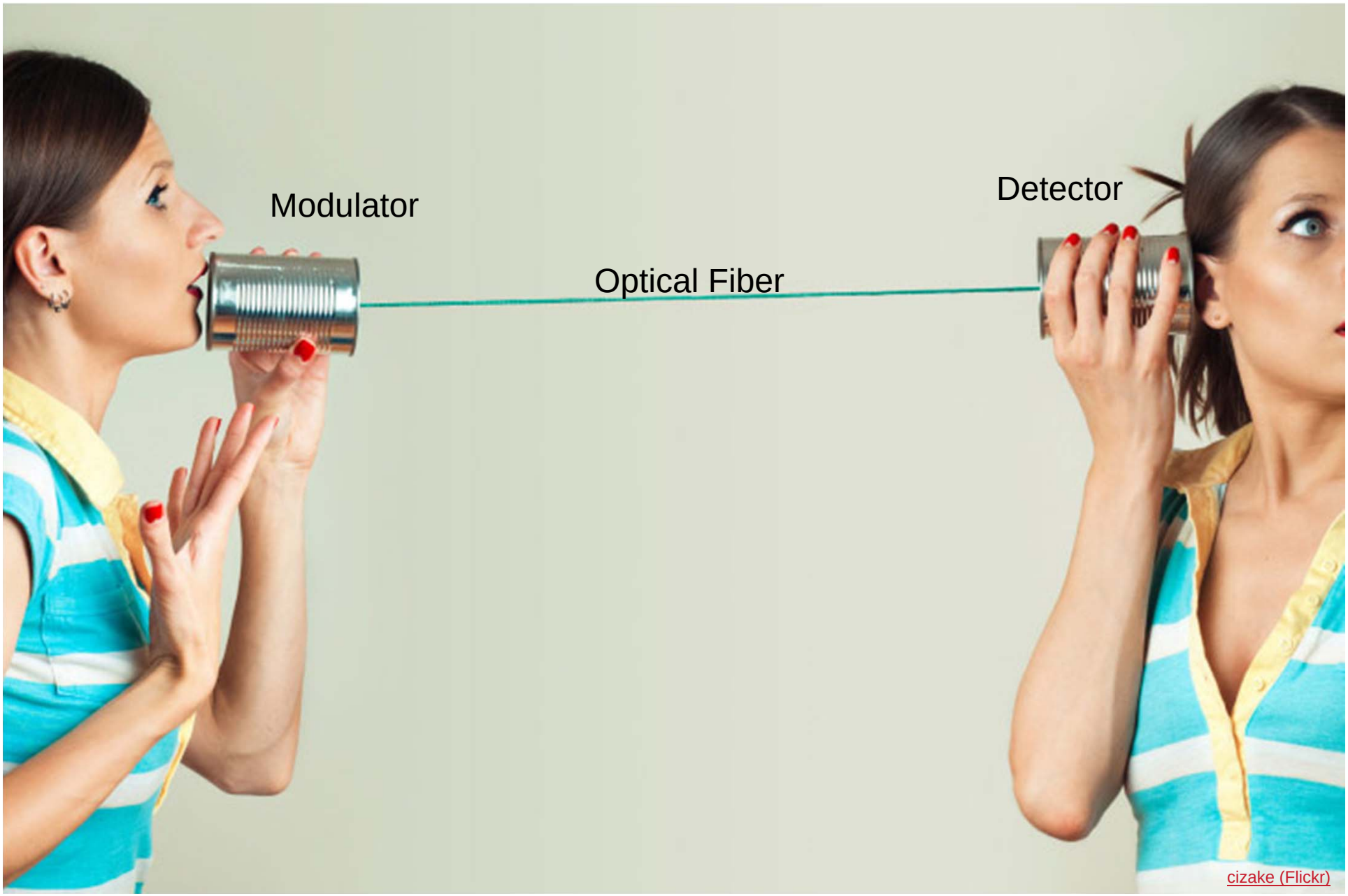
# The Flexibility of Coherent Optical Transceivers

Kim Roberts

# Optical Fiber Communications



# Spectral Efficiency Matters

- **Exponential growth of data at 30%-50% per year**
- **>1000 Tb/s of new end-to-end traffic in year 2020**
- **Optical Spectrum Squeezed for Bits/Second/Hz**

# Cost Matters!

# Reach Matters

# in

# Optical Transmission

# (and ladders)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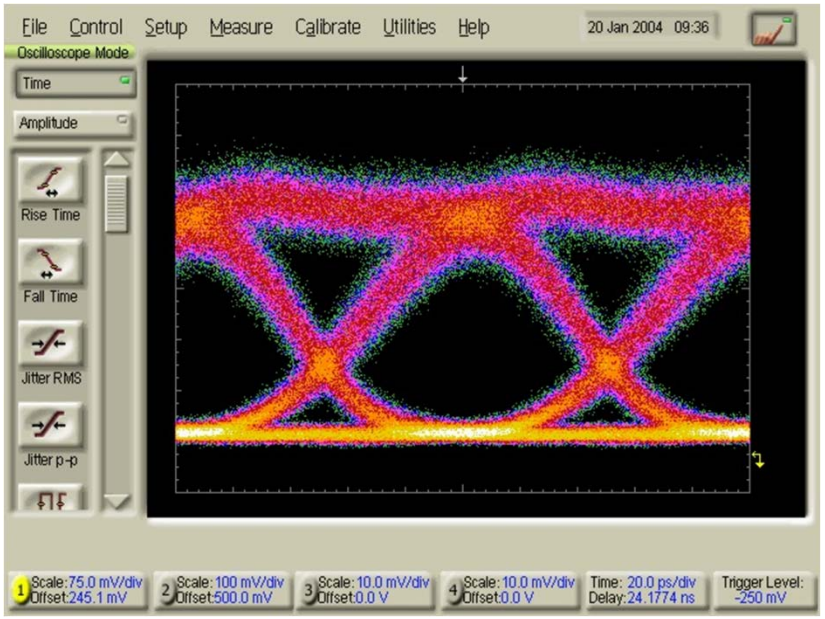
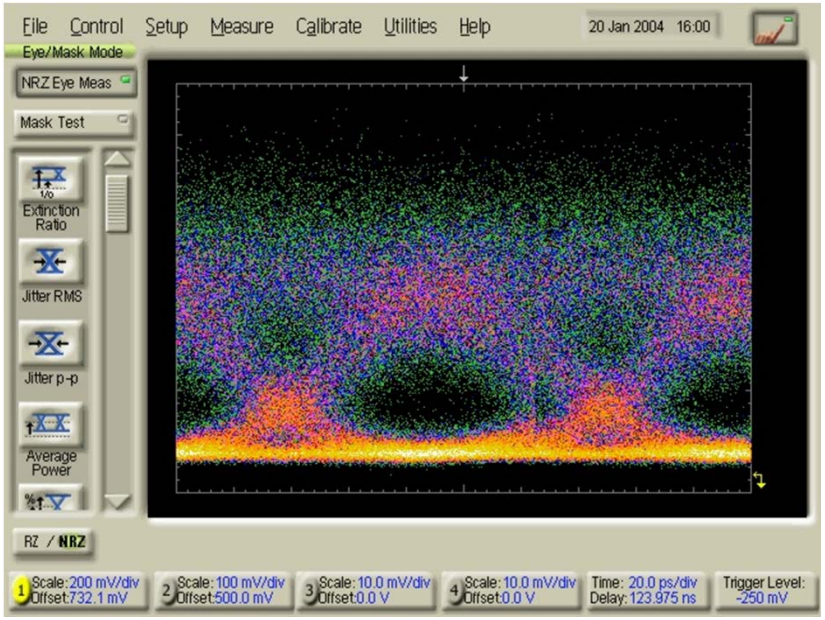
# Physical Barriers

# Noise

# Amplified Spontaneous Emission (ASE)

- Amplifiers are used to overcome fiber losses.
- Optical Noise is added by each amplifier.




$$\rho(\lambda) = 2\, h\, \nu\, n_{sp}\, (G(\lambda) - 1)$$

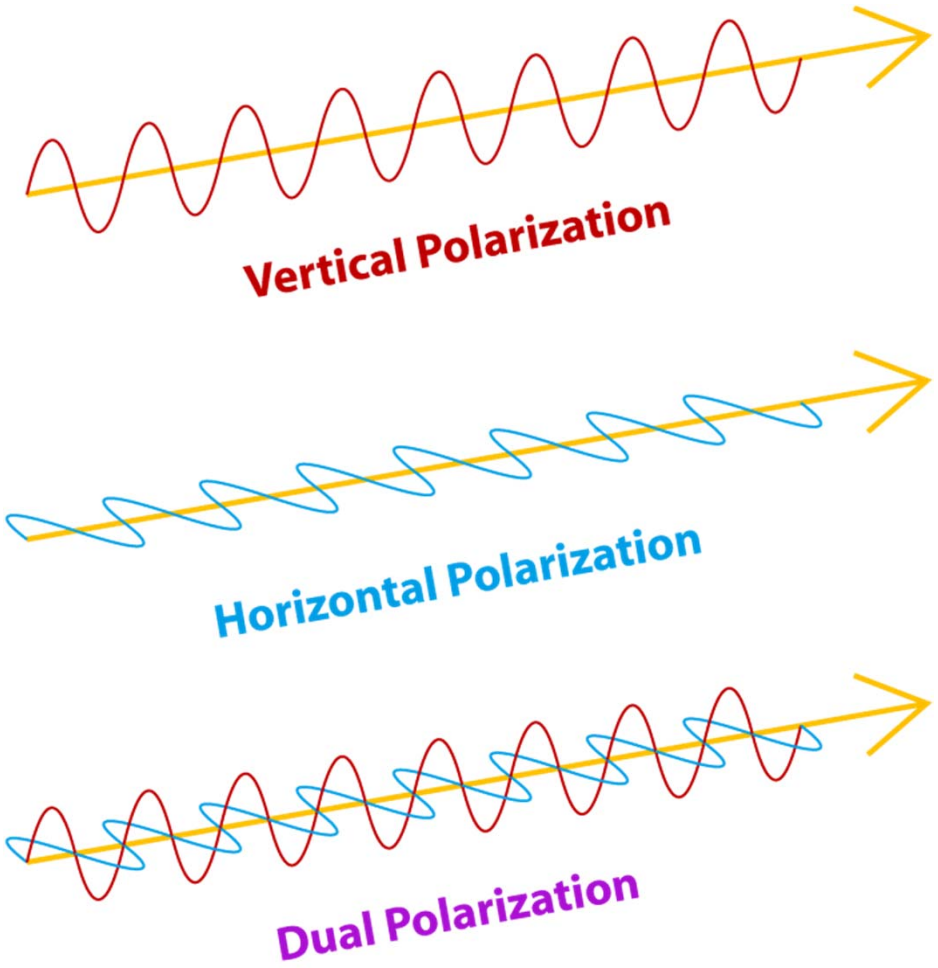
# OSNR

- Optical Signal to Noise Ratio
- Power in optical signal divided by the power in 0.1 nm of the noise spectrum
- Expressed in dB.
- For amplifiers and a line system, delivering a high OSNR is good.
- For a receiver, tolerating a low OSNR is good.

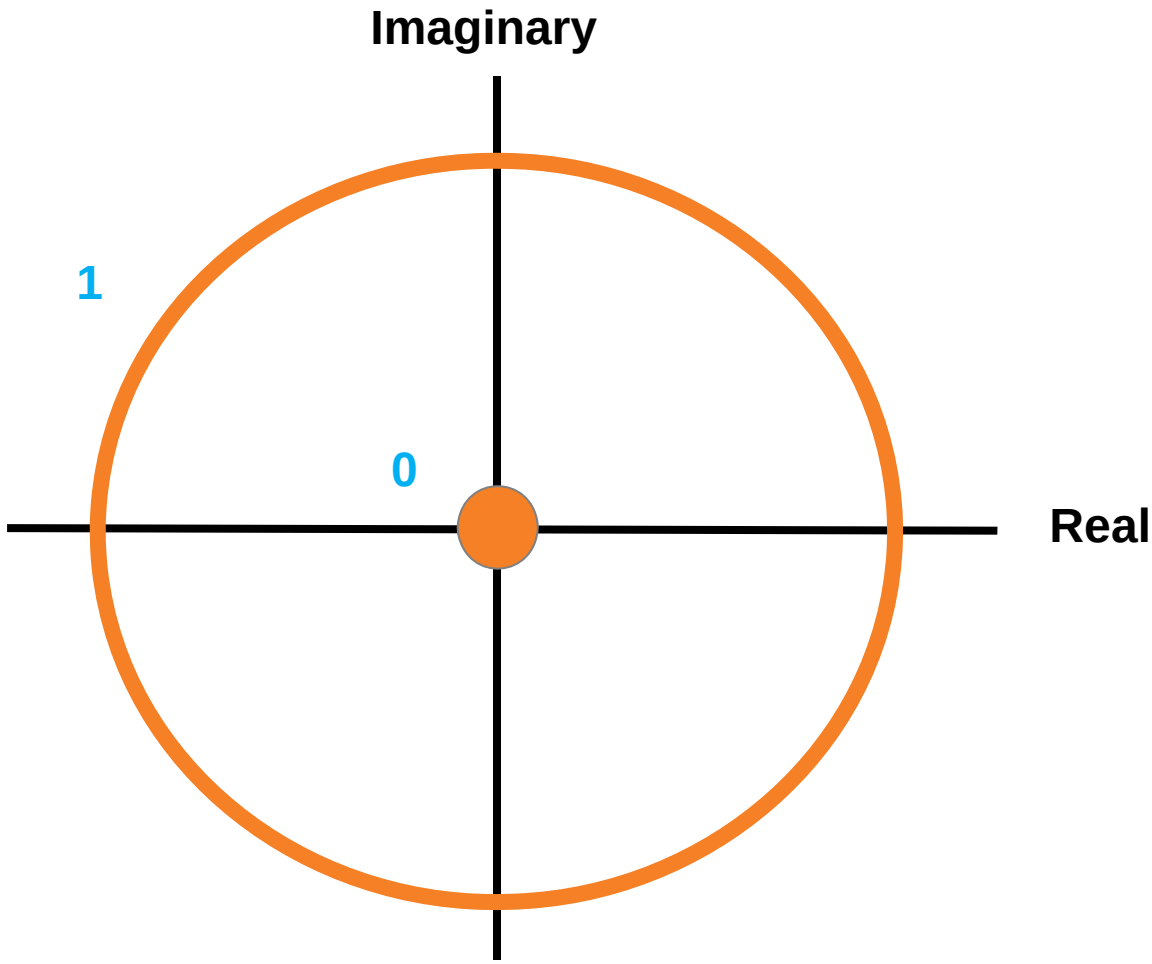
# Optical Fiber Nonlinearity

- **The Kerr effect** $n_{NL}(\omega) \approx n(\omega) + n_2 |E|^2$
- **Self Phase Modulation**
- **Cross Phase Modulation**

# Dual Polarization



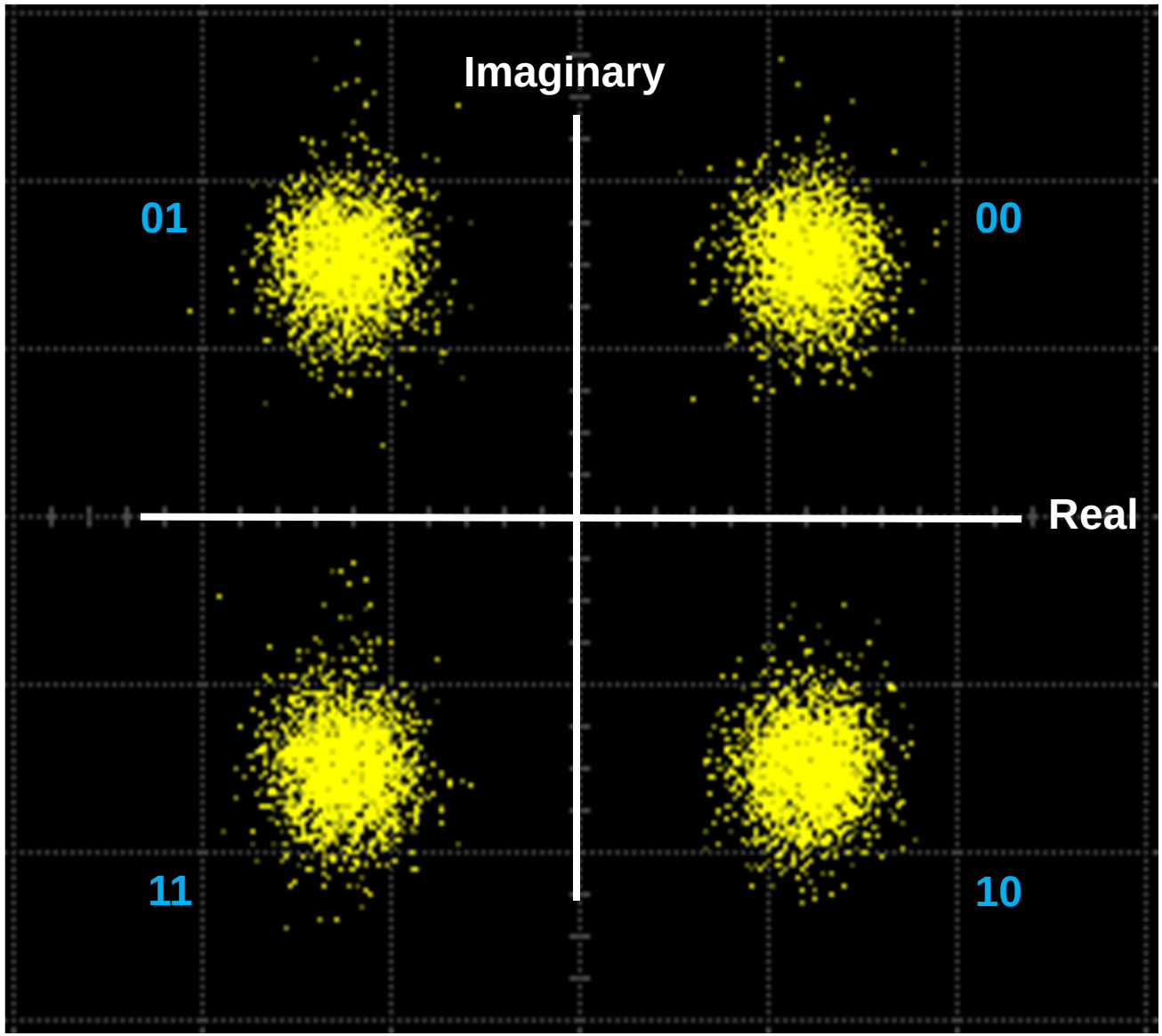
# Amplitude Shift Keying



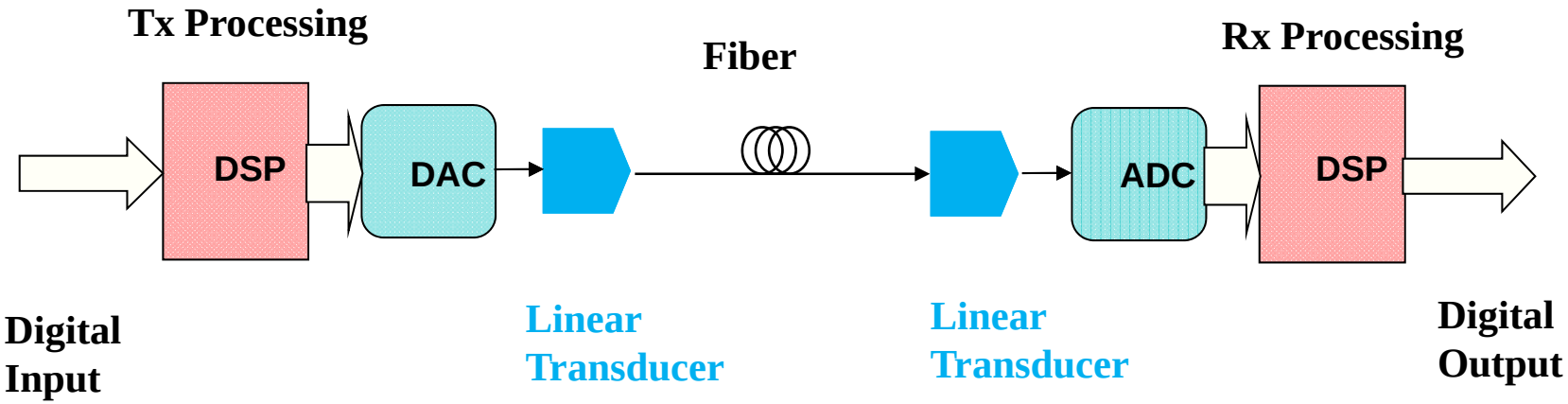

One bit encoded in the amplitude, per symbol

1 bit x 10 Gsymbols/second = 10 Gb/s

# Quadrature Phase Shift Keying (QPSK)

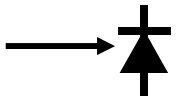


# Digital Processing

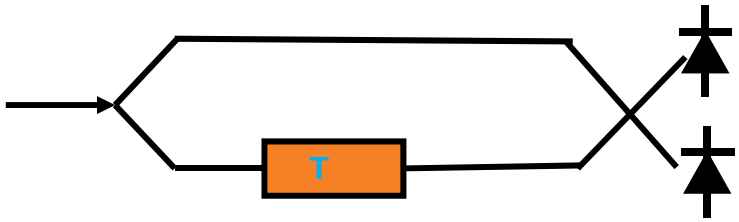



**Linear conversion between E-field and digital**
**Allows simple linear filtering**

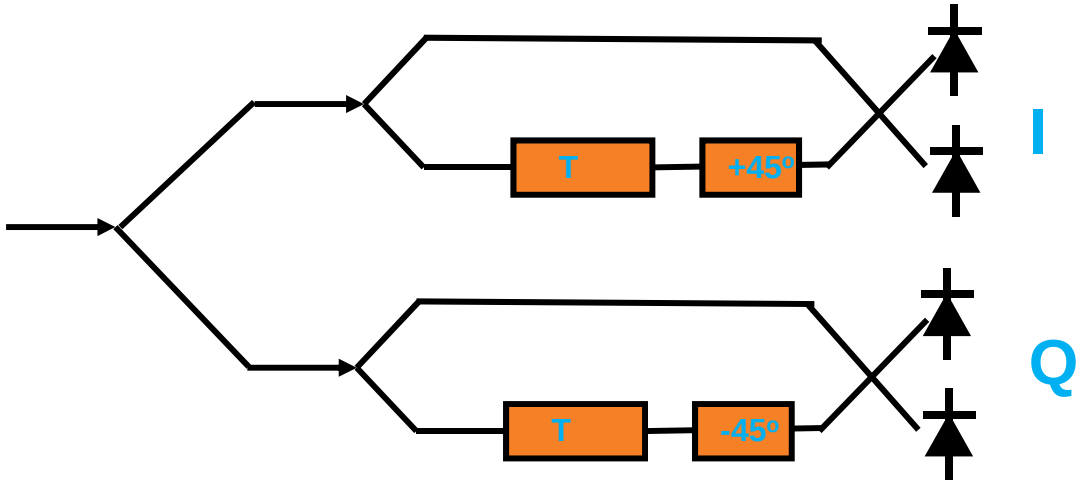
# Incoherent Detection



Direct Detection

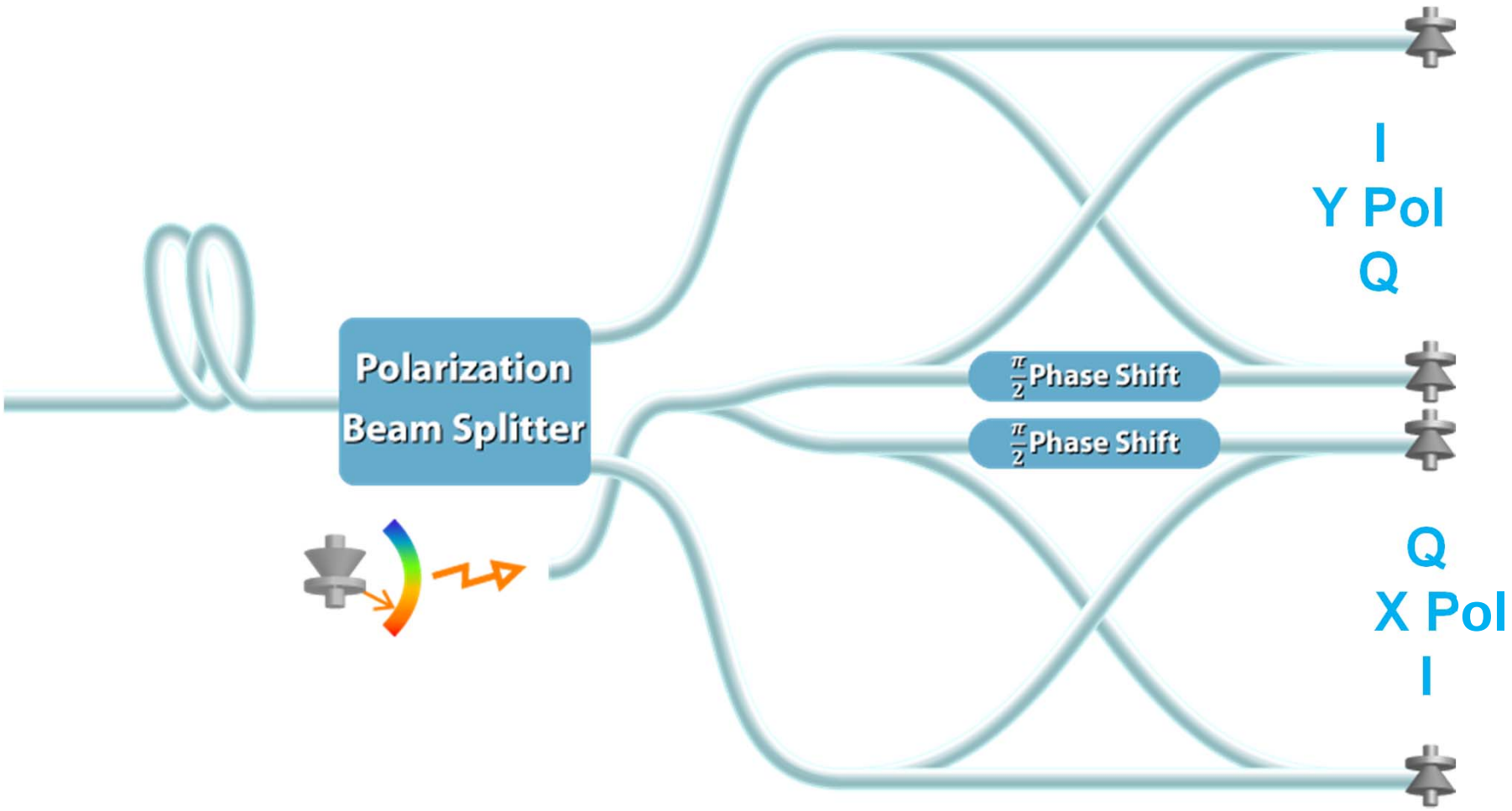



Differential BPSK




Differential QPSK

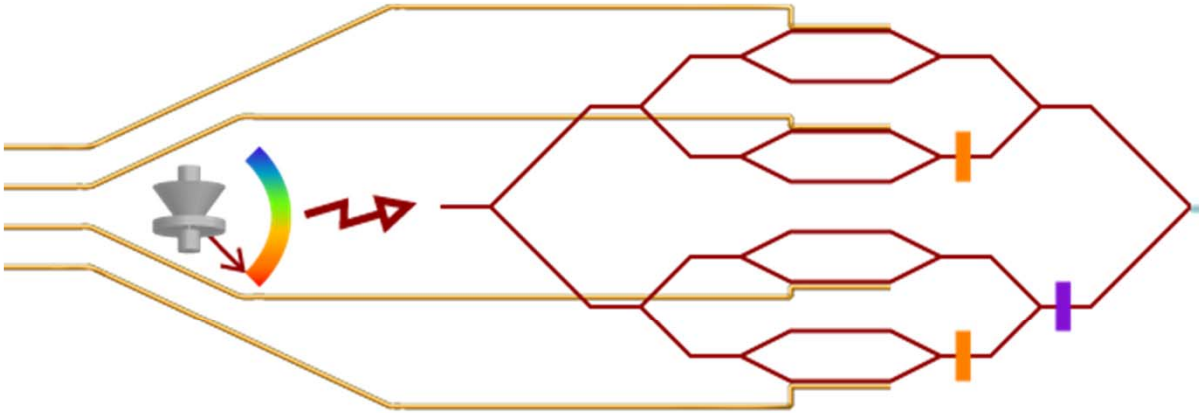
# Coherent Detection



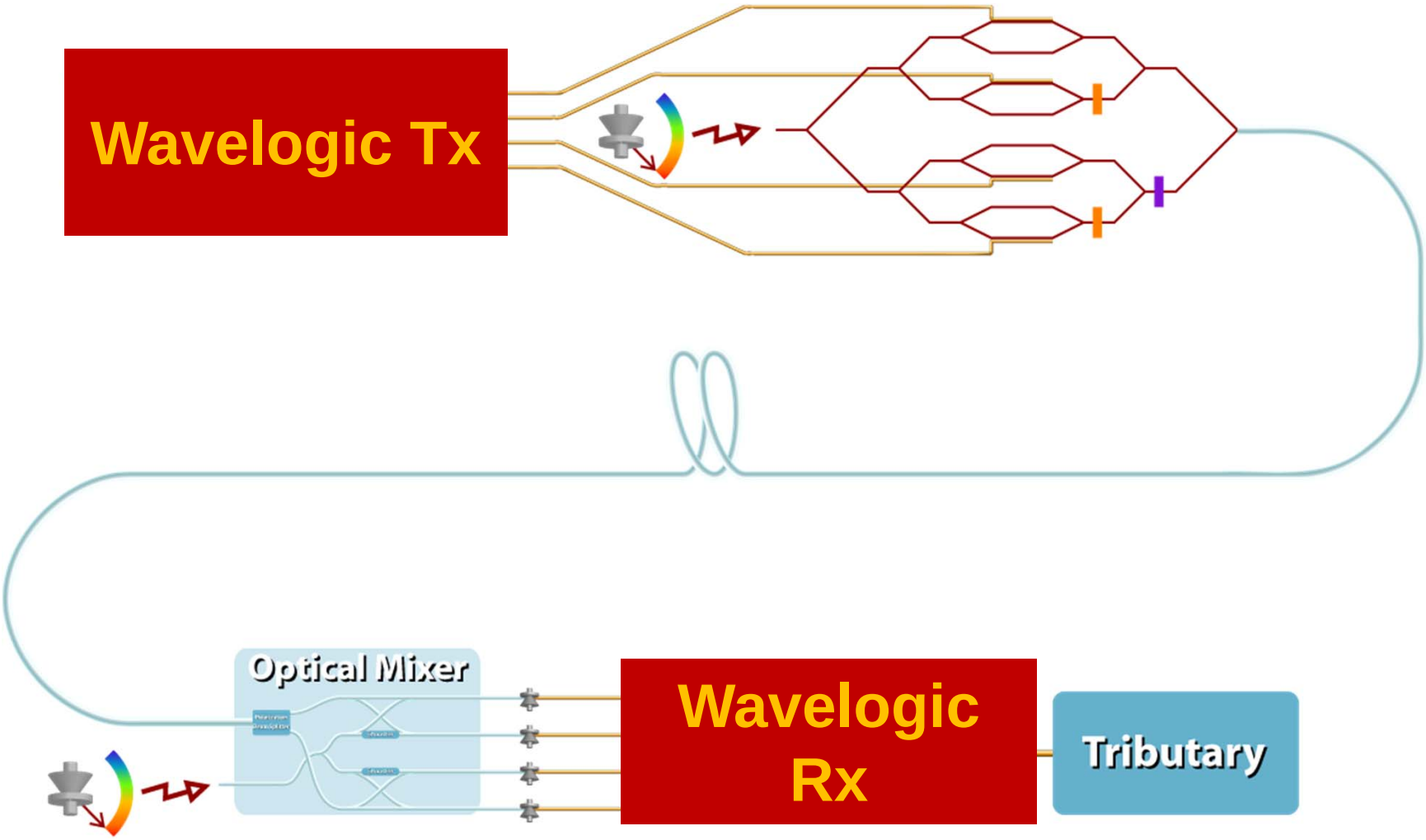
# Linear Modulation of E-field

Four
Dimensional
Linear
Modulation

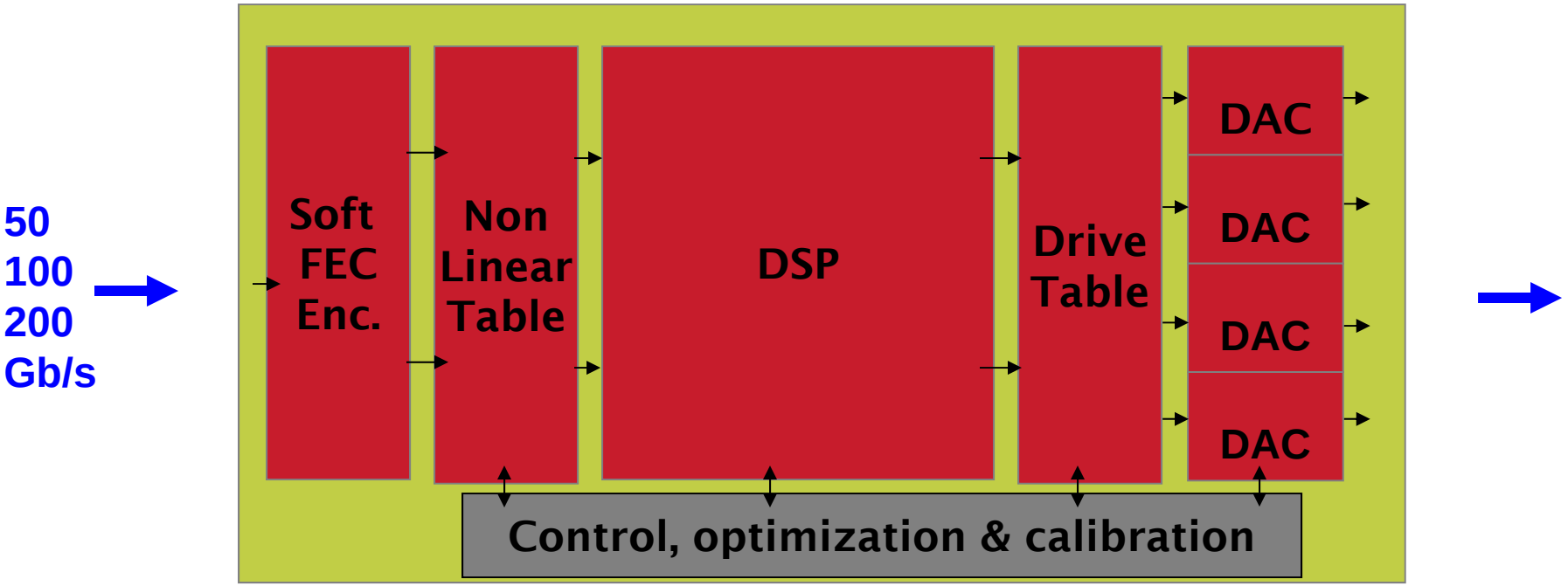
Four
Electrical
Drive
Signals



# Coherent Optical Engine



# WaveLogic 3 Transmit Processing

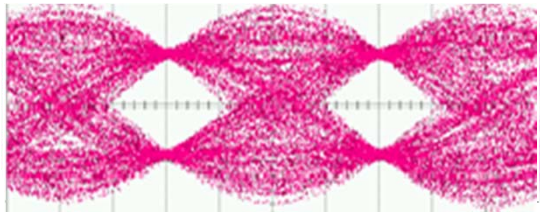



## ~ 22M Gates

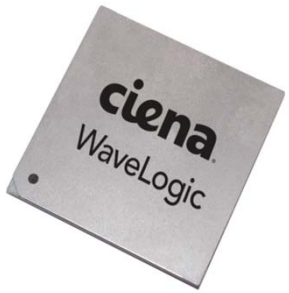
- DSP = 20Mgates, DAC = 2Mgates

# Spectral Shaping

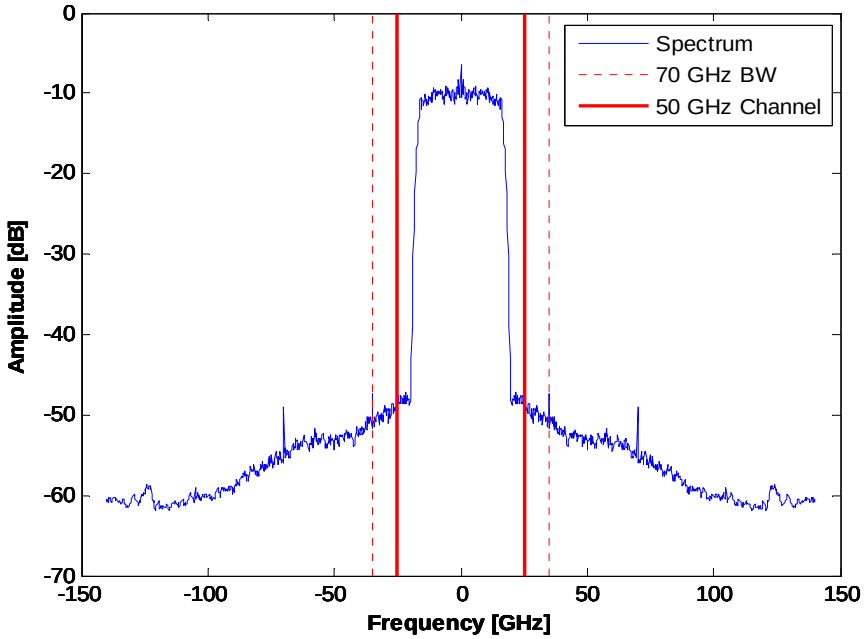
- Minimize spectral utilization for a given capacity to increase spectral efficiency
- DAC technology enables this



time

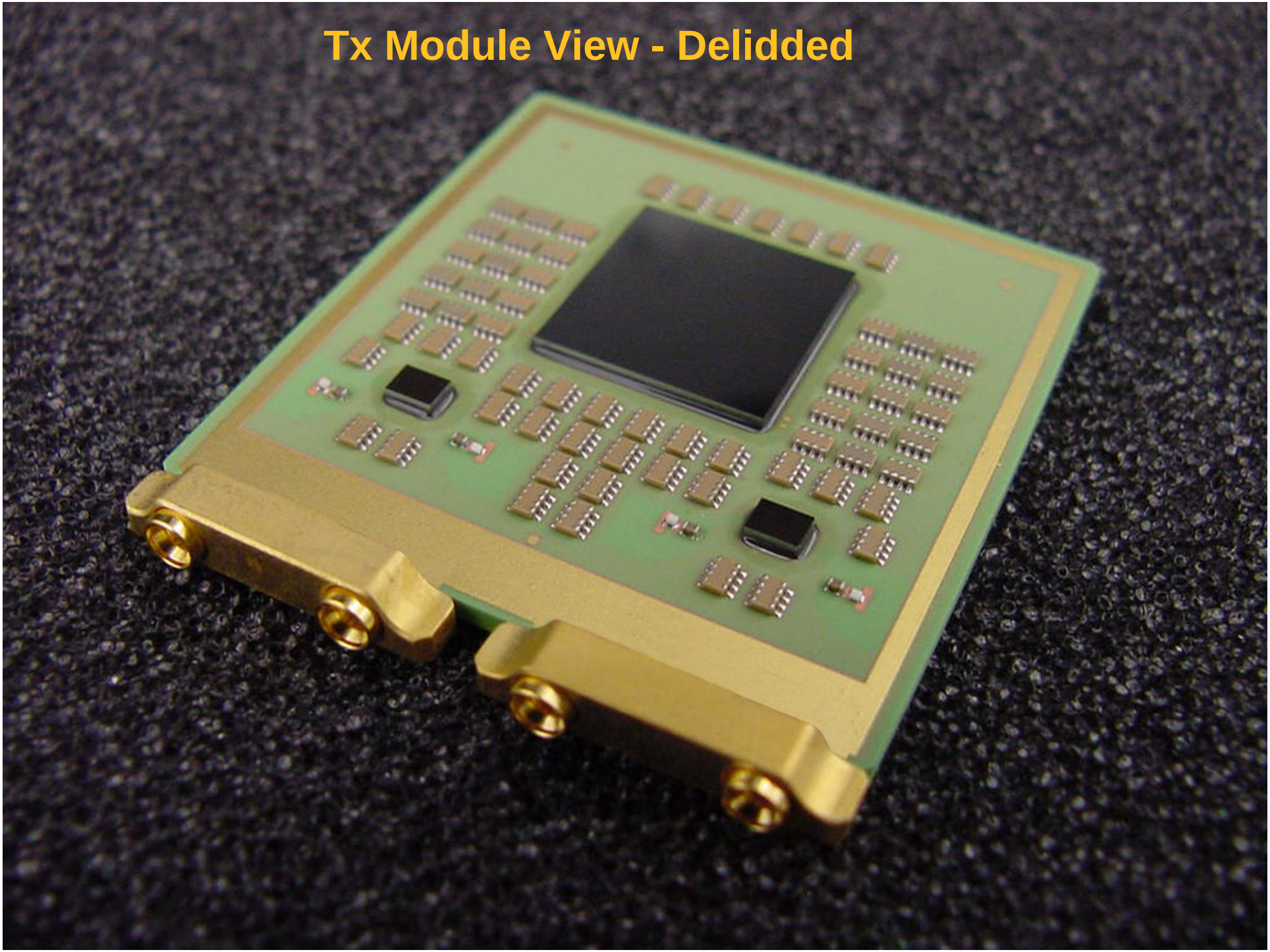



$\alpha = 1.0$

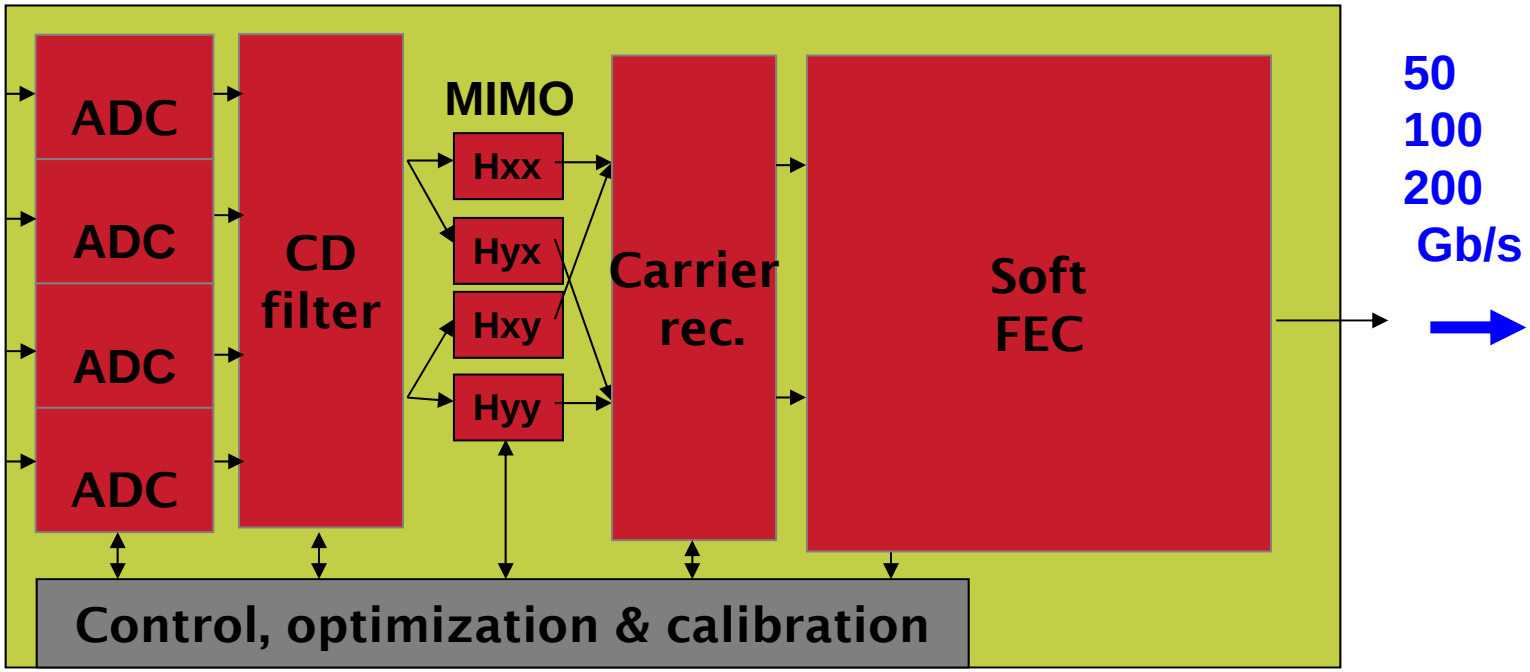



frequency

# Tx Module View - Delidded

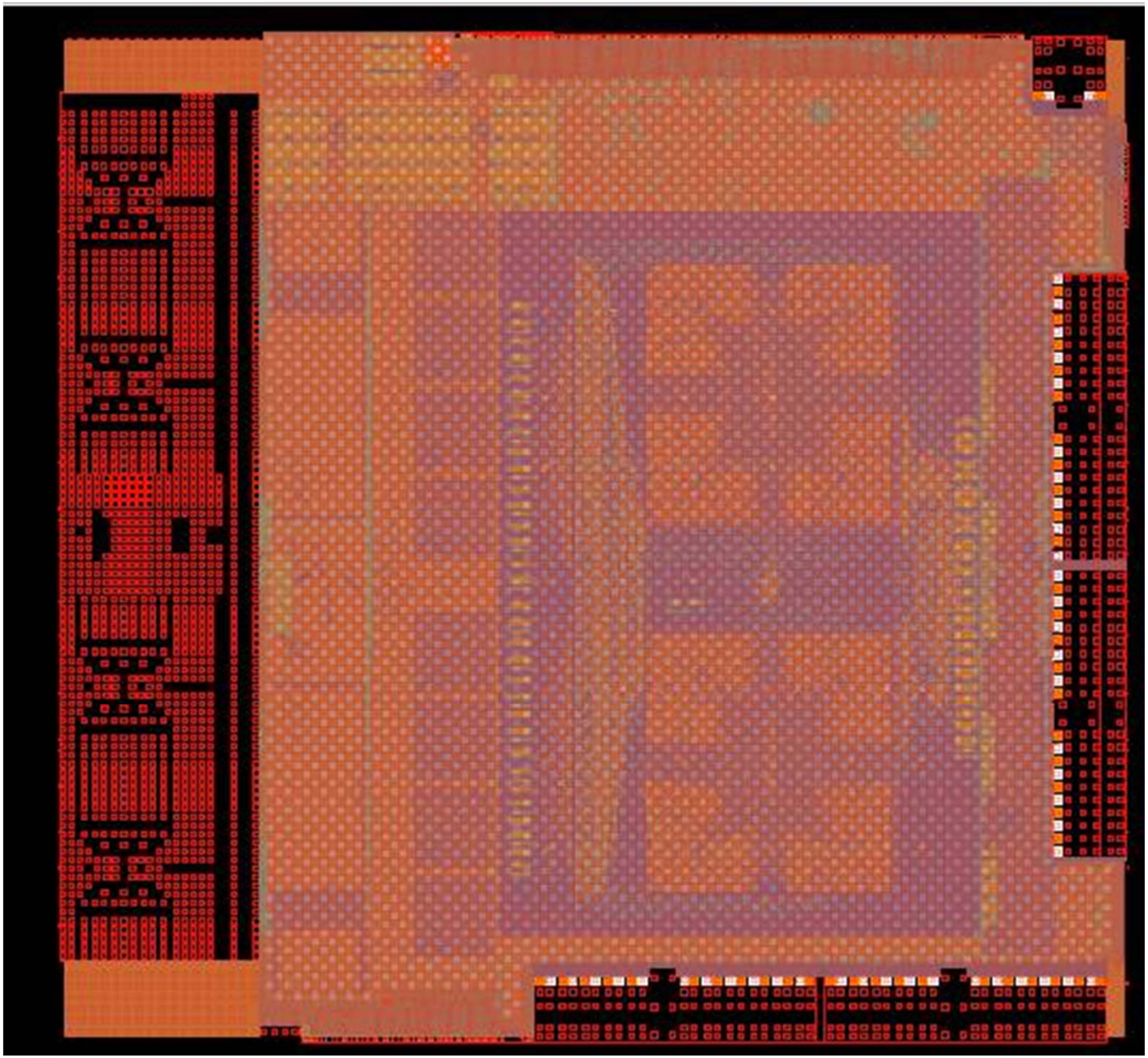


# WaveLogic 3 Receive Processing



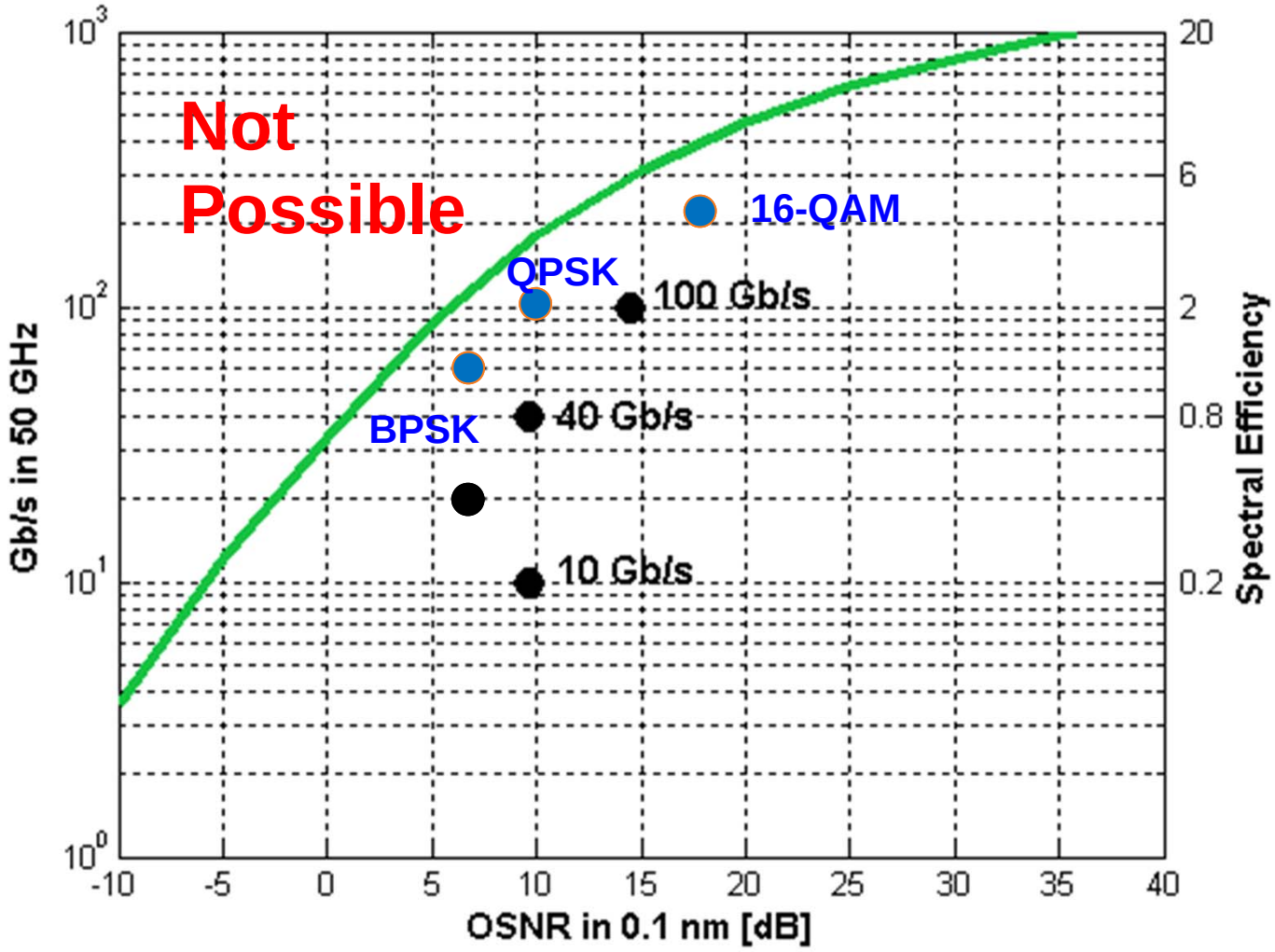
# WaveLogic 3 Rx ASIC

- 70T ops/s
- 32 nm CMOS
- 150M gates
- 3.7 km wire

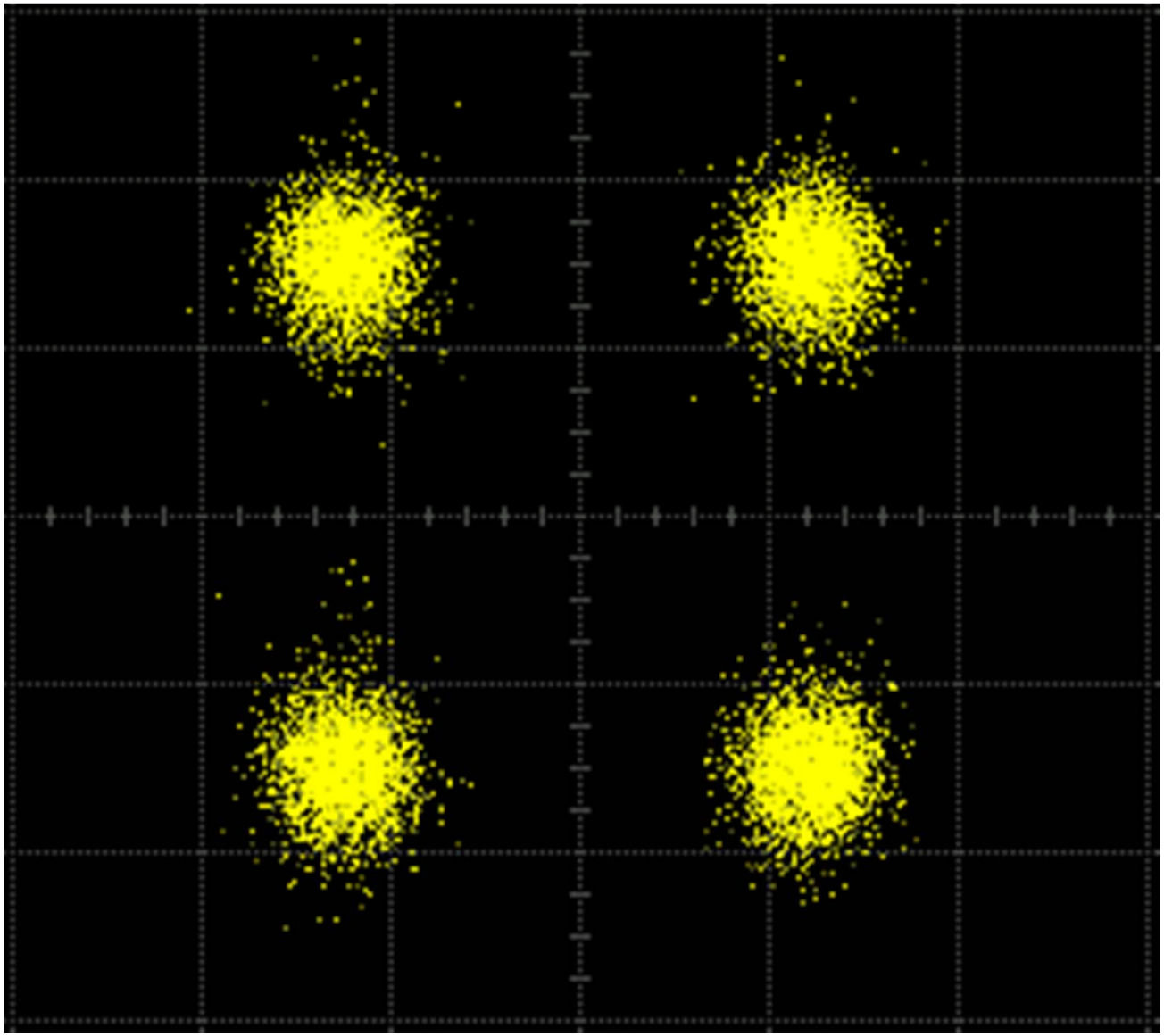


# WaveLogic 3  Flexible Transceiver

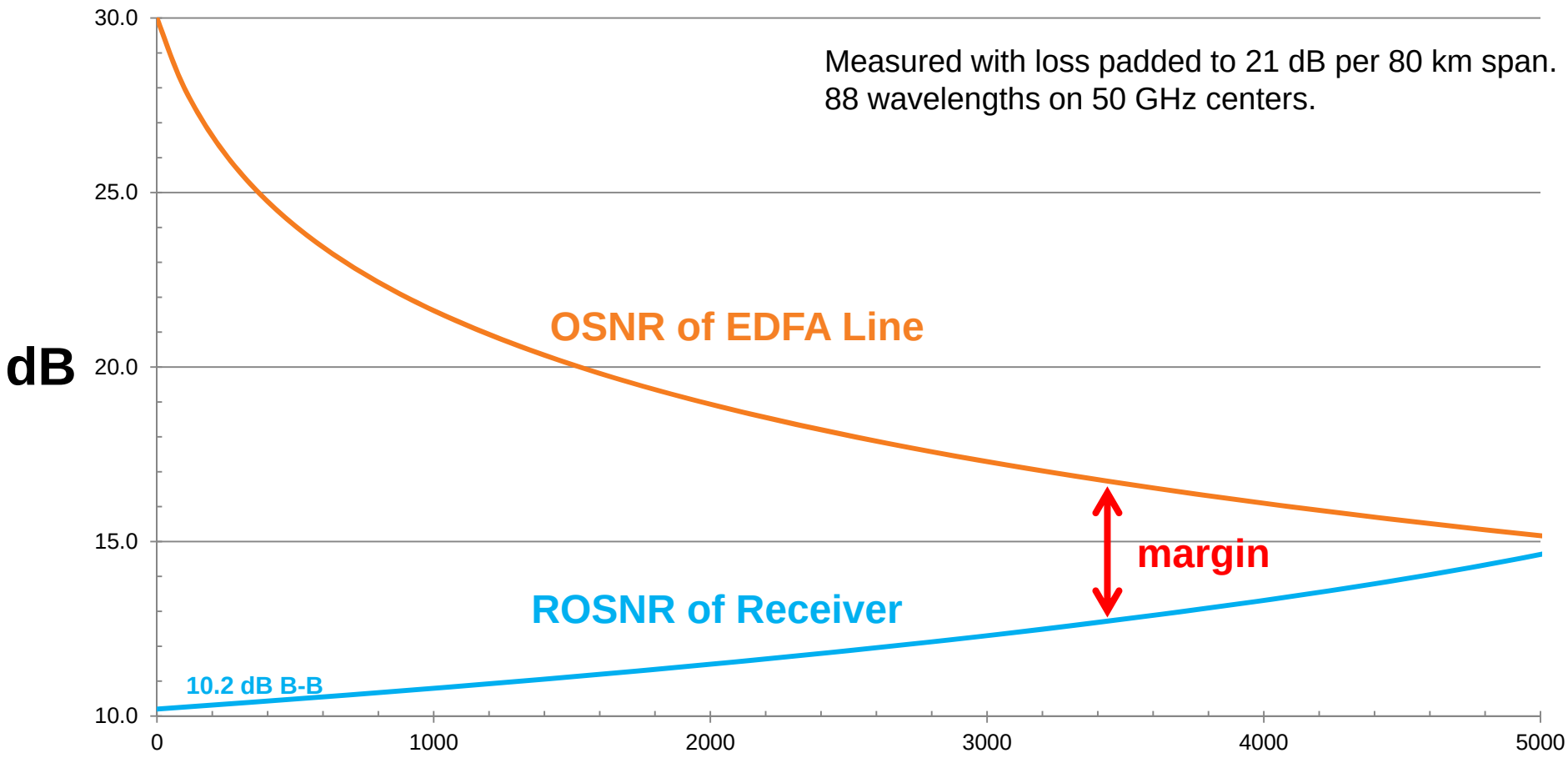
# Spectral Efficiency is ultimately limited by OSNR



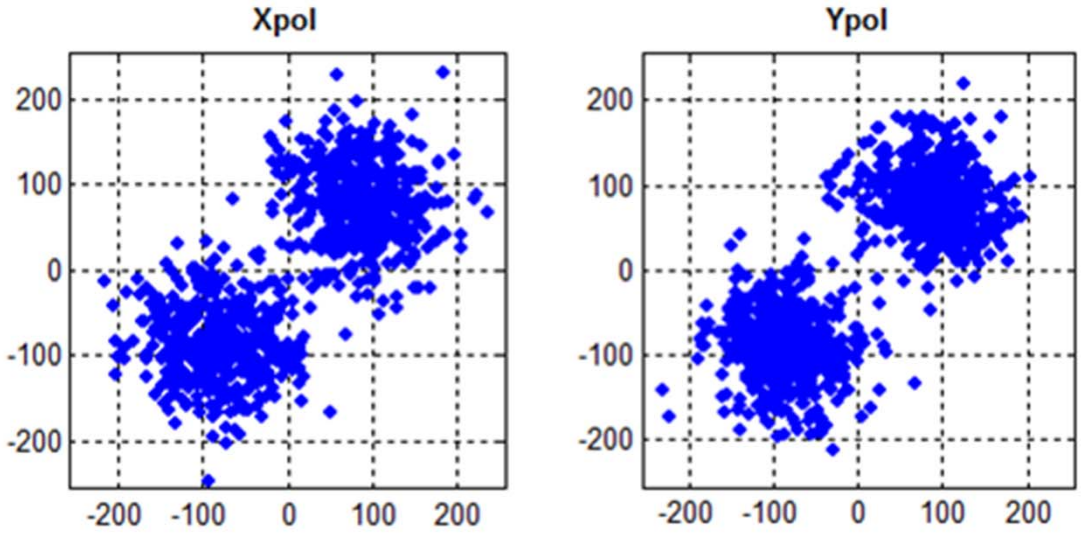
# QPSK:  100 Gb/s in 50 GHz

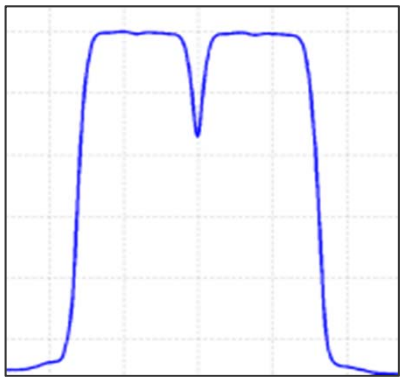


# Typical Reach with QPSK

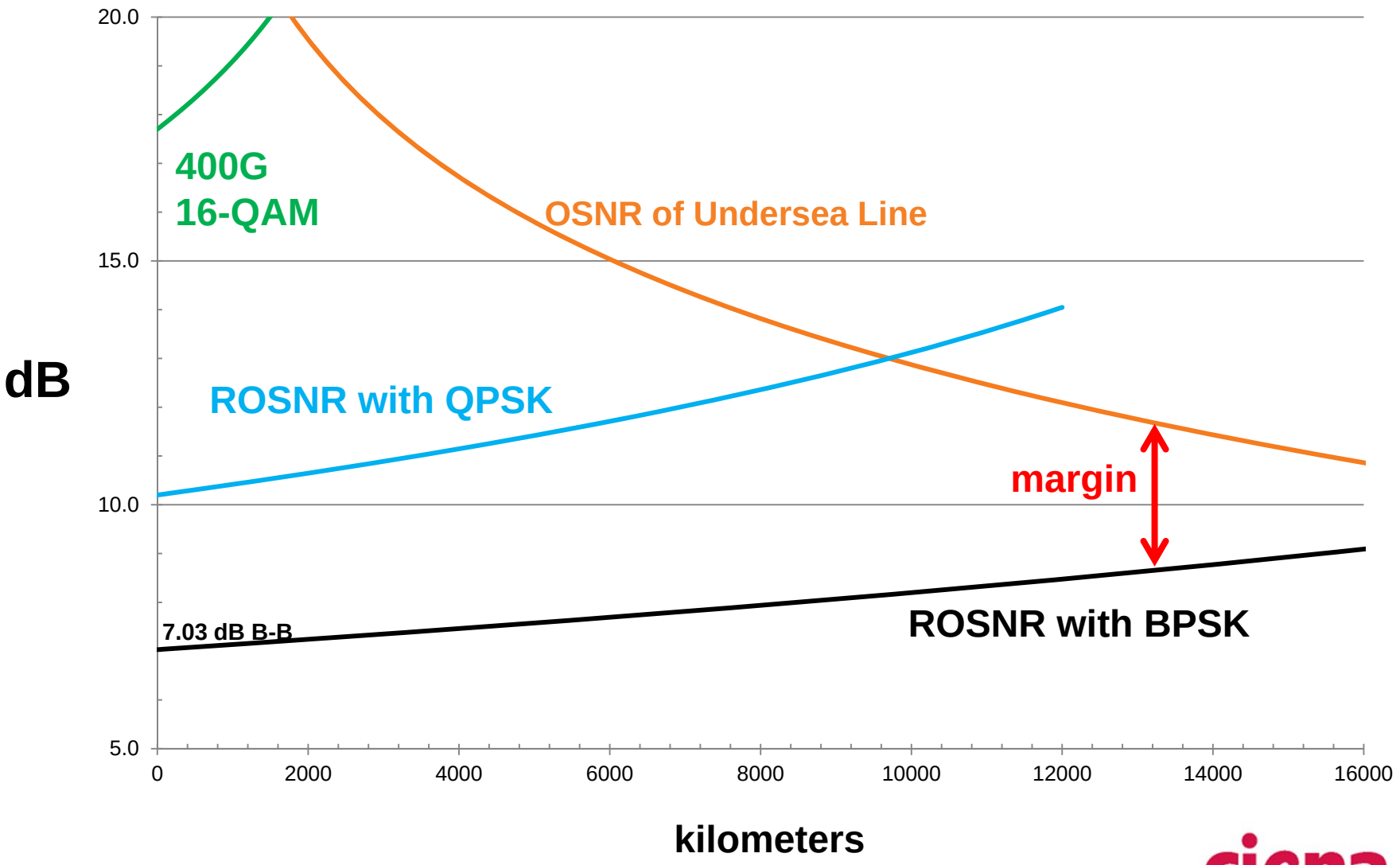


# BPSK: Transpacific Reach on Existing Cables

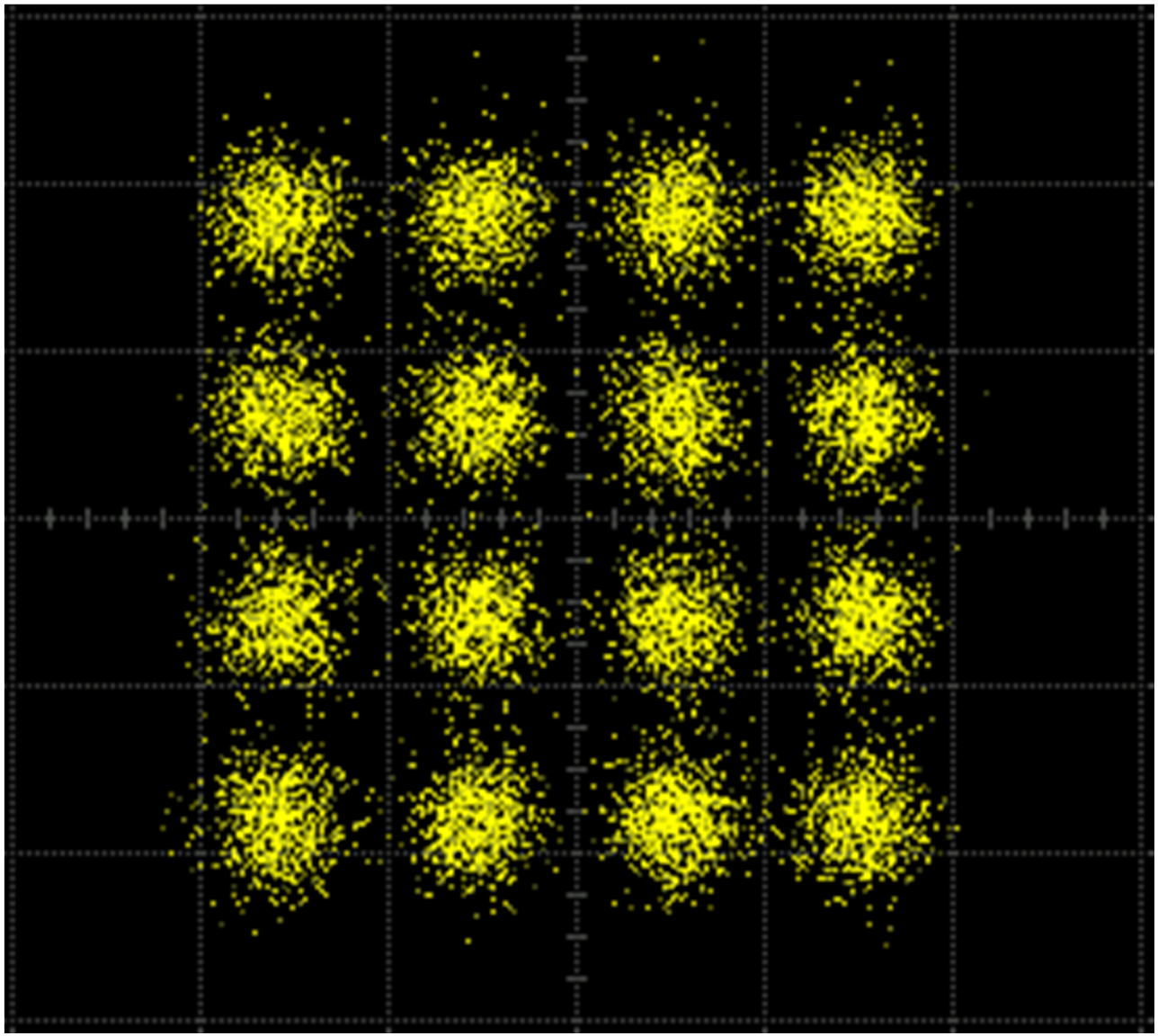


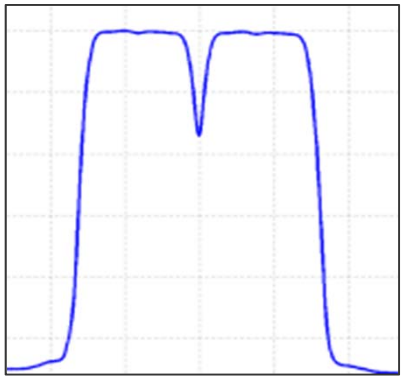



# Undersea Performance



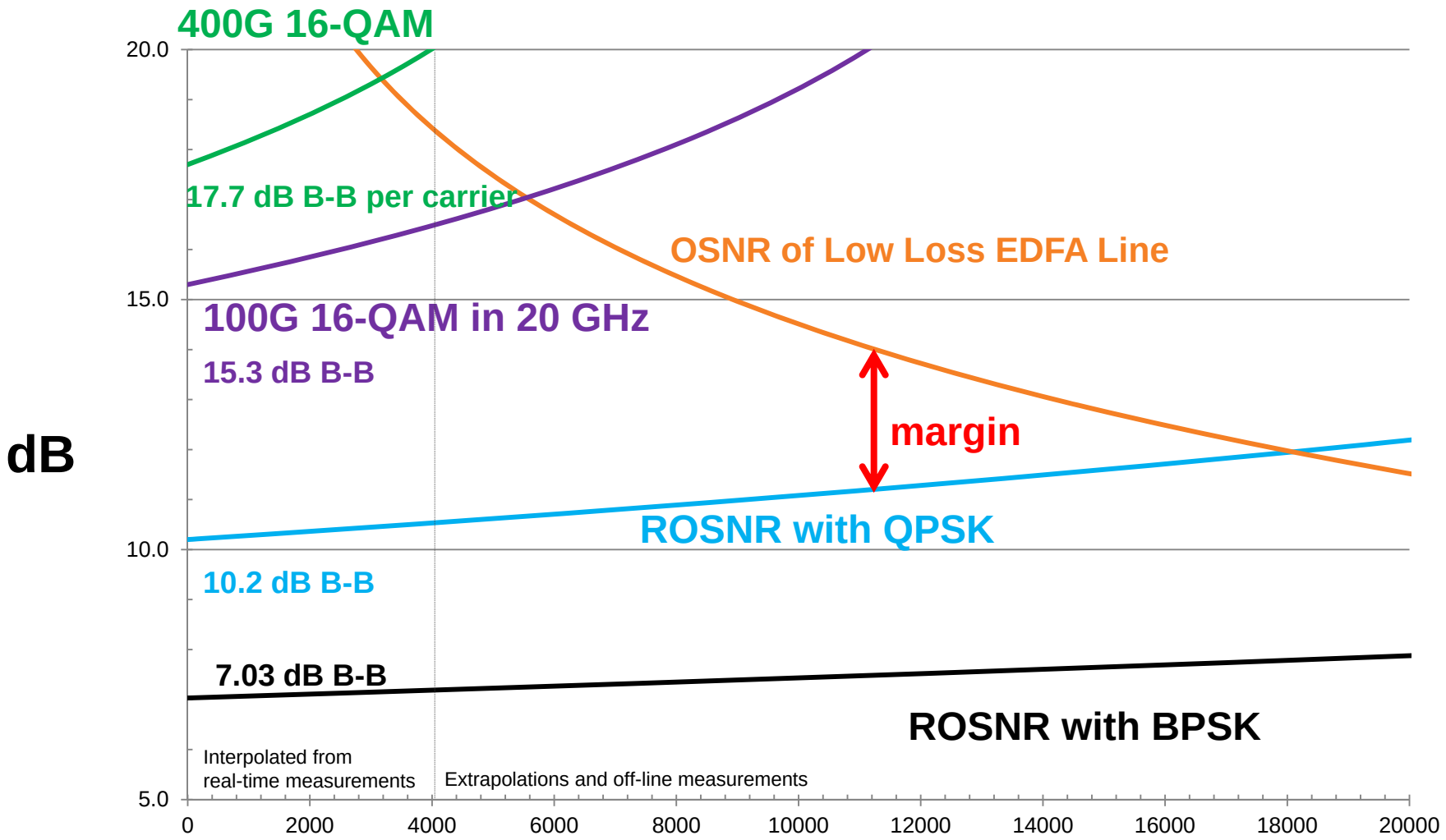
# 16-QAM: 400 Gb/s in 83 GHz for Regional Networks





**4.8 bits/second/Hertz**
**750 km typical reach**

# Typical Performance with Low Loss Fiber



# Flexible Transciever

Received Constellation, X-Polarization

Received Constellation, Y-Polarization

- 35 Gbaud,  captured from Rx after 300 km
- Production WaveLogic 3 Hardware
- Firmware by Ian Roberts
- 10GE  test set;  traffic daisy-chained
- Error Free, even during transitions