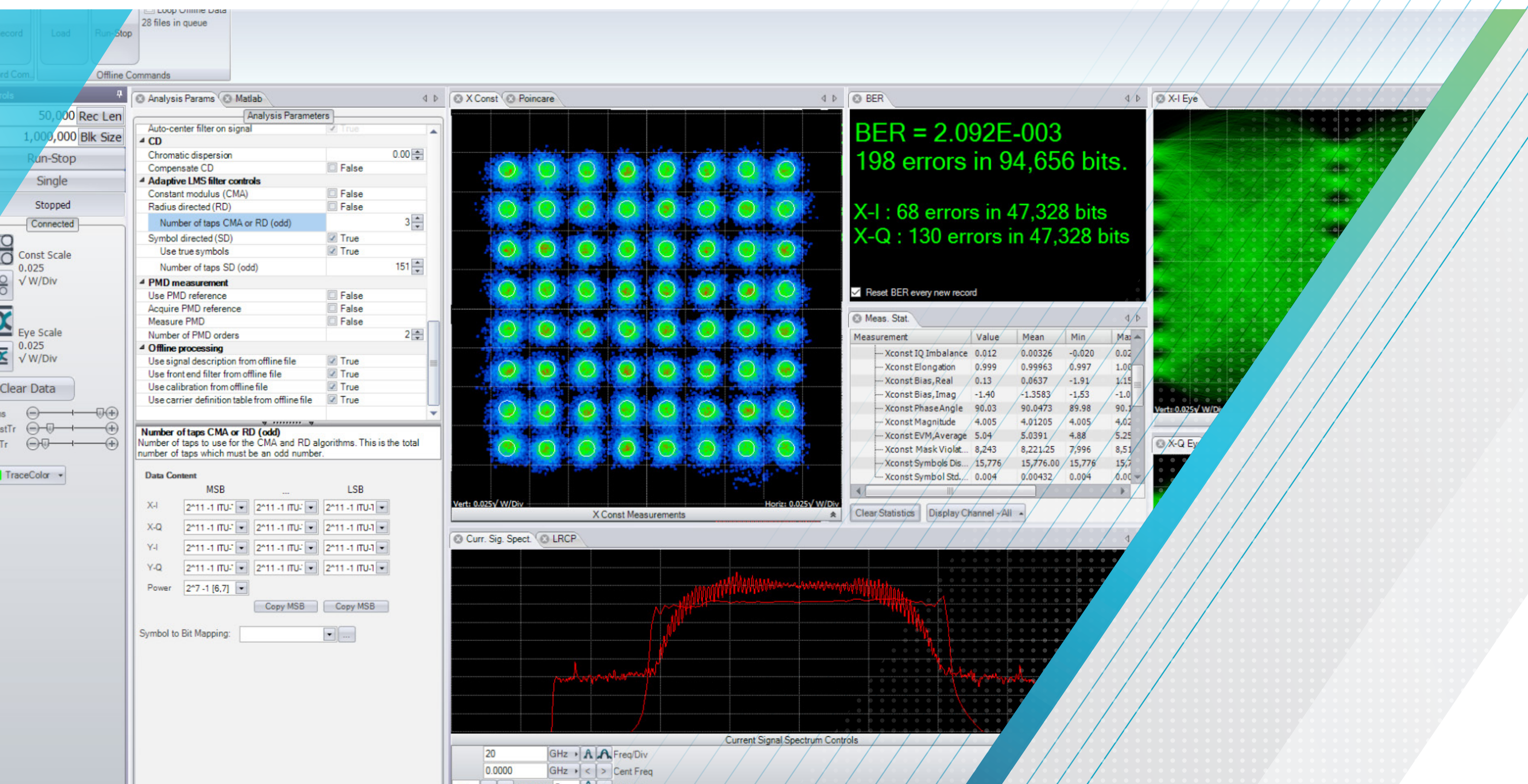
# Coherent Optical Measurements

## Common Transmitter and Receiver Impairments

POSTER

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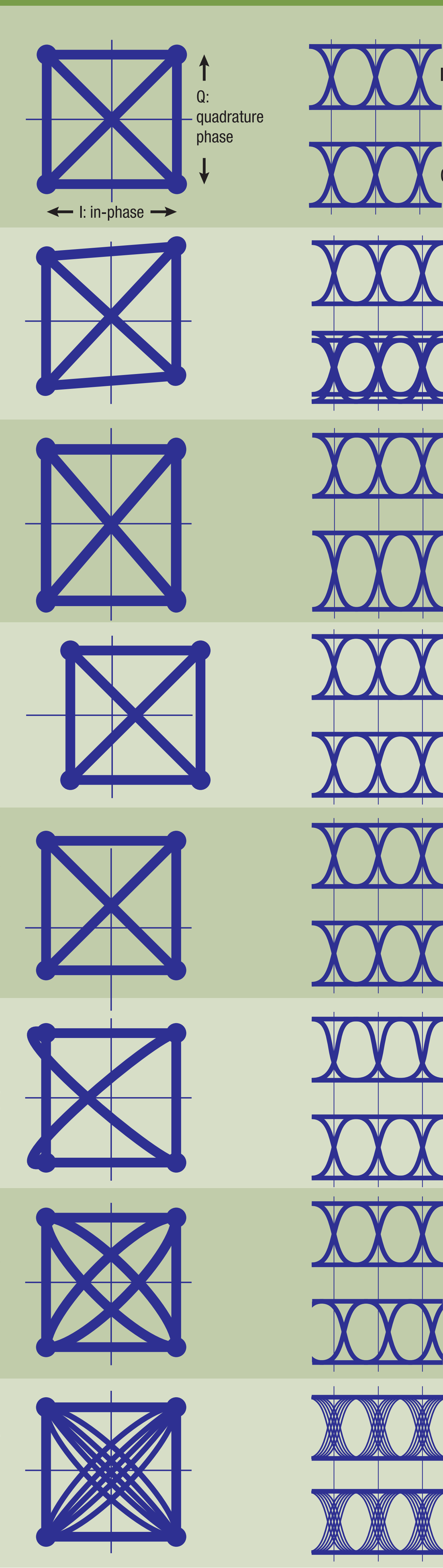
## Common Transmitter and Receiver Impairments

### Common Modulation Formats

| Format | Polarization | 28 GBaud | 32 GBaud | 40 GBaud | 46 GBaud | 56 GBaud | 64 GBaud |
|---|---|---|---|---|---|---|---|
| NRZ/PAM2 – 1 bit per Baud (symbol) | Single Polarization | 28 Gb/s | 32 Gb/s | 40 Gb/s | 46 Gb/s | 56 Gb/s | 64 Gb/s |
| BPSK – 1 bit per Baud (symbol) per polarization | Single Polarization | 28 Gb/s | 32 Gb/s | 40 Gb/s | 46 Gb/s | 56 Gb/s | 64 Gb/s |
| | Dual Polarization | 56 Gb/s | 64 Gb/s | 80 Gb/s | 92 Gb/s | 112 Gb/s | 128 Gb/s |
| PAM4 – 2 bits per Baud (symbol) | Single Polarization | 56 Gb/s | 64 Gb/s | 80 Gb/s | 92 Gb/s | 112 Gb/s | 128 Gb/s |
| QPSK – 2 bits per Baud (symbol) per polarization | Single Polarization | 56 Gb/s | 64 Gb/s | 80 Gb/s | 92 Gb/s | 112 Gb/s | 128 Gb/s |
| | Dual Polarization | 112 Gb/s | 128 Gb/s | 160 Gb/s | 184 Gb/s | 224 Gb/s | 256 Gb/s |
| 8PSK – 3 bits per Baud (symbol) per polarization | Single Polarization | 84 Gb/s | 96 Gb/s | 120 Gb/s | 138 Gb/s | 168 Gb/s | 192 Gb/s |
| | Dual Polarization | 168 Gb/s | 192 Gb/s | 240 Gb/s | 276 Gb/s | 336 Gb/s | 384 Gb/s |
| 8QAM – 3 bits per Baud (symbol) per polarization | Single Polarization | 84 Gb/s | 96 Gb/s | 120 Gb/s | 138 Gb/s | 168 Gb/s | 192 Gb/s |
| | Dual Polarization | 168 Gb/s | 192 Gb/s | 240 Gb/s | 276 Gb/s | 336 Gb/s | 384 Gb/s |
| 16QAM – 4 bits per Baud (symbol) per polarization | Single Polarization | 112 Gb/s | 128 Gb/s | 160 Gb/s | 184 Gb/s | 224 Gb/s | 256 Gb/s |
| | Dual Polarization | 224 Gb/s | 256 Gb/s | 320 Gb/s | 368 Gb/s | 448 Gb/s | 512 Gb/s |
| 32QAM – 5 bits per Baud (symbol) per polarization | Single Polarization | 140 Gb/s | 160 Gb/s | 200 Gb/s | 230 Gb/s | 280 Gb/s | 320 Gb/s |
| | Dual Polarization | 280 Gb/s | 320 Gb/s | 400 Gb/s | 460 Gb/s | 560 Gb/s | 640 Gb/s |
| 64QAM – 6 bits per Baud (symbol) per polarization | Single Polarization | 168 Gb/s | 192 Gb/s | 240 Gb/s | 276 Gb/s | 336 Gb/s | 384 Gb/s |
| | Dual Polarization | 336 Gb/s | 384 Gb/s | 480 Gb/s | 552 Gb/s | 672 Gb/s | 768 Gb/s |

### Constellation/Eye Measurements and Common Transmitter Impairments




**Ideal Constellation**

measurement: **Phase Angle**

**Phase Angle:** The phase angle between the two tributaries, measured in degrees. 90° is ideal.

possible transmitter impairment: **I/Q Quadrature Error**
The modulator I/Q quadrature bias is not optimal.

measurement: **Elongation**

**Elongation:** The mean inter-symbol spacing of the quadrature (Q) signals divided by the mean inter-symbol spacing of the in-phase (I) signals. "Tall" constellations have Elongation > 1.

possible transmitter impairment: **I/Q Gain Imbalance**
"Tall" constellations due to Q gain greater than I gain.
"Wide" constellations due to I gain greater than Q gain.

measurement: **Real Bias**

**Real Bias:** The real part of the mean value of all symbols divided by the magnitude; expressed as a percent. A positive value means the constellation is shifted right.

possible transmitter impairment: **Real Bias Error**
The modulator real, or I, bias point is not optimally set.

measurement: **Imaginary Bias**

**Imaginary Bias:** The imaginary part of the mean value of all symbols divided by the magnitude; expressed as a percent. A positive value means the constellation is shifted up.

possible transmitter impairment: **Imaginary Bias Error**
The modulator imaginary, or Q, bias point is not optimally set.

measurement: **Crossing Point**

**Crossing Point:** The crossing point of average transitions is not centered vertically within the eye.

possible transmitter impairment: **Duty Cycle Distortion**
The driver amplifier may be assymetrically limiting the signal. This could be caused by improper modulator bias of either I or Q, most likely the one showing the distortion, or assymetric modulator driver amplifier limiting due to amplifier bias error.

measurement: **I/Q Data Skew**

**I/Q Data Skew:** The timing difference between the I or Q data and the power average eye.

possible transmitter impairment: **I or Q Data Delay**
I or Q data is being delayed relative to the other. Most often this is due to electrical delays prior to the signal input to the modulator.

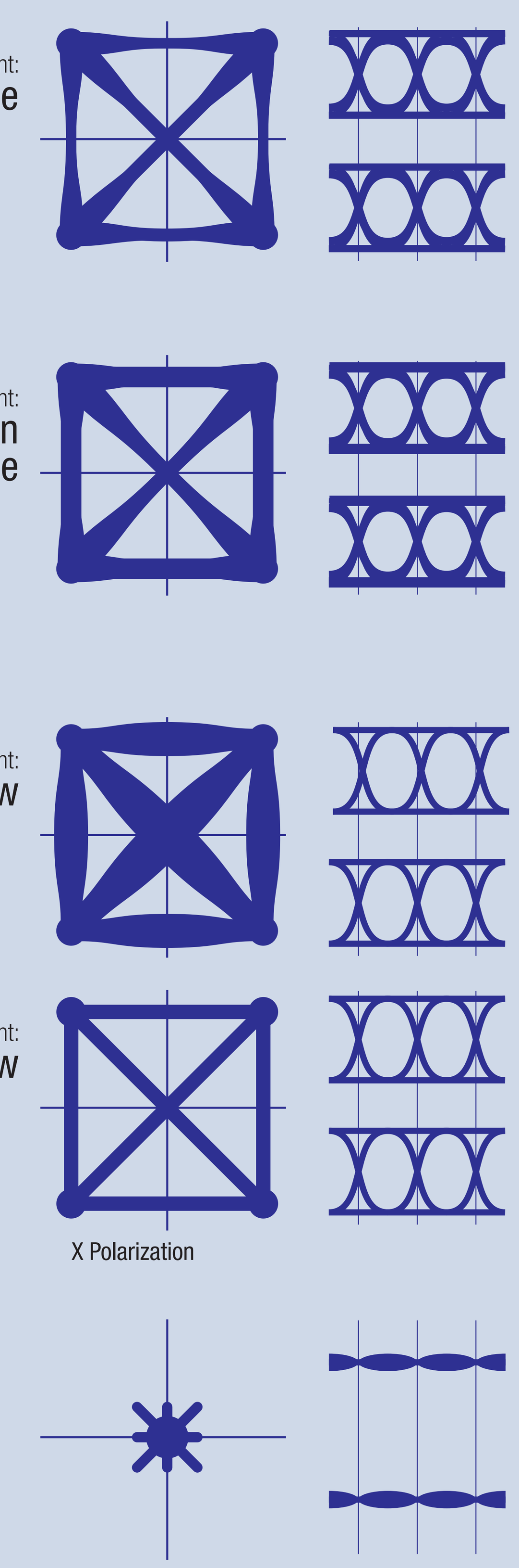
measurement: **Data Jitter**

**I/Q Data Jitter:** The measure of rapid amounts of I/Q data skew.

possible impairment: **Data Jitter**
Either I or Q, or both, have noticeable amounts of jitter. (In the eye diagram shown, the jitter is not correlated between I and Q.) Jitter can be decomposed into many different types all of which occur in the electrical domain before the inputs to the modulator.

### Constellation/Eye Measurements and Common Receiver Impairments

Impairments in transmitters may be simple to diagnose due to the obvious relationships between transmitter gain and bias settings and their result on the constellation and eye diagrams. Impairments in receivers can be more difficult to diagnose in part due to the fact that polarization and phase of the incoming signal is very rarely aligned with the absolute polarization and phase of the receiver hardware. The result of this is that receiver impairments, IQ Phase Angle Error for instance, do not cause the constellation to be tilted as it would for transmitter phase angle error. Rather the affects of the impairments will likely be spread across all polarizations and phases of the recovered signal.




measurement: **Phase Angle**

possible receiver impairment: **IQ Phase Angle Error**
Optical phase angle error within the receiver does not appear as a tilted constellation as with transmitter phase error. Instead, it appears as a dispersion of transitions as they approach their maximum value.

measurement: **IQ Gain Imbalance**

possible receiver impairment: **IQ Gain Error**
IQ gain error in the receiver looks very similar to phase angle error. One noticable difference may be that the rails appear thicker than with IQ phase angle errors.

measurement: **IQ Skew**

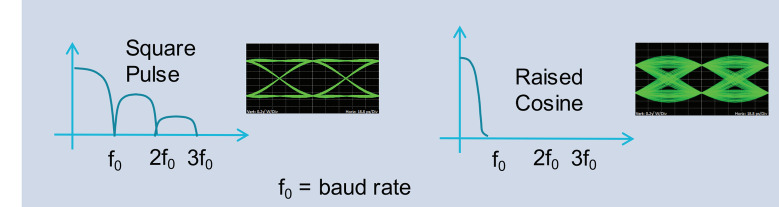
possible receiver impairment: **IQ Skew Error**
If I and Q are being skewed inside the receiver, one eye diagram may be visibly shifted with respect to the other. The constellation traces will become slightly thinner as they approach the constellation points.

measurement: **XY Skew**

possible receiver impairment: **XY Skew Error**
On a single-polarization signal, the unused polarization should appear with minimal signal. If the receiver is adding skew between the X and Y polarizations, there will be crosstalk appearing from one polarization to the other. Normally the constellation for the unused polarization should be a minimal point and the eye diagram a minimal line. As the skew and resulting crosstalk increases, increasing data structure can be seen on the unused polarization.

### Bandwidth Requirement

- Square Pulse (sin(πfT)/(πfT) shaped spectrum)
  - "Capturing 5th harmonic" means >2.5 times baud rate.
  - Older NRZ standards required 0.75 times baud rate with specific roll-off shape.
- Raised Cosine Spectrum
  - Bandwidth requirement is 0.5 times baud rate with specific roll-off or specified channel.
  - Total bandwidth requirement is (1+Alpha)*0.5*Baud_Rate.



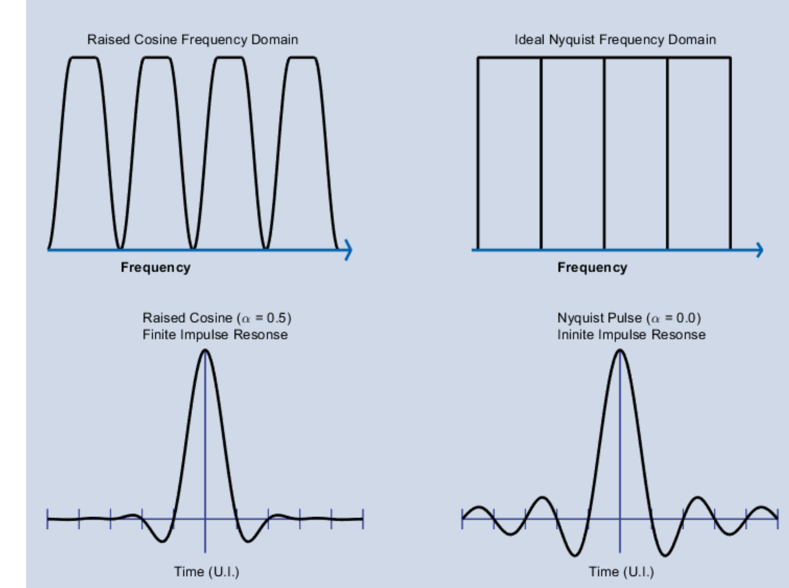

| | Raised Cosine | | |
|---|---|---|---|
| $f_0$ GBd | 6-dB BW | Total BW α = 0.15 | Total BW α = 0.05 |
| **32** | 16 | 18.4 | 16.8 |
| **64** | 32 | 36.8 | 33.6 |
| **80** | 40 | 46 | 42 |
| **120** | 60 | 69 | 63 |

Bandwidth Values in GHz
Total BW → where spectrum goes to zero

### Pulse Shaping

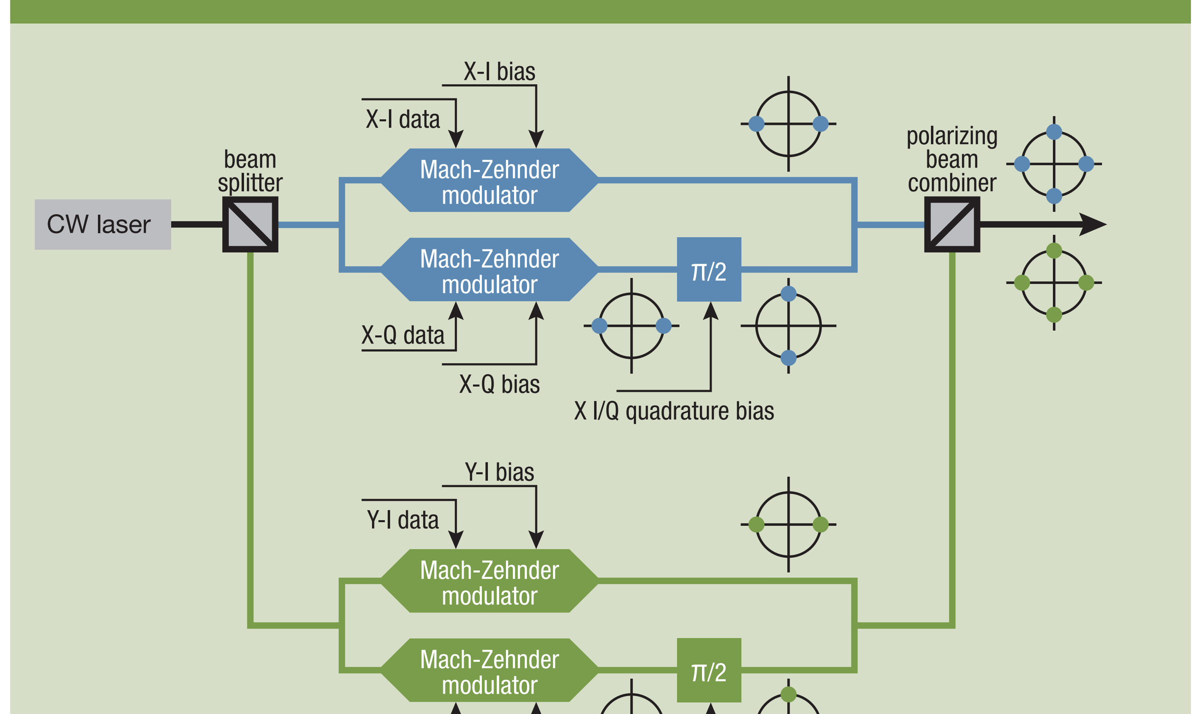
**Minimum ISI with minimum Bandwidth**

- In DWDM network channels are placed close together.
- Goal is to minimize ISI while not having signal content outside of the allocated frequency band.



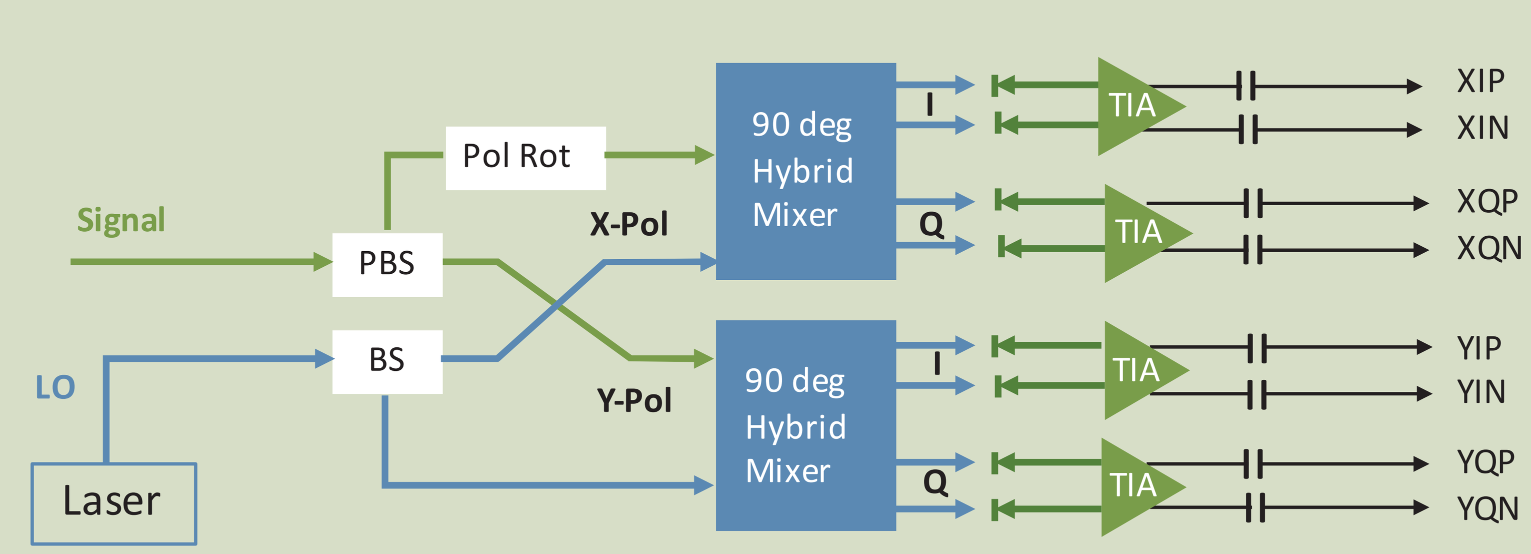

Frequency Domain (above) and Time Domain (below) representation of a raised cosine filter. Left signal has a roll-off factor of 0.5, leading to a finite impulse response, while the right has a roll-off factor of 0 leading to an infinite impulse response.

### OIF Reference Transmitter



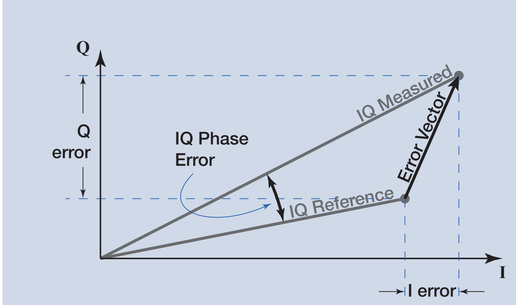

Optical polarization multiplexed quadrature modulated transmitter as outlined by the Optical Internetworking Forum.

### Dual Pol Coherent Receiver




### EVM Measurement

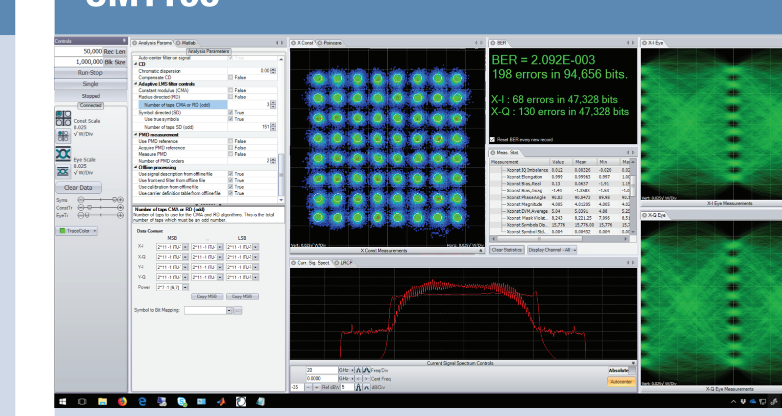
Error Vector Magnitude (EVM) provides a metric for quantifying the quality of a complex modulated signal. The rms EVM is usually expressed in percent of the magnitude of the longest reference vector.




$$EVM_{rms} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} EVM(n)^2}$$

EVM measurement specification per IEC/TR 61282-10, Version 1.0.

### OM1106

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