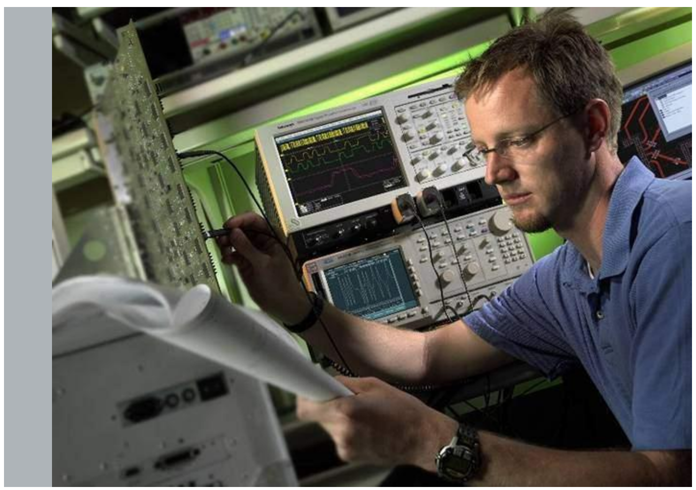
Advancing Test in Coherent Transmission Systems



Daniel van der Weide

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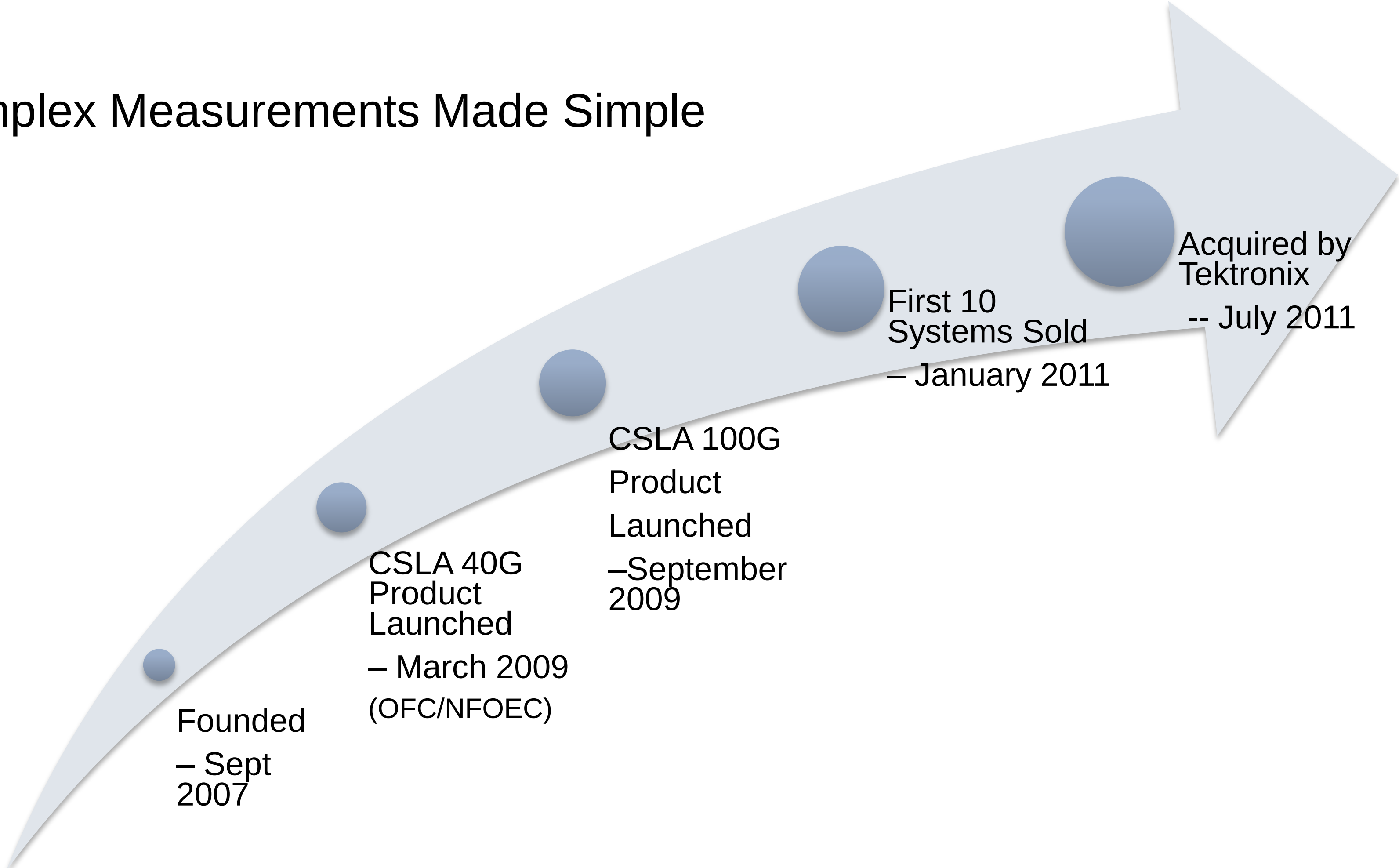
Optametra History

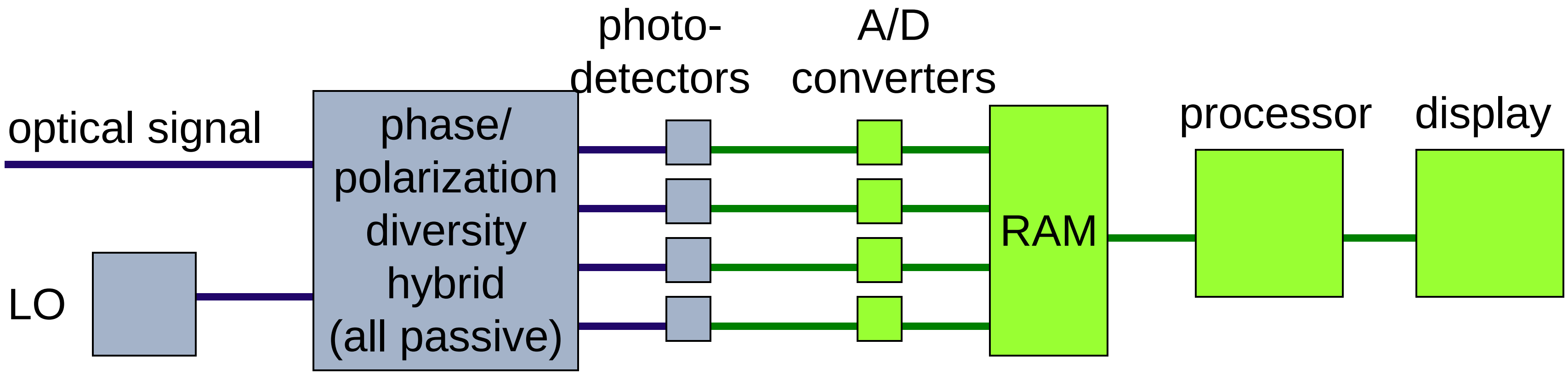
Complex Measurements Made Simple



What does a Coherent Lightwave Signal Analyzer do?

- Enables total calibration to make hardware “golden”
  - Analog front end path gains, phase angles
  - Frequency response
  - Path delays (skew)
- Removes laser frequency offset
- Removes laser phase fluctuations
- Presents resulting modulation field
  - Constellation
  - Eye Diagram
  - Q plot
  - EVM
- Can also *model* receiver function and even impairments
  - Remove CD, ISI, etc.; measure BER
  - Emulate a delay-line interferometer for differential signaling

Coherent Lightwave Signal Analyzer Architecture

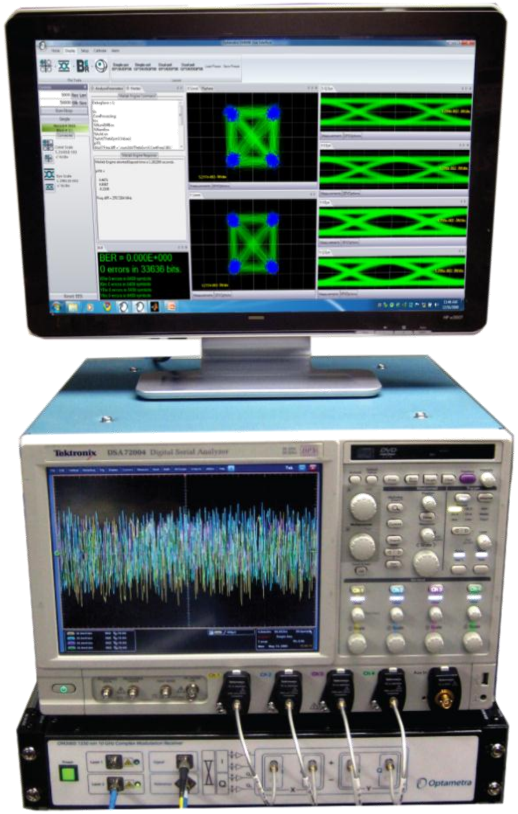


- The optical signal analyzer uses burst-mode coherent detection – it includes a local oscillator laser and a phase/polarization diverse hybrid
- Outputs from several photodetectors are digitized by high speed (e.g. 50 Gs/s) A/D converters for an interval of time and stored in RAM
- A microprocessor asynchronously reads the values from RAM and computes the required parameters of the signal
- All the information about the signal over the interval of time is known
  – electric field (in-phase & quadrature parts) in both polarization states
- In principle any signal parameter can be deduced by an appropriate algorithm

OM4000 Optical Modulation Analyzer Series

Complete and open solutions to complex measurement challenges in long-haul fiber-optic communications

- Advanced dual-polarization in-phase and quadrature receiver with integrated signal and reference tunable laser sources
- Open-architecture MATLAB-based computational engine offers powerful phase-recovery analyses with polarization, bit-error rates, and record/playback
- Graphical user interface controls frequently-used instrument functions:
  - Laser control
  - Modulation schemes
  - PRBS or user-generated data
- Works with all major real-time oscilloscopes
- Easily upgradable



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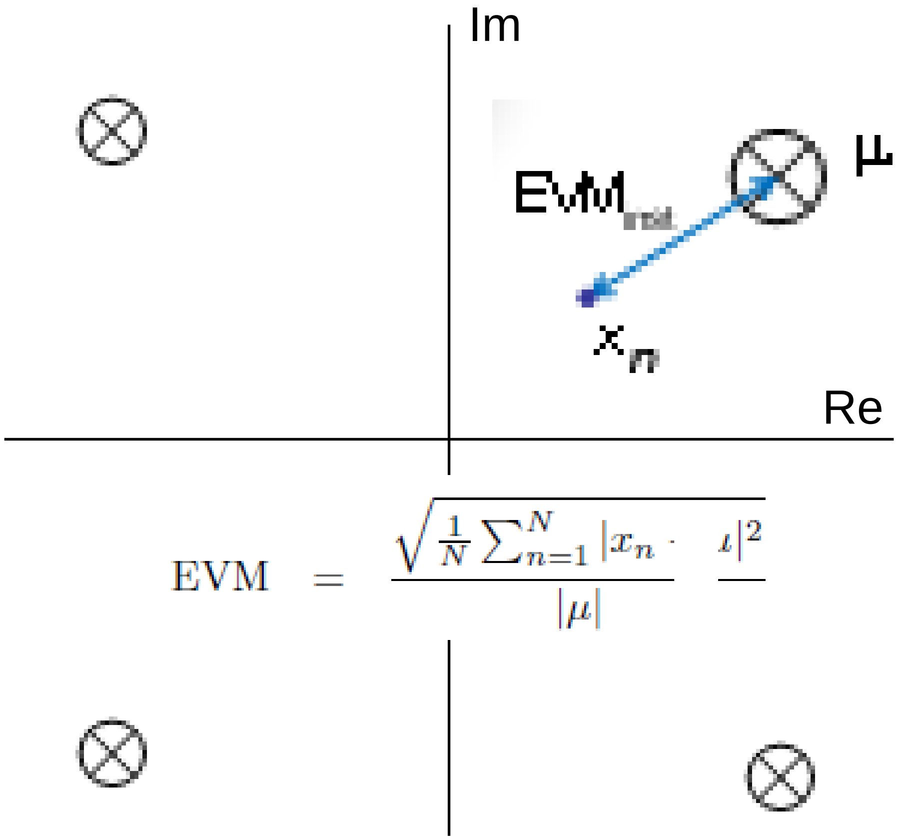
Why do I need a Coherent Lightwave Signal Analyzer?

- Understand and optimize optical networks employing advanced modulation
  - Measure constellation parameters, quadrature and modulator bias values, symbol masks, EVM, signal and phase spectra, BER, Q vs. decision threshold
  - Save time, enable a wider range of users
- Transition from R&D to qualification and production environments
  - Enable automation
- Test equalization and phase recovery algorithms
  - CD, PMD, ISI
- Understand effects of bandwidth limitations
  - At the transmitter, digitizer, and receiver

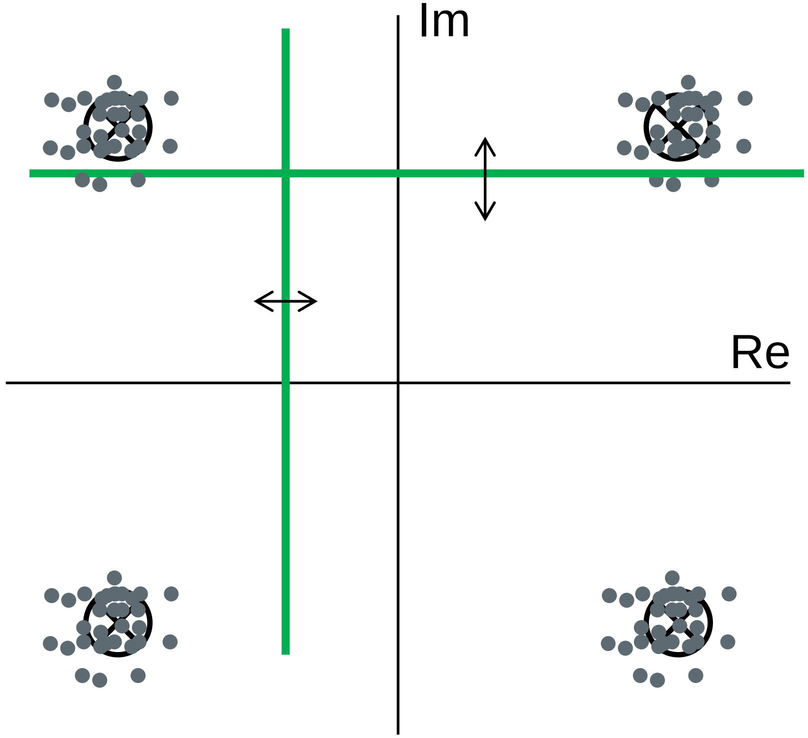
Measuring TX Constellation Imperfections: EVM



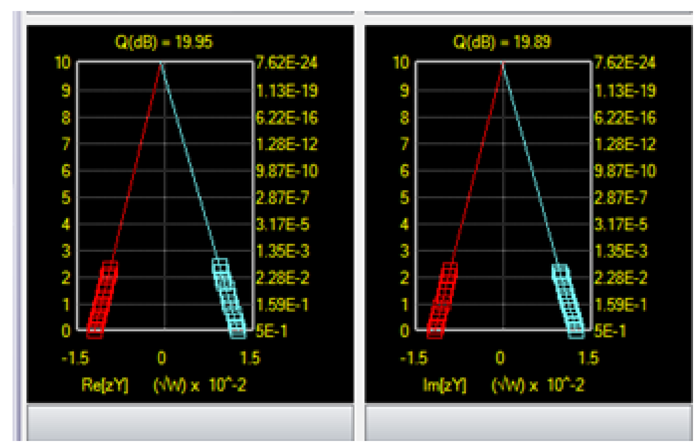
$$\mathrm{EVM} = \frac{\sqrt{\frac{1}{N}\sum_{n=1}^{N}|x_n - \mu|^2}}{|\mu|}$$

- Distance of a symbol point from the ideal location.
- Instantaneous or rms value
- Normalized to ideal symbol magnitude
- QAM EVM often normalized to largest symbol magnitude

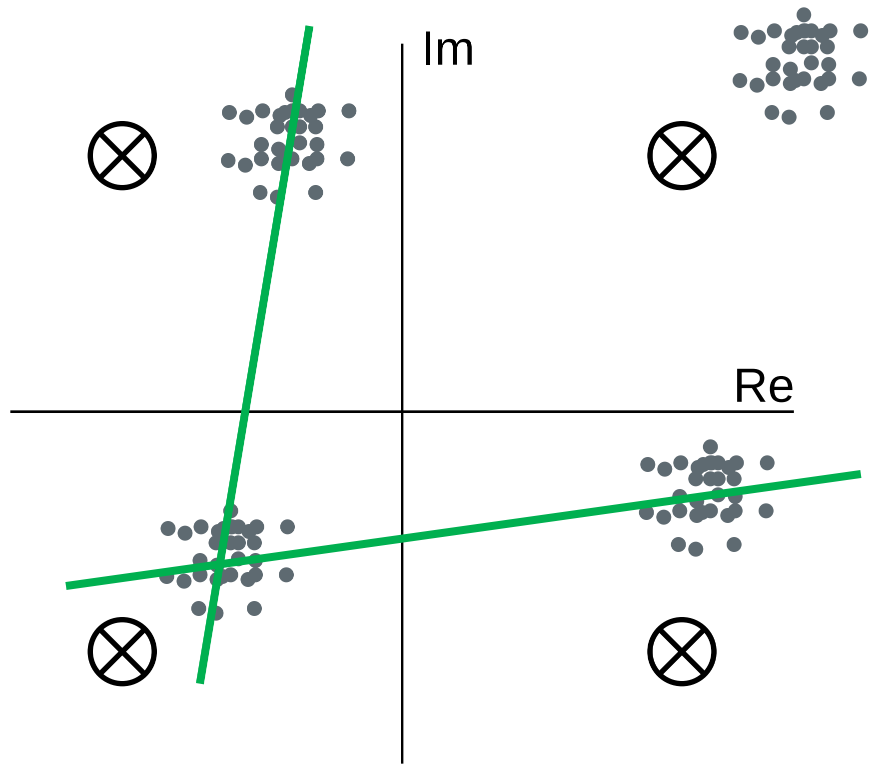
Measuring TX Constellation Imperfections: Q-factor

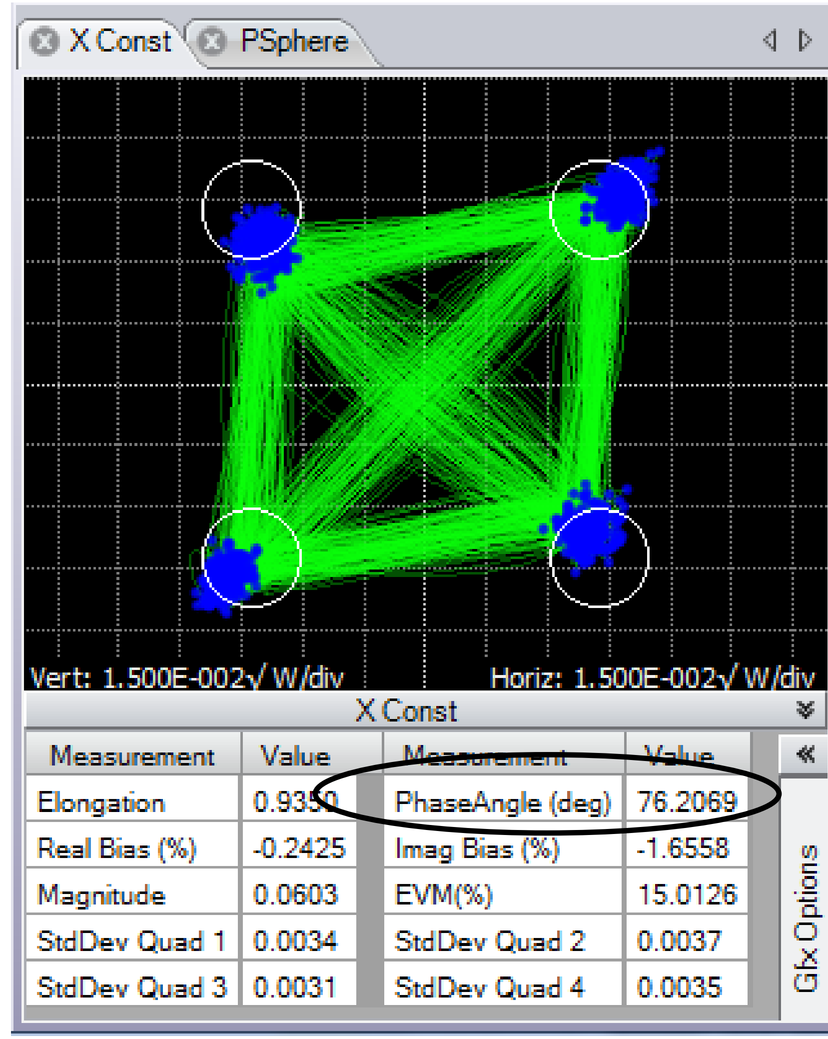


- Counts errors as decision threshold is moved.
- Errors fitted to error function in “Q-space”
- → Plot, max-Q and optimum decision threshold

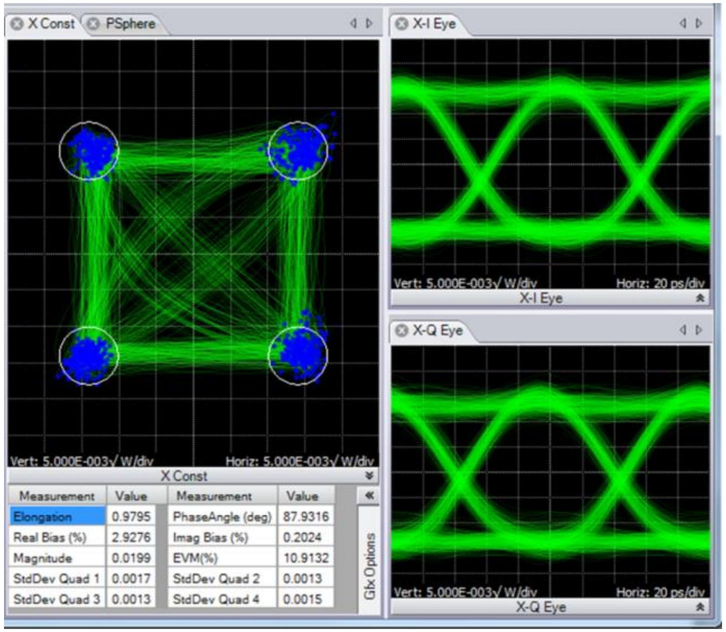


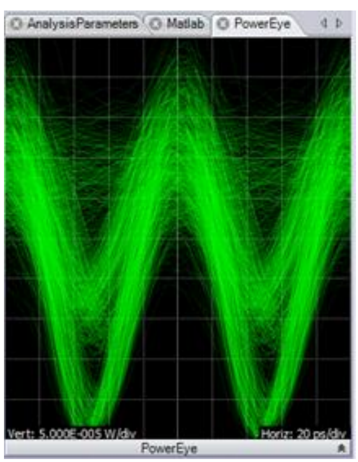
Measuring TX Constellation Imperfections: Phase Angle

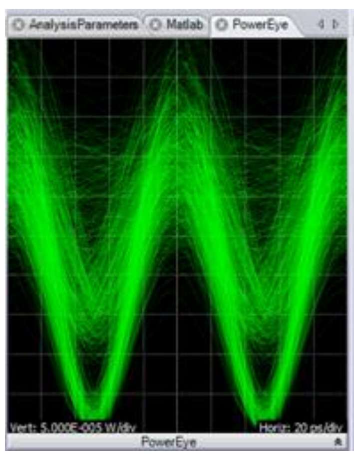


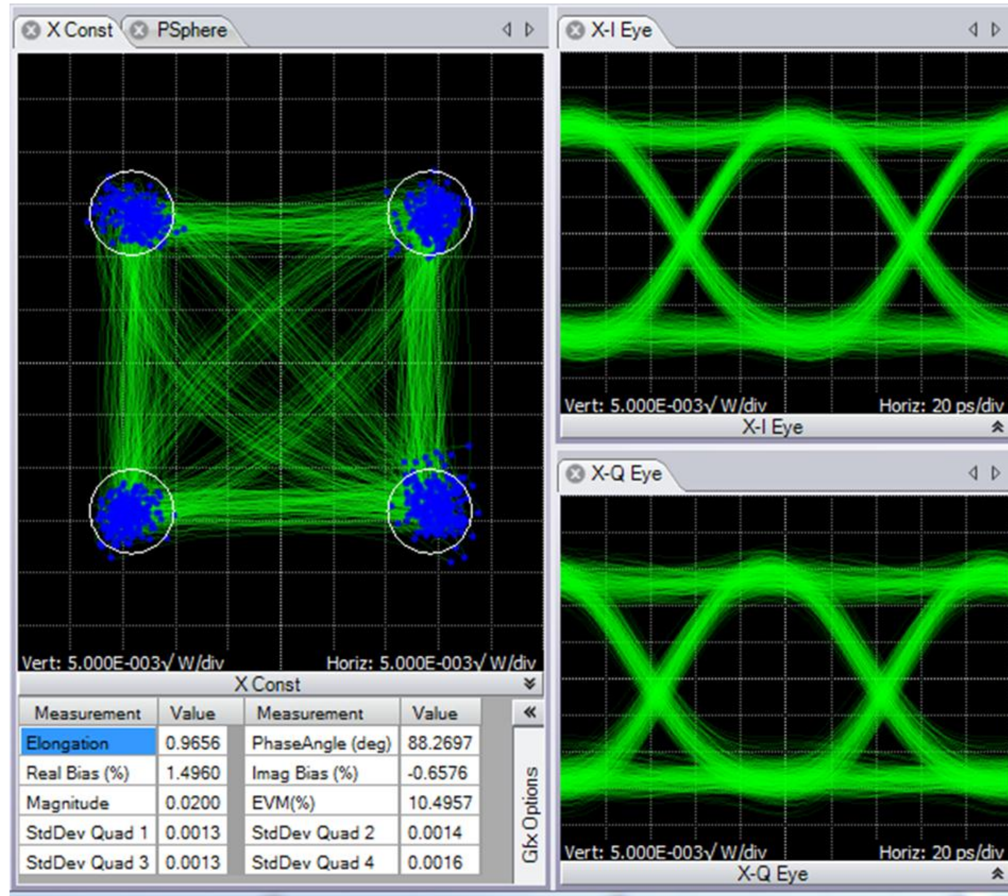


Example: Modulator Bias Adjustment









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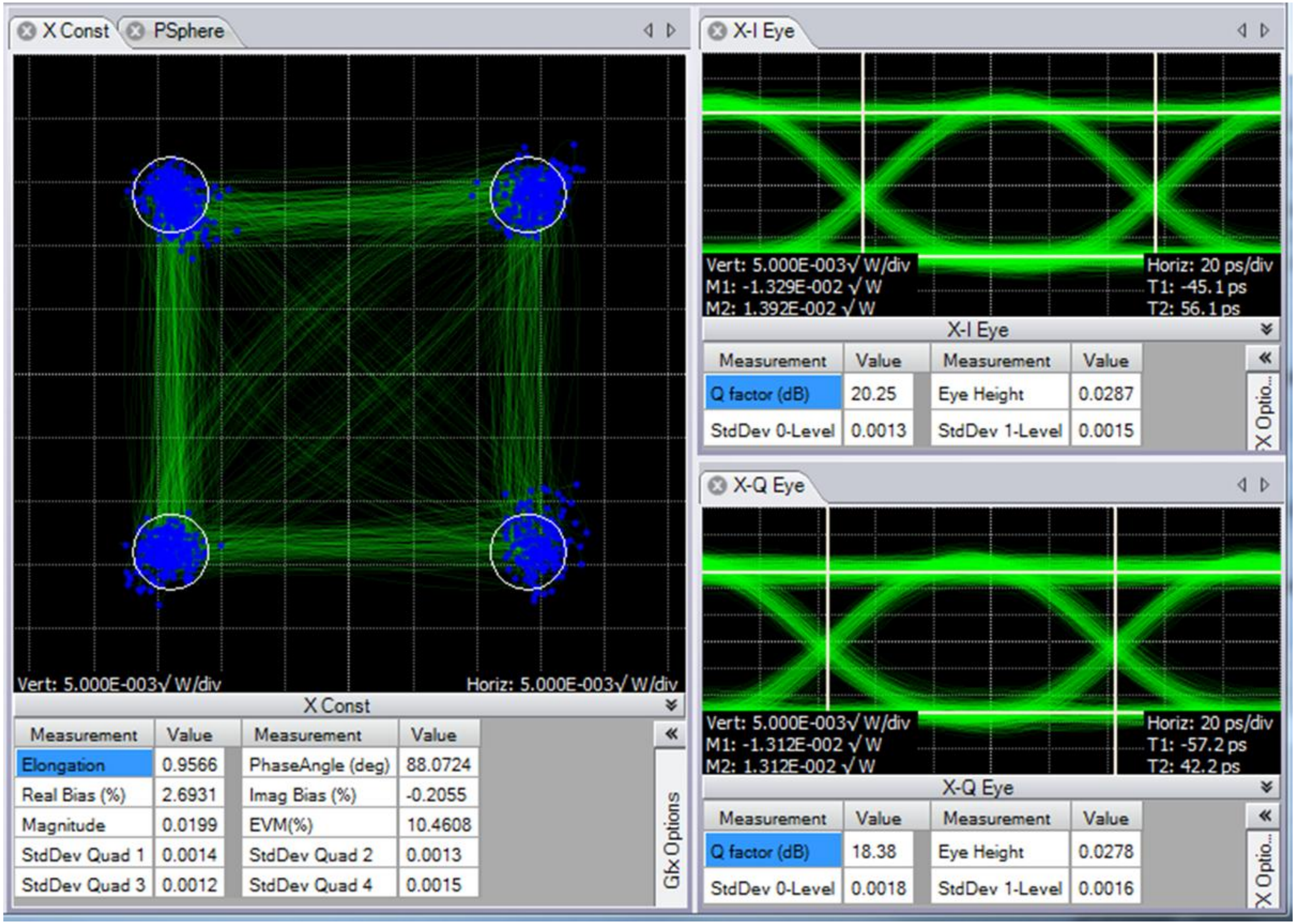
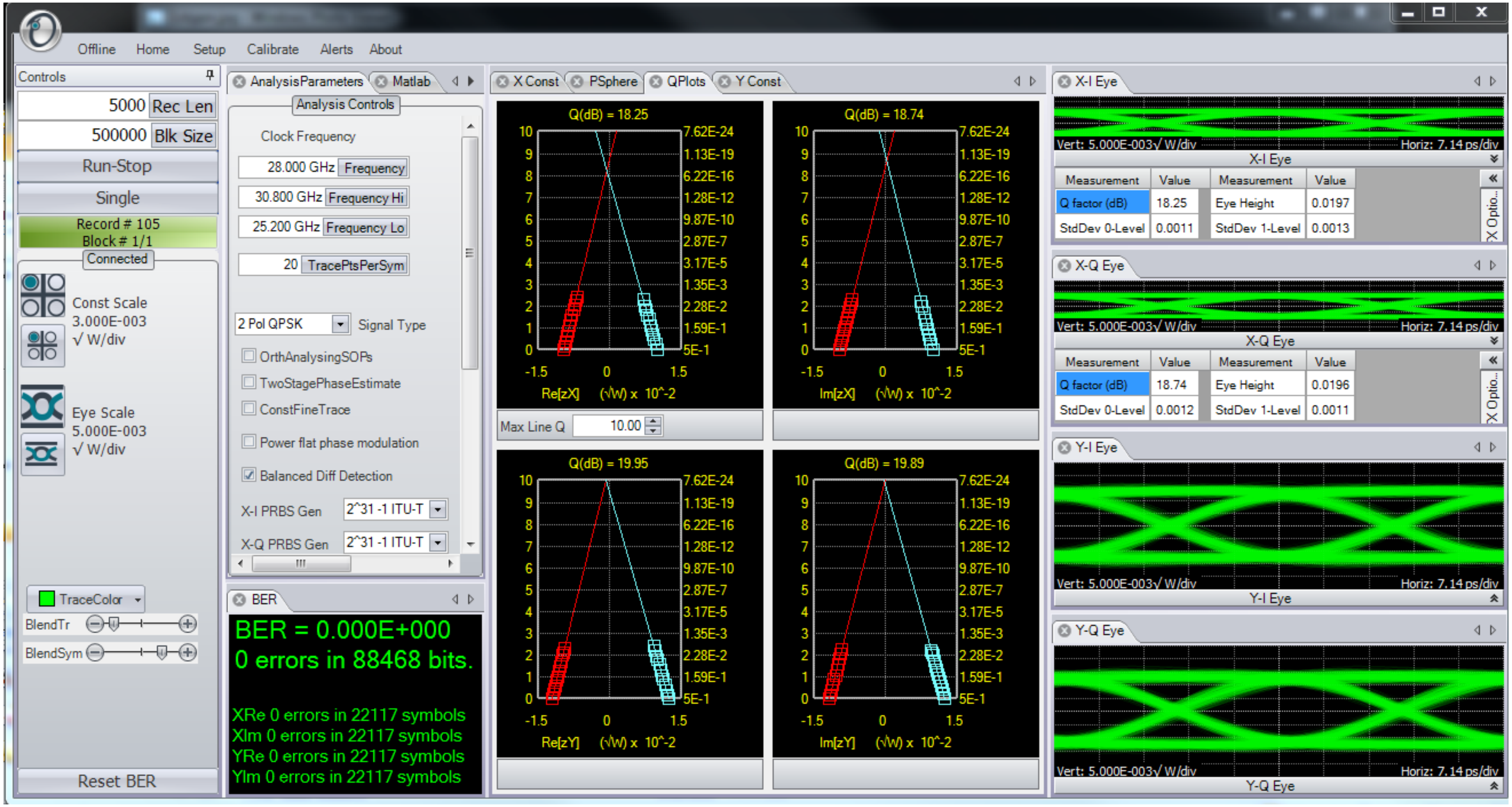
Example: Adjusting Tributary Timing Skew



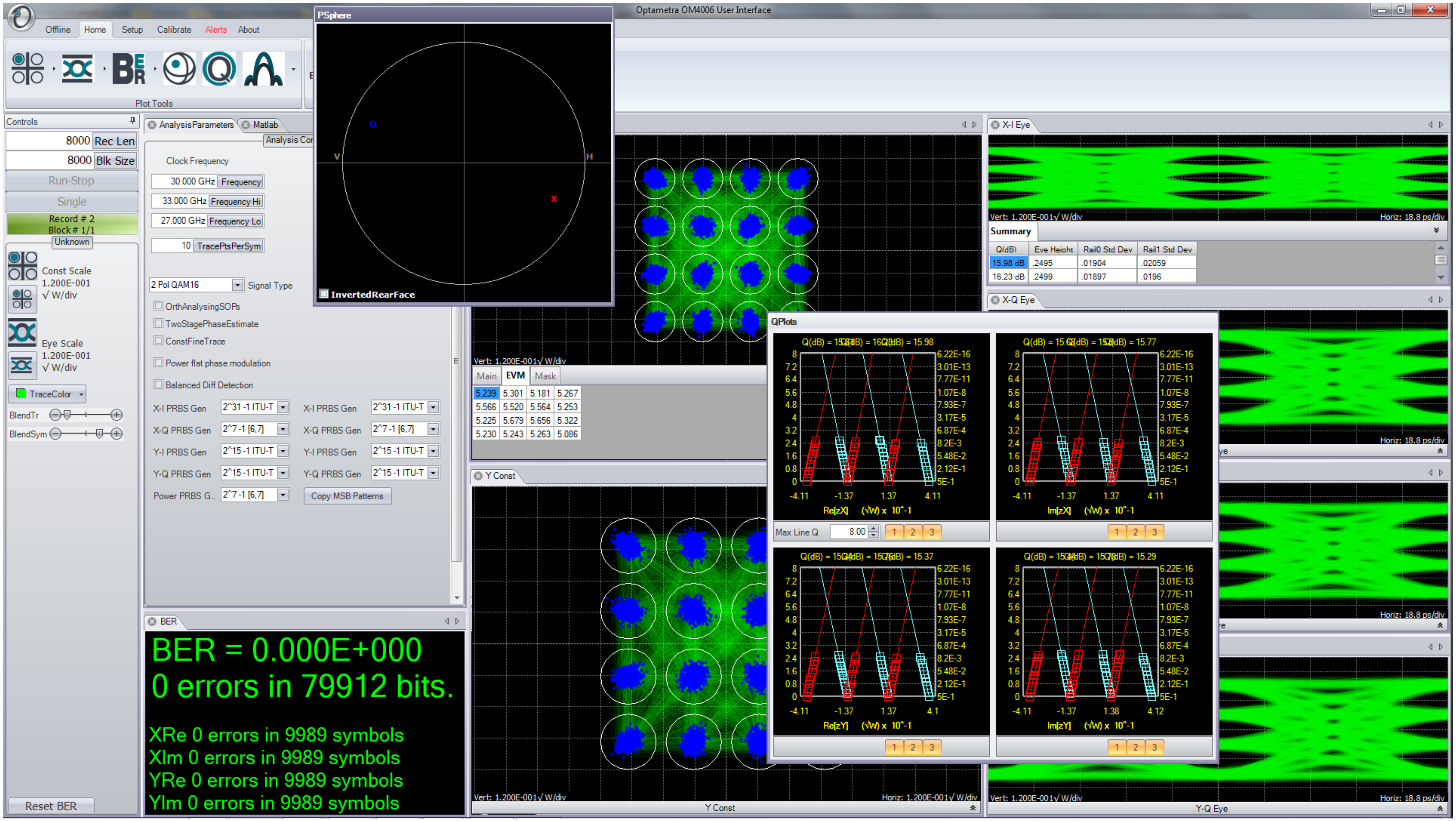
Measurements Available for QPSK Signals



Measurement	Value	Measurement	Value
Q factor (dB)	18.25	Eye Height	0.0197
StdDev 0-Level	0.0011	StdDev 1-Level	0.0013

Measurement	Value	Measurement	Value
Q factor (dB)	18.74	Eye Height	0.0196
StdDev 0-Level	0.0012	StdDev 1-Level	0.0011

Measurements Available for QAM Signals



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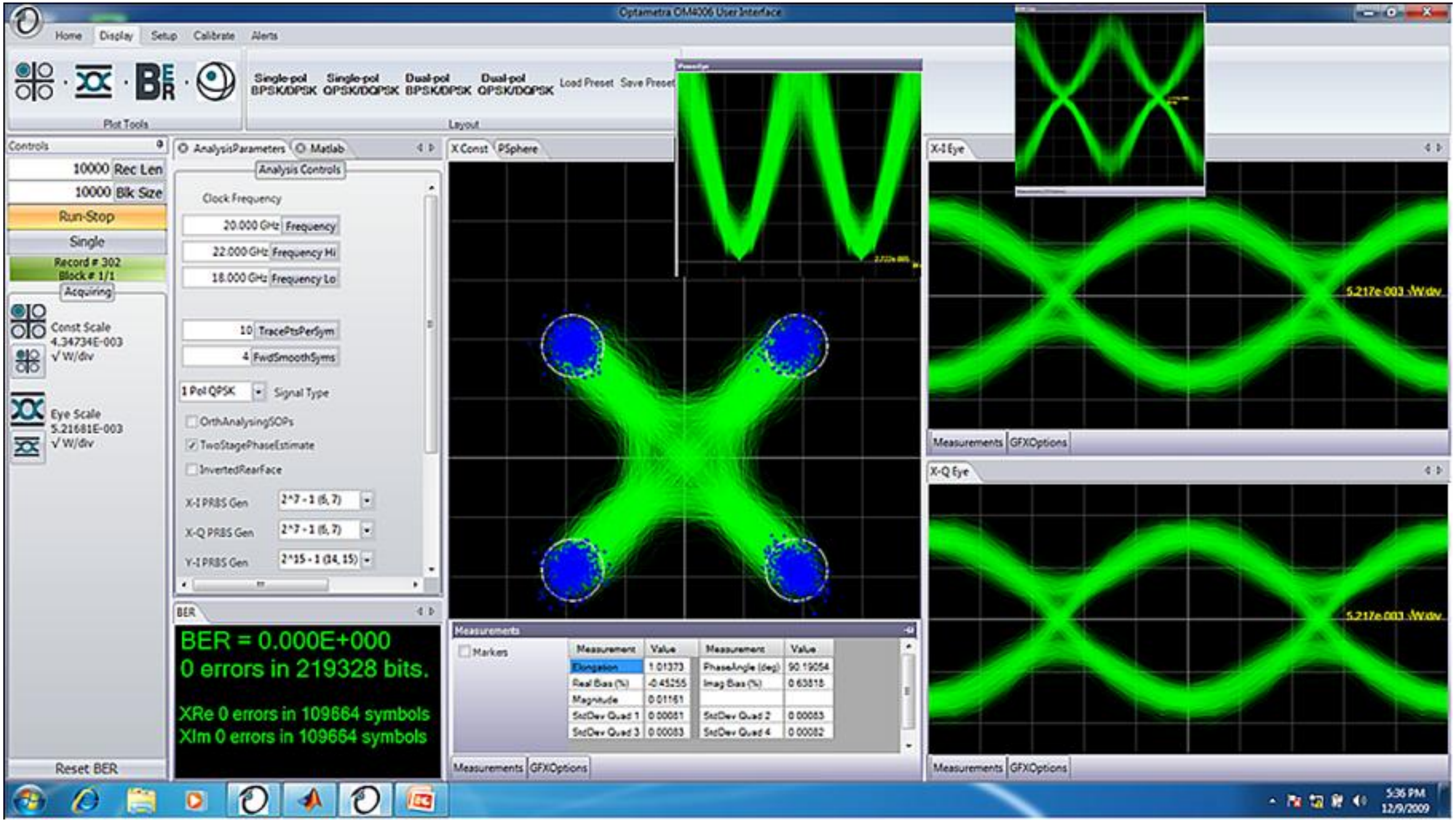
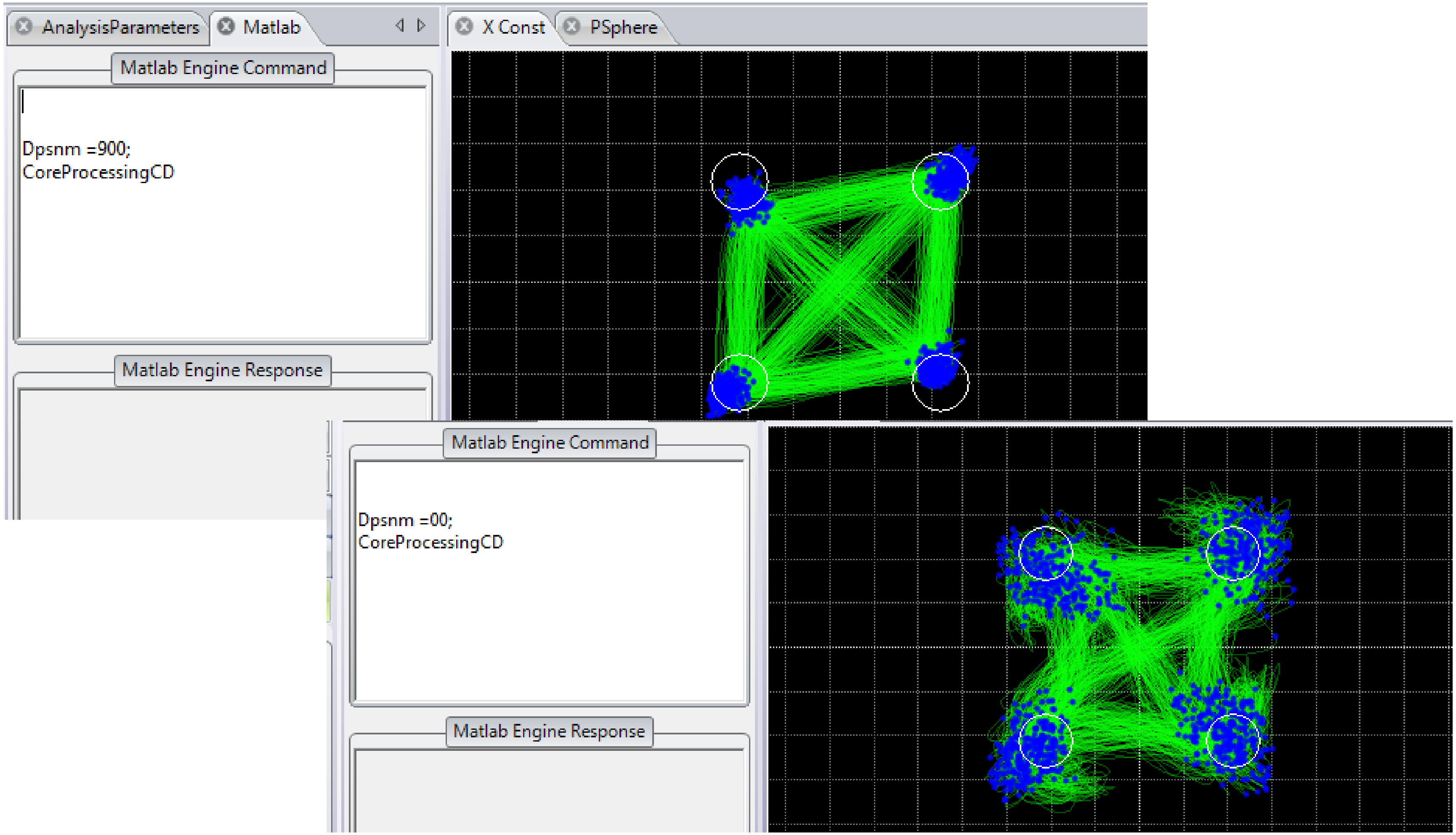
20 G RZ DQPSK

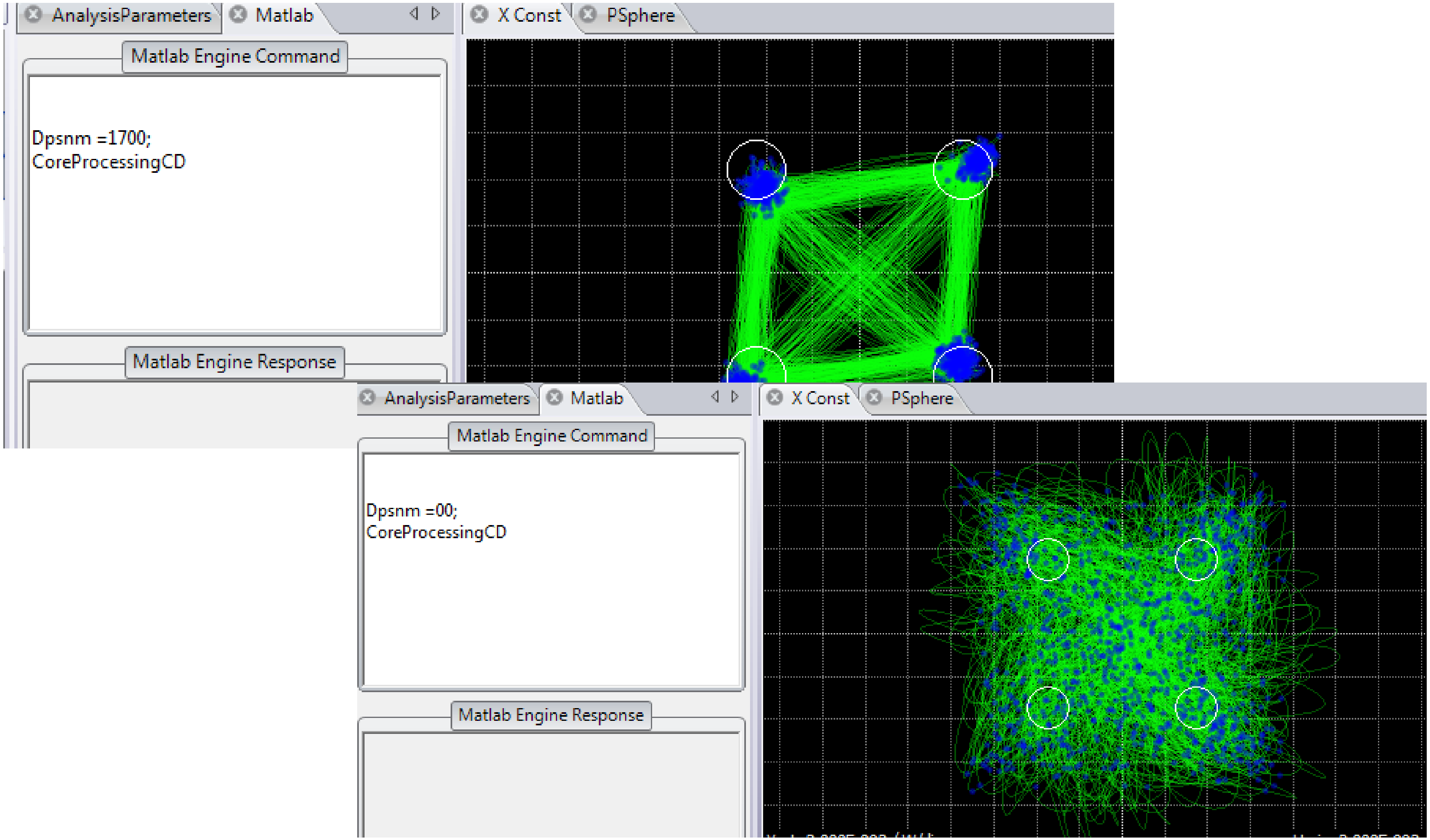


Optametra OM4006 User Interface
Home
Display
Setup
Calibrate
Alerts
Single-pol BPSK/DPSK
Single-pol QPSK/DQPSK
Dual-pol BPSK/DPSK
Dual-pol QPSK/DQPSK
Load Preset
Save Preset
Plot Tools
Layout
Controls
10000 Rec Len
10000 Blk Size
Run-Stop
Single
Record # 302
Block # 1/1
Acquiring
Const Scale 4.34734E-003 √W/div
Eye Scale 5.21681E-003 √W/div
Reset BER
AnalysisParameters
Matlab
Analysis Controls
Clock Frequency
20.000 GHz Frequency
22.000 GHz Frequency Hi
18.000 GHz Frequency Lo
10 TracePtsPerSym
4 FwdSmoothSyms
1 Pol QPSK Signal Type
OrthAnalysingSOPs
TwoStagePhaseEstimate
InvertedRearFace
X-I PRBS Gen 2^7-1 (6, 7)
X-Q PRBS Gen 2^7-1 (6, 7)
Y-I PRBS Gen 2^15-1 (14, 15)
BER
BER = 0.000E+000
0 errors in 219328 bits.
XRe 0 errors in 109664 symbols
XIm 0 errors in 109664 symbols
X Const
PSphere
X-I Eye
X-Q Eye
5.217e-003 √W/div
Measurements
GFXOptions
Markers
Measurement
Value
Elongation 1.01373
Real Bias (%) -0.45255
Magnitude 0.01161
StdDev Quad 1 0.00081
StdDev Quad 3 0.00083
PhaseAngle (deg) 90.19054
Imag Bias (%) 0.63815
StdDev Quad 2 0.00083
StdDev Quad 4 0.00082
5:36 PM
12/9/2009

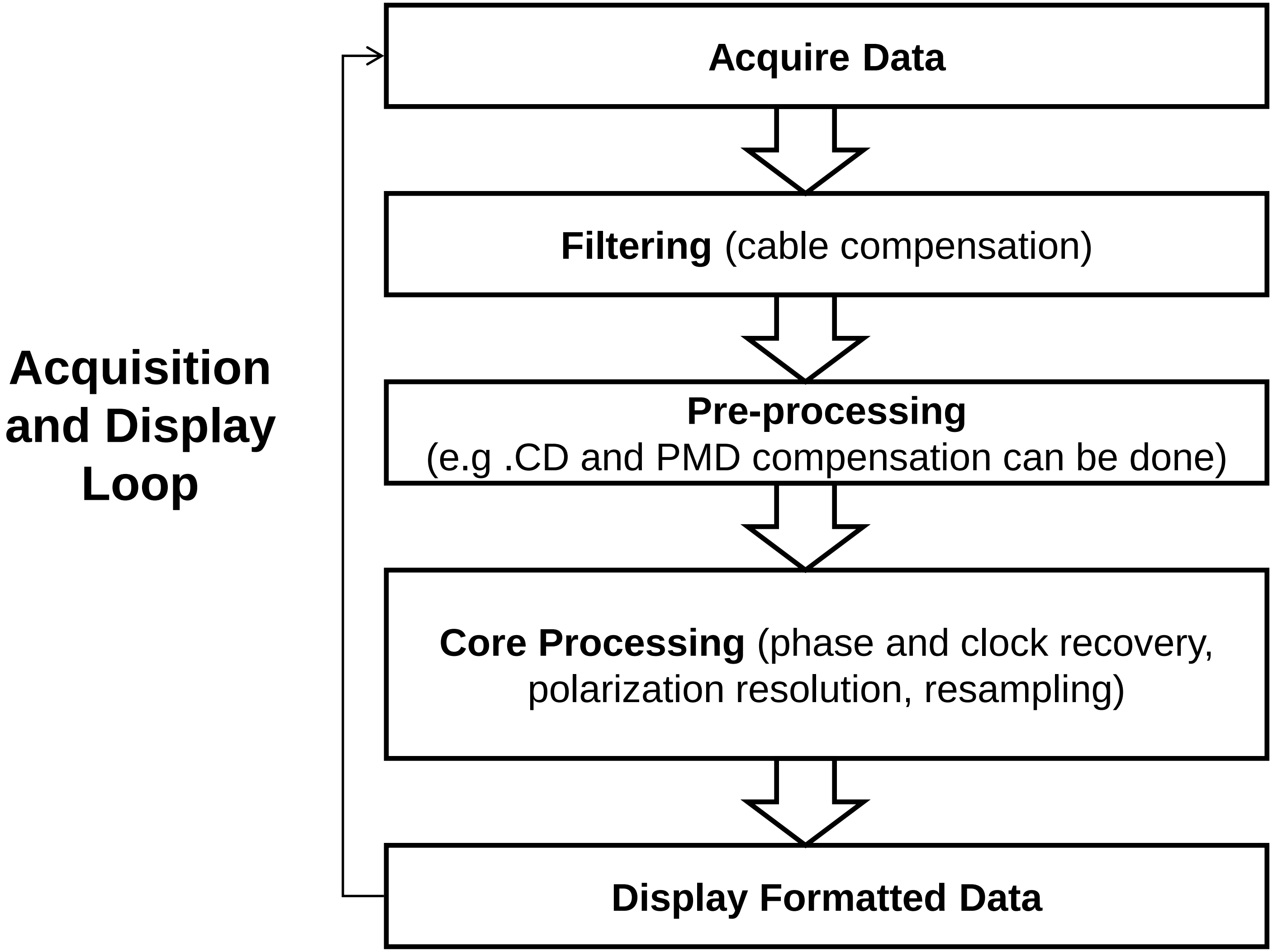
One DC Module being Compensated. CD = 900 ps/nm



2 CD Modules CD = 1700 ps/nm



Data Acquisition and Processing Flow



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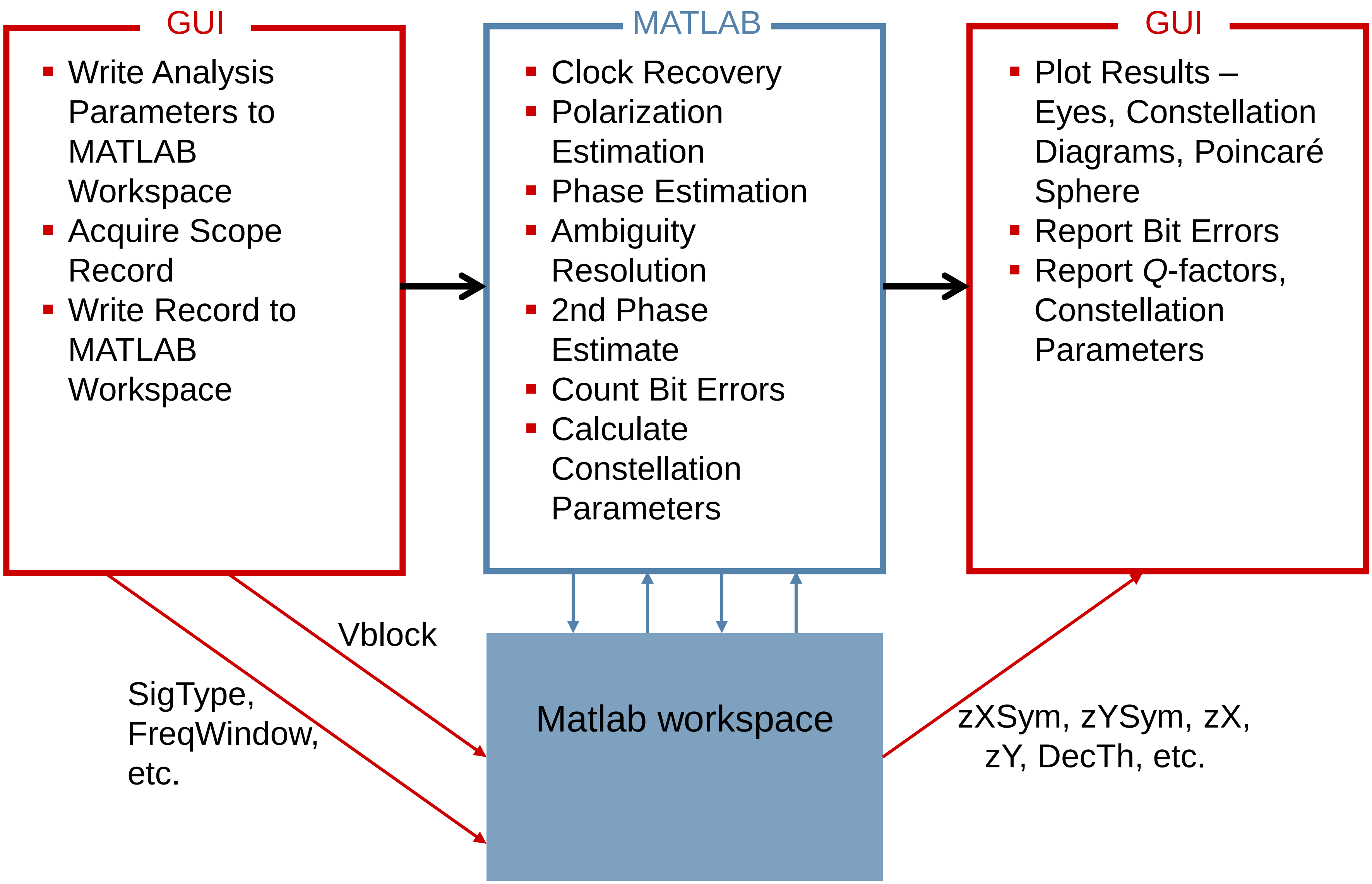
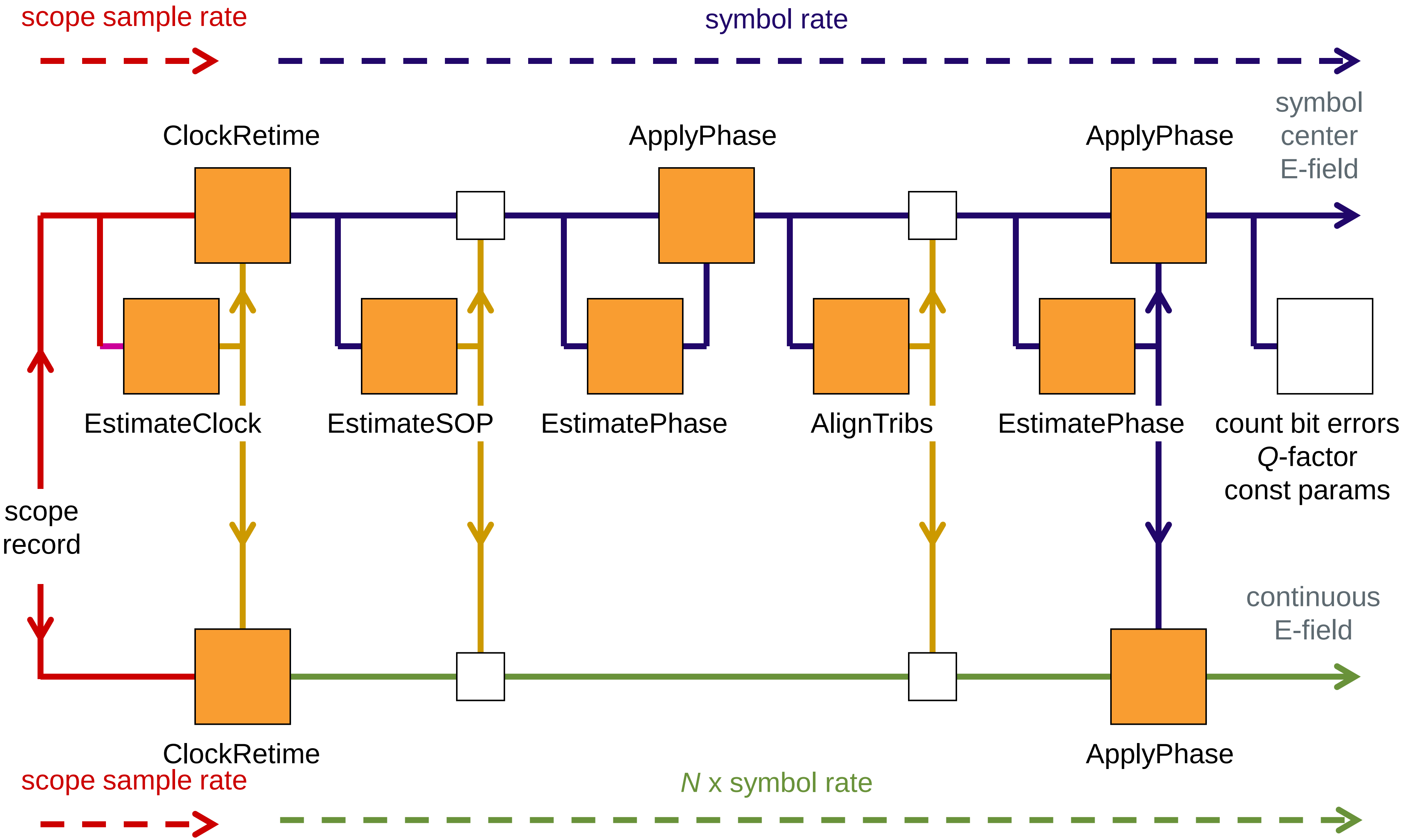
Interaction Between GUI and MATLAB®



Flow Diagram (single pol case)



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Optametra Product Family

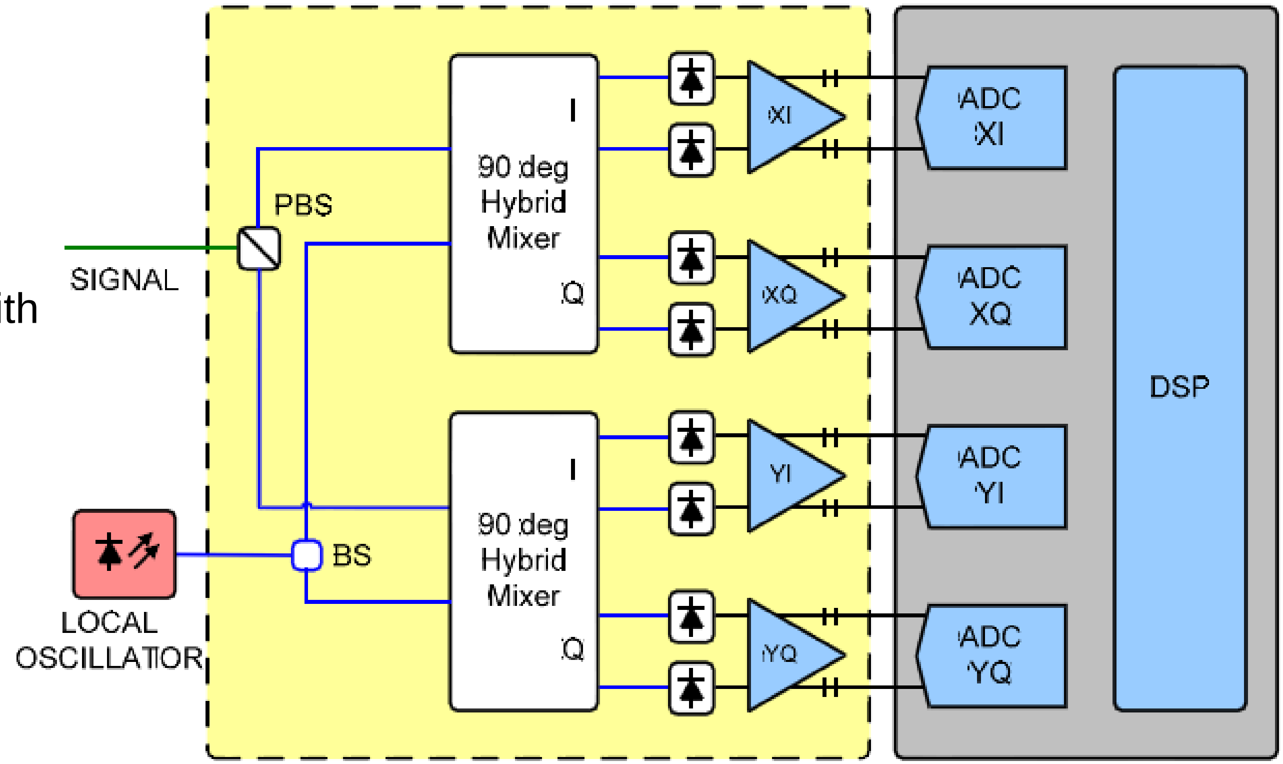
- OM4000 Optical Modulation Analyzer Series
- OM1106 Signal Analysis Software
  - Optional hardware support
- OM1206 Signal Analysis Test Set
  - Software portion of the OM4106
  - Includes tools for customer hybrid receiver calibration/ test
- OM2010 Tunable Laser Source
  - Provides additional laser sources

Coherent Receiver Impairments

- Bandwidth
- Group delay variation
- I-Q Crosstalk (hybrid phase angle error)
- CMRR
- Polarization crosstalk
- Channel gain imbalance
- Channel delay mismatch
- RF mismatch effect on group delay
- Frequency-domain crosstalk
- Nonlinearity

Coherent Receiver Testing

Replace input signals with reference signals



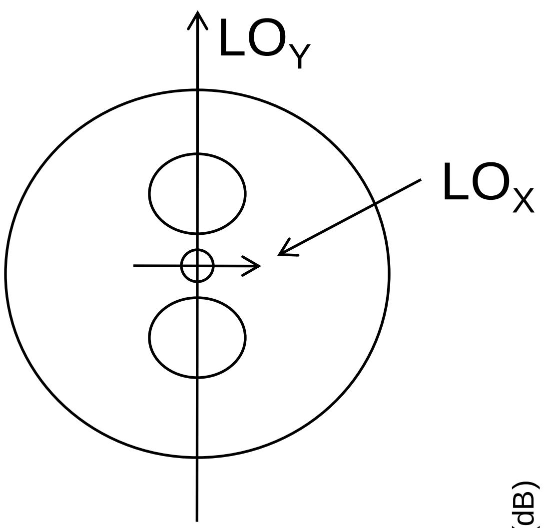
Replace ADC with real-time oscilloscope

New OIF Agreement
IA OIF2009.033.06

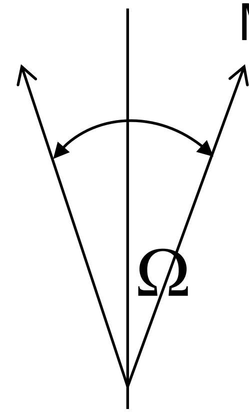
Test overall:
- Path gains
- Cross talk
- Phase angles

At any frequency or wavelength

Sources of Polarization Crosstalk

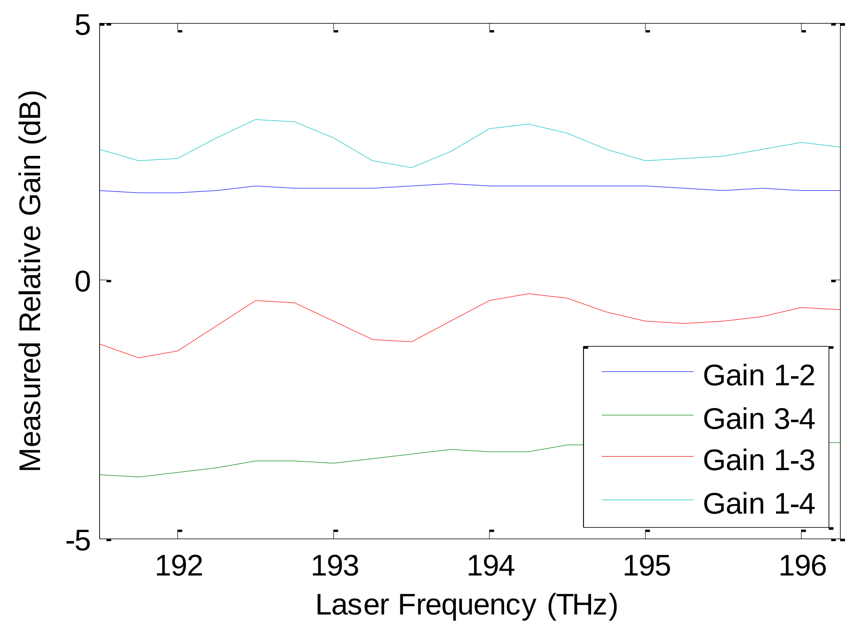


Resulting LO
Moves with λ and Temp

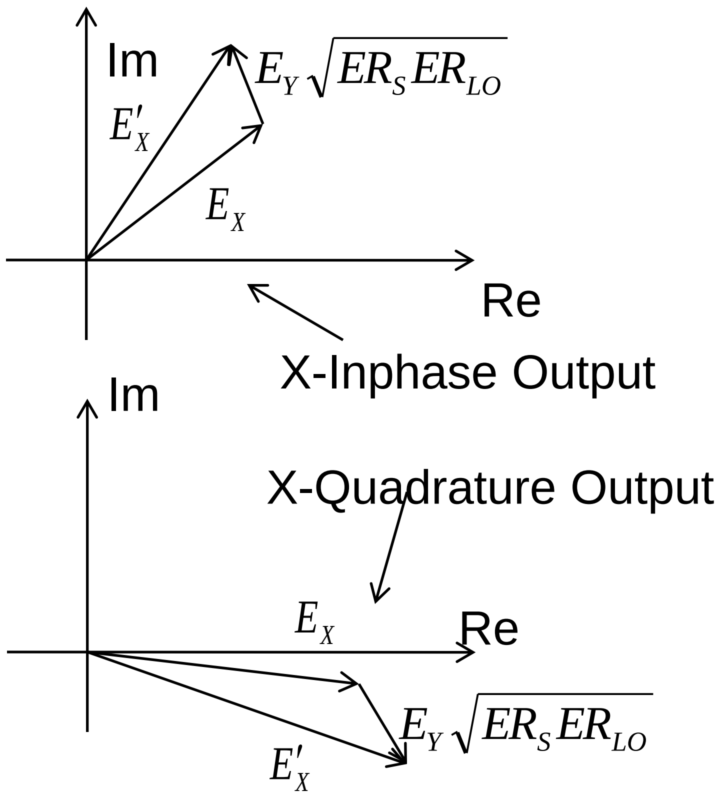


$$\Omega \approx 1/\sqrt{ER}$$

- Imperfect LO Laser Extinction
- Imperfect Key or Splice Alignment
- PM-fiber-induced Rotation
- Finite PBS Extinction Ratio



Effect of pol-crosstalk on Phase Angle



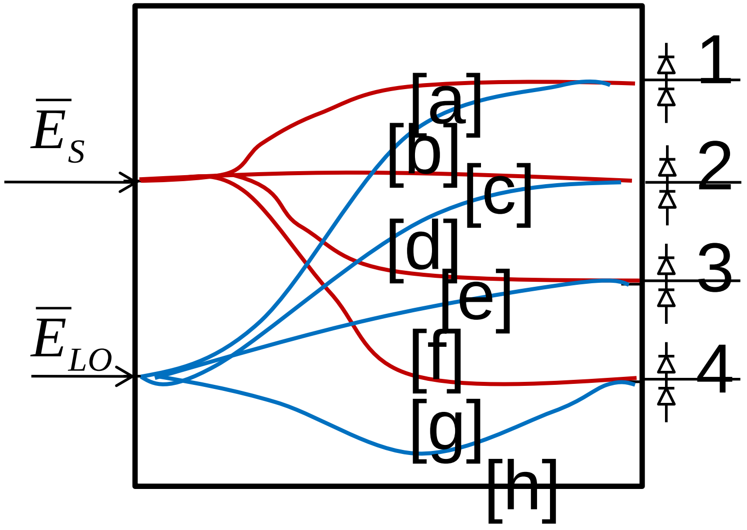
Apparent E_X is modified by E_Y leakage

20 dB + 20dB: ±1.2°
15 dB +15dB: ±3.6°

Effect scales up if E_Y larger than E_X

Simple Hybrid Receiver Representation

$$V_1 = R_1\left(\left[b\right]\overline{E}_{LO}\right)^* \bullet \left(\left[a\right]\overline{E}_S\right) = \hat{p}_1 \bullet \overline{E}_S$$



$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = \begin{bmatrix} \hat{p}_1 \\ \hat{p}_2 \\ \hat{p}_3 \\ \hat{p}_4 \end{bmatrix} \overline{E}_S \qquad \begin{bmatrix} E_{Sxr} \\ E_{Sxi} \\ E_{Syr} \\ E_{Syi} \end{bmatrix} = \left[H\right]^{-1} \begin{bmatrix} \mathrm{V}_1 \\ \mathrm{V}_2 \\ \mathrm{V}_3 \\ \mathrm{V}_4 \end{bmatrix}$$

$$\begin{bmatrix} \mathrm{V}_1 \\ \mathrm{V}_2 \\ \mathrm{V}_3 \\ \mathrm{V}_4 \end{bmatrix} = \begin{bmatrix} \mathrm{Re}\{\hat{p}_{1x}\} & \mathrm{Im}\{\hat{p}_{1x}\} & \mathrm{Re}\{\hat{p}_{1y}\} & \mathrm{Im}\{\hat{p}_{1y}\} \\ \mathrm{Re}\{\hat{p}_{2x}\} & \mathrm{Im}\{\hat{p}_{2x}\} & \mathrm{Re}\{\hat{p}_{2y}\} & \mathrm{Im}\{\hat{p}_{2y}\} \\ \mathrm{Re}\{\hat{p}_{3x}\} & \mathrm{Im}\{\hat{p}_{3x}\} & \mathrm{Re}\{\hat{p}_{3y}\} & \mathrm{Im}\{\hat{p}_{3y}\} \\ \mathrm{Re}\{\hat{p}_{4x}\} & \mathrm{Im}\{\hat{p}_{4x}\} & \mathrm{Re}\{\hat{p}_{4y}\} & \mathrm{Im}\{\hat{p}_{4y}\} \end{bmatrix} \begin{bmatrix} E_{Sxr} \\ E_{Sxi} \\ E_{Syr} \\ E_{Syi} \end{bmatrix}$$

Optical Hybrid Calibration

$$\mathbf{V} = [H]\mathbf{E}$$

$$\begin{matrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{matrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{23} \\ h_{31} & h_{32} & h_{33} & h_{34} \\ h_{41} & h_{42} & h_{43} & h_{44} \end{bmatrix} \begin{bmatrix} E_{xr} \\ E_{xi} \\ E_{yr} \\ E_{yi} \end{bmatrix}$$

$$\mathbf{E} = [H]^{-1}\mathbf{V}$$

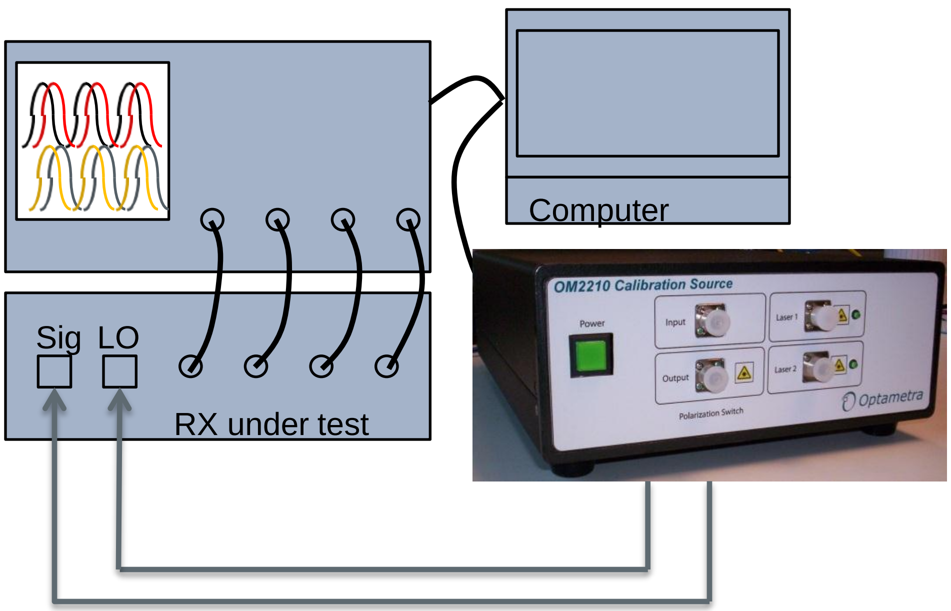
- Apply Ex or Ey, measure phase angle
  - How to set Ex? Ey?
  - What about crosstalk effect on angle?

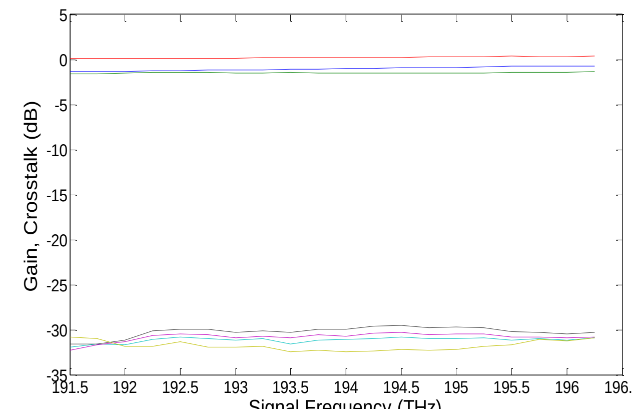
Or

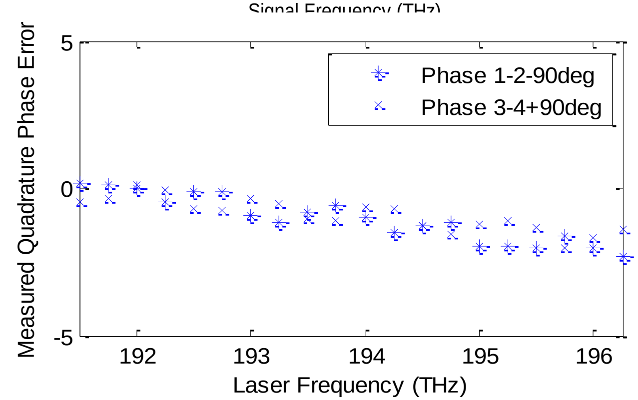
- Apply E1 and E2, find all hybrid parameters
  - E1·E2 = 0 (new coordinate system)
  - Rotate back to hybrid system
- Entire H is needed to find H-1
- This gives full impact of finding E given V

Hybrid Phase Angle, Gain, and Crosstalk

- Excites RX under test with heterodyne signal
- Two orthogonal polarizations
- Computer takes data from scope and calculates hybrid parameters
- Tunable laser permits full-band testing







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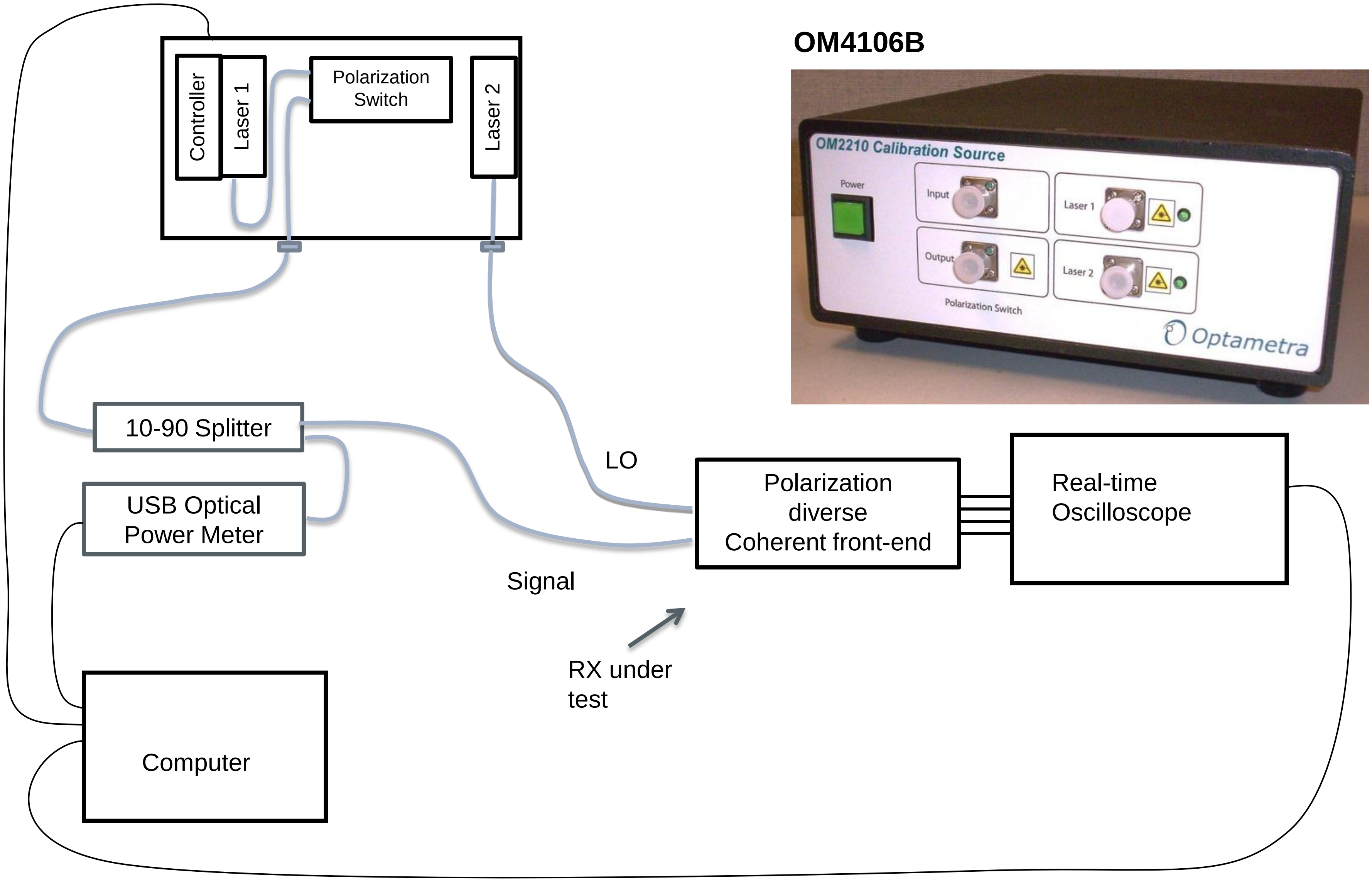
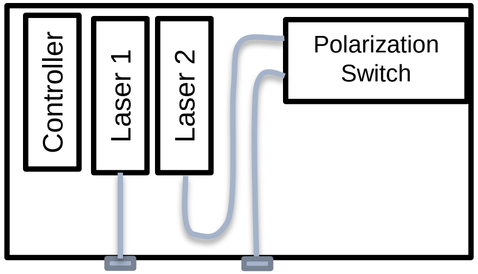
Receiver Testing Detail

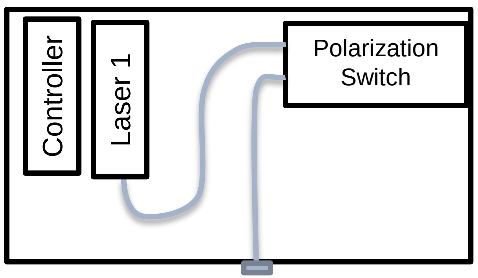


Calibration Kit Options



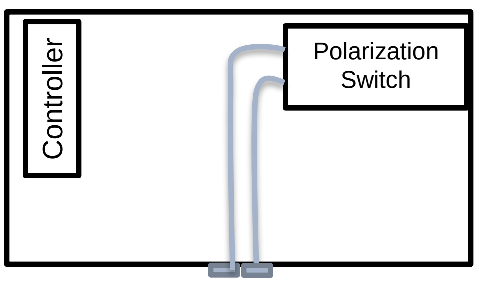
OM4106B/ OM3105B-603 C-band Calibration Source and Software. Includes 2 lasers. Use this option when C-band receiver has no Optametra sources.

OM4106B/ OM3105B-604 L-band Calibration Source and Software. Includes 2 lasers. Use this option when L-band receiver has no Optametra sources.



OM4106B/ OM3105B-601 C-band Calibration Source and Software. Includes 1 laser. Use this option when C-band receiver has an Optametra Reference Laser.

OM4106B/ OM3105B-602 L-band Calibration Source and Software. Includes 1 laser Use this option when L-band receiver has an Optametra Reference Laser.



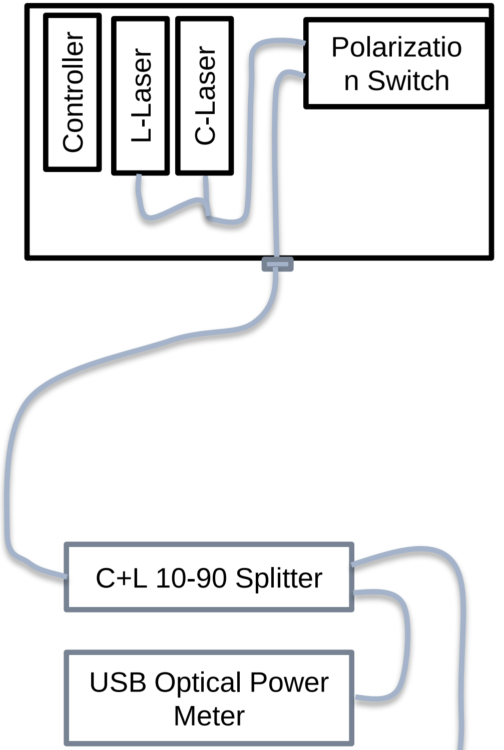
OM4106B/ OM3105B-600 Calibration Source and Software. Includes no lasers. Use this option when receiver has 2 Optametra sources for Reference and Signal.

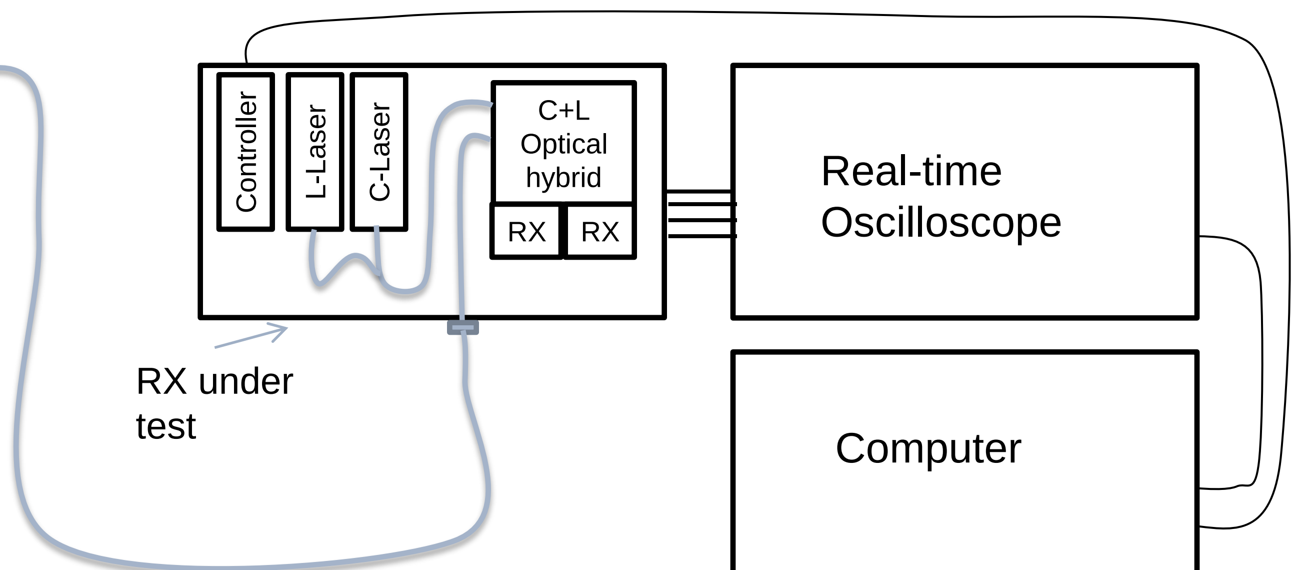
Kit also includes optical power splitter and USB optical power meter not shown. A real time sampling scope is required for calibration (not provided).

C+L Calibration Kit

OM4106B/ OM3105B-605 C or L-band Calibration Source and Software. Includes 2 lasers combined to make a C+L source. Use this option when receiver has a similar Optametra C+L Reference.

Typical Coherent Receiver Calibration test set up (below). Computer and Real-time oscilloscope are not part of the kit. Receiver purchased separately.





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Conclusions

- Coherent Lightwave Signal Analyzers can quantify quality of transmitter signal
- Optametra also offers tools for receiver characterization
- Heterodyne analysis can be used to extract a simple hybrid matrix describing the analog receiver front end
- Measuring integrated receiver properties allows inclusion of optical and electrical cross-talk effects

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