Advancing Test in Coherent Transmission Systems

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Optametra History

Founded – Sept 2007

CSLA 40G Product Launched – March 2009 (OFC/NFOEC)

CSLA 100G Product Launched – September 2009

First 10 Systems Sold – January 2011

Acquired by Tektronix -- July 2011

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
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
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

- 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

\[ \text{EVM} = \sqrt{\frac{1}{N} \sum_{n=1}^{N} |x_n - \mu|^2} \]

\[ \mu \]

\[ x_n \]

\[ |\mu| \]

\[ |x_n| \]
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

Diagram with Q-factor plots and constellation maps.
Measuring TX Constellation Imperfections: Phase Angle
Example: Modulator Bias Adjustment
Example: Adjusting Tributary Timing Skew
Measurements Available for QPSK Signals
Measurements Available for QAM Signals

BER = 0.000E+000
0 errors in 79912 bits.

XRe 0 errors in 9989 symbols
Xlm 0 errors in 9989 symbols
YRe 0 errors in 9989 symbols
Ylm 0 errors in 9989 symbols
20 G RZ DQPSK
One DC Module being Compensated. CD = 900 ps/nm
2 CD Modules CD = 1700 ps/nm
Data Acquisition and Processing Flow

Acquire Data

Filtering (cable compensation)

Pre-processing
(e.g., CD and PMD compensation can be done)

Core Processing (phase and clock recovery, polarization resolution, resampling)

Display Formatted Data
Interaction Between GUI and MATLAB®

GUI
- Write Analysis Parameters to MATLAB Workspace
- Acquire Scope Record
- Write Record to MATLAB Workspace

MATLAB
- Clock Recovery
- Polarization Estimation
- Phase Estimation
- Ambiguity Resolution
- 2nd Phase Estimate
- Count Bit Errors
- Calculate Constellation Parameters

GUI
- Plot Results – Eyes, Constellation Diagrams, Poincaré Sphere
- Report Bit Errors
- Report Q-factors, Constellation Parameters

Vblock
SigType, FreqWindow, etc.

Matlab workspace
zXSym, zYSym, zX, zY, DecTh, etc.
Flow Diagram (single pol case)

- **ClockRetime**
- **EstimateClock**
- **EstimateSOP**
- **EstimatePhase**
- **AlignTribs**
- **ApplyPhase**
- **EstimatePhase**

Scope sample rate → Symbol rate →

- **count bit errors**
- **Q-factor**
- **const params**

Scope record → N x symbol rate →

Continuous E-field
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

New OIF Agreement IA OIF2009.033.06

Replace ADC with real-time oscilloscope

Test overall:
- Path gains
- Cross talk
- Phase angles
  At any frequency or wavelength
Sources of Polarization Crosstalk

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

Resulting LO Moves with $\lambda$ and Temp

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

\[ V_1 = R_1 \left( [b] E_{LO} \right)^* \cdot \left( [a] E_S \right) = \hat{p}_1 \cdot \overline{E_S} \]

\[
\begin{bmatrix}
V_1 \\
V_2 \\
V_3 \\
V_4
\end{bmatrix} =
\begin{bmatrix}
\hat{p}_1 \\
\hat{p}_2 \\
\hat{p}_3 \\
\hat{p}_4
\end{bmatrix}
\overline{E_S} =
\begin{bmatrix}
E_{Sxr} \\
E_{Sxi} \\
E_{Syr} \\
E_{Syi}
\end{bmatrix} = [H]^{-1}
\begin{bmatrix}
V_1 \\
V_2 \\
V_3 \\
V_4
\end{bmatrix}
\]

\[
\begin{bmatrix}
\text{Re} \{ \hat{p}_{1x} \} & \text{Im} \{ \hat{p}_{1x} \} & \text{Re} \{ \hat{p}_{1y} \} & \text{Im} \{ \hat{p}_{1y} \} \\
\text{Re} \{ \hat{p}_{2x} \} & \text{Im} \{ \hat{p}_{2x} \} & \text{Re} \{ \hat{p}_{2y} \} & \text{Im} \{ \hat{p}_{2y} \} \\
\text{Re} \{ \hat{p}_{3x} \} & \text{Im} \{ \hat{p}_{3x} \} & \text{Re} \{ \hat{p}_{3y} \} & \text{Im} \{ \hat{p}_{3y} \} \\
\text{Re} \{ \hat{p}_{4x} \} & \text{Im} \{ \hat{p}_{4x} \} & \text{Re} \{ \hat{p}_{4y} \} & \text{Im} \{ \hat{p}_{4y} \}
\end{bmatrix}
\begin{bmatrix}
E_{Sxr} \\
E_{Sxi} \\
E_{Syr} \\
E_{Syi}
\end{bmatrix}
\]
Optical Hybrid Calibration

\[ V = [H]E \]

\[ V_1 = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \end{bmatrix} \begin{bmatrix} E_{xr} \\ E_{xi} \end{bmatrix} \]

\[ V_2 = \begin{bmatrix} h_{21} & h_{22} & h_{23} & h_{23} \end{bmatrix} \begin{bmatrix} E_{xr} \\ E_{xi} \end{bmatrix} \]

\[ V_3 = \begin{bmatrix} h_{31} & h_{32} & h_{33} & h_{34} \end{bmatrix} \begin{bmatrix} E_{yr} \\ E_{yi} \end{bmatrix} \]

\[ V_4 = \begin{bmatrix} h_{41} & h_{42} & h_{43} & h_{44} \end{bmatrix} \begin{bmatrix} E_{yr} \\ E_{yi} \end{bmatrix} \]

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

- 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
  - \( E_1 \cdot E_2 = 0 \) (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
Receiver Testing Detail

- Controller
- Laser 1
- Polarization Switch
- Laser 2
- 10-90 Splitter
- USB Optical Power Meter
- Computer
- RX under test
- LO
- Signal
- Real-time Oscilloscope
- Polarization diverse Coherent front-end
- OM4106B
- Power
- Input
- Output
- Laser 1
- Laser 2
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.
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