宽带OFDM光通信系统和相干光测试解决方案

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议程

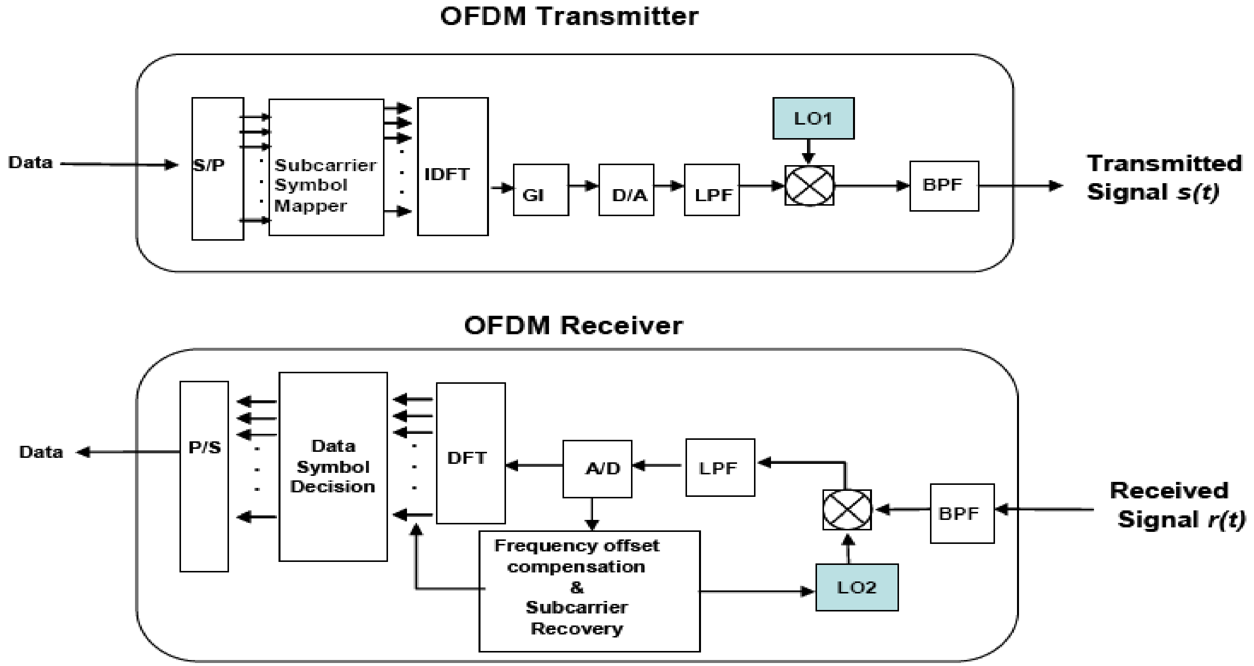
- 宽带OFDM光通信发展概况
- 宽带OFDM光通信基本原理
- 宽带OFDM光通信系统测试难点与挑战
- 泰克宽带OFDM光通信系统测试解决方案
- 泰克宽带OFDM光通信系统测试解决方案优点小结

宽带OFDM光通信特点及发展概况

- 被称之为“第四代移动通信技术”，其核心技术为OFDM。正交频分复用OFDM(Orthogonal Frequency Division Multiplexing)是一种无线环境下的高速传输技术。
- OFDM由多载波调制(MCM)发展而来。美国军方早在上世纪的50-60年代就创建了世界上第一个MCM系统，
- 在1970年衍生出采用大规模子载波和频率重叠技术的OFDM系统。但在以后相当长的一段时间，OFDM迈向实践的脚步放缓。
- 90年代，OFDM开始被欧洲和澳大利亚广泛用于广播信道的宽带数据通信，数字音频广播(DAB)、高清晰度数字电视(HDTV)和无线局域网(WLAN)。随着DSP芯片技术的发展，格栅编码技术、软判决技术、信道自适应技术等成熟技术的应用，OFMD技术的实现和完善指日可待 。
- 2008年5月，日本KDDI 研究所开发出光OFDM高速传送技术，在世界首次成功实现不使用分散补偿光纤长途传送每秒100Gbps的信号，达到现有以太网技术标准10倍的通信速度。

OFDM技术基本原理

- 正交频分复用OFDM（Orthogonal Frequency Division Multiplex)是一种多载波调制方式，通过减小和消除码间串扰的影响来克服信道的频率选择性衰落。它的基本原理是将信号分割为N个子信号，然后用N个子信号分别调制N个相互正交的子载波。由于子载波的频谱相互重叠，因而可以得到较高的频谱效率。近几年OFDM在无线通信领域得到了广泛的应用。

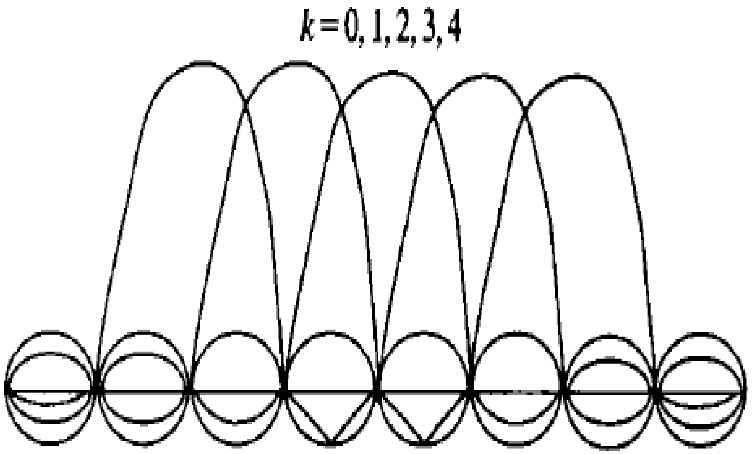


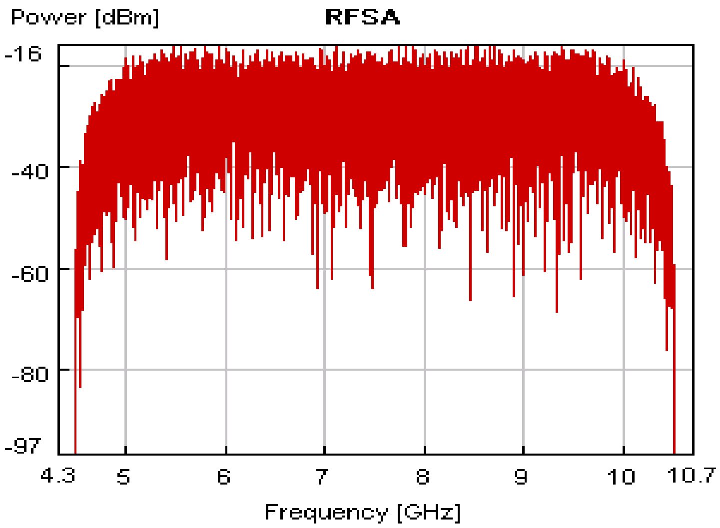
S/P: Serial-to-parallel GI: Guard Time Insertion D/A: Digital-to-Analog (I)DFT: (Inverse) Discrete Fourier Transform LPF: Low Pass Filter BPF: Band Pass Filter

OFDM技术基本原理(续)

- 正交频分复用OFDM（Orthogonal Frequency Division Multiplexing）调制是多载波调制的一种，其基本思想是将串行的信号流转成并行的多路子数据流，再去并行地调制多路子载波。
- OFDM子载波的正交性

OFDM信号频谱图





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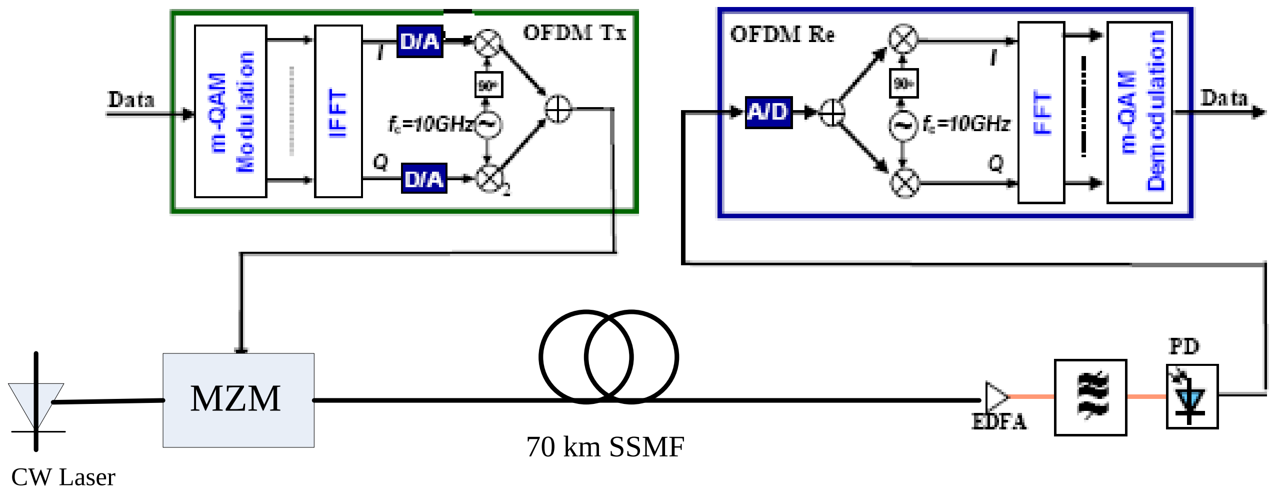
宽带OFDM光通信系统

- 宽带OFDM光通信系统原理图



宽带OFDM光通信系统测试难点与挑战

- 产生宽带OFDM信号——信号源
  - OFDM产生——传统信号源难以产生宽带OFDM信号
- 验证和分析宽带OFDM信号——接收机
  - 通用信号接收
    - 传统频谱仪？没有时间信息
    - 矢量信号分析仪？分析带宽不够、信号定位……
    - 专用接收机
  - 宽带、超宽带接收
    - 专用接收机
    - 示波器——带宽足够

IF RF

宽带OFDM光通信系统测试难点与挑战-对测试设备的要求

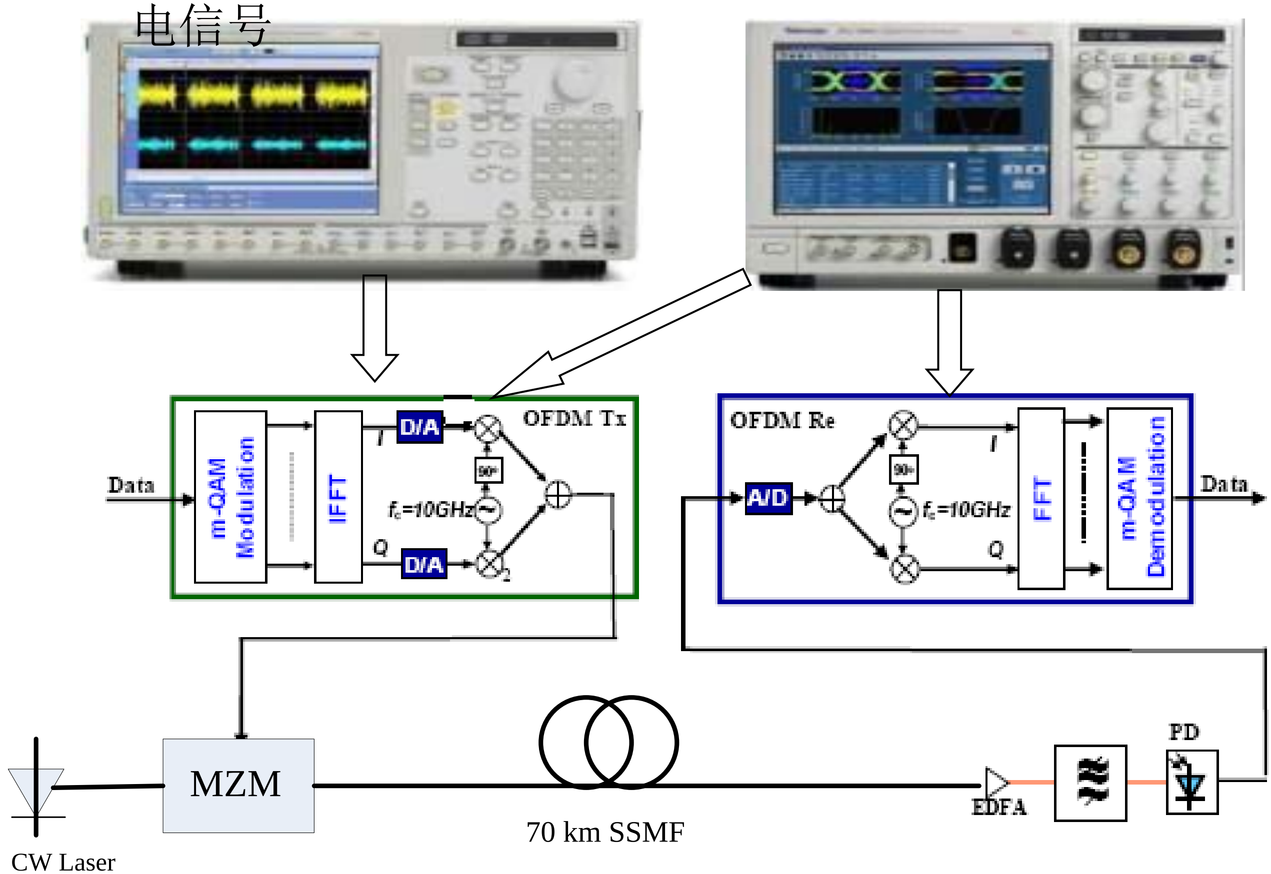
- 信号源
  - 能够简洁地灵活地生成OFDM信号
  - 需要能够满足OFDM带宽(大于3GHz)
  - 能够识别、增强或者回放已采集的信号
  - 能够模拟现实情况
- 接收机
  - 需要足够宽实时分析带宽
  - 含有准确时间信息
  - 数据方便采集、存储以及多种分析
  - 数据处理

泰克宽带OFDM光通信系统测试解决方案

- 宽带OFDM光通信系统测试系统构建

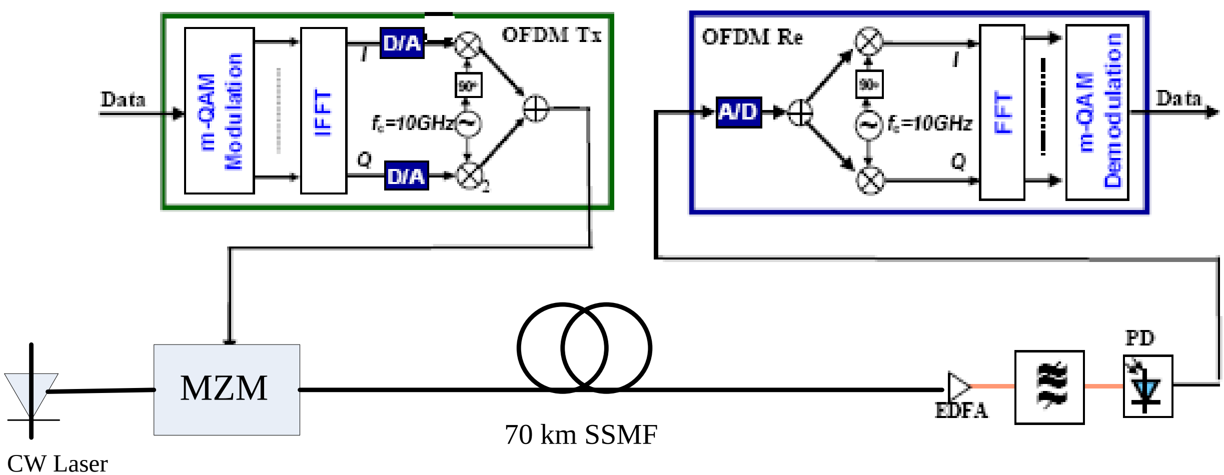
生成宽带OFDM电信号

验证和分析宽带OFDM电信号



泰克宽带OFDM光通信系统测试方案－系统测试原理

- 将Matlab或RFXpress产生的OFDM信号数据载入AWG7122B，利用宽带示波器观测电域OFDM信号的频谱和波形，确定正确产生OFDM信号；
- 将电OFDM信号调制上光载波，调节MZM的偏置和OFDM信号的功率，使MZM工作于线性区，观察光域频谱和眼图；
- 利用DPO73304D宽带示波器采集和接收、下变频OFDM信号，观察传输后及下变频后的频谱和眼图；
- 利用matlab把DPO73304D示波器采集的波形数据进行解调，解调出OFDM信号中的原始信息，测误码率。



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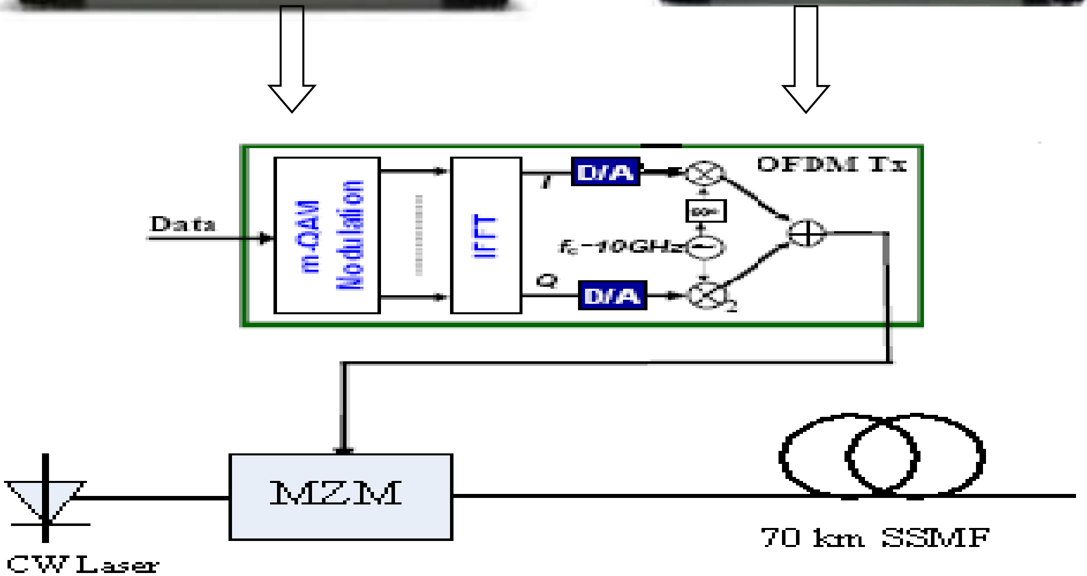
宽带OFDM光通信系统发射端－生成OFDM系统构建

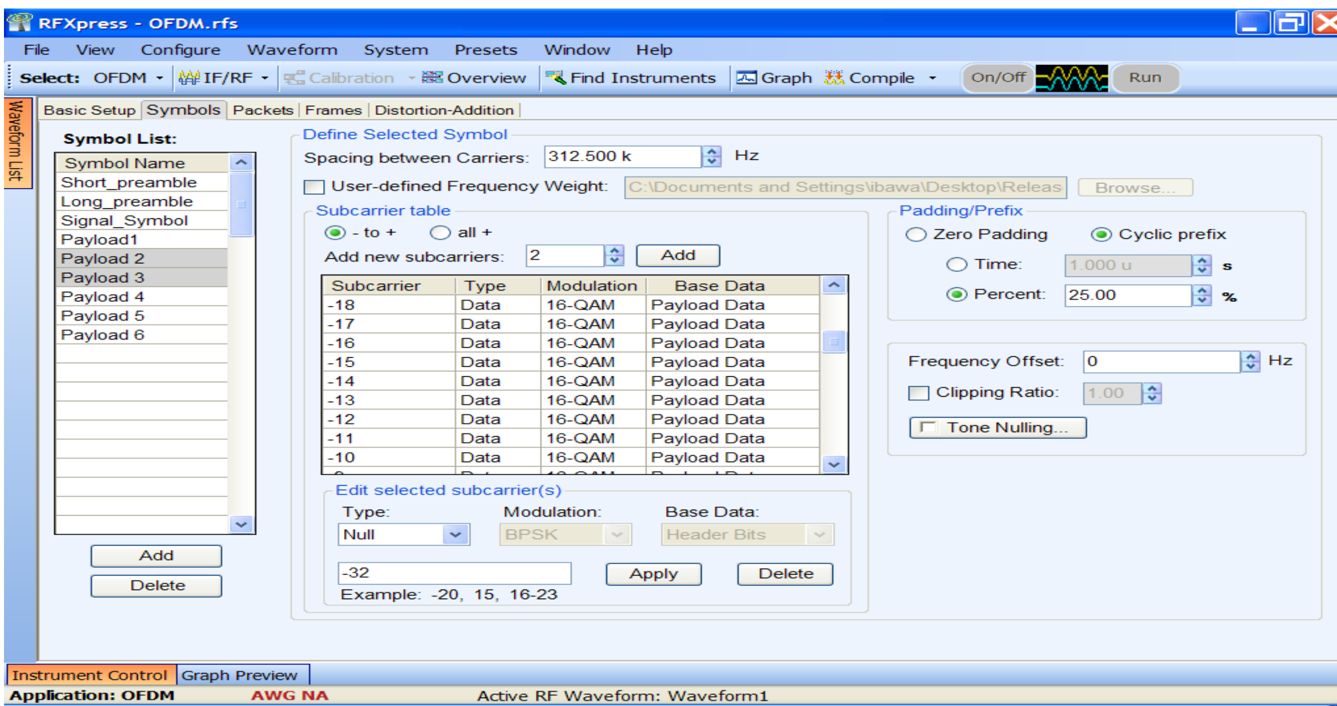
生成宽带OFDM
电信号

验证和分析宽带OFDM电信号



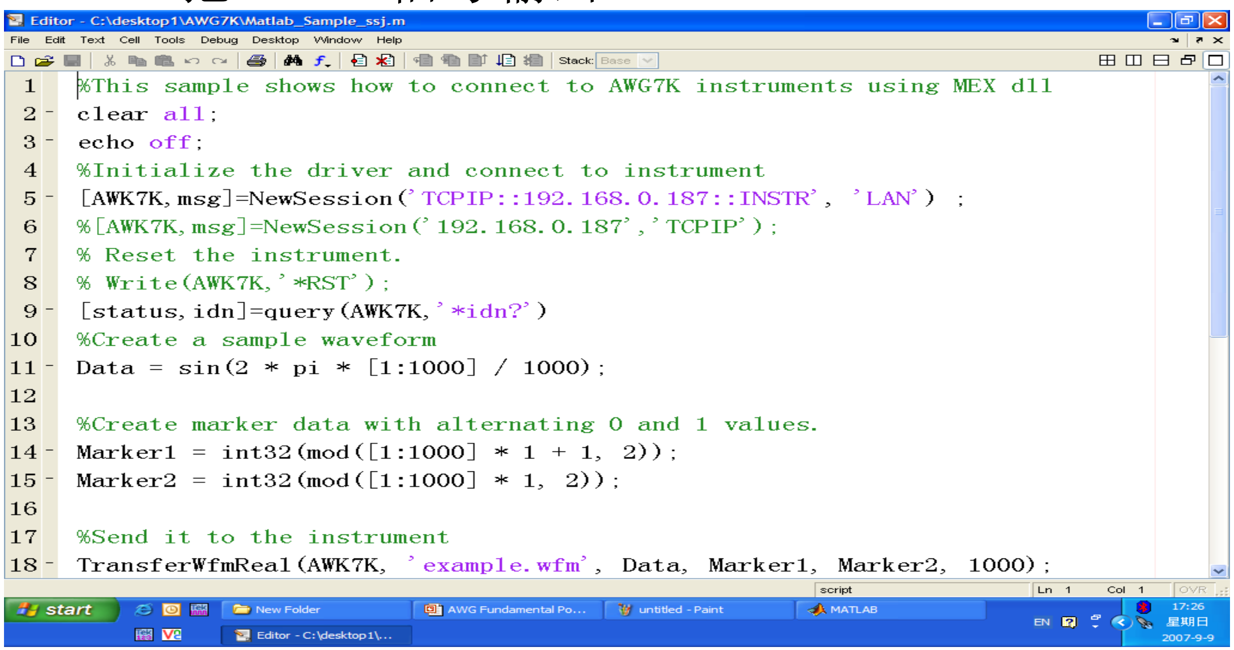
业内唯一的**OFDM**信号生成信号源AWG7122C＋软件RFXpress

- RFXpress——基带、中频和射频信号生成软件
  - 一可以设置OFDM 的所有参数
  - 一设置用户自己定义的数据-符号-数据包-数据帧
  - 一支持RS(Reed-Solomon)编码、卷积和加扰
  - 一可以在信号加入诸如相位噪声、多径或量化损伤
  - 一支持多种子载波调制，包括各种BPSK, QPSK, QAM (16,32,64,256) and 8-PSK



信号源AWG7122C＋Matlab生成宽带**OFDM**信号

- AWG7122C和Matlab可以实现无缝连接,方便快捷地创建各种波形。
- 把Matlab装在AWG7122C系列仪器上或者安装在PC上.
- 利用Matlab仿真软件产生宽带OFDM电信号，然后利用AWG7122C把OFDM信号输出。



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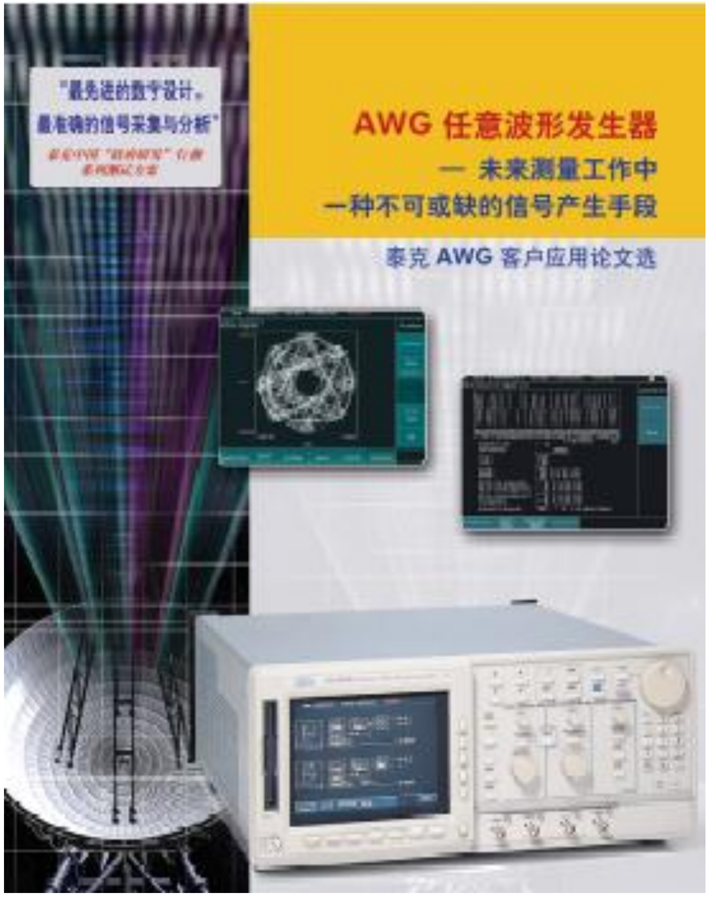
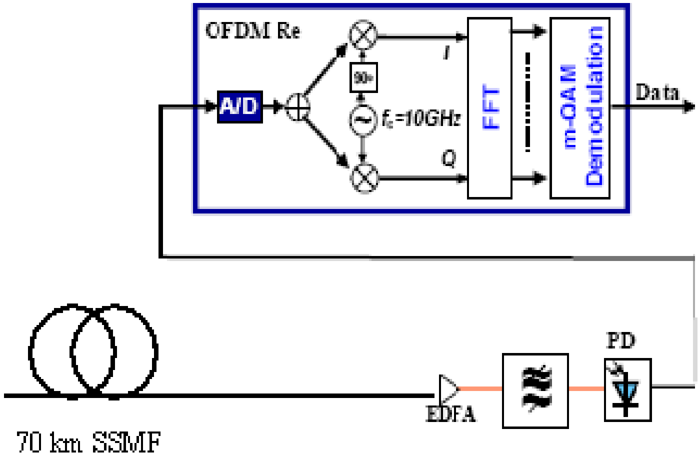
任意波形发生器——一种在未来不可或缺的信号源

- 任意信号发生器的几个用途
  - 产生基带IQ信号
  - 产生中频/射频信号
  - 混合模拟/数字测试
  - 产生多路信号
  - 替代一些传统信号源(如函数信号产生器)
  - 替代一些定制信号源(如特殊脉冲发生器、雷达模拟信号，低频相位标准等)
- 任意信号发生器能输出“现实世界”各种信号
  - 信号加扰的产生:插入噪声、毛刺、交调等
  - 模拟复杂的信道



宽带OFDM光通信系统接收端验证－验证OFDM信号系统构建

验证和分析宽带OFDM电信号



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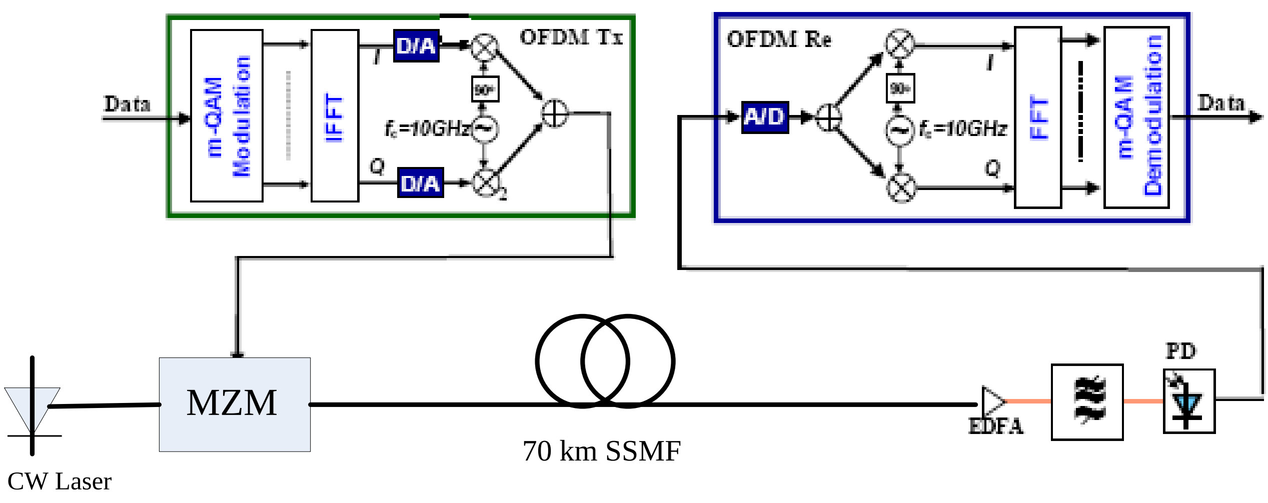
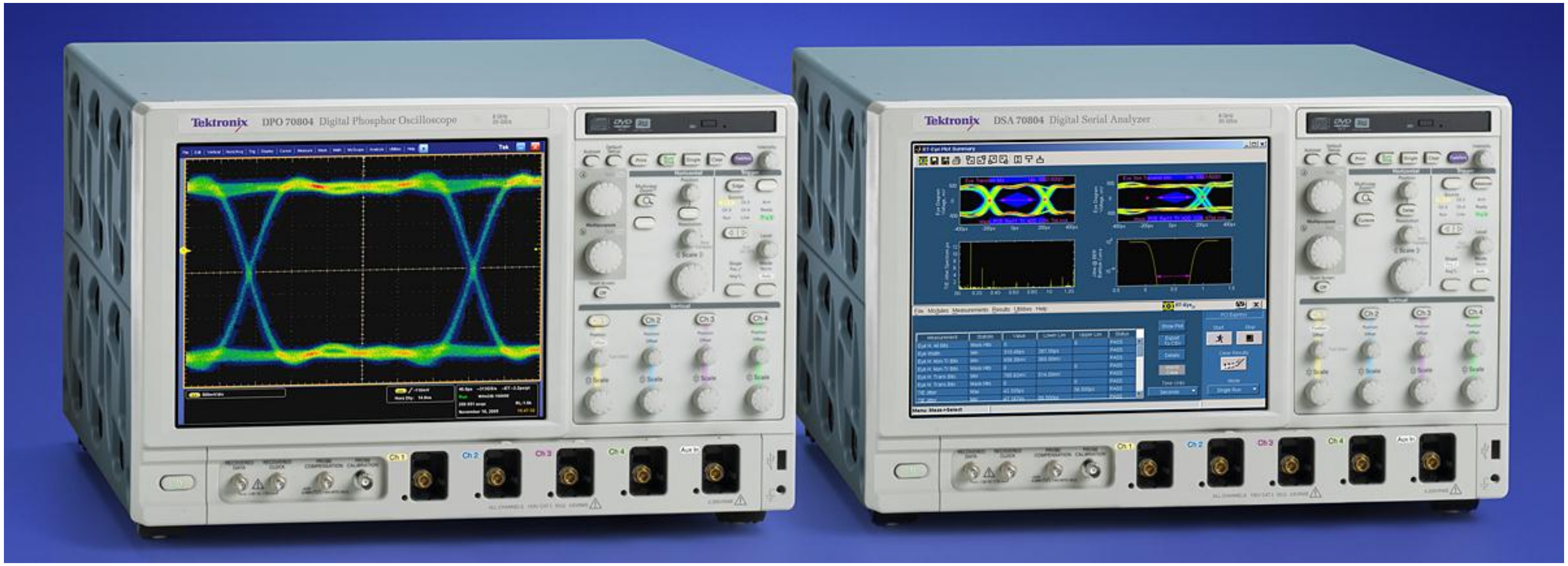
宽带OFDM光通信系统接收端验证—验证和分析OFDM信号

- 将Matlab或RFXpress产生的OFDM信号数据载入AWG7122C，利用宽带示波器观测电域OFDM信号的频谱(SignalVu软件分析频谱)和波形，确定正确产生OFDM信号；
- 利用DPO73304D宽带示波器采集和接收、下变频OFDM信号，观察传输后及下变频后的频谱，并利用泰克DPOJET软件测试抖动和眼图；
- 利用matlab把DPO73304D示波器采集的波形数据进行解调，解调出OFDM信号中的原始信息，测误码率或观测星座图和EVM。



Tektronix OFDM高速光通信信号采集、验证和分析解决方案-硬件平台

- 新超高性能数字荧光示波器:
  DPO70000D Series
- 新超高性能串行数字分析仪:
  DSA70000D Series



性能毫无折中的第三代数字示波器

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新超高性能数字荧光示波器DPO73304D-毫无折中的性能

一流的性能

带宽	采样速率	记录长度
23 GHz 在全部4条通道上同时实现	**50** GS/s 在全部4条通道上同时实现	**250** M最大值 同时在全部4条通道上实现

在一台仪器中提供了高度匹配的4路实时性能

只有泰克DPO70000满足了新兴的4通道测量串行标准测量要求

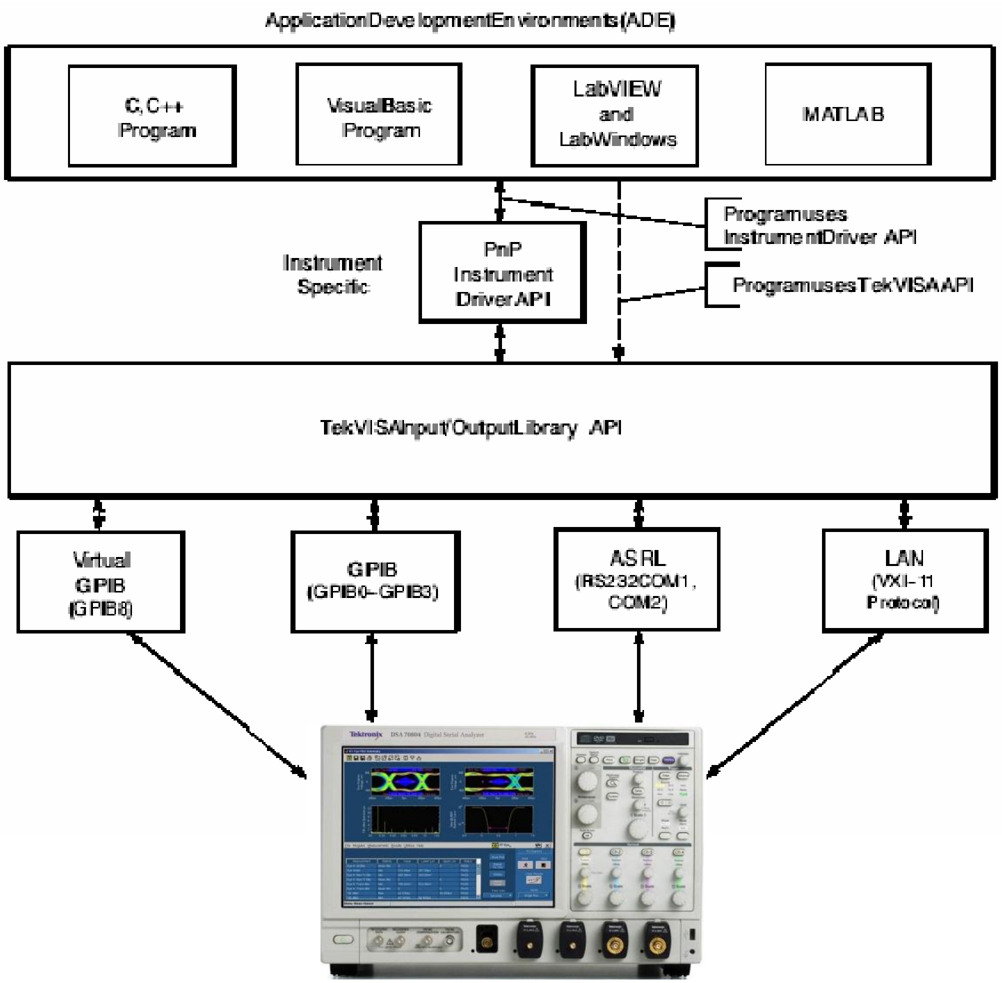
示波器作为宽带、超宽带信号采集和分析工具

- 110M以上的调制信号，如何分析？
  - 频谱仪是窄带接收机
  - VSA、RTSA动态范围高，但是110M以上的调制信号无法分析
  - 专用接收机
- 示波器——最通用的宽带接收机
  - 泰克示波器，可以提供最高达33GHz带宽，可直接采集分析Ku波段以内的射频信号
  - 配合各种分析软件，对调制参数进行测量
  - 使用示波器采集和存储信号

Insight

新超高性能数字荧光示波器:DPO73304D扩展能力

- 支持多种开发环境
  - C, C++, VB, LabView, LabWindows, **Matlab**
- TekVisa 与Tek示波器核心的通讯可通过
  - Virtual GPIB
  - GPIB
  - LAN



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泰克宽带OFDM光通信系统测试解决方案优点小结

一、一整套完整的系统测试方案

二、超宽带信号源AWG－业内唯一能产生宽带OFDM信号的信号源

- 超高带宽（9.6G），超高采样率（24G）
- 可以直接产生射频，中频，基带信号
- 基于AWG的高级OFDM信号仿真软件RFXpress，方便产生各种复杂的OFDM信号
- 对实际回波信号进行二次“改造”：如加“噪声”加“干扰”
- 与各种软件兼容如:Matlab等
- 与泰克的宽带示波器搭成无缝环路

三、宽带示波器

- 带宽33GHz
- 采样率4个通道同时达到50GHz
- 存储器四通道通道到250M点
- DPOJET软件最专业的抖动眼图测试软件
- SignalVu 频谱分析软件
- 与各种软件兼容如:Matlab等

泰克光OFDM高速光通信解决方案配置

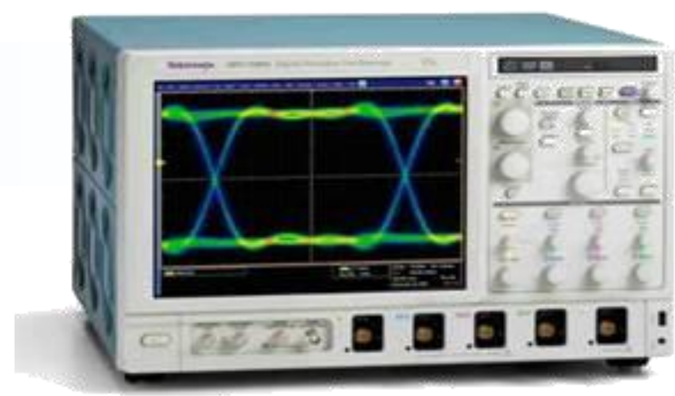
AWG7122B: 任意波形产生器

RFXpress OFDM 生成软件

DPO73304D: 数字荧光示波器

DPOJET 眼图抖动测试软件

SignalVu 频谱分析软件



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Optical Modulation Analyzer Solutions for Coherent Optical Testing

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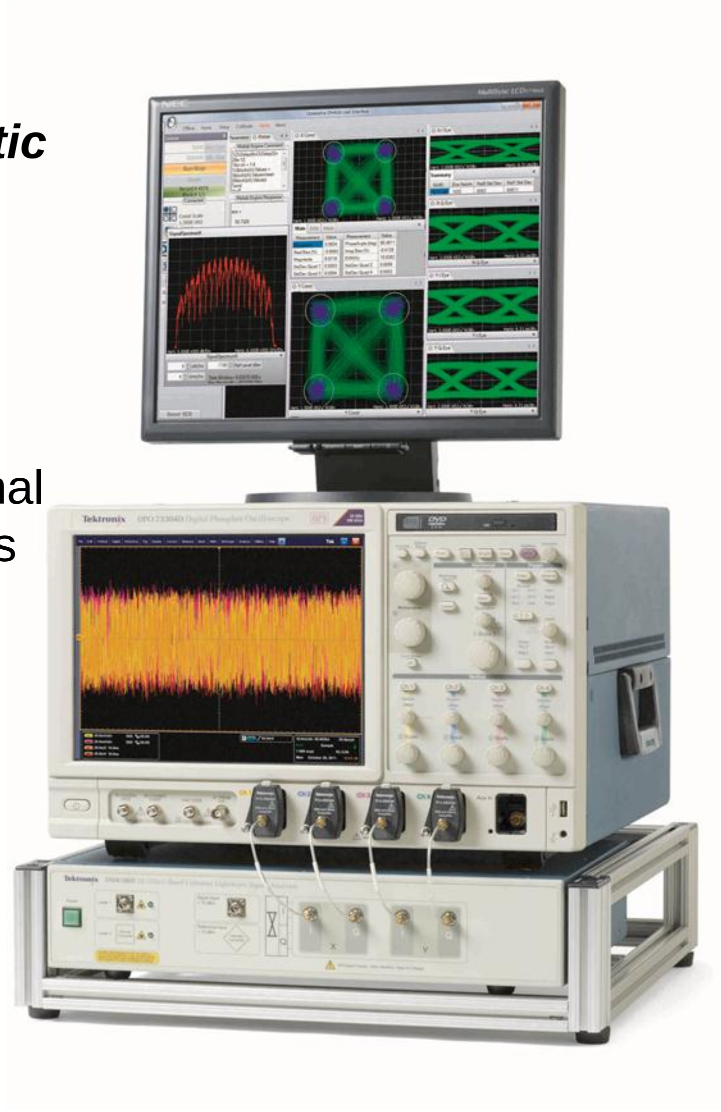
Outline

- Coherent modulation background material
- Introduction to the Coherent Lightwave Signal Analyzer
- Measurement capabilities
- Hardware configurations
- Receiver test and transmitter test value proposition
- Summary/Conclusion

OM4106D 33 GHz Coherent Lightwave Signal Analyzer for > 100 Gb/s Analysis

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

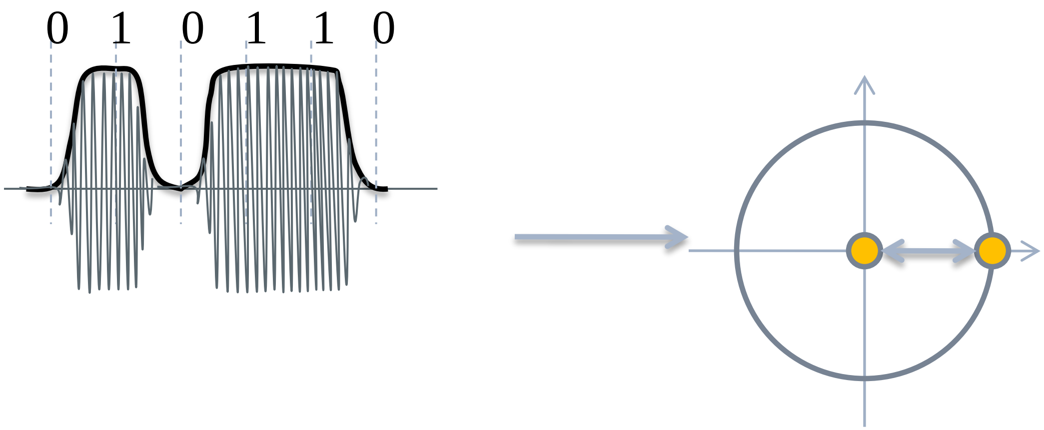


- Advanced dual-polarization in-phase and quadrature receiver with integrated signal and reference tunable laser sources
- Open-architecture MATLAB-based computational engine offers powerful phase-recovery analyses with polarization, bit-error rates, and record/playback
- Intuitive graphical user interface controls frequently-used instrument functions:
  - Laser control
  - Modulation schemes
  - PRBS or user-generated data
- Accessories available to easily verify optical calibration

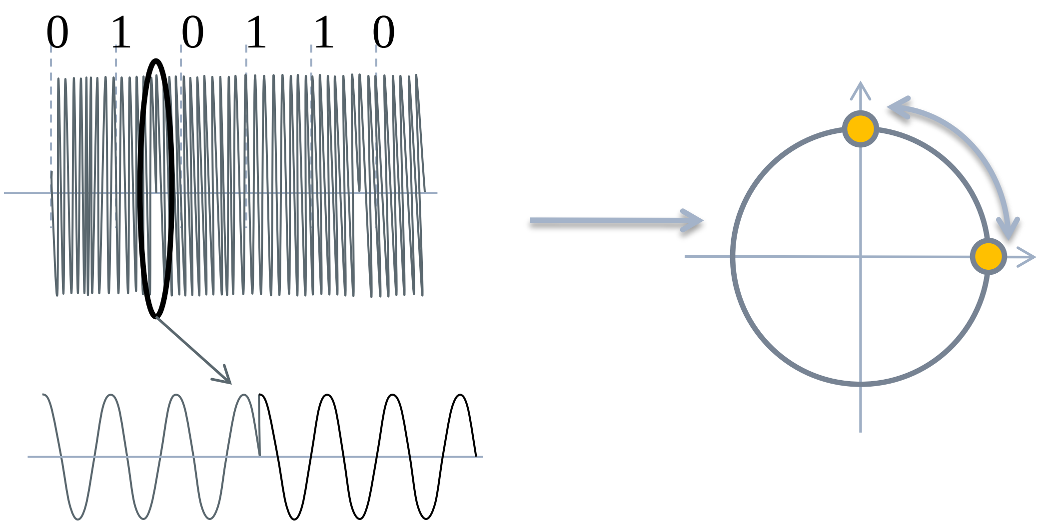
Why do I need a Coherent Lightwave Signal Analyzer?

- 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

Optical Modulation Methods

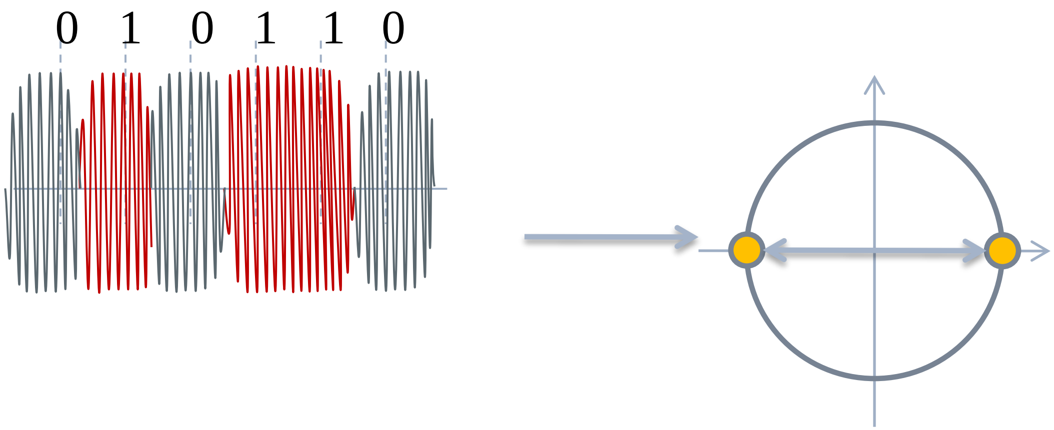


Pure AM (OOK)

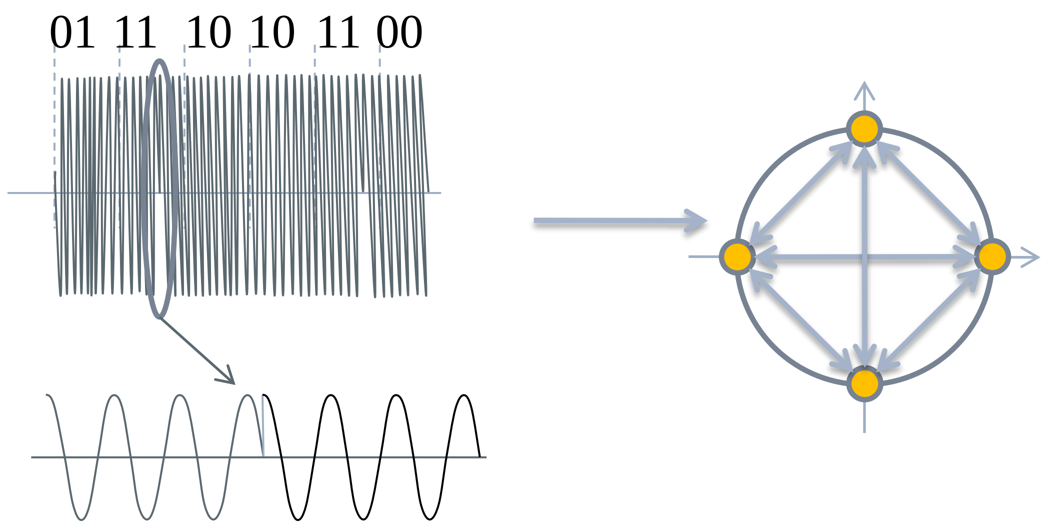


Pure PSK

Optical Modulation Methods continued



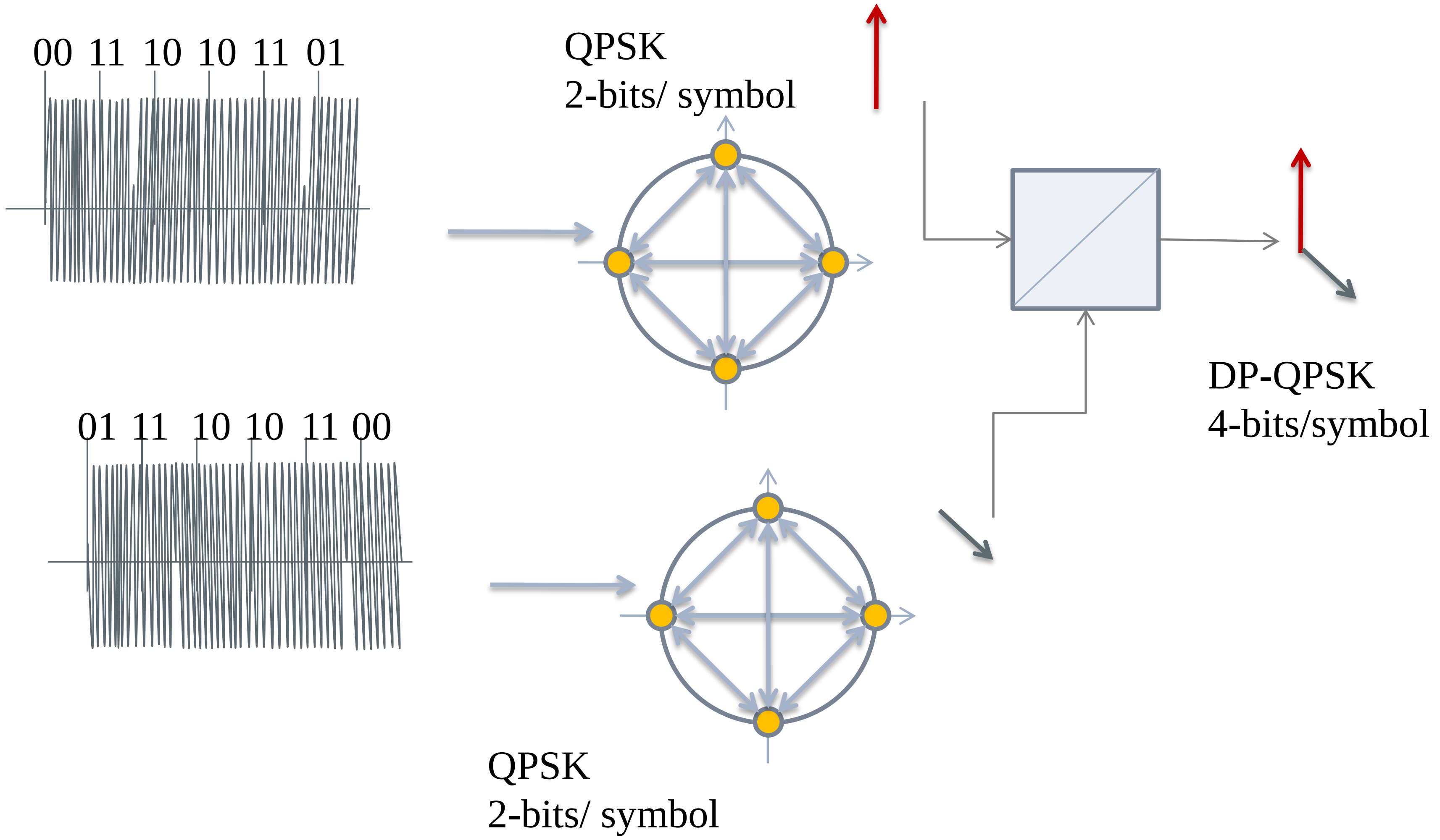
Typical BPSK



Typical QPSK

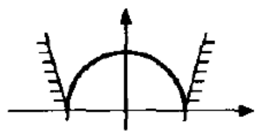
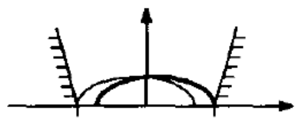
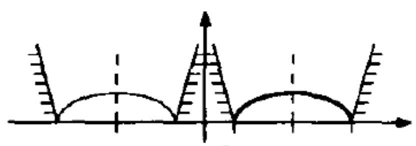
2-bits/ symbol

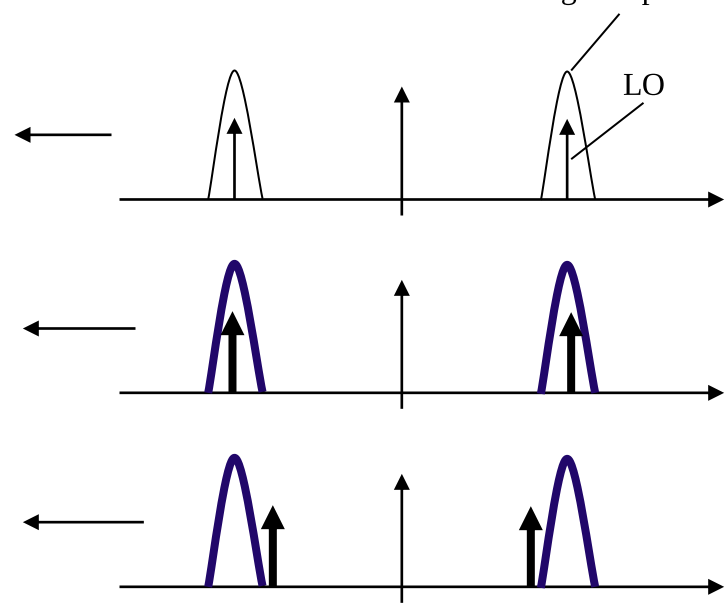
Optical Modulation Methods continued



Intradyne + DSP Make It Work

TABLE I
COHERENT OPTICAL TRANSMISSION SYSTEMS (IF = INTERMEDIATE FREQUENCY; B = BANDWIDTH OF BASEBAND SIGNAL)

system	IF spectrum	IF
homodyne		IF = 0 Optical PLL
intradyne		IF < B
heterodyne		IF > B



Without PLL, frequency and phase error must be corrected in DSP

- Derr, 1992, PTL

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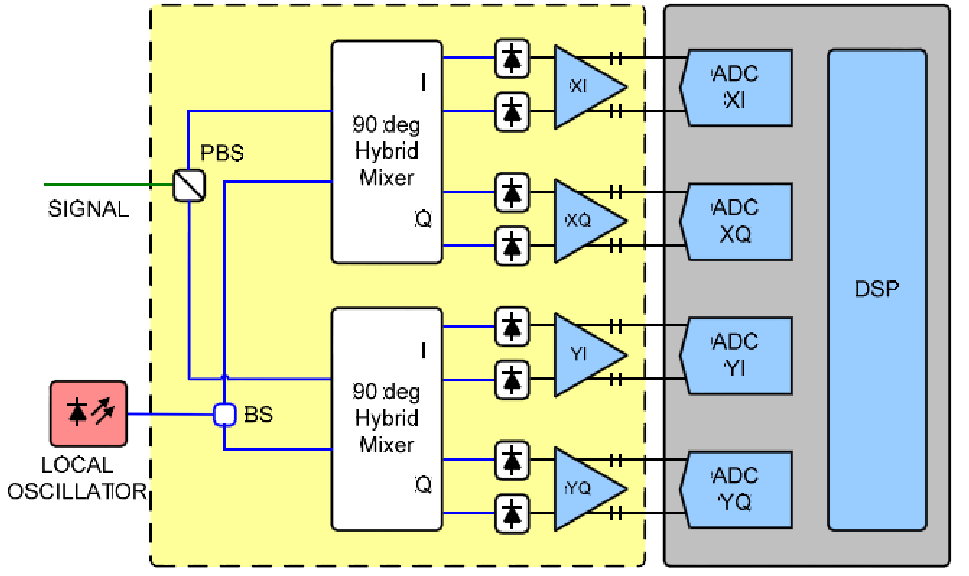
Integrated Dual Polarization Intradyne Coherent Receivers

Replace input signals with reference signals



Replace ADC with real-time oscilloscope

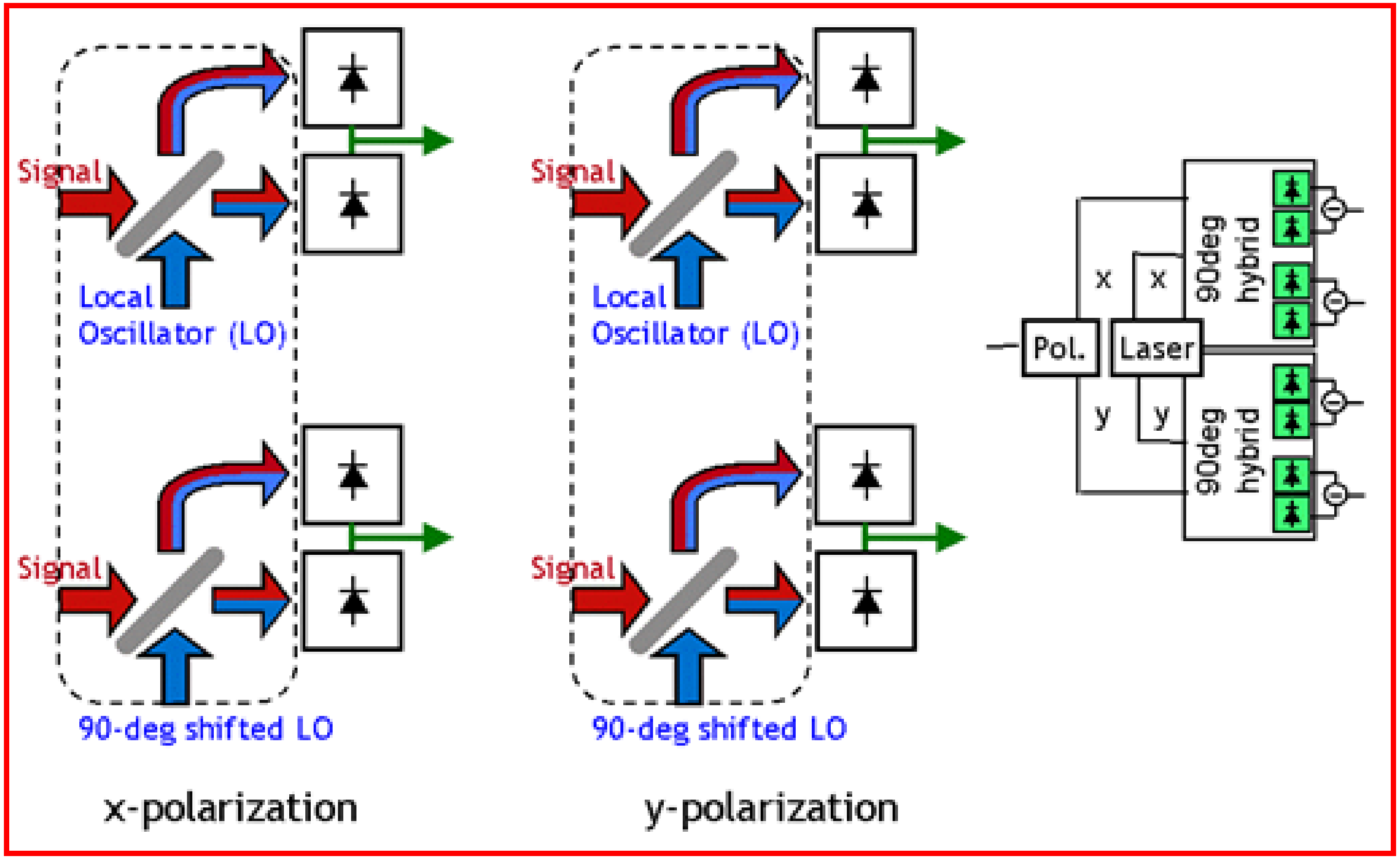
New OIF Agreement
IA OIF2009.033.06

Test overall:

- Path gains
- Cross talk
- Phase angles

At any frequency or wavelength

Coherent Detection



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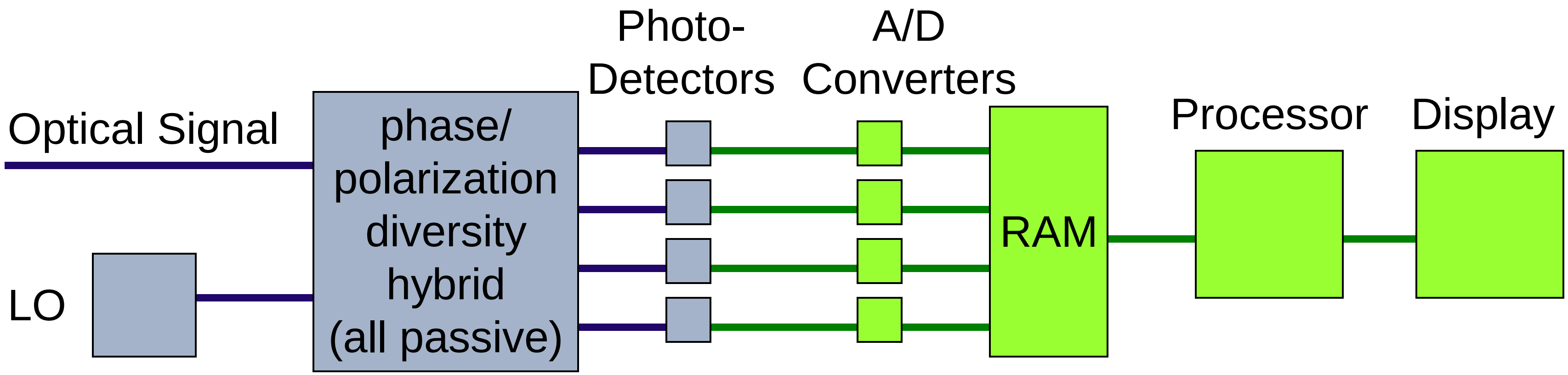
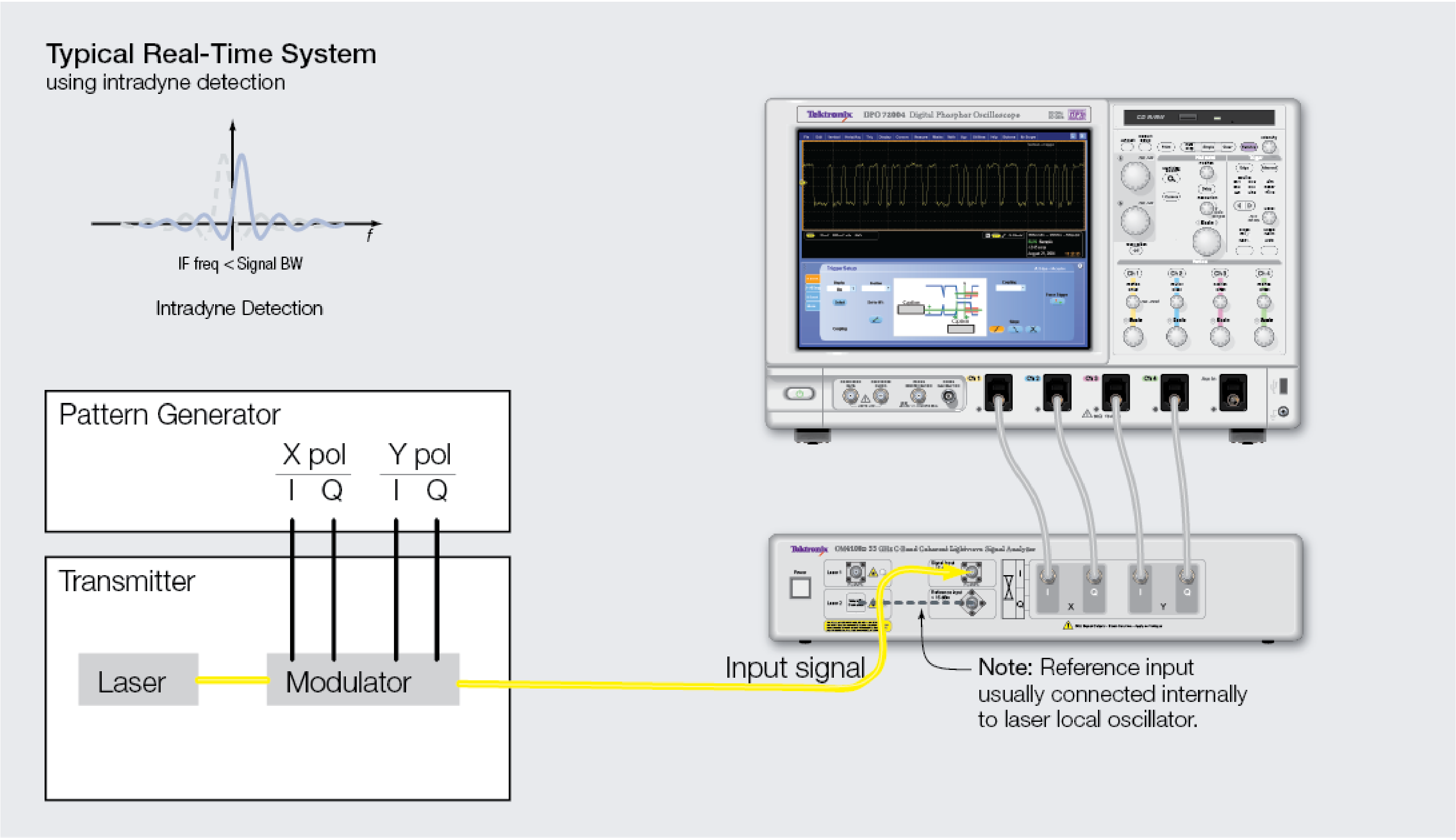
Coherent Lightwave Signal Analyzer Architecture

- 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
- So in principle any signal parameter can be deduced by an appropriate algorithm

Typical Configuration with Real-Time Scopes



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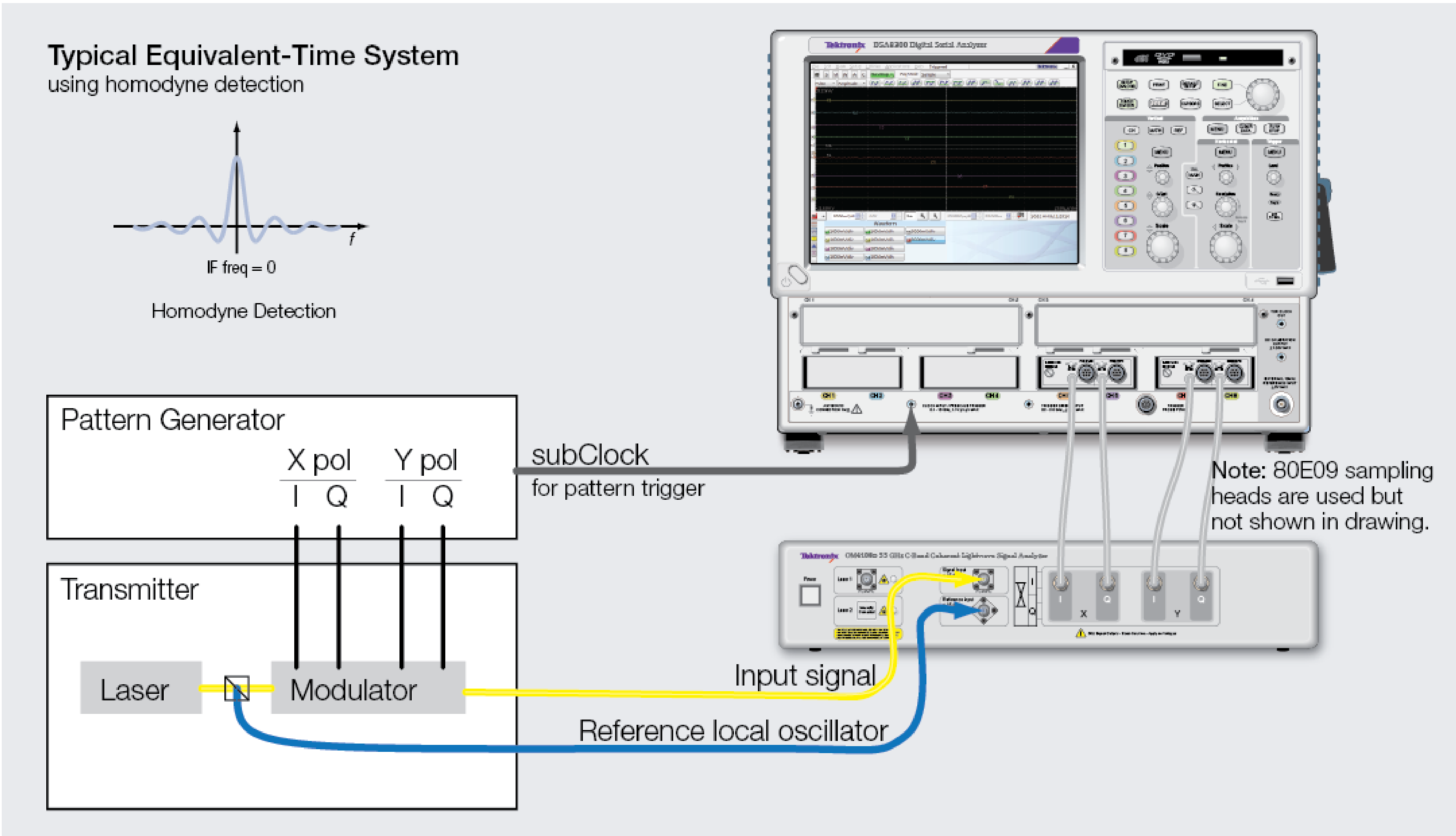
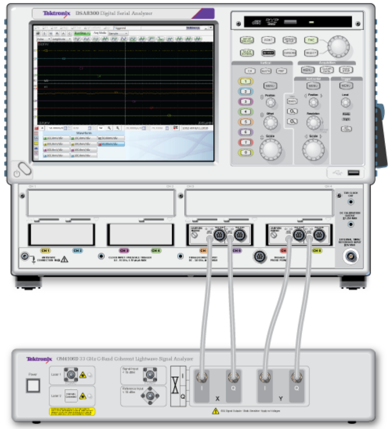
Typical Configuration with Sampling Scopes



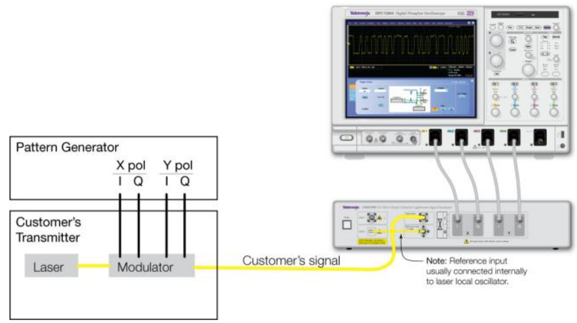
NEW

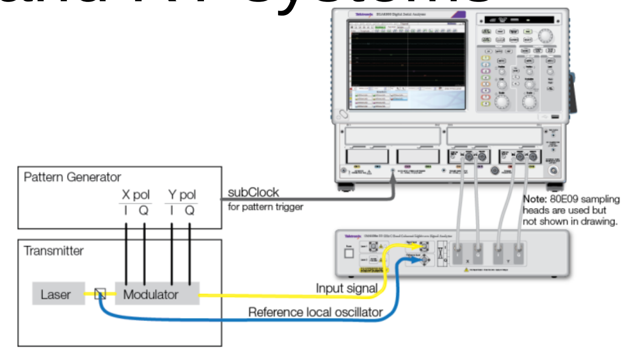
OM4106D support for the DSA8300 Sampling Scope



- The OM4106D and the OM1106 software have been modified to support the DSA8300 sampling scope.
- Any existing OM4106D is capable of supporting both DSA/DPO70k real-time scopes and the DSA8300 sampling scopes with a software upgrade.
- Using the sampling scope for acquisition provides greater vertical resolution at a lower total system price compared to real-time solutions.
  - 16 bits vertical resolution and 450uV rms noise floor at 60 GHz provide added dynamic range and accuracy.
  - Up to 60 GHz sampler bandwidth on four channels provides future-proof capability for next-gen baud rates.
  - Timing jitter as low as 450fs RMS lets you see signal jitter. (as low as 100fs when using the 82A04B Phase Reference Module)

Differences between ET systems and RT systems





	Real-Time Systems	Equivalent-Time Systems
Target Customers	Often favored by Network Equipment Manufacturers and system integrators due to high RT sample rate and intradyne detection.	Often favored by optical component manufacturers due to very high vertical and time resolution. Homodyne detection is often fine.
Optical detection	Intradyne – high sampling rate of RT scope allows frequency and phase tracking to be performed mathematically. No separate laser reference is required.	Homodyne – due to low sampling rate of ET scope a separate laser reference, split prior to the customer's modulator, must be provided to allow proper frequency and phase tracking.
Vertical Resolution	Determined by real-time scope vertical resolution.	Determined by equivalent-time scope vertical resolution.
Maximum data rate	With 33GHz RT scope: 60Gbaud With 20GHz RT scope: 40Gbaud	With 80E09: 60Gbaud (limited by OM4000) With 80E07: 60Gbaud (limited by 80E07)
Measurements available	All that are supported today.	All supported today except for: PMD, laser freq. error, laser phase noise, true BER (equivalent BER may be supported)
System Price	Largely affected by choice of real-time scope.	Can be lower due to lower scope price.

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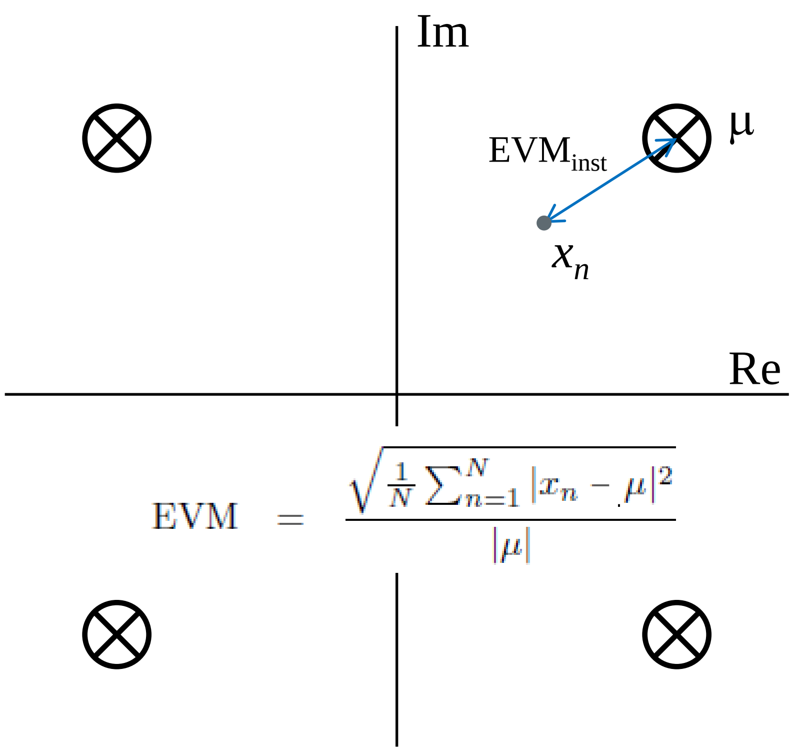
Instrument Requirements for Equivalent-Time Systems

- **OM4106D Coherent Lightwave Signal Analyzer**
  (the same instrument works for ET and RT)
  opt. EXT must be ordered to allow reference laser input
  other options may be ordered as desired
- **DSA8300** Digital Serial Analyzer Sampling Oscilloscope
- **80E09** Dual 60GHz Electrical Sampling Modules, 2 required
  (80E10 will also work, but offer no advantage over 80E09 for coherent optical testing.)

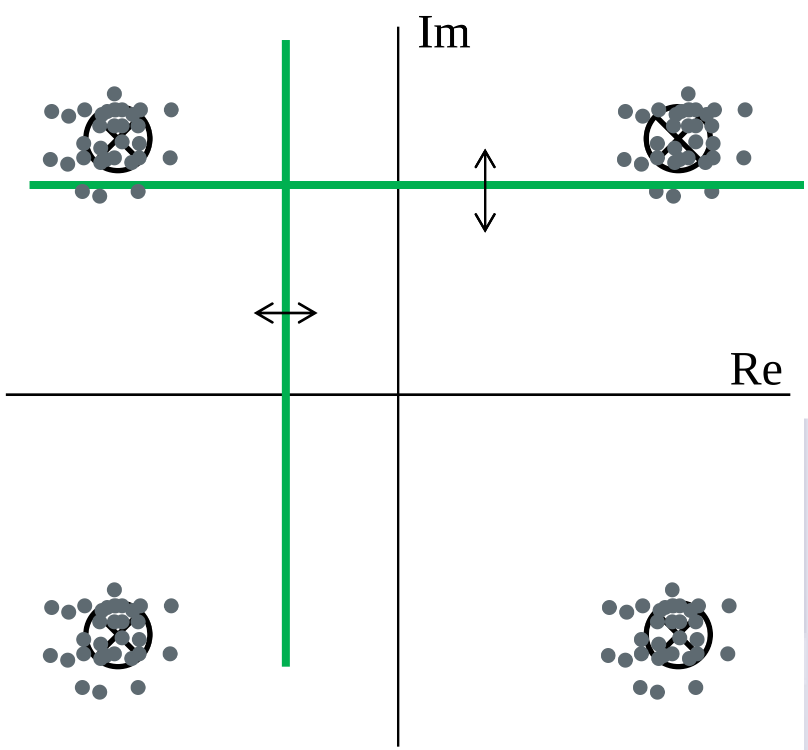
Measuring TX Constellation Imperfections: EVM



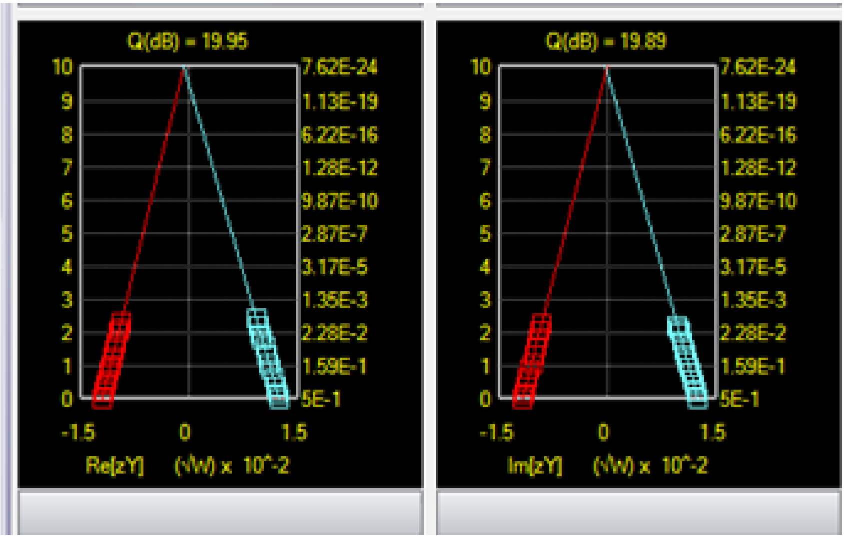
$$\text{EVM} = \frac{\sqrt{\frac{1}{N}\sum_{n=1}^{N}|x_n - \mu|^2}}{|\mu|}$$

- 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

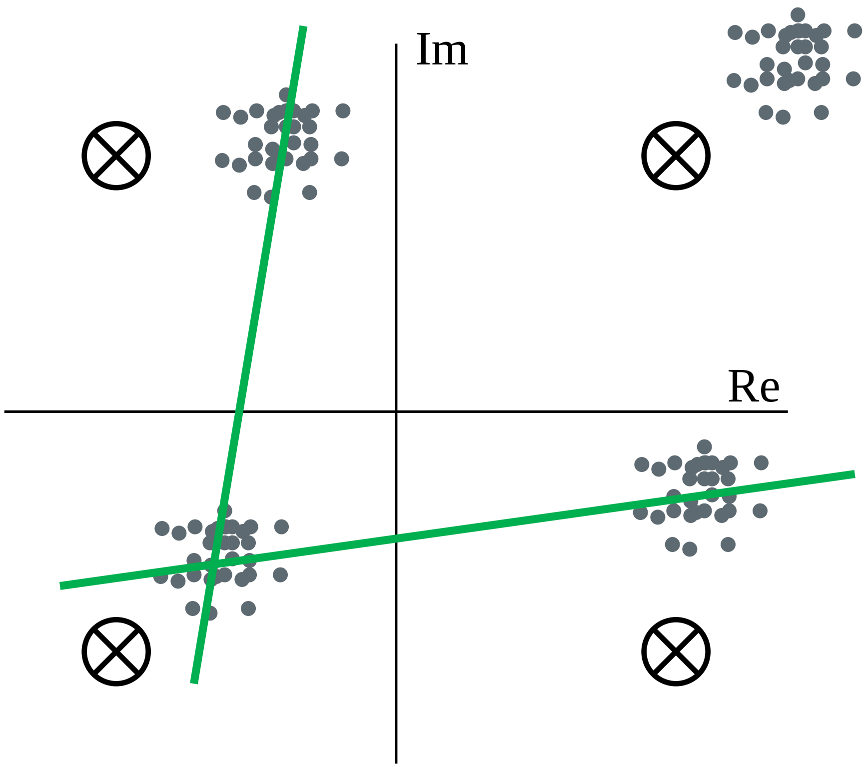
Measuring TX Constellation Imperfections: Q-factor

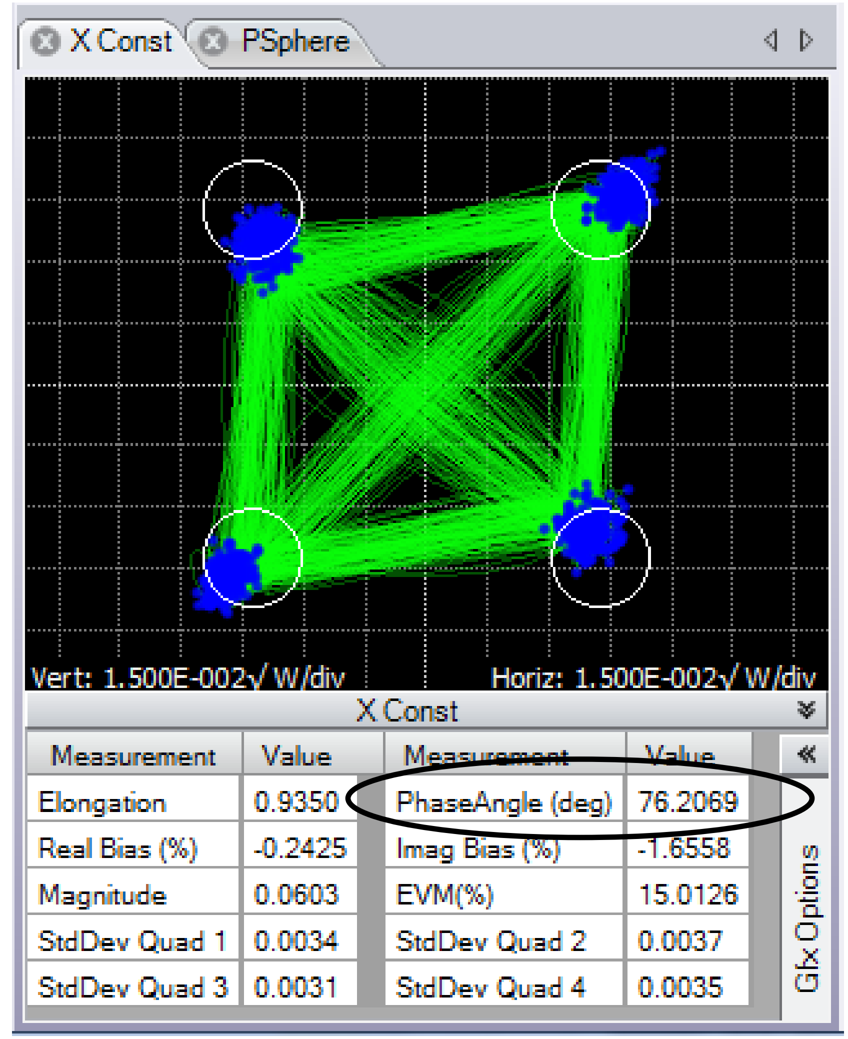


- Counts errors as decision threshold is moved.
- Errors fitted to error function in "Q-space"
- → Plot, max-Q and optimum decision threshold



Measuring TX Constellation Imperfections: Phase Angle





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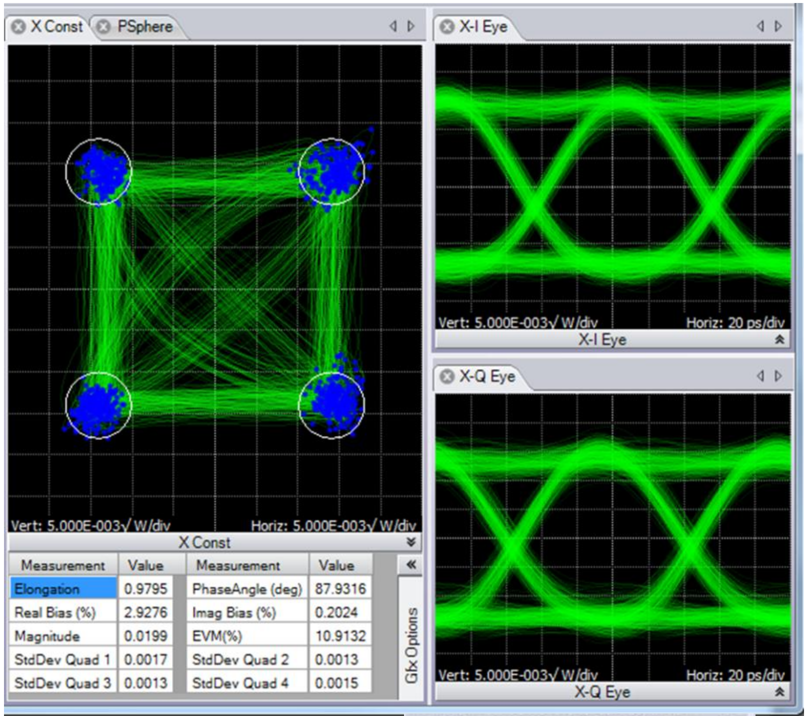
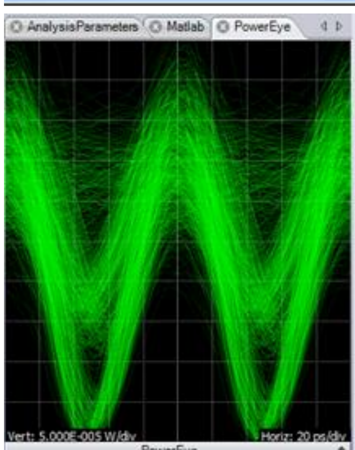
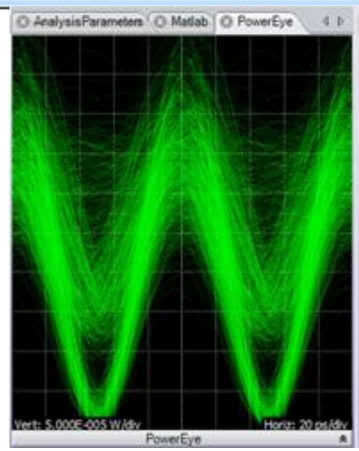
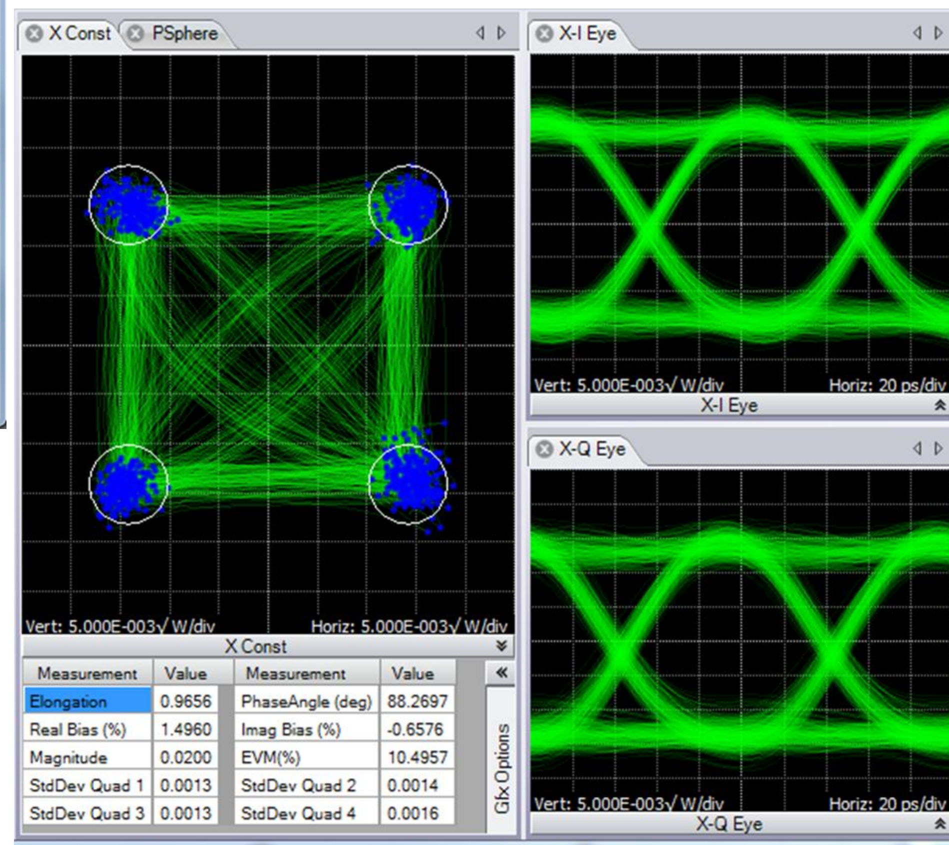
Example: Modulator Bias Adjustment

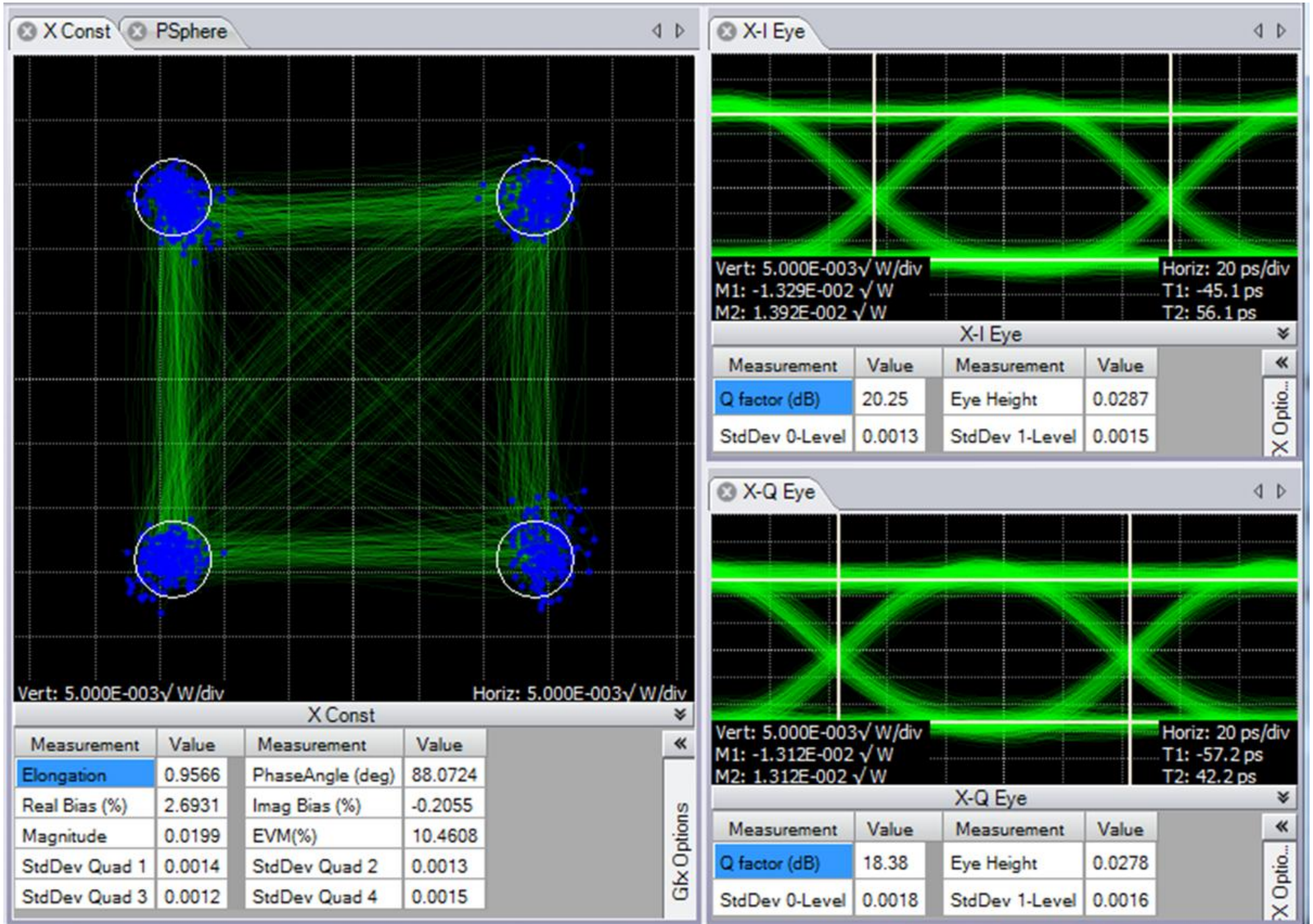








Example: Adjusting Tributary Timing Skew



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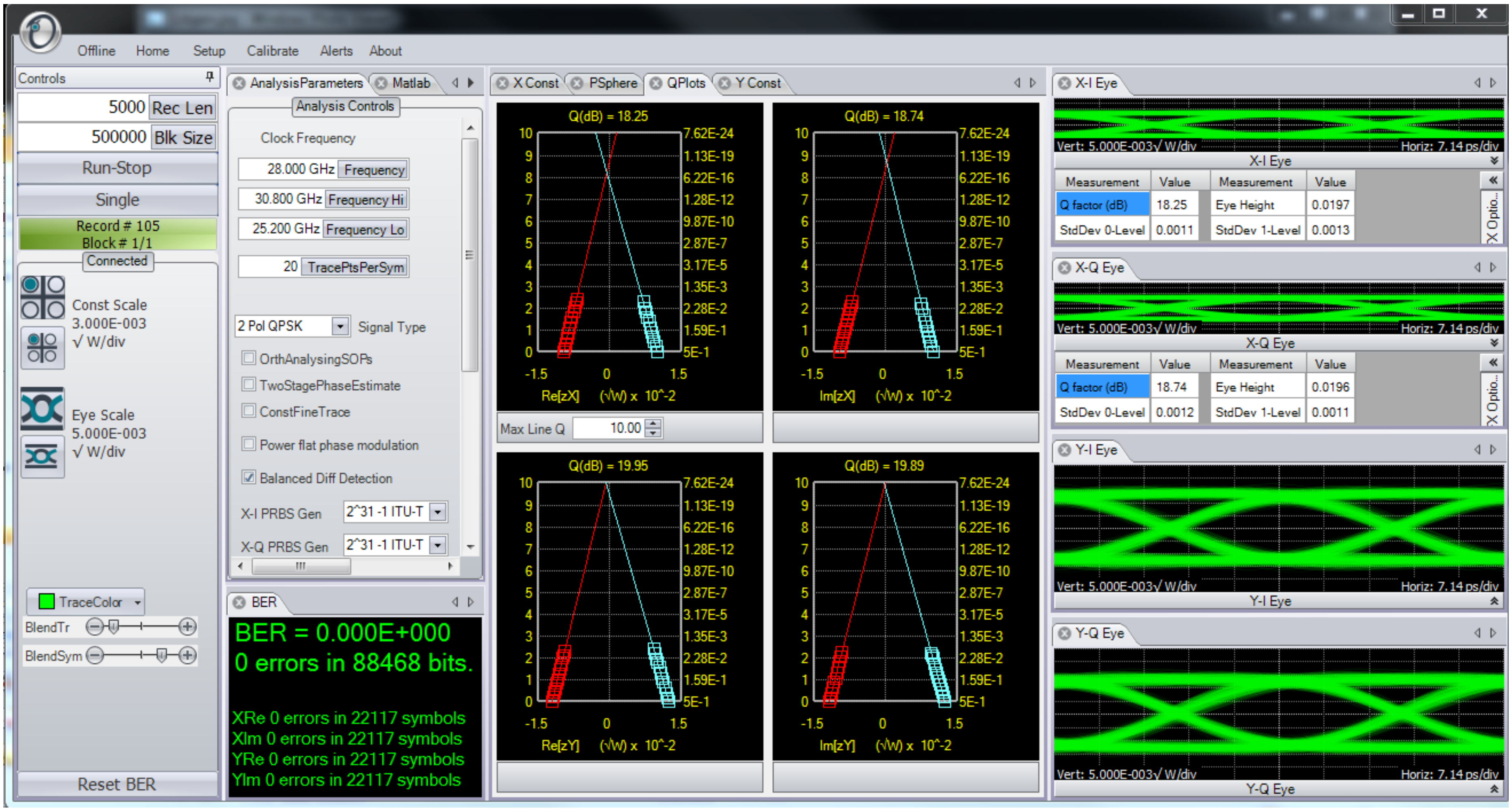
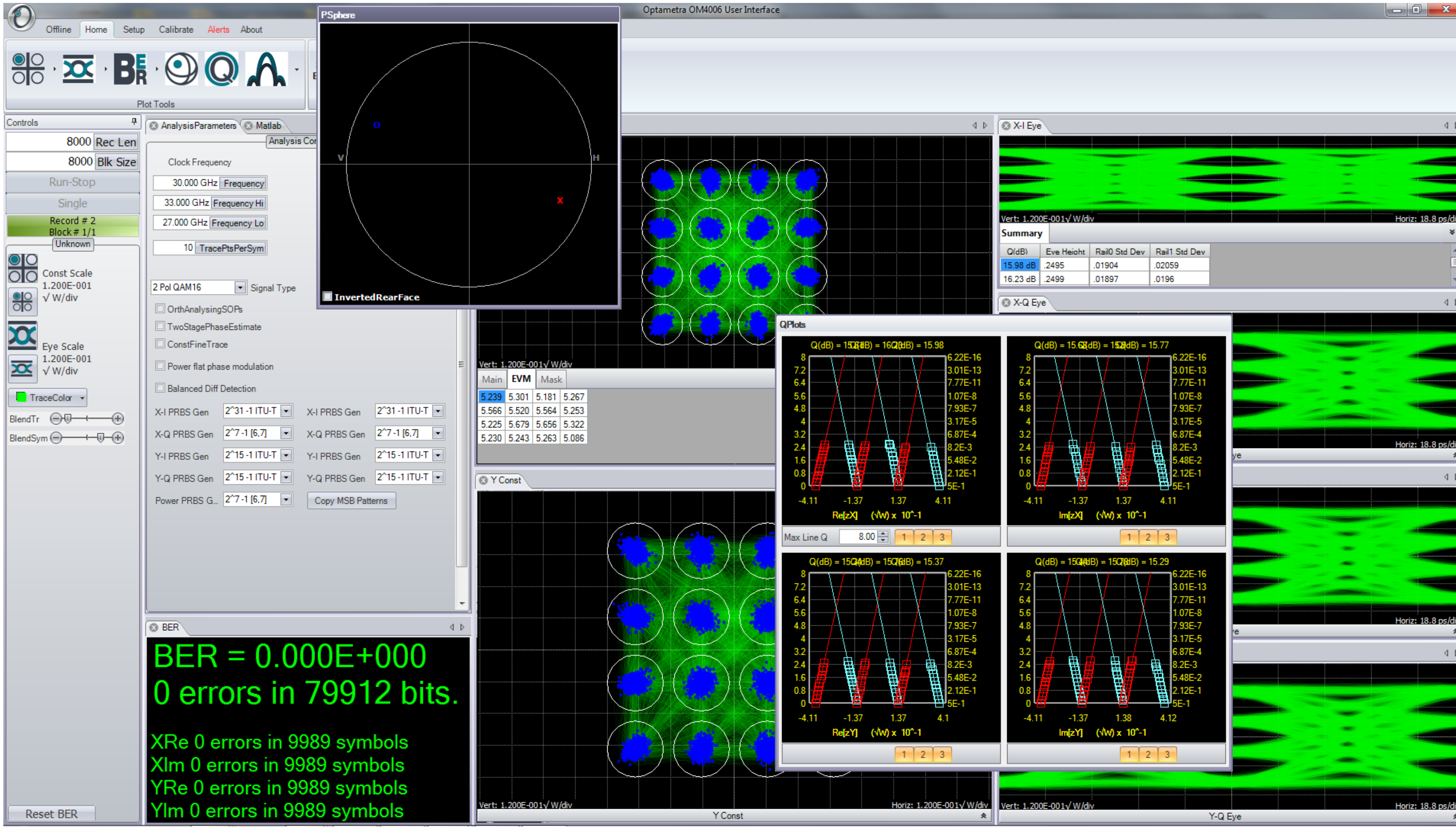
Measurements Available for QPSK Signals



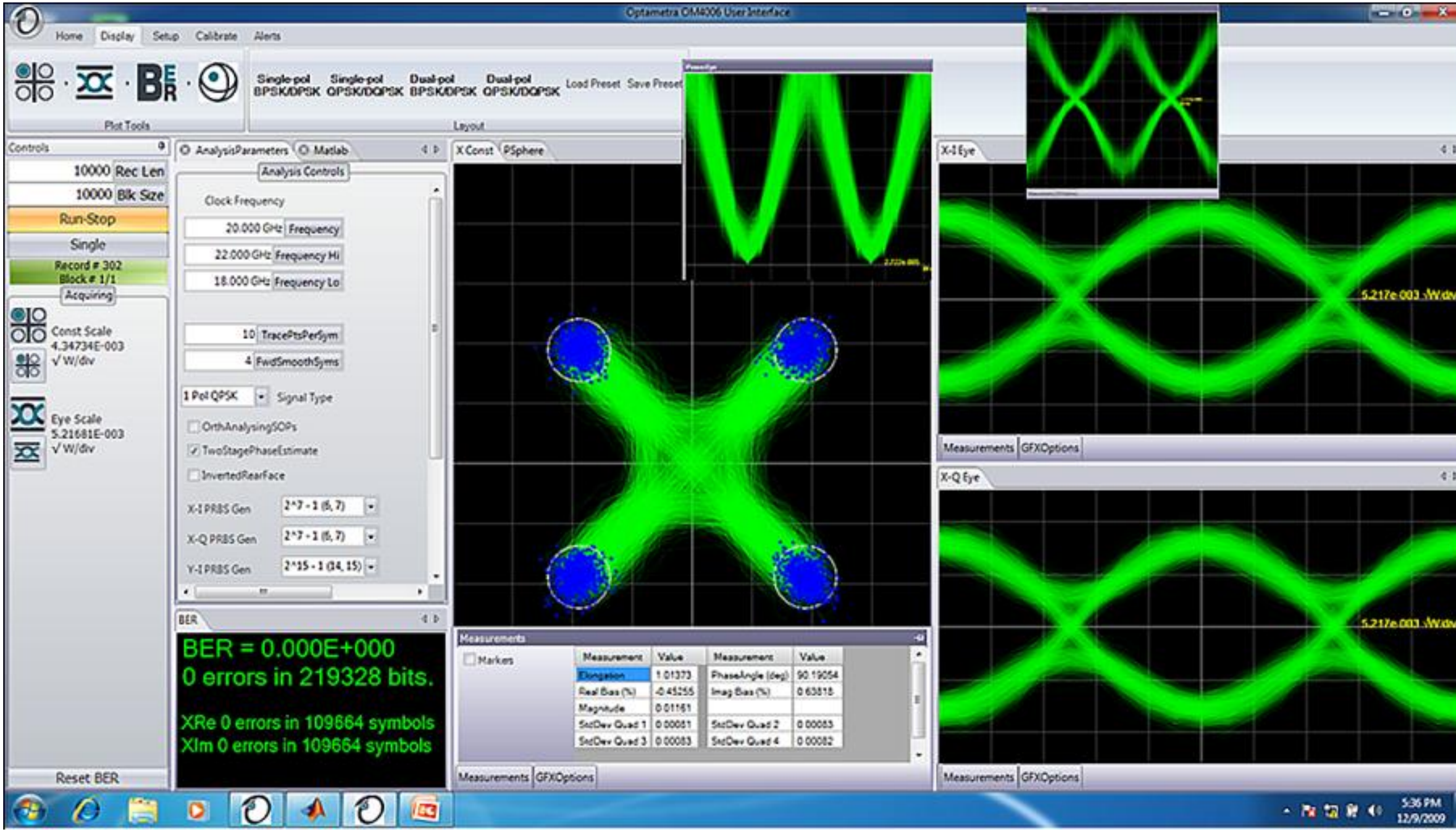
Measurement	Value	Measurement	Value
Q factor (dB)	18.25	Eye Height	0.0197
StdDev 0-Level	0.0011	StdDev 1-Level	0.0013

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

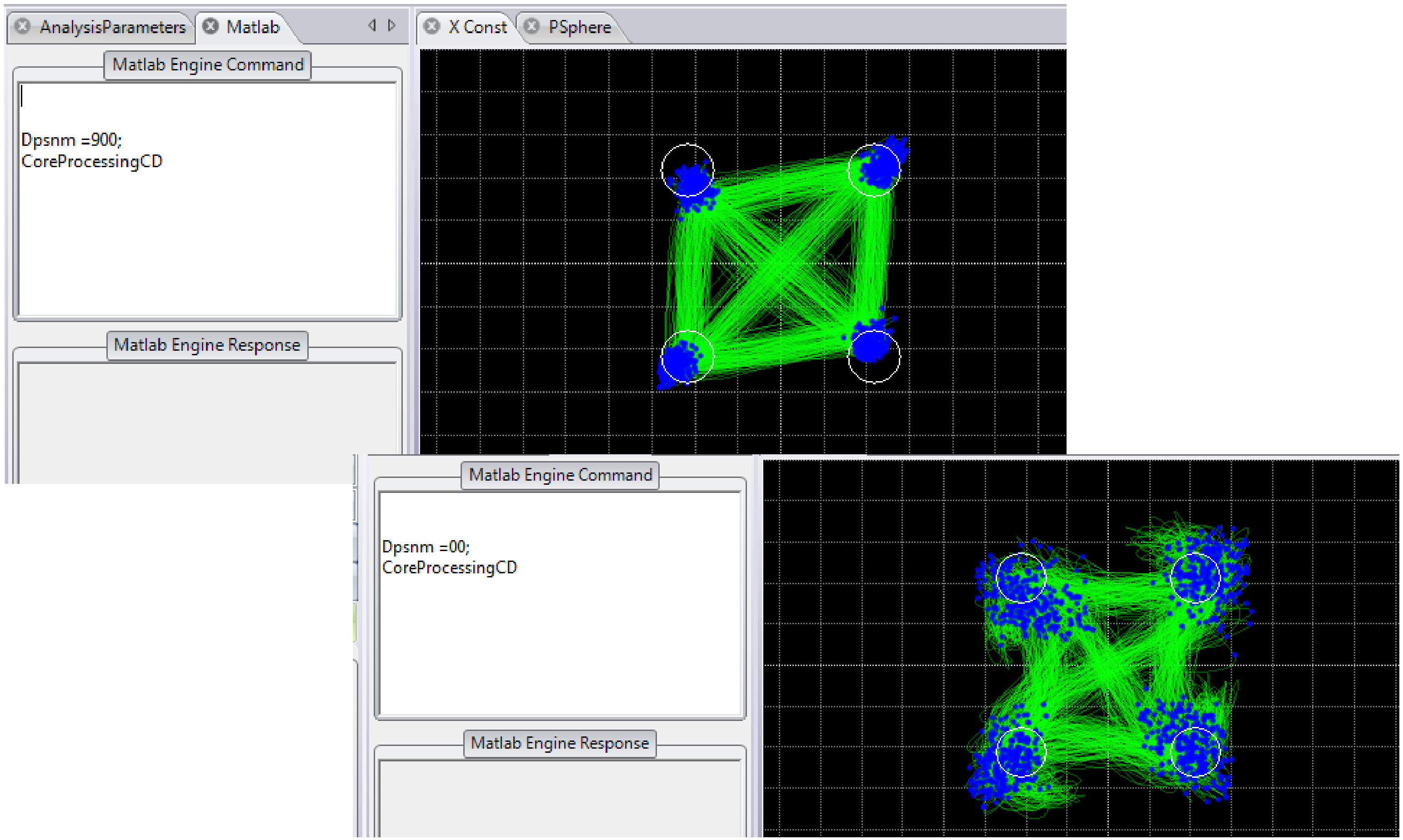
Measurements Available for QAM Signals



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 (%) 0.63818
StdDev Quad 2 0.00083
StdDev Quad 4 0.00082
5:36 PM
12/9/2009

One CD Module Being Compensated. CD = 900 ps/nm



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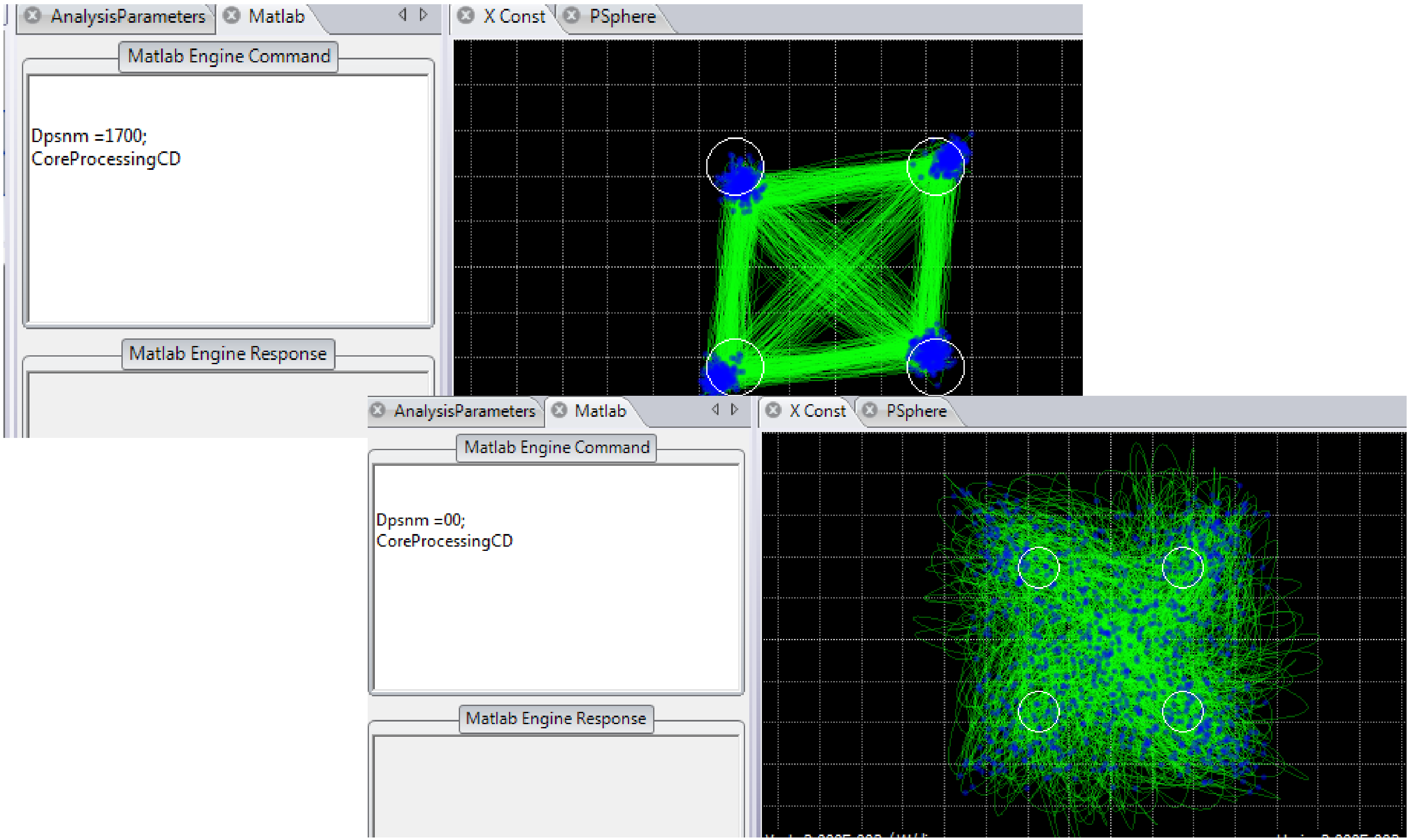
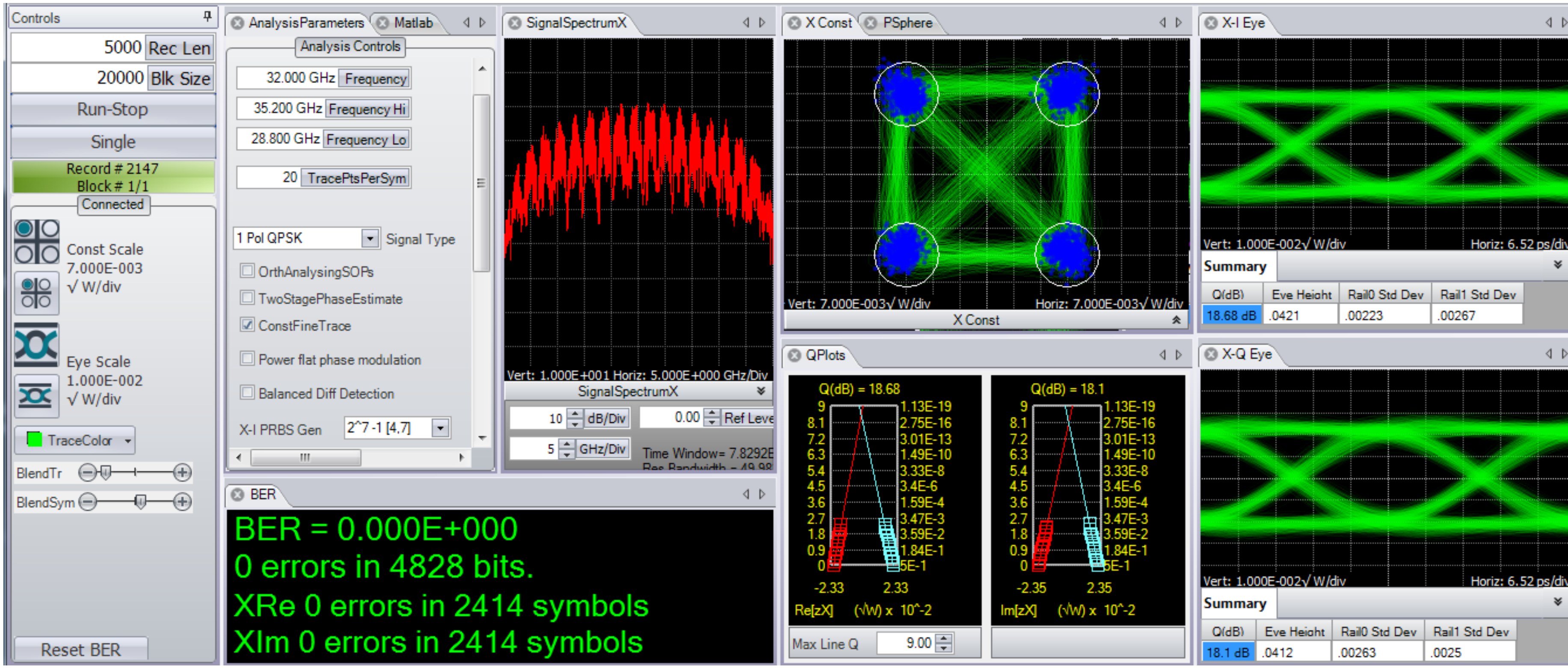
2 CD Modules CD = 1700 ps/nm



32 Gbaud Optical Signal Digitized with the DSA73304D in 50Gs/s mode (~23 GHz BW)



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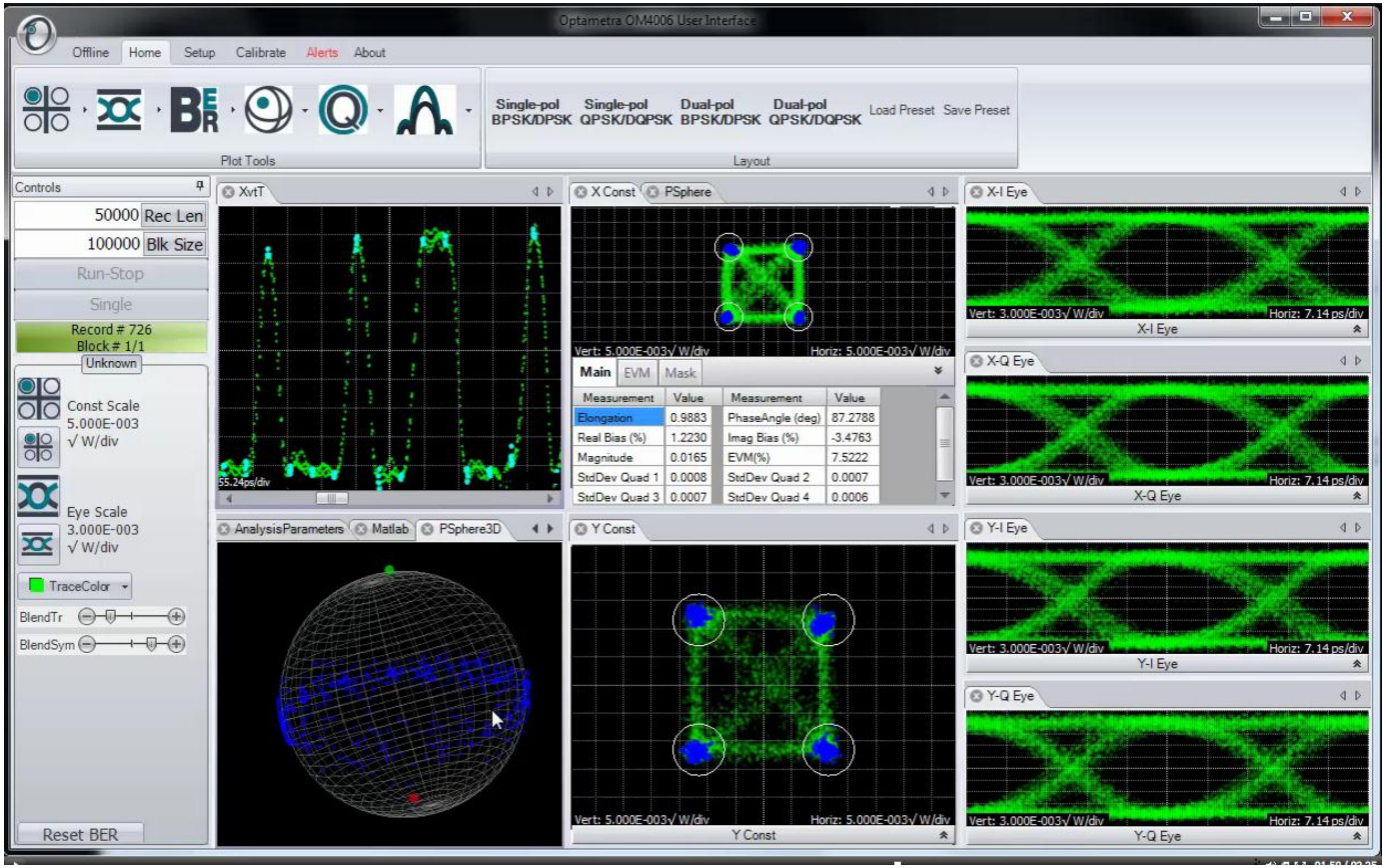
Equivalent Time Scope–based Analysis

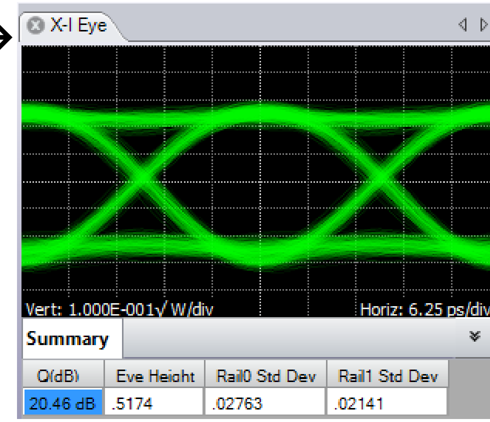


Measurement	Value	Measurement	Value
Elongation	0.9883	PhaseAngle (deg)	87.2788
Real Bias (%)	1.2230	Imag Bias (%)	-3.4763
Magnitude	0.0165	EVM(%)	7.5222
StdDev Quad 1	0.0008	StdDev Quad 2	0.0007
StdDev Quad 3	0.0007	StdDev Quad 4	0.0006

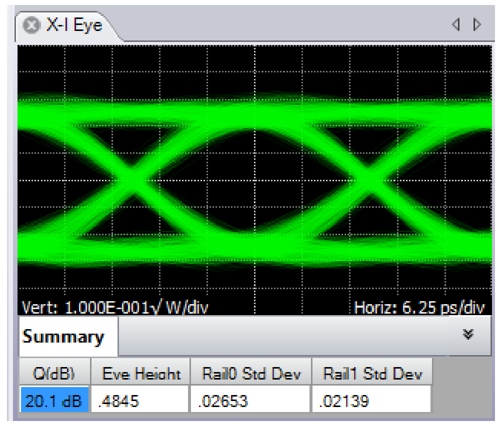
- Note that this is the same software used with real-time scopes, now modified to support sampling scopes.

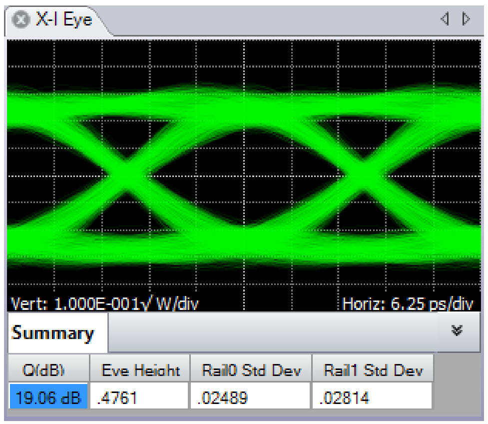
Effect of Front-end Bandwidth and Sampling Rate on a Data Signal

33GHz DSA73304D 100Gs/s→



DSA73304D 50Gs/s →





20GHz 50Gs/s DSA72004B

20GHz 40Gs/s →

32 Gb/s electrical data

100G Transceiver Testing

OM4106 TX Test

- Wavelength range
- Quadrature phase angle
- Constellation bias.
- Std. dev. by quadrant
- Eye crossing points
- Q-factor
- EVM, noise-loaded BER
- I/Q skew
- Total skew
- Polarization ER
- Laser phase noise

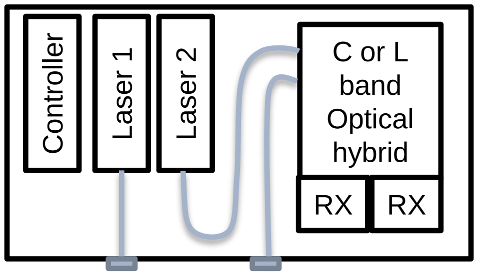
OM1206/ OM2210 RX Test

- Wavelength range
- LO freq error tolerance
- Quadrature phase angle
- Channel skew
- Crosstalk, channel gain w/ Ref TX
  - Q-factor
  - Std. dev. by quadrant
  - Eye crossing points
  - EVM, noise-loaded BER
  - LO phase noise

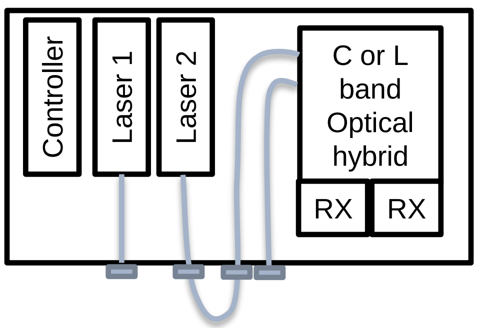
Transponder Level Test with Framing, Scrambling, FEC

- The following measurements are still valid for random data
  - Q-factor (soon), SNR, extrapolated BER (soon)
  - EVM
  - Mask violation
  - Constellation bias
  - Phase Angle
  - Laser phase vs. time
  - Laser phase spectra
  - Laser frequency offset
  - TX timing skew (harder to measure with random data)
  - Signal spectrum
- BER can't be measured with random data

OM4106 Single Band Options



OM4006\ OM4106 Base product is either C or L band. Laser 2 is internally connected for use as the Reference Laser (LO).



EXT Modifies base product to allow use of external laser for Reference Laser (LO). Includes armored PM jumper cable for use of internal laser.

Shown with base model receiver. Can also be ordered with C+L

All OM4000 Series can be ordered as B or D units. The D unit is only compatible with Tektronix oscilloscopes

Other software and service items are also available. Please see www.tek.com

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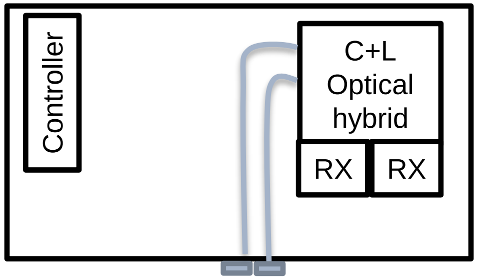
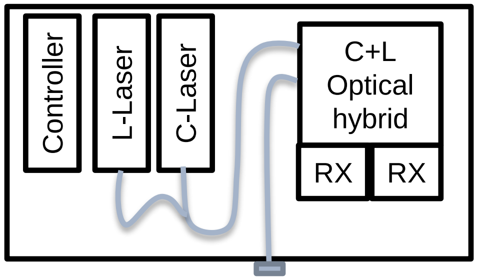
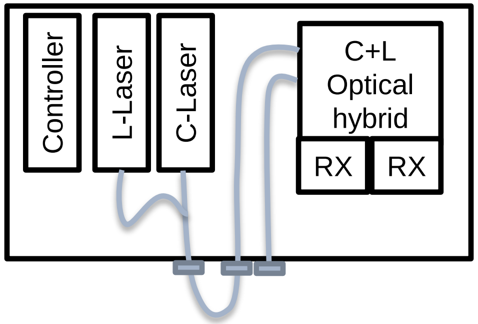
OM4106 C+L Configuration Options



OM4006\ OM4106 NL Base C+L receiver for operation over C+L (1530 to 1610nm). No lasers are included in base C+L model.



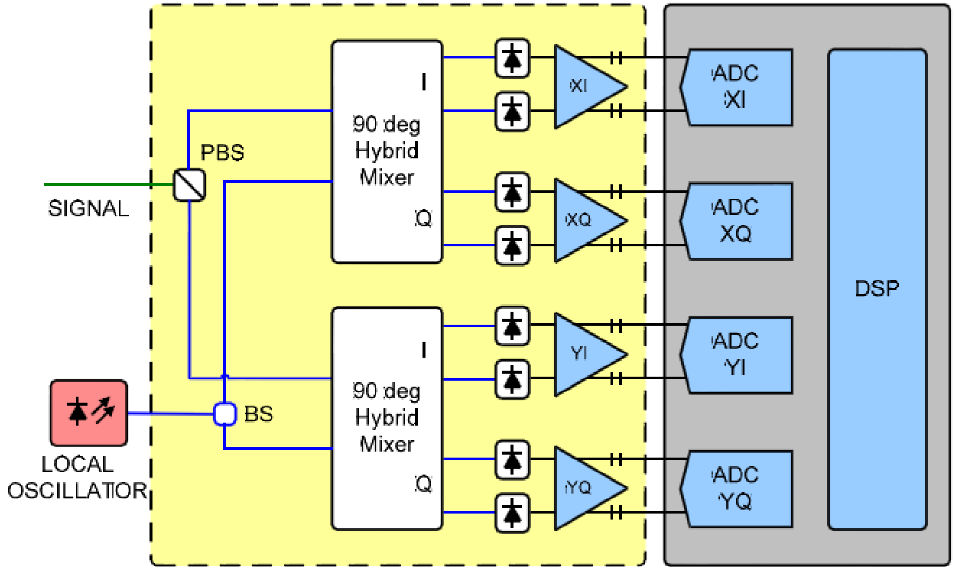
OM4006\ OM4106 CL Modifies base C+L product to include 1 C and 1 L band laser internally coupled to the Optical Receiver



EXT Modifies base product to allow use of external laser for Reference Laser (LO). Includes armored PM jumper cable for use of internal laser.
REQUIRED for operation with a sampling scope.

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

Optametra/Tektronix Innovations

- Signal processing algorithms designed for optical recovery of optical signals
- Decision-based Q-factor plots for QPSK and higher order constellations
- Ambiguity resolution to provide consistent identification of X-I, X-Q, etc.
- Direct Matlab interface
  - Enable quick calculations based on any variable
  - Functionality can be customized
  - Custom variables can be retrieved remotely
- Lasers included for rapid calibration verification
- Optametra User Interface
  - Easy to use
  - Customizable
- Data and screen-shots collected remotely via WCF interface
- Calibration source for direct measurement of receiver properties
- Ready compatibility with 3rd party receivers
- High bandwidth single-oscilloscope 4-channel measurement system

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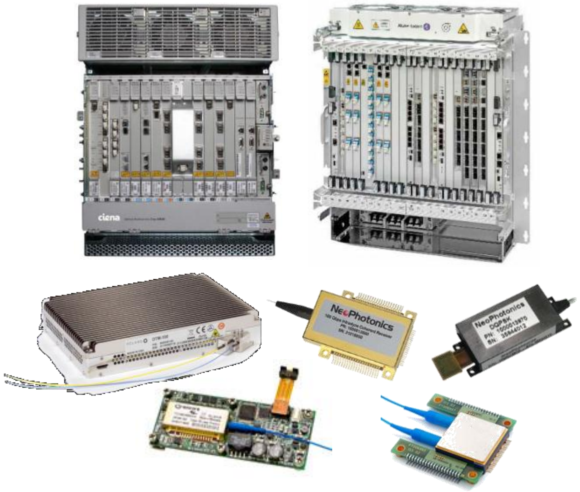
Customer Types

Commercial Longhaul Transmission System Ecosystem



Network Equipment Manufacturers (NEMs)
Developing complete systems for coherent systems.

Examples: ADVA, Alcatel-Lucent, Ciena, Cisco, Huawei

Component Manufacturers (CMs)
Developing modules/components used by NEMs

Examples: JDSU, Emcore, Finisar, Fujitsu, Corning, Oclaro, u^{2}t, Neophotonics, Mitsubishi

Government/Defense

Systems integration and staying abreast of latest communications technologies.

Examples: Boeing, Measurement Analysis Corporation, Air Force Research Labs, other government “agencies”

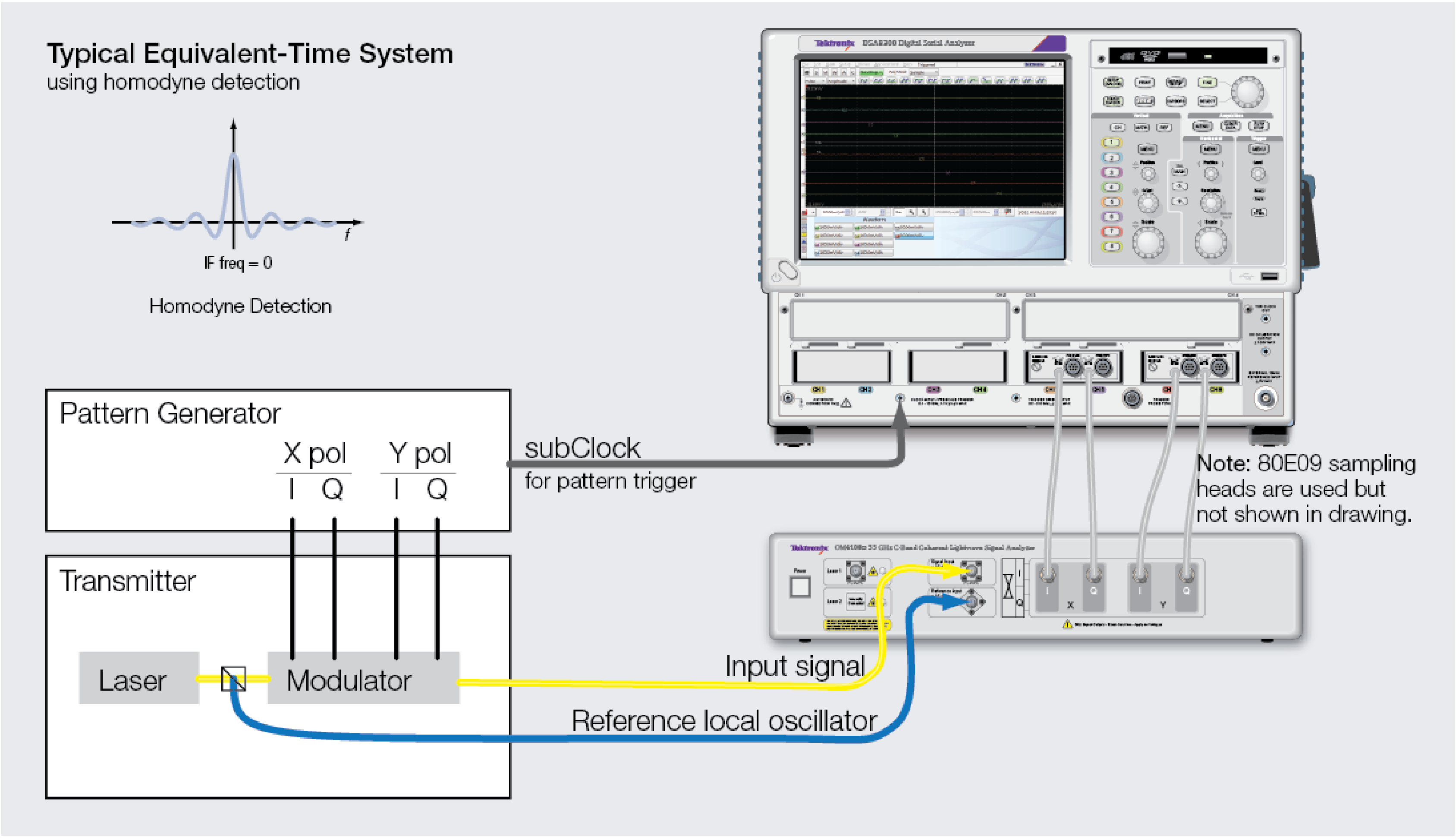
Universities

Education and development of next-generation technologies

Examples: ChangChun University, Tamagawa University, Georgia Tech.

Note: Customer listed here are examples and not necessarily current Tektronix OMA customers.

Typical Configuration for Transmitter Component Testing



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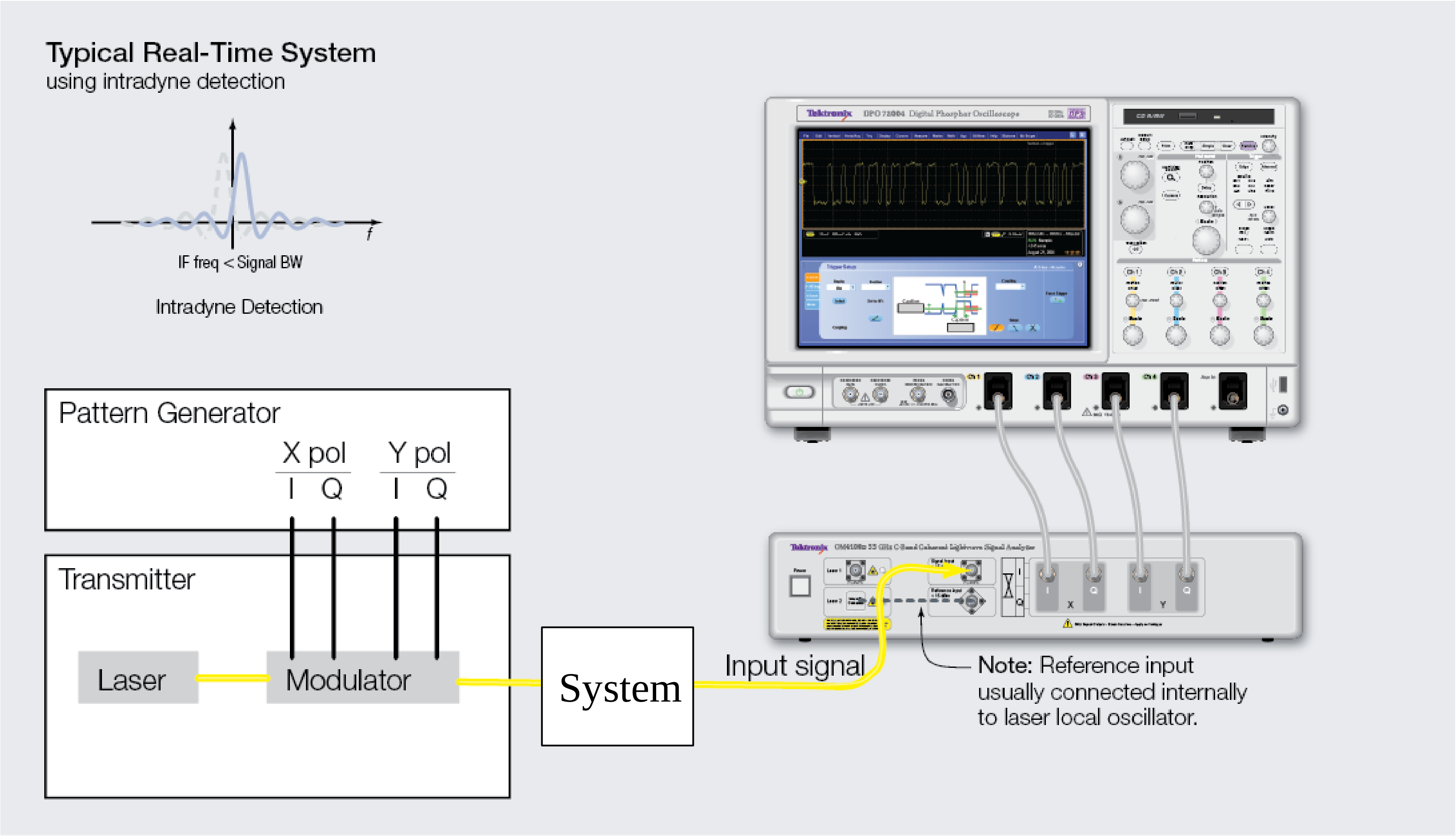
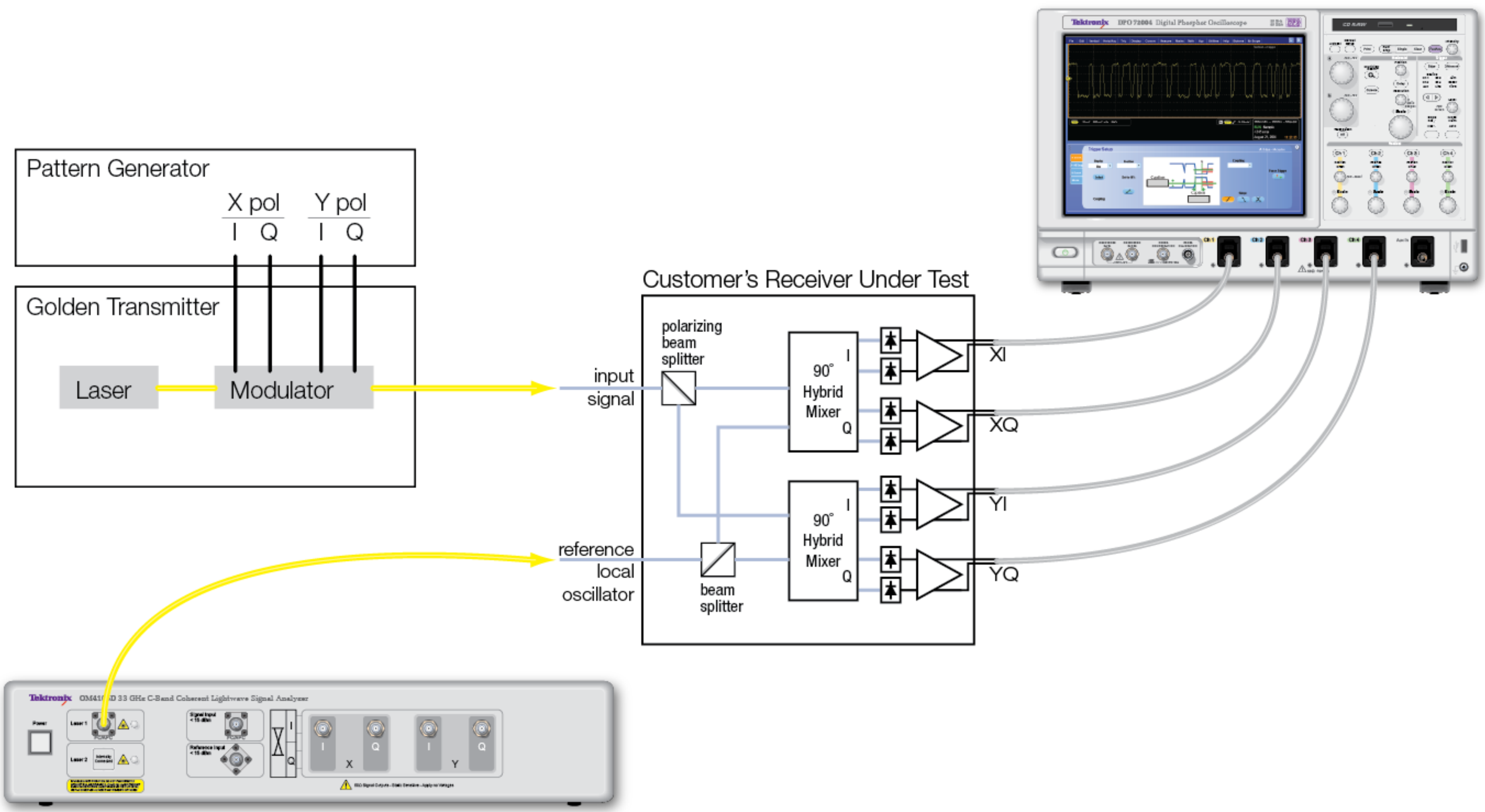
Typical Configuration for Transmitter System Testing



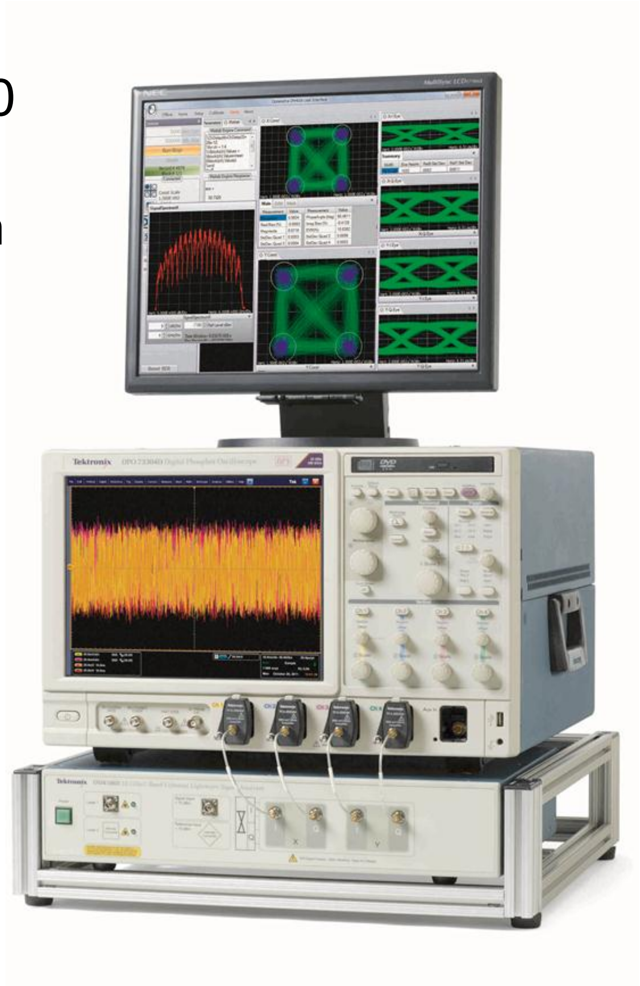
Typical Configuration for Receiver Testing



An OM4106D, OM2210, or OM2012 could be used as the LO.

Conclusions

- OM4000 Series Analyzer and DPO70000 Series Oscilloscope
  - Oscilloscope best matched to application
  - Best coherent signal analysis algorithms ("designed for optical")
  - Preferred user interface
  - Open architecture DSP based in Matlab



Thank you!!!