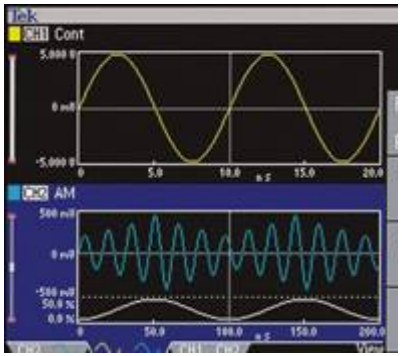
高速光通讯测试



Bright Zeng

泰克科技（中国）有限公司

Tektronix

主题

- 采样示波器基础及应用
- 光信号测试的项目以及要点
- 如何改善光信号测试的精度，一致性以及重复性
- 泰克10G/25G/40G/100G的测试方案

采样示波器基础：采样示波器的特点

- 高带宽

  目前，泰克DSA8200示波器的带宽高达80G+

- 高等效采样率

  泰克DSA8200示波器等效采样率高达1000T以上

- 高垂直电压分辨率

  泰克DSA8200示波器的ADC分辨率为14bit

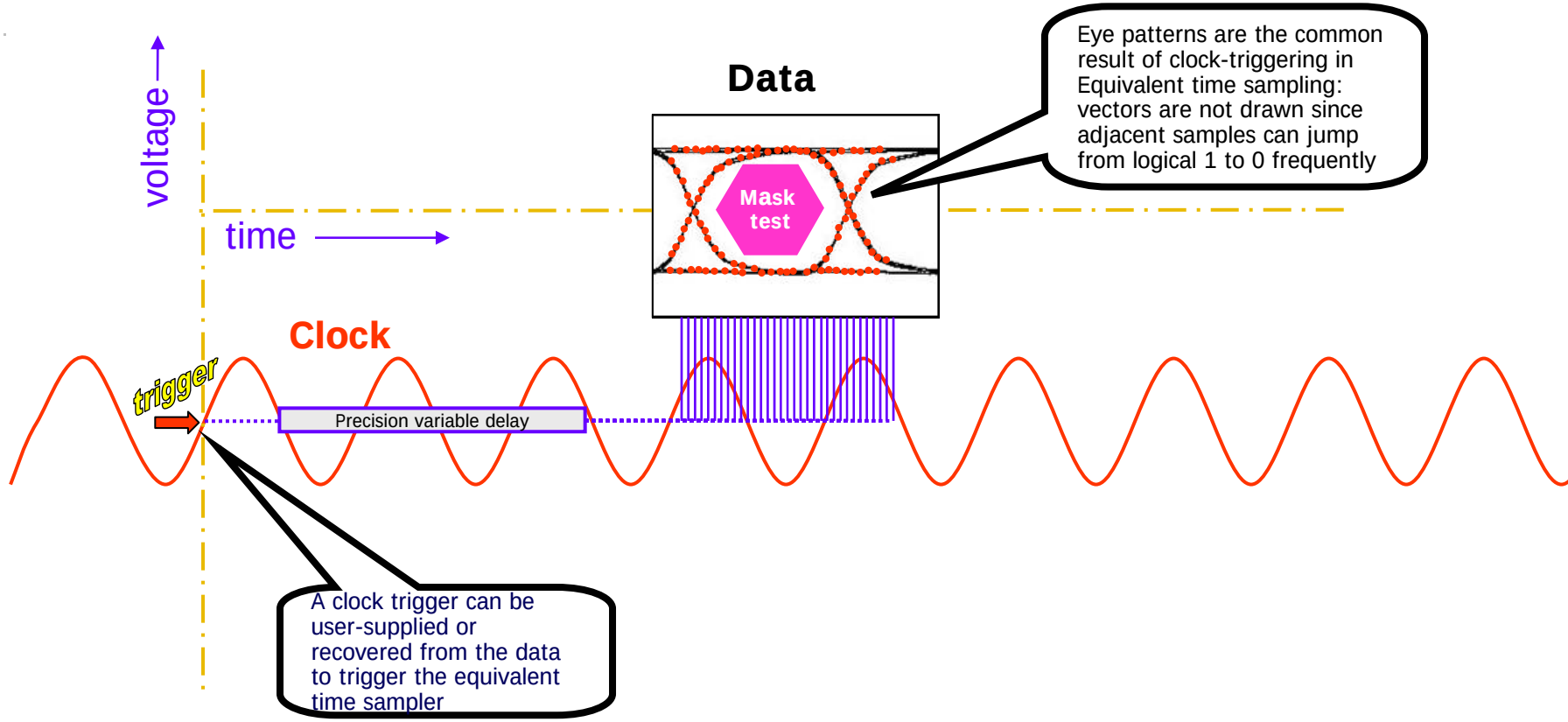
- 低触发抖动

  泰克DSA8200触发抖动低至200fs

- 低本底噪声

  泰克80Exx噪声低至400uV（RMS）

采样示波器采样原理：
需要同步触发信号，多次触发完成捕获



- *When a clock signal is used to trigger the equivalent-time 8200 scope the sampled DATA signals generally create EYE PATTERNS (between clock triggers the sampled DATA could be either a logical 1 or 0)*

采样示波器的优势及应用

- 带宽高达80GHz以上
  进行高速的周期脉冲测试
  进行高速的串行数据分析

- 噪声低、高垂直分辨率(14bit)
  进行高速的眼图测试以及噪声分析。

- 超低的触发抖动(使用82A04的模块使触发抖动减少至200fs)
  进行高速的串行数据抖动分析

光接口主要标准

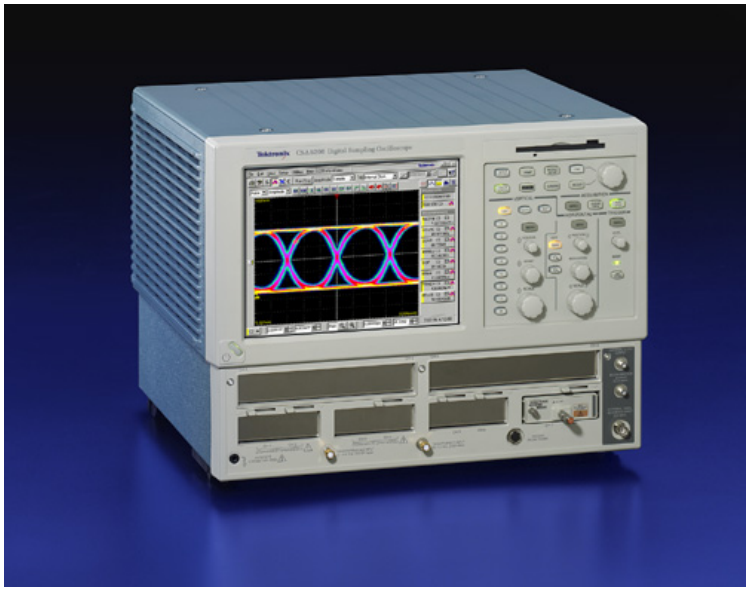
- Fiber Channel 光接口速率：
  - Fiber Channel 1：速率1.063Gbps
  - Fiber Channel 2：速率2.125Gbps
  - Fiber Channel 4：速率4.250Gbps
  - Fiber Channel 10G：速率10.52Gbps
- 以太网光接口速率：
  - 100Base-FX：速率125Mbps
  - 1000Base-SX/LX：速率1250Mbps
  - 10GBase-R/W：速率10.3125/9.953Mbps
  - 802.3ba :40G-base SR/LR ,100G-base SR10.
- SDH光接口速率：
  - 155Mbps、622Mbps、2.488Gbps、9.953Gbps……

Example-IEEE P802.3ba -物理层规范定义

Reach	40 GbE	100 GbE	Solution
1m Backplane	40GBASE-KR4	✘	4 x 10 Gb/s (reuse 10GBASE-KR)
10m Copper Cable	40GBASE-CR4	100GBASE-CR10	n x 10 Gb/s (reuse 10GBASE-KR)
100m OM3 MMF	40GBASE-SR4	100GBASE-SR10	n x 10 Gb/s
10km SMF	40GBASE-LR4	100GBASE-LR4	4 x 10 Gb/s and 4 x 25 Gb/s
40km SMF	✘	100GBASE-ER4	4 x 25 Gb/s

使用Tektronix DSA8200能完成什么测试？

- **核心测试**
  - 眼图测试
  - 抖动测试
  - 幅度域
    - 平均光功率(AOP)
    - 消光比(ER)
    - 光调制幅度(OMA)



光接口的测试项目

- 发送器眼图模板Transmitted Eye Mask
- 平均光功率Average Optical Power
- OFF发送器的平均发送光功率（OFF Average Power）
- 光调制幅度Optical Modulation Amplitude
- 消光比测试Extinction Ratio：
- 中心波长Center Wavelength：
- RMS频谱宽度RMS Spectral Width：
- 边模抑制比Side Mode Suppression Ratio
- 相对强度噪声Relative Intensity Noise OMA
- 发送器色散与代价Transmission Dispersion and Penalty
- 受压的接收器灵敏度Stressed Receiver Sensitivity in OMA (Max)
- 数据相关抖动Data Dependent Jitter
- 受压的眼图抖动Stressed Eye Jitter
- 垂直眼图关闭代价Vertical Eye Closure Penalty
- 误码率Bit Error Rate

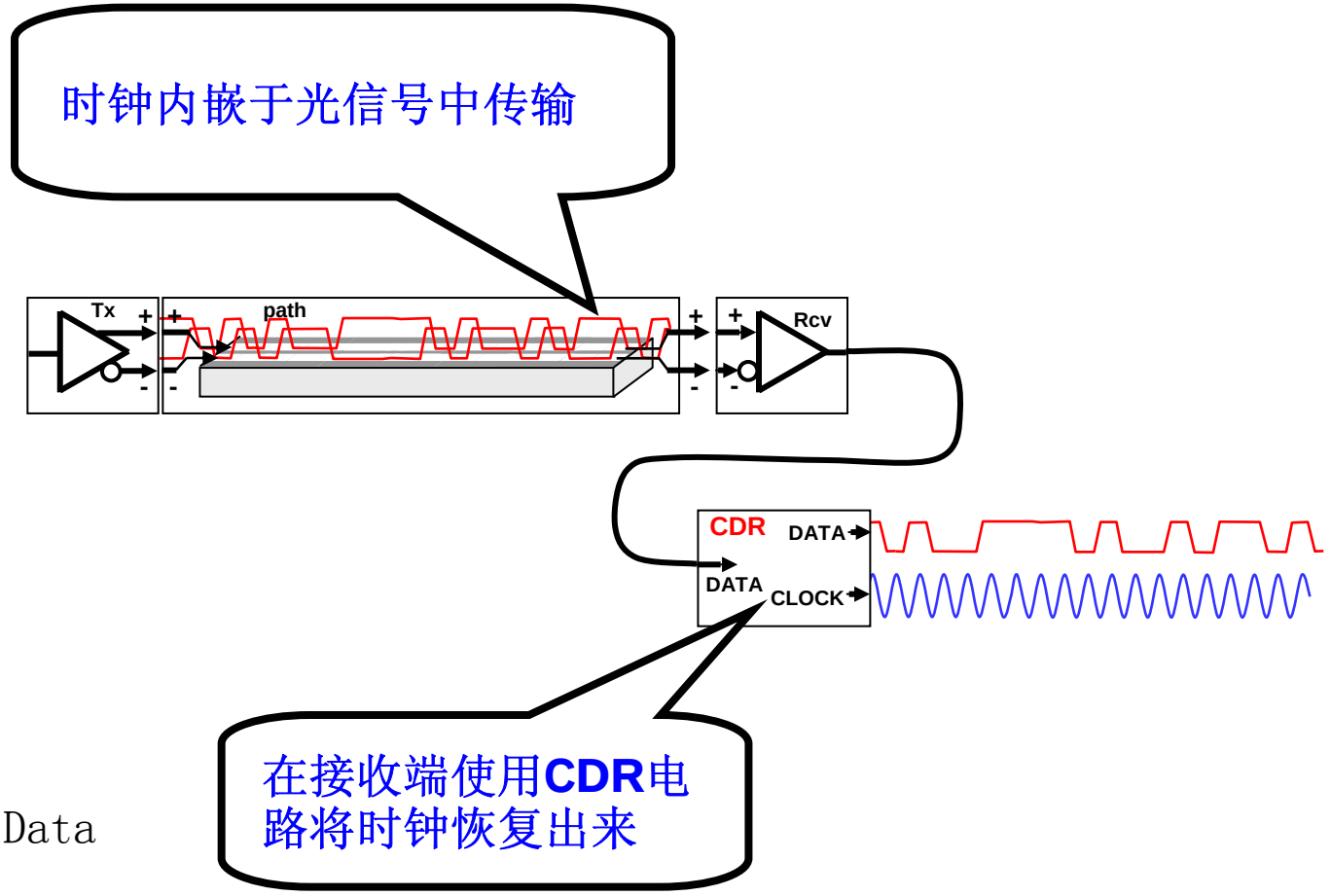
使用Tektronix DSA8200需要那些配置？

- **核心测试**
  - 光采样模块（滤波器）
    - 带有4阶Besel-Thomson低通滤波器，且滤波器的带宽为DUT数据率的0.75倍
  - 时钟恢复单元/模块(CRU)
    - 可以恢复DUT数据率相对应的时钟，且该CRU具有带宽为DUT数据率1/1667的低通滤波器

光接口物理层测试的几项要求

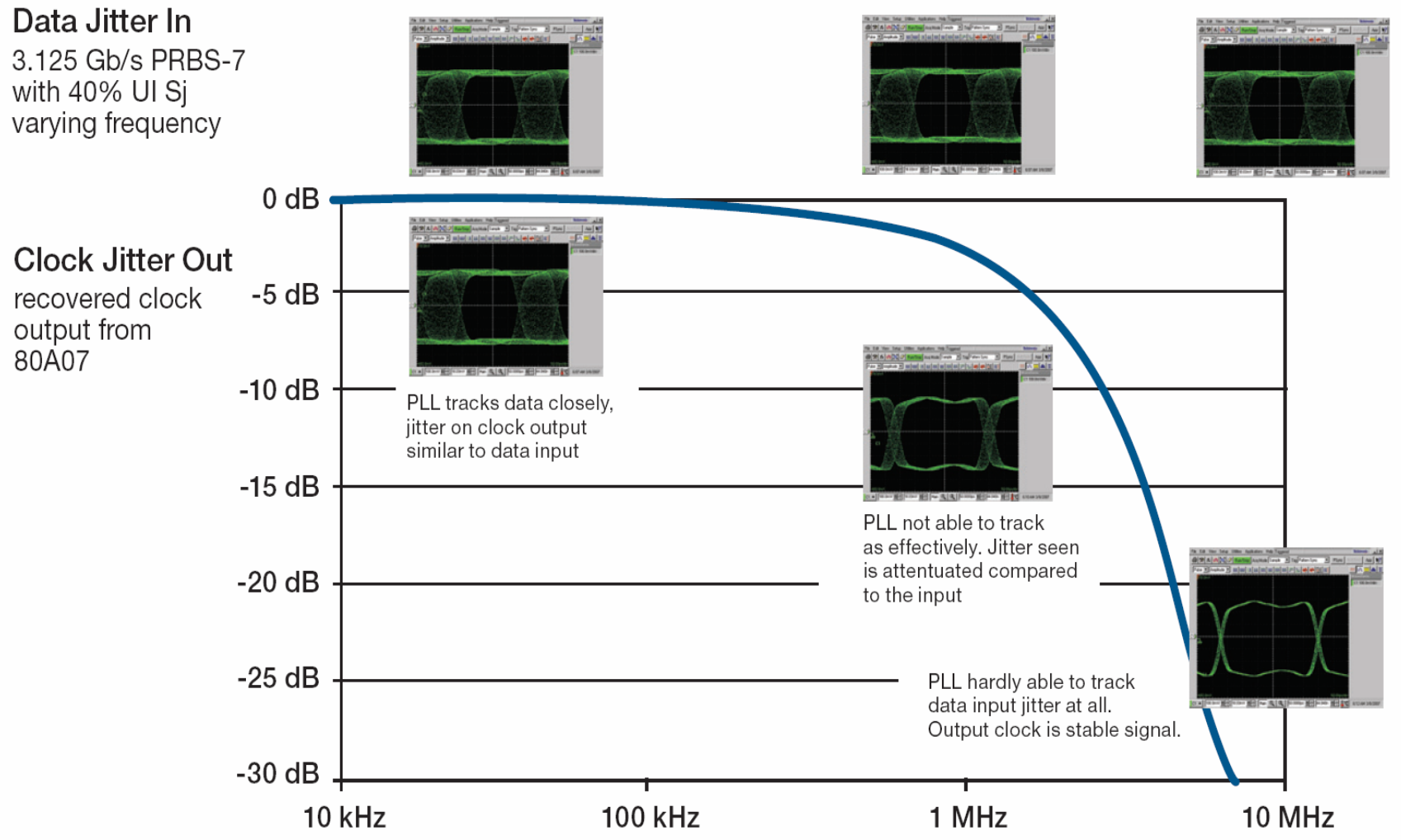
- 对时钟恢复CDR的要求
- 对噪声，灵敏度的要求
- 对滤波器的要求
- 对波长的要求

光接口物理层测试：对CRU的要求



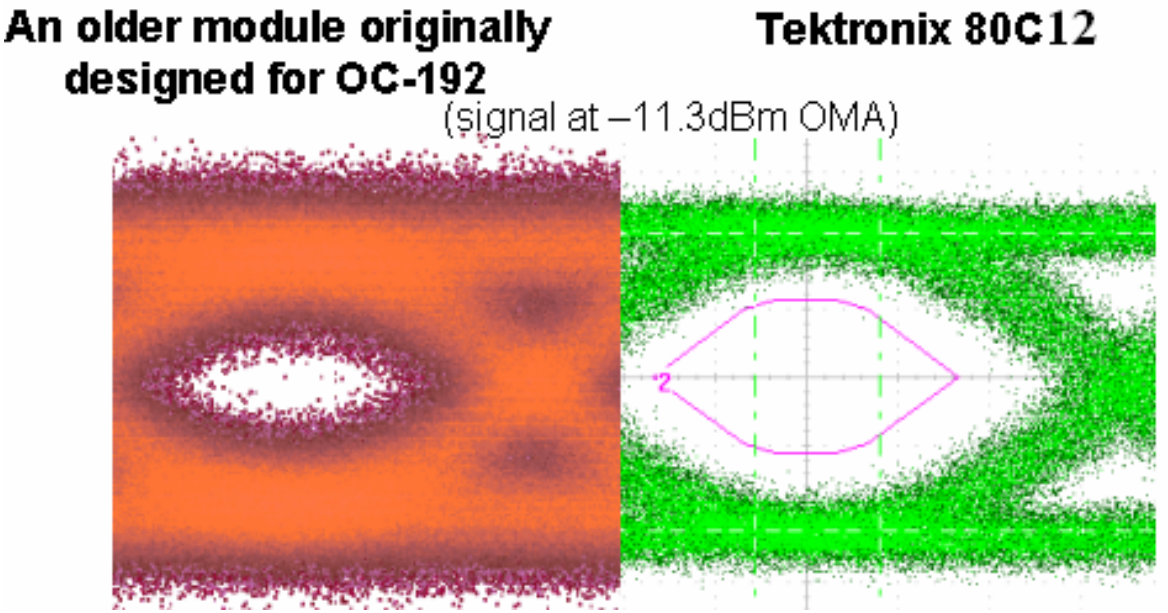
要求CDR的环路带宽为Data rate/1667

光接口物理层测试：对CRU的要求



光接口物理层测试：噪声/灵敏度要求

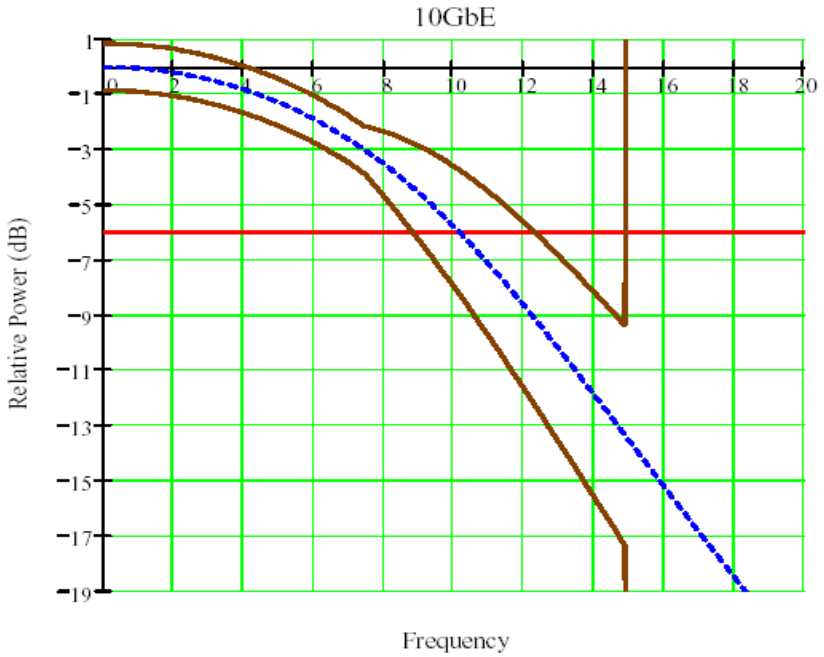
在测试小功率光模块或者超长波长光模块时，DUT的光功率会很小。所以模块的噪声必须很低灵敏度很高，达到一定的信噪比，测试的结果才能准确，而显示出来的信号噪声是真正属于信号的，而不是模块自身的噪声.



光接口物理层测试：对滤波器的要求

测试眼图模板时，需要使用Optical Reference Receiver 光参考接收器(O/E + Filter), 信号首先经光电转换, 然后经4th Order Bessel-Thomson 滤波器过滤，按业界规范要求，此滤波器的带宽要是被测信号速率的0.75倍

业界测试光接口 所使用的4th Order Bessel-Thosom 滤波器的频响如下:



不一样的速率，有不一样的滤波器要求

光接口物理层测试：对波长的要求

- 目前，按照光信号在光纤中的传播方式有单模与多模之分；其波长也不一样。主流的波长有780、850、1310、1550nm
- 单模：9um光纤直径，波长多为1310、1550nm
- 多模：62.5um光纤直径，波长多为780、850nm

光通信中的性能参数：OMA与ER

- 逻辑1和逻辑0:

  光功率高的状态是逻辑1，反之则为逻辑0.

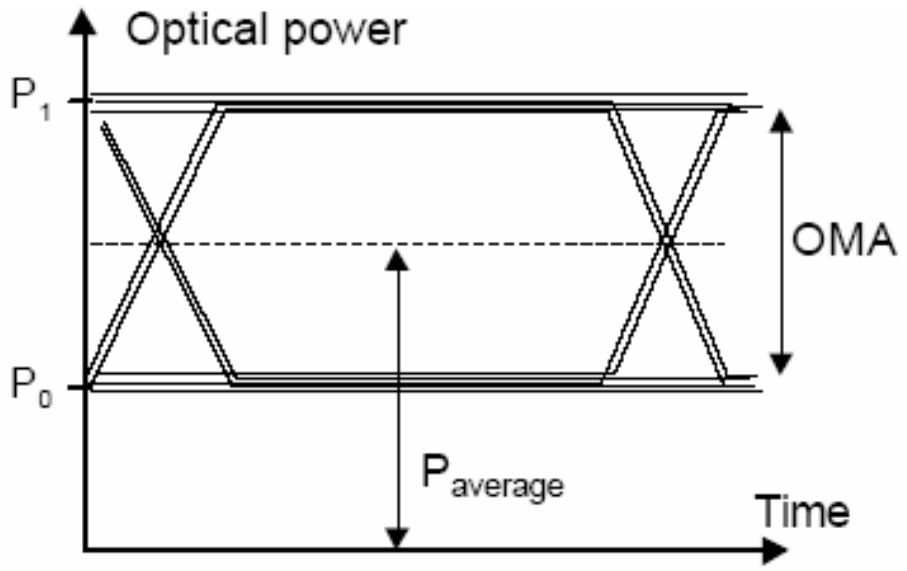
  光功率常用:dBm = 10log(Power(mW)/1(mW))

- OMA:Optical Modulation Amplitude

  逻辑1和逻辑0光功率差:

  OMA=P1-P0

  有时也定义成:



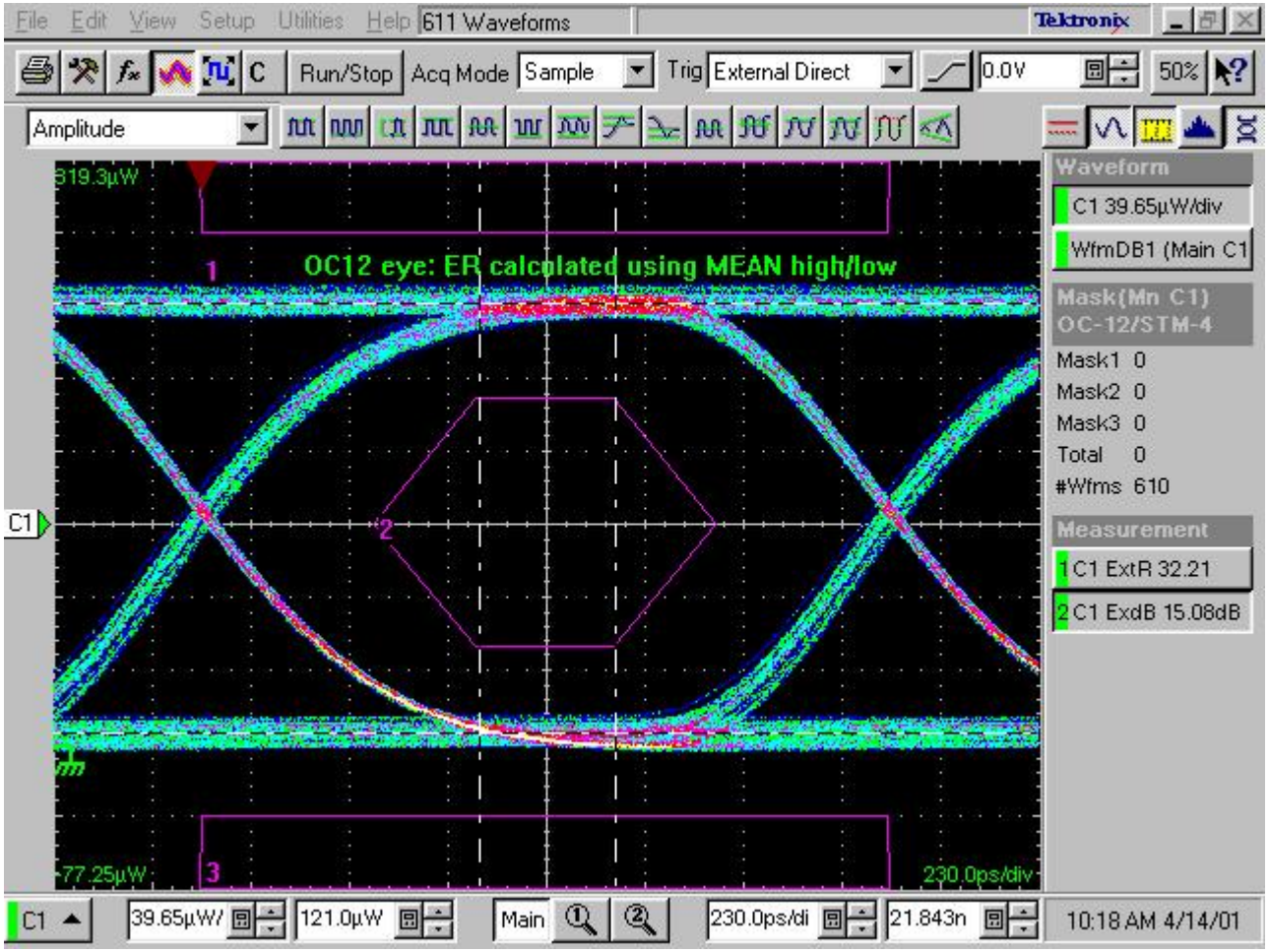
$$OMA = 2P_{average} * \frac{\frac{P1}{P0} - 1}{\frac{P1}{P0} + 1}$$

ER:Extinction Ratio,消光比

$$P_{average} = \frac{P1 + P0}{2}$$

$$ER = \frac{P1}{P0}, dB = 10\log_{10}\frac{P1}{P0}$$

光通信中的性能参数：OMA与ER



消光比与OMA

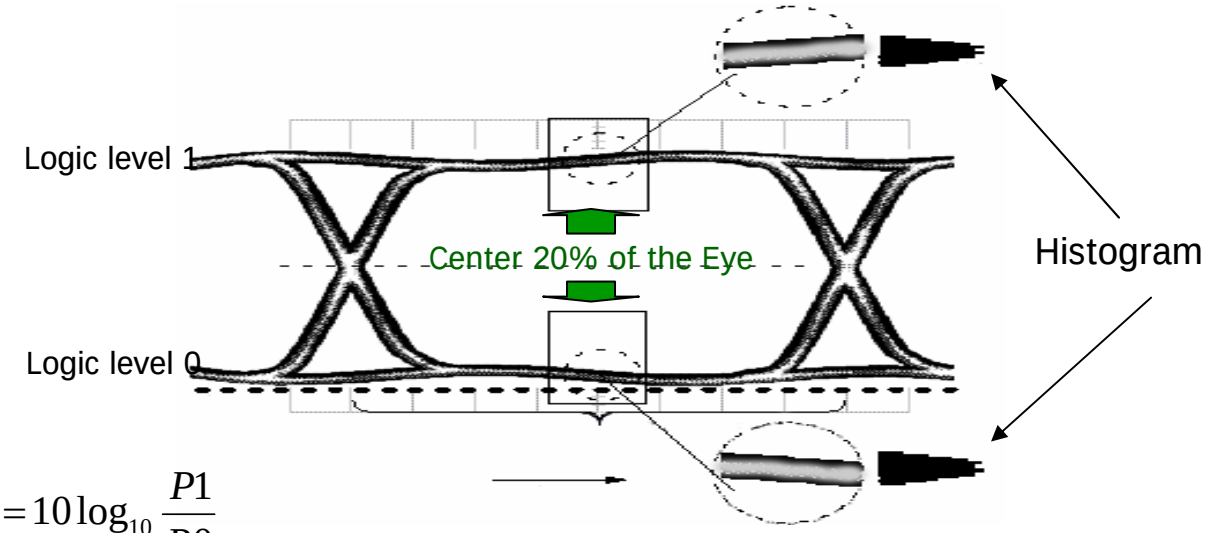
- 对线性衰减的传输系统,ER为常数.但是OMA是在减小的.这也就是随着信号从发送端到接收端眼图变窄的现象.
- OMA越高,信号在光纤中就能传输的更远.ER越高,传输系统对外部噪声的抗敏感度越高,鲁棒性越好.

消光比测试–光接口测试的最大难点

- 工业标准对消光比的描述 (ER)
- 什么是消光比(ER)
- 消光比的重要性
- 影响消光比测试精度和可重复性的因素
- 泰克DSA8200 提高消光比测量的解决方案-“ER Calibrated”
- 标准消光比测量和经过“ER Calibrated”消光比测量结果比较

消光比的定义

- ER (Extinction Ratio) 为光模块发射逻辑“1” 时的平均光功率和发送逻辑“0”时的平均光功率之比.
  - 在光眼图的中心的20%的位置测量直方图的平均值



$$ER = \frac{P1}{P0}, dB = 10\log_{10}\frac{P1}{P0}$$

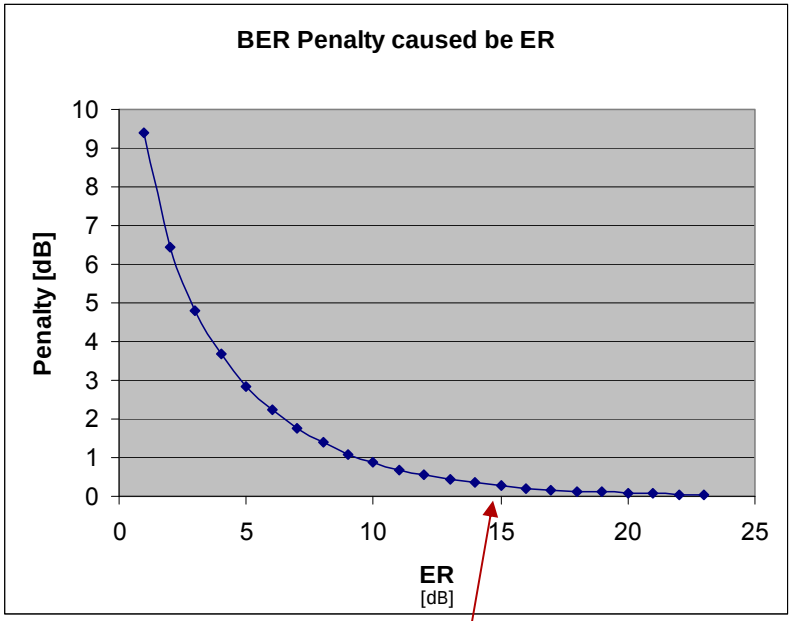
- ER 测量结果与逻辑“0”时电平和暗电平的相对值有很多影响 (当激光器完全关闭不发光时)
  - 很小的0电平的变换/偏离都会明显的影响消光比的测试结果

为什么消光比测量结果非常重要?

- 标准规范中规定了消光比的性能指标以确保网络的互通性; 所以对这一领域的各个提供商来说满足规范要求极为重要.
- 除满足规范要求外还有其他各原因也突显消光比测量的重要性:
  - 不同的元器件，模块和系统有不同的设计裕量
  - 良好的消光比性能可以改善误码率，是考量总体性能和质量的关键测量项目
  - 消光比测量值的波动直接影响产品的一次通过率，减小产出率和收益
  - 当验货检查结果和提供商不一致时使得工作复杂化

消光比应该在什么范围之内呢?

- ER 可以说明有多少光被浪费 (相对暗电平的偏置的光功率没有承载任何信息)
- 在ER小于5dB后光功率损耗急剧加大，也就是说额外还需要光功率
- 如果ER大于15或是18，对此性能影响非常小



当ER > 15dB时对BER的改善非常小

➔ **That's why standards don't ask for 20 dB of ER**

➔ **And, that is why the precision of ER measurements is not critical beyond ER > 15 dB**

第一类误差来源：直流偏置校准(Dark Cal)

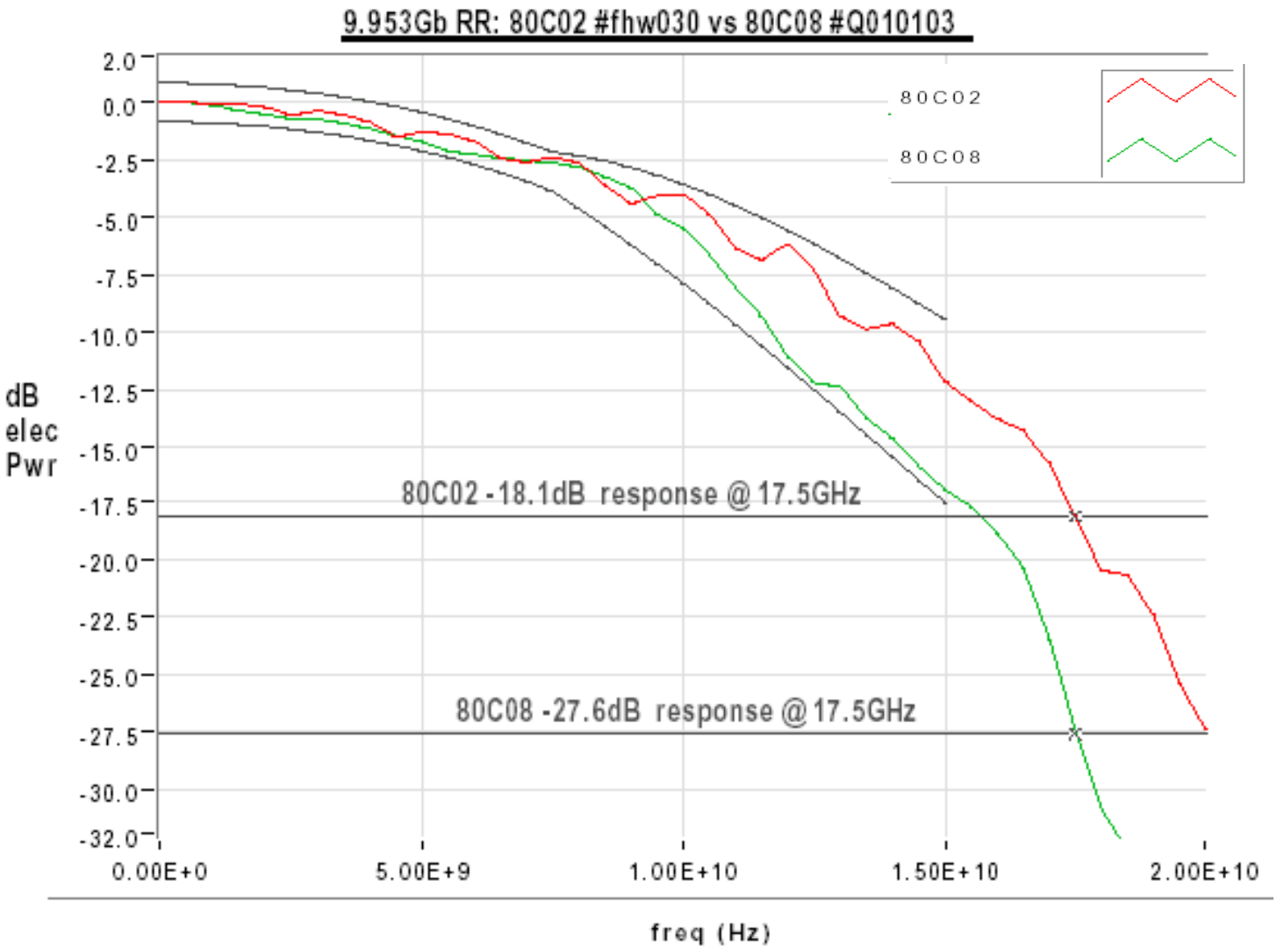
- 垂直偏置中的误差会导致相当大的 ER误差。
  - *适当的暗电平电平校准和进行补偿过的光模块测试激光眼图的结果为
    逻辑“1”电平 **200uW**
    逻辑“0”电平 **7uW**
    (**ER = 28.6-to-1 or 14.56 dB**).
  - *如果在相同的测试中包含+2uW 的偏置误差，那么
    逻辑“1”电平 **202uW**
    逻辑“0”电平; **9uW**
    (**ER = 22.4-to-1 or 13.51 dB**).
    22%的线性变化, (或 -1.05 dB 差别）
- 光模块中的偏置随着温度而变化
  *(即使是很小的温度的改变，也需要运行暗电平校准或补偿。）

第二类误差来源-影响消光比测量精度的其他原因

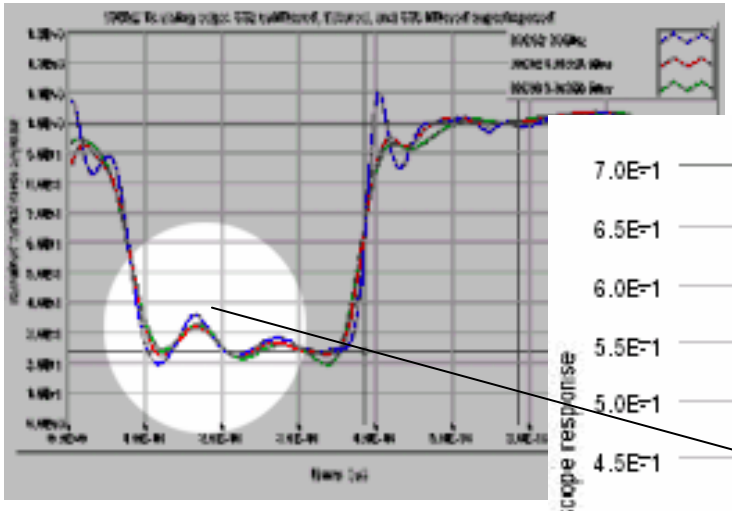
- 4阶BT频响在不同频段存在的偏差
  - 中高频段范围
  - 低频失真 (near DC; finite settling time “dribble-up”)
- 群延迟
- 采样器的低频响应
- A/D的非线性失真
- 采样示波器模块结构影响: 滤波器的射频开关引入损耗和失真，尤其在高频段

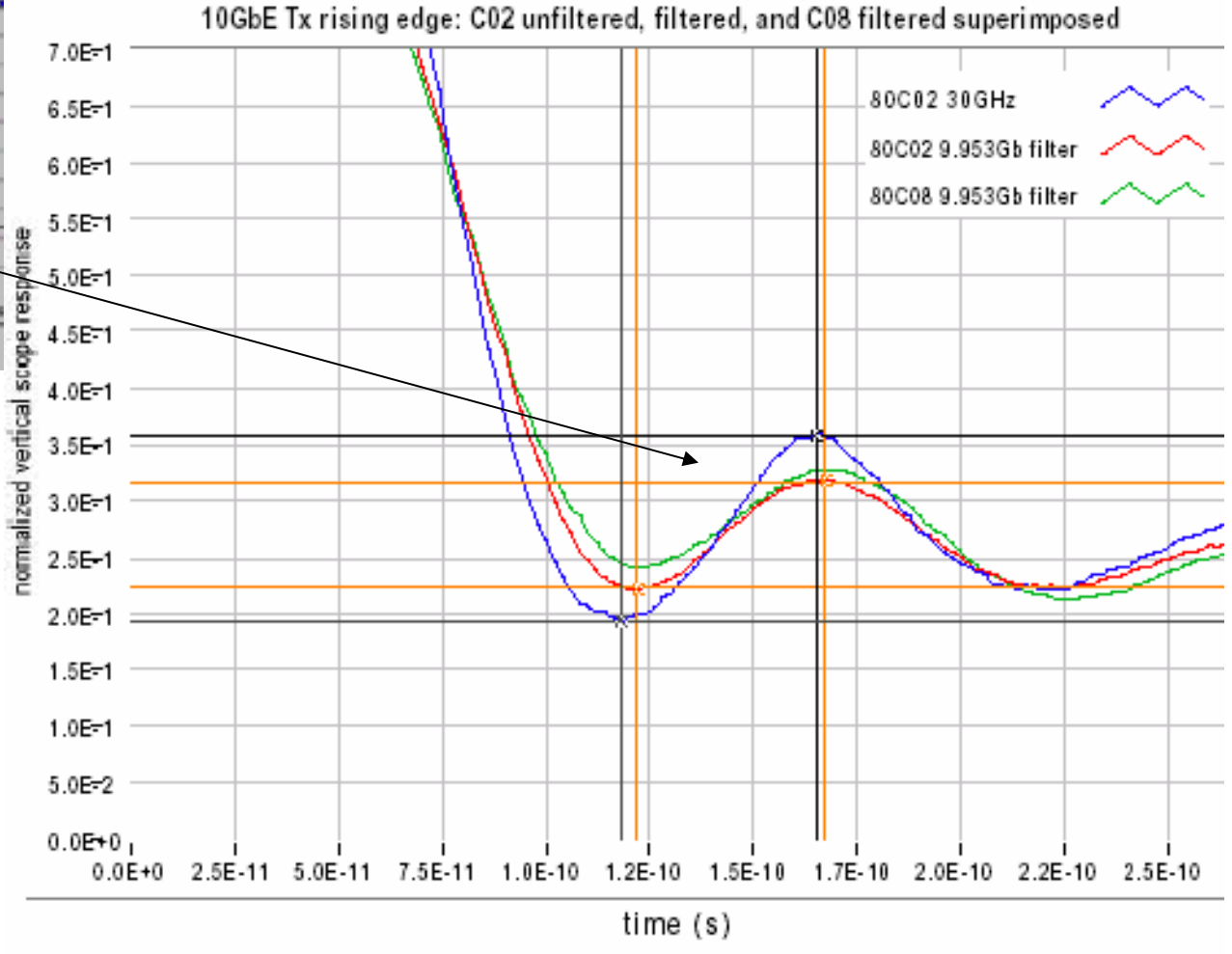
- 无法通过暗电平校准消除
- 这类误差影响一般都被忽略
- 在某些光采样示波器中没有直接或是间接的对这一指标进行说明
- DUT的一些特性有可能激化这类误差

影响精度的其他原因:光参考接收机的频率响应



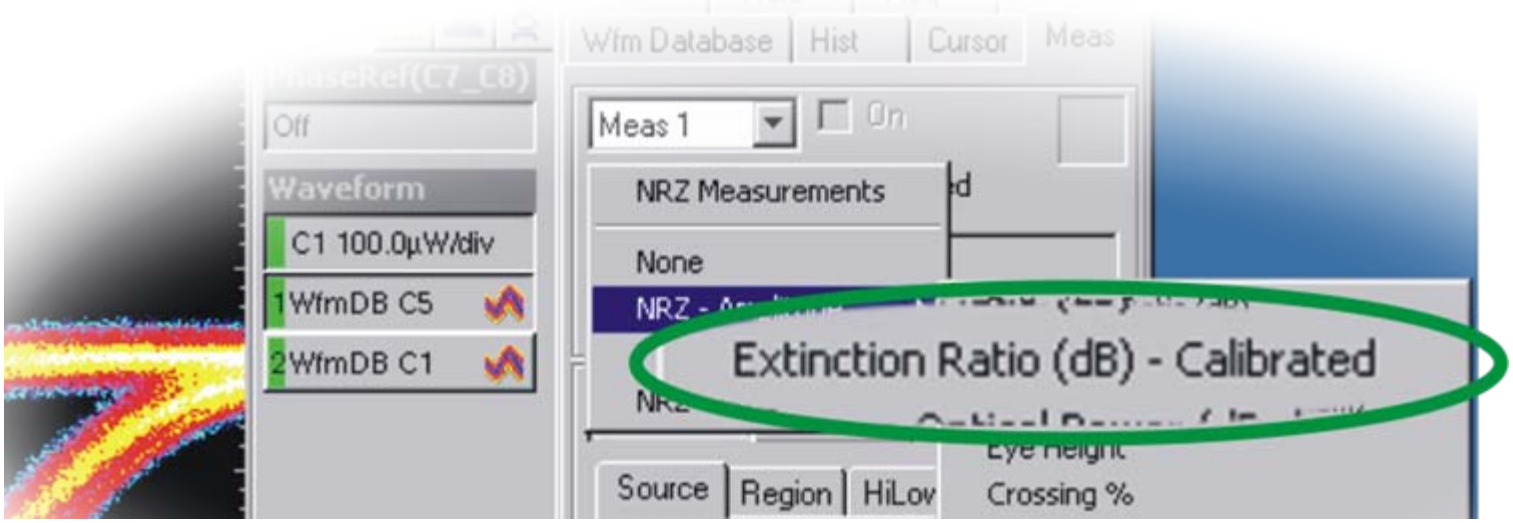
影响精度的其他原因:光参考接收机的瞬态响应



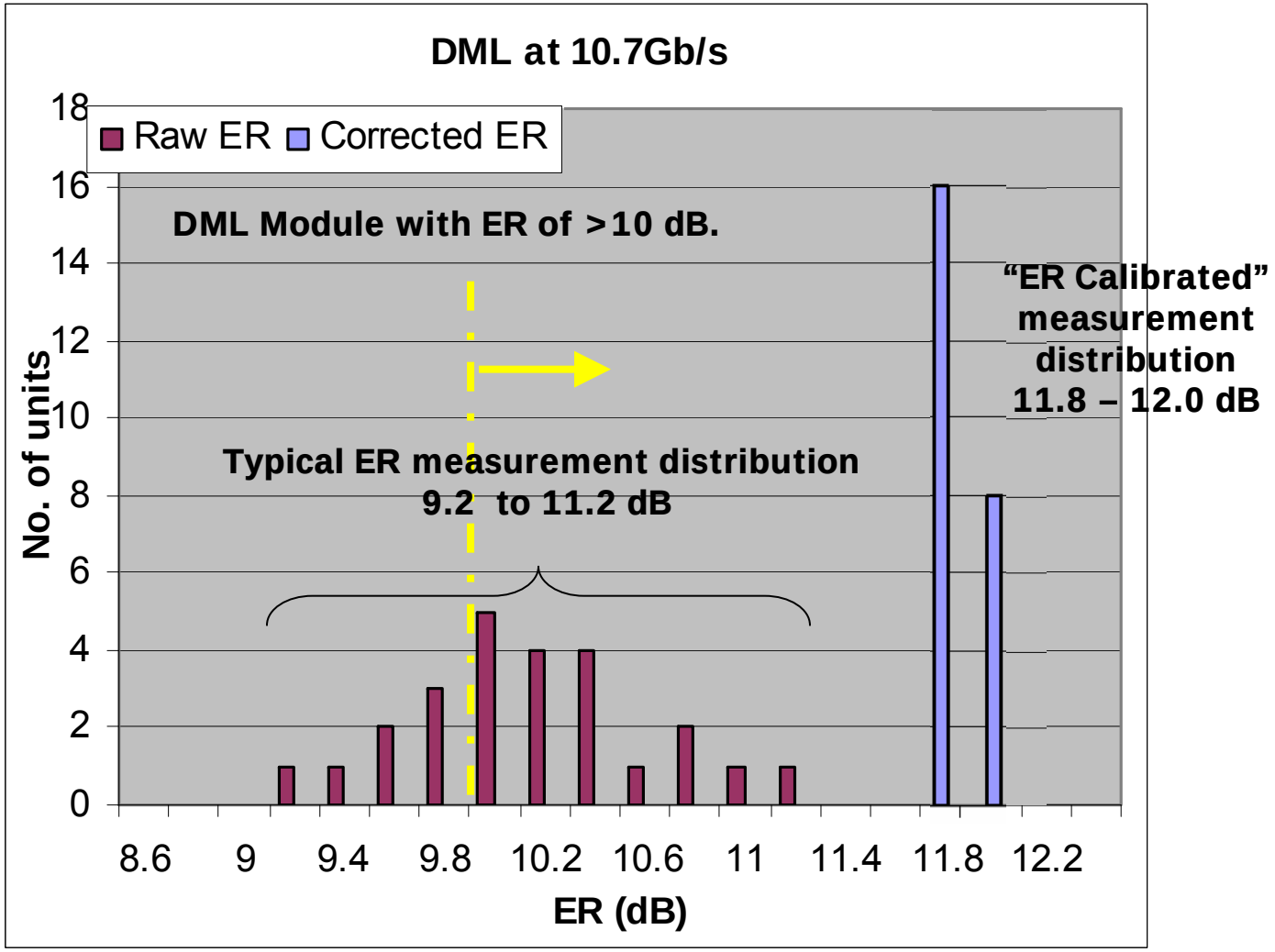


泰克的解决方案：准确可重复的消光比测量

- 生成消除第二类误差来源的校准因子
- 通过专门的高精度消光比校准源提供校准
- 在工厂完成校准过程并将参数存于模块内
- 通过“ER Calibrated”测试项提供校准测试结果
  (同时保留旧的测试项目)
- 能同时提供绝对精度和可重复性测试指标



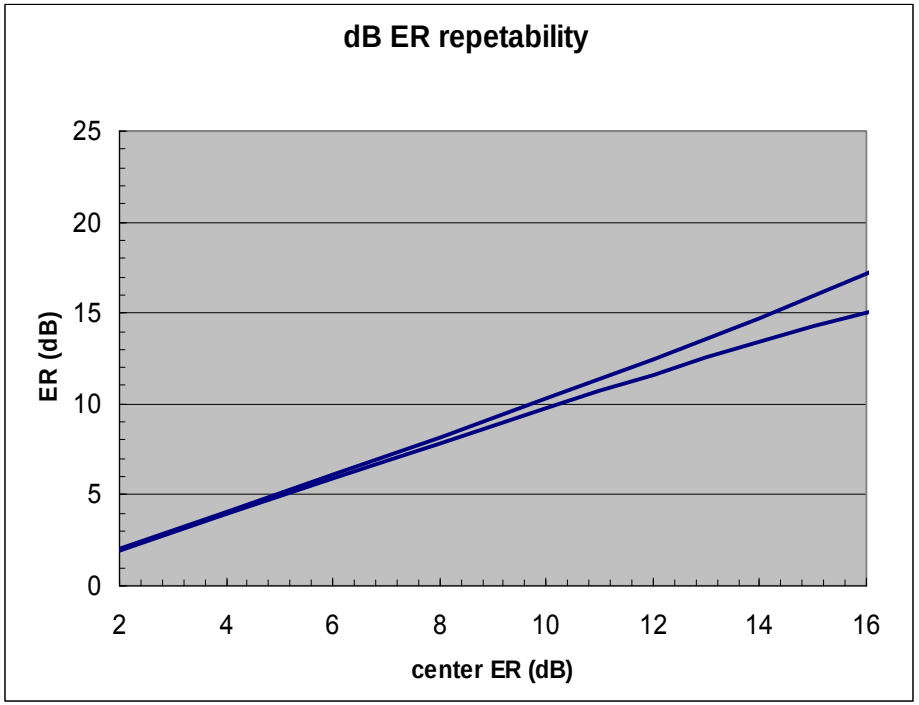
标准消光比和经过校准的消光比测量值分布比较-DML（直接调制激光器 ）

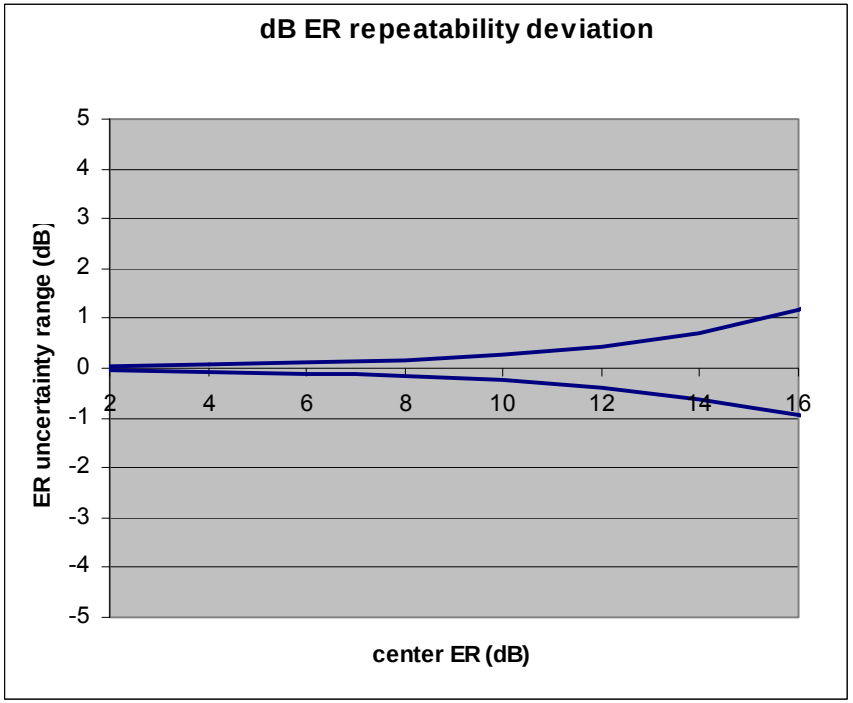


消光比校准后的规格—测试重复性

提供业内最优的消光比可重复性测试

经过ER Calibrated 典型的重复度可达: +/- 0.6 % (-0.25dB / +0.27dB at 10 dB)

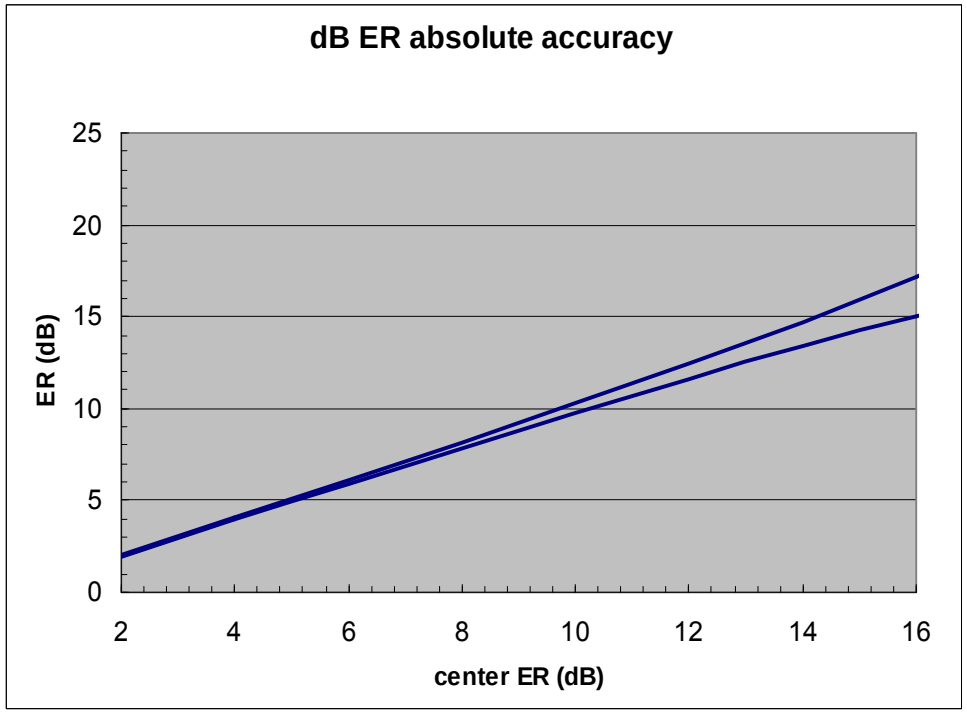


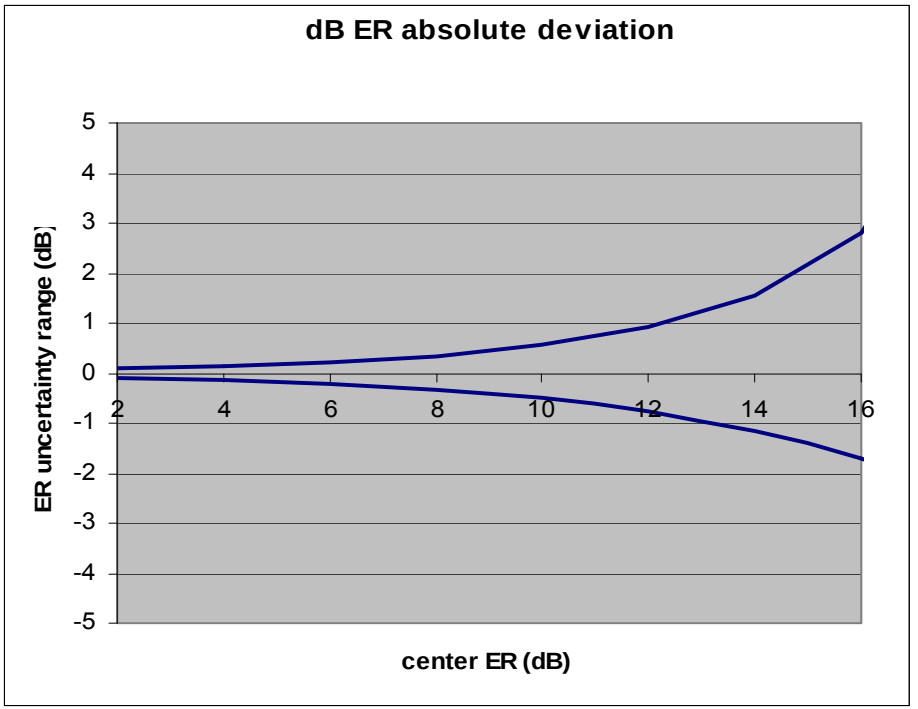


消光比校准后的规格－测试精度

业内唯一可以提供高精度经过校准的消光比测试

经过ER Calibrated绝对精度可以达到: +/- 1.2 % (-0.49dB /+0. 56dB at 10 dB)

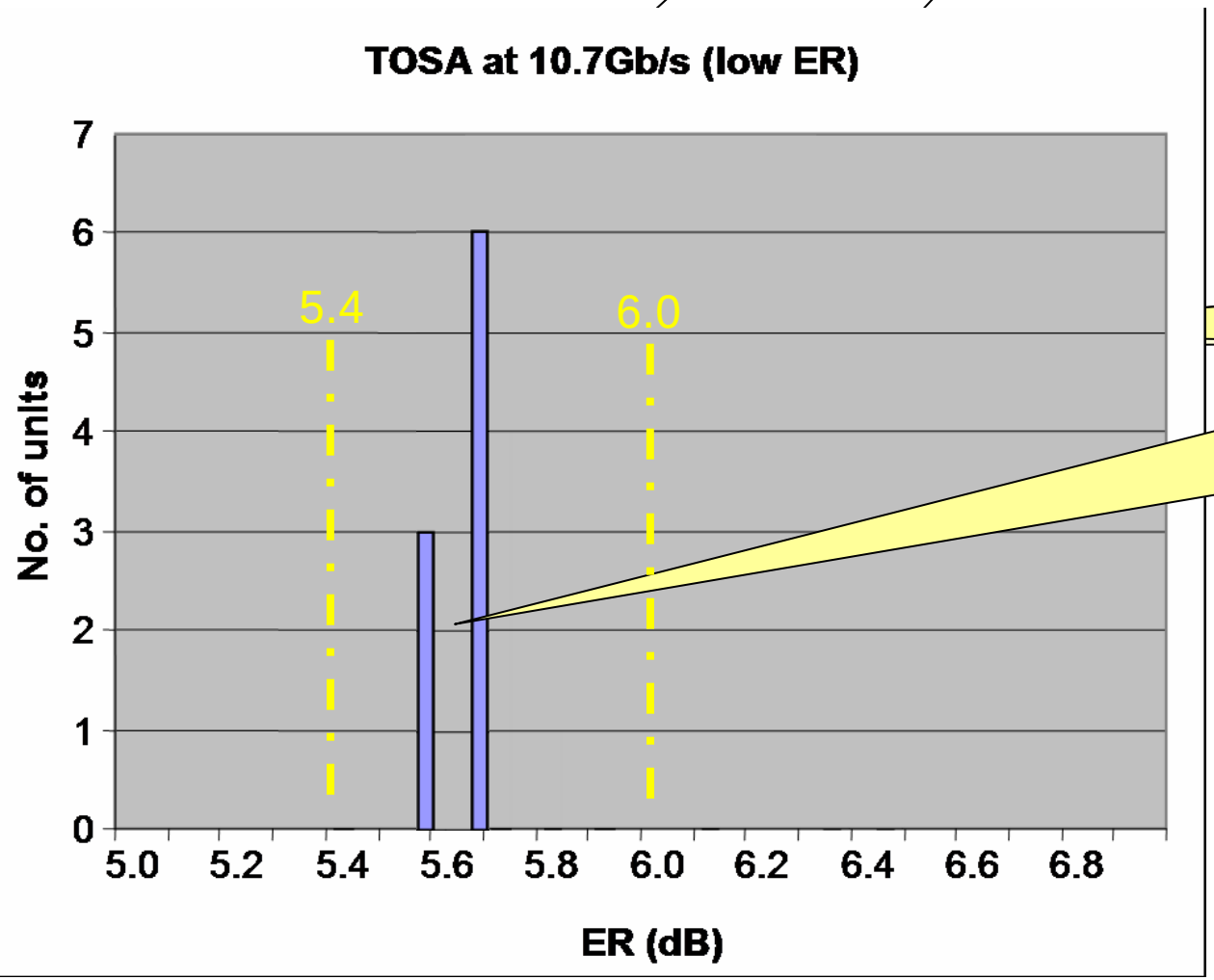




未较准消光比和经过校准的消光比测量值分布比较

You manufacture modules with ER >5.4 dB and <6dB.

低成本VCSEL
("垂直腔面发射激光器")
in a TOSA
("光发射次模块")



With the DSA8200 "**ER Calibrated**" everyone has this!

泰克的解决方案：准确可重复的消光比测量

- 去除影响消光比精度的第二类误差源，改进测试的可重复性和测试精度
- 通过专门的校准信号源和验证信号源保证校准结果

- 对于制造企业来说这意味着：

  更好的产出比，或更长的传输距离，或更多的裕量

- 对器件和模块以及模块使用者来说意味着

  质量和一致性验证更清晰

- 使用DSA8200的ER Calibrated增加你竞争力

定购新模块和升级已有模块

- ER Calibrated is available on new DSA8200 Optical Modules as Option 01 for:
  - 80C11
  - 80C08C
  - 80C02

- ER Calibrated can be added to your existing DSA8200 Optical Modules by ordering 80CXXUP, Option 01 for the same modules.

模块概览

155 Mb/s to 12+ Gb/s Optical Test

- **80C07B**
  2.5 GHz BroadWavelength Multirate 155 Mb/s to 2.5 Gb/s Optical Module
- **80C12**
  Up to 10GHzBroadWavelengthMultirate 1 Gb/s to 10 Gb/s Optical Module
- **80C08C**
  10 GHz Broad Wavelength Multirate 10 Gb/s Optical Module
- **80C11**
  30 GHz Long Wavelength Multirate 10 Gb/s Optical Module

40 Gb/s and 100 Gb/s Optical Test

- **80C10B**
  Multirate Datacom and Telecom 40 Gb/s and 100 Gb/s

80C10B and NEW 80C10B F1 and NEW 80C25GBE

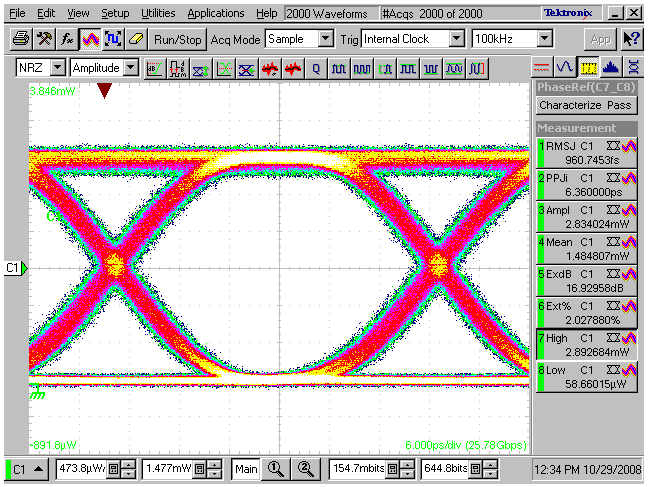
- *Performance: 80C10B*
  - Up to 80 GHz Optical Bandwidth
  - Industry's Best Noise Performance @ 40G and beyond
  - Best signal fidelity

NEW

- *Versatility: 80C10B F1*
  - Only single module solution to 100GbE (4x25), OC768, G.709 FEC, OTU3, and 40GbE in a single module

NEW

- *Focus: 80C25GBE*
  - 100GbE (4x25) compliance test solution



25.78Gb/s

Next Generation Of Optical Test

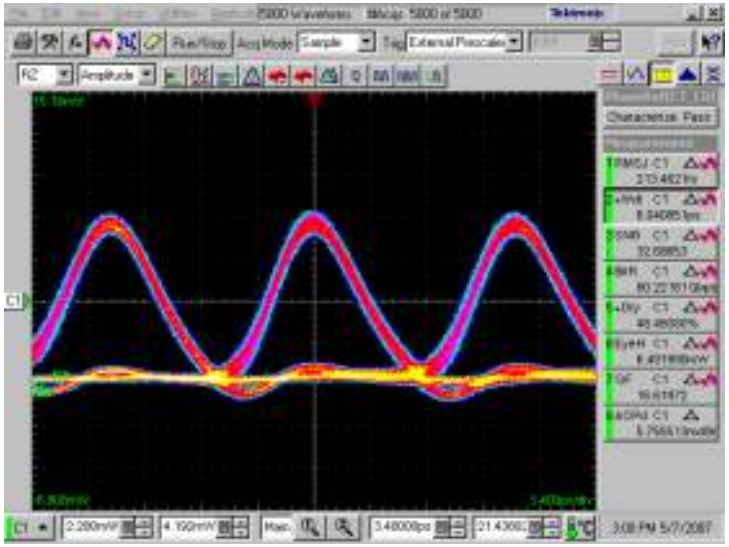
NEW NEW

Optical Bandwidth / Integrated ORR	Tektronix 80C10B	Tektronix 80C10B Option F1	Tektronix 80C25GBE
- Full bandwidth	80 GHz	65 GHz	65 GHz
- Selectable bandwidths	65 & 30 GHz	-	-
40Gbs G.709 FEC Telecomm - 43.018 GHz	✓	✓	-
40GbE Datacom - 41.25 GHz	NEW ✓	✓	-
OC768 40 GHz Telecom - 39.8 GHz	✓	✓	-
100GbE-4X FEC Datacom - 27.739 GHz	-	✓	✓
100GbE-4X Datacom - 25.78 GHz	-	✓	✓

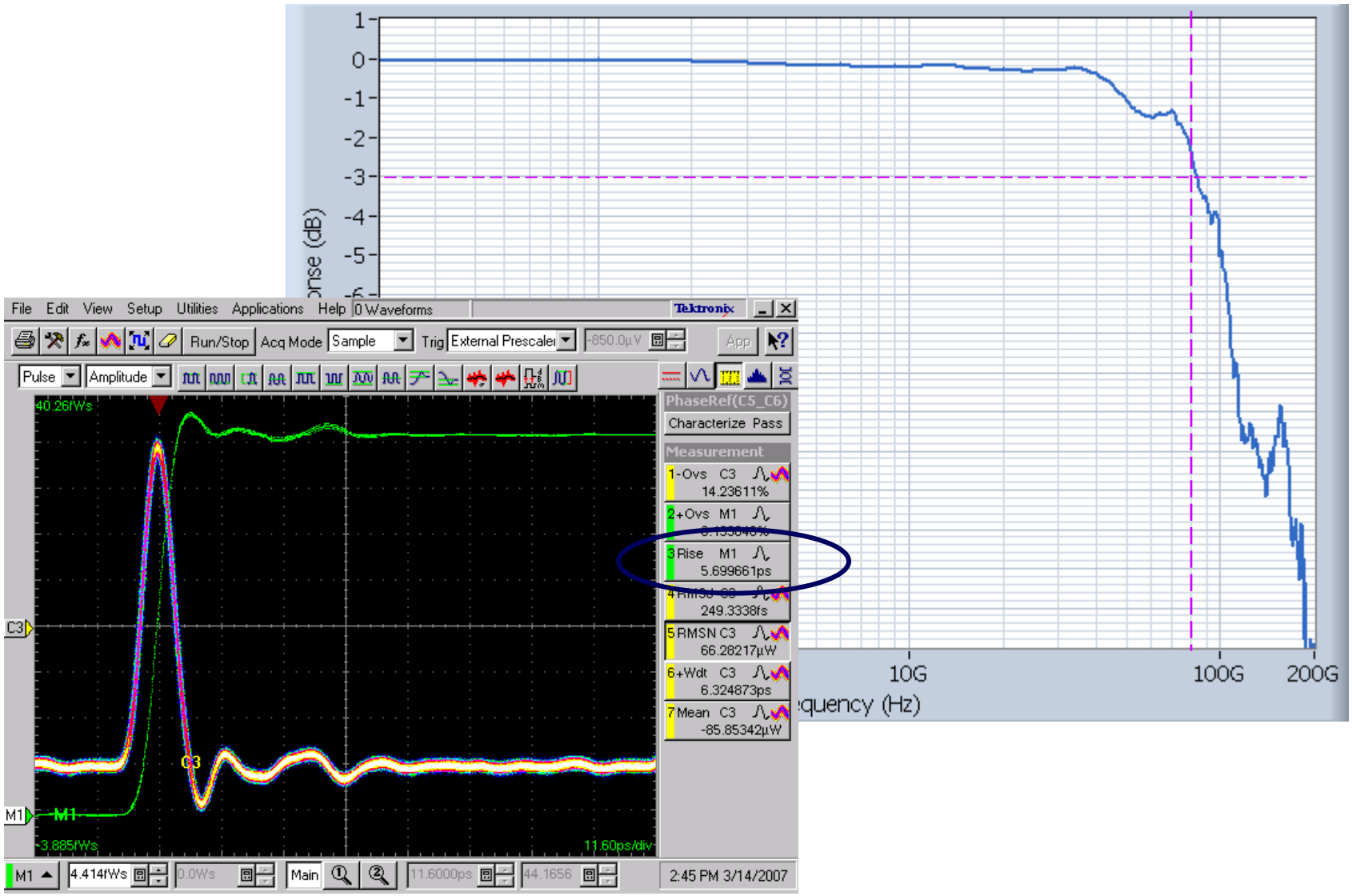
Tektronix Strengths
Tektronix 80C10B, 80C10BF1 and 80C25GBE

- Industry's widest optical bandwidth
- Superior signal fidelity and sensitivity
- Best system to system measurement repeatability, mask margins…yield
- Guaranteed compliance test solution
  - Reference receiver specs are guaranteed

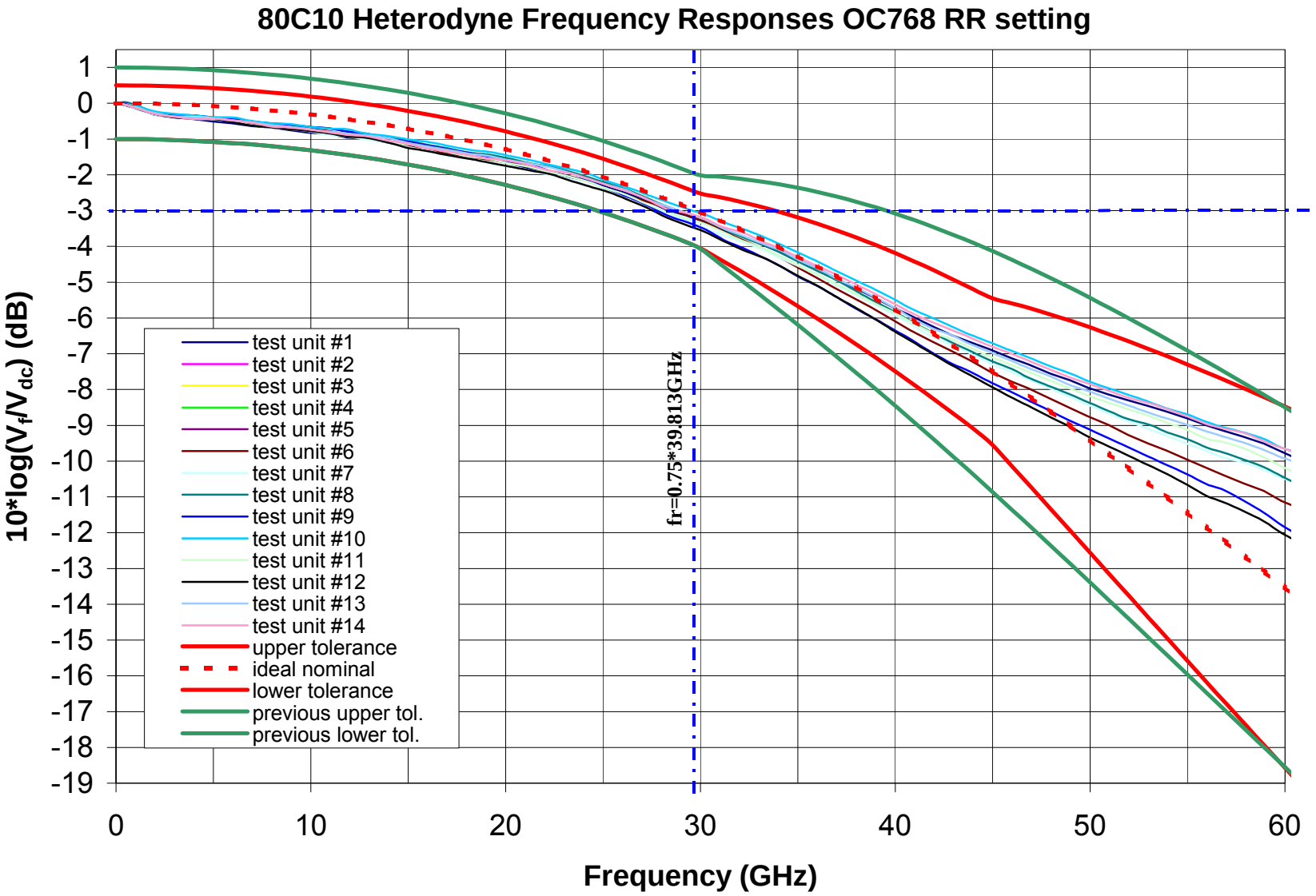
- Lowest test system cost:
  - **80C10B**: supports optical reference receivers and full bandwidth for 80 GHz, 65 GHz, OC768/STM-256, ITU-T G.709 FEC, and 40GBase-LR, and 4x10G LAN PHY (OTU3)
  - **80C10BF1**: support optical reference receivers for 40GBase-LR, OC768, G.709 FEC, 4x10G LAN PHY (OTU3), 100GBase-R4 FEC , and 100GBase-R4 in a single module
  - **80C25GBE**: supports optical reference receivers for 100GBase-R4 FEC , and 100GBase-R4 for focused manufacturing test solution



80C10B Performance Leadership

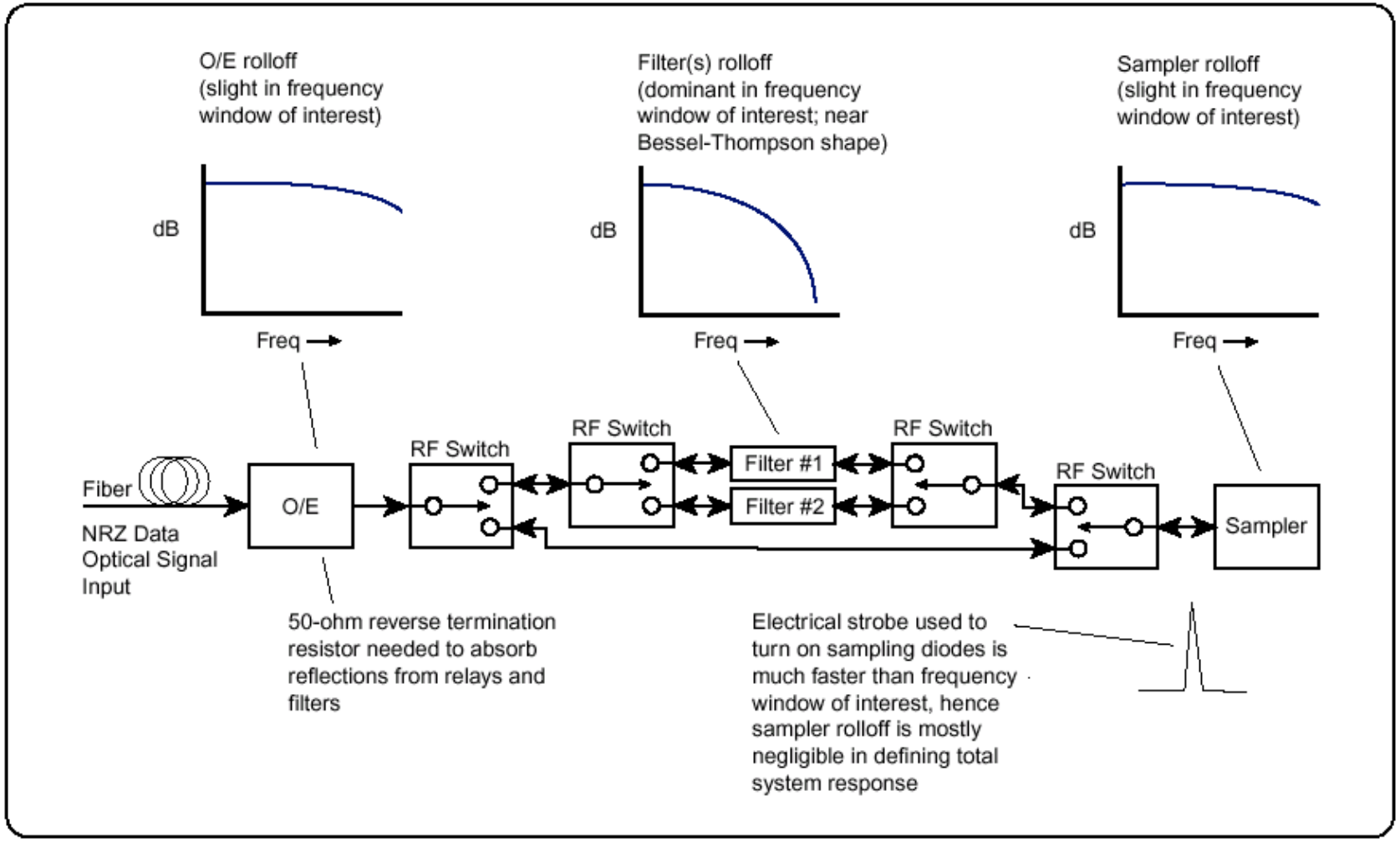


Reference Receiver Repeatability – 39.8Gbps



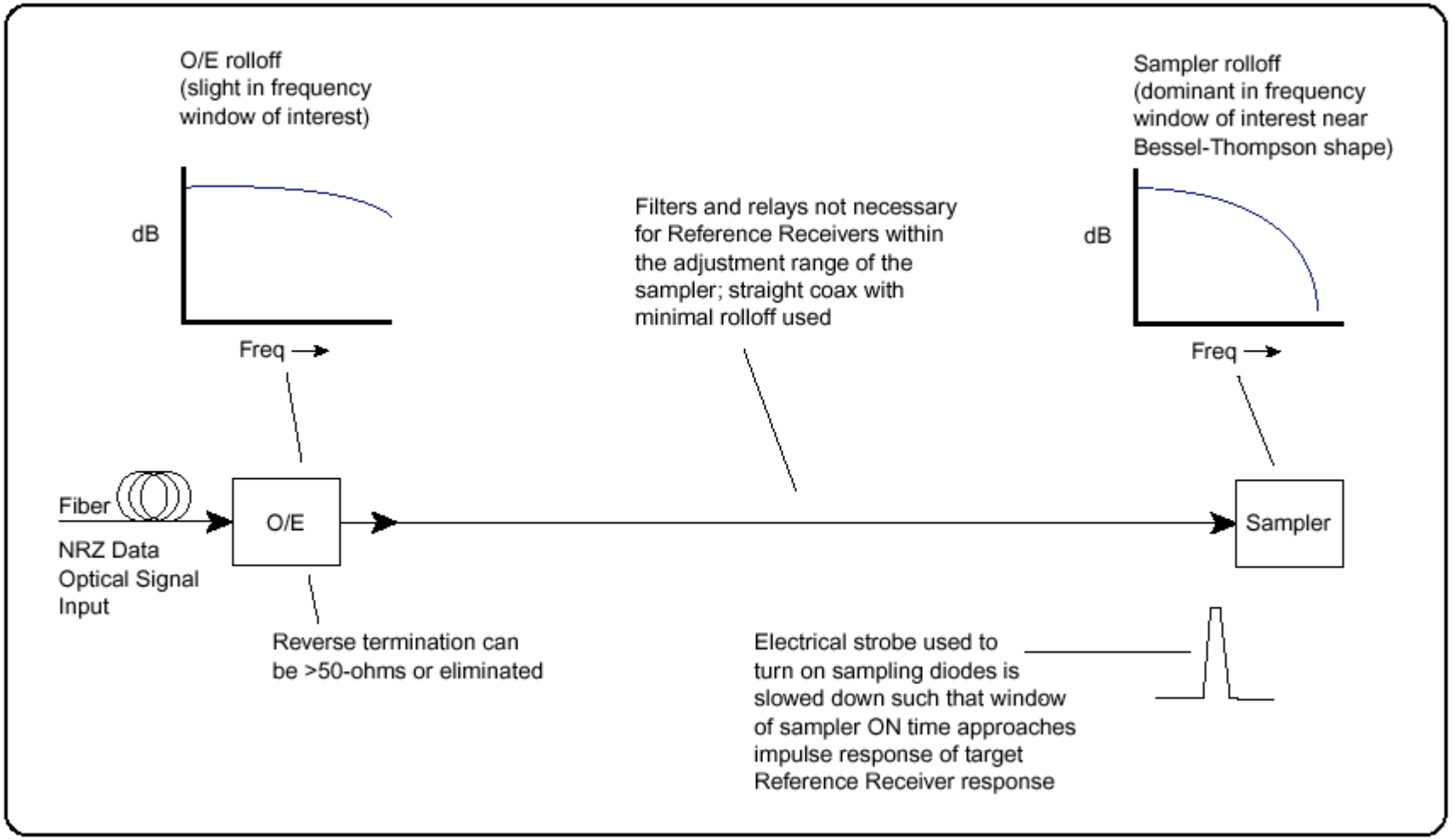
Superior 40 Gbps Reference Receiver Performance

Traditional ITU Filtering Methodology



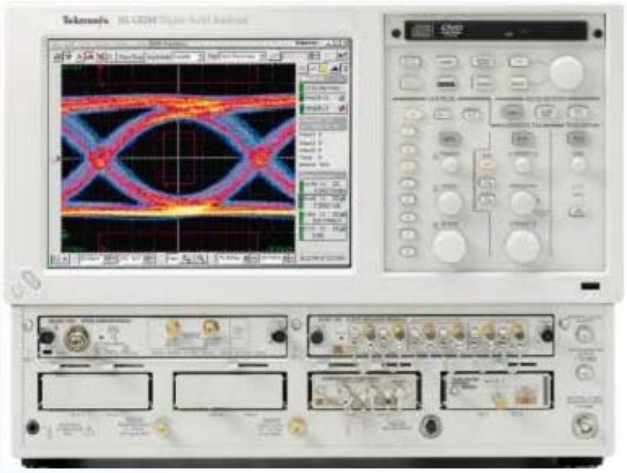
Superior 40 Gbps Reference Receiver Performance

Tektronix Proprietary Filterless Design



10/40/100GbE Optical Compliance testing in ONE Instrument

Tektronix DSA8200 Opt. JNB
+ 80C08C-CR4
+ 80C10B-F1
+ 82A04 & 80A06



The only ALL-IN-ONE single instrument solution with:

- All reference receiver Filters from 8.5Gb/s thru 44.5Gb/s
- Highest repeatability & best sensitivity
- Integrated Clock Recovery @ 10G
- SMF and MMF support @ 10G
- 200 fs $_{RMS}$ timebase stability
- 4x fast acquisition throughput over alternative
- Jitter, Noise, and BER Analysis
- Calibrated Extinction-Ratio measurements @ 10G
- Differential electrical 50 GHz optional (no module swap needed)

All-In-One 10-100Gbps Optical Compliance Testing

Optical Reference Receivers from 8.5Gb/s to 44.5Gb/s for Physical Layer Compliance Testing of

- Telecom,
- Datacom,
- Storage Area Network Transmitters

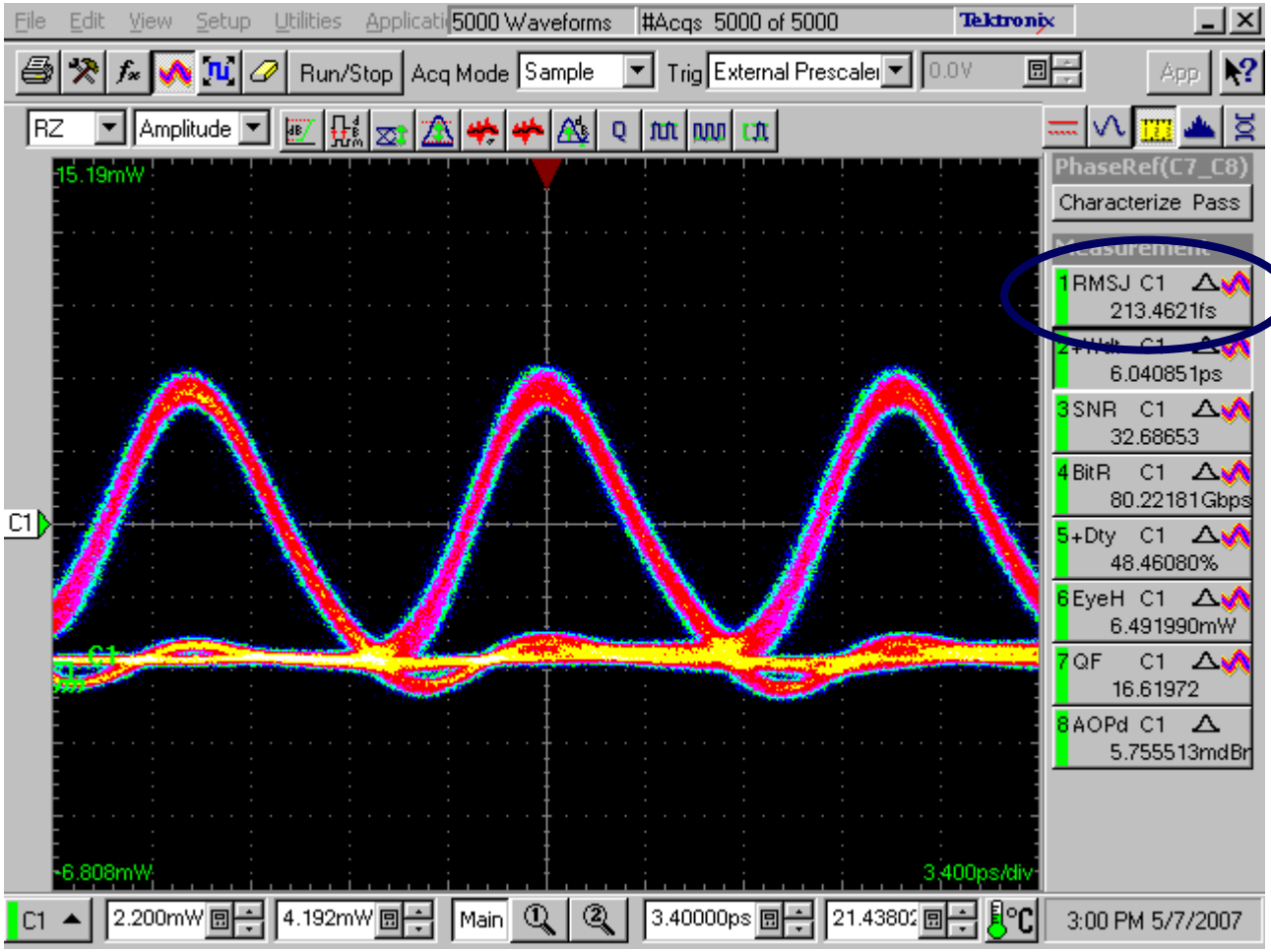
Standard	Line Rate	80C08C	80C10BF1
10GBase-W, OC-192 / STM-64	9.953 Gb/s	✓	
10GBase-R 10GBase-LRM	10.3125 Gb/s	✓	
10GBase + OTU2 FEC	11.096 Gb/s	✓	
8GFC 10GFC 10GFC + FEC	8.50 Gb/s 10.519 Gb/s 11.317 Gb/s	✓	
OC192 + G.975 FEC OTU2 (OC192 + G.709 FEC)	10.664 Gb/s 10.709 Gb/s	✓	
100GBase-SR10	10 x 10.3125 Gb/s	✓	
100GBase-LR4 100GBase-ER4	4 x 25.781 Gb/s		✓
100GBase-LR4 + FEC 100GBase-ER4 + FEC	4 x 27.739 Gb/s		✓
40GBase-SR4 40GBase-LR4	4 x 10.3125 Gb/s	✓	
40GBase-LR	41.25 Gb/s		✓
OC-768 / STM-256 VSR-2000	39.813 Gb/s		✓
OTU3 (OC-768 + G.709 FEC), VSR-2000 + FEC 4x10G LAN PHY (OTU3)	43.018 Gb/s 44.50 Gb/s		✓

The most versatile 10G to 100G Testing Solution

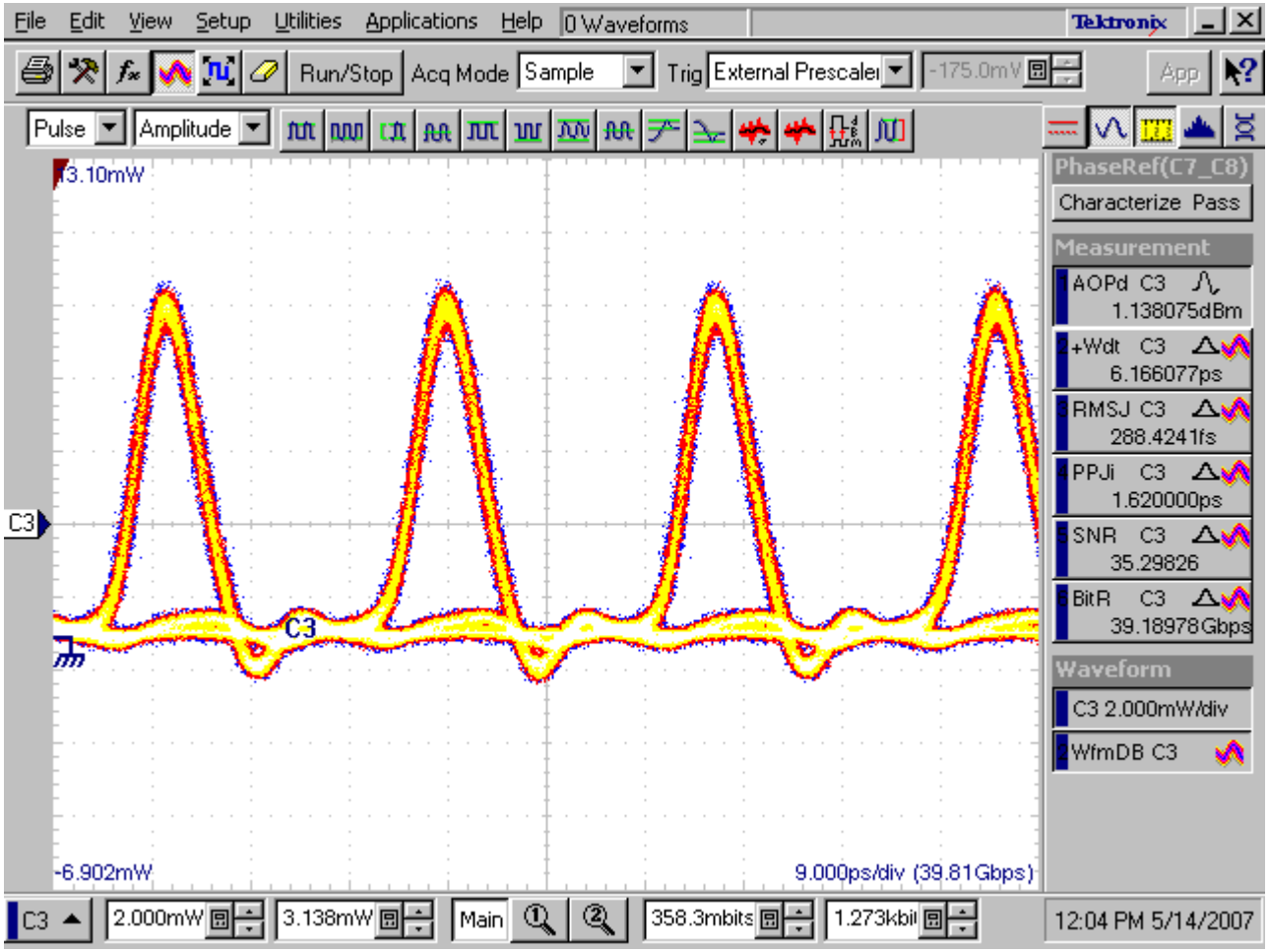
- NRZ, RZ, Optical Duo-Binary line-coding
- Over 80GHz unfiltered optical bandwidth for device characterization
- Tightest 10- 44Gb/s Reference Receiver manufacturing tolerances for highest measurement repeatability
- Best signal fidelity through proprietary filtering and low-noise technology
- Future reference receiver filters can be added via factory upgrade.

80Gb/s RZ Eye Diagram

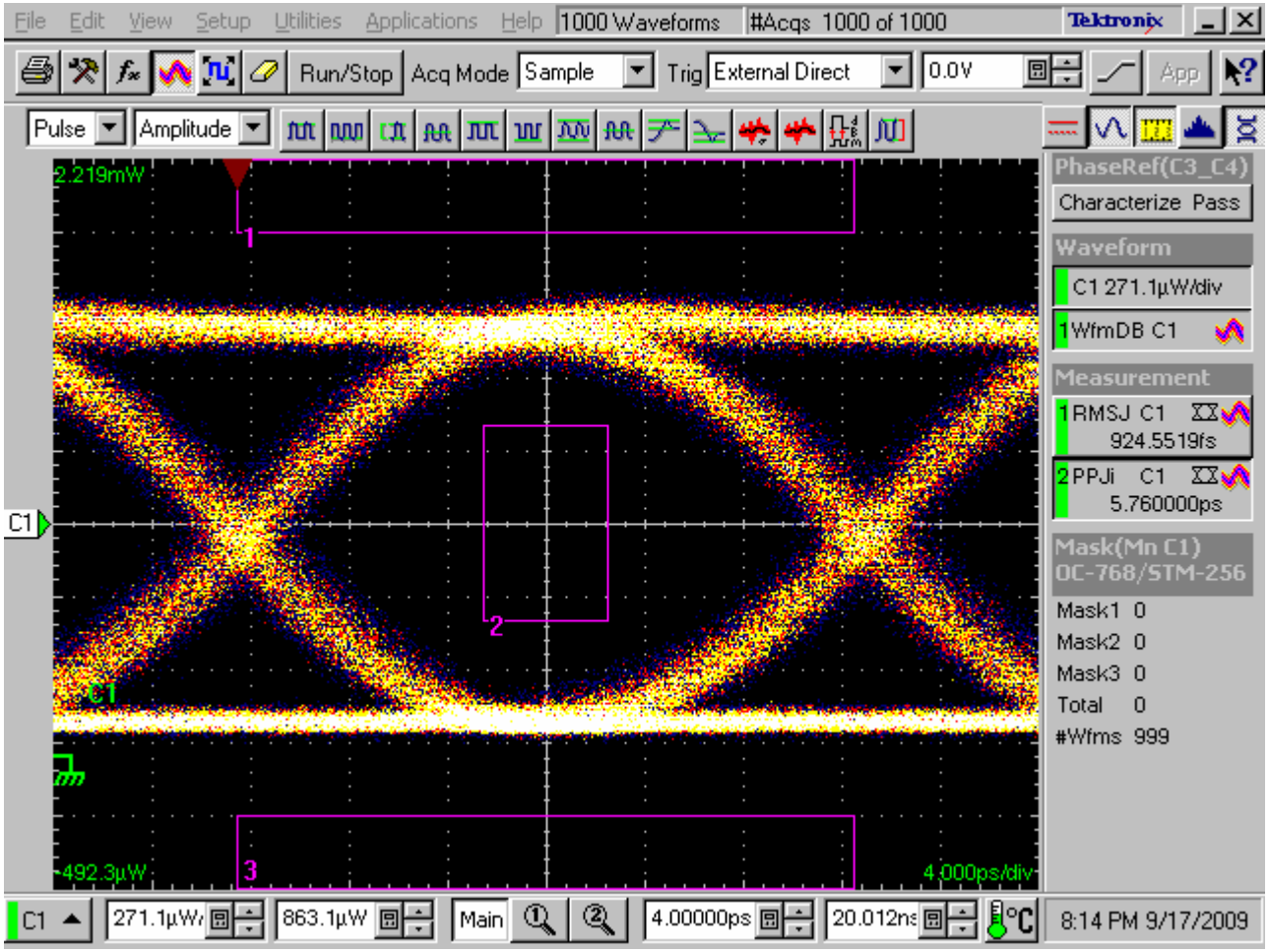
- AOP=0dBm



40Gb/s RZ eye diagram



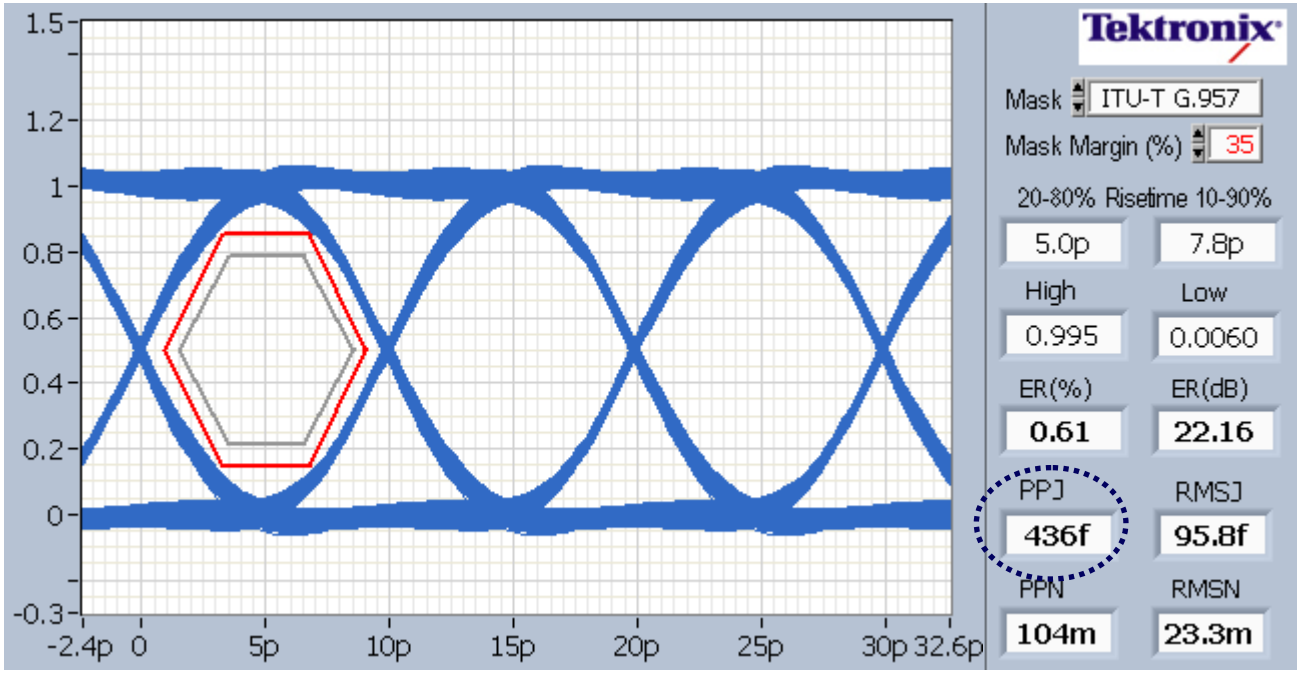
40Gb/s RZ Eye Diagram(实测结果)



80C10B 100Gbps NRZ Performance

Simulated eye diagrams based on measured 80C10B impulse response

- Full bandwidth setting (PRBS10)

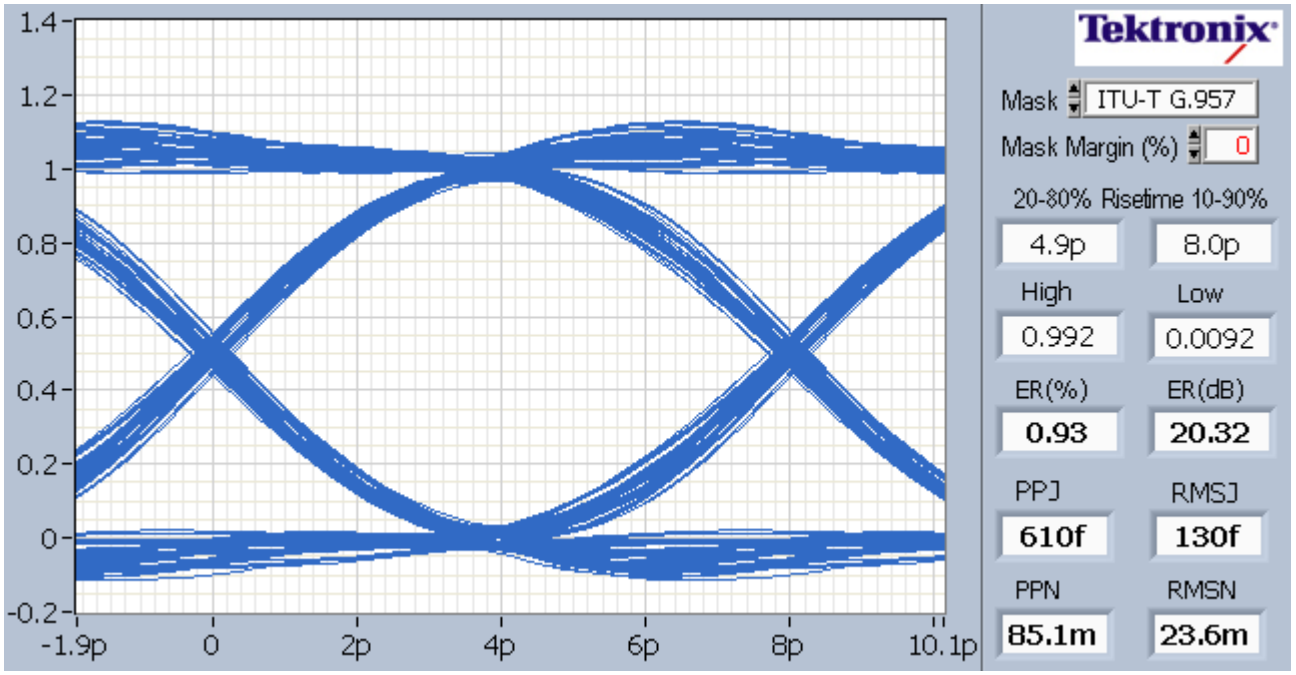


Note: effects of timebase jitter not included

80C10B 125Gbps NRZ Performance

Simulated eye diagrams based on measured 80C10B impulse response

- Full bandwidth setting (CJTPAT)



Note: effects of timebase jitter not included