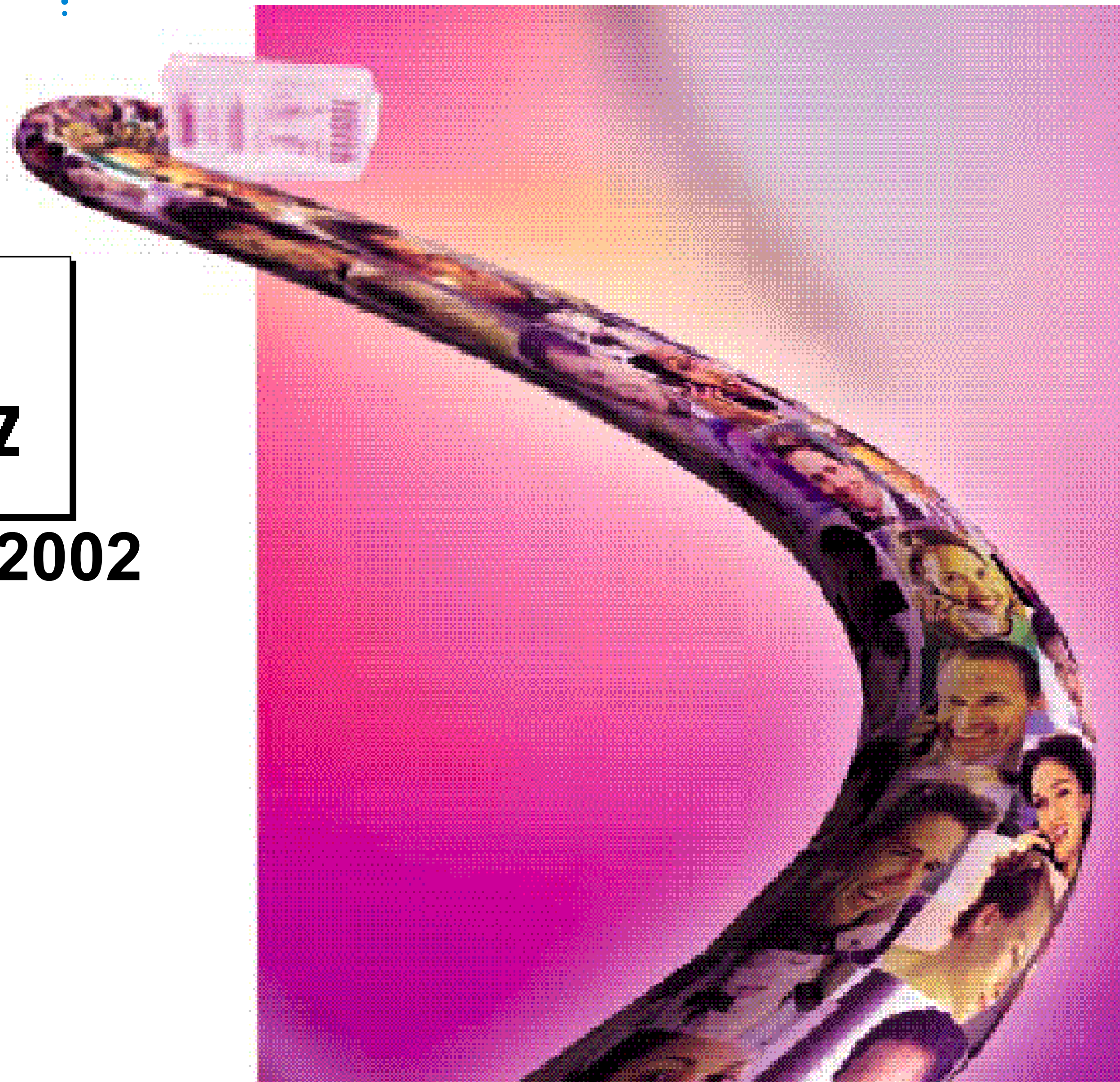
Slides 1-10:
Industry Buzz

Slides 11-42:
High-Speed
Waveform eSeminar

Agilent Technologies



THE 40G
INDUSTRY BUZZ

September 5, 2002

presented by:

Larry DesJardin

THE 40G Industry Buzz

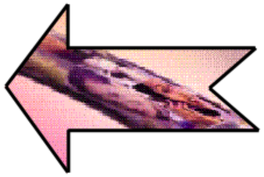
- *Industry Update & Commentary*
- “Late Breaking News” from Agilent

SFI-5 Specification Status

- **APPROVED!!!!**
- **Parts being sampled…**

THE 40G Industry Buzz

- **Industry Update & Commentary**
- ***"Late Breaking News" from Agilent***

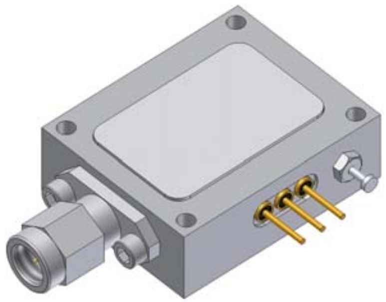


Agilent Technologies

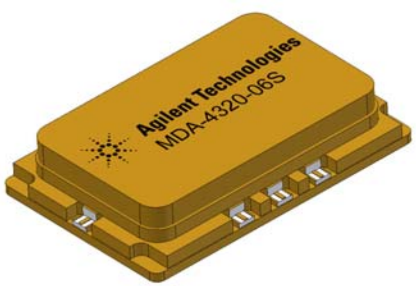
Late Breaking Agilent News

New Optical High Speed Modules:

- **Agilent 20& 40Ghz VCO in Coaxial Package**
  - **Freq: 19.9, 21.5, 39.8, and 43.1Ghz**
  - **Low Jitter. 3-7dBm output power**
  - **Size 1.20”x0.95”x0.40”**



- **Agilent 20& 40Ghz VCO in SMT Package**
  - **Freq: 19.9, 21.5, 39.8, and 43.1Ghz**
  - **Single or Differential Output**
  - **Hermetic package 0.7”x0.4”x0.2”**



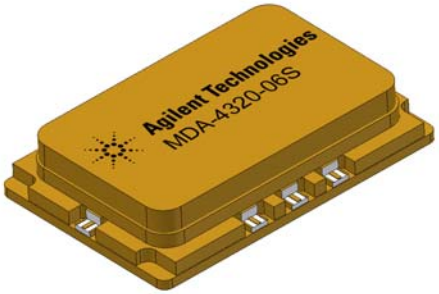
See Resource Page for more info.

Agilent Technologies

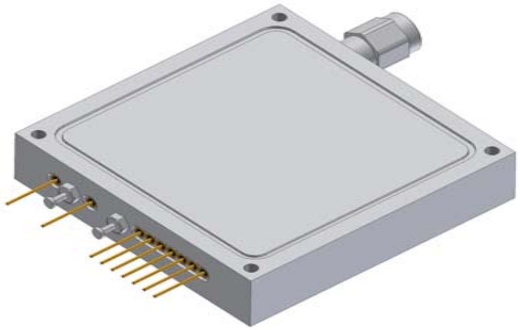
Late Breaking Agilent News

New Optical High Speed Modules:

- **Agilent Driver Amp in SMT & Coaxial Package**
  - **Freq: 40Khz to 43Ghz**
  - **>6Vp-p output pwr**
  - **15dB and 20dB gain**



- **Agilent 20Ghz Phase Lock Pwr Clock Driver**
  - **Freq: 19.9 or 21.5Ghz**
  - **>16Vp-p Output Voltage**
  - **Hermetic package 2.0x2.0x0.4”**



Contact Nam Lee. Email:nam_lee@agilent.com

Tel (408) 970-2822

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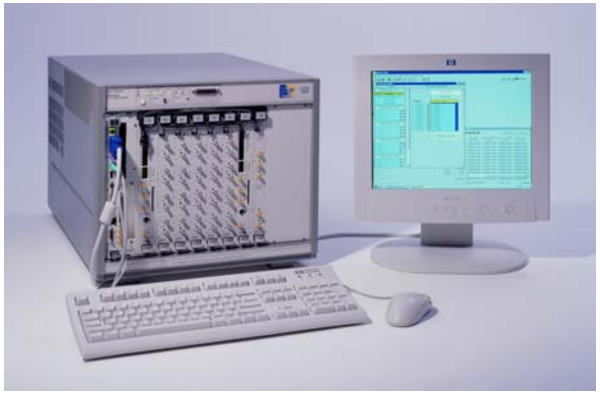
Late Breaking Agilent News
New Tunable Laser Source:

- **Agilent 81600B All Band Tunable Laser Source**
  - **Industry widest tuning range**
  - **Complete S, C, L Band Coverage** (1440nm – 1640nm)
  - **Fastest Sweep Speed** (up to 80 nm/s) **with guaranteed performance**
  - **Up to +8 dBm output power**

http://advanced.comms.agilent.com/cm/rdmfg/tls/81600b/index.shtml

Late Breaking Agilent News
New Bit Error Ratio Tester:



- **Agilent ParBERT 81250B 45G**
  - **38-45Gb/s**
  - **Add 2.7Gb/s or 10.8Gb/s tribs**
  - **Variable threshold & delay**
  - **Integrated CDR**
  - **Differential output, 2V/single ended.**
  - **SONET editor**

See Agilent web site for more information

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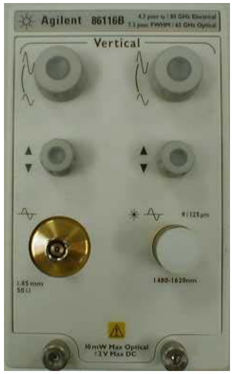
Late Breaking Agilent News

New Communication Analyzer Products:

- **Agilent 86116B 65 GHz Optical; 80 GHz Electrical**
  - For 40 Gb/s component testing
  - Highest optical and electrical bandwidth
  - Very fast rise times; high pulse fidelity



- **Agilent 86117A/B Dual Electrical Channels**
  - Either 50 or 65 Ghz dual electrical BW
  - Fast rise times
  - High pulse fidelity

Agilent web site to have more information

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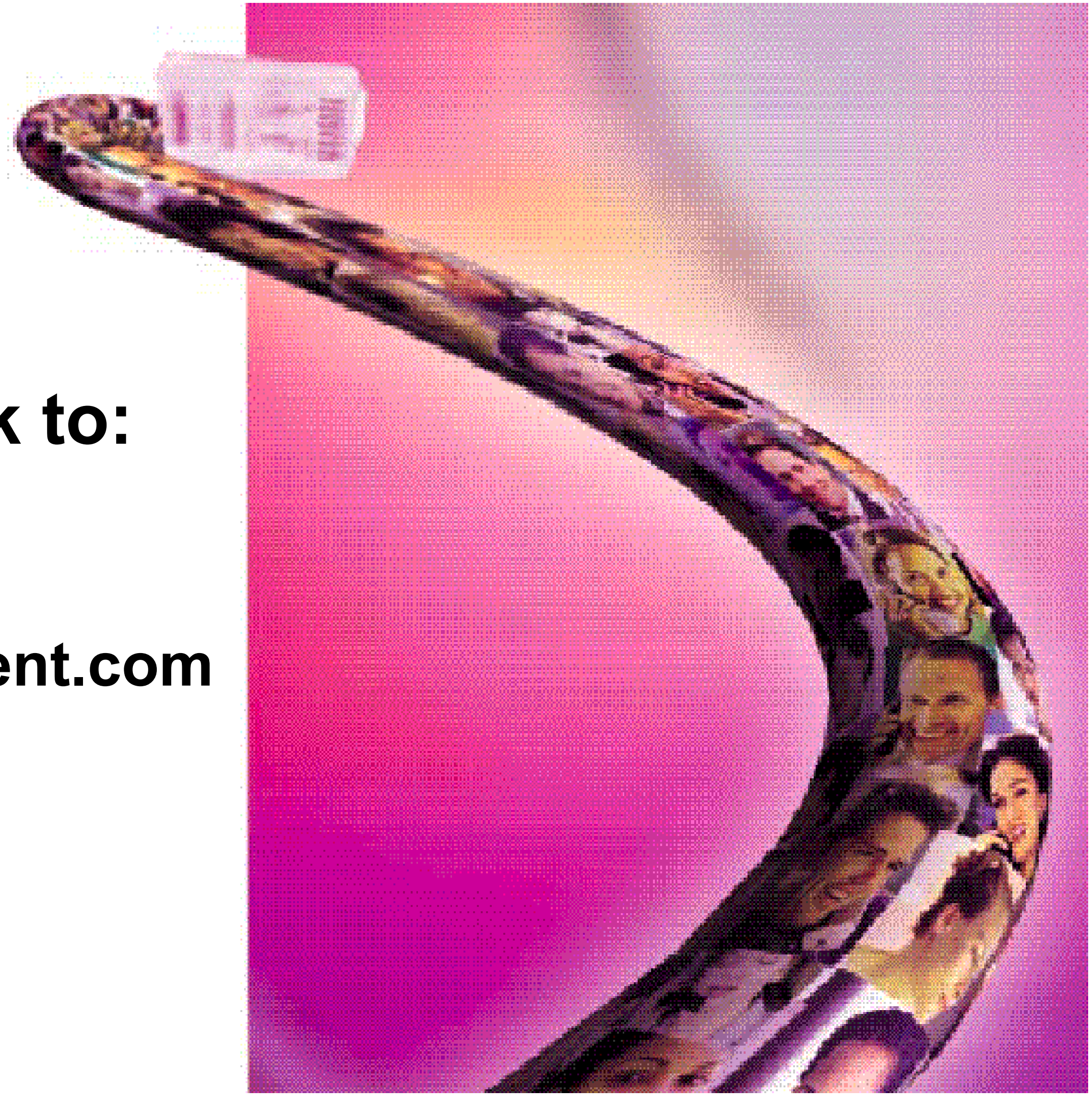
THE 40G INDUSTRY BUZZ



Send any feedback to:

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High-speed Waveform Measurement Challenges

September 5, 2002

presented by:

Mike Resso
Lightwave Division
Santa Rosa, CA

Agenda

- Fundamentals for measurements of very high-speed waveforms
- Technology behind current state of the art
- Recent breakthrough developments that dramatically increase measurement capabilities

Communications speeds continue to advance at a steady pace

- **SONET/SDH rates**
  - 155, 622, 2488 &9953 Mb/s
  - 40 Gb/s development in progress
- **Ethernet rates**
  - 10, 100 & 1000 Mb/s
  - 10 Gb/s development in progress

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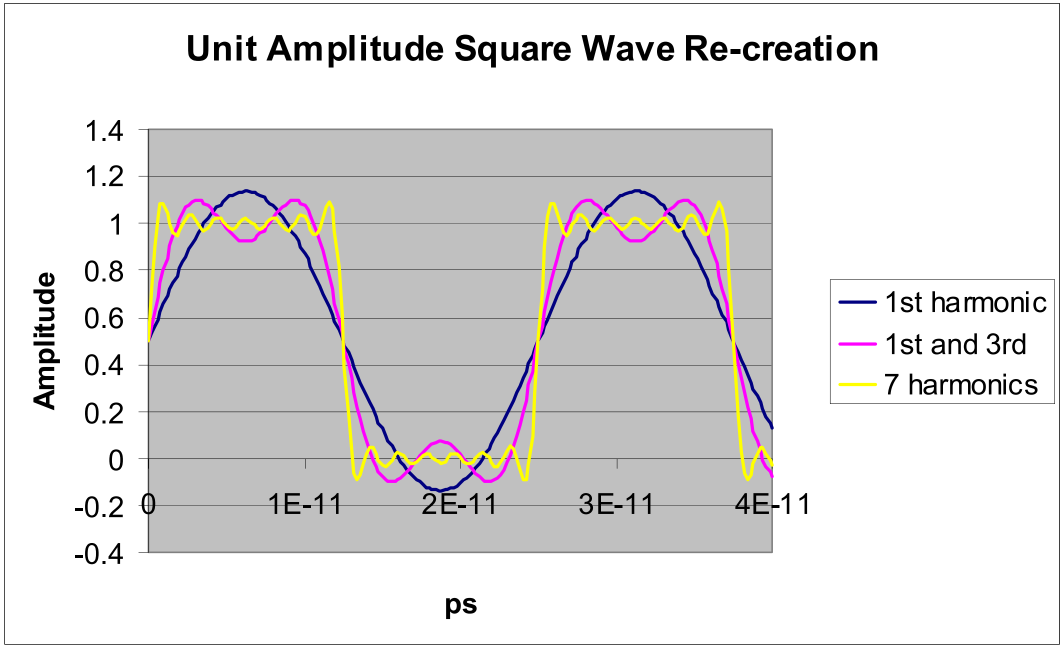
High fidelity waveform measurements require significant bandwidth: How much is enough?

- **Good measurement practice for simple pulse measurements**
  - See at least third harmonic
  - Preferably 5th harmonic for accurate wave shapes
- **Rule-of-Thumb**
  - 3x Bandwidth =5% error
  - 5x Bandwidth =1% error



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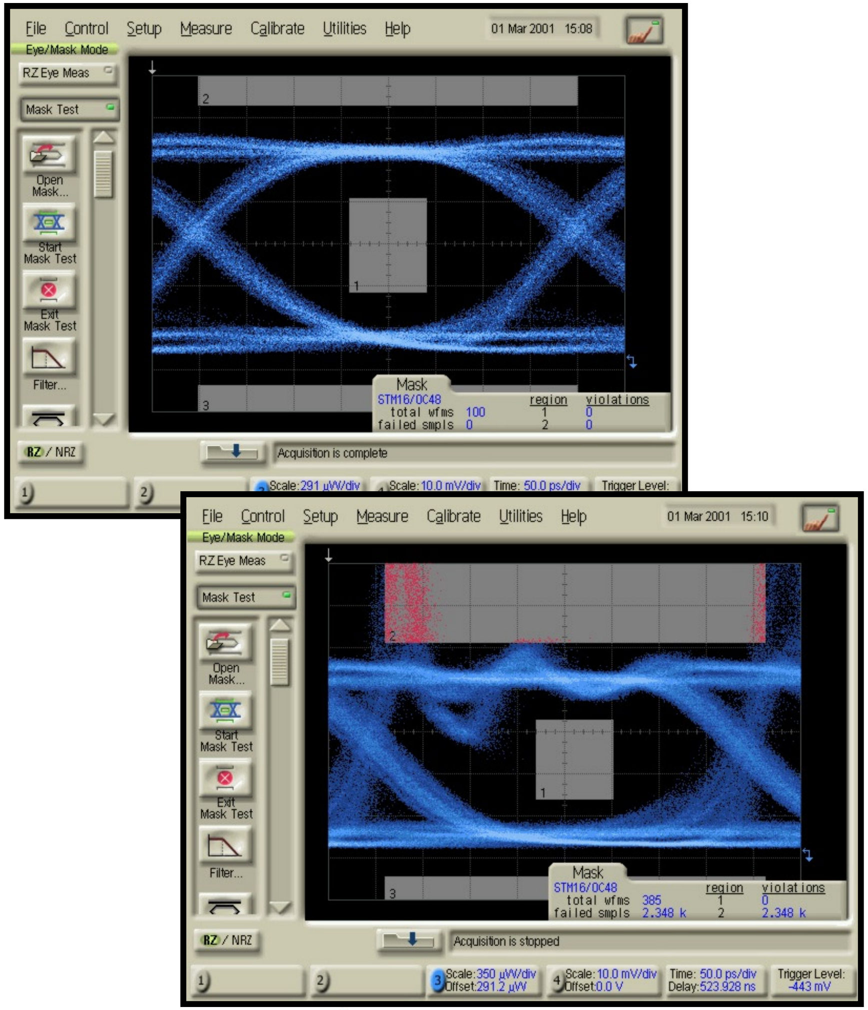
Reduced bandwidth reference receivers used for standards compliance verification

- **Key intent: verify that a transmitter will function properly in a communications system**
  - This is much different than verifying the correct shape of a waveform
- **Need a methodology that yields consistent measurements across the industry**
- **Optical reference receiver:**
  - This is much different than verifying the correct shape of a waveform
  - Bandwidth at 75% of optical baud rate
- **Example: 10 Gb/s reference receiver has 7.5 GHz bandwidth**



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Oscilloscope performance: A stable state of the art for approximately 10 years

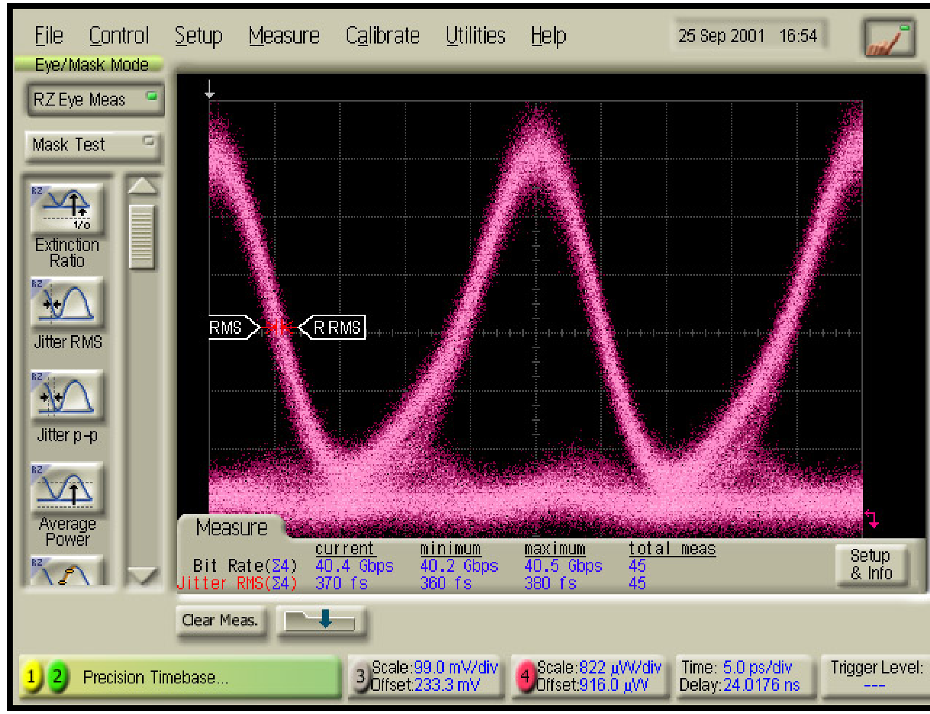
- 50 GHz electrical measurement capability has existed since before 1990
- 30 GHz optical bandwidth available before1991
- Jitter performance (also important for high-fidelity waveforms) approximately 1 ps rms (since 1990)

- Adequate for all rates up to 10 Gb/s

Where do we stand for 40 Gb/s measurements?

40 Gb/s transmission requires significant improvements in measurement instrumentation

- Return-to-zero (RZ) modulation formats
  - Extremely narrow pulse widths
  - Fast rise and fall times
  - Small amounts of instrumentation jitter can severely degrade displayed waveform
- RZ specific issues reside mainly in the optical domain
  - NRZ to RZ conversion at the electro-optic modulator
    - Optical measurements can require more bandwidth than the electrical measurements

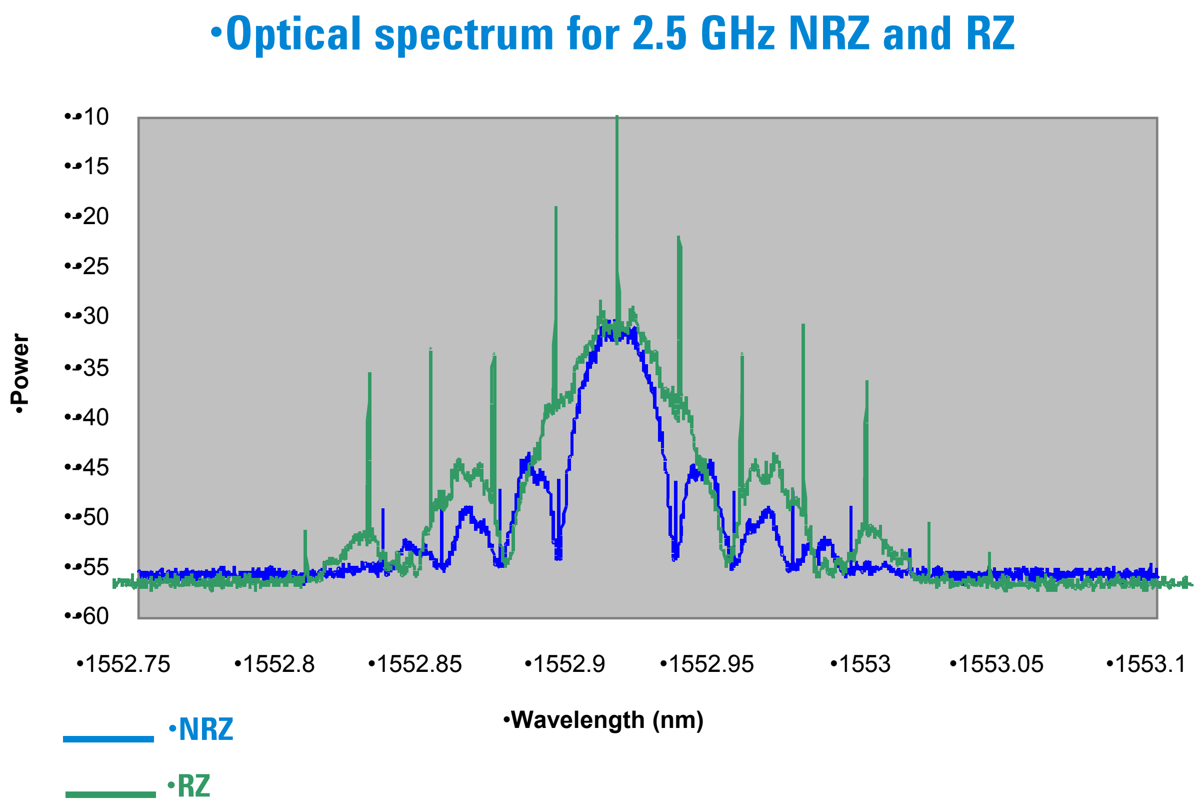


Question: Why use RZ Format?

Answer 1: Reduces Inter Symbol Interference

Answer 2: Approaches soliton transmission

RZ signal spectrum is wider than the NRZ signal at the same data rate



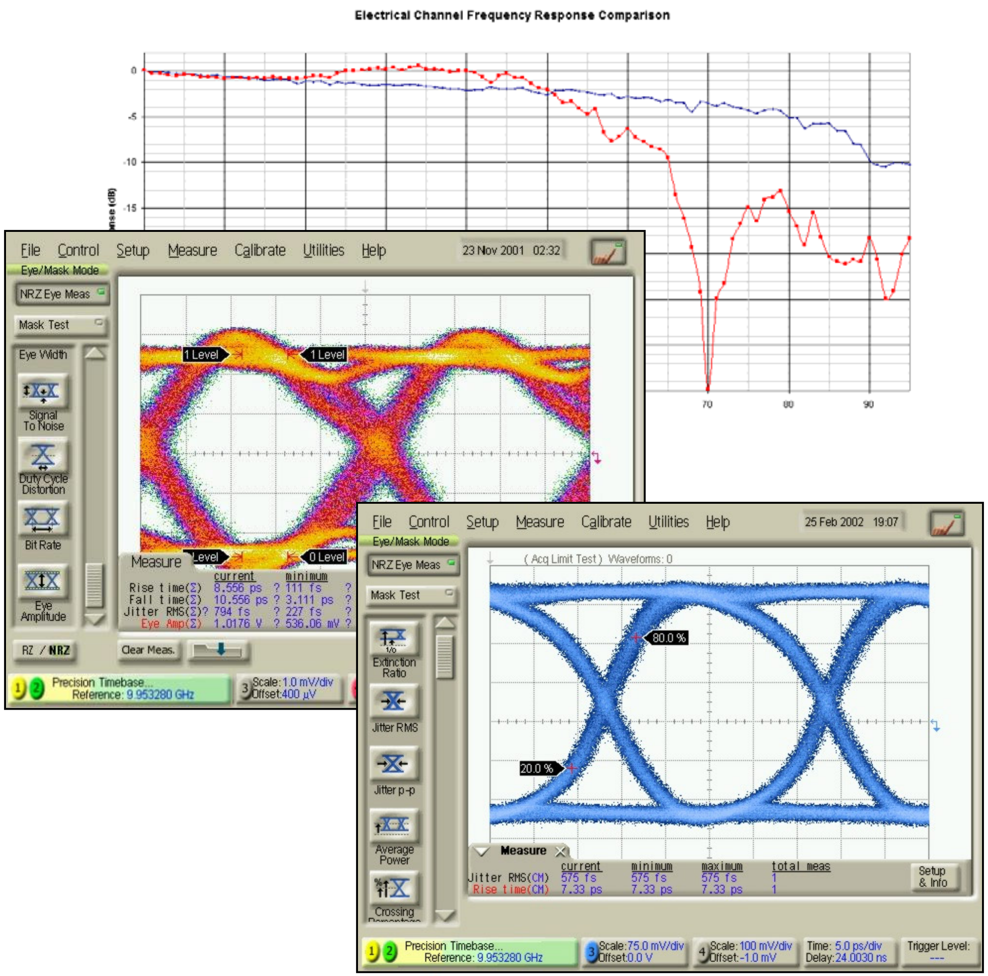
Accurate waveform measurements require a proportional increase in measurement bandwidth

Measurements of 40 Gb/s electrical waveforms present new challenges

- Cables are lossy
- Cable frequency response has high-frequency rolloff
- Specialized connectors

Measurement bandwidth is a subset of a more important parameter: frequency response

- Anytime you bandlimit a signal, the resulting waveform is incorrect. Error magnitude depends on frequency content of the signal and scope response
- Several different frequency responses can have identical bandwidth values
- Can lead to significantly different waveform shapes
  - Abrupt rolloffs or “peaking” prior to rolling off can lead to overshoot and ringing in the time domain response
  - Well behaved, gentle rolloff is ideal for a bandlimited measurement



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Why has measurement performance not kept pace with communications speeds?

- Main contributors:
  - Electrical samplers: The heart of the wide-bandwidth sampling oscilloscope
  - High-speed photodetectors: Required for the analysis of optical signals
  - Circuitry capable of maintaining timing precision to sub-picosecond accuracy: Key element for minimization of oscilloscope jitter

Electrical sampling circuits

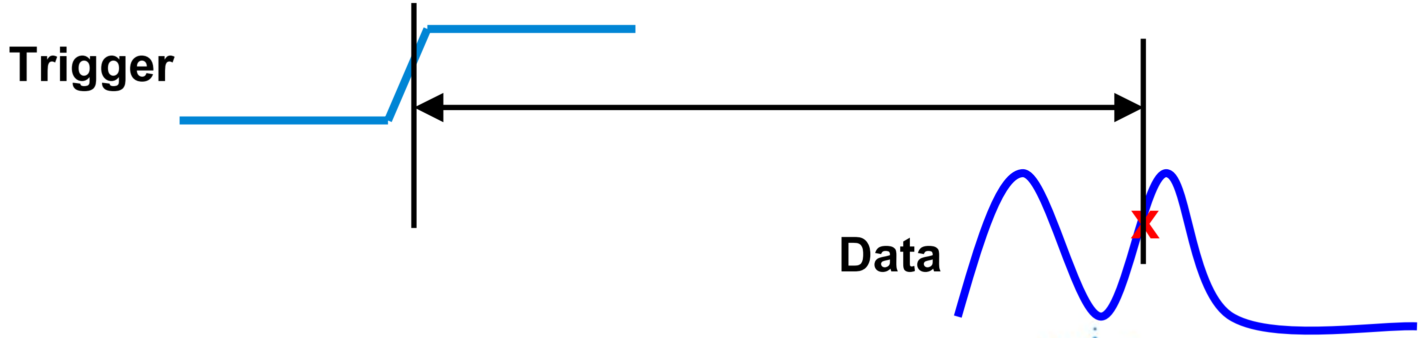
- A sampler will determine the amplitude of the signal at a discrete point in time
- Based on microwave circuit technology
- DC coupled, ultra-wide-bandwidth, well-behaved frequency response circuitry is extremely difficult to design and build
  - DC coupling is required for several measurements including extinction ratio
- Sampler efficiency often is traded for higher bandwidth
- Electrical cabling degrades measurement fidelity
  - 30-40 cm of good cable can reduce effective measurement bandwidth from 75 GHz to 50 GHz

Photodetector limitations

- Similar to electrical samplers, an optical front end to an oscilloscope must have:
  - DC coupling
  - Wide bandwidth
  - Well behaved frequency response
  - High responsivity/low noise

Timing accuracy leads to waveform jitter

- How much uncertainty exists in determining the precise time when a sample is taken
- A trigger event determines when the sampling process should begin
- The time between a trigger event and the sampling event is often several nanoseconds
- Maintaining sub-picosecond timing precision over a multiple nanosecond time span is extremely difficult



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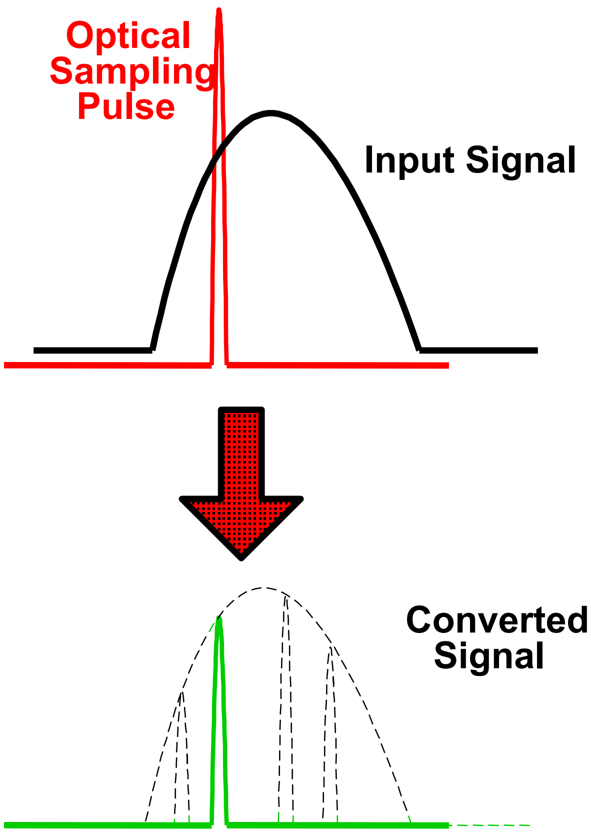
New measurement techniques provide breakthrough performance

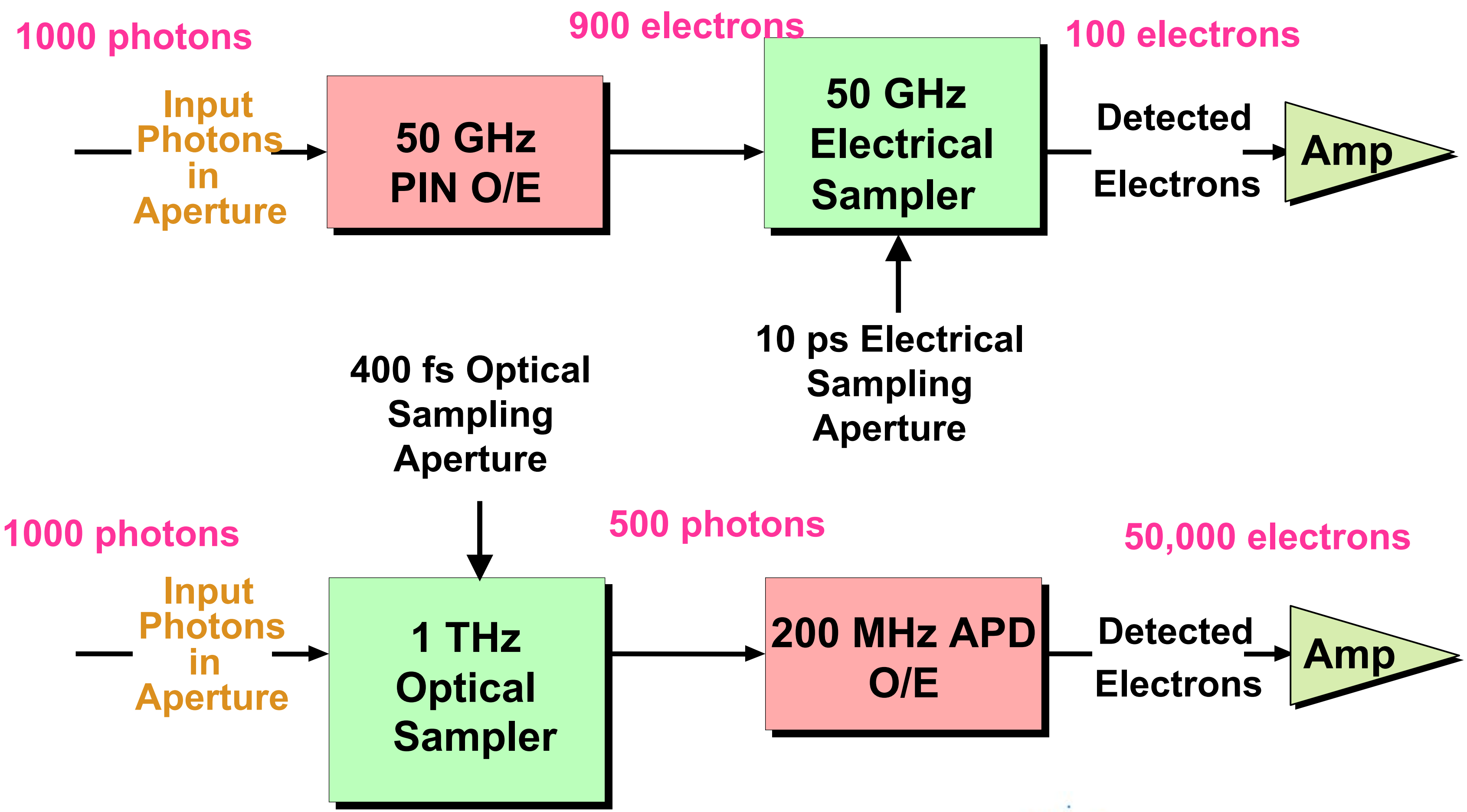
- **Optically based sampling techniques yield bandwidths approaching 1 Terahertz**
- **Ultra-compact sampler in a remote-able housing yields up to 75 GHz of bandwidth for electrical waveforms**
- **Phase-based triggering technique yields jitter performance approaching 100 femtoseconds (rms).**

Optical sampling concept

- Sampling bandwidth is determined by the width of the sampling pulse
  - Use very fast optical pulses (~100fs) to sample the signal under test
- Noise can be dominated by the bandwidth of the electronics
  - Minimize electrical noise by sampling in the optical domain
  - Convert to the electrical domain in a low-bandwidth intermediate frequency
- Perform multiple samples to construct the waveform



Traditional electrical sampling architecture vs. new optical sampling architecture



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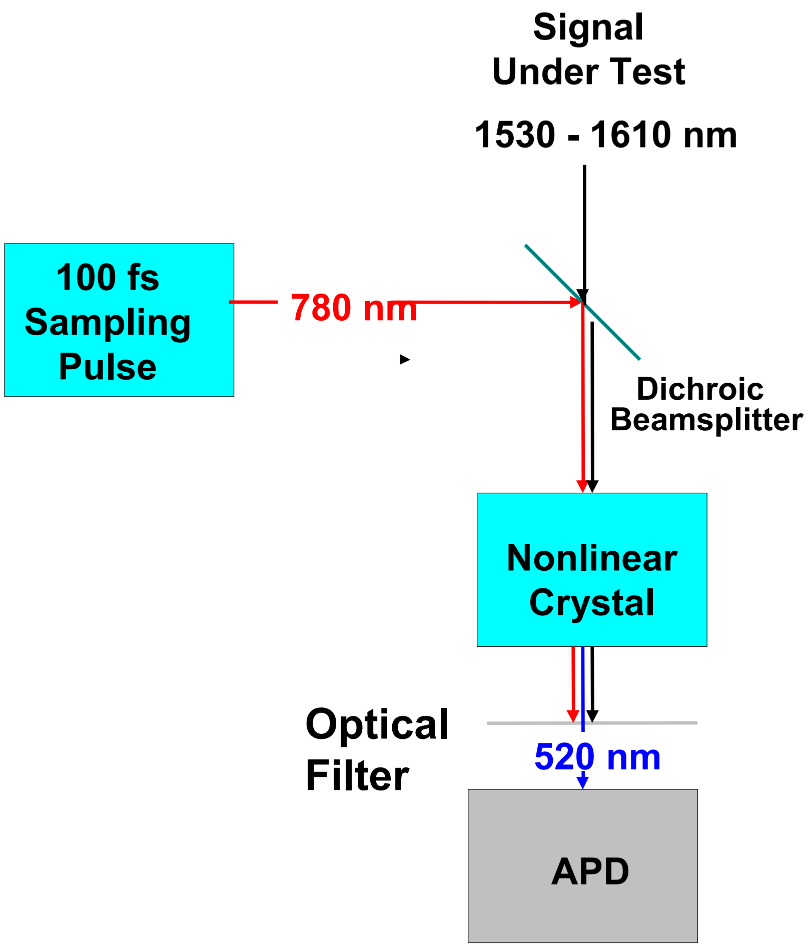
Optical domain sampling architecture

- Signal under test is linearly combined with ultrafast 780 nm sampling pulse from fiber ring laser
- Within the nonlinear crystal, the signals interact to create an 520 nm “IF” proportional to the amplitude of the sample
- An avalanche photodiode (APD) has extremely high conversion gain to generate many electrons to maintain a high signal-to-noise ratio



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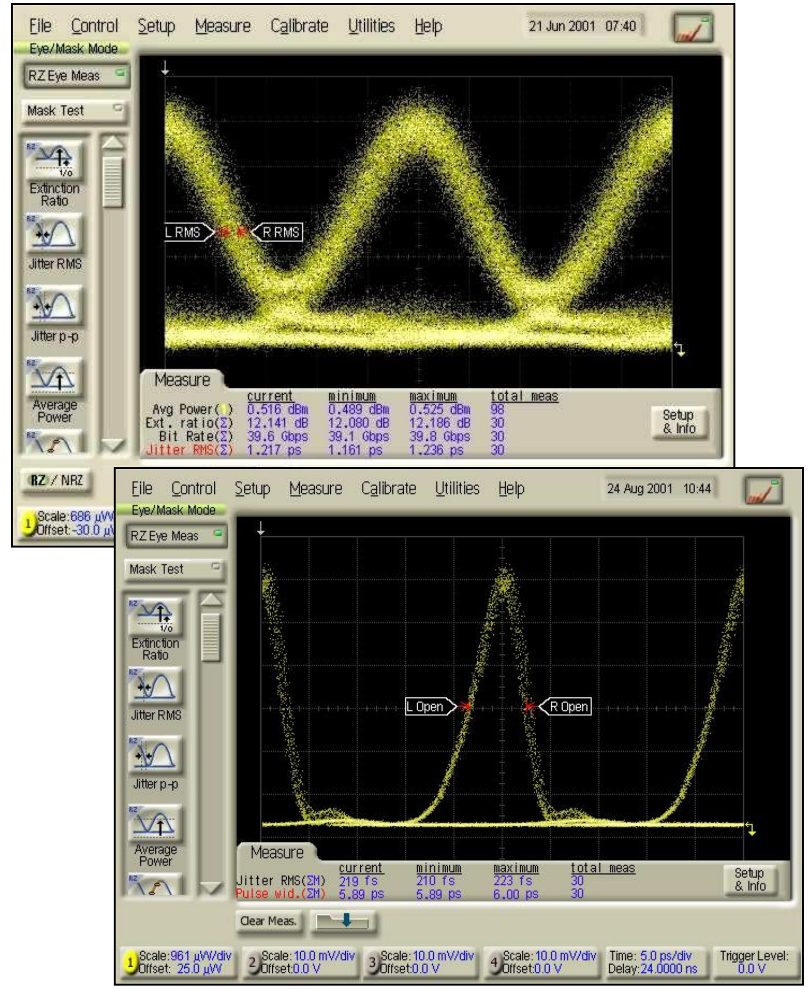
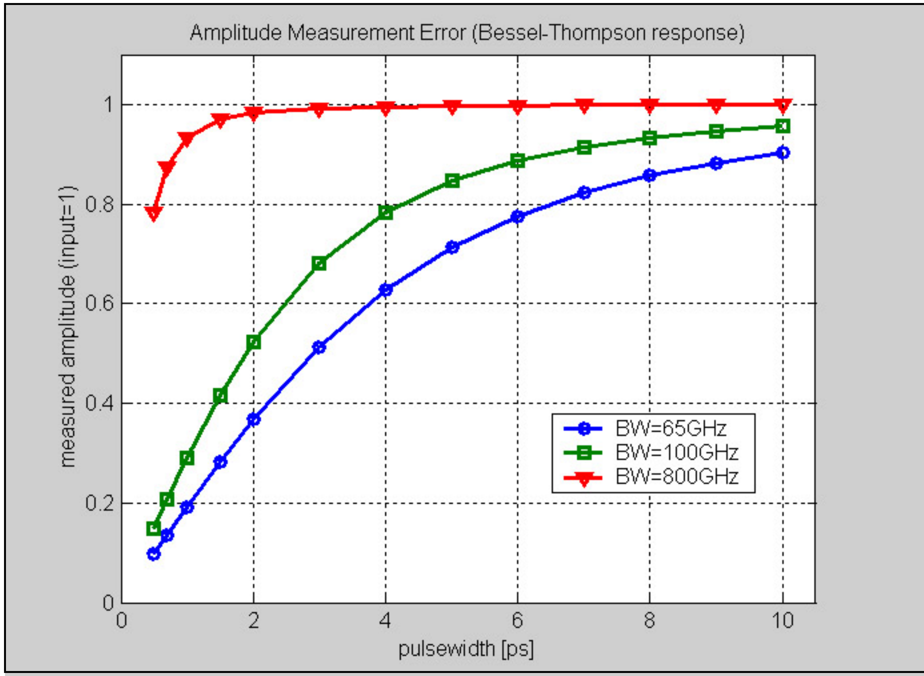
Comparing conventional electrical and optical sampling oscilloscopes

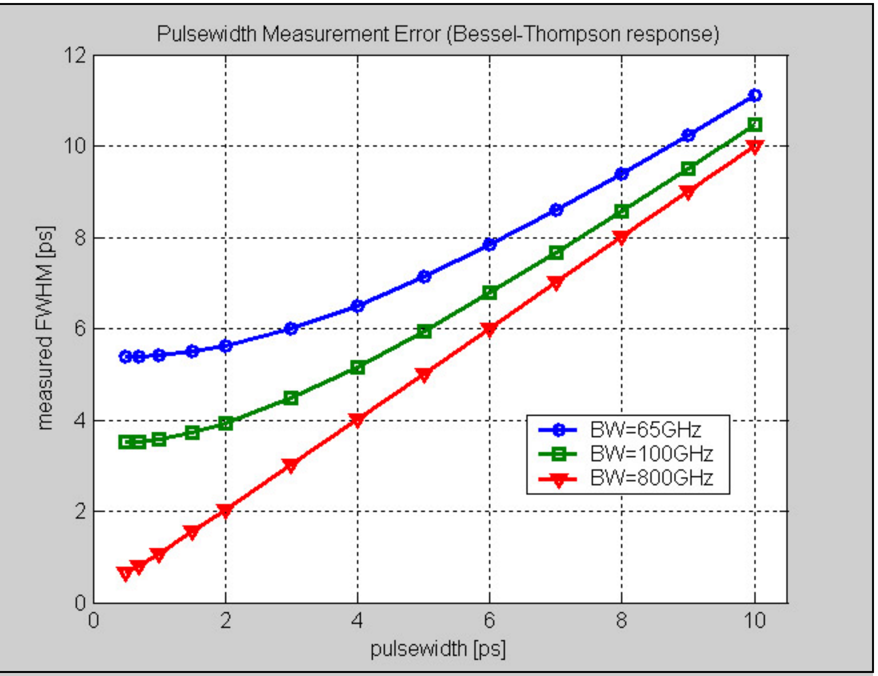
- Problems eliminated through optical sampling
  - Insufficient bandwidth causes pulse to never reach full amplitude (effects several measurements)
  - Noise from instrument electronics masks true signal characteristics
  - Edgespeeds increase (effects several measurements)



Wide bandwidth provides a significant improvement in measurement accuracy



Amplitude measured vs. Pulsewidth (normalized to 1 unit actual height)



Pulsewidth measured vs. actual pulsewidth

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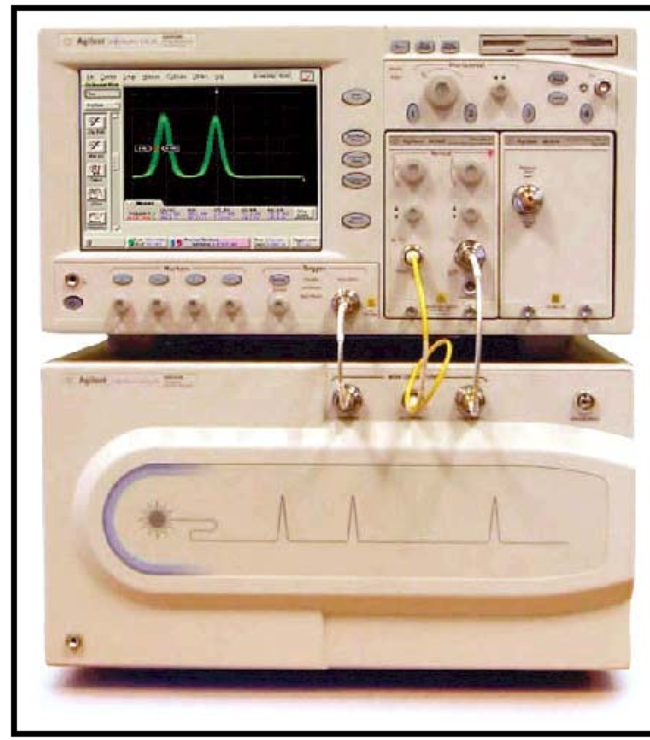
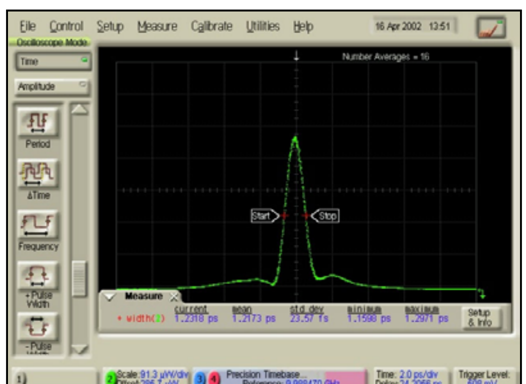
Optical sampling oscilloscopes (TeraScope)

- Provides over 800 GHz measurement bandwidth for accurate waveform analysis
  - 40 Gb/s, 80 Gb/s, 160 Gb/s…..
- A simple addition to the Agilent DCA you already own
  - Performs and operates like a common wide bandwidth sampling oscilloscope





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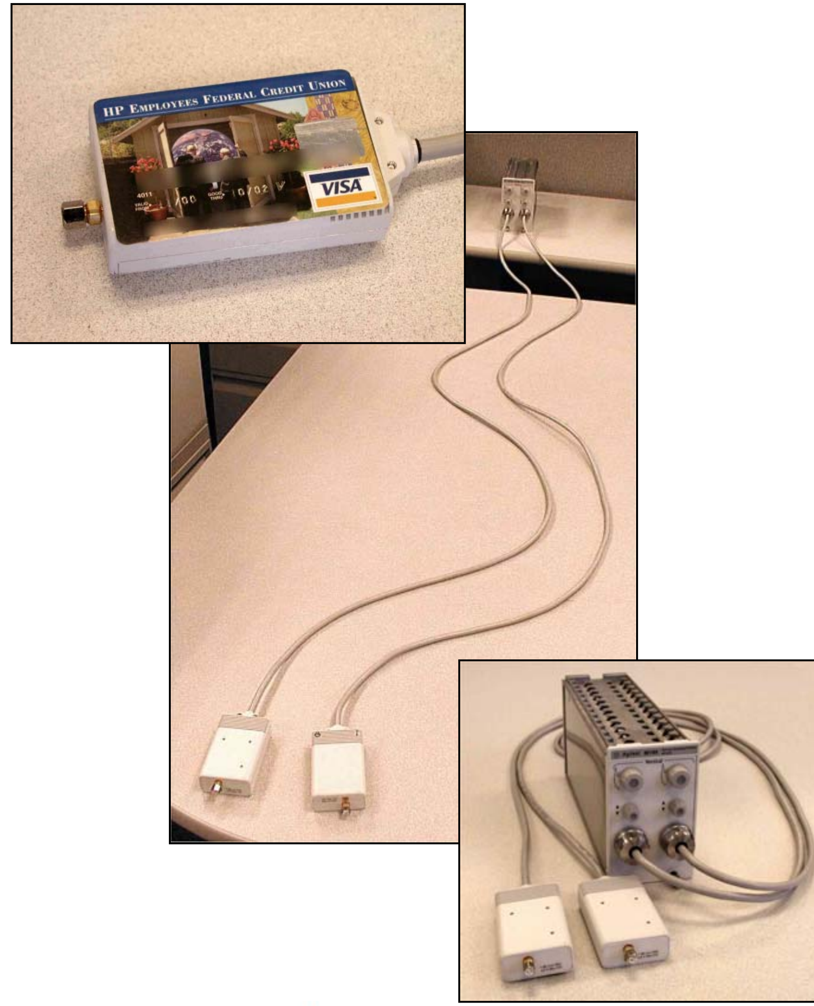
Increasing precision of electrical waveform measurements

- **Compact, remote sampler yields increase in useable bandwidth**
- **Key issues**
  - **Minimize cable lengths**
  - **Small lightweight housing (like a 2 cm thick credit card) allows easy mounting on probe stations**
  - **Up to 2 meter placement from instrument mainframe**



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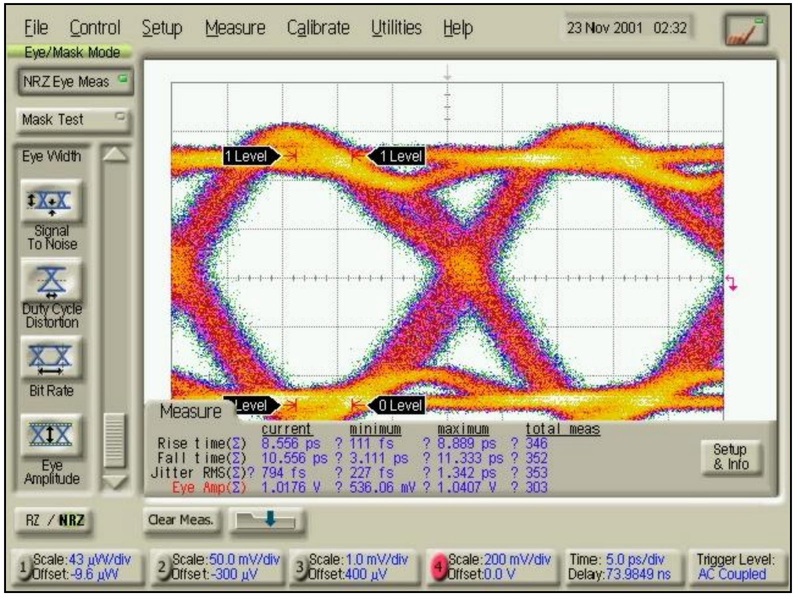
Extensive sampler redesign

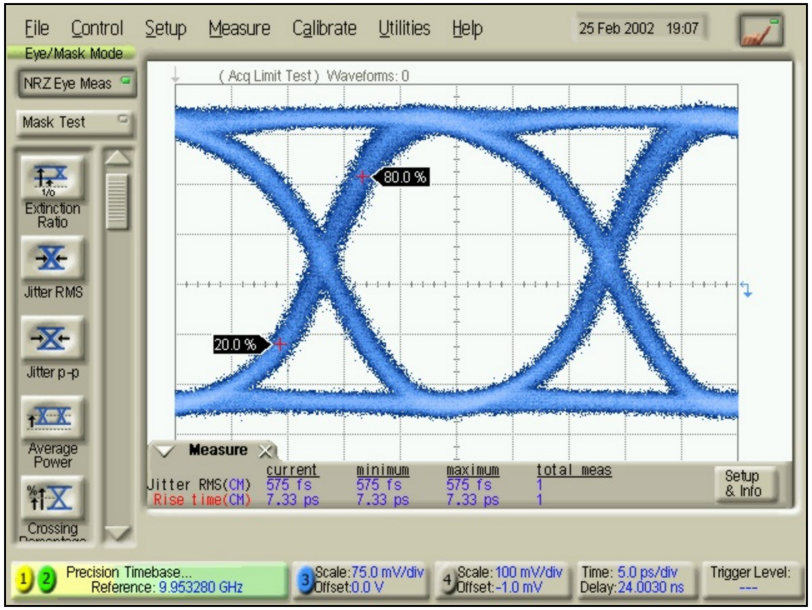
- Higher bandwidth sampler requires extremely fast, narrow sampling pulse
  - Redesigned "shockline" transmission lines
- Compact integrated circuit
  - New process allows smaller geometries and precision circuitry
- Careful design of overall frequency response minimizes waveform distortion

Over 70 GHz of bandwidth and minimal cabling yields significant improvements in waveform fidelity

Measurement of 43 Gb/s 81250 ParBERT with early 50 GHz channel, 0.5 meter cabling



Measurements of 43 Gb/s 81250 ParBERT direct connection, over 70 GHz bandwidth, precision timebase



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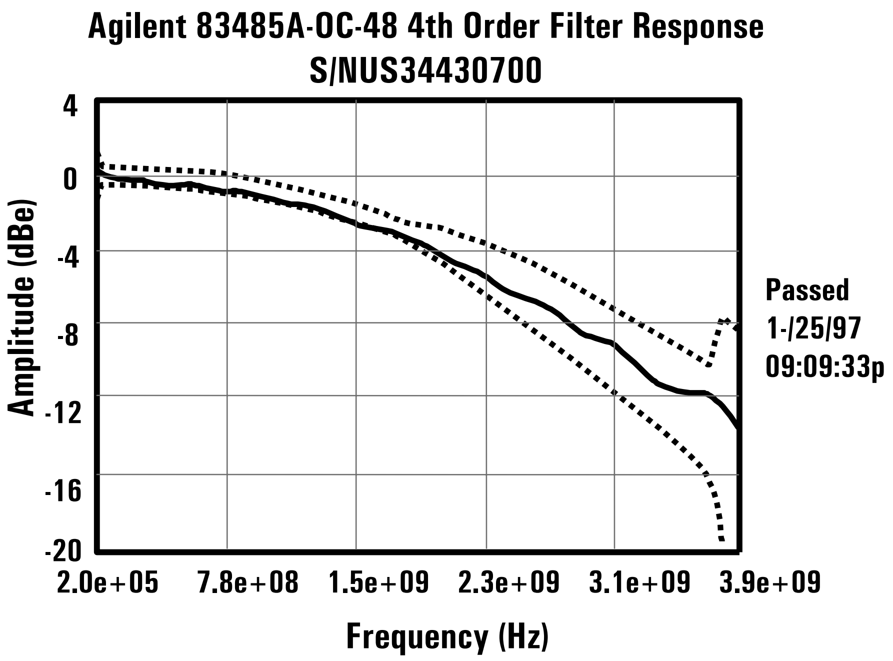
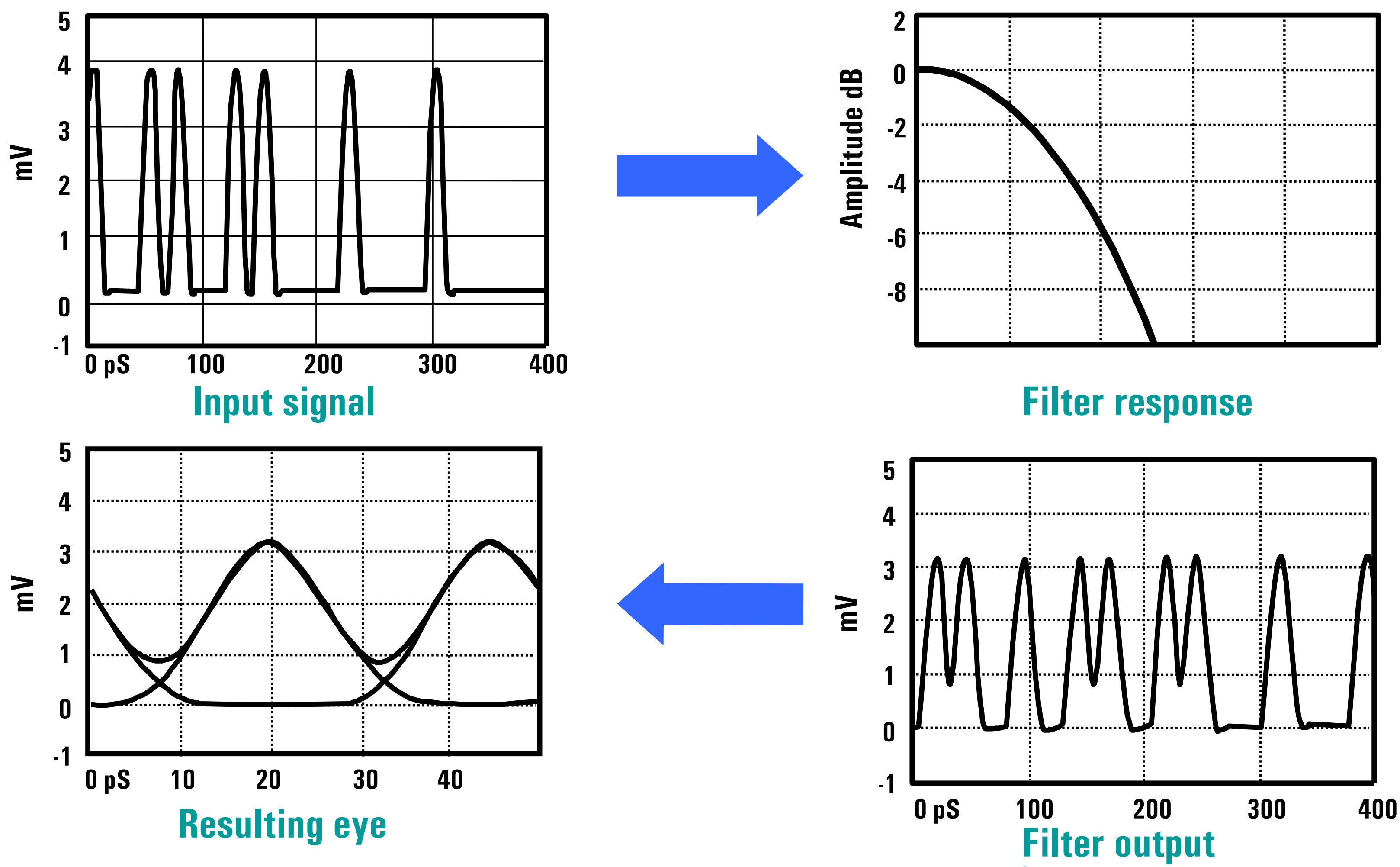
Reference receivers

- Typical reference receiver frequency response follows a fourth order Bessel Thomson low-pass response (why?)
- -3dB bandwidth typically set to 75% of the optical bit rate
  - A reference receiver for a 2.5 Gb/s system would have a 1.88 GHz bandwidth



Measurements for RZ waveforms Using a 75% of bit rate receiver



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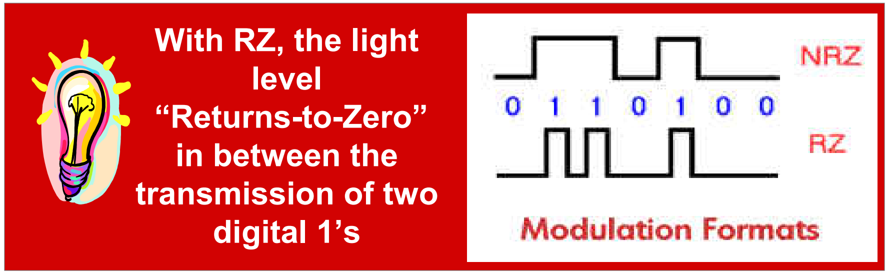
Measurements for RZ waveforms: An RZ reference receiver

- Has not been defined by the standards committees
- Receiver needs to be designed in parallel with key RZ waveform specifications
- “75% of bit rate” is likely to be insufficient
- Currently, most systems are proprietary diminishing the urgency for a reference receiver



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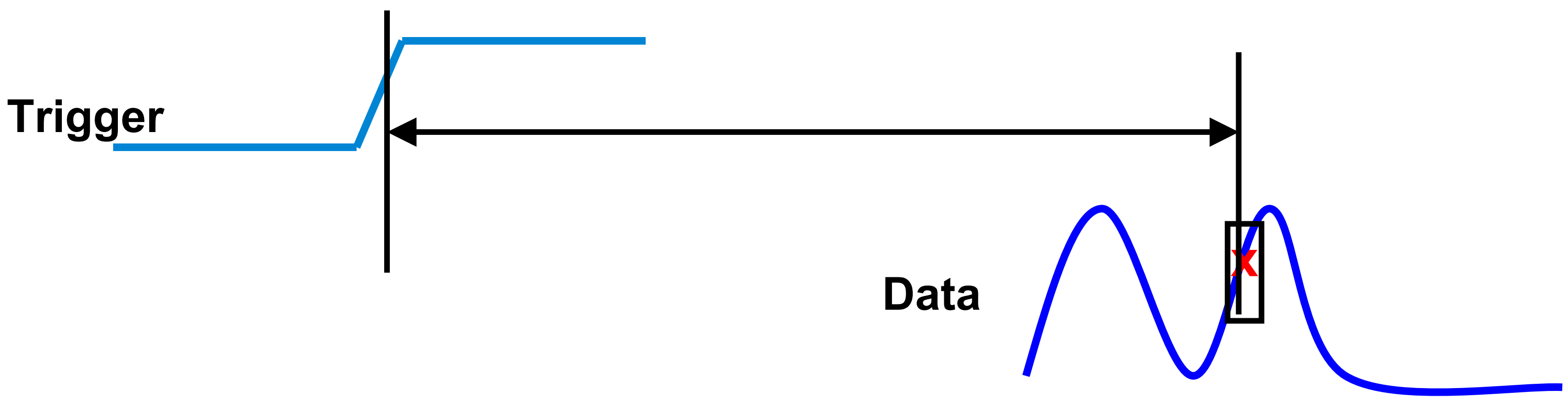
Timing issues also present problems

How much uncertainty exists in determining where In time a sample is taken?

- For sampling oscilloscopes this is referred to as jitter
- Typical performance has been adequate for 10 Gb/s measurements
- 40 Gb/s?



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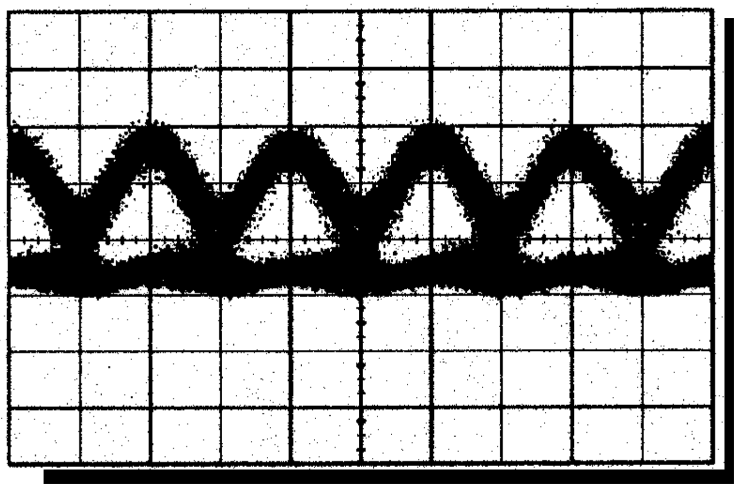
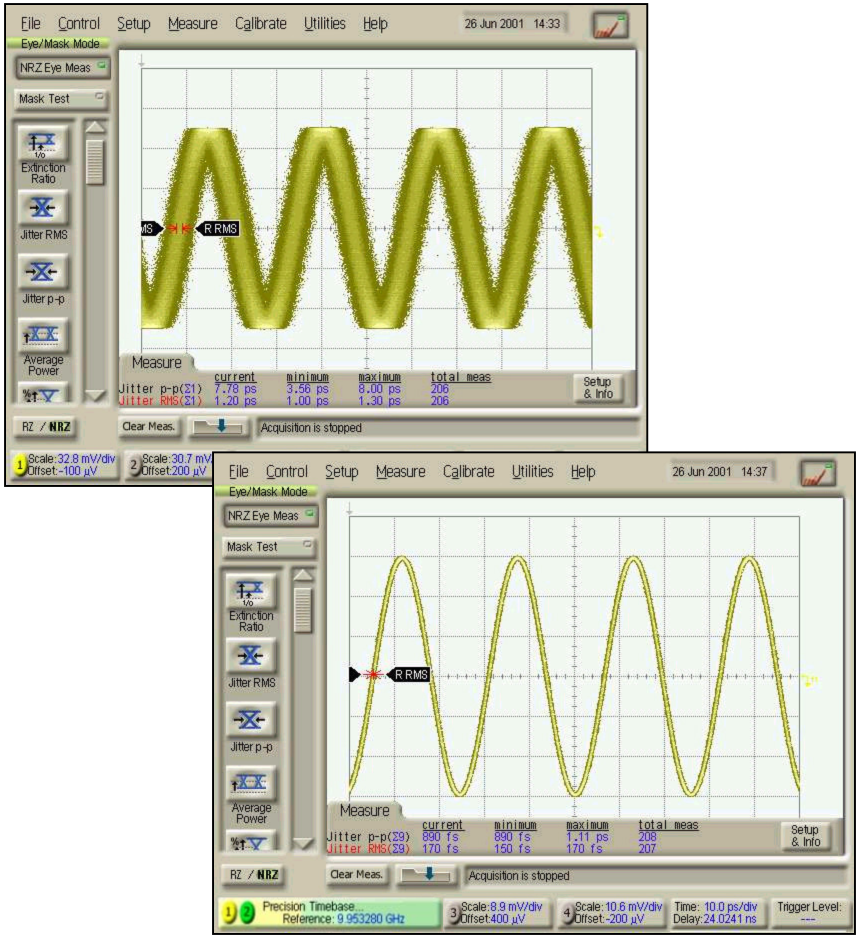
Typical oscilloscope jitter performance distorts true jitter of 40 Gb/s signals

- Typical oscilloscope jitter is 1 ps rms
  - Eye closure depends on peak to peak jitter which is 6 times or more larger than rms
- The bit period for 40 Gb/s is 25 ps
  - 1 ps jitter becomes greater than 6 ps peak to peak
  - Greater than 25% eye closure due to the oscilloscope alone
- Is the eye closure real, or is it caused by the oscilloscope?



New triggering scheme reduces oscilloscope jitter by more than a factor of 5

- **Technique is based upon a phase measurement rather than absolute time**
- **If phase of sampling point can be determined with a precision of 1 or 2 degrees, timing uncertainty approaches 100 fs.**
  - **All data is superimposed into one clock cycle**
  - **Similar to triggering on a clock signal, this always yields the eye diagram**
  - **Oscilloscope jitter is now negligible, even at 40 Gb/s**
- **Triggering bandwidth increased to 43 GHz**



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Conclusions

- Recent breakthroughs provide significant improvements in measurement capability for the highest speed digital communications waveforms
- The work is not finished, and several improvements are in progress
  - Continue to provide feedback on what we can do better

Thank You!

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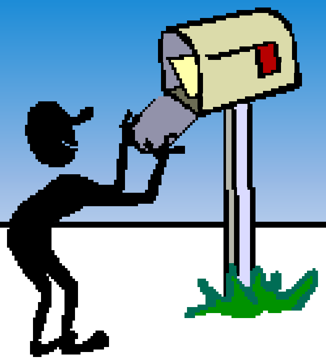

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