From DC up to 30 GHz
"Real-Time" oscilloscope Acquisition

"Advanced Measurements …not only Signal Integrity " *- July2009*

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Agenda

- **How to achieve 30 GHz BW and 80 GS/s SR ?**
  - front-end architecture
  - DBI technology
- **Frequency Response Optimization**
  - Flatness
  - Pulse Response
  - Eye Response
- **Time and Frequency Domain Analysis**
  - Advanced FFT and Spectrum Analysis
- **Emulating / De-embedding / Processing**
  - Cable de-embedding
  - Using the S-parameters
  - User-defined custom algorithms

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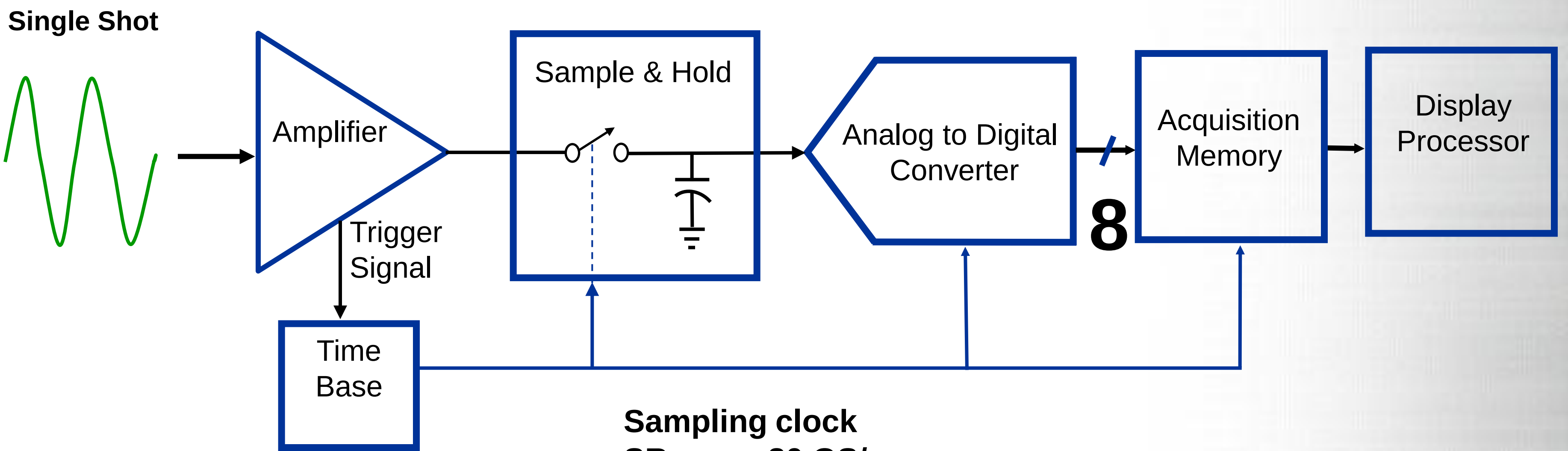
Real-Time Oscilloscopes

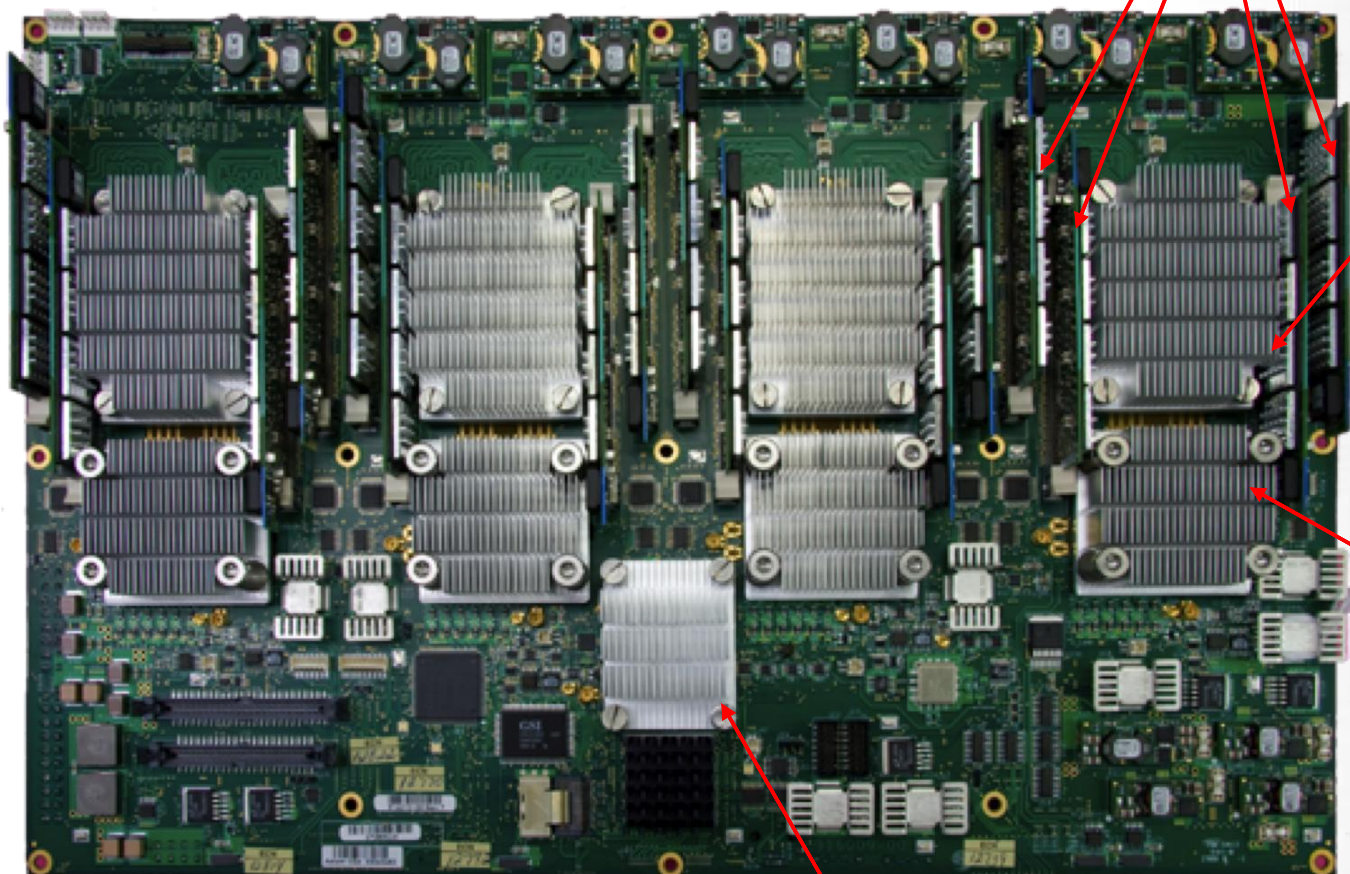
Front-end architecture



Sampling clock
SR max= 80 GS/s

- **High SR allows the acquired waveform samples to represent exactly the signal under test (Nyquist requirement)**
- **Track and Hold and A/D converters cover the entire bandwidth of the scope**
- **Trigger controls the storage of the digitized samples in memory**

WaveMaster 8 Zi Acquisition Board



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Front End Architecture
Sample and Hold

- **“Sample-and-Hold” (MSH) front-end architecture to attain 16GHz Bandwidth**
  - Track and Hold circuits are placed immediately after high bandwidth front end amplifier.
  - ADCs can then digitized the tracked signals
    - MSH simplifies analog routing of high frequency signals
  - 15 GHz Edge Trigger chip
- **Monolithic 40GS/s ADC**

Digital Bandwidth Interleaving

US007058548B2

(12) **United States Patent**
Pupalaikis et al.

(10) **Patent No.: US 7,058,548 B2**
(45) **Date of Patent: Jun. 6, 2006**

(54) **HIGH BANDWIDTH REAL-TIME OSCILLOSCOPE**

(75) Inventors: **Peter J. Pupalaikis**, Ramsey, NJ (US); **David C. Graef**, Campbell Hall, NY (US)

(73) Assignee: **LeCroy Corporation**, Chestnut Ridge, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/693,188**

(22) Filed: **Oct. 24, 2003**

(65) **Prior Publication Data**

US 2004/0128076 A1 Jul. 1, 2004

Related U.S. Application Data

(60) Provisional application No. 60/420,937, filed on Oct. 24, 2002.

(51) **Int. Cl.**
G01R 23/00 (2006.01)

(52) **U.S. Cl.** **702/189**; 702/75; 702/76; 341/155; 341/126

(58) **Field of Classification Search** 702/189, 702/66, 67, 69–71, 73–76, 106, 112, 124, 702/126, 110, 190, 191, 195, 197, 198; 324/76.19, 324/76.22, 76.23, 76.24, 76.28, 76.29, 76.31, 324/76.38, 76.41–76.47; 327/91, 94, 100, 327/107, 129; 341/122, 123, 126, 155; 375/224, 375/225, 316; 708/300, 309, 311; 331/42, 331/43, 30–32, 64, 135; 382/260
See application file for complete search history.

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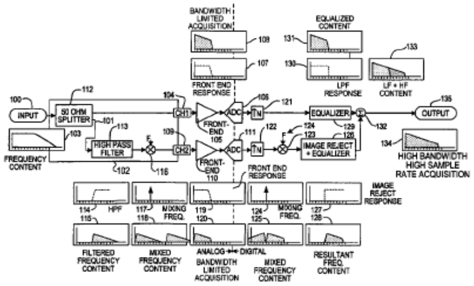
(74) *Attorney, Agent, or Firm*—Frommer Lawrence & Haug LLP; William S. Frommer

(57) **ABSTRACT**

A method and apparatus for digitizing a data signal. An input analog data signal, is received and split into a plurality of split signals. At least one of the split signals is mixed with a predetermined periodic function with a predetermined frequency. The split signals are then digitized and combined mathematically to form a single output data stream that is a substantially correct representation of the original input signal.

28 Claims, 23 Drawing Sheets



"DBI is a technology which combines the resources of multiple channels resulting in a channel with the sum of the individual source channels resources".

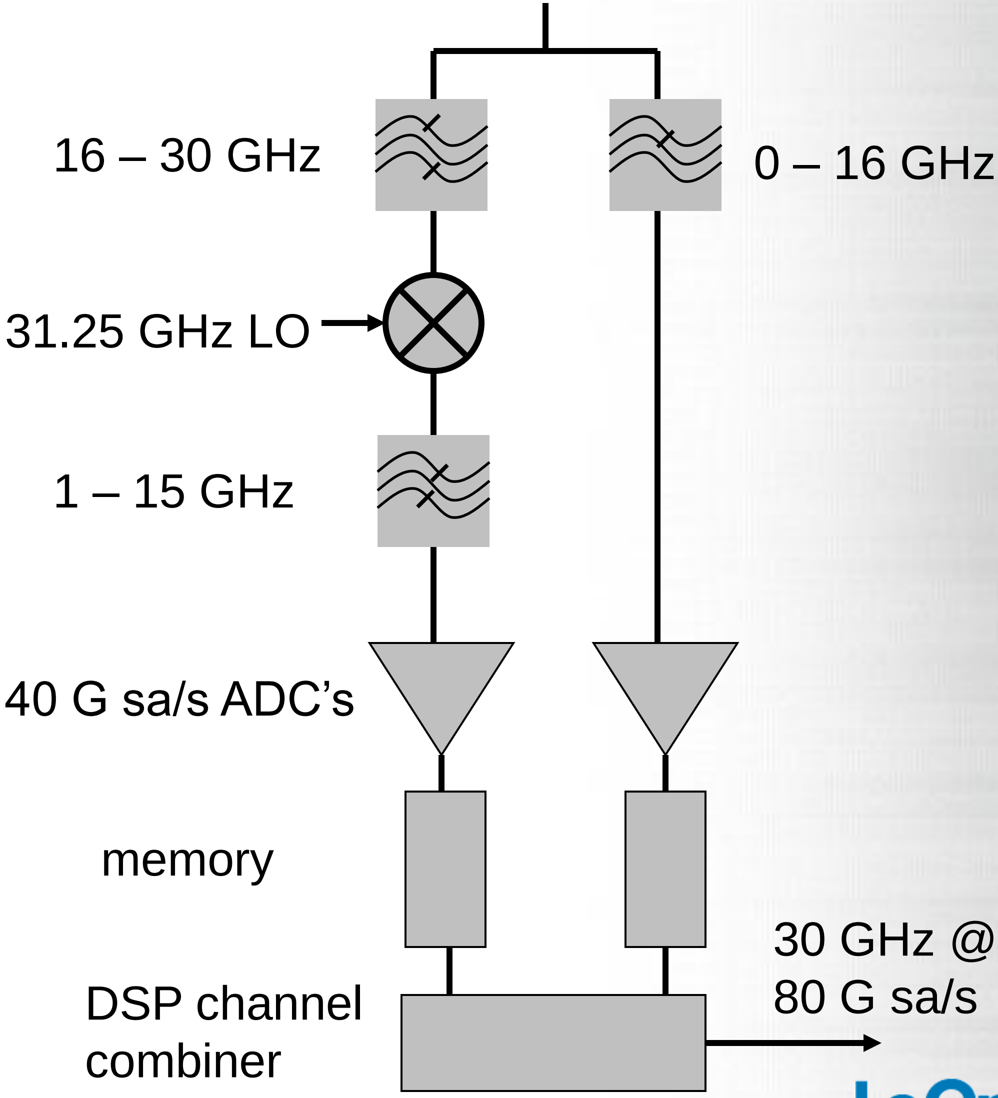
- ✓ **Memory**
- ✓ **Sample Rate**
- ✓ **Bandwidth**

DBI Explained

Bandwidth Interleaving

An innovative method to stay ahead of the BW curve

- Separate signal into frequency bands
- Down-convert high band to low frequency
- Digitize down-converted and low-band simultaneously
- Use DSP to compensate delay, phase and amplitude and combine bands



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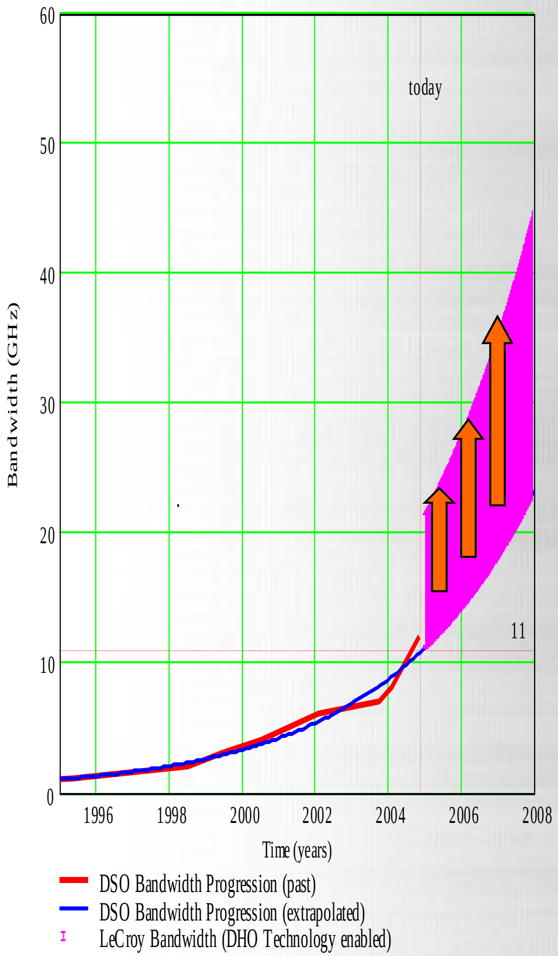
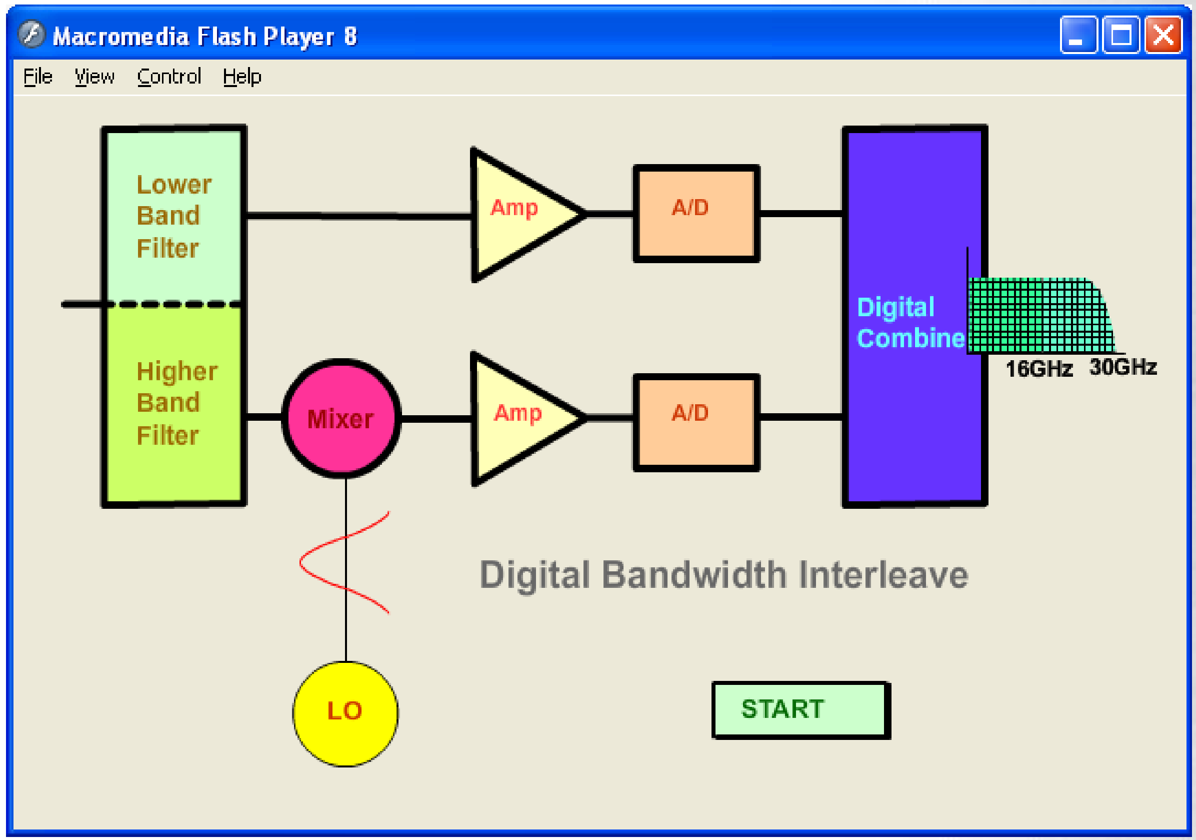
DBI – A Whole New Ballgame

- **Moore's Law:**
  - *Transistors density continues to double every 18 months; the speed of circuit is doubling every three years*.
- **Test Equipment manufacturers use the same technology employed by state of the art devices under test**
- **DBI is a new way to extend the bandwidth and the sample rate of a silicon platform**
- **i.e. …. a step function to the Moore's Law**



Bandwidth Interleaving – Animation

DBI Animation - Click Here



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  - Flatness
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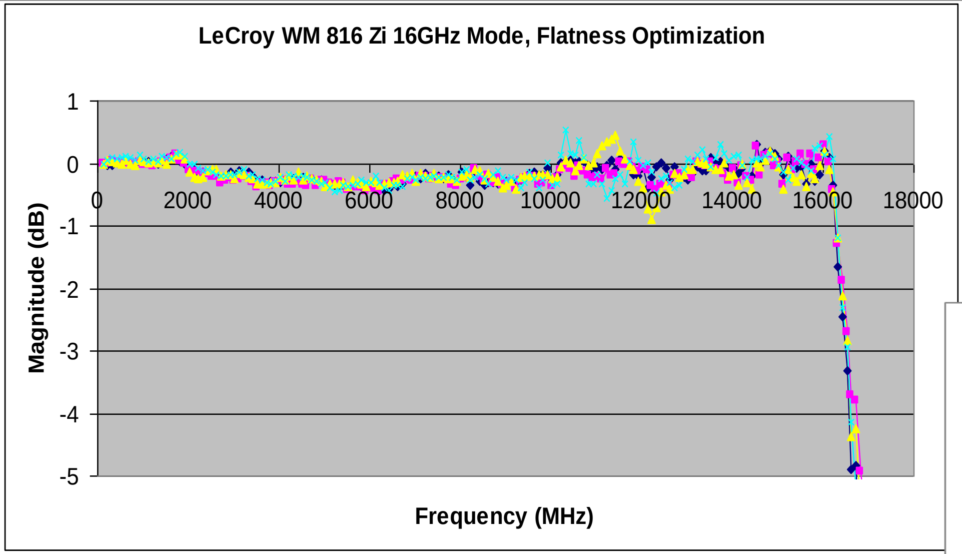
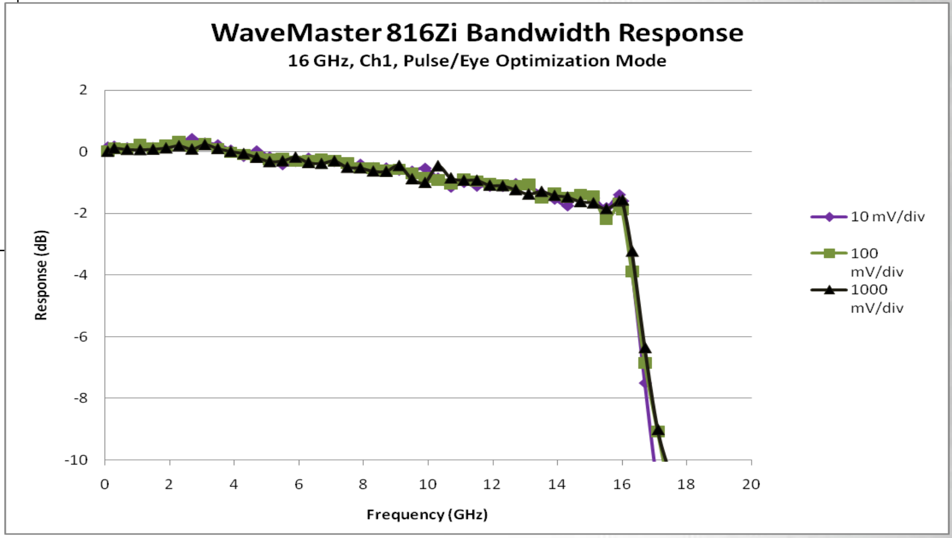
Frequency Response Optimization

LeCroy Real-Time 7 Zi and 8 Zi platforms



Flatness Optimization Mode

Pulse/Eye Optimization Mode



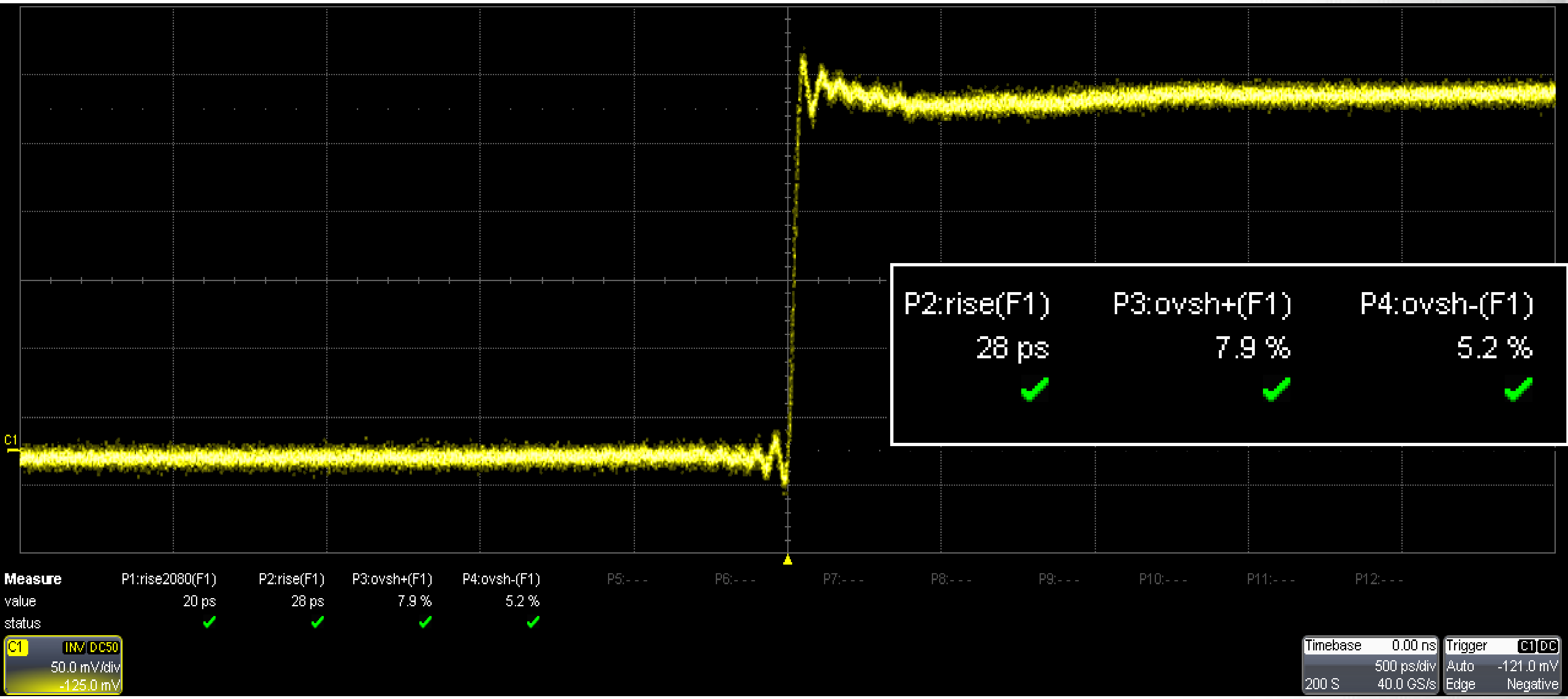
Frequency Response (i.e. Magnitude Response roll-off and Phase Response) influences rise time and the overshoot of the step response in time domain.

A "brick wall" rolloff produces higher overshoot and shorter rise time.
A "slow" rolloff produces less overshoot but longer rise time.

User can optimize frequency response to his application

Optimization Mode	Magnitude Response	Phase Response “Group Delay”	Benefits	Tradeoff	Typical Application
Pulse Response	4^{th} order Bessel-Thompson	Minimum Phase	Closely mimics an analog scope.	Slower edge speed	**General purpose**
Eye Diagram	4^{th} order Bessel-Thompson	Linear Phase	Linear Phase Response reduces overshoot and improves edge speed.	Increased preshoot since preshoot and overshoot are equalized (Doesn’t matter for serial data)	**Serial Data Testing**
Flatness	Brickwall	Linear Phase	Maximum flatness in the pass band.	Increased Overshoot (Doesn’t matter for sine waves or modulation)	**Spectral Analysis**

"Flatness Mode" Optimization



$$\text{Scope Only Risetime} = \sqrt{\text{Measured Risetime}^2 - \text{Input Risetime}^2}$$

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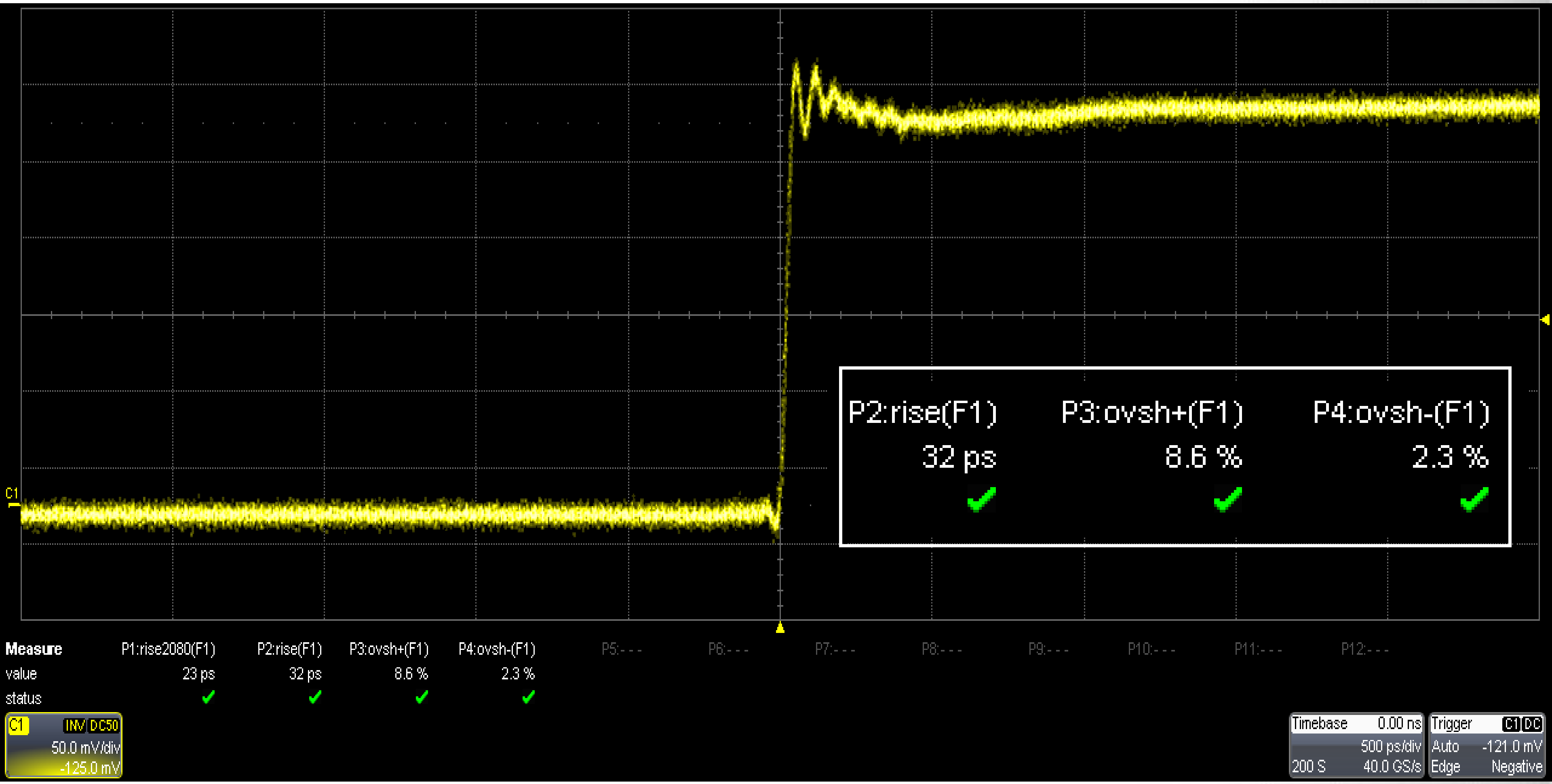
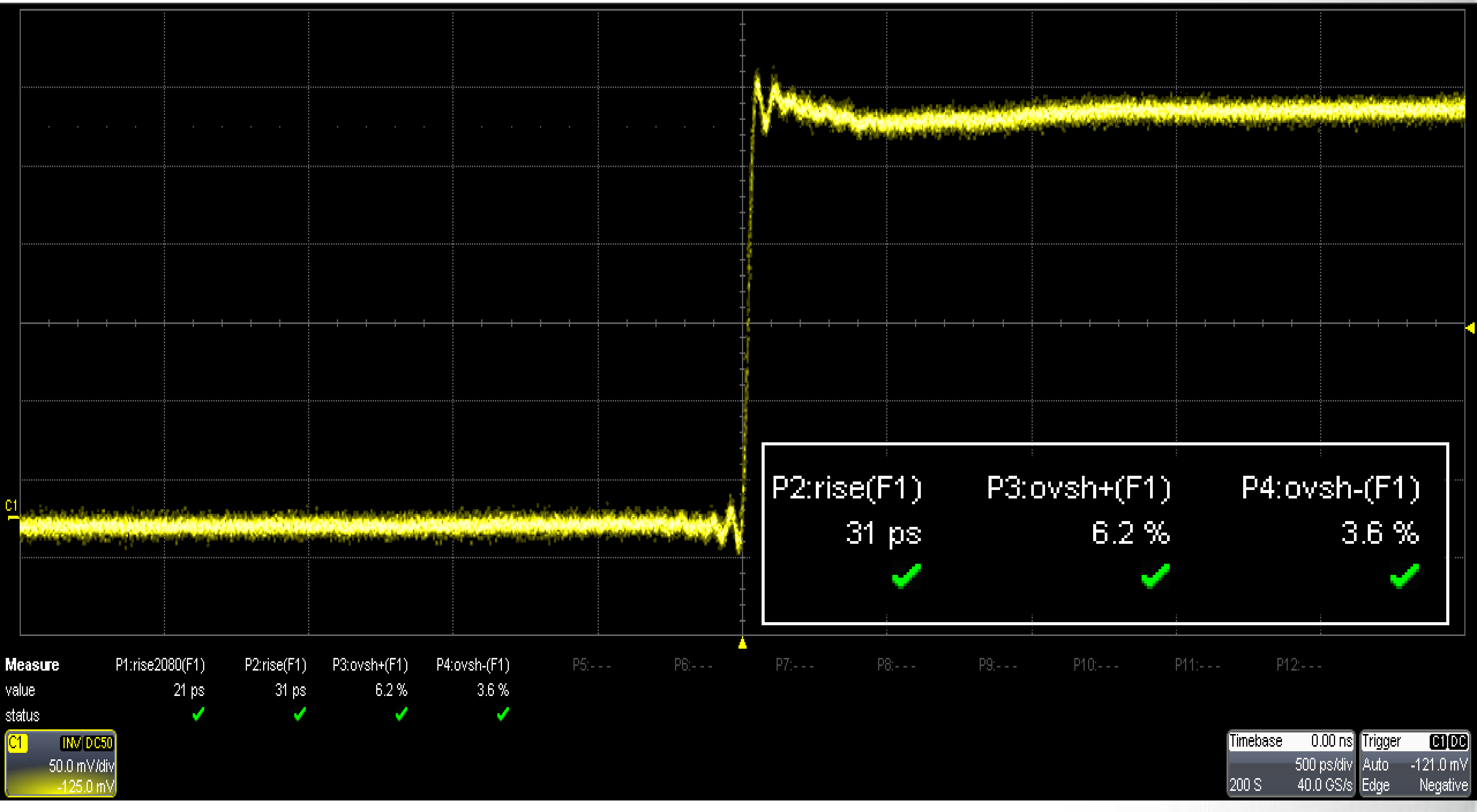
"Pulse Response Mode" Optimization



“Eye Diagram Mode” Optimization



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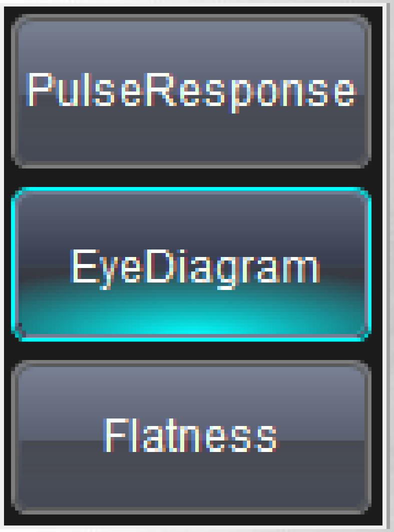
Frequency Response Optimization

Example : Real-Time 16GHz Oscilloscope

	Pulse Response	Eye Diagram	Flatness
Measured Risetime (10%-90%)	29ps	27ps	25ps
Preshoot	2%	6%	8%
Overshoot	13%	6%	8%
Magnitude Response Bandwidth Shape	Bessel	Bessel	Flat
Phase Response	Minimum	Linear	Linear



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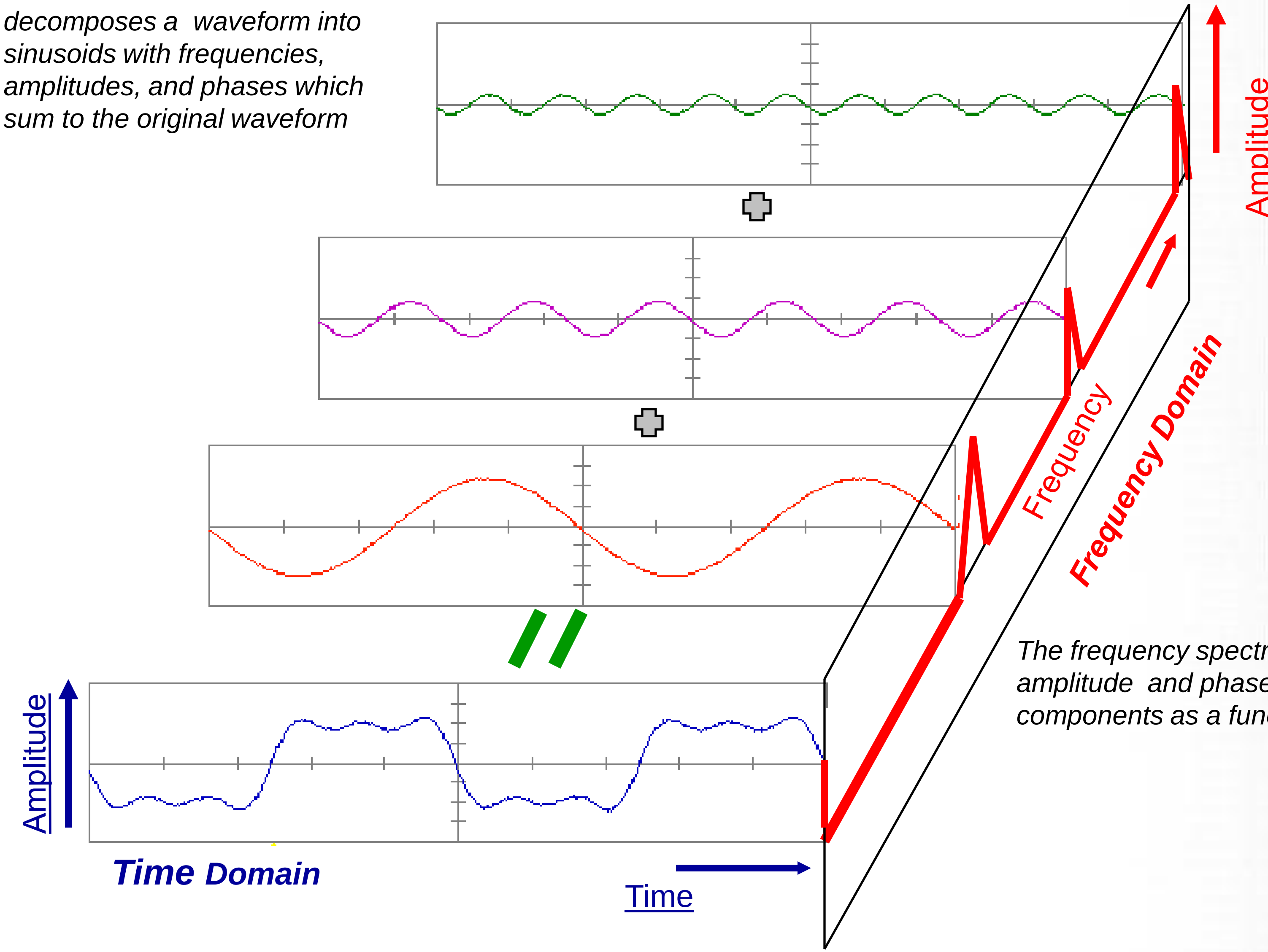
Time and Frequency Domain

FFT Basics

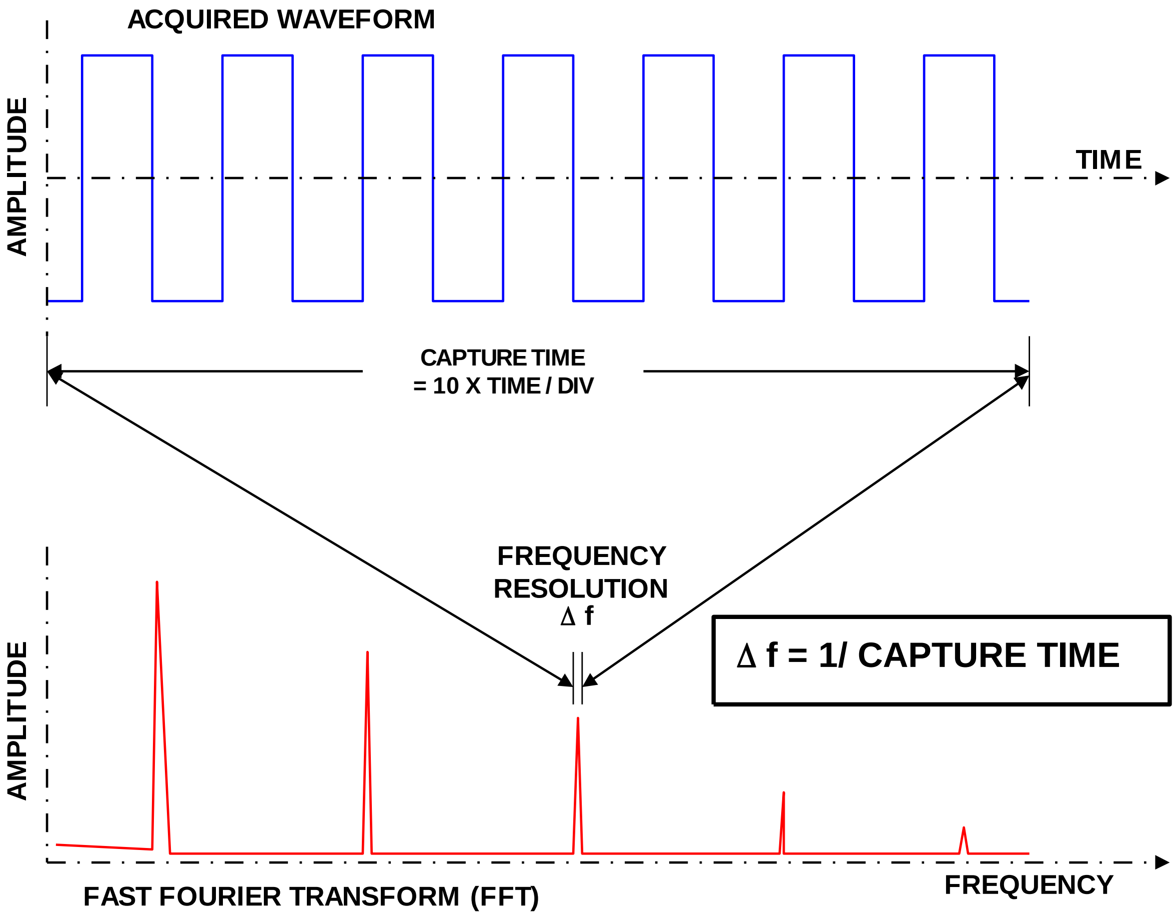
The Fourier transform decomposes a waveform into sinusoids with frequencies, amplitudes, and phases which sum to the original waveform



The frequency spectrum displays the amplitude and phase of the waveform components as a function of frequency

Frequency Resolution, Δf

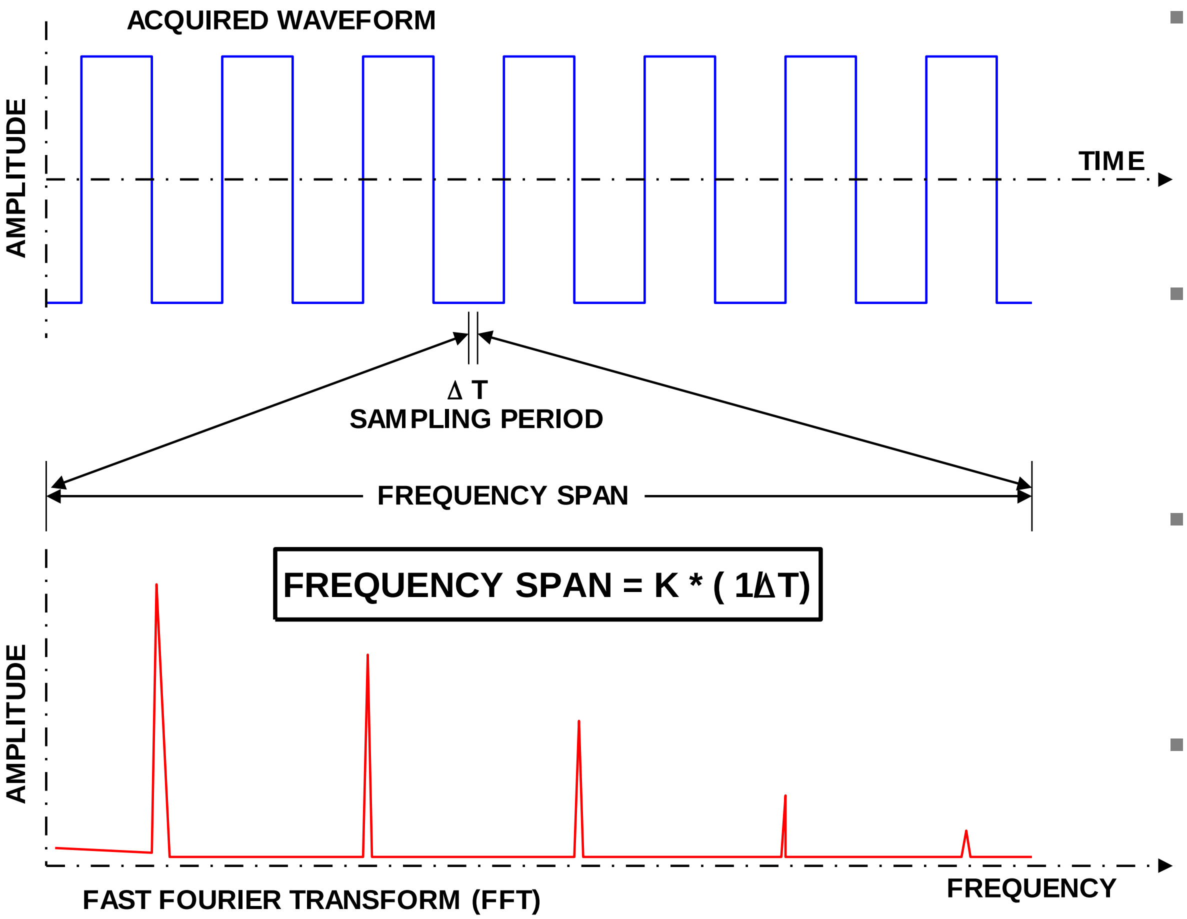
FFT Basics



- **The frequency spectrum of an FFT is quantized with a step size, Δf, defined by the resolution bandwidth**
- **The resolution bandwidth of the FFT is the reciprocal of the capture time**
- **The greater the required frequency resolution (smaller Δf) the longer the record length must be**
- **A resolution bandwidth of 1Hz requires a 1 second record length**

Frequency Span Range

FFT Basics

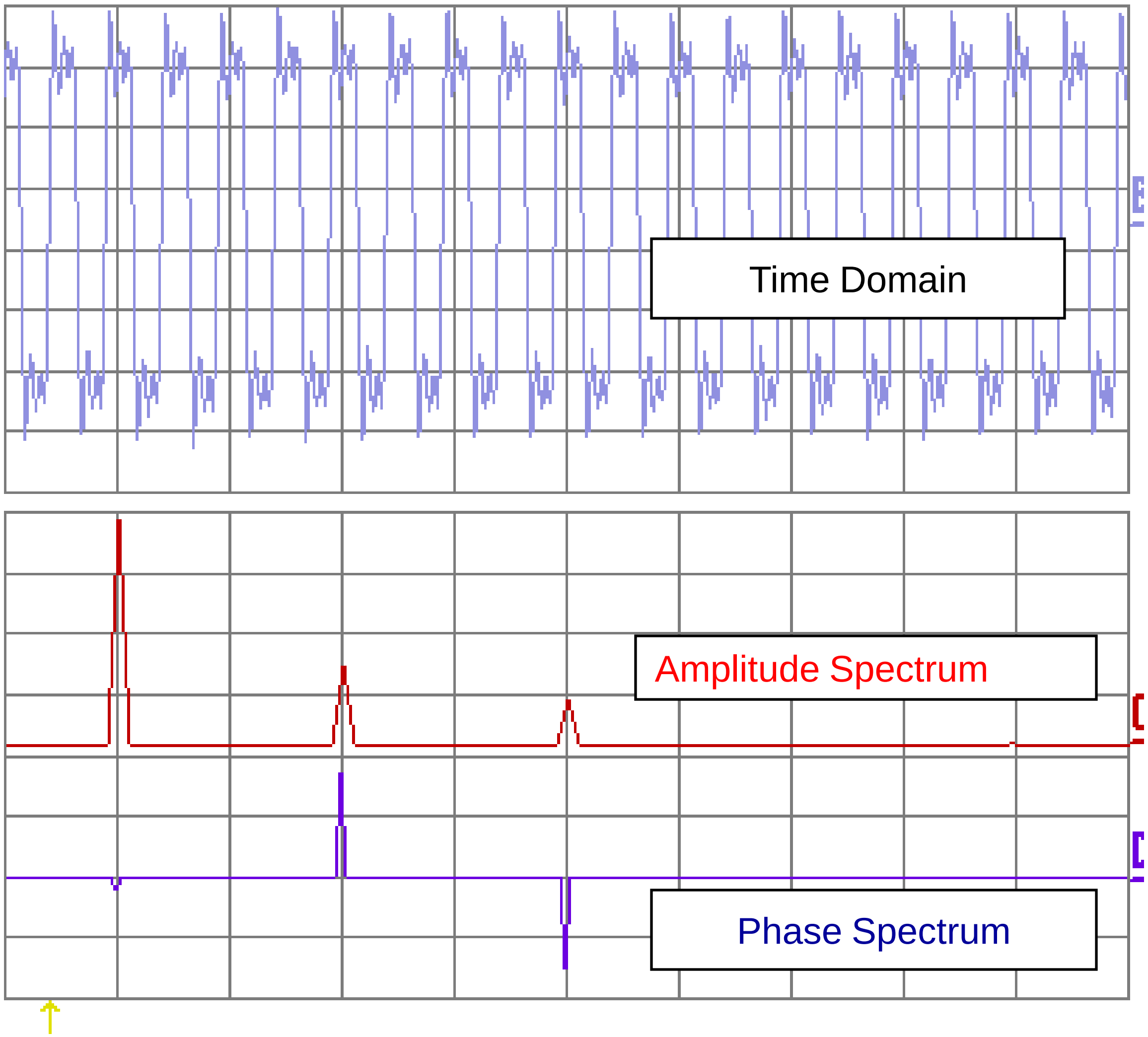


The Frequency Span or Nyquist frequency is proportional to the effective acquisition sampling rate

- **The frequency span, or Nyquist frequency, of the FFT is proportional to 1/2 the effective sampling rate**
- **The effective sampling rate is the acquisition sampling rate**
- **The Sparsing math function can be applied to reduce the FFT span**
- **The effetive sampling rate with sparsing is the acquisition rate divided by the sparsing factor**

Magnitude And Phase Spectra

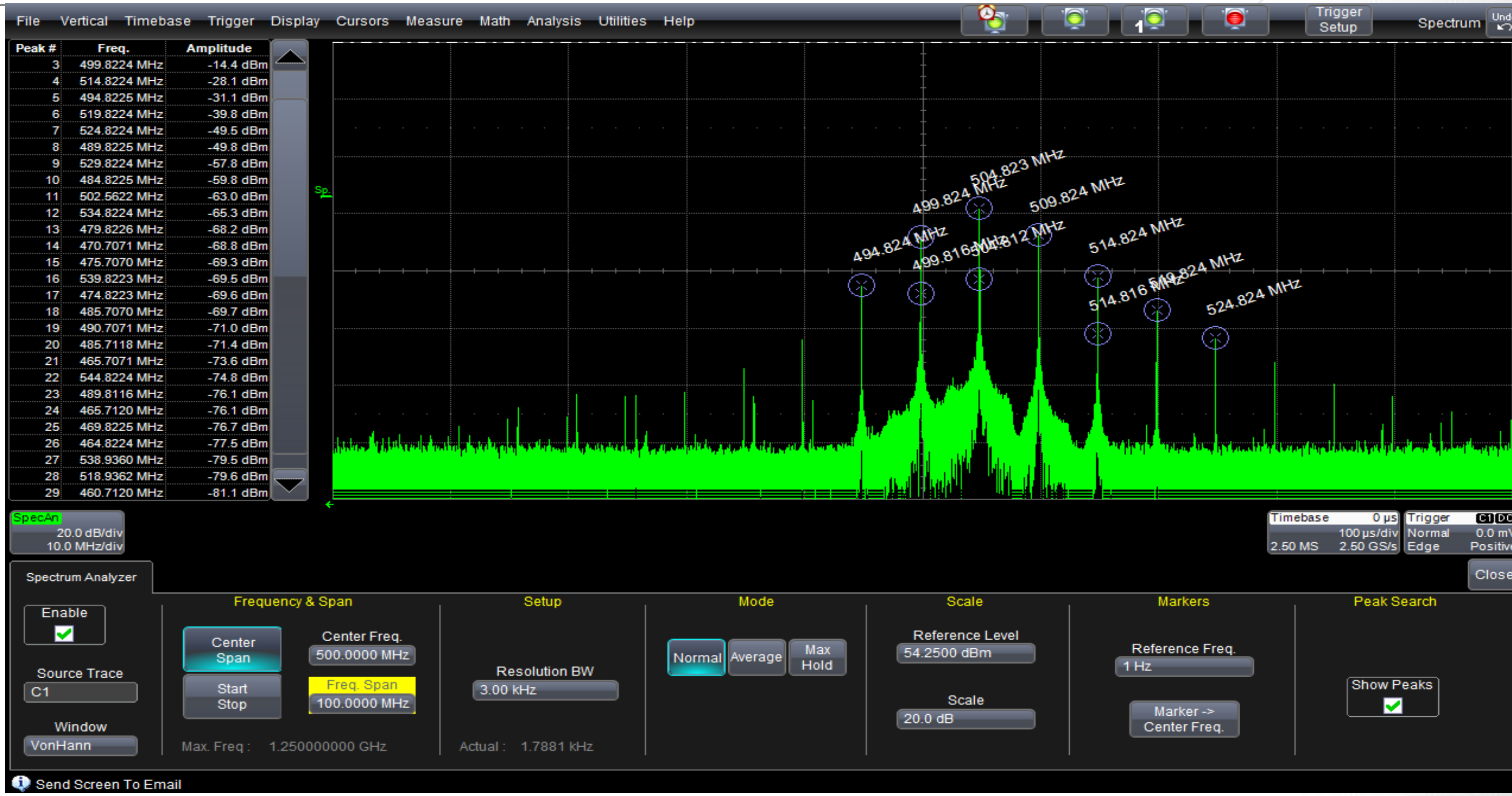
FFT Basics



- The frequency domain output of the Fourier transform is complex
- A complete description must include: Magnitude and Phase
  OR
  Real and Imaginary components
- The magnitude spectrum can be displayed in linear units or units of power
- Vertical scale formats can be linear or logarithmic

SPECTRUM Analyzer Option

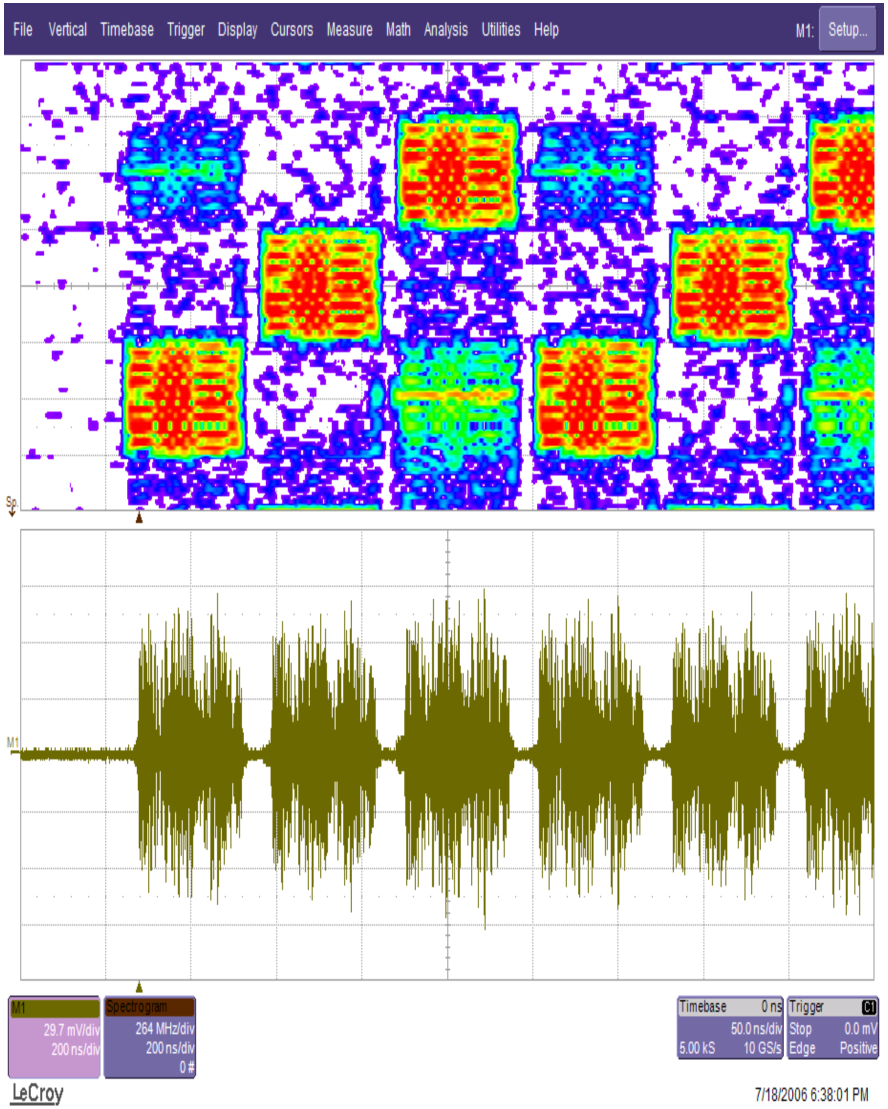
Simplifies Frequency Analysis, Adds Capability

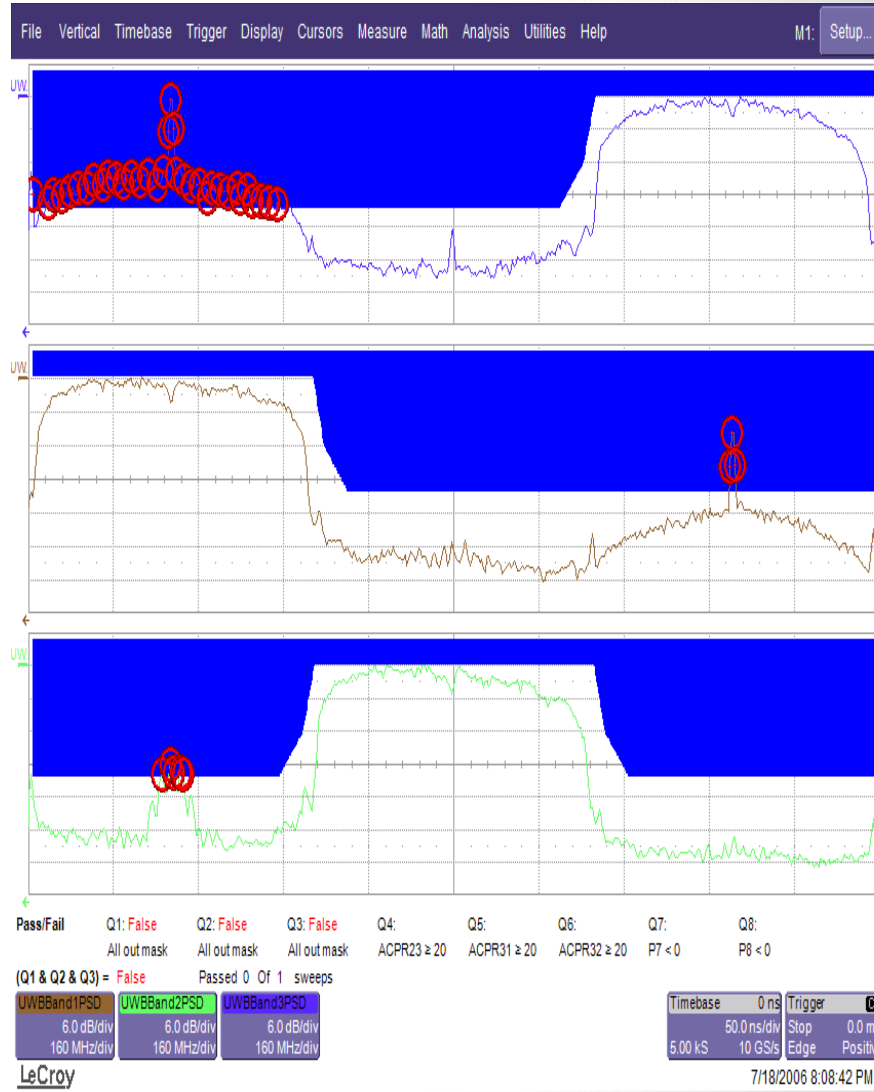


- **Common User Interface as RF Spectrum Analyzer :**
  - Center Frequency, Span, Resolution BW
  - Averaging and Max Hold, Ref level
  - Find Peaks capability

Spectral display with mask test

Example of UWB with TFC 1 packet





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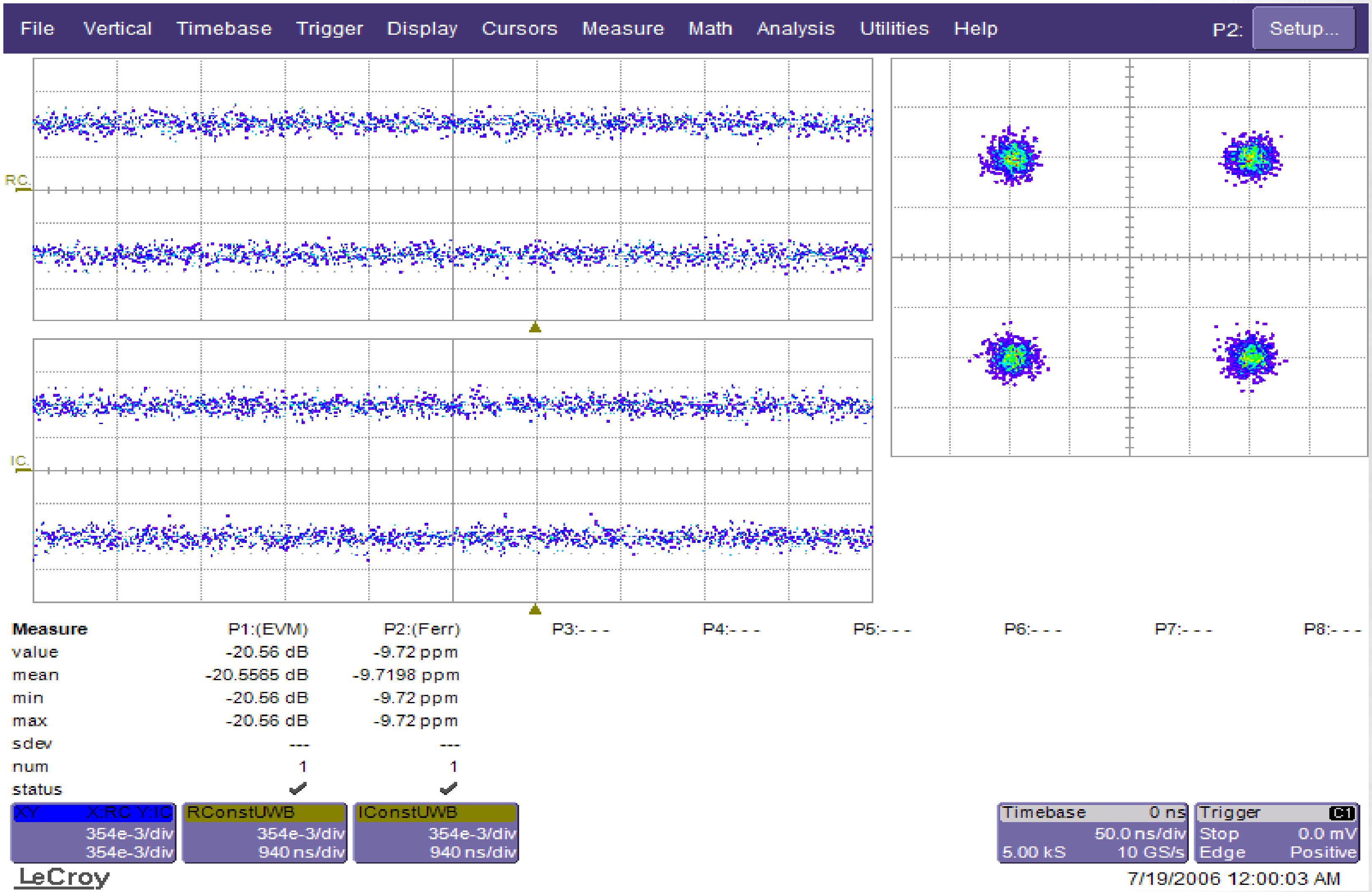
EVM / Constellation display

Example of UWB with TFC 1 packet



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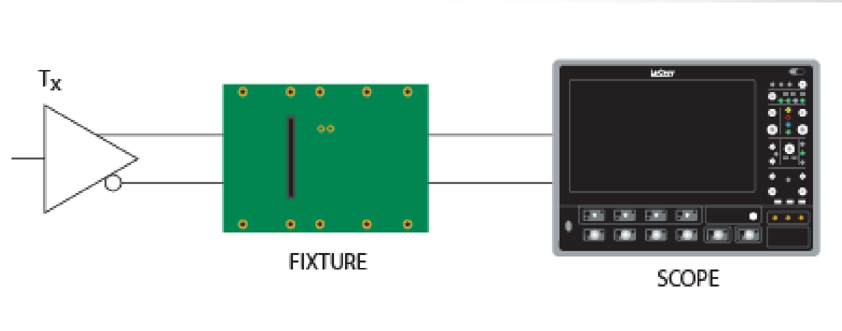
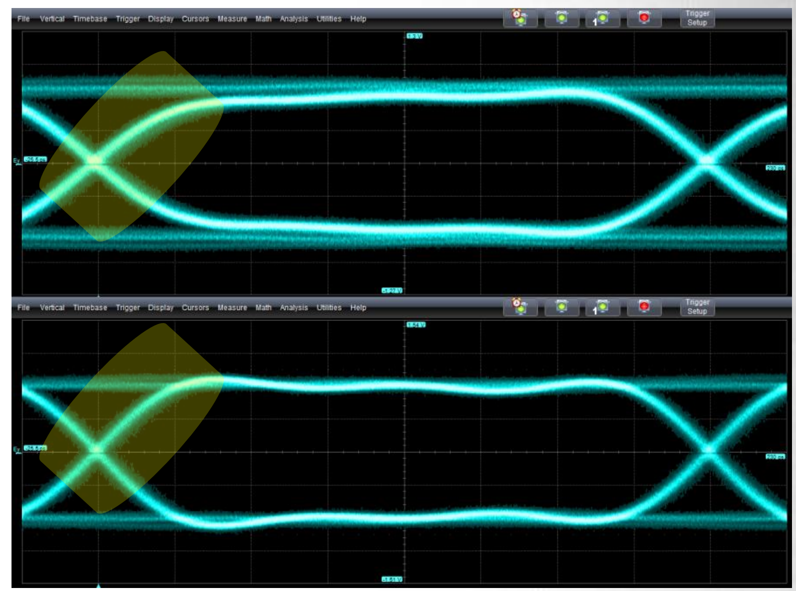
Cable/Fixture/Serial Data Channel
De-embedding

- ✓ ***De-embedding gives the user the ability to view their waveforms as if the cable/fixture/serial data channel was not present.***



- ✓ ***Cable/fixture/serial data channel effect is defined by user-supplied S-parameter file.***

- ✓ ***Should be always done when frequency content is increasing into the microwave range***



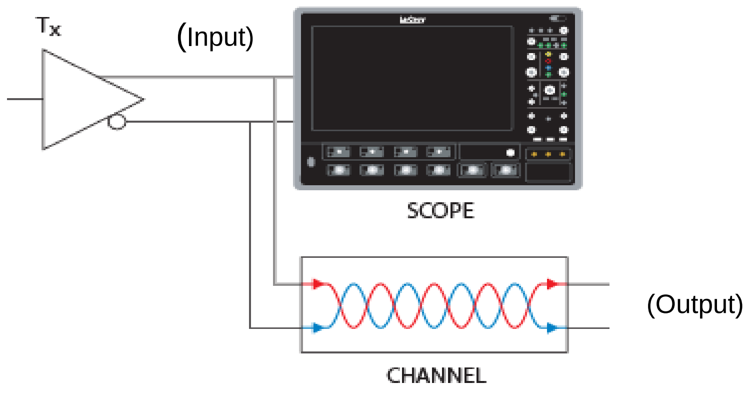
Cables and fixture de-embedding effects on a PCIs Gen 2 signal

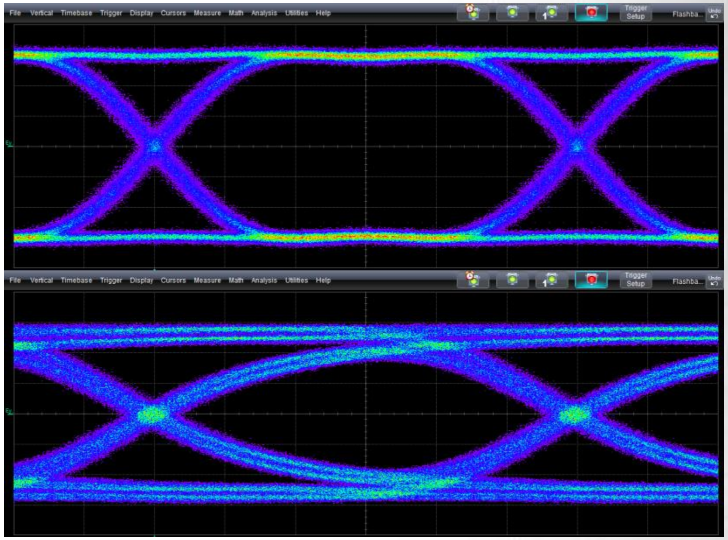
Serial Data Channel Response Emulation

- *Channel emulation gives the user the ability to view their waveform as if it were passing through a serial data channel that isn't present.*

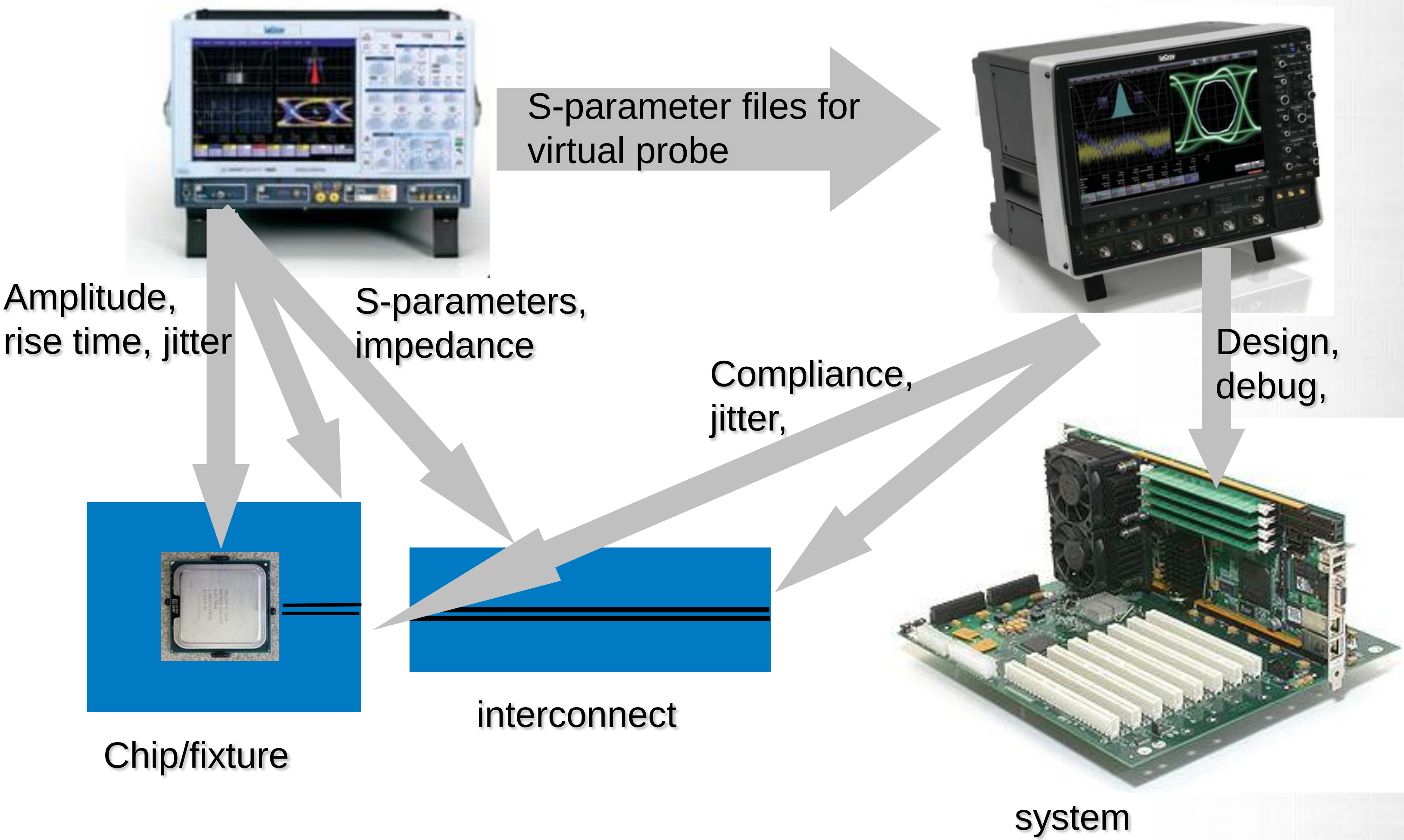
- *The channel effect is defined by a user-supplied s-parameter file.*

- *Useful to model worst-case scenarios and understand how design margins are maintained in those situations*





Sampling and Real-Time good companion
for Signal Integrity Measurements



"Advanced Measurements ....not only Signal Integrity" - From DC to 30Ghz Real-Time Acquisition