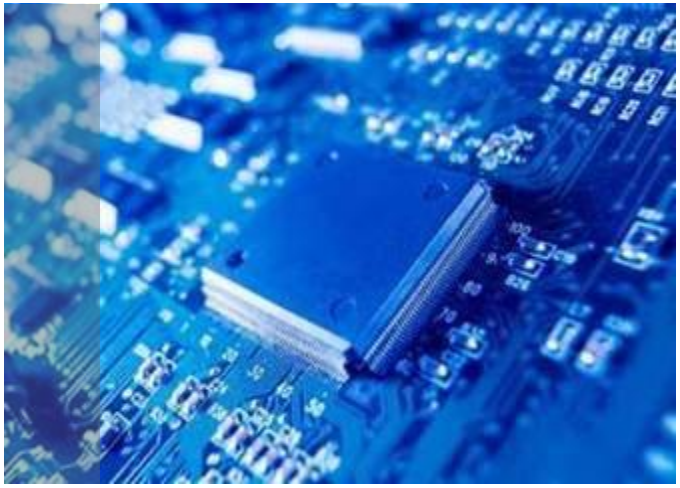
업계 최고의 대역폭/최저 noise 마진의 70GHz real time scope의 ATI 기술 및 응용분야



이기응 이사

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Market Trends

High Speed Communications

- Carriers seeking more network capacity in transceiver design
- Small timing margins leading to new jitter separation methods
- Optical modulation analysis is a design requirement
- Instrument must provide precise low-noise measurements

Wideband RF Technologies

- Meeting demands for more visibility/information
- Deploying wideband chirp technology in advanced radars
- Increase in use of microwave frequencies for communication links
- Instrument must provide wider bandwidth & higher resolution

Emerging Customer Needs

*"…need to move to a **higher bandwidth** for this DP-QPSK project and I need 4 channels of low noise A to D…."*

– *Optical Networks Designer, Telecommunications Mfr.*

*"…my low-level signals are 40-50 mVpp and I need 5 mV vertical resolution measurements with **low noise**…."*

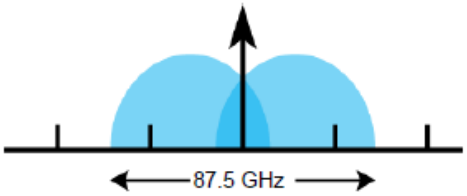
– *Sr. Hardware Engineer, Networking Co.*

Customer Challenges for 400G and Beyond

- As 100G coherent optical systems are being deployed, architecture for 400G systems and beyond are in development
  - No industry consensus on how to build superchannels for 400G
- The T&M system must have the flexibility to support any combination of system parameters

system rate	# of carriers	modulation format
400 Gb/s[1]	2	DP-16QAM
500 Gb/s[2]	5	DP-QPSK
500 Gb/s[3]	10	DP-QPSK
1.0 Tb/s[4]	10	DP-QPSK
1.5 Tb/s[5]	8	DP-16QAM

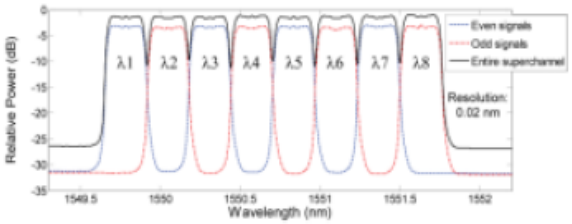
400 Gb/s, 2 carriers



500 Gb/s, 10 carriers

1.0 Tb/s, 10 carriers

1.5 Tb/s, 8 carriers



Sources:
[1] *Beyond 100G, Fujitsu Network Communications, Inc.*
[2] *Dawn of the Terabit Age, Infinera Corporation*
[3] *Coherent Super-Channel Technologies, OSA Webinar, Infinera Corporation*
[4] *Super-Channels: DWDM Transmission at100Gb/s and Beyond, Infinera Corporation*
[5] *1.5-Tb/s Guard-Banded Superchannel Transmission over 56× 100-km (5600-km) ULAF Using 30-Gbaud Pilot-Free OFDM-16QAM Signals with 5.75-b/s/Hz Net Spectral Efficiency, Alcatel-Lucent, Bell Labs*

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The top-to-bottom past 100G standards (Main actors only, not a comprehensive table)

Distance	Standard	Modulation/signaling	e.g.
X,000 km	OIF, OTN, ITU	Complex optical	DP-QPSK
10 to 40 km	Ethernet	New Coherent + Ethernet;silicon ph.	100GBASE-LR4
100 m to 2km	Ethernet	NRZ MM and SM	100GBASE-SR4
10 m	Ethernet	NRZ over cable or el.<->opt. cable	100GBSE-CR4 InfiBand-EDR
Backplane < 1m	Ethernet, OIF CEI	NRZ, PAM4, silicon photonics	100GBASE-KR4, KP4, CEI LR
Interconnect module to chip, chip to chip	OIF CEI Ethernet	NRZ	VSR CAUI4

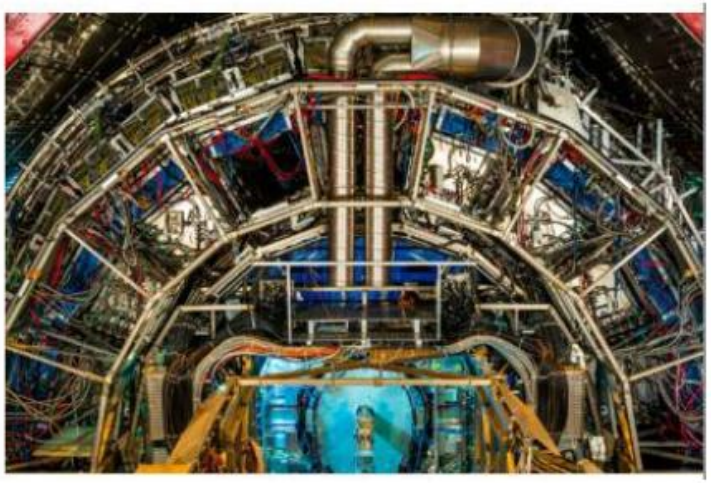
100G across the board

Emerging 100G industry, leverages an assortment of standards and technologies to support the broad set of Submarine -> Continental -> Metro -> Campus -> Data-Center -> Back-Plane -> Chip to Chip requirements.

Data Capture Challenges

Accurate capture of high bandwidth single-shot signals

- Signal Fidelity
  - Low noise, high ENOB
  - Excellent single-shot fidelity needed
  - Minimum channel-to-channel jitter
- Security of data
  - Each experiment can be very expensive; must not lose data
- Small physical size
- Throughput
  - Runtimes can be very long for a single analysis



Customer Needs for Wideband Signal Analysis (>160MHz)

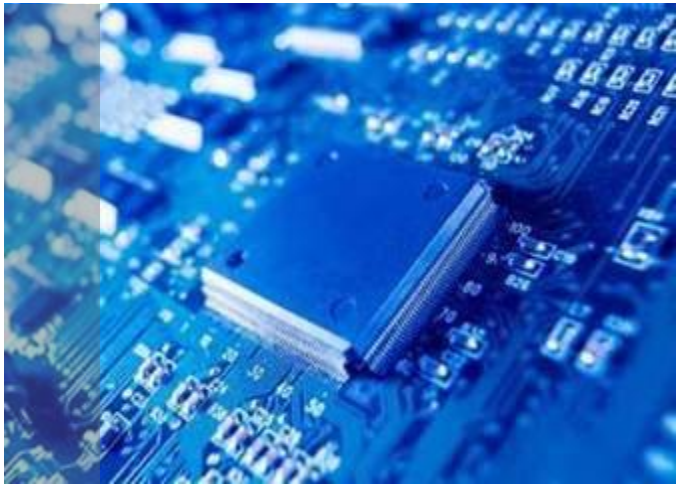
- Radar Target Classification
  - Chirps and phase coding
  - Narrow pulse widths
- Fat Data Pipes
  - Imagery intelligence
  - Data communications
  - Voice
- Frequency Agile Comms
  - Wide band hopping
  - Low probability of intercept
  - Spectrum efficiency
- T&M Challenges
  - Utilize real-time BWs that exceed traditional spectrum analyzer BW
  - Center frequencies extend above X-band (8-12 GHz)

100G/400G Market Conditions

- Current NRZ designs (25GBd) have two options for throughput increase
  - 56 GBd NRZ/400G networking
    - Targeted toward supporting a broad set of reach objectives ranging from die-to-die through to chip-to-chip
  - 28 GBd PAM4, with early discussions of 56 GBd PAM4
    - Extend beyond 100mm channels
  - T&M Challenge
    - Validation and compliance techniques will require low BER measurements to ensure detection of low-probability events/floors

CEI-56G Project	Application	Loss dB	Max Reach mm
Ultra Short Reach USR	Chip-to-OE (within MCM)	not stated	10
Extra Short Reach XSR	Chip-to-OE (Chip-to-PHY)	5 to 10 @ 28G	50
Very Short Reach VSR	Chip-to-Module	10 to 20 @ 28G	100
Medium Reach MR	Chip-to-Chip	15 to 25 @14G	500
Long Reach LR (not a project)	*Backplane (Chip-to-Fabric)*	*25 to 50 @ 14G*	*1000*

Tektronix DPO70000SX Real Time Oscilloscope – Featuring ATI Technology



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Asynchronous Time Interleaving Technology

Path to 70GHz Real Time Bandwidth

- Patented signal acquisition architecture
- Unique method for digitizing full spectrum that maintains signal path symmetry
- Preserves signal-to-noise ratio for higher signal fidelity
- Enables 70GHz bandwidth

Tektronix

Tektronix Real-Time Oscilloscopes to Achieve 70 GHz Performance

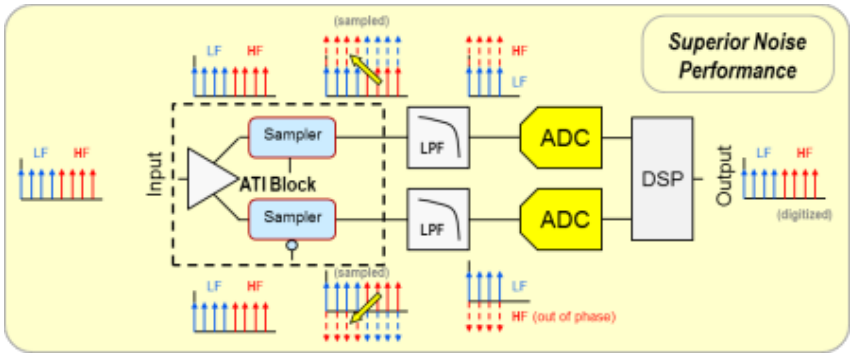
Next Generation Oscilloscopes to Incorporate Breakthrough Low-Noise Architecture for High Speed, High Precision Test Applications

BEAVERTON, Ore., March 19, 2013 – Tektronix, Inc., the world's leading manufacturer of oscilloscopes, today announced that lab testing has shown that its next generation performance oscilloscopes – due for availability in 2014 – will deliver real-time bandwidth of 70 GHz, with significant upside potential. The new oscilloscope platform will deliver the performance and signal fidelity needed for applications such as 400 Gbps and 1 Tbps optical communications and fourth generation serial data communications. Tektronix also announced an investment program that will give customers a cost-effective migration path to the new platform.

The extraordinary gain in bandwidth performance, with improved signal fidelity, is due in part to the development by Tektronix engineers of a patent pending signal processing architecture called Asynchronous Time Interleaving. The new real-time oscilloscope platform will also include a number of other enhancements and refinements to improve overall performance and measurement precision.

"With these latest innovations, Tektronix is continuing to push the envelope on what can be achieved in high-fidelity, high-speed data acquisition systems," said Kevin Ilcisin, chief technology officer, Tektronix. "The development of the industry's first production-ready Asynchronous Time Interleaving architecture is a significant breakthrough that will improve signal-to-noise ratio beyond the frequency interleaving approach used by competing oscilloscope vendors."

Tektronix ATI Technology



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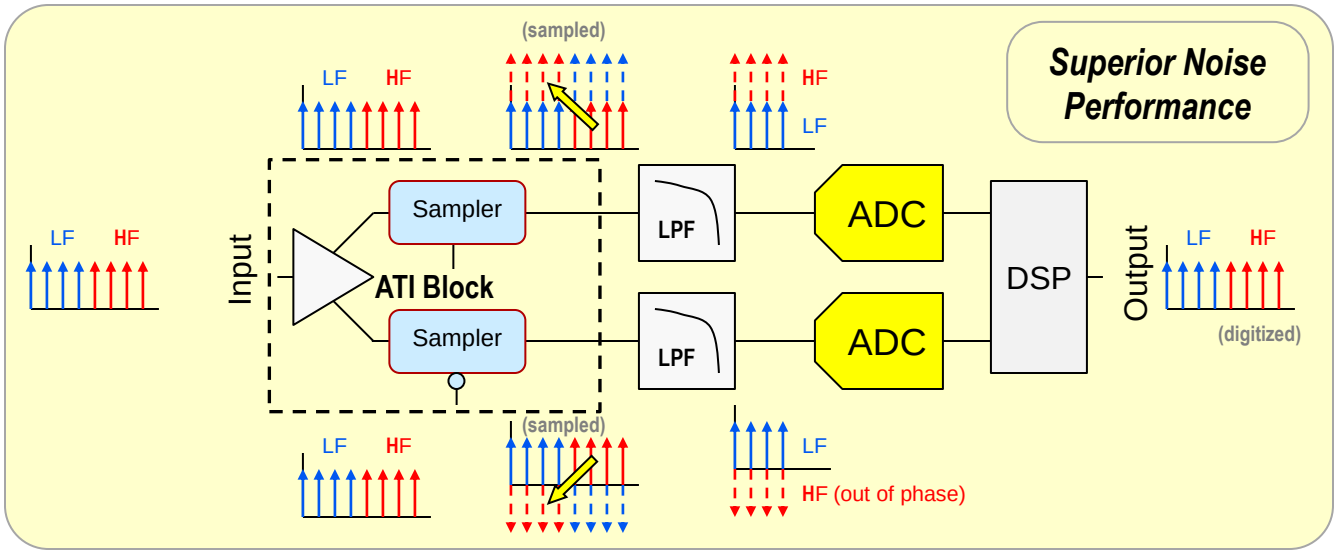
Comparing Methods: Tek Advantage

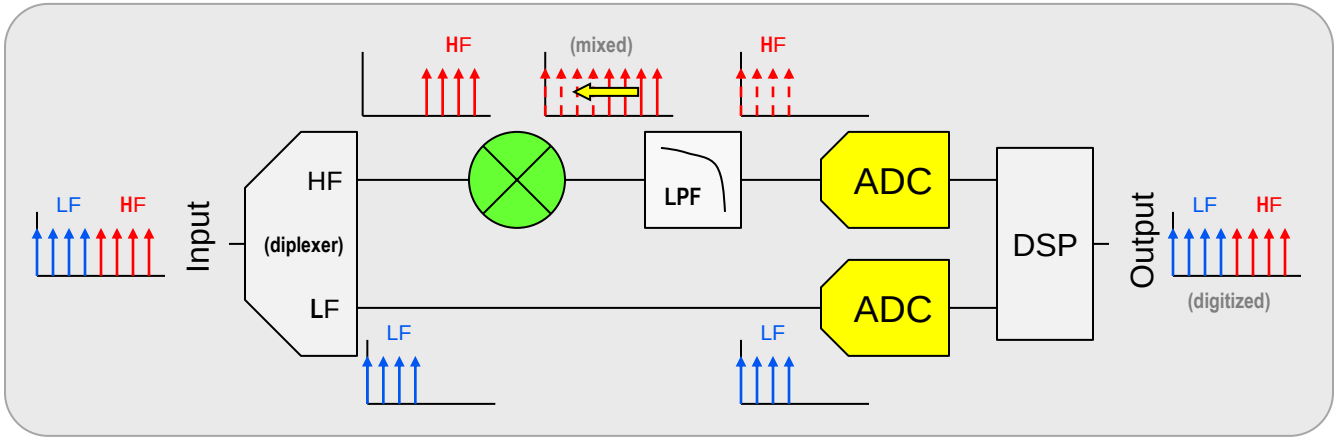
Superior Noise Performance for High-Bandwidth Data Converters

Tektronix Architectural Innovation



- ✓ **Improved SNR**
  - Each ADC sees full spectrum
  - **Signal reconstruction involves *averaging* → improves SNR**
- ✓ **Signal-path symmetry**
- ✓ **Patented architecture**

Legacy Frequency Interleaving



- Each ADC sees **half** spectrum
- **Signal reconstruction involves *summation* → no improvement in SNR**

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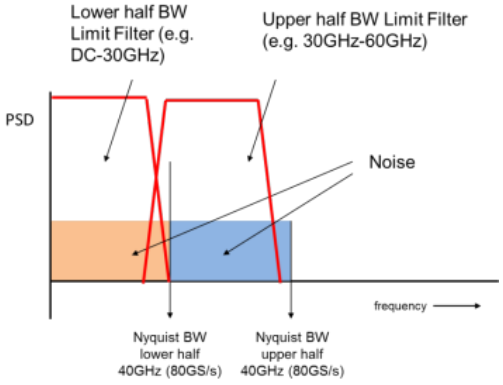
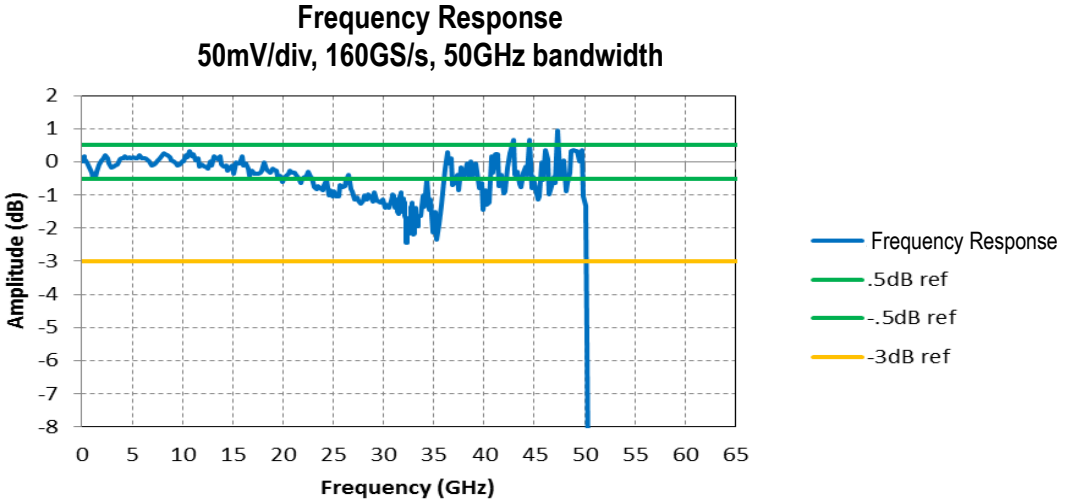
Legacy Frequency-Interleaved Channels

- "Stitching" via DSP is complicated. Due to path differences, compensation must occur adding to complexity.
- Recovery of the exact center of spectrum, the lower- and higher-band overlap, is problematic.

Legacy frequency interleaving suffers a bandwidth dip. This mid-band dip is greater than 2dB low, which means that measurements made in this region will be reported as 20% or more lower than the real signal amplitude.





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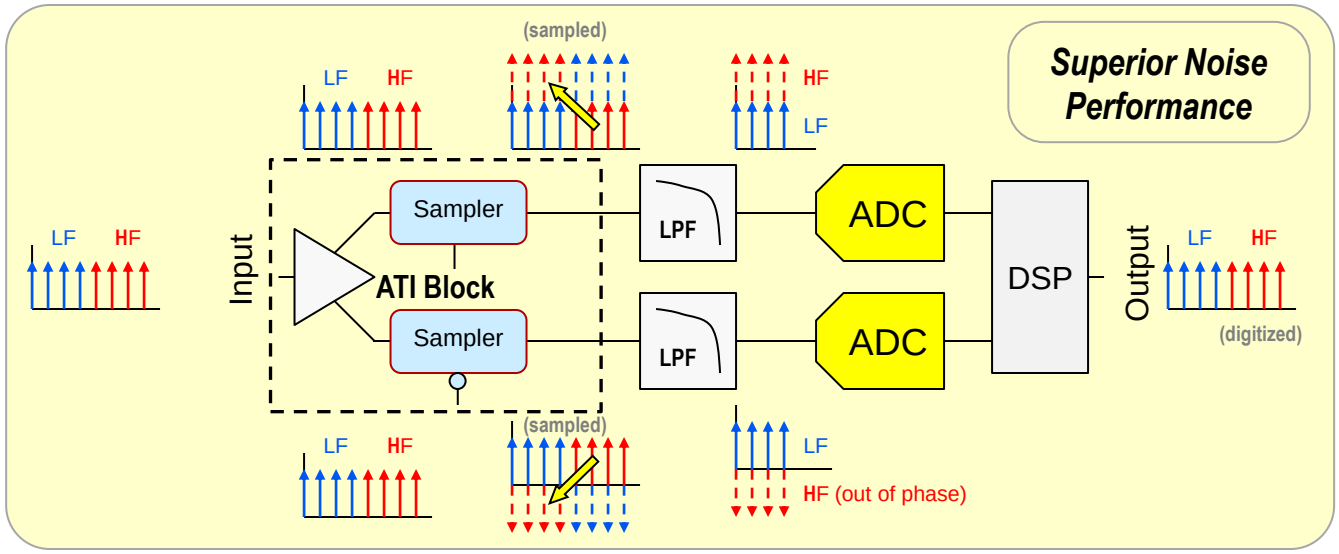
Asynchronous Time Interleaving (ATI)

Tektronix Architectural Innovation



- ✓ **Improved SNR**
  - Each ADC sees full spectrum
  - **Signal reconstruction involves *averaging* → improves SNR**
- ✓ **Signal-path symmetry**
- ✓ **Patented architecture**

- Entire signal sent through two paths
- Samplers fold High Frequencies onto Low Frequencies
  - One Sampler 0° phase, another Sampler 180° phase
- Both signals routed to individual ADC
- Both copies of signal "unfolded" by DSP to reveal entire signal content
- Copies added together, then divided by 2 for reconstruction

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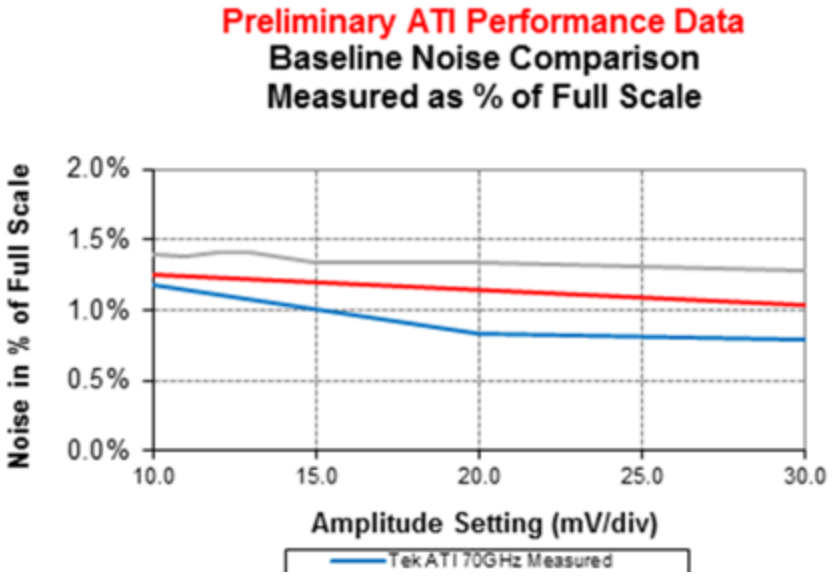
70GHz ATI Preliminary Baseline Noise

- Current data indicates that our noise will be substantially lower, even when comparing to our wider bandwidth!
- Final performance will depend on final calibration



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Introducing 70GHz ATI Real Time Oscilloscope

- New Ultra-High Performance 70GHz Asynchronous Time Interleaving (ATI) Architecture
- New Compact Oscilloscope package
- New UltraSync high performance multi-instrument synchronization bus

Lowest Noise. Highest Fidelity. Maximum Performance.

Tektronix

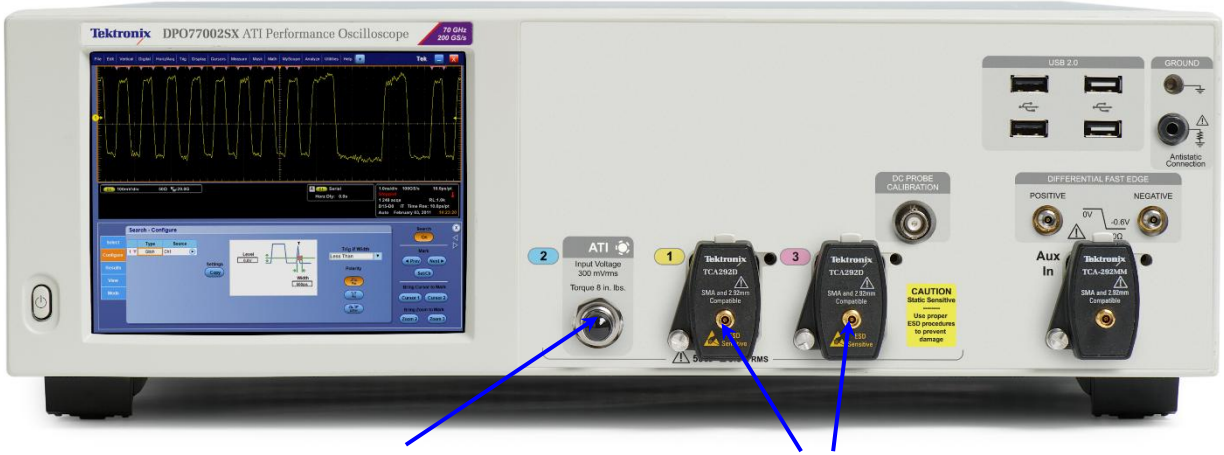
ATI Performance Oscilloscope

- 70GHz Analog Bandwidth, 4.3ps rise time (20%-80%)
- 200GS/s Sample Rate
- <125fs jitter noise floor
- ≥25GHz Edge trigger bandwidth
- Compact 5 ¼" Oscilloscope package

✓ Low-noise ATI architecture

✓ Best-in-class signal capture

✓ Compact package with precise multi-unit sync



- 1 channel x 70GHz bandwidth
- Single-ended, 100mV$_{fsr}$ to 300mV$_{fsr}$
- 200GS/s sample rate
- Up to 1 Gsamples record length

[OR]

- 2 channels x 33GHz bandwidth
- Single-ended, 62.5mV$_{fsr}$ to 6V$_{fsr}$
- 100GS/s sample rate per channel
- Up to 1 Gsamples record per channel

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Key Applications

Optical Modulation Analysis for Long Haul Networks

- 400GBaud requiring faster oscilloscopes
  - Including the ability to synchronize multiple high-performance oscilloscopes

Fundamental Research Applications

- Need accurate capture of high bandwidth single-shot signals

Wideband Radar, Advanced Communications

- Ka band (40GHz) and V band (70GHz) test & validation needed that spectrum analyzers can't support

High-Speed Datacom

- Move to 56Gb is coming, time to validate silicon and system modules

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100G (DataComm Industry) Portfolio and Core financial contributors

STD/Year	Module Interconnect	LAN Side	Per/Lane data rate	Instrumentation	ENOB/SNR	ENOB/JNF	SIGGEN/JNF
2007	--na--	802.3ap : (10G KR/CR, 40G KR4)	10Gbps	BW: 20 GHz	4.4		680fs
2008	XLAUI	802.3bg : (40G FR)	40Gbps	BW: 44 GHz ORR	5.2		?
2009	CEI 3.0 (2M/yr)	802.3ba : (100G LR4/ER4)	25.78Gbps	BW: 44 GHz	4.9	5.2	360fs
2014	KR4 (6M/yr)	802.3bj : (100G KR4/CR4/KP4)	25.78Gpbs	BW: 33 GHz	4.9	5.86	387fs:Pre
2015	CAUI4 (4M/yr)	802.3bm: (100G SR4) (10M/yr)	25.78Gbps	BW: 33 GHz ORR	5.1	5.86	380fs:Pre|410fs:Opt
2016	CEI 3.1 (PAM) (7M/yr)	802.3bs : (400G LR8) (15M/yr)	56Gbps	BW: 40GHz/66 GHz	6.74	6.98	200fs:Pre

		Characterization	Validation/ System	Debug
DataComm (Electrical)	100GbE NRZ/PAM4	DSA8300 + 80E10B + CR286A + PPG3202	DSA8300 + CR286A + PPG3202 -or- DPO77002SX/ MSO73304DX	DPO77002SX/ MSO73304DX
	400GbE NRZ/PAM4	DSA8300 + 80E10B + CR286A + PPG3202	DSA8300 + CR286A + PPG3202 -or- DPO77002SX	DPO77002SX
DataComm (Optical) < 40KM	100GbE NRZ/PAM4	DSA8300 + 80C10/15 + CR286A + PPG3202	DSA8300 + 80C10/15+ CR286A + PPG3202 –or- MSO73304DX	DSA8300 + 80C10/15+ CR286A + PPG3202 –or- MSO73304DX
	400GbE PAM4	DSA8300 + 80C10/15 + CR286A + PPG3202	DSA8300 + 80C10/15+ CR286A + PPG3202 –or- MSO73304DX	DSA8300 + 80C10/15+ CR286A + PPG3202 –or- MSO73304DX
Coherent: Inter-City Submarine/ Terrestrial Long-Haul	100G DP-QPSK	4x DPO77002SX	4/2x DPO77002SX	2x DPO77002SX
	200G DP-16QAM	4x DPO77002SX	4/2x DPO77002SX	2x DPO77002SX
	400G 2XDP-16QAM	4x DPO77002SX	4/2x DPO77002SX	2x DPO77002SX

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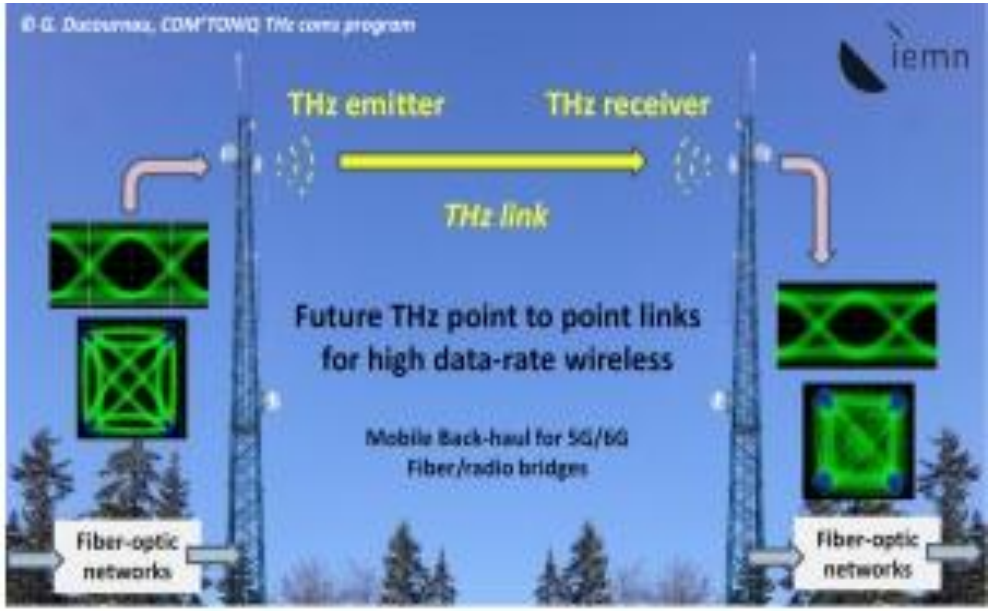
World's Fastest Wireless to Optical Bridge



including Tektronix
1)AWG70001A 50Gs/S waveform generator,
2)OM5110 46Gbaud muli-format complex optical transmitter
3) DPO77002SX ATI 70GHz real time oscilloscope

- Tektronix, IEMN Collaborate to Demonstrate World's Fastest Wireless to Optical Bridge

- The world's first demonstration of a world record breaking wireless system capable of transmitting data at 400 GHz (0.4 THz) using advanced signal coding (up to QAM-16) and key advanced THz devices

- The demonstration involved sending 32 Gbit/s signals over distances of 25 m and will provide the basis for future THz communications applications

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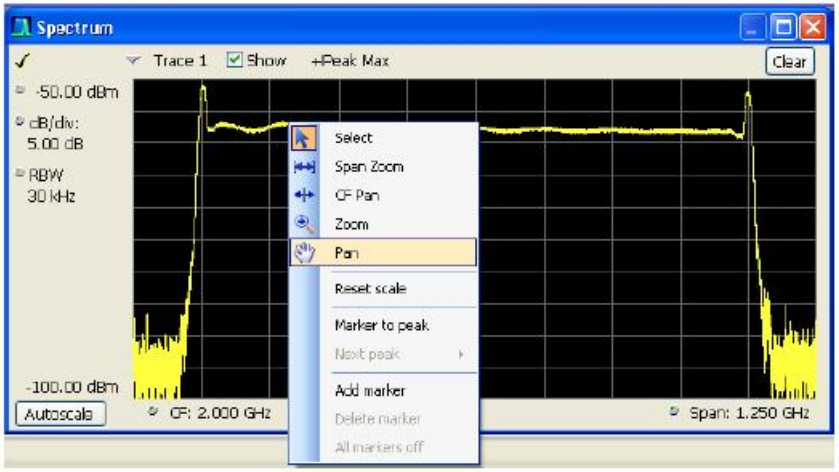
SignalVu & DPO70000SX - Integrating the Best of Both Worlds

- **Industry's most powerful scope for RF applications**
  - 70 GHz analog BW
  - Sophisticated triggering
  - Deep memory
  - Signal processing (Math)

- **Industry's most powerful user interface for RF measurements**
  - Time Overview
  - Drag & Drop Measurements
  - Pan & Zoom
  - Correlated markers (frequency, phase and time domains)
  - Automated pulse measurements
  - FastFrame segmented memory

SignalVu Powerful User Interface



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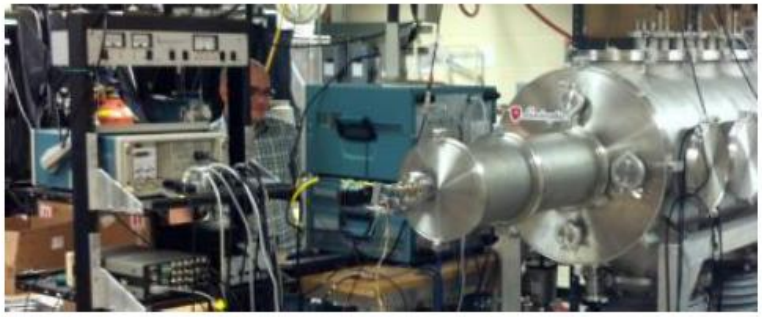
Fundamental Research Applications

- Extremely precise acquisition system
  - Most accurate capture of ultra-high bandwidth signals
  - Fast trigger for narrow pulse-width capture

- Compact, scalable for high channel count data
  - Higher channel count in less rack space
  - Flexible configurations that increase channel count
  - Removable SSD for data security
  - UltraSync architecture ensures precise multi-unit timing
  - Distributed processing enables faster data results



Instrument Size Comparison – Compact and Bench Models

- Efficient rack-space for higher channel count
- Flexible location
  - Near DUT for shorter cables to preserve signal fidelity
  - Position monitor/mouse for convenient operation

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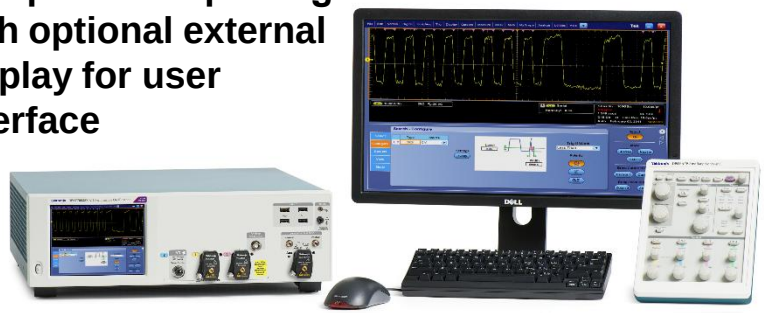
Scalable Performance

- Compact instrument for increased configuration flexibility
- UltraSync high performance synchronization for multi-unit configurations
- Design goal <500fs$_{RMS}$ channel-to-channel jitter

Compact 5 ¼" package with optional external display for user interface



Additional performance using multiple units

Configuration flexibility with precisely-synchronized timing

UltraSync High Performance Synchronization & Control bus

- **12.5 GHz Sample Clock Reference**
- **Coordinated Trigger, <500fs rms ch-to-ch jitter**
- **High speed data path**

UltraSync Multi-unit Synchronization

- Sample clock synchronization
  - 12.5 GHz sample clock
- Trigger bus
  - Channel-to-channel jitter <500fs$_{RMS}$
- Control & Data Bus
  - UI, PI, DataStore in Master
  - PCIe Gen 2 x 4 lanes
  - Data processed in each Extension, aggregated in Master
- Configuration Manager software assists in correct connection
- Two cable lengths
  - LPO7USYNC1M – 1 meter UltraSync cable
  - LPO7USYNC2M – 2 meter UltraSync cable

Multi-unit configurations

- UltraSync High Performance Synchronization & Control Bus

“Master”

- **12.5 GHz Sample Clock Reference**
- **Coordinated Trigger, <500fs rms ch-to-ch jitter**
- **High speed data path**

“Extension”

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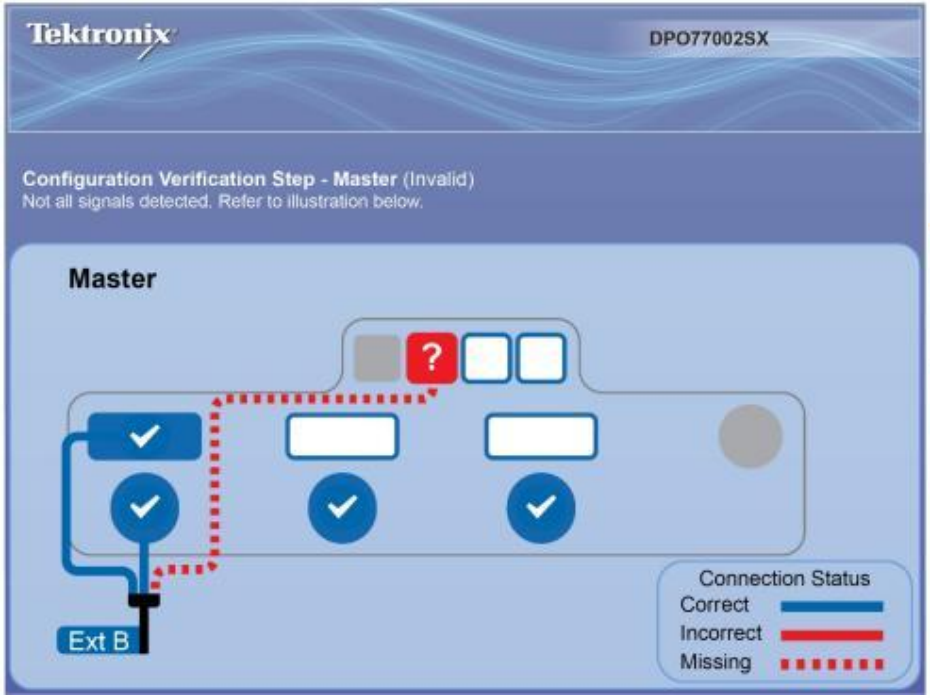
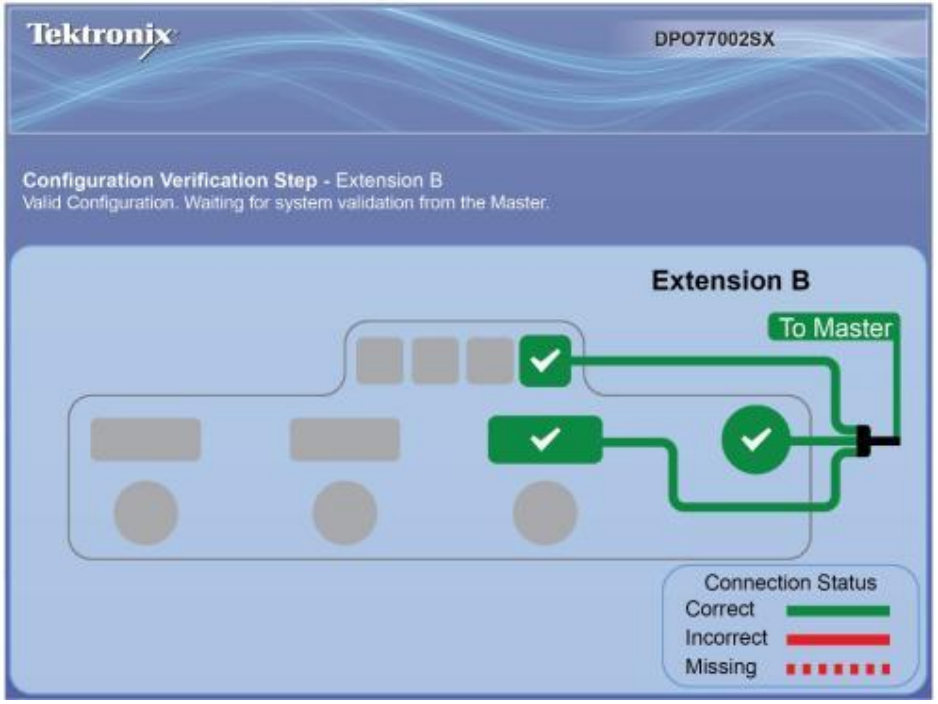
Configuration Manager

- Manages multi-unit startup, verifies UltraSync connections





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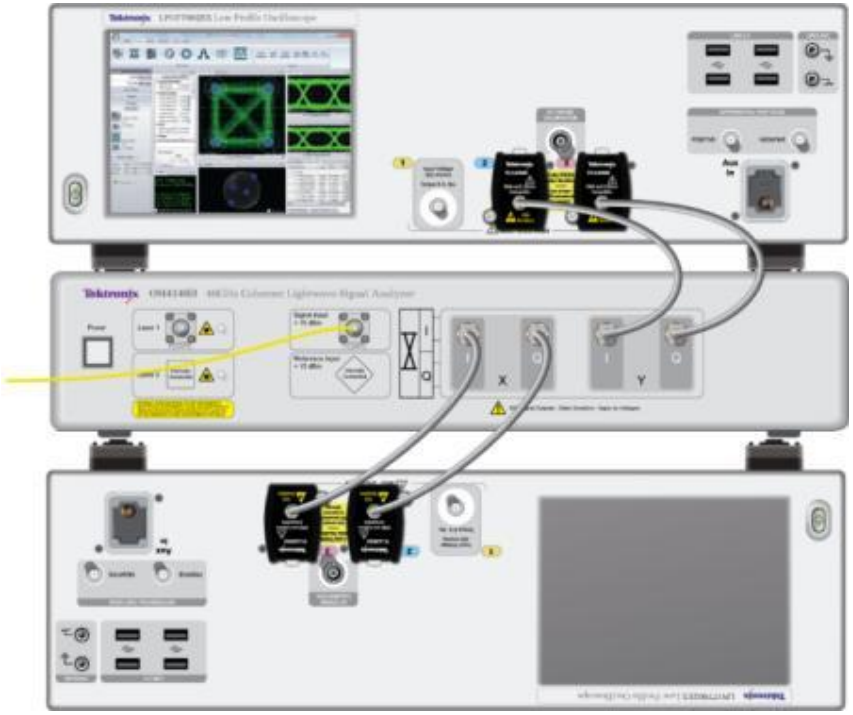
Coherent Lightwave Signal Analysis Configuration

- 4-channel (2-pol) 33GHz, 100GS/s, 1Gsample/ch
- <500fs$_{rms}$ channel-to-channel jitter
- Scopes behave as one unit
- OM4000 software connection is same as in single-scope case

Minimize Signal Path Length

- ATI input channel location and inverted stacking minimize signal path length
- Reduce losses and maximize measurement SNR
- Supported for bench or rack mounted configurations

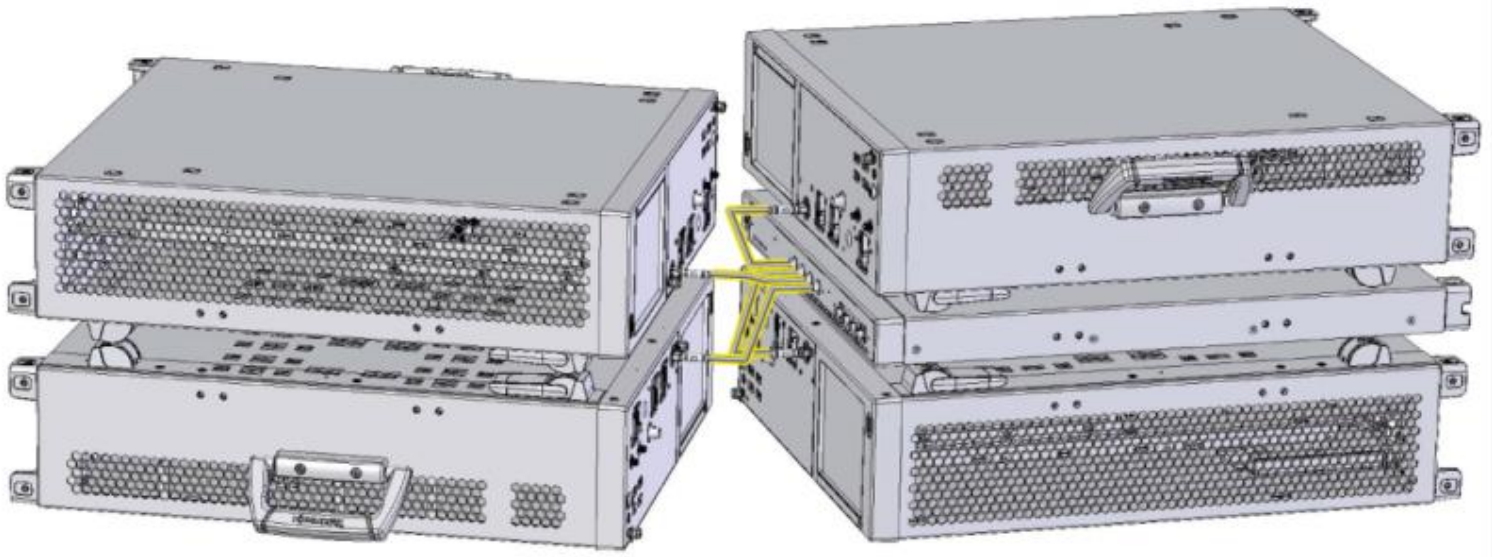


Flip-stacking for minimum cable length

Minimizing System Connectivity Impacts

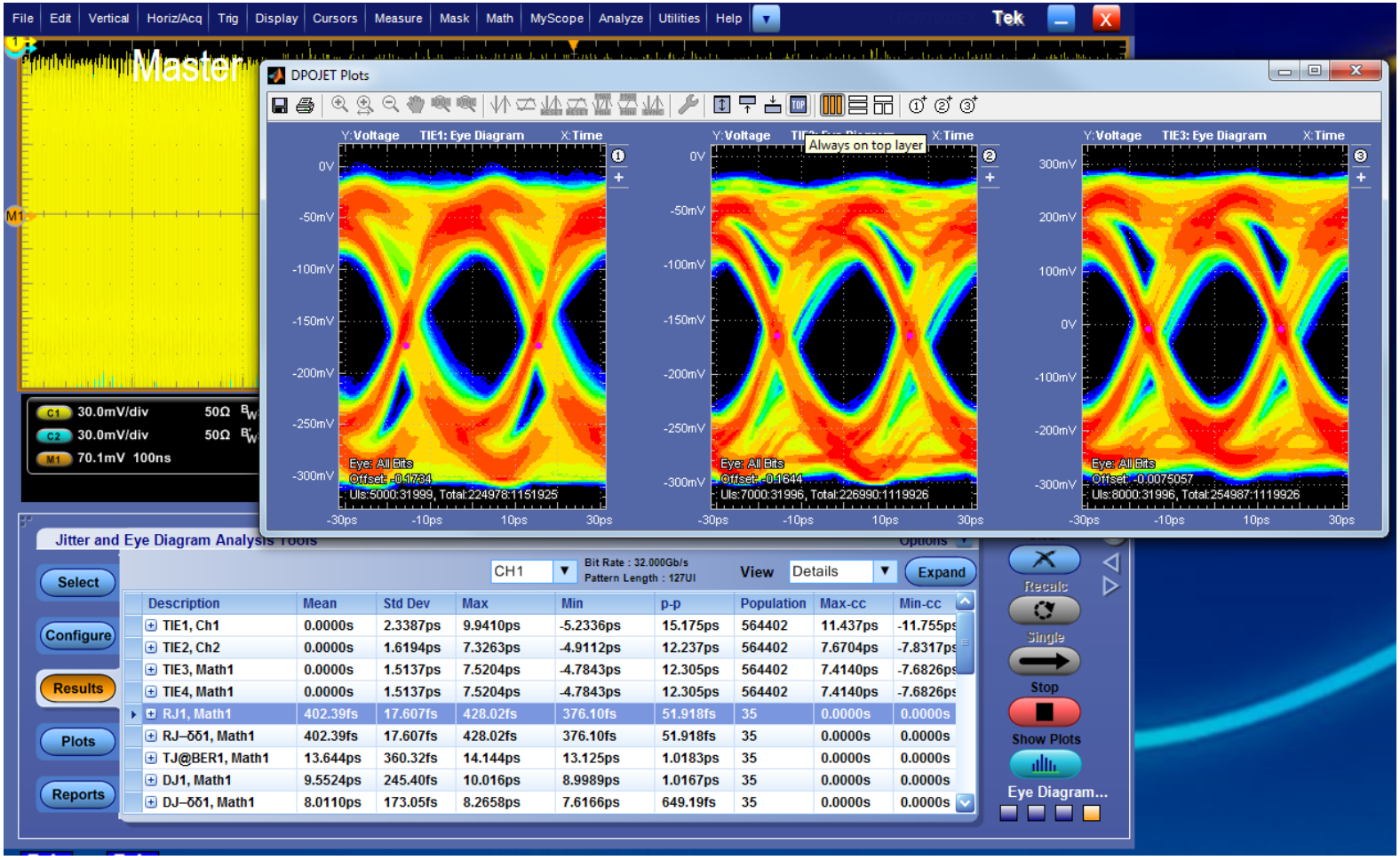
Use case: 400G testing – 4x 70GHz scope channels

ATI connectors located in center of the instrument allows the most compact connection to the receiver



Multi-unit performance – differential eye

- 32GB/s differential output from PPG3204 – early data



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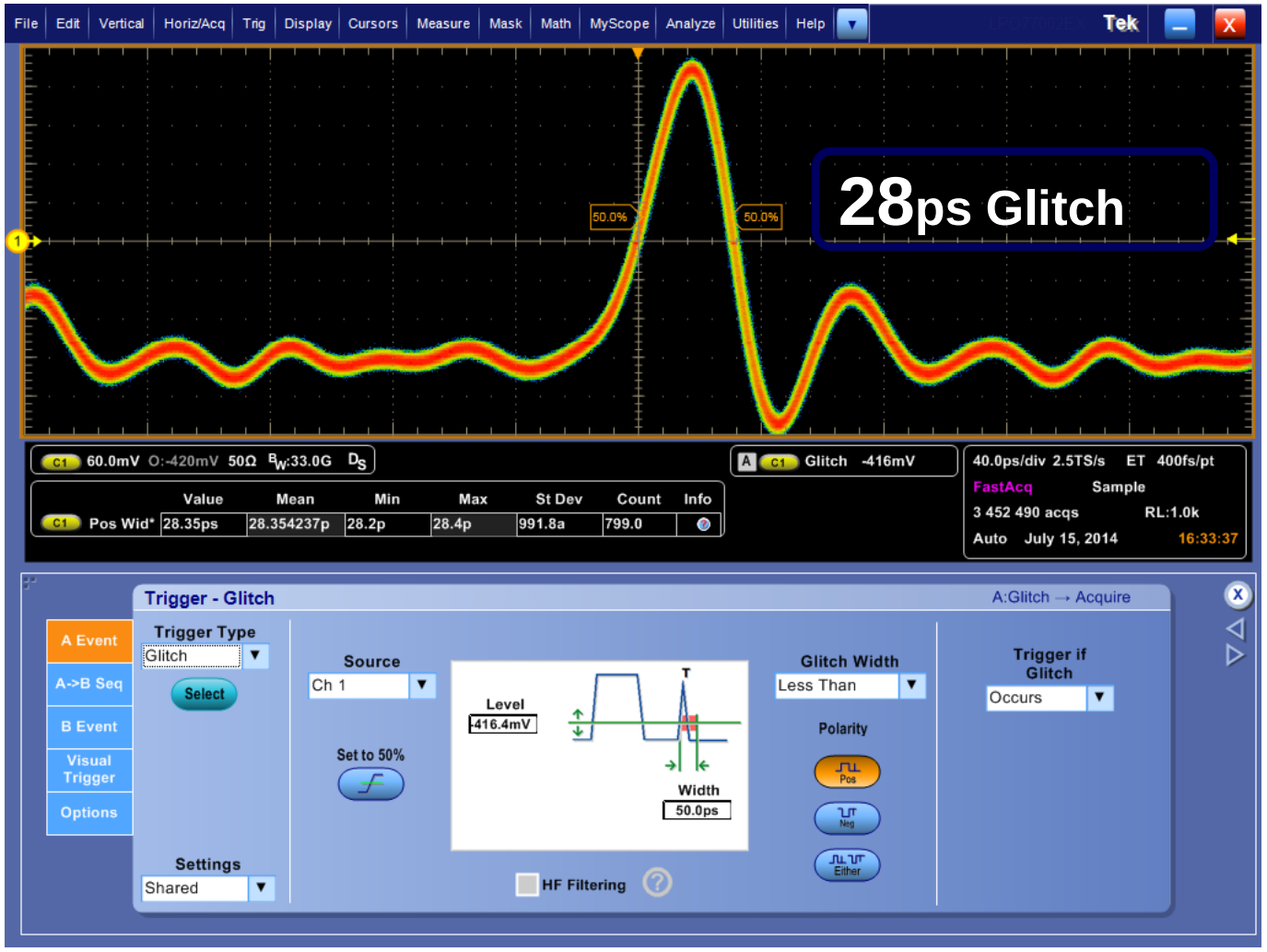
New trigger improvements

- New: ≥25 GHz Edge Trigger Bandwidth
- New: <30ps Glitch Trigger
- New: 40ps Resolution Timer Performance
- New: RF Envelope Trigger type
- New: >10GHz Aux Trigger Bandwidth
- Pinpoint Trigger
- Visual Trigger

Glitch trigger performance

- Minimum Glitch Width < 30ps



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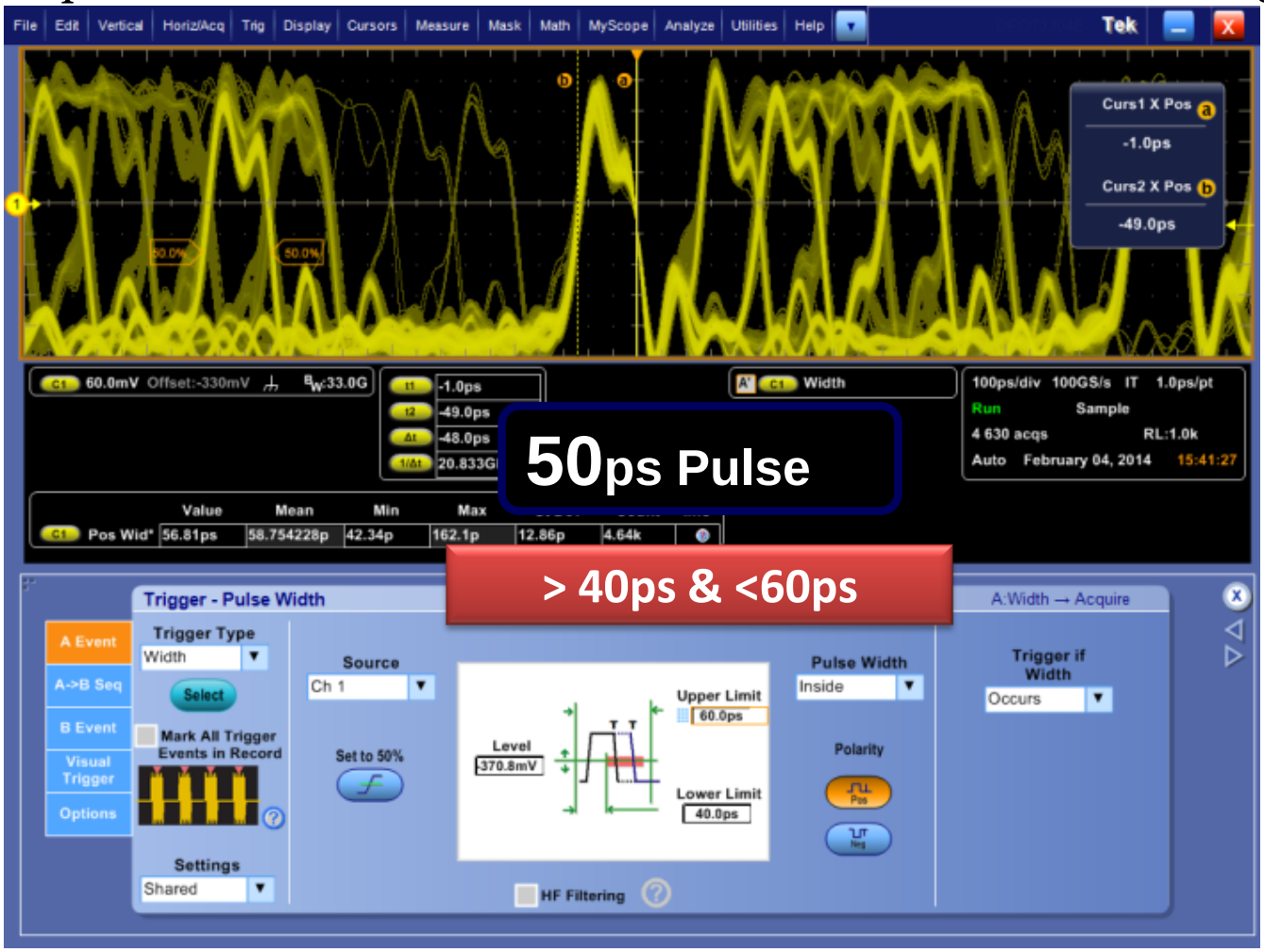
Trigger resolution

- 40ps minimum setting with 5ps resolution
- Example: Smallest Pulse in 20Gb/s PRBS 11 Signal



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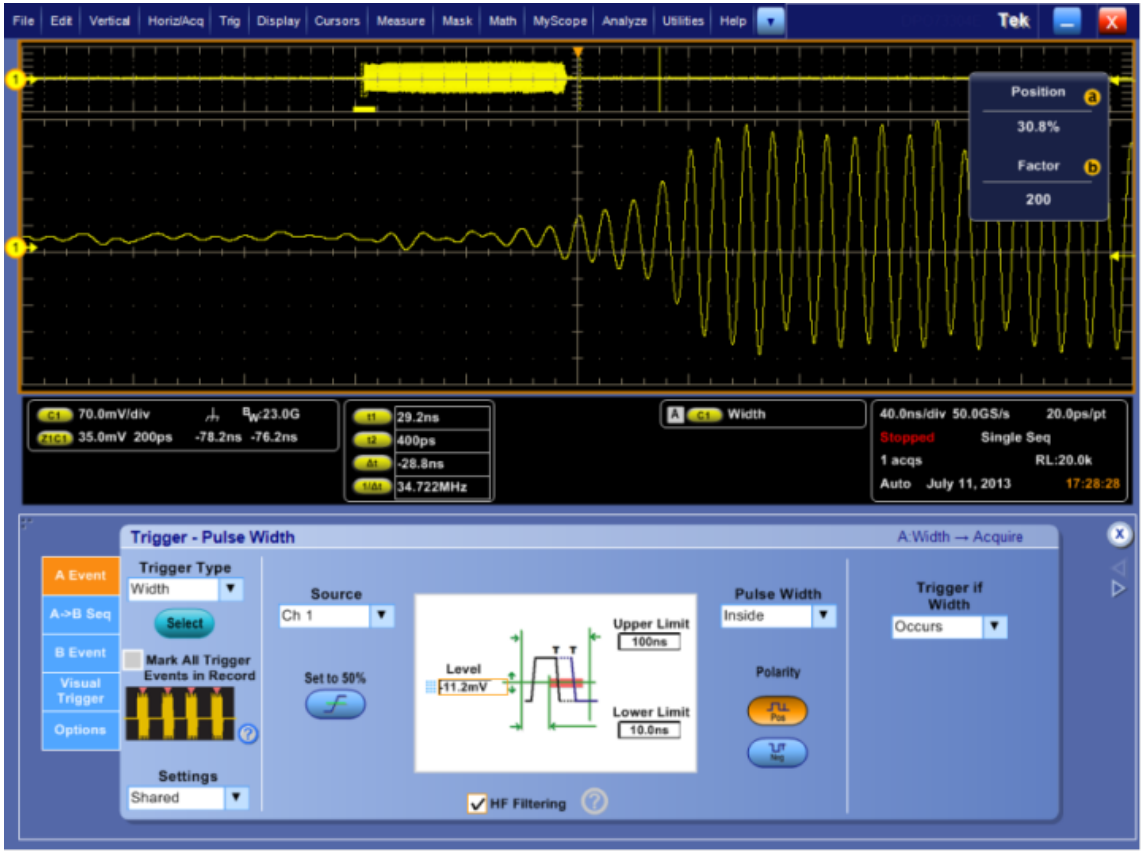
RF Envelope trigger

- Trigger on Envelope of signal instead of Carrier



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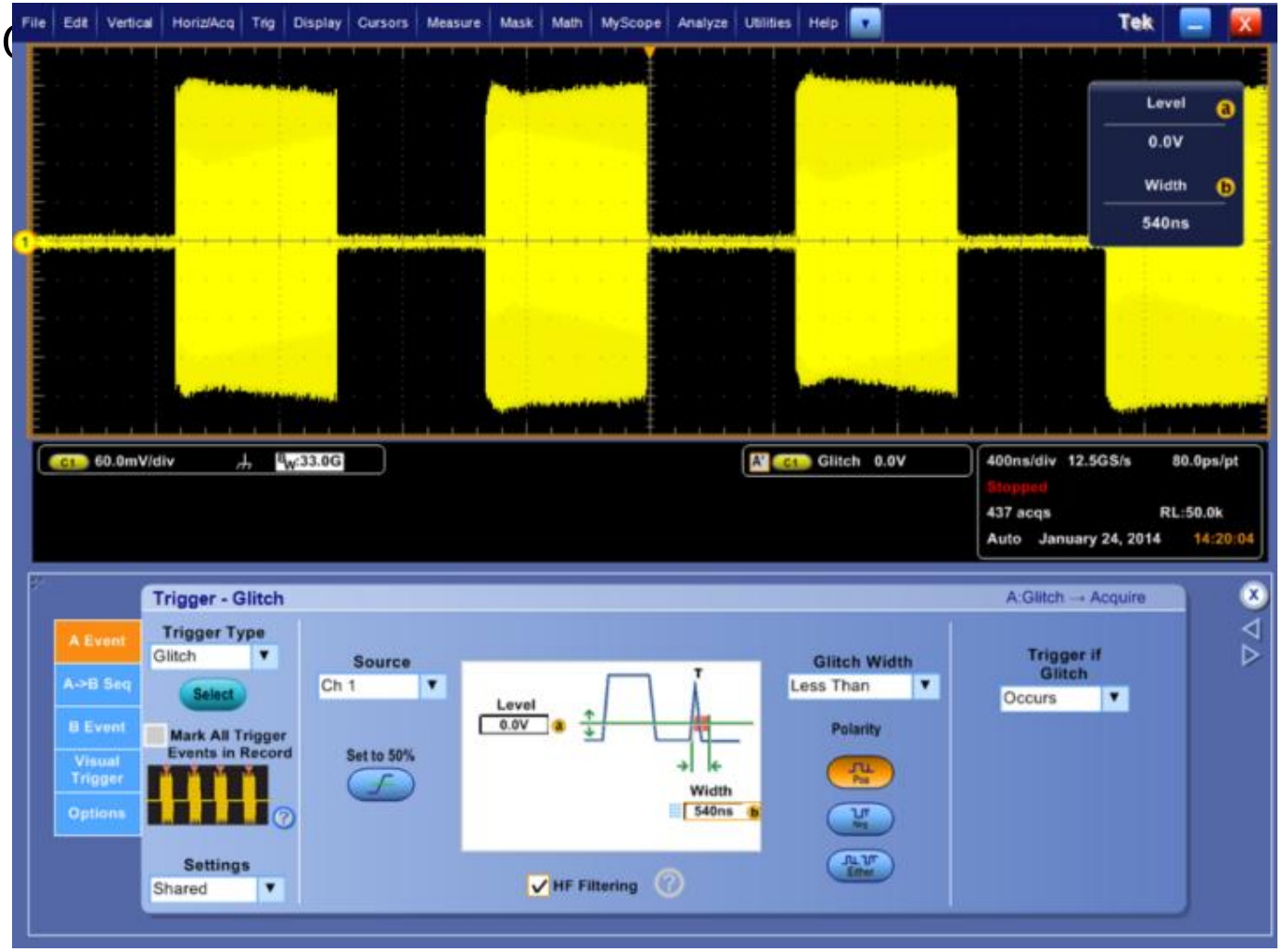
RF Envelope trigger

- Selectively trigger on Burst of specified wi



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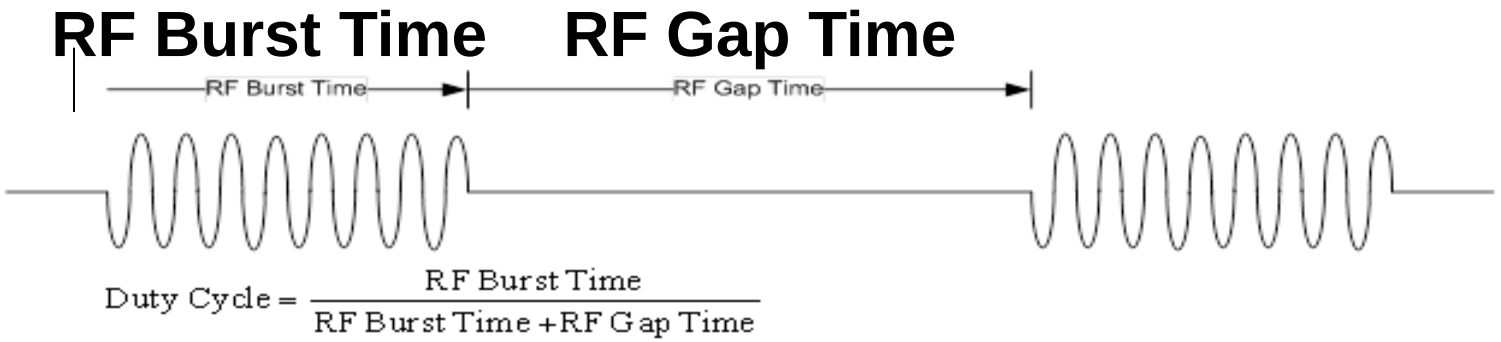
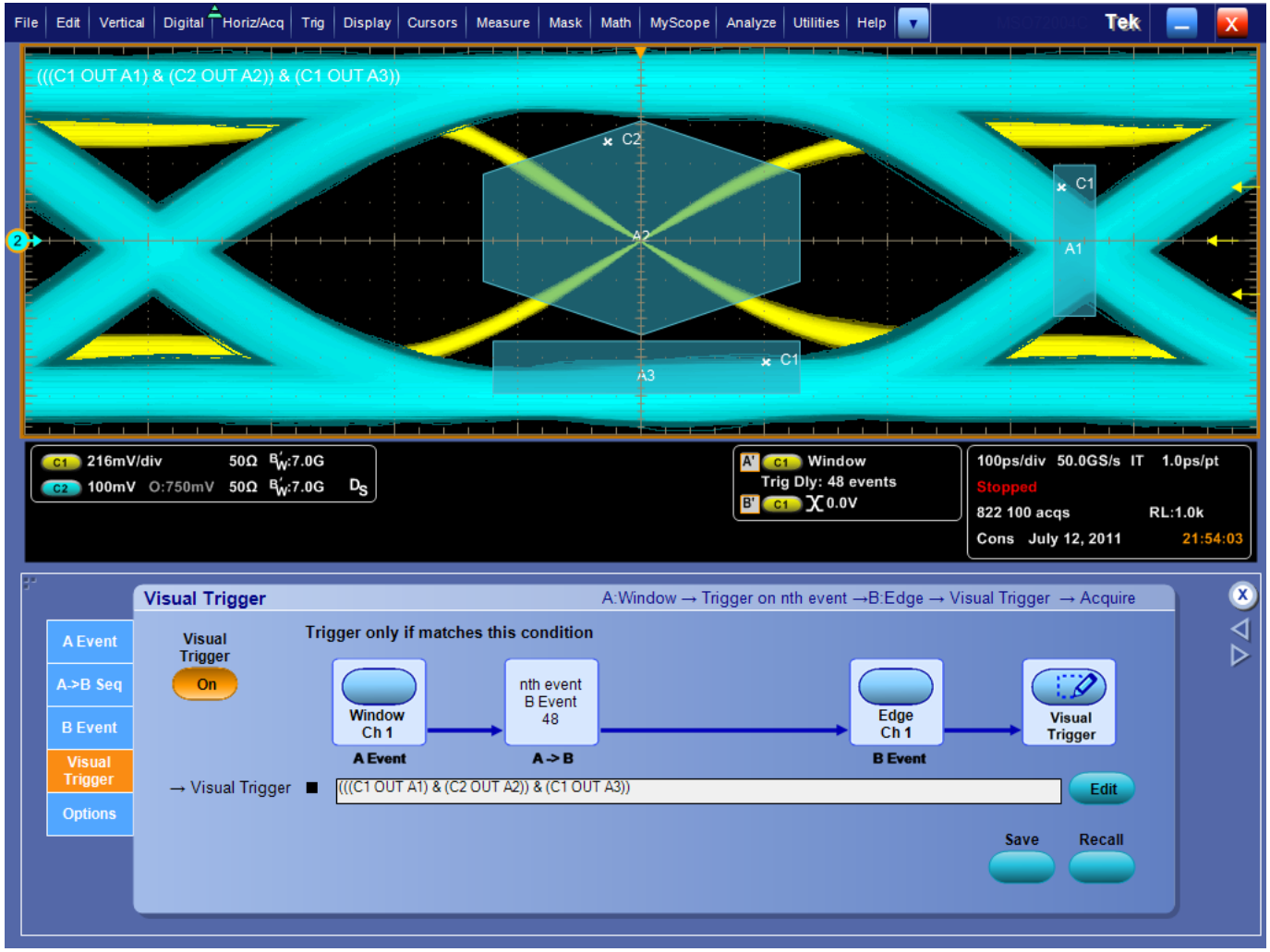
RF Envelope Trigger Performance



Mode/Function	Measured
Minimum RF Burst Time	20ns
Minimum RF Gap Time	30ns
Minimum Carrier Frequency	500 MHz
Maximum Carrier Frequency	> 20 GHz
Rise/Fall Envelope Detector	< 4ns
Minimum 8b/10b Data Rate	1.5 Gb/s

Visual Triggering to Bandwidth of Instrument



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DPO70000SX Series

DPO70000SX Models			Acquisition Performance			
			Channels			
			Bandwidth			
			Sample Rate			
			(1 Ch)	(2 Ch)	(4 Ch)	(8 Ch)
70GHz (ATI)	DPO77002SX		1 Ch 70 GHz 200 GS/s	2 Ch 33 GHz 100 GS/s		
	DPS77004SX (2-unit system w/UltraSync)			2 Ch 70 GHz 200 GS/s	4 Ch 33 GHz 100 GS/s	
33GHz	DPO73304SX			2 Ch 33 GHz 100 GS/s	4 Ch 23 GHz 50 GS/s	
	DPS73308SX (2-unit system w/UltraSync)				4 Ch 33 GHz 100 GS/s	8* Ch 23 GHz 50 GS/s
DPO7AFP	Auxiliary Front Panel					

* 6 Ch access available initially

Scalable Performance series

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