



From the Designers: Optimize Scope Measurements and Features

Bill Driver

Senior Product Manager

Agenda

- Overview
- Probing
- Systems
- Specifications
- Memory and Sample Modes

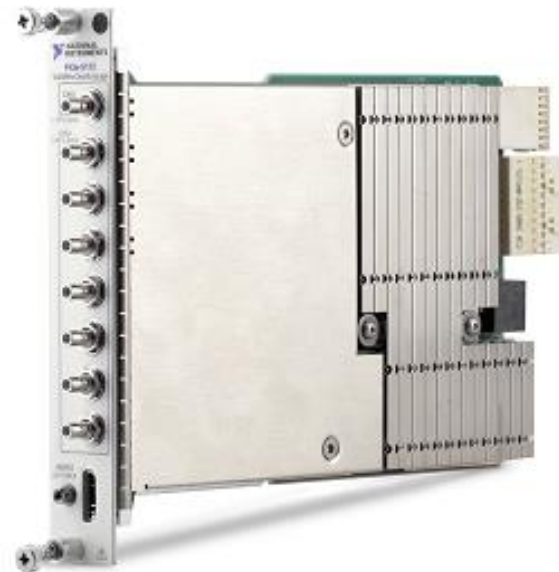
PXI Oscilloscope



NI 5162
5GSps, 1.5GHz



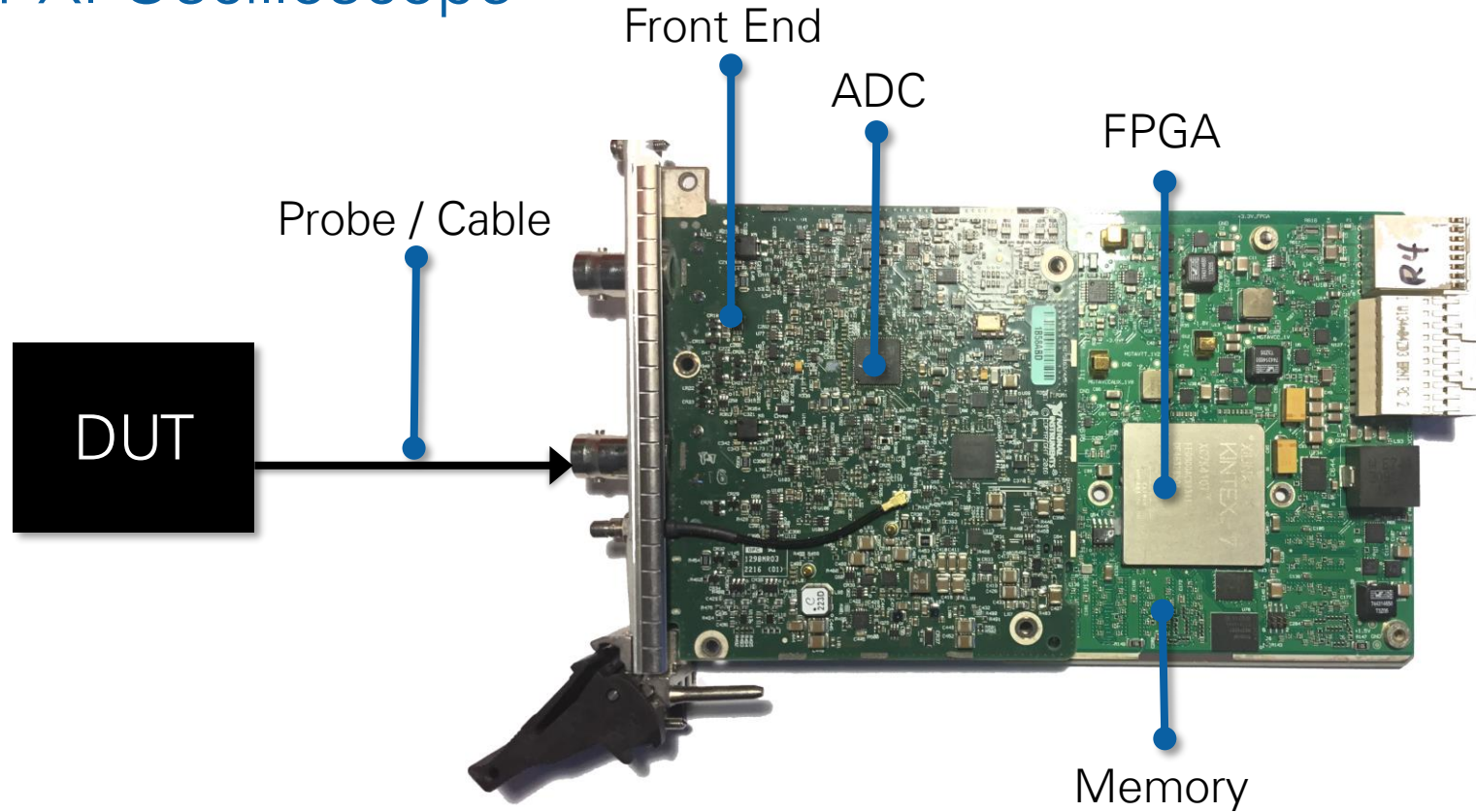
NI 5164
1GSps, 400MHz



NI 5172
250MSps, 100MHz

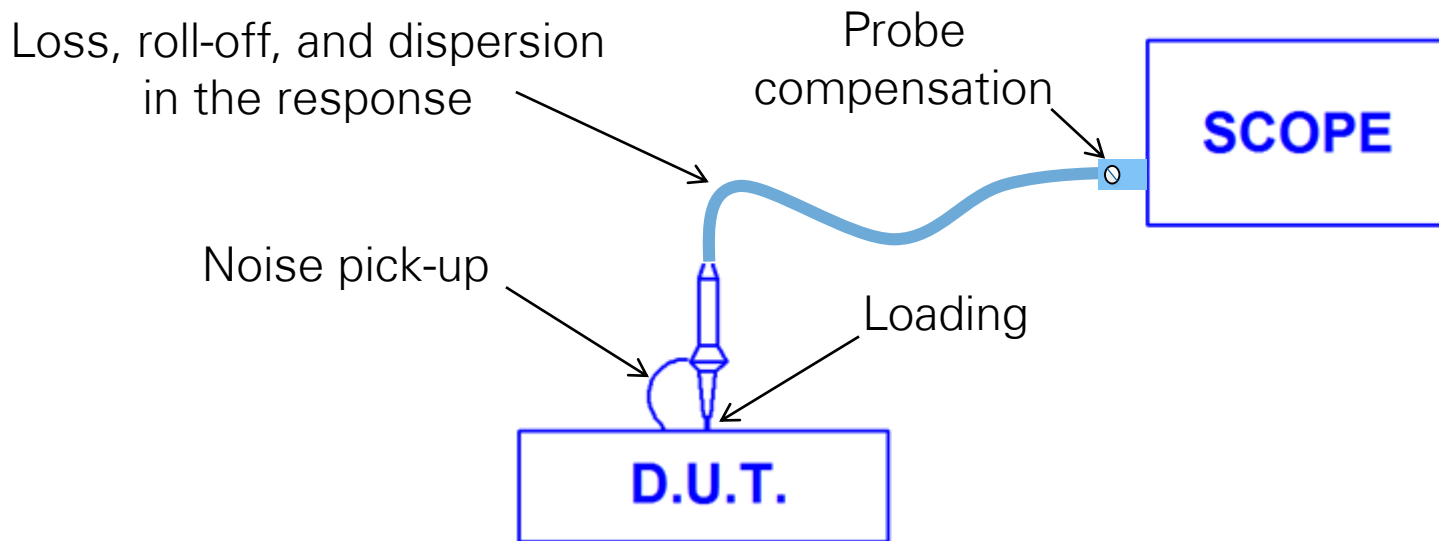


PXI Oscilloscope



Probing

Probing



Active Probes vs Passive Probes



	Passive	Active
Cost	~\$150	~\$1,000/GHz
Typical Input Capacitance	~10pF	1pF
Voltage Range	>300 V	1 to 10 V
Bandwidth	200 to 500MHz	>1GHz
Scope Setting	1M Ω	50 Ω
External Power Required?	no	yes

Active probes are generally preferred for high bandwidth applications and/or applications where minimal high frequency loading is important.

NI Passive Probes - 10:1 and 100:1

- Up to 500 MHz bandwidth
- High voltage, up to 400V
- Tip impedance: $10\text{ pF} \parallel 10\text{ M}\Omega$ (typical)
- Some probes have 1:1 switch
 - ... 1:1 setting: heavy loading & low BW *e.g. 5MHz*
- Scope is always set to 1Meg
- Probe compensation required



SP500X:
10:1, 500MHz,
300V max, $11\text{pF} \parallel 10\text{M}\Omega$ tip



SP500C:
100:1, 500MHz,
300V max, $4.6\text{pF} \parallel 100\text{M}\Omega$ tip



CP500X:
1.2m length, 10:1, 500MHz,
 $10\text{pF} \parallel 10\text{M}\Omega$ tip



CP400X:
2m length, 10:1, 400MHz,
 $13\text{pF} \parallel 10\text{M}\Omega$ tip

NI Active Probes

- Single ended and differential
- Up to 2.5 GHz bandwidth
- Voltages
 - SE: $\pm 8V$
 - Differential: $\pm 15V$ Differential, $\pm 30V$ Single-ended
- Tip impedance: $1\text{ pF} \parallel 50\ \Omega$ (typical)
- Scope is always set to $50\ \Omega$



SA1000X:
10:1, 1 GHz,
 $\pm 20V$ max, $0.9\text{pF} \parallel 50\ \Omega$ tip



SA1500X:
10:1, 1.5 GHz,
 $\pm 20V$ max, $0.9\text{pF} \parallel 50\ \Omega$ tip

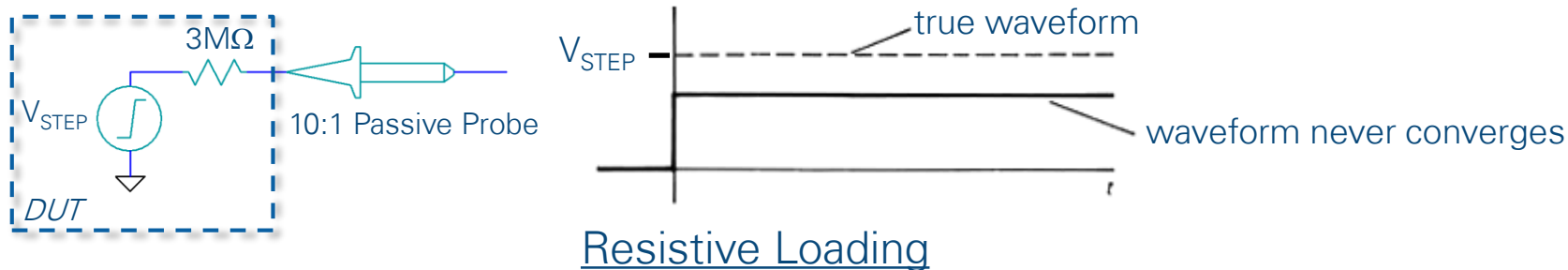
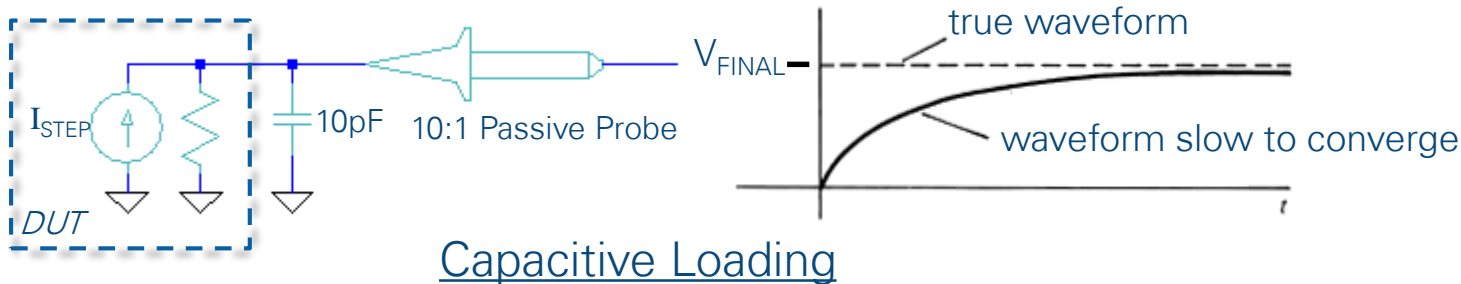


SA2500X:
10:1, 2.5 GHz,
 $\pm 20V$ max, $0.9\text{pF} \parallel 50\ \Omega$ tip



NI 5191:
800 MHz, 10:1
 $2\text{pF} \parallel 100\text{k}\Omega$ tip

Probe Loading



Probe Loading: Coax Cable vs. Passive Cable Divider

1.2m Length RG58 Cable:

Heavy loading: $C_{\text{LOADING}} = 112\text{pF}$



1.2m Length Cable Divider Probe (NI CP500X) :

Light Loading: $C_{\text{LOADING}} = 10\text{pF}$



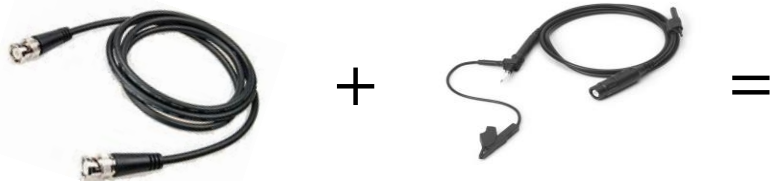
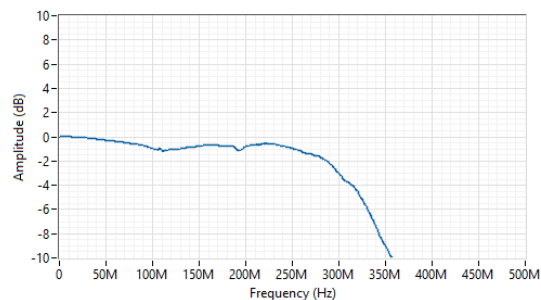
*BNC connector
for DUT end.*

Passive Probe Connectivity

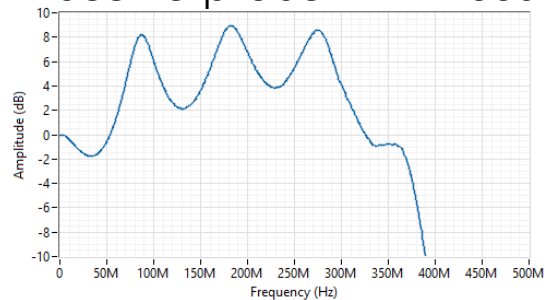


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Passive probe



Passive probe + 1m coax



Passive Probes with coax cables should not be combined

Probing: Minimize Ground Lead Inductance

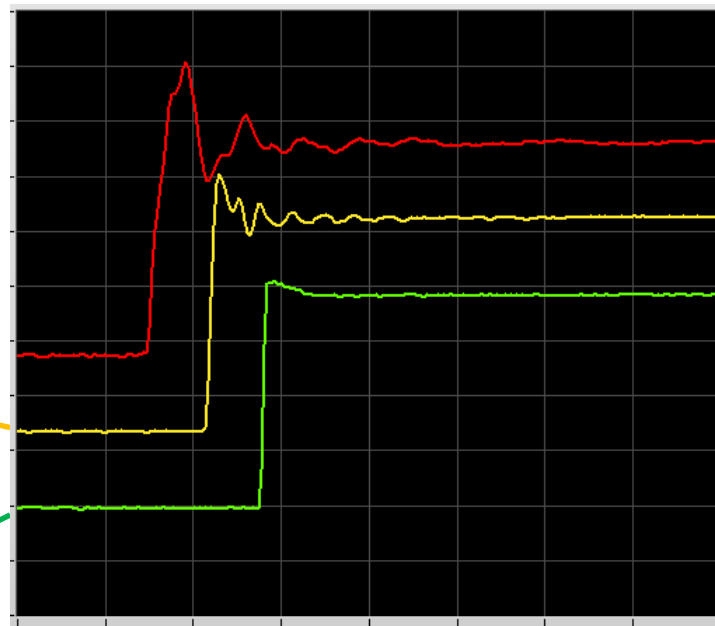
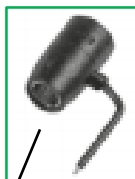
30cm
clip lead



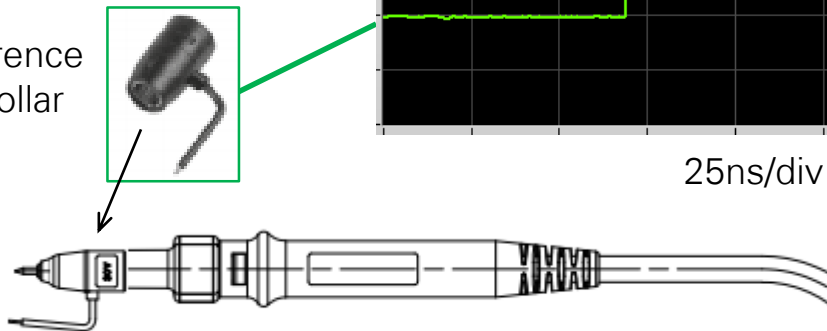
Reference
lead with
crocodile clip



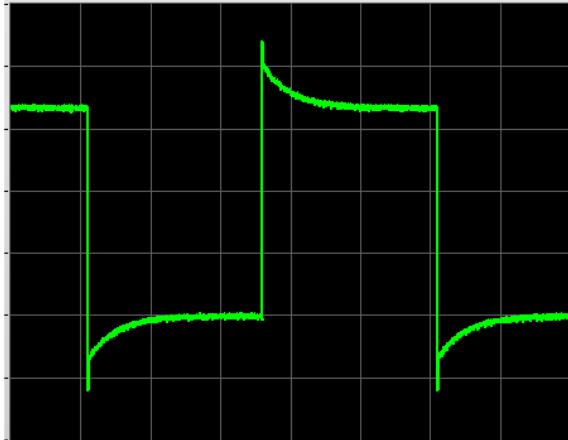
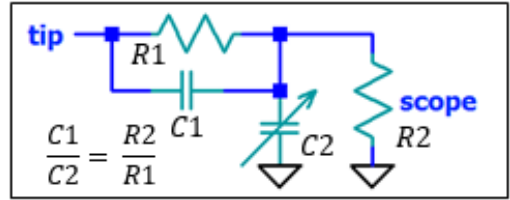
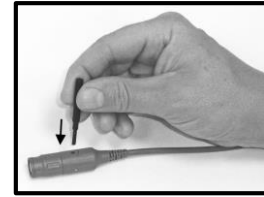
Push-on reference
grounding collar



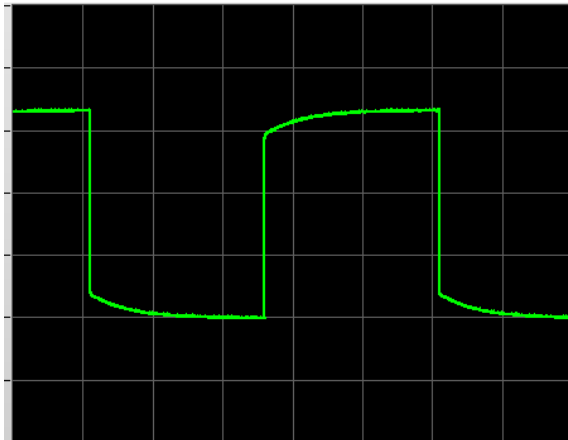
25ns/div



Passive Probe Compensation



Overcompensated

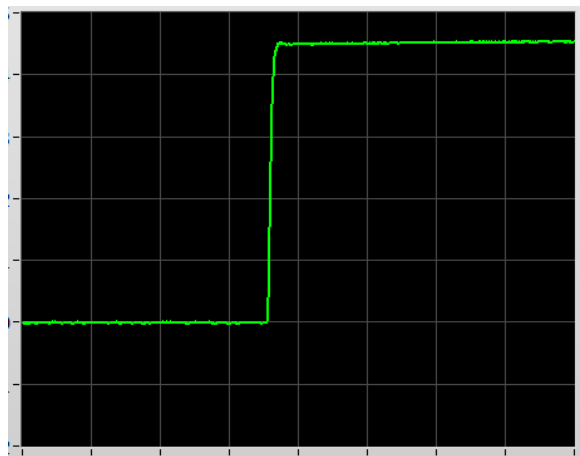


Undercompensated

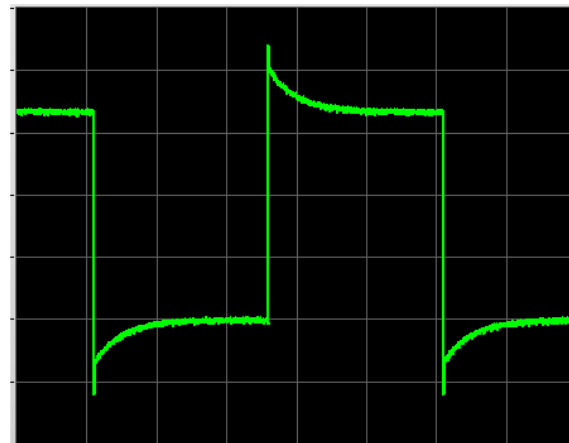


Properly Compensated

Passive Probe Compensation – Time Duration



200ns/div

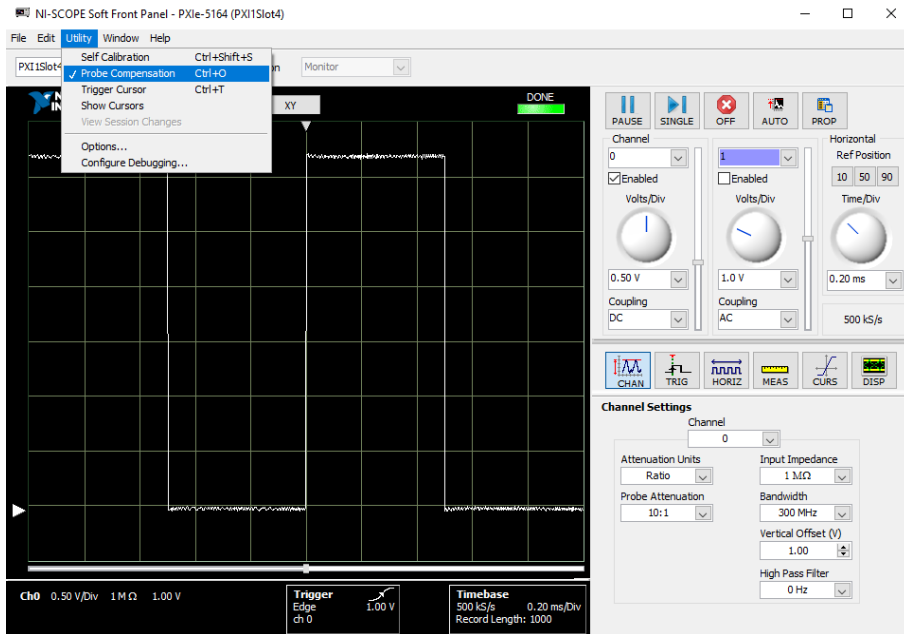


200us/div

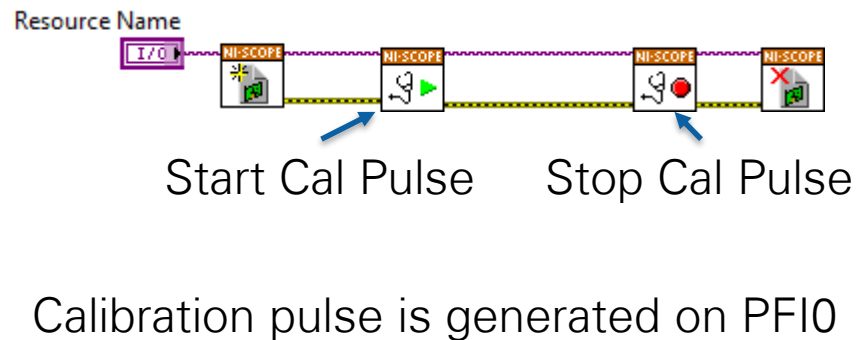
Amplitude error is 25%!!!

How To Compensate a NI PXIe Oscilloscope

- NI-SCOPE Soft Front Panel



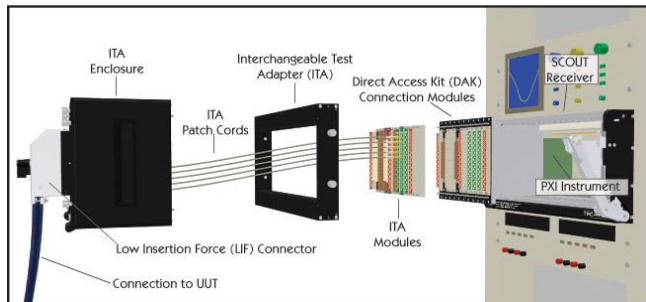
- NI LabVIEW



System

Mass Interconnects

- Benefits
 - Enhanced Electrical Performance
 - Eliminates Conventional Wiring Harnesses
 - Reduced System Integration Time and Costs



Images courtesy of Mac-Panel

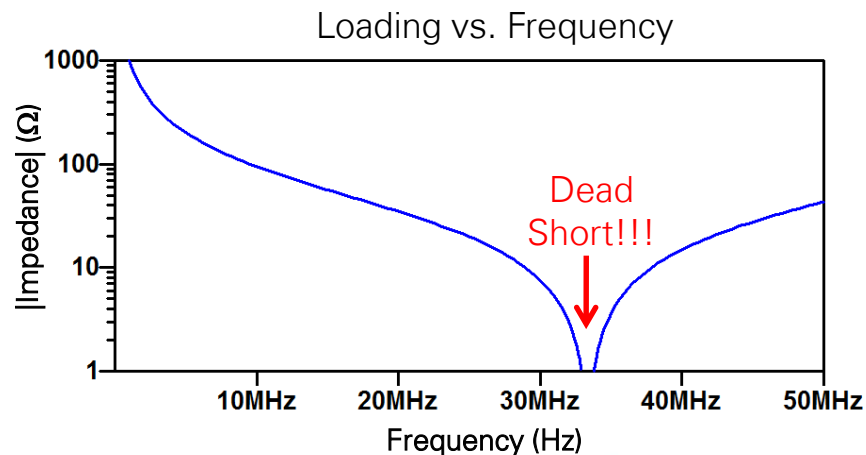
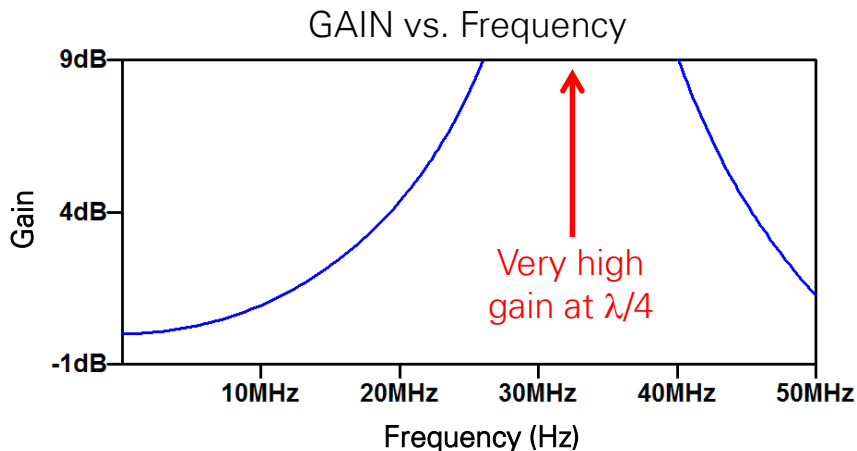
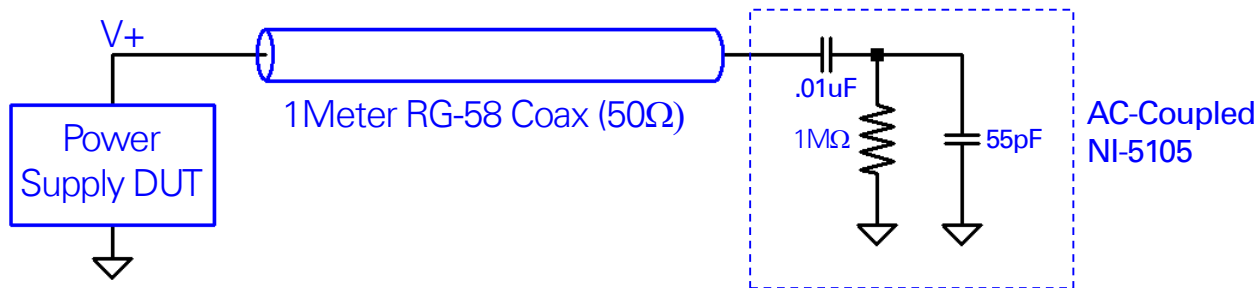


G¹⁸



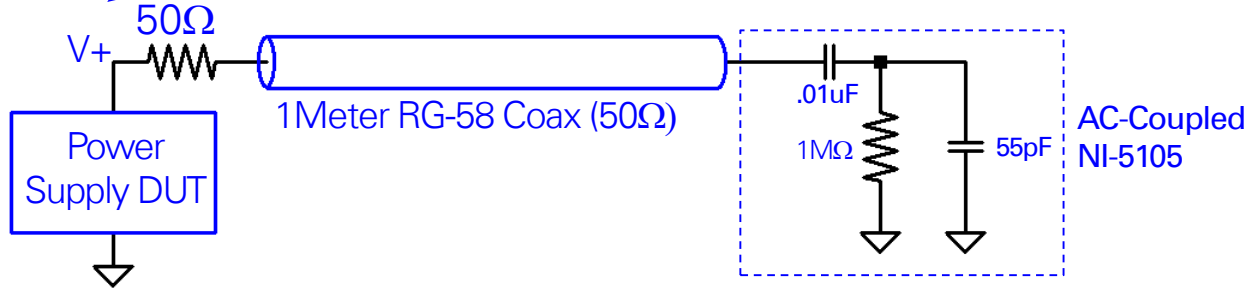
Image courtesy of Virginia Panel

Measuring Power Supply Noise Using Only Coax

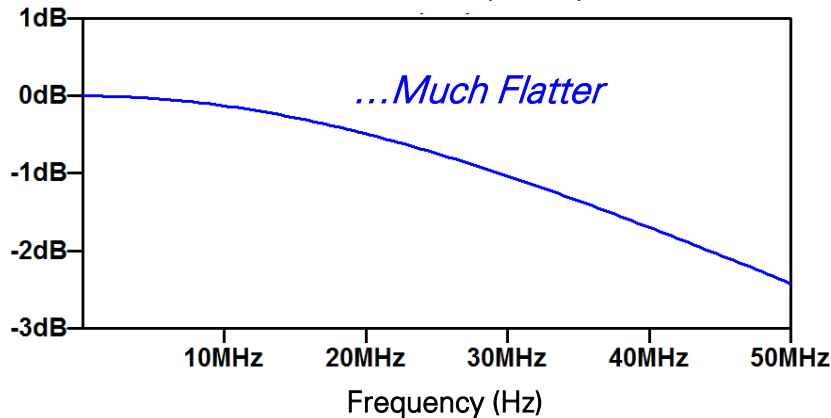


Add Back Termination Resistor

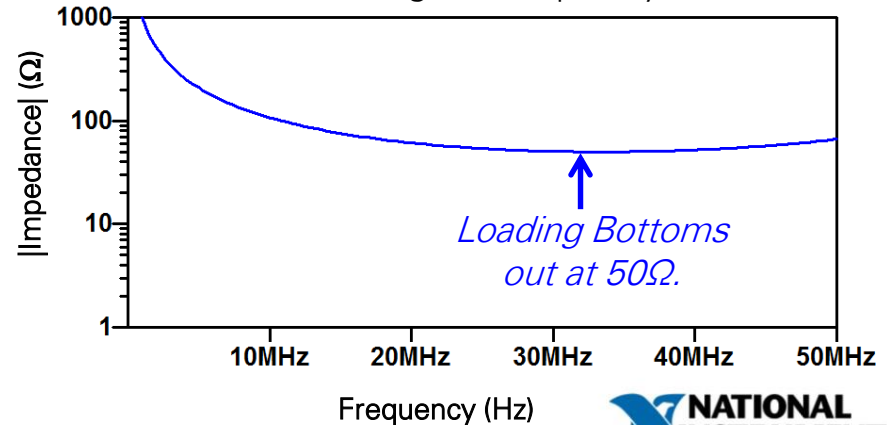
Back Termination Resistor Added



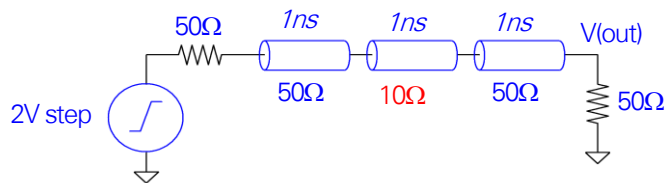
GAIN vs. Frequency



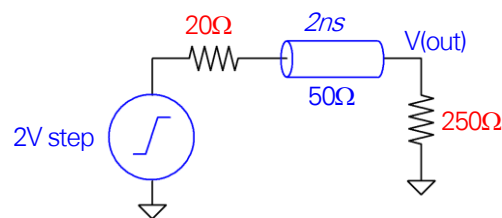
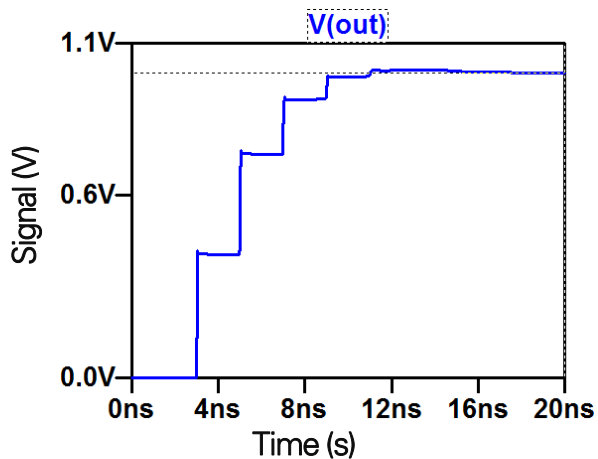
Loading vs. Frequency



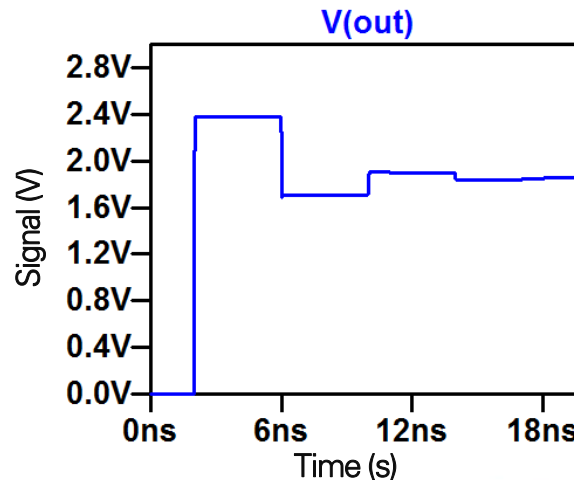
Transmission Line Systems: Impedance Mismatch



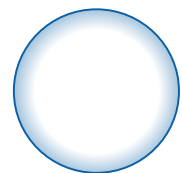
*Characteristic Impedance
Change Along Signal Path*



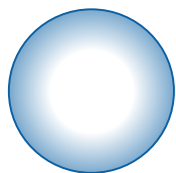
Source/Load Mismatch



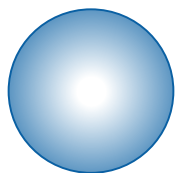
Transmission Line Systems: Skin Effect



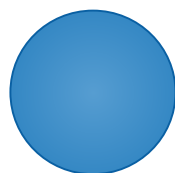
$t=100ps$
 $10\Omega/m$



$t=1ns$
 $1\Omega/m$

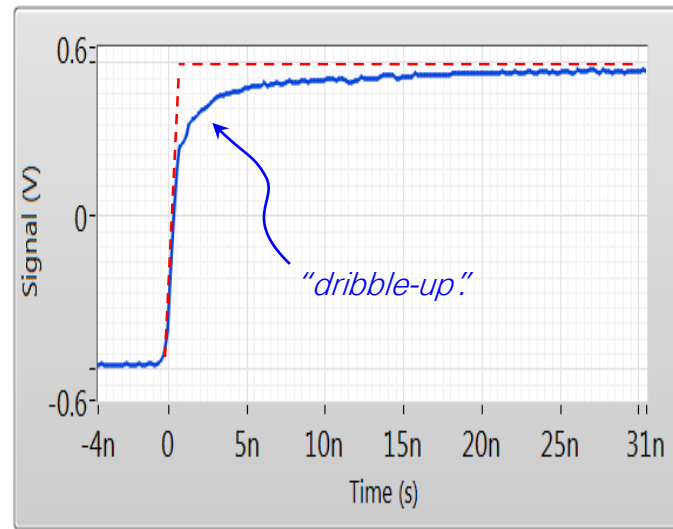


$t=10ns$
 $0.2\Omega/m$

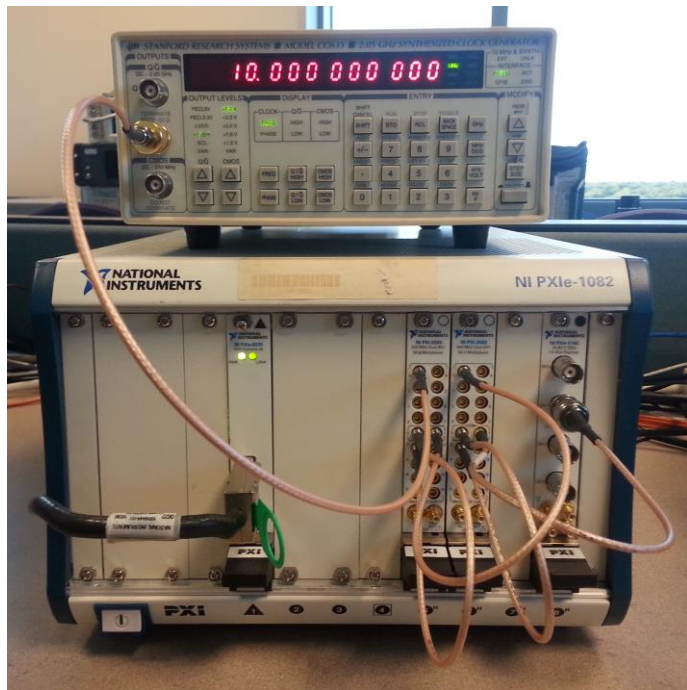


$t=\infty$
 $0.033\Omega/m$

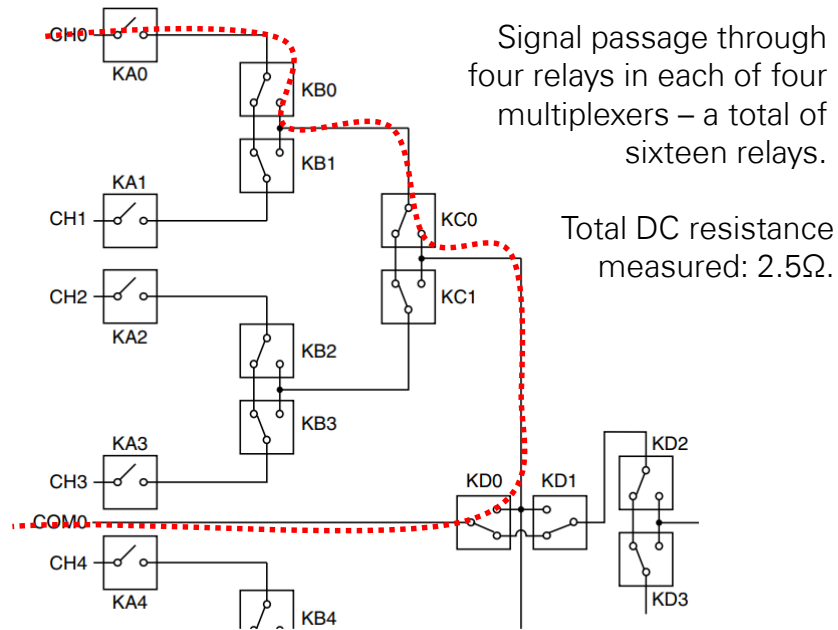
Cross section of current flow in a coax center conductor over time after applying a step. Initially, current only flows at the surface at high frequency. This is sometimes called “dribble-up”.



Example: Loss in Relay Matrices

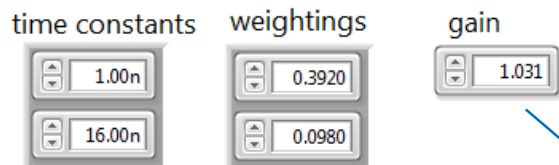
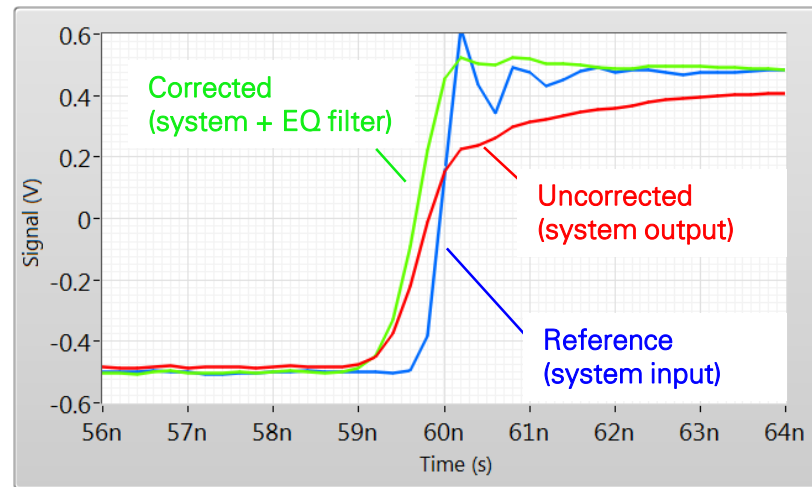
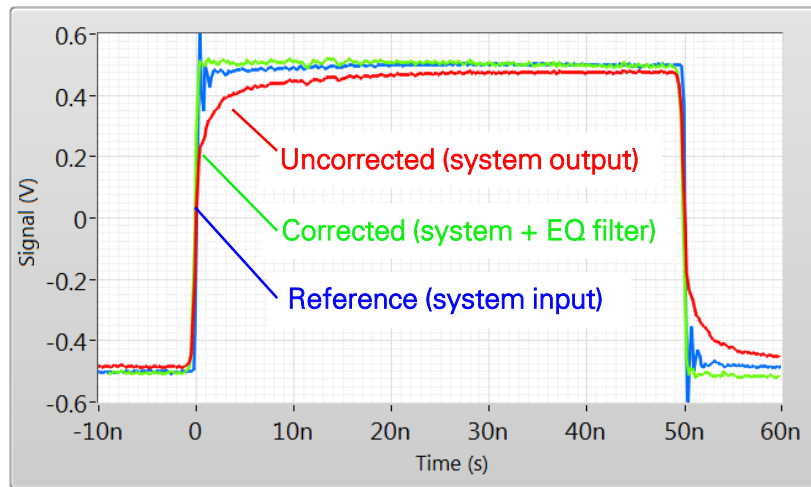


Two NI-2593 relay multiplexers cascaded with an NI-5162 oscilloscope; a 10MHz square wave signal passed through four 8:1 multiplexer sections.



One of Four

Equalization Filter VI Used to Correct for Loss (Setup of Previous Slide)

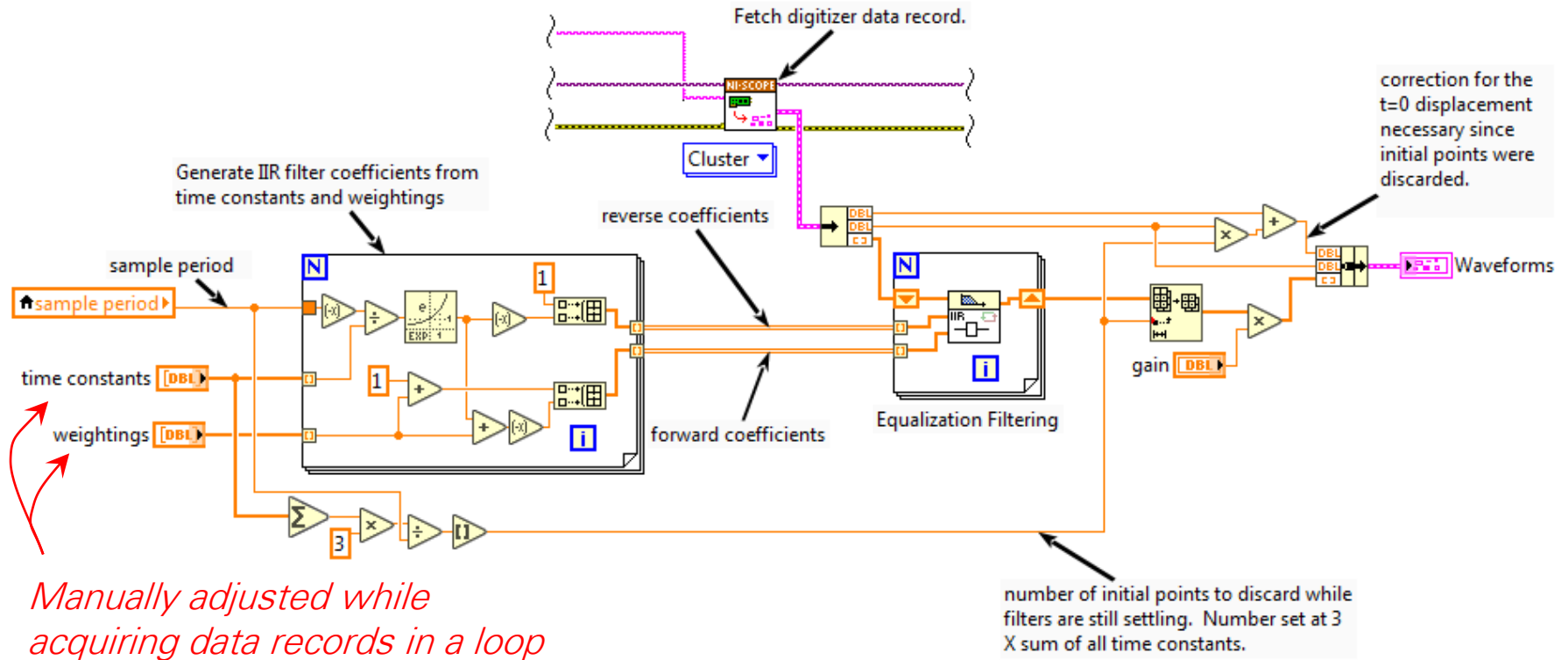


Simple two pole equalization filter.
Adjustment easily performed by eye.

Gain error correction needed
due to DC resistance in path.

Zoomed-in View of Rising Edge

Simple Equalization VI



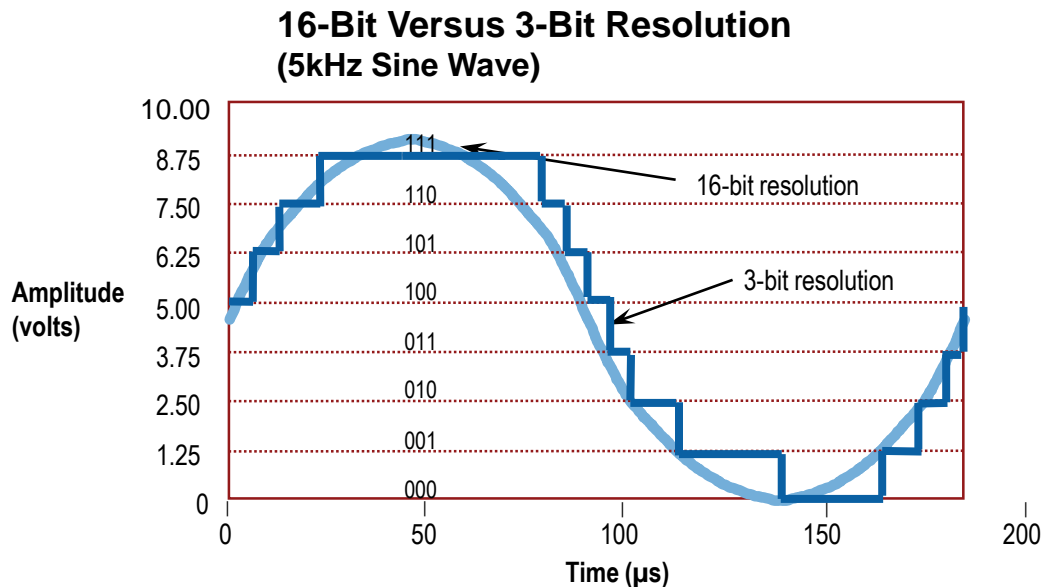
Specifications

Specification Basics

- ADC Resolution
- Spectral
- Bandwidth
- Rise Time
- Coupling

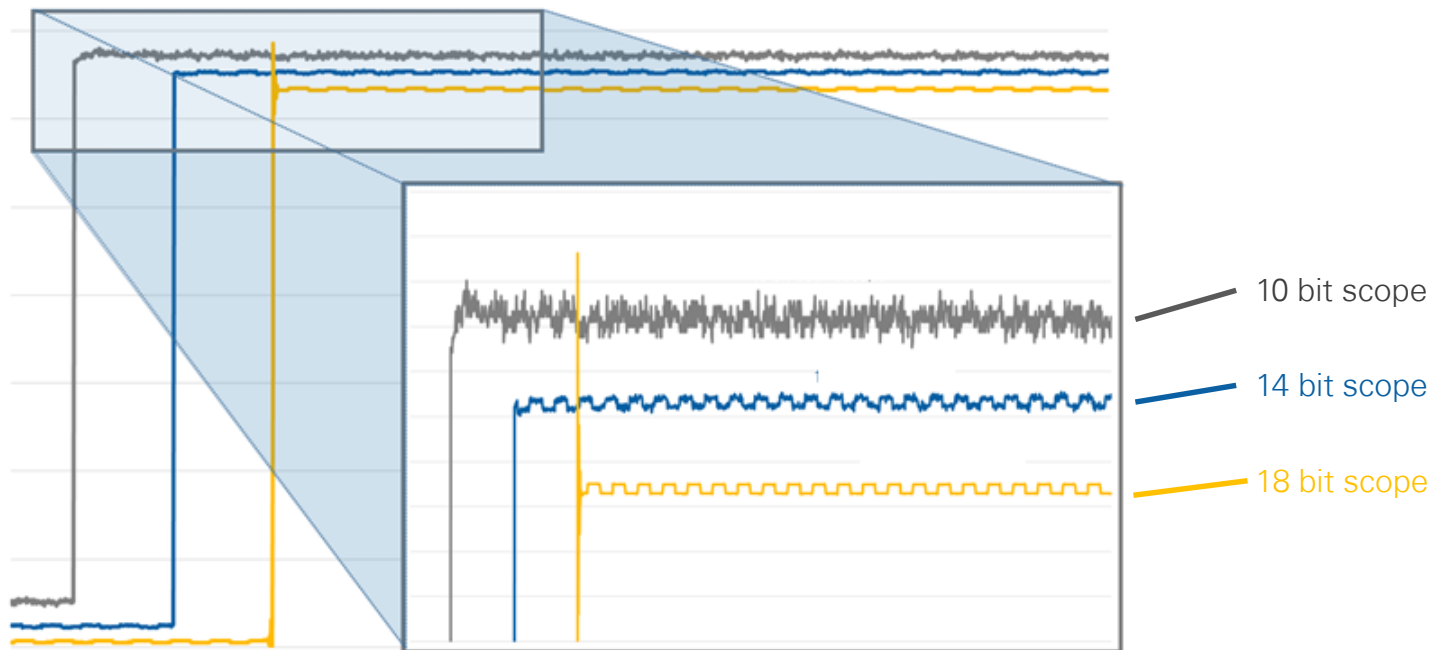
ADC Resolution

- The number of discrete values represented within a range
- 3-bit resolution = $2^3 = 8$ voltage levels, 16-bit = $2^{16} = 65,536$ levels



Higher ADC Resolution

- Enables viewing of small signals



ADC Resolution - ENOB – Effective Number of Bits

$$ENOB = \frac{SINAD - 1.76 \text{ dB}}{6.02 \text{ dB}}$$

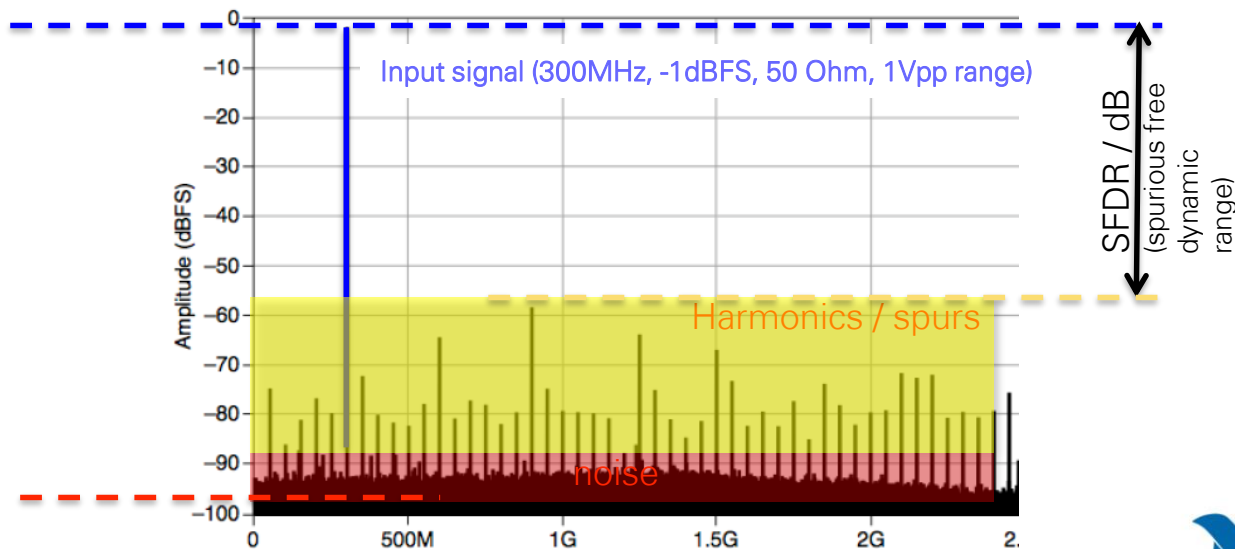
- Expresses the scope's true resolution
- Derived directly from SINAD, Signal to Noise + Distortion
- ENOB can be affected by:
 - Higher instrument bandwidth
 - Higher input frequency
 - Lower instrument resolution
 - High impedance vs 50 Ohm input
 - Sensitive input ranges

Spectral – Frequency Domain

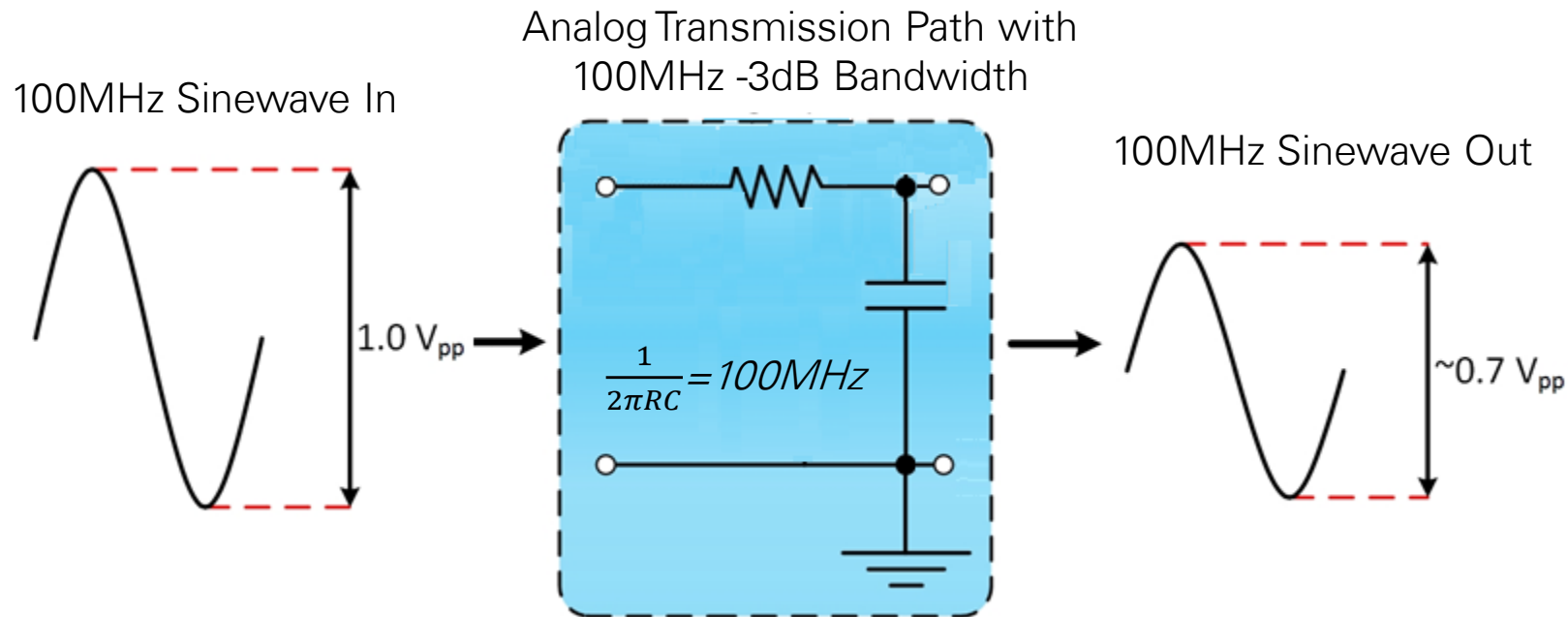
Signal to Noise Ratio (SNR) = $20\log((\text{Full Scale Sine Input rms})/(\text{noise rms}))$ [dBFS]

Signal to Noise+Distortion (SINAD) = $20\log((\text{Full Scale Sine Input rms})/(\text{noise rms}+\text{harmonics rms}))$ [dBFS]

Spurious Free Dynamic Range (SFDR) = $20\log((\text{Full Scale Sine Input rms})/(\text{strongest spur spectral line}))$ [dBc]



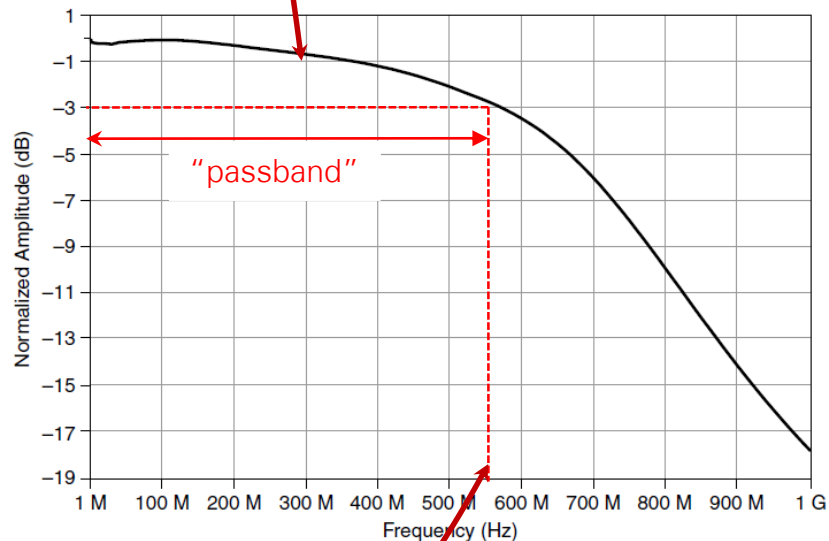
Bandwidth



Bandwidth of NI Instrument

Continuous roll-off in passband!
Here it is -1dB at 360MHz.

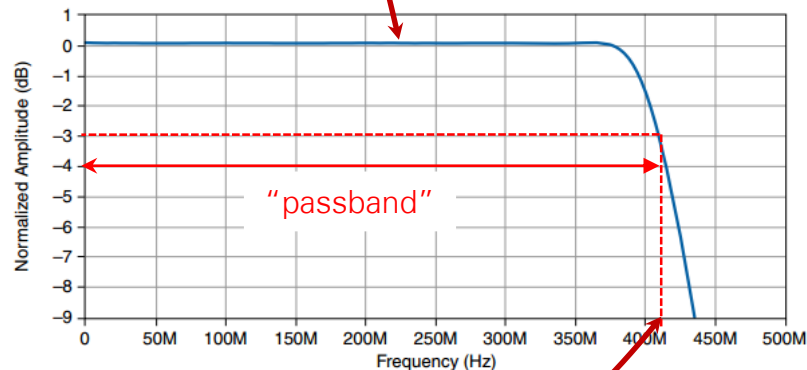
Figure 3. NI 5160 50 Ω Frequency Response, 1 V_{pk-pk}, 2.5 GS/s, Characteristic



560MHz, margin: product spec'd at 500MHz.

Very flat response to 350MHz

Figure 3. 50 Ω Full Bandwidth Frequency Response, 1 V_{pk-pk}, Characteristic



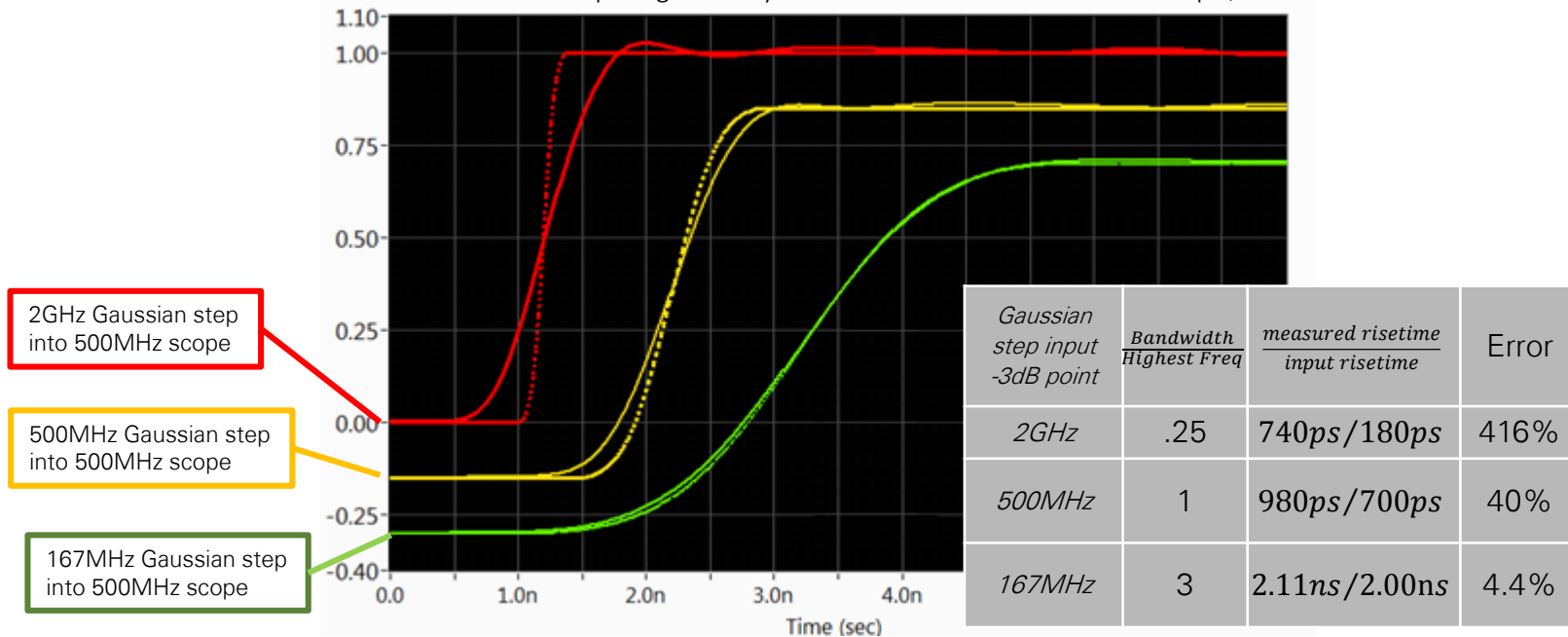
415MHz, margin: product spec'd at 400MHz.

At NI, oscilloscope bandwidth is specified based on the -3dB point.

Bandwidth Impact on Time Domain Measurements

- Bandwidth should be 3-5 times the highest frequency component

Various Gaussian steps digitized by a 500MHz Bandwidth Oscilloscope, NI-5160



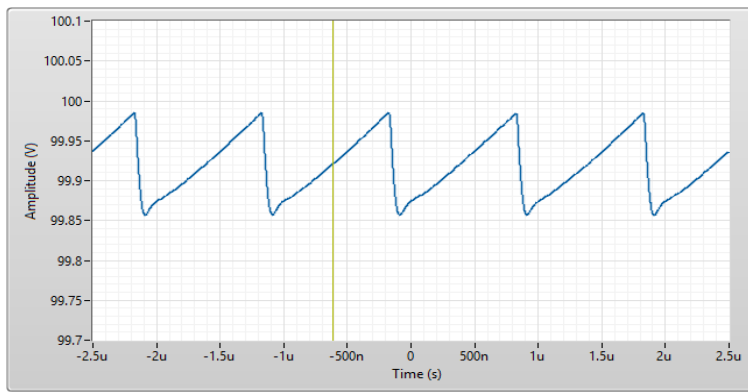
$$t_{r_{\text{measurement}}} = \sqrt{t_{r_{\text{scope}}}^2 + t_{r_{\text{probe}}}^2 + t_{r_{\text{signal}}}^2}$$

When Examining Details on Large Offset

- AC Coupling – Uses a capacitor to filter out the DC signal component
 - Allows use of most sensitive ranges with a large DUT DC voltage offset e.g. Power supplies
 - Useful to remove DC (acts as voltage offset) component to gain resolution

When Examining Details on Large Offset

- DC Coupling
 - When measurements require fast settling vs. discharge of AC capacitor
 - Use Vertical Offset to center input signal
 - Allows for measurement of DC component and AC component with higher resolution



Using 2.5V input range
to measure 100V input
NI 5164

Averaging to Reduce Noise

- Advantage: Does not lower bandwidth
- Disadvantage: Requires a repetitive signal and accurate triggering

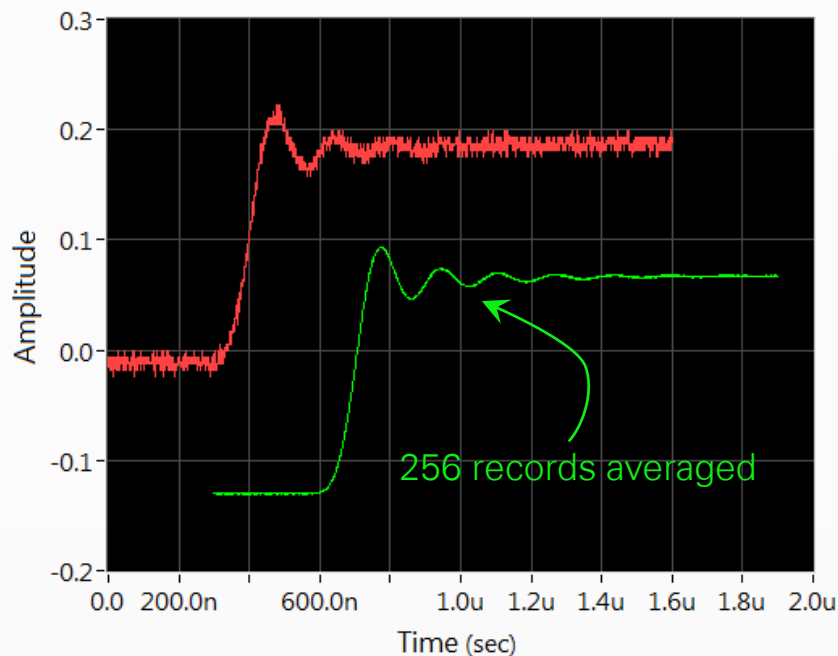
4 averages \rightarrow $1/2$ Noise Voltage \rightarrow 1 bit improvement

16 averages \rightarrow $1/4$ Noise Voltage \rightarrow 2 bit improvement

64 averages \rightarrow $1/8$ Noise Voltage \rightarrow 3 bit improvement

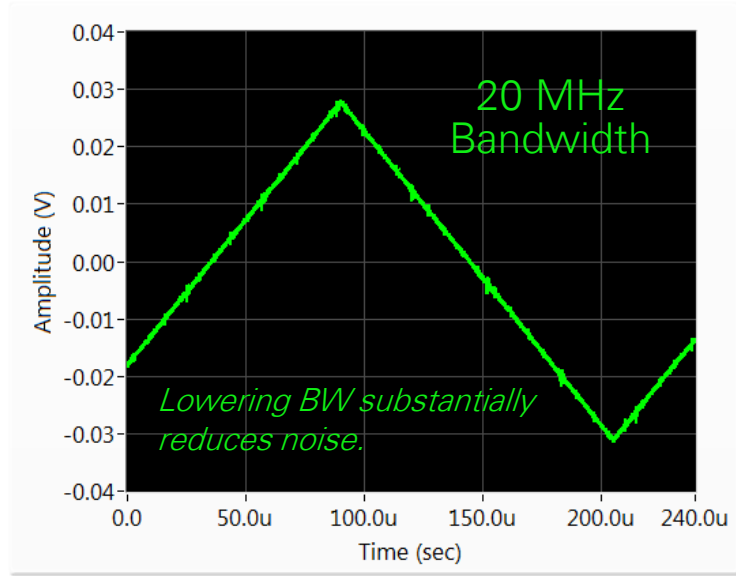
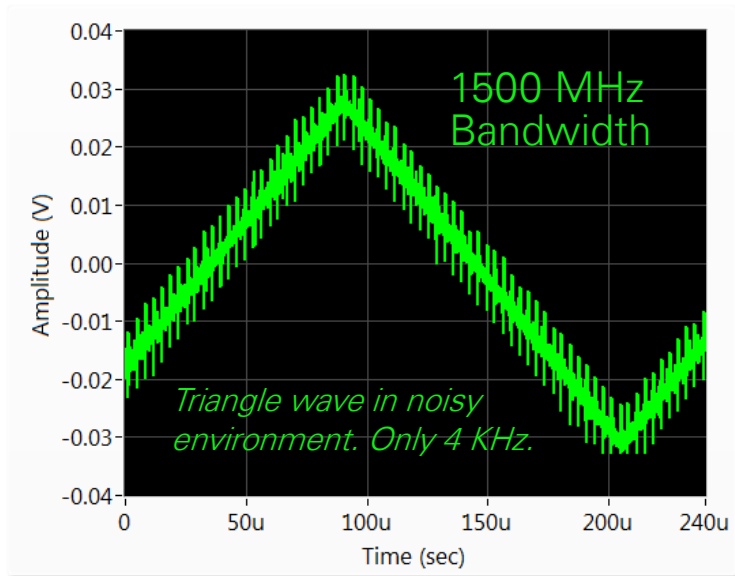
... 256 averages \rightarrow 4 bit improvement

- Ultimately limited by ADC quantization effects and correlated noise



Bandwidth Limited Filters

- Eliminates noise above the frequency range of interest



Memory & Sampling Modes

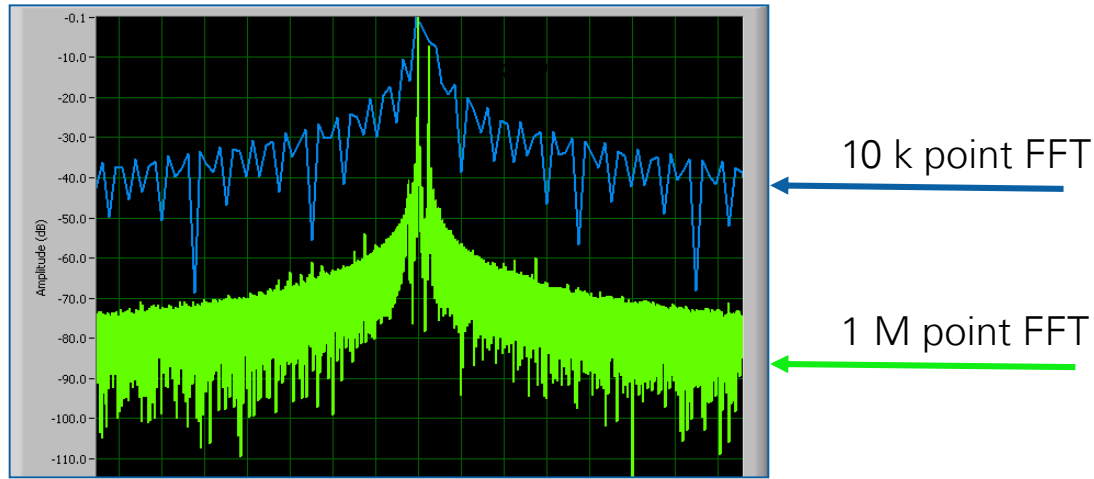
Memory Depth

- A function of Sample rate
- The more memory, the longer a sample can be acquired at a given sample rate
- $\textit{Time Interval} = \frac{\textit{Onboard Acquisition Memory}}{\textit{Sample Rate (S/s)}}$

Deep Memory and the Frequency Domain

- Deeper memory on digitizers allows for better FFTs because the FFT resolution increases with record length
- PXI digitizers have tremendous advantage over box scopes when taking large FFTs due to the very fast data transfer rate to the host PC

Frequency Resolution = Sampling Rate / Record Size

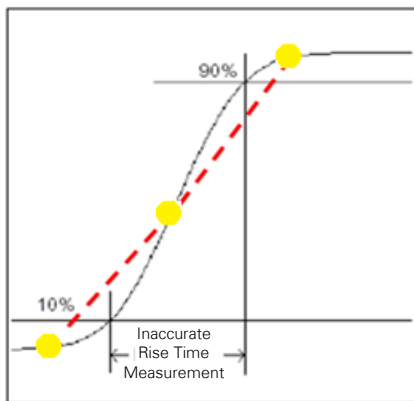


Sampling Modes

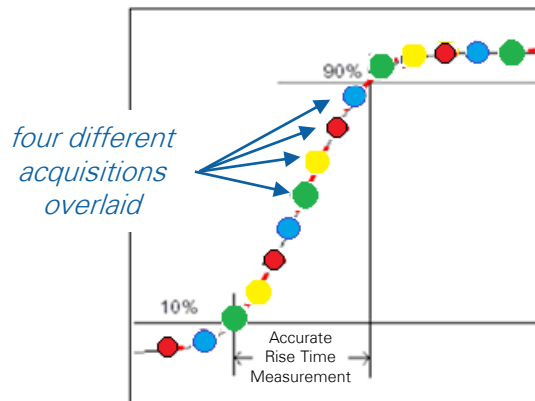
- Real-Time Sampling
 - Standard sampling mode for Scopes/Digitizers/DAQ Boards
- Random Interleaved Sampling (RIS)
 - Construct waveform by overlaying multiple acquisitions of a repetitive waveform
 - Increases apparent sample rate

Random Interleaved Sampling (RIS)

- Apparent sample rate increased by 10X or more
- Accomplished by overlaying triggered acquisitions
- *Repetitive signal required!* — not for one-time events
- Also called “Equivalent-Time Sampling” (ETS)



Real Time Sampling Example



Random Interleaved Sampling Example

Takeaways

- Probing
 - Always compensate passive probes or cable dividers
 - Reduce length of ground lead
- Systems
 - Be aware of how your system affects your measurement
- Small Measurements
 - Maximize sensitivity setting to lower noise
 - Average to reduce unwanted noise
 - Enable noise filters to reduce unwanted noise
- Bandwidth
 - 3-5x highest frequency component
- Sampling modes
 - RIS only usable for repetitive signals