NATIONAL INSTRUMENTS™

From the Designers:
Optimize Scope Measurements and Features

Bill Driver

Senior Product Manager

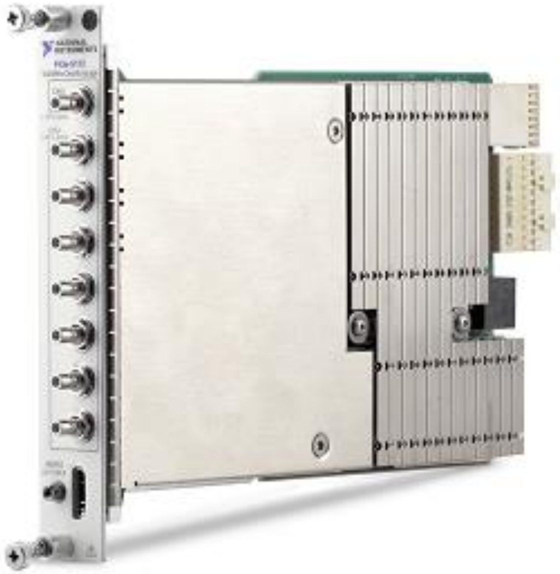
Agenda

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

PXI Oscilloscope

NI 5162
5GSps, 1.5GHz

NI 5164
1GSps, 400MHz



NI 5172
250MSps, 100MHz

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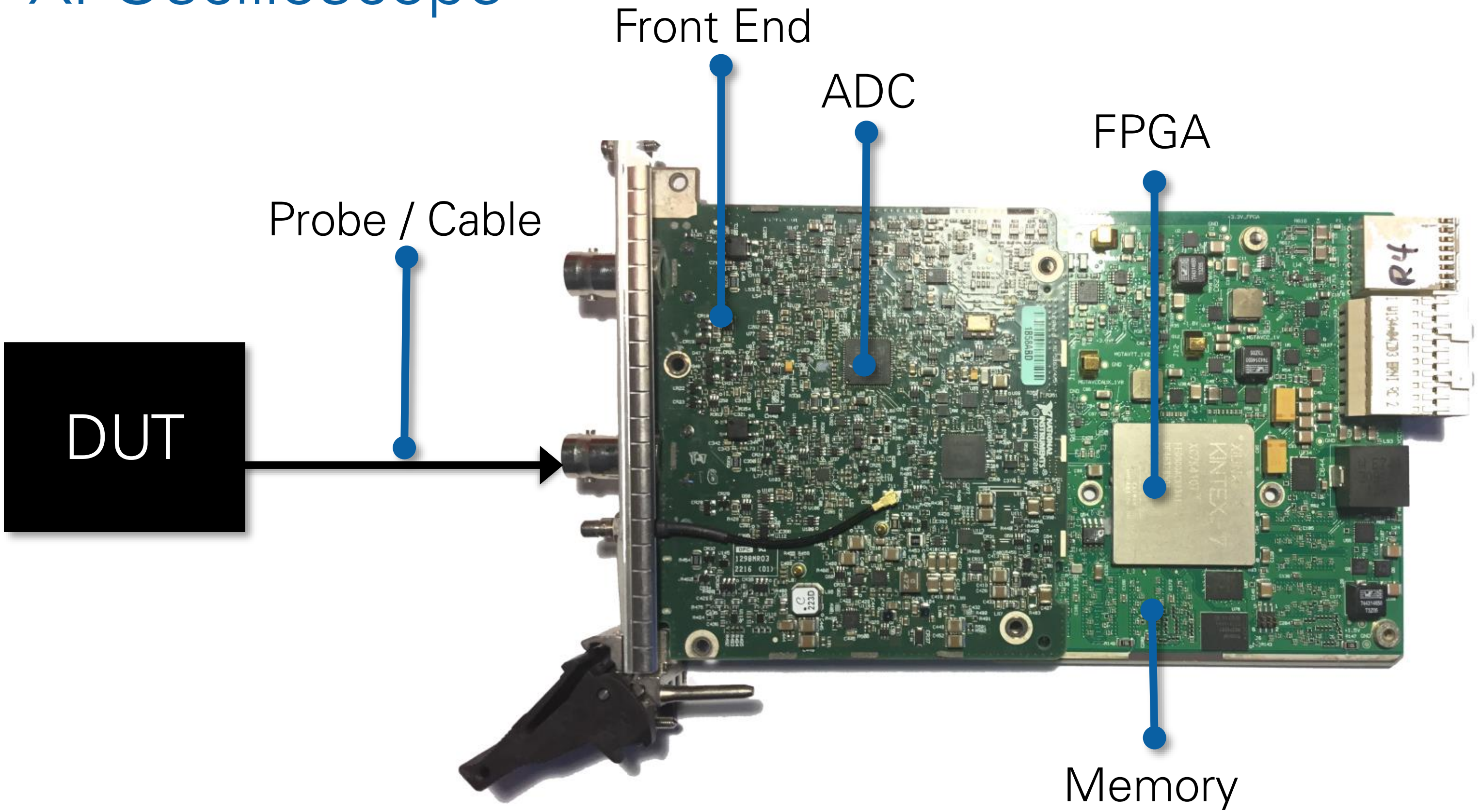
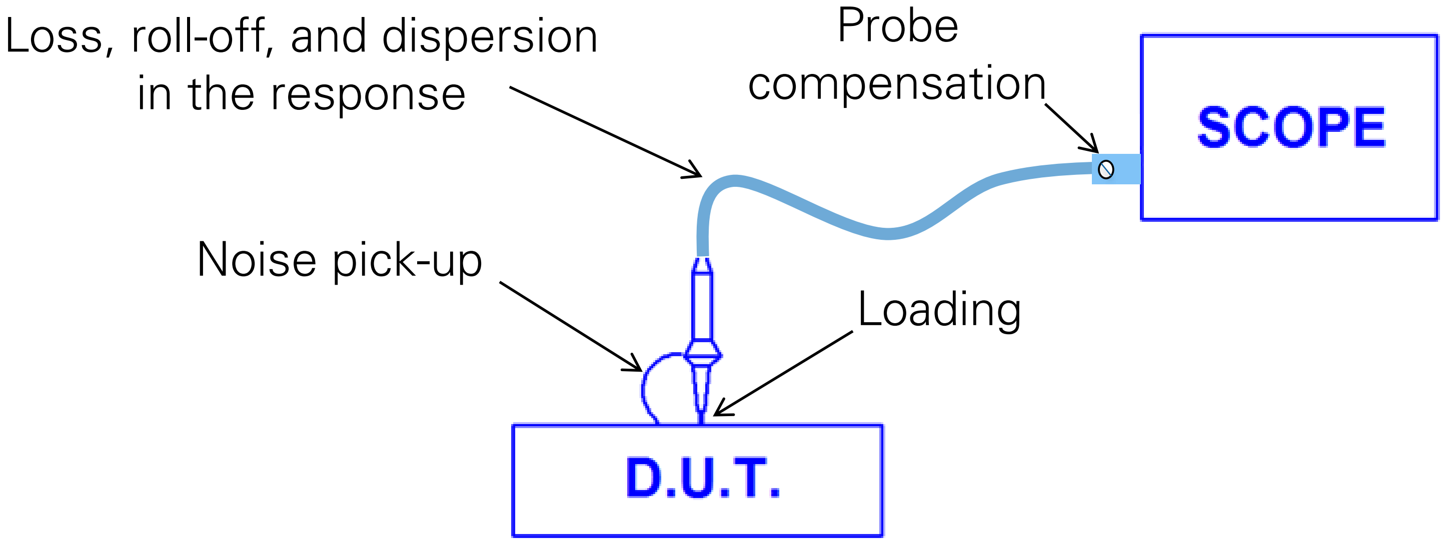
PXI Oscilloscope



Probing

Probing


Loss, roll-off, and dispersion
in the response
Probe
compensation
SCOPE
Noise pick-up
Loading
D.U.T.

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	1MΩ	50Ω
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 pF ||10 MΩ (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, 11pF||10MΩ tip

SP500C:
100:1, 500MHz,
300V max, 4.6pF||100MΩ tip

CP500X:
1.2m length, 10:1, 500MHz,
10pF||10MΩ tip

CP400X:
2m length, 10:1, 400MHz,
13pF||10MΩ tip

NI Active Probes

- Single ended and differential
- Up to 2.5 GHz bandwidth
- Voltages
  - SE: ±8V
  - Differential: ±15V Differential, ±30V Single-ended
- Tip impedance: 1 pF || 50 Ω (typical)
- Scope is always set to 50 Ohm

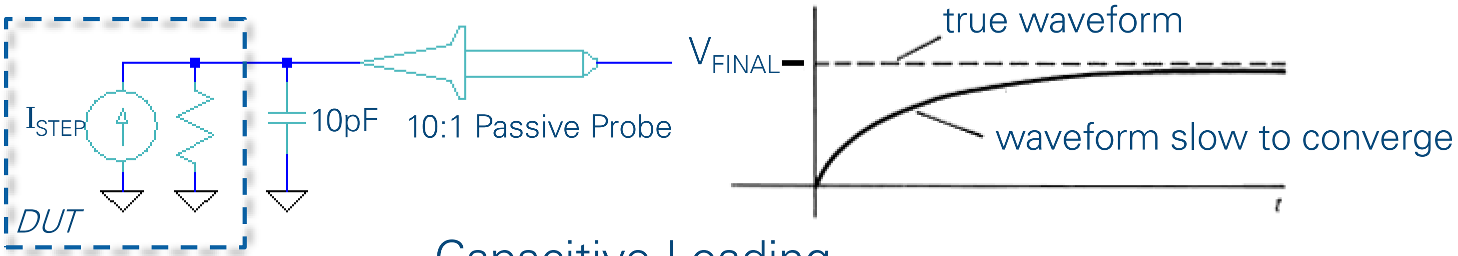
SA1000X:
10:1, 1 GHz,
±20V max, 0.9pF||50Ω tip

SA1500X:
10:1, 1.5 GHz,
±20V max, 0.9pF||50Ω tip

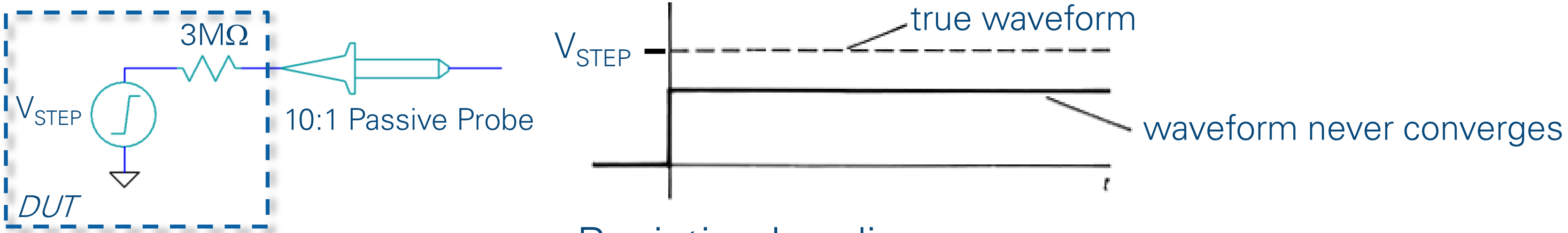
SA2500X:
10:1, 2.5 GHz,
±20V max, 0.9pF||50Ω tip

NI 5191:
800 MHz,10:1
2pF||100kΩ tip

Probe Loading



Capacitive Loading



Resistive Loading

Probe Loading: Coax Cable vs. Passive Cable Divider

1.2m Length RG58 Cable:
Heavy loading: $C_{LOADING}$ = 112pF

1.2m Length Cable Divider Probe (NI CP500X) :
Light Loading: $C_{LOADING}$ = 10pF

BNC connector for DUT end.

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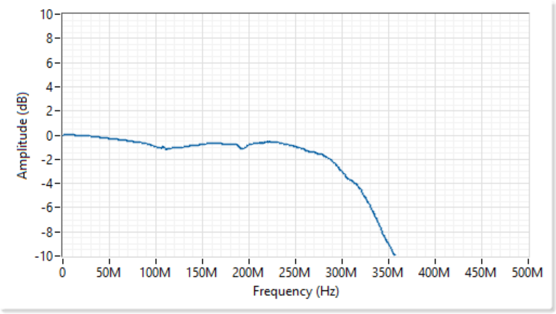
Passive Probe Connectivity

=

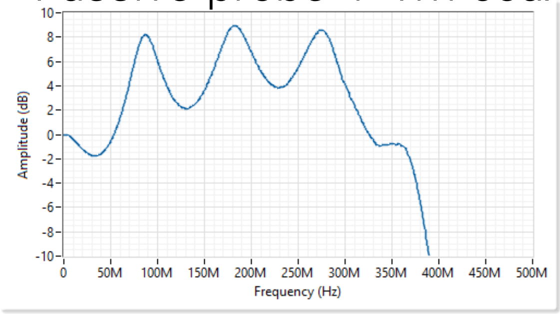
Passive probe



+

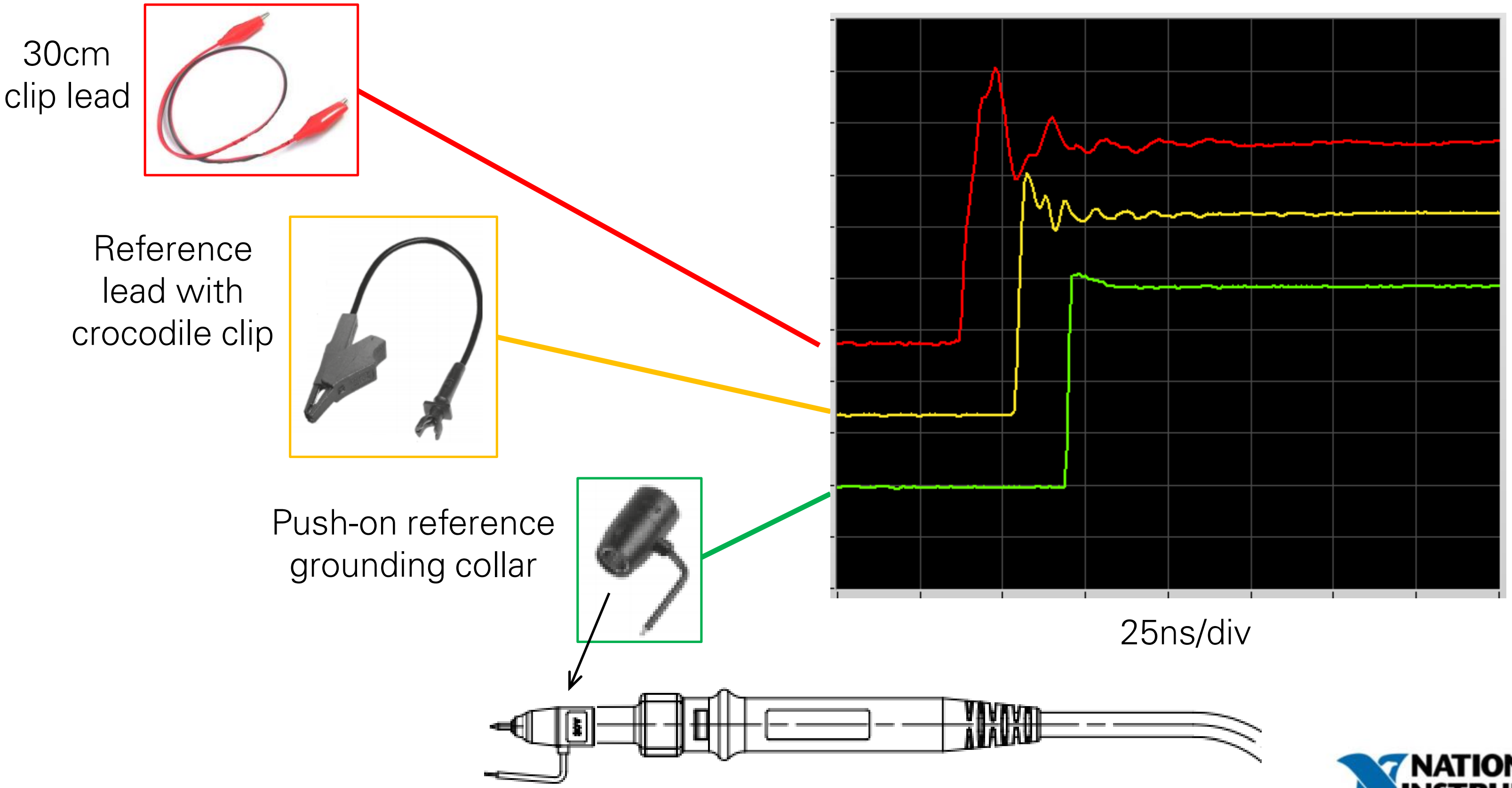
=

Passive probe + 1m coax



Passive Probes with coax cables should not be combined

Probing: Minimize Ground Lead Inductance



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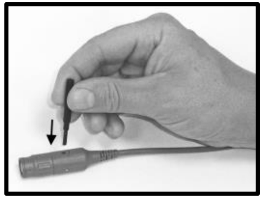
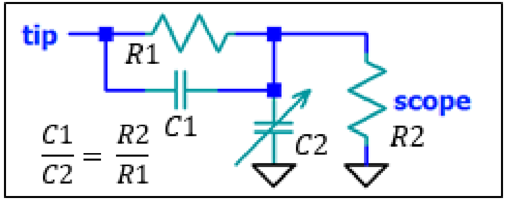
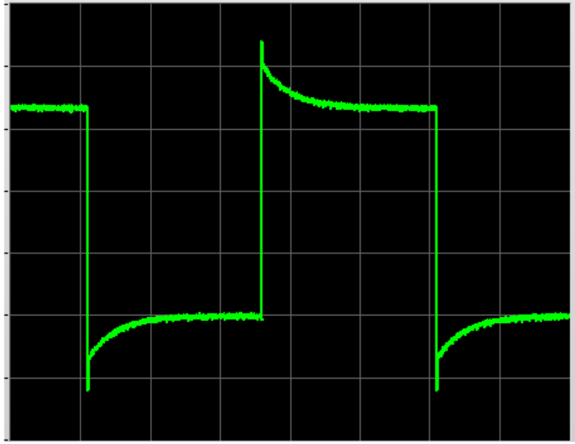
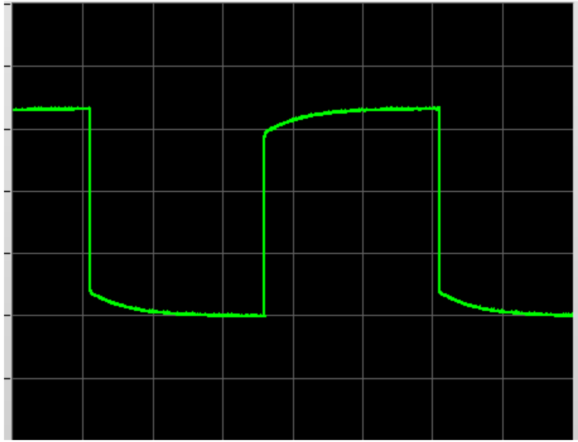
Passive Probe Compensation



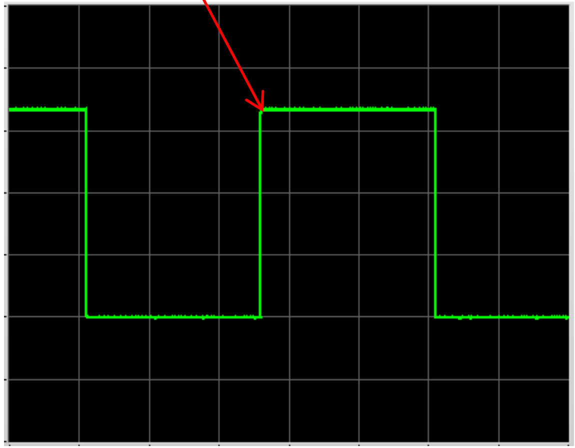




Overcompensated

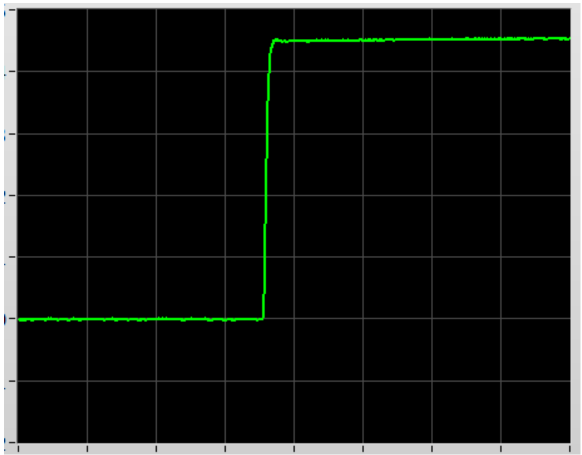


Undercompensated

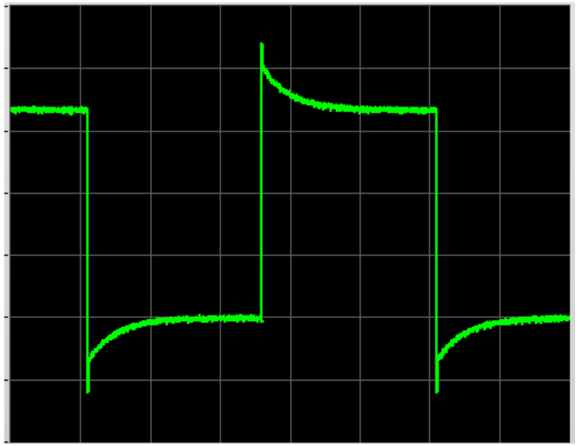


Properly Compensated

Passive Probe Compensation – Time Duration



200ns/div

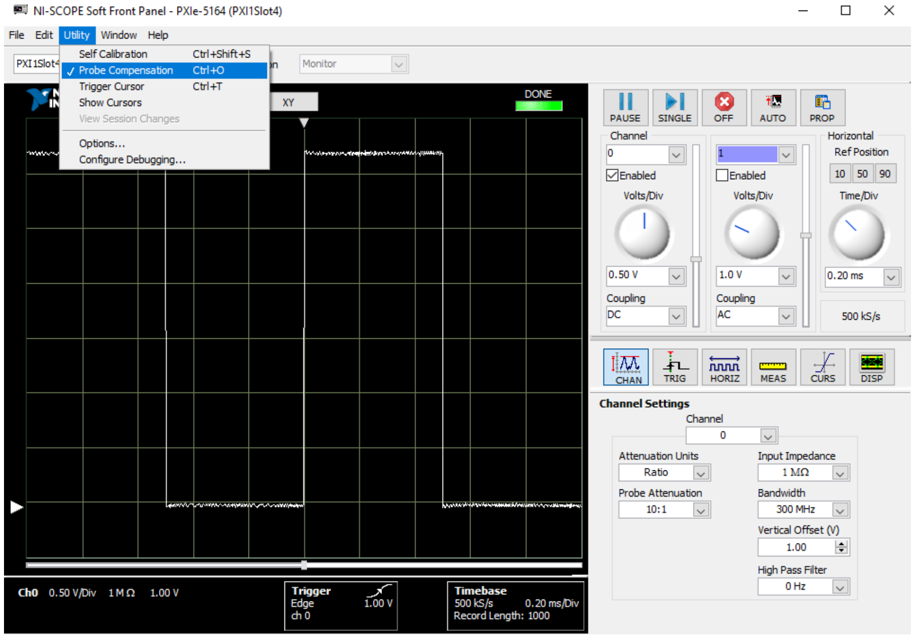


200us/div

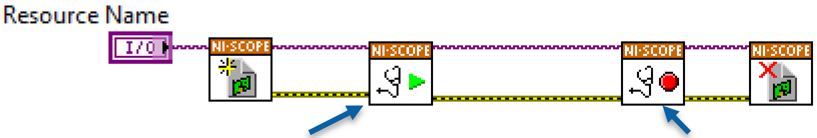
Amplitude error is 25%!!!

How To Compensate a NI PXIe Oscilloscope

- NI-SCOPE Soft Front Panel



NI LabVIEW



Start Cal Pulse

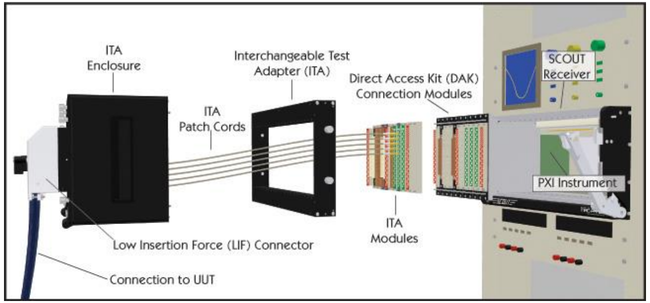
Stop Cal Pulse

Calibration pulse is generated on PFI0

System

Mass Interconnects

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



Images courtesy of Mac-Panel

Image courtesy of Virginia Panel

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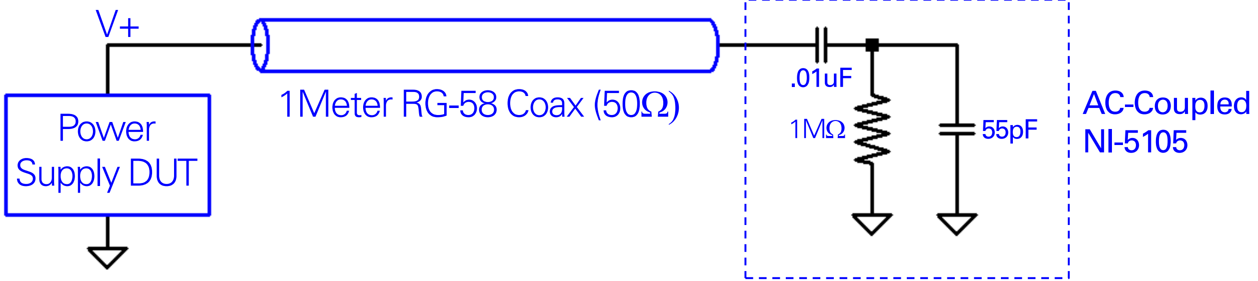
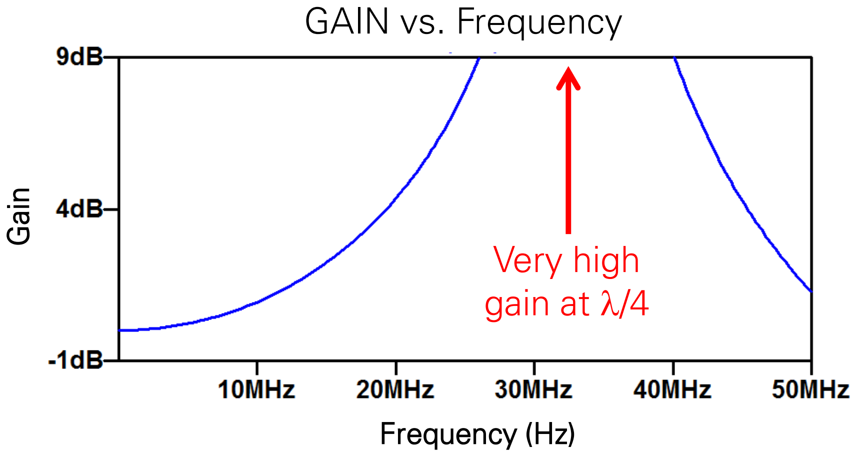
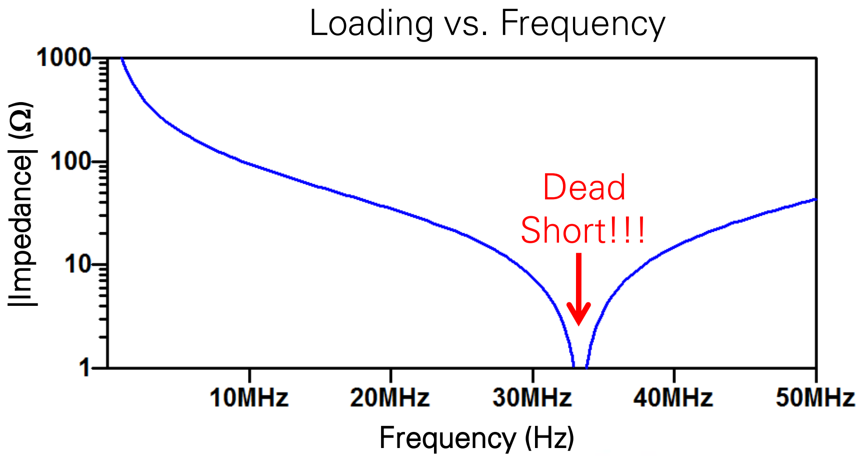
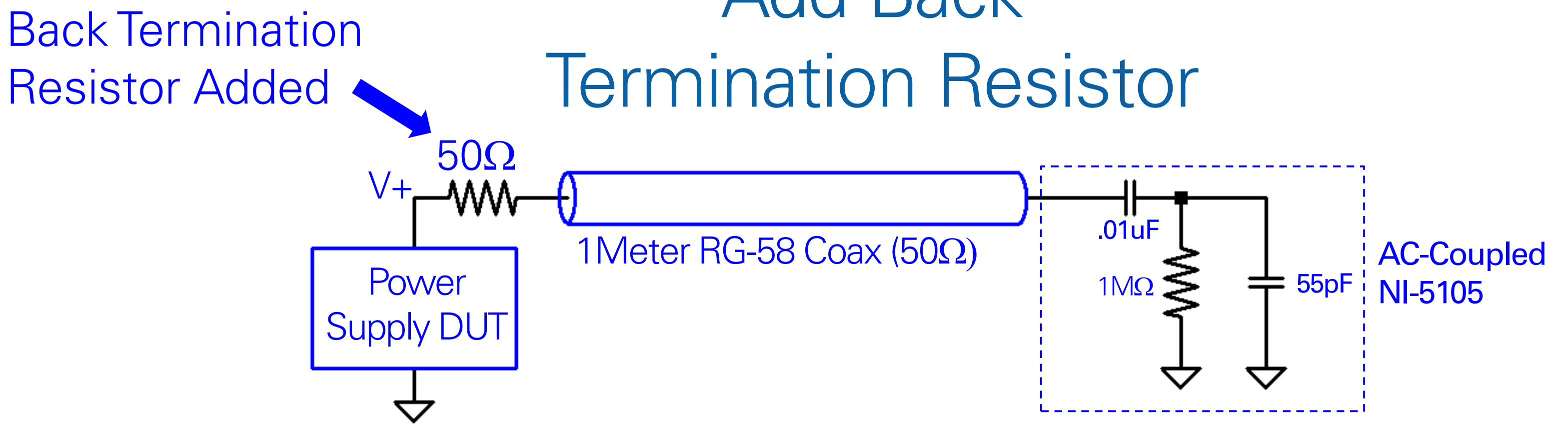
Measuring Power Supply Noise Using Only Coax



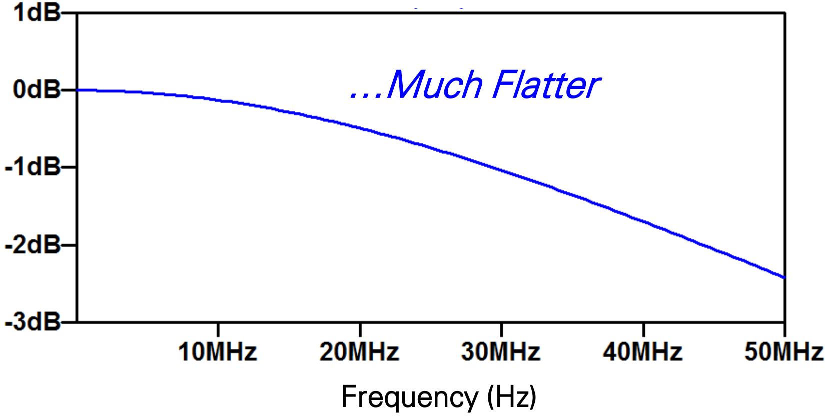




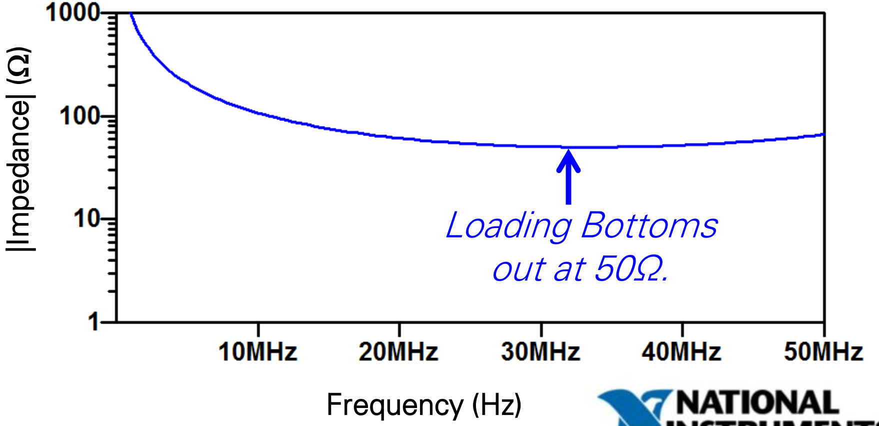
Add Back Termination Resistor



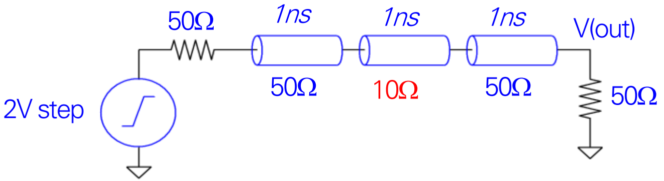
GAIN vs. Frequency



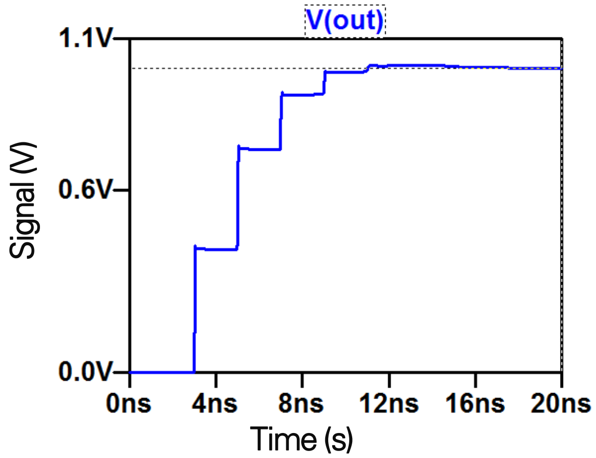
Loading vs. Frequency

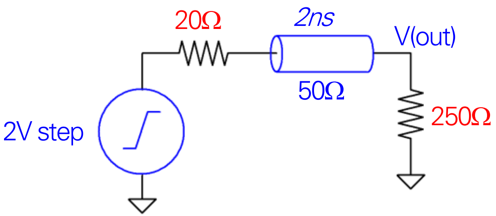


Transmission Line Systems: Impedance Mismatch

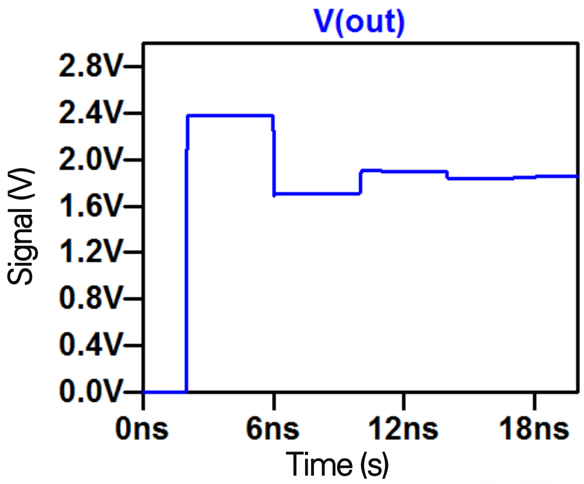


Characteristic Impedance Change Along Signal Path





Source/Load Mismatch



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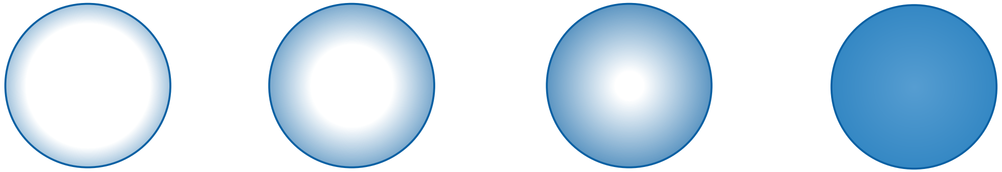
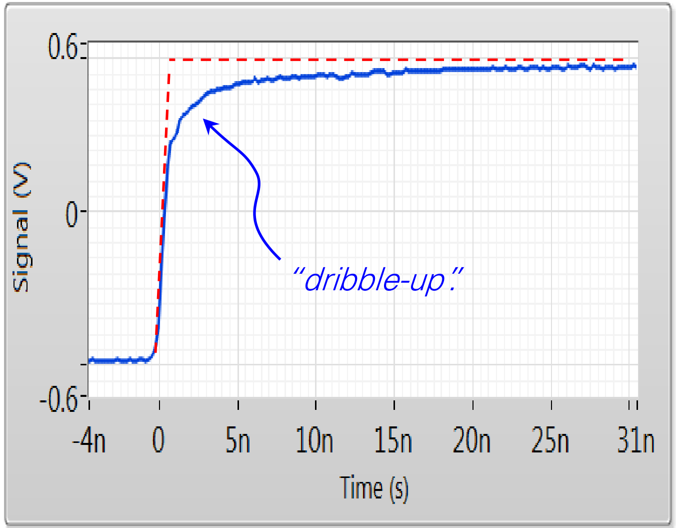
Transmission Line Systems: Skin Effect



$t=100ps$	$t=1ns$	$t=10ns$	$t=\infty$
$10\Omega/m$	$1\Omega/m$	$0.2\Omega/m$	$0.033\Omega/m$

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".



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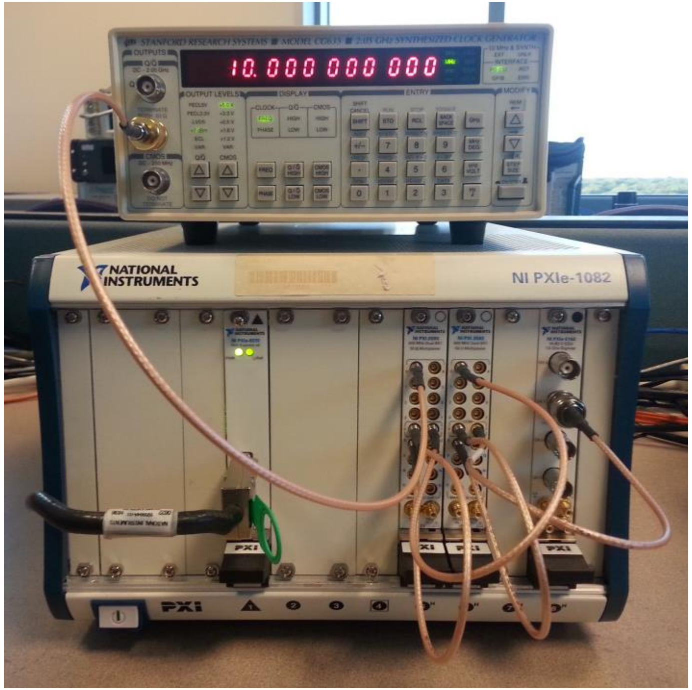
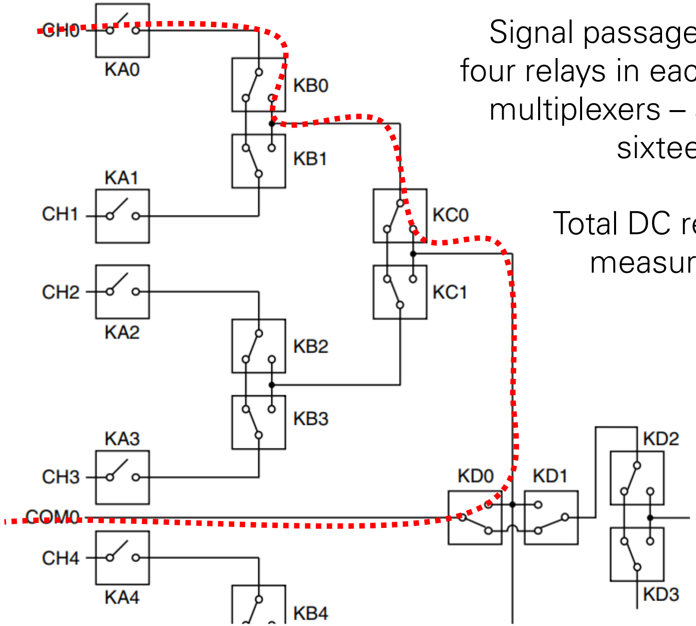
Example: Loss in Relay Matrices



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

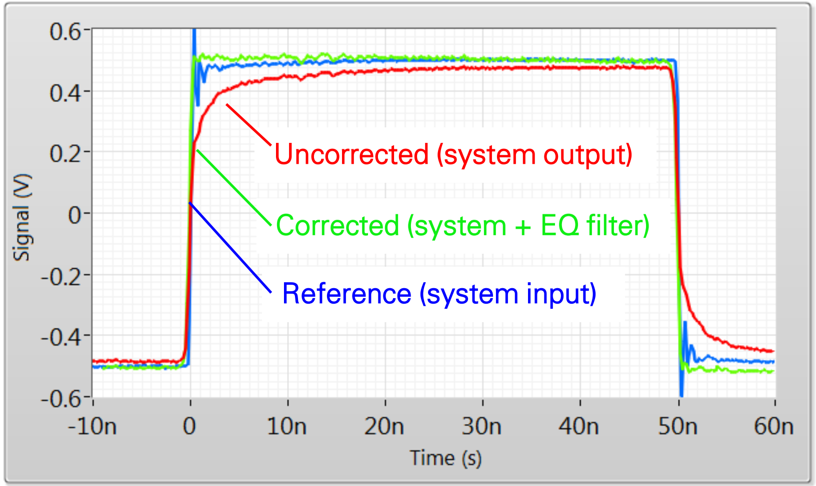


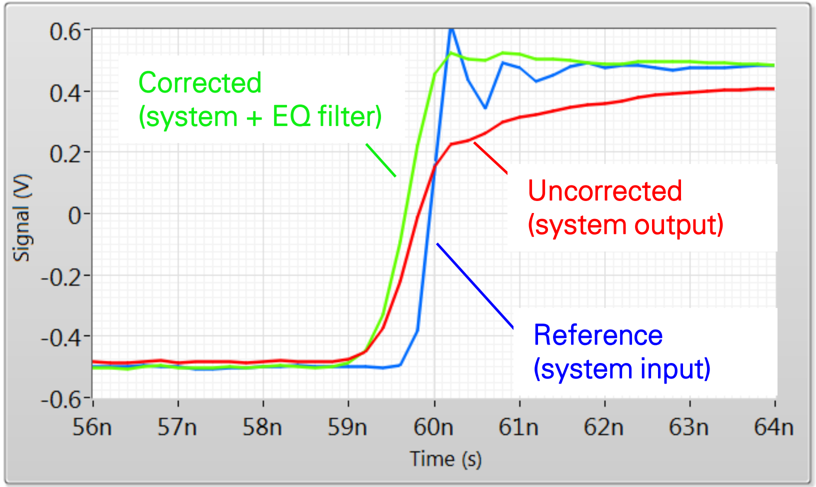
Signal passage through four relays in each of four multiplexers – a total of sixteen relays.

Total DC resistance measured: 2.5Ω.

One of Four

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





Zoomed-in View of Rising Edge

time constants: 1.00n, 16.00n

weightings: 0.3920, 0.0980

gain: 1.031

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

Gain error correction needed
due to DC resistance in path.

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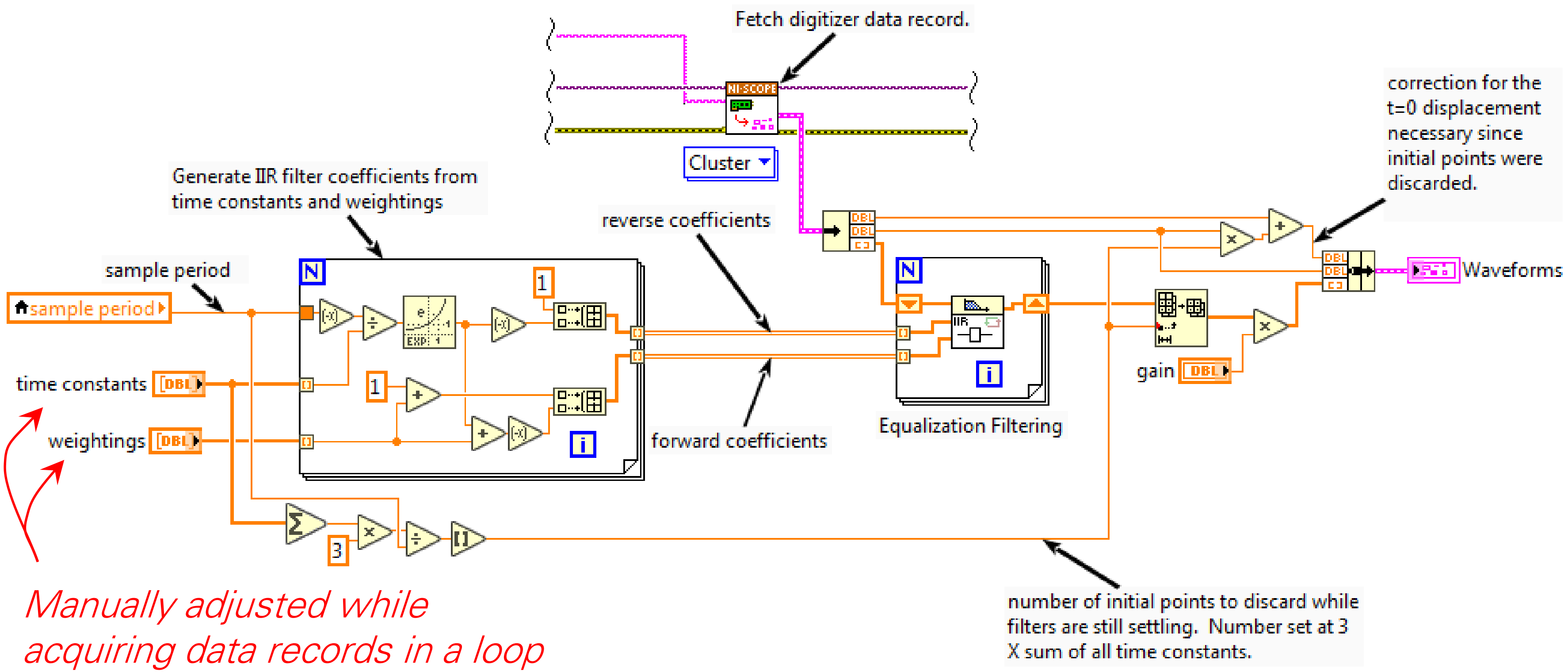
Simple Equalization VI



Manually adjusted while acquiring data records in a loop

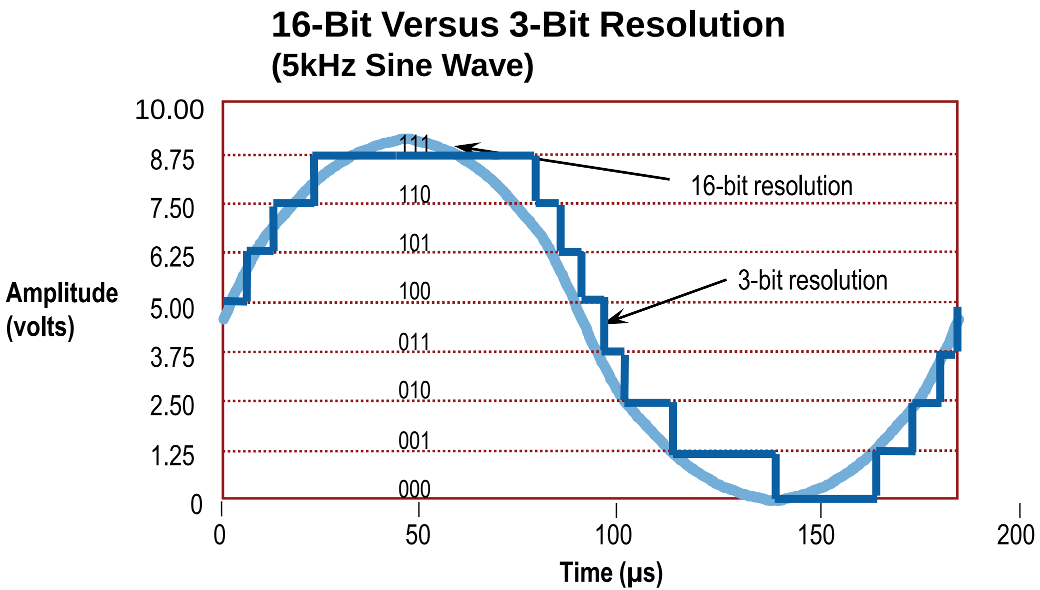
Specifications

Specification Basics

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

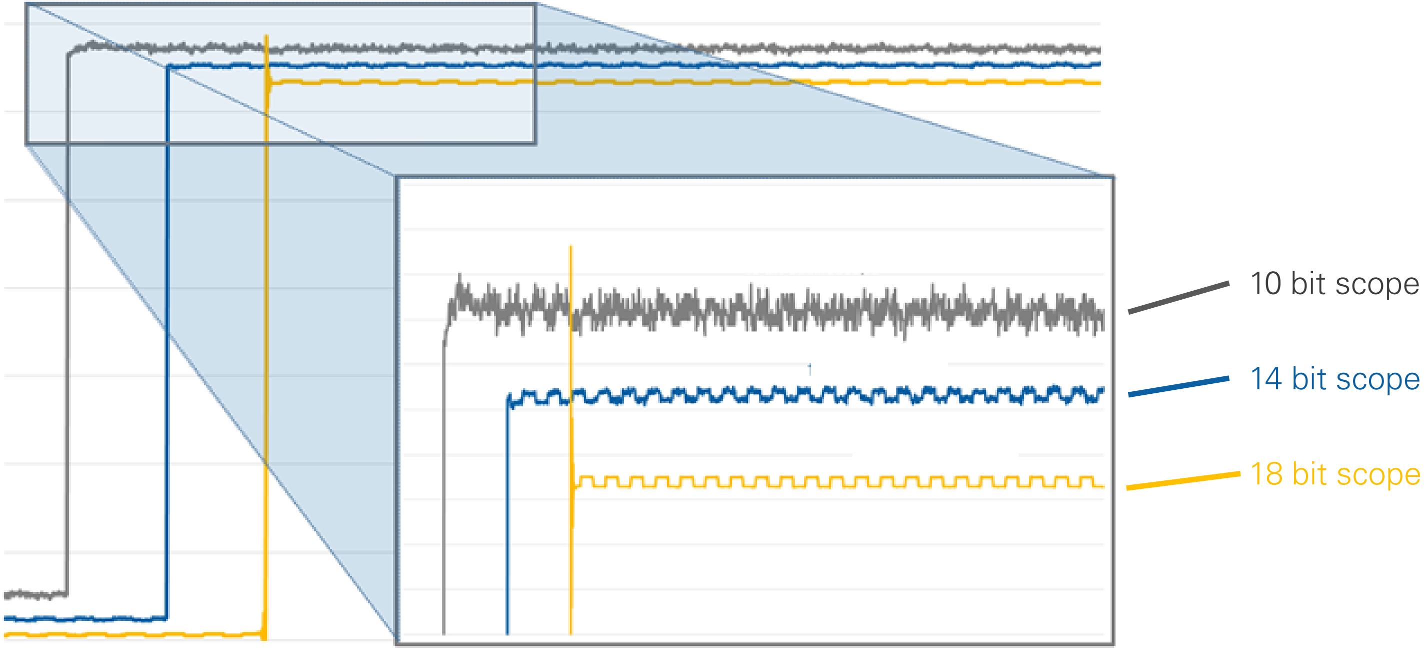
ADC Resolution

- 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

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

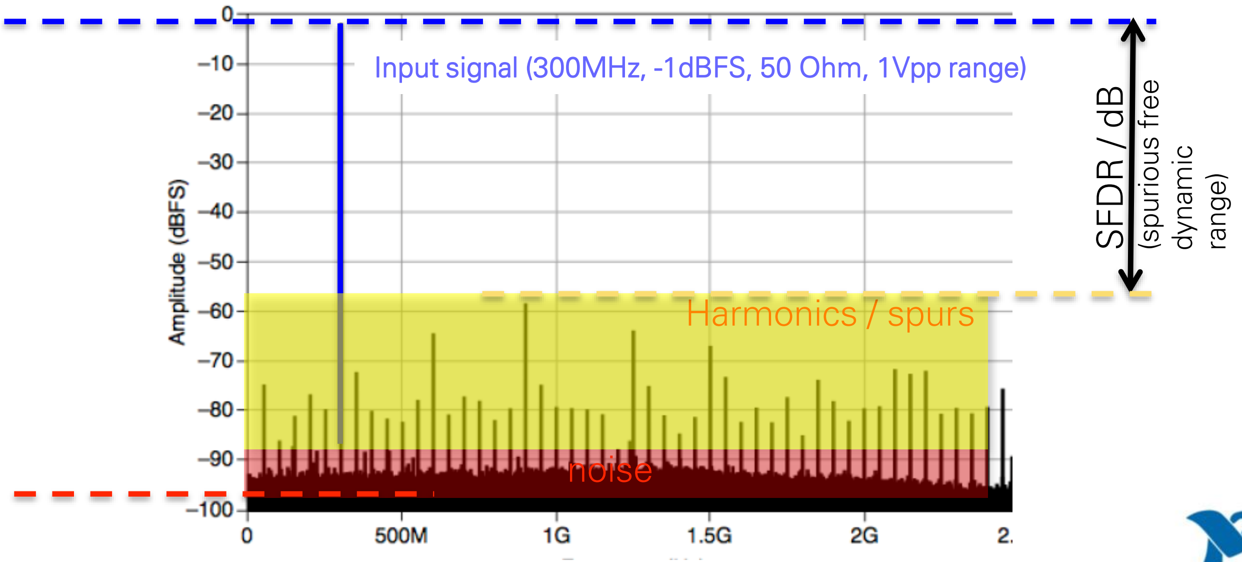
- Expresses the scope's true resolution
- Derived directly from SINAD, Signal to Noise + Distortion
- ENOB can be affected by:
  - Higher instrument bandwidth
  - Higher input frequency
  - Lower instrument resolution
  - High impedance vs 50 Ohm input
  - Sensitive input ranges

Spectral – Frequency Domain

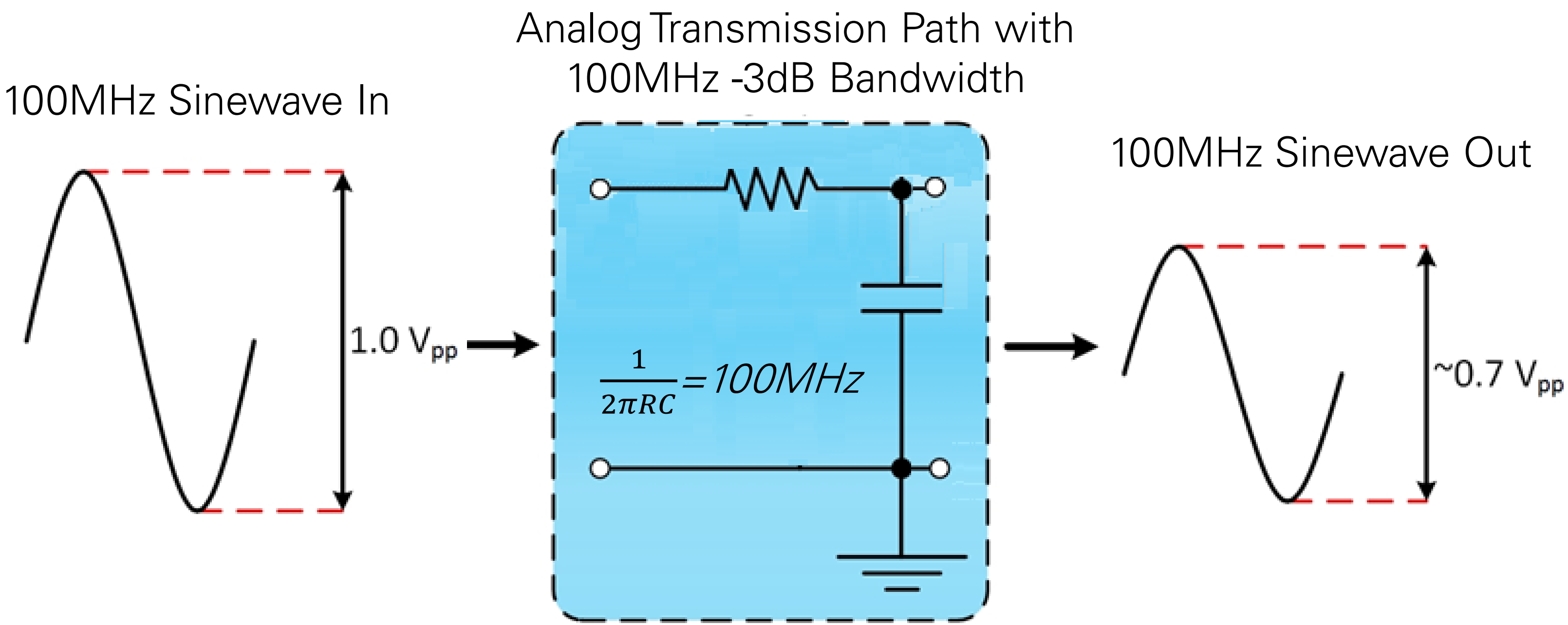
Signal to Noise Ratio (SNR) = *20log((Full Scale Sine Input rms)/(noise rms))* [dBFS]

Signal to Noise+Distortion (SINAD) = *20log((Full Scale Sine Input rms)/(noise rms+harmonics rms))* [dBFS]

Spurious Free Dynamic Range (SFDR) = *20log((Full Scale Sine Input rms)/(strongest spur spectral line))* [dBc]



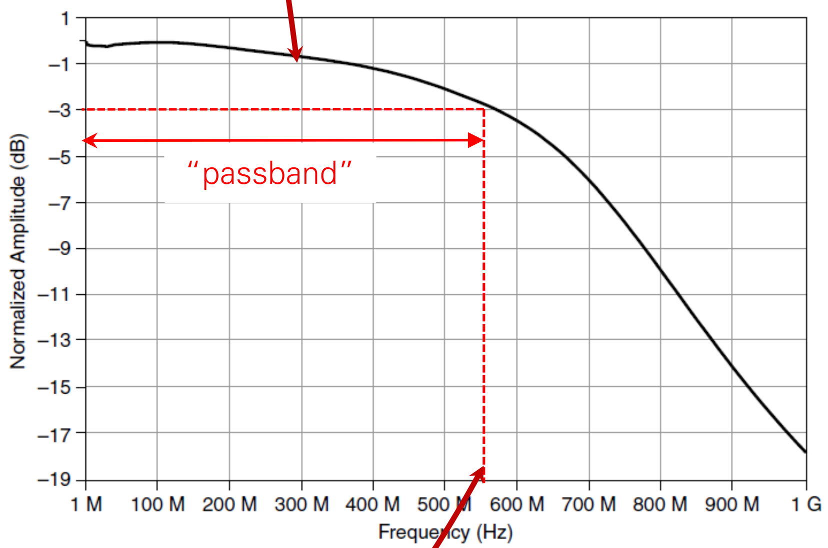
Bandwidth


100MHz Sinewave In
1.0 Vpp
Analog Transmission Path with
100MHz -3dB Bandwidth
$\frac{1}{2\pi RC} = 100MHz$
100MHz Sinewave Out
~0.7 Vpp

Bandwidth of NI Instrument

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

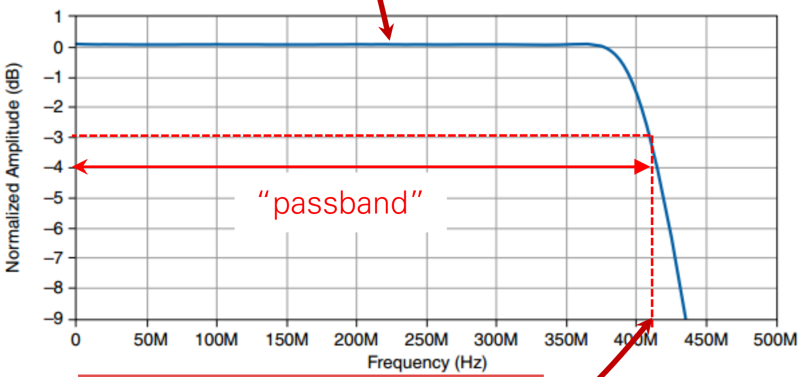
Figure 3. NI 5160 50 Ω Frequency Response, 1 $V_{pk\text{-}pk}$, 2.5 GS/s, Characteristic



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

Very flat response to 350MHz

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



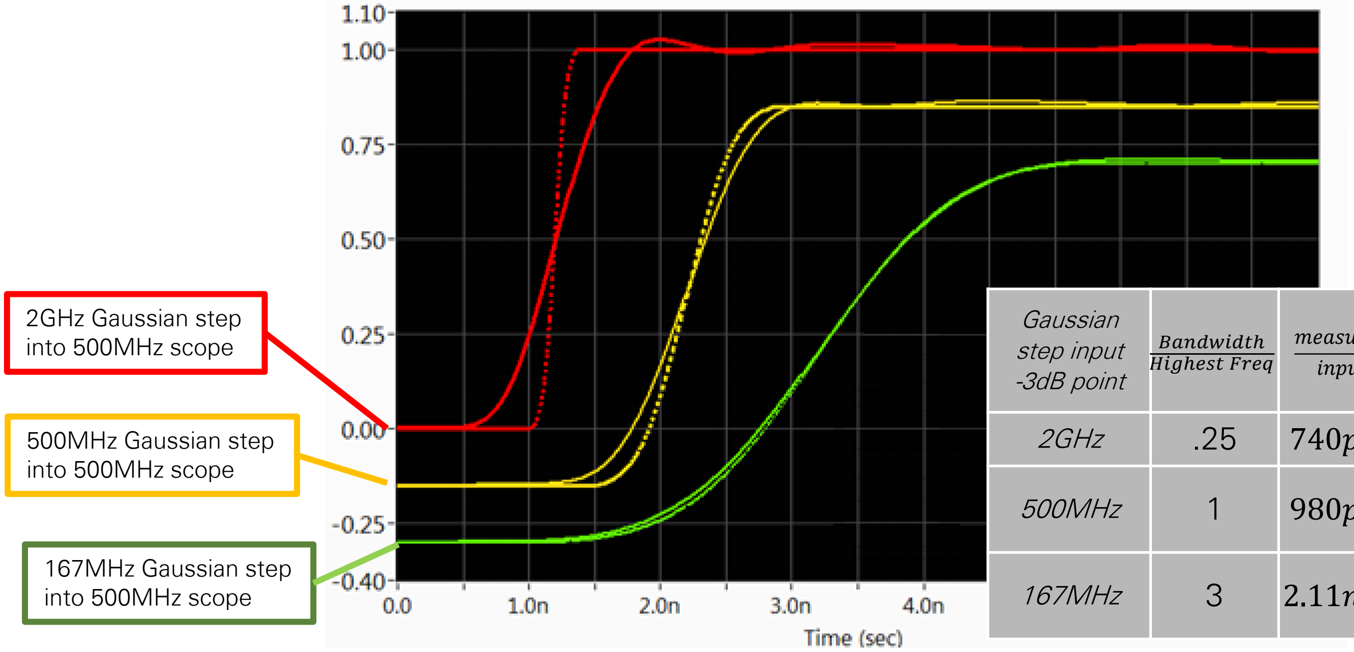
415MHz, margin: product spec'd at 400MHz.

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



Gaussian step input -3dB point	$\frac{\textit{Bandwidth}}{\textit{Highest Freq}}$	$\frac{\textit{measured risetime}}{\textit{input risetime}}$	Error
2GHz	.25	$740ps/180ps$	416%
500MHz	1	$980ps/700ps$	40%
167MHz	3	$2.11ns/2.00ns$	4.4%

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

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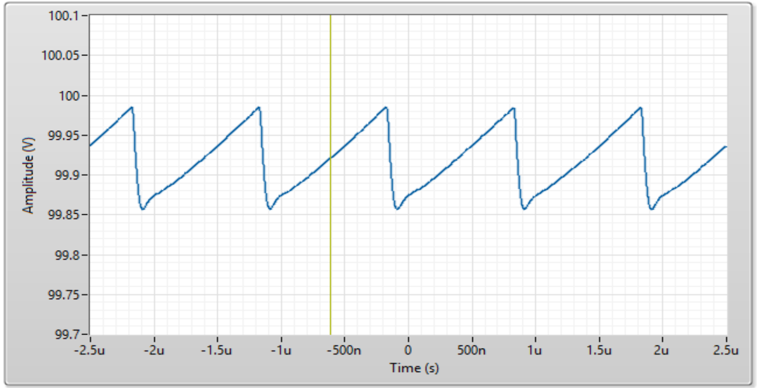
When Examining Details on Large Offset

- 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



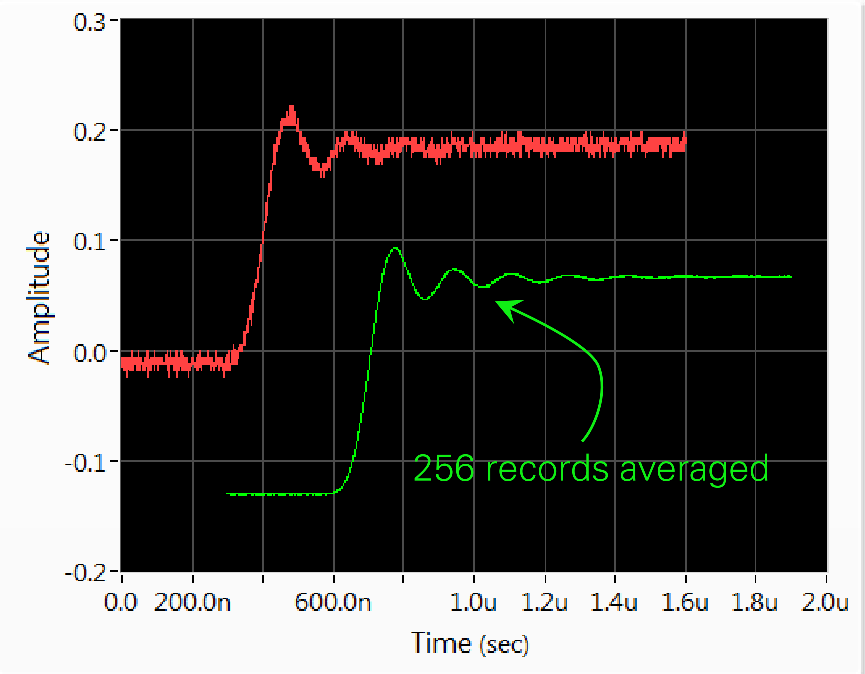
Using 2.5V input range to measure 100V input
NI 5164

Averaging to Reduce Noise

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

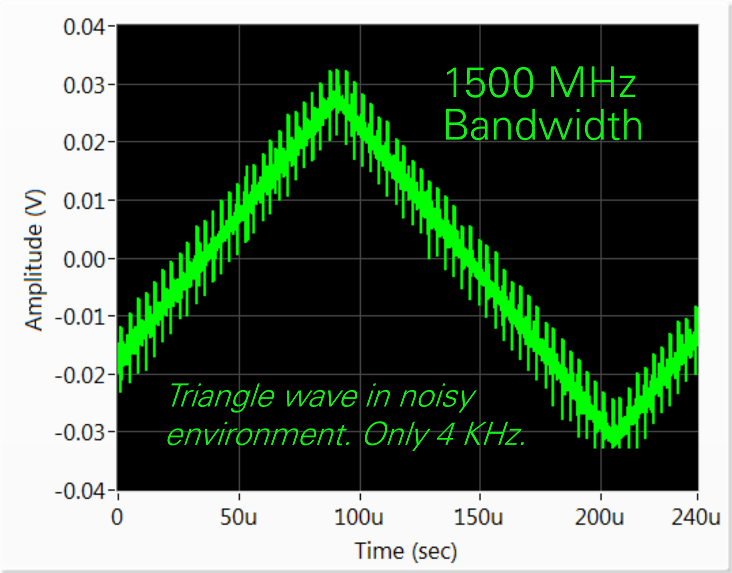
4 averages → $^1/_2$ Noise Voltage → 1 bit improvement
16 averages → $^1/_4$ Noise Voltage → 2 bit improvement
64 averages → $^1/_8$ Noise Voltage → 3 bit improvement
… 256 averages → 4 bit improvement

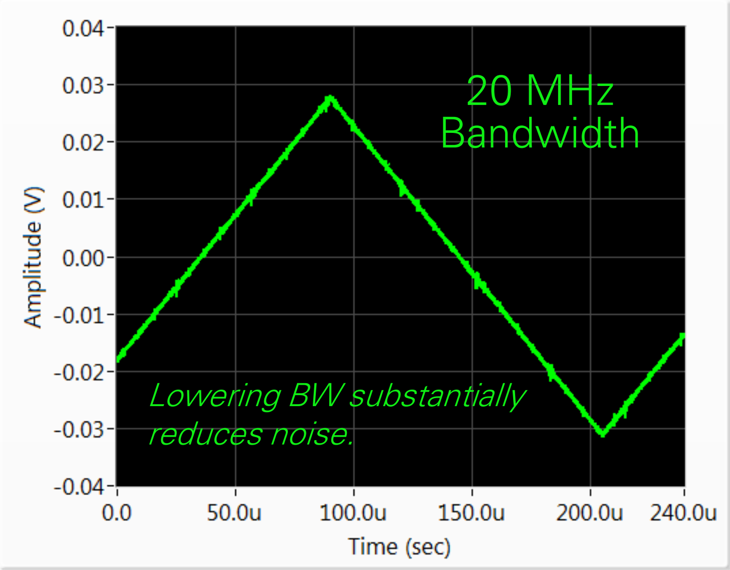
- Ultimately limited by ADC quantization effects and correlated noise



Bandwidth Limited Filters

- Eliminates noise above the frequency range of interest





Memory & Sampling Modes

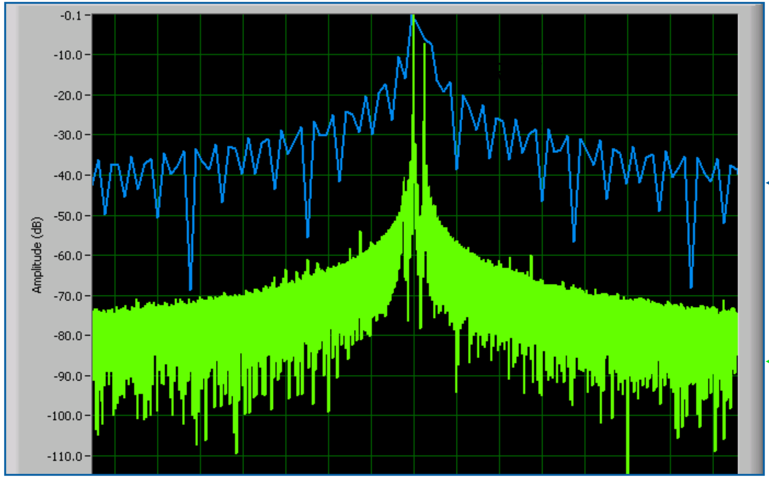
Memory Depth

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

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



10 k point FFT

1 M point FFT

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Sampling Modes

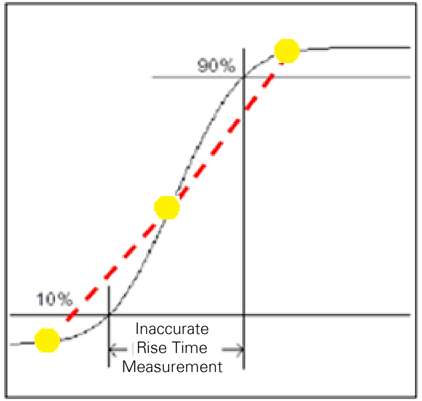
- Real-Time Sampling

  --- Standard sampling mode for Scopes/Digitizers/DAQ Boards

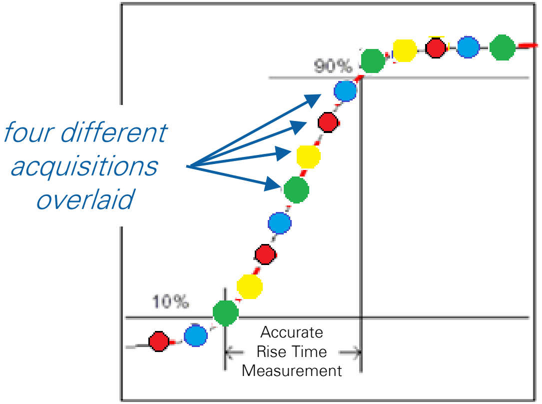
- Random Interleaved Sampling (RIS)
  - Construct waveform by overlaying multiple acquisitions of a repetitive waveform
  - Increases apparent sample rate

Random Interleaved Sampling (RIS)

- Apparent sample rate increased by10X 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