SI & PI Test Using Oscilloscope

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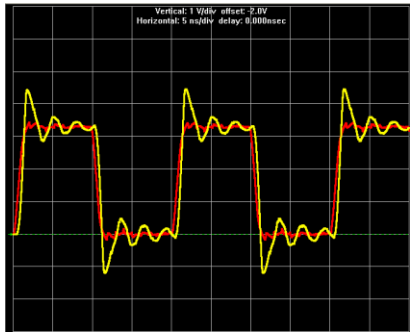
KEYSIGHT TECHNOLOGIES

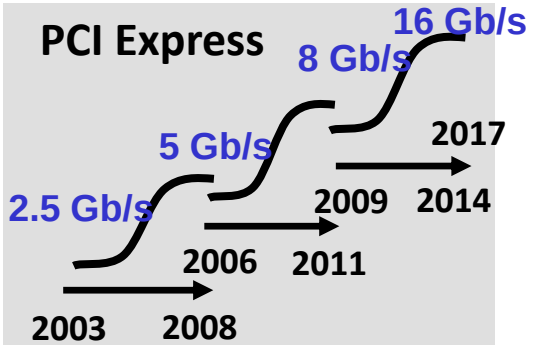
Challenges In Digital Design Today

- **Higher Data Rates Are Causing Signal Integrity (SI) Problems:**
  - Need to include high-frequency effects like interconnects in simulation and layout
  - Need high quality probes and fixtures
  - Need to minimize jitter

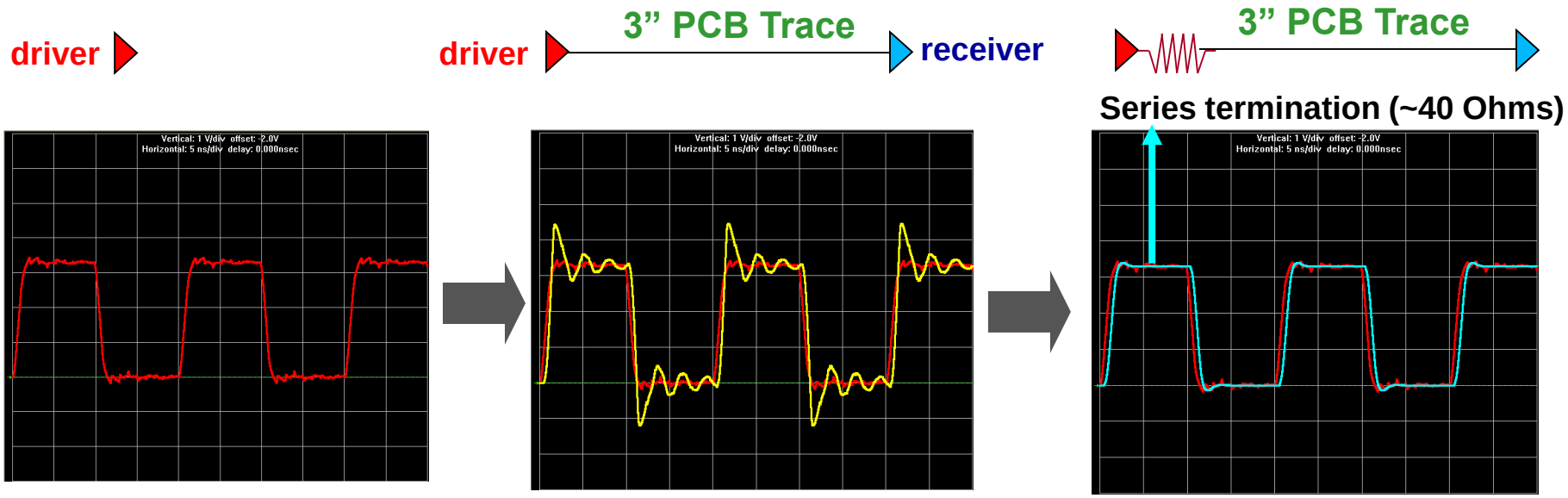


- **FPGAs Are Commonplace:**
  - Can't use a Reference Design without some analysis
  - Harder to simulate the overall performance

- **Standards Evolve Every 2-3 Years:**
  - Measurement requirements get tighter
  - Need to buy new equipment each time



What Is Signal Integrity?



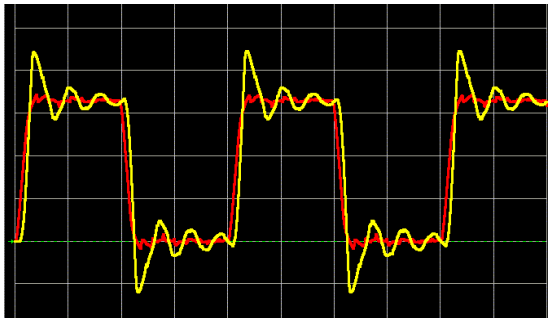
Signal Integrity = Where the electrical properties of the interconnects can cause significant distortions in digital signals.

- >1 GHz of bandwidth
- <1 ns risetime
- Typically >2 Gb/s data rate with embedded clock

Signal Integrity = Paying attention to RF effects, ie. impedance

Four Signal Integrity Problems And Their Causes

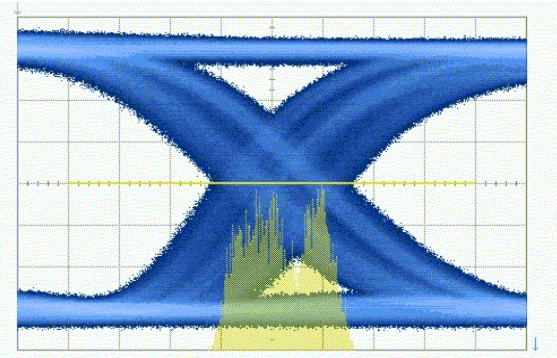
1. Poor signal quality of one net: reflections and distortions from impedance discontinuities in the signal or return path



2. Crosstalk between multiple nets: mutual C and mutual L coupling

3. Rail collapse (Ground Bounce) in the power distribution system: voltage drops across impedance in the power/ground network

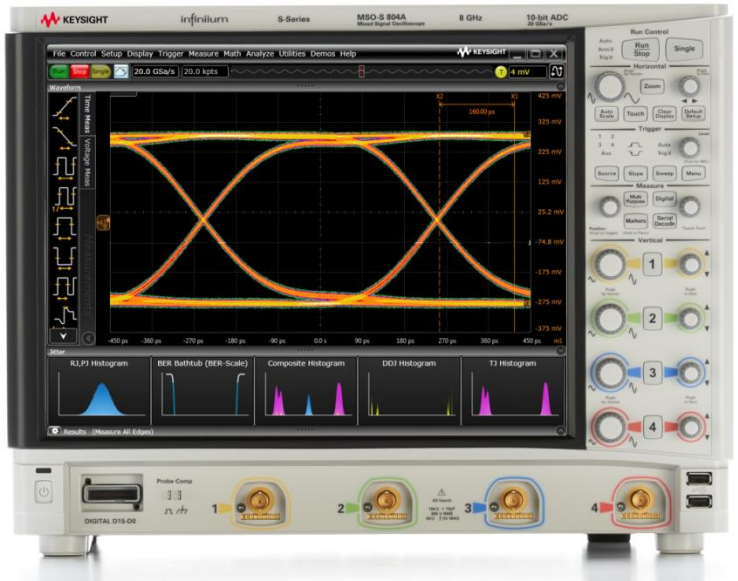
4. Jitter from causes listed above and variety of other sources including clock distribution, data dependent effects, and EMI



The Message is all About

Signal Integrity

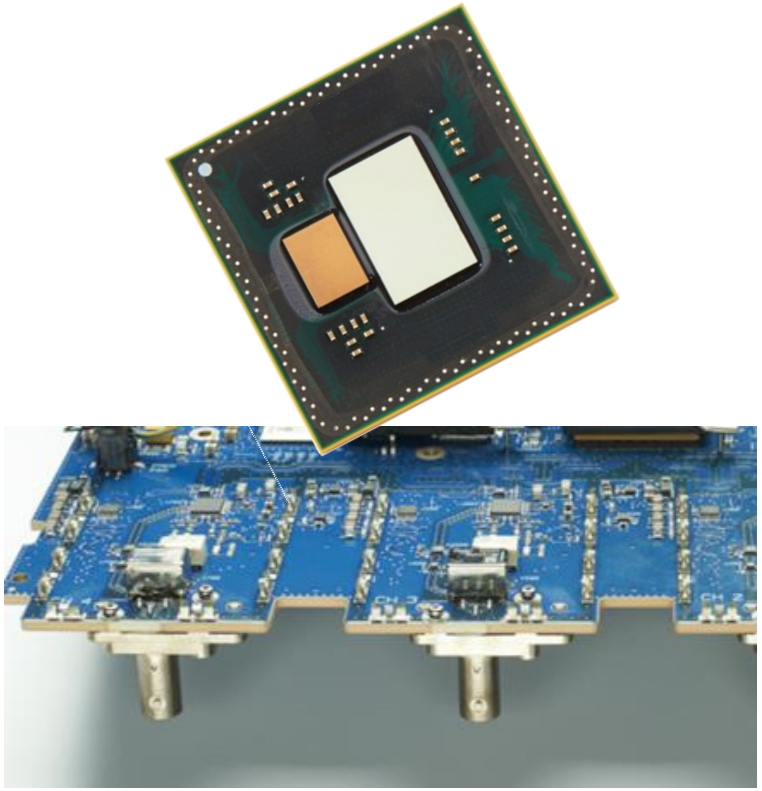
– S-Series
  - “The new standard for superior measurements”
  - “Industries best signal integrity”



World's Fastest ADC + Low Noise Front End

Designed in House

- 10 bits up to 8 GHz
  - 4x the resolution of an 8-bit scope
- 40 GSa/s sample rate
- Up to 8.1 system ENOB
- Low noise front-end designed to support the custom technology inside the scope

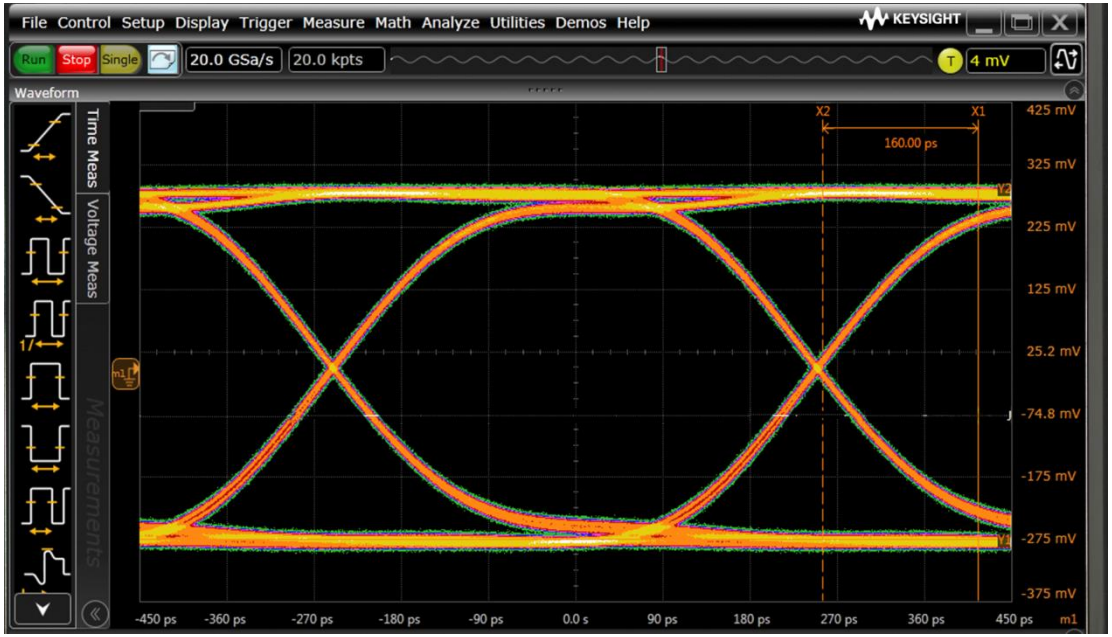


See the signal that your DUT sees without unnecessary noise

KEYSIGHT TECHNOLOGIES

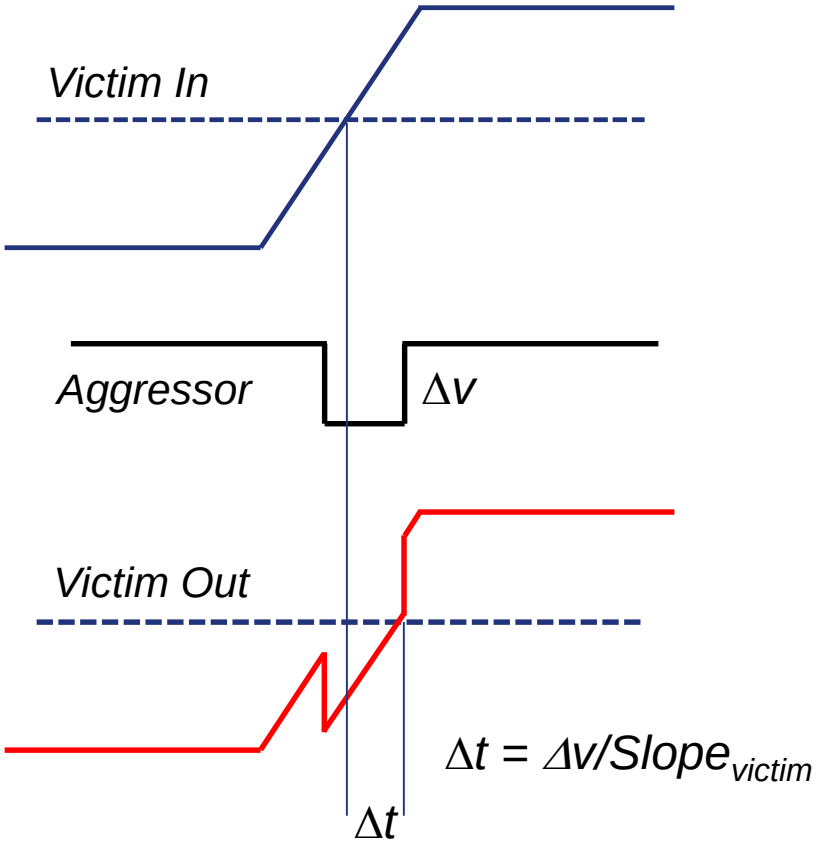
What Difference Does Low Noise, Low Jitter, AND Flat Response Make?

- Accurate measurements
- Repeatable measurements
- Cleaner eye diagrams
- You see what the DUT sees

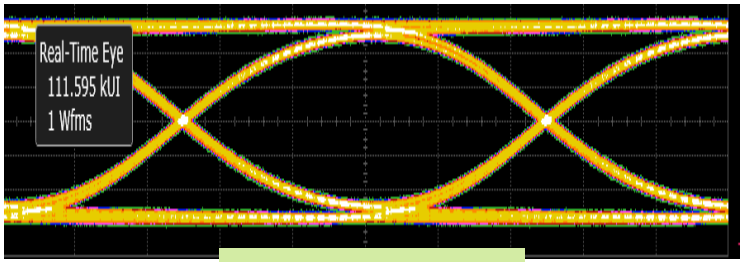


Crosstalk Overview

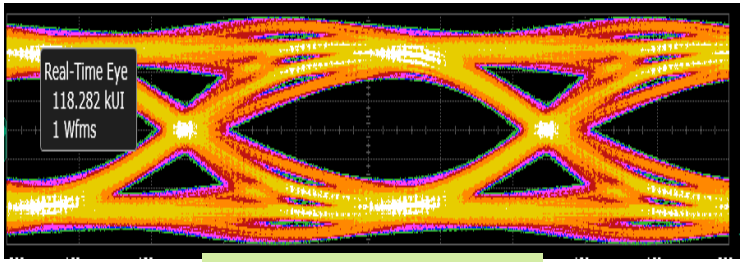
Amplitude interference uncorrelated with data pattern.



Impact on Eye



No crosstalk

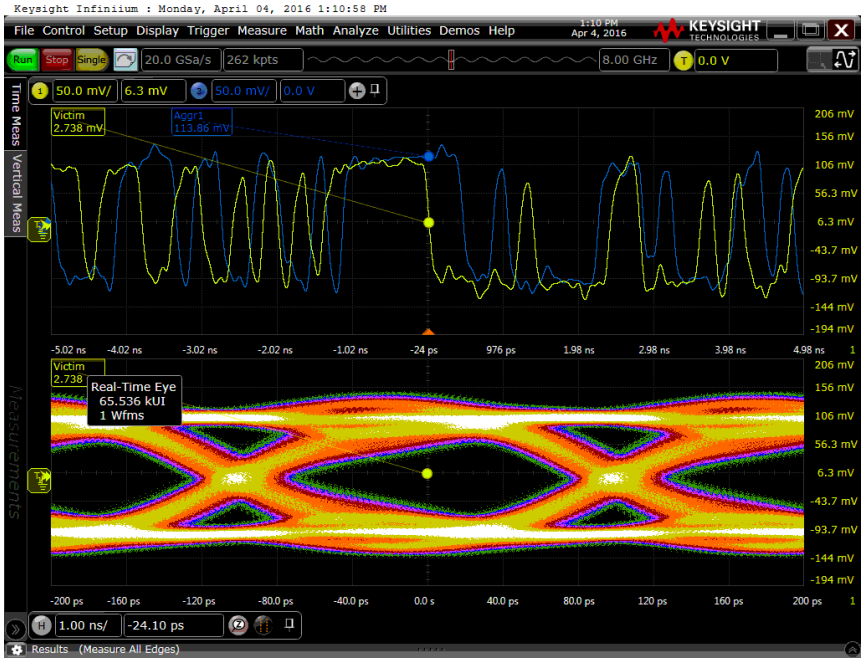


With crosstalk

Far-End Crosstalk (FEXT)

No Serial Aggressor

FEXT Serial Aggressor

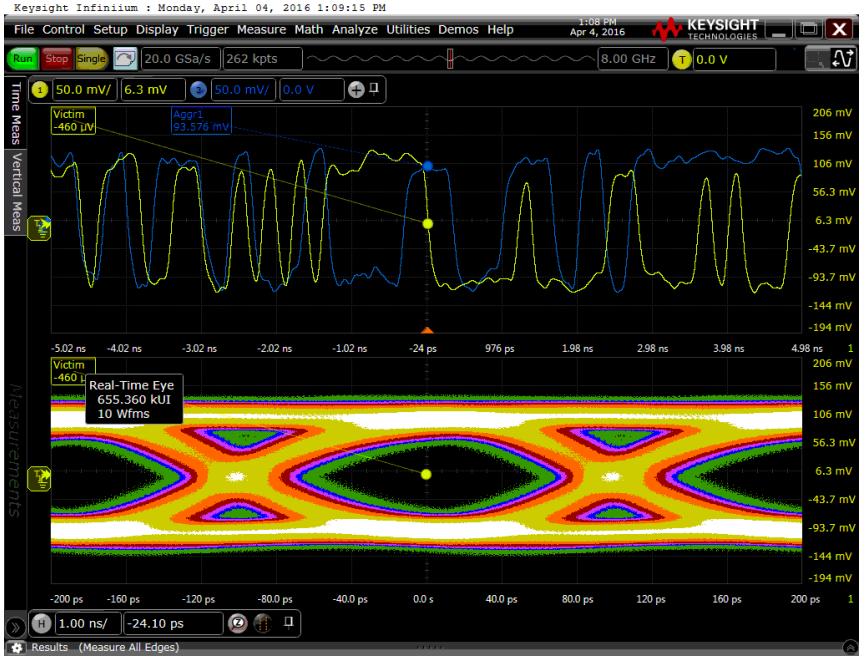


Data rate and pattern of the aggressor and victim are the same, the eye diagram of the victim will show a bulging indicative of FEXT.

Near End Crosstalk (NEXT)

No Serial Aggressor

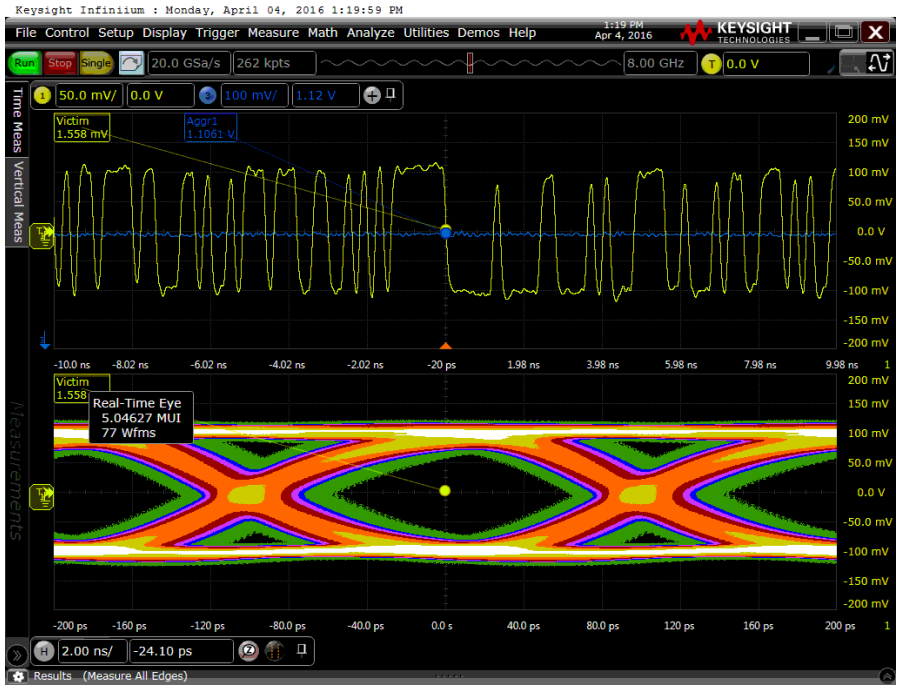
NEXT Serial Aggressor



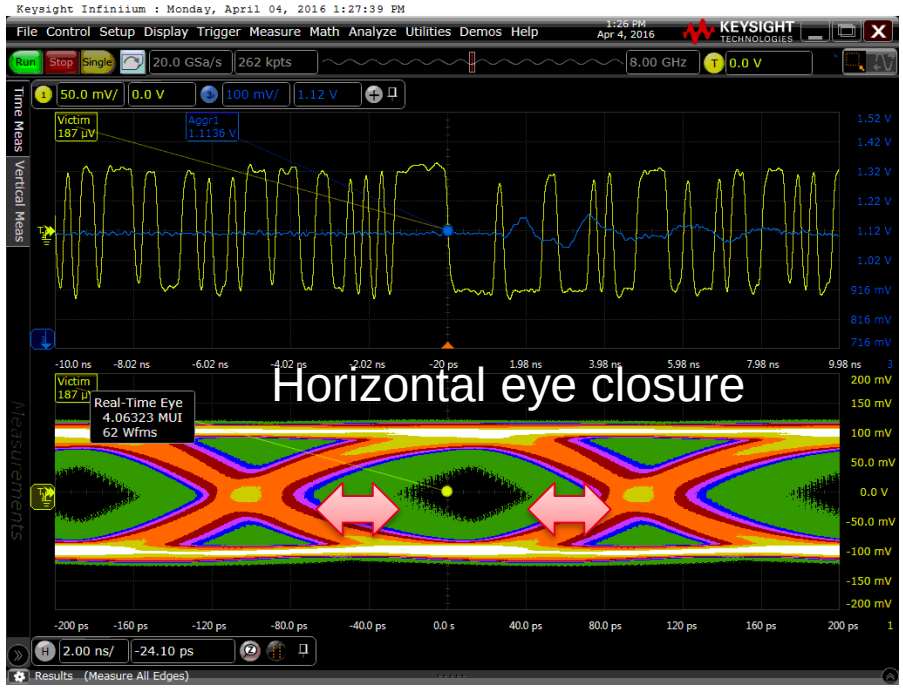
Power Supply Aggressor – PSIJ

Power Supply Induced Jitter

No Power Aggressor



With PSIJ Aggressor



High frequency noise in the power supply, induces horizontal jitter.

Power Supply Aggressor – VDAN

Voltage Dependent Amplitude Noise

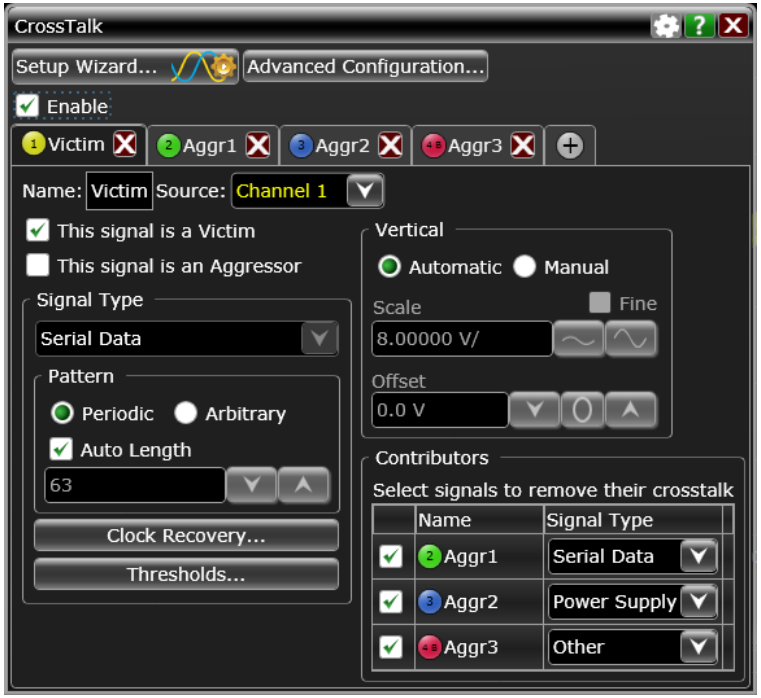
No Power Aggressor

With Power VDAN Aggressor

Noise on V_{cc} is transferred to logic high bits, but not affecting the logic low bits, which are tied to ground.

Features of the Crosstalk Analysis Application

1. Analyze up to four signals (aggressors or victims) at once
2. No crosstalk model or simulation files required
3. Identify aggressors by probing around
4. Report the amount of crosstalk present on victims
5. Work for both NEXT and FEXT, automatically determined by the app
6. Work for power supply analysis
7. Plot waveform without crosstalk on the scope which can be:
   - Used by SDA, EZJIT Complete, InfiniiSim, Equalization and Mask test
   - Saved as a waveform file



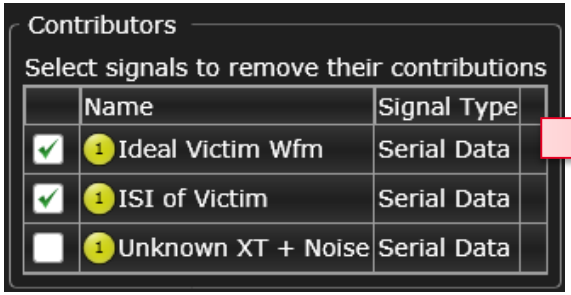
Overcome Inaccessible Aggressor Signals

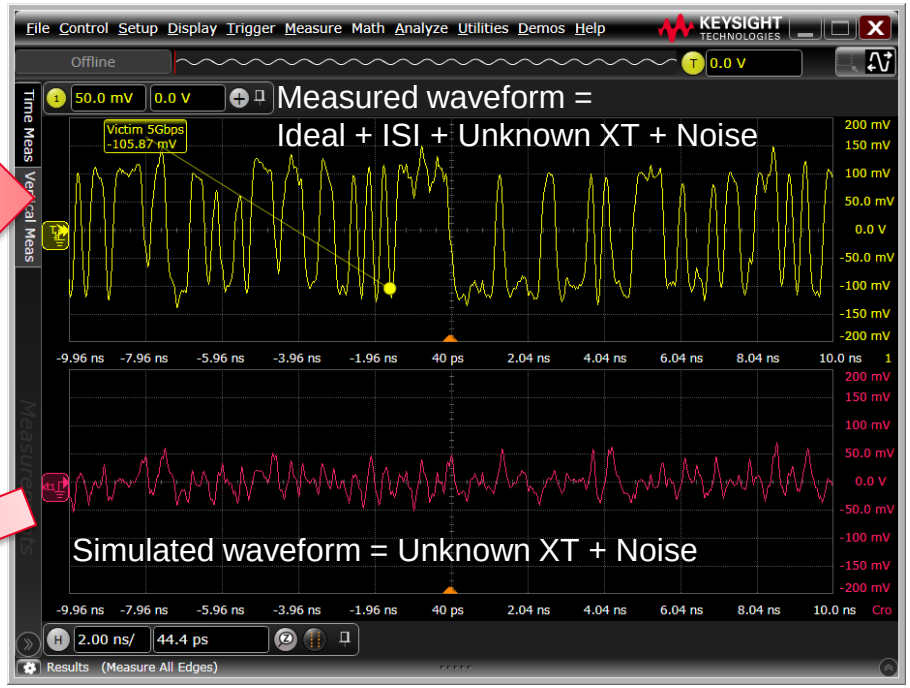
- The crosstalk application can remove the ideal, ISI and return a waveform with “ Unknown XT + Noise” (residual).

- Perform further analysis on this residual waveform with measurements such as FFT, markers, etc. to root cause the source of aggressor.

Remove: Ideal + ISI of Victim

Show: Only Unknown XT + Noise



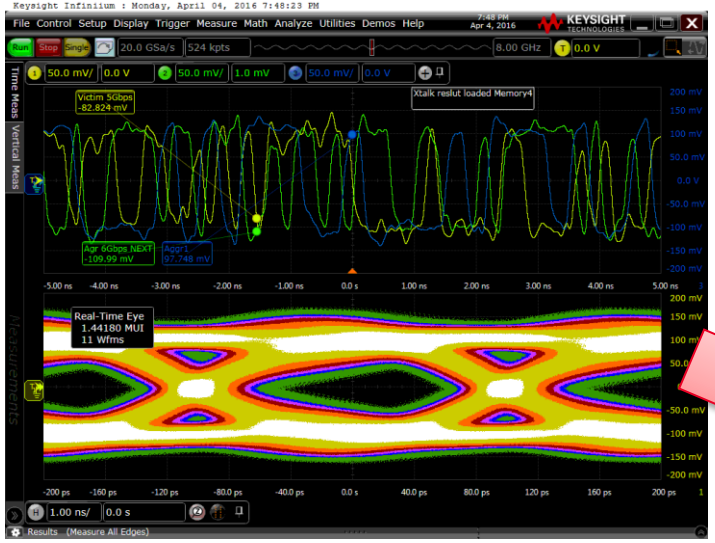


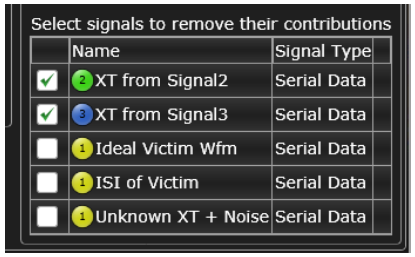
FFT on Unknown XT + Noise

Removing NEXT and FEXT with Crosstalk App

NEXT and FEXT Aggressors Off

With NEXT and FEXT Aggressors





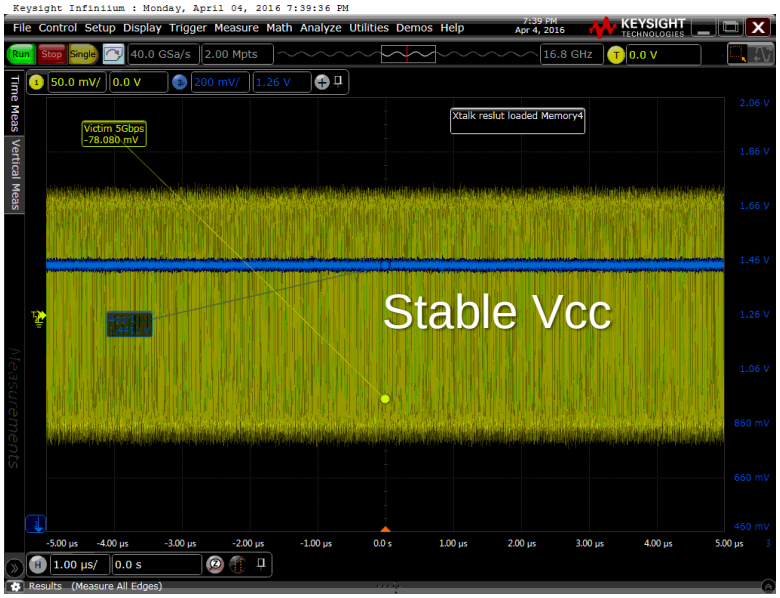
Use the crosstalk app to remove effect of NEXT and FEXT

NEXT and FEXT Removed

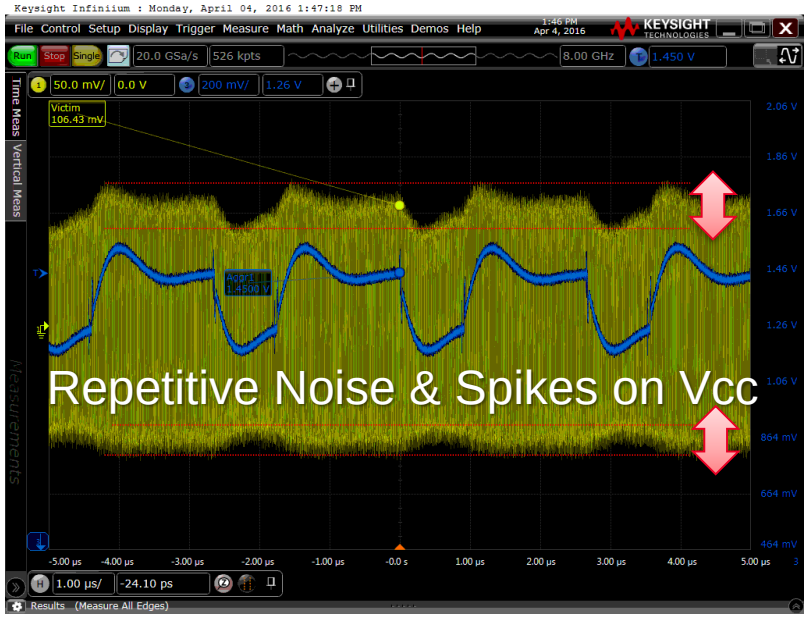
Power Supply Aggressor (VDAN) on Victim

Voltage Dependent Amplitude Noise

No Power Supply Aggressor

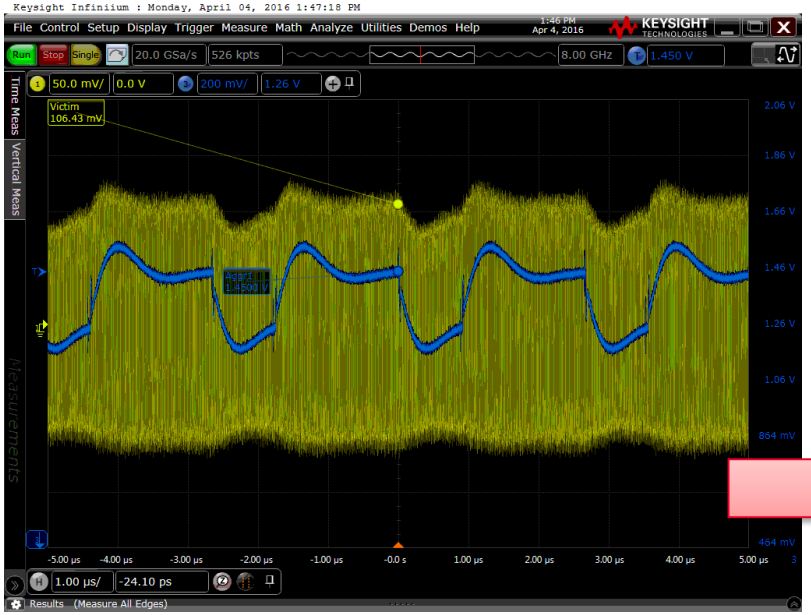


With Power Supply Aggressor



Removing Power Supply Aggressor (VDAN)

With Power Supply Aggressor

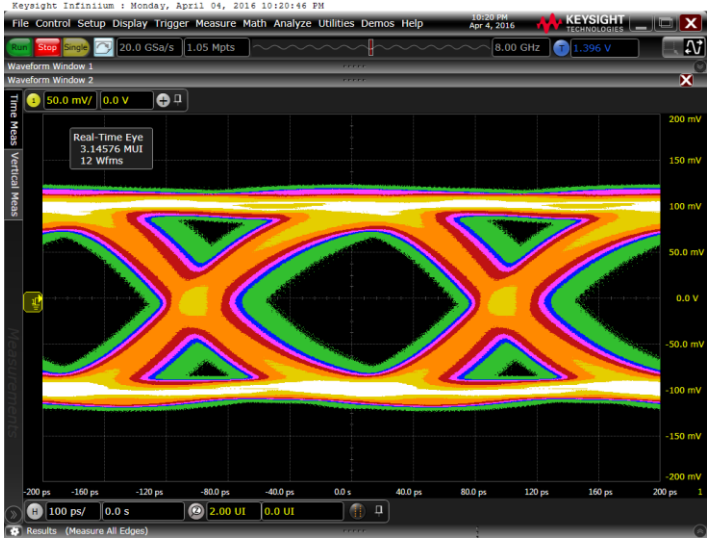


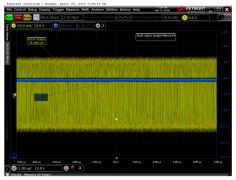
Power Supply Aggressor Removed

Use the crosstalk app to remove effect of power supply crosstalk

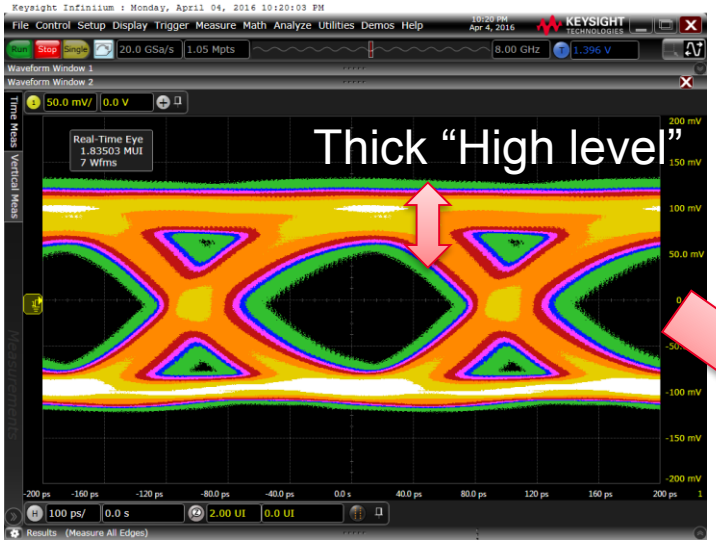
Removing Power Supply Aggressor (VDAN)

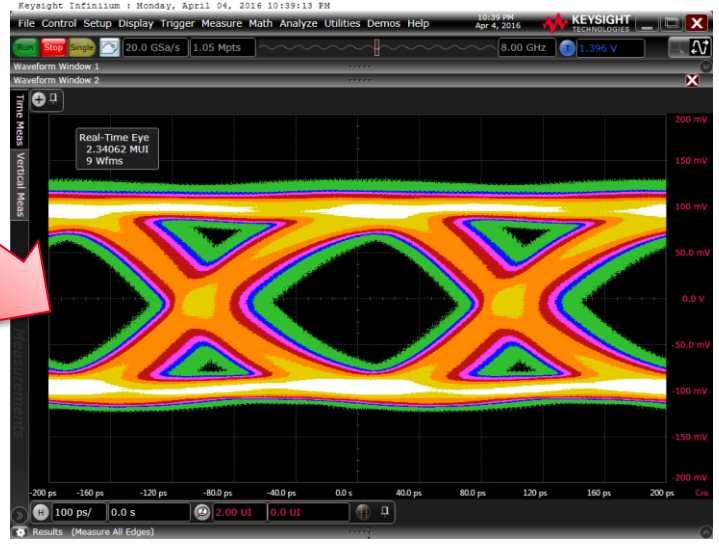
Measured Victim Without Aggressor

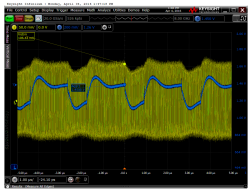


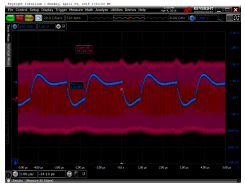


Victim With Power Supply Aggressor





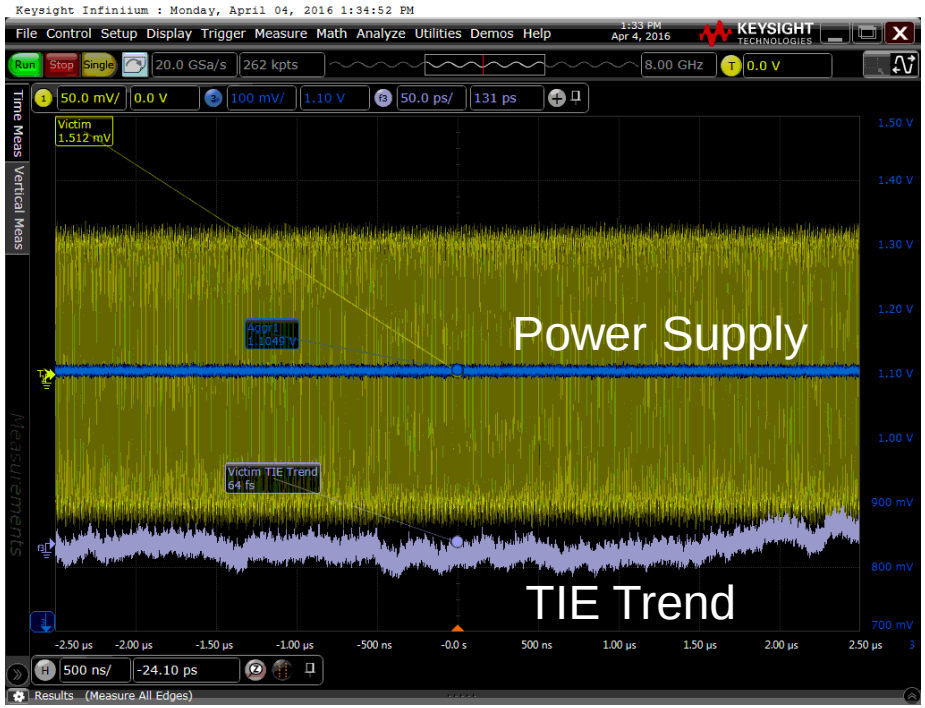




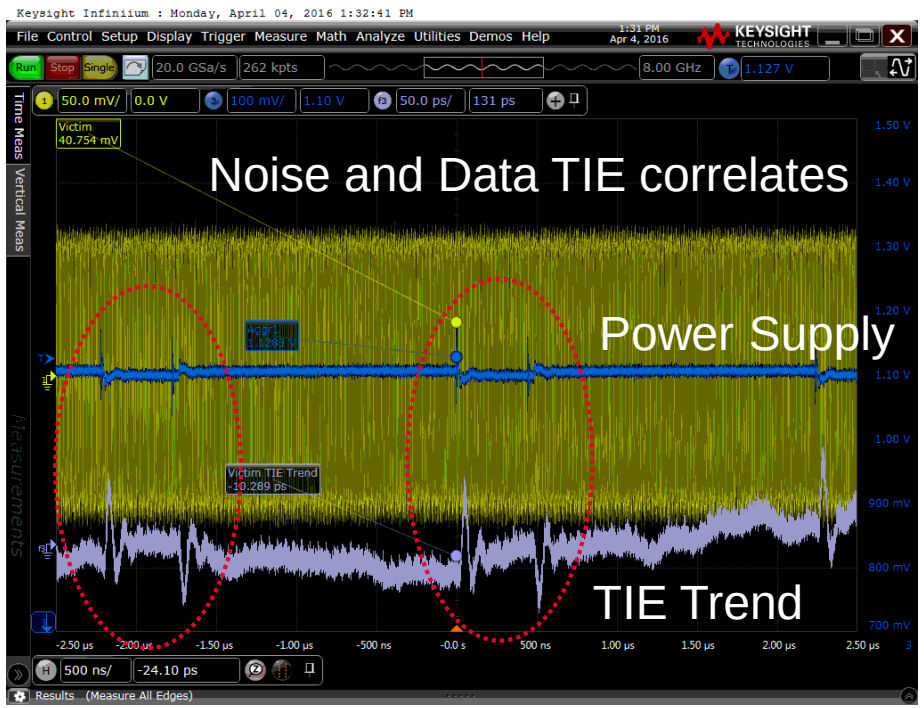
Victim after Power Supply Aggressor removed

Power Supply Induced Jitter (PSIJ) Crosstalk on Victim

No Power Supply Aggressor

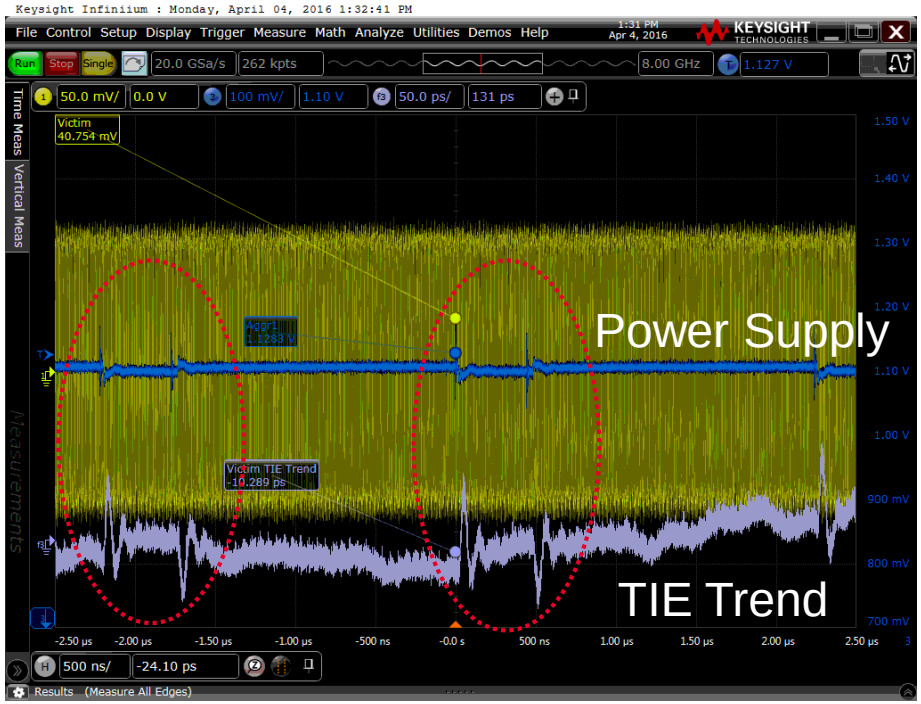


With Power Supply Aggressor

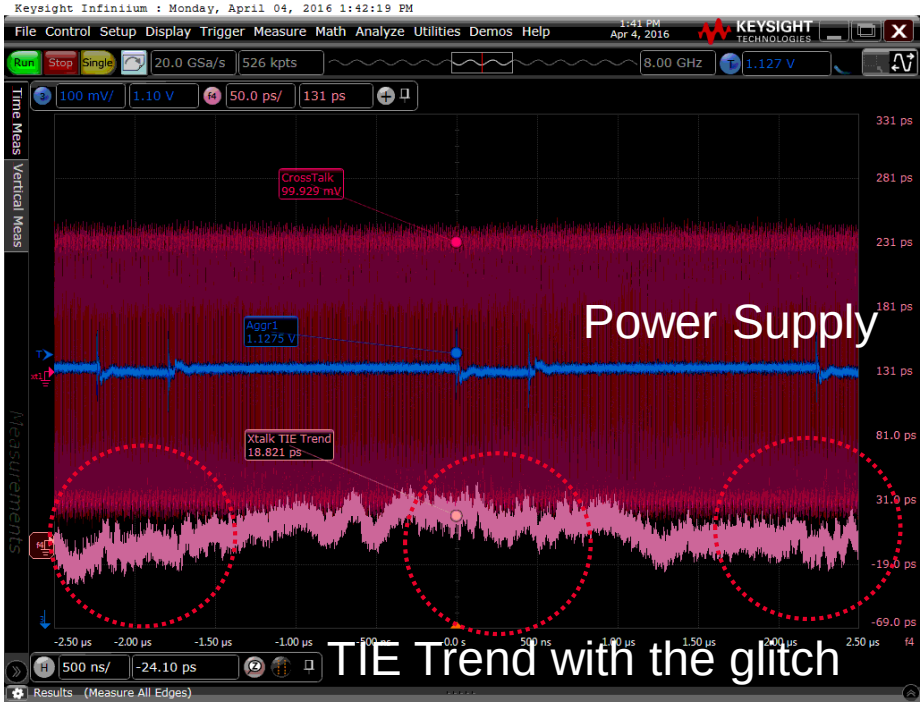


Removing PSIJ from Victim

With Power Supply Aggressor

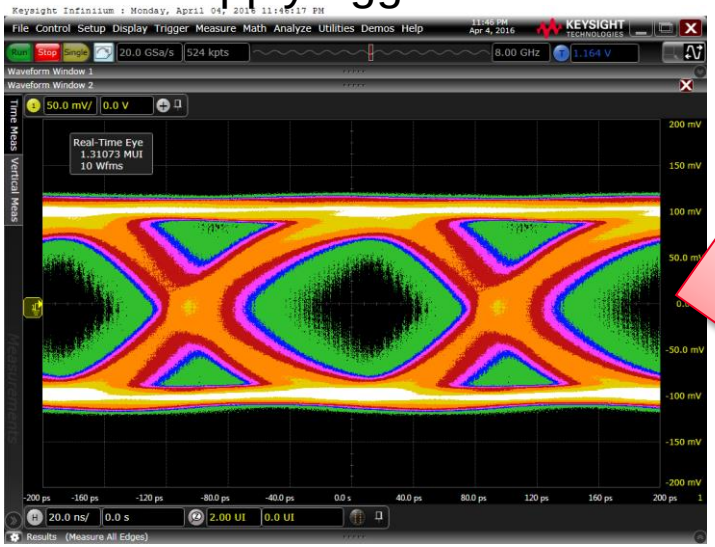


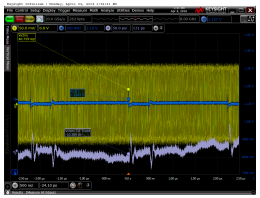
Power Supply Aggressor Removed with Improvement on Data TIE Trend



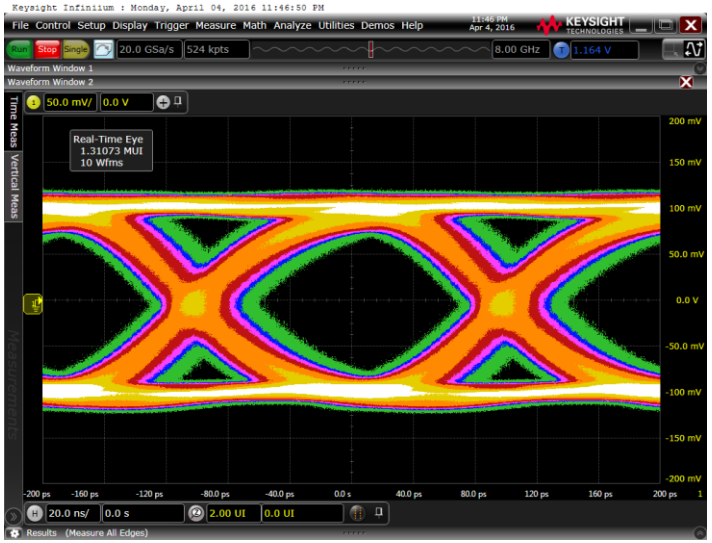
Removing PSIJ from Victim

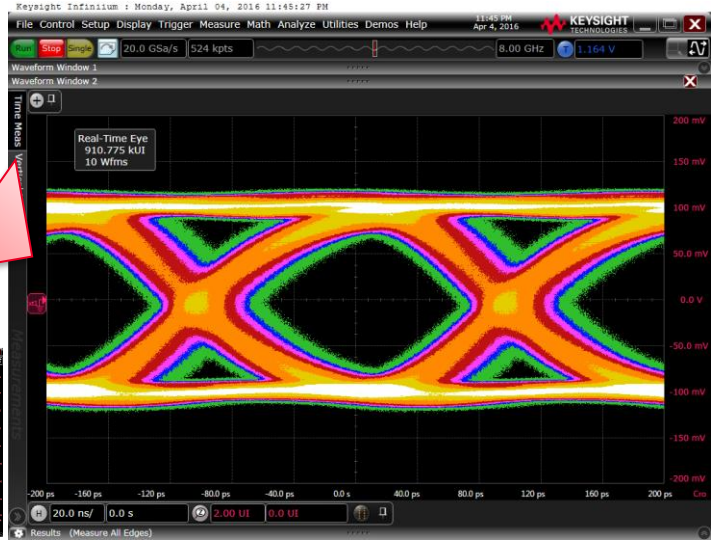
Measured Victim with Power Supply Aggressor

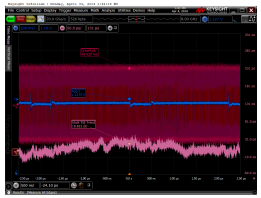




Measured Victim Without Aggressor



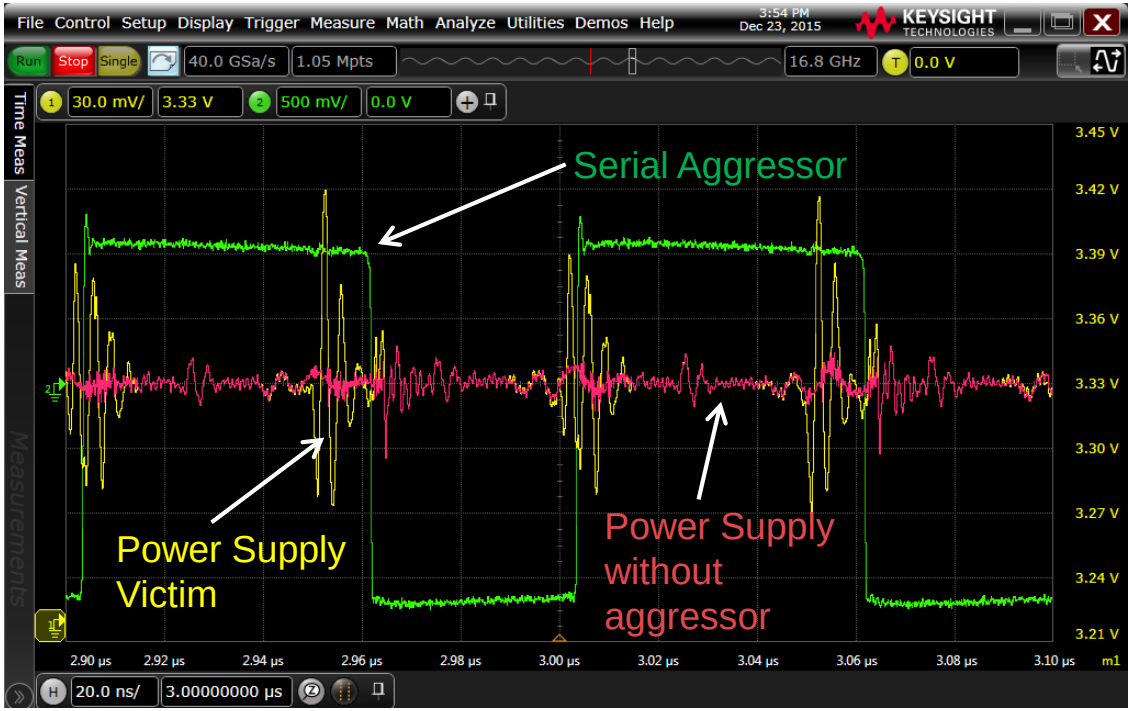




Victim after Power Supply Aggressor removed

Power Supply Victim

Example of power supply victim due to clock edges

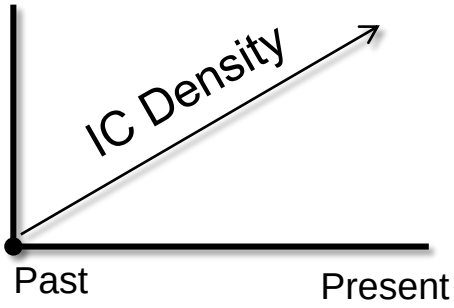


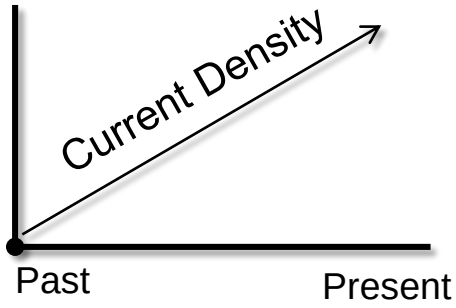
Note the large ringing in the yellow power supply that is correlated with the edges of the clock.

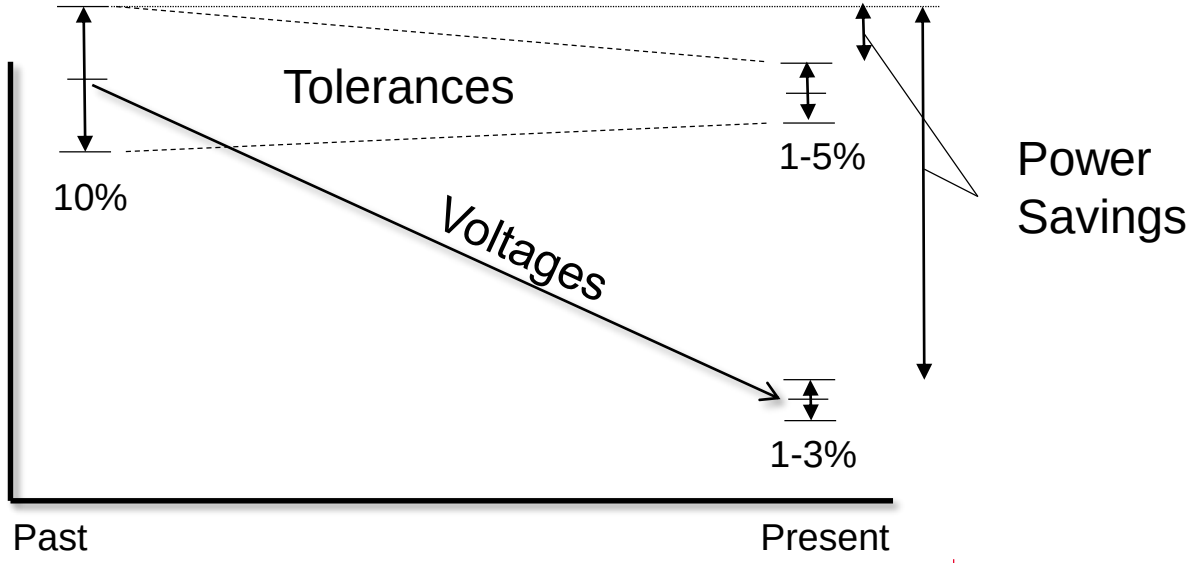
The Case For Power Integrity

Power and Current Density

Moore's Law: transistors on an integrated circuit will double every two years.



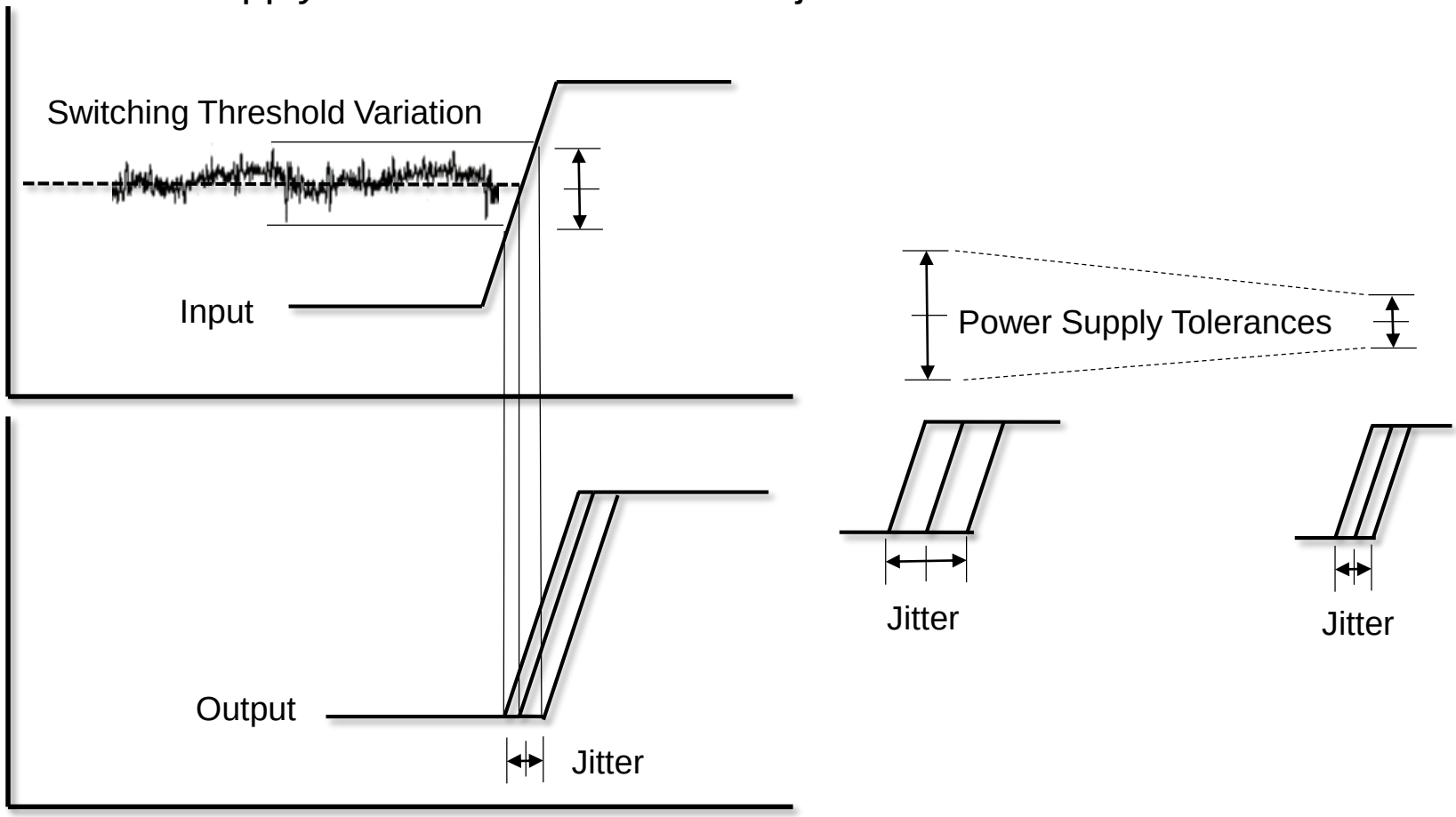




The Case For Power Integrity

Power Supply Induced Jitter (PSIJ)

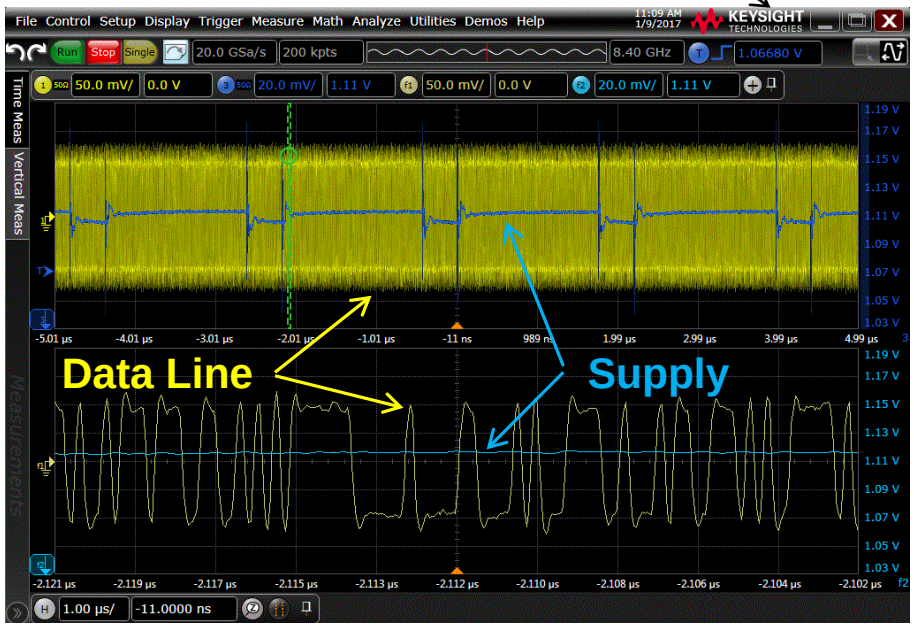
Power supply noise causes clock/data jitter.

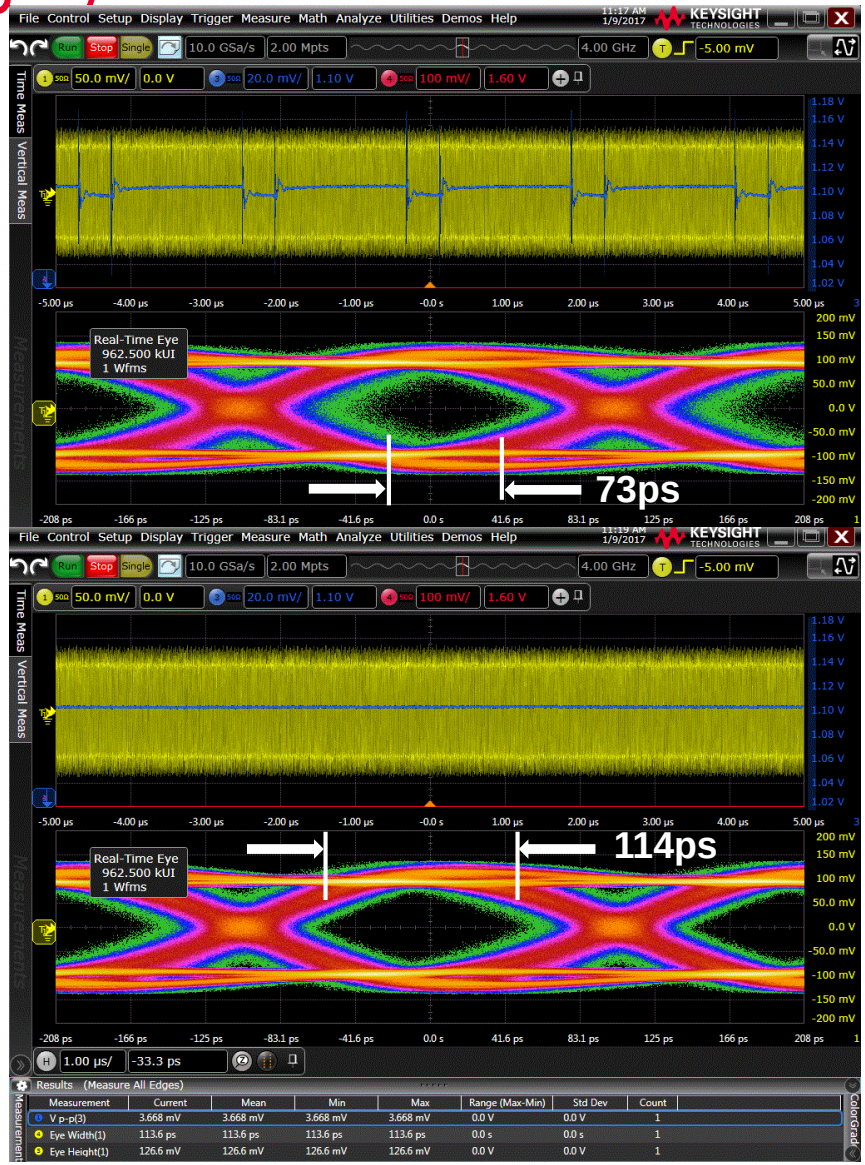


The Case For Power Integrity

PSIJ Example

FPGA 1.10V Supply with 115mV$_{pp}$ Noise (~±5%)

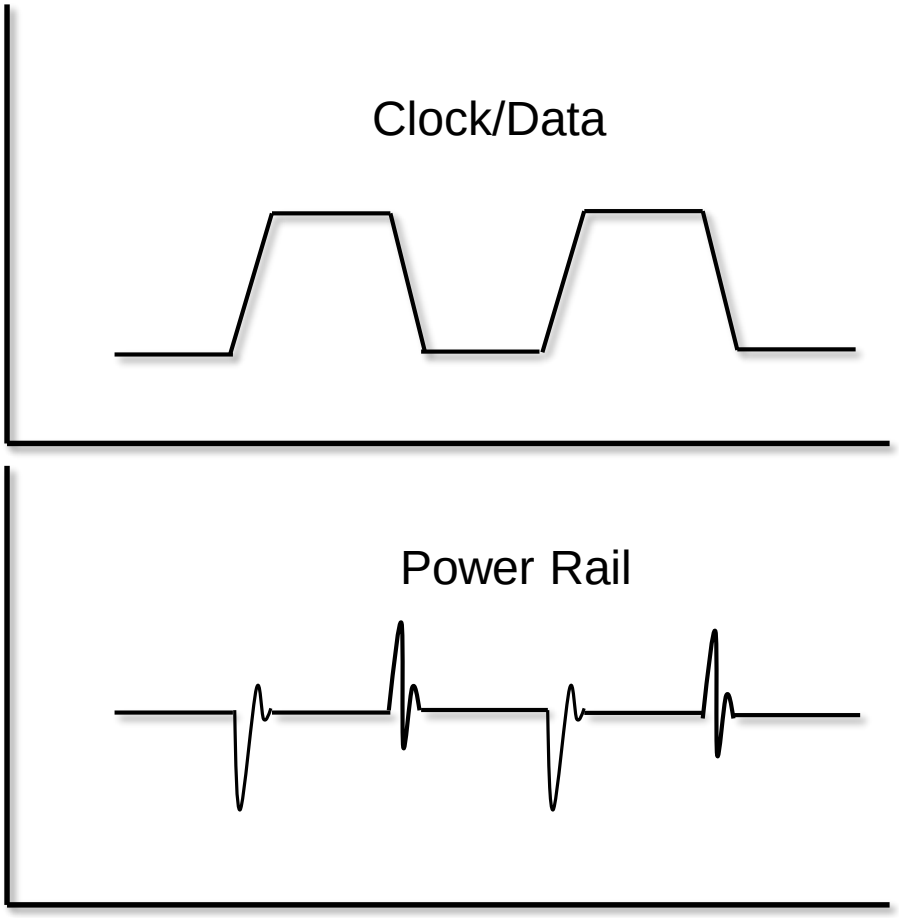




Same FPGA 1.10V Supply now with only 3mV$_{pp}$ Noise

The Case For Power Integrity

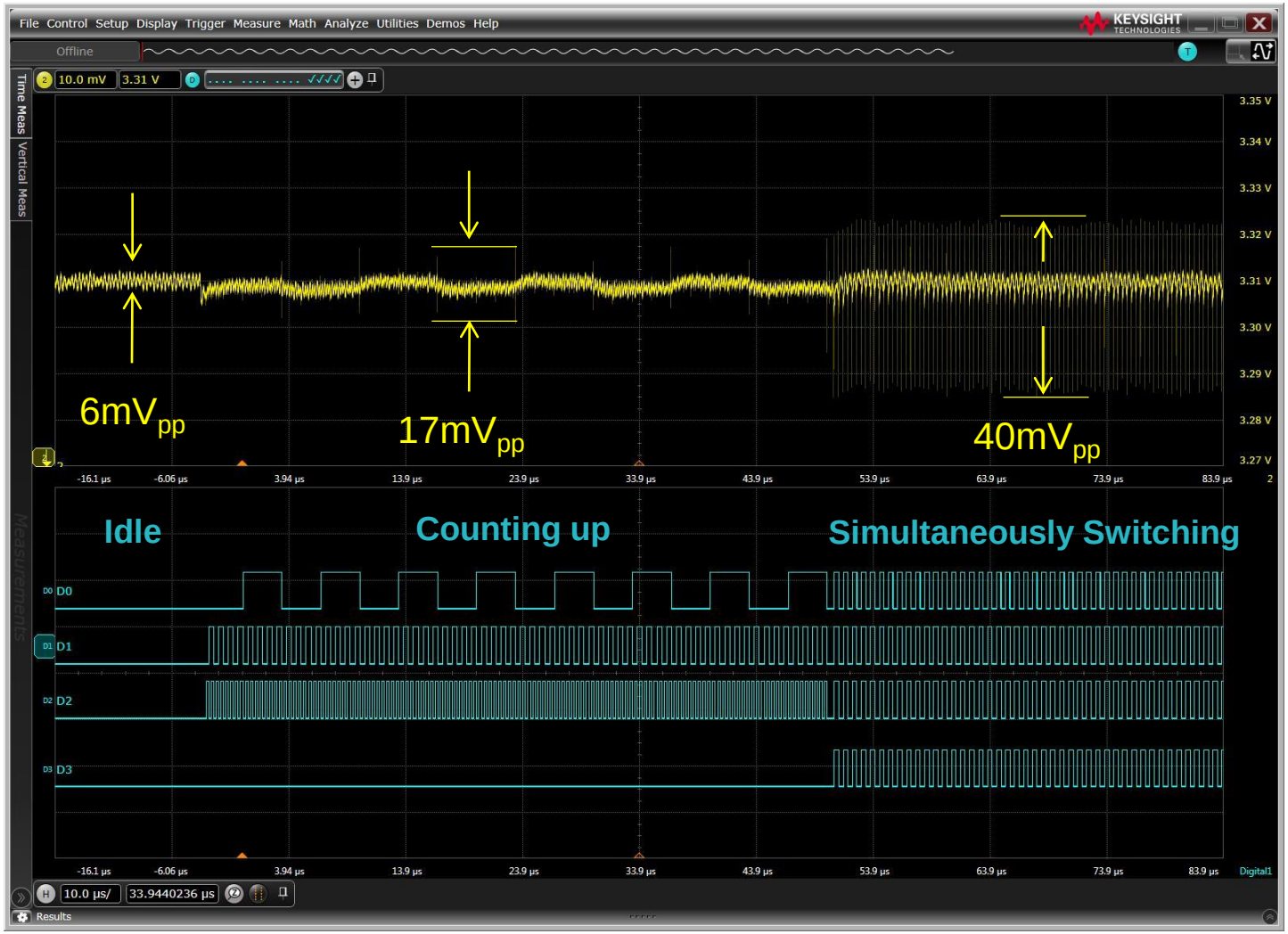
Switching Loads



Switching loads can cause high frequency supply noise with content easily exceeding 1GHz

The Case For Power Integrity

Switching Loads Example

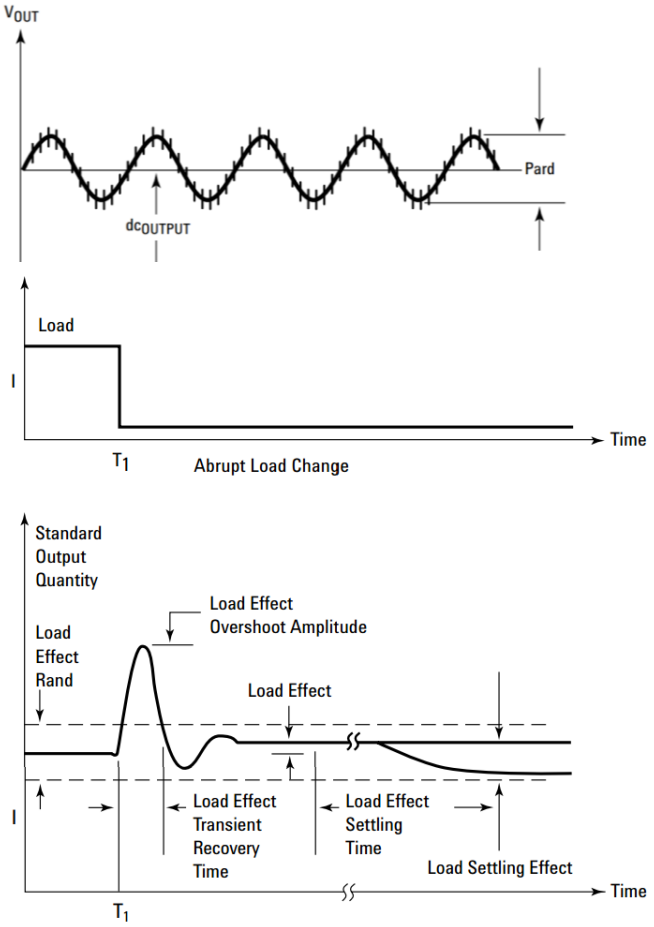


Power Integrity Measurements

Examples Of Measurements Made Using An Oscilloscope

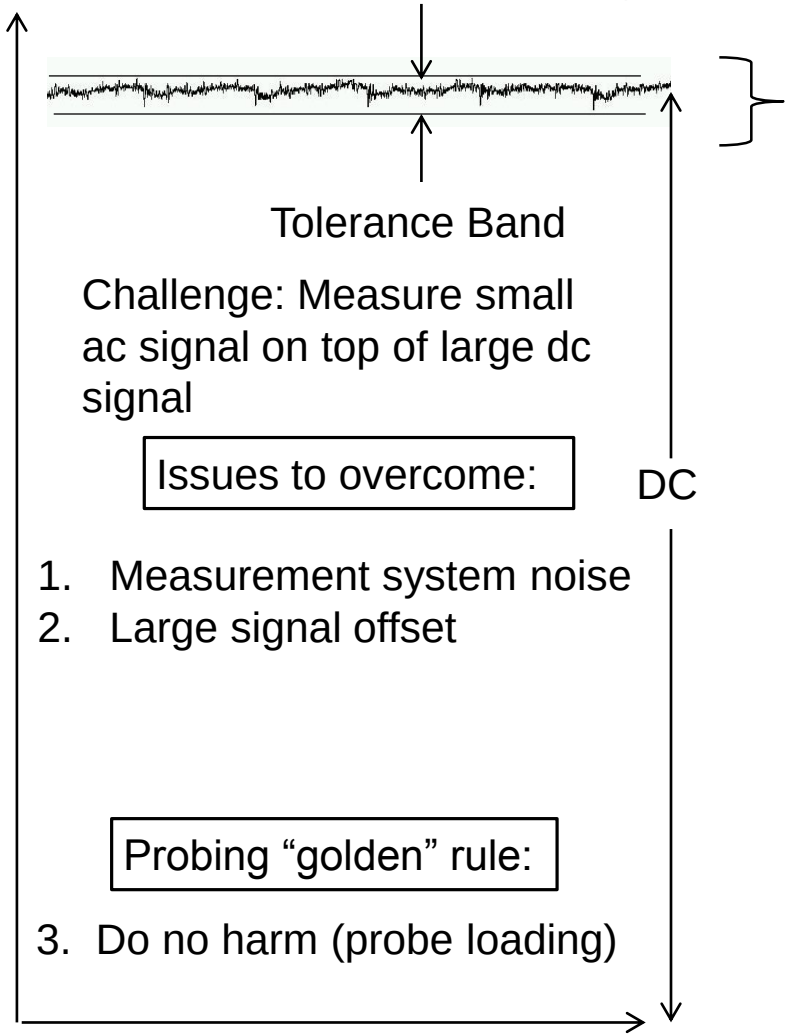
Common Power Integrity Measurements

- Supply drift
- PARD (Periodic and Random Disturbances)—noise, ripple and switching transients on power rails.
- Static and dynamic load response.
- High frequency transients and noise
- Programmable power rail response..
- Product validation at extended temperatures.



Power Integrity Measurements

Fundamental Challenge



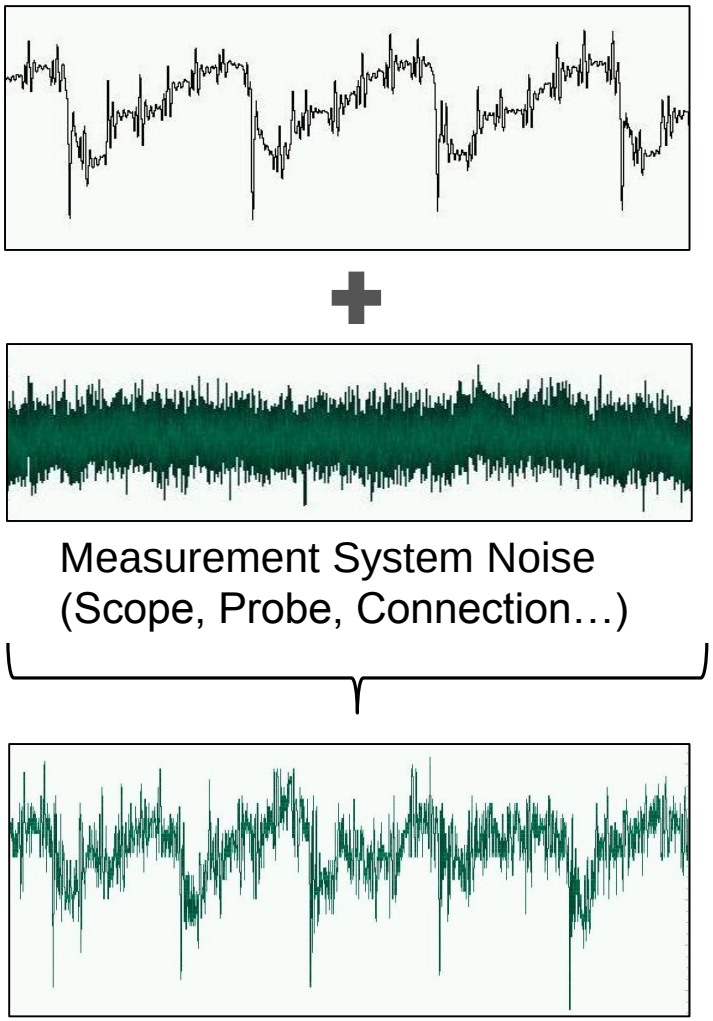
Challenge: Measure small ac signal on top of large dc signal

Issues to overcome:

1. Measurement system noise
2. Large signal offset

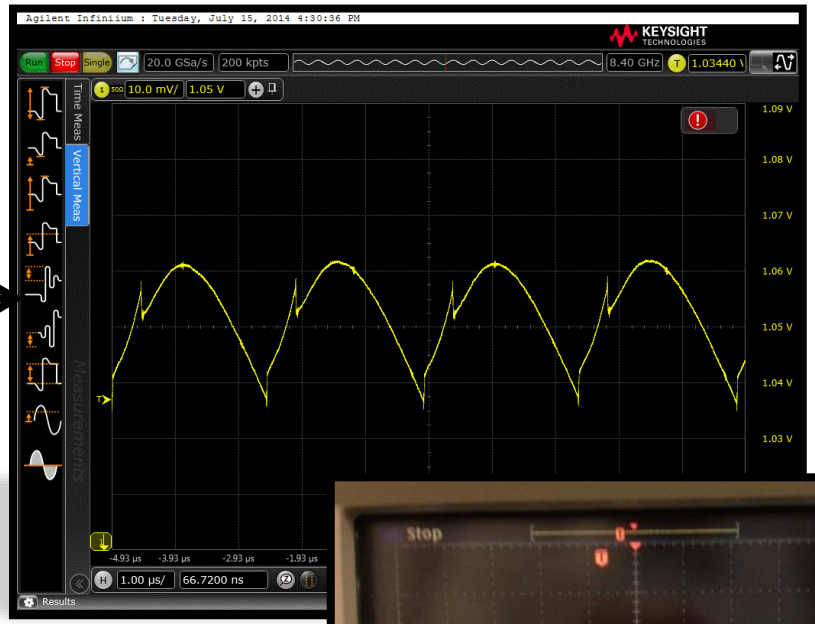
Probing "golden" rule:

3. Do no harm (probe loading)

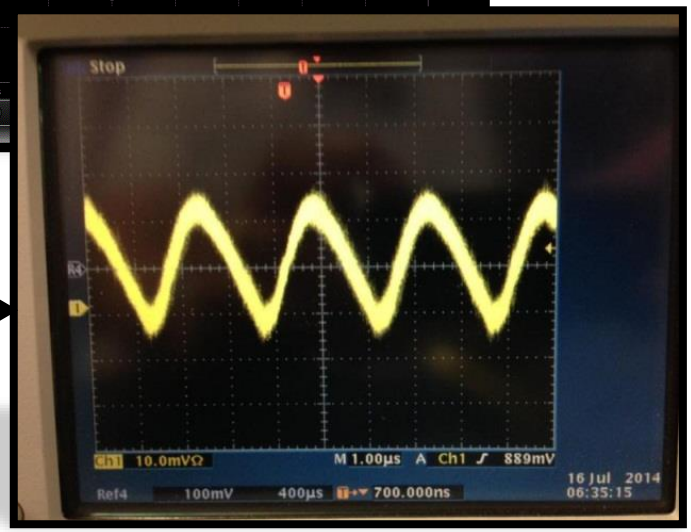


N7020A Power Rail Probe

Make measurements like this.



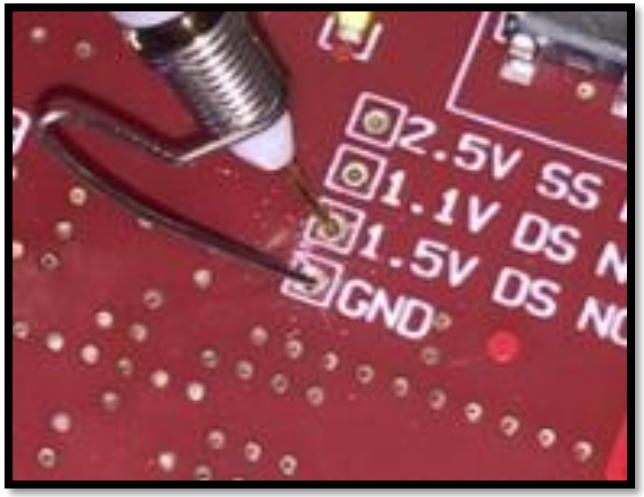
Instead of like this



Top Concerns For Power Rail Measurements

Key Attributes of a Measurement Solution

1. Low noise
2. Support for popular rail voltages
3. Low Loading
4. High Bandwidth

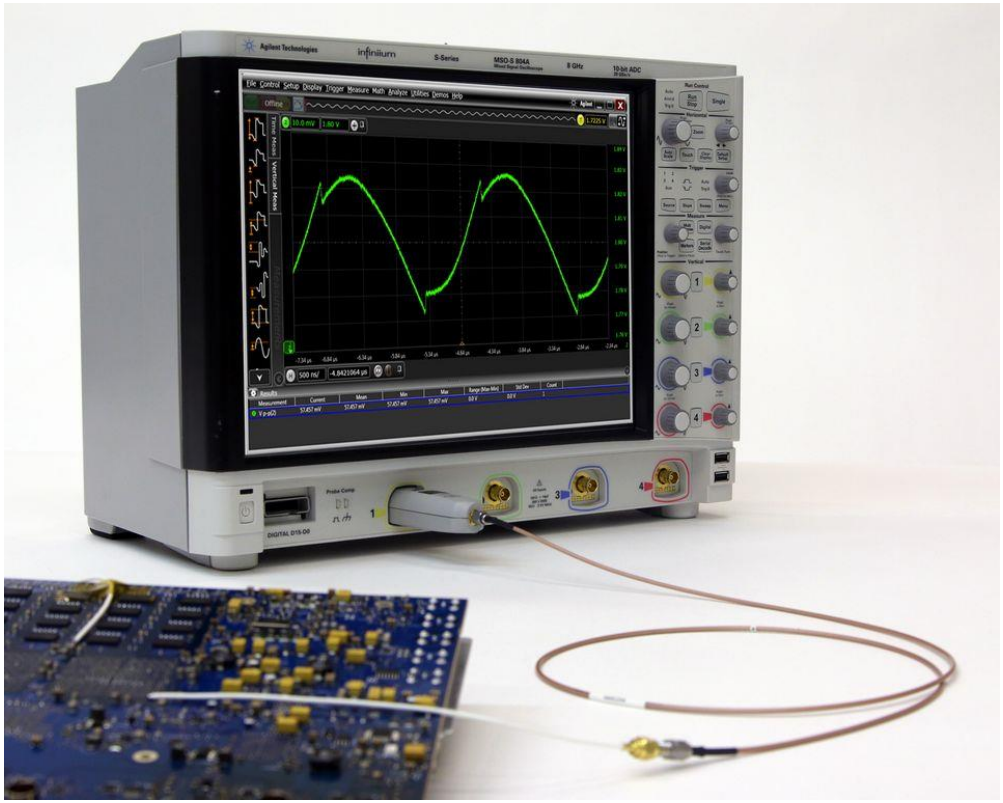


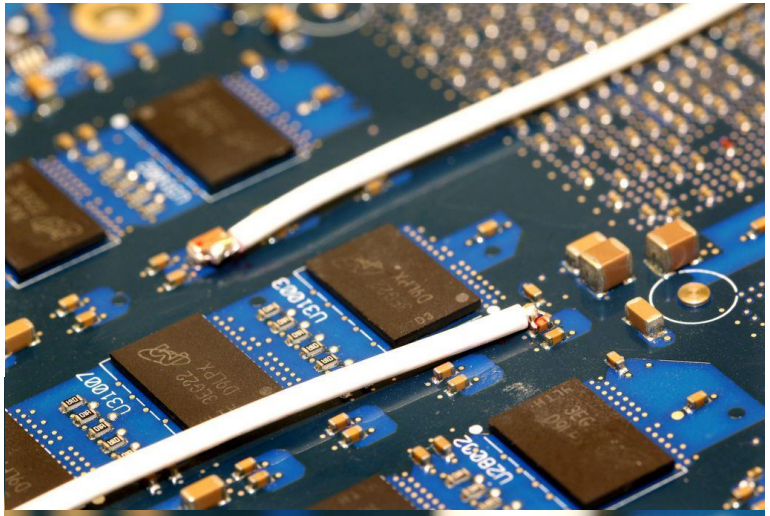
N7020A Power Rail Probe

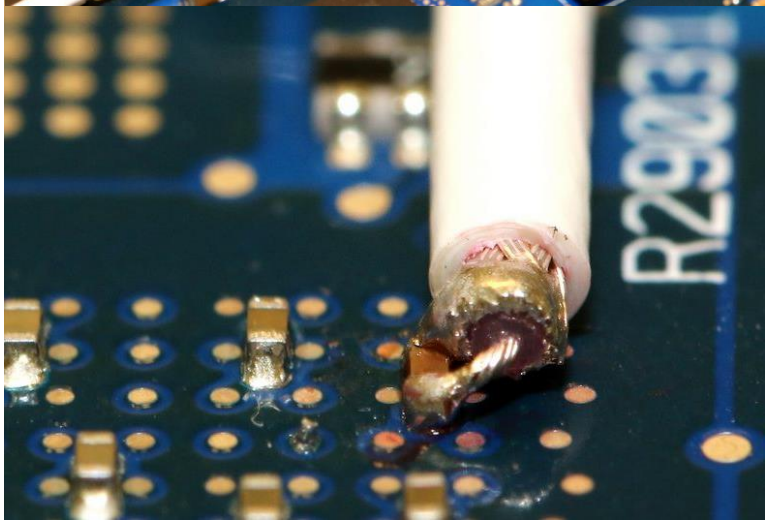
Characteristics and Specifications: N7020A Power Rail Probe	
Probe Bandwidth (-3dB)	**2GHz**
Attenuation Ratio	**1:1**
Offset Range	**± 24V**
*** Input Impedance @ DC**	**50kΩ +/-2%**
Probe Noise	**10% increase to the noise of the connected oscilloscope**
Active Signal Range	± 850mV about offset voltage
Probe Type	Single-ended
Included accessories	N7021A—Coaxial Pigtail Probe Head (qty 3) ($175 us)
	N7022A –Main Cable ($240)
	N7023A—350MHz Browser
Maximum non-destructive input voltage	+/-30V (DC + peak AC)
Output impedance	50Ω
Cable length	N7021A Main Cable: 48” N7022A Coaxial Probe Head: 8”
Ambient operating temperature	Probe Pod: -10 – +55°C,
	N7021A Main Cable, N7022A Pigtail Probe Head: -40 – + 85° C
	N7023A Browser: -30 -- +70°C

N7020A Power Rail Probe

Coaxial Probe Head

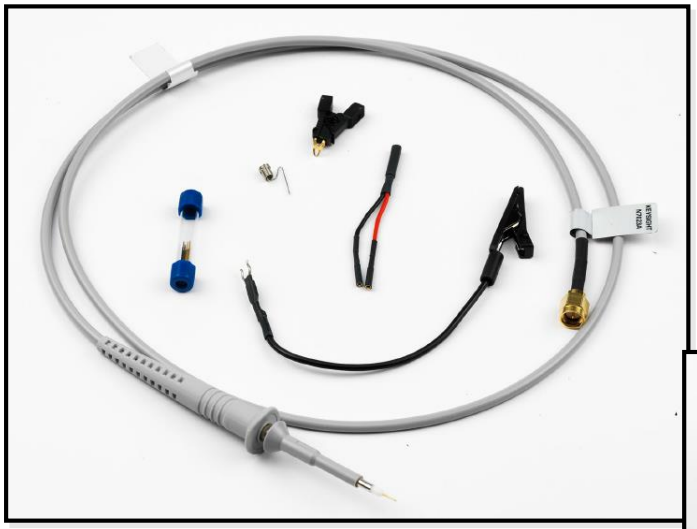


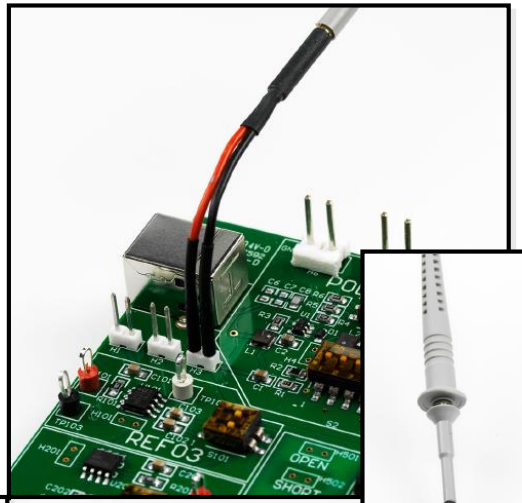


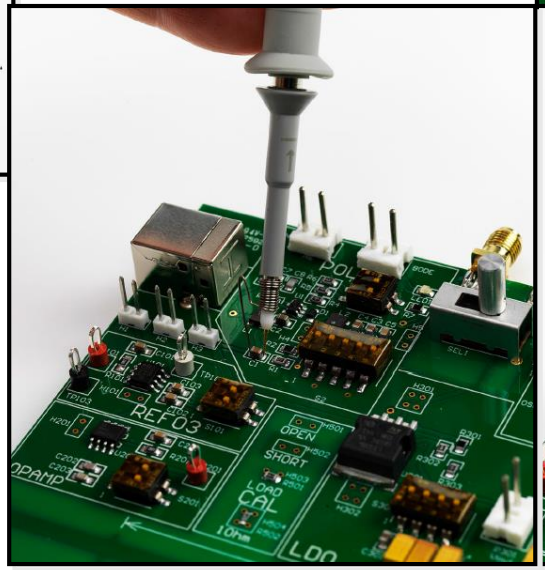


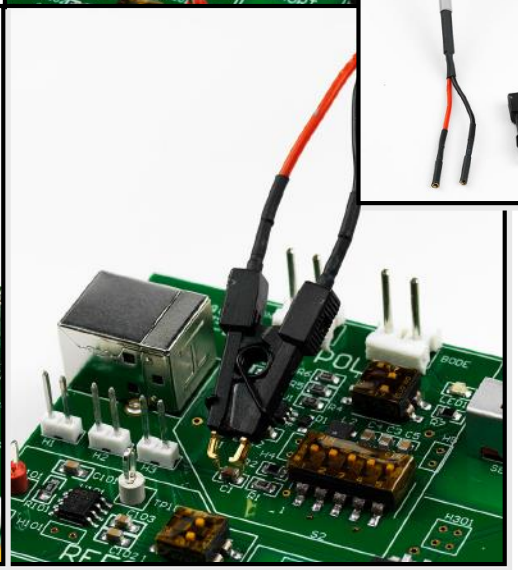
N7023A Power Rail Probe Browser

350 MHz , 1:1, Mini-Passive Probe Style





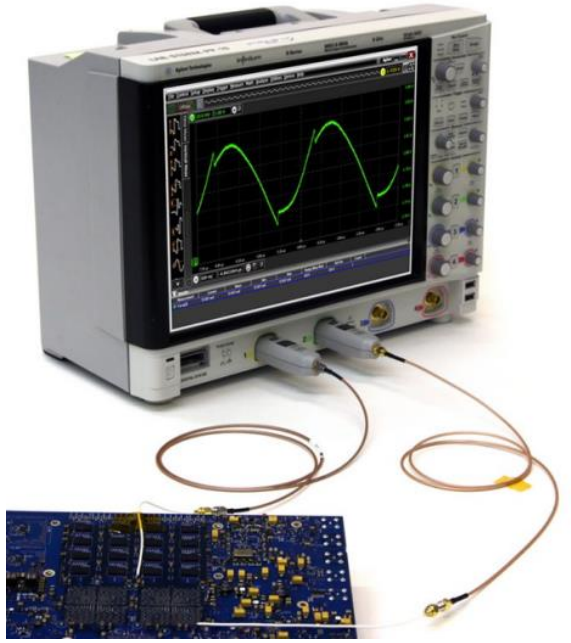




Infiniium S-Series Specifications

...and usefulness for power rail measurements

- Low noise front end at small vertical set tings
- Full 10-bit ADC support with full BW do wn to 16 mV full screen
- Analog and DSP-based bandwidth limit filters
- Measurement capability including FFTs, axis annotation, dynamic delta markers



Top Concerns For Power Rail Measurements

Key Attributes of a Measurement Solution

1. Low noise
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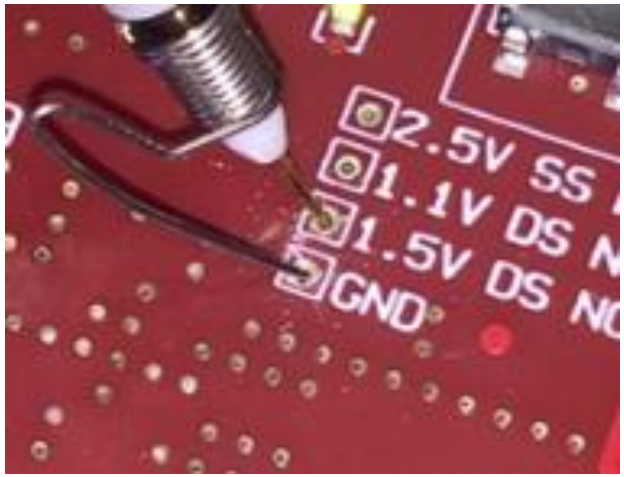
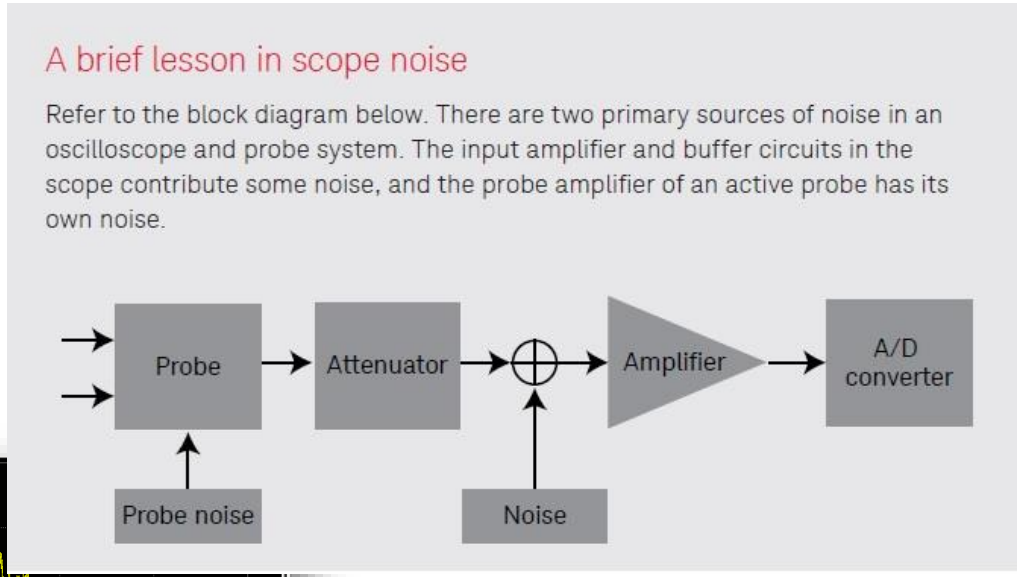
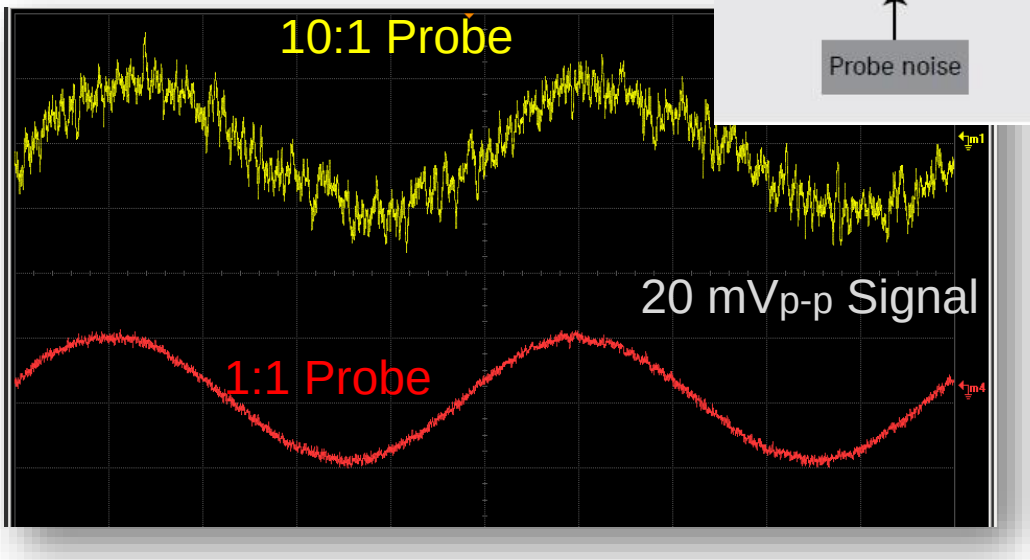
4. High Bandwidth



Probe Attenuation Ratio: High Impact on Noise

N7020A: Attenuation ratio:	1:1 down to 1.09 mV/div





N7020A Power Rail Probe

Low Noise

Characteristics and Specifications: N7020A Power Rail Probe	
Probe Bandwidth (-3dB)	2GHz
Attenuation Ratio	**1:1**
Offset Range	± 24V
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Probe Noise	**10% increase to the noise of the connected oscilloscope**
Active Signal Range	± 850mV about offset voltage
Probe Type	Single-ended
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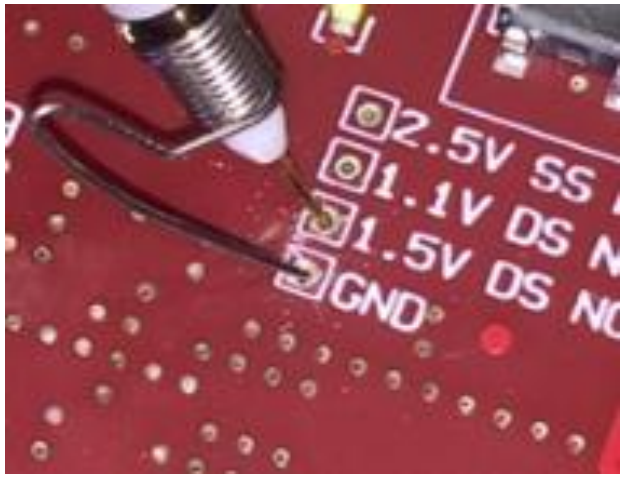
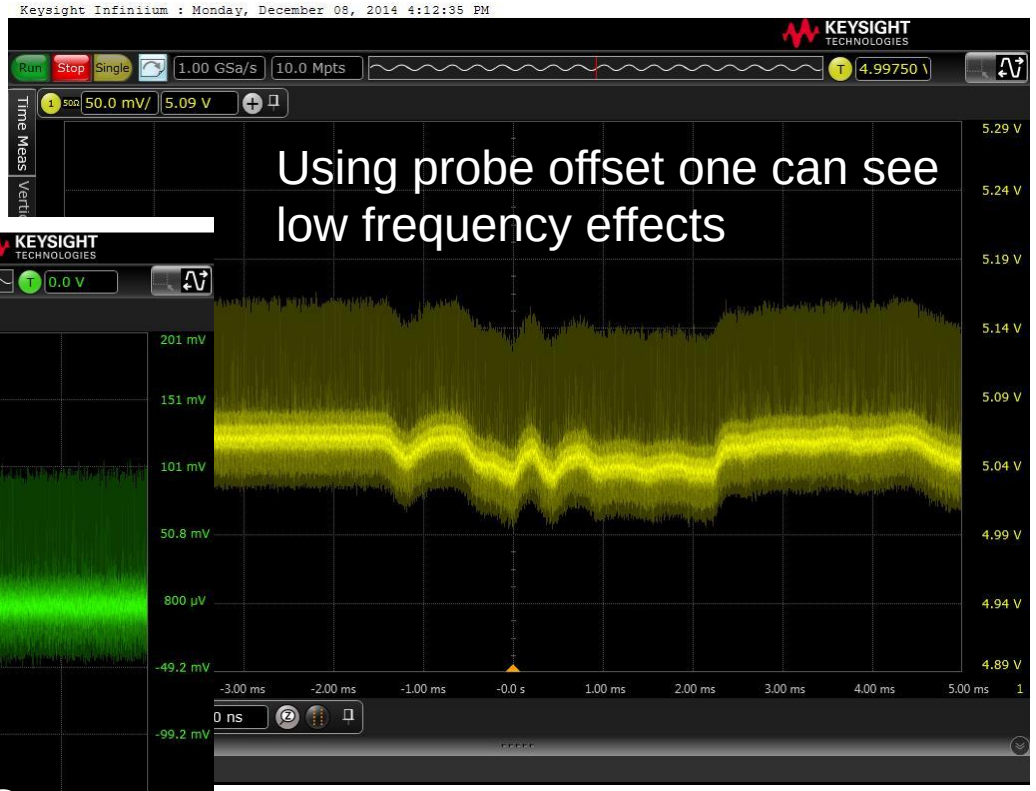
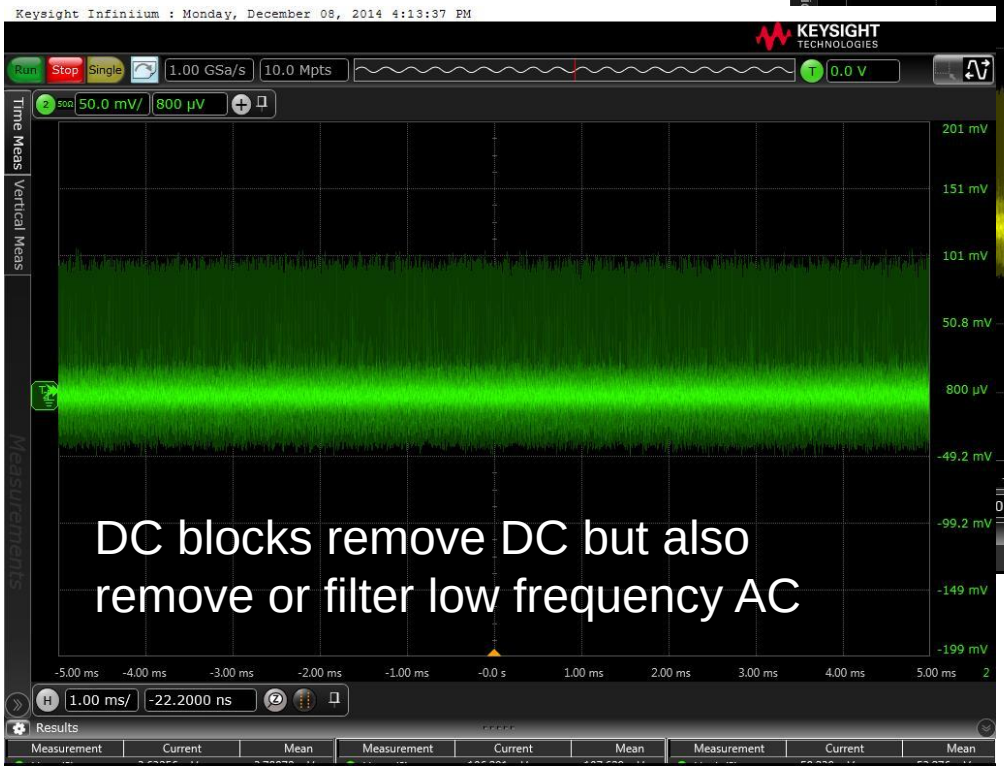


Using A DC Blocking Cap

Lose Lower Frequency Content

Observing the same 5V supply using a DC block and probe offset.





DC Block

Can damage scope if cap discharges into scope front end

N7020A Power Rail Probe

Support For Popular Rail Voltages

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Probe Bandwidth (-3dB)	2GHz
Attenuation Ratio	1:1
Offset Range	**± 24V**
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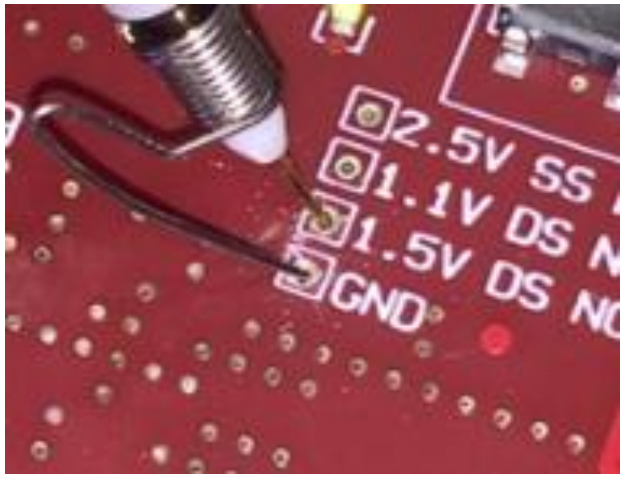
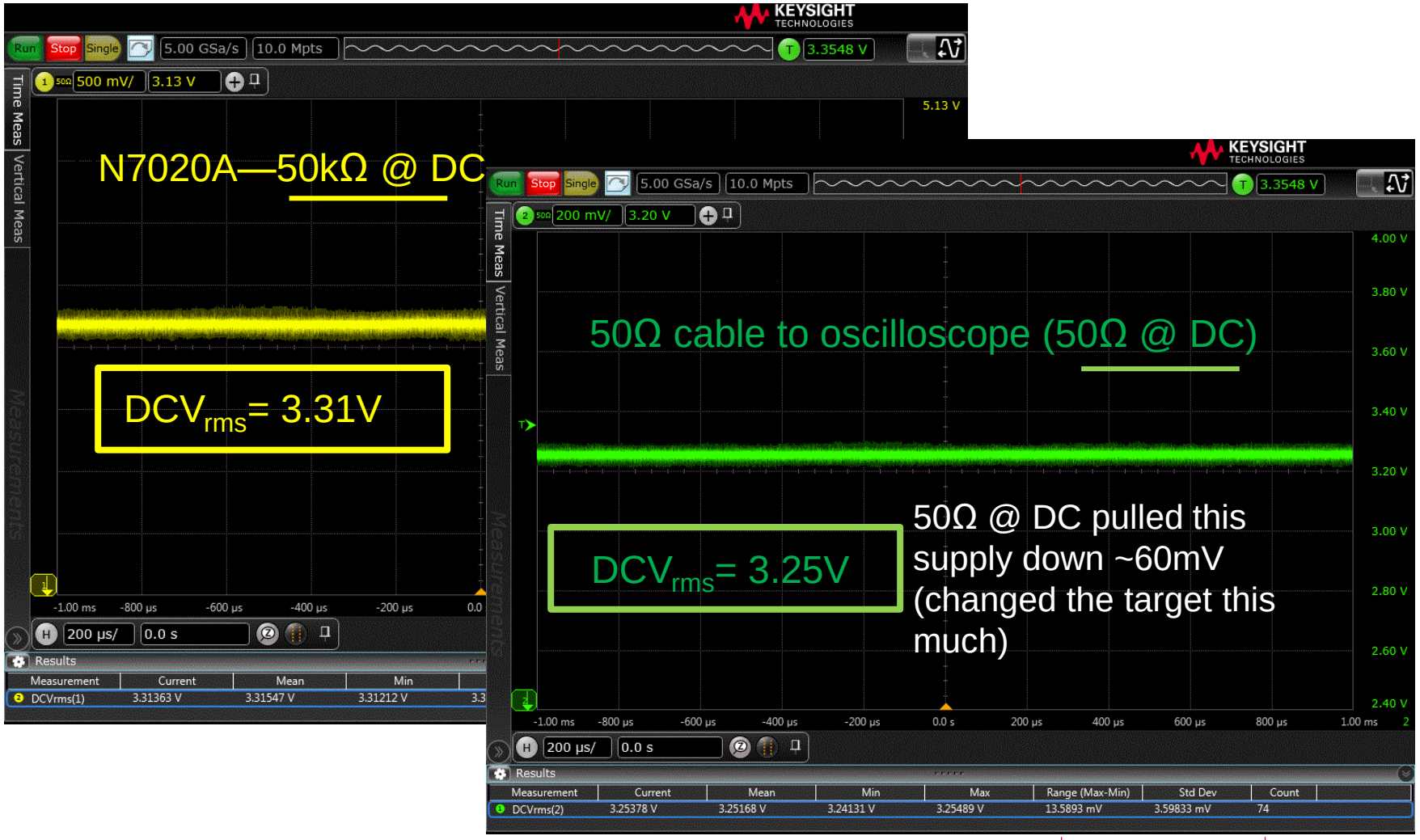


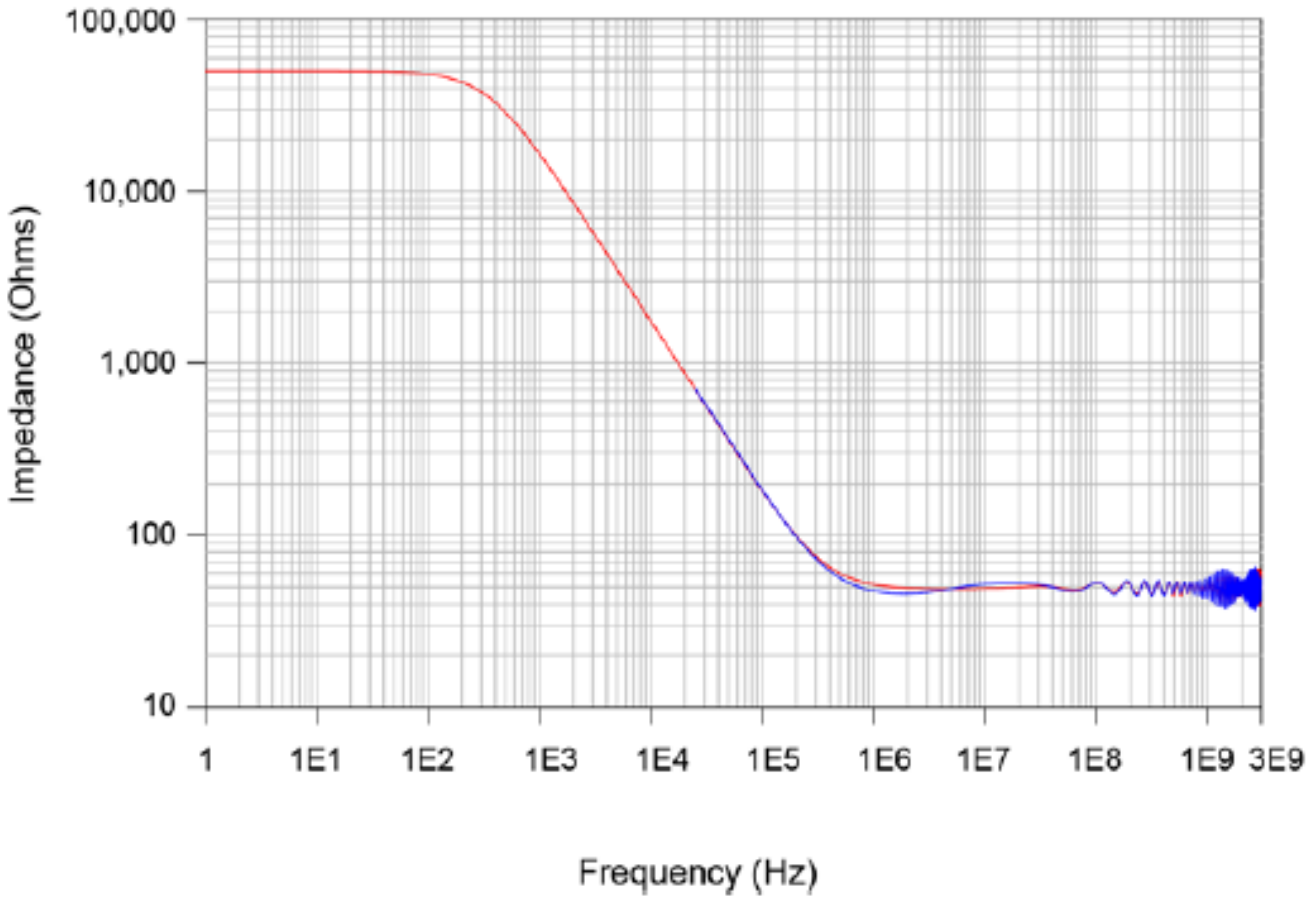
Probe/Connection Loading

Impedance At DC



N7020A Input Impedance vs. Frequency

Input Impedance @ DC	50kΩ +/-2%
@ >1 MHz	50Ω



N7020A Power Rail Probe

Low Loading

Characteristics and Specifications: N7020A Power Rail Probe	
Probe Bandwidth (-3dB)	2GHz
Attenuation Ratio	1:1
Offset Range	± 24V
*** Input Impedance @ DC**	**50kΩ +/-2%**
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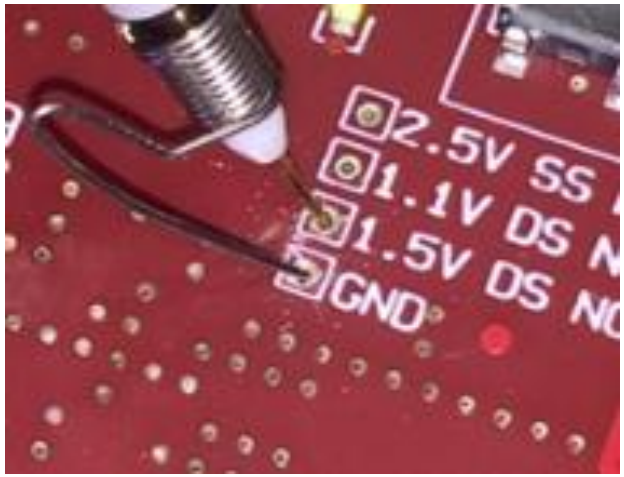
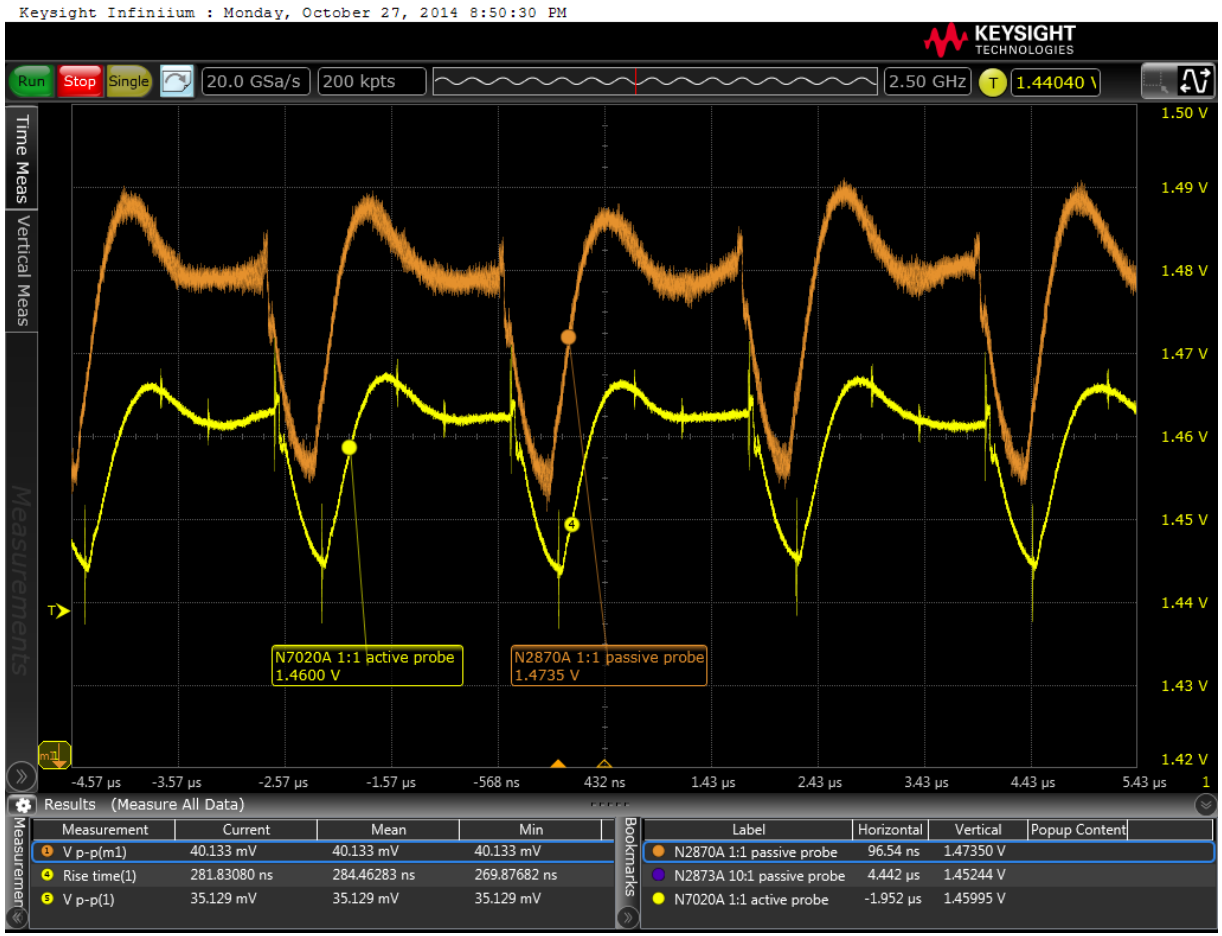


Having Enough BW is Critical



N2870A **35 MHz**, 1:1

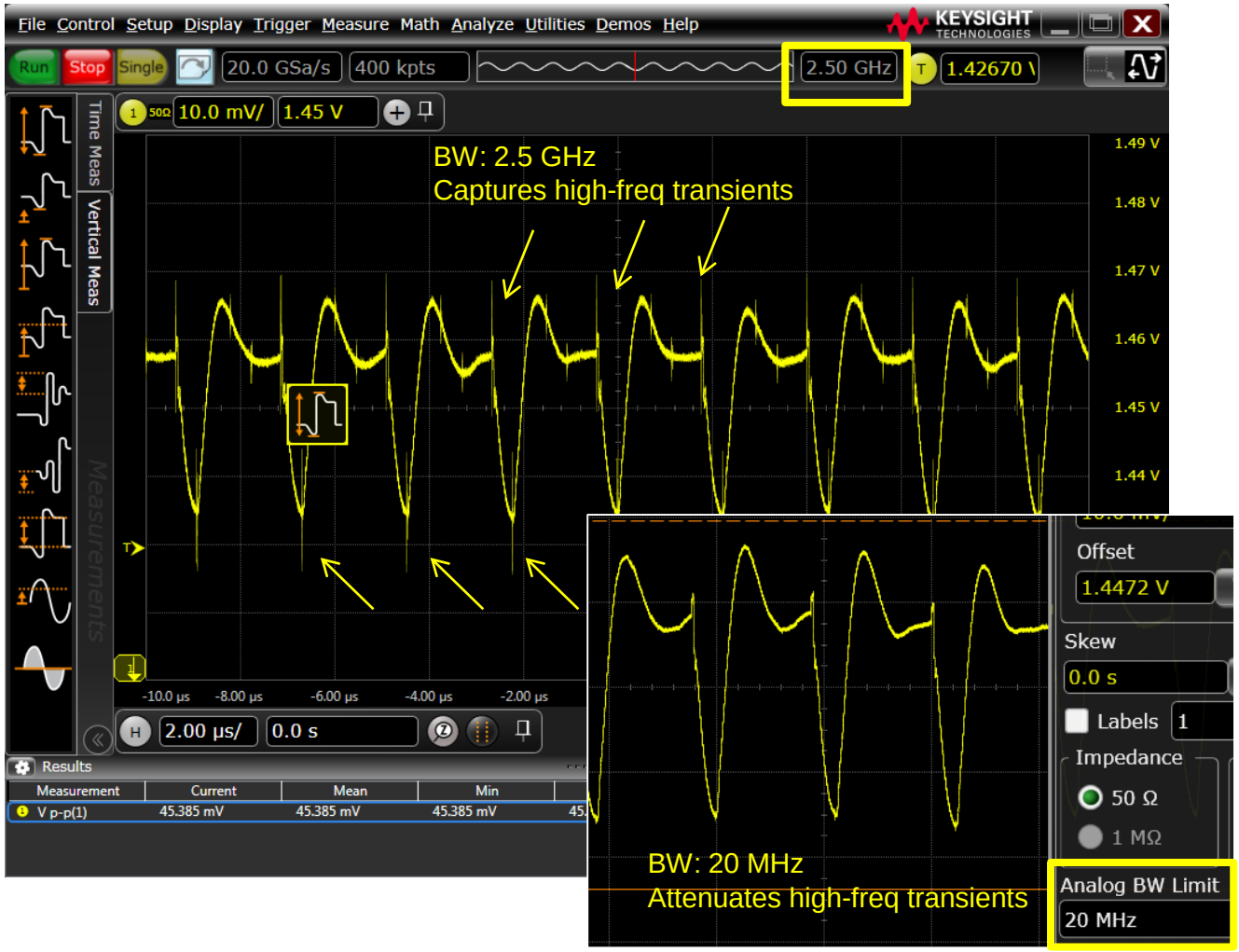
N7020A **2 GHz**, 1.1:1

Power Integrity Measurements

Tradeoff with BW limiting—Use What is Needed

Switching currents cause transients that can easily exceed 1GHz.

Supply noise is a leading cause of clock/data jitter.



N7020A Power Rail Probe

High Bandwidth

Characteristics and Specifications: N7020A Power Rail Probe	
Probe Bandwidth (-3dB)	**2GHz**
Attenuation Ratio	1:1
Offset Range	± 24V
* Input Impedance @ DC	50kΩ +/-2%
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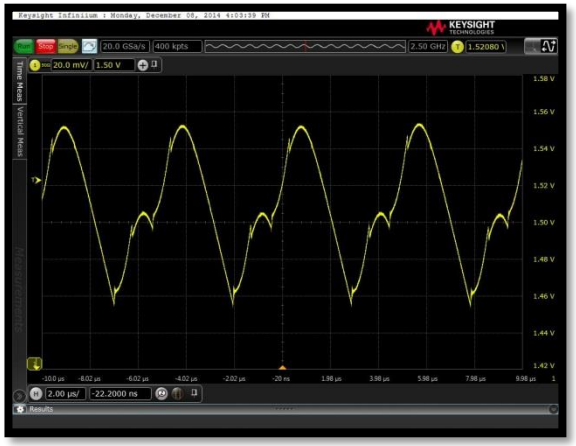
Summary

N7020A Power Rail Probe

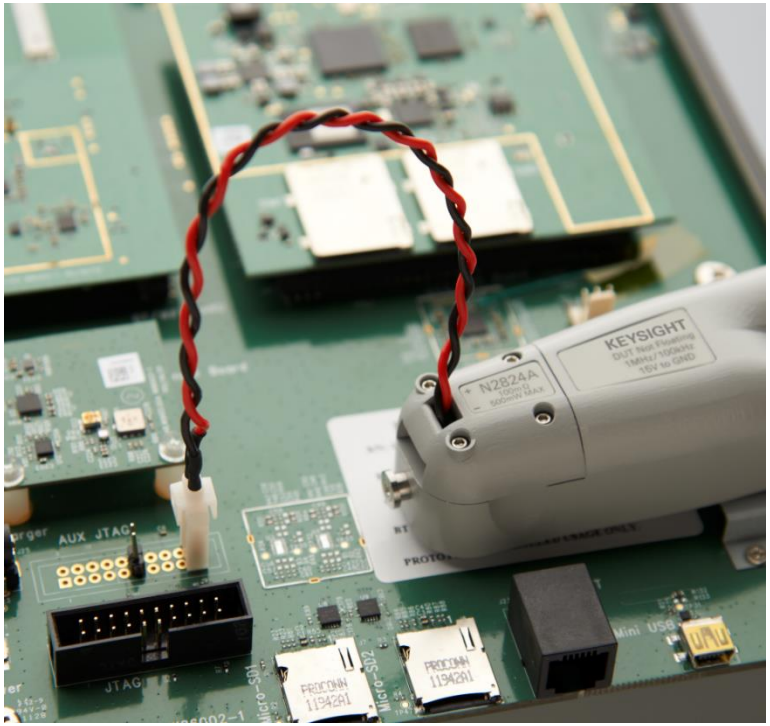


1. Low noise
   - 1:1 attenuation for great signal:noise
2. Support for popular rail voltages
   - +/- 24V at maximum sensitivity without using a DC block
3. Low Loading
   - 50kΩ at DC minimizes loading of power rail
4. High Bandwidth
   - 2GHz for capturing noise caused by switching currents.

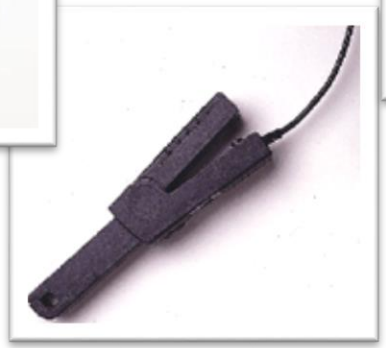
What You CAN Do With the S-Series Scope

Sensitive current measurements

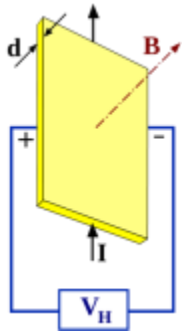
- high-sensitivity, low-level current measurements
- support measurements from **50 uA** to 5 A on Keysight oscilloscopes.



Types of Oscilloscope Current Probes

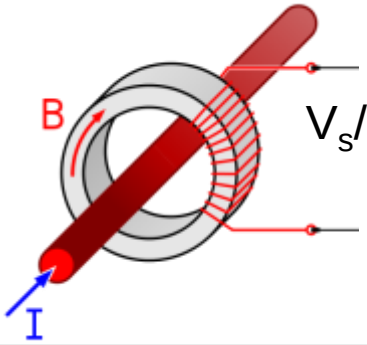


Oscilloscope Current Probe Technologies



$V_H \propto B$

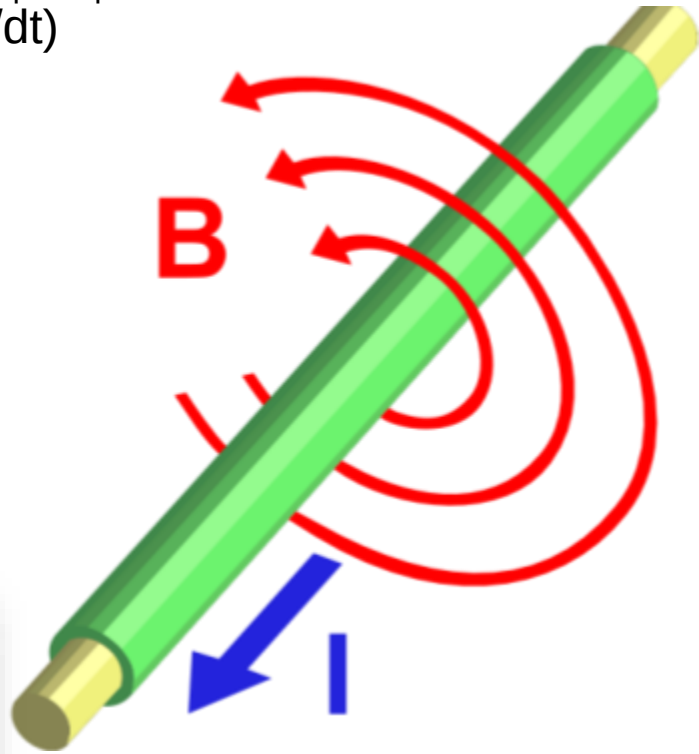
Hall Effect sensor--DC/low Freq



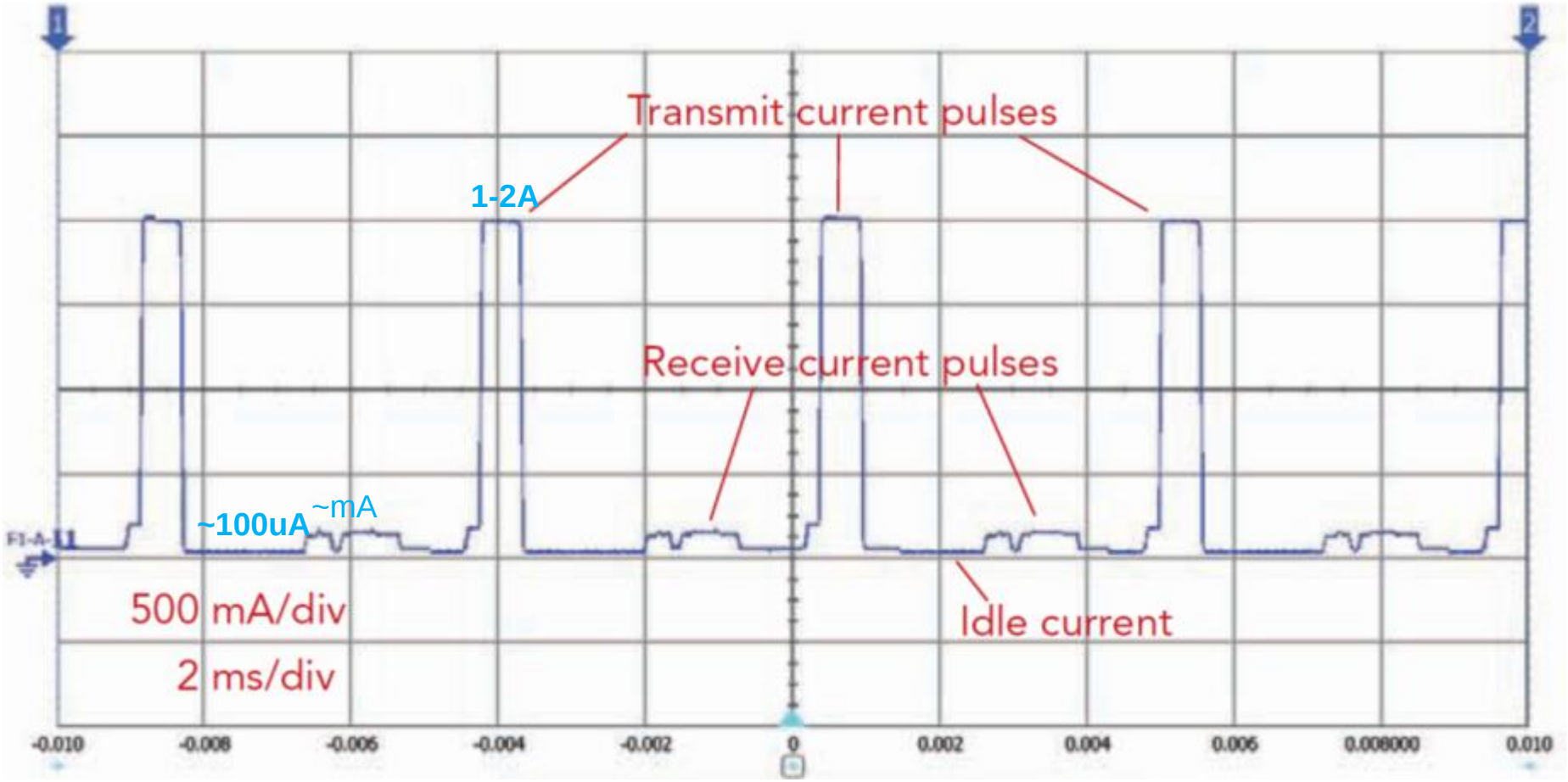
$V_s/V_p = N_s/N_p = I_p/I_s$
$f(d\Phi/dt)$

Transformer--AC

Hybrid AC/DC



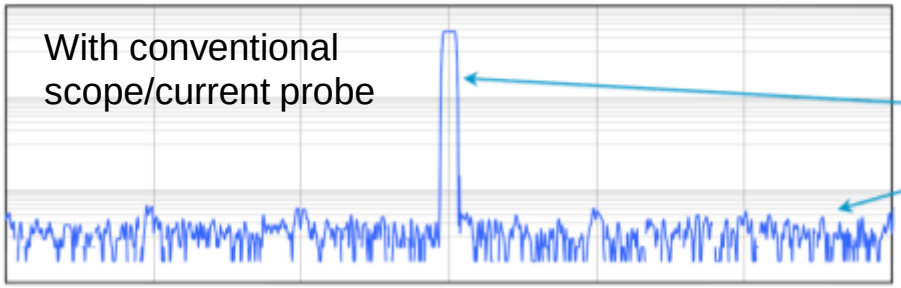
Current Measurement Challenge – mobile device current consumption



Current Measurement Challenge
- Vertical resolution and Dynamic range

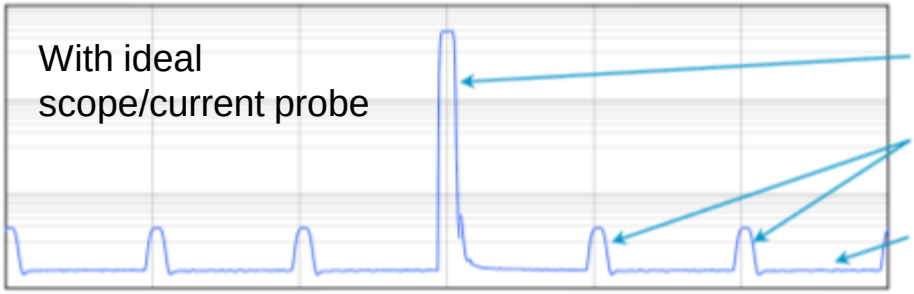
Two issues
- Insufficient resolution/sensitivity
- Insufficient dynamic range

100uA< X <10mA



2A

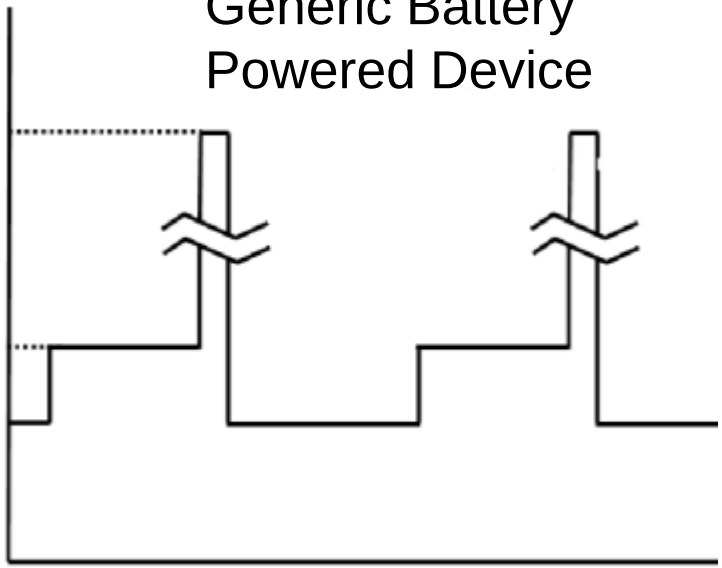
?



2A

mA

100 uA



8 bits isn't enough
2A/256 = 8mA

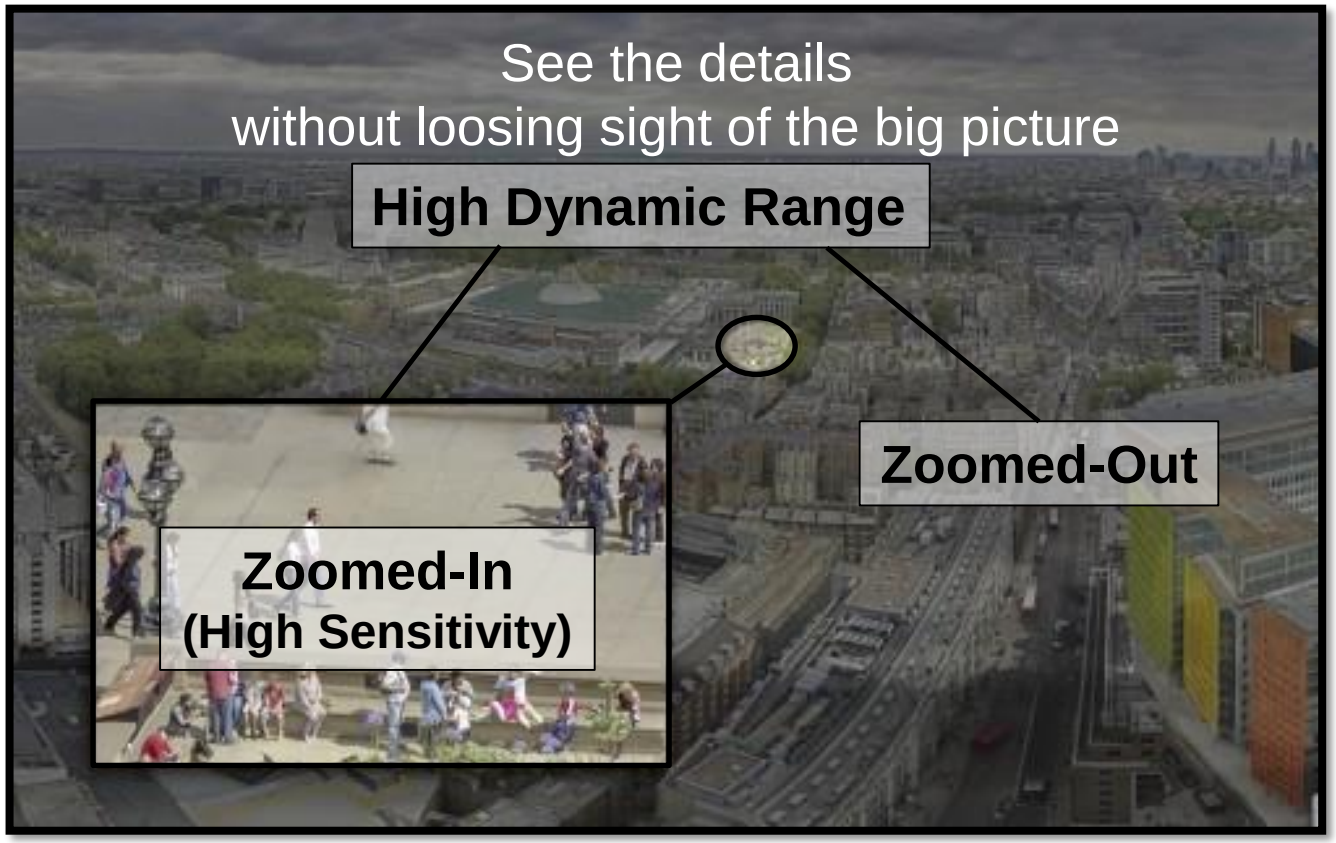
Current Measurement Challenge –

Example with a clamp-on current probe (N2893A, 0.1V/A)

You can measure the peaks (at 700mA) but how would you measure the low level currents?

You may want to move up the waveform and zoom in on the low levels, but the waveform is buried into noise.

Big Picture vs. Little Details



N2820A/21A – Key Features and Performances

N2820A/21A Overview

- Measure currents as low as 50 µA
- Measure currents as high as 5 A
- Measure AC and DC
- Wide dynamic range -- >20,000:1
- Bandwidth
  - 3 MHz Zoom-Out Channel
  - 500 kHz Zoom-In Channel
- AutoProbe interface (1MΩ output)
- Make-before-break (MBB) interface
- Interchangeable, user selectable R_{sense} modules – 20 mΩ, 100 mΩ and user defined R module
- New scope measurements – current consumption over time (Charge in AmpH)
- Compatible with InfiniiVision 3kX, 4kX, 6kX and Infiniium 9k, S-series

N2820A 2-channel

N2821A 1-channel

Customer Benefits Over Other Methods

- N2820A/21A allows a customer to make current measurements on “sub circuits ” as opposed to system currents
- Customers can easily make current measurement with the familiar instrument (oscilloscope) that is already on their bench
- Make a current measurement that is triggered from a voltage measurement and do various measurements and analysis built into the scope
- Better visualization of waveforms on scopes
  - Better repeatability over clamp-on type current probes
  - No need to calibrate or degauss the probe frequently
  - Lower noise and drift

Sense Resistor Heads

- 500 mW
- 250 µA - 5 A
- <±1% tolerance
- 20 ppm/°C
- For smaller voltage drop or lower burden on your circuit
- Order N2822A for replacement part

20 mΩ

- 500 mW
- 50µA – 2.2 A
- <±1% tolerance
- 20 ppm/°C
- For higher sensitivity, BW and lower noise
- Order N2824A for replacement part

100 mΩ

- Use your own sense R on your target
- Choose between 1 mΩ to 1 MΩ
- Check the resistor power rating ($P = I^2R$)
- Order N2825A for replacement part

User defined

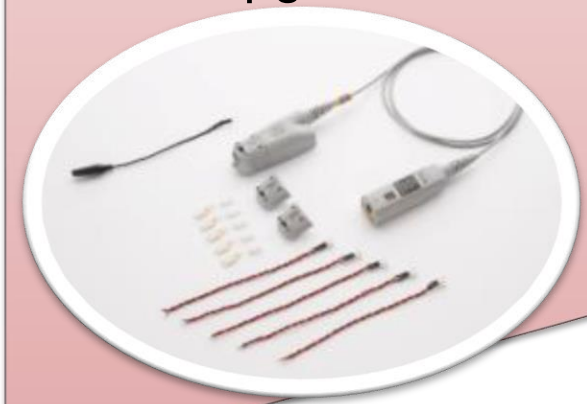
2 channel vs. 1 channel

N2820A 2 channel

- Zoom-in “and” Zoom-out (both at a time)
- Two channels at different gains
- 86 dB (20,000:1) of wider dynamic range
- More accurate current consumption measurement

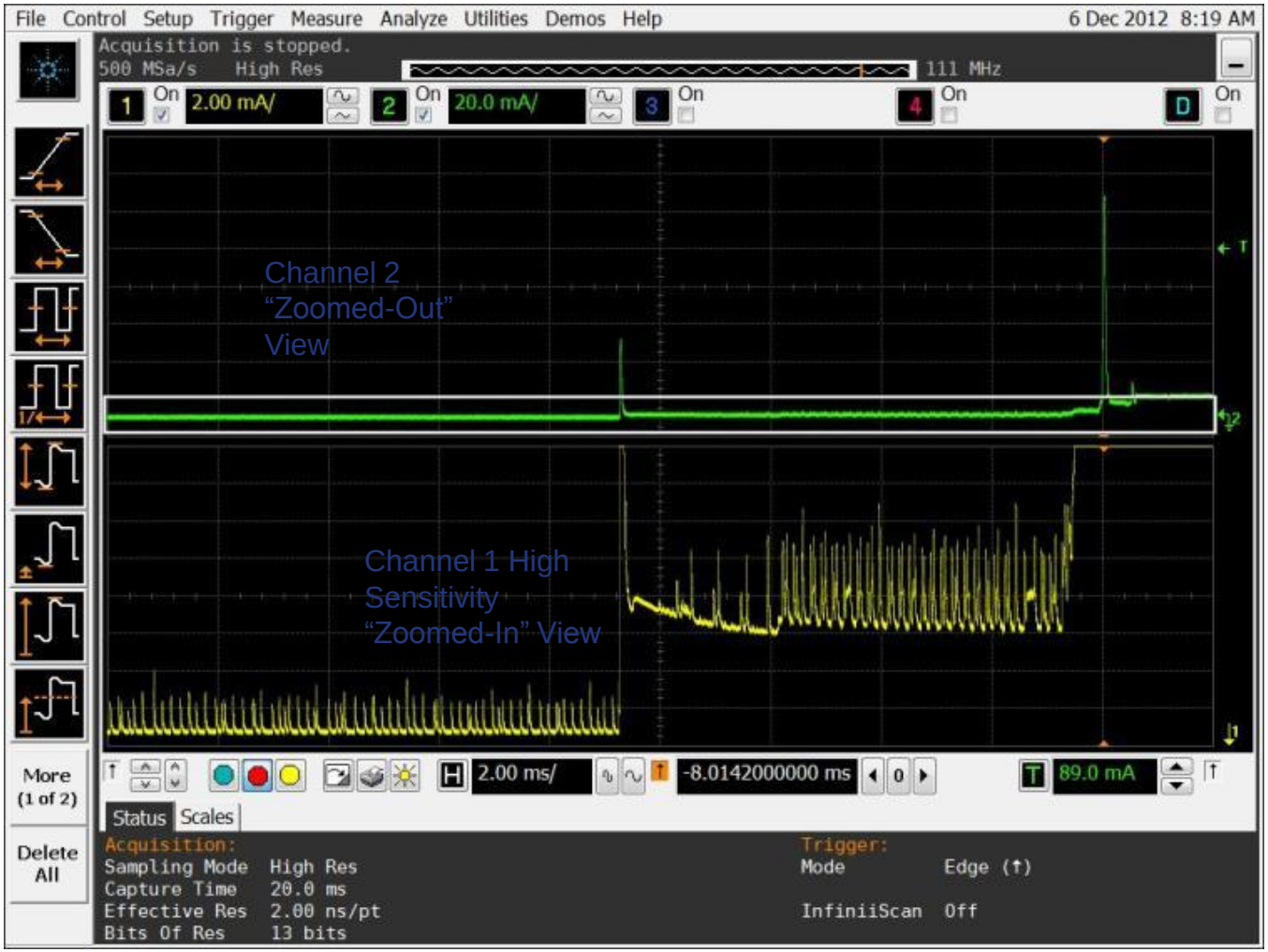
N2821A 1 channel

- Zoom-in “or” Zoom-out (one at a time)
- Normal 60 dB (1,000:1) dynamic range
- Lower cost
- NOT upgradeable to 2-ch



Two channel, Zoom-in/Zoom-out Configuration

– mobile device standby mode (with Infiniium 9000H scope)



N2820A High Sensitivity High Dynamic Range Probe

20 mΩ

- 500 mW
- 250 µA - 5 A
- ± 1% tolerance
- For smaller voltage drop or lower burden on your circuit
- Order N2822A for replacement head

100 mΩ

- 500 mW
- 50 µA - 2.2 A
- ± 1% tolerance
- For higher sensitivity, bandwidth and lower noise
- Order N2824A for replacement head

User-defined

- Use your own sense R on your target
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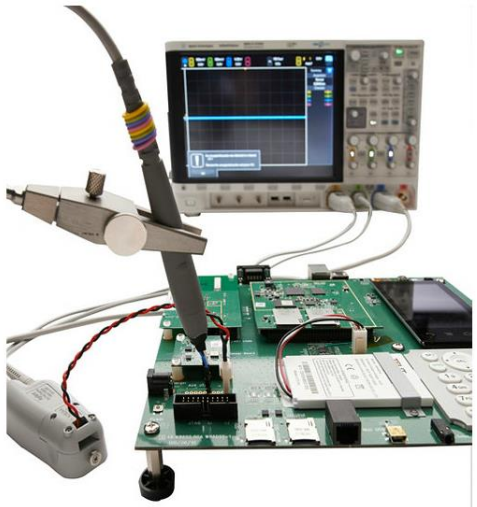
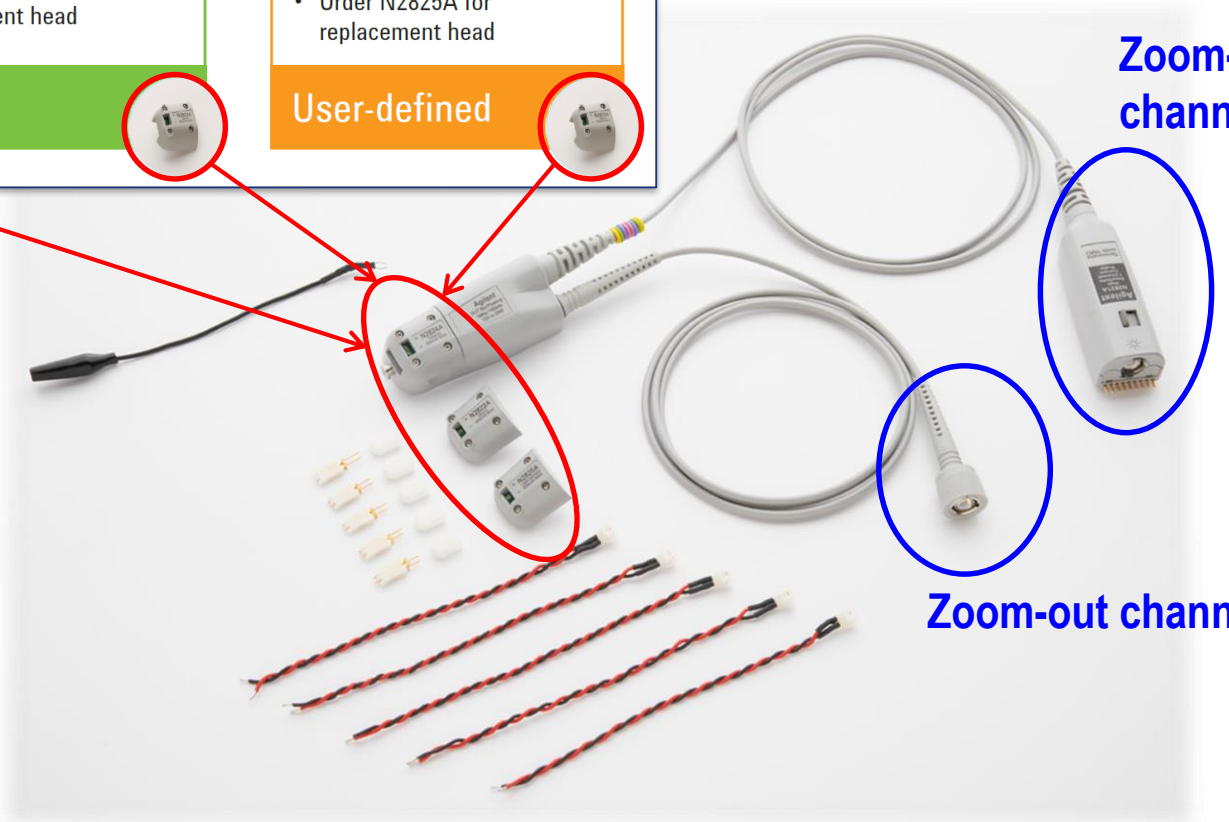
- Check the resistor power rating ($P = I^2R$)
- Order N2825A for replacement head





Questions