
Measurement Techniques
Design Verification & Evaluation
EVERYTHING TEST
Instrument Selection & Optimization

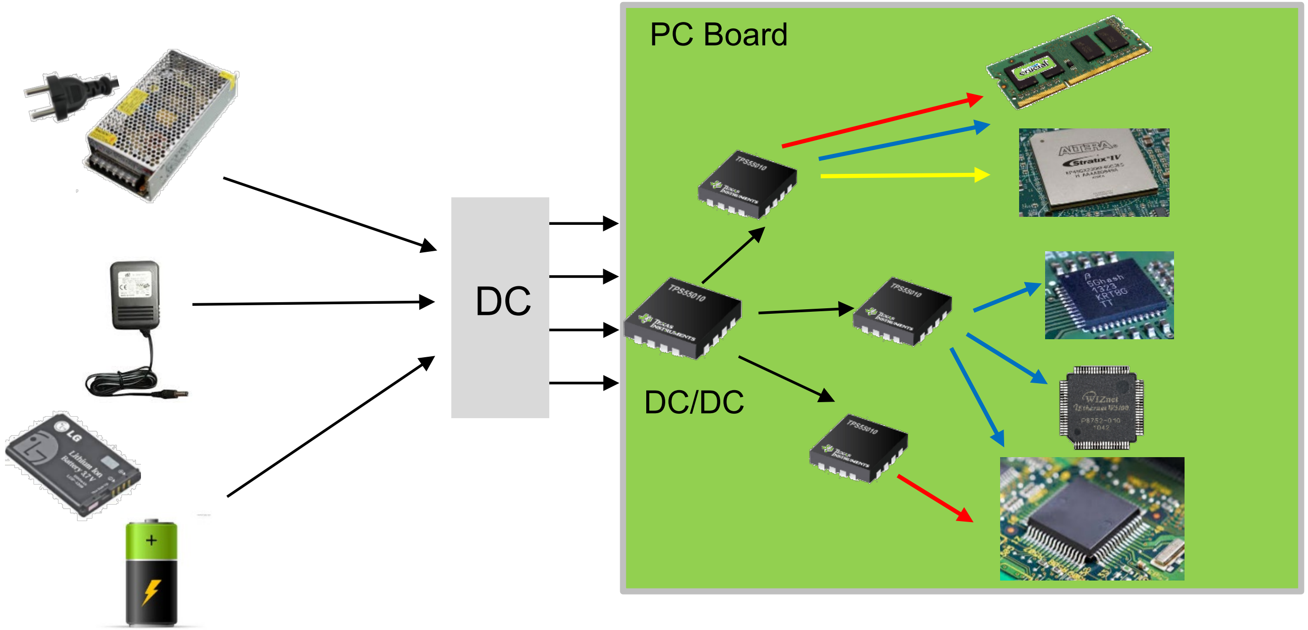
Power Integrity Measurement Fundamentals

DIGITAL TEST

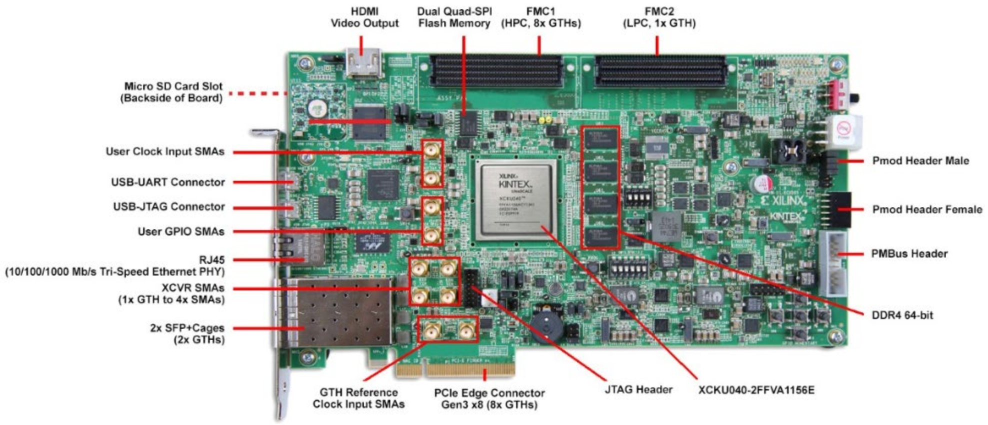
Joel Woodward
Oscilloscope Product Planning
ROHDE & SCHWARZ

Make ideas real

Typically Lots of Power Rails



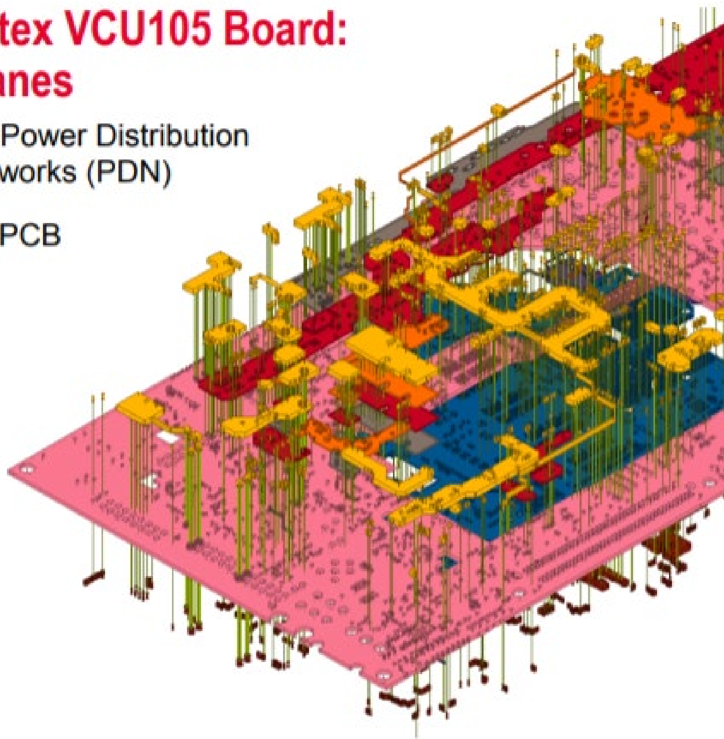
PDN (Power Distribution Network) Example



Xilinx Kintex VCU105 Board: Power Planes

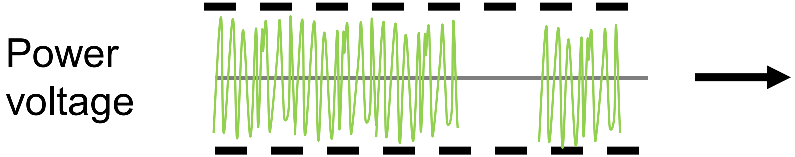
15 Major Power Distribution Networks (PDN)

16 Layer PCB

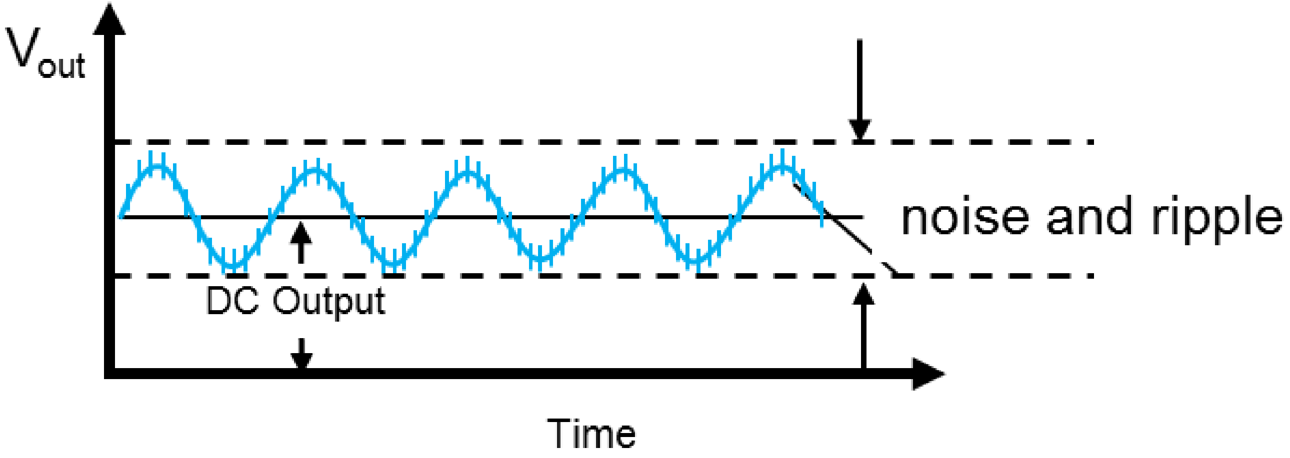


Power Rail Testing

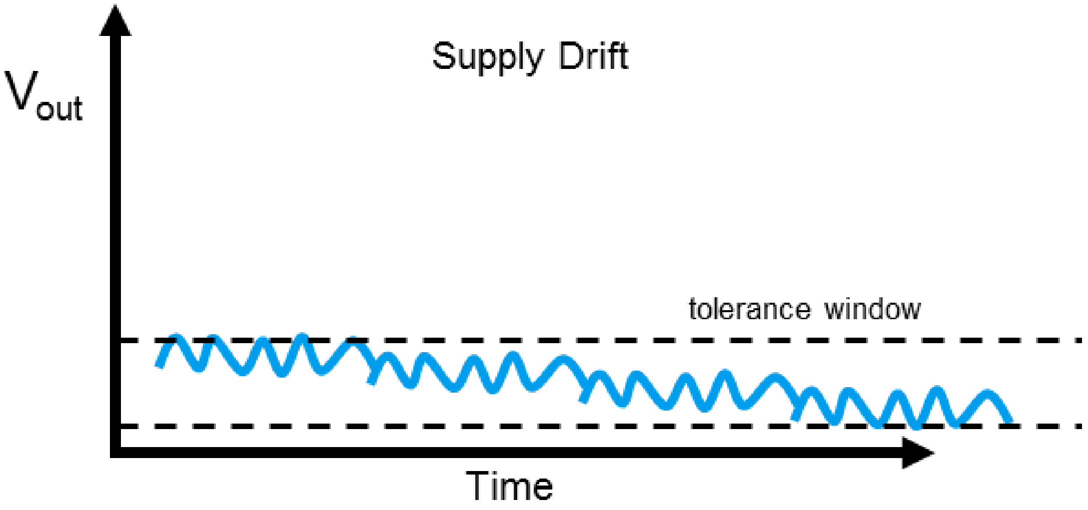
- IC suppliers specify # of power rails, voltage for each, and tolerance for each.
  - FPGAs, ASICs, CPUs, DDR memory…
- Measurements: sequencing, noise / ripple, drift, load/step response, EMI



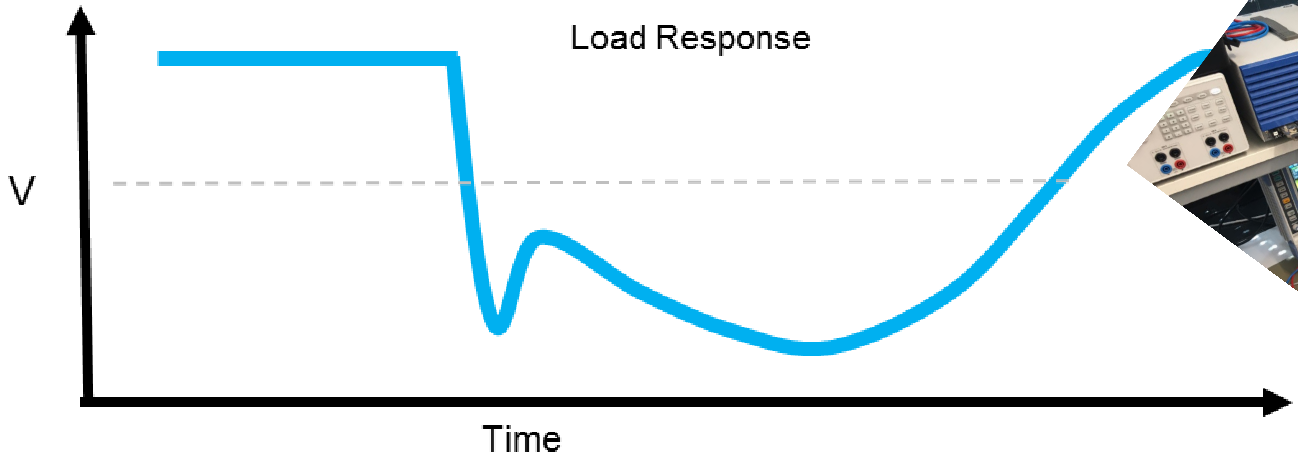
Power Rail Measurements: Noise / Ripple (Vpp)

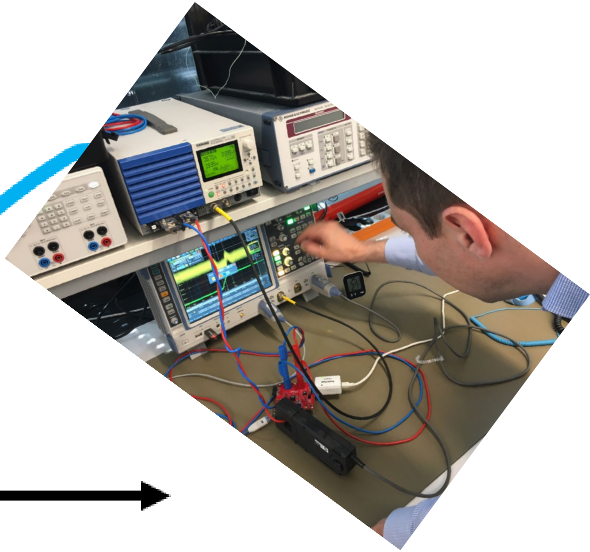


Power Rail Measurements: Supply Drift

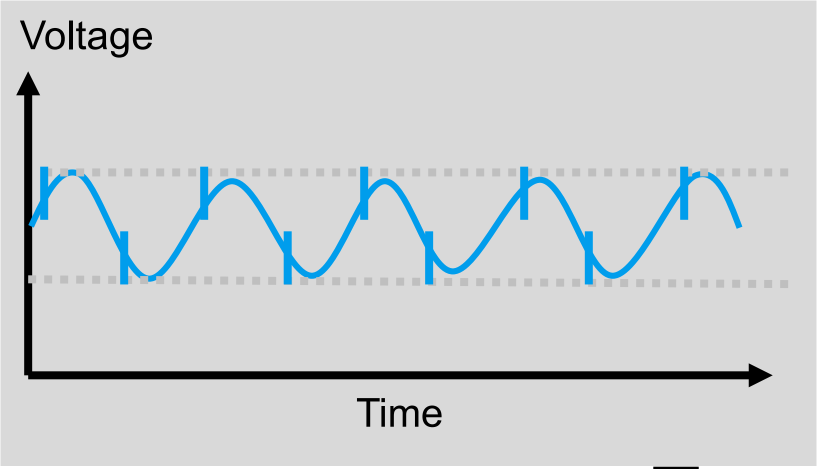


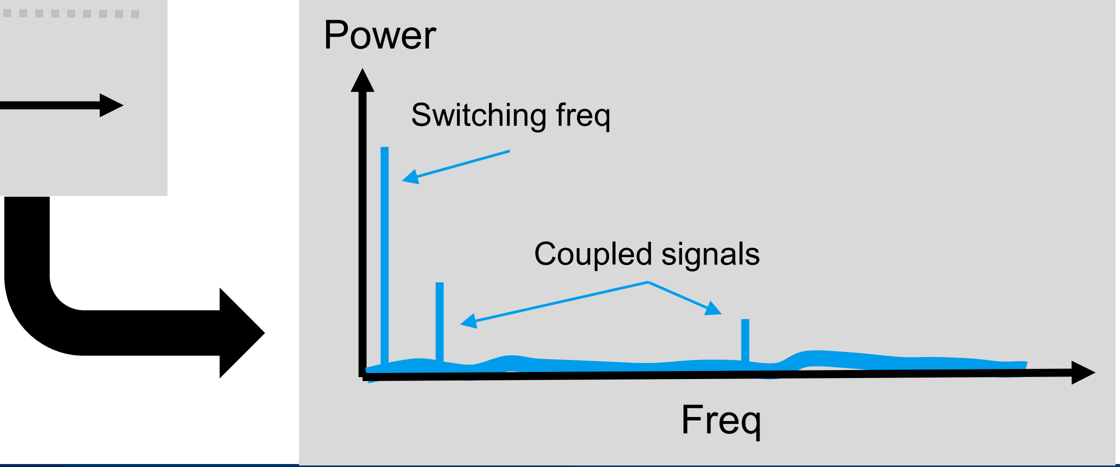
Power Rail Measurements: Load/Step Response



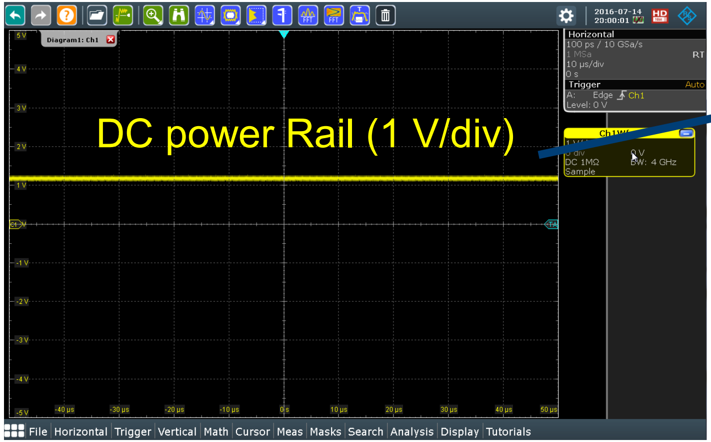


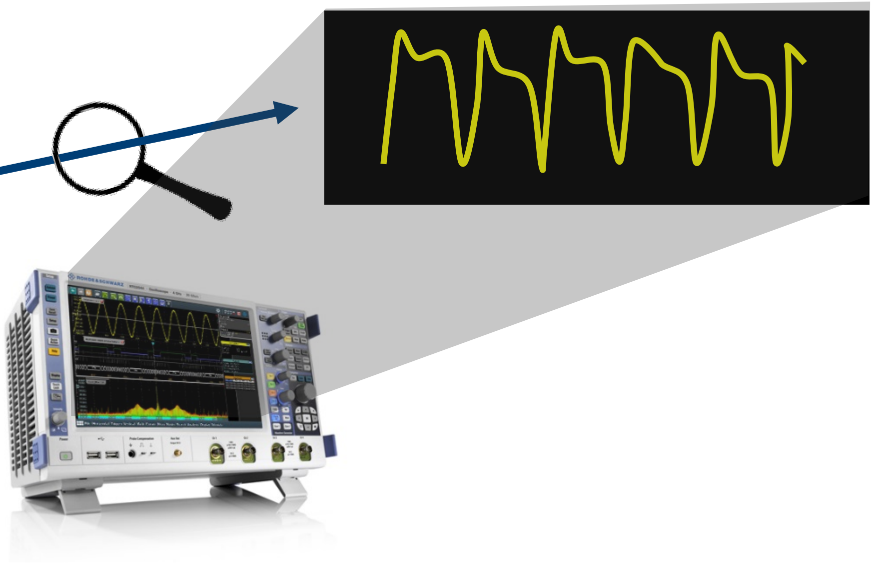
Power Rail Measurements: Coupled signals (EMI)





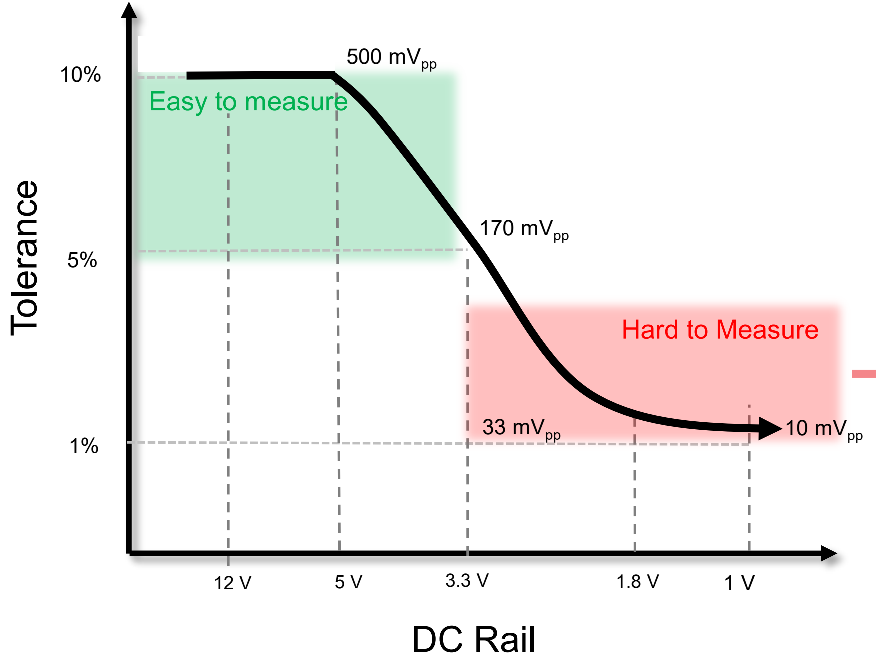
Oscilloscope:
Primary tool for power rail analysis





Power Rail Measurement Challenges

Lower rail voltages and smaller tolerances



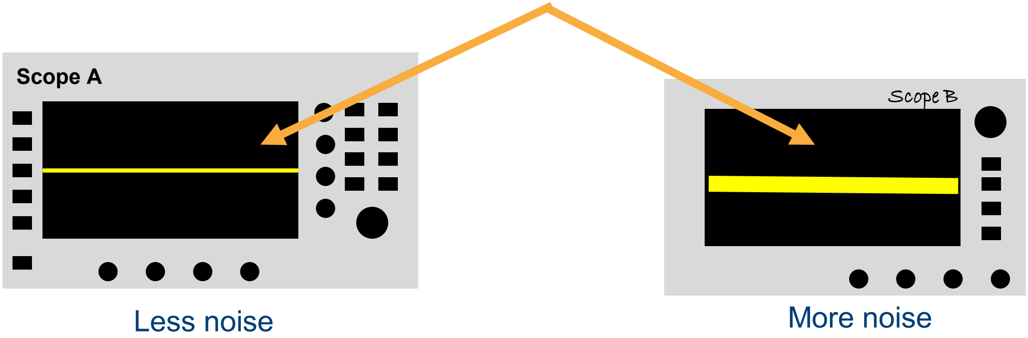
Examples

Rail Value	Tolerance	Need to measure
3.3 V	1%	33 mV_{pp}
1.8 V	2 %	36 mV_{pp}
1.2 V	2 %	24 mV_{pp}
1 V	1 %	10 mV_{pp}

Scope measurement noise can approach or exceed needed signal measurement values

Measurement Noise…
is a function of what scope you use

You will never be able to measure signal attributes smaller than the intrinsic noise of the scope.

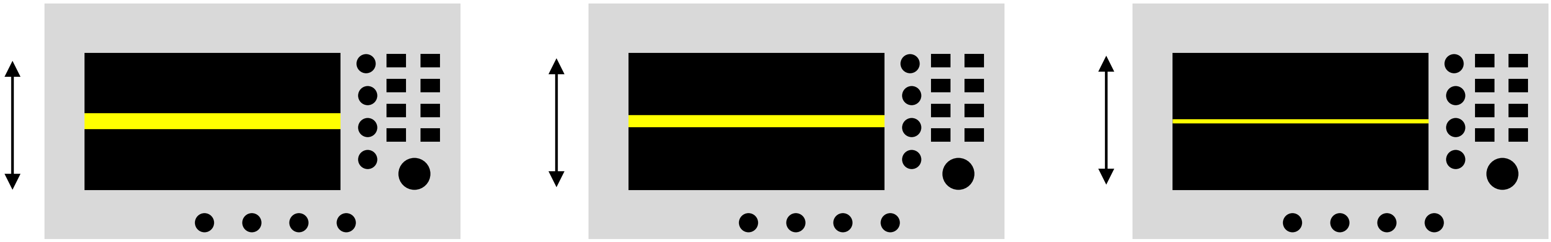


Intrinsic measurement noise with all input signals disconnected.

Measurement noise…

is a function of full-scale vertical scaling (% of full vertical)

10 mV full screen | 100 mV full screen | 5 V full screen

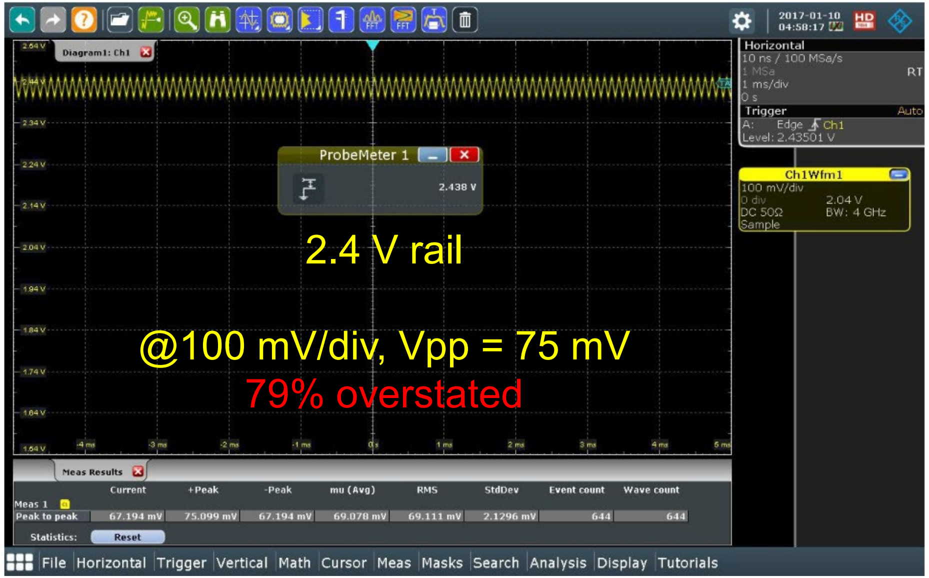


Least noise | More noise | Even more noise

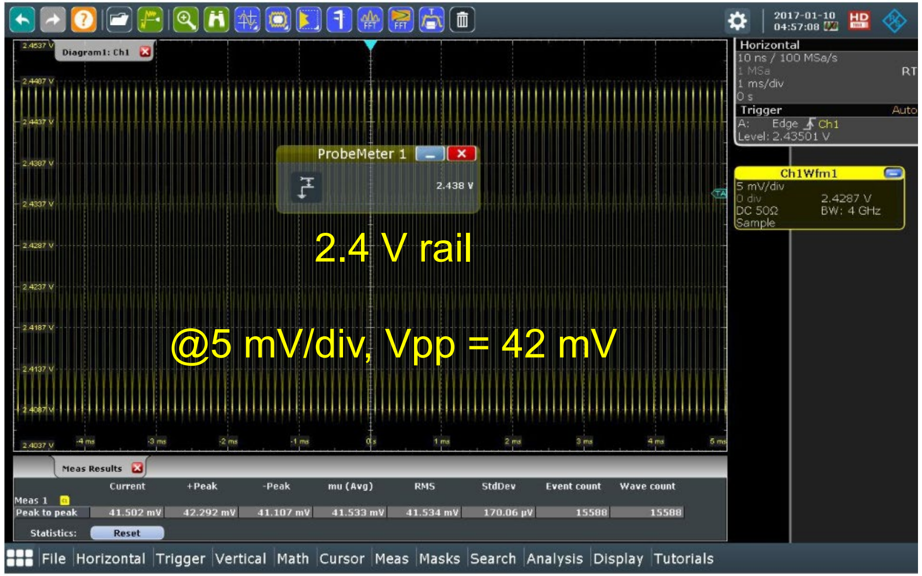
Measurement Noise: Insufficient Internal Offset Impacts

Requires using a higher vertical sensitivity → more noise

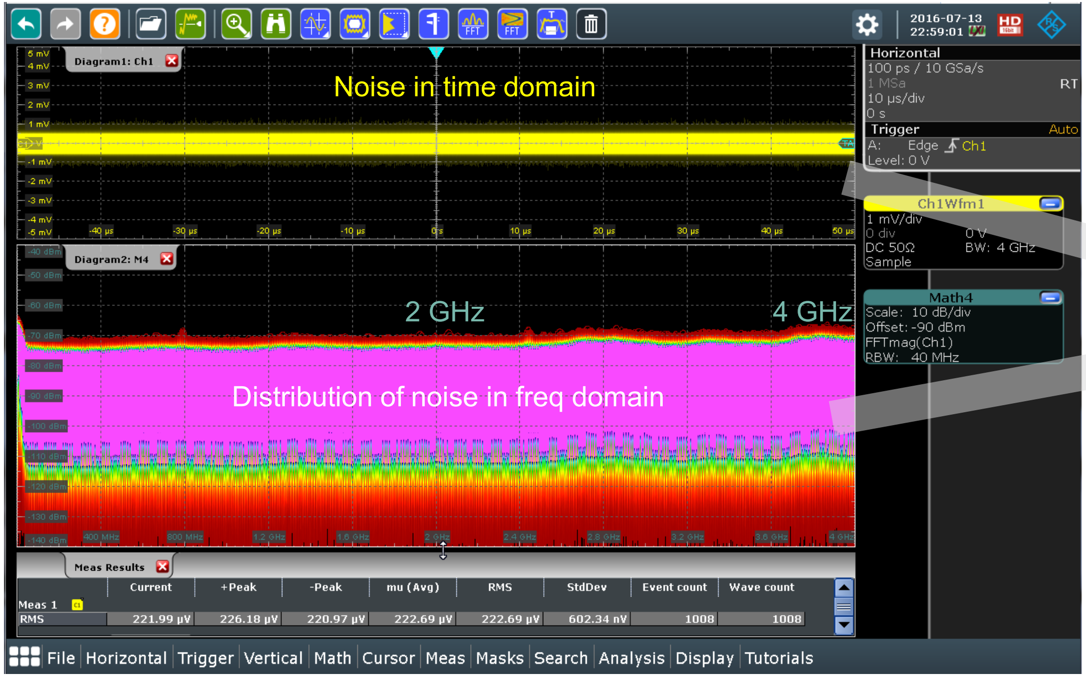
Using max built-in scope offset



Using built-in probe offset



Measurement Noise…
is a function of Measurement bandwidth



Noise in time domain

=

∫ freq domain form 0 to BW

More measurement bandwidth = more measurement noise

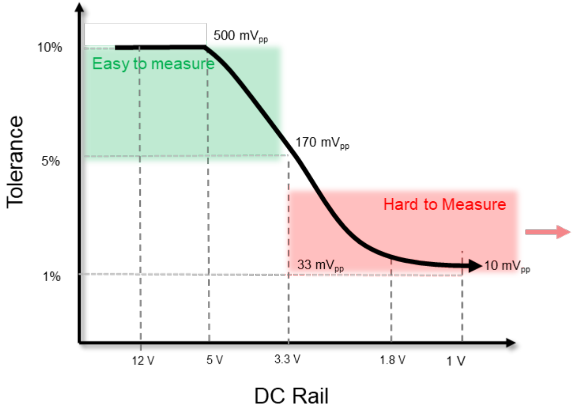
Measurement Noise…

is a function of measurement signal path (50Ω / 1 MΩ) +probe + probe accessories

Measurement Considerations

How important is measurement accuracy?

1. Learn & use scope settings that impact accuracy
2. Investment in low-noise scope with needed BW for your power rail needs
3. Investment in specialized power rail probes



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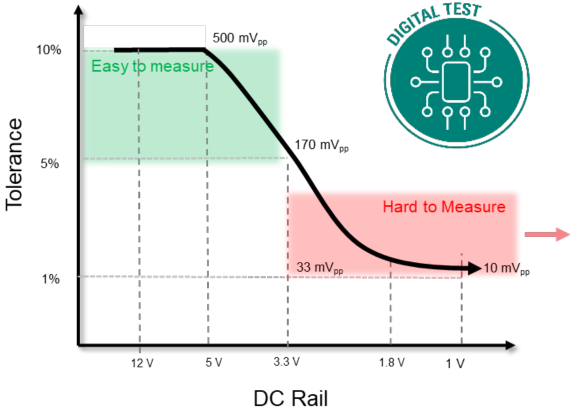
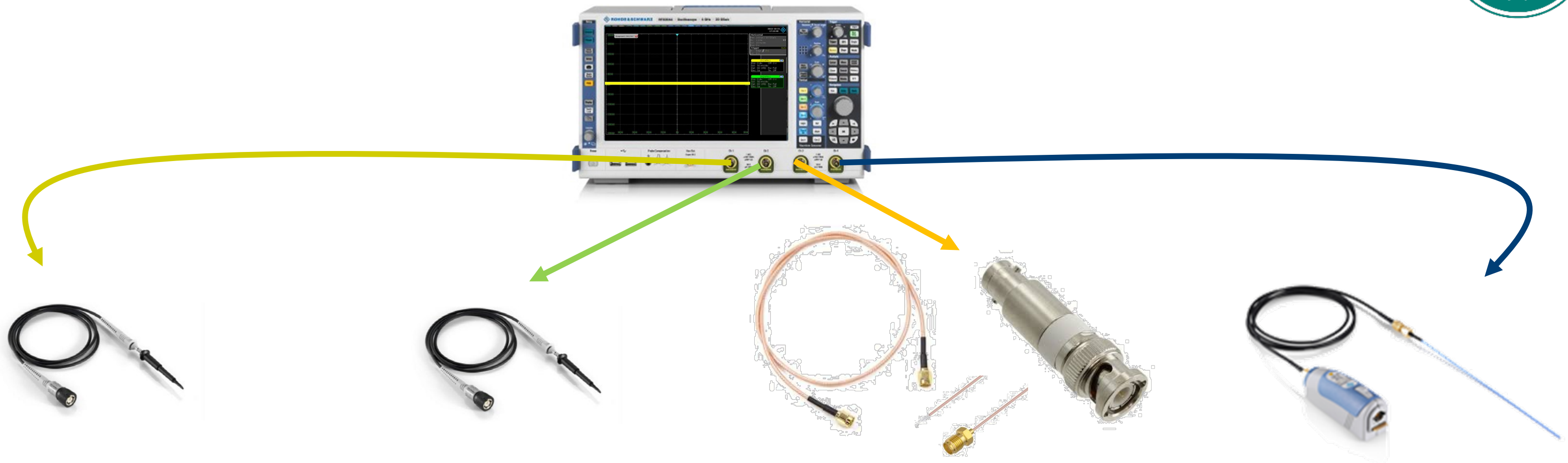


Four Measurement Approaches



Standard
10:1
passive
probe

Low BW
1:1
passive
probe

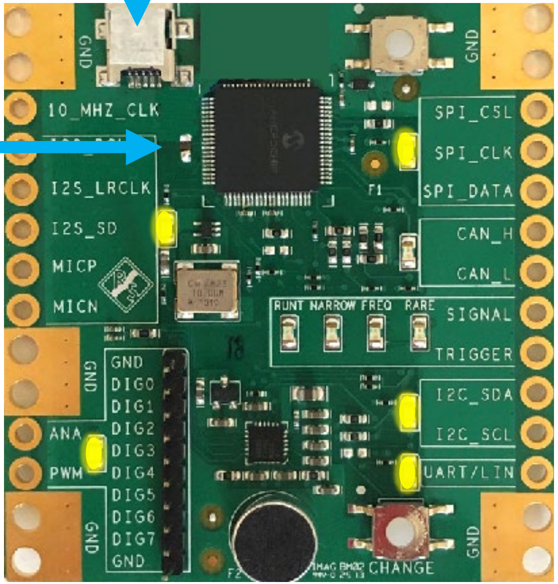
50 Ω cable
(with blocking cap)

Specialized
power rail
probe

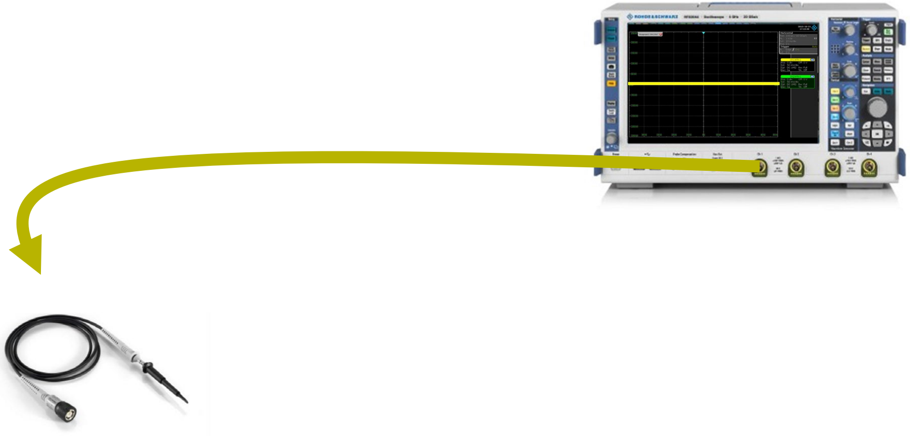
Device Under Test – 3.3V Power Rail

USB power

3.3 V rail



10:1 Passive Probe



Standard
10:1
passive
probe

Low BW
1:1
passive
probe

50 Ω cable
(with blocking cap)

Specialized
power rail
probe

10:1 Passive Probe

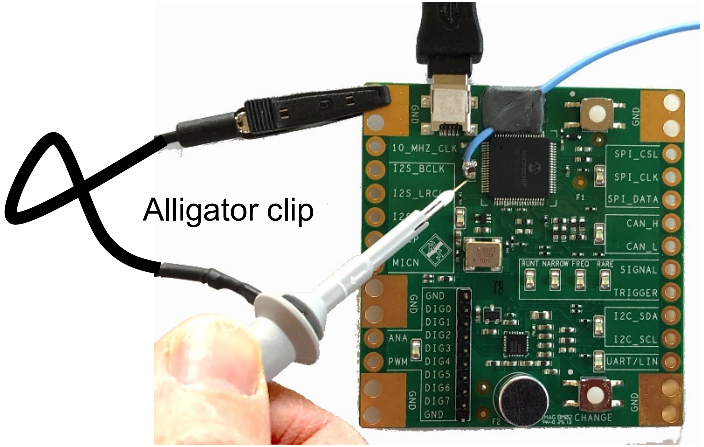
Advantages

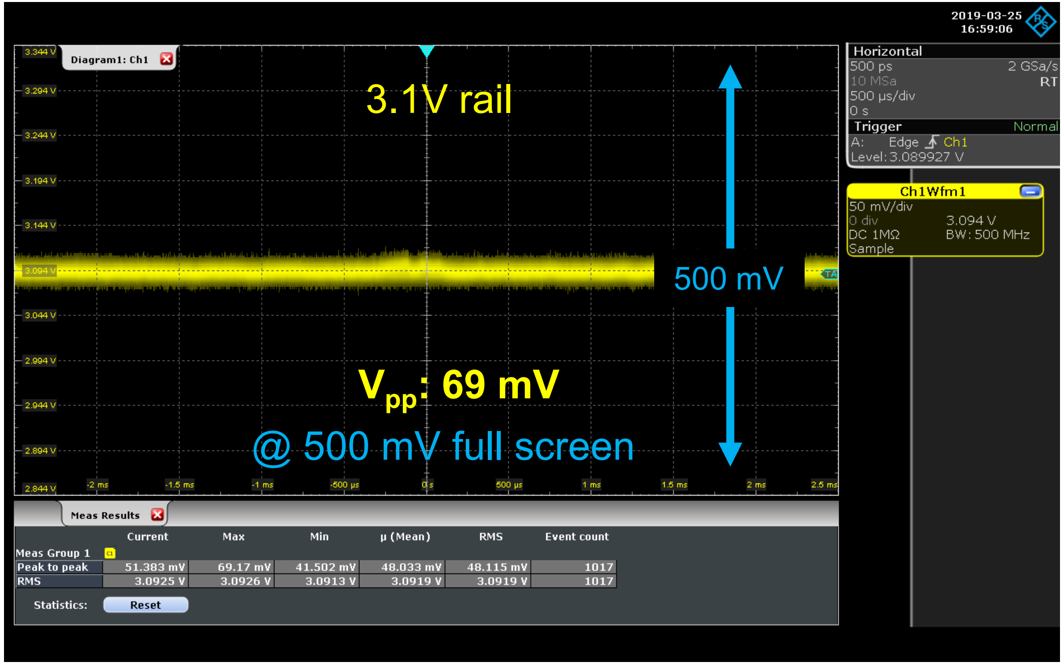
- Comes standard with most scopes
  - no extra expense
- 1 MΩ loading at DC
  - Preserves expected DC value
- Easy to connect using browser tip
  - Multiple ground alternatives

Disadvantages

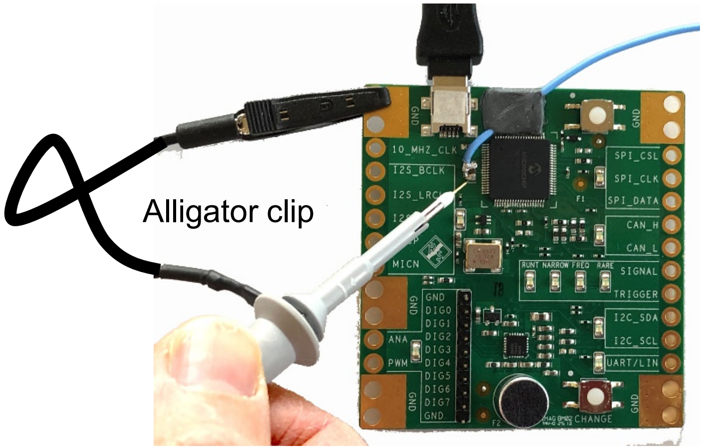
- Significant noise
  - 10:1 attenuation
  - Minimum vertical setting of 10 mV/div
- Long grounds
- BW limited (500 MHz for ZP-10)
- No solder-in alternative

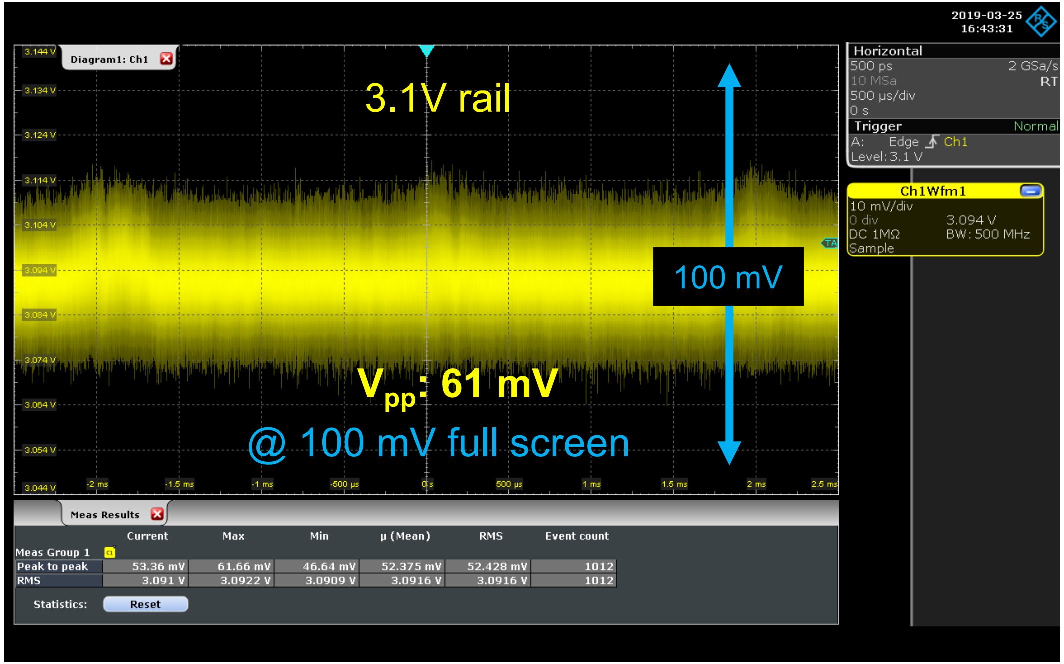
10:1 Passive Probe with Alligator Clip





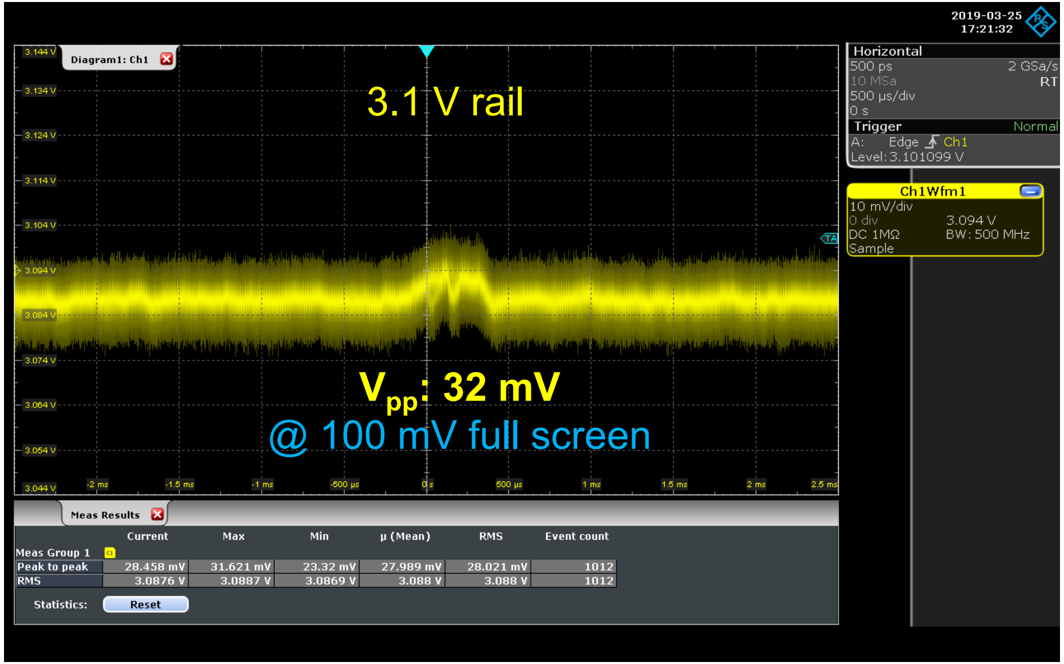
Noise: Function of Vertical Full Scale



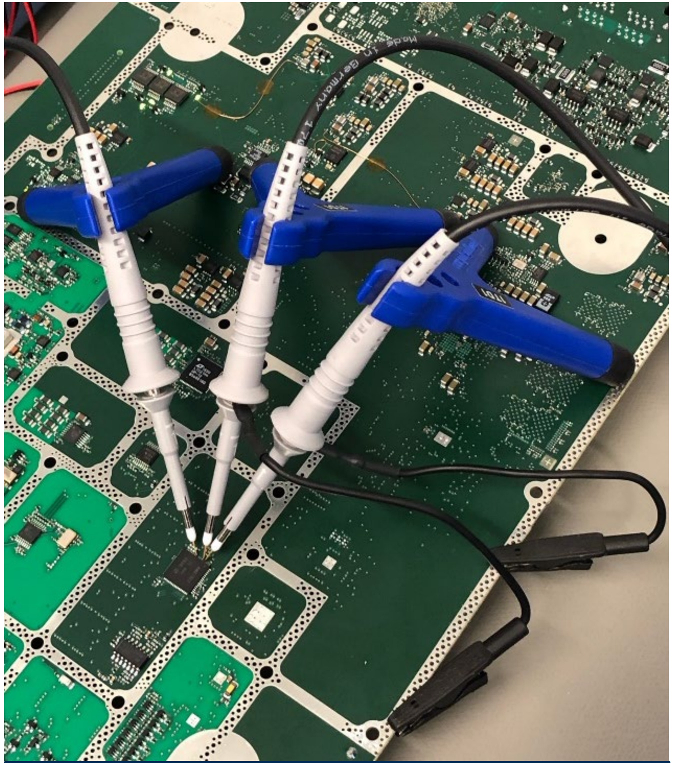


Noise: Function of Probing Accessories

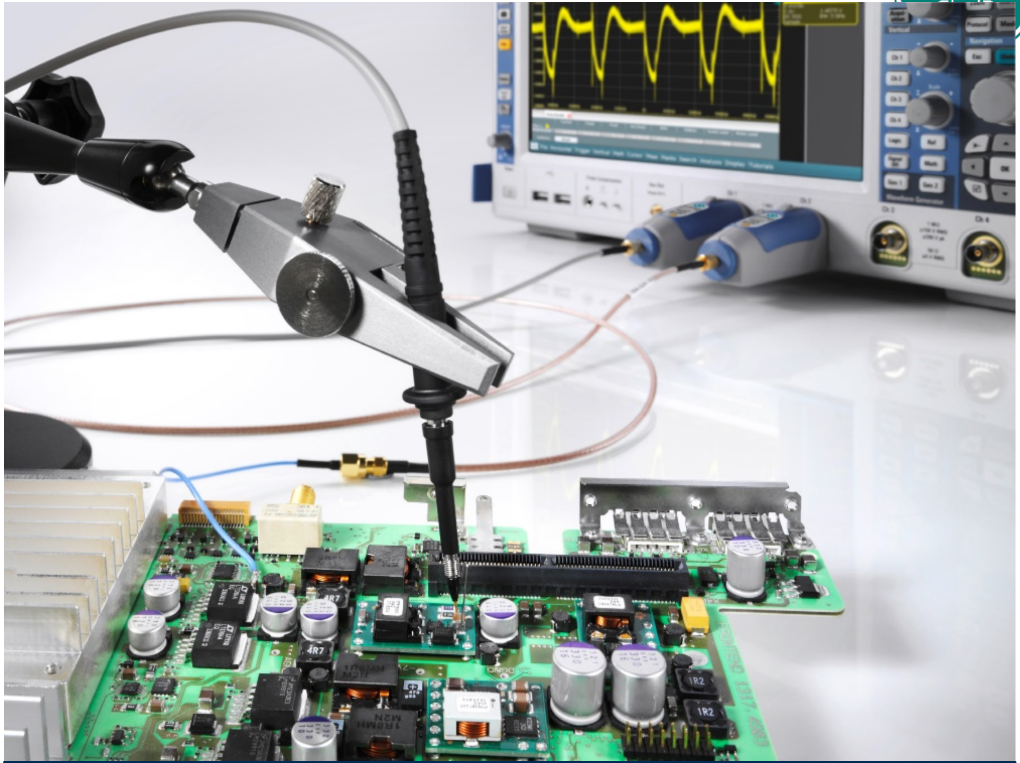
Ground spring



ADD an extra hand



Probe Positioner 2 Leg



3D Probe Positioner

1:1 Passive Probe

Standard
10:1
passive
probe

Low BW
1:1
passive
probe

50 Ω cable
(with blocking cap)

Specialized
power rail
probe

1:1 Passive Probe

Advantages

- ► Low cost
- ► Excellent 1 MΩ loading at DC
  - – preserves expected DC value
- ► Ability to scale to 1 mV/div
- ► Easy to connect using browser tip
  - – Ground spring ground alternative

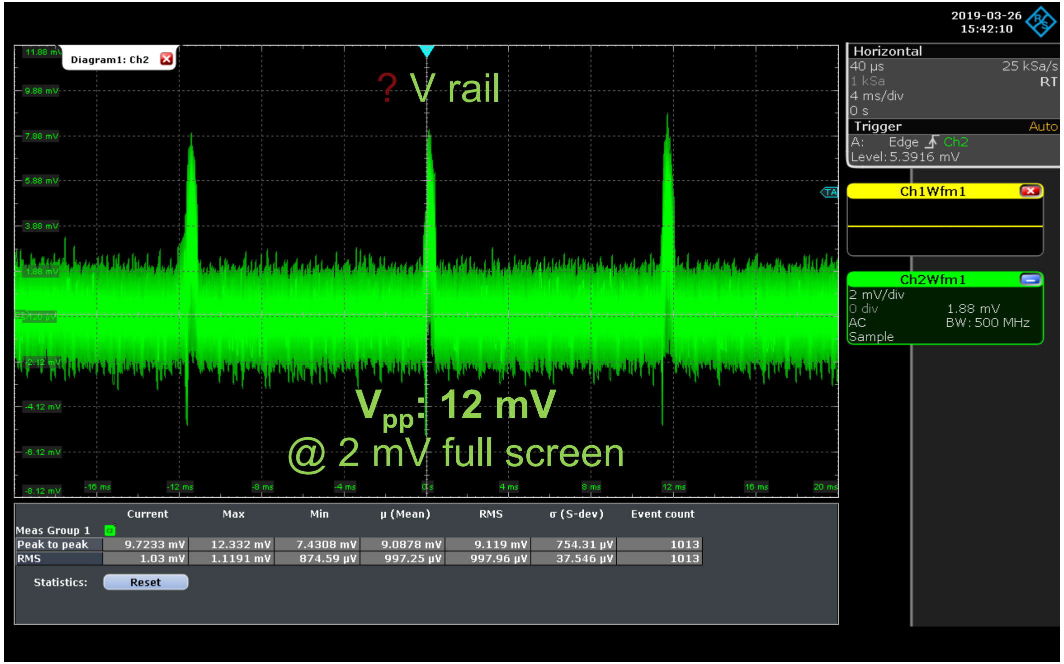
Disadvantages

- ► Limited BW
  - – 38 MHz for ZP-1X
  - – under reports V_{pp} measurements
  - – masks high freq signal coupling
- ► Limited offset – may require AC coupling
- ► No solder-in alternative

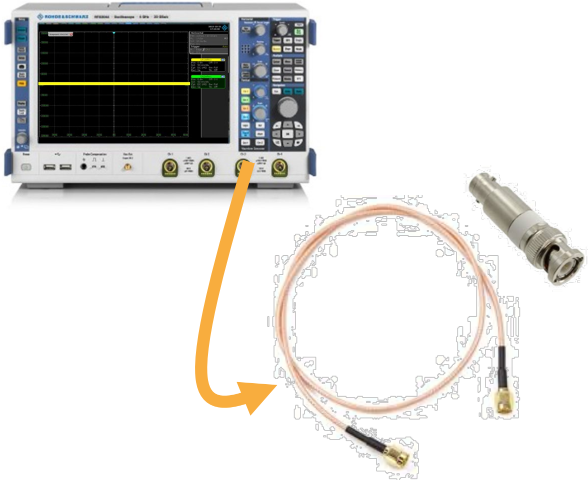
38 MHz 1:1 Passive Probe with Ground Spring

Ground spring

Not enough offset, required AC coupling



50Ω Path



Standard **10:1** passive probe	Low BW **1:1** passive probe	50 Ω cable (with blocking cap)	Specialized **power rail** probe

50Ω Path

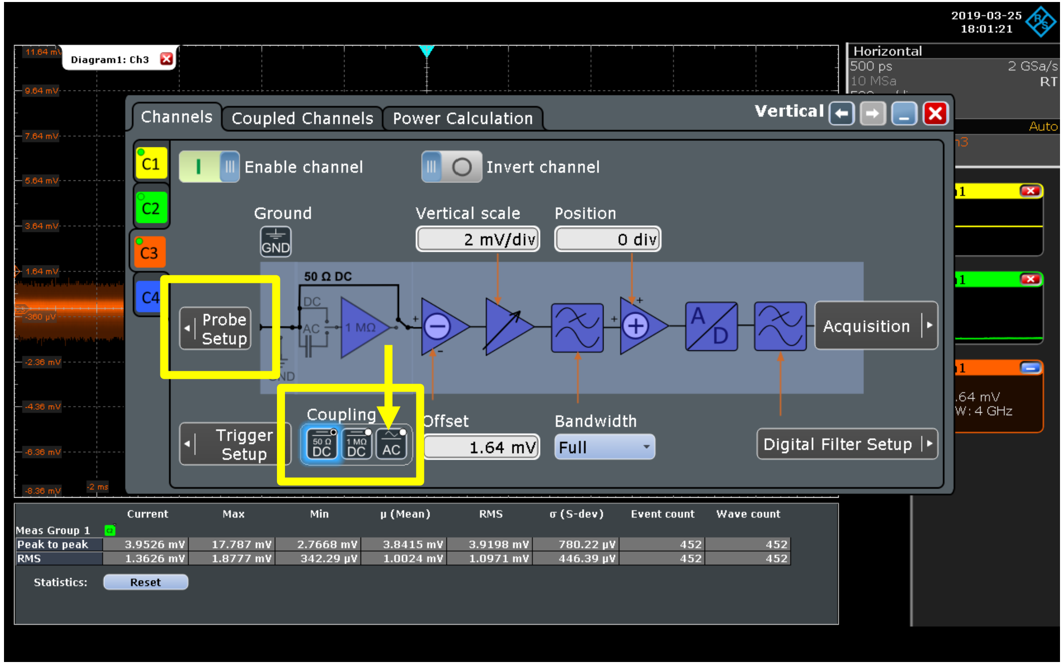
Advantages

- ► 50 Ω scope path typically has less noise than 1M Ω scope path
- ► SMA connector or solder-in pigtail allows for measurement consistency and ease of access

Disadvantages

- ► 50 Ω loading at DC reduces power rail voltage
- ► Insufficient offset (requires blocking cap or AC coupling)
  - Masks DC drift
  - Eliminates ability to see true DC voltage

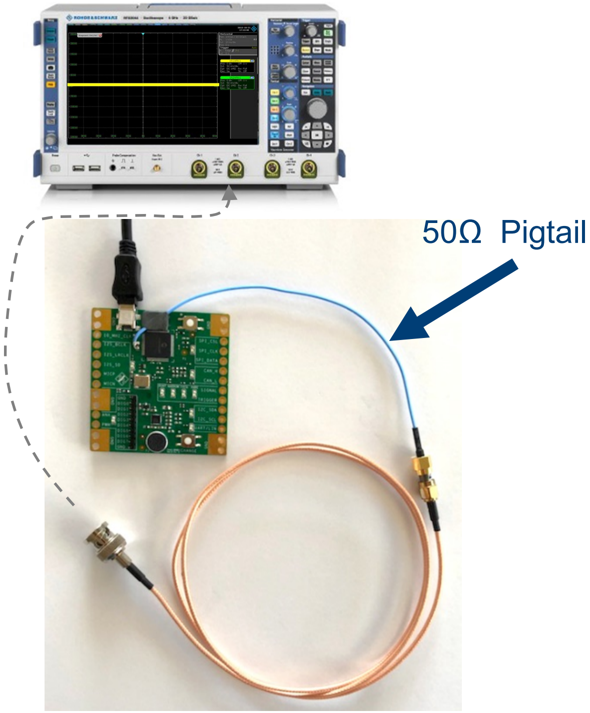
50Ω Path: AC Coupling

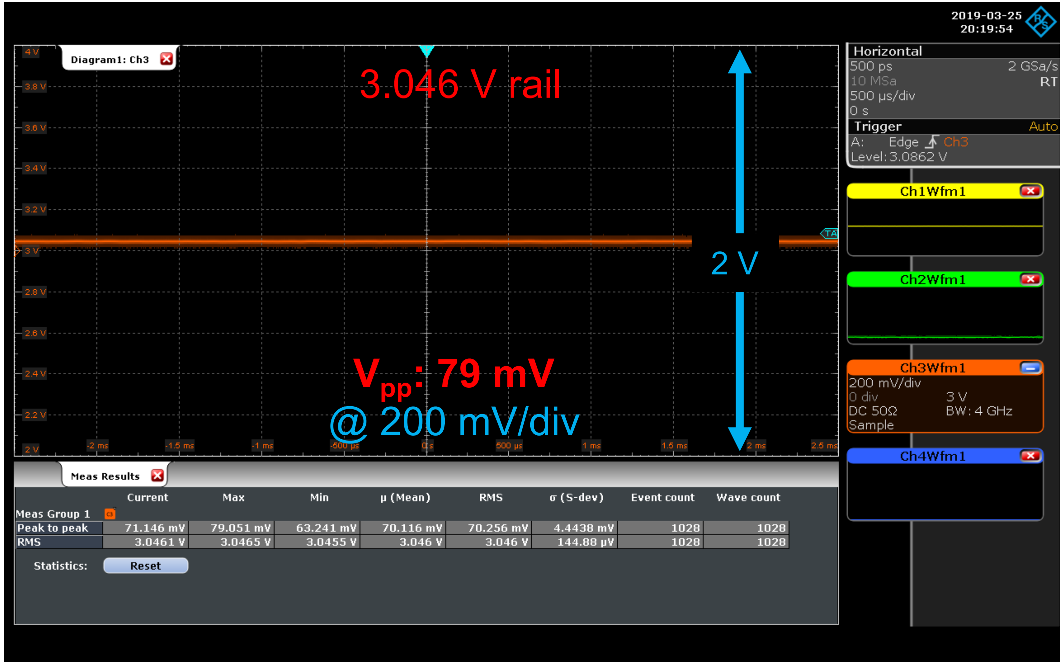


- Set to 50Ω path (channels setup)
- Attenuation to 1:1 (probe setup)
- 50Ω path (limited offset may require AC coupling)

50Ω Path:

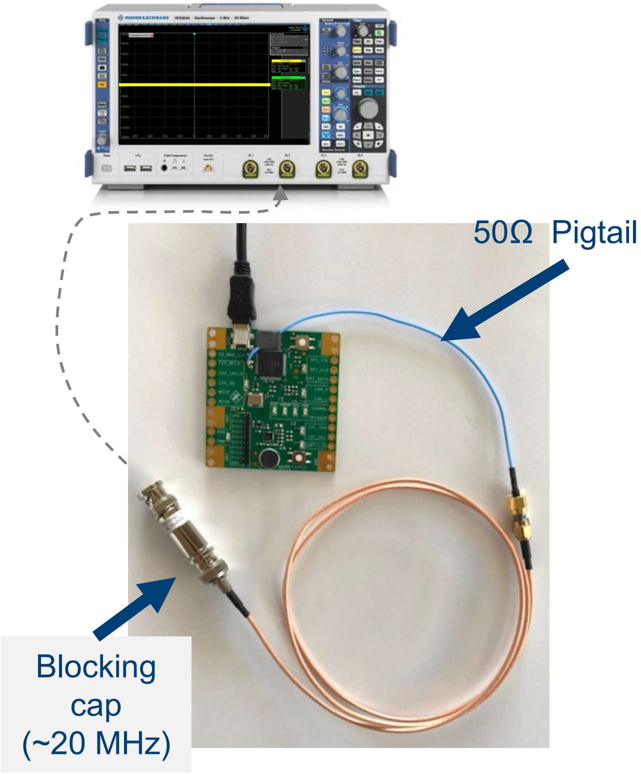
Sufficient offset not available: Requires 200 mV/div scaling.

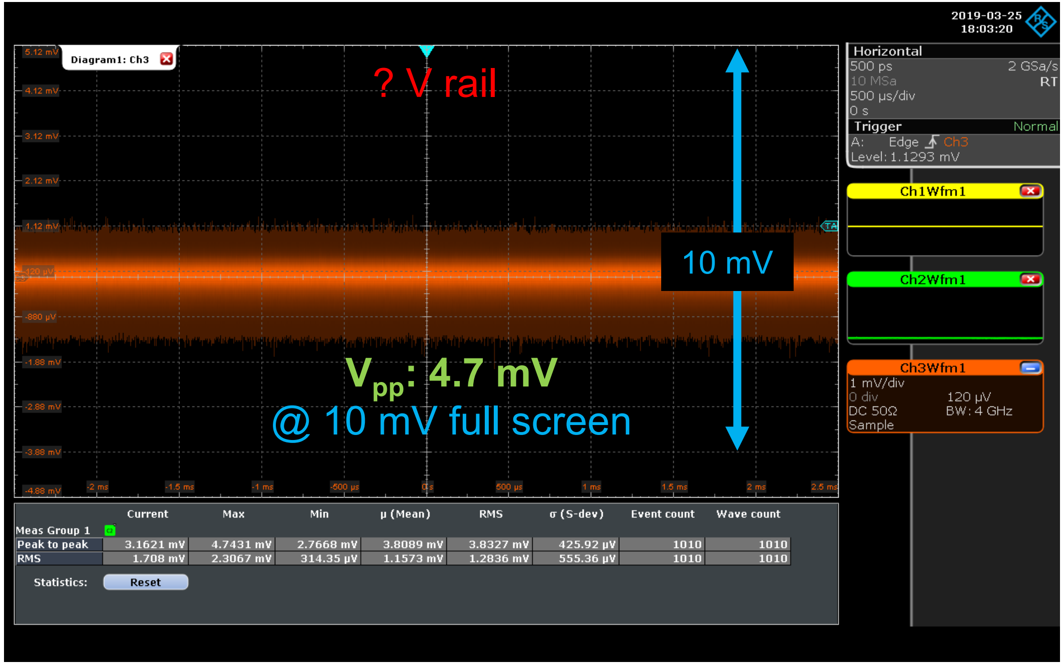




50Ω Path with Blocking Cap (3dB BW = ~20 MHz)

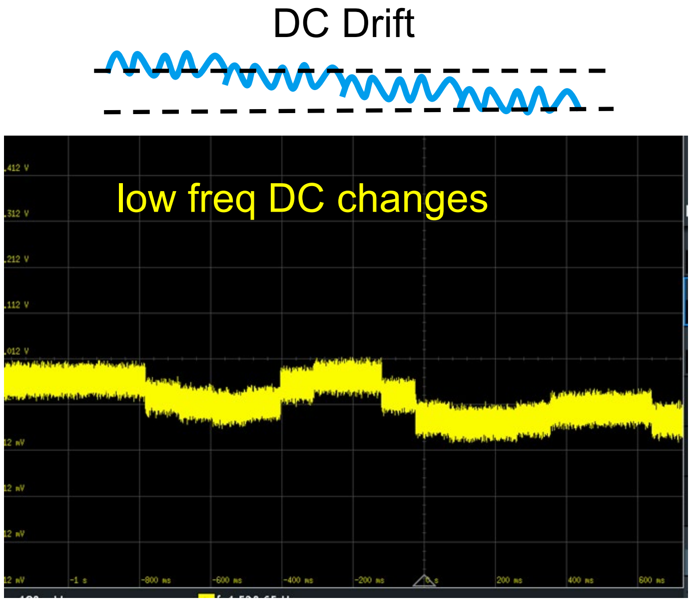
No ability to measure absolute vertical values

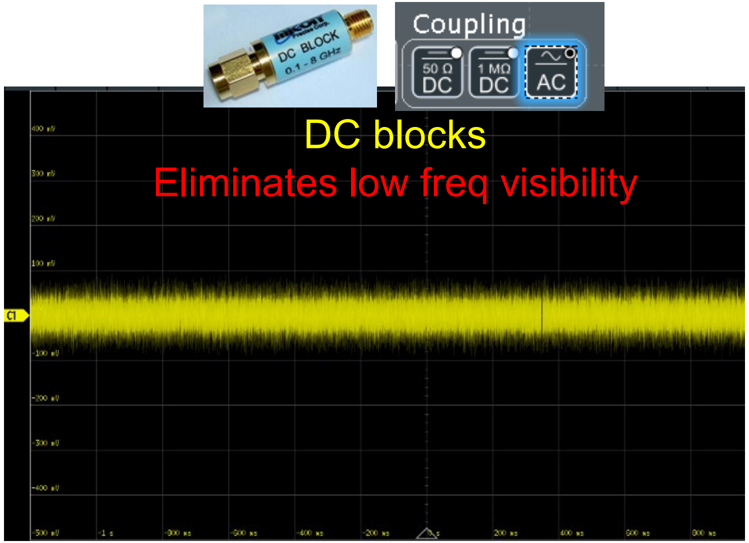




Blocking Caps (and AC coupling) Create Measurement Problems

AC coupling mode and blocking caps eliminate ability to see DC changes

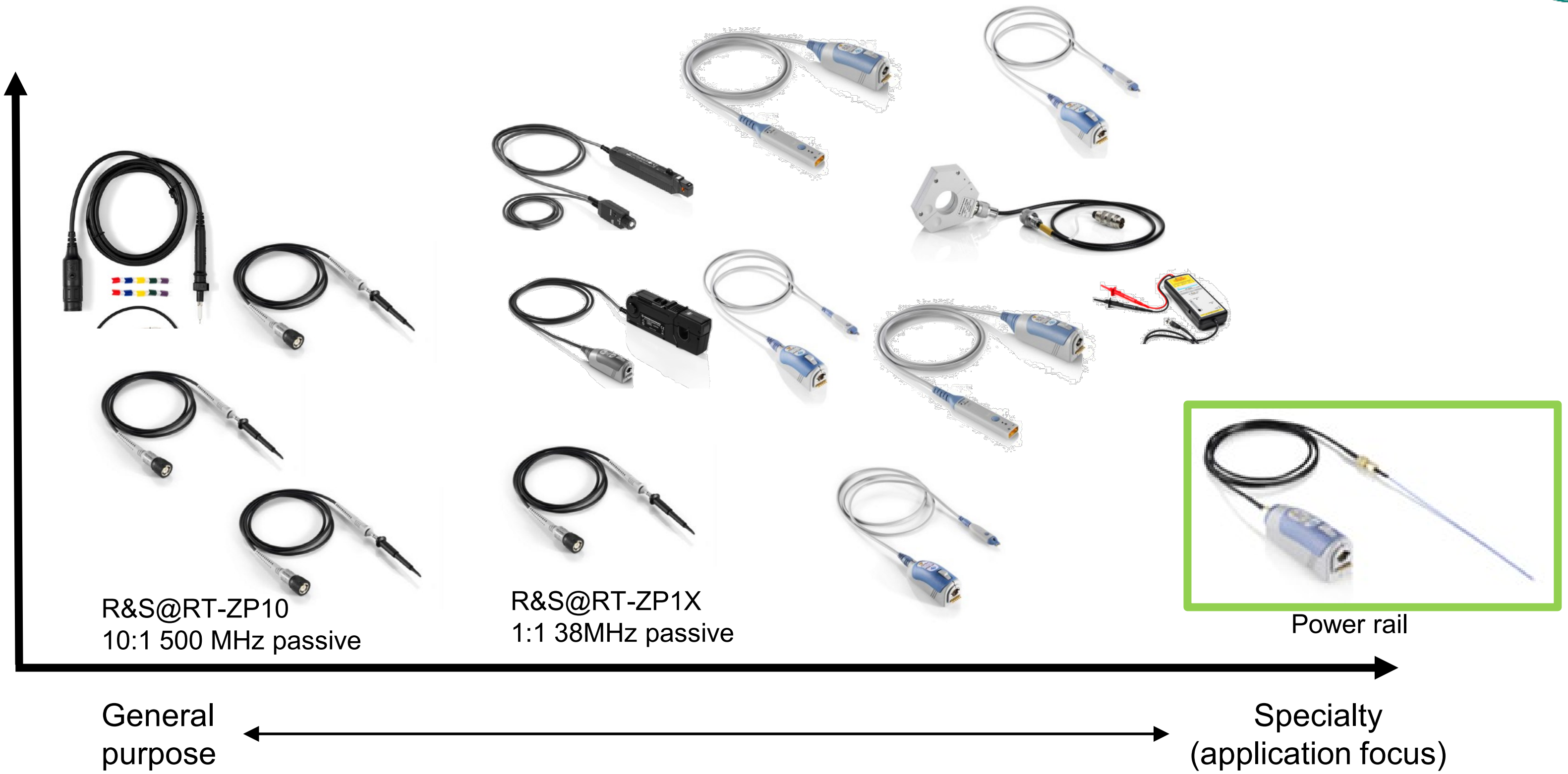




Power Rail Probes

Standard **10:1** passive probe	Low BW **1:1** passive probe	50 Ω cable (with blocking cap)	Specialized **power rail** probe

Lots of Probes for Different Applications



Power Rail Probes…Specialty Tool

Circular saw
Great for a bunch of stuff.
Can't cut door jambs.

Jamb saw.
Does one task really well.
Not useful for anything else.

Power Rail Probe

Advantages

- Low noise (typically 1:1 attenuation ratio)
- Built-in offset (typically at least +/- 12V)
- Excelling loading at DC (typically 50 KOhms)
  - Power rail retains DC value
- Browser and solder-in connection

Disadvantages

- Initial investment expense
- Requires solder-in/SMA for full BW

Power Rail Probe Specs

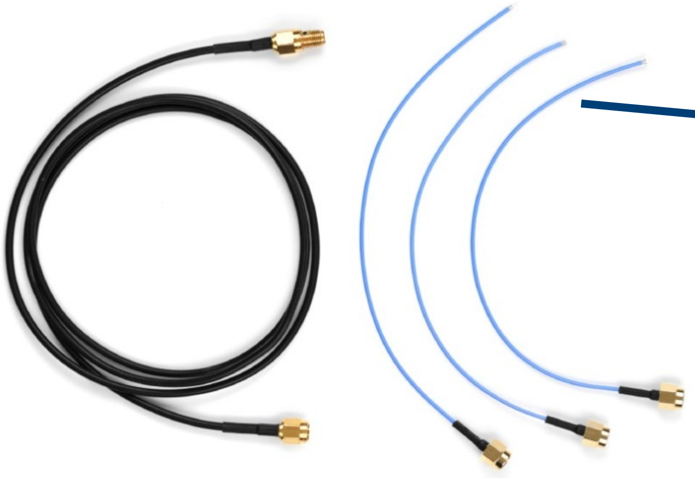
R&S example

- Designed uniquely for measuring small perturbations on power rails
- Active, single-ended probe
- Low noise with 1:1 attenuation
- Offset compensation capability
- Built-in DC meter

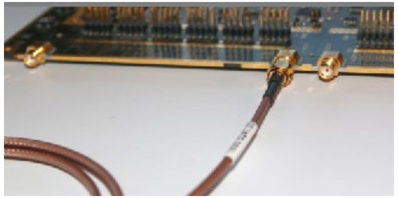
Key Specifications	
Attenuation	**1:1**
BW	**2 GHz**
Browser BW	350 MHz
Dynamic Range	±850 mV
Offset Range	**> ±60 V**
Probe Noise Scope standalone Scope + Probe (at 1 GHz, 1mV/div)	 107 µV AC_{rms} **120 µV AC_{rms}**
Input Resistance	**50 kΩ** @ DC
R&S ProbeMeter	Integrated
Coupling	DC or AC

Typical Power Rail Probe Solder-in Technique

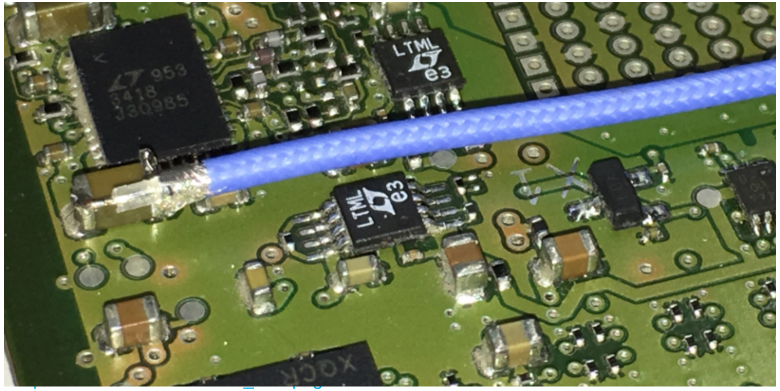
Active probe head, main cable and solder-in cables



Direct connect to SMA



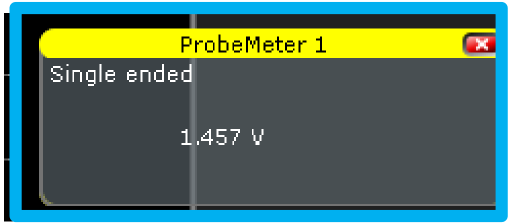
50 Ω SMA coaxial solder-in (2.5 GHz BW)



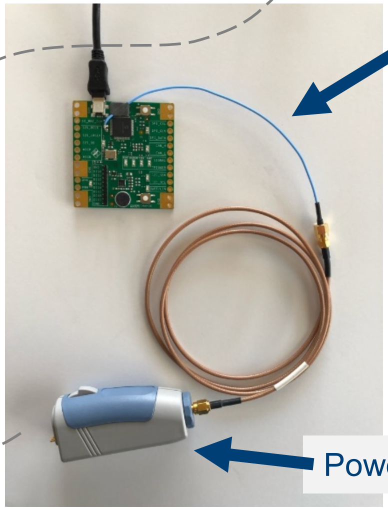
Some Power Rail Probes have an Integrated Voltmeter

R&S probes call this a "ProbeMeter"

- Separate circuit with 18-bit ADC inside the probe
- Independent of scope ADC
- Measures DC value with 0.05% accuracy
  - > 10X more accurate than scope channel for DC measurement
- Eliminates need to attach a separate DVM in parallel to accurately measure DC



Integrated Volt Meter
with cut/paste DC offset

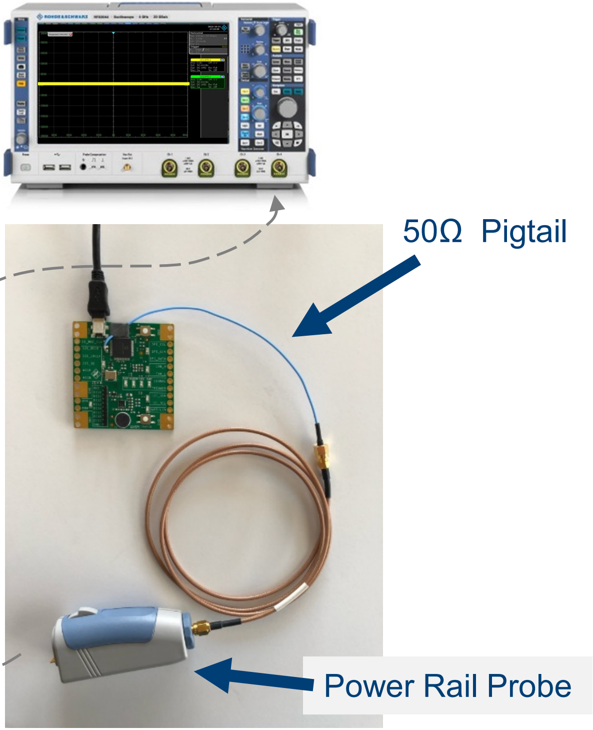


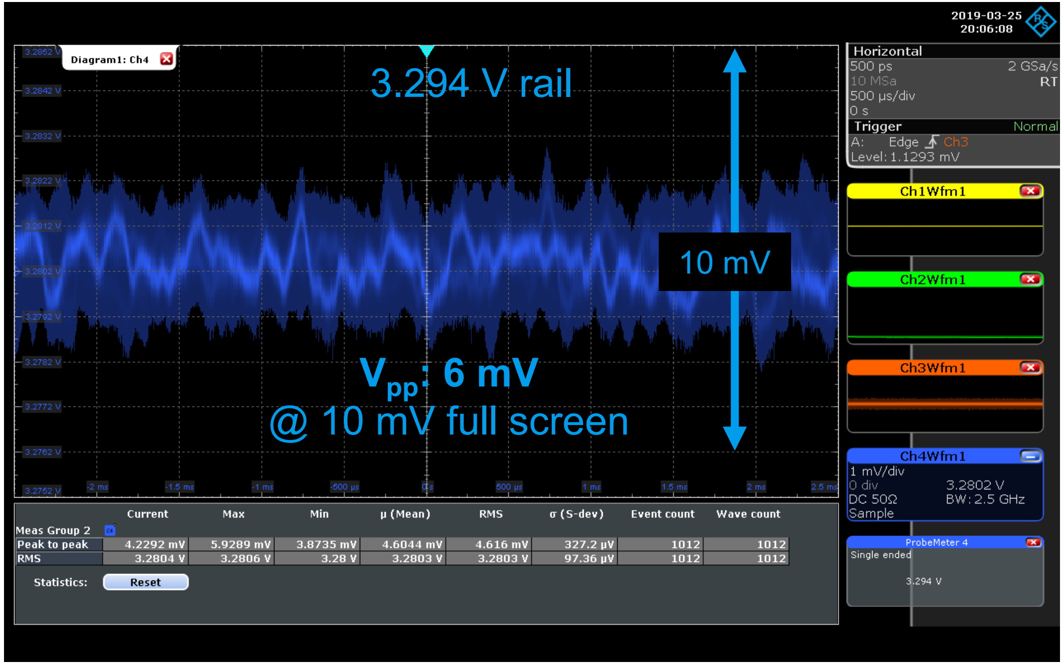
50Ω Pigtail

Power Rail Probe

3.293 V rail

Power Rail Probe





Measurement Technique Results Comparison

Noisy
10 MΩ DC loading
Limited BW
Limited scaling

Vpp: 69 mV

Standard
10:1
passive
probe

Low noise
1MΩ DC loading
Limited BW
Limited offset

Vpp: 14 mV

Low BW
1:1
passive
probe

Low noise
50 Ω loading
Inability to see drift
Inability to see DC value

Vpp: 15 mV

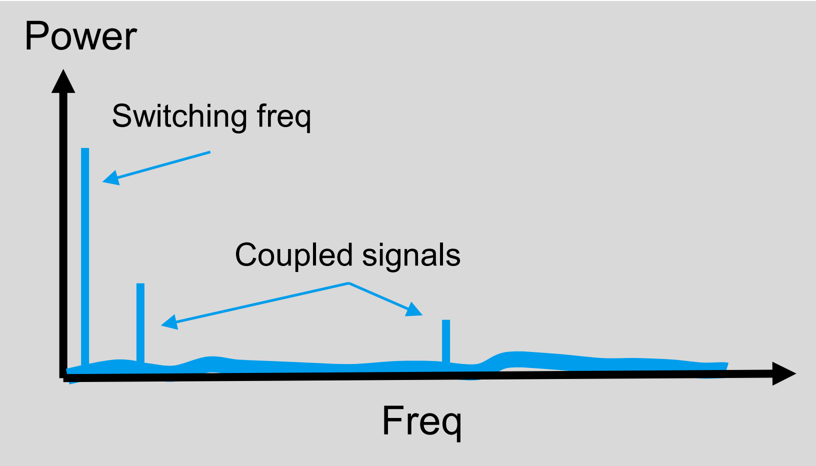
50 Ω cable
(with blocking cap
or AC coupling)

Low noise
50 KΩ loading
High BW
Built-in offset

Vpp: 6 mV

Specialized
power rail
probe

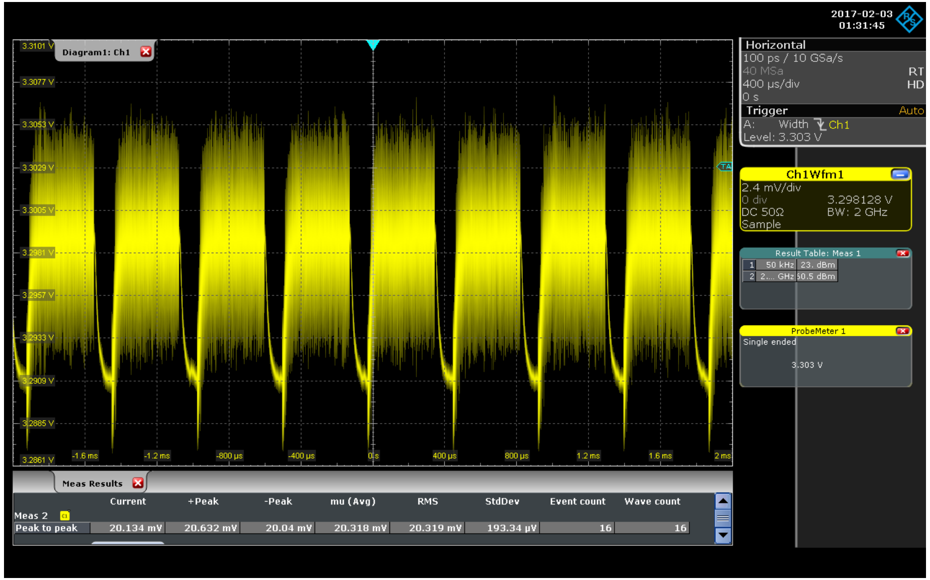
How Much Bandwidth or PI Measurements?



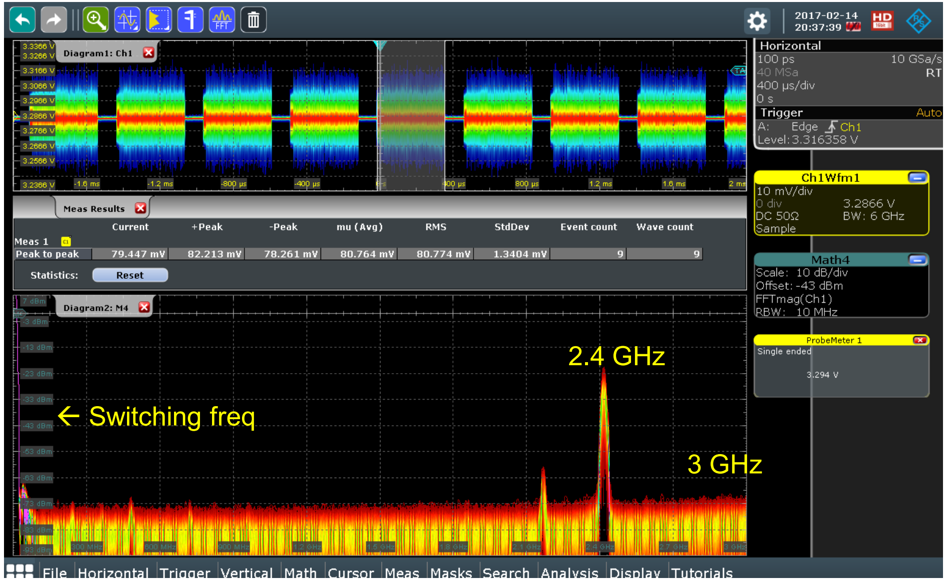
How Much Bandwidth Do You Need?

Use the FFT to help you determine

How much is needed here?



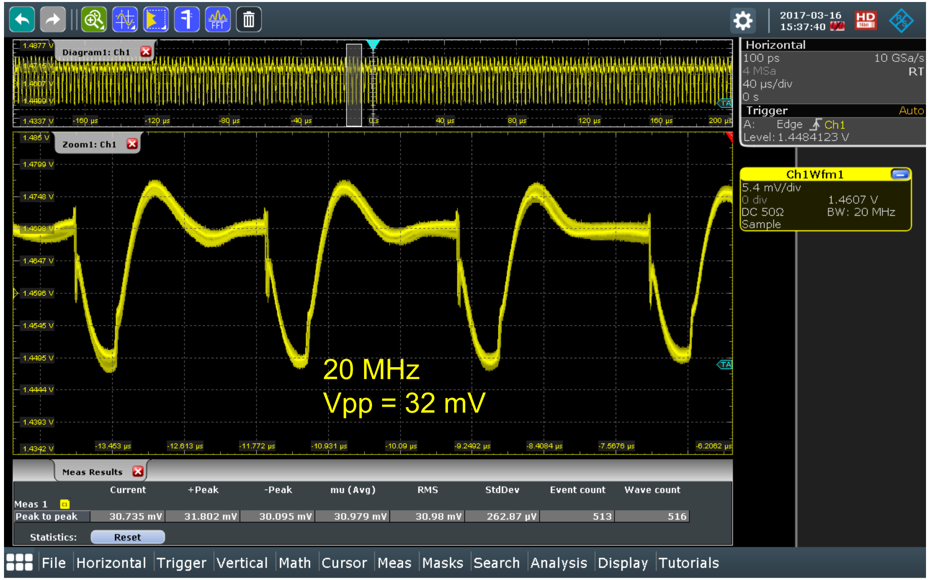
How much is needed here?



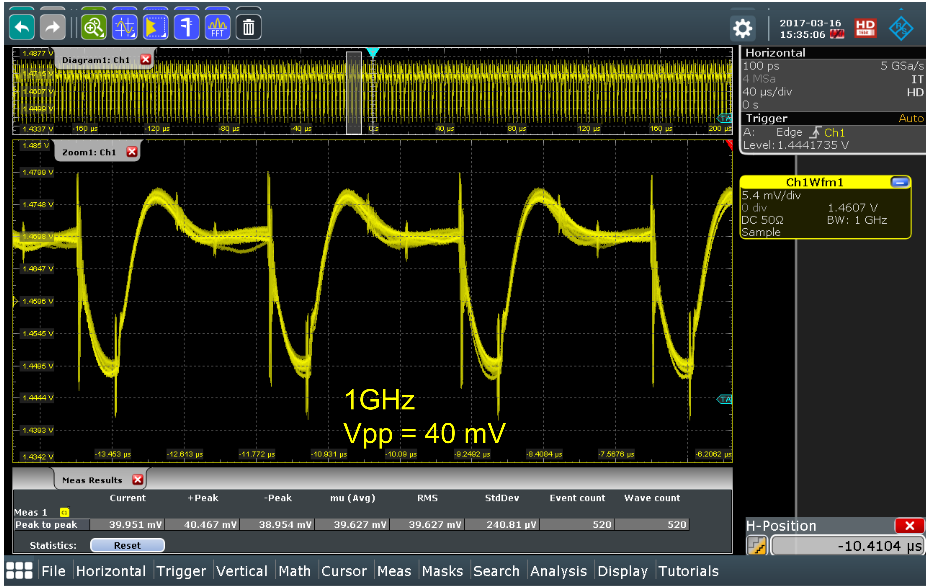
How Much BW Do You Need?

Start high and reduce. Use FFT to help determine how much.

20 MHz

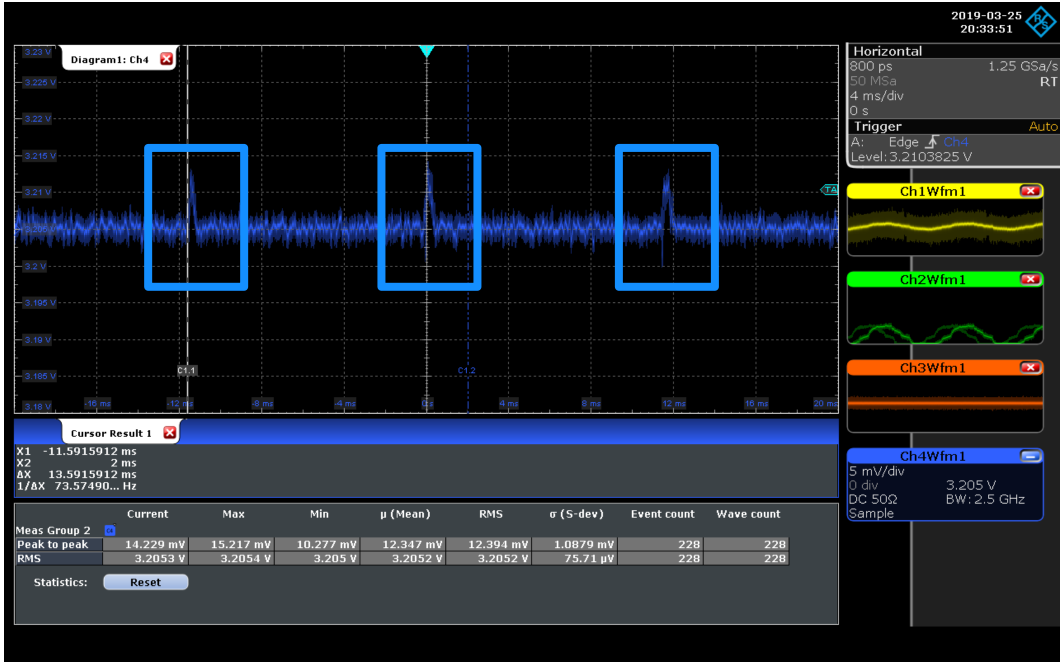


1 GHz



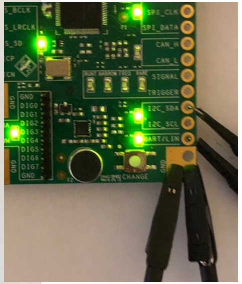
Extra Credit: What's Causing Periodic Rail Spikes?

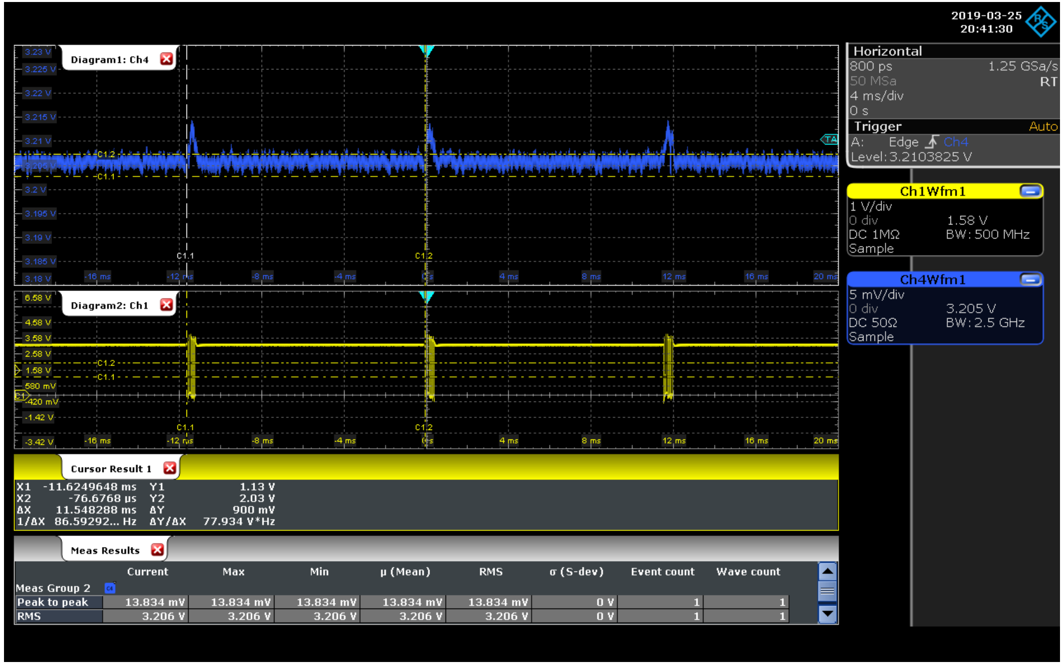
Timebase at 4 ms / div



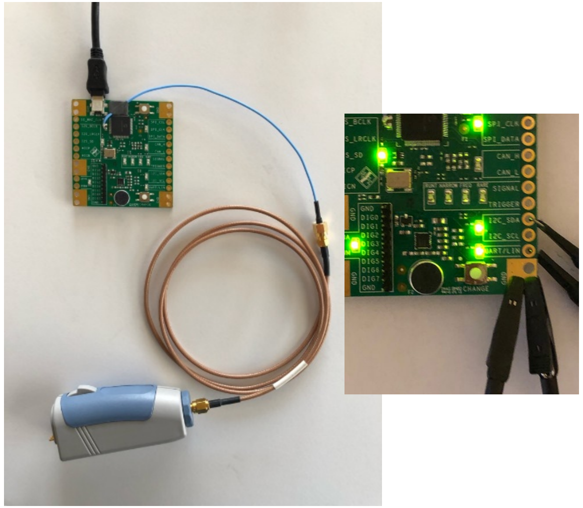
Power Rail Peaking Corresponds to I²C Packets

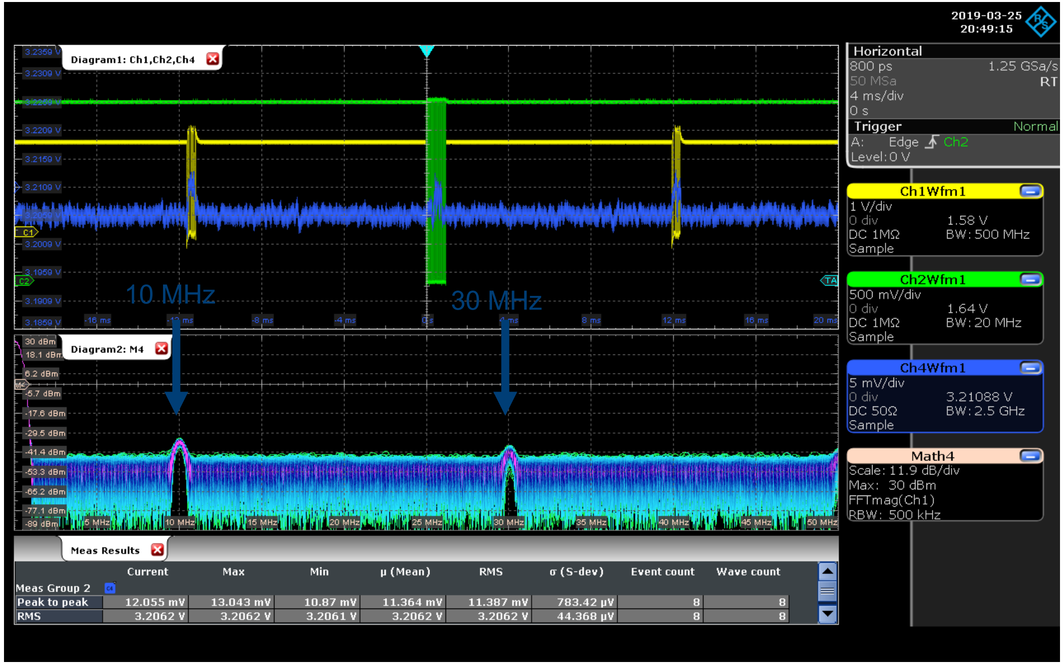
Attach to I²C signals





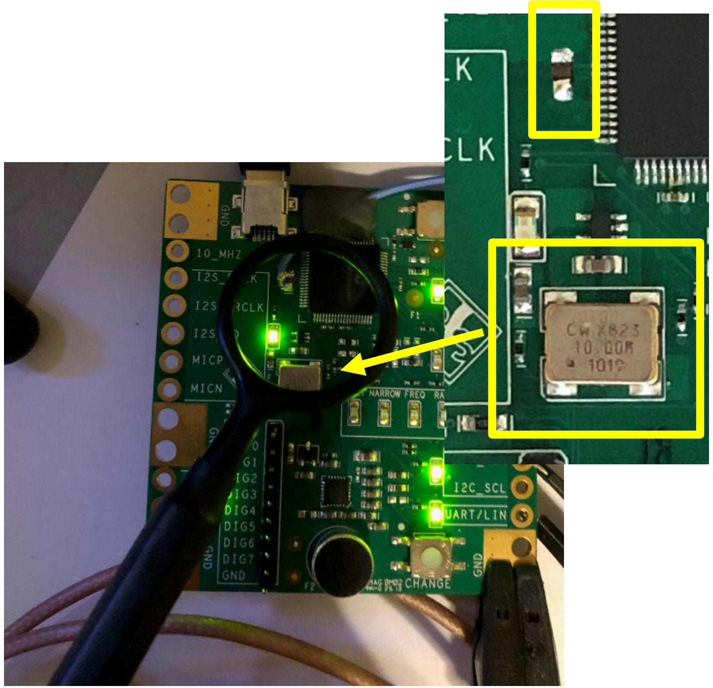
FFT on Power Rail Show 10 MHz and Harmonic Tones

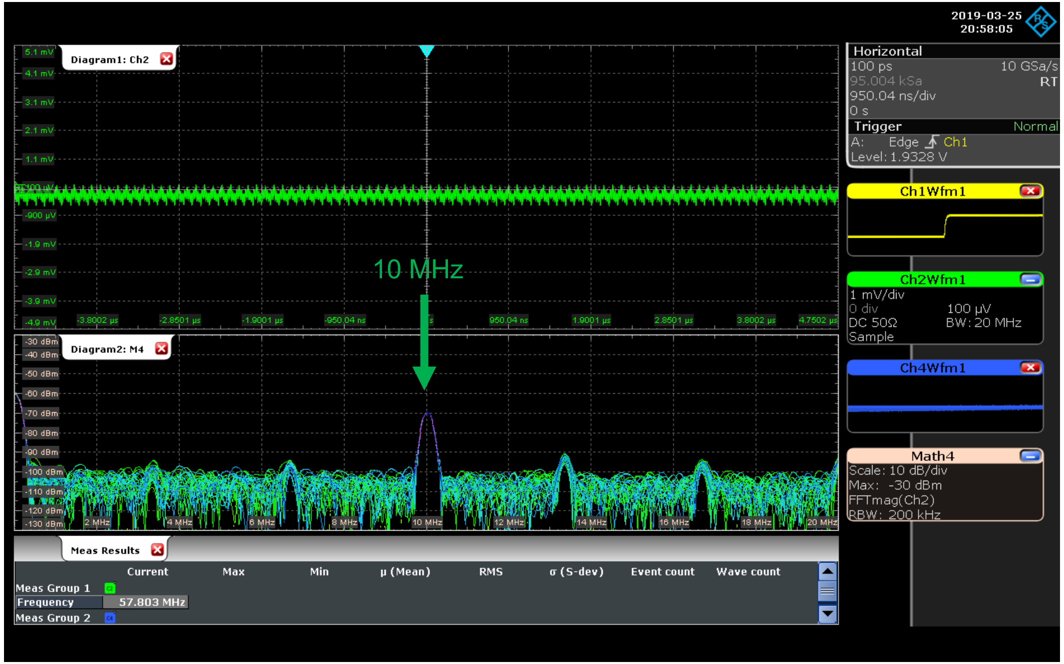




Near Field Probe

10 MHz EMI…. coming from 10 MHz oscillator



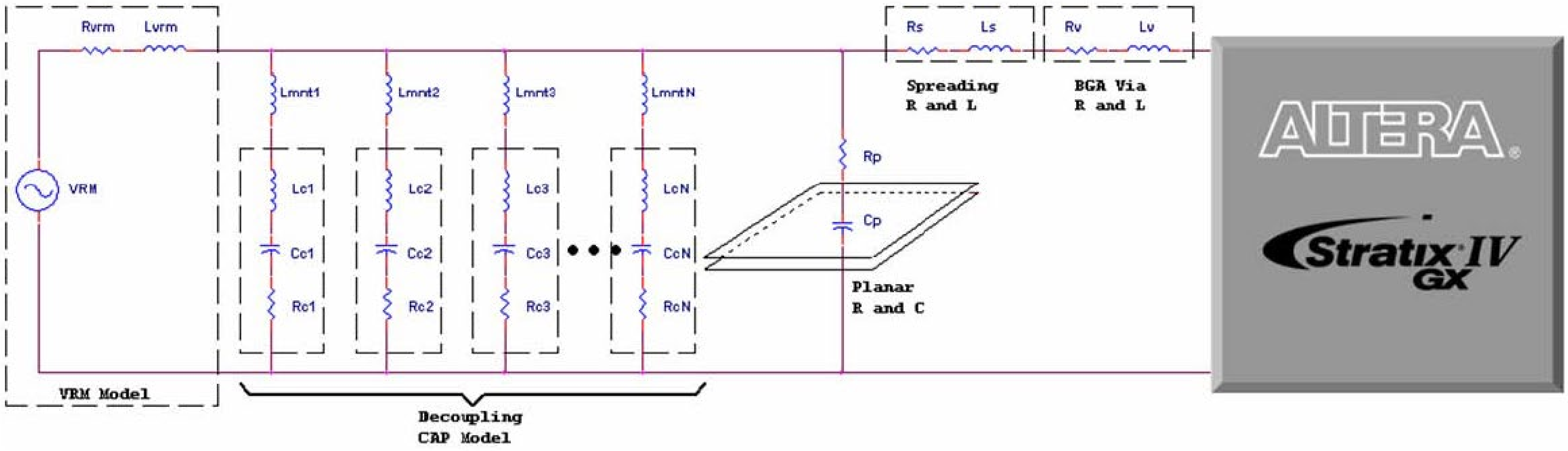


What is the typical root cause for PI problems?

Impedance

Power Delivery Network (PDN): Impedance

The network has an **impedance** (Z_{PDN}) associated with the path from the Voltage Regulator Module (VRM) to the load (e.g. FPGA)



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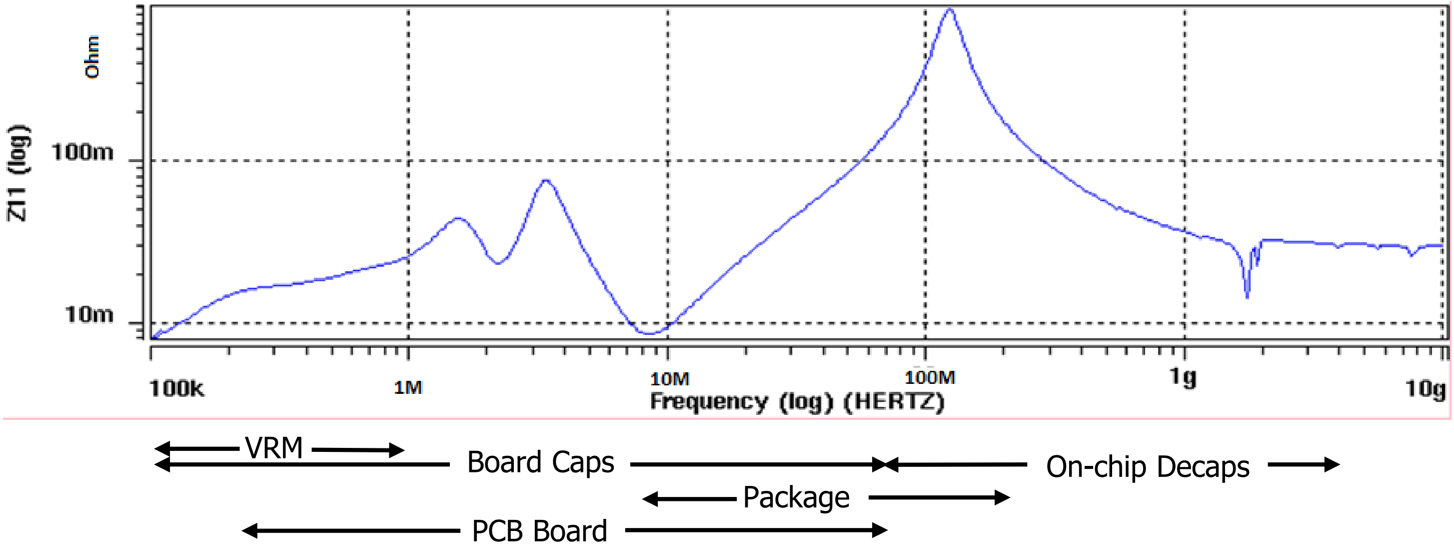
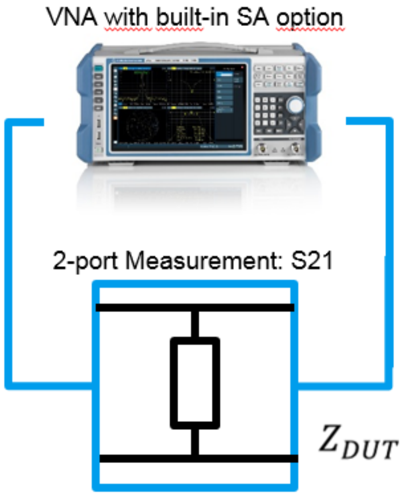
PDN Impedance:



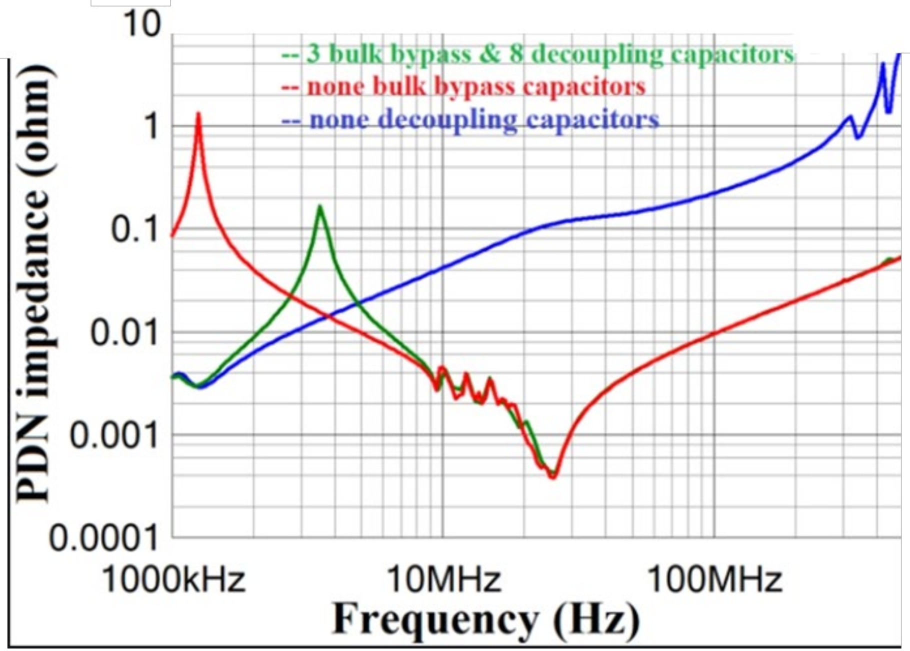
→ resonances cause PI problems
→ resonances cause EMI / EMS problems

How to measure with a VNA?



$$Z_{DUT} = 25 * \frac{S_{21}}{1 - S_{21}}$$

Find and Fix Impedance Issues



SUMMARY / Q&A

1. Use a scope with low noise
2. Adjust vertical scale to most sensitive setting (noise reduction)
3. Apply bandwidth limit filters (noise reduction)
4. Use a power rail probe (offset + noise reduction + excellent DC loading)
   - During design, consider how you are going to probe your prototype
     - Browser (more noise, lower BW)
     - SMA (low noise, easy access)
     - Across a bypass cap (SMA coax with pigtail solder accessory)

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Additional Information

R&S Power Rail Probe Web Page

https://www.rohde-schwarz.com/us/product/rtzpr20-productstartpage_63493-376514.html

Probes and Accessories Brochure

https://scdn.rohde-schwarz.com/ur/pws/dl_downloads/dl_common_library/dl_brochures_and_datasheets/pdf_1/Probes_and_accessories_bro_en_3606-8866-12_v1500.pdf

Application cards:

Accurate and fast power integrity measurements: Application card

https://cdn.rohde-schwarz.com/pws/dl_downloads/dl_common_library/dl_brochures_and_datasheets/pdf_1/RT-ZPR20_Accurate_ac_en_5214-9515_92_v0100.pdf

Verifying power integrity for DDR memories:

https://www.rohde-schwarz.com/us/applications/verifying-power-integrity-for-ddr-memories-application-card_56279-415355.html

Power Integrity Video

https://www.youtube.com/watch?v=4gw-GQD9hR4

Five Tips for fast, accurate power integrity measurements

https://cdn.rohde-schwarz.com/campaigns-media/data/forms/en/Five-techniques_power-integrity-measurements_misc_en_5215-0434-92_v0100_96dpi.pdf