Power Integrity:
Challenges, best practices and test solutions for sensitive electronic designs

Presenters:
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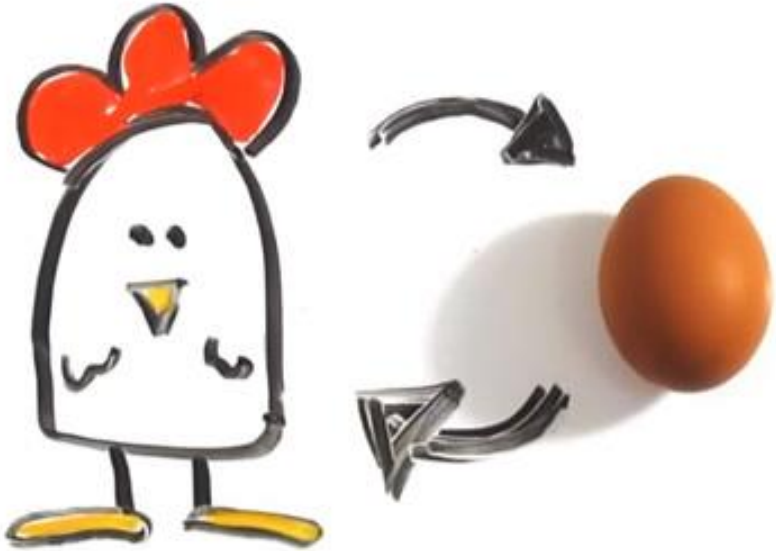
Andreas Ibl, Product Manager Oscilloscopes at Rohde & Schwarz
Andrea D’Aquino, Product Manager Network Analysis at Rohde & Schwarz

ROHDE&SCHWARZ

SI



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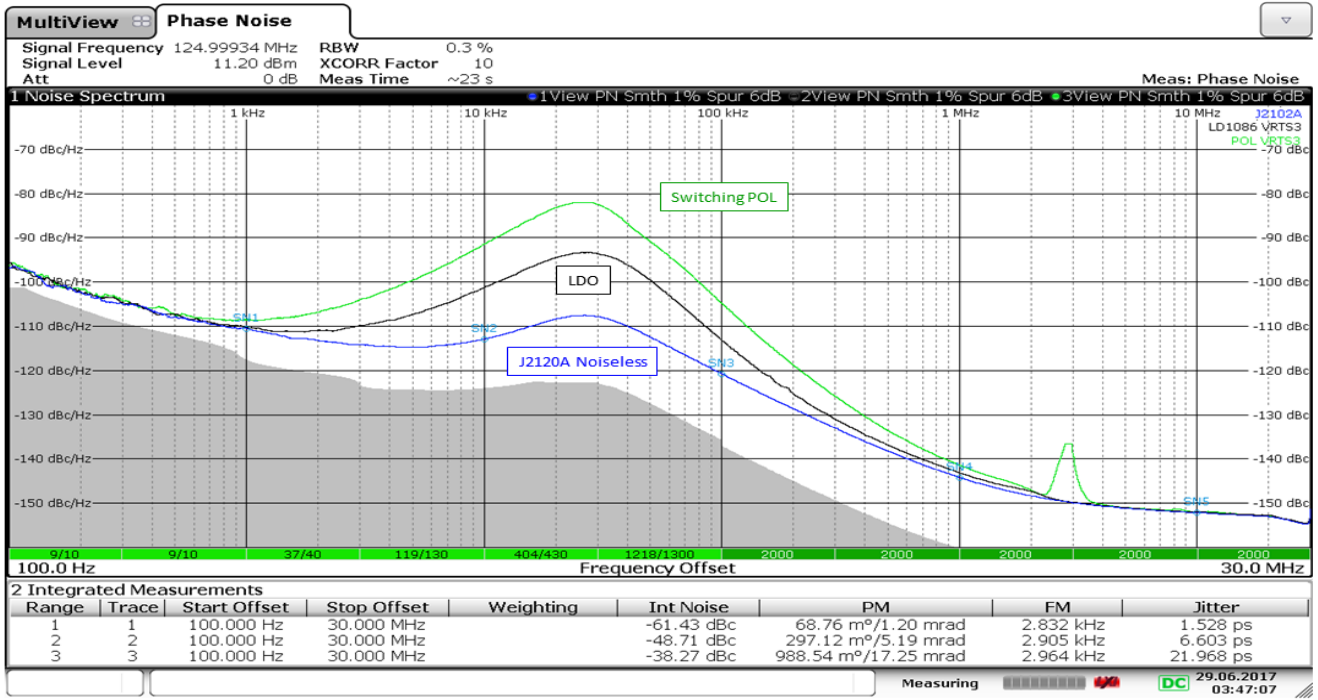
PI

PI → SI

Power Supply Induced Jitter



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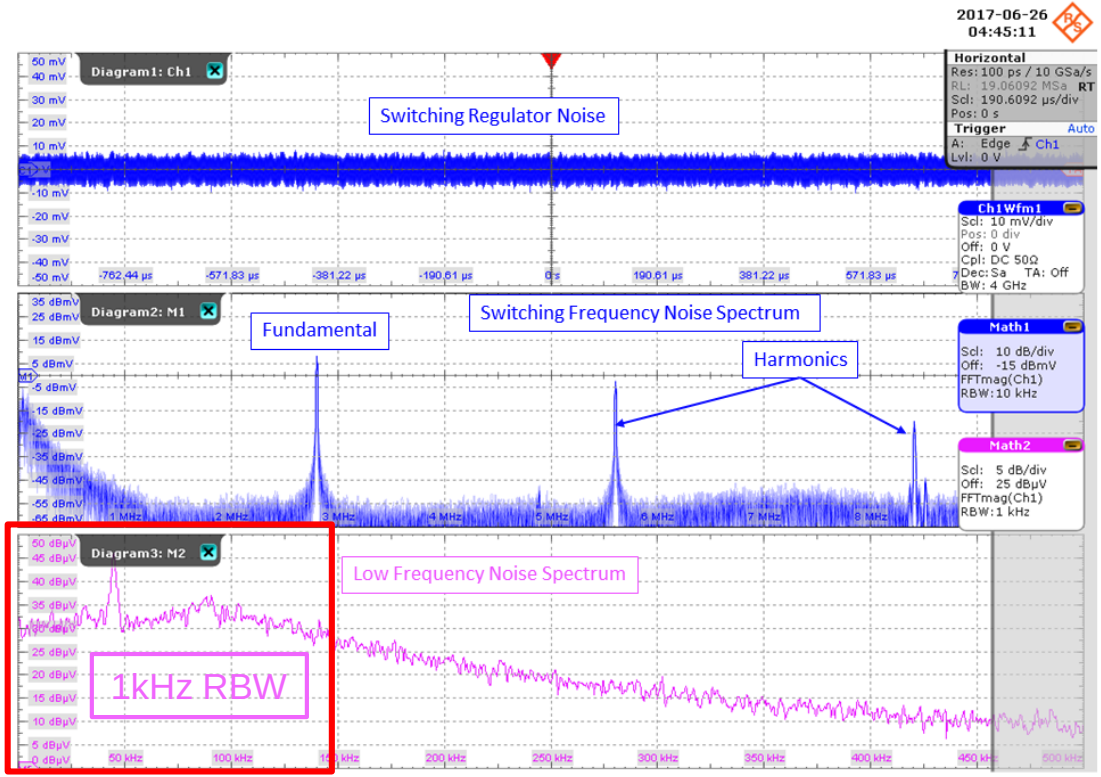
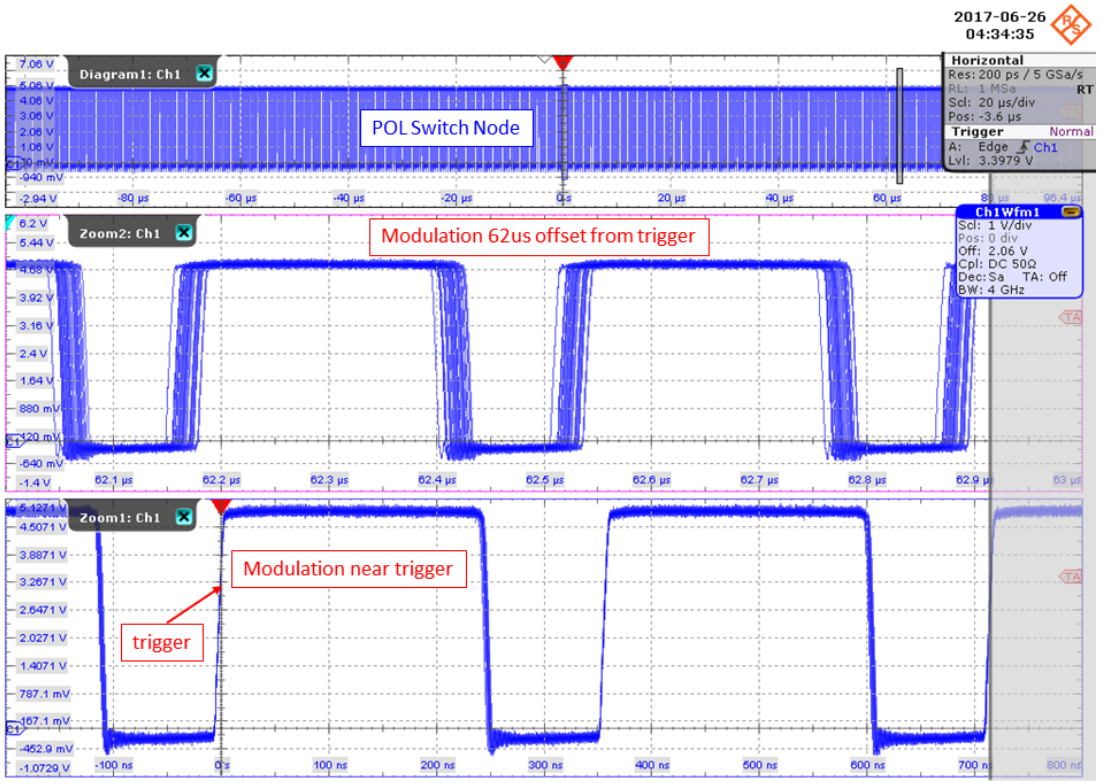
Unexpected Noise – 2.8MHz POL

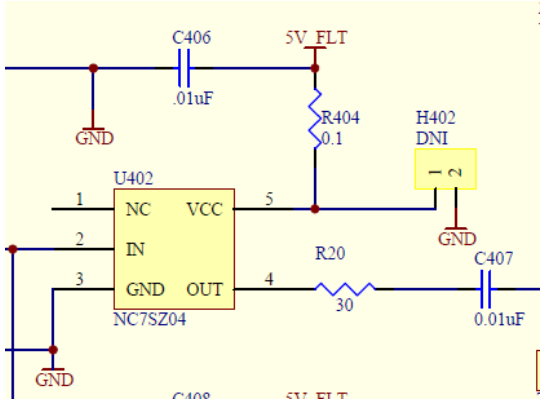


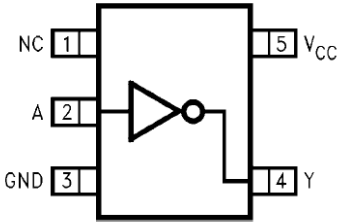
Jitter Induced Jitter

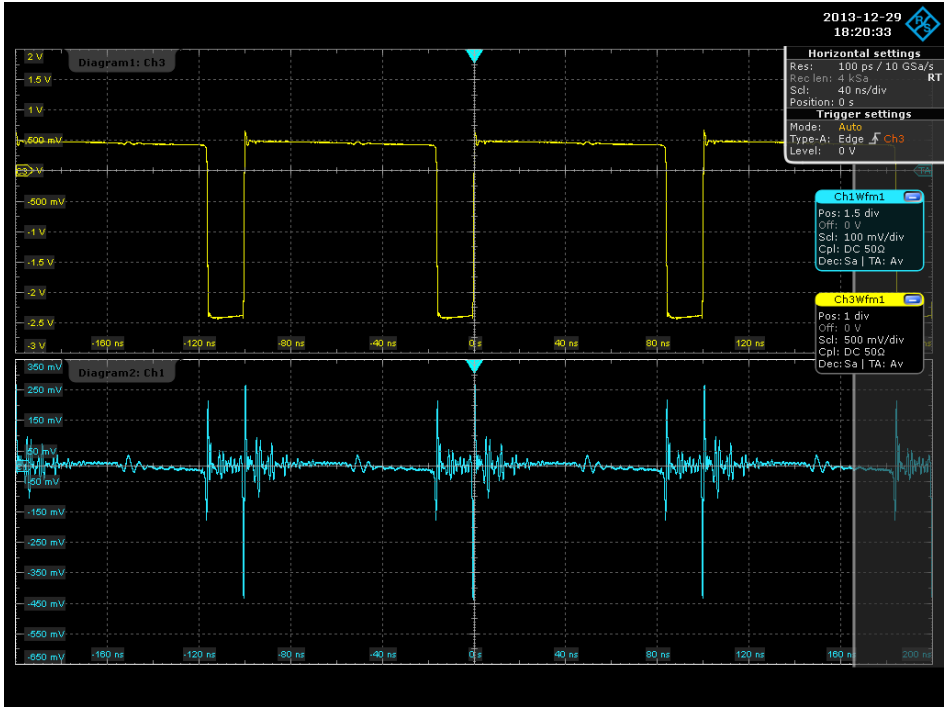


PI ← SI

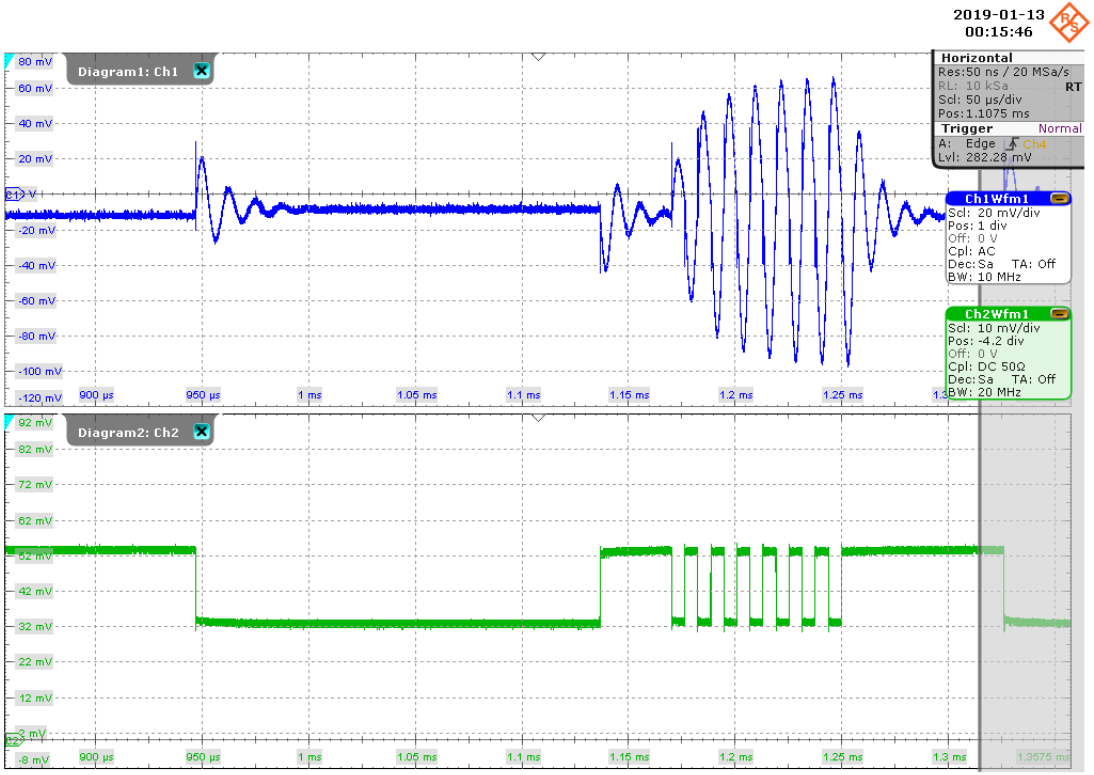
Noise Induced by a Single Logic Gate



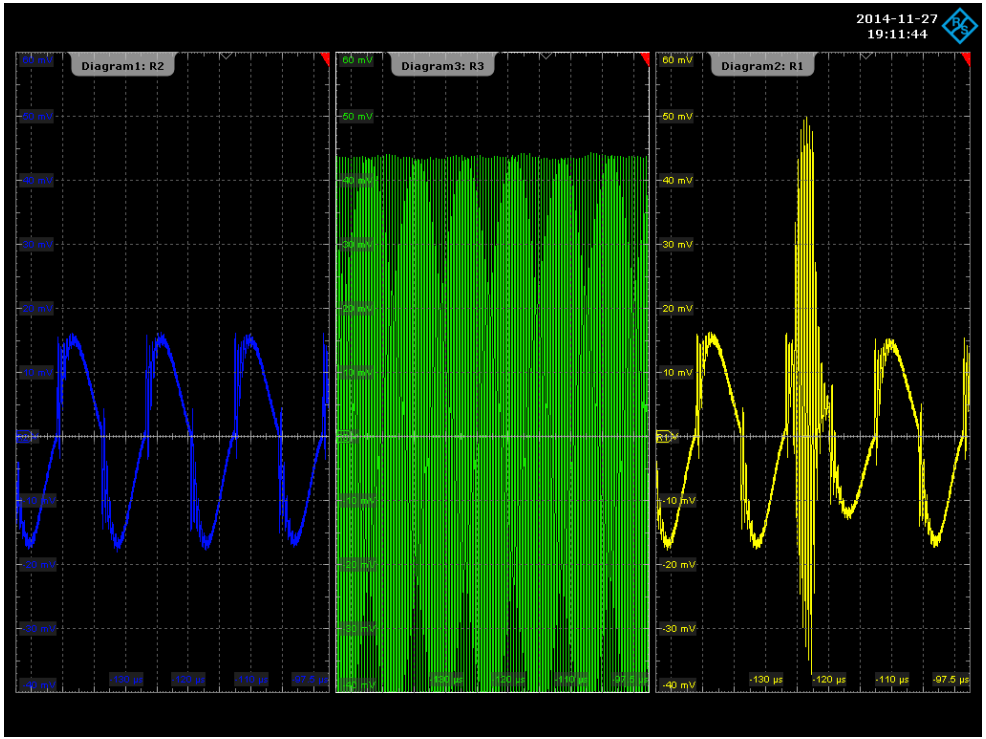




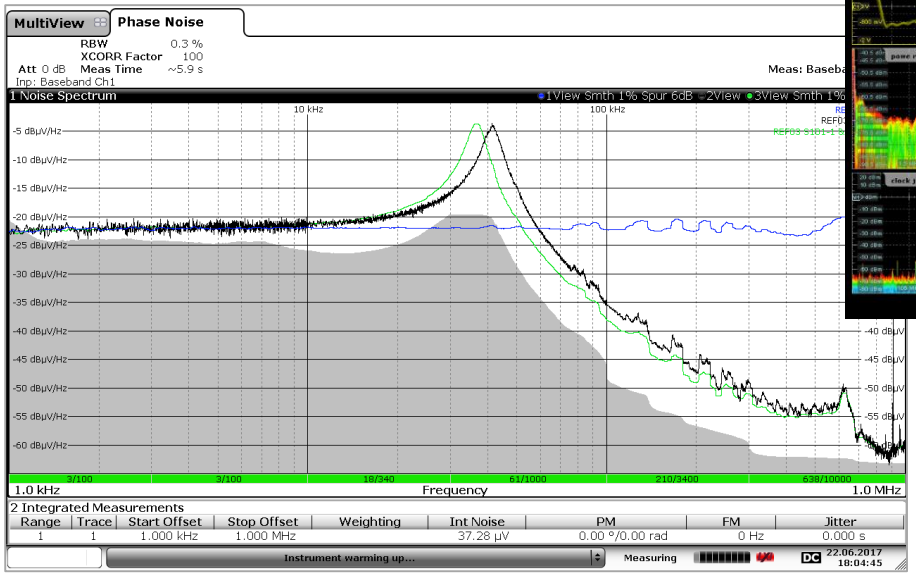
Dynamic Response

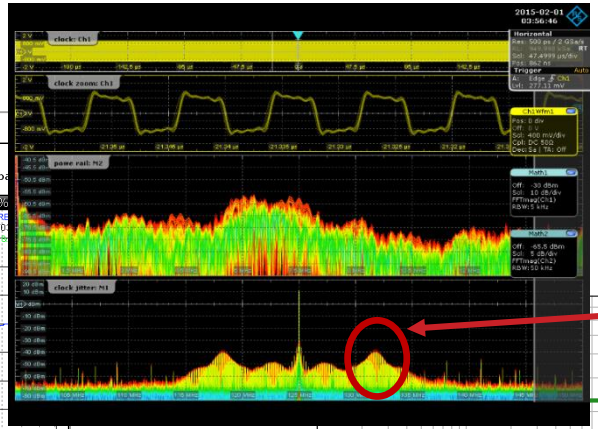


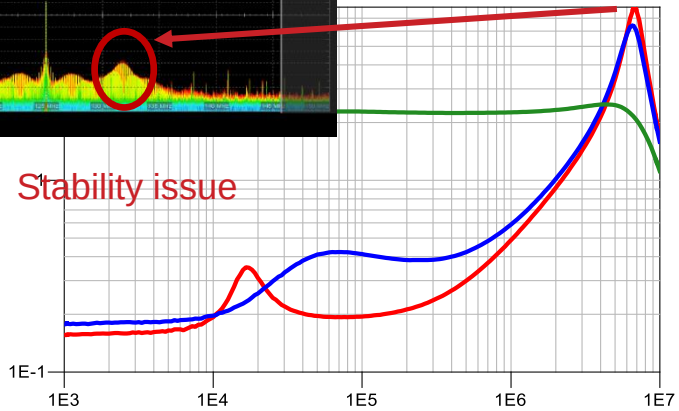
Rogue Waves



Impedance is the Common Denominator





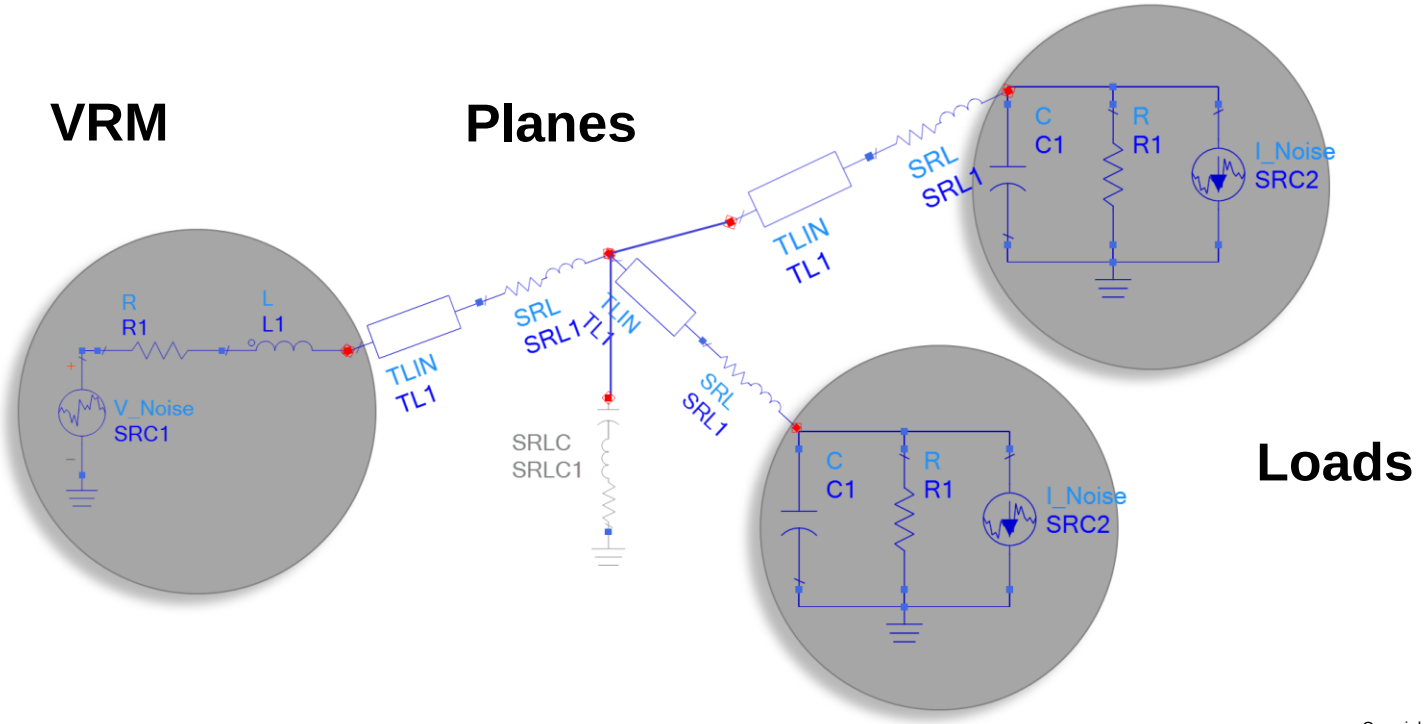


What is Power Integrity?

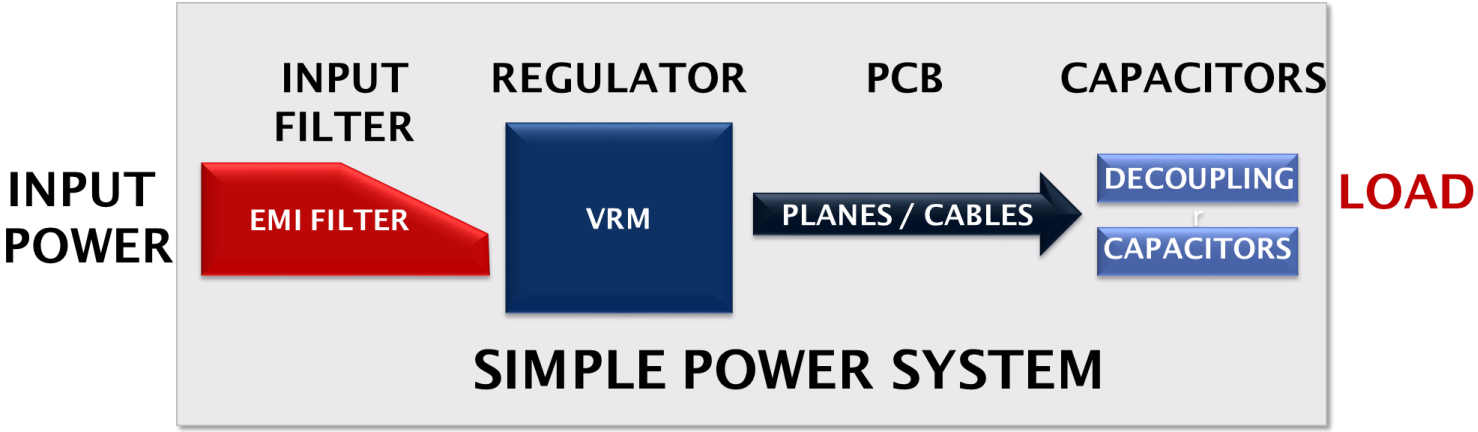
Power integrity (PI) is simply the assurance that power applied to a circuit or device is appropriate for the desired performance of the circuit or device

This is not just about keeping voltages within limits!!!

The PDN Highway

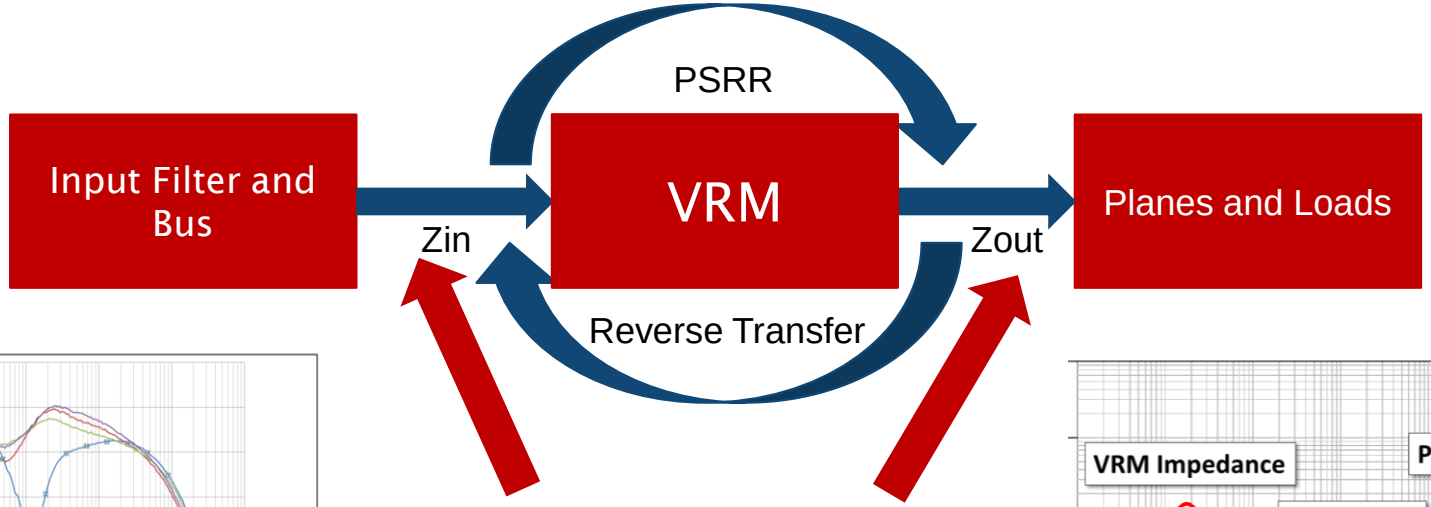


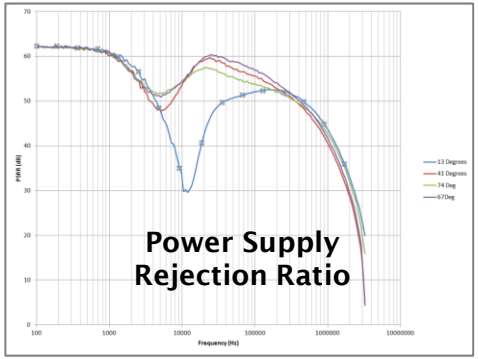
A Simple Power Distribution Network (PDN)



IT'S ALL ABOUT THE LOAD

Resonances Degrade Performance

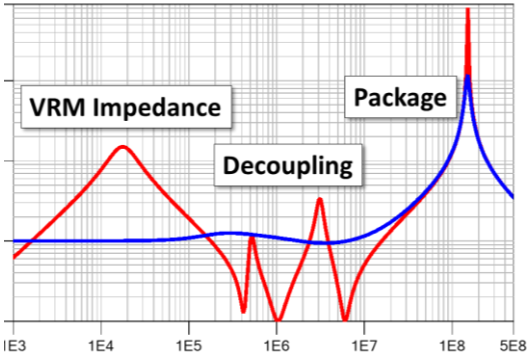




PSRR - (S21)

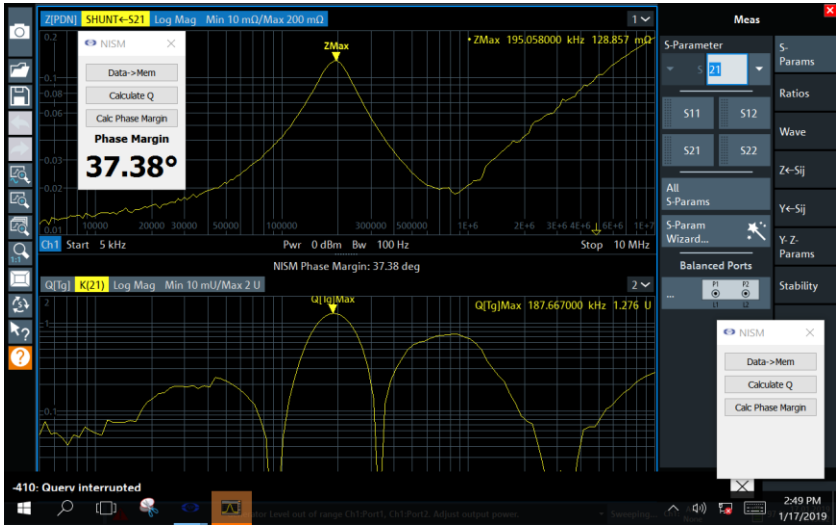
Stability concerns exist at both the input and the output

The Ideal PDN is Flat



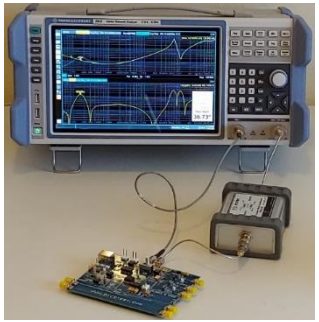
It Tells Us About Stability

NISM - In-System Test for Phase Margin



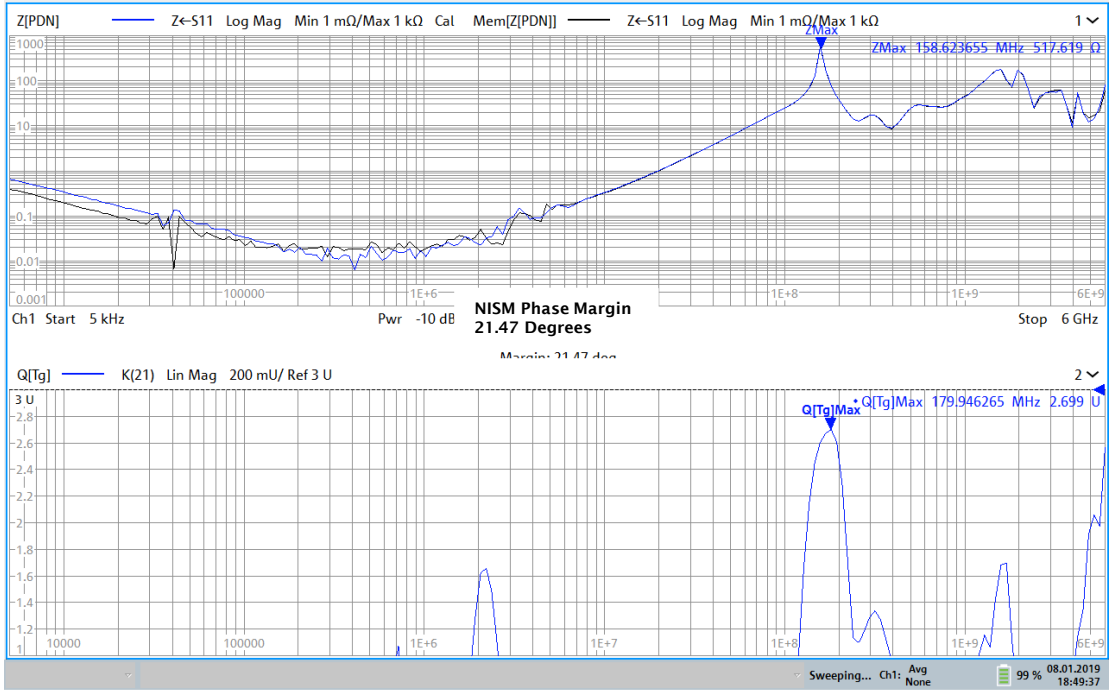
- Phase margin derived from Output Impedance
  - Accurate up to 65 degrees
- Proven Accuracy

From 2-Port Impedance to Stability Margin



- **It's called 'NISM'**
  Non-Invasive Stability Measurement
- And it's available for R&S ZNL!!
- Performed using a simple cursor operation
- As accurate as a Bode plot and often accurate when a Bode plot isn't

Stability from Output Impedance – No Frequency Limits



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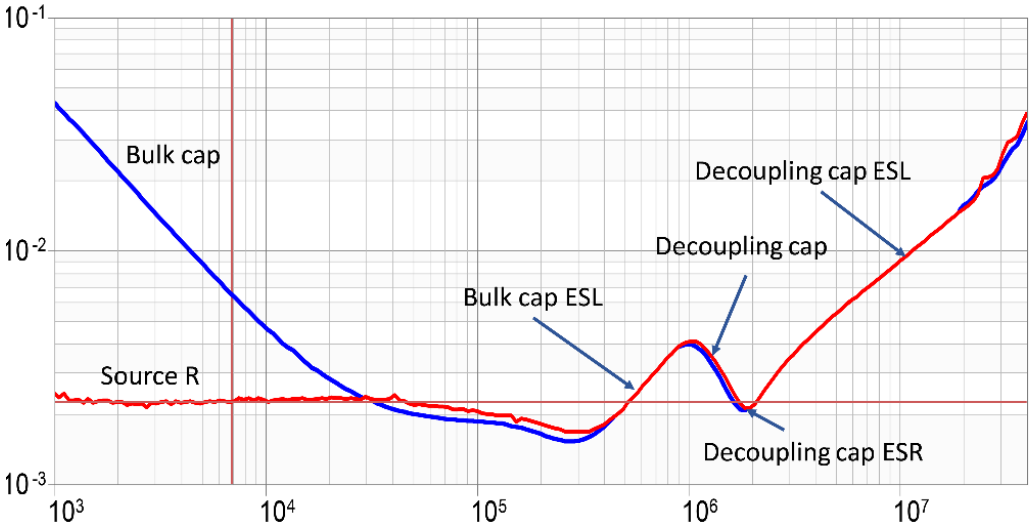
Opamp Measurement

Works over all frequencies

What Power Rail Impedance Plots Tell Us



Flat=resistor

Rising=inductor

Falling=capacitor

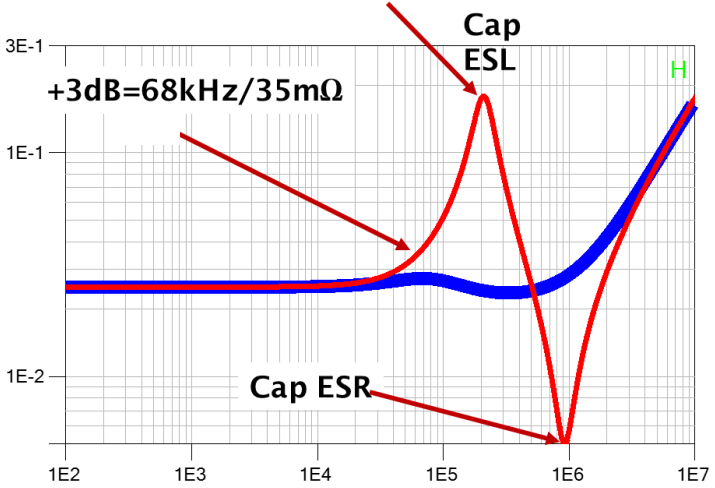
Motherboard measurement power on (red) and off (blue)

How to Fix Poor Impedance

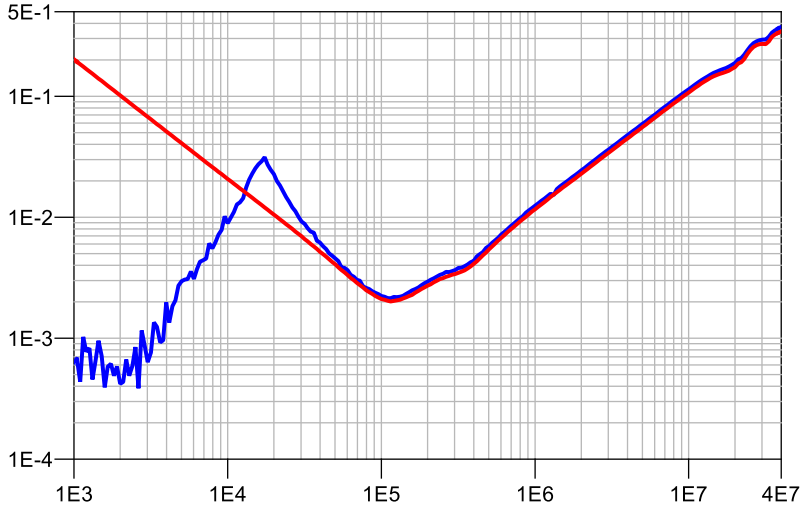
Minimize L and **MAXIMIZE** R

1. Determine L from resonance or 3dB point
2. Determine R from below resonant frequency
3. Set $C = \frac{L}{R^2}$
4. Set Cap ESR = R

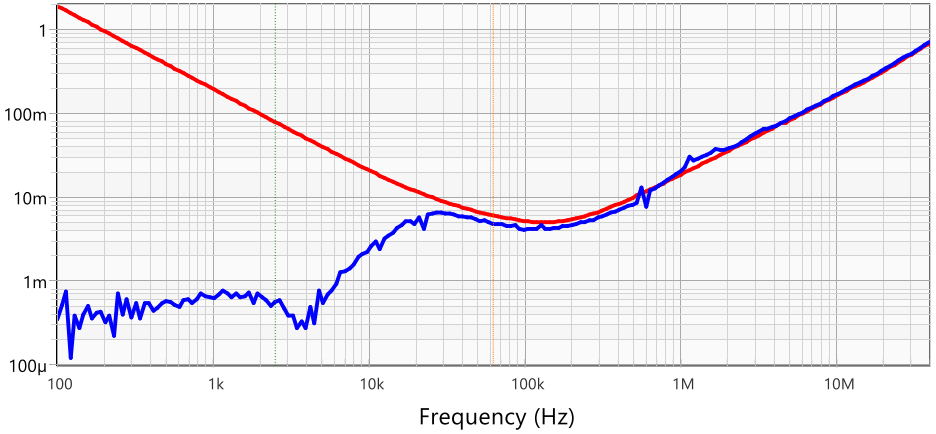
Undersized output capacitor reveals the inductance resulting from the internal pole and slope compensation



Before and After



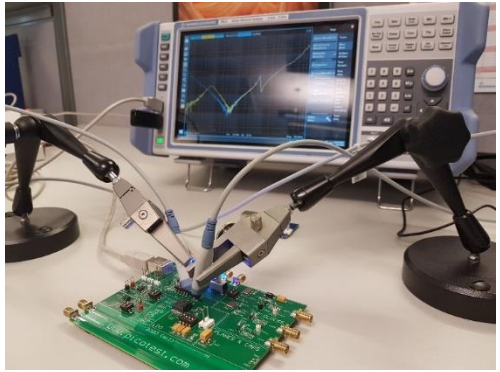
Reduced L (reduce filter inductor/raised Fsw)
Removed Ceramic output capacitors
Installed Tantalum capacitors

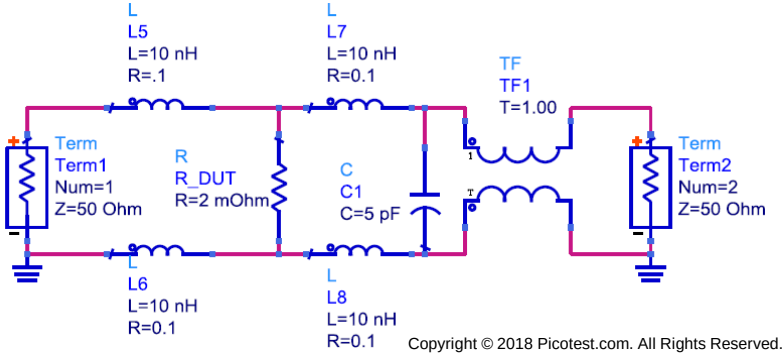


Impedance

2-Port – Ground Loop

- Due to the existence of a DC ground loop through the connecting cable braids, a 50Ω coaxial transformer is required for shunt-through measurements

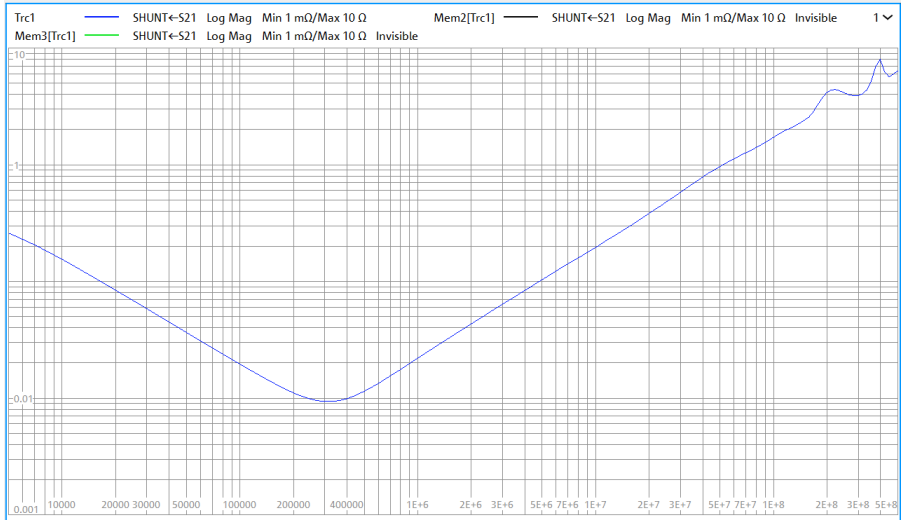




Measure Potential Output Capacitors

The 2−port shunt−through method can easily measure capacitors with ESR below 1mΩ

Low ESR caps must be mounted in a calibrated PCB for measurement



Five techniques for fast, accurate power integrity measurements

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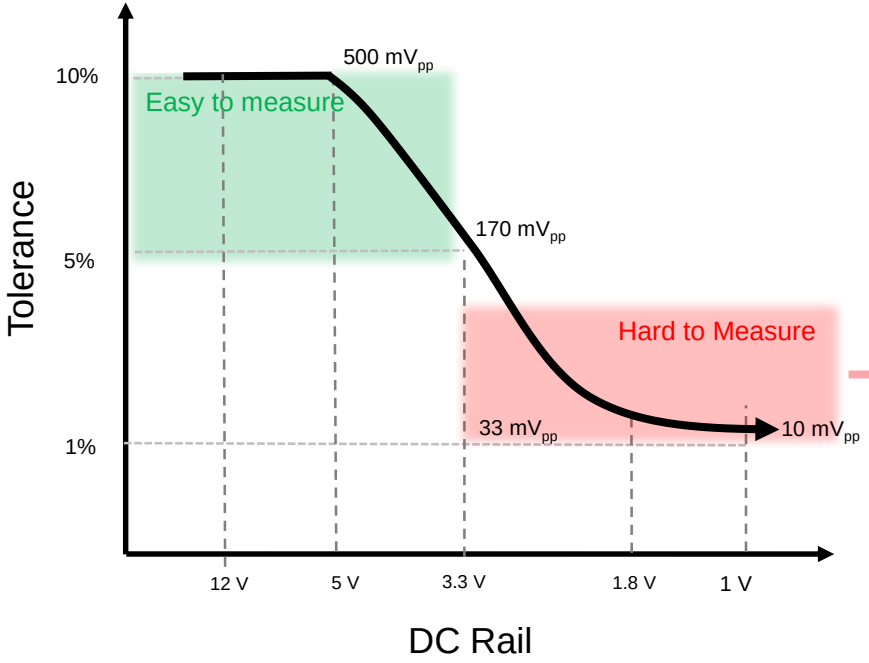
Power Rail Measurement Challenges

Lower rail voltages and smaller tolerances



Examples

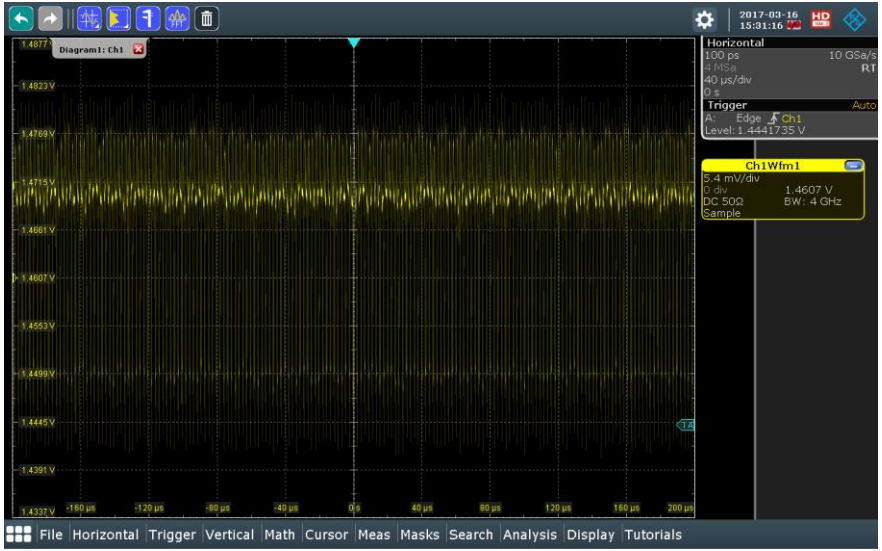
Rail Value	Tolerance	Need to measure
3.3 V	1%	33 mV_{pp}
1.8 V	2 %	36 mV_{pp}
1.2 V	2 %	24 mV_{pp}
1 V	1 %	10 mV_{pp}

1. Adjust viewing characteristics

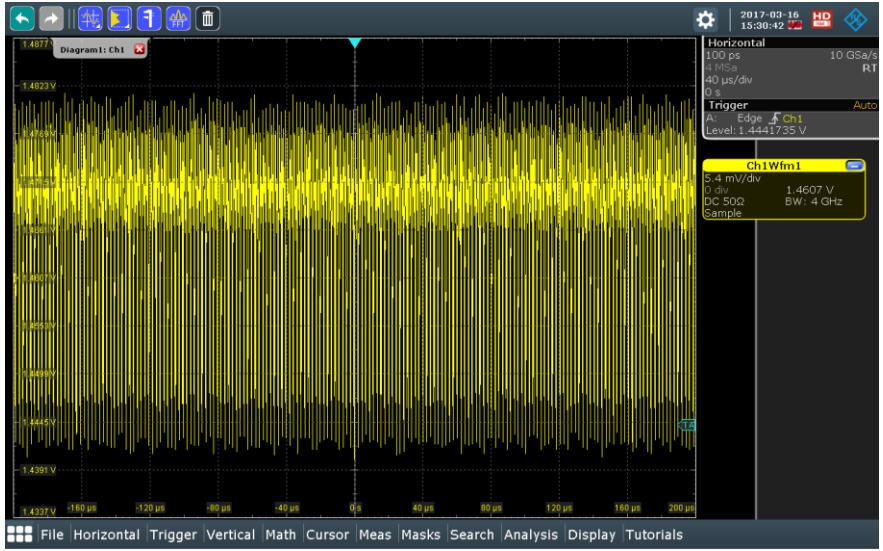
1. Adjust viewing characteristics

Waveform intensity

Default – 50%

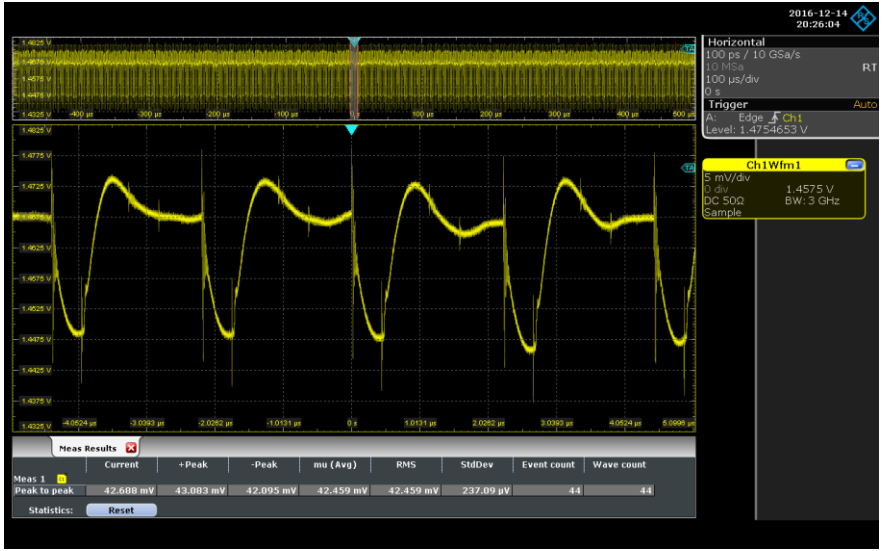


Adjusted to 90%



1. Adjust viewing characteristics

Infinite Persistance



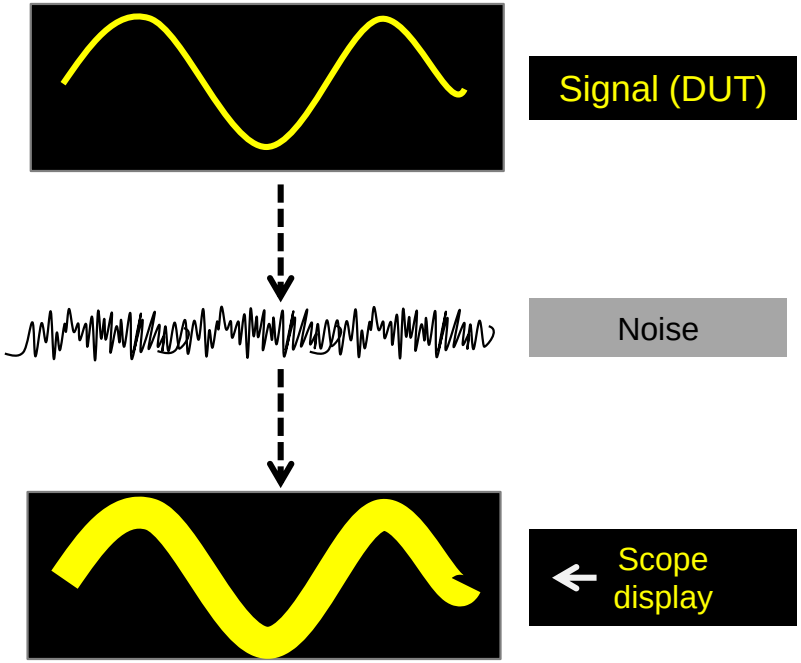
1. Adjust viewing characteristics

Color Grading

- Benefits:
  - More easily identify pixels that are hit less frequently.
  - See how often anomalies occur

2. Lower Noise

Several Factors Make It Difficult to Measure Small Signals



Consequences

Large measurement deviation

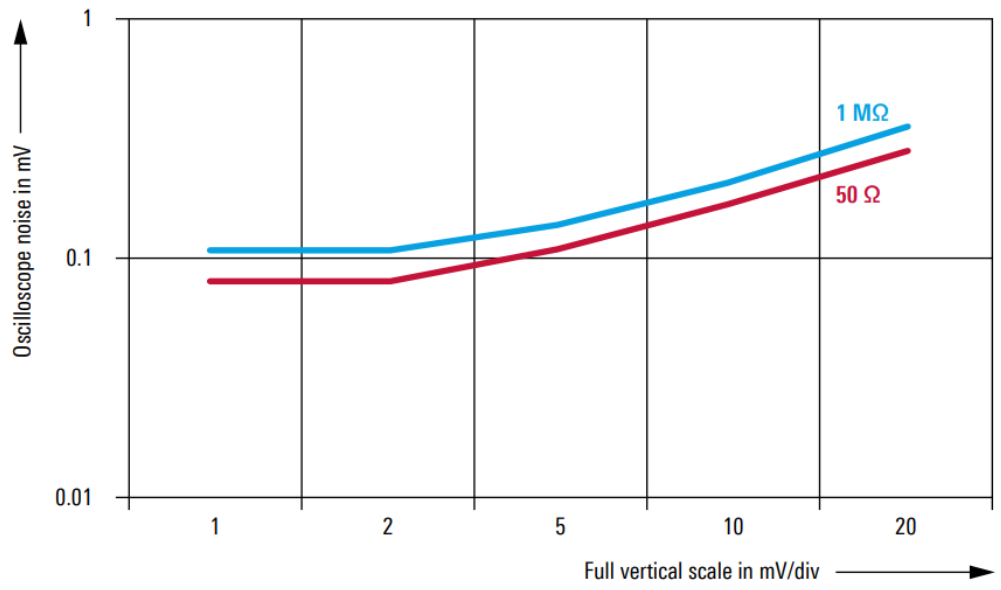
Measured V_{pp} >> Actual V_{pp}

Can mask/hide anomalies

2. Lower Noise

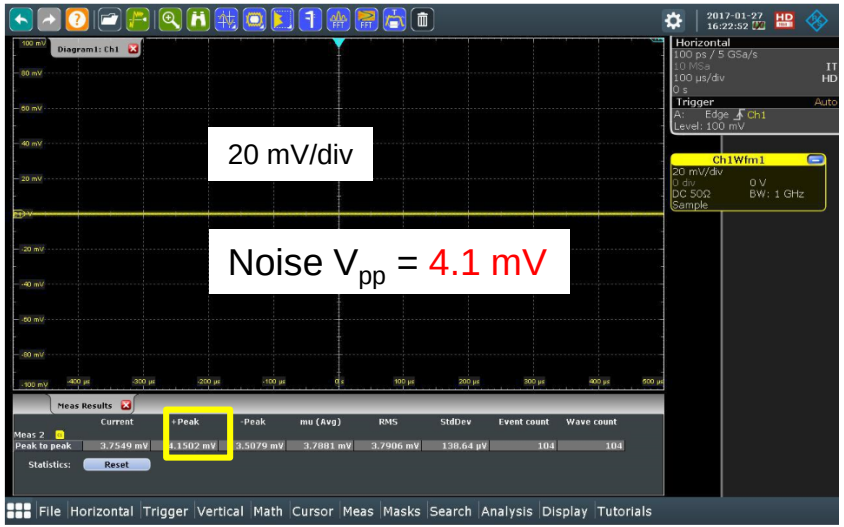
Choose signal path that has the lowest noise

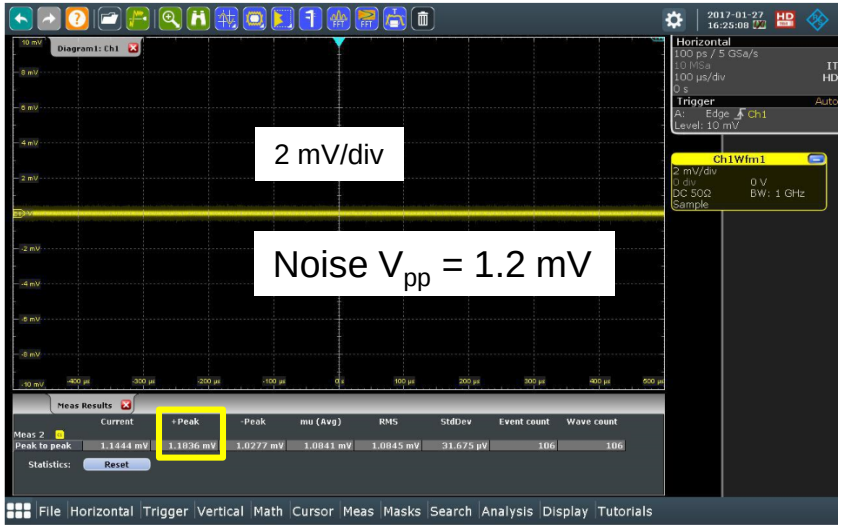
Comparison of noise on 50 Ω and 1 MΩ paths on the R&S®RTO digital oscilloscope at increasing vertical sensitivities



2. Lower Noise

Use the most sensitive vertical scale



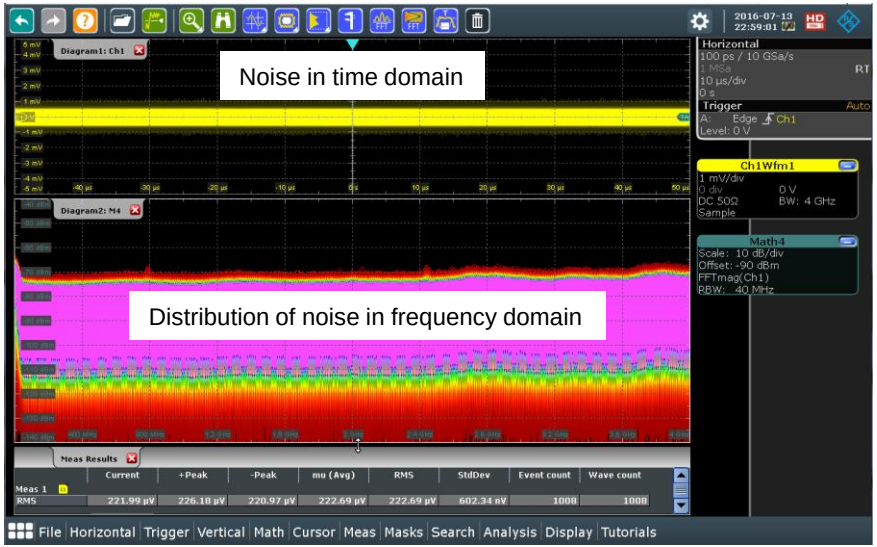


All other settings are identical

Use the smallest V/div setting to get the most accurate measurement (lowest noise)

2. Lower Noise

Limit bandwidth

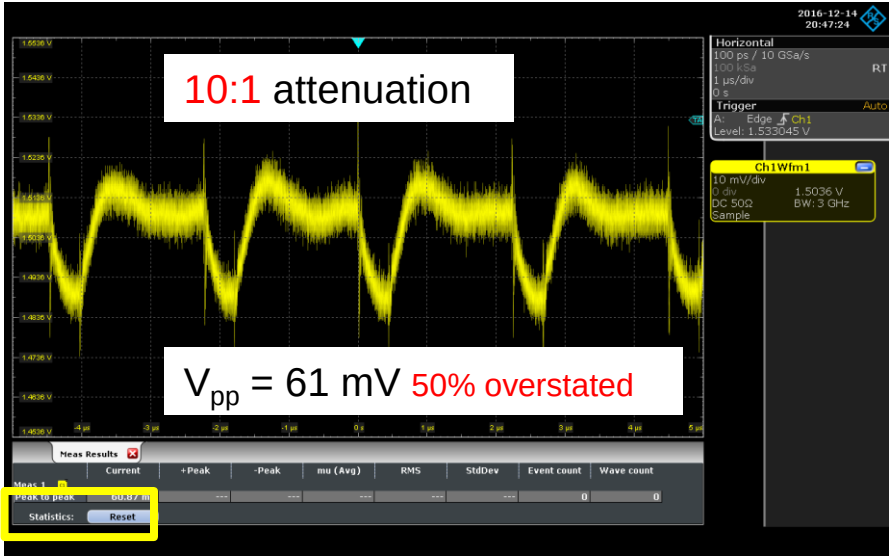


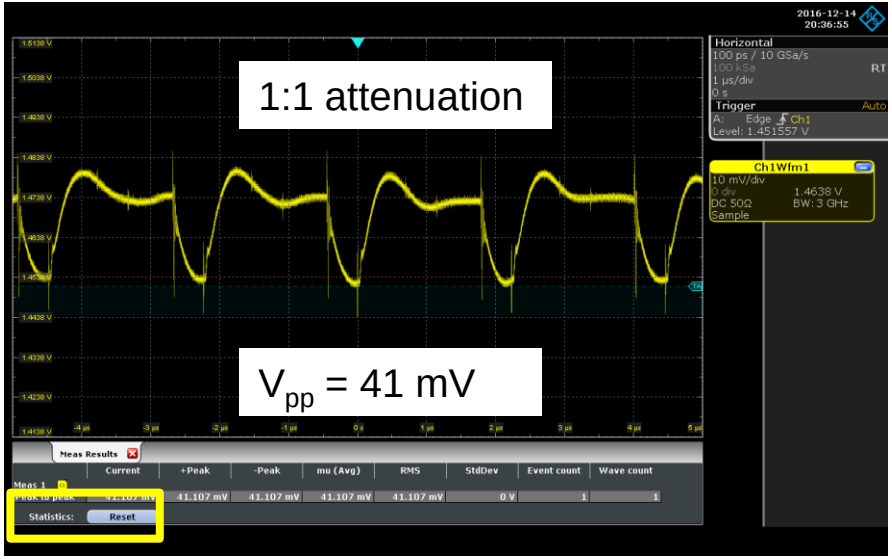
2. Lower Noise

Choose the right probe

10:1

1:1





2. Lower Noise

RT-ZPR20 & ZPR40 Power Rail Probe

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

Key Specifications	
Attenuation	**1:1**
ZPR20 BW ZPR40 BW	**2 GHz(*)** **4 GHz(**)**
Browser BW	350 MHz
Dynamic Range	±850 mV
Offset Range	**> ±60 V**
ZPR20 Noise Scope (RTO) standalone Scope + Probe Noise (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

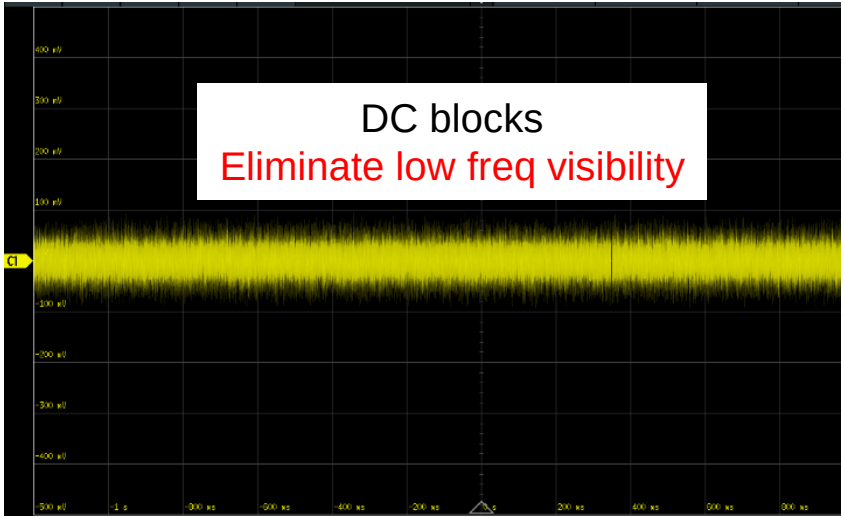
ZPR20

ZPR40

(*) 2.4 GHz typical 3 dB point
(**) 4.0 GHz typical 3dB point

3. Achieve sufficient offset

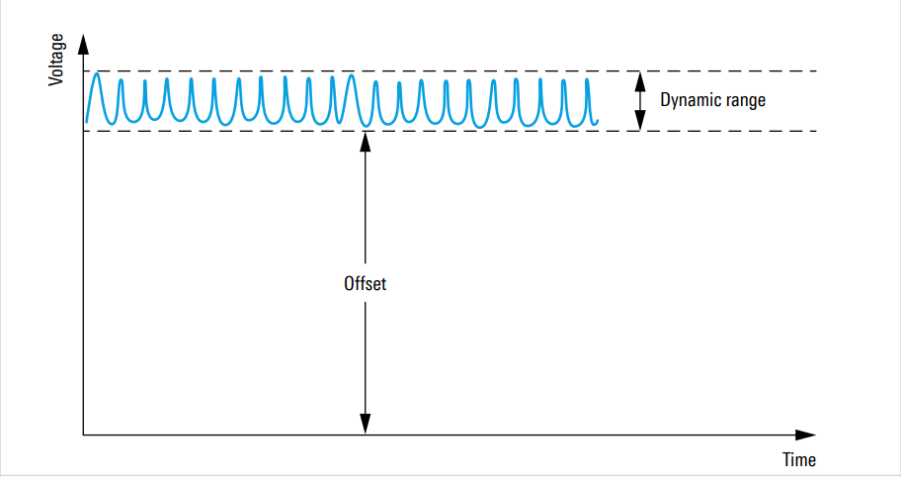
DC Drift



3. Achieve sufficient offset

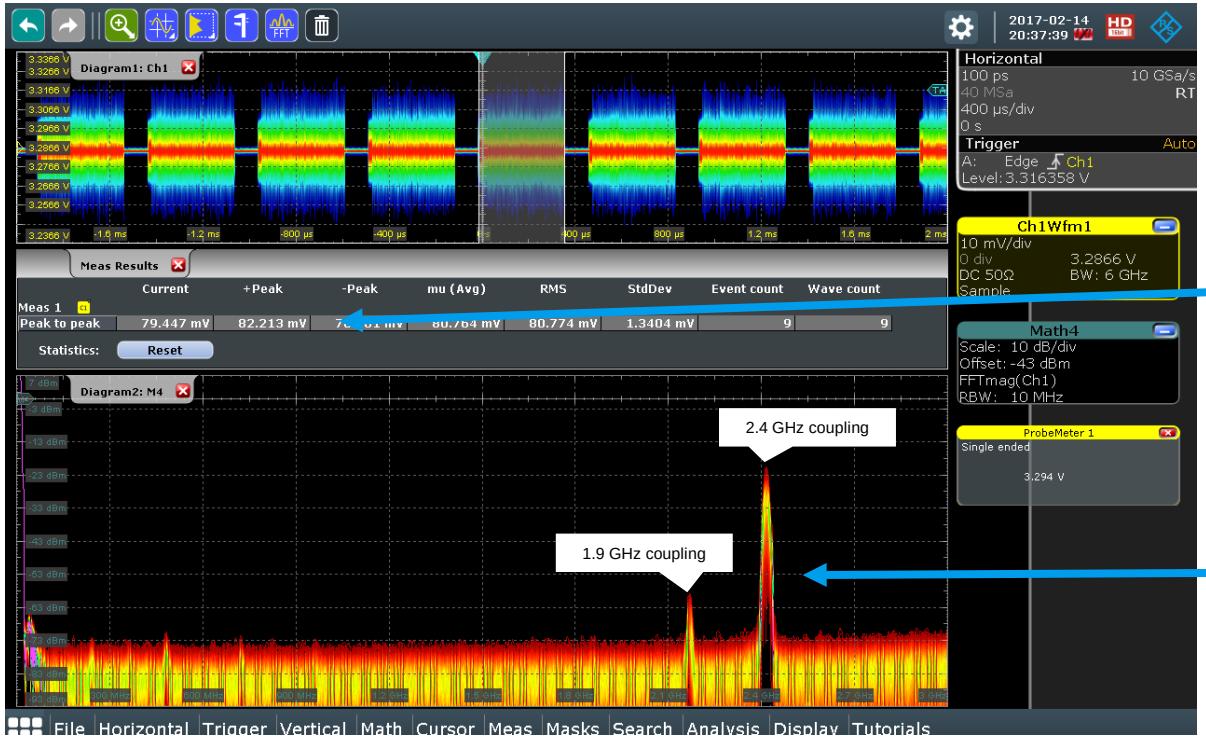
Probes with built-in offset

R&S®RT-ZPR20 power rail probe with ±60 V built-in offset for zooming in on a wide range of DC power rail standards



4. Evaluate switching and EMI

Frequency domain view



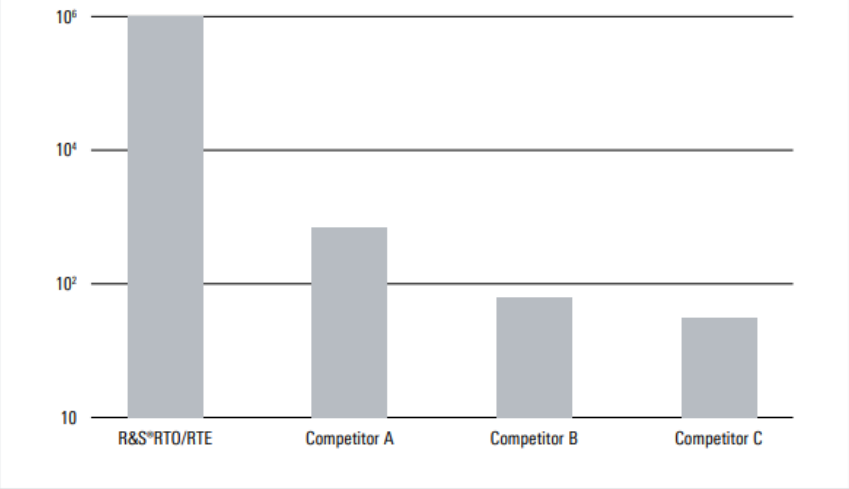
V_{pp} with statistics

High BW shows coupled sources

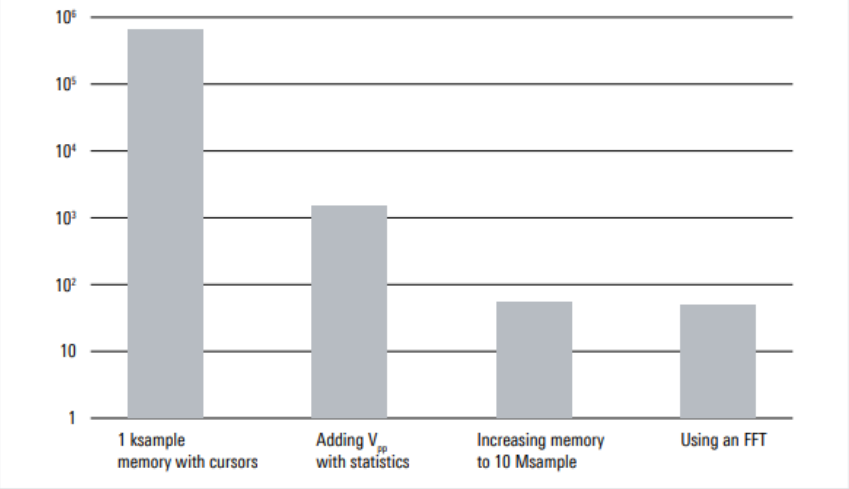
5. Accelerate measurement time

Update rate impact on speed of power integrity measurements

Comparison of the R&S®RTO and R&S®RTE update rate with other oscilloscopes in the industry (log scale)



Impact of measurements, memory depth increases, and the use of an FFT on the update rate of the R&S®RTO oscilloscopes (log scale)

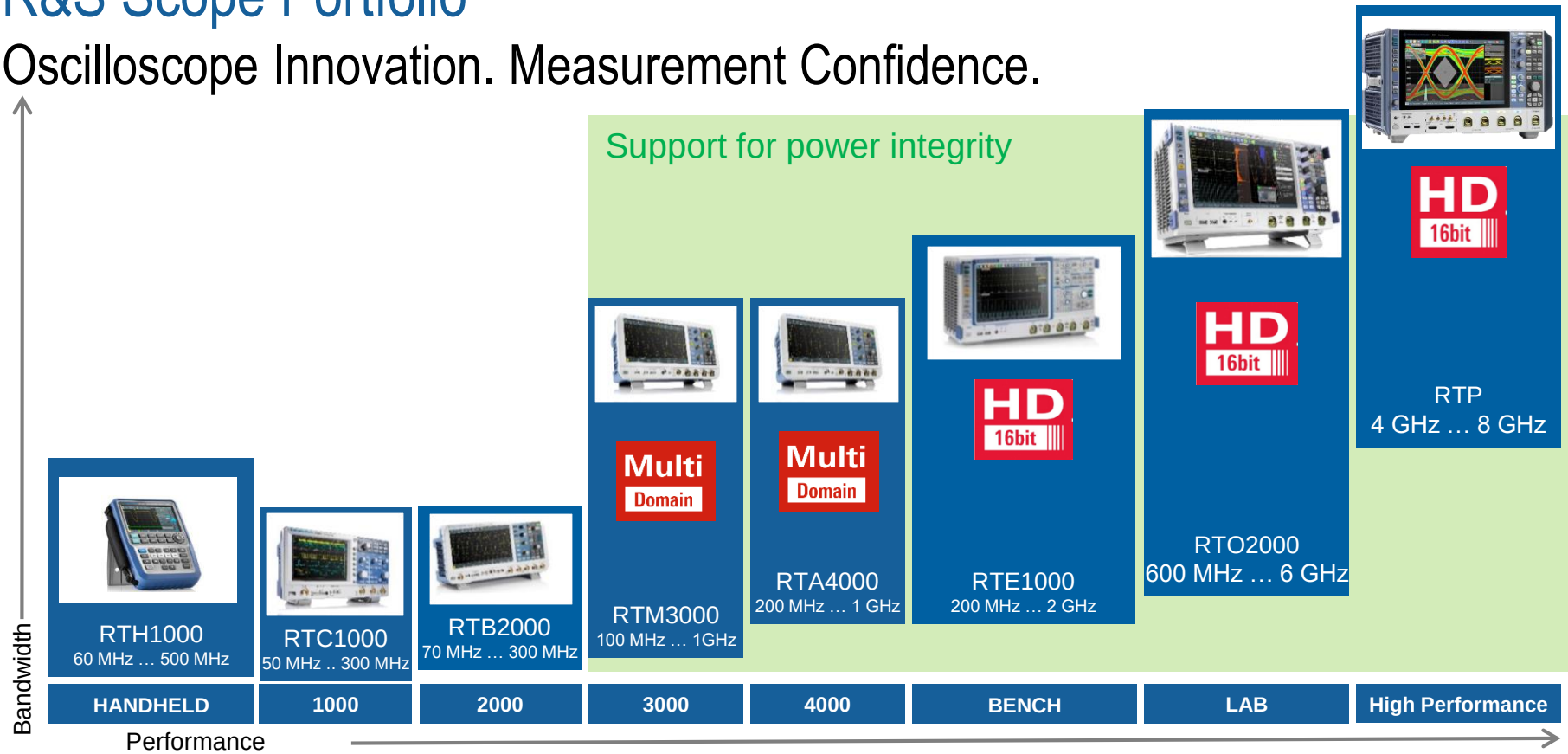


Conclusion

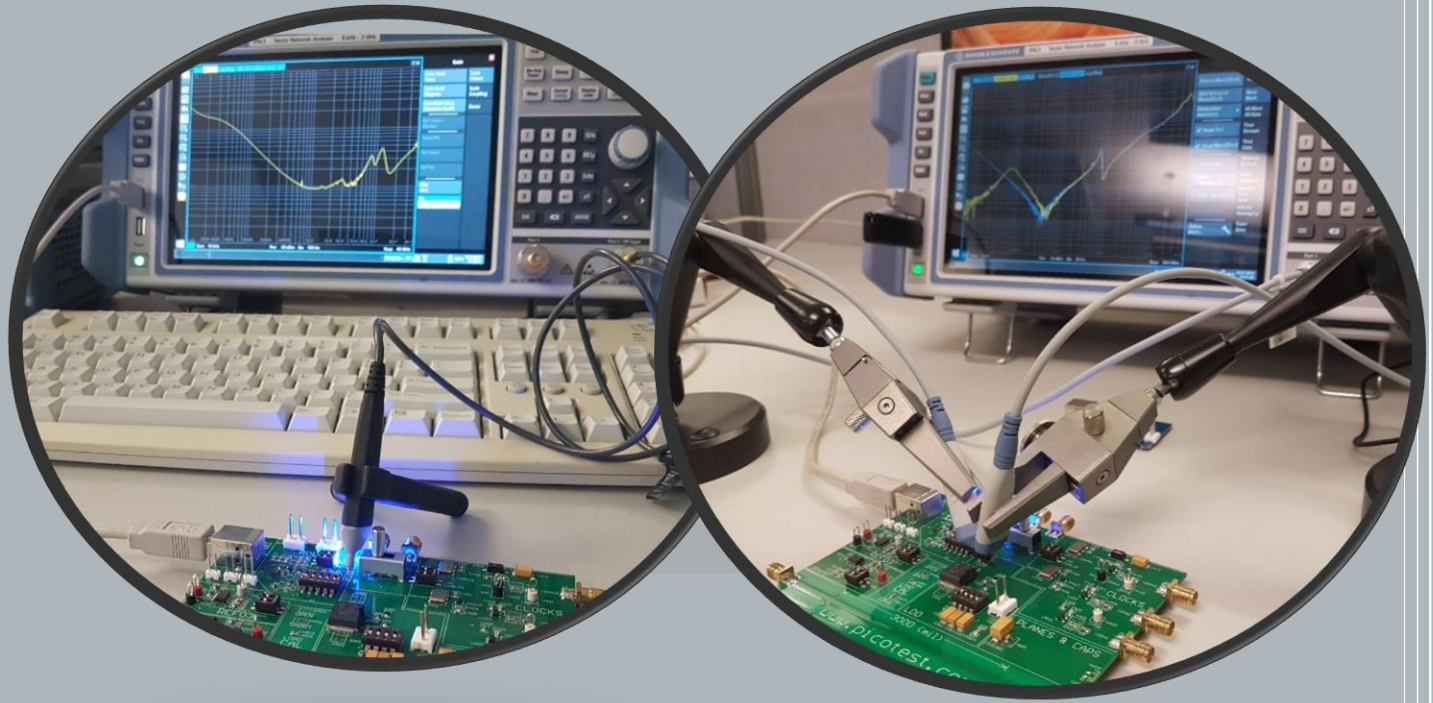
- Choosing a scope with low noise is critical to accurate power integrity measurements
- Coupling the scope with a 1:1 probe with built-in offset, high bandwidth, high DC impedance and an integrated R&S®ProbeMeter delivers superior capability and measurements
- Understanding and correctly setting a number of oscilloscope attributes such as vertical scaling and bandwidth limit filters increases the accuracy of results
- Adding frequency domain view enables users to quickly isolate coupled signals
- Fast update rates let users test power rails more quickly

R&S Scope Portfolio

Oscilloscope Innovation. Measurement Confidence.



Accurate PDN Impedance Measurements



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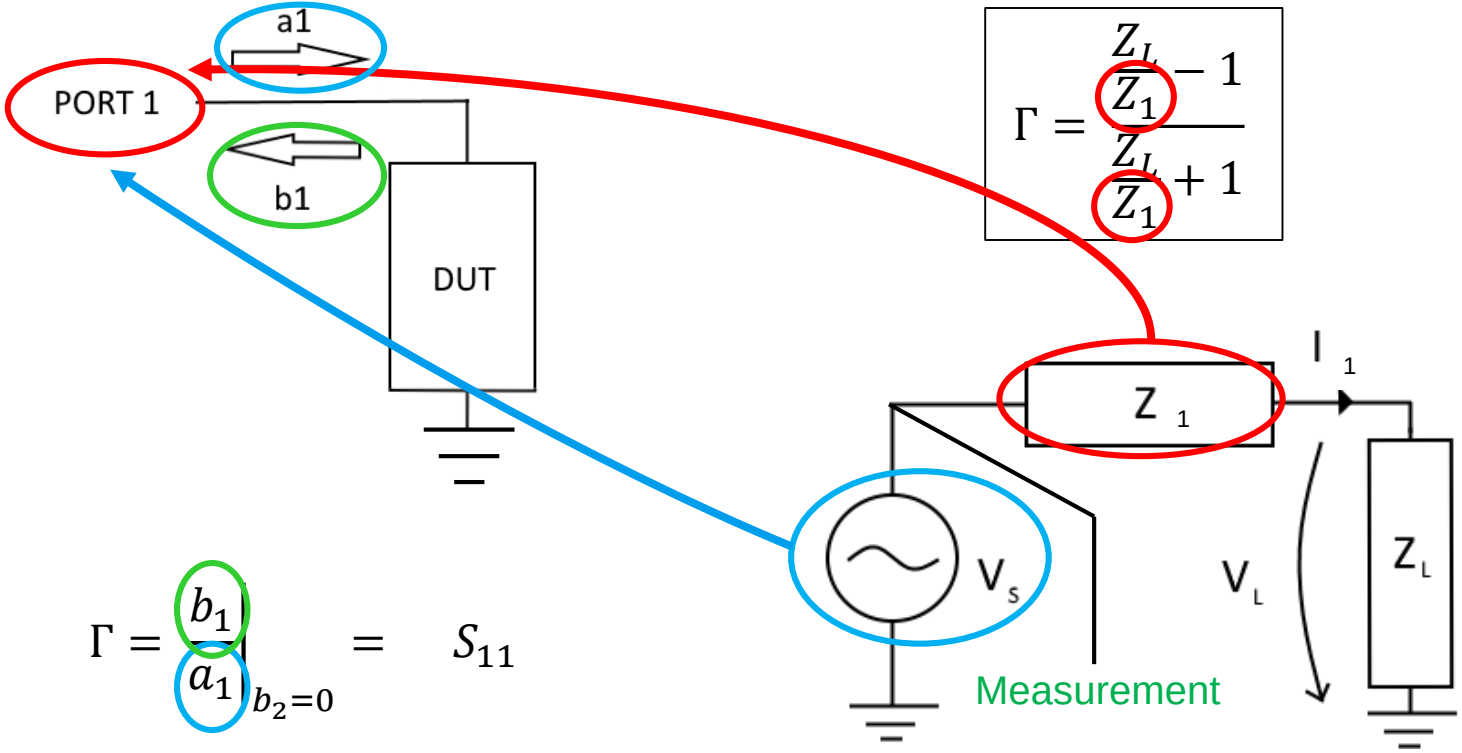
Measure PDN Impedance with R&S®ZNL

- Reflection setup

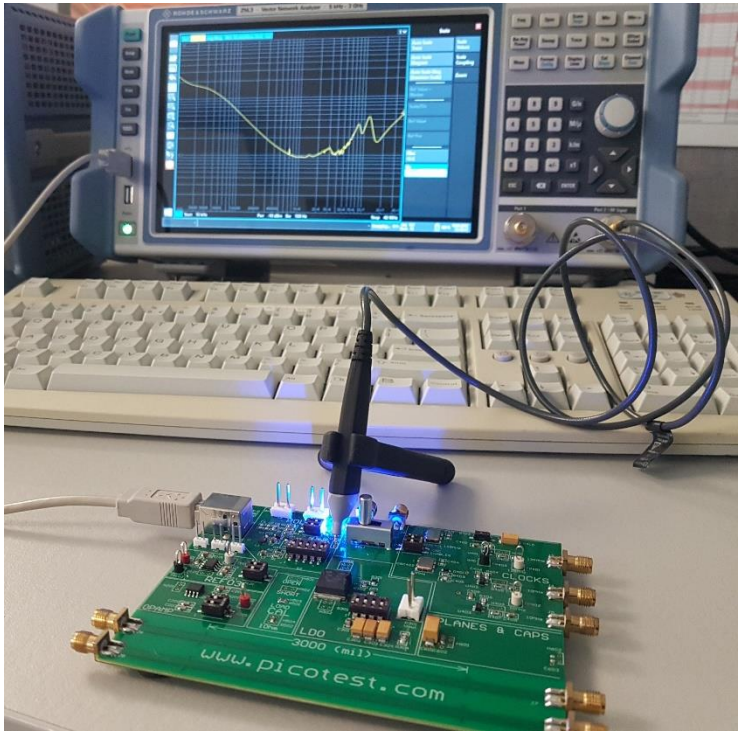
- Shunt-transmission setup

Reflection setup



$$\Gamma = \frac{b_1}{a_1}\Big|_{b_2=0} = S_{11}$$

Reflection setup



$$Z_L = Z_1 \cdot \frac{1 + S_{11}}{1 - S_{11}}$$

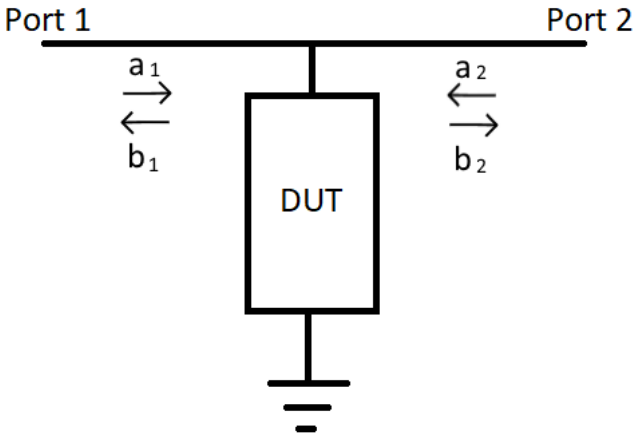
$$Z_1 = Z_{PORT} + Z_{PROBE}$$

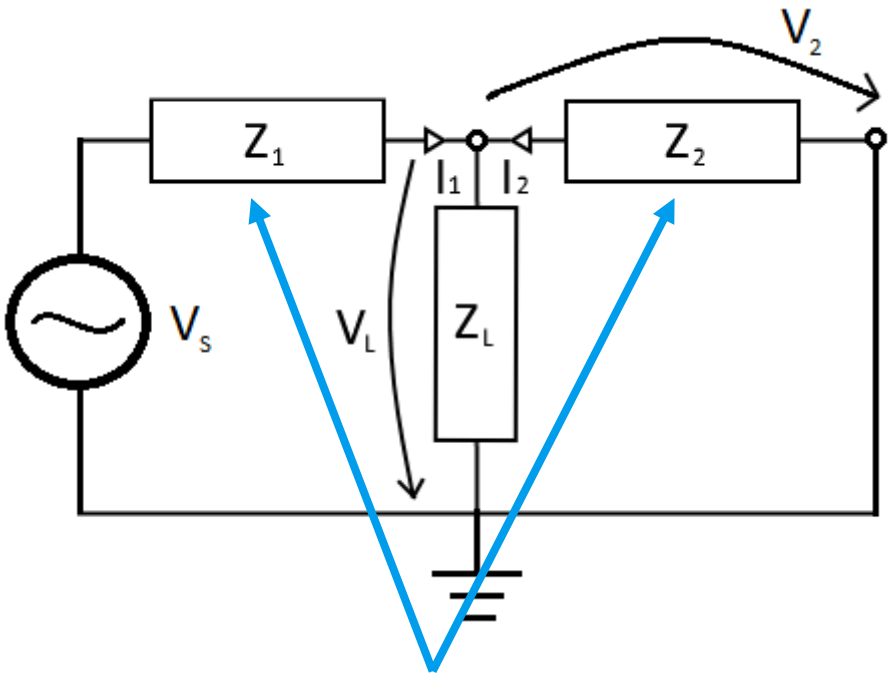
or

50 Ω

if calibrated @ measurement plane

Shunt-Transmission setup





$$Z_0 \stackrel{\text{def}}{=} Z_1 = Z_2 = 50\Omega$$

$$Z_L = \frac{50}{2} \cdot \left(\frac{S_{21}}{1 - S_{21}} \right)$$

Shunt-Transmission setup

$$Z_L = 25 \cdot \left(\frac{S_{21}}{1 - S_{21}} \right)$$

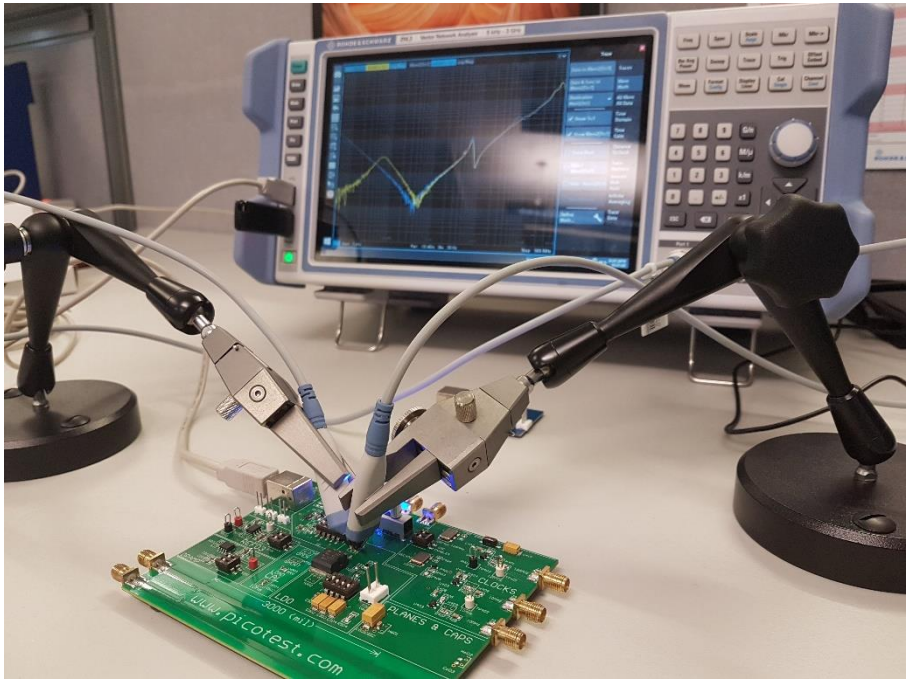
Best impedance dynamic range (mΩ ~ kΩ)

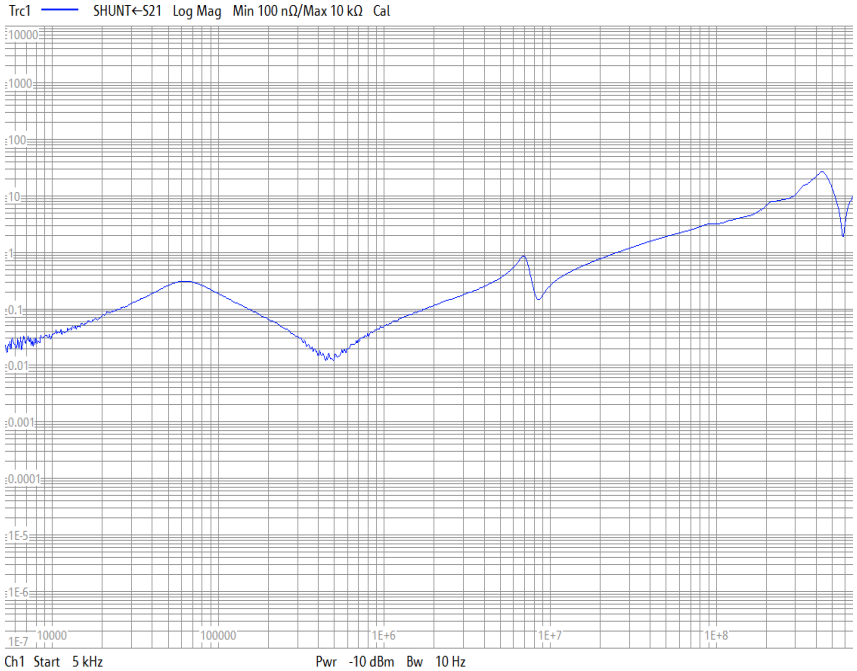
$$Z_{PDN\ target} \simeq \frac{V_{L\ noise}}{I_{L\ worst-case}}$$

Low (nom. V supply * ripple %)

High (worst transient)

Shunt-Transmission setup





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Please contact the presenters by email if you have any questions or comments

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