PSRR – Why Measure It, the Measurement Errors and How to Correct Them

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Submitted Abstract

Modern distributed systems are noise sensitive. Power rail noise is one of the most significant sources of jitter in high-speed systems, phase noise in RF systems, and noise in A/D and D/A converters. Recommendations abound, from adding ferrite beads and ceramic caps, to LDOs to clean the power supply rails. The most basic of measurements is the frequency domain PSRR measurement. Many manufacturers include data for their components, but in the system, they act very differently than they do in isolation. Measuring PSRR challenges the best of test engineers' ability, making us question even the manufacturers’ data. This presentation discusses the major PSRR measurement errors and how to correct them. That’s the key to getting accurate PSRR results.

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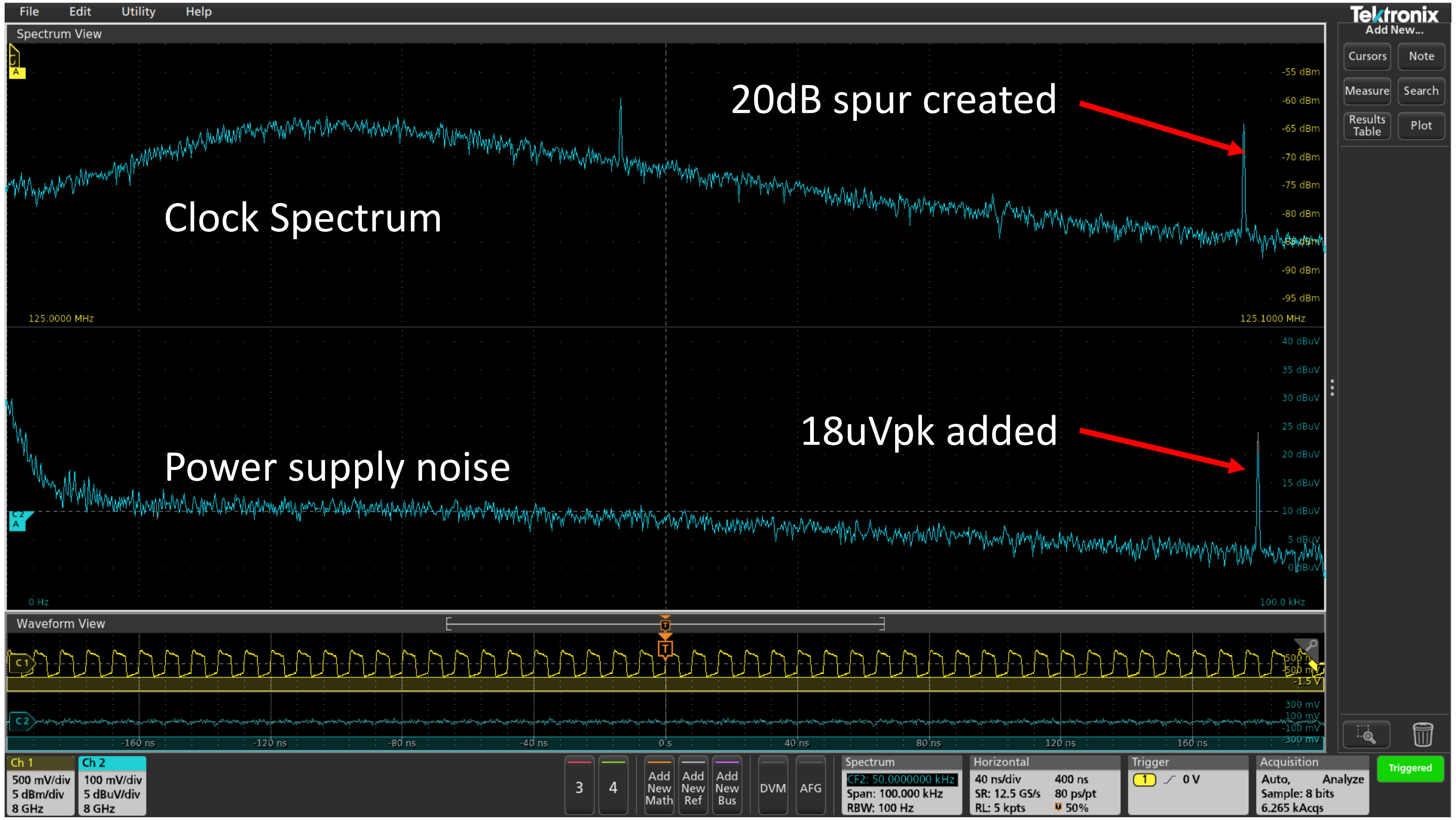
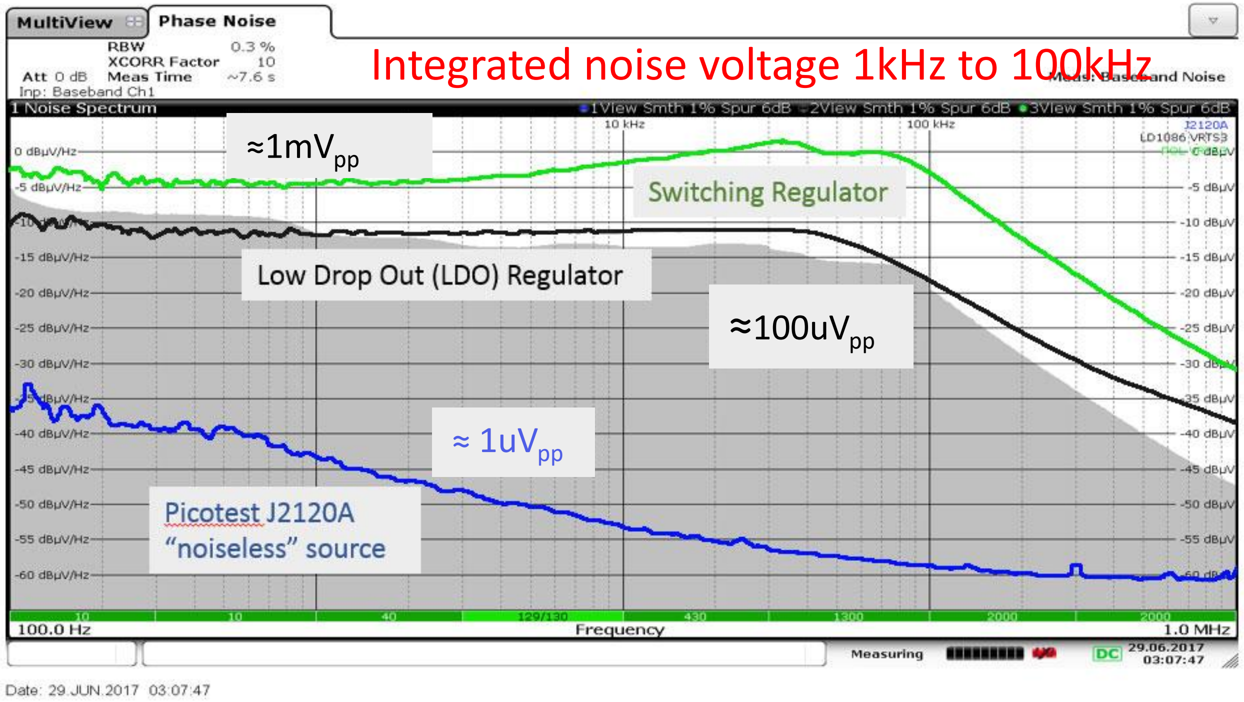
Why Measure PSRR?

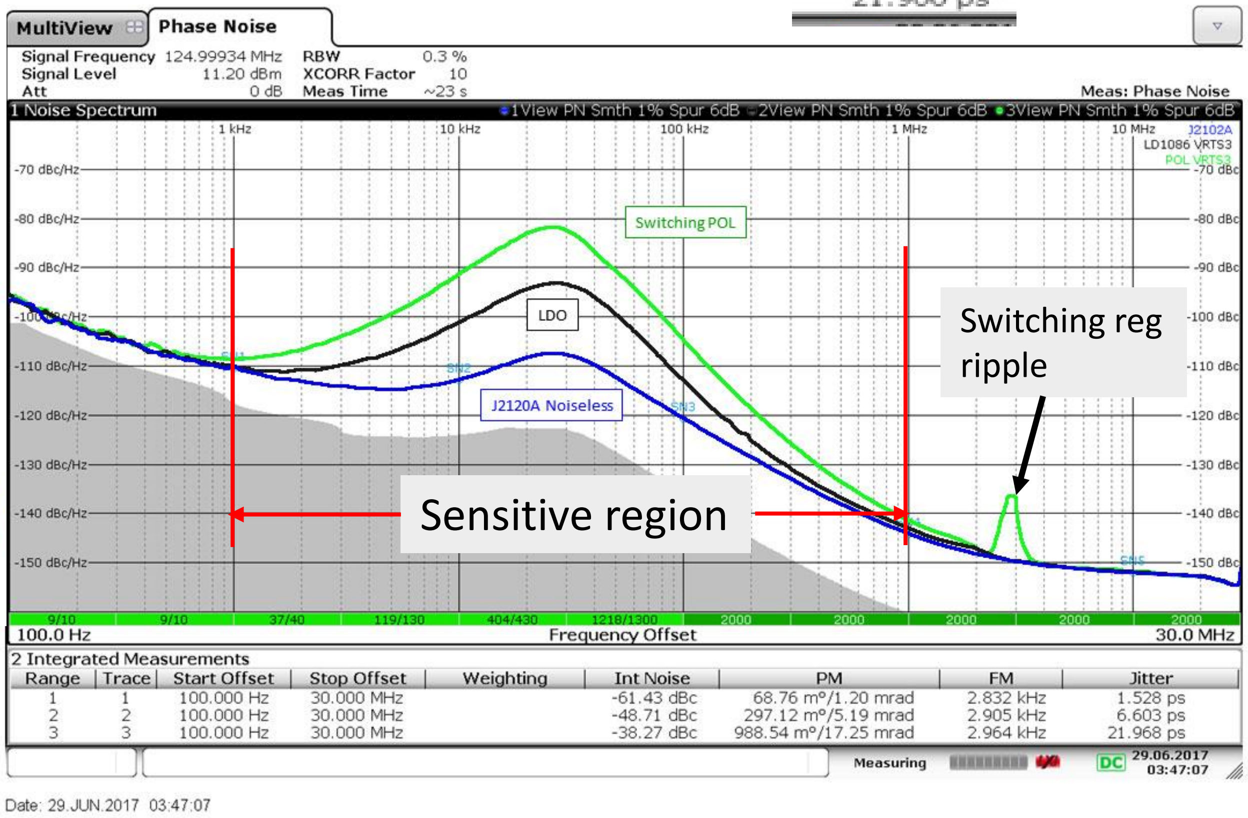
Even Tiny Noise Gets Into Sensitive Circuits

One common method of assessing the phase noise - jitter relationship is through the Power Supply Modulation Ratio (PSMR) test, where this sensitivity is measured at many frequencies and a noise mask is developed to verify the system level performance



Measuring the Direct Impact on Phase Noise





Range	Trace	Start Offset	Stop Offset	Weighting	Int Noise	PM	FM	Jitter
1	1	100.000 Hz	30.000 MHz		-61.43 dBc	68.76 m°/1.20 mrad	2.832 kHz	1.528 ps
2	2	100.000 Hz	30.000 MHz		-48.71 dBc	297.12 m°/5.19 mrad	2.905 kHz	6.603 ps
3	3	100.000 Hz	30.000 MHz		-38.27 dBc	988.54 m°/17.25 mrad	2.964 kHz	21.968 ps

Reducing It to a Simpler Form

Table 2: **Recommended Operating Conditions**[1][2] ***(Cont'd)***

Symbol	Description	Min	Typ	Max	Units	
V_{CCBATT}[11]	Battery voltage	1.0	–	1.89	V	
GTX and GTH Transceivers						
$V_{MGTAVCC}$[12]	Analog supply voltage for the GTX/GTH transceiver QPLL frequency range ≤ 10.3125 GHz[13][14]	0.97	1.0	1.08	V	**110mVpp**
	Analog supply voltage for the GTX/GTH transceiver QPLL frequency range > 10.3125 GHz	1.02	1.05	1.08	V	**30mVpp**
$V_{MGTAVTT}$[12]	Analog supply voltage for the GTX/GTH transmitter and receiver termination circuits	1.17	1.2	1.23	V	**30mVpp**
$V_{MGTVCCAUX}$[12]	Auxiliary analog Quad PLL (QPLL) voltage supply for the transceivers	1.75	1.80	1.85	V	**50mVpp**
$V_{MGTAVTTRCAL}$[12]	Analog supply voltage for the resistor calibration circuit of the GTX/GTH transceiver column	1.17	1.2	1.23	V	**30mVpp**

As the amplitude of the noise should be limited to less than 10 mVpp, the power supply filter should be designed to attenuate the noise from the switching regulator to meet this requirement

https://support.xilinx.com/s/question/0D54U00005VU9noSAD/power-supply-for-mgt-groups-of-virtex-7-fpga-xc7vx690tffg19272?language=en_US

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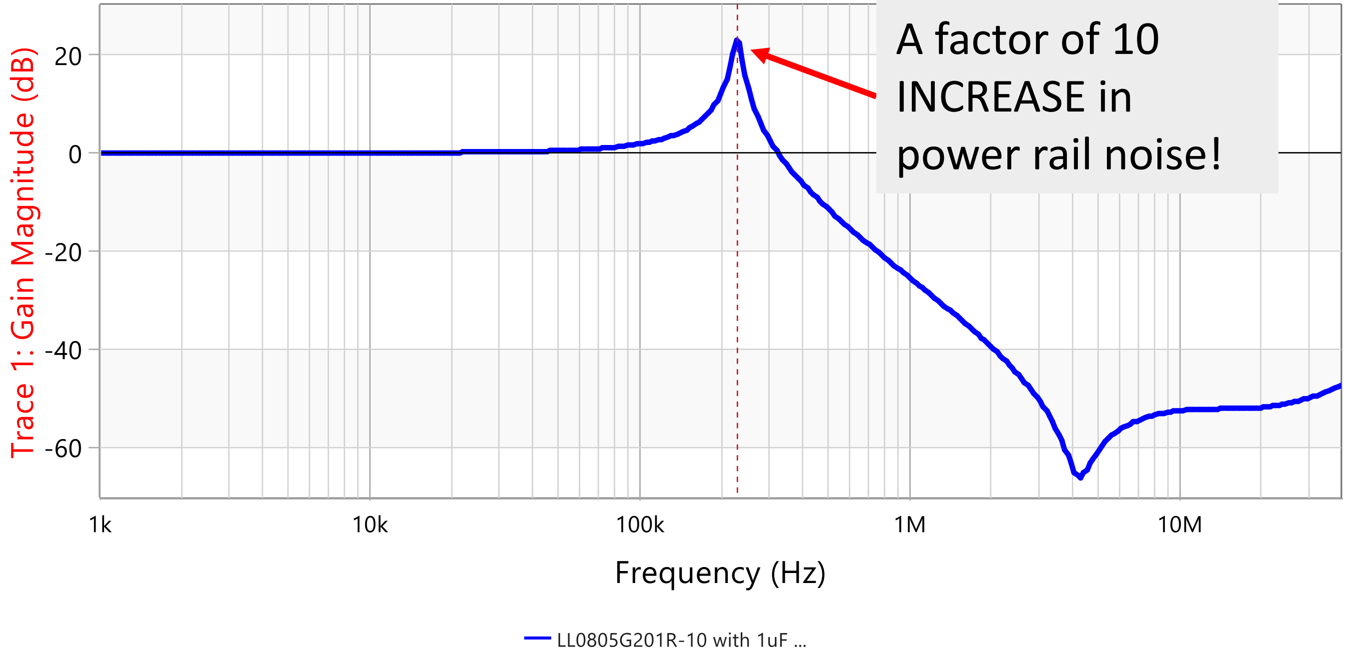
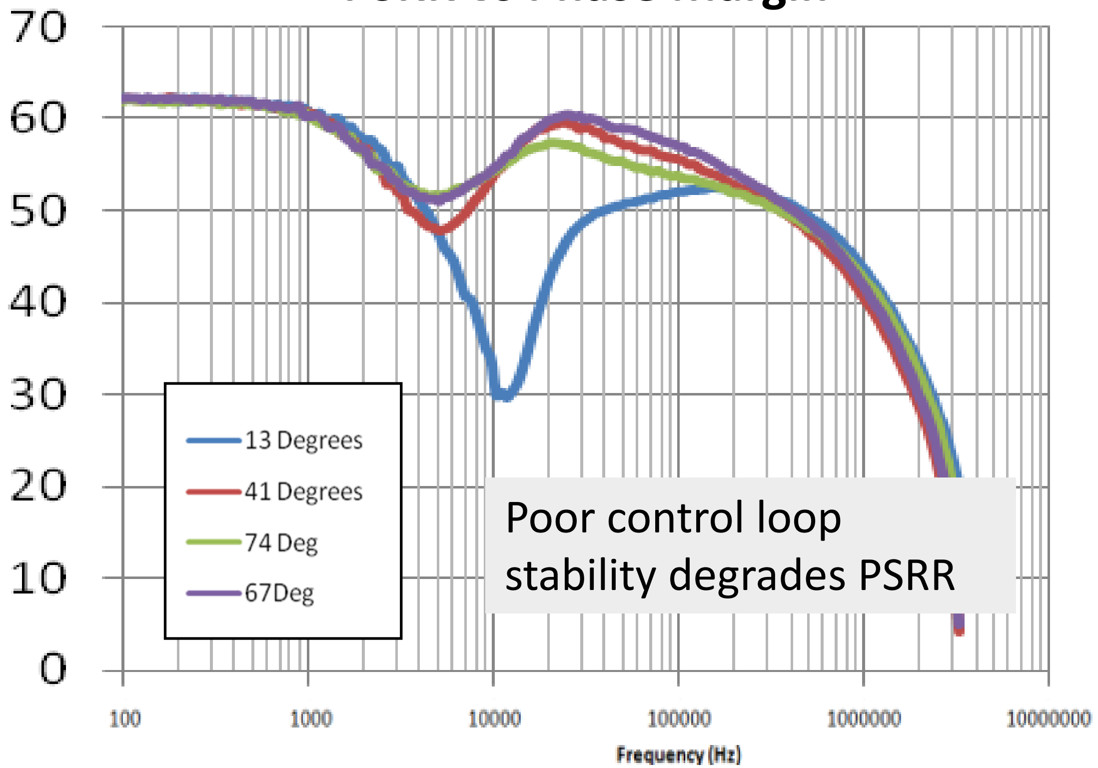
System “Components” Also Effect PSRR

Ferrite Bead “Attenuation”- Not Everywhere!



Florian Hämmerle showed the effects of a ferrite bead in a USB oscilloscope during OMICRON Lab Symposium 7



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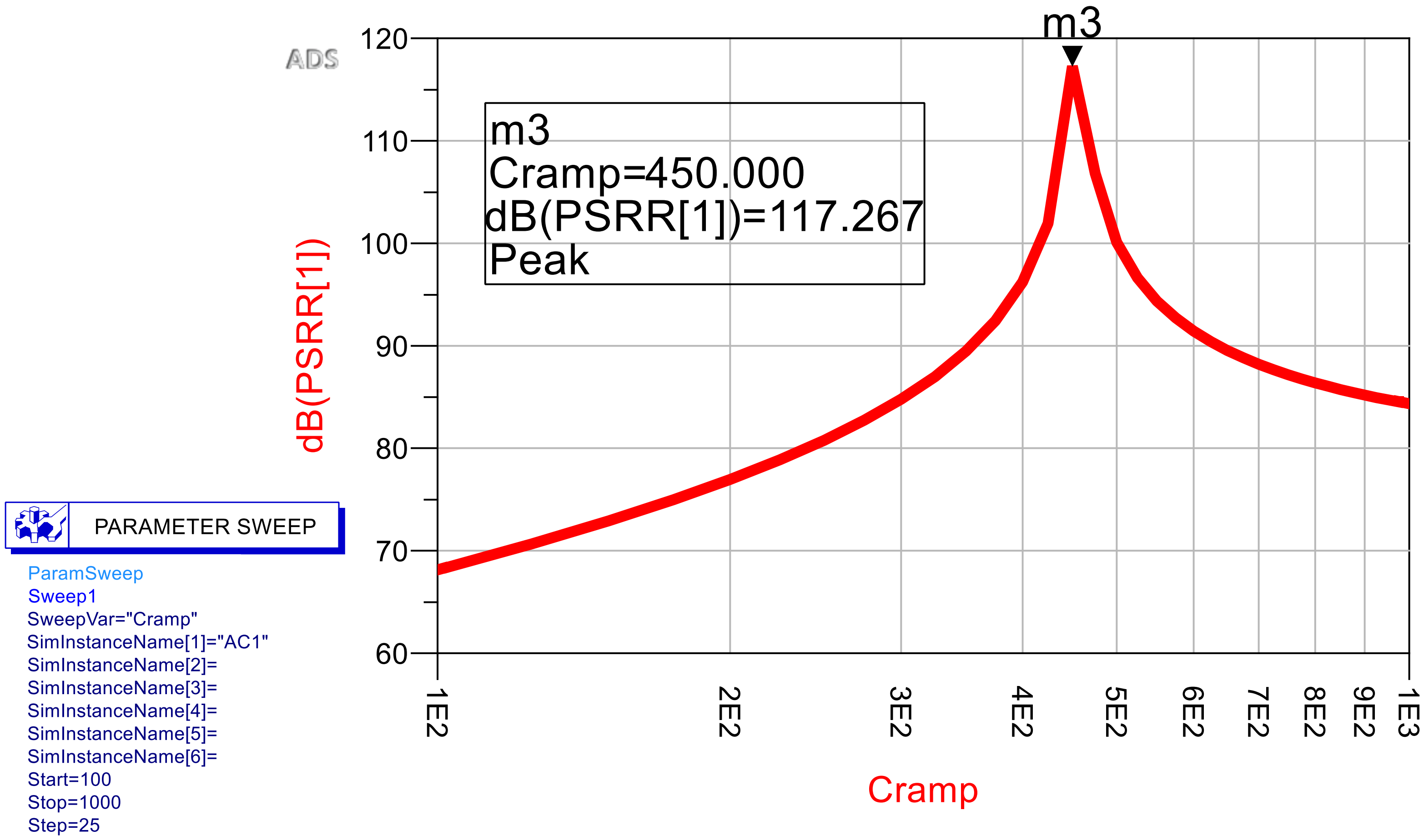
And Even Slope Compensation Impacts PSRR

In my presentation "Measurement-based Modelling and Simulation of DC-DC Converters" at Electronica 2018, I showed the impact of current mode control slope compensation on PSRR

Clearly, PSRR is an important consideration as it impacts the load, and it's impacted by many parameters by the voltage regulator, the PCB components, and the sensitivity of the load

This is why it is so important for us to measure it, preferably in-system, at the system level

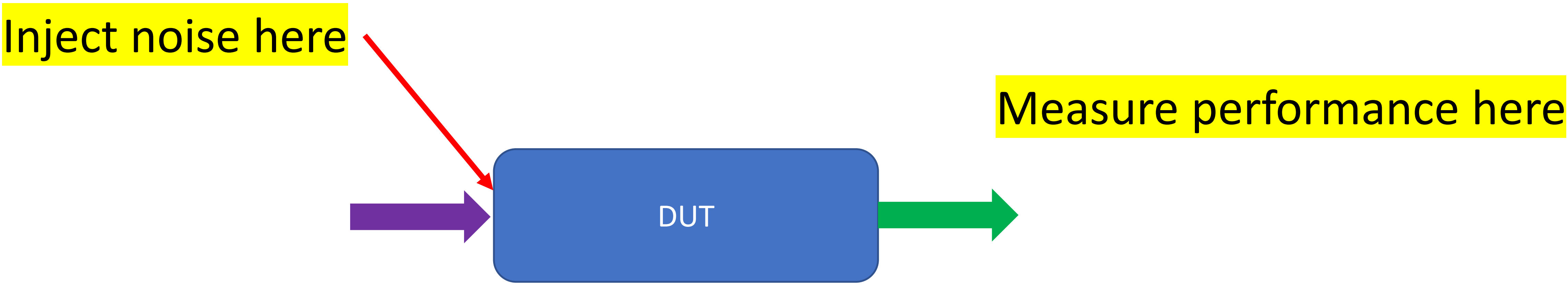


It’s Abundantly Clear Why We Must Measure PSRR

- Many loads are extremely sensitive to power supply noise. Increased power rail noise can cause Bit Error Rate failures due to phase noise/jitter
- Filters comprised of ferrite beads and ceramic capacitors are often recommended, but these WILL significantly INCREASE noise if not properly damped
- VRM control loop stability can be degraded by the PCB effects and decoupling capacitors. This can degrade PSRR, resulting in higher noise
- Slope compensation of switching regulator also impacts PSRR and so can be optimized for the best PSRR

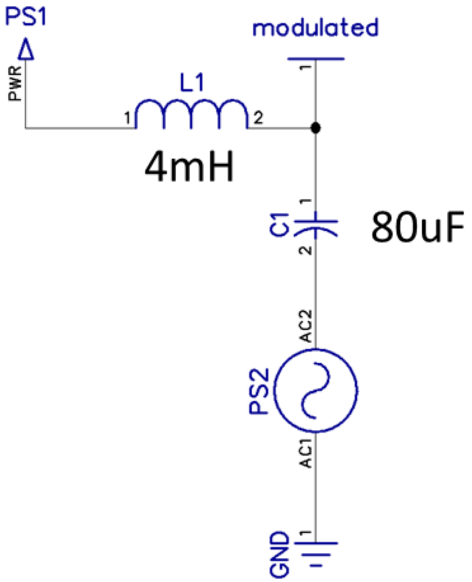
https://www.signalintegrityjournal.com/articles/573-designing-power-for-sensitive-circuits

The PSRR Measurement Setup



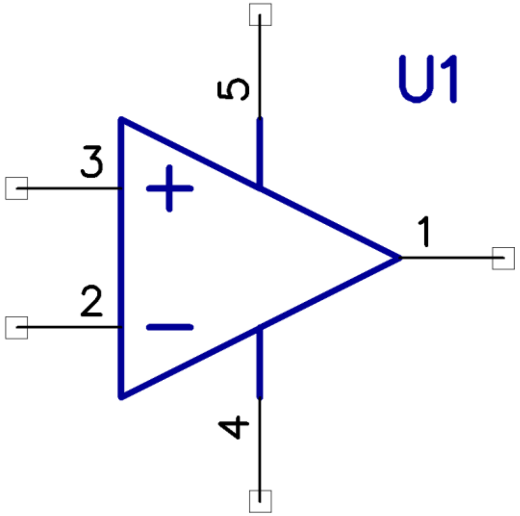
Noise Injection Methods

Bias Tee



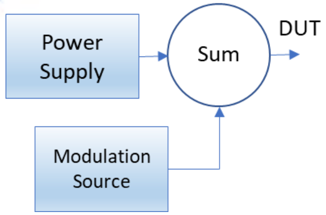
Very poor bandwidth
Really small signals

Power Amp

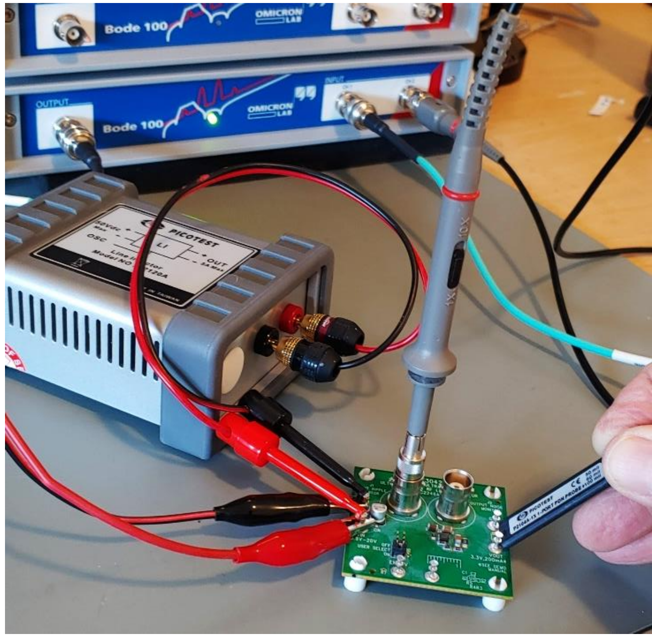


Poor bandwidth
Stability issues
Low power

Line Injector
(open loop summer)



Wide Bandwidth
No loop – no stability issue
Low power to high power
Variable voltage drop (remote sense filter)



The power supply modulation setup is the same for PSRR, PSMR, and PSNR

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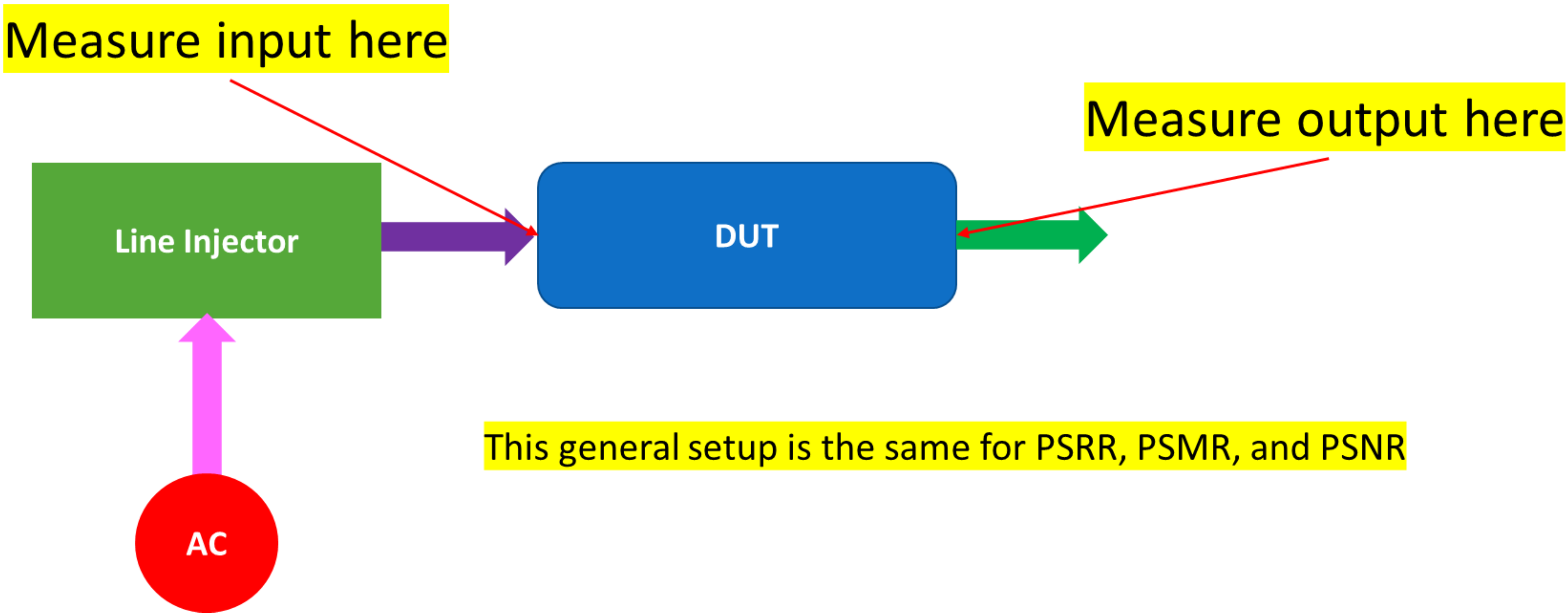
The PSRR Test



This general setup is the same for PSRR, PSMR, and PSNR

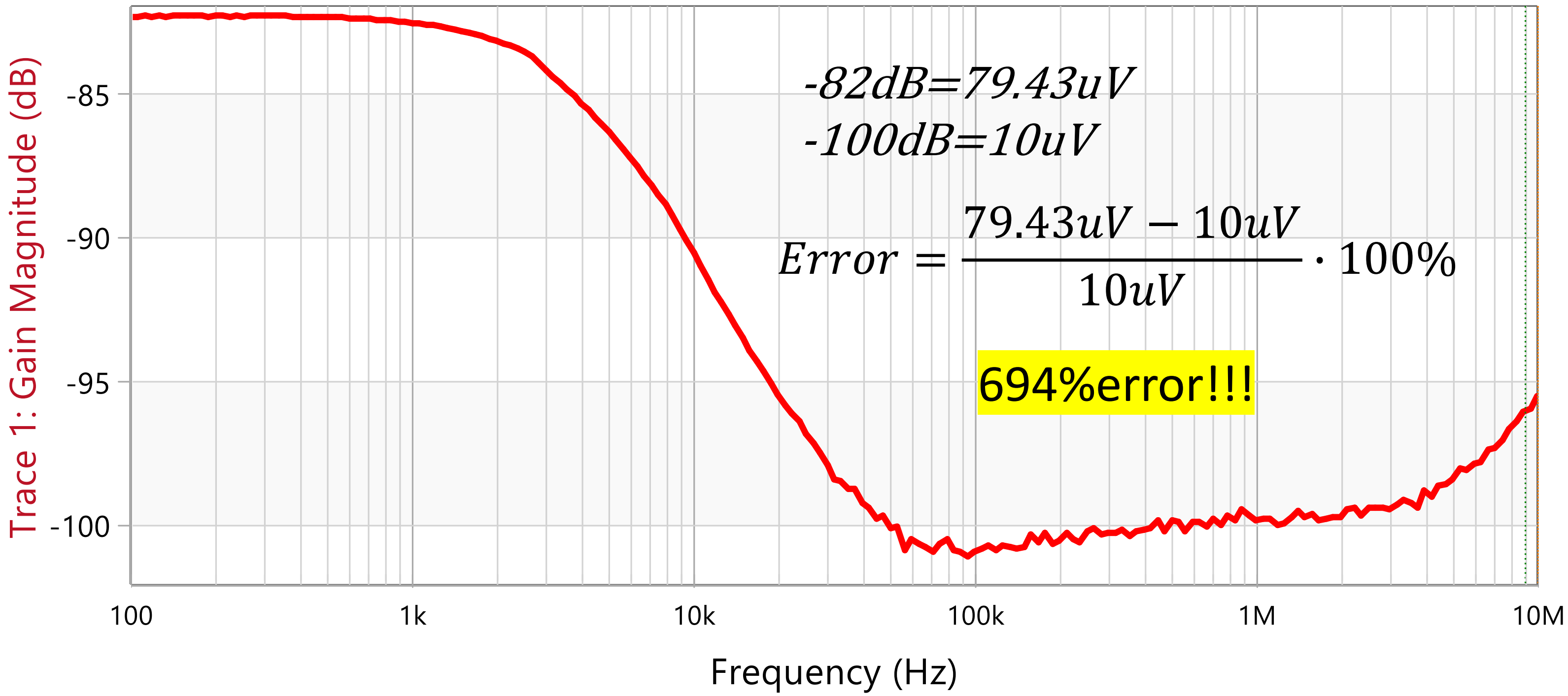
Measuring a 100dB Attenuator

Before measuring something that you don't know, measure something you DO know

With uV sensitivities required by sensitive circuits, many new high performance Linear Regulators and LDOs can provide 100dB PSRR

At low frequency, the error is 694% but it corrects itself at higher frequency

WHY???



$$Error = \frac{79.43uV - 10uV}{10uV} \cdot 100\%$$

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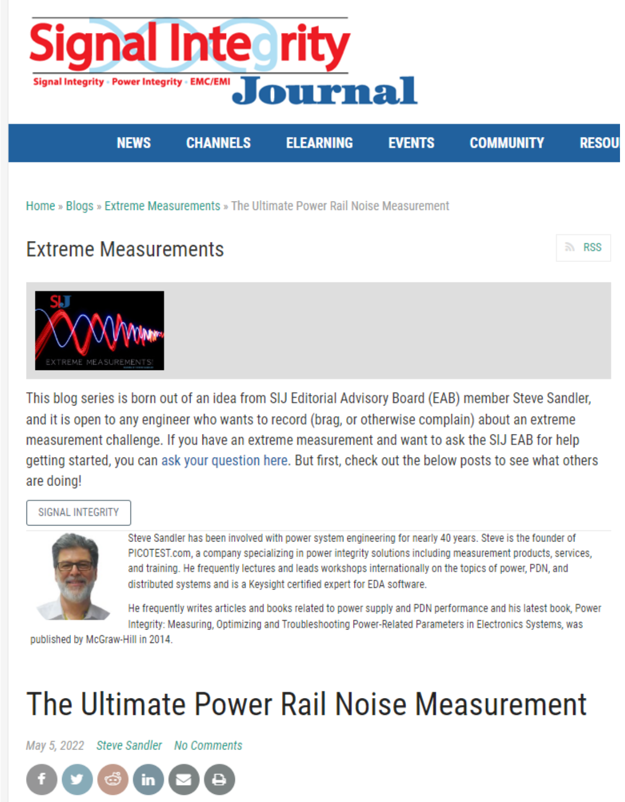
This Isn't as Easy as It Looks!



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Extreme Measurements

RSS

This blog series is born out of an idea from SIJ Editorial Advisory Board (EAB) member Steve Sandler, and it is open to any engineer who wants to record (brag, or otherwise complain) about an extreme measurement challenge. If you have an extreme measurement and want to ask the SIJ EAB for help getting started, you can ask your question here. But first, check out the below posts to see what others are doing!

SIGNAL INTEGRITY

Steve Sandler has been involved with power system engineering for nearly 40 years. Steve is the founder of PICOTEST.com, a company specializing in power integrity solutions including measurement products, services, and training. He frequently lectures and leads workshops internationally on the topics of power, PDN, and distributed systems and is a Keysight certified expert for EDA software.

He frequently writes articles and books related to power supply and PDN performance and his latest book, Power Integrity: Measuring, Optimizing and Troubleshooting Power-Related Parameters in Electronics Systems, was published by McGraw-Hill in 2014.

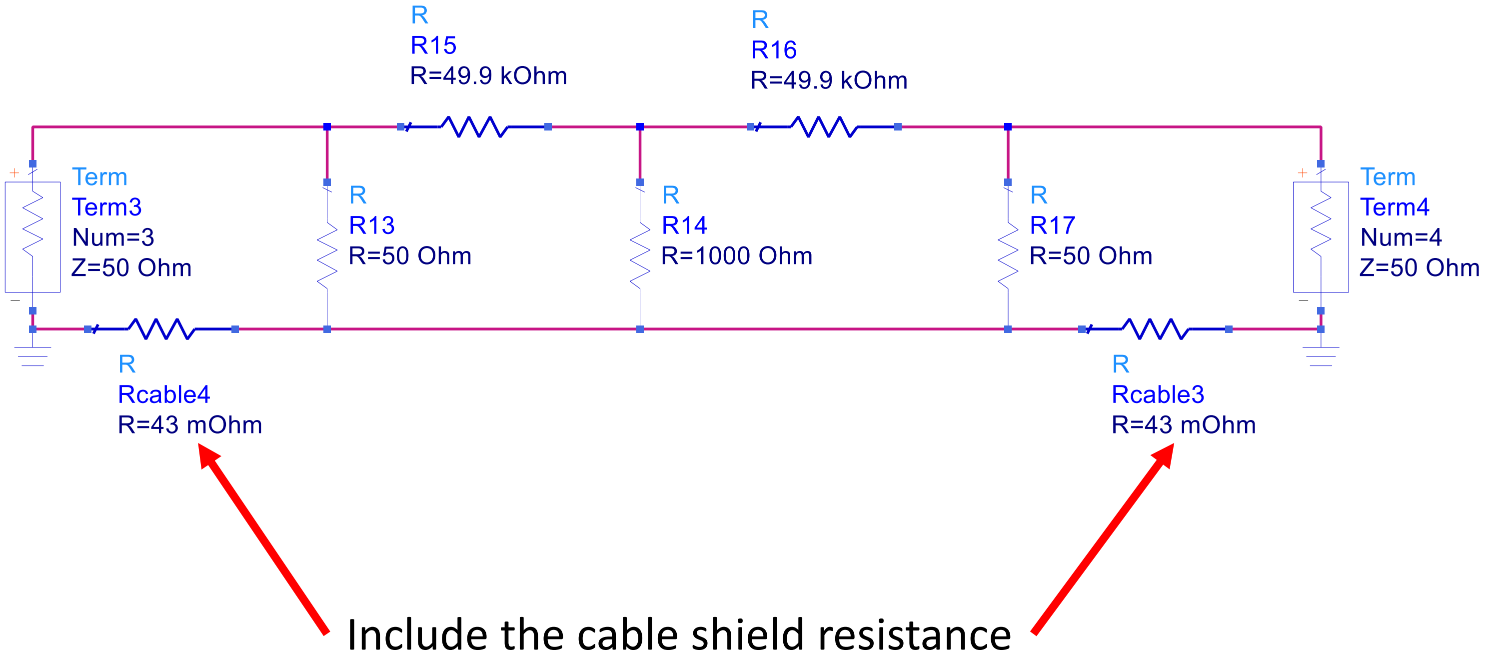
The Ultimate Power Rail Noise Measurement

May 5, 2022 Steve Sandler No Comments

- **The output signals can be really tiny (like micro-Volts)**
- **Measured in one instrument? Ground loop error**
- **Differential probe? Too noisy**
- **Injecting high frequency?**
- **Interconnects in the way**

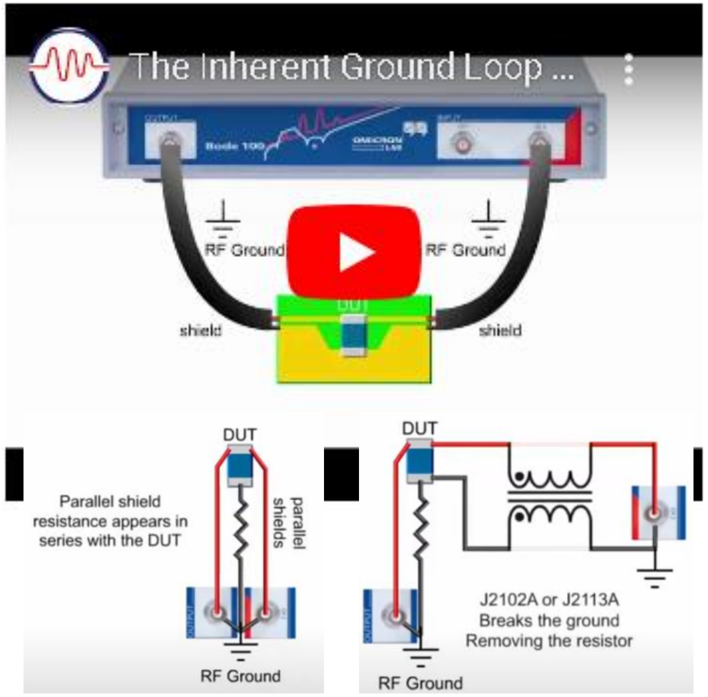
https://www.signalintegrityjournal.com/blogs/15-extreme-measurements/post/2484-the-ultimate-power-rail-noise-measurement

What Causes the Error??



The AC modulation current flows through the resistance of both cable shields, providing a shield voltage (similar to ground bounce)

https://www.picotest.com/measurements/2-port.html



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There Ya Go

$Vin := 2$

$Rsource := 50$

$R\_atten\_in := 49.9$

$Rshield1 := 0.0001$

$Rshield2 := 0.0001$

$Atten := 100000$

$Atten\_dB := 20 \cdot \log(Atten) = 100$

The voltage across the shield is:

$$Vshield := \frac{Vin \cdot \frac{Rshield1 \cdot Rshield2}{Rshield1 + Rshield2}}{Rsource + R\_atten\_in + \frac{Rshield1 \cdot Rshield2}{Rshield1 + Rshield2}}$$

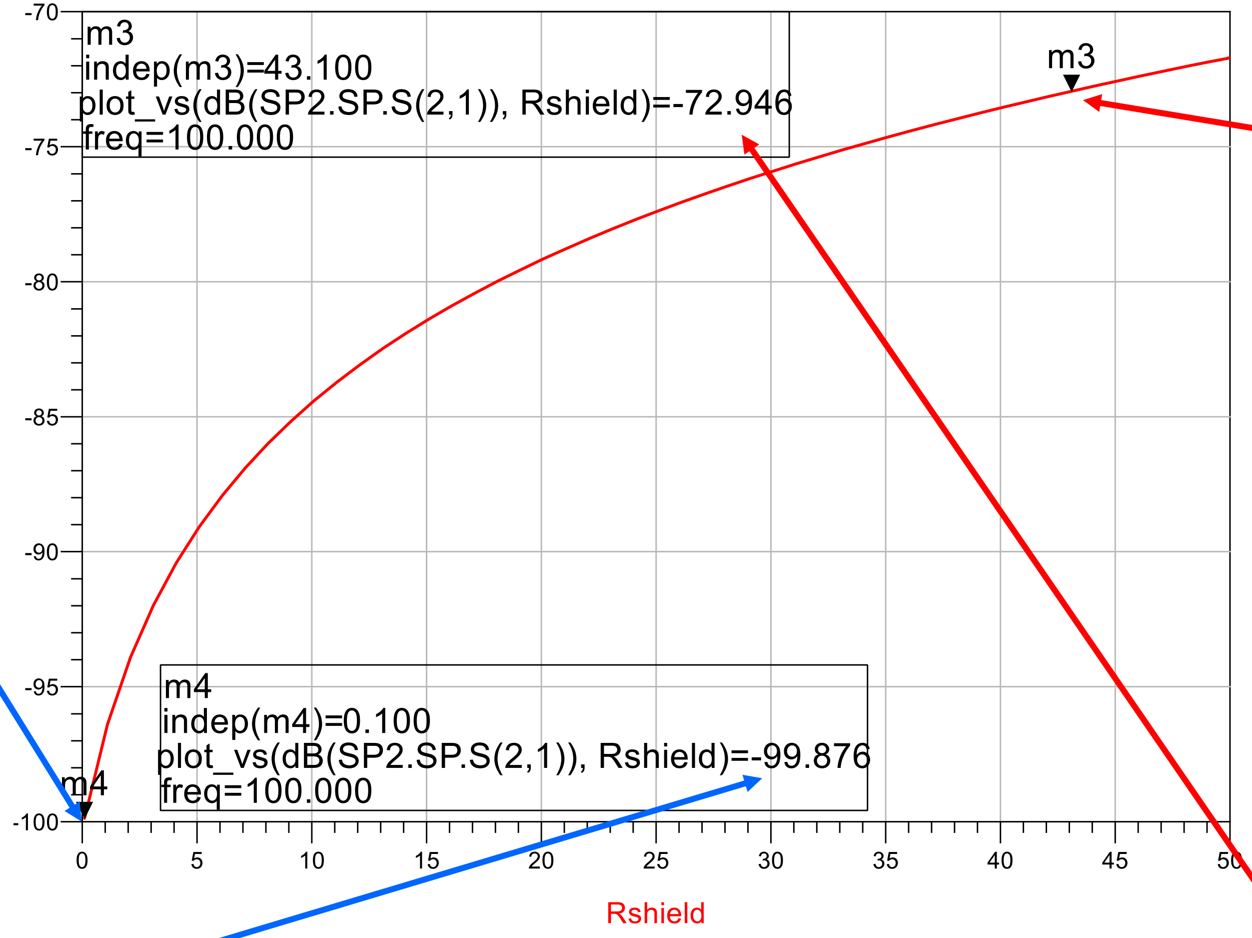
$Vshield = 1.001 \times 10^{-6}$

$$Vatten\_in := \frac{Vin \cdot R\_atten\_in}{Rsource + R\_atten\_in + \frac{Rshield1 \cdot Rshield2}{Rshield1 + Rshield2}}$$

$Vatten\_in = 9.99 \times 10^{-1}$

$$Vout := \frac{Vatten\_in \cdot 2}{Atten} + Vshield = 2.098 \times 10^{-5}$$

$$Atten\_measured := 20 \cdot \log\left(\frac{Vout}{Vin}\right) = -99.584$$



$Vin := 2$

$Rsource := 50$

$R\_atten\_in := 49.9$

$Rshield1 := 0.043$

$Rshield2 := 0.043$

$Atten := 100000$

$Atten\_dB := 20 \cdot \log(Atten) = 100$

The voltage across the shield is:

$$Vshield := \frac{Vin \cdot \frac{Rshield1 \cdot Rshield2}{Rshield1 + Rshield2}}{Rsource + R\_atten\_in + \frac{Rshield1 \cdot Rshield2}{Rshield1 + Rshield2}}$$

$Vshield = 4.303 \times 10^{-4}$

$$Vatten\_in := \frac{Vin \cdot R\_atten\_in}{Rsource + R\_atten\_in + \frac{Rshield1 \cdot Rshield2}{Rshield1 + Rshield2}}$$

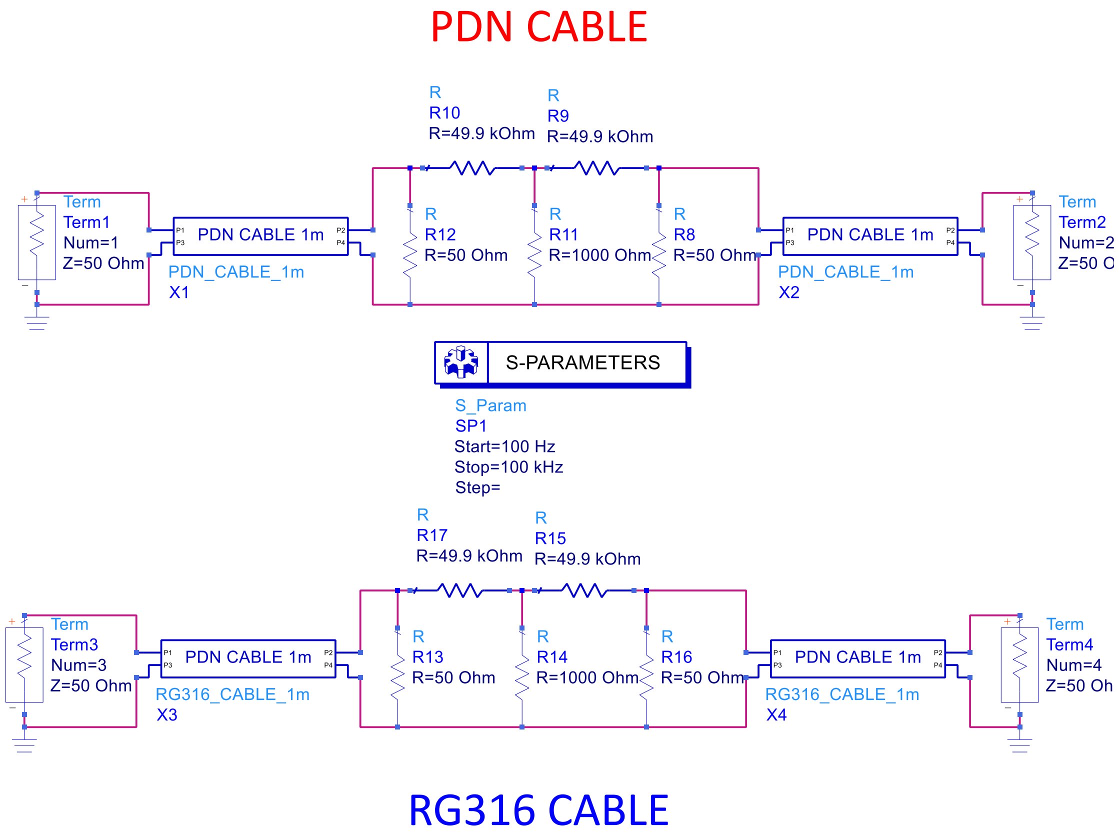
$Vatten\_in = 9.988 \times 10^{-1}$

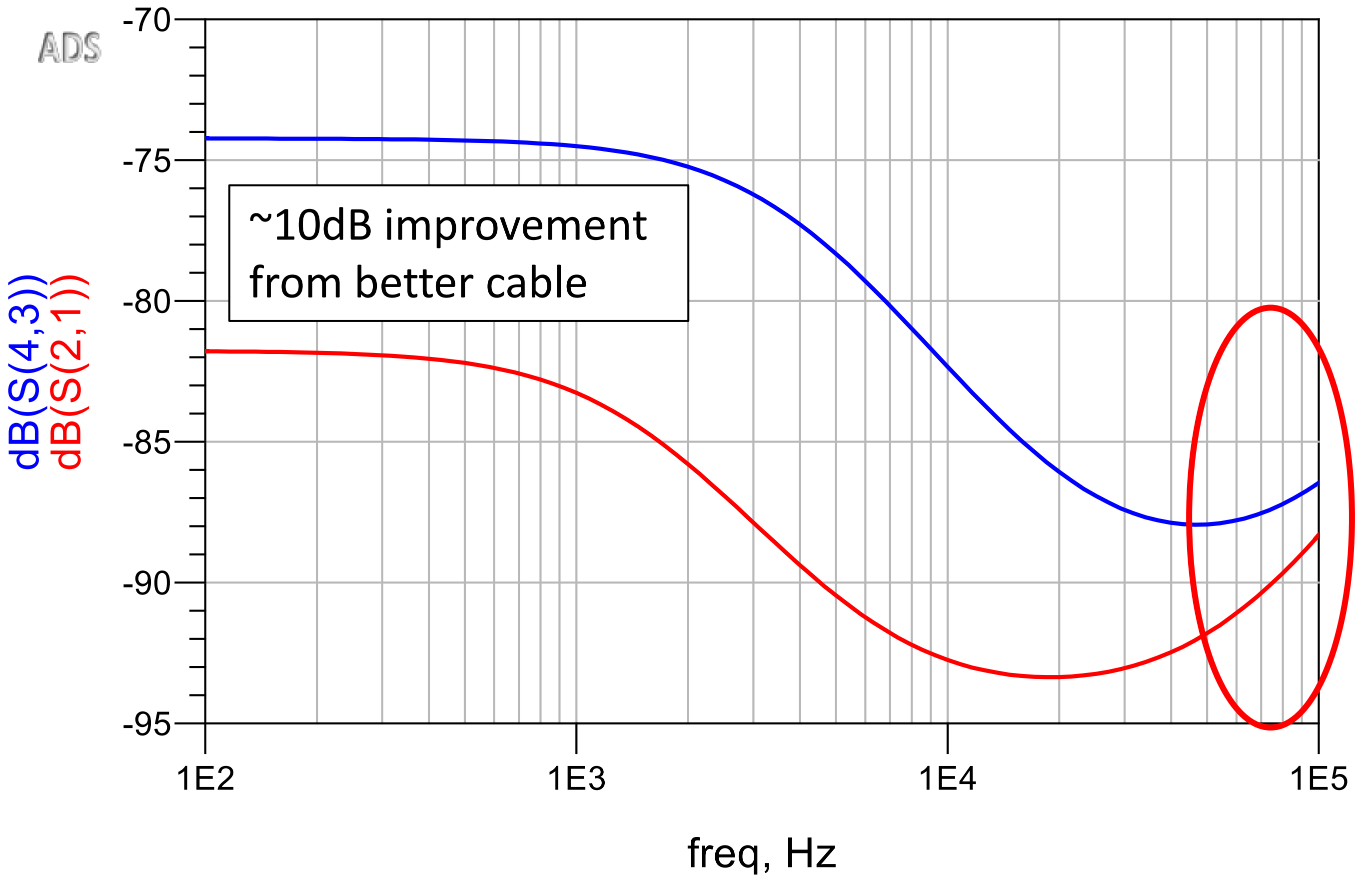
$$Vout := \frac{Vatten\_in \cdot 2}{Atten} + Vshield = 4.503 \times 10^{-4}$$

$$Atten\_measured := 20 \cdot \log\left(\frac{Vout}{Vin}\right) = -72.95$$

Including the Cables

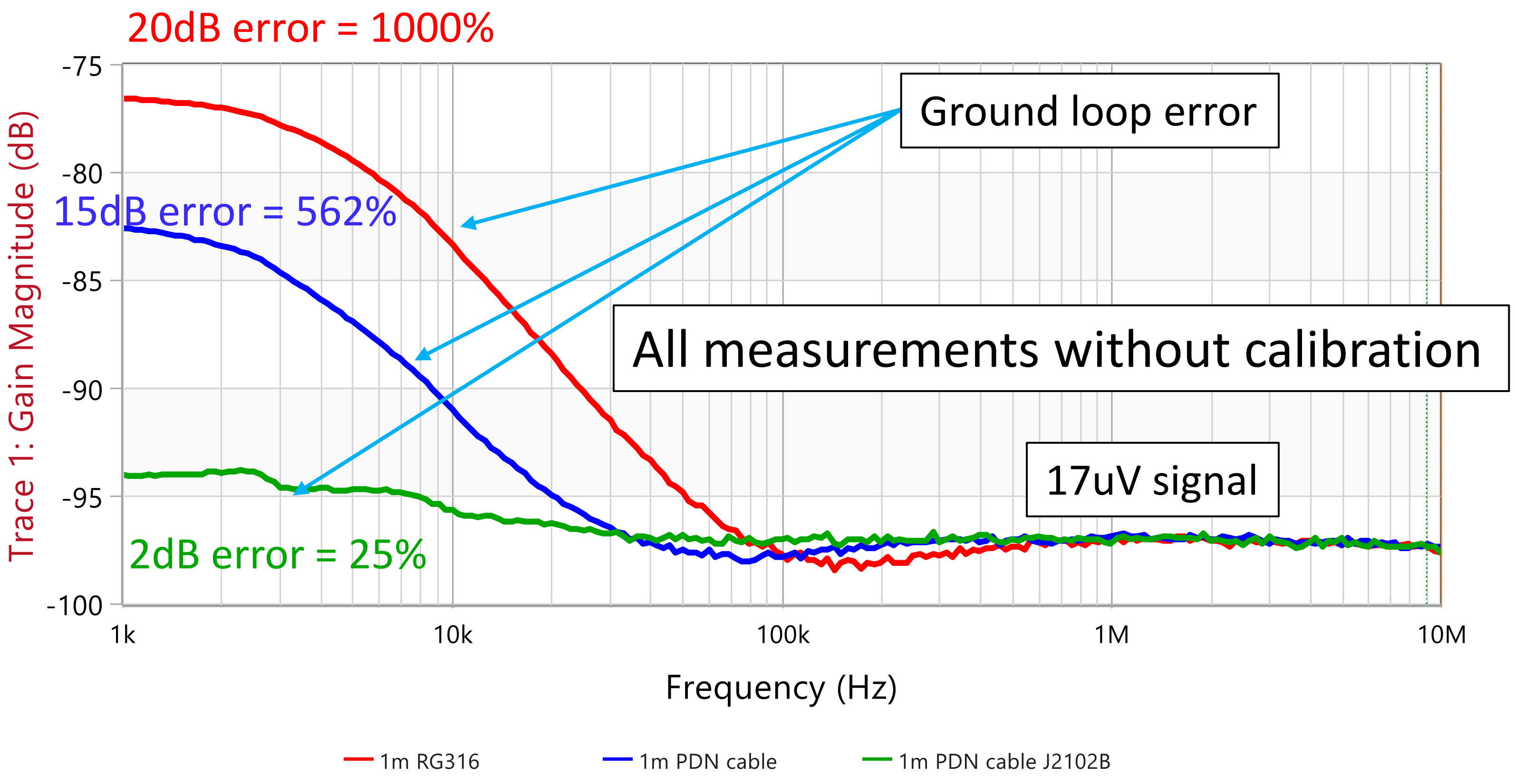
- Cable shield resistance creates the low frequency error
- Different cables have different shield resistance
- At higher frequencies, the cable coupling starts to correct it





So How Do We Fix It??

- Cables matter. Use low shield resistance cables
- Improve the coupling on the output side by adding a high CMRR coaxial isolator
- Calibrate the SHORT whenever possible
- While it seems like a differential probe will help, it won't. They are very noisy

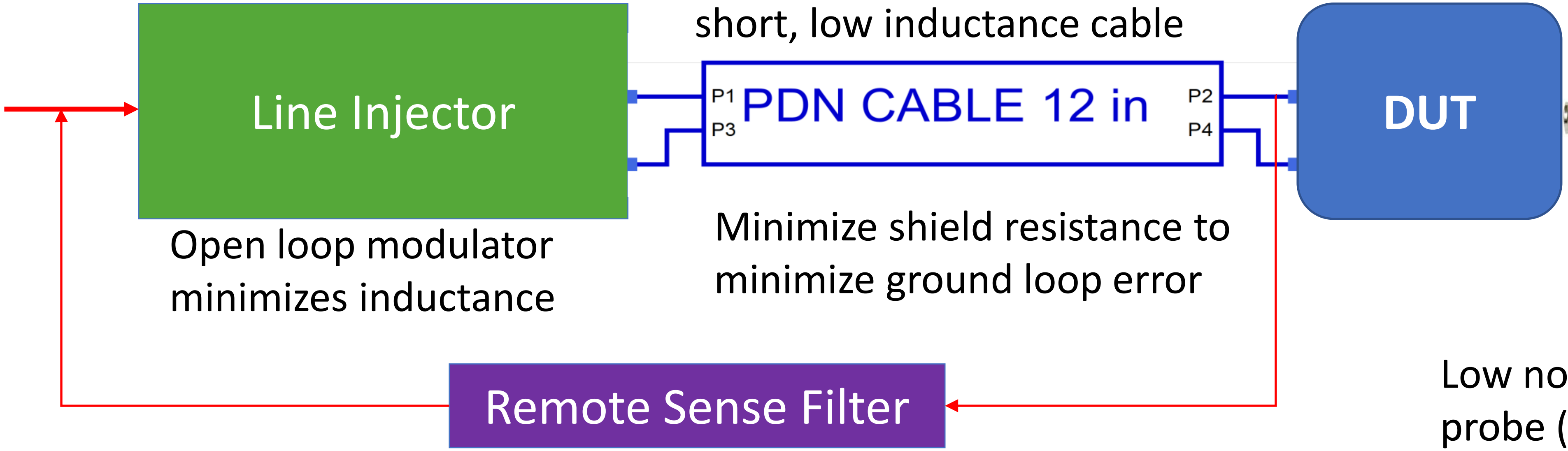


The Ideal Setup

Adding a common mode transformer or differential amplifier reduces the ground loop

≈100-200mΩ resistance provides cable damping

Minimize inductance by using short, low inductance cable



Open loop modulator minimizes inductance

Minimize shield resistance to minimize ground loop error

A remote sense filter keeps the DC voltage fixed while allowing the modulation signal to pass through

https://www.picotest.com/images/download/AppNoteRemoteSenseVer05Final.pdf

Low noise, low impedance probe (P2104A) is ideal, but low resistance passive probe PML 111O helps

https://www.signalintegrityjournal.com/blogs/15-extreme-measurements/post/2484-the-ultimate-power-rail-noise-measurement

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Not Done Yet – the Capacitors!!

- The interconnecting cable inductance and the modulator resistance form a low pass filter with the DUT capacitors
- Many high-speed specifications recognize this and require their removal for testing purposes
- Yes, THRU calibration at the capacitors can correct this, but the received signals at the output will likely be too small to measure

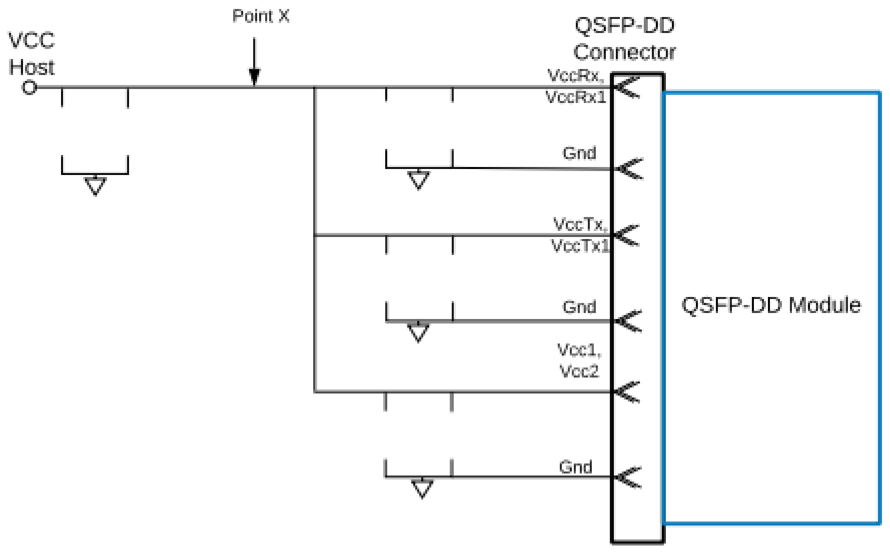


Figure 11: Module Noise Output Measuremnt

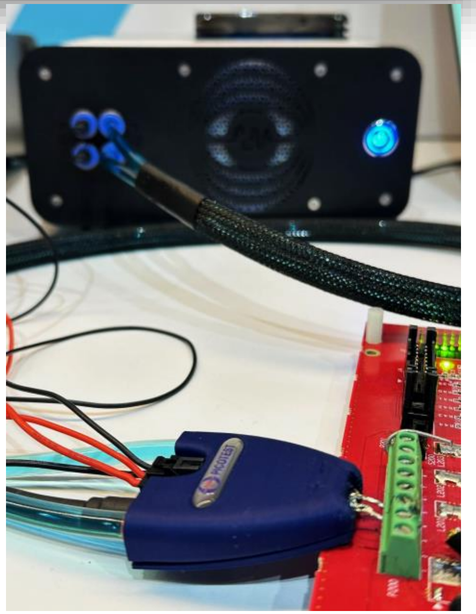
Extreme Measurement

- Even after removing the capacitors, some loads present a very low resistance
- This can be due to a low input voltage, high power switching regulator (which is negative resistance at low frequency)
- Many high-speed circuits such as transceivers also present a very low resistance, typically on the order of 0.5 Ohms
- In this case, the impedance of the interconnect quickly degrades the bandwidth
- We can correct this by eliminating the interconnect!

Photo courtesy of Tektronix

Moving the modulator into a probe head removes the interconnect! Problem solved!!

Well, almost. There is still power loss to contend with, so you can see this probe is water-cooled!!



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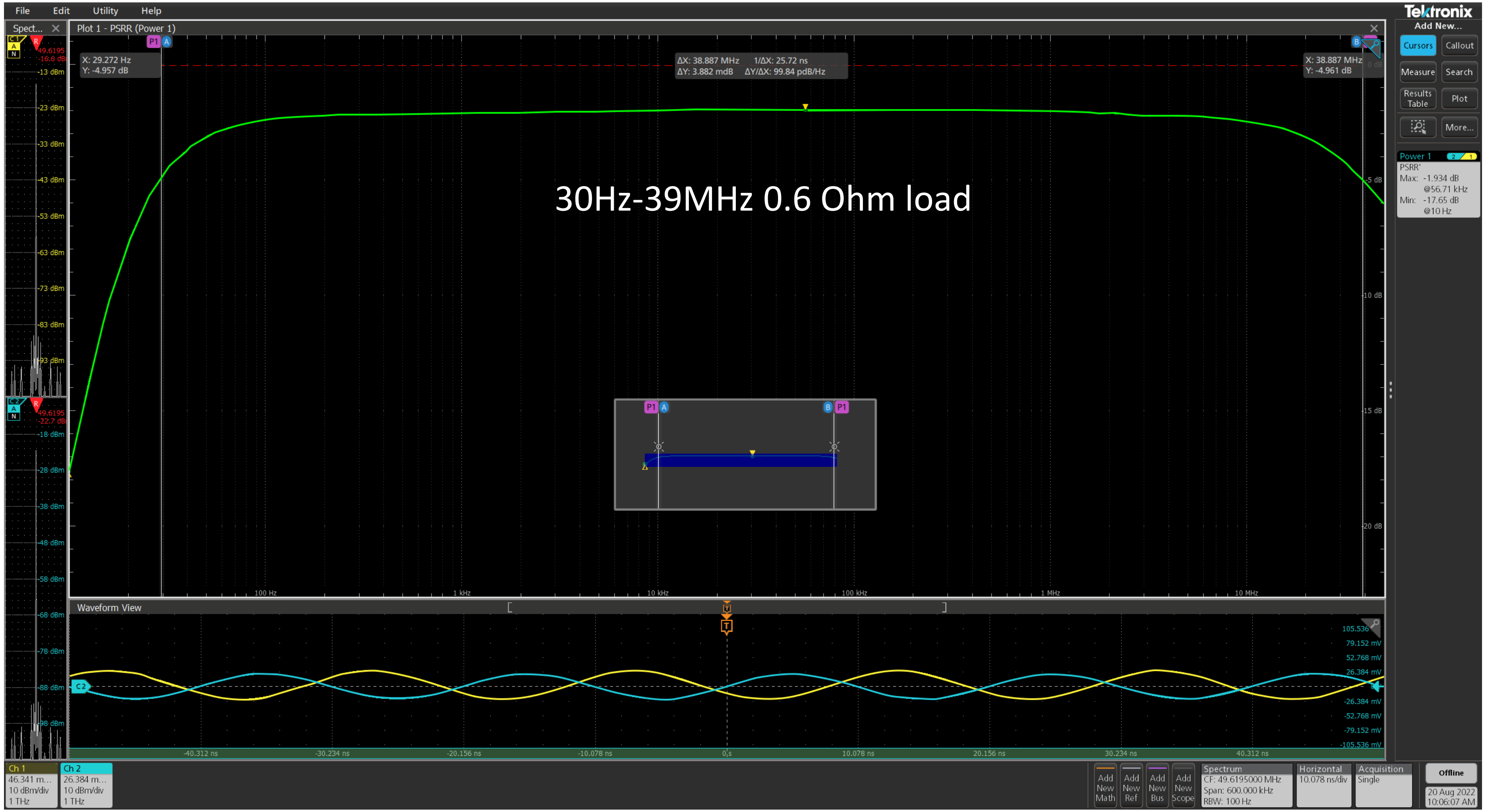
The End Result

Moving the modulator into a probe head eliminated the interconnect, allowing modulation up to 39MHz (-3dB) or even higher into the low resistance load!!



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Thank You for Attending!

Learn more about the products and accessories we discussed today by visiting:

- www.picotest.com
- www.omicron-lab.com
- Picotest PSRR Solution page: https://www.picotest.com/measurements/PSRR.html

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