Power Integrity Pocket Guide

Important considerations to making
the most accurate Power Integrity Measurements

ROHDE&SCHWARZ

Power Integrity
Pocket Guide

Clean and stable power rail voltages are the basis for the proper performance of any electronic design. The continuing demand for higher performance, higher level of integration and lower power consumption drives supply voltages down, making voltage tolerances tighter and power rail qualification a challenging task.
Therefore, making accurate power integrity measurements continues to be an ever-increasing challenge, and for precise results, it is important to use the right tools regardless of whether it is an oscilloscope, probe or a vector network analyzer. This pocket guide evaluates important considerations in making the most accurate power integrity measurements.

For a digital copy of the Power Integrity Pocket Guide and other power integrity resources, please visit:
http://resources.rohde-schwarz-usa.com/pi_guide
http://www.picotest.com

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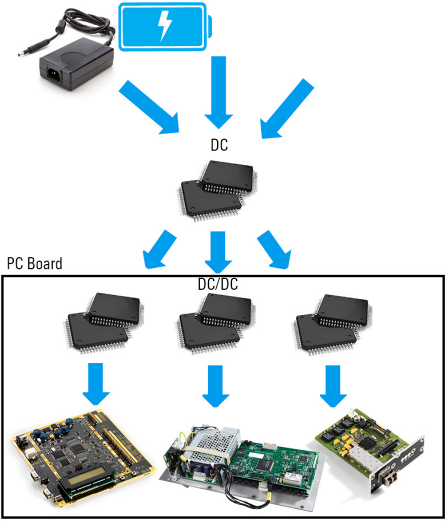
What is Power Integrity?

Power Integrity is the analysis of DC power rails to determine the quality of DC power from the output to the DC converter to the ICs.



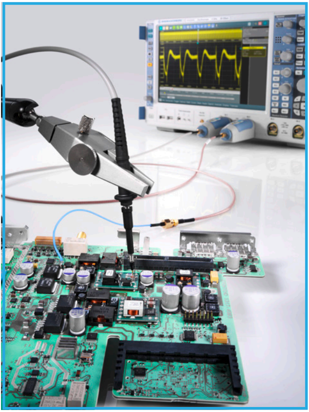
What is Power Integrity?

Clean and stable power rail voltages are the basis for proper performance of any electronic design. The continuing demand for higher performance, higher level of integration and lower power consumption drives supply voltages down, making voltage tolerances tighter and power rail qualification a challenging task.

Rail Value	Tolerance	Need to Measure
3.3 V	2%	66 mV_{pp}
1.8 V	3%	30 mV_{pp}
1.2 V	2.5%	30 mV_{pp}
1 V	2%	20 mV_{pp}

What is Power Integrity?

Ripple, noise and load-step response measurements on integrated circuits such as CPUs, DDR memories and FPGAs require very low noise and broadband probing solutions that can measure in the single-digit millivolt range. Qualifying the power supply for sensitive analog receiver circuits means measuring very small disturbances at relatively high DC offset levels.



What Do Power Integrity Issues Cause?

- ICs have sporadic anomalies
  - FPGAs, ASICs, ADCs, DACs, MCUs, DDR memory
  - IC suppliers specify # of power rails, voltage for each, and tolerance for each
  - Common support issues for FPGA users
- Increased jitter (can cause design to not work)
- EMI: Coupling of other sources on power rails (display, clock, RF signal...)

Relatively new effects such as crosstalk between power rails and high-speed data lines and significant RF signal coupling easily exceed 2 GHz and put the entire system performance at risk – to the point of complete device failure.

Power Rail Measurement Challenges

Lower Voltage Rails and Smaller Tolerances

Lower rail voltages and smaller tolerance are making it more difficult to make accurate power rail measurements.

As rails get smaller, so has the tolerance associated with these rails. Even older standards like 5V and 3.3V rails may now have tighter tolerances than a few years back.

Not Easy

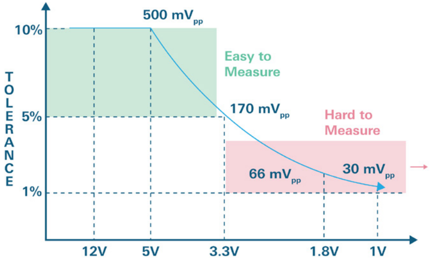
Rail Value	Tolerance	Need to Measure
3.3 V	1%	33 mV_{pp}
1.8 V	2%	36 mV_{pp}
1.2 V	2%	24 mV_{pp}
1 V	1%	10 mV_{pp}

Power Rail Measurement Challenges

Lower Voltage Rails and Smaller Tolerances

Measuring 10% tolerance on 5V is 500mV, this is simple to do on any scope.

Measuring 1% tolerance on a 1V signal is 10mV, this is very difficult on most scopes. At these levels scope noise may impact the measurement.



What's the challenge?

With the tighter tolerances and smaller voltages, accurately measuring PARD and drift is significantly more difficult.

1. Limited oscilloscope offset makes it difficult to zoom in on the waveform sufficiently.

2. Noise from the oscilloscope eats in to tolerance margin.

3. Noise from the probing system eats in to the tolerance margin.

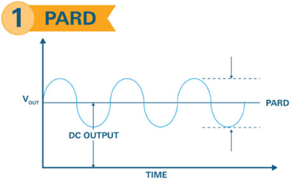
4. Oscilloscope and probe may not have enough bandwidth to see coupling sources.

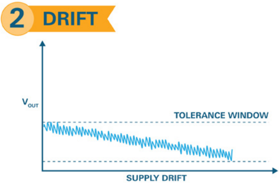
5. Capturing enough waveforms to make sure you see potential outliers can be difficult.

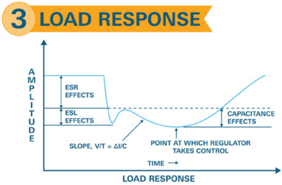
6. Viewing coupling sources in the frequency domain can be a challenge.

Common Power Integrity Measurements

Common Power Integrity Measurements include:
PARD (Periodic and Random Disturbances)



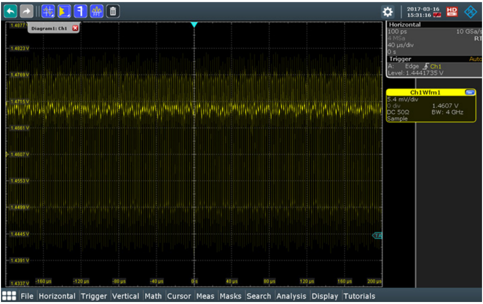




Waveform Intensity

Let's start by talking about a few simple techniques to give you additional visual information about each power rail. These won't impact measurement accuracy, but rather just makes it easier to get insight visually faster and easier. Normally, a scope's default intensity is set so that users can see various signal intensity levels.

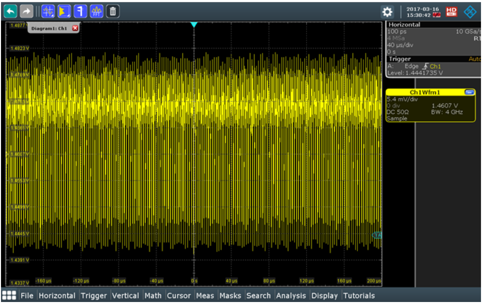
Default – 50%



Waveform Intensity

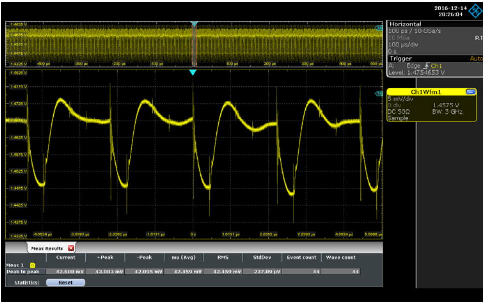
For power integrity measurements, the major concern is to find worst-case violations and not really how frequently the signals occur. Increasing the waveform intensity allows for a better view of worst case violations that happen less frequently.

Adjusted to 90%



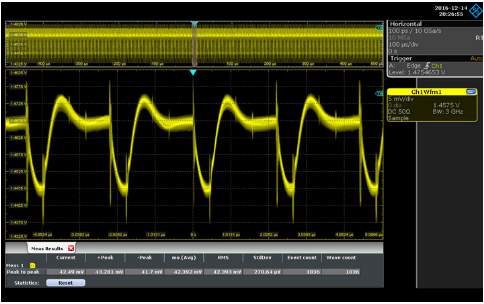
Improving the Display

There are several more techniques to give you additional visual information about each power rail. Again, these won't impact measurement accuracy, but rather just makes it easier to get insight visually faster and easier.



Infinite Persistence

Turning on infinite persistence provides a good view of power rails and the amount of total noise on them. Looking at a V_{pp} measurement with stats will show ripple and noise. Measurements results will be the same whether infinite persistence is on or not. It's simply a way of visually seeing how much of the V_{pp} contribution is due to noise.



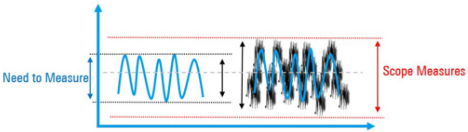
Color Grading

Another technique to get additional visual information about each power rail is turning on color grading. In this example, it much easier to see transients when color grading is turned on.

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

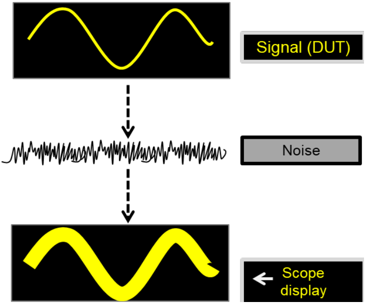
Oscilloscope Noise Can Make it Difficult to Measure Small Signals

So, what's so hard about making power rail measurements with scopes? There are several issues that make it difficult to measure small signals with scopes. For example, noise inherent to the scope and the probe used is problematic and results in overstated measurements.



Noise Limits Power Rail V_{pp} Measurement Accuracy

Noise from the oscilloscope and probe is an enemy for measurement accuracy. When a signal enters an oscilloscope, front-end noise gets added to the signal before the ADC. Each stored sample point now includes not only the value of the original signal, but with some offset based on how much noise was present when the sample was acquired. On your scope, you will see this manifest with a thick waveshape….not to be confused with fast update rate.



Noise Limits Power Rail V_{pp} Measurement Accuracy - Consequences

- **Large measurement deviation**
  On your scope, you will see this manifest with a thick waveshape
- **Measured V_{pp} >> Actual V_{pp}**
  V_{pp} ripple measurement will be greater than what they really are
- **Can mask/hide anomalies**
  You will never be able to measure signals that are smaller than the noise on your scope

Using More Sensitive Vertical Setting

No scope has enough offset to address common power rails for todays products - ranging from under a volt to over 12V. In the case of the RTO, the scope natively has 1V built-in offset compensation at 20mV/div for example. This results in two negative factors:

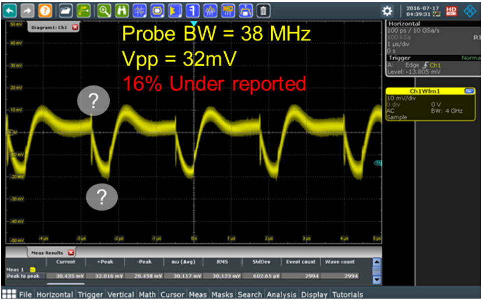
- The scope is only using a fraction of its ADC vertical resolution,
- Noise is a function of full screen vertical voltage. The scope is using bigger vertical scale than is needed, resulting in additional noise

Using max built-in scope offset

Using built-in probe offset

Bandwidth vs. Noise Tradeoff

Having sufficient probe bandwidth (BW) ensures measurement accuracy. The following examples show a very low-noise measurements from a 1:1 passive probe with 38 MHz of BW.

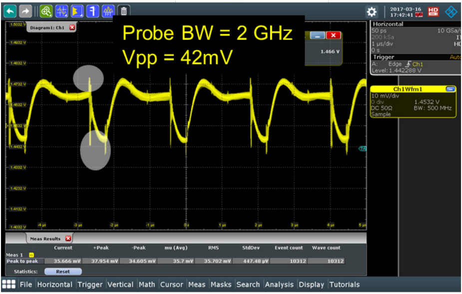


1:1 ZP1X passive 38 MHz BW

500 MHz BWL filter, 1:1 Probes

Bandwidth vs. Noise Tradeoff

But the 38 MHz of BW misses high frequency transients that are required for a precise measurement captured by a probe with 2 GHz BW. While the 1:1 passive 38 MHz probe delivers low-noise measurements, it misses higher frequency transients and hence under reports V_{pp} measurements.



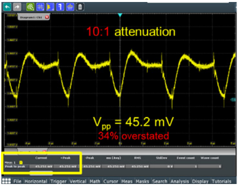
1:1 ZPR20 active 2 GHz BW
Captures high-frequency transients

500 MHz BWL filter, 1:1 Probes

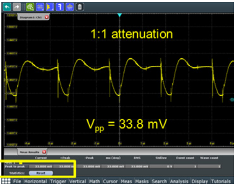
Noise due to Probe Attenuation Ratio

The choice of a probe is critical for measurement accuracy. Attenuation is a critical factor for low noise. Here's a compare of a 10:1 probe vs a 1:1 probe using 500 MHz bandwidth limit on each. Note the thickness of waveform using the 10:1 probe. This is noise and will cause overstated V_{pp} measurements.

10:1 (10 mV/div)



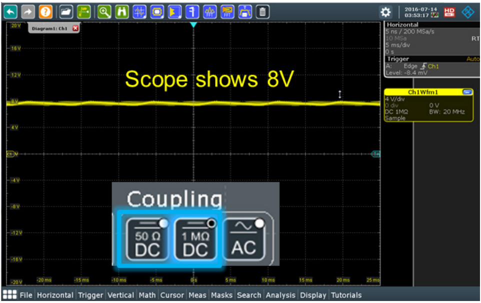
1:1 (10 mV/div)



Challenges with Insufficient Scope Offset

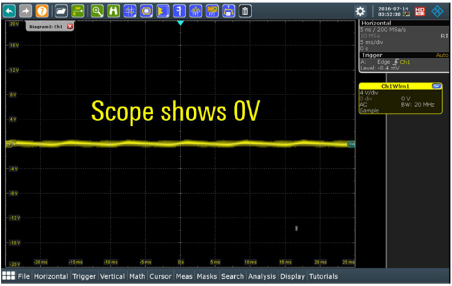
Oscilloscopes do not have enough offset to address common power rails - ranging from under a volt to up to 40V. This results in two negative factors:

1. The scope is only using a fraction of its ADC vertical resolution.
2. Noise is a function of full screen vertical voltage. The scope is using bigger vertical scale than is needed, resulting in additional noise.



Challenges with Insufficient Scope Offset

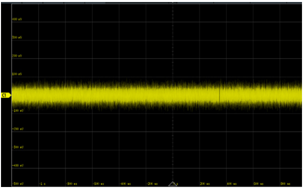
Using a blocking cap, or if offered AC coupling mode on the scope, eliminates DC offsets making it possible for the scope to see power rails. Even if the scope doesn't have sufficient offset. However, these approaches limit the ability to see DC values.



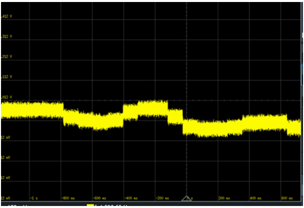
DC block

Challenges with Insufficient Scope Offset

Worse, if there is any low frequency DC drift, AC coupling and blocking caps eliminate the ability to see this drift.



DC Blocks Eliminate Low Frequency Visibility



With ZPR20 See Low Frequency DC Changes

Frequency Domain View

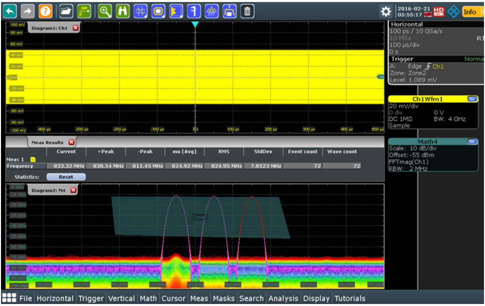
Characterizing power rails typically involves ensuring there are no unwanted signals coupled onto the power rail. In addition, users sometimes need to look at switching harmonics. These are impossible to determine by looking at time domain waveforms, but are easy to see in the frequency domain using a scope's FFT.

Finding Coupled Signals

How much bandwidth is needed for frequency domain views? It depends on the potential signals including clocks and fast edge harmonics that may be coupled onto the power rail. Looking at the power rail in the time domain provides critical insight into V_{pp}. However, to find and isolate coupled signals on the power rail, such as this 2.4 GHz Wi-Fi signal, a frequency domain view is required.

Zone Triggering in Frequency Domain

Zone triggering is an application that allows users to set up a geometric shape at a certain power level and frequency span. If the scope finds a power rail signal that enters this zone, the scope will trigger on this event.

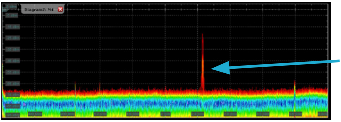


Faster Update Rates

Certain types of signals require a fast update rate to see. Scopes with slower update rates may have difficulty showing modulated signals. Here's an example of a power rail measurement in the time domain. Seeing the modulation, lets you know to look in the frequency domain.

Fast update rate shows modulated signal on power rail.

Difficult to see on scopes with slower update rate.



Gives an indication that a freq domain view is needed

Find Worst-case Violations Faster

Finding worst-case violations requires a fast update rate (how quickly the oscilloscope triggers, processes the information and plots it to the display). Slow update rates require 10x to 1,000x the time to capture the same amount of information.

$V_{pp} = 37MV$

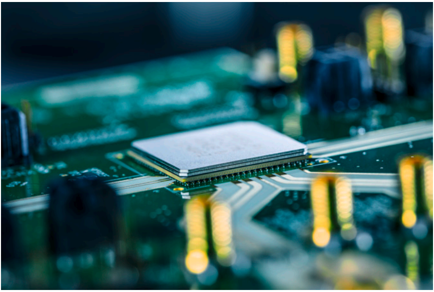
The worst case Vpp measurement is understated due to slow update rate. You'd need to let the oscilloscope run 10x longer to see the actual worst case Vpp.

$V_{pp} = 39MV$

The worst case Vpp measurement is more accurate due to fast update rate. This was achieved 10x faster than a slower update rate would provide.

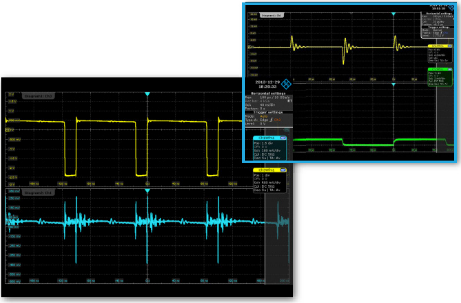
Why Impedance is a Critical Metric

One of the biggest challenges in measuring power integrity is trying to gain access to something that can be measured. Access isn't very good, and it is getting more difficult as things get more highly integrated. When looking on the board, control loops often aren't available. However, often it is possible to get to an output capacitor. Once there is access to an output capacitor, one can measure impedance. The resulting impedance measurement is directly relatable to all closed loop characteristics.



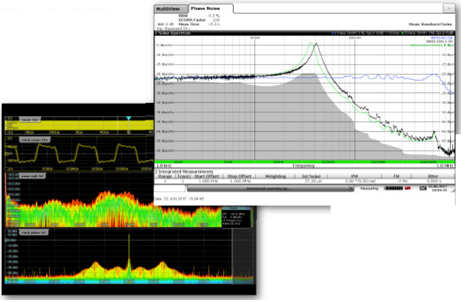
Impedance Tells Us About: High Speed Transients

While power integrity is now often related to high-speed systems, there are also many tough power integrity problems that occur below 50 milliwatts. For example, a high-speed logic driver, single gate logic, with about 40 milliamps and 250 picosecond edges is a tough challenge. It's not high current, but it's fast.



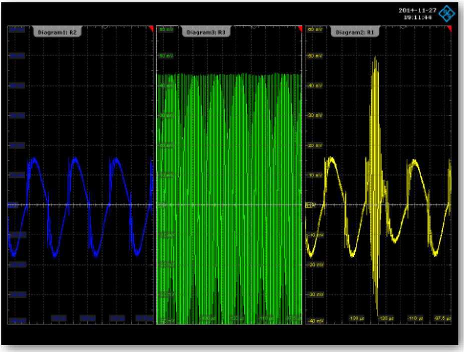
Impedance Tells Us About: EMI, Jitter and LNA Noise

EMI jitter and low-noise amplifier phase noise is primarily the function of power supply noise. Power supply noise can almost always be correlated to impedance.



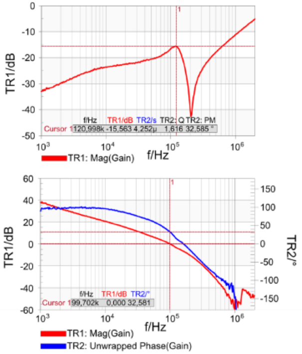
Impedance Tells Us About: Rogue Waves

Impedance even provides information about rogue waves. What is a rogue wave ? A rogue wave occurs when an impedance structure has more than one resonance, and they are both excited at the same time - phased in such a way that one gets stacked right on top of the other.



Impedance Tells Us About: Control Loop Stability

Determining control loop stability is getting to be a challenge, because most voltage regulators today don’t have access for Bode plots. Even if they do have access, most regulators today have nested control loops. They may be seen on the outside of the package, but it is difficult to know anything about the ones that are inside the package. Thus a method of measuring stability from impedance was created.

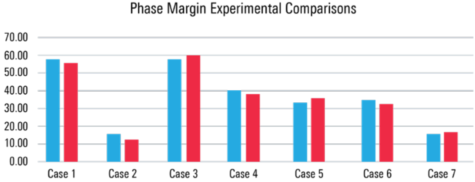


Open-Loop, Closed-Loop, Bode Relationship

There is a relationship between closed-loop performance and open-loop performance. The exact relationship is 1/(1+T), where T is a loop-gain vector. In order to know closed-loop performance, knowing the open-loop performance, one can just divide by 1+T. But how is T determined? By re-arranging the equation and solving for T. By measuring the open-loop and closed-loop, the Bode plot can be re-drawn, because they're related by 1/(1+T). The previous page showed an example with the Bode plot and the non-invasive measurement. It's a very simple cursory measurement.

Determining Control Loop Stability

How accurate is it? Theoretically perfect. Testing is generally limited by measurement noise and that typically limits the accuracy to about one degree.

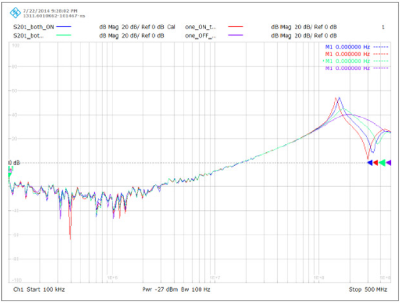


Experimental data is proven to be accurate to within ±1 Deg., while noiseless simulation is accurate to better than ±0.3 Deg.

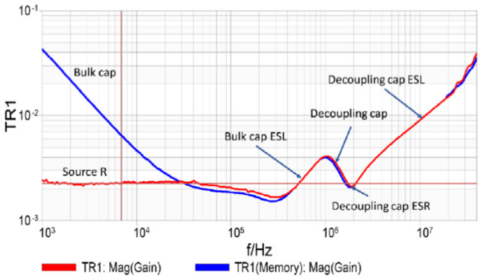
Non-invasive assessment is simpler, more accurate, and doesn't suffer from the frequency limitations of an FRA.

Impedance Measurements Have an Unlimited Frequency Range

Impedance is also beneficial because it has an unlimited frequency range. If a design has a gigahertz ADC and uses a front-end amplifier, there is a need to be able to measure stability at a gigahertz. If you're building a power supply and need to measure your PDN burst to the speed of your transceivers, that could easily be several gigahertz. This test method allows for measuring impedance to gigahertz frequencies using a vector network analyzer and calibration is simple.



Interpreting Impedance Results



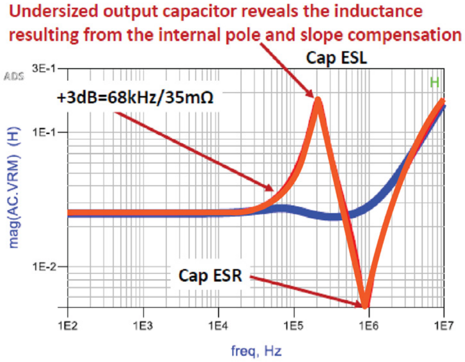
Flat = resistor
Rising = inductor
Falling = capacitor

Motherboard measurements:
Power On (red), Power Off (blue)

How to Fix Poor Impedance

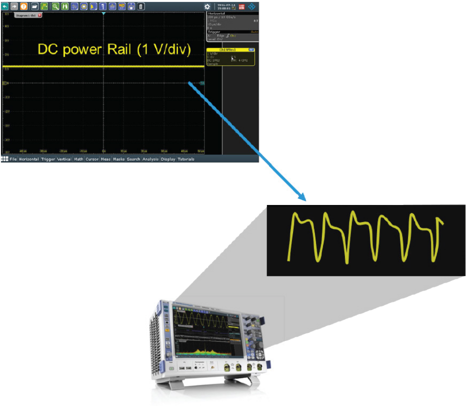
Minimize L and MAXIMIZE R

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



Oscilloscopes: The Primary Tool for Power Rail Analysis

Oscilloscopes are a primary tool for measuring AC attributes of DC signals including ripple and PARD.

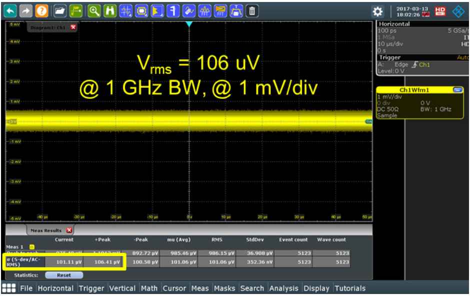


What should you look for in a PI solution from an oscilloscope?

- Low noise to minimize measurement system impact on tolerance testing
- 2-4 GHz of bandwidth to capture high-frequency coupling
- Fast update rate to capture worst case outliers quickly
- Excellent frequency domain capability so you can view both time and frequency content easily
- Deep acquisition memory to capture long time periods at high sample rates

50 Ω Check at 1 mV/div

The best approach is to start with a scope that has lower noise than other scopes. How do you determine how much noise your scope has? You can do a quick check. Remove all inputs to the scope and see how much noise the scope has a 1mV/div.

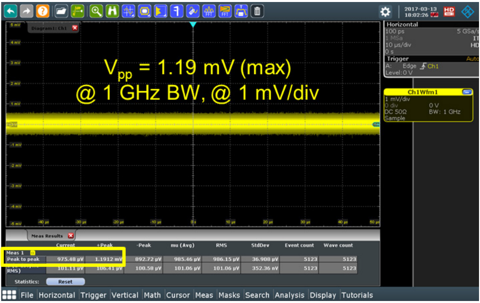


R&S RTO2000 Series

50 Ω Check at 1 mV/div

Scope vendors characterize V_{rms} in datasheets, but not V_{pp}

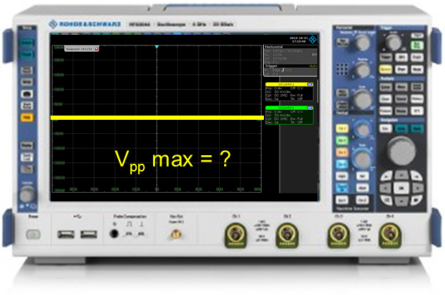
For power integrity measurements, a V_{pp} AC_{rms} measurement will be lower and more impressive, but a V_{pp} amplitude measurement is what you will care about.



R&S RTO2000 Series

Characterizing Your Scope's V_{pp} Noise in 5 Minutes

Noise is directly related to full screen vertical scale. So, at each larger vertical scale, the scope will have more overall noise. You can quickly check each vertical setting that you will be using for power integrity measurements.

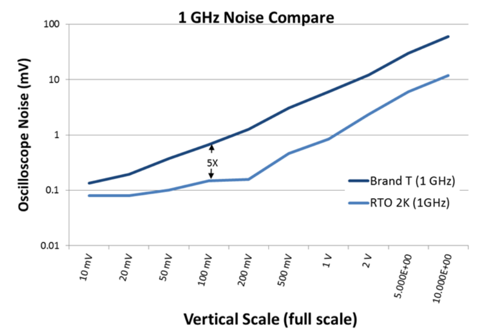


Characterizing Your Scope's V_{pp} Noise in 5 Minutes

1. Disconnect all inputs (Can perform with probe attached)
2. Set sample rate (e.g.10 Gsa/s), memory depth, (e.g.1 Mpts), path, and BW to mirror your requirements
3. Turn on V_{pp} measurement with stats for channel 1
4. Adjust vertical setting to cover the smallest vertical setting you will use
5. Record V_{pp} value
6. Repeat for all other vertical scales that you may use.
7. Repeat for all channels that may be used (will have variation from channel to channel)

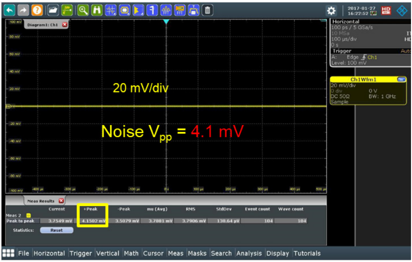
Choose a Scope That Has Low Noise

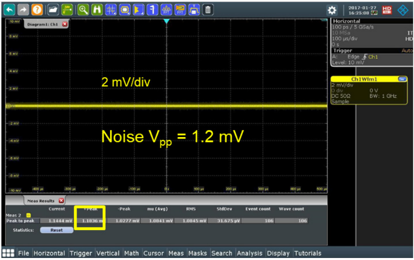
Comparison Between Two Oscilloscopes with Equivalent Bandwidth



Use Most Sensitive Vertical Setting Possible

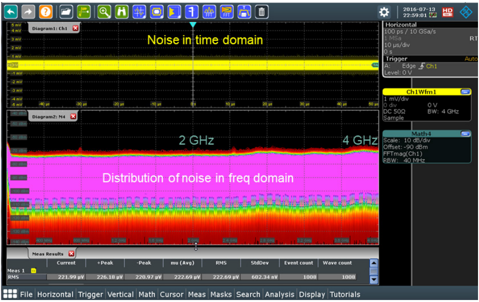
Scopes will have less noise on smaller vertical settings. Here’s an example at 20 mV/div and 2 mV/div where noise is almost 4 times lower.





Noise Compare: Time Domain vs Spectral Content

Another technique to make more accurate measurements is to get rid of broadband noise. Here's an FFT of the scope's trace…with no signals connected to the input. The scope has a Gaussian noise distribution. If all of the noise is integrated in the frequency domain, the result will provide the same value as the noise measurements in the time domain.



Reduce Noise with BWL Filters

By turning on a BWL filter, the overall system noise is reduced. The more filtering, the lower the noise. In this example, there is 10X less noise with 20 MHz vs full system BW of 4 GHz

All other settings are identical

4 GHz	Vpp = 2.54 mV
200 MHz	Vpp = 0.592 mV
20 MHz	Vpp = 0.316 uV

Highest noise

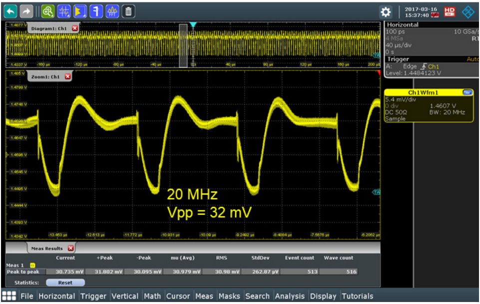
↕

Lowest noise

How Much Bandwidth Do You Need?

Measurement bandwidth (BW) will also impact measurement accuracy. One can get very low-noise measurements from a 1:1 probe with 20 MHz of BW, but the probe misses high frequency transients that are required for a precise measurement that can be seen with a 1 GHz bandwidth.

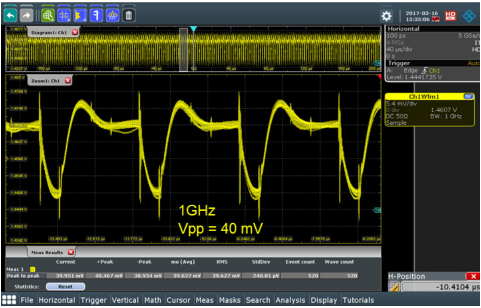
Bandwidth = 20 MHz



How Much Bandwidth Do You Need?

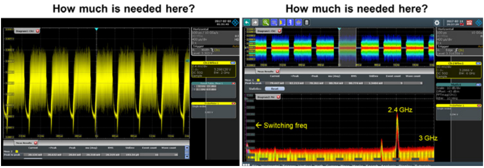
Measurement bandwidth (BW) will also impact measurement accuracy. One can get very low-noise measurements from a 1:1 probe with 20 MHz of BW, but the probe misses high frequency transients that are required for a precise measurement that can be seen with a 1 GHz bandwidth.

Bandwidth = 1 GHz

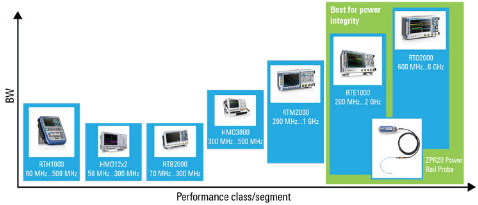


How Much Bandwidth Do You Need?

How much bandwidth do you need? It depends on your power rails and its impossible to tell in the time domain. A rule of thumb is BW=.35/risetime if you knows what edge speed is needed. However, it is not known what coupled signals may be present. One way to determine this is to look at the scope's FFT without any signals connected, then connect to a power rail and look for the what upper frequencies have content that differs.



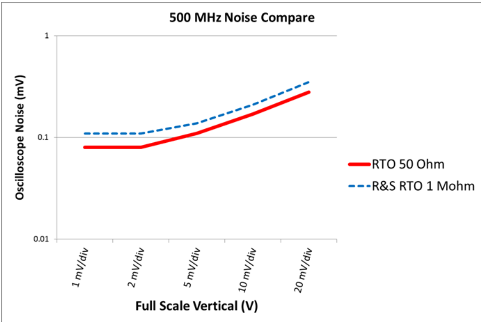
Rohde & Schwarz Oscilloscope Portfolio



Most oscilloscope manufacturers will have a certain class of scopes that are better suited for power integrity measurements. These scope generally have sufficient BW, the lowest noise in the portfolio, deep memory, BW limit filters, and other attributes that make for better PI measurements. The same holds true for R&S. In the R&S oscilloscope portfolio, two families, the RTO and RTE are best suited for PI measurements.

Choosing Between 50Ω vs 1MΩ

Are measurements more accurate using the scope's 1Mohm input - which has good DC impedance, but more noise and is BW limited to 500 MHz? Or is it better to use the 50 Ohm path which is quieter and offers more bandwidth, but has only 50 Ohm loading at DC and hence a bigger impact on getting accurate DC values? The best approach is to use the lower-noise 50 Ohm path with more BW, and couple with a power rail probe that provides high DC impedance.

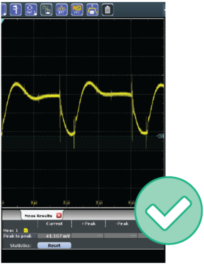


What to Look For in a Probe

A. 1:1 Attenuation and Low Noise
B. High Offset
C. High Bandwidth (>4 GHz)
D. High Input Impedance

Passive Probe

Power Rail Probe



What should you look for in a PI solution from a probe?

- 1:1 attenuation and low noise
- High bandwidth (>4GHz)
- High offset
- High input impedance

Probing Methods

There are many methods to probe a power rail:

- Passive 10:1 probe
- Passive 1:1 probe
- Direct connect 50Ohm pig tail
- AC coupling
- DC Block
- Dedicated Power Rail Probe

Probing Methods

10:1 Probe

- 10:1 attenuation adds noise
- <500MHz bandwidth
- Good offset due to 10:1 attenuation
- Good input impedance at very low frequencies
- Heavier loading at >100MHz

Probing Methods

10:1 Probe

Benefit:

- Most common probe.
- 10:1 increases oscilloscope's offset capability.

Limitations:

- 10:1 attenuation increases noise, eating in to tolerance level.
- Limited bandwidth.
- Higher loading, especially at frequencies above 100MHz.

Probing Methods

1:1 Probe

- 1:1 attenuation is low noise
- <50MHz bandwidth limits capability
- Offset is limited to scope offset
- Good input impedance at very low frequencies

Probing Methods

1:1 Probe

Benefit:

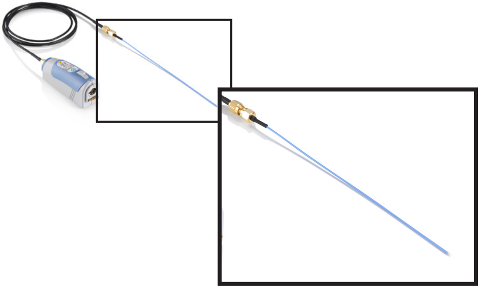
- Lower noise.
- Inexpensive.
- Easy to use/connect.

Limitations:

- Very limited bandwidth (typically less than 50MHz).
- Relies on scope's offset capability or AC coupling to remove offset.

Probing Methods

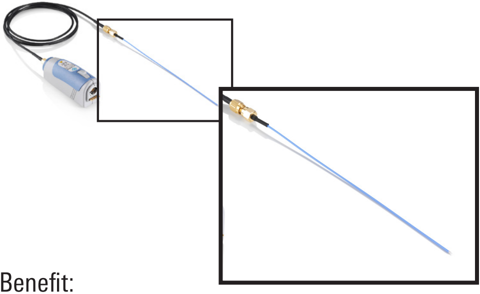
Direct connect 50-ohm pig tail



- ✓ Direct connect is low noise
- ✓ Bandwidth to limit of scope
- ✓ DC block removes offset
- ✗ DC block misses drift
- ✗ Poor input impedance

Probing Methods

Direct connect 50-ohm pig tail



Benefit:

- Lower noise.
- Inexpensive.
- Bandwidth up to scope bandwidth.

Limitations:

- Relies on scope’s offset capability or DC block to remove offset.
- Higher loading on DUT.

Probing Methods
AC Coupling

Benefit:
- Removes DC component so you can zoom in on waveform.

Limitations:
- Typically only 1MOhm path limits bandwidth.
- Eliminates the ability to see drift over time.
- Eliminates the ability to see absolute vertical value.

Probing Methods
DC Block

- Direct connect is low noise
- Bandwidth to limit of scope
- DC block removes offset
- DC block misses drift
- Poor input impedance

Probing Methods
DC Block

Benefit:

- Removes DC component so you can zoom in on waveform.

Limitations:

- Eliminates the ability to see drift over time.
- Eliminates the ability to see absolute vertical value.

Probing Methods
Dedicated Power Rail Probe

- 1:1 is low noise
- Bandwidth >4GHz allows you to capture high frequency coupling
- Built-in offset supports up to 60V
- Excellent input impedance minimalizes loading

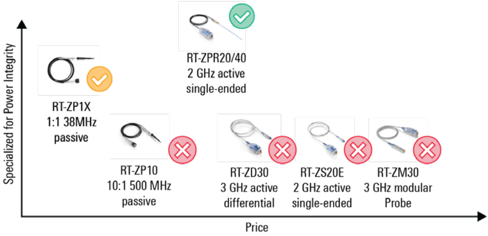
Probing Methods
Dedicated Power Rail Probe

Benefit:

- 1:1 attenuation and low noise.
- Over 4GHz bandwidth captures high-speed transients and coupling.
- Built-in offset allows you to zoom in on the waveform for more accurate measurements.
- High input impedance limits impact to DUT.
- Integrated 16-bit DC Voltmeter for fast voltage level confirmation.

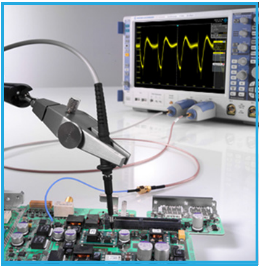
Limitations: None.

Choosing the Right Probe



RT-ZPR20/40 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



RT-ZPR20/40 Power Rail Probe

Key Specifications	
Attenuation	**1:1**
Probe BW	**2(*) or 4(**) GHz**
Browser BW	350 MHz
Dynamic Range	±850 mV
Offset Range	**> ±60 V**
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

(*) 2.4 GHz band visible due to slow frequency roll-off
(*) 5 GHz band visible due to slow frequency roll-off

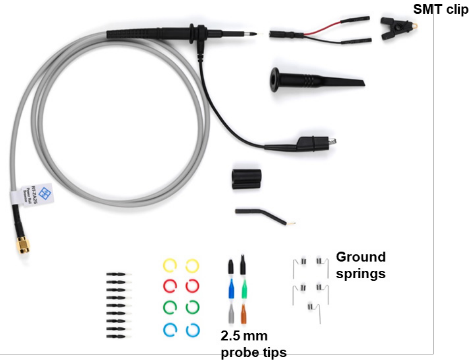
Check to See Connection Options

The probe is active, and the probe head terminates into an SMA connector for precise measurements. There are multiple ways to connect the SMA end of the main cable to your power rail. The probe can connect to your DUT via:

- A direct SMA (full BW)
- A solder-in coax cable (full BW) - often soldered across a blocking cap
- An SMT clip, or a 2-pin plug. (reduced BW)

Power Rail Browser

A 350 MHz browser is included standard, and often useful to make less precise quick measurements. The browser connects to the active probe head via a SMA connector giving you the benefits of minimal loading and good bandwidth with high fidelity while measuring. The browser has a 2.5 mm tip is compatible with existing passive probe accessories like the ground spring.



RTE/RTO/RTP Oscilloscopes & Power Rail Probe

When combined with an RTP, RTO or RTE oscilloscope, the ZPR20 power rail probe will quickly help you characterize your power rail. In addition to the industry's fastest update rate (1MWf/s) that will help you find worst case violations quicker than any other solution.

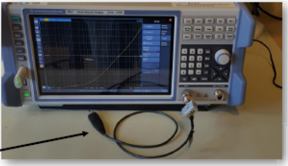
Impedance Measurements Using a Vector Network Analyzer

Unlike many other power integrity measurements that are measured with an oscilloscope, impedance measurements are most accurately performed on a vector network analyzer (VNA).

1-Port VNA Measurements

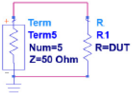
The simplest impedance measurement to make with a vector network analyzer is the one port measurement. It's a reflection measurement. Every vector network analyzer can do it. A basic short-open-load calibration is simple to do. You can add a Picotest hand-held transmission line probe for making this measurement.

1-Port
Probe



Practical measurement range from 1Ω – 2kΩ

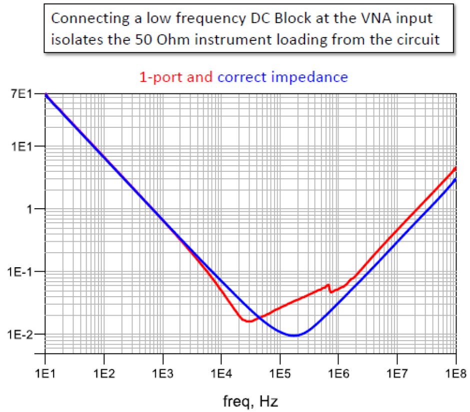
1-Port



$$Z_{ref} \cdot \frac{1 + S11}{1 - S11}$$

PICOTEST

1-Port VNA Measurements

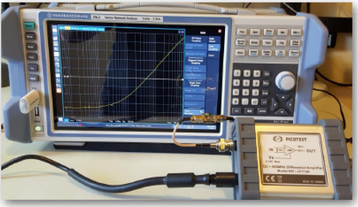


1-Port VNA Measurements

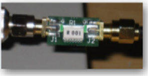
One port measurements are rarely used because they have an impedance range that almost always disagrees with what is needed. Specifically, the one port impedance measurement has limitations at its low impedance range. Most documents claim to be accurate above about one ohm. In practice it may be closer to 100 milliohms and, if calibrated well maybe as low as 10 milliohms. But practically speaking, one port starts at about one ohm. It goes up several thousand ohms, but how many of us are building power distribution networks that have target impedances above an ohm? Not many. So, this does turn out to be a reasonably good measurement for measuring the stability of op-amps and voltage references, and generally not so much for power distribution networks.

2-Port VNA Measurements

Two-port measurements are perfect for power integrity. Measurements are possible down to about one milliohm and can go up to about ten ohms. They can actually go quite a bit higher than that, typically several hundred ohms, which is good for measuring inductors.



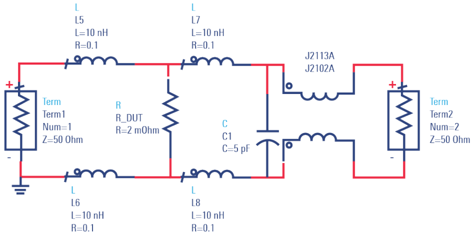
Can use 2-port
probe ≥ 10 milliOhms



PICOTEST

Using Ground Breakers

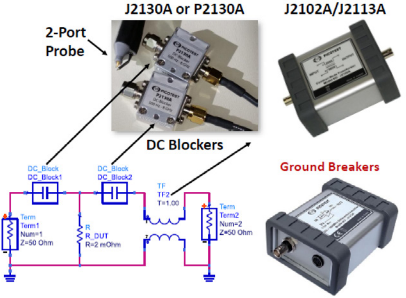
There is also a need to get below a milliohm. Can you measure 100 micro-ohms with a two-port measurement? Yes, but it's a very difficult measurement and generally requires external additions. A DC ground loop is formed by the cable shields and so a "ground breaker" is required for the low impedance 2-port measurement. There's a DC ground loop because the vector network analyzer is a perfect ground. The front panel of the vector network analyzer is an RF ground plane. It's perfect, or as close as one can get to perfect.



PICOTEST

Using Ground Breakers

Picotest makes a solid state floating amplifier that floats one of the channels to eliminate the ground loop. This allows you to measure one milliohm relatively easily and 250 micro-ohms with not much trouble. To achieve 100 micro-ohms, a pre-amplifier is also needed on the receiver side. Basically, it's a matter of getting signals large enough to get out of the noise, and the receiver bandwidth small enough to minimize the noise.

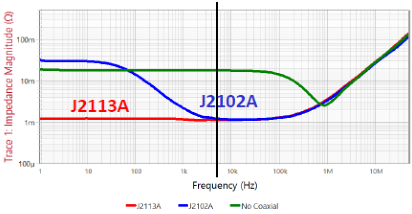


PICOTEST

Using Ground Breakers

Let's look at what a measurement looks like with or without the DC ground loop blockers for a one milliohm resistor. The initial result is shown in the green trace - it's measuring almost 20. The blue and red traces reflect the addition of the Picotest groundbreakers.

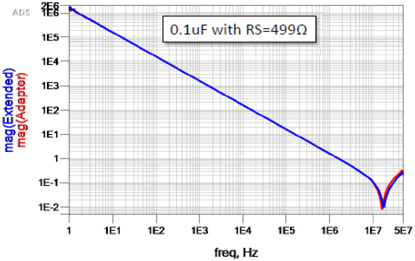
$$Z_{DUT} = \frac{Z_{ref}}{2} \cdot \frac{S21}{1 - S21}$$



1mΩ measurement with and without ground breakers

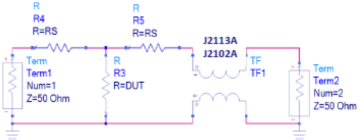
2-Port Extended Range

The measurement range can be scaled by inserting series resistors or using attenuating transmission line probes.



RS=499Ω can measure approximately 1mΩ to 4kΩ

$$Z = \frac{(Z_{ref} + R_s)}{2} \cdot \frac{S21}{1 - S21}$$



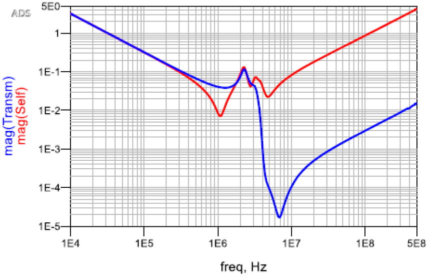
PICOTEST

Self Impedance vs Transmission Impedance

Self impedance is measured at a singular point while transfer impedance is measured at two different points

Blue Trace: Transmission impedance using 2-port probe

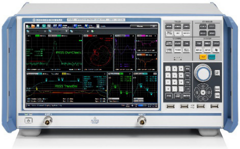
Red Trace: Self impedance using hand held probe



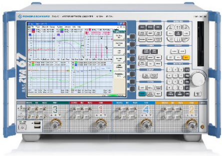
PICOTEST

Rohde & Schwarz Vector Network Analyzers

Economy
ZNL/ZND



Midrange
ZNB/ZNC



High End
ZVA

Multiport
Solutions

Further Resources and Reference

For a digital copy of the Power Integrity Pocket Guide and other power integrity resources, please visit:

http://resources.rohde-schwarz-usa.com/pi_guide

http://www.picotest.com

Literature

"Power Integrity: Measuring, Optimizing, and Troubleshooting Power Related Parameters in Electronics Systems." *Power Integrity: Measuring, Optimizing, and Troubleshooting Power Related Parameters in Electronics Systems*, by Steven M. Sandler, McGraw-Hill Education, 2014.

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