APPLICATION NOTE

10 Tips for Making Your Best Power Integrity Measurements

KEYSIGHT

Table of Contents

Introduction

Thanks to Moore's law, electronic products contain ever-increasing functionality and features. Affordable microcontrollers enable devices and services with improved performance and richer features, such as household appliances, automobiles, medical devices, wearables, the Internet of Things, smartphones, and the cloud.

One burden designers of these products face is providing "clean" power to the devices and circuits. Designing the power distribution networks (PDN) of modern products requires significant resources of time, people, and equipment. Real-time oscilloscopes measure DC power supplies in these products.

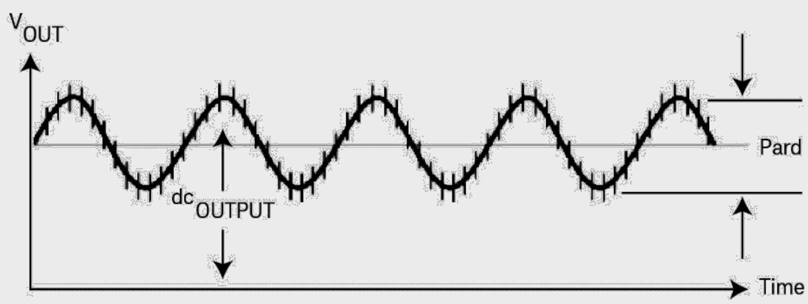
Keysight oscilloscopes offer many software applications related to this discussion, including the Keysight D9010POWA power integrity analysis software. A software application can make accurate measurements faster and easier, reducing human error. This application note offers 10 tips and fundamental techniques for measuring and analyzing DC power supplies, as well as selecting and evaluating tools for DC power supply measurements.

PDNs and power integrity

Power integrity (PI) is a broad term used in the electronics industry referring to the analysis of how effectively power is converted and delivered from the source to the load in a system. The power is delivered through a power distribution network (PDN), which consists of passive components and interconnects from the source to the load, including packaging, up to the semiconductor. It typically includes measurements from DC to multi-gigahertz. Some common PI measurements are:

- periodic and random deviation (PARD)
- load response
- noise

PARD is the deviation of the DC output from its average value with all other parameters constant. It is a measure of the undesirable AC and noise components that remain in the DC output after the regulation and filtering circuitry. It is measured in root mean square (RMS) or, more commonly, peak to peak over a bandwidth range of 20 Hz to 20 MHz. PARD-like variations occurring below 20 Hz are known as drift.



Load response can refer to a static or transient load and is a measure of a supply's ability to remain within specified output limits for a predetermined load. This usually includes a measurement of the transient recovery time of the supply to settle within a predefined settling band in response to a load.

Noise is deviation of the DC supply from its nominal value. It can include random noise, like thermal noise, and spurious signals, such as switching coupling from adjacent circuits or PARD and load response.

The Problem

The importance of "clean" power has increased in proportion to the density and speed of the successive generations of products under design. DC power rail deviations can be the single biggest source of clock and data jitter in digital systems. A drop in the power supply to a digital device can decrease the propagation delay through gates in that device, resulting in reduced timing margins or even bit failures. Supply tolerances have shrunk to 5% or less to combat this.

As the switching speeds and slew rates of digital devices increase, the probability of inducing switching noise into the power supply also increases. The resulting noise happens at the bandwidth of the switching current and can easily exceed 1 GHz.

Reduced signal amplitudes in digital systems enable faster switching speeds. Reduced signal amplitudes also create a need for reduced noise margins on power supplies.

Improving efficiency or reducing power consumption is another reason to place tighter tolerances on power supplies. If a supply once had a 10% tolerance and that tolerance falls to 5%, the design can experience up to a 5% reduction in power consumed.

The challenge facing designers is to measure ever smaller and faster AC signals riding on top of their DC supplies. To reduce the learning curve, Keysight D9010POWA power integrity analysis software can help you quickly make informed decisions about steps you need to take to clean up your DC power supplies on a Keysight oscilloscope. For example, users can see what their DC supply or digital signals would look like if they were immune to the negative effects of each other.

DC power supply noise

Ideally, there wouldn't be any noise on your DC power supplies. How did it get there?

Simple Gaussian noise on the supply results from unavoidable thermal noise — the electronic noise generated by the thermal agitation of electrons. Typically, this is not the largest source of noise.

The dominant sources of noise on DC power supplies are switching noise from the supply itself and noise induced by the switching currents of devices in the circuit, which create transient current demands. The noise created by the switching events may appear random in time; however, it tends to be coherent with clocks in the system.

Thinking about the noise on the DC supply as being a combination of "signals," like supply switching noise and switching current noise, superimposed on the DC supply will make measurement and analysis easier.

Measurement challenge

Engineers measuring power supply noise often prefer to use an oscilloscope because of its wide bandwidth, ease of use, and availability. Oscilloscopes also provide unique insights into the cause of noise.

Real-time wideband oscilloscopes and their associated probes have noise of their own. This noise can cause issues if the noise of the oscilloscope and probes is similar in magnitude to the noise of your DC supply.

Dynamic range presents another challenge to measuring DC supply noise. Your supply of interest is at some DC level, and the small AC signals (noise) riding on it that you want to measure are only a tiny fraction of the DC level. The desire is to zoom in on the AC noise — place the scope in a more sensitive range to observe the details of the noise while also at a lower scope noise level (see "A brief lesson in scope noise"). Depending on the oscilloscope and probe used, it may prove impossible to offset them enough to accomplish this.

Tip 1. Choose the Lowest Noise Oscilloscope Measurement Path

This may seem obvious: If you are about to measure the noise riding on your DC supply, you want the noise of your oscilloscope measurement system to be as small as possible. Unfortunately, many users stumble here, not knowing they may have better options. The oscilloscope measurement path consists of the oscilloscope and the scope input termination — 50 Ω or 1 MΩ.

For many oscilloscopes, the 50 Ω input is a lower-noise path than the 1 MΩ path. Figure 1 shows the baseline noise of the 50 Ω input and 1 MΩ input of a Keysight MXR054B high-definition oscilloscope (500 MHz, four channels).

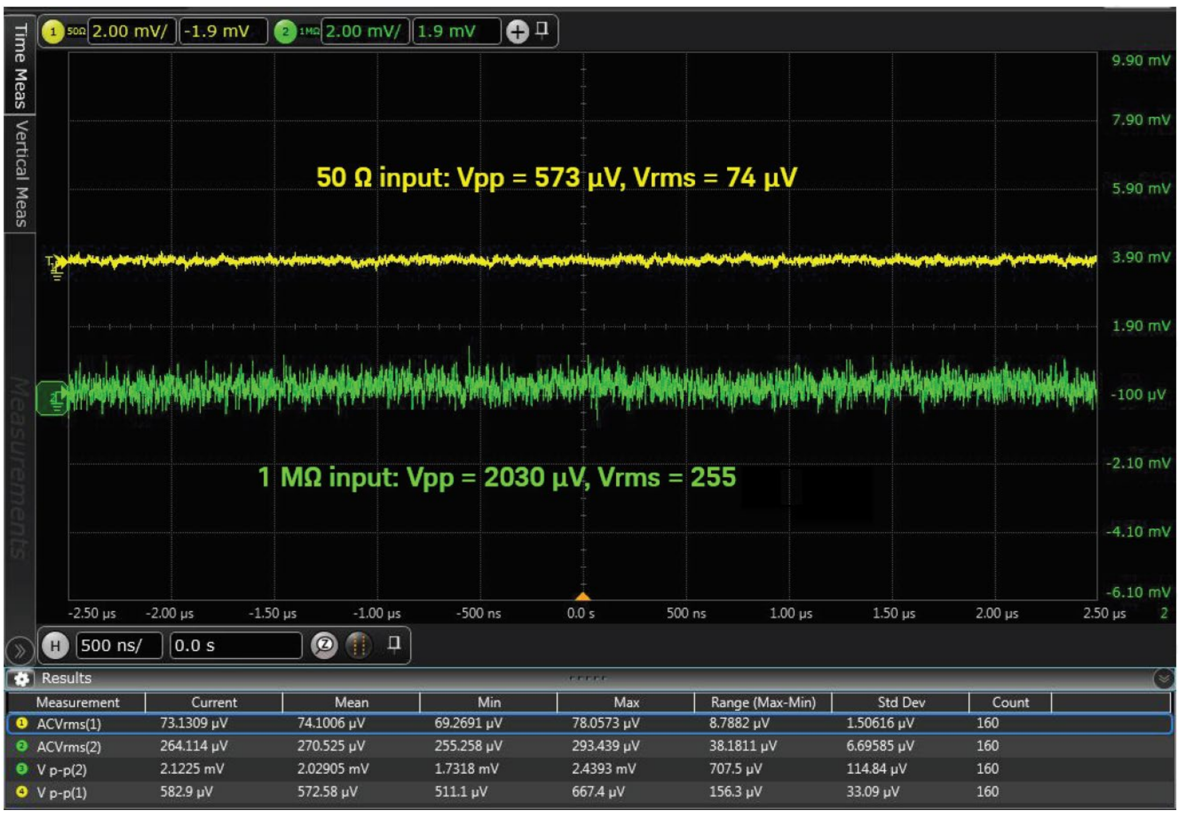


Figure 1. Baseline noise comparison of 50 Ω and 1 MΩ scope input of a Keysight Infiniium MXR054B

This type of measurement, commonly called a null measurement, tracks the baseline noise of your oscilloscope measurement system. It is a sanity check similar to shorting the leads together on a digital multimeter (DMM) before making a continuity or resistance measurement. It is a good practice to perform a null measurement on your complete oscilloscope measurement system — including probe — to be confident that your scope and probe are appropriate for the power supply noise measurements you are about to make.

To make a null measurement, configure your oscilloscope and probes as you intend to use them when making your supply noise measurement. Then short the input to ground (or short the inputs together on a differential probe) and measure the noise.

Tip 2. Limit Bandwidth to Reduce Measurement System Noise

More bandwidth is better, right? Not always. The noise voltage of an oscilloscope and probe is a function of frequency. Limiting the bandwidth to just the amount necessary for the given measurement reduces the amount of oscilloscope and probe noise in the measurement. Consider the measurements shown in Figure 2. For these measurements, we performed the null measurement described above using a Keysight MXR B-series oscilloscope (6 GHz, 10-bit ADC, 16 GSa/s) with an N7020A power rail probe (2 GHz, 1:1 attenuation). Table 1 summarizes the results.

Table 1. Null measurement noise results at various bandwidths

Bandwidth	Vpp	Vrms
Null measurement		
2 GHz	1,040 µV	110 µV
1 GHz	860 µV	90 µV
500 MHz	800 µV	80 µV
20 MHz	460 µV	60 µV

Figure 2. Baseline noise at various bandwidth limits with the Keysight N7020A power rail probe and MXR B-series oscilloscope

Tip 3. Use 1:1 Attenuation to Reduce Measurement System Noise

Oscilloscope probes come in a variety of attenuation ratios. You are probably most familiar with the 10:1 passive probe. One benefit of using a 10:1 probe is that it allows you to measure signals that otherwise would exceed that maximum input to the scope. The downside of attenuation is that the size of the scope noise relative to the size of the signal you are measuring increases proportionally to the attenuation ratio. See “A brief lesson in scope noise” for details.

Consider the measurement result shown in Figure 3. Both a 10:1 probe and a 1:1 probe are measuring the same signal simultaneously — a 20 MHz 50 mVpp sine wave. The only difference between the two measurements is the attenuation ratio. The 1:1 measurement is 52 mVpp, while the 10:1 measurement is 65 mVpp. The higher attenuation ratio overstates the measurement by at least 25% because of the reduced signal-to-noise ratio resulting from the higher attenuation ratio. From this, we can see that when measuring small signals where oscilloscope and probe noise can be problematic, it is best to use as small an attenuation ratio as possible or available.

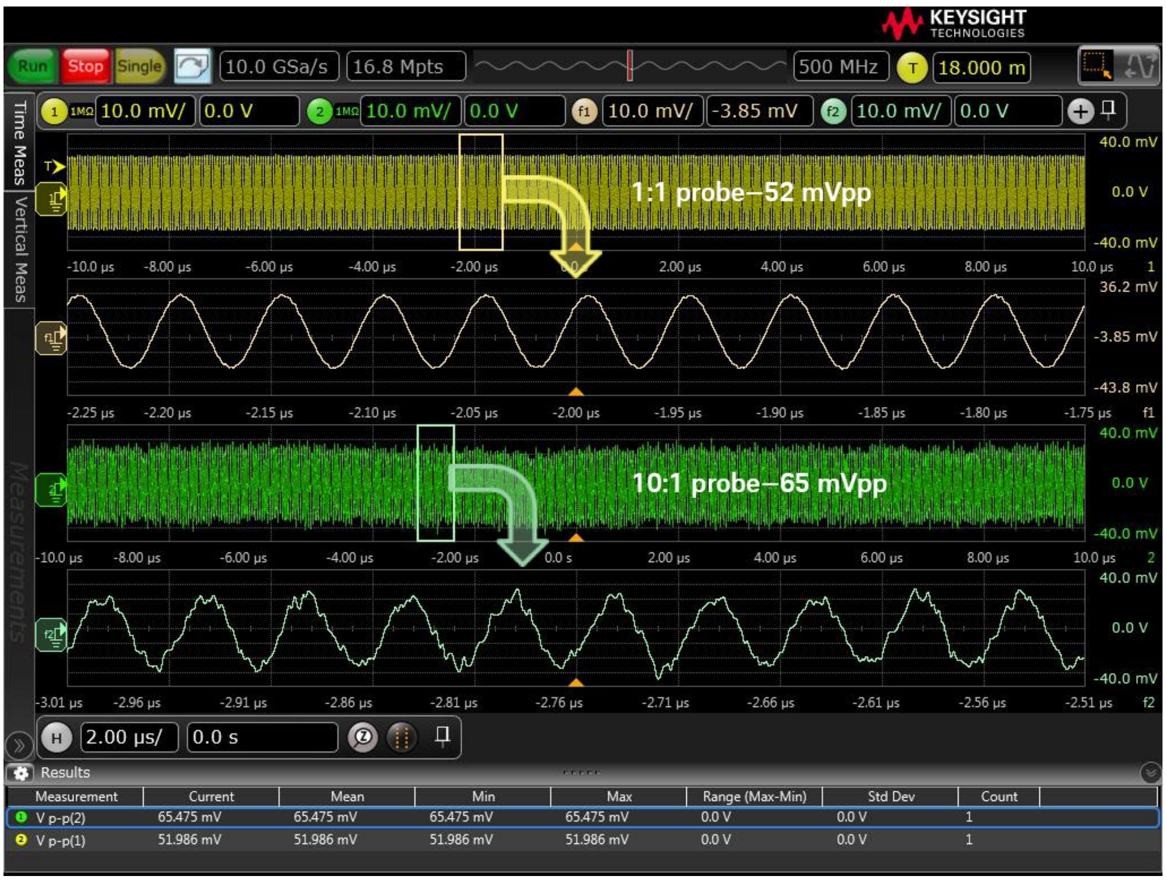


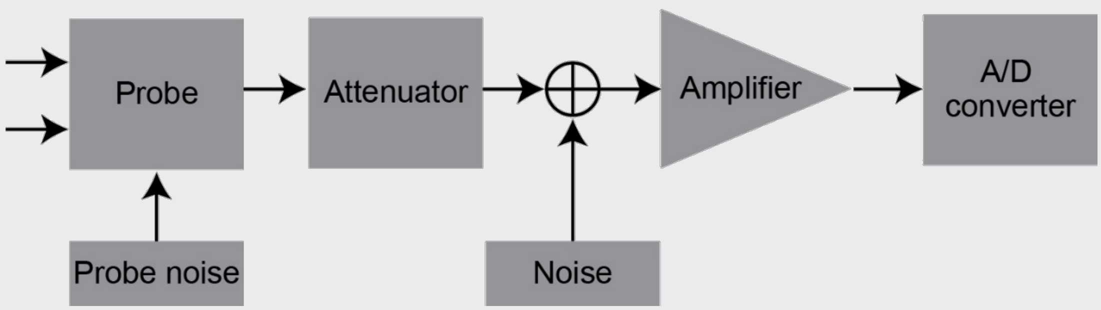
Figure 3. Noise comparison of a 1:1 and 10:1 probe measuring a 50 mVpp sine wave

A brief lesson in scope noise

The block diagram shows the two primary noise sources in an oscilloscope and probe system. The input amplifier and buffer circuits in the scope contribute some noise, and the probe amplifier of an active probe has its own noise.

Scopes use an attenuator to vary the vertical scale factor. The scope's noise arises after this attenuation occurs. When the attenuator is set to something greater than 1:1 (the most sensitive scope hardware ranges), the noise will appear to be larger relative to the signal at the input connector of the scope.

Consider a scope with a basic sensitivity of 5 mV / division with no attenuation inserted (1:1). For this example, we will say this scope has a noise floor of 500 μVrms at 5 mV / division. If we change the sensitivity to 50 mV / division, the scope inserts a 10:1 attenuation in series with the input. The noise then appears as if it were 5 mVrms relative to the input (500 μV*10). The same thing happens when you attach a probe with attenuation to the scope. The scope noise appears larger relative to the signal at the input to the probe by the amount of the attenuation.



Tip 4. Use Probe Offset to Increase Dynamic Range

Probe offset is a feature of active probes that enables the user to remove DC content from signals under measurement. This feature is especially useful when a small AC signal is riding on a DC signal, as is the case when measuring power rail noise. Figure 4 shows the noise measurement results on a 1.5 V supply with and without the use of probe offset. The attenuation applied by the oscilloscope at the larger V / division settings causes the difference.

A word of caution: Most active probes that provide offset also have large, non-1:1 attenuation ratios, which works against the goal of reducing oscilloscope measurement system noise. Some probes, such as the Keysight N7020A power rail probe, provide offset capabilities and a 1.1:1 attenuation ratio. In the case of the N7020A, the offset range is ± 24 V.

Figure 4. Measuring the noise on a 1.5 V DC supply with no offset and with the use of probe offset

Tip 5. Understand the Limitations of DC Blocks

A DC block is a specialized large-value capacitor that you can place in series with the signal before the input to the oscilloscope. The benefit of a DC block is that it removes the large DC component so you can place the scope in a more sensitive range — the same measurement principle as mentioned previously regarding the use of a probe offset. The limitation of a DC block is that it blocks low-frequency AC content, such as drift or supply compression, in addition to the DC content.

Figure 5 shows a 5 V DC supply measurement using a DC block compared to the N7020A power rail probe with probe offset. This example shows that measurements made with a DC block would exclude the low-frequency supply drift and could be misleading. Additionally, because the DC information is blocked, it is not included in the measurement, so it cannot be determined from the scope what DC value the supply noise is riding on. Obtaining this information would require the use of a DMM or similar measurement. Illustrating this point, Figure 6 compares measurements made on a 1.5 V double data rate 3 (DDR3) supply using a DC block and an N7020A power rail probe with offset.

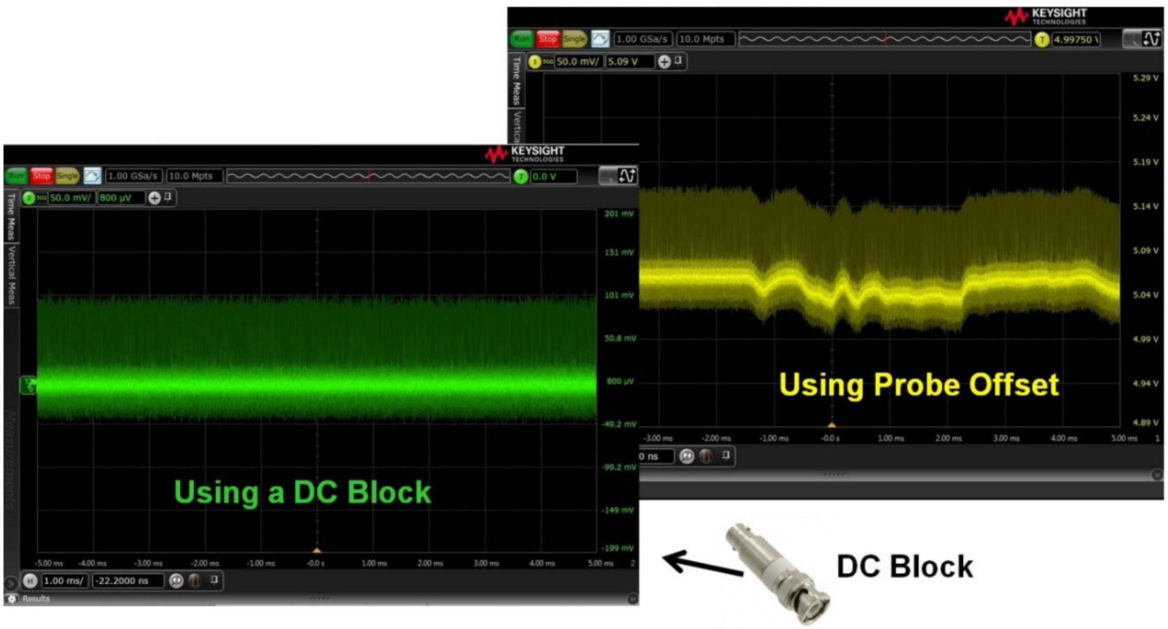


Figure 5. Illustrating the loss of low-frequency content, such as supply drift of compression, when using a DC block to measure DC supply noise

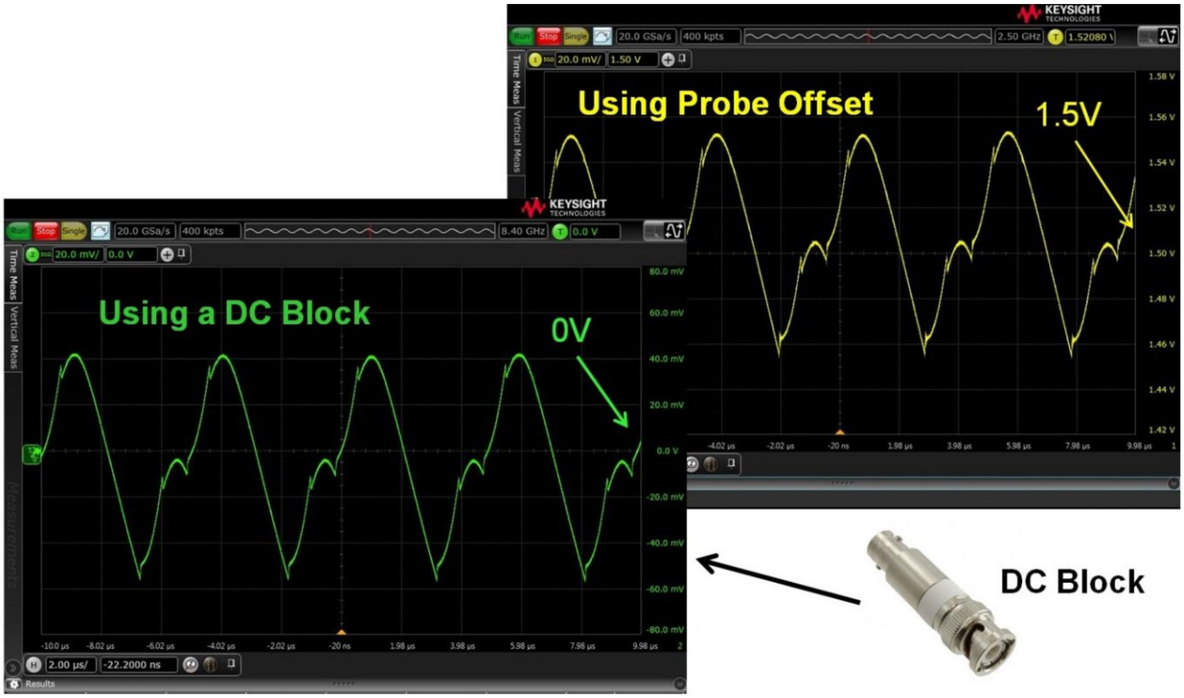


Figure 6. Illustrating the loss of DC content from the oscilloscope measurements when using a DC block. Additional steps, such as measuring the DC value with a DMM, are necessary to understand what DC value the noise is riding on.

Tip 6. Minimize Oscilloscope and Probe Loading of the Supply

Any time an oscilloscope probes a system, it becomes part of that system because of the electrical contact it makes. This process changes the behavior of the system under measurement. This is known as loading, and the goal is to minimize it as much as possible.

When measuring DC supplies, a common source of excessive loading happens when a user attaches a 50 Ω coaxial cable to the supply and the 50 Ω input of the scope. By choosing the 50 Ω scope input for its low noise and the coaxial cable for its shielding and low ground inductance, the user means well. But the 50 Ω termination of the scope will load the supply 20 mA/V. For example, a 3.3 V rail probed this way will experience a 66 mA load from the oscilloscope.

A better approach would be to use a probe like the N7020A power rail probe, which has a DC input impedance of 50 kΩ. Figure 7 shows a comparison of these two approaches. First, we measured the supply with a DMM, and the result was 3.31 V. Next, we probed the supply with the N7020A power rail probe, and there was no change to the supply — still 3.31 V. Finally, we probed the supply by connecting directly to the 50 Ω scope input, and the supply dropped from 3.31 V to 3.25 V.

Not all supplies will realize this adverse effect. Some supplies will have enough excess capacity to drive this additional load. Other supplies may not have enough excess capacity to drive this load, or this additional load may affect the behavior of the PMIC (power management IC) in systems that contain one, so beware.

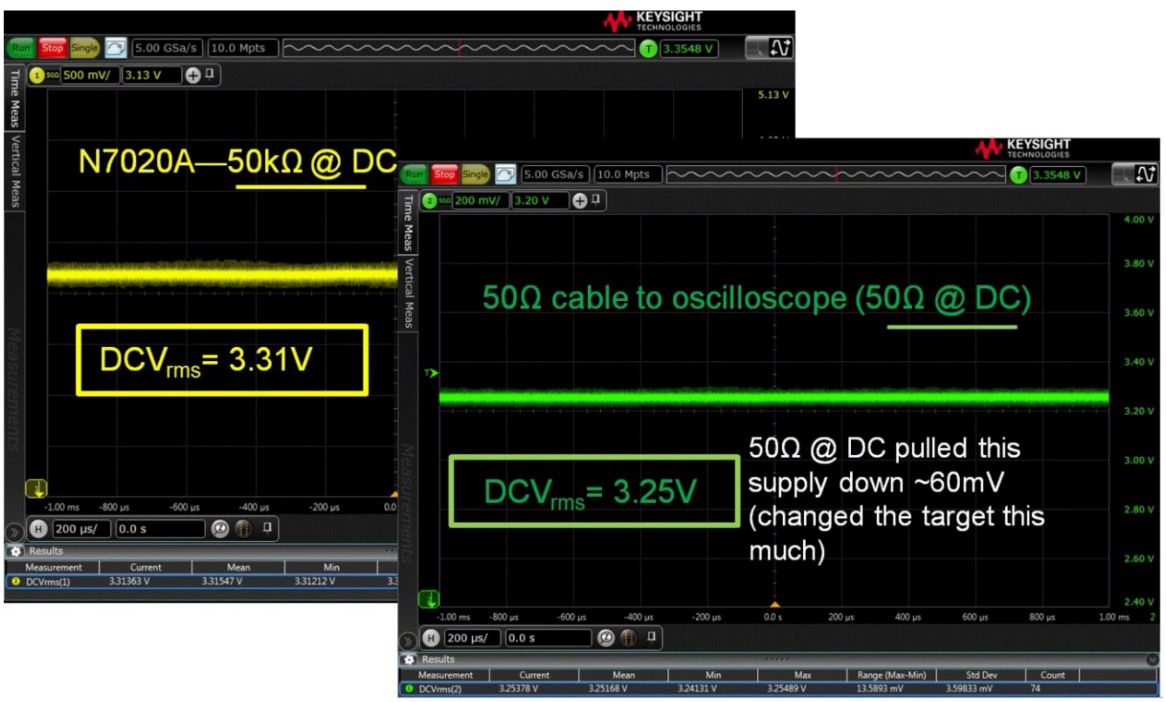


Figure 7. The effects of probe loading on a supply. A 3.3 V supply probed with the N7020A power rail probe with its 50 kΩ impedance at DC and the same supply probed by direct connection to the 50 Ω input of the scope.

Tip 7. Use the Frequency Domain for Analysis

Using an oscilloscope's fast Fourier transform (FFT) capabilities to view signals in the frequency domain can help identify sources that contribute to the noise on a supply.

In this example, we have a switching DC / DC converter converting 5 V to 3.3 V. The switcher operates at 2.8 MHz. Elsewhere on the PC board is a 10 MHz clock and 125 MHz clock running. Referring to the previous tips, we will use the 1.1:1 attenuation ratio of Keysight's N7020A power rail probe, apply 3.3 V of probe offset, and limit the bandwidth to 500 MHz to measure the noise on the 3.3 V supply. The probe connects to a Keysight MXR B-series oscilloscope. Figure 8 shows the results of this measurement in the time domain. From the time domain view, we can see a signal of ~360 ns period, which is the remnants of the 2.8 MHz, but it is not obvious that the 10 MHz and 125 MHz clocks are creating noise on the 3.3 V supply.

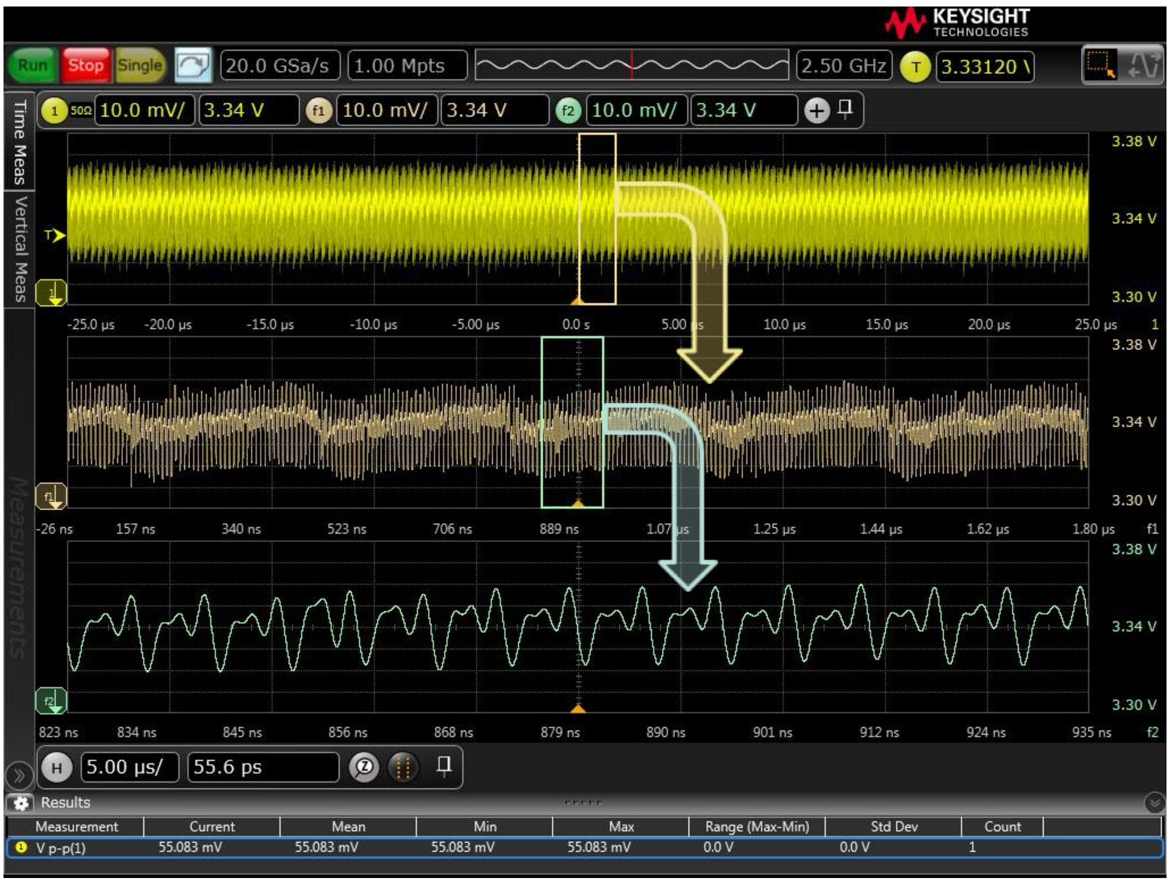


Figure 8. Time domain view of 3.3 V DC supply. Remnants from a 2.8 MHz switcher appear in the middle zoomed-in trace. It may not be evident that the 10 MHz and 125 MHz clocks are noise sources in the bottom zoomed-in trace.

Figure 9 shows the same data in the frequency domain. Here, using FFTs, we have set up two windows covering two different frequency ranges, and we can clearly see a peak at 2.8 MHz, which correlates to the frequency of the switching converter and spikes at 10 MHz and 125 MHz, representing noise coupling in from the two clocks. Viewing the noise in the frequency domain in addition to the time domain provides additional insight into the source of the noise.

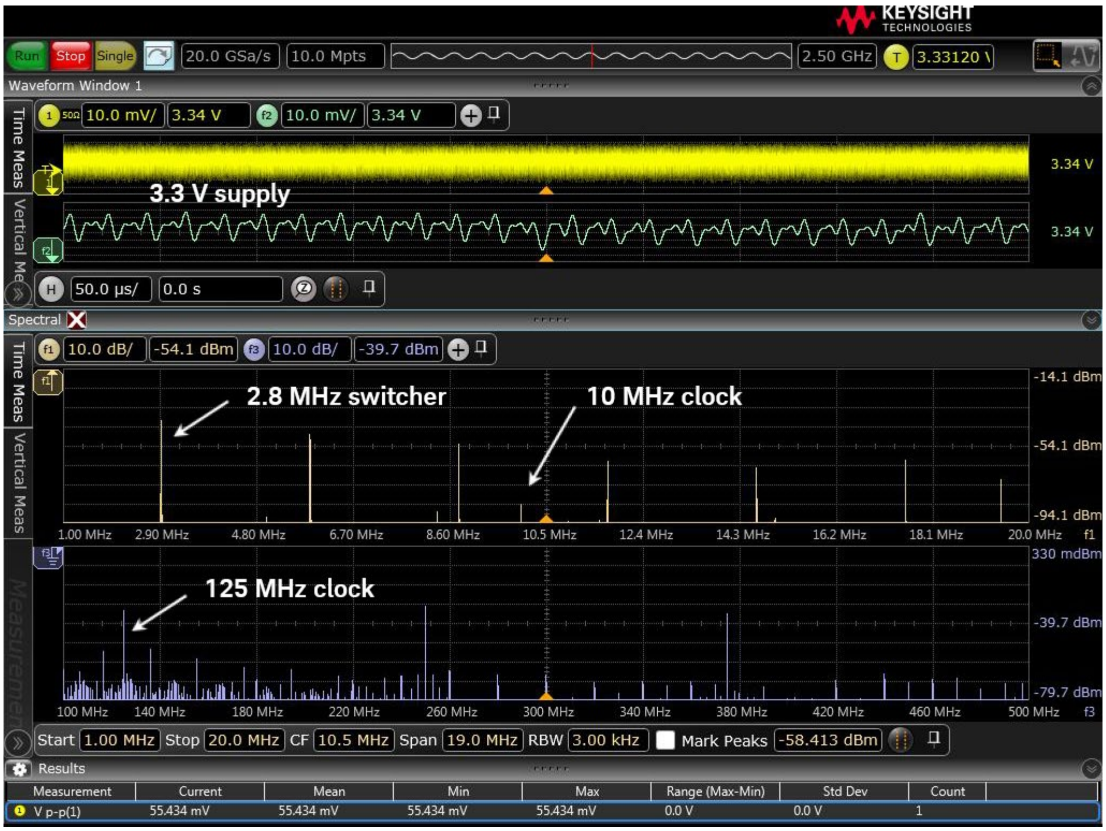


Figure 9. Using FFTs to confirm that noise from the 2.8 MHz switcher and 10 MHz and 125 MHz clocks are on the 3.3 V supply

FFT considerations in scopes

An oscilloscope will capture a finite amount of time on each trigger based on the amount of memory and the sampling rate. The fast Fourier transform (FFT) cannot "see" frequencies in the incoming signal that are below the inverse of the scope's time capture window. The lowest frequency the FFT can analyze is 1 / [1 / (sampling rate) X (memory depth)]. To see a suspect source in the FFT, be sure to set the depth to capture enough samples.

For example, if your switching supply operates at 33 kHz, you would need to capture 1 / (33 kHz) or 30 microseconds of signal activity to see it in the FFT. A sampling rate of 16 GSa/s would require 480,000 points in memory. The FFT typically operates only on the data that is on the screen.

Tip 8. Use Triggering to View and Measure Signal Components in the Supply Noise

Triggering can help you visualize and measure components of supply noise that are coupling into the supply from, and are phase coherent to, other elements in the system. To demonstrate this, we used the same measurement system as Tip 5 (N7020A probe with offset and bandwidth limiting) and targeted with a 2.8 MHz switching regulator delivering 3.3 V and a 10 MHz clock in the system.

Figure 10 shows the measurement results. We can see the 2.8 MHz clock and its harmonics in the FFT, along with a spike at 10 MHz that represents the clock. From this, we know that the clock is coupling noise into the 3.3 V supply. Then we trigger on the clock and turn on averaging. Doing so eliminates all the random noise and other signal components that are not coherent with the clock. The result will be those portions of the supply noise that correlate to the 10 MHz clock. Figure 11 illustrates this point.

Figure 10. Measurement results of a 3.3 V supply and a 10 MHz clock in the target system. Using an FFT, we verify that the 10 MHz clock is creating noise on the 3.3 V supply.

Figure 11. Triggering on the 10 MHz clock and enabling averaging removes all random noise and signals that are not coherent with the clock. The resulting view is of the noise on the supply related to the 10 MHz clock.

Tip 9. Have Enough Bandwidth

In Tip 2, we discussed the value of limiting the bandwidth of the measurement to only that needed to minimize noise for the task at hand. An opposite pitfall can await users who do not have enough bandwidth for the task — they may miss high-frequency noise and transients that can adversely affect clocks and data in their systems.

Switching currents from things like clocks and data can create high-frequency supply noise. Likewise, these same devices are susceptible to this high-frequency supply noise. In many modern systems, this noise can require > 1 GHz of bandwidth to observe, so choosing a probe with enough bandwidth is important.

Figure 12 shows a side-by-side comparison using a common 35 MHz 1:1 probe and the 2 GHz N7020A probe measuring the noise on a 1.5 V DDR3 memory supply. This illustrates the ability of the higher-bandwidth probe to capture the high-frequency noise that can be troublesome in many modern digital systems.

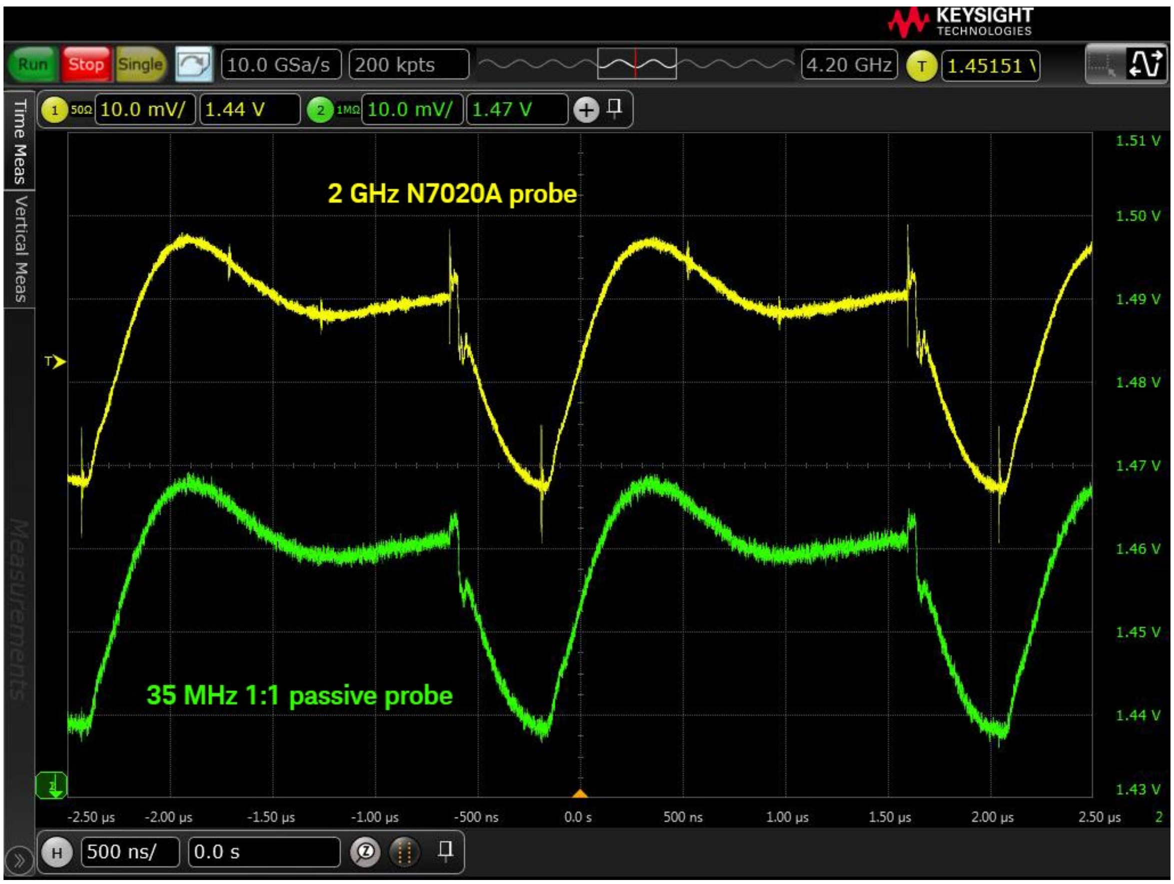


Figure 12. Comparison of a 35 MHz 1:1 passive probe and the 2 GHz N7020A power rail probe measuring the noise on a 1.5 V DDR3 memory supply. The lower-bandwidth probe misses the high-frequency noise and spikes that are troublesome in high-speed digital systems.

Tip 10. The N7020A Power Rail Probe

The previous tips will help minimize oscilloscope measurement system noise when measuring power supply noise and identify sources of noise in the power supply. These techniques work even better with specialized tools that are designed to measure power supply noise.

For example, the N7020A power rail probe, shown in Figure 13 (and used in some previous examples), is the first probe to measure noise on DC power supplies. This probe has a 1.1:1 attenuation ratio (Tip 3) and ± 24 V of offset (Tip 4), and it connects to the 50 Ω scope input (Tip 1). It has 2 GHz bandwidth to capture the high-frequency noise and transients that can cause clock and data jitter (Tip 7). When used with an oscilloscope like the Keysight Infiniium MXR B-series, it can be bandwidth-limited (Tip 2) to reduce noise when you do not need the full 2 GHz bandwidth.

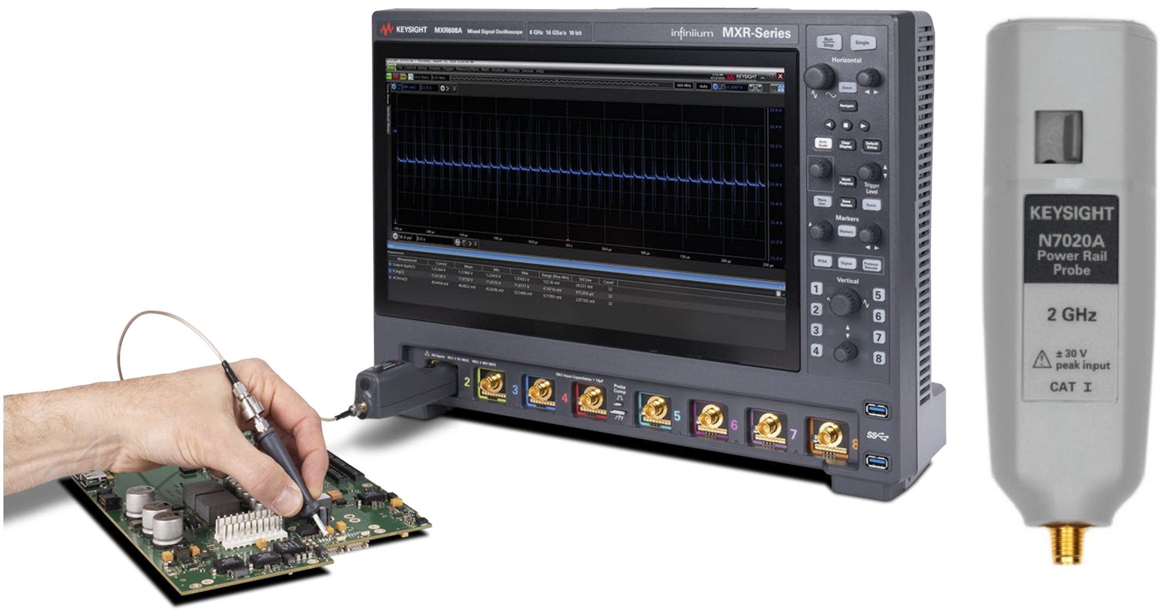


Figure 13. N7020A power rail probe (right) was designed specifically for measuring power supply noise and works with a variety of Keysight oscilloscopes, including the Infiniium MXR B-series high-definition oscilloscopes (left)

Characteristics and Specifications: N7020A Power Rail Probe

Tip		Description
Tip 9	Probe bandwidth (-3 dB)	2 GHz
Tip 3	Attenuation ratio	1.1:1
Tip 4	Offset range	± 24 V
Tip 6	Input impedance at DC	50 kΩ ± 2%
	Active signal range	± 850 mV about offset voltage
	Probe noise (2 GHz)	10% increase in the noise of the connected oscilloscope
	Probe type	Single-ended
	Included accessories	N7021A — coaxial probe head
		N7022A — main cable
	Maximum non-destructive input voltage	± 30 V (DC + peak AC)
Tip 1	Output impedance	50 Ω
	Ambient operating temperature	Probe pod: 0 to 40 °C
		N7021A main cable, N7022A coaxial probe head: 0 to 85 °C

Summary of Tips and Techniques

Tip 1: Use the 50 Ω scope input, which usually has the lowest noise, and begin with a null measurement, so you know how much noise your oscilloscope measurement system has.

Tip 2: Don’t use more bandwidth than necessary.

Tip 3: Stick with smaller attenuation ratio probes when possible — ideally a 1:1 probe.

Tip 4: Use probe offset to zoom in on the signal.

Tip 5: If you choose to use a DC block, use it wisely.

Tip 6: Beware of loading your supply through the scope’s 50 Ω termination (50 Ω at DC).

Tip 7: Use FFT for analytical insight.

Tip 8: Trigger on suspect noise sources and use averaging to eliminate uncorrelated noise.

Tip 9: Use enough bandwidth to capture troublesome transients and noise.

Tip 10: Use the N7020A power rail probe.

Learn More

- N7020A Power Rail Probe, 2 GHz
- D9010POWA Power Integrity Analysis Software
- Infiniium MXR B-Series Real-Time Oscilloscopes

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