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The Need for a Specialized Power Integrity Probe

Would you like to minimize oscilloscope and probe noise when measuring DC power rails? Do you need more offset than is available in your oscilloscope so you can zoom-in to view and analyze small signals on top of DC power supplies? Would you like to have input impedance greater than 50 Ω at DC so your oscilloscope doesn’t load your DC power rails? Do you need more bandwidth so you can track down transients on your DC power supplies that can adversely affect your clock and data? If so, the Keysight Technologies, Inc. N7020A power rail probe is the right tool for the job.

Developed specifically to help engineers with precise DC power rail testing, the N7020A power rail probe was designed to minimize noise and maximize the offset range of the measurement system while providing high bandwidth and low target loading.

The Challenge

The increased functionality, higher density, and higher frequency operation of many modern electronic products has driven the need for lower supply voltages. It is common in many designs today to have 3.3, 1.8, 1.5 and even 1.1 V DC supplies—each of them having tighter tolerances than in previous product generations.

Engineers need to zoom-in on power rails to look for transients, measure ripple, and analyze coupling. An oscilloscope often does not have enough offset to be able to shift the DC power rail to the center of the screen for the required measurements. Even if the oscilloscope being used has enough offset to center the supply on the screen, the oscilloscope will load the supply with 50 ohms to ground and sink 30mA per volt of the supply. This can change the behavior of the supply resulting in inaccurate characterization. Placing a DC blocking capacitor in the signal path eliminates the offset problem but also eliminates relevant DC information such as DC supply compression or low frequency drift.

A low noise measurement solution is of paramount importance so it doesn’t confuse the noise of the probe and oscilloscope with the noise and ripple of the DC supply being measured. Using probes (active or passive) that are higher than 1:1 attenuation can help with the offset difficulty but will also decrease the signal-to-noise ratio and negatively affect measurement accuracy. Using the oscilloscope’s 50 Ω input with a passive coaxial cable offers a 1:1 attenuation ratio probing method but results in higher-than-desired DC loading of the supply being measured and has the offset limitations mentioned earlier. Ripple, noise, and transients riding on DC supplies are a major source of clock and date jitter in digital systems. Dynamic loading of the DC supply by the processor, memory, or similar items occurs at the clock frequency and can create high speed transients and noise on the DC supply that can easily have content above 1 GHz. Designers need high-bandwidth tools to evaluate and understand high-speed noise and transients on their DC power rails.
The Challenge (Continued)

![Image](image.png)

Figure 1. Using the N7020A power rail probe, with 2 GHz bandwidth and 50 kΩ DC resistive loading, to see the AC and DC components of a DC power rail.

Power Integrity “What If” Analysis with the N8846A PI Analysis Application

Power supply induced jitter (PSIJ) can be one of the largest sources of clock and data jitter in digital systems. Similarly, noise on DC supplies is often caused by switching currents from the transitions of clock and data in these systems. Many designers would like a relatively easy method of determining how much of their systems data jitter is PSIJ and/or how much of the noise on the DC supplies is coming from specific clocks, data lines or other toggling sources.

A common self reflection among power integrity engineers and technicians is wondering if it is worth trying to clean up the supply more--how much margin will it buy back? Or, which of these data lines or toggling signals is causing the noise on the DC supply and how much?

Keysight offers the N8846A Power Integrity analysis application for those who are looking for answers to these kinds of questions. The Power Integrity application lets users define a DC supply as either a victim of, or an aggressor to, other periodic transitioning signals and predicts the amount of adverse interaction involved. In this way users can see what their DC supply and/or toggling signals would look like if they were immune to the negative effects of each other. With this insight, users can make informed decisions about what, if any, next steps they would take to clean up the DC supplies.
Key N7020A Power Rail Probe Characteristics

**Low noise:** The N7020A power rail probe is a 1:1 attenuation ratio active probe. This low attenuation ratio provides a superior signal-to-noise ratio compared to other probes, both passive and active. This means users are not giving up margin to measurement system noise and get a clear picture of all the details of their signal.

**Large offset range:** ± 24 V of probe offset. This enables users to center the signal on screen and zoom-in to observe and measure signal details.

**Low DC loading:** The N7020A power rail probe has a large 50 kΩ DC input impedance, minimizing the probe DC loading of the rails it probes.

**High bandwidth:** With 2 GHz bandwidth, the N7020A power rail probe can capture fast transients and noise caused by switching currents within the user’s system.
Key N7020A Power Rail Probe Characteristics (Continued)

Key measurements

- **Supply drift**: Because the probe passes through both AC and DC signal components to the oscilloscope, it is possible to accurately measure low frequency DC supply drift or supply compression.

- **PARD (periodic and random disturbances)**: The probe’s extremely low noise means that it will not contribute significant error to measurements of the DC supply’s ripple and noise.

- **Load response**: The large input active voltage range of the N7020A power rail probe makes it possible to analyze large deviations of the DC supply that may result from dynamic loading.

- **High-frequency transient and noise characterization**: With 2 GHz of bandwidth, the probe can help characterize transients and noise on the DC supply that may be offensive to clocks and digital data.

![Diagram](image)

Figure 4. Examples of types of power integrity measurements.
# N7020A Probe and Accessory Characteristics and Specifications

<table>
<thead>
<tr>
<th></th>
<th>Probe with N7022A main cable and N7021A pigtail cable</th>
<th>Probe with N7023A browser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probe bandwidth (–3 dB)</td>
<td>2 GHz</td>
<td>350 MHz</td>
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<tr>
<td>Attentuation ratio</td>
<td>1:1</td>
<td></td>
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<tr>
<td>Risetime (calculated, 10 to 90%)</td>
<td>175 ps</td>
<td>1.0 ns</td>
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<tr>
<td>Offset range</td>
<td>± 24 V</td>
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<tr>
<td>Input impedance at DC $^1$</td>
<td>50 kΩ</td>
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<tr>
<td>Input dynamic range</td>
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</tr>
<tr>
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<td>10% of the noise of the oscilloscope that it is attached to</td>
<td></td>
</tr>
<tr>
<td>Probe type</td>
<td>Single-ended</td>
<td></td>
</tr>
<tr>
<td>Included accessories</td>
<td>N7021A coaxial pigtail probe head (qty. 3)</td>
<td>N7023A browser</td>
</tr>
<tr>
<td></td>
<td>N7022A main cable</td>
<td></td>
</tr>
<tr>
<td>Maximum non-destructive input voltage</td>
<td>± 30 V (DC + peak AC)</td>
<td></td>
</tr>
<tr>
<td>Output impedance</td>
<td>50 Ω</td>
<td></td>
</tr>
<tr>
<td>Cable length</td>
<td>N7021A coaxial pigtail probe head: 8”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N7022A main cable: 48”</td>
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</tr>
<tr>
<td></td>
<td>N7023A browser: 45”</td>
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</tr>
<tr>
<td>Ambient operating temperature</td>
<td>Probe pod: −10 to 55 °C</td>
<td>N7023A browser: −10 to 55 °C</td>
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<tr>
<td></td>
<td>N7021A main cable, N7022A coaxial pigtail probe head: −40 to 85 °C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N7023A browser: −10 to 55 °C</td>
<td></td>
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<td>Ambient non-operating temperature</td>
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<td>N7021A main cable, N7022A coaxial pigtail probe head: −40 to 85 °C</td>
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<td></td>
<td>N7023A browser: −30 to 70 °C</td>
<td></td>
</tr>
<tr>
<td>Operating humidity</td>
<td>Probe pod: Up to 85% RH</td>
<td>N7023A browser: Up to 80% RH at 31 °C, decreasing linearly to 40% at 50 °C</td>
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<tr>
<td></td>
<td>N7021A main cable, N7022A coaxial pigtail probe head: Up to 85% RH</td>
<td></td>
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<tr>
<td>Non-operating humidity</td>
<td>Probe pod: Up to 85% RH</td>
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<td>N7021A main cable, N7022A coaxial pigtail probe head: Up to 85% RH</td>
<td>N7023A browser: Up to 85% RH</td>
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<td>Operating altitude</td>
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<tr>
<td>Non-operating altitude</td>
<td>15,300 m</td>
<td></td>
</tr>
<tr>
<td>Replacement parts</td>
<td>N7021A Pigtail coax (set of 3)</td>
<td></td>
</tr>
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<td></td>
<td>N7022A Main cable</td>
<td></td>
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<tr>
<td></td>
<td>N7023A Browser (incl all browser accessories listed below)</td>
<td></td>
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<td></td>
<td>N4829A probe tip kit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N4836A dual-lead adapter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N2837A ground lead</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N4838A ground spring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1400-3652 SMD micro grabber</td>
<td></td>
</tr>
</tbody>
</table>

1. Denotes specification.
Compatible Oscilloscopes – N7020A Power Rail Probe

The N7020A probe is compatible with the Keysight oscilloscopes shown below. Up to four probes can be connected to the oscilloscope at the same time. The table also lists the minimum required firmware version for the oscilloscope.

The N7020A probe is designed for oscilloscopes with 50 Ω AutoProbe interface channel inputs. The AutoProbe interface provides power and control to the probe.

Table 1. Compatible oscilloscopes

<table>
<thead>
<tr>
<th>Infiniium oscilloscopes</th>
<th>Required firmware version</th>
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<tbody>
<tr>
<td>S-Series</td>
<td>≥ 5.20</td>
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<tr>
<td>9000 Series</td>
<td>≥ 5.20</td>
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<tr>
<td>6000 X-Series</td>
<td>≥ 6.10</td>
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<tr>
<td>4000 X-Series</td>
<td>≥ 4.00</td>
</tr>
<tr>
<td>3000T X-Series</td>
<td>≥ 4.00</td>
</tr>
<tr>
<td>3000A X-Series</td>
<td>≥ 2.39</td>
</tr>
</tbody>
</table>

Is your oscilloscope software up-to-date? Keysight periodically releases software updates to support your probe, fix known defects, and incorporate product enhancements. To download the latest firmware, go to www.keysight.com and search for the oscilloscope’s topic. Click on the “Drivers, Firmware and Software” tab.

When using a N7020A probe with an Infiniium S-Series oscilloscope, users will achieve precise measurements. Infiniium S-Series oscilloscopes provide support for 10 vertical bits in hardware for vertical sensitivities as small as 16 mV full screen. This means all 10 bits of the ADC are used to produce a resolution of 16.6 µV. S-Series noise at 1 mV/div with 1 GHz bandwidth is 90 uV_{AC, rms} and lower noise levels can be achieved by averaging or additional bandwidth limiting.
The N7020A power rail probe comes with a set of three N7021A pigtail cables and an N7022A main cable.

### N7021A Pigtail Cables

The Keysight Technologies N7021A pigtail cables are a replaceable accessory for use with the N7020A oscilloscope power rail probe. These cables are intended to be solder-connected to the power rail of interest and connected to the N7020A power rail probe’s main cable. The cables have a small diameter so they occupy less space and are very flexible. They are constructed of high-quality materials, and their solid center conductor can withstand multiple soldering and unsoldering cycles so the cables can be reused.

- **Small size:** Constructed of small-diameter flexible coax to minimize intrusions into target systems.
- **Durable:** Solid center conductor can be soldered and unsoldered multiple times allowing these cables to be reusable.
- **Convenient:** Pre-trimmed—no cable preparation necessary—and come three to a package.
- **SMA termination:** Have SMA terminations for easy, reliable connection to the N7020A power rail probe.

![Image](image-url)

Figure 6. High temperature capable: Can be used to make measurements inside temperature chambers from –40 to 85 °C.

### N7022A Main Cable

The N7022A main cable is a replacement cable for the Keysight N7020A oscilloscope power rail probe. It is designed to be flexible and durable while still providing high signal fidelity.

- **Durable:** Constructed of high-quality materials to withstand repeated flexing, twisting, and bending.
- **Convenient:** 1.2 m (48”) length makes for easy connection to the target without the need to have the oscilloscope nearby.
- **SMA termination:** Has SMA terminations for easy, reliable connection to the N7020A power rail probe.
Included Accessories

Keysight N7023A Power Rail Probe browser and included browser accessories

The N7023A power rail probe browser is intended for use with the Keysight N7020A power rail probe. The N7023A browser leverages the mechanical components from our popular passive probes to create a convenient browsing style accessory for the N7020A power rail probe.

- 350 MHz bandwidth
- 1:1 attenuation ratio
- SMT clip for hands-free probing of capacitors
- Twin lead adapter for connecting to 2-pin headers or other accessories
- Replacement spring loaded and rigid tips included

Figure 8. N7023A Power Rail Probe browser kit (left). N7023A browser connect to N7020A Power Rail Probe (right).

Figure 9. N7023A Browser accessories being used to probe a small capacitor (left) and a 2-pin, 0.1 inch pitch header (right).
Included Browser Accessories

2.5 mm ground spring: The ground spring provides the highest performance connection for the N7023A power rail probe browser. Its flexible construction makes it easy to vary the span between the input and ground to accommodate the device being probed.

15 cm ground lead: This ground lead can be used to reach grounding locations that are farther away from the probing location than can be reached by the ground spring.

Dual lead adapter: The dual lead adapter allows you to easily connect the N7023A power rail probe browser to popular 0.1” pin headers with 0.025” square pins. This dual lead adapter has no shorting hazards since all external metal surfaces are insulated.

Dual lead adapter with Micro SMD clip: The Micro SMD clips were designed to provide fast and convenient hands-free probing of surface mount capacitors. The Micro SMD clip is used in conjunction with the dual lead adapter.
Two Power Integrity Tools Working Together – N7020A Power Rail Probe and N8846A Power Integrity Analysis Application

The Keysight N7020A Power Rail Probe is a powerful tool for making power integrity measurements with its low noise, large offset range, loading DC loading and high bandwidth. Likewise, the Keysight N8846A Power Integrity Analysis application is a powerful tool for analyzing power supply induced jitter or switching current loads on a DC supply due to its ability to analyze adverse interactions and their effects without the need for simulation or complex modeling. Together the products complement each other and provide an even more powerful means of measuring and analyzing power integrity.

Note that the N7020A and N8846A are not included together and need to be purchased separately.

The following is a brief example of these two tools working together.

In this example the N7020A Power Rail Probe is used to measure the 1.1 V supply of an FPGA that is transmitting a serial data stream. The 1.1 V supply has about 115 mVpp noise or about ± 5% noise.

Figure 14. FPGA DC supply and the serial data captured by the S-Series oscilloscope.
An eye diagram was created of the serial data of the FPGA. It can be seen that the width of the eye is approximately 73 ps.

The next step was to ‘clean up’ the supply. Modifications were made to the circuit to reduce the noise on the 1.1 V supply as much as possible. This resulted in the 1.1 V supply being nearly noiseless with 3 mVpp noise (< 1%). A new eye diagram of the serial data was created and shows that the width of the eye for serial data is nearly 50% wider than when the DC supply was noisier. The only thing that has changed between these measurements is the noise on the 1.1 V supply. This shows that there was approximately 40 ps of PSIJ of the serial data line.
Wouldn’t it be convenient if there were a means of knowing how much impact the noise on the 1.1 V supply is causing without having to go through all the work of actually cleaning up the supply? That’s what the combination of the N7020A Power Rail Probe and N8846A Power Integrity Analysis application can do.

Shown below is original 1.1 V supply with noise on it, the serial data and the eye diagram for the serial data. The lower eye diagram is what the Crosstalk Analysis application is predicting the eye would look like if the adverse effects of the 1.1 V supply were removed from the serial data. The results are the same as when we actually cleaned up the supply.
Two Power Integrity Tools Working Together – N7020A Power Rail Probe and N8846A Power Integrity Analysis Application (Continued)

Figure 17. Results from the N8846A PI analysis application showing the eye diagram of the FPGA serial data before and after the effects of the DC supply noise are removed. Notice that the results are nearly identical to the previous results where the supply was physically change to reduce noise.

Shown below is the same data as above, only the time base has been changed so that the some details of the serial data and power supply can be seen. The yellow trace is the original serial data and the red trace is the serial data with the adverse effects of the power supply removed. A slight shift in timing can be observed which contributes to the increased width of the eye diagram. Obtaining these analysis results was quick and simple using the Power Integrity Application setup wizard to tell the application that the serial data line was the victim and the aggressor was the 1.1 V supply.

Figure 18. Expanded timebase view of the FPGA serial data with and without the effects of the DC supply noise.
N8846A Power Integrity (PI) Analysis Application

The PI analysis application lets users define a dc supply as either a victim of, or an aggressor to, other periodic transitioning signals and quantifies the amount of adverse interaction involved. In this way, users can see what their dc supply and/or digital signals would look like if they were immune to the negative effects of each other. With this insight, users can make informed decisions about what, if any, next steps they would take to clean up their dc supplies.

The PI Analysis application works optimally with the N7020A Power Rail probe. Although it can work with other probes used to capture power rail data, the best results will be obtained when used with the N7020A due to its low noise and large offset range.

Key features of the N8846A PI Analysis application

- No crosstalk simulation or modeling is required when using the PI Analysis application.
- Analyze the adverse interactions between power supplies and digital lines. Power supply induced jitter (PSIJ) or voltage-dependent amplitude noise when the power rail is the aggressor. Simultaneous switching noise (SSN) when the power rail is the victim.
- Before-and-after views of the victim waveform are presented for quick and easy visual qualitative assessment.
- Waveforms are automatically labeled for easy recognition—“victim”, “aggressor” and “crosstalk removed”.
- Quantitative analysis unique to the victim signal type is also presented—before-and-after peak-peak noise measurements and FFT’s if the supply is the victim, before-and-after eye diagrams of the digital signal when it is the victim.
- Additional measurements can be performed on either the before or after waveforms at the user’s discretion (math functions, waveform measurements, jitter analysis, et cetera).
- Analysis can also be performed on saved waveform data. This allows users to study their data offline or to study previous revisions of data.
- Quick an easy setup wizard guides the user through selections and automatically identifies signals probed by the N7020A Power Rail probe as being power supplies.
Types of Analysis

Power supply aggressor crosstalk

Power supplies can be a significant source of interference on a data line, creating both noise and jitter. This type of interference may simply be referred to as “power supply noise,” but its effects are similar to traditional crosstalk, and so it is straightforward to think of a power supply as just another source of crosstalk. Noise and voltage drift in a power supply can affect the timing of the serial data waveforms they are driving. Timing errors can occur through a number of different mechanisms, such as phase changes which are caused by voltage-dependent driver impedances and frequency changes caused by voltage-controlled oscillators. The resulting jitter is called power supply induced jitter (PSIJ). In another case, the power supply may be directly connected to the transmission line when the logic level switches to that value. Noise and bias on the voltage rail can therefore transfer directly to the bit stream. The interference may be present only when the bit stream is at a particular logic level (for Vcc aggressors it might present only when the logic level is high, whereas for GND aggressors it might present only when the logic level is low). It is therefore possible to have the high voltage bits experience a lot of noise while the low bits have little (or vice versa). This is a non-linear (or voltage dependent) type of interference.

Power supply victim crosstalk

The signal integrity of power supply voltages (including ground) can be affected by the circuits they are driving. One common example of this is simultaneous switching noise (SSN), which can produce ground bounce (the Vcc rail can also “bounce” and may be referred to as Vcc sag). SSN can occur as a result of parasitic inductances that lie between the device (chip) ground and the system (board) ground. As the voltage on the output changes state, it draws a current through the switching transistors. As that current flows to ground, it causes a voltage drop across the parasitic inductances. That voltage drop in turn changes the voltage you would measure at the device ground. The voltage measured there may bounce up and down in correlation with data transitions. The effect is amplified when more than one line is switching states at the same time since this will draw more current. In addition depending on the impedance and the various switching delays, the ground bounce may appear to have a ringing effect as well.
Example Analysis – Power Supply As Victim

Previously an example was shown using the PI Analysis application with the power supply as the aggressor and its adverse effects on the timing of the digital signal. Following is an example where the power supply is the victim. This example uses a 3.3 V DC supply output from a POL (point of load) DC/DC converter powering a digital circuit. The supply was measured using the N7020A Power Rail probe connected to a Keysight S-Series High-definition Oscilloscope. The results from this measurement are shown in Figure 20. The supply (top trace) can be seen to have a lot of noise on it. Performing a horizontal zoom (second from the top) it can be seen that there is a low frequency ripple and some high frequency noise on the supply. Evaluating this data in the frequency domain (doing an FFT) we can see that the low frequency ripple happens at about 2.9 MHz which is the frequency of the switching DC/DC converter (third from top). Finally, we can also see that the high frequency noise is likely caused by a 125 MHz clocked system (bottom trace). This analysis led to the theory that the 125 MHz digital system was a major cause of noise on the supply—but how much? Is it worth fixing? How much improvement could be gained?

Figure 19. N7020A Power Rail Probe and S-Series High-definition oscilloscope measuring the noise on a 3.3 V supply.
Results from the PI Analysis application are shown below. The red trace in the upper grid is what the power rail would look like if it were not being affected by the 125 MHz digital signal (crosstalk removed). The lower two grids are frequency domain views (FFT) of the power rail before and after the crosstalk was removed respectively. The reduction of spikes based on the 125 MHz clock are clear in the bottom FFT. The analysis also reports that the peak-peak noise on the power rail dropped from 117 mVpp to 54 mVpp or approximately a 54% reduction in peak-peak noise. Based on this quick and simple analysis, the engineer or technician responsible for this design could decide if the improvement is worth the effort of making changes to the design.

Figure 20. The clock of the digital was probed and is being analyzed as the aggressor to the power rail as shown in the PI setup wizard dialogue (next page).

Figure 21. Output from the N8846A PI application showing a reduction in the noise on the 3.3 V supply after the affects of the switching loads were removed.
Compatible Oscilloscopes – N8846A Power Integrity Analysis Application

The N8846A Power Integrity Analysis application is compatible with the oscilloscopes and firmware revisions shown in table 6. The application can also run offline using waveform memories as inputs.

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<thead>
<tr>
<th>Infiniium oscilloscopes</th>
<th>Required firmware version</th>
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<tbody>
<tr>
<td>S-Series</td>
<td>≥ 6.10</td>
</tr>
<tr>
<td>9000 Series</td>
<td>≥ 6.10</td>
</tr>
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</table>

Ordering Information – N8846A Power Integrity Analysis Application

To purchase the Power Integrity analysis application with a new or existing Infiniium Series oscilloscope, order the following model numbers.

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<th>9000 Series</th>
<th>Infiniium offline</th>
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<td>–</td>
</tr>
<tr>
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<td>User-installed N8846A-1FP</td>
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<tr>
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<td>Server-based N5435A-123</td>
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<td>N5435A-123</td>
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<td>Factory-installed –</td>
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<td>Infiniium S-Series High-Definition Oscilloscopes - Data Sheet</td>
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<tr>
<td>Infiniium 9000 Series Oscilloscopes - Data Sheet</td>
<td>5990-3746EN</td>
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