

Keysight Technologies

Evaluating Oscilloscopes for Low-Power Measurements

Application Note



Introduction

Increasing market demand for products that are portable, mobile, green, and that can stay powered for long periods of time is driving a change in new-product innovation. It's low power, not performance, that is king. The ever-increasing need for power reduction drives engineering teams to devise innovative methods and architectures. The low-power mega trend has resulted in a changing landscape for devices, sub-systems, and system-level products. A key requirement to fuel low-power innovation is the ability to measure and characterize device and sub-system power consumption. Oscilloscopes designed with innovative technologies for addressing the challenges of low-power measurements can be a huge boost in an engineer's ability to gain insight, understand, debug, and characterize those designs.

This application note articulates key low-power measurement attributes for oscilloscopes including software features and probes. It will use the Keysight Technologies, Inc. Infiniium S-Series oscilloscopes and N2820A current probe in examples. The principles in this application note can be applied to all oscilloscopes used for low-power measurements.

Limitation on Getting Good Low Power Measurements

There are many factors that go into making a good low power measurement. Some are inherent in the scope and some in the probe. The basis for low-power consumption measurements are current probes. Since power = $V \cdot I$ and voltage for many low-power applications is steady, current measurements are a good proxy for power. Historically, current probes have been designed to clamp around a power line, and either measure the Hall Effect, use transformer technology, or a hybrid between the two methods to continuously report an associated current value for display on an oscilloscope's display.

Low-power measurements challenge testing in several ways. The two biggest challenges are dynamic range (impacted by noise) and sensitivity as shown in Figure 1.

Traditional current probes have limited dynamic range, and the total dynamic range is a function of both the probe itself as well as the scope to which it is connected. We are going to take a closer look at each of these components and offer some best practices to help give you the most accurate current measurement on a low power device possible.

Noise

Let's look first at some low-power challenges related to the oscilloscope. Noise inherent to the oscilloscope diminishes the ability to see small signal detail. At higher vertical scaling, oscilloscopes have more absolute noise. At lower vertical full screen values, oscilloscopes have lower absolute noise. Oscilloscope users will never be able to see detail lower than the noise of the oscilloscope. Noise values are typically characterized and published by oscilloscope vendors. However, plugging a current probe onto a oscilloscope will result in an increased noise level. For oscilloscopes with high signal integrity, the overall noise is typically more a function of the probe than the oscilloscope itself. Users will be able to see signals, as long as these signal values exceed the noise levels of the oscilloscope and connected probes. If noise values exceed the smallest resolution, noise will be the limiting factor in low-power measurements. Noise reduction techniques will be covered later in this application note.

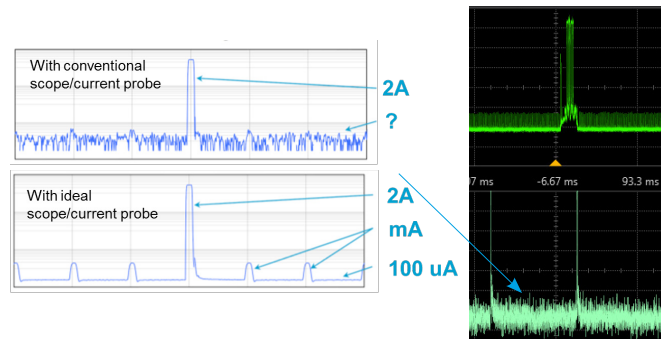


Figure 1. Vertical sensitivity is a key challenge for low-power measurements. Scaling to see peak power and noise buries important signal details of low power states.

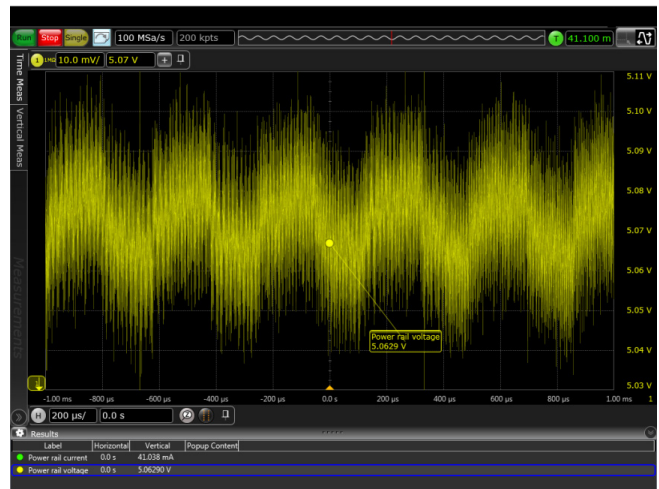


Figure 2. If you've tried to zoom in on a power rail voltage to see additional detail, you've probably experienced noise issues. Noise buries signal detail. The key to success is reducing overall system noise to bring out signal characteristic from the noise.

Resolution

Another limiting factor in seeing small current signals is the resolution of your oscilloscope. Resolution is the smallest current value a scope can measure for a specific full-scale vertical setting. Current measurement resolution is calculated by dividing the full screen current value by the number of quantization levels a scope offers. Oscilloscopes with 8-bit ADCs offer 2^8 , or 256 quantization levels. Oscilloscopes with 10-bit ADCs offer 2^{10} , or 1024 quantization levels.

The signal shown in Figure 3 shows a mobile device that moves from a power conservation mode to a higher power state, then back to sleep mode. To capture the signal, the oscilloscope must be scaled to capture the highest power level. For this example, full scale is set to a value of 200 mA/div, or full scale of 1.6 A. On an 8-bit scope, resolution in this example equals 1.6A divided by 2^8 (256 quantization levels), or 6.25 mA. The user will not be able to see detail smaller than this value where power saving mode visibility is needed. On a 10-bit scope like the Infiniium S-Series, in this example resolution will be 1.6 A divided by 2^{10} (1024 quantization levels) or 1.56 mA. A user will get four times the resolution of an 8-bit scope, but still will not be able to see signals smaller than 1.56 mA for this example.

Vertical Scaling Impact on Resolution

In addition to the quantization levels and inherent resolution of your oscilloscope, vertical scaling on the oscilloscope itself has an impact on resolution. For example scaling the waveform to take the whole display of the scope enables the scope's analog-to-digital (ADC) converter. If a signal is scaled to take up only $\frac{1}{2}$ of the vertical display on an 8-bit oscilloscope, you've just decreased the number of ADC bits being used from 8 to 7 and will see decreased resolution. If you scale the waveform to consume full vertical scale, you will be using all 8 bits of the oscilloscope's ADC. To get the best resolution, engineers must use the most sensitive vertical scaling setting while keeping the waveform on the display.

The combination of the ADC, the scope's front-end architecture, and the probe used determines how low the oscilloscope hardware that supports vertical scaling can go. At a certain point, each family of scopes has a vertical

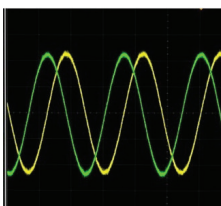


Figure 3. A mobile device requires vertical oscilloscope scaling of 200 mA/div or 1.6 A full screen to capture the high power modes as well as the low-power modes. Oscilloscope resolution in this example equals 1.6 A divided by the number of quantization levels the scope's ADC provides.

value where scaling beyond this point doesn't decrease absolute noise. Rather, noise will be more pronounced than expected—even though the knobs of the scope allow the user to dial a smaller setting. Vendors will often refer to this as the point where the scope moves into software magnification. Turning the scope's vertical scale to a smaller number simply just magnifies the displayed signal and doesn't result in any additional resolution as the user would naturally expect. For a 1:1 current probe connected to the scope's $50\ \Omega$ path, most traditional scopes employ software magnification below 10 mA/div.

To maximize resolution for low-power measurements check to see how sensitive your scope's vertical scaling can be before going into software magnification. As an example, for voltage through the $50\ \Omega$ path, Infiniium S-Series oscilloscopes support vertical scaling in hardware down to 2 mV/div. This is $3\frac{1}{2}$ times more sensitive than the previous generation, Infiniium 9000 Series.

Let's take a resolution sensitivity example using a current probe. With a N2820A current probe attached with a 100 m Ω sense resistor, the S-Series oscilloscope can be scaled at 1 mA/div, full screen value will be 8 mA. Resolution will be a value of 8 mA divided by 1024 quantization level, or 8 μ A.



Traditional scope
 – 8 bits of vertical resolution
 – $2^8 = 256$ Q levels

313 μ A



S Series ADC
 – 10 bits of vertical resolution
 – $2^{10} = 1024$ Q levels



78 μ A

Minimum resolution
 @ 80 mA full screen

Figure 3(a). Adjusting vertical scaling to a more sensitive setting increases resolution. So does using a scope that has more ADC bits. In this example, the S-Series scope provide four times the current resolution as its 8-bit counterpart when both are at the same vertical scaling of 80 mA.

Sense Resistor Current Probes

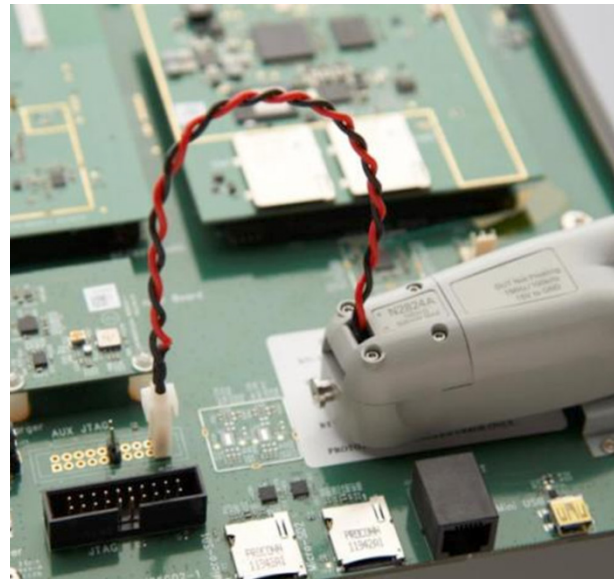
Even if you have an oscilloscope with great resolution, low noise and high number of bits in the ADC your ability to see and make low power signals and measurements will be hampered by the dynamic range and sensitivity of your current probe.

To mitigate dynamic range limitations, oscilloscope vendors have created current probes with higher dynamic range capabilities. The basis for these probes is a small resistor placed in line with a power rail. The probes do not require forming a ring around a power line like conventional current probes, making connections easier. Several connection methods exist for users who have designed in a connection method, as well as for users who need to make a connection, but didn't initially modify their design for current probe measurement consideration.

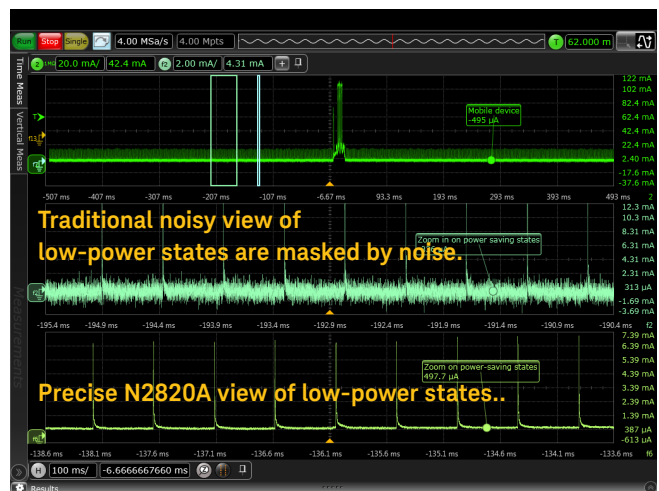
When sense resistor probes are placed in line with power rails, current flows across a very small resistor in the probe head. The voltage drop across the resistor is measured, and based on the knowledge of the resistor value, current values can be calculated and presented continuously on the scope. The probing technology creates a very small change in the power rail voltage known as the burden voltage.

Sense resistor current probes feature an additional capability to address dynamic range limitations. The voltage drop across the sense resistor creates an opportunity for designers that didn't exist with conventional clamp current probes. Sense resistor probes often include technology that features two different gain circuits. One low-gain circuit provides a conventional view of the current signal by presenting the entire signal to the scope. A second circuit provides a higher gain view of a specific vertical region of the waveform. This allows the probe to clamp around a narrower vertical region and to present just this region to the scope resulting in a dramatic increase in dynamic range up to 20,000:1 and seeing currents as small as 500 nA.

To learn more about traditional clamp on current probes vs a sense resistor technology to make low-power measurements, refer to the application note titled *Revolutionary Probing Technology in Current Probes to Make Low-Power Measurements* listed at the end of this document.



4(a)



4 (b)

Figure 4. Keysight's N2820 Series current probe is an example of this probing technology. The probes come with pre-defined probe heads that have sense resistors of 20 mΩ and 100 mΩ, or a user can customize a probe head with a sense resistor of another value. The sense resistor technology coupled with clamped gain circuits allows users to see currents as small as 500 nA. The probe allows users to see a zoomed-out view simultaneously with a zoomed-in view of low-power activity as shown in Figure 4(b).

Noise Reduction

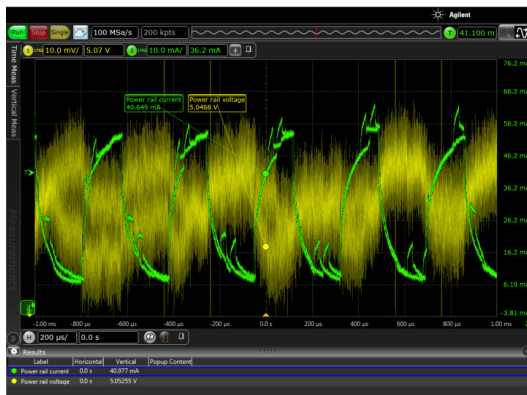
The application note previously discussed challenges associated with making power measurements when signal values are buried in the noise of the probe/oscilloscope. Current probes generally have more noise than the oscilloscope. Evaluating your scope's ability to reduce overall noise is critical for low-power measurements.

Bandwidth limiting is one way to reduce unwanted broadband noise. Current probes have frequency responses that limit bandwidth. For example, your current probe may have a bandwidth limit of 3 MHz. Turning on a 20 MHz analog filter

on the scope will not further reduce overall bandwidth, but will eliminate some additional broadband noise.

If your signal is repetitive, turning on averaging will significantly reduce the noise of low-power signals. Averaging is a great noise reduction technique and the more averages, the greater the noise reduction. Users need to remember that averaging is only applicable to repetitive signals, and that while averaging impacts displayed waveforms, averaging doesn't reduce signal noise on the trigger path.

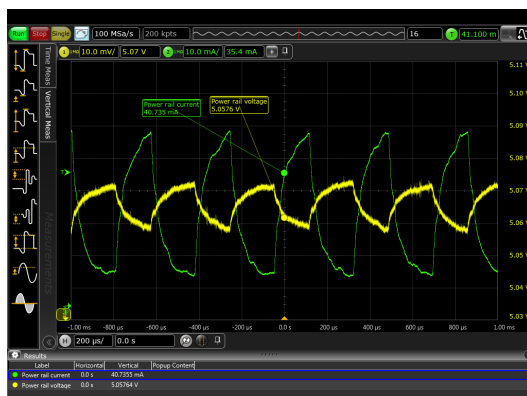
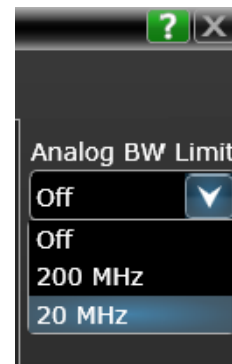
If your signal isn't repetitive, high-res mode is another technique that can assist in noise reduction. High-resolution mode combines adjacent samples and performs a low-pass DSP filter to reduce noise. This oversampling technique works on signals that aren't repetitive, or can be employed in combination with averaging. The tradeoff of turning on high-res mode is limiting overall bandwidth if your scope isn't architected with an excess sample rate to bandwidth ratio.



Initial signal with no noise reduction



Same signal with BW limiting of 20 MHz



Same signal with averaging additionally applied

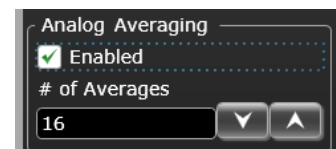


Figure 5. Noise reduction techniques enable better viewing and measurement for low-power signals. A low-power USB signal is shown without any noise reduction (top), with bandwidth limiting (middle), and with averaging (lower).

Power Calculations

When attached to scope inputs, current probes report current magnitude. Often voltage from a power rail stays at a nearly constant DC value allowing measurements from a current probe to provide a good relative approximation of current consumption without hooking up an additional voltage probe. Transitioning between low-power and higher-power states when current changes typically results in voltage variations. To make more accurate power measurements it is often desirable to simultaneously connect probes for voltage and current. Users can then use a math function to multiply the results to show instantaneous or rms power values.

Low-power measurements can have additional math computational requirements, especially when measuring power consumption over a fixed period of time, or during a particular mode. For this reason, it's critical to evaluate what math and gating capabilities are available for your scope. As an example, a user might need to multiply a constant times channel 1 current, and add this value to a second constant multiplied by channel 2 current results. Or a user may want to multiply current times voltage and integrate this power measurement over a certain period of time. For this reason, users will want to see what math capabilities are available for a specific family of scopes.

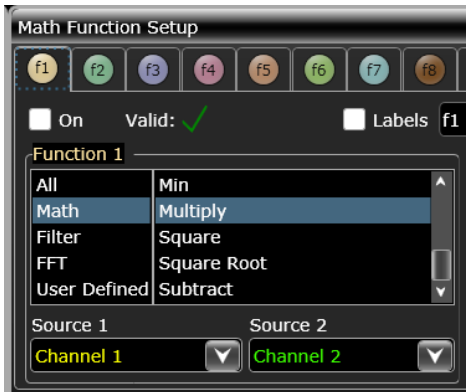


Figure 6. With channel 1 connected to a current probe and channel 2 connected to a voltage probe, a math function can be used to calculate instantaneous or rms power. Infiniium scopes provide the proper units and will show "watts" when doing power calculations as shown above.

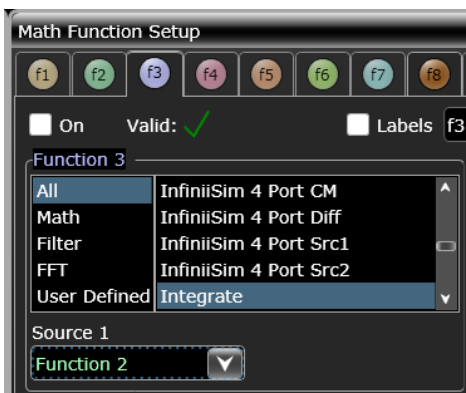


Figure 7. Infiniium scopes offer 16 independent math functions. An integration function can be used to calculate the total energy under a specific power waveform as shown.

Gating

Gating is a capability that oscilloscopes provide which is helpful for low-power measurements. Users can specify a gated region and measurement results can be set uniquely for this specified horizontal region. When selecting a scope for low-power measurements, find out what the scope's gating capabilities are. How many gates? How easy is it to make measurements on each gated region?

As an example, Infiniium S-Series oscilloscopes offer 16 independent math functions. Each function can operate on a channel or on another function. A variety of math operators are available including multiplication, addition, integration, differentiation, and others required for power calculations. Measurements can be made on channels or on math functions. This makes it easy to report results in the radix that makes sense. Figure 9 shows an example of a USB power measurement. Measurement results in this example are reported in watts for power, coulombs for charge, and joules for energy. All of the unit values were calculated automatically by the oscilloscope's analysis engine and its knowledge of which probes were identified as current probes or voltage probes.

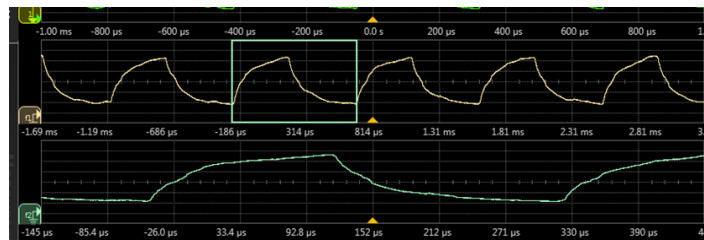


Figure 8. Infiniium S-Series offer measurement gating or any region specified, by using one of the available 16 math functions as a gate. Measurements and analysis can be made uniquely on each gated region. In the example above a gate has been applied to the orange waveform. The gated region is shown in green.



Figure 9. Keysight's Infiniium S-Series provides math, gating, and measurements to report low-power measurement in the correct unit designation values such as watts, joules, and coulombs. This figure shows a low-power USB power measurement. Channel 1 was connected to the power rail for voltage measurements while channel 2 provides a current measurement on the power rail. Power, energy, and charge measurement results have been set uniquely for the designated gated regions.

Roll Mode

Another useful oscilloscope feature for low-power testing is roll mode. In roll mode, the oscilloscope operates with a much slower time base setting and continuously. The updates show the waveforms moving from right to left on the display. This allows users to see changes over an extended period of real time, in real time—often tens of seconds. For example, connecting an oscilloscope in roll-mode to a mobile phone will show a continuously low power state with frequent high power states appearing periodically when the phone makes a short-term exchange with a nearby base station. Roll mode enables engineers to get a high-level view of power activity as it is happening in real time. At any point in time when an event of interest occurs, the user can press stop on the oscilloscope and it will show on its display the activity leading up to the specified event.

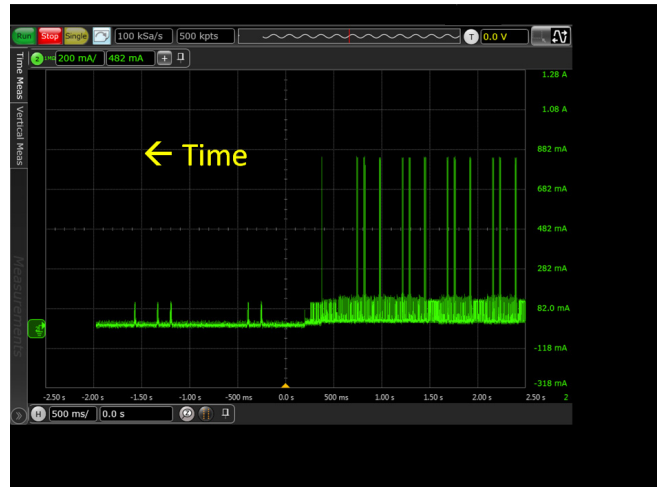


Figure 10. Roll mode provides a method for continuously viewing large amounts of time associated with system activity. Roll mode can be particularly useful for seeing power transitions in real time.

Summary

If you are developing low-power technologies or products, your choice of scope and current probes will dramatically impact your ability to test and analyze. Several innovations in oscilloscopes and current probe technology target better testing of low powered designs. Infiniium S-Series and the N2820A Series of current probes provide capabilities not found elsewhere for low-power measurements. This includes a 10-bit ADC for increased resolution, vertical scaling down to 2mV/div for 1:1 voltage probes to better view small signal detail, sense resistor and high-gain circuits for measuring small current values, advanced math, up to 16 independent gated regions, measurement on both waveforms and math functions, bandwidth limit filters, and high-resolution mode and averaging for noise reduction.

Related Literature

Publication title	Publication type	Publication number
Keysight Infiniium S-Series Oscilloscopes (500 MHz to 8 GHz)	Data sheet	5991-3904EN
N2820A/21A High-Sensitivity, High Dynamic Range Current Probes	Data sheet	5991-1711EN
New Probing Technology Enables High Sensitivity, Wide Dynamic Range Current Measurement	Application note	5991-1951EN
Evaluating Current Probe Technologies For Low-Power Measurements	Application note	5991-4375EN

To download these documents, click on the publication number.

Product web site

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