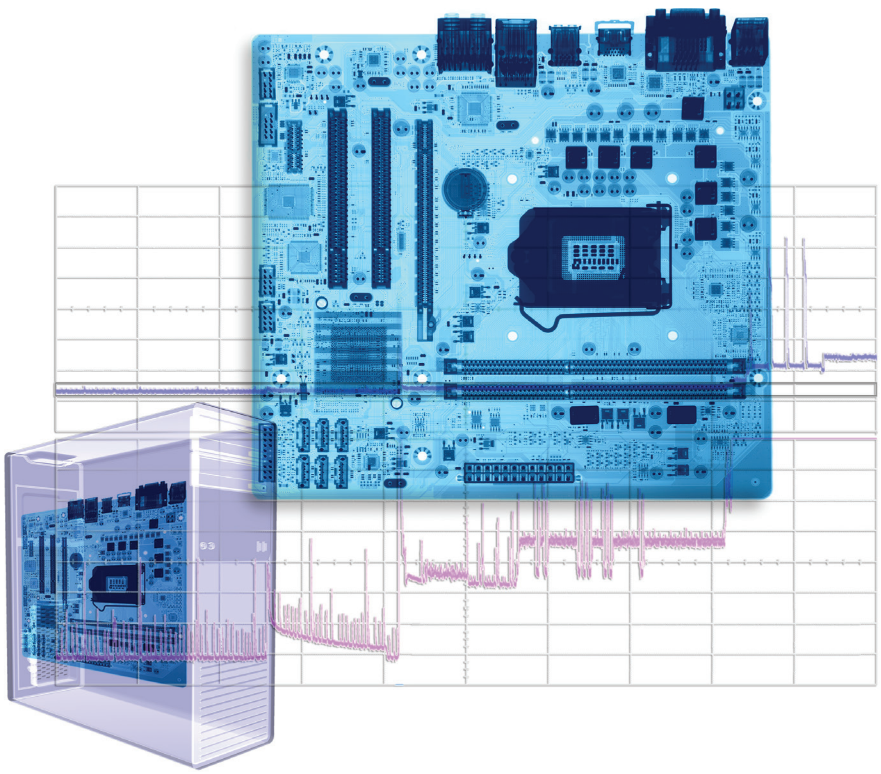
Evaluating Current Probe Technologies for Low-Power Measurements

Application Note



Introduction

To continue to make advancements in low power designs, be they battery powered devices or "Green" environmental friendly devices, designers are tasked with devising ever more sophisticated power saving schemes. Designers of low power products require more sophisticated tools to help them develop these cutting-edge power saving methods. Oscilloscopes and an accompanying current probe are being increasingly used to develop, characterize and debug power saving alternatives. This application note will evaluate oscilloscope current probes for their usefulness in making low power measurements. It will also demonstrate a new class of current probes from Agilent Technologies that will transform the way low power measurements can be made. This gives you a new option that will revolutionize the way you think about and make low power measurements in your product design.

Evaluation Criteria—Needs

These are several areas that should be considered as you look at evaluating an oscilloscope current probe for a low-power application. Since the goal is to reduce the overall power consumption of the device and to monitor the power dissipation, it follows that we can look at the current draw to characterize that power. Making measurements of current in low power applications presents challenges and needs that can be unique to these situations.

- Repeatability—as designers optimize their systems, making changes to the hardware or software, they want to know if those changes made it better, worse, or the same. They don't want measurement variation to overshadow the impact of their changes.

- Sensitivity—it is common for low power designs to have several modes of operation including a very low power state. In the low power state the current is usually less than 1 milliamp, so it is necessary to have a measurement system that is sensitive enough to detect that low current.

- Dynamic range and resolution—as low power products enter and exit their power saving modes the current can change suddenly from sub-milliamp to amps—a range of 1,000:1 or greater—creating the need to measure sub-milliamp current in the presence of amps.

- Small size—the size of an oscilloscope probe proportional to the size of the target has always been valued by users. A small probe means less physical disruption of the target and enclosure; this is especially important for mobile electronics and other high density products.

- Operating temperature range—many low power circuits are part of a product operating in high or low temperature environments. Designers of wireless sports trackers, wireless medical devices, servers, laptops, mobile phones, remote surveillance and monitoring equipment, et cetera would like to test their products at extended temperature ranges.

Current Probes Available

An oscilloscope current probe is actually a current transducer producing an output voltage proportional to the input current being measured. The output voltage is acquired by the oscilloscope, scaled appropriately then displayed and measured in amps. There are many different methods to make current measurements, but presently there are two typical methods employed by oscilloscope current probes and thus two different types of current probes to evaluate:

1. Clamp-on current probes—these probes sense the magnetic field produced by current flowing through a conductor.

2. Sense resistor current probes—these probes are actually voltage probes that measure the voltage across a resistor produced by current flowing through it. This is similar to how a digital multimeter (DMM) works.

A brief review of the theory of operation of the two types of current probes will provide a foundation for our comparison.

Figure 1. Clamp on current probe example; Agilent Technologies 1147B

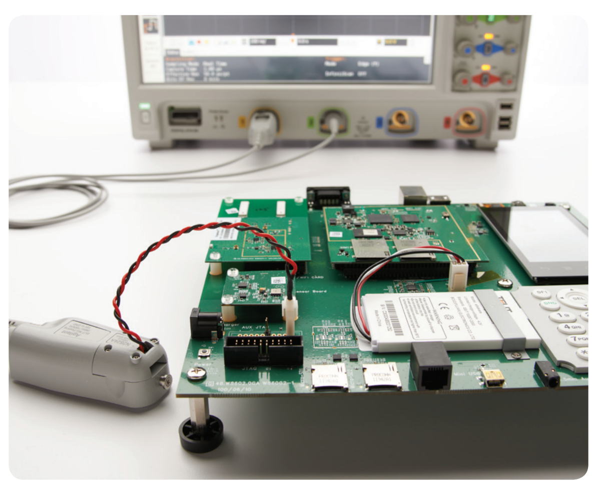


Figure 2. Sense resistor current probe example; Agilent Technologies N2820A

Theory of Operation

Clamp-on current probes

There are models of this type of current probe available from all oscilloscope vendors. These probes have been in wide use since the 1960's for measuring power and have changed very little since that time. These probes typically measure both DC and AC and are comprised of a Hall Effect element, for measuring DC, teamed with an AC transformer for measuring AC. They have typical bandwidths from DC to 100 MHz.

The Hall Effect element, shown conceptually in Figure 3, is comprised of a conducting plate through which a current, I, is passed. When placed close to wire or trace with current flowing through it, the Hall Element is exposed to the magnetic field produced by the current flow of the device under test. The magnetic B field, through the Lorentz force, causes the electrons to move to one side of the plate resulting in a voltage across the plate. The voltage is proportional to the B field which in turn is proportional to the current flowing through the wire or trace.

The AC portion of the current probe is a current transform with a ferrite core. The ferrite core is actually split (shown in Figure 3), so that the core can be open and closed to clamp around the wire under test. The Hall Element is assembled into the core resulting in an AC and DC measurement.

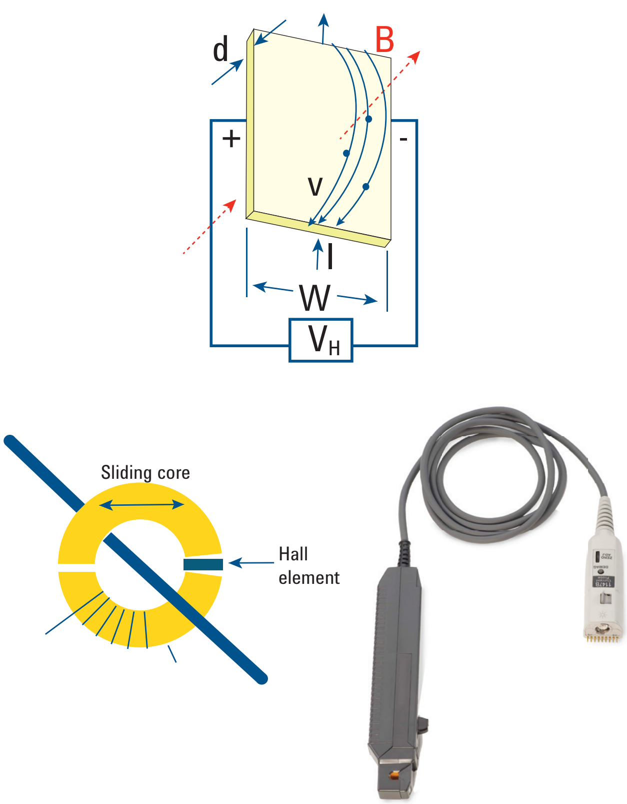


Figure 3. Elements of an AC/DC clamp-on current probe

Sense resistor current probes

Presently this type of oscilloscope current probe is only available from Agilent Technologies—the N2820A and N2821A current probes. Used as a current probe this type of probe is actually a high sensitivity, high dynamic range, differential voltage measuring probe. Shown conceptually in Figure 4, the probe contains two differential amplifiers that measure the voltage across a sense resistor produced by current flowing through the resistor. The resistor can be placed on the high side or the low side of the circuit (Figure 4 shows the resistor on the low side). The two amplifiers have different gains producing different sensitivities and providing a wide dynamic range measurement. When the probe is attached to the oscilloscope, the oscilloscope software automatically displays measurements in amperes. The probe comes with a 20 mΩ and a 100 mΩ sense resistor head whose resistance value is automatically sensed by the scope when the probe is connected to the scope. The probe also comes with an user defined head which allows the probe to be used with the user's sense resistor on the target. The user will need to input the value of the sense resistor being used and the oscilloscope software scales the display and measurements appropriately.

It is worth noting that some designers of low power products use current sense resistors in some fashion or other to measure current in their low power systems. Some use a DMM to measure the voltage across the resistor and calculate the current while others have built their own measurement devices similar to the sense resistor current probe. These approaches are sometimes adequate but most users prefer a complete solution that is integrated with the oscilloscope. It may seem curious that the DMM is not being used to directly measure current. That is because DMMs use a resistor of approximately 100 Ω in the µA—mA range. The I*R voltage drop across the 100 Ω resistor –knows as burden voltage—in addition to the I*R drop through the test leads and connections is too large for these users to tolerate.

Throughout this application note we will be using the N2820A/21A to demonstrate the characteristics of a sense resistor current probe.

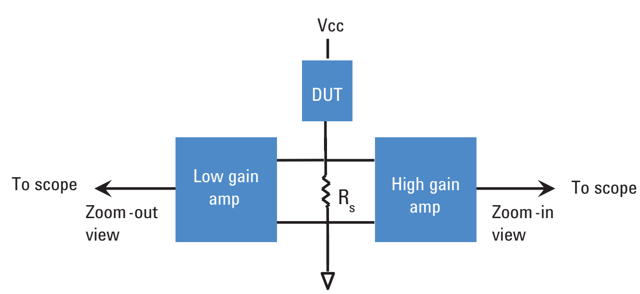


Figure 4. Elements of a sense resistor current probe

Repeatability

Some power saving approaches may only result in small changes in the current being drawn but the accumulated impact they have over a long period of time can result in big savings, for example sleep current. Figure 5 shows the current profile of a typical battery powered device. Because these devices can have long durations of sleep between short intervals of activity a small change in sleep current can add up to big savings.

Repeatability—clamp-on current probes

Clamp-on current probes suffer from small repeatability errors, 10—100mA's is common. This type of error is small when measuring 1A—50A's, typical for a switch-mode power supply, but is unacceptable when measuring sleep or active current in a low power device. There are two primary sources of repeatability error in clamp-on current probes—residual magnetism and thermally or mechanically induced stress. When the clamp-on probe is exposed to the larger current of the communicate cycle shown in Figure 5 there will be some residual magnetism of the ferrite core. This residual magnetism creates an erroneous output from the Hall Effect element. Additionally, the Hall Effect element is susceptible to the Piezoresistive effect where thermal or mechanical stresses change the resistance of the Hall Effect element, thus changing the voltage across the element. Current probes are active probes and therefore self-heating which in turn results in induced thermal stresses on the Hall Element. The active circuit inside current probes consumes current proportional to the current it is measuring so the thermal stresses vary as the current the probe is measuring varies. The end result is that over a cycle like the one shown in Figure 5 the error could be 100 to 1000 times larger than the sleep or active current being measured.

Repeatability—sense resistor current probes

When measuring the current in a profile like that shown in Figure 5 the sense resistor used by the N2820A/21A current probes will experience temperature fluctuations due to the small amount of power dissipated in the resistor. The thermal coefficient for current sense resistors is typically 20—100 ppm. If the resistor experienced a 100 °C temperature difference over a cycle like that shown if Figure 5 such that there was a difference of 100 °C from the first time it measured sleep current to next time it measured sleep current the effect would be 0.2% to 1%. Compared to the clamp-on type current probe with hall effect sensor on it, the N2820A/21A current probes see very little offset drift with time and temperature.

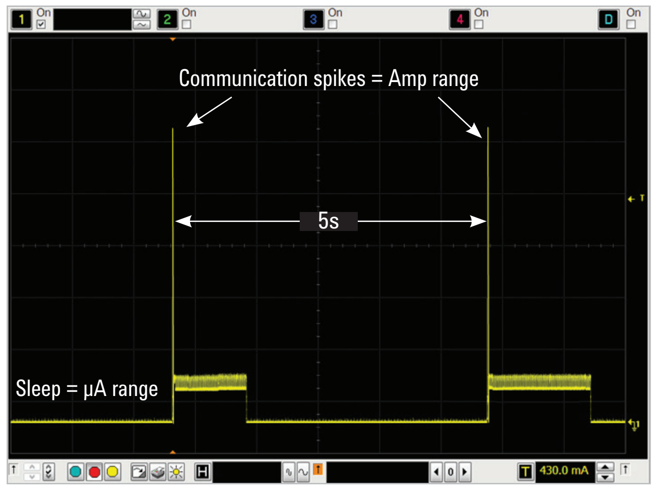


Figure 5. Current profile of a typical battery powered device, in this case a mobile phone in standby mode. Over the 5 sec timespan this mobile phone can go from sleeping in the µA range to communication in the Amp range, so the current probe needs to be able to measure that range µA to Amp.

Sensitivity

Current probe sensitivity refers to the probes ability, as a current transducer, to produce an output voltage large enough to be measured by the oscilloscope when the probe is measuring small current like that found in low power designs, typically < 1mA. In other words, how small a current can be measured with the probe? There are several factors that determine the minimum measurable current, primarily the probes current-voltage transfer function and the noise of the probe/oscilloscope combination. Oscilloscope probe manufacturers publish this number saving the user the burden of determining it.

Sensitivity—clamp-on current probes

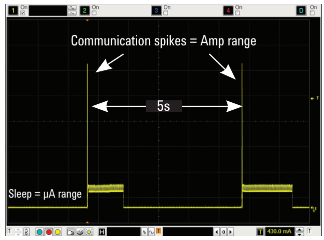
The clamp-on current probes suitable for measuring small current have current--voltage transfer functions of either 0.1 V/A or 1.0 V/A. Current probes with a 0.1 V/A transfer function will output 0.1 V to the oscilloscope per 1 A being measured. With a 0.1 V/A clamp-on current probe connected to the oscilloscope the smallest V/div is 10 mV/div. Factoring in probe/oscilloscope noise the published minimum measureable current using this style of probe is approximately 10–30 mA. While a 1.0 V/A clamp-on current probe will output 1 V per 1 A being measured, the published minimum measurable current is 1–3 mA. Low power designs frequently have current less than 1 mA, which makes clamp-on current probes not well suited for this application.

Sensitivity—sense resistor current probes

The sensitivity of a sense resistor current probe is adjustable by changing the value of the sense resistor. A larger resistor creates a larger voltage for the probe to measure. The Agilent N2820A and N2821A sense resistor current probes have μV sensitivity which means that the voltage across the sense resistor can be quite small. Good results can be achieved with voltage drops across the resistor of less than 50μV. The published minimum measurable current for these probes is 500 nA, making them well suited for measuring small current in low power designs.

Resolution and Dynamic Range

Recall from Figure 5, that a low power device changing states can rapidly increase or decrease the current in the circuit by a factor of 1,000:1 or more. To be able to measure both the maximum and minimum current at the same time on the oscilloscope requires a current probe/oscilloscope solution with enough dynamic range to cover the large swing while still providing the resolution to measure the small signals.



Resolution and dynamic range—clamp-on current probes

Consider, as an example, a sleep current of 300 μA and a peak current of 2 A—a 6,700:1 ratio. (For this example we will ignore the sensitivity limitations of the clamp-on current probes and the current probe/oscilloscope noise.) Assume an 8-bit oscilloscope is set-up so that the 2 A peak current fills the screen. A scope's ADC with a resolution of 8 bits can encode an analog input to one in 256 different levels, since $2^8 = 256$. Therefore the smallest resolvable signal for the oscilloscope is 2 A/256 or 8 mA. To resolve 300 μA in the presence of 2 A would require 13-bits.

Resolution and dynamic range—sense resistor current probes

As we have discussed the Agilent N2820A and N2821A sense resistor current probes have two probe amplifiers measuring the voltage across the sense resistor. The two amplifiers have different gains producing different sensitivities providing a wide dynamic range measurement. The N2820A has two outputs, one for each amplifier, which can be connected to 2 channels of the oscilloscope. The two channels provide a "zoomed-in" view and a "zoomed-out" view simultaneously. This is shown conceptually in Figure 6. Figure 7 shows the N2820A in use measuring the transition from sleep to communicate for a mobile phone. Notice the signal detail captured in the sleep state using the N2820A.

See the details without losing sight of the big picture

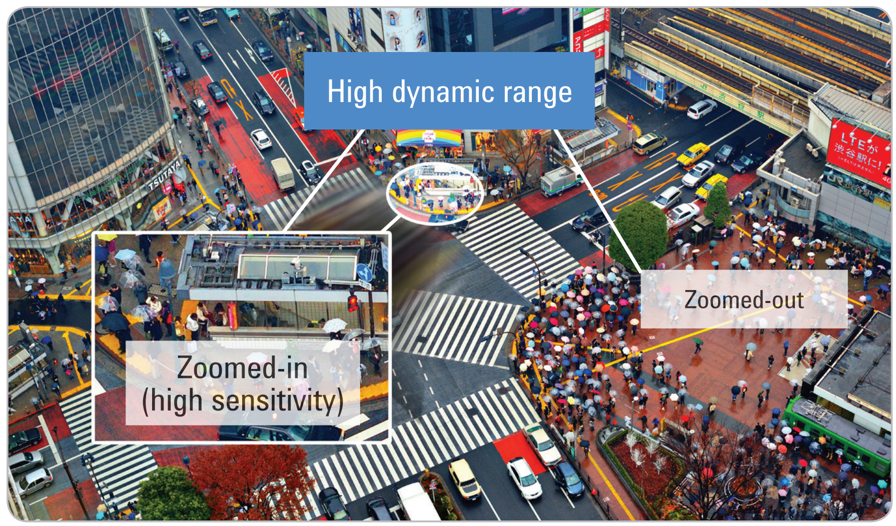


Figure 6. Zoomed-in and Zoomed-out approach of the N2820A sense resistor current probe.

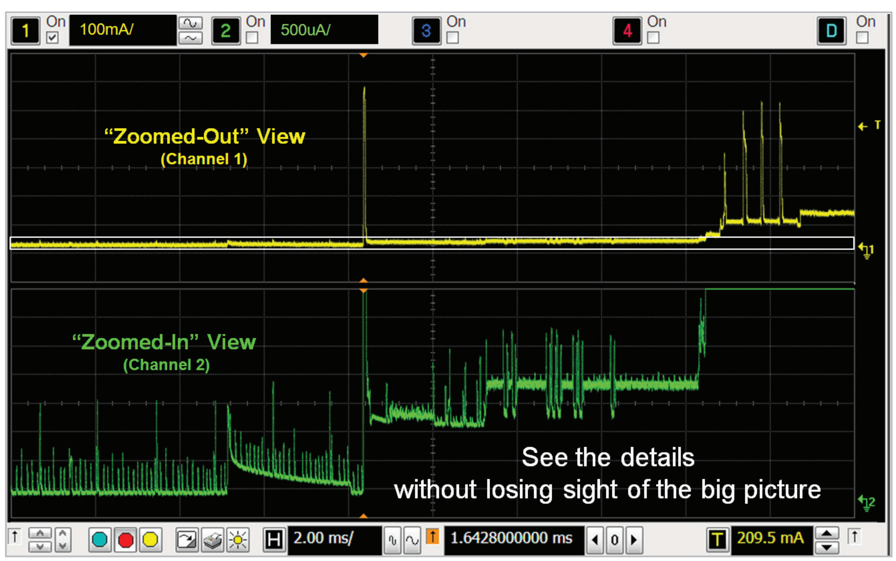


Figure 7. The N2820A in use measuring the current for a mobile phone.

Continuing to use the previous example of a device with a minimum current of 300 µA and a maximum current of 2 A, we can illustrate the dynamic range of the N2820A current probe. Placing a 0.02 Ω 0.5 W resistor in the circuit, the N2820A is capable of measuring current as small a 250 µA and as large as 5 A—a ratio of 20,000:1. Referring to the table (Figure 8) it can be noted that a resistor value of 0.1 Ω could have also been used (min—50 µA, max 2.2 A). Typically the smallest resistor value necessary to make the measurement is the preferred choice.

Sense resistor value	Minimum measurable	Maximum measurable	Ratio max/min	
0.001 Ω	5 mA	22 A	4,400:1	Limited by resistor power of 0.5 W used in the example
0.005 Ω	1 mA	10 A	10,000:1	
0.02 Ω	250 µA	5 A	20,000:1	
0.1 Ω	50 µA	2.2 A	44,000:1	
1 Ω	5 µA	710 mA	142,000:1	
10 Ω	500 nA	120 mA	240,000:1	

Figure 8. Measurable current ranges for the N2820A and N2821A current probes based on a 0.5 W sense resistor on the device under test.

Small Size

The size of an oscilloscope probe proportional to the size of the target has always been valued by users. If the probe is large relative to the target it is probing the user will need to make drastic modifications to the enclosure or configuration of the target. This can adversely affect shielding, airflow and functionality, not to mention being inconvenient.

Small size—clamp-on current probes

One of the primary uses for clamp-on current probes is in the design and verification of switch mode power supplies where they are clamped around the wires of the supply. In this type of application their size is rarely a concern and they are valued for their convenient clamp-on operation. In low power applications the target is often small or densely packed and the circuits of interest are contained on printed circuit boards leaving no wires for the probe to clamp-on to. To give you an idea of the size delta, Figure 9 shows the relative size of a clamp-on current probe and a mobile phone.

Figure 9. Size comparison of a clamp-on probe and a mobile phone.

Small size—sense resistor current probes

Figure 10 shows the N2820A probing an accelerometer inside of a small mobile wireless device. The sense resistor used is a 0402 SMT resistor with small 42 AWG wires connected to the probe. The small wires easily route out through existing openings in the enclosure. Because the probe is measuring the voltage across the sense resistor no current is flowing through the wires, so very small wires are acceptable.

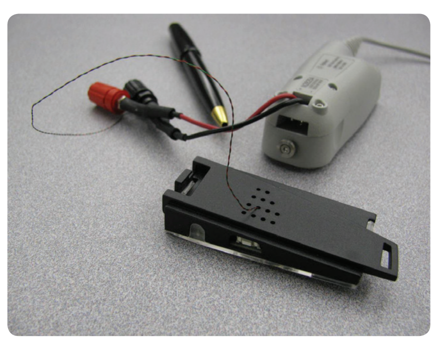


Figure 10. Agilent N2820A current probe connected to measure the current from a mobile wireless device.

Operating Temperature Range

Mobile devices can be exposed to temperature extremes either by being in contact with the human body or the outdoor environment. Automobile emergency assist electronics for example operate in a low power state when the car is not running and need to function over the temperatures extremes the car is exposed to. Designers of these and similar products desire to test their products inside of an environmental temperature test chamber. Figure 11 shows the desired operating temperature testing ranges of some popular products.

Operating temperature range—clamp-on current probes

Oscilloscope manufactures publish the operating temperature ranges for their clamp-on current probes. Clamp-on current probes have a typical operating temperature range of 0 to 50 °C. Comparing this range to those shown in Figure 11 it can be concluded that clamp-on current probes cannot be used by many applications to make measurements inside an environmental temperature chamber. Additionally, it is not practical to create a loop of wire extending the circuit outside the chamber because it would alter the function of the circuit under test significantly.

Operating temperature range—sense resistor current probes

The N2820A and N2821A measure voltage drop across a sense resistor. The probe can be connected to the sense resistor through a length of twisted-pair wire up to 6 feet long or shielded twisted-pair wire up to 10 feet long. In this way the target device with sense resistor can be placed inside of the temperature chamber while leaving the N2820A/21A outside of the chamber. This gives the Agilent N2820A and N2821A sense resistor current probes the ability to make current measurements from –55 to 150 °C. Figure 12 and 13 illustrates this type of measurement set-up.

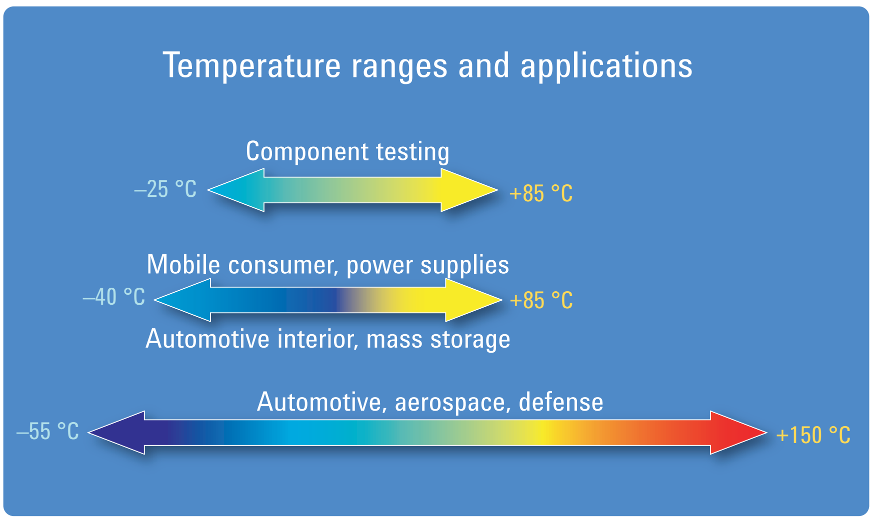


Figure 11. Operating temperature ranges for popular applications

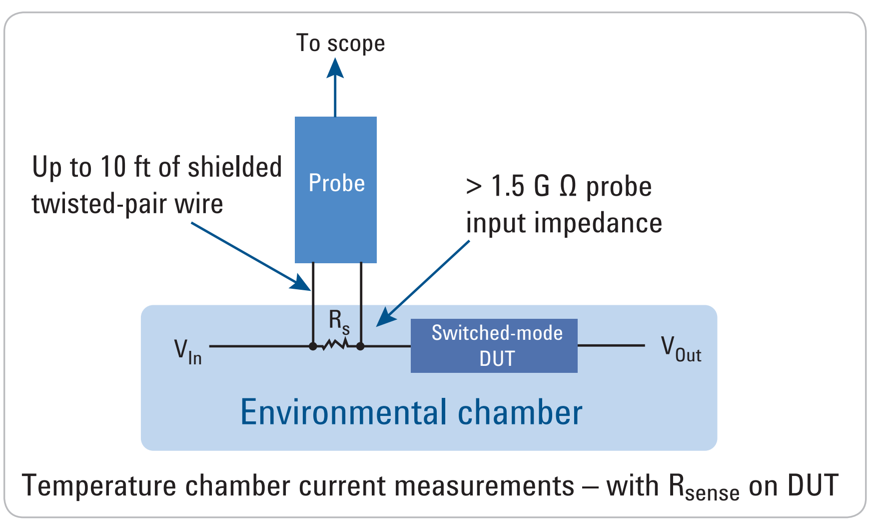


Figure 12. Using the Agilent N2820A/21A sense resistor current probes to make measurements on a switched mode DC/DC converter in a temperature chamber.

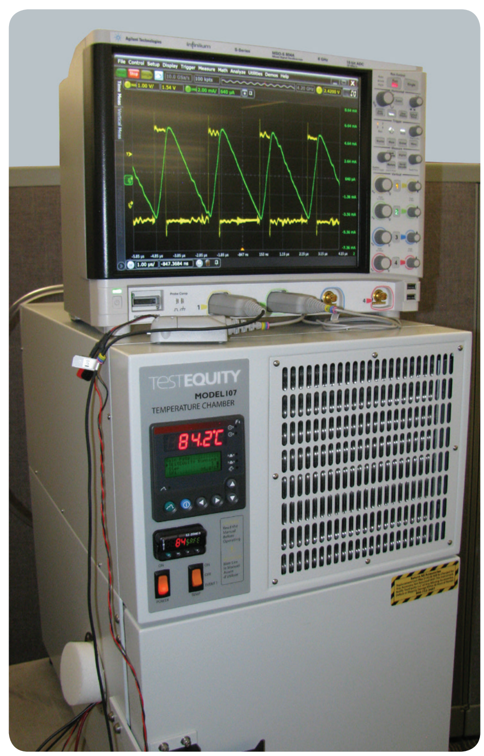


Figure 13. The twisted-pair wire enables the probe itself to be outside of the temperature chamber.

Summary and Conclusion

Oscilloscope current probes are widely used to make power measurements. Low power measurements place a premium on a probes repeatability, sensitivity, resolution, dynamic range, size and measurement temperature range. At present, two types of AC/DC oscilloscope current probes are available—clamp-on current probes and sense resistor current probes. With these considerations in mind, the clamp-on current probes do not provide the necessary features to be useful for low power measurements. However in each of these categories the option of a sense resistor based current probe does possess the necessary capability to make accurate and informative low power measurements. The Agilent N2820A and N2821A sense resistor current probes can address all of the challenges presented and offer a few additional benefits when used with an Agilent technologies oscilloscope. See below for more information on scope compatibility and where to go for more information for the N2820A and N2821A current probes.

Oscilloscope Features and Probe Compatibility

	InfiniiVision 3000 X-Series	InfiniiVision 4000 X-Series	InfiniiVision 6000 X-Series	Infiniium S-Series
Bandwidth	100 MHz – 1GHz	200MHz – 1.5GHz	1 GHz – 6GHz	500MHz – 8GHz
Sample rate (max)	4 GSa/s, 5 GSa/s	5 GSa/s	20 GSa/s	20 GSa/s
Memory (max)	4 M points	4 M points	4 M points	800 M points
ADC resolution	8 bits	8 bits	8 bits	10 bits
Analog channels	2 or 4	2 or 4	2 or 4	4
Digital channels	16-ch MSO	16-ch MSO	16-ch MSO	16-ch MSO
Update rate (max)	1,000,000 /sec	1,000,000 /sec	450,000 /sec	1,000 /sec
N2820/1A current probe	√	√	√	√
1146B clamp on current probe	√	√	√	√
N2780/1/2/3B clamp on current probes	√	√	√	√

Unique features using N2820A together with an Agilent oscilloscope

Current consumption over time measurement

A new measurement becomes available with the ability to see both the high power and low power on the same screen. With these current waveforms captured, you now can calculate the average current consumption of the system over time. Agilent's oscilloscopes provide an area under the curve measurement (charge) where you can easily calculate the integrated current consumptions over time.

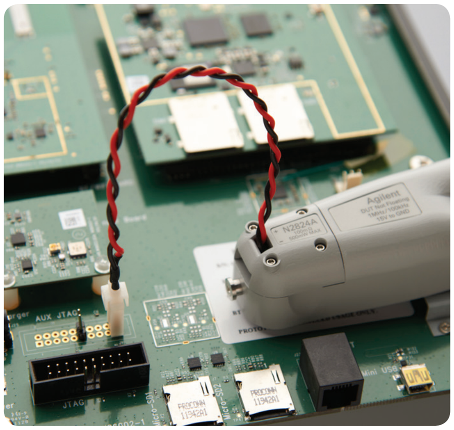
Overdrive protection

Another unique feature of using the N2820A current probes with Agilent oscilloscopes is the way the probe accounts and handles the rapid change in input signals during these quick transitions from low to high. The zoomed-in channel first amplifies low-level signals, and then "clamps" the input signal in order to not overdrive the scope's input amplifier when the input signal switches from a standby/low-level mode to an on/high-level mode, which can cause distortion.

Agilent Current Probe Overview

N2820/21A High sensitivity current probe

The ultra-sensitive N2820A AC/DC current probe can support measurements from 50 uA to 5 A on Agilent oscilloscopes. The N2820A interface uses a make-before-break (MBB) connector, allowing you to quickly probe multiple locations on your DUT without having to solder or unsolder the leads. The N2820A 2-channel current probe connects to two oscilloscope channels to provide simultaneous low- and high-gain views for wider dynamic range measurement, while the N2821A 1-channel current probe provides one user-selectable view at a time.



Agilent N2820/21A resistor sense current probe

1146B 100 kHz current probe

The 1146B AC/DC current probe provides accurate display and measurement of currents from 100 mA to 100 Arms, dc to 100 kHz, without breaking into the circuit. A battery level indicator and overload indicator help ensure proper readings. It connects directly to the scope through a 2-m coaxial cable with an insulated BNCDC to 100 kHz, 0.1 V/A; 100 mA to 10 Arms

Agilent 1146B current probe

1147B/N2893A and N2780/81/2/3B current probe

The 1147B/N2893A/N2780B Series current probes are high bandwidth, active current probes, featuring flat bandwidth, low noise (2.5 mArms) and low circuit insertion loss. In conjunction with the power supply (model N2779A), the N2780B Series probe can be used with any oscilloscope having a high-impedance BNC input. The 1147B/N2893A current probes come with AutoProbe interface that does not require an external power supply.

Agilent N2780 family of current probes

Related Literature

Publication title	Publication type	Publication number
Agilent InfiniiVision X-Series literature		
Agilent InfiniiVision 6000 X-Series Oscilloscopes (1 GHz to 6 GHz)	Data sheet	5991-4087EN
Agilent Infiniium S-Series Oscilloscopes (500 MHz to 6 GHz)	Data Sheet	5991-3904EN
Agilent InfiniiVision 3000 X-Series Oscilloscopes (100 MHz – 1 GHz)	Data sheet	5990-6619EN
Agilent InfiniiVision 4000 X-Series Oscilloscopes (200 MHz – 1.5 GHz)	Data sheet	5990-1103EN
N2820A/21A High-Sensitivity, High Dynamic Range Current Probes	Data sheet	5991-1711EN
Infiniivision Oscilloscope Probes and Accessories Selection Guide	Data sheet	5968-8153EN
Infiniium Oscilloscope Probes and Accessories Selection Guide	Data sheet	5968-7141EN
Evaluating Oscilloscopes for Low Power Measurements	Application note	5991-4268EN
New Probing Technology Enables High Sensitivity, Wide Dynamic Range Current Measurement	Application note	5991-1951EN
7 Hints That Every Engineer Should Know When Making Power Measurements with Oscilloscopes	Application note	5991-9340EN
Evaluating Oscilloscope Signal Integrity	Application note	5991-4088EN

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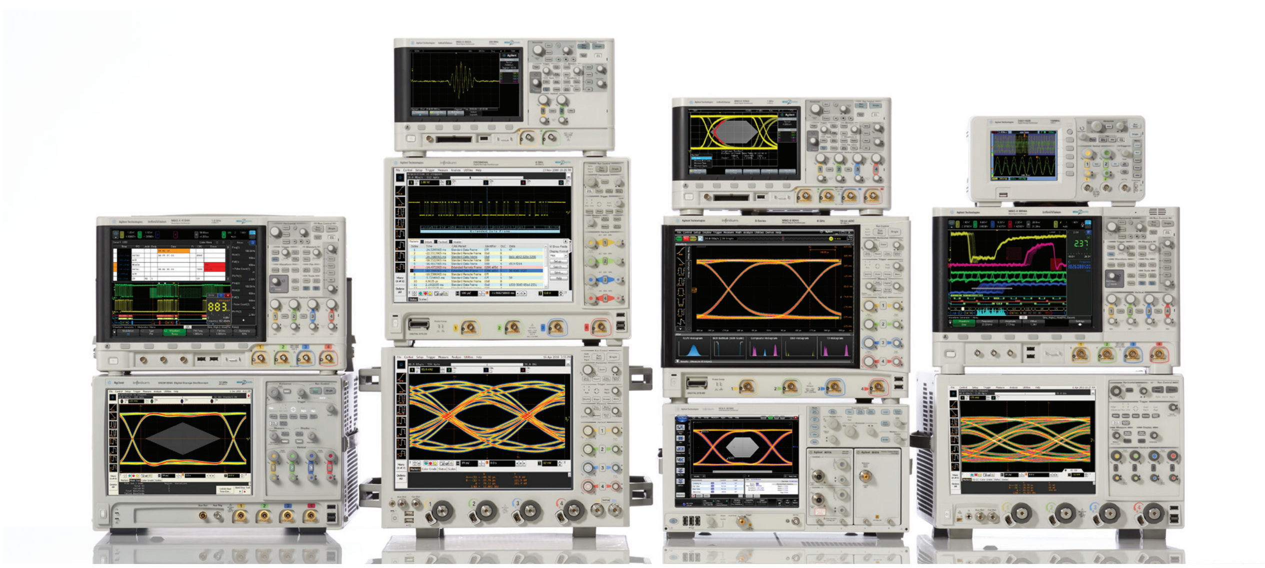

Product web site

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