

Evaluating Oscilloscope Current Probes for Low Power Measurements

Introduction:

Customers expect better battery life or improved energy efficiency from the new products they purchase. Designers of these products require ever more sophisticated tools to develop ever more sophisticated power saving schemes. The oscilloscope and current probe has long been a trustworthy tool for making power measurements. This article will evaluate oscilloscope current probes for their usefulness in making low power measurements.

Evaluation Criteria—Needs:

Measuring current in low power applications presents challenges and needs that can be unique to these situations. Evaluating current probes on these needs will prove beneficial. The needs are:

- Repeatability
- Sensitivity
- Dynamic range and resolution
- Small size

Current Probes Available:

Presently there are two types of AC/DC oscilloscope current probe available:

1. Clamp-on current probes
2. Sense resistor current probes

Theory of Operation:

Clamp-on Current Probes: Models of this type of probe are available from all oscilloscope vendors. They are comprised of a Hall Effect element for measuring DC teamed with an AC transformer.

The Hall Effect element is comprised of a conducting plate through which a small current is passed. Placed close to a wire of a device under test (DUT) with current flowing through it the Hall element is exposed to the magnetic B field produced by the current in the wire. The B field forces the electrons moving across the Hall element to move to one side of the plate resulting in a voltage across the plate. The voltage is proportional to the B field which is proportional to the current flowing through the wire of the DUT.

The AC portion of the current probe is a current transformer with a ferrite core. The ferrite core is split so that the core can be open and closed to clamp around the wire under test. The Hall Element is assembled into the core.

Sense Resistor Current Probes: Presently this type of probe is only available from Keysight Technologies—the N2820A and N2821A current probes. This type of probe uses multiple differential amplifiers to measure the voltage produced across a sense resistor when current flows through it. The amplifiers have different gain producing different sensitivities and can be used in combination to provide a wide dynamic range measurement. The user inputs the value of the sense resistor and the oscilloscope software scales the display and measurements appropriately.

It is worth noting that some designers already use sense resistors 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 use data acquisition units. The DMM is not used to directly measure current because it uses a resistor of approximately 100Ω in the μA — mA range and the resulting $I \cdot R$ voltage across the resistor (burden voltage) is too large for users to tolerate.

Repeatability:

As designers optimize their systems, making changes to hardware or software, they need to know if the changes made it better, worse, or the same. Measurement variation cannot overshadow the impact of their changes. Figure 1 shows the current profile of a typical battery powered device.

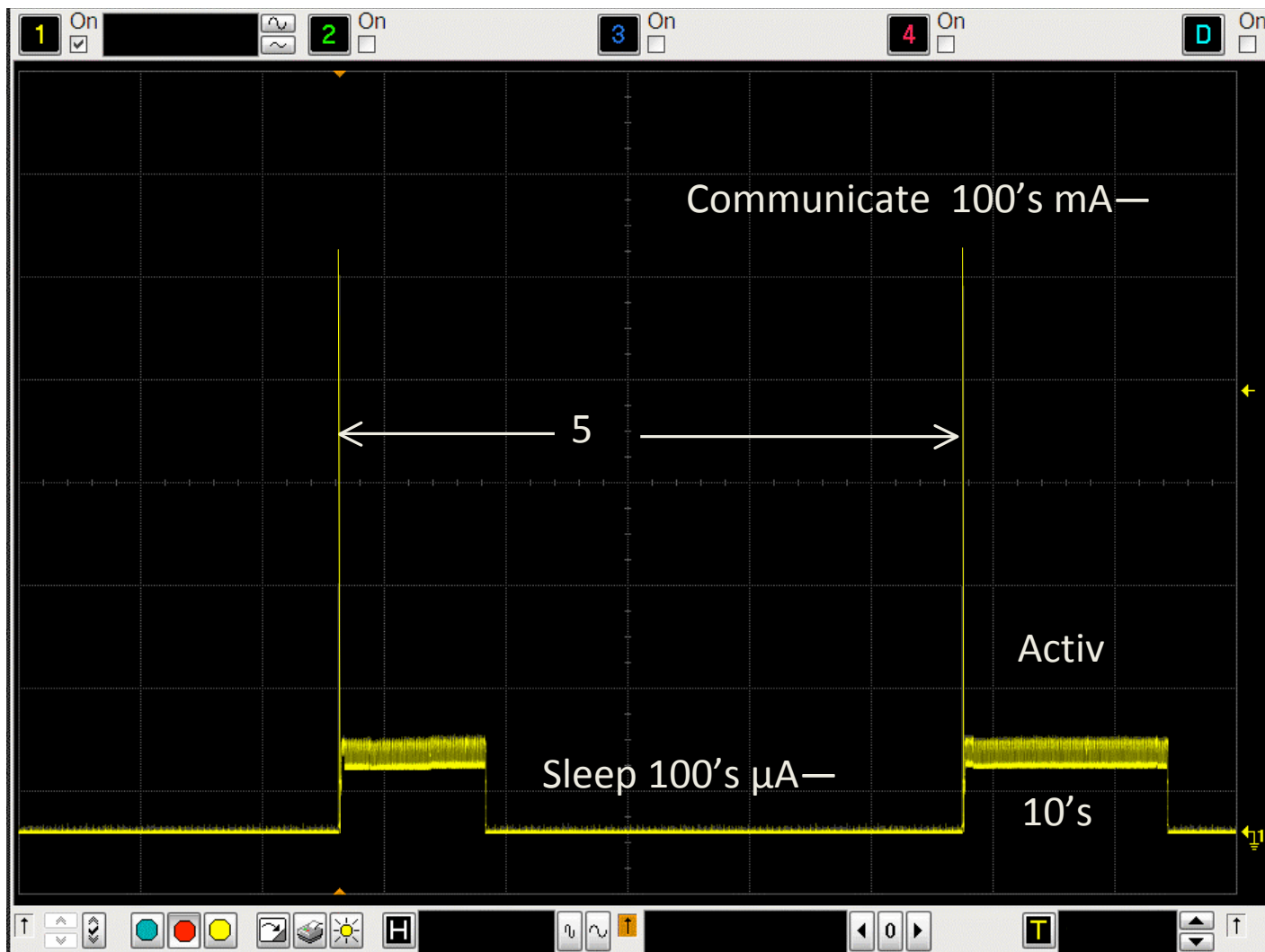


Figure 1—Current profile of a typical battery powered device, in this case a mobile phone in standby mode.

Repeatability—Clamp-on Probes: These probes suffer from small repeatability errors, 10—100mA's is common. There are two primary sources of repeatability error, residual magnetism and thermally or mechanically induced stress. After exposure to the larger current of the communicate cycle shown in Figure 1 there can be residual magnetism of the ferrite core creating an erroneous output from the probe. Additionally, the Hall element is susceptible to the Piezoresistive effect where stresses change the resistance of the Hall element thus changing the voltage across it and changing its output. These probes are active probes, and therefore self-heating, which results in thermal/mechanical stress of the Hall element. The probe circuit uses current proportional to the current being measured so thermal stresses vary as the current the probe is measuring varies. The result is that over a cycle like that shown in Figure 1 the error could be 100 to 1000 times larger than the sleep current.

Repeatability—Sense Resistor Current Probes: When measuring the current in a profile like that shown in Figure 1 the sense resistor will change temperature as the current changes. The thermal coefficient

for current sense resistors is typically 20—100ppm. If the resistor experienced a 100C temperature difference over a cycle like that shown in Figure 1 such that there was a difference of 100C from the first time it measured sleep current to next time it measured sleep current the effect would be 0.2% to 1%.

Sensitivity:

Current probe sensitivity is a probe's ability, as a transducer, to output a voltage large enough to be measured by the oscilloscope when measuring small current. Several factors determine the minimum measurable current, primarily the probe's current-voltage transfer function and the noise of the probe/oscilloscope combination. Oscilloscope manufacturers publish this number saving the user the burden of determining it.

Sensitivity—Clamp-on Current Probes: Probes suitable for measuring small current have transfer functions of 0.1V/A or 1.0V/A. Probes with a 0.1V/A transfer function output 0.1V to the oscilloscope per 1A being measured. Factoring in probe/oscilloscope noise the published minimum measurable current using this style of probe is approximately 10--30mA. A 1.0V/A probe will output 1V per 1A being measured. For a 1.0V/A probe the published minimum measurable current is 1--3mA. These probes are not well suited for measuring current <1mA.

Sensitivity—Sense Resistor Current Probes: Sensitivity is adjustable by changing the value of the sense resistor. Larger resistors create larger voltages for the probe to measure. The Keysight N2820A and N2821A sense resistor current probes have μ V sensitivity meaning the voltage across the sense resistor can be relatively small for the probe to make a measurement. The published minimum measurable current for these probes is 500nA.

Resolution and Dynamic Range:

Recall from Figure 1, 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. Measuring both the maximum and minimum current at the same time requires a current probe/oscilloscope combination with enough dynamic range to cover the large swing while providing the resolution to measure the small signals.

Resolution and Dynamic Range—Clamp-on Current Probes: Consider, as an example, a low power design with a sleep current of 300 μ A and a peak current of 2A (a 6,700:1 ratio) with an 8-bit oscilloscope set-up so that the 2A peak current fills the screen. Ignoring sensitivity limitations of the probe and probe/oscilloscope noise, the smallest resolvable signal for the oscilloscope is $2A/2^8$ ($2/256$) or 8mA. To resolve 300 μ A in the presence of 2A requires 13-bits of vertical resolution.

Resolution and Dynamic Range—Sense Resistor Current Probes: Recall that these probes have multiple amplifiers measuring the voltage across the sense resistor. Each amplifier has different gain producing different sensitivities and they can be used in combination to provide a wide dynamic range measurement. The Keysight N2820A probe has two outputs that can be connected to 2 channels of the oscilloscope. The two channels provide a “zoomed-in” and a “zoomed-out” view simultaneously. Figure

2 shows the N2820A measuring the transition from sleep to communicate for the same device presented in Figure 1. Notice how much more signal detail is captured using the N2820A.

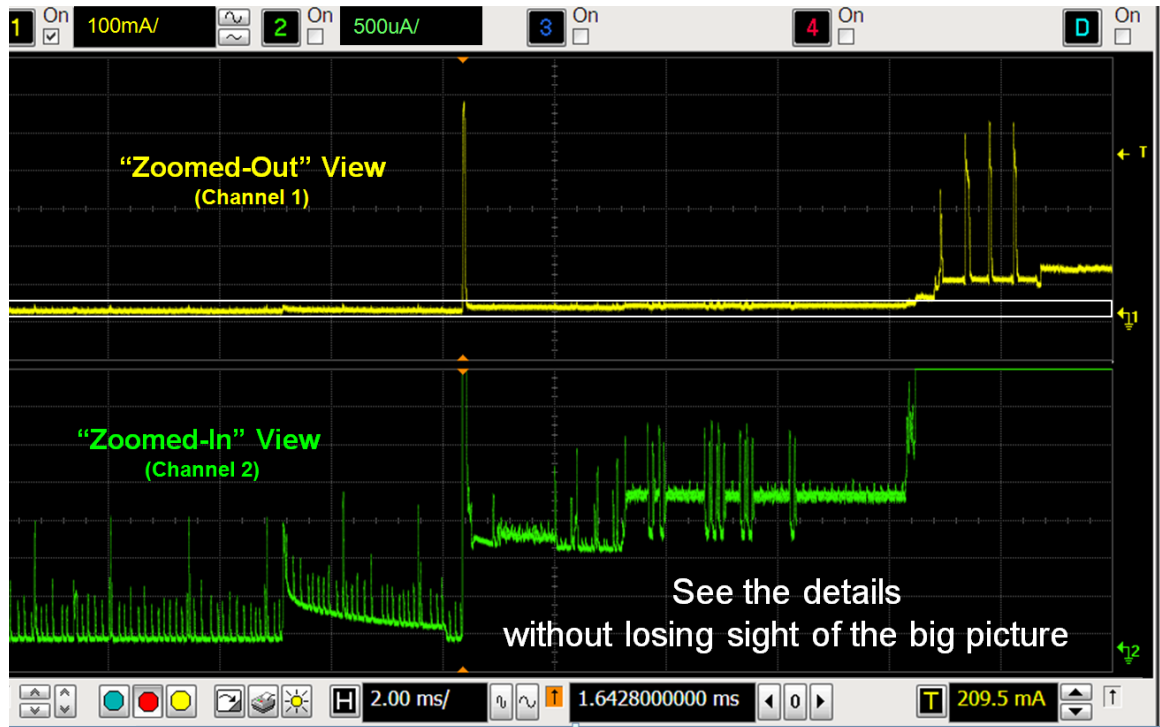


Figure 2—The N2820A in use measuring the current for a mobile phone.

Small Size

If a probe is large relative to the target, the user will need to make drastic modifications to the enclosure or configuration of the target to accommodate the probe. This can adversely affect shielding, airflow, and functionality, not to mention being inconvenient.

Small Size—Clamp-on Current Probes: 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. Figure 3 shows the relative size of a clamp-on current probe and a mobile phone.

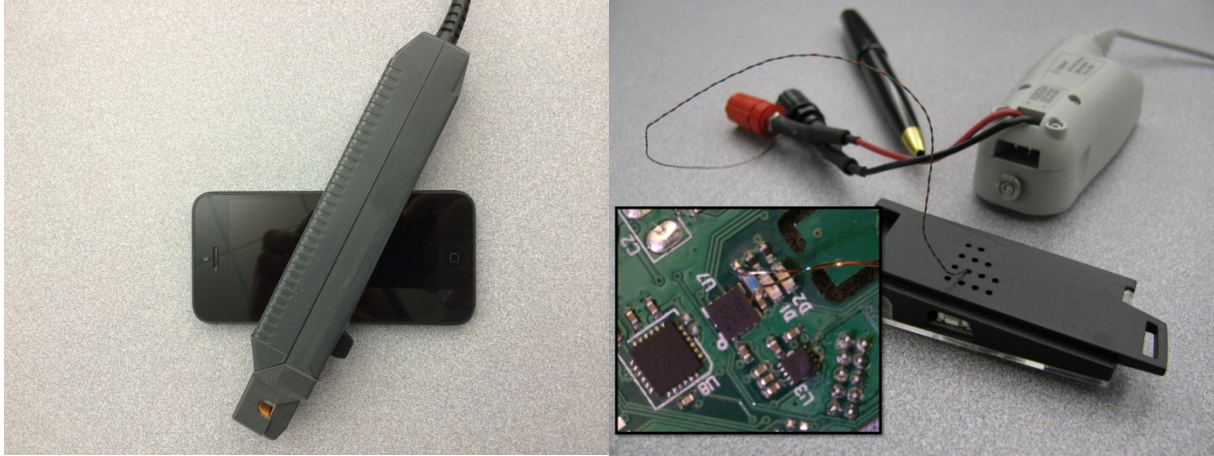


Figure 3—Clamp-on (L) and sense resistor (R) current probes.

Small Size—Sense Resistor Current Probes: Figure 3 shows the N2820A probing an accelerometer inside of a small mobile wireless device. The sense resistor used is a 0402 SMT resistor with small 36 AWG wires connected to the probe. The small wires easily route out through existing openings in the enclosure.

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 and size. At present, two types of AC/DC oscilloscope current probe are available—clamp-on current probes and sense resistor current probes. Clamp-on current probes do not provide all the necessary features to be useful for low power measurements while sense resistor current probes tend to excel at making low power measurements.