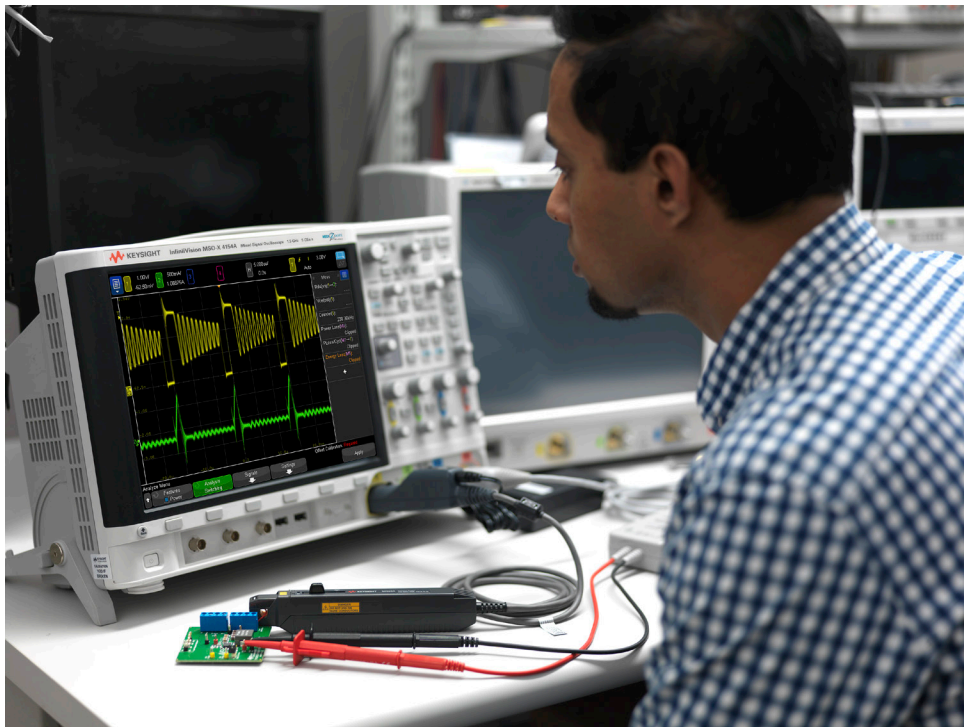


How to Select the Right Current Probe



Overview

Oscilloscope current probes enable oscilloscopes to measure current, extending their use beyond just measuring voltage. Basically, current probes sense the current flowing through a conductor and convert it to a voltage that can be viewed and measured on an oscilloscope. The most commonly used technique to measure current is magnetic field sensing of a current carrying conductor. However, there are many different types of current probes you can choose from and each probe has an area where it performs best. When they're used properly for the applications they are designed to work with, you get the best results.

This application note will introduce you to the common types of current probe solutions, the fundamental principles, the advantages and limitations between each current probe type, and the practical consideration for using current probes for oscilloscope applications to make the most out of them.

Types of Current Probes

Current probes are widely used in making power device or power supply current measurements and they are becoming indispensable tools to make accurate current measurements with oscilloscopes. To address those current measurement needs, there are a number of different techniques to measure electric current, but the most common techniques used with oscilloscopes are:

1. Sense resistor or current shunt: based on Ohm's law
2. Clamp-on current probe: either AC transformer or hybrid Hall effect sensor/AC transformer
3. Rogowski coil: a convenient probe for large AC current measurement

Sense Resistor or Shunt Resistor

A direct way of measuring current on your DUT is to use a shunt resistor in the current flow, measure the voltage drop across the resistor, and convert the voltage into current by using the Ohm's law formula (i.e., $I = V/R$). This method is an invasive measurement in that the sense/shunt resistor and the voltage measurement circuit or probe are electrically connected and are a part of the DUT. Therefore, there are many considerations to take into account.

Selecting the sense resistor

Selecting the resistor value, accuracy, temperature coefficient, and physical dimension are all dependent on the amount and characteristics of the current being measured. The larger the resistor value, the more accurate the measurement will be with the greater SNR. However, a larger resistor value will result in increased power dissipation at the resistor, resulting in unwanted voltage drop, called burden voltage. Also on top of the burden voltage penalty, there are trade-offs between the sense resistor values and measurement noise, sensitivity and bandwidth. To lower the burden voltage impact, users may want the smallest sense resistor values possible, but lower sense resistor has a negative effect from the measurement perspective. The larger sense resistor value means increased voltage drop on the sense resistor and less voltage for the load, causing system performance and efficiency issue. This is a balancing act.

R_{sense}	Burden Voltage	Noise	Sensitivity	BW
↑	↑	↓	↑	↑
↓	↓	↑	↓	↓

Figure 1. There are trade-offs between the sense resistor values and measurement noise, sensitivity and bandwidth.

Input common mode voltage

This defines the input common mode voltage of the probe or the sensing device (amplifier) with regards to ground.

High side/low side monitoring

When measuring load current, you may choose to place the sense resistor either between the supply voltage and the load (high side), or between the load and ground (low side). Low side sensing is more desirable and easier because the common mode voltage is nearly ground. High side sensing can be beneficial in that it directly monitors the current delivered by the supply, which allows for the detection of load shorts.

4 terminal Kelvin measurement configuration

This effectively eliminates the wire resistance and temperature coefficient of the loads. The Kelvin connection is essential for accurate current sensing and is particularly well suited for high current applications.

Advantages

- Depending on how the system is implemented, one can achieve very high sensitivity and high bandwidth measurement.
- Small and cheap.

Limitations

- There is a tradeoff between burden voltage and measurement accuracy (noise, sensitivity and bandwidth).
- The larger sense resistor value for more accurate measurement means increased voltage drop on the sense resistor and less voltage for the load, causing system performance and efficiency issue.
- This method is an invasive measurement in that the sense/shunt resistor and the voltage measurement circuit or probe are electrically connected and are a part of the DUT.

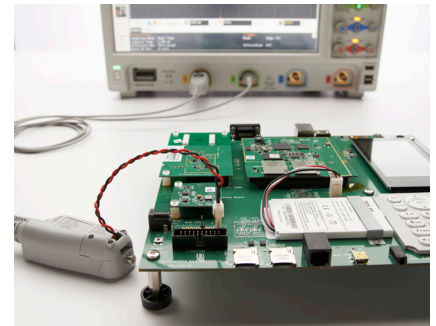


Figure 2. Keysight's N2820A/21A high sensitivity current probe utilizes sense resistor technology to measure low level current down to 500nA with an oscilloscope.

Clamp-on Current Probes

The other common type of current probes is a magnetic core current probe, or clamp-on current probe. This is an indirect type of current sensing technique where the probe is clamped around the current carrying wire or conductor to make non-contact current measurement. The probe's output generates a voltage signal proportional to the amplitude of the measured current. This allows for a non-invasive or isolated measurement where the probe is not electrically connected to the DUT.

There are AC and AC/DC versions of clamp-on current probes and there are various current conversion factors available. Current probes are designed to sense the strength of the electromagnetic field around the conductor and convert it to a corresponding voltage for measurement by an oscilloscope.

There are two sensor techniques used in the clamp-on current probes that are most common. One is Hall effect sensor to measure DC or low frequency signals. A Hall effect sensor is a transducer that varies its output voltage in response to a magnetic field. The other common technique is to use a current transformer. The AC current flowing in the transformer core produces a magnetic field in the core, which then induces a current in the secondary winding circuit that is fed into the scope. The secondary winding will have an induced voltage proportional to the current through the primary winding. This technique is used to measure AC current only.

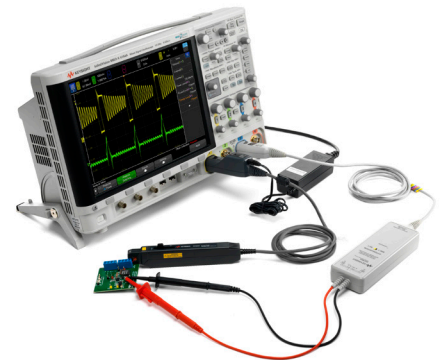


Figure 3. Clamp-on current probe is an indirect type of current sensing technique where the probe is clamped around the current carrying wire or conductor to make non-contact current measurement.

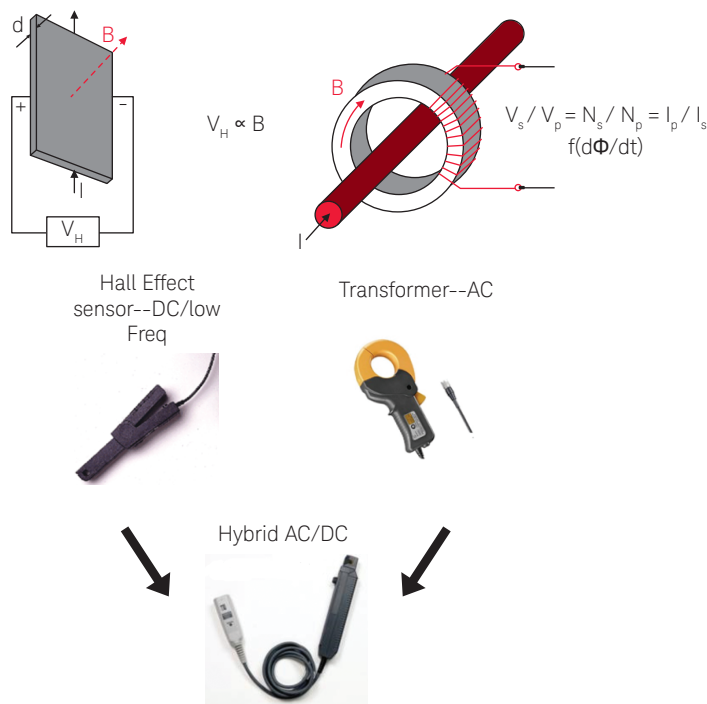


Figure 4. A Hybrid AC/DC current probe integrates both Hall effect sensor and the current transformer for measuring AC and DC current.

The other popular technique used is a hybrid AC/DC current probe, integrating both Hall effect sensor element for measuring DC and low frequency contents and the current transformer measuring AC into a single probe.

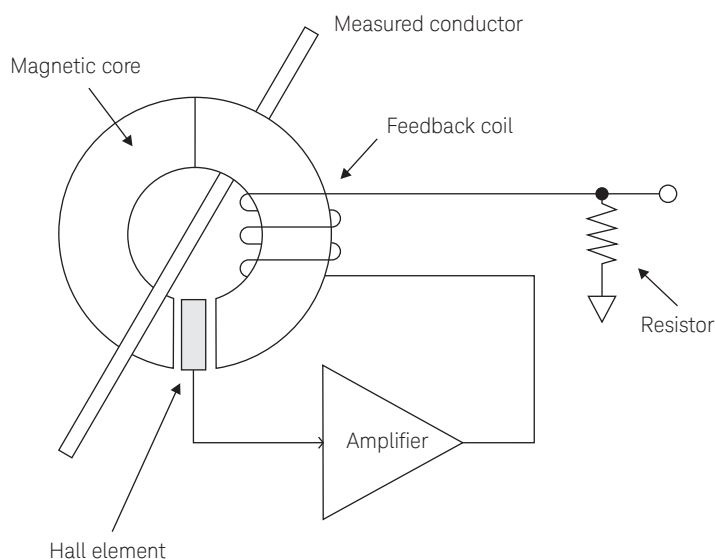


Figure 5. A popular technique used in most Keysight clamp-on current probes is a hybrid AC/DC current probe, integrating a Hall effect sensor and a current transformer.

Advantages

- Galvanic isolation between the probe and the DUT.
- They can be placed anywhere on the current path without breaking the circuit.
- Low insertion impedance.

Limitations

- Degaussing and offset error elimination – For accurate measurement, probe needs to be occasionally degaussed and compensated for any DC offset that remains on the probe after degaussing.
- High price: Hall effect sensor is among the most expensive type of current sensor.

Rogowski Coil

If you are dealing with more than a couple tens of amperes of AC current and want to make flexible current measurements, consider the Rogowski current probe.

A Rogowski coil is an electrical transducer used for measuring AC currents, such as high speed transients, pulsed currents of a power device, or power line sinusoidal currents at 50 or 60 Hz. The Rogowski coil has a flexible clip-around sensor coil that can easily be wrapped around the current-carrying conductor for measurement and can measure up to a couple thousand amperes of very large currents without an increase in transducer size.

How does Rogowski coil work?

The theory of operation behind the Rogowski coil is based on Faraday's Law which states that the total electromotive force induced in a closed circuit is proportional to the time rate of change of the total magnetic flux linking the circuit.

The Rogowski coil is similar to an AC current transformer in that a voltage is induced into a secondary coil that is proportional to the current flow through an isolated conductor. The key difference is that the Rogowski coil has an air core as opposed to the current transformer, which relies on a high-permeability steel core to magnetically couple with a secondary winding. The air core design has a lower insertion impedance, which enables a faster signal response and a very linear signal voltage.

An air-cored coil is placed around the current-carrying conductor in a toroidal fashion and the magnetic field produced by the AC current induces a voltage in the coil. The Rogowski coil produces a voltage that is proportional to the rate of change (derivative) of the current enclosed by the coil-loop. The coil voltage is then integrated in order for the probe to provide an output voltage that is proportional to the input current signal.

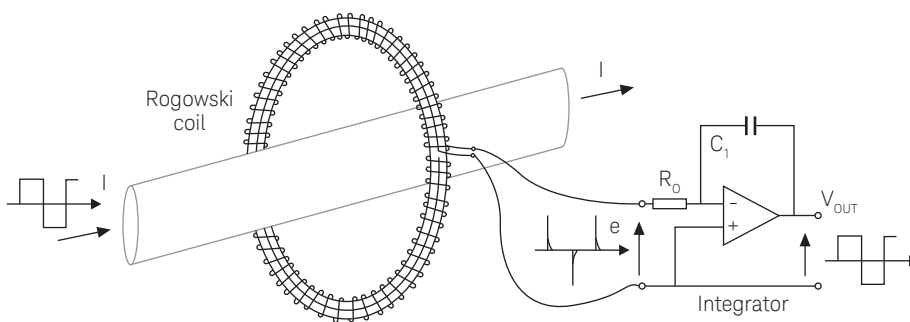


Figure 7. The Rogowski coil produces a voltage that is proportional to the rate of change (derivative) of the current enclosed by the coil-loop.



Figure 6. Keysight provides three Rogowski coil current probes for measuring up to 3,000 Apk of large current.

Advantages

Rogowski coil current probes offer many advantages over different types of current transducers or sensing techniques.

- **Large current measurement without core saturation**

Rogowski coils have the capability to measure large currents (a very wide range from a few mA to more than a few kA) without saturating the core because the probe employs non-magnetic “air” core. The upper range of the measurable current is limited by either the maximum input voltage of a measuring instrument or by the voltage breakdown limits of the coil or the integrator circuit elements. Unlike other current transducers, which get bulkier and heavier as the measurable current range grows, the Rogowski coil remains the same small size coil independent of the amplitude of current being measured. This makes the Rogowski coil the most effective measurement tool for making several hundreds or even thousands of amperes of large AC current measurements.

- **Very flexible to use**

The lightweight clip-around sensor coil is flexible and easy to wrap around a current-carrying conductor. It can easily be inserted into hard-to-reach components in the circuit. Most Rogowski coils are thin enough to fit between the legs of a TO-220 or TO-247 power semiconductor package without needing an additional loop of wire to connect the current probe. This also gives an advantage in achieving high signal integrity measurement.

- **Wide bandwidth up to > 30 MHz**

This enables the Rogowski coil to measure the very rapidly changing current signal – e.g., several thousand A/μsec. High bandwidth characteristic allows for analyzing high-order harmonics in systems operating at high switching frequencies, or accurately monitoring switching waveforms with rapid rise – or fall-times. advantage in achieving high signal integrity measurement.

- **Non-intrusive or lossless measurement**

The Rogowski coil draws extremely little current from the DUT because of low insertion impedance. The impedance injected into the DUT due to the probe is only a few pico-Henries, which enables a faster signal response and very linear signal voltage.

- **Low cost**

Compared to a Hall effect sensor/transformer current probe, the Rogowski coil typically comes in at lower price point.

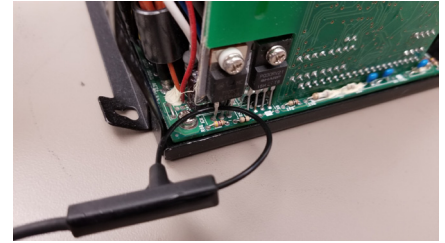


Figure 8. The lightweight clip-around sensor coil is flexible and easy to wrap around a current-carrying conductor.

Limitations

- **AC only**

Rogowski cannot handle DC current. It is AC only.

- **Sensitivity**

Rogowski coil has a lower sensitivity compared to a current transformer due to the absence of a high permeability magnetic core.

Key Questions to Ask When Selecting Current Probes

- Determine if you are measuring AC, DC or AC riding on top of DC.
- What's the max current you are supposed to measure?
- What's the minimum current you are supposed to measure?
- What's the common mode voltage of the current signal you're measuring?
- How fast is your target current signal?
- What's the size of DUT?
- How many current probes or voltage probes you'd use at the same time?
- What's the max voltage of the conductor to be measured?
- What type of scope do you intend to use with?
- How much of budget do you have?

Comparison

The chart below compares the major attributes of a sensor resistor, clamp-on current probe and Rogowski coil current probe. Refer to this when you have to choose a current probe for your application.

	Sense Resistor or Shunt Resistor	Clamp-on Current Probe	Rogowski Coil Current Probe
AC or AC/DC	AC/DC	AC/DC or AC	AC
Bandwidth	DC to GHz	Up to 150 MHz	Up to 30 MHz
Optimum current range	uA – A's	mA – 100's of A	A's to > kA's
Noise	Low	Low to medium	Medium to high
Magnetic saturation	None	Yes	None
Head/sensor size	Small	Medium to large	Small
Insertion impedance	None	Moderate	None
Non-intrusive, isolated measurement	No	Yes	Yes
Requires degaussing and offset elimination	No	Yes	No
Pricing	Low to medium	High	Medium
Keysight current probe models	N2820A/21A	1146B, 1147B, N2893A, N7026A, N2780B/81B/82B/83B	N7040A/41A/42A

Conclusions

There are a number of different ways of measuring electric current, where each method has advantages and limitations, and each probe has an area where it performs best. When they're used properly, the way they are designed to, you get the best results. Now you have a better understanding of different types of current probes, the fundamental principles, and the advantages and limitations between each current probe types.

To learn more about Keysight's current probing solutions, check out www.keysight.com/find/probes and select the **Oscilloscope Current Probes**.

www.keysight.com/find/probes

Learn more at: www.keysight.com

For more information on Keysight Technologies' products, applications or services, please contact your local Keysight office. The complete list is available at: www.keysight.com/find/contactus

