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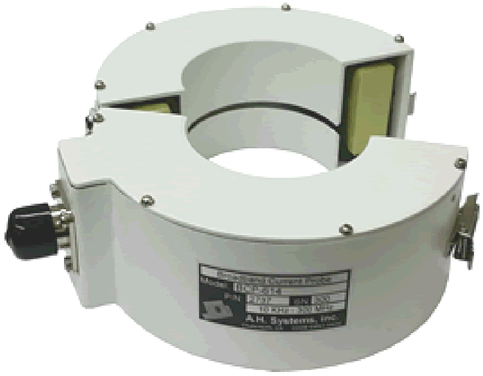
Understanding and Implementing RF Current Probes

Current probes generate and measure RF currents, combining great diagnostic utility with ease of use. However, a basic knowledge of these devices is necessary to maximize their effectiveness.

Used in a variety of industrial and scientific applications, current probes are designed to generate and measure RF currents without making direct contact with the source conductor. Measurements can be made on single- and multi-conductor cables, as well as ground and bonding straps.

This article discusses types of current probes and the applications for which they are suited, as well as how current probes are used. We also examine the physical and electrical parameters to consider when selecting a current probe.

How do Current Probes Work?



Current probes are RF transformers that measure, or produce, a voltage in a 50-ohm load proportional to the current flowing through the probe window (i.e., its inner diameter, also called its aperture). Current probes are non-contact devices, in that they do not directly touch the source conductor or the line's metallic surface.

Current probes are available in two forms: monitoring probes and injection probes. A monitoring probe is primarily used to measure current on the line(s). Within the monitoring probe are resistive components that act to flatten the probe's response while measuring currents, meaning users can concentrate on a single factor, since they're essentially operating with a flat bandpass across the current probe's specified range.

An injection probe is used to inductively couple large RF currents into conductors passing through their aperture. The conductors are signal, control, and power circuits of equipment under test for conducted susceptibility or immunity. Essentially, an injection probe is used to "disturb" the device under test by introducing current, gauging whether the device still will operate properly under a particular load.

Some applications will call for the use of both probe types, while others only will require a monitoring probe or an injection probe. Examples of several setups are described in this guide to performing a **basic bulk current injection test**.

Both monitoring and injection current probes are available with either a split core or a fixed core. Split-core probes are hinged at one side and can be clamped around the cables/straps through which current is being measured. Fixed-core probes do not boast this feature, meaning the user will need to break the circuit to place lines through the probe aperture.

Current probes offer vast utility as a diagnostic tool, serving testing applications across a diverse set of industries, including military and defense, aerospace, automotive, and commercial purposes. Within these industries, current probes are used to perform common-mode and differential-mode current measurements — for example, a common-mode current measurement to predict radiated emissions levels. Current probes also can be applied to bulk current injection testing, conducted emissions measurements, noise measurements, and common-mode impedance measurements.

When measuring a two-conductor cable, the probe can measure the effects of both currents leaving and currents returning, as well as measure the resultant magnitude of the combined wires' current flow passing through the aperture. However, when taking measurements of multiple conductors, users should exercise caution, as the measurement will represent the net current; any return current will negate the forward current. For example, a user running 100 watts through their aperture, through two wires, still will return a measurement of zero.

Additionally, the balance of a twisted pair circuit can be determined by measuring each wire individually and then measuring both wires simultaneously. The ratio of the two measurements shows how well the balance has been achieved. A shielded multiple wire cable can be measured to show how much resultant leakage current is occurring.

Note that the current probes discussed herein are only valid for use on a 50-ohm circuit (e.g., use with 50-ohm impedance instruments including spectrum analyzers, vector network analyzers, high-end EMI receivers, oscilloscopes). Further, maximum current level is limited by core saturation, and maximum response is best located by moving the current probe along the wire.

Understanding Current Probe Parameters and Principles

Proper use of current probes is built upon an understanding of their functionality and working principles.

The most sensible place to start in determining a current probe that meets your needs is its physical size. Make sure the current probe aperture is large enough to clamp around the maximum size conductor or conductor bundle to be measured.

In general, the smaller the aperture, the more efficient coupling. Larger aperture current probes, meanwhile, are optimized either for low- or high-frequency coupling efficiency. A current probe's outer dimensions only factor into the decision if the probe will be placed inside a small area or inside a fixture during the test.

The primary specification relating to monitoring current probes is transfer impedance: the ratio of output voltage from the current monitoring probe to current running through the probe's aperture. A current probe's sensitivity is directly related to its transfer impedance.

Ampere's law can be applied to solve for unknown current flowing through a probe's aperture. To calculate the unknown current, clamp the current probe over the conductor of interest, and then connect the output connector to a receiver or a spectrum analyzer. Measure the voltage — typically, in dB above one microvolt (dBµV) — at the desired frequency and subtract the correction factor/transfer impedance (in dB ohms / dBΩ).

The result will be the current running through the conductor under test, which can be expressed using the following equation: $I\ (\mathrm{dB\mu A}) = V\ (\mathrm{dB\mu V}) - TI\ (\mathrm{dB\Omega})$, where

I (dBµA) = Unknown current in decibels relative to one microamp / dBµA
V (dBµV) = Receiver reading in dBµV
TI (dBΩ) = Transfer Impedance in dBΩ

Or, when data is taken in (µV): $IP = VS / ZT$, where

IP = Unknown current in µA
VS = Receiver reading voltage in µV
ZT = Transfer Impedance in ohms

The determination of whether to use a current probe with lower transfer impedance versus a probe with higher transfer impedance depends on the application.

A current probe with lower transfer impedance is desirable when taking high current or pulse measurements. For example, a probe with lower transfer impedance is ideal for measuring both 60 Hz or 400 Hz power line frequencies, pulse signals, or high-level RF fields. Lower transfer impedance values are usually achieved with internal resistive loading, which offers several advantages in these applications.

Internal resistive loading limits the lower signals that can be measured but increases the peak amplitude of low duty cycle pulse signals that can be measured. The frequency response is flattened, and greater measurement accuracy is obtained when interpolating a flat response.

The farther the low frequency and high frequency roll-off, the wider the application of the probe for time domain measurements. In broadband applications, phase shifts over the flat portion of the transfer impedance are constant. It also warrants mention that, in broadband applications, an attenuator or a bandpass filter should be utilized to protect the receiver

Conversely, a monitoring current probe with higher transfer impedance is desirable when measuring low-level RF currents because the higher the transfer impedance, the more sensitive the current probe. Stated differently, higher transfer impedance enables the greater measurement dynamic range.

For example, working with a low-level limit (e.g., a 50 dBµA limit), A.H. Systems’ BCP-610 monitoring current probe, which features a Zt of 0.025, would need to measure 1.25 µV (about -105 dBm) — a meager signal that would get lost in the noise floor of a common spectrum analyzer. However, a user applying A.H. Systems’ BCP-620 monitoring current probe — which has a Zt of 1 to 5 ohms — to that same 50 dBµA limit would be measuring 50 µV to 250 µV (about -73 to -59 dBm).

This relationship can be defined by the equations ZT = 10 (TI / 20) and TI = 20 * Log (ZT).

Transfer impedance generally is not a consideration when using an injection current probe since injection probes are dedicated primarily to transmitting (versus receiving). An injection current probe is characterized by its insertion loss (dB). The insertion loss describes the inefficiency of the clamp relative to direct injection into a 50-ohm circuit.

Finally, while injection probes typically cost more than monitoring probes, price primarily is based on the power levels the probe is designed to handle, as well as its operating frequency range. A more robust device capable of handling higher currents (or, in the case of injection probes, capable of greater input power) is likely to cost more.

A comparison between both types of probes and their specifications is **available here**.

Conclusion

A.H. Systems has built its expertise over years of helping customers identify the optimal current probes to meet their needs. As of this writing, A.H. Systems offers two current probe series, both featuring a split core for ease of use:

- The BCP-XXX series comprises monitoring current probes used to measure the RF currents on the cable(s) passing through their aperture, covering a range from 20 Hz all the way to 500 MHz. These probes are available in both 1.25” and 2.6” aperture sizes.
- The ICP-XXX series comprises injection current probes used to inject current into the power and signal cables of equipment under test to determine conducted RF susceptibility.

To learn more about current probes, their functionality, or the applications, contact **A.H. Systems**. Additionally, you can explore A.H. Systems’ **current probe offerings here**.