Agilent P-Series Power Sensor

Internal Zeroing and Calibration for RF Power Sensors

Application Note

Agilent Technologies

Introduction

RF power sensors and meters are used to add traceability and ensure accurate RF power measurements. The zero and calibration procedure must often be performed on the sensors and meters to ensure accurate measurements and involves multiple connections to an external calibration source. This article introduces Agilent's internal zero and calibration approach, which helps reduce measurement uncertainty associated with calibrating with an external source.

By Alan B.Anderson

The primary use of an RF power sensor and RF power meter combination is to add traceability and accuracy to test systems as well as for making accurate and absolute RF power measurements. The environment may change, whether a lab test bench or a production line, either on RADAR systems, mobile phones or base stations. However, in most cases, a power meter and sensor will be used as the principal route to a traceable absolute power measurement.

An accurate RF power measurement is the zero and calibration procedure that the user often must perform on a sensor and meter in order to make the subsequent measurements accurate. This article will discuss the role that this process fulfills and consider how it applies to current power-sensing techniques. In particular, Agilent's 'internal zero and calibration' approach will be introduced, which eliminates multiple connections with an external calibration source, with the benefits of reduced measurement uncertainty, reduced connect wear and faster test times.

Sensor Technology and Zeroing and Calibration

Commercially available sensors rely on three types of RF detectors- thermistors, thermocouples and diodes. Each sensor type typically consists of a RF connector interface, possibly including an internal attenuator or direct current (dc) block capacitor, and the RF detector, followed by signal conditioning/processing circuitry. Figure 1 shows this for a diode-detector-based sensor.

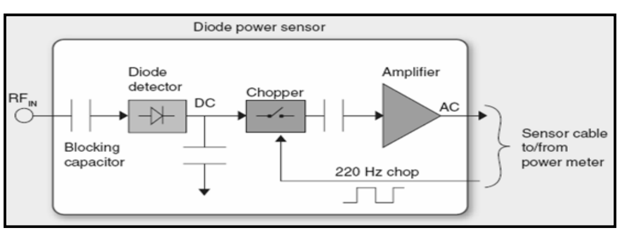

Figure 1. Diode-based power sensor block diagram

For a thermistor detector, the detection relies on the dissipation of the incident RF power heating the detector and thus affecting a change in its resistance. By using a bridge circuit and dc substitution, the detector is making a closed loop measurement of RF power. So, in measuring the amount of substitute electrical power that must be applied to balance the RF heating effect, a measure of the power that would be dissipated in a 50 Ω load is obtained.

To improve the accuracy of this measurement, a calibration factor is applied. This accounts for mismatch loss because the actual thermistor does not provide a perfect 50 Ω load, and also for the effective efficiency because all the RF power is not necessarily dissipated in the thermistor itself, and therefore measured.[1] This calibration factor will vary over the RF frequency range of the sensor and is generated when the sensor is calibrated either when it is produced, or as part of its periodic calibration cycle. It is typically constant over power levels and temperature.

So, when making a power measurement with a thermistor power sensor due to the use of the dc substitution approach, no further user calibration is required. However, a zeroing operation is required to null any offset effects of the measurement instrumentation.

For a thermocouple and diode detector, there is no inherent capability to measure RF power prior to the devices being calibrated. These detectors are often termed 'open-loop' in that they rely on a calibration prior to use. They each output a voltage that is proportional to the input RF power. However, to make it meaningful, it also requires a scaling factor. This scaling factor is usually derived when the user connects the sensor to a known RF source-typically a 50 MHz, 0 dBm calibrator (also known as a reference oscillator)-thus providing a closed-loop system and allowing the scaling factor to be calculated. This process will subsequently be referred to as a 'user calibration'.

Consider an output of 2 mV from a thermocouple or diode power sensor. This is the result of an unknown incident power at 50 MHz being applied. The output value only becomes meaningful when the sensor is calibrated with 0 dBm, 50 MHz, which yields, say, a 1 mV output. So, by calculating the scaling factor as 1 watt per volt and applying it to the output of 2 mV, a measurement of 2 mW is the result. Calibration factors, as introduced for the thermistor power sensor are also applied to transfer this scaling factor to other frequencies; however, they rely on the closed loop calibration being undertaken prior to them being applied.

In addition, both diode and thermocouple sensing types are also require to be zeroed prior to making a power measurement. The zero function removes residual offsets in the instrumentation when no power is applied. Typically, the user calibration and zeroing operation is performed at the same time and is often referred to as a 'zero and cal'.

Before the calibration process can be validated, zeroing must take place. Here, when no RF power is incident on the detector, the power meter measures the output of the sensor. Furthermore, if the zero measurement yielded 0.2 mV, the post-zeroing calibration value (previously 1 mV) should be 1 mV – 0.2 mV = 0.8 mV. This value would then be used to generate a scaling factor of 0.8 watt per volt.

In the majority of power sensors, the user calibration and zeroing process is applied immediately before a power measurement is made. This is because of a unique characteristic among RF test instrumentation: the power meter and sensor are separate and that the measurement plane is located away from the meter wherever the sensor is located. The main reasons to split the system into a meter and sensor are:

- To locate the measurement reference plane as close to the device under test (DUT) as possible. To minimize the degradation in accuracy from cabling loss and additional mismatch uncertainty from a degraded impedance match.
- To facilitate the interchangeability of the RF sensor, providing flexibility in power range and frequency coverage at a lower cost by allowing part of the system to be interchanged.

Therefore, the sensor, cable and meter are often being used for the first time together, or have been disconnected and reconnected while assembling a test station. So for maximum accuracy, a user calibration and zeroing is carried out on the system prior to a measurement.

The Evolution of Zero and Calibration

In modern RF power sensors [2], the detector is non-linear over part of its usable range (i.e., the detected output voltage is not always linearly proportional to input power). Additional levels of correction beyond frequency calibration factors must, therefore, be made because the calibration factors are no longer constant over power and temperature ranges.

For example, extended-dynamic range diode detectors make linearity correction over power level, which typically comprises a 50 MHz linearity characterization, which is then applied to all other frequencies. The most convenient way to combine the calibration factor correction and the linearity correction is to make all corrections relative to the frequency and power level of the RF source used for the user calibration.

Further linearity correction may also be applied at different frequencies. This correction has been termed frequency-dependent linearity correction or FDLC [3]. Also, temperature changes in linearity have been accounted for by using different linearity corrections at different temperatures. This overlaying of linearity, calibration factor and FDLC essentially means that for each temperature, frequency and power level, a unique correction factor must be applied to relate the sensor's output voltage to the input RF power. For implementation purposes these corrections are made relative to the user calibration reference source and rely on characterization data generated when the sensor is produced, or as part of its periodic calibration cycle.

The user calibration is akin to taking a global positioning system (GPS) reference for your position and using it to fix your position on a map. The knowledge of your position at one point on the map does not ensure you to know your whereabouts when you moves to other locations. The only way to do this is to trust the details of the map to provide the answers to what height you are and where you are as you move about. The GPS acts as the user calibration and the detail on the map represents the sensor characterization, where your knowledge of your position (the measurement) is only as good as your initial reference fix and the validity and how up-to-date and accurate the map is.

Traditional sensors that operating within their square-law region represents a flat landscape of restricted area, but modern peak and average sensors with extended dynamic range represent large hills and valleys over a greater area. Hence, more recent sensors place greater importance on the accuracy of the map (the correction factors and characterization), than the initial GPS reading (the user calibration). Figure 2 shows the response behavior or 'map' for Agilent's P-series power sensor. The periodic calibration of the sensor is essentially a check or update of the details of the map.

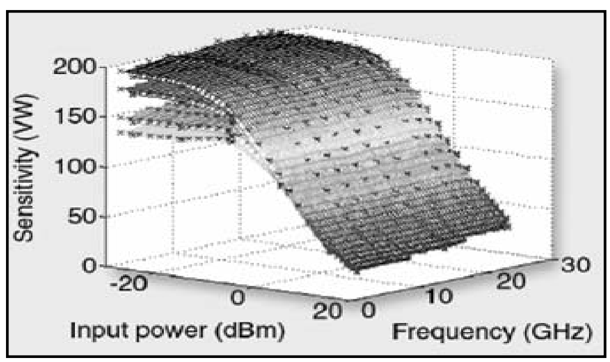

Figure 2. P-Series power sensors 4-D correction factors (characterization of detected voltage over power, temperature and frequency)

During the evolution of this power sensors, a subtle change has occurred where once a user calibration was performed to provide the power accuracy and traceability of a power measurement. This has increasingly shifted to a reliance on the factory characterization and periodic calibration cycle to ensure accuracy.

A common misconception of the user calibration is that it can detect changes in the response of a sensor and make adjustments. However, because the sensor and meter combination may also have changed, any conclusions about a change in the RF detectors behavior cannot be made. The closed-loop also contains the connector interface, amplifier circuitry, cabling and the power meter. So the primary function of the user calibration is to combine the sensor, meter and cable, but not to detect a change in the detectors behavior.

In recognition of this, the Agilent P-series N1921/2A wideband power sensors have taken a new approach to the user calibration. The sensor no longer needs to be disconnected from the DUT and connected to a 50 MHz, 0 dBm reference signal. By introducing a known dc reference signal after the RF to dc detection process, all the functions of a user calibration can be achieved without inconvenience. Taking this a step further, transistor switches have been introduced behind the detector to allow a zero to be made while RF is still incident on the RF detector (see Figure 3). This patent-pending approach is termed as 'internal zero & cal'.

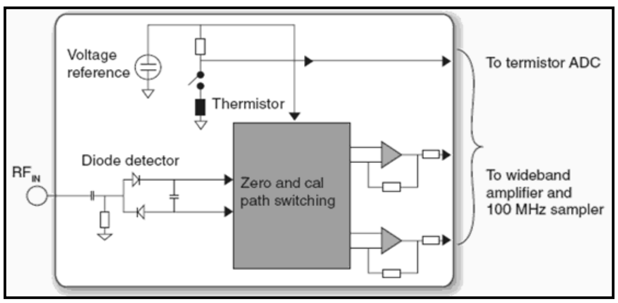

Figure 3. P-Series power sensor's 'internal zero and cal' block diagram

This capability removes the need for connection and disconnection from the calibration source, thereby reducing test times, measurement uncertainty, and wear and tear on connectors. It is especially useful in manufacturing and automated test environments.

The precision voltage reference device starts with accuracy of ±3 ppm, and after attenuation and buffering; the stability works out at ±500 ppm (±0.05 %). This compares favorably to the 0 dBm, 50 MHz calibrator found on most power meters. For the N1911/2A power meter, the accuracy specification is ±0.4 % (25 ±10 °C) and ±1.2 % (0 to 5 °C). Therefore, along with eliminating the associated mismatch uncertainty between the sensor and power reference, there is improved accuracy in the calibration process with this internal calibration.

The N1921/2A power sensors do not rely on the external calibrator on the N1911/2A power meter for calibration (this is included in the power meter to calibrate existing Agilent sensors), so connecting to it offers a means to check the integrity of the detector circuitry and connector. However, this is limited, as it cannot prove or guarantee that the entire operating range of the system is functioning to full accuracy.

What errors can calibration catch? This is best covered with a few examples. A power sensor may have been exposed to input power that is beyond its absolute maximum rating (damage level), and this could have several effects:

- The attenuator that is located within the sensor in front of the detector may have failed such that no RF power propagates to the detector. A user calibration or, for the P-series power sensor, a measurement on a known good source (possibly a calibrator) will detect this failure.
- The actual detector may have been stressed, either to the point of a catastrophic failure, or experiencing accelerated aging. The former effect can be detected by connection to a known source, but the aging effects may be more subtle and are difficult to detect immediately- either from a user calibration or using a known good source.
- For a thermocouple, if the maximum power is exceeded, the 'scaling factor' for the sensor may be modified, and although this can be corrected for by repeating the user calibration, it is likely to reduce the life of the sensor.

The power sensor and meter are used in a variety of situations and environments, some, like system calibrations and installation testing, require several connections and disconnections. The effect of multiple connections can be connector wear and tear. The accuracy impact of this wear and tear manifests itself in two forms:

1. The VSWR of the sensor will be degraded, causing greater mismatch uncertainty.
2. The coupling of RF into the detector circuit will be modified, potentially invalidating the applied correction factors. So although the measurement may appear accurate at 50 MHz, with a calibrator, the effect at another frequency may be quite significant.

A calibration kit for a network analyzer is used to transfer connector standards to a reference plane, and care must be taken, not only to not over tighten a connection, but also to ensure that the gauge of the DUT connector is in good shape and will not damage the instrument's connector. The same care needs to be applied with a power sensor in its use to transfer power accuracy to a DUT.

Conclusion

Agilent's internal zero and calibration capability for the power sensor and meter eliminates multiple connections with an external calibration source, with the benefits of reduced measurement uncertainty, reduced connect wear and faster test times. All RF power-sensing technologies rely on some form of correction to achieve optimal accuracy for a power measurement. Whether using an internal or external source of sensor calibration, neither guarantees the validity of the applied corrections, nor the accuracy of the overall measurement. This is achieved when the calibration is used in conjunction with an accurate characterization (when the correction factors are generated) and careful use as well as handling of the sensor and its RF interface.

References

1. The terms in italics are common power measurement specific terms, which are given in a more complete definition in App. Note 1449-3, Fundamentals of RF and Microwave Power Measurements (Part 3), Power Measurement Uncertainty per International Guides, Agilent Technologies.
2. Modern RF sensors are considered as sensors with internal memory (EEPROM) in order to retain Calibration and Correction Factor data, with an extended operating range.
3. Refer to Measuring Power Levels in Modern Communication Systems (Microwaves & RF, October 2000) at www.home.agilent.com/upload/cmc_upload/All/EPSG090442.pdf.
4. This application note can be obtained in the RF Design webpage at www.rfdesign.com/mag/radio_context_internal_zero/index.html.

About the Author

Alan B. Anderson is a senior development engineer with Agilent Technologies, whom he joined in 1997 when it was previously Hewlett Packard. He graduated from the University of Glasgow with a European M.Eng. in 1997 and holds an MBA from Edinburgh Business School (2003). At Agilent, he has developed a range of peak and wideband RF power sensors. He can be reached at alan_anderson3@agilent.com.

Agilent Email Updates

www.agilent.com/find/emailupdates
Get the latest information on the products and applications you select.

Agilent Direct

www.agilent.com/find/quick
Quickly choose and use your test equipment solutions with confidence.

Agilent Open

www.agilent.com/find/open
Agilent Open simplifies the process of connecting and programming test systems to help engineers design, validate and manufacture electronic products. Agilent offers open connectivity for a broad range of system-ready instruments, open industry software, PC-standard I/O and global support, which are combined to more easily integrate test system development.

Remove all doubt

Our repair and calibration services will get your equipment back to you, performing like new, when promised. You will get full value out of your Agilent equipment throughout its lifetime. Your equipment will be serviced by Agilent-trained technicians using the latest factory calibration procedures, automated repair diagnostics and genuine parts. You will always have the utmost confidence in your measurements.

Agilent offers a wide range of additional expert test and measurement services for your equipment, including initial start-up assistance onsite education and training, as well as design, system integration, and project management.

For more information on repair and calibration services, go to

www.agilent.com/find/removealldoubt

www.agilent.com

For more information on Agilent Technologies' products, applications or services, please contact your local Agilent office. The complete list is available at:

www.agilent.com/find/contactus

Phone or Fax

United States:
(tel) 800 829 4444
(fax) 800 829 4433

Canada:
(tel) 877 894 4414
(fax) 800 746 4866

China:
(tel) 800 810 0189
(fax) 800 820 2816

Europe:
(tel) 31 20 547 2111

Japan:
(tel) (81) 426 56 7832
(fax) (81) 426 56 7840

Korea:
(tel) (080) 769 0800
(fax) (080) 769 0900

Latin America:
(tel) (305) 269 7500

Taiwan:
(tel) 0800 047 866
(fax) 0800 286 331

Other Asia Pacific Countries:
(tel) (65) 6375 8100
(fax) (65) 6755 0042
Email: tm_ap@agilent.com
Revised: 09/14/06

Product specifications and descriptions in this document subject to change without notice.

Printed in USA, March 14, 2007
5989-6509EN

Agilent Technologies