Advanced Energy RF Calibration Process

Overview

Advanced Energy (AE) designs and produces power supply products with very tight power output specifications. For example, a ±1% output power accuracy is typical of our Paramount and Navigator II products. In order to ensure a repeatable calibration, the calibration standard must be more accurate than the product specification. This paper discusses how this is accomplished at AE.

Introduction

External Standards - Limitations

At the kilowatt levels our power supplies produce, it is not possible to obtain a measurement standard that provides better than ±1% power accuracy from the National Institute of Standards and Testing (NIST) or any other organization.

Non-AE products, until recently, offered at best 3% accuracy. At present, it is possible to purchase an RF power meter with 1% accuracy, but this still does not meet the less-than-1% accuracy requirements for use as a standard for a 1% generator.

AE's Approach

Because external standards were not available, AE created a tool called a calorimeter that we used to generate RF measurement standards. These standards meet the stringent less-than-1% accuracy requirements. The calorimeter, along with transfer and floor standards, provides the basis for AE's process of establishing and controlling the repeatability of our RF generators.

The Calorimeter

Theory Behind the Calorimeter Approach

Figure 1 shows the calibration process, and Figure 2 is a block diagram of the AE calorimeter. A 50-Ω resistive load is used to convert the electrical energy into heat. A constant flow of water is pushed through the load, and the temperature difference from inlet to outlet is measured.

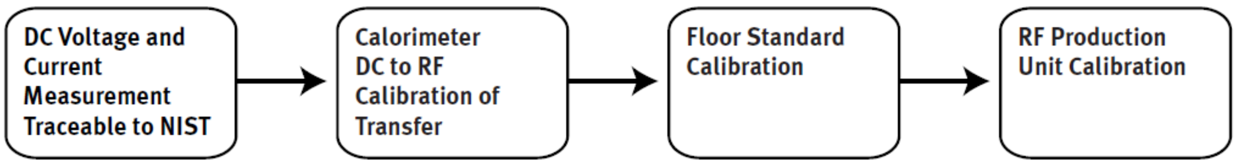

Figure 1: Calibration process review

Because of potential variations in flow rate, absolute accuracy error of the thermal measurement, potential thermal losses from the load, and other factors, AE has chosen to use a relative measurement approach—also known as the substitution method. In this approach, the effect of the RF is compared to the heating effect of DC power. When the heating effects are the same, the DC power is measured to determine the equivalent RF power.

It is very easy to measure DC power accurately with commercially available equipment. Precision shunts for current measurements and very high-precision voltmeters are readily available. By comparing the heating of water from a DC source to an RF source, AE achieves a much more precise measurement of power and removes the variation from the sources listed above.

By constantly switching between DC and RF power, we are able to compare the "true" power measurements. The load is allowed to reach thermal equilibrium under each condition and then a series of readings are taken and averaged. After this has occurred for the DC and then the RF, an offset is calculated, which is the difference between the two input power conditions as measured by the thermal difference between the input and output RTD. The operator continues to adjust the power level of the RF generator until the offset is effectively zero. At this point, and after the readings are stable, a final measurement is taken that then relates a reading from the RF transfer standard to RF power.

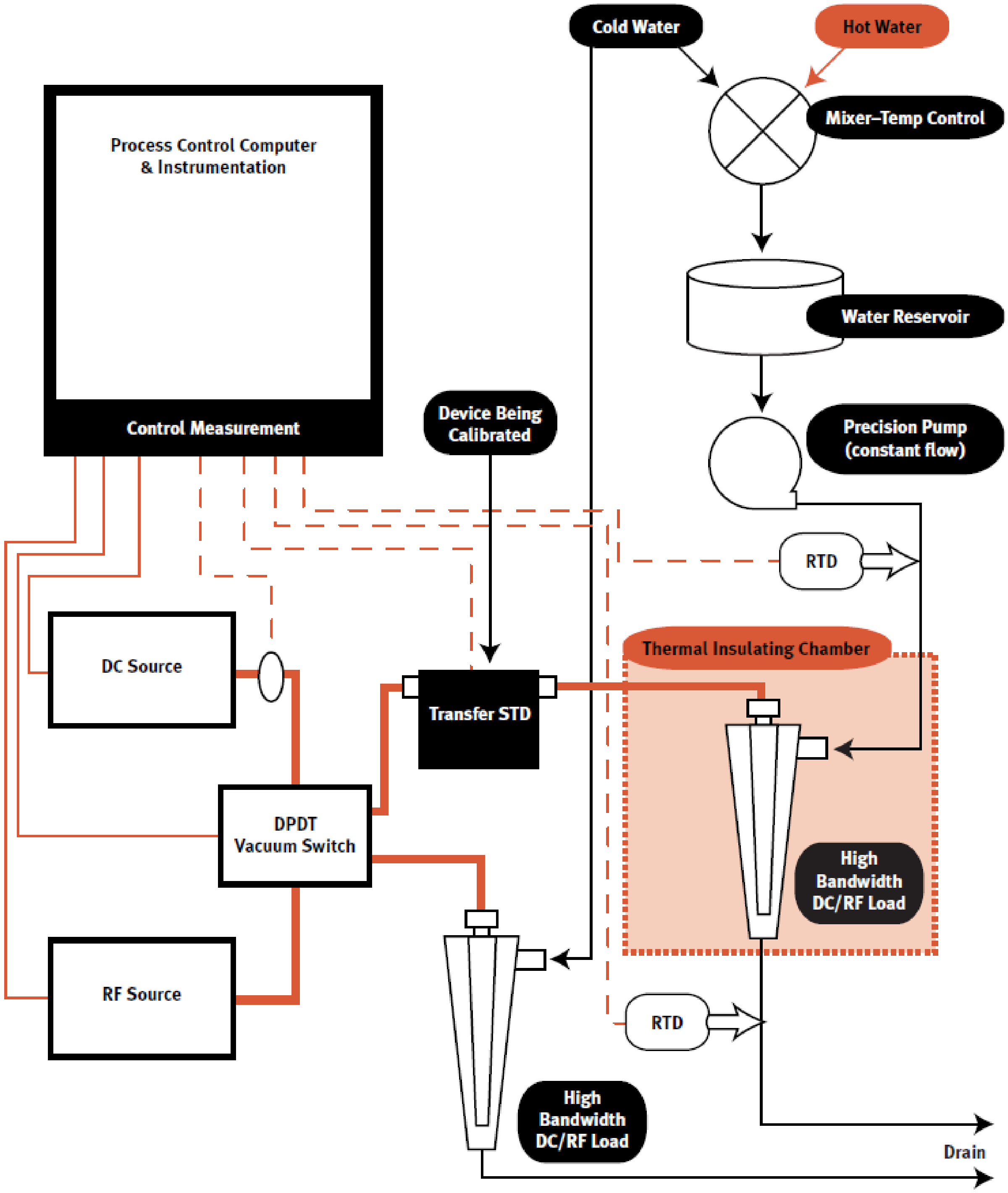

Figure 2: AE calorimeter block diagrams

The numbers of readings that are averaged are dependent upon the power level being run. This process allows AE to precisely calibrate a transfer standard at one power level and one frequency. It typically takes several hours to get one calibration point. Transfer standards are typically used for a single frequency and several power levels.

TRANSFER STANDARD

Circuit Block Diagram

Figure 3 is a circuit block diagram for the transfer standard. For RF measurements, the sensor is a stripline coupler. Because we are taking all measurements at 50 Ω, we only use the forward power measurement, or more accurately, a forward voltage measurement. The signal is then passed through a low pass filter, which removes the second and higher harmonics. The AC voltage from this filter is multiplied real-time, which results in a DC voltage that is proportional to V2/R, or power. The signal is then amplified to produce a voltage out that is linear with power and is calibrated to have a specified full-scale reading. The absolute linearity of this standard has been proven to be within 0.5% over a 30 dB range.

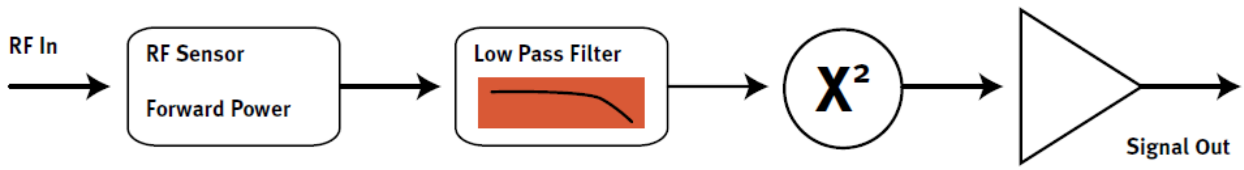

Figure 3: 13 MHz measurement standard

Historical Measurements—Repeatability Over Time

Using the uncertainty guidelines as set in NIST technical note 1297, the uncertainty of statistically validated measurements can be expressed using the following formula:U = kuc(y)where U is the expanded uncertainty of the measurement, k is the coverage factor, y is the measurand, and uc is the standard uncertainty.

Continuing with the example of the 13.56 MHz standards, for our 3 kW transfer standards, uc has been measured to be no greater than 0.08% for standards that have been in use for longer than one year. Using a coverage factor of three for a 99% confidence level, the expanded uncertainty for the 13.56 MHz, 3 kW transfer standards has been measured to be less than 0.25%.

This is significant because this measurement is essentially the repeatability of the transfer standards in addition to that of the calorimeter. One thing that cannot be stated is that this measurement represents the “true” watt. The expanded uncertainty above is more accurately stated as the repeatability of the AE watt at 13.56 MHz.

FLOOR STANDARD

The circuit block diagram for the floor standard is identical to the transfer standard (Figure 3). The reason for the separate existence of a floor standard is primarily due to the length of time taken to make calorimeter runs. Currently, it takes on the order of two days to calibrate one transfer standard, and it is simpler to use one transfer standard to calibrate several floor standards. That is, using the transfer standard to calibrate the floor standards leads to a much greater capability to support a manufacturing process that can require a very large number of floor standards.

Also, by using the transfer standards less often, they have much less risk of drift due to repeated use. This is why the transfer standards are calibrated every three months while the floor standards are calibrated monthly.

Process of Calibration

The floor standards are verified to be within 0.3% of the transfer standards for the points at which they are verified. Outside of this control band, they are adjusted back to the center. Inside this control band, the floor standards are not adjusted.

Variable Frequency Calibration

For RF products with variable frequencies, there is another level of calibration that occurs to control and validate the variable frequency response of the unit. The process is as follows

1. A transfer standard is calibrated for the low-, mid-, and high-frequency limits of the power supply.
2. Filter characteristics of the transfer standard are determined using a network analyzer.
3. The floor standard is characterized against the transfer standard under power conditions for the entire frequency range in 50 discrete steps.
4. The unit is calibrated against the floor standard for the entire frequency range in the same number of discrete steps.

For additional information, please contact Advanced Energy at advancedenergy.com.