TECHNICAL NOTES

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Mismatch Compensation Techniques in the SureCAL® Power Sensor Support Package

OVERVIEW:

This Technote discusses the use of mismatch compensation algorithms in the SureCAL® Power Sensor Support Package. The SureCAL® Power Sensor Support Package is a flexible software product used to calibrate a wide variety of RF and Microwave Power Sensors.

CALIBRATION FACTOR and EFFECTIVE EFFICIENCY:

The chief parameter to be measured for all power sensors is called Calibration Factor. Calibration Factor is a measure of how much RF energy is detected by a given sensor in comparison with the RF energy *available at it's input*. Calibration Factor should not be confused with Effective Efficiency, a similar quantity, which expresses how much RF energy is detected by a given sensor in comparison with the energy *absorbed by the sensor's input*. The critical difference between the two terms is that Calibration Factor includes an allowance for the portion of RF energy which is not absorbed by the sensor, but is instead reflected back to the Source, while Effective Efficiency does not.

A simple formula can be used to relate the two values:

$$\eta_e = \frac{K}{1 - |\Gamma_l|^2}$$

where: $\eta_e =$ Effective Efficiency
$K =$ Calibration Factor
$\Gamma_l =$ Reflection Coefficient of Sensor Input Port

Calibration Factor is commonly expressed as a percentage. That is, a Calibration Factor of 100% implies that all RF energy available at the sensor input was detected, while a value of 95% implies that only 95% of the available RF energy was detected.

Calibration Factors are used to compensate the readings of power meters which only register detected power. The available power may be calculated from detected power as follows:

$$P_a = \frac{P_d}{K \div 100}$$

where: $P_a =$ Power available at sensor input (in Watts)
$P_d =$ Power detected by sensor (power meter reading in Watts)
$K =$ Calibration Factor (in %)

Calibration Factors are also commonly expressed in dB units. The following formula can be used to convert percent Cal Factors to dB Cal Factors:

$$K_{dB} = 10LOG(K \div 100)$$

where: $K_{dB} =$ Calibration Factor (in dB)
$K =$ Calibration Factor (in %)

When using dB Cal Factors to correct a power meter reading, the following formula is used: [1]

$$P_a = P_d - K_{dB}$$

where: $P_a =$ Power available at sensor input (in dBm)
$P_d =$ Power detected by sensor (power meter reading in dBm)
$K_{dB} =$ Calibration Factor (in dB)

MISMATCH ERRORS:

In practice, power sensors rarely absorb all of the RF energy available at their inputs. This would only happen if the sensor's Load impedance was a *perfect* match to the signal's Source impedance. Consequently, there is almost always a portion of the signal reflected back, and therefore not detected.

When calibrating a power sensor, this "lost" signal can become the single largest source of error in determining a sensor's true Calibration Factor. Depending on the amount of signal reflected and it's phase relationship to the non-reflected portion of the signal, an error can be generated which adds or subtracts several percentage points from the true Calibration Factor.

To compensate for these mismatch errors, the Source and Load impedance must be known precisely, including their phase characteristics. This can be accomplished using a Vector Network Analyzer, such as a Hewlett Packard 8510. The following formula is used by the $^{Sure}CAL^{®}$ Power Sensor Support Package to compensate for mismatch errors:

$$P_a = P_{z0} \frac{(1 - |\Gamma_l|^2)}{|1 - \Gamma_s \Gamma_l|^2}$$

where: $P_a =$ Power absorbed by the load (sensor input)
$P_{z0} =$ Power available to a perfectly matching load
$\Gamma_s =$ Complex vector of Source Reflection Coefficient and Phase
$\Gamma_l =$ Complex vector of Load Reflection Coefficient and Phase

The above compensation is made **only** if vector impedance data is available for both the Standard and Unit Under Test sensors. This data must be entered manually in the appropriate sensor data files to be utilized by the program.

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[1] Most equipment manufacturers use this formula, but not all have been consistent when using dB Cal Factors. Some power meters may require reversing the sign of the dB Cal Factor to achieve correct compensation. The $^{Sure}CAL^{®}$ Power Sensor Support Package prints a note to this effect on the datasheets of affected sensors.

MISMATCH COMPENSATION UNCERTAINTY:

The use of a vector compensation algorithm does not guarantee an error-free transfer of Calibration Factors from a Standard Sensor to a Unit Under Test Sensor. When working optimally, it can reduce mismatch errors by an order of magnitude, but other sources of error remain. Continuing sources of error include:

Uncertainty of vector impedance data

Determination of precise vector impedance data is a demanding task and can be compromised by poor maintenance of Network Analyzer Calibration Kits and by the skill level of the operator.

Inaccuracies in Phase data can become significant for very small reflection signals. It is possible (for situations where the impedance match is already very good) that using the compensation algorithm can introduce more error than it removes. This scenario is unlikely to produce large errors, however.

Inability to fully compensate for large impedance mismatches

Even if the accuracy of vector impedance data is good, the compensation formula cannot reduce *large* mismatch errors to zero. Do not assume that using vector mismatch compensation removes the need for a good impedance match.

Connection Repeatability

When using mismatch compensation, connection repeatability can replace impedance mismatch as the largest source of error. Errors of over 1% are likely if care is not taken to apply appropriate and consistent torque to coaxial RF connections.

REFERENCES:

1. J. M. Crickenberger, “Calibration Laboratories Technical Guide”, NIST Handbook 150-2, August, 1995.
2. A. Fantom, “Radio Frequency and microwave power measurement”, Peter Peregrinus Ltd., London, U. K., 1990.