APPLICATION NOTE

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TEGAM

THE GLOBAL SOURCE FOR PROVEN TEST AND MEASUREMENT TECHNOLOGY

100 mW Feedthrough Power Standard

Accurate Microwave Measurements Require Traceable Standards

Commercially available power meters and sensors have measurement ranges up to several watts. Accurate measurements with these devices require periodic calibration with traceable standards.

Conventional calibrations typically take place in the 1mW to 10mW range. This range can be extended downwards for highly sensitive diode sensors by means of a calibrated attenuator. Raising the calibration level above 10mW, to calibrate higher power sensors well above their noise floor, has been more of a problem. For example, one calibration technique separates the front end attenuator from the sensor, and calibrates the two devices independently. However, this creates measurement uncertainty when the data is combined.

This app note describes a basic technique for generating an accurate 100 mW power source. The technique extends the advantages of a lower power calibration to higher power units. Calibration is a relatively simple operation with excellent and traceable accuracy. The resulting standard can be an integral part of a TEGAM System IIA Power Sensor Calibration System, which allows accurate SWR/Return Loss measurements, as well as creation of sensor calibration factors.

Power Standard Principles

An essential element in the creation of a calibrated power source is use of a terminating or feedthrough power standard. The TEGAM range of power standards is based on the concept of DC substitution. Two thermistor beads mounted in a microwave structure are heated by a DC bias power such that they reach a particular resistance. (The beads are contained within a temperature controlled chamber to isolate them from changes in ambient temperature.) When RF power is incident on the thermistor beads, this also causes them to be heated. The DC bias power is then reduced to maintain constant resistance in the beads. The ratio of the change in DC bias power and RF incident power is the calibration factor of the power standard.

In their coaxial terminating mount (for example, a TEGAM Model 1110 or 1111), the two beads are essentially identical in performance. They are connected in parallel to incident RF and in series to the DC bias power. With individual values of 100 Ω, they create an RF impedance of 50 Ω and a DC resistance of 200 Ω.

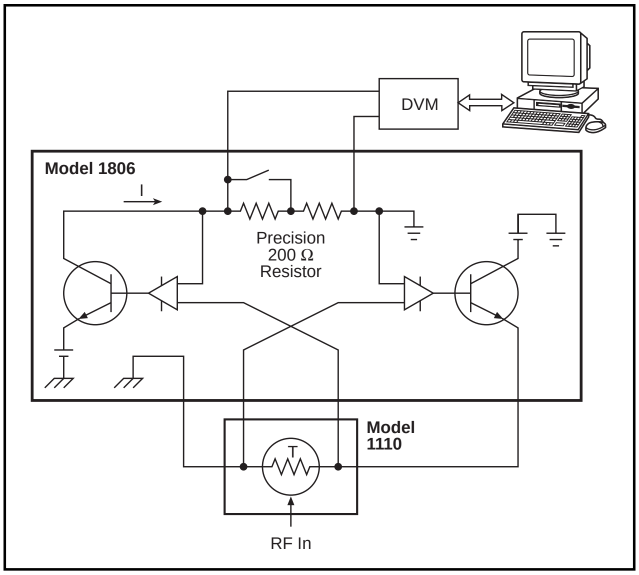

FIGURE 1. PRECISION POWER METER

<u>Bridge Technique Allows Simple Power Measurement</u> — A bridge technique, such as that used in the Model 1806 Dual Type IV Power Meter, maintains the thermistor beads at a constant resistance (Figure 1). An accurate resistance, which mirrors the power dissipation in the beads, allows the bias power to be measured with a digital voltmeter. Changes in bias power due to incident RF energy are represented by a change in voltage across this resistor.

<u>Structure Design Provides Accuracy Over a Wide Range</u> — When at temperature, the beads absorb 30 ± 0.7 mW of DC bias power with no incident RF energy. This allows practical operation between 10 μW and 25 mW of RF power. The microwave structure that holds the beads is designed to offer as perfect a 50 Ω impedance as possible across its entire operating band. This structure and technique has been shown to have excellent stability and repeatability. Such devices can be calibrated directly by NIST and other standards laboratories.

Still, most power sensors are terminating devices. Therefore some method must be established that allows transfer of a calibration standard. Such a technique is discussed below.

Creation of a Calibrated Source

The combination of a terminating mount with a power splitter forms a feedthrough mount. This component arrangement, plus a signal source and RF control unit, are the basic elements of a precision RF power source.

In the TEGAM Model 1806 Power Meter, the bridge automatically modifies the DC bias in response to RF energy. To create a precision RF power source, a TEGAM Model 1805B RF Power Level Control Unit is used with the reverse concept. Using the Model 1805B, the DC bias is reduced by an accurately known fixed amount and a control signal produced that increases the amount of incident RF energy to compensate for the reduction. Figure 2 shows how this concept is used to create a calibrated source.

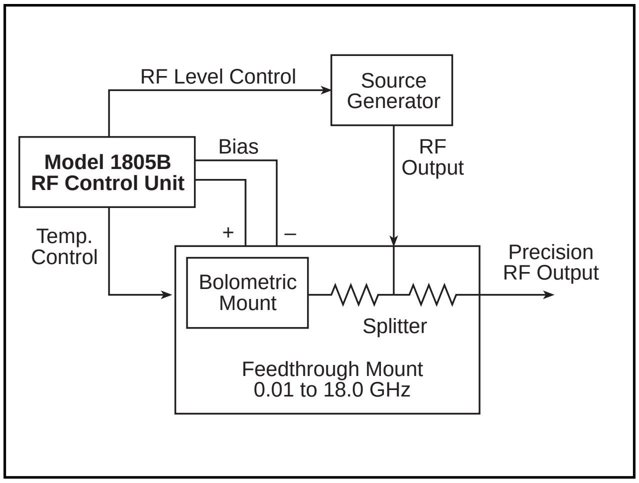

FIGURE 2. PRECISION RF POWER SOURCE

In Figure 2, the generator supplies power to the midpoint of a power splitter. Approximately one-fourth of this energy is incident upon the terminating mount. The 1805B adjusts the generator level such that the heating from the RF energy just balances the heating loss due to the preselected drop in DC bias power. At the same time, an approximately equivalent power is made available at the other port of the splitter.

The advantage of this arrangement is that the center point of the splitter is virtually a constant voltage point, and the SWR at the splitter output port is thus dominated by that side arm of the splitter. This SWR is specified as 1.06:1 from DC to 18 GHz and can be as low as 1.0:1 at low frequencies. Low SWR minimizes mismatch error in the transfer of calibrations. In addition, the stability of the thermistor mount means that the combination can be accurately calibrated, and will perform well with wide variations in generator characteristics.

The combination of a terminating mount and splitter is used in designing TEGAM feedthrough mounts, Models F1109, F1116 and F1119. Although such mounts cannot be calibrated by NIST, they can be calibrated by an appropriate terminating mount that has been calibrated by NIST. This is illustrated in the equations below.

For example, the substituted DC bias power, P_{DC}, may be selected as 10 mW on the 1805B. The imperfections of the mount at a particular frequency will cause a power P_{RF} to be available at the splitter output. P_{RF} can be measured by a terminating mount and the feedthrough mount can be allocated a calibration factor K_2 at that frequency, defined as:

$$K_2 = \frac{P_{dc}}{P_{RF}}$$

By definition, the power available at the feedthrough mount output is:

$$P_{RF} = \frac{P_{dc}}{K_2}$$

Since the splitter has excellent symmetry, the range of calibrated powers is basically dependent on selections available in the RF control unit. In the Model 1805B, possible selections have nominal values of 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 mW.

Power Sensors and Their Calibration

The majority of commercially available power sensors use either a thermocouple or diode element. Thermocouple devices measure true RMS power as they respond to the heating effect of the incident RF energy. They typically operate in the –30 dBm to +20 dBm range. Above +10 dBm (10 mW), they usually have some nonlinearity. Therefore, the optimum calibration range is between 1mW and 10 mW. Examples of such sensors are the HP8481A from Hewlett Packard, the 6910 from Marconi Instruments and the MA4701A from Anritsu.

Diode devices operate in the square law region of the diode and typically work over the range –70 dBm to –20 dBm. A suitable power level for calibration is –30 dBm. This can be done with a feedthrough mount set for 1 mW (0 dBm), using a 30 dB calibrated precision attenuator between the source output and the device being calibrated. Examples of such sensors are the HP8481D from Hewlett Packard, the 6920 from Marconi Instruments, and the MA4702A from Anritsu.

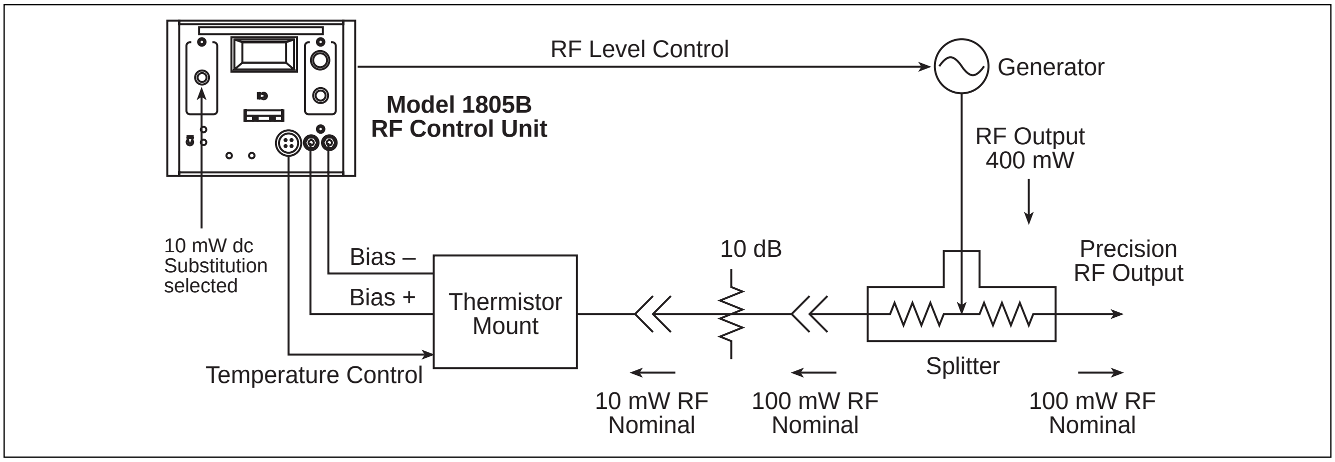

FIGURE 3. 100 mW-PRECISION RF-POWER SOURCE

However, the problem originally posed is the measurement of power levels higher than +20 dBm. Sensors for these levels are created by taking a thermocouple sensor and adding an attenuator to the input. Examples of such devices are the HP8481H from Hewlett Packard and the 6930 from Marconi Instruments.

The HP8481H, for example, works over the 10 MHz to 18 GHz range, and from –10 to +35 dBm. A calibration performed at 1 mW would be too close to the noise floor of the power meter. Even 10 mW would be only 20 dB above the noise floor.

As mentioned earlier, one solution is to remove the front end attenuator and calibrate it and the sensor separately. The two calibrations then have to be combined taking into account the mismatch between the two devices. This is tedious and may result in unacceptable uncertainty.

A better alternative is to calibrate the combination directly at 100 mW (+20 dBm). This is 30 dB above the noise floor, but below the level at which heating and other mechanisms begin to affect sensor linearity. The following section describes a technique for generating a 100 mW calibration signal.

Calibrated 100 mW Feedthrough Mount

In the feedthrough arrangement of Figure 3, the TEGAM 1805B DC control tries to produce enough power from the generator such that the incident RF energy to the thermistor beads in the terminating mount, plus the reduced bias, creates as much heat as the total bias power did originally. The difference in bias is selected on the front panel of the TEGAM 1805B. If the RF power from the side arm of the splitter is reduced by an attenuator, the 1805B will try to increase the generator power to stabilize the beads as before. In this case a 10 dB attenuator is used.

As shown in Figure 3, if a nominal 10 mW of RF power is needed to stabilize the thermistor beads, i.e., 10 mW of bias drop has been selected on the 1805B, then 400 mW is required from the generator. In turn, this means that 100 mW is available at the output of the splitter.

The mount, attenuator and splitter in Figure 3 form a feedthrough mount that must be calibrated. Calibration can proceed as for a standard feedthrough mount, except that the terminating mount is limited to 25 mW. In this case, a good calibration level would be 10 mW, which is equivalent to a 1 mW setting on the 1805B. As before, the calibration factor K_2 is given by:

$$K_2 = \frac{P_{dc}}{P_{RF}}$$

where P_{DC} is the 1805B setting, and P_{RF} is the output power. (See the calibration setup in Figure 4.) In this case, however, instead of K_2 being close to 1, it is approximately 0.1. As before, when used to calibrate a sensor, the precision power available at the splitter output is given by:

$$P_{RF} = \frac{P_{dc}}{K_2}$$

Unlike the standard feedthrough mount, however, the available nominal RF powers are 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 mW.

The attenuator used can have a variety of values, but a practical limit is 13 dB. This results in a 200 mW maximum signal and a 10 mW minimum, to be used for its own calibration. The splitter would be dissipating 400 mW, just within its 0.5W limit (1W maximum input power).

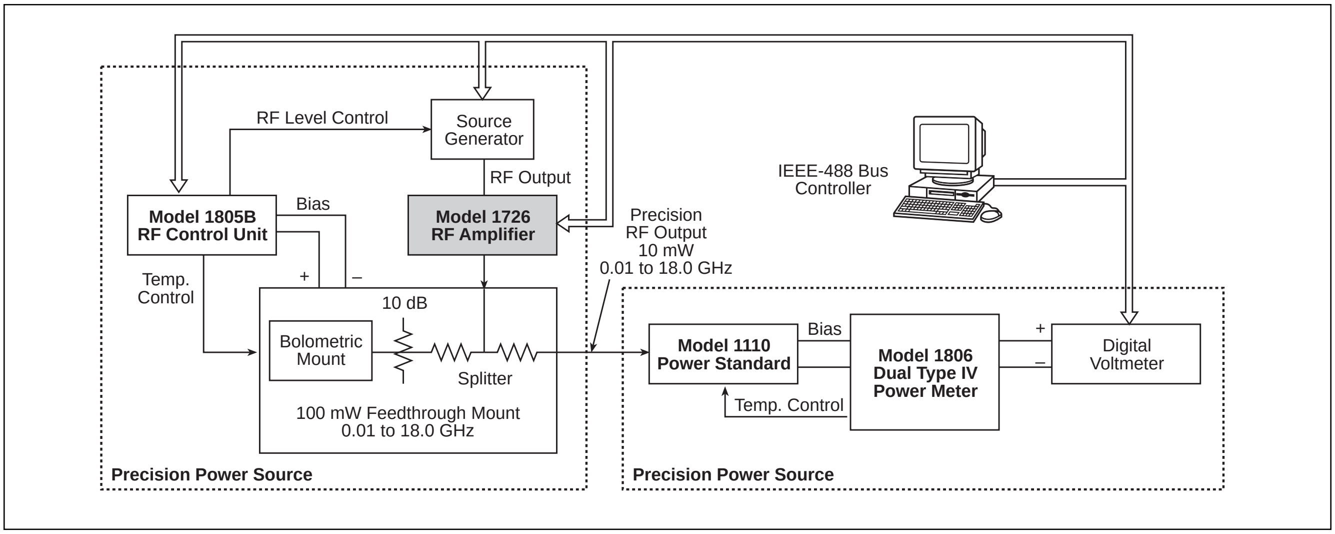

FIGURE 4. 100 mW CALIBRATION SETUP

Table 1 shows actual calibration data for a 100 mW feedthrough mount. This was produced using a Model 1726 Amplifier in the TEGAM System IIA Automatic Power Meter Calibration System, shown in Figure 4.

TABLE 1. ACTUAL CALIBRATION DATA FOR A 100 mW MOUNT

Freq. (MHz)	Cal Factor	Freq. (MHz)	Cal Factor
10.000	.1036	350.000	.1085
20.000	.1069	400.000	.1084
30.000	.1081	450.000	.1083
40.000	.1085	500.000	.1083
50.000	.1088	550.000	.1082
60.000	.1089	600.000	.1082
70.000	.1089	650.000	.1081
80.000	.1089	700.000	.1080
90.000	.1089	750.000	.1080
100.000	.1089	800.000	.1079
150.000	.1089	850.000	.1077
200.000	.1088	900.000	.1076
250.000	.1086	950.000	.1074
300.000	.1082		

Accuracy Discussion

Listed below is a breakdown of individual instrumentation errors and the resulting total uncertainty resulting from the transfer of calibration from a NIST calibrated standard terminating mount to a 100 mW feedthrough mount at 10 mW. The total uncertainty is expressed as a Root Sum Squared (RSS) value, calculated as the square root of the sum of individual errors squared.

Inaccuracy of DC Substitution (1806)	±0.003%
Digital Voltmeter Accuracy	±0.002%
Digital Voltmeter Linearity	±0.04%
Connector Repeatability	±0.1%
Temperature Drift of Standard Mount	±0.05%
Instability of Calibration Factor with Time	±0.1%
Inaccuracy of dc Substitution (1805B) at 1 mW	±0.6%
RSS Total	**±0.62%**

The following is a similar breakdown for the transfer to a device under test (DUT) at 100 mW.

Inaccuracy of DC Substitution (1805B) at 10 mW	±0.15%
Connector Repeatability	±0.1%
Temperature Drift of Feedthrough Mount	±0.05%
Thermal Imbalance of Feedthrough Mount (1 mW to 10 mW)	±0.1%
Instability of Calibration Factor with Time	±0.1%
RSS Total	**±0.23%**

The techniques described in this app note all but eliminates the mismatch errors in going from a terminating standard to a feedthrough standard. Errors can also be eliminated in going from a feedthrough to a DUT, if the vector value of the DUT reflection coefficient is known. If it is not known, then SWR specifications of 1.06:1 and 1.20:1 for the feedthrough standard and DUT, respectively, would give a worst case mismatch error of 0.54%. A known value for the feedthrough mount of 1.03:1 would reduce this to about 0.26%.

The uncertainty value can be calculated by the TEGAM System IIA software for each frequency involved, either from specified or measured data. An overall RSS uncertainty value of 0.66% is thus obtainable for a direct calibration at 100 mW, excluding NIST uncertainty, source effects and residual mismatch errors.

It should be recognized that providing a precision 100 mW (+20 dBm) source using the TEGAM System IIA technique, it is necessary to have a generator capable of delivering 400 mW (+26 dBm). Actually, since thermistor mounts and attenuators are not perfect devices, somewhat more than +26 dBm is needed. Considering cable losses to the splitter, and depending on frequency, as much as +29 dBm may be needed. Generators do not normally have this power available, which compels the use of an external amplifier (i.e., the Model 1726 in Figure 4).

As with any power calibration, harmonic levels can be critical. Unfortunately, it usually is the case that the higher the amplifier power level the higher the harmonic levels because of distortion. A total harmonic power 30 dB below the fundamental can cause up to a 0.1% error in the actual power available at the splitter output. Calibrating a broadband sensor to a first approximation will compensate for this. However, this is not good practice and should not be relied upon.

Conclusion

The 100 mW Feedthrough Power Standard shown in Figure 5 is an excellent means of directly calibrating higher power sensors. With this standard, calibration can be done in a single step as with normal sensitivity sensors, and the calibration factor produced can be used immediately.

Power meters normally have some means for checking which power range sensor is attached, and adjust their readout range accordingly. Calibration factors are thus still in the nominal range from 90 to 100%. This technique provides the calibration factor directly — sensor and front end attenuator do not have to be calibrated independently and combined performance calculated.

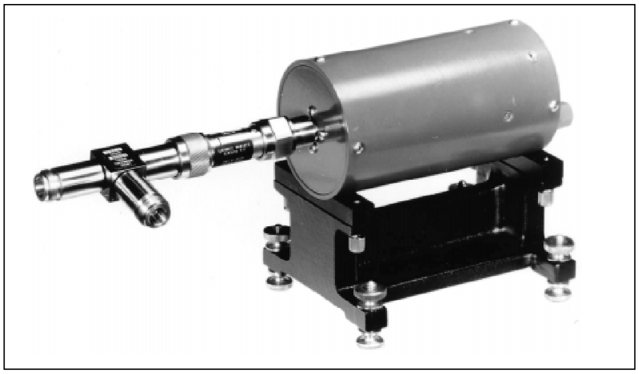

FIGURE 5. 100 mW FEEDTHROUGH POWER STANDARD

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