APPLICATION NOTE

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Answers to Frequently Asked Questions on System II

Summary of FAQs

The TEGAM System II Sensor Calibration System is employed around the world by many different organizations and users. It is normal for certain questions to come up regarding the system's use and capabilities, especially since it is regularly updated and improved.

This application note outlines frequently asked questions about System II, which are common to several applications. The detailed answers will help users resolve many functional issues and get the most out of their equipment.

The app note covers the following FAQs:

1. How can I minimize Feedthrough Mount downtime?
2. Can 75 Ω sensors be calibrated with the System II?
3. How do I set the reference calibration factor at a frequency outside the range of the signal generator?
4. Can you provide further analysis of uncertainty figures?
5. What are the limitations when using an amplifier to boost power?
6. Are the power requirements of the System II important?

Answers to FAQs

1. How can I minimize feedthrough mount downtime?

In coaxial power sensor calibration the workhorse of the System is the Feedthrough Power Standard, i.e., the Models F1109, F1116, F1117, and F1119. They are at the heart of the precision source of the System II, the part that is used to derive the calibration factor for the sensor-under-test. An example of a Feedthrough Power Standard is shown in Figure 1. Its use in a precision source mode with the Model 1805B RF Control Unit and signal generator is shown in Figure 2.

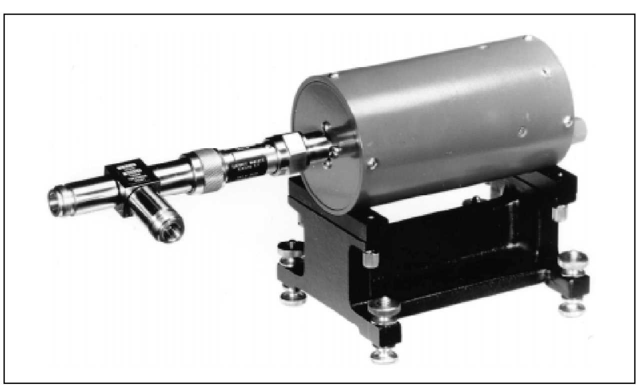

FIGURE 1. TYPICAL FEEDTHROUGH POWER STANDARD

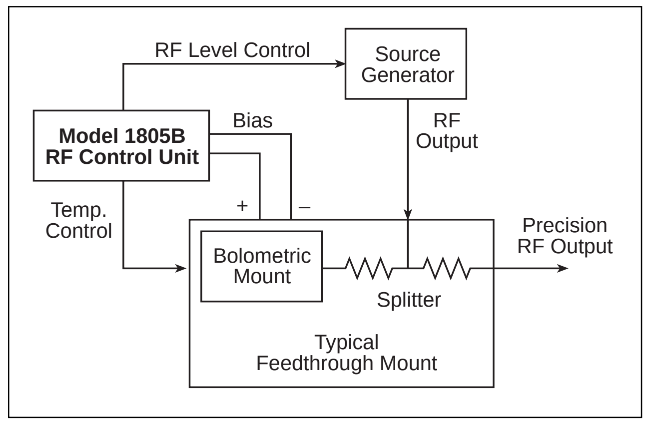

FIGURE 2. PRECISION RF POWER SOURCE

The constant use of the Feedthrough Power Standard causes wear of the connector interfaces. The type "N" connectors used in the F1109, F1116, and F1119 are quite robust, and can last several years with good care. However, the F1117 uses the 3.5mm connector, which is more easily damaged than the type "N."

Traceability for System II is usually through a Terminating Power Standard, such as the M1110. This can be sent out to a national standards laboratory such as the National Institute for Standards and Technology (NIST), Boulder, Colorado, for calibration. It can also be provided with traceable calibration by TEGAM. It can then be used with the Model 1806 Dual Type IV Power Meter to transfer calibration factors to the Feedthrough Power Standard within the precision power source.

Because of robust design, the Feedthrough Power Standard is almost never out of service. However, should the output connector of the Feedthrough Power Standard become damaged or worn, use of System II comes to a halt until it can be replaced or repaired.

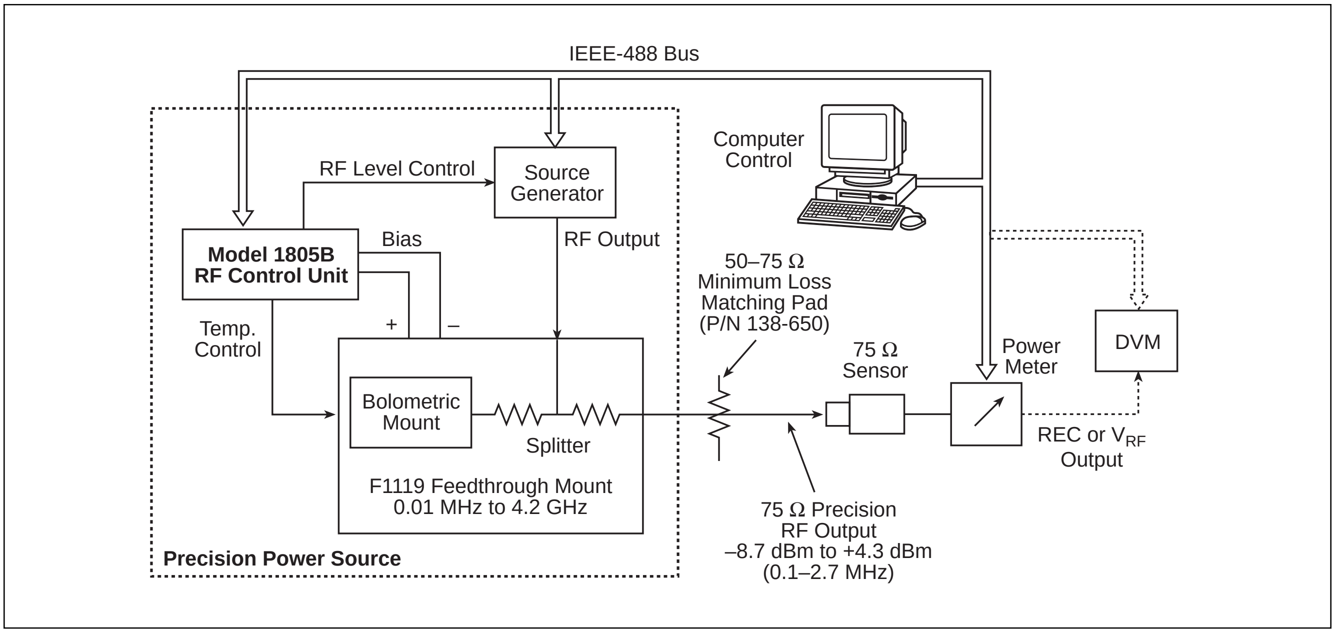

FIGURE 3. 75 Ω SENSOR CALIBRATION SETUP

TEGAM provides a repair service for all mounts, but during the process of shipment, repair, and return, the calibration system is down. A second mount provides a backup, but at a cost. One solution is to order a new splitter from TEGAM, which comes complete with its S_g data file. The existing splitter can be removed from the Feedthrough Power Standard by first loosening the collar. This, of course, voids any calibration and should not be performed while the standard is within warranty, unless specifically directed to do so by TEGAM. Also, the following procedure should only be performed by a qualified calibration technician. Even so, TEGAM can not guarantee calibration results after the splitter has been replaced.

The new splitter can be attached to the mount in a manner similar to the old one, including tightening of the tamper-proof collar. The repaired standard is then calibrated using a terminating standard and the S_g data file for the new splitter, which provides gamma correction for the resulting calibration factors. This procedure is explained in more detail in System IIa product manuals.

The splitters used in the TEGAM power standards are superior to similar commercially available products. For this reason, plus the fact that they come with S_g calibration data suitable for use with the System IIA software, they have individual part numbers for each power standard. The splitter part numbers are as follows:

Power Standard Model	Splitter Part Number
F1109	102-475-1
F1116	102-373-2
F1117	136-155-5
F1119	102-373-5

When replacing the splitter care should be taken to tighten all connectors to recommended torques. These torques are 14 inch-lbs for type “N” and 8.5 inch-lbs for 3.5mm units.

2. Can 75 Ω sensors be calibrated with the System II?

Sensors such as the Hewlett Packard HP8483A have a 75 Ω characteristic impedance. As such they cannot be directly calibrated by a 50Ω set-up. Not only are the impedances wrong, but the connectors will *only mate destructively*.

However, the System IIA software has the ability to correct for the loss incurred, when using an adapter or attenuator between the Power Standard and the sensor-under-test. Thus a minimum loss matching pad with the correct connector dimensions can be used between the Power Standard 50Ω output and the sensor’s 75 Ω input, as long as the loss through the minimum loss matching pad is known. Figure 3 shows the use of an intermediate device between the standard and the sensor-under-test.

TEGAM part number 138-650 is a minimum loss matching pad, with male 50Ω type N, and female 75 Ω type N connectors.

It has a nominal loss in power terms of 5.72dB, and comes complete with full “S” parameters. It is limited to the frequency range from 100kHz to 2.7GHz, which covers the vast majority of 75 Ω sensors.

The “S” parameter data file supplied with the device is suitable for use with the F1119 Feedthrough Power Standard. The approximately 6dB power loss through the device means that for a nominal calibration power of 1mW at the sensor-under-test, the System IIA should be set to 4mW operation. This is done by having a signal generator capable of giving out at least +13dBm, and setting the 1805B RF Control Unit to 4mW.

It must be noted that, although the minimum loss matching pad is limited to 2.7GHz operation, its “S” parameter file includes data to 4.2GHz. This extra data is there purely to satisfy the file compatibility function of the System IIA software, and has no electrical significance.

The user can produce limited range calibration files to match calibration frequencies to the specific needs of the sensor being calibrated. This is explained in detail in the System IIA software manual, IM-235. This can be achieved by creating a secondary set of feedthrough mount and minimum loss matching pad data files from the full range calibration files of these calibrated devices. This is explained in section 4-6. These secondary files will then be called up by the user at the appropriate time during the sensor calibration process instead of the full files.

Alternatively, the specific frequency range can be selected at the time of calibration of the sensor-under-test. This is explained in section 2-3.5.1.

The device needs to be calibrated on a regular basis as with all adapters and attenuators used in calibration. The recommended interval is one year. At present this is a complex process involving special airline adapters, and can only be performed at TEGAM. Nevertheless, it is a cost effective way of providing the means to calibrate power sensors at 75 Ω.

3. How do I set the reference calibration factor at a frequency outside the range of the signal generator?

Although coaxial power standards cover a full sensor band, not every user needs to calibrate sensors at every frequency. Some end users have definite bands of interest, and choose to calibrate their instruments for only that band. In doing so, of course, they do not need a generator that covers any other frequencies except those in the band of interest.

Since most sensors do not have an inherent absolute accuracy, they have to be aligned to some reference. (Thermistor based sensors such as the HP8478B are, on the contrary, absolute devices, and need no reference frequency for alignment.) In the case of many manufacturers of power meters, this reference is a 1mW, 50MHz source within the power meter. The frequency of 50MHz is thus chosen as a reference point for daily alignment of the sensors.

The calibration routine in System IIA acknowledges this fact, and allows the user to first select the reference frequency, and then to select the calibration factor to be assigned at that frequency. (Power meters normally have only a limited range of calibration factors for which the instrument can be adjusted. For example it may only be from 80% to 100%. No calibration factor over 100% can then be used. The calibration factor at the reference frequency is then chosen such that none of the calibration factors at the other frequencies exceed 100%.)

For example it may be that the calibration factor at a reference frequency of 50MHz is to be 96%. However, the calibration of the sensor is only to cover the range from 2 to 8GHz, and the user only has a generator covering that same range. The System IIA program asks if the user wishes to reference the power sensor at 1mW, thus:

"DO YOU WANT TO REFERENCE THE POWER SENSOR AT 1mW?"

Typing “Y” gives the program the affirmative. The program then gives the user the ability to select the reference frequency from the standard NIST traceable listing. In this example 2GHz could be chosen. It is actually only needed to give the program some input, and should be chosen such that the generator can provide the frequency. The program will then ask for the arbitrary assigned calibration factor at that frequency, thus:

"ENTER THE DESIRED REFERENCE CALIBRATION FACTOR IN (XX%):"

In the case of the example, the figure “100” could be entered. Once again its value is not important, as it is only being used to give the software some number to satisfy it.

The program will now prompt the user to adjust the power meter/sensor so that the displayed power level is read by the power meter. Here the software is assuming that the sensor is connected to the Feedthrough Power Standard. It has calculated the power emanating from that standard, and has then calculated what the power meter should read. Another assumption made by the software is that the power meter calibration factor control is set to 100%, since it does not want the power meter to adjust for the very response that the calibration system is trying to measure.

Since the user is using a generator that may have available the frequency chosen for reference, the output from the

Feedthrough Power Standard is not relevant. However, the user can, as it were, fool the system by now using the power meter's own internal reference source as follows:

a. Ignore the screen suggested settings.
b. Set the power meter calibration factor control to the calibration factor required at the reference frequency—in this example 96%.
c. Attach the power sensor to the power meter reference oscillator output.
d. Adjust the power meter adjustment screw such that the power meter reading is exactly 1.00mW.
e. Reattach the power sensor to the Feedthrough Power Standard.
f. Reset the calibration factor control on the power meter to 100%.
g. Press RETURN/ENTER on the controller.

The software will then continue with the remainder of the calibration selection process and perform the calibration over the limited range of frequencies required by the user. The resulting calibration will then be referenced to the correct frequency, even though that frequency is not within the range of the specific calibration run.

4. Can you provide further analysis of Uncertainty Figures?

The System II software has the ability to calculate the uncertainty of the calibration factors measured during the calibration process. It does this by having access to the uncertainty files of the standards, and having the specified characteristics of the calibration instruments, such as the TEGAM Model 1805B, within its memory.

This function is appropriate for thermistor based sensors, in that it gives an absolute uncertainty value for each frequency point independent of every other one. It is not, however, appropriate for other sensor types.

Devices such as the HP8481A have no intrinsic accuracy at any one frequency. They do, however, have a frequency response which is stable over long periods of time. To make use of these two facts, each HP power meter has a 1mW, 50MHz source, to act as a reference. On a regular basis the user of the sensor is expected to reference it to this 1mW source by adjusting the gain of the power meter. All of the sensor's calibration factors are thus referenced to the performance at 50MHz.

It stands to reason then that for the uncertainty calculation for the calibration factors, the uncertainty at 50MHz should be declared as 0%, since it is the reference. Any systematic errors that are the same at all frequencies then cancel out.

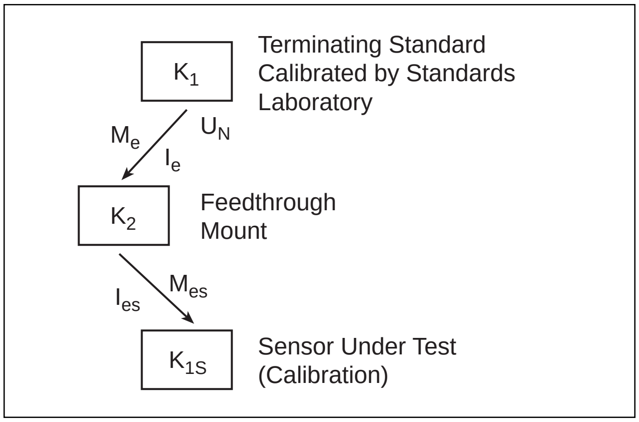

FIGURE 4. A TYPICAL TRACEABILITY SEQUENCE

A typical calibration sequence has a TEGAM Terminating Standard being calibrated by NIST, and given calibration factors with specific uncertainty values. Next, a Feedthrough Power Standard is calibrated. During this process extra uncertainty factors enter into the uncertainty equation. Finally, a sensor is calibrated by the Feedthrough Power Standard. Yet another set of factors are added into the uncertainty calculations. The general uncertainty calculation is shown below. The steps in the calibration process and their equivalent uncertainties are shown in Figure 4.

$$U_{total} = \sqrt{U_N^2 + I_e^2 + M_e^2 + I_{es}^2 + M_{es}^2}$$

where:

U_N is the NIST uncertainty,
I_e is the instrumentation error in transferring calibration to the feedthrough power standard,
M_e is the associated mismatch error,
I_{es} is the instrumentation error in transferring to a sensor, and
M_{es} is the associated mismatch error.

The uncertainty value is based on a Root Sum Squared (RSS) calculation.

When using Gamma correction techniques, the M_e and M_{es} figures can be assumed to be all but zero. A residual of 0.1% is assumed for each.

Using one frequency as the reference means that certain of the instrumentation errors, although not known, are the same for all frequencies. In a relative measurement they thus become zero. Table 1 shows the effect of the various aspects of the instrumentation errors in the calibration of the Feedthrough Power Standard. First is shown the absolute process and secondly the relative process.

Table 2 shows the same thing for the calibration of the sensor using the Feedthrough Power Standard. The total uncertainty at any frequency is now given by:

TABLE 1. COMPARISON OF INSTRUMENTATION ERROR (I_E) FOR ABSOLUTE CALIBRATION AT EACH FREQUENCY COMPARED TO CALIBRATION UNCERTAINTY RELATIVE TO A REFERENCE FREQUENCY AT 1 mW WHEN TRANSFERRING FROM A TERMINATING TO A FEEDTHROUGH POWER STANDARD.

Item	Absolute (±%)	Relative (±%)
DC Substitution (1805B)	0.600	0.000
DC Substitution (1806)	0.003	0.000
Digital Voltmeter Accuracy	0.001	0.000
Digital Voltmeter Nonlinearity at Calibration Factor	0.400	0.400
Digital Voltmeter Nonlinearity at Reference Frequency	—	0.400
Connector Repeatability	0.100	0.100
Thermistor Temperature Effects	0.050	0.000
Thermistor Linearity	0.100	0.000
Instability of Calibration Factor with Time	0.100	0.100
RSS Value	±0.74	±0.58

TABLE 2. COMPARISON OF INSTRUMENTATION ERROR (I_{ES}) FOR ABSOLUTE CALIBRATION AT EACH FREQUENCY COMPARED TO CALIBRATION UNCERTAINTY RELATIVE TO A REFERENCE FREQUENCY AT 1 mW WHEN TRANSFERRING FROM A FEEDTHROUGH POWER STANDARD TO A SENSOR.

Item	Absolute (±%)	Relative (±%)
DC Substitution (1805B)	0.600	0.000
Connector Repeatability	0.100	0.100
Temperature Drift of Mounts	0.050	0.050
Thermistor Linearity	0.100	0.000
Instability of Calibration Factor with Time	0.100	0.140
RSS Value	±0.63	±0.17

$$U_{total} = \sqrt{U_N^2 + U_{ref}^2 + I_{er}^2 + M_{er}^2 + I_{esr}^2 + M_{esr}^2}$$

where:

U_{ref} is the NIST uncertainty of the terminating standard at the reference frequency, for example at 50MHz,

I_{er} is the random part of the uncertainty of the instrumentation when calibrating the Feedthrough Power Standard,

M_{er} is the associated residual mismatch error,

I_{esr} is the random part of the uncertainty of the instrumentation when calibrating the sensor, and

M_{esr} is the associated residual mismatch error.

Both U_n and U_{ref} have to be included as they are uncorrelated and assumed to be random.

Typical results are as follows:

If U_{ref} = 0.35% and

if U_n = 0.34%, then U_{total} = 0.79%

if U_n = 0.40%, then U_{total} = 0.82%

if U_n = 0.66%, then U_{total} = 0.97%.

5. What are the limitations when using an amplifier to boost power?

The splitter arrangement of a Feedthrough Power causes a loss in power of at least 6dB between the signal generator and the sensor-under-test. Most microwave generators are capable of 10mW (+10dBm), and can thus support a calibration level of 1 and possibly 2mW.

To achieve a 10mW calibration level, a signal of at least +16 or +17dBm is required. This can normally be provided by an amplifier. However, some care needs to be taken when using an amplifier to prevent a signal generator from being used outside its normal operating level range.

Figure 5 shows how an amplifier can be used to boost the signal from a generator so as to achieve a calibration level of +10dBm.

Assume that the amplifier has a gain of 20dB. The calibration is to take place at 10mW, i.e., +10dBm. The splitter loses 6dB so that the input level to the splitter of the Feedthrough Power Standard must be +16dBm. The input cable has a loss of 1dB so that the amplifier output needs to be +17dBm. The amplifier input should thus be -3dBm!

If the calibration is to take place at 5mW, i.e., +7dBm, then the corresponding generator output level is -6dBm.

A particular generator may only be specified to operate over the range from 0 to +10dBm. The leveling loop of the precision source involving the Model 1805B, the signal generator, and the Feedthrough Power Standard may then not be stable down to a level of -6dBm from the source.

To prevent this from happening an attenuator can be inserted between the signal generator and the amplifier. A 6dB attenuator in the previous example would prevent the generator from having to operate below 0dBm. The attenuator would have the effect of reducing the amplifier gain by 6dB.

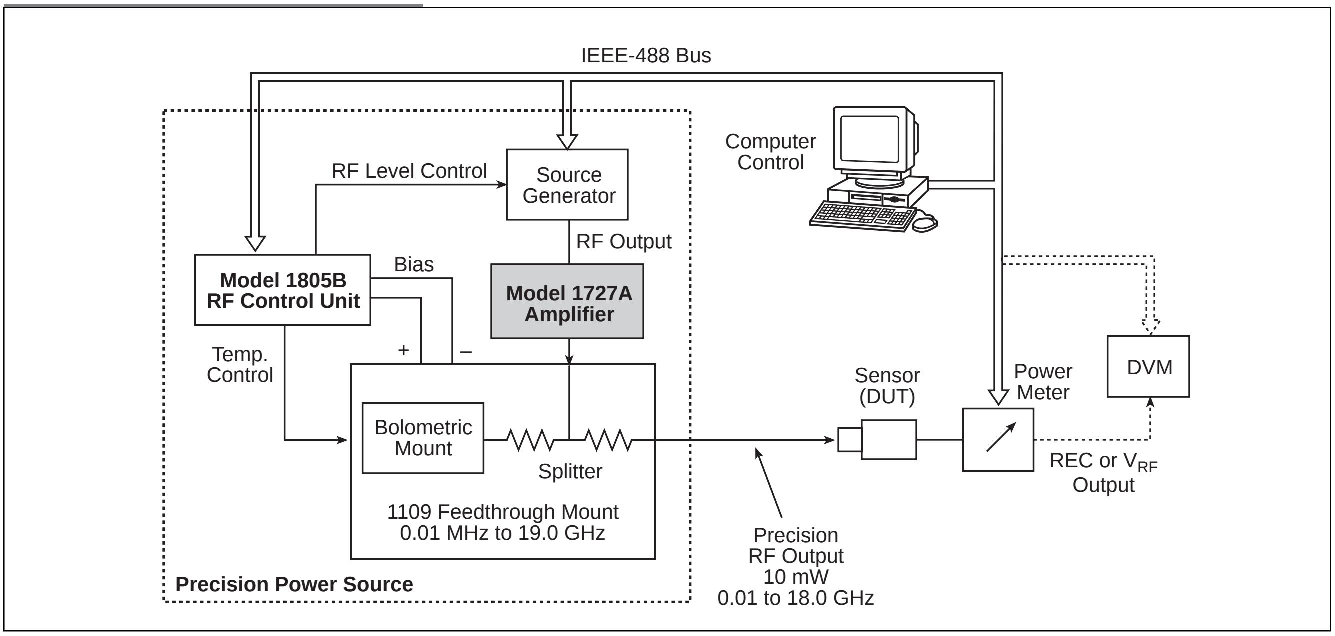

FIGURE 5. SYSTEM IIA-CONFIGURATION USING MODEL 1727A

6. Are the power requirements of System IIA important?

In the precision source shown in Figure 2, there are some losses incurred in various parts of the system. There are also some inefficiencies in certain items. These all add up to a complex picture when estimating the power budget through the system.

Firstly, the splitter used in the Feedthrough Power Standard has a theoretical loss of 6.02dB from input to output. In addition it is not perfect so that the loss can be a little higher. The thermistor mount attached to one side is neither a perfect 50Ω, nor does it have a perfect efficiency in converting input power to a change in its dc bias. These two effects are measured when the whole standard is calibrated.

A typical 18GHz feedthrough power standard has a calibration factor approximately equal to 100% at the lower frequencies. However, at 18GHz its calibration factor may be down to 80%. Since the DC bias drop caused by the 1805B is constant with frequency, this means that the signal to the power standard must be about 1dB higher at the high frequency end than at the lower end. While it is true that this means that the calibration level is also about 1dB higher than nominal, the generator still has to supply more power.

A second source of loss is in the connecting cable between the generator and the Feedthrough Power Standard. Depending on its length it could be 1.5dB more lossy at 18GHz than at 100MHz.

These two items add in such a way that the generator has to supply some 2.5dB more power at the high frequencies than at the low frequencies. For a nominal 1mW calibration level, the generator thus has to deliver perhaps +6.5dBm at 100MHz (4.5 mW), and +9dBm at 18GHz (7.9mW).

The picture becomes more severe with the new 26.5GHz standards. Cable losses can easily be 2dB and the mounts might drop to a calibration factor of 70% at the high end. This equates to the generator needing 3.5dB more power at the high end. Unfortunately, many generators can provide less power around 26.5GHz. For a 1mW nominal calibration level, the generator might need to supply +10dBm (Figure 6). If the generator only has 4mW guaranteed above 20GHz, it is not powerful enough to even calibrate at a nominal 0.5mW!

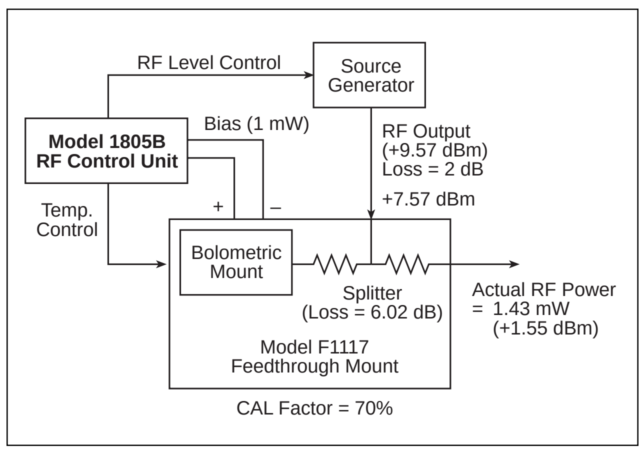

FIGURE 6. POWER BUDGET FOR PRECISION POWER SOURCE SHOWING A TYPICAL F1117 AT 26.5 GHz

References

1. System IIA Automatic Power Meter Calibration System, Operation and Installation Manual, IM-198.
2. System IIA Software Operations Manual, IM-235
3. 50-75Ω Minimum Loss Matching Pad (P/N 138-650) Operation Manual, IM-255.
4. IEEE Standard Application Guide for Bolometric Power Meters, IEEE STD 470-1972.

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