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AN AUTOMATED POWER METER CALIBRATION SYSTEM

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SUMMARY

Instruments required for calibrating microwave power meters have been redesigned to be calculator controllable and to provide calibrations from 0.01 to 18 GHz at eleven power levels from 0.5 to 10 mW. Using these instruments as a system, System II, calibration factors may be determined at rates of about 1.5 seconds per point with little operator attention.

A highly symmetrical resistive power splitter is used to provide nearly equal incident power to the device under test and to a calibrated standard over the entire frequency range. The power into the splitter is held at a selected level by the calibrated standard and an RF power level controller. The output of the device under test is measured by a Hoge-Larsen Two-E.M.F. Bridge and a digital voltmeter for a thermistor or barretter mount. The IEEE 488 bus output from the voltmeter or from a power meter under test is read by a calculator. Temperature control is required for the bolometer mounts for long term stability.

Alternatively two bolometer mounts may be compared using a pair of bridges and temperature controllers with the resistive power splitter.

Abstract

A computer aided measurement system for automatically calibrating microwave power meters, bolometer mounts and other power sensors is described. The theory for calibrating bolometer mounts using a power splitter is given. Techniques for using the system are discussed.

INTRODUCTION

The system considered here is useful for calibrating thermistor mounts, barretter mounts and microwave power meters having IEEE 488 bus outputs. Calibration may be made at power levels from zero to ten milliwatts in one milliwatt steps. The frequency range is ten megahertz to eighteen gigahertz. Depending upon the measurement technique used, uncertainties of one tenth to one percent above that of the calibration standard may be obtained.

The advantage of this system is that measurements may be made in a few seconds per frequency and the data of course may be printed or plotted automatically. This short measurement time permits measurements at many frequencies, typically the 110 frequencies routinely used by the National Bureau of Standards. This gives better detail in the data, requiring less interpolation. Human error is reduced and multiple measurements may be made to reduce random errors.

The method used is to provide a known incident microwave power to the device being calibrated and relating this to the indicated power or the direct

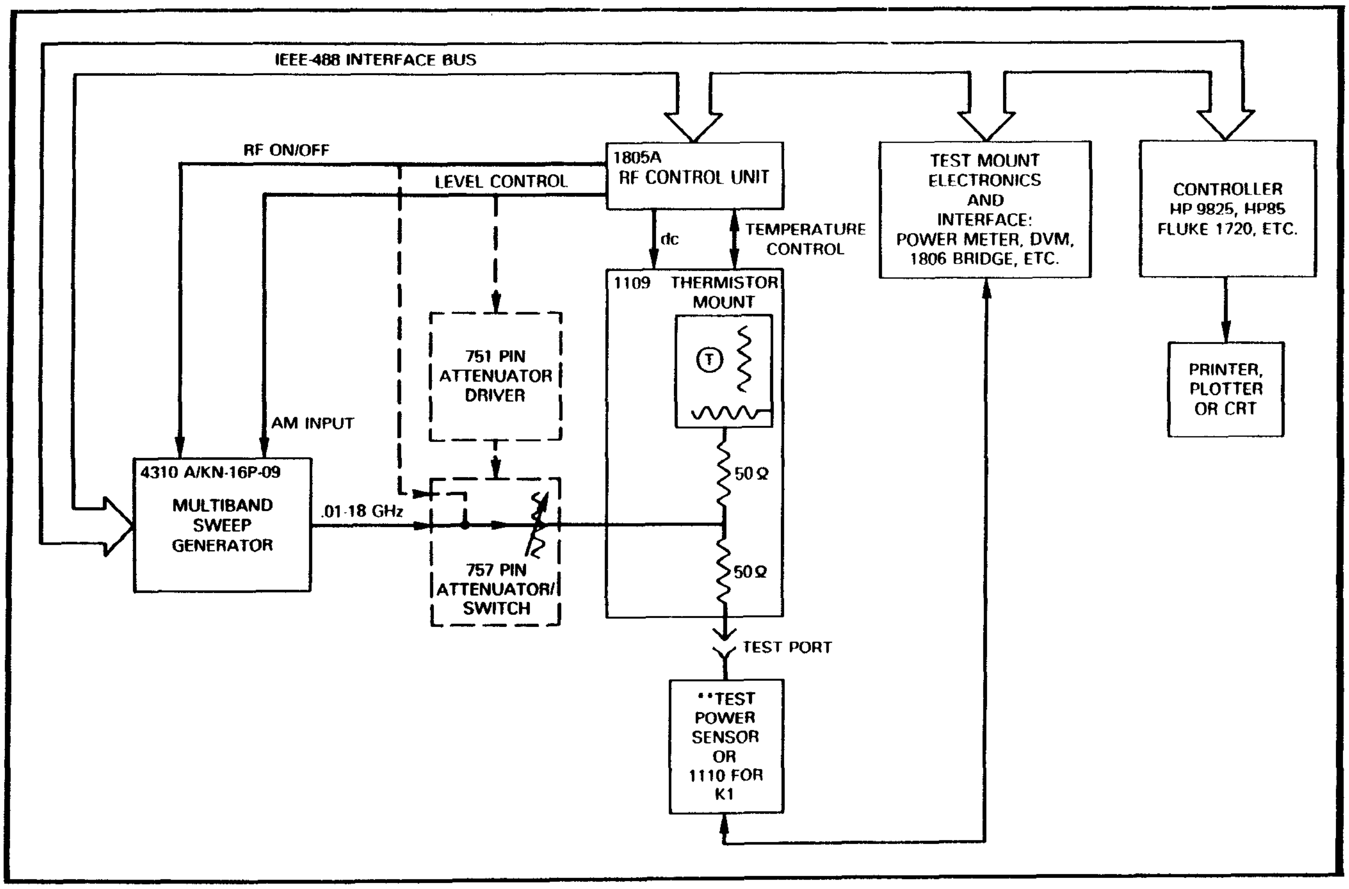

Figure 1 Calfactor System II, Functional Block Diagram

current substituted power in the case of bolometer mounts as described in reference one.

System Components

Three new, or rather improved, devices make the system possible:

The first is a bus controlled microwave power level controller. This contains a self balancing bridge which supplies direct current to a bolometer mount bringing the bolometer to the correct resistance with no microwave power applied. On command the direct current is reduced by a selected amount and the controller brings the bolometer back to the correct resistance by increasing the microwave incident power. The controller increases the microwave power either by adjusting the output of the generator if the generator has an external output control or by means of a combination switch and PIN attenuator. Thus the microwave power is increased by an accurately known amount. This is a modified version of the controller described in reference two.

The second is a dual power bridge. This contains two self-balancing bridges of the type developed by Neil Larsen at the National Bureau of Standards and discussed in reference three. It also contains two temperature controllers to regulate the temperature of the bolometer mount used by the above controller and the bolometer under test. The bridges hold the bolometers at a constant resistance. The voltage across the bolometer is measured by a direct current digital voltmeter, the output of which is read by the external calculator-controller.

The third is a combination power splitter and thermistor mount. The power splitter operates from zero to eighteen gigahertz and provides accurately equal power incident from each of its output parts. The thermistor mount has a useful frequency range of ten megahertz to eighteen gigahertz. The thermistor mount is connected to one output port of the power splitter and operated by the power level controller. The output of the controlled generator is fed into the input of the power splitter. Thus known levels of incident power are available from the second output port of the power splitter.

A functional diagram of the system is shown in Figure 1.

THEORY

For a general three port as shown in Figure 2:

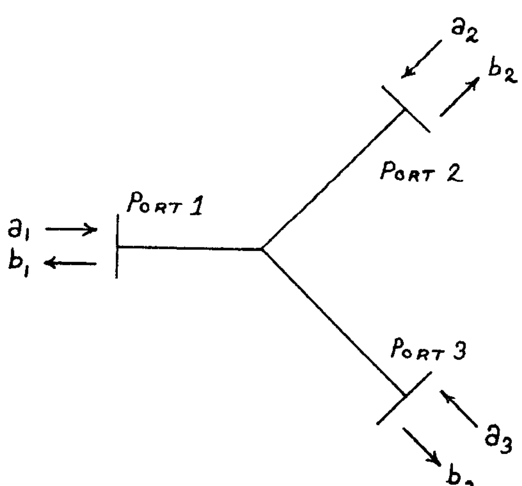

Figure 2 THREE PORT

$$b_2 = S_{21}\, a_1 + S_{22}\, a_2 + S_{23}\, a_3 \qquad (1)$$

$$b_3 = S_{31}\, a_1 \quad S_{32}\, a_2 + S_{33}\, a_3 \qquad (2)$$

$$\text{Therefore, } a_1 = \frac{1}{S_{21}}(b_2 - S_{22}\, a_2 - S_{23}\, a_3) = \frac{1}{S_3}, (b_3 - S_{32}\, a_2 - S_{33}\, a_3) \qquad (3)$$

$$\text{or } \frac{1}{S_{21}}\left(b_2 - S_{22}\, a_2 + \frac{S_{21}}{S_{31}} S_{32}\, a_2\right) = \frac{1}{S_{31}}\left(b_3 - S_{33}\, a_3 + \frac{S_{31}}{S_{21}} S_{23}\, a_3\right) \qquad (4)$$

But $a_2 = \Gamma_2\, b_2$ and $a_1 = \Gamma_3\, b_3$

$$\text{Therefore, } \frac{b_2}{S_{21}}\left(1 - S_{22}\Gamma_2 + \frac{S_{21}}{S_{31}} S_{32}\Gamma_2\right) = \frac{b_3}{S_{31}}\left(1 - S_{33}\Gamma_3 + \frac{S_{31}}{S_{21}} S_{23}\Gamma_3\right) \qquad (5)$$

$$\text{or } \frac{b_2}{b_3} = \frac{S_{21}}{S_{31}}\left[\frac{1 - \left(S_{33} - \frac{S_{31}}{S_{21}} S_{23}\right)\Gamma_3}{1 - \left(S_{22} - \frac{S_{21}}{S_{31}} S_{32}\right)\Gamma_2}\right] \qquad (6)$$

The incident power, $PI_n = b_n^2/Z_{on}$

$$\text{so } \frac{PI_2}{PI_3} = \left[\frac{S_{21}}{S_{31}}\right]^2 \left[\frac{1 - \left(S_{33} - \frac{S_{31}}{S_{21}} S_{23}\right)\Gamma_3}{1 - \left(S_{22} - \frac{S_{21}}{S_{31}} S_{32}\right)\Gamma_2}\right]^2 \frac{Z03}{Z02} \qquad (7)$$

Noting that for a Thevinen's source,

$$b_n = b_{Gn} + a_n\, \Gamma_{Gn} \qquad (8)$$

And with a load Γ_{Ln}

$$b_n = b_{Gn} + b_n\, \Gamma_{Gn}\, \Gamma_{Ln} \qquad (9)$$

$$\text{or} \quad b_n = b_{Gn} / 1 - \Gamma_{Gn}\, \Gamma_{Ln} \qquad (10)$$

$$\text{And} \quad b_m = b_{Gm} / 1 - \Gamma_{Gm}\, \Gamma_{Lm} \qquad (11)$$

So the incident power ratio is

$$\frac{b_n^2\, Z_{om}}{b_m^2\, Z_{on}} = \left[\frac{b_{Gn}}{b_{Gm}}\right]^2 \left[\frac{1 - \Gamma_{Gm}\, \Gamma_{Lm}}{1 - \Gamma_{Gn}\, \Gamma_{Ln}}\right]^2 \frac{Z_{om}}{Z_{om}} = \frac{P_{In}}{P_{Im}} \qquad (12)$$

Therefore, equation (7) may be written

$$\frac{P_{I2}}{P_{I3}} = R \left[\frac{1 - \Gamma_{G3}\, \Gamma_3}{1 - \Gamma_{G2}\, \Gamma_2}\right]^2 \qquad (13)$$

Where R is the splitter ratio, $\left[\frac{S_{21}}{S_{31}}\right]^2 \left[\frac{Z_{o3}}{Z_{o2}}\right] \approx 1$

And Γ_{Gn} is the equivalent source reflection Coefficient of splitter arm n, $\left(S_{nn} - \frac{S_{n1}}{S_{m1}} S_{mn}\right) \approx 0$

Since for an ideal power splitter $S_{31} = S_{21} = \frac{1}{2}$ and $S_{22} = S_{33} = S_{32} = S_{23} = \frac{1}{4}$.

The calibration factor, K_1, of a bolometer mount is defined as the ratio of DC substituted power to the incident microwave power or

$$K_1 = P_{DC}/P_I \qquad (14)$$

Therefore, with bolometer mounts on the two splitter output ports

$$\frac{P_{I2}}{P_{I3}} = R\left[\frac{1-\Gamma_{G3}\Gamma_3}{1-\Gamma_{G_2}\Gamma_2}\right]^2 = \frac{P_{DC2}/K_{12}}{P_{DC3}/K_{13}} \quad (15)$$

For the system being discussed a thermistor mount is attached to port 3, therefore, the system may be calibrated by placing a bolometer mount with known $K_1 = K_{1S}$ on port 2 and measuring $P_{DC2} = P_{DC2S}$ and $P_{DC3} = P_{DC3S}$ then

$$\frac{P_{DC2S}}{P_{DC3S}}\frac{K_{13}}{K_{1S}} = R\left[\frac{1-\Gamma_{G3}\Gamma_3}{1-\Gamma_{G2}\Gamma_S}\right]^2 \quad (16)$$

Then if the mount with known K_{1S} is replaced by a mount of unknown K_{1X}

$$\frac{P_{DC2X}}{P_{DC3X}}\frac{K_{13}}{K_{1X}} = R\left[\frac{1-\Gamma_{G3}\Gamma_3}{1-\Gamma_{G2}\Gamma_X}\right]^2 \quad (17)$$

Therefore, dividing equation (16) by equation (17)

$$\frac{K_{1X}}{K_{1S}}\frac{P_{DC2S}}{P_{DC3S}}\frac{P_{DC3X}}{P_{DC2X}} = \left[\frac{1-\Gamma_{G2}\Gamma_X}{1-\Gamma_{G2}\Gamma_S}\right]^2 \quad (18)$$

or

$$K_{1X} = K_{1S}\frac{P_{DC3S}}{P_{DC2S}}\frac{P_{DC2X}}{P_{DC3X}}\left[\frac{1-\Gamma_{G2}\Gamma_X}{1-\Gamma_{G2}\Gamma_S}\right]^2 \quad (19)$$

Measurement Techniques

In equation (19), the expression

$$\left[\frac{1-\Gamma_{G2}\Gamma_X}{1-\Gamma_{G2}\Gamma_X}\right]^2 \approx 1 \quad (20)$$

since Γ_{G2}, Γ_X and Γ_S are small and Γ_X and Γ_S are nearly equal for mounts of the same general design. In another paper it will be shown how this error may be eliminated.

Values of K_{1S} are entered into the system along with the frequencies at which they are known. With the calibrated mount on the measuring port of the system a calibration run is made and P_{DC3S} and P_{DC2S} are stored.

Values of K_{1X} are obtained by replacing the calibrated mount with the mount to be calibrated then a measurement run is made and P_{DC3X} and P_{DC2X} are measured. From these values and the stored values, K_{1X} is calculated according to equation (19) as a function of frequency.

Once the system is calibrated the bolometer mounts may be calibrated at a rate of a few seconds per frequency. Power meters with IEEE bus output may also be calibrated. The calibration factor of the power meter is defined as the ratio of output to the incident microwave power then by substituting the output for P_{DC2X} in equation (19) the system calibrates power meters with equal efficiency.

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