Power Measurement System for 1 mW at 1 GHz

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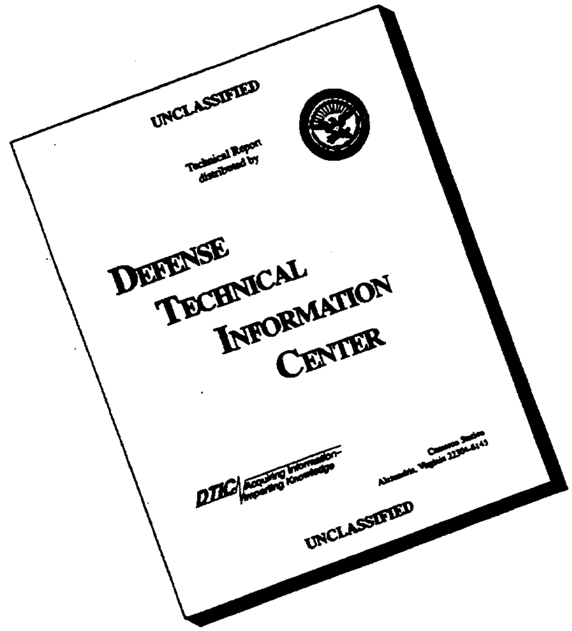

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ABSTRACT

An automated measurement system designed to measure power accurately at the level of 1 mW and at the frequency of 1 GHz is described. The system consists of commercial IEEE Std-488 bus-controlled instruments, a computer controller, and software. The results of a series of measurements are output to the computer display and, optionally, to a printer. The results are the mean of the measurement series and an estimate of the systematic and random uncertainty. The total estimated uncertainty for the average of six consecutive measurements of a nominal 1 mW, 1 GHz source is typically less than 1 percent. The system can measure any power from 0.1 to 10 mW at any microwave frequency by making appropriate changes to the software and possibly, the hardware.

Key words: automated measurement; microwave; microwave power measurement; power; power measurement; power measurement system.

POWER MEASUREMENT SYSTEM FOR 1 mW at 1 GHz

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1. INTRODUCTION

This system is especially designed to accurately measure microwave power at the level of 1 mW and the frequency of 1 GHz. Specifically, it supports the calibration of the Wavetek 8502A[1] pulse power meter, which has a 1 mW, 1 GHz calibrator output port. The manufacturer's specification on the power level of that output is ±1.5 percent. Use of the system is not restricted to this specific application; relatively simple modifications to the software would make it possible to measure other power levels and frequencies.

The microwave power measurement method is based on the dc substitution technique. The system is implemented using a commercial version of the NIST-developed Type IV microwave power meter, a commercial coaxial thermistor mount, a digital voltmeter, and a dedicated computer controller. The Type IV power meter is not direct reading; the substituted dc power is calculated using readings obtained from the digital voltmeter. The computer controls the measurement process, calculates the results, and prints them out. The measurement results include an estimate of uncertainty for each data set. The automation also allows the implementation of a procedure that adequately corrects for thermistor mount drift caused by external temperature changes. The system is packaged in a combination operating/shipping case.

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[1] Certain commercial instruments and software products are identified in this document in order to adequately specify the instrument supported and the measurement system. Such identification does not imply recommendation or endorsement by NIST nor does it imply that the identified items are necessarily the best available for the purpose.

2. OPERATION

2.1 Initial Steps

Before turning on the Type IV power meter be certain that the thermistor mount is connected to it. The output of the Wavetek 8502A calibrator is found to be more stable after a 2 hour warmup, rather than the 30 minutes specified by the manual. If possible, the 2 hour warmup period is recommended for both the 8502A and the power measurement system. It is also recommended that the thermistor mount be attached to the calibrator output for at least 30 minutes before making the measurement. This will minimize the temperature drift of the mount, improving the measurement accuracy.

Before turning on the computer, load the disk marked "System and Program" in the drive, then turn on the power. The operating system will be automatically loaded. The computer screen will display the time and the several soft-key options: SET CLOCK, LOAD PROGRAM, and EXIT. (The soft keys, or function keys, are the set of eight dark grey keys along the top of the keyboard labeled F1 through F8.) Set the time if needed, and then press the LOAD PROGRAM soft key. The measurement program will be loaded and run.

2.2 Measurement

The first screen displayed by the program is shown in figure 2.1. To see instructions on how to operate the 8502A (to turn the calibrator output on and off), press F1. To enter the serial number of the 8502A being measured, press F2; the serial number will then be printed with the measurement result. To change the number of repeated measurements to be averaged in a set (at least 6 to 10 is recommended), press F3. To begin the measurement set, press F4. To exit the program, press F5.

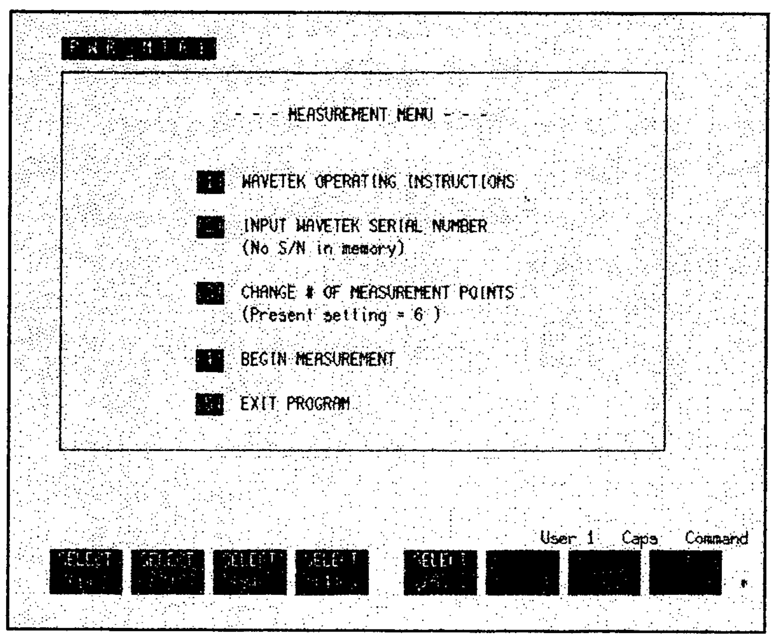

Figure 2.1. Screen display of the measurement menu.

Figure 2.2 shows the screen that appears when the first item is selected from the Measurement Menu. It gives brief instructions for manually controlling the 8502A calibrator output based on information given in the instrument's operating manual. The four numbered steps shown on the screen should be carried out before proceeding with the measurement.

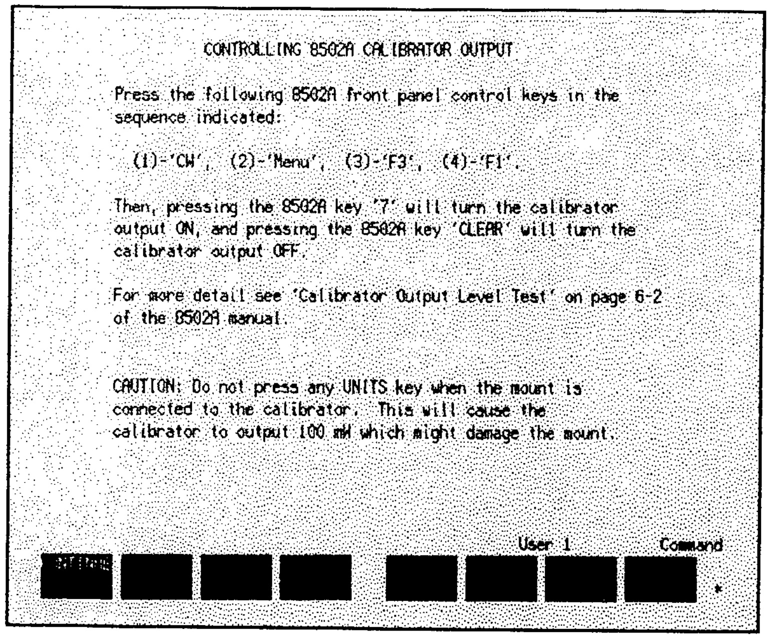

Figure 2.2. Screen display of operating instructions for the calibrator output.

Figure 2.3 shows the screen that appears when F4 is pressed to start the measurement. Just before the message TURN RF ON (PRESS 8502A KEY '7') is displayed, the computer will beep once. At that point press key 7 on the 8502A to turn the rf on and wait for a pair of beeps from the computer. The message will change to TURN RF OFF (PRESS 8502A 'CLEAR'). After pressing the CLEAR key, wait until a single beep sounds again, before pressing key 7 to begin the next measurement in the set. This sequence will be automatically repeated until all the measurements making up the set have been made.

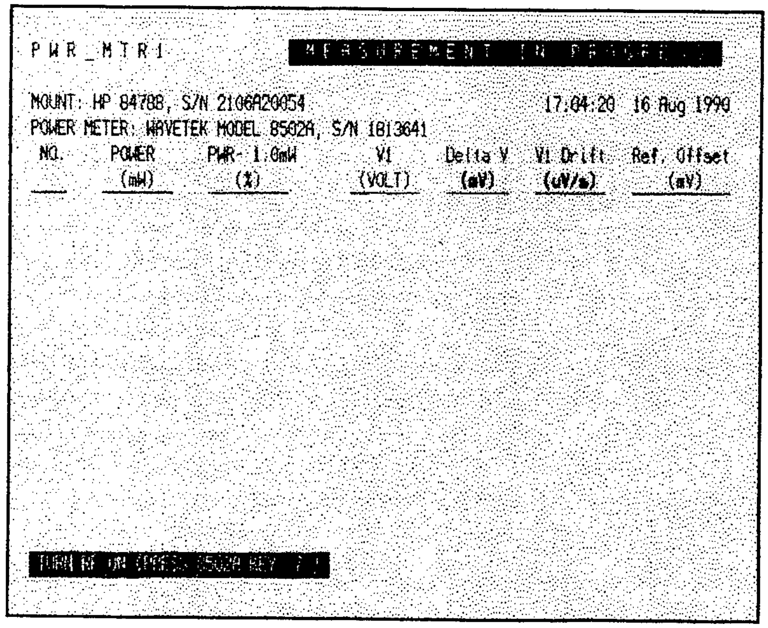

Figure 2.3. Screen display while the measurement is made.

When the desired number of measurements is complete, the final screen that is displayed is shown in figure 2.4.

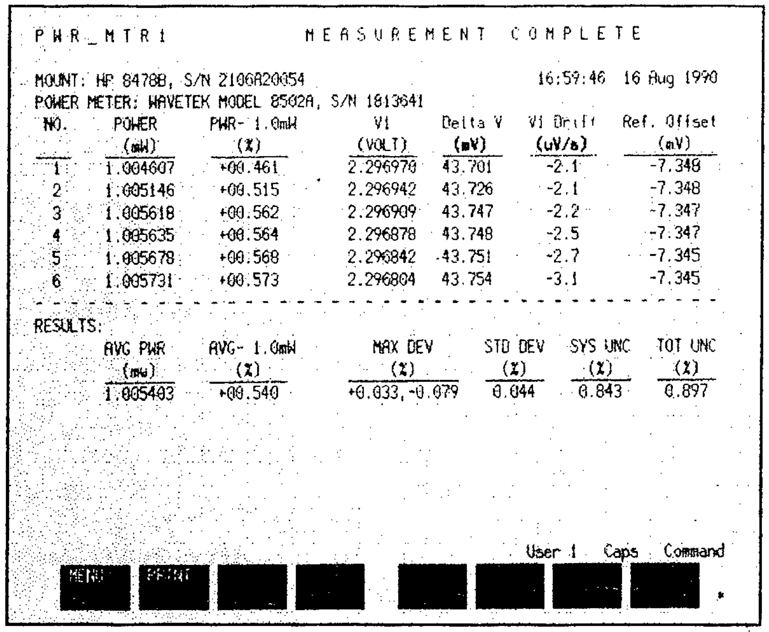

Figure 2.4. Screen display of the measurement results.

The upper part of the display summarizes each measurement in the set as explained in table 2.1 below.

Table 2.1. Explanation of the upper part of the measurement screen

Column Heading	Explanation
NO.	Number of the power measurement.
POWER	Result of the power measurement in milliwatts.
PWR - 1 mW	Percent deviation of the measured power from 1 milliwatt.
V1	Power meter voltage with the rf off (see section 3.1).
Delta V	Change that occurs in the power meter voltage when the rf is turned on.
V1 Drift	Drift of V_1 in μV/s that occurred from the beginning of the measurement until it was complete. Note that if the drift is greater than 10 μV/s the measurement should be repeated after waiting a period of time for the mount temperature to further stabilize.
Ref. Offset	The compensation element channel is used as the voltage reference; this column shows the voltage difference between the measurement thermistor channel and the compensation thermistor channel when the rf is off.

The final results are displayed on the screen below the horizontal dashed line. The explanation of each column is given in the following table.

Table 2.2. Explanation of the results section of the measurement screen

Column Heading	Explanation
AVG PWR	Average power in milliwatts computed from the measured data set.
AVG - 1mW	Percent deviation of the average power level from 1 milliwatt.
MAX DEV	The maximum positive and negative deviations from 1 milliwatt.
STD DEV	The standard deviation of the individual measurements.
SYS UNC	The total calculated systematic uncertainty in the measurement.
TOT UNC	Total uncertainty; the systematic uncertainty plus three times the standard deviation of the mean.

3. SYSTEM DESCRIPTION

3.1 Theory of Operation

The NIST Type IV power meter is not a direct reading instrument. An external precision dc voltmeter must be connected to the power meter, and the power is calculated from the voltmeter readings. The power, P, is given by

$$P = \frac{1}{R_0}\left(V_1^2 - V_2^2\right), \tag{3.1}$$

where V_1 is the output voltage without rf power, V_2 is the voltage with rf power, and R_0 is the operating resistance of the mount. Note that the so-called "bolometric power" is simply the change of the mount dc bias power as rf power is applied and removed.

It can be seen from eq (3.1) above that, as the rf power becomes small, V_2 approaches V_1. Because of the uncertainty "magnification" that occurs in the computed difference of two nearly equal numbers, the power measurement uncertainty becomes very large as the power decreases. The solution to this problem is to measure the difference between V_1 and V_2 directly. This requires a reference voltage generator (RVG) which is set nominally equal to V_1 and, in effect, stores V_1.

When an RVG is used, the expression for calculating power from measured voltages becomes,

$$P = \frac{1}{R_0}\left(2V_1 - \Delta V\right)\Delta V, \tag{3.2}$$

where R_0 and V_1 were previously defined, and ΔV is the change in the power meter voltage when rf is applied. In providing for a first-order correction of mount drift, the value of V_1 and ΔV are estimated by assuming linear drift and measuring several other voltages while the rf is off, as shown in figure 3.1.

The diagram in figure 3.1 depicts the outputs of the power meter and RVG as a function of time while the rf is cycled on and off. The measurement sequence of five voltage and time readings used to calculate the power and correct for the mount drift is also shown. Note that the reference voltage generator is not set equal to V_1, nor is it constant with time. This is because it is convenient to use the compensation element of the mount, biased by the second power meter channel, as the reference voltage generator. Thus the RVG does drift during the measurement, but this change is also corrected, to first order, by the measurement series.

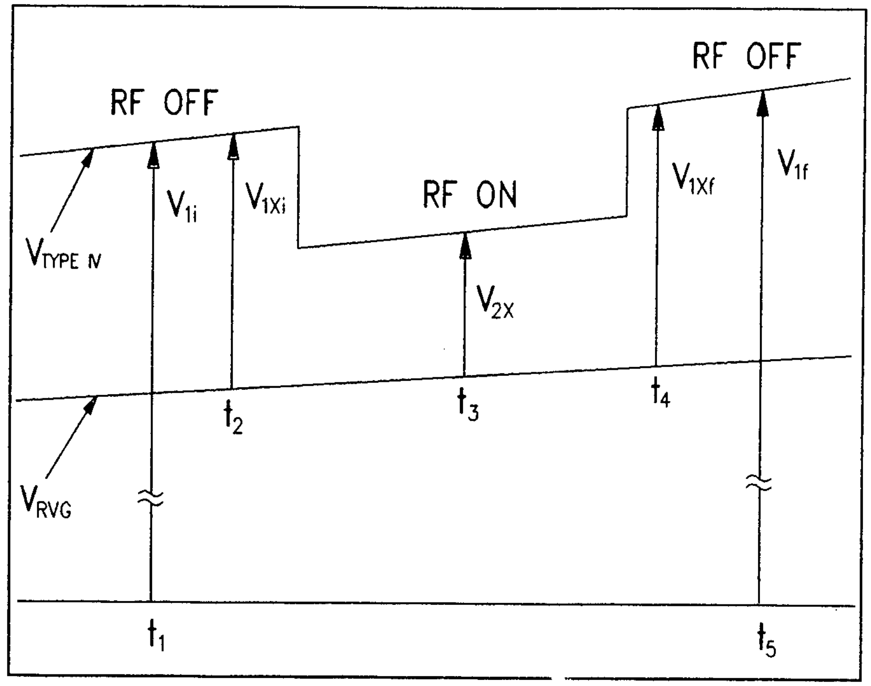

Figure 3.1. Measured power meter voltages vs time.

In terms of the measured voltages, the values to be used in eq (3.2) are given by,

$$V_1 = V_{1i} + \left(\frac{t_3 - t_1}{t_5 - t_1}\right)(V_{1f} - V_{1i}) \tag{3.3}$$

and,

$$\Delta V = V_{2X} - \left[V_{1Xi} + \left(\frac{t_3 - t_2}{t_4 - t_2}\right)(V_{1Xf} - V_{1Xi})\right]. \tag{3.4}$$

3.2 Hardware

The system block diagram is shown in figure 3.2. The input switching to the digital voltmeter (DVM) is done with the multiplexer internal to the DVM. The dual power meter also has an IEEE Std-488 bus interface with controlled output switching, but it is not used in this application. The specifications for the instruments are given in appendix A.

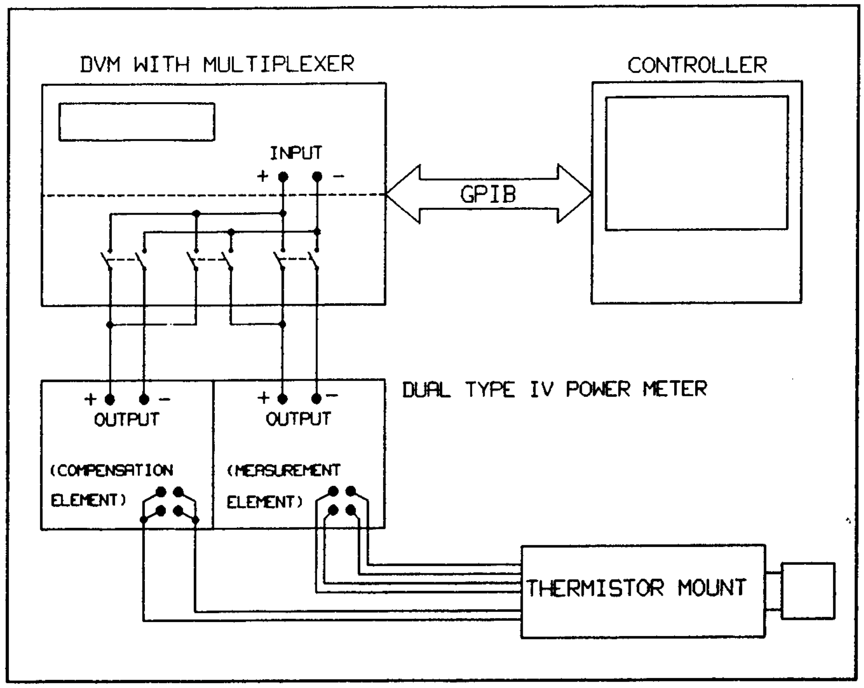

Figure 3.2. System block diagram.

3.3 Software

A software listing is included as appendix B. Comments at the beginning of the code define the variables (and their location) that one might want to change for other applications such as a different power level or a new mount calibration factor.

4. ERROR ANALYSIS

4.1 Systematic Error Components

The factors contributing to the total systematic uncertainty are:

1. Uncertainty in the dc voltage measurements.
2. Uncertainty in the thermistor mount effective efficiency calibration.
3. Mismatch uncertainty due to the source (8502A calibrator output) reflection coefficient and the thermistor mount reflection coefficient.
4. The "dual element substitution error" associated with the coaxial thermistor mount.
5. Type IV power meter uncertainty. There are four sources of possible error internal to the power meter. They are, the reference resistors, the operational amplifier open loop gain, input offset voltage, and input bias current. The Type IV error analysis [1] indicates that all of them are negligible compared to the four factors listed above.

The first four of these items will be considered individually in the following sections.

4.1.1 Voltmeter Uncertainty

The effect of uncertainty in the individual voltmeter readings can be determined by taking the total differential of the expression for power, eq (3.2),

$$\mathrm{d}P = \frac{2}{R_0}\left[\Delta V\,\mathrm{d}V_1 + \left(V_1 - \Delta V\right)\mathrm{d}\Delta V\right], \tag{4.1}$$

where, in terms of the measured parameters,

$$\mathrm{d}V_1 = \left(1 + T_{1f}\right)\delta V_{1i} + T_{1f}\,\delta V_{1f}, \tag{4.2}$$

$$\mathrm{d}\Delta V = \delta V_{2X} + \left(1 + T_{2f}\right)\delta V_{1Xi} + T_{2f}\,\delta V_{1Xf}, \tag{4.3}$$

$$T_{1f} = \frac{t_3 - t_1}{t_5 - t_1}, \tag{4.4}$$

and,

$$T_{2f} = \frac{t_3 - t_2}{t_4 - t_2}. \tag{4.5}$$

The quantities δV_{1i}, δV_{1f}, δV_{1Xi}, δV_{1Xf}, and δV_{2X}, are the uncertainties in the measured values of V_{1i}, V_{1f}, V_{1Xi}, V_{1Xf}, and V_{2X}. These uncertainties in the measured voltages are based on the voltmeter specifications, which are usually given in two parts as a fraction of reading term, α, and a fraction of full scale term, ß. The general expression for the voltmeter uncertainty is given by,

$$\delta V = \alpha\, V_{reading} + \beta\, V_{fullscale}. \tag{4.6}$$

Figure 4.1 shows the uncertainty in power measurement as a function of power level near 1 mW, as calculated using the above procedure (in the calculations, the sign of the independent terms are chosen to give the maximum contribution to the total uncertainty) for the voltmeter, power meter, and measurement configuration used in this system.

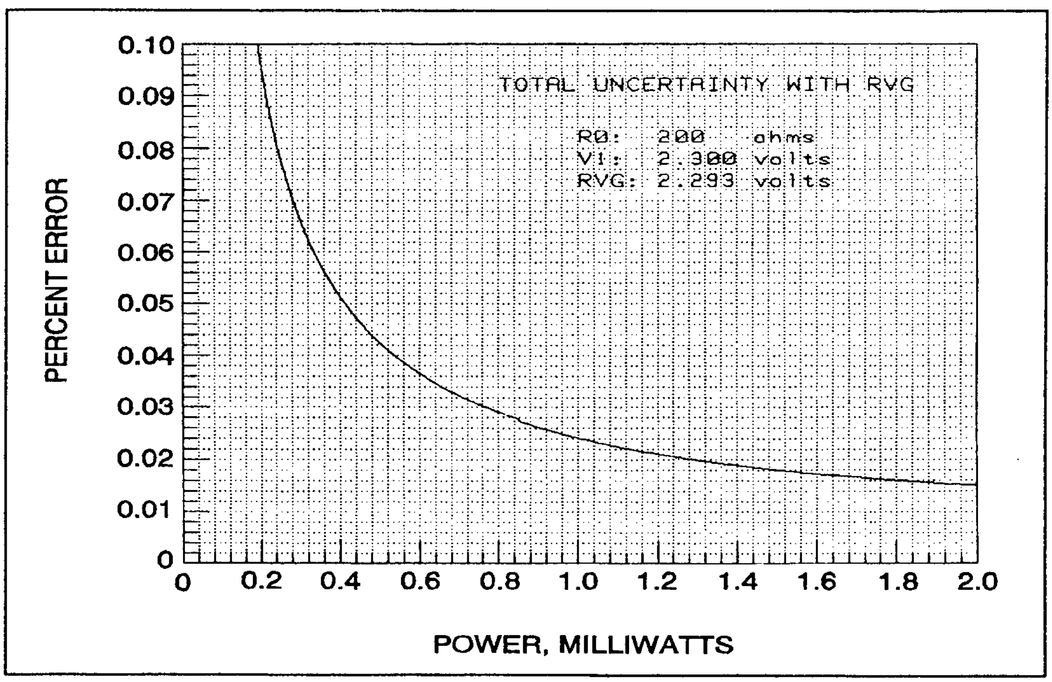

Figure 4.1. Power measurement uncertainty from the DVM.

4.1.2 Uncertainty in Thermistor Mount Effective Efficiency

This is the uncertainty of the NIST thermistor mount calibration. The NIST calibration also gives a value for the mount calibration factor C_f, which is the factor used in this measurement rather than effective efficiency alone, and is defined later in this section. The values listed on the report of calibration will, of course, be constant for any given mount, until the unit is recalibrated.
The thermistor mount should be recalibrated periodically.

4.1.3 Mismatch Uncertainty

The net power delivered to a termination by a source is given by,

$$P_t = P_0 \frac{1 - |\Gamma_t|^2}{|1 - \Gamma_g \Gamma_t|^2}, \tag{4.7}$$

where P_0 is the power the source would deliver to a nonreflecting termination, Γ_g is the generator reflection coefficient, and Γ_t is the termination reflection coefficient. Ideally, the calibrator should deliver a net power of 1 mW to the power detector being calibrated, but that can only be accomplished if the complex reflection coefficients of the power detector, generator, and calibrating thermistor mount are known, which is generally not the case. Assuming, then, that the calibrator output specification is the power delivered to a nonreflecting load, P_0, the measured output is given by,

$$P_0 = \frac{P_m}{\eta_m} \frac{|1 - \Gamma_g \Gamma_m|^2}{1 - |\Gamma_m|^2}, \tag{4.8}$$

where P_m is the bolometrically measured power, η_m is the effective efficiency of the thermistor mount, Γ_g is the generator reflection coefficient, and Γ_m is the thermistor mount reflection coefficient. The denominator of eq (4.8) is the mount calibration factor,

$$C_f = \eta_m \left(1 - |\Gamma_m|^2\right), \tag{4.9}$$

so that eq (4.8) becomes,

$$P_0 = \frac{P_m}{C_f} |1 - \Gamma_g \Gamma_m|^2. \tag{4.10}$$

The value of Γ_m has been measured during the NIST calibration, but only an upper limit to the magnitude of Γ_g is known (from the source return loss specification). Thus, only the limits to the term involving the reflection coefficients are known,

$$\left(1 - |\Gamma_g||\Gamma_m|\right)^2 \leq |1 - \Gamma_g \Gamma_m|^2 \leq \left(1 + |\Gamma_g||\Gamma_m|\right)^2, \tag{4.11}$$

so that P_0 is also only known within the limits,

$$\frac{P_m}{C_f}\left(1 - |\Gamma_g||\Gamma_m|\right)^2 \leq P_0 \leq \frac{P_m}{C_f}\left(1 + |\Gamma_g||\Gamma_m|\right)^2. \tag{4.12}$$

This uncertainty in P_0 is the mismatch uncertainty and its relative value is given to first order by,

$$\pm 2\,|\Gamma_g||\Gamma_m|. \tag{4.13}$$

The return loss specification on the calibrator output is greater than 25 dB, which results in a value for $|\Gamma_g|$ of $\leq$ 0.056. The value of $|\Gamma_m|$ for the thermistor mount provided is 0.019; together these give a mismatch uncertainty in P_0 of $\pm$0.21 percent.

4.1.4 Dual Element Error

The power detector is a dual-element coaxial thermistor mount. Dual-element bolometer units are nonlinear with power level as a result of a dc-rf substitution error that arises because the two elements are not identical [2]. The error is of concern in this measurement because it is being made at 1 mW, while the NIST calibration of mount efficiency is done at 10 mW. The only way to determine the error magnitude is by direct measurement.

In this case, the method used was to connect the coax mount to one arm of a nominally equal power splitter (for this measurement, a waveguide "magic tee" in WR-90), and a single-element waveguide mount to the other arm. The ratio of the two bolometric powers was determined at 10 mW and again at a randomly selected level between 10 mW and 0.1 mW. The change in the ratios as determined at the two power levels was a measure of the dual-element error.

Figure 4.2 shows results for two identical model waveguide mounts at 9.1 GHz. The increased spread of the data as the power level decreases is typical of bolometric measurements because of the small change in dc power that occurs at low microwave power levels. The -10 dB point on the plot is approximately equal to 1 mW.

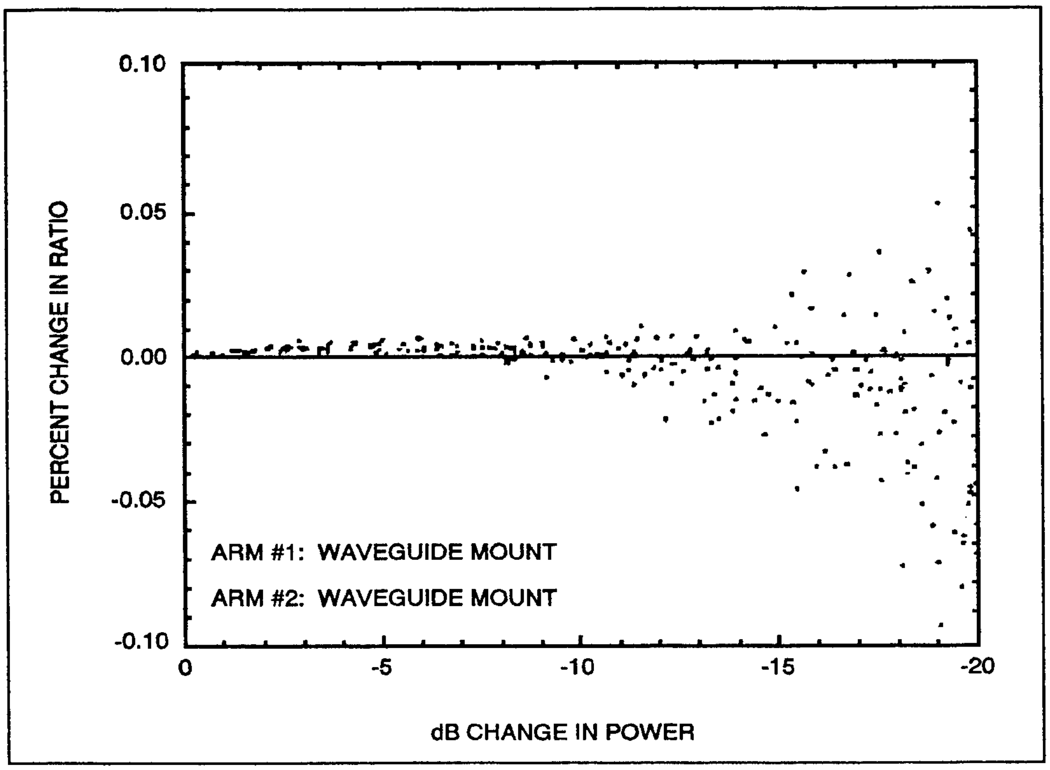

Figure 4.2. Change in the power ratio of 2 waveguide mounts vs power level.

Figure 4.3 is the result for a coax mount compared with one of the waveguide mounts. The change in ratio at the 1 mW level (-10 dB point) is about 0.035 percent. This is the uncertainty that can be expected in the effective efficiency and thus the power measurement at 1 mW, given the calibration is done at 10 mW.

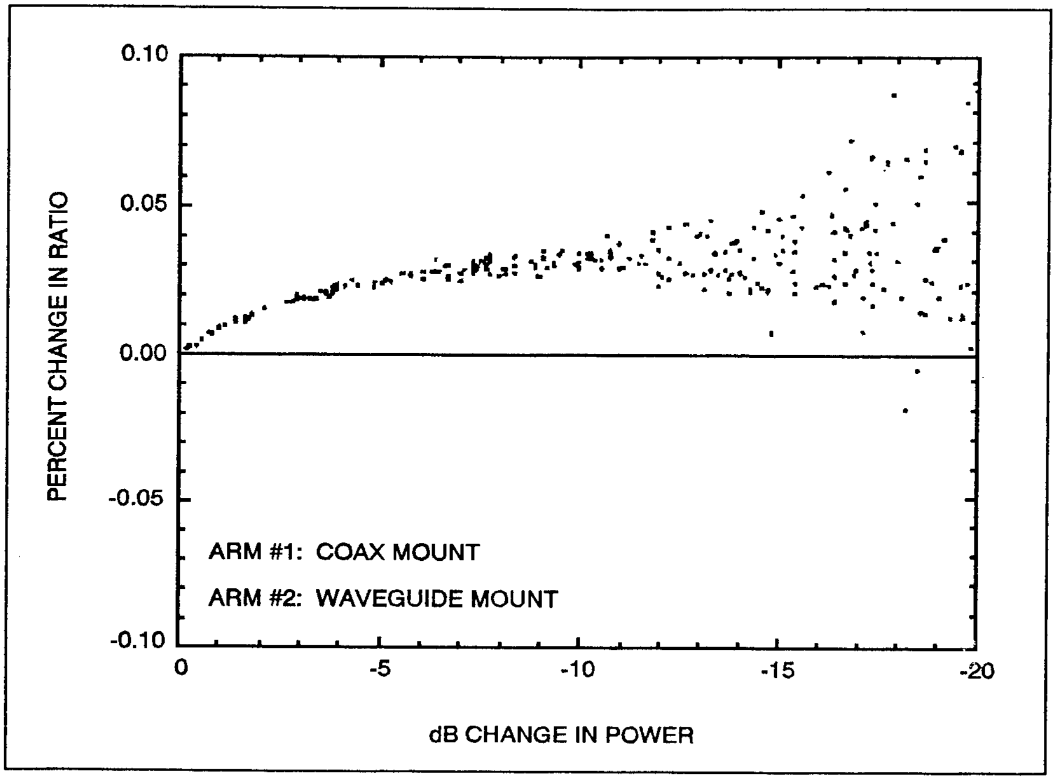

Figure 4.3. Change in the power ratio of a coax mount to a waveguide mount vs power level.

4.2 Random Error

In section 2.2, figure 2.4 shows the measurement screen. The last three columns under the Results section show the standard deviation, the systematic uncertainty, and the total uncertainty of that measurement set. The random contribution to the total uncertainty is chosen to be three times the standard deviation of the mean.

5. REFERENCES

[1] Larsen, N.T. A new self-balancing dc-substitution rf power meter. IEEE Trans. Instrum. Meas. IM-25: 343-347; 1976 December.

[2] Engen, G.F. A dc-rf substitution error in dual-element bolometer mounts. IEEE Trans. Instrum. Meas. IM-13: 58-64; 1964 June-Sept.

APPENDIX A

Instrument Specifications

1. Digital voltmeter: 6½ digit resolution; 3 volt dc range with 0.0025% of reading and 0.0002% of full scale accuracy; 300 mV dc range with 0.0035% of reading and 0.0013% of full scale accuracy; IEEE Std-488 bus; optional integrated reed relay multiplexer.
   Note: meters with other dc ranges such as 100 mV, 1 volt, and 10 volts are also usable. For instance, a 6½ digit meter with 0.00034% of reading and 0.002% of full scale accuracy on the 100 mV range, 0.00024% of reading and 0.00033% of full scale accuracy on the 1 volt range, and 0.00023% of reading and 0.00016% of full scale accuracy on the 10 volt range, gives results comparable to the 3 volt-300 mV meter.

2. Multiplexer: integrated with the DVM (or separate unit); minimum 6 single-pole, single-throw contacts; maximum thermal offset of 3μV; IEEE Std-488 bus.

3. Dual NIST Type IV power meter (or two single units).

4. Coaxial thermistor mount: type N male connector; temperature compensation thermistors; dc bias power $\approx$ 30mW; maximum $|\Gamma| < 0.025$; NIST calibration at 1 GHz.

5. Computer controller: programmable in Hewlett Packard Work Station Basic version 5.13 ("Rocky Mountain Basic"), or TransEra "HT Basic" with IEEE Std-488 capability; IEEE Std-488 bus.

APPENDIX B

Software Listing

```
100    File$="PWRM1"                   ! Started:9001111632/FRC
105    Rev$="9011210805" ! FRC         ! NTL author of the subprograms
110    !                               ! Errors, Select_v, and Hp_3457
115    !
120    ! This program application is the measurement of the 1 mW
125    ! calibrator output of the Wavetek 8501A peak power meter.
130    !
135    !
140    ! NOTES:
145    !
150    !  This version measures V1 and delta V with the compensation element
155    !  used as an RVG.  It also calculates the measurement uncertainty.
160    !
165    !  Total measurement uncertainty includes:
170    !   Mount calibration factor uncertainty of ±0.5973% (For #20054
175    !   with Cal Factor of 0.9897)
180    !   and calculated mismatch uncertainty for the source (|Gamma|<=0.056)
185    !   and the mount (|Gamma|<=0.019) of ± 0.21%.
190    !   The total is 0.8073% plus the DVM and Type IV contribution.
195    !
200    !
205    ! INSTRUMENTS CONTROLLED:         ADDRESS
210    !   1.  HP3457A  DVM                722
215    !   2.  HP2225A  PRINTER            701
220    !
225    !
230    ! DESCRIPTION OF THE MAIN INITIAL VALUE VARIABLES:
235    !
240    ! - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
245    !  The following are in the labeled common named "/Dvm/":
250    !
255    ! ** "Dvm_name$" - the DVM identifier (ie, HP3457A)
260    !
265    !  * "P0" - power level in milliwatts. The measurement results are
270    !           compared with this value.  Default setting is 1 mW.
275    !
280    !  * "R0" - mount operating resistance in ohms.  Normally 200 ohms
285    !           for a coax mount and may be either 100 or 200 ohms for
290    !           a waveguide mount.  Default setting is 200 ohms.
295    !
300    ! - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
305    !  The following are in the labeled common named "/Mount/":
310    !
315    !  * "Mount$" - bolometer mount identifier (manufacturer,
320    !               model, and serial number).
325    !
330    !  * "Cf" - NIST measured mount calibration factor.  Default setting
335    !           is 0.9897 for the supplied mount. Value must be changed
340    !           after mount replacement or recalibration.
345    !
350    ! - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
355    !  The following are in the labeled common named "/Errs/":
360    !
365    !  * "Cfu" - total quoted uncertainty of the NIST measured mount
370    !            calibration factor.  Default setting is 0.5973% for the
375    !            supplied mount.
380    !
385    !  * "Mmu" - calculated mismatch uncertainty.  Default setting is
390    !            0.21% as indicated in the notes above.
395    !
400    ! - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
405    !  The following is in the labeled common named "/Wavetek/":
410    !
415    !    "Sn$" - records the serial number of the Wavetek meter
420    !            being measured.  It can be input before the measure-
425    !            ment from an item on the initial menu.
430    !
435    ! - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
440    !
445    !  CHANGING INITIAL VALUE OF VARIABLES
450    !
455    !  * |These variables are initally defined in the subprogram "Set_up".|
460    !    |To change them, move to the subprogram by executing, "EDIT S".  |
465    !    |Change the values as needed and "Re-store" the program if the   |
470    !    |changes are to be permanent.                                    |
475    !
480    !
485    ! ** |This variable is initally defined in the subprogram "Hp_3457".|
490    !    |If a different DVM is used, along with the name, the percent  |
```

```
495   !     |of reading and the percent of full scale specifications must   |
500   !     |also be changed in that subprogram.  Execute "EDIT hp3457" to  |
505   !     |move to the subprogram.                                        |
510   !
515   ! * * * * * * * * * * * * * MAIN  PROGRAM * * * * * * * * * * * * * *
520   !
525   OPTION BASE 1
530   COM /Dvm/ P0,R0,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
535   COM /Dvm/ Dvm_name$[40]          !DVM ID
540   COM /Errs/ Dp,V1c,V1i,V1f,V1xi,V1xf,V1x,V2x,T1fac,T2fac,Cfu,Mmu
545   COM /Mount/ Mount$[40],Cf        !Mount ID
550   COM /Wavetek/ Sn$[7]             !For the serial number
555   REAL P(100,1)                    !For the power measurements
560   CONTROL 2,1;0                    !Turn PRT ALL off
565   KEY LABELS OFF                   !Turn off key labels
570   !
575   CALL Set_up                      !For mount & measurement parameters
580   CALL Hp_3457                     !Get DVM parameters
585   CALL Init                        !Hardware initialization
590   Nt=6                             !Default No. of meas
595   LOOP                             !To repeat measurement sets
600     CALL Menu1(Nt,Quit)
605     IF Quit THEN Quit              !Terminate
610     CALL Hdr                       !Screen header
615     REDIM P(Nt,1)                  !Redimension
620     FOR N=1 TO Nt                  !Measurement loop
625       DISP N
630       CALL Meas(N,P1)              !Do the measurement
635       P(N,1)=P1                    !Fill array for statistics
640       WAIT 1                       !Wait before measuring again
645     NEXT N
650     CALL Stats(P(*))               !Calculate the statistics of the run
655     OUTPUT 722;"TRIG AUTO"         !Let DVM continue reading
660     PRINT TABXY(30,1),CHR$(128);CHR$(136);"  M E A S U R E M E N T   C O M P L E T E   "
665     CALL Menu2                     !Post measurement soft keys
670   END LOOP
675 Quit:                              !Terminate program
680   CLEAR SCREEN
685   END
690   !
695 !* * * * * * * * * * *  S U B    P R O G R A M S  * * * * * * * * * * * *
700 !
705 M: SUB Meas(N,P1)
710     OPTION BASE 1
715     Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priotity
720     Lcl_prty=Sys_prty+1            !Set local priority 1 higher for ON KEY
725     ON KEY 0 LABEL " ",Lcl_prty GOTO Bail_out
730     !
735     COM /Dvm/ P0,R0,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
740     COM /Dvm/ Dvm_name$[40]        !DVM ID
745     COM /Errs/ Dp,V1c,V1i,V1f,V1xi,V1xf,V1x,V2x,T1fac,T2fac,Cfu,Mmu
750     COM /Mount/ Mount$[40],Cf      !Mount ID
755     !
760     CALL Dvm(V1i,T1i)              !V1 before rf turn_on
765     OUTPUT 722;"CHAN 0"            !Connect for delta V
770     WAIT .2                        !
775     CALL Dvm(V1xi,T1xi)            !Initial delta V1 (V1xi) with rf off
780     Vt=V1xi+V1i-SQR(V1i^2-9.E-4*R0)!Calculate threshold for Rf sub
785     CALL Rf(1,Vt)                  !Calls for rf ON and determines when
790     WAIT 1                         !For source to settle
795     CALL Dvm(V2x,T2x)              !Read delta V2 (V2x) with rf on
800     CALL Rf(0,Vt)                  !Calls for rf OFF and determines when
805     WAIT 1                         !Wait again
810     CALL Dvm(V1xf,T1xf)            !Final delta V1 (V1xi) with rf off
815     OUTPUT 722;"CHAN 1"            !Reconnect for V1
820     WAIT .2
825     CALL Dvm(V1f,T1f)              !Final V1 with rf off
830     !
835     T1fac=(T2x-T1i)/(T1f-T1i)      !First timing factor
840     V1c=V1i+T1fac*(V1f-V1i)        !V1 corrections
845     !
850     T2fac=(T2x-T1xi)/(T1xf-T1xi)   ! Second timing factor
855     V1x=V1xi+T2fac*(V1xf-V1xi)     !Delta V corrections
860     Dv1=(V1f-V1i)*1.E+6            !Change in V1
865     Dv1_dt=Dv1/(T1f-T1i)           !Drift rate of V1 in mV/sec
870     Dv2=V2x-V1x                    !Change in V2 - (delta V)
875     !
880     CALL Errors                    !Calculate errors
885     !
```

```
890      P1=1000/R0*(2*V1c-(Dv2))*(Dv2) !Power in mW
895      P1=P1/Cf                       !Cal factor correction
900      !
905      GOSUB Printout                 !Print results
910      SUBEXIT                        !Normal exit
915 P:                                  !Printout
920 Printout:                           !
925      IMAGE 3D,5X,Z.6D,5X,S2Z.3D,8X,Z.6D,2X,3D.3D,5X,S2D.D,8X,2D.3D
930      PRINT USING 925;N,P1,100*(P1-P0)/P0,V1c,Dv2*1.E+3,Dv1_dt,V1x*1.E+3
935      RETURN                         !
940      !
945 Bail_out:                           !As it says
950      OUTPUT 722;"TRIG AUTO"         !DVM continue reading
955      PRINT
960      PRINT TABXY(30,1),CHR$(128);CHR$(136);"  M E A S U R E M E N T   S T O P P E D           "
965      PAUSE
970      !
975 Exit:                               !Finished
980    SUBEND ! SUB Meas
985    ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
990    !
995 Rf:SUB Rf(On,Vt)                    !Turn rf ON/OFF
1000     IF On THEN
1005       DISP CHR$(129);" TURN RF ON (PRESS 8502A KEY '7') ";CHR$(128) !Tell operator
1010       BEEP 1000,.01                !Get his attention
1015       LOOP                         !Wait for rf to be turned on/off
1020         CALL Dvm(V,T)              !Read DVM
1025         WAIT 1                     !
1030       EXIT IF V>Vt                 !If rf is turned ON
1035       END LOOP
1040     ELSE
1045       DISP CHR$(129);" TURN RF OFF (PRESS 8502A 'CLEAR') ";CHR$(128) !Tell operator
1050       BEEP 1000,.01                !Get his attention
1055       WAIT .2
1060       BEEP 1000,.01
1065       LOOP                         !Wait for rf to be turned on/off
1070         CALL Dvm(V,T)              !Read DVM
1075         WAIT 1                     !
1080       EXIT IF V<Vt                 !If rf is turned OFF
1085       END LOOP
1090     END IF
1095     DISP ""
1100   SUBEND
1105   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
1110  !
1115 Dvm:SUB Dvm(V,T)                   !DVM reading
1120     SEND 7;UNL LISTEN 22           !Get dvm's attention
1125     TRIGGER 7                      !trig to read
1130     ENTER 722;V                    !Read DVM
1135     T=TIMEDATE                     !Get the time
1140   SUBEND
1145   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
1150   !
1155 Init:SUB Init                      !Initialize instruments
1160     !
1165     CLEAR 722                      !Clear 3457
1170     OUTPUT 722;"TERM SCANNER"      !Connect input to scanner
1175     OUTPUT 722;"NPLC 10"           !10 PLC
1180     OUTPUT 722;"DCV -1"            !Auto Range
1185     OUTPUT 722;"TRIG AUTO"         !Set up for single readings
1190     !
1195     OUTPUT 722;"CHAN 1"            !Connect for V1, floating DVM
1200     WAIT 1                         !Make sure everything is settled
1205   SUBEND
1210   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
1215   !
1220 H:SUB Hdr
1225   !
1230     OPTION BASE 1
1235     CLEAR SCREEN
1240     !
1245     COM /Dvm/ P0,R0,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
1250     COM /Dvm/ Dvm_name$[40]        !DVM ID
1255     COM /Mount/ Mount$[40],Cf      !Mount ID
1260     COM /Wavetek/ Sn$[7]           !For the serial number
1265     !
1270     PRINT TABXY(1,1),CHR$(137)&"P W R _ M T R 1"&CHR$(136)
1275     PRINT TABXY(30,1),CHR$(136);CHR$(129);"  M E A S U R E M E N T   I N   P R O G R E S S  ";CHR$(128)
1280     !
```

```
1285     PRINT TABXY(1,3),CHR$(140);"MOUNT: ";Mount$;CHR$(136)
1290     PRINT TABXY(59,3),CHR$(140);TIME$(TIMEDATE);"  ";DATE$(TIMEDATE);CHR$(136)
1295     PRINT TABXY(1,4),CHR$(140);"POWER METER: WAVETEK MODEL 8502A, S/N ";Sn$;CHR$(136)
1300     !
1305     DIM A$[80],B$[80],C$[80],D$[80],Scr$[80]  !String variables to build IMAGE statement
1310 Ima:DATA "#,"" NO."",4X,"" POWER  "",4X,""PWR-"""
1315 Imc:DATA  "#,""mW"",6X,""   V1    "",3X,""Delta V"",3X,""V1 Drift"",3X,""Ref. Offset"""
1320     RESTORE Ima
1325     READ Scr$                        !Read as IMAGE statement
1330     OUTPUT A$ USING Scr$
1335     OUTPUT B$ USING "#,2D.D";P0
1340     RESTORE Imc
1345     READ Scr$
1350     OUTPUT C$ USING Scr$
1355     D$=A$&B$&C$
1360     PRINT D$
1365     !
1370     IMAGE "ä    Ç",4X,"ä  (mW)  Ç",4X,"ä   (%)   Ç",7X,"ä (VOLT) Ç",3X,"ä (mV)  Ç",3X,"ä (uV/s) Ç",3X,"ä    (mV)   Ç"
1375     PRINT USING 1370
1380     !
1385   SUBEND ! Hdr
1390   !****************
1395 E:SUB Errors
1400     OPTION BASE 1
1405     COM /Dvm/ P0,R0,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
1410     COM /Dvm/ Dvm_name$[40]         !DVM ID
1415     COM /Errs/ Dp,V1c,V1i,V1f,V1xi,V1xf,V1x,V2x,T1fac,T2fac,Cfu,Mmu
1420     !
1425     CALL Select_v(V1i,Aa1i,Bb1i,Ss1i)      !Aa_ - fraction of reading error
1430     CALL Select_v(V1f,Aa1f,Bb1f,Ss1f)      !
1435     CALL Select_v(V1xi,Aa1xi,Bb1xi,Ss1xi)  !
1440     CALL Select_v(V1xf,Aa1xf,Bb1xf,Ss1xf)  !Bb_ - fraction of FS error
1445     CALL Select_v(V2x,Aa2x,Bb2x,Ss2x)      !Ss_ - fullscale reading
1450     !
1455     GOSUB With_rvg                   !
1460 !   GOSUB Servo_errors               !Very small error - not used for this application
1465                                      !sub routine removed
1470 Total_error:!  Without RVG.
1475     Total=Without+Eerr+Ierr
1480     !
1485     SUBEXIT
1490   !
1495 With_rvg:                            ! Eq's derived 900111/FRC
1500     Dv1i=Aa1i*V1i+Bb1i*Ss1i          ! Delta-V due to initial V1 measmnt
1505     Dv1f=Aa1f*V1f+Bb1f*Ss1f          ! Delta-V due to final V1 measmnt
1510    !
1515     Dv1xi=ABS(Aa1xi*V1xi)+Bb1xi*Ss1xi  ! Delta due to initial V1x measmnt
1520     Dv1xf=ABS(Aa1xf*V1xf)+Bb1xf*Ss1xf  ! Delta-V due to final V1x measmnt
1525    !
1530     Dv2x=ABS(Aa2x*V2x)+Bb2x*Ss2x       ! Delta-V due to V2x measmnt
1535    !
1540     Dv1c=(1+T1fac)*Dv1i+T1fac*Dv1f    !Error in corrected V1
1545     Dv1x=(1+T2fac)*Dv1xi+T2fac*Dv1xf  !Error in delta V correction
1550    !
1555     Dpv1=ABS((V2x-V1x)*Dv1c)         ! Delta-power due to V1 measmnt errors
1560     Dpv1x=ABS((V1c-V2x-V1x)*Dv1x)    ! Delta-power due to V1x   "        "
1565     Dpv2x=ABS((V1c-V2x-V1x)*Dv2x)    ! Delta-power due to V2x   "        "
1570     Dp=2*(Dpv1+Dpv1x+Dpv2x)/R0       ! Sum (2 & R0 left out above)
1575     Dp=Dp*1.E+3                      ! Dp in mW
1580     RETURN
1585     !
1590   SUBEND
1595   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
1600   !
1605 Hp3457:SUB Hp_3457
1610     OPTION BASE 1
1615     COM /Dvm/ P0,R0,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
1620     COM /Dvm/ Dvm_name$[40]         !DVM ID
1625     Dvm_name$="HP 3457"
1630     !FOR DVM:          VALUE       QUANTITY (HP 3457, 1 yr, 167 ms, 6-1/2 dig)
1635 Nc: DATA            3.03E6       ! number of counts, full scale
1640 A1: DATA            4.5E-5       ! fraction-of-rdg error, range R1, 1 yr
1645 A2: DATA            3.5E-5       ! fraction-of-rdg error, range R2, etc.
1650 A3: DATA            2.5E-5       ! fraction-of-rdg error, range R3
1655 A4: DATA            4.0E-5       ! fraction-of-rdg error, range R4
1660 A5: DATA            5.5E-5       ! fraction-of-rdg error, range R5
1665 B1: DATA           385.          ! fraction-of-FS error, counts, range R1, 10 PLC
1670 B2: DATA            40.          ! fraction-of-FS error, counts, range R2
1675 B3: DATA             7.          ! fraction-of-FS error, counts, range R3
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1680 B4: DATA          20.           ! fraction-of-FS error, counts, range R4
1685 B5: DATA           7.           ! fraction-of-FS error, counts, range R5
1690 R1: DATA           0.0303       ! lowest range (including overrange), volts
1695 R2: DATA           0.303        ! next range up
1700 R3: DATA           3.03         ! next range up
1705 R4: DATA          30.3          ! next range up
1710 R5: DATA         300.           ! next range up
1715      READ Nc,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
1720      !
1725 Convert_fs_errs:! Normalize FS count errors to fractional errors
1730      B1=B1/Nc
1735      B2=B2/Nc
1740      B3=B3/Nc
1745      B4=B4/Nc
1750      B5=B5/Nc
1755   SUBEND
1760   !
1765 Select:SUB Select_v(V,Aa,Bb,Ss)
1770      OPTION BASE 1
1775      COM /Dvm/ P0,R0,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
1780      COM /Dvm/ Dvm_name$[40]         !DVM ID
1785      SELECT ABS(V)                   ! V may be of either polarity
1790      CASE <=R1                       ! Start at lowest range
1795        Aa=A1                         ! Fraction of rdg error for V on range R1
1800        Bb=B1                         ! Fraction of FS error for V on range R1
1805        Ss=R1                         ! Fullscale reading for V, range R1
1810        Range=1                       ! Range_no number for plot
1815      CASE <=R2                       ! Uprange if necessary
1820        Aa=A2
1825        Bb=B2
1830        Ss=R2                         ! Etc. for range R2
1835        Range=2
1840      CASE <=R3                       ! And again
1845        Aa=A3
1850        Bb=B3
1855        Ss=R3
1860        Range=3
1865      CASE <=R4
1870        Aa=A4
1875        Bb=B4
1880        Ss=R4
1885        Range=4
1890      CASE <=R5
1895        Aa=A5
1900        Bb=B5
1905        Ss=R5
1910        Range=5
1915      CASE ELSE
1920        BEEP
1925        PRINT "Voltage is in excess of 300 volts.  Don't be ridiculous."
1930        PAUSE
1935      END SELECT
1940   SUBEND
1945   !
1950 S:SUB Set_up                         !Initialize mount parameters
1955      OPTION BASE 1
1960      COM /Dvm/ P0,R0,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
1965      COM /Dvm/ Dvm_name$[40]         !DVM ID
1970      COM /Errs/ Dp,V1c,V1i,V1f,V1xi,V1xf,V1x,V2x,T1fac,T2fac,Cfu,Mmu
1975      COM /Mount/ Mount$[40],Cf
1980      Mount$="HP 8478B, S/N 2106A20054"
1985      Cf=.9897                        !Mount calibration factor
1990      Cfu=.5973                       !Calibration factor uncertainty in %
1995      Mmu=.21                         !Mismatch factor uncertainty in %
2000      R0=200                          !Mount operating resistance in ohms
2005      P0=1.0                          !Comparison power in mW.  Note that
2010                                      !the following line limits this setting
2015                                      !to a 0.1 mW resolution.
2020      P0=DROUND(P0,2)                 !Limit P0 to 1 place beyond decimal
2025   SUBEND
2030   !
2035 Stats:SUB Stats(REAL P(*))
2040      OPTION BASE 1
2045      COM /Dvm/ P0,R0,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
2050      COM /Dvm/ Dvm_name$[40]         !DVM ID
2055      COM /Errs/ Dp,V1c,V1i,V1f,V1xi,V1xf,V1x,V2x,T1fac,T2fac,Cfu,Mmu
2060      ALLOCATE Dum(SIZE(P,1),1)       ! Use Dum(*) to preserve P(*)
2065      GOSUB Sd                        ! Standard dev. of original set
2070      !
```

```
2075     Sys_err=Cfu+Mmu+100*Dp/Mean    !Systematic error % (See header notes)
2080     Sdm=Sd/SQR(SIZE(P,1))          !Standard Deviation of the mean
2085     Tot_unc=Sys_err+300*(Sdm/Mean) !Total uncertainty % with 3*SD mean
2090     !
2095     GOSUB Prt                      !Print results
2100     DEALLOCATE Dum(*)
2105     SUBEXIT
2110     !
2115 Prt:PRINT "- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -"
2120     PRINT "RESULTS:"
2125     !
2130     DIM A$[128],B$[128],C$[128],D$[128],Scr$[128]  !String variables to build IMAGE statement
2135 Imd:DATA "#,8X,""AVG PWR "",4X,""AVG-"""
2140 Ime:DATA  "#,""mW"",6X,""    MAX DEV    "",3X,""STD DEV"",3X,""SYS UNC"",3X,""TOT UNC"""
2145     RESTORE Imd
2150     READ Scr$                      !Read as IMAGE statement
2155     OUTPUT A$ USING Scr$
2160     OUTPUT B$ USING "#,2D.D";P0
2165     RESTORE Ime
2170     READ Scr$
2175     OUTPUT C$ USING Scr$
2180     D$=A$&B$&C$
2185     PRINT D$
2190     !
2195     IMAGE 8X,"ä  (mw)  Ç",4X,"ä   (%)   Ç",7X,"ä      (%)      Ç",3X,"ä  (%)  Ç",3X,"ä  (%)  Ç",3X,"ä  (%)  Ç"
2200     PRINT USING 2195
2205     IMAGE 8X,Z.6D,5X,S2Z.3D,8X,SZ.3D,K,SZ.3D,4X,Z.3D,5X,Z.3D,5X,Z.3D
2210     PRINT USING 2205;Mean,100*(Mean-P0)/P0,100*Maxpdv/Mean,",",100*Maxndv/Mean,100*Sd/Mean,Sys_err,Tot_unc
2215     RETURN
2220     !
2225 Sd:!
2230     MAT Dum= P
2235     Sum=SUM(Dum)                 ! Sum of the elements in P(*)
2240     Mean=Sum/SIZE(P,1)           ! Mean of P(*)
2245     MAT Dum= P-(Mean)            ! Dum(*) contains deviations from mean
2250     Maxpdv=MAX(Dum(*))           ! Largest positive deviation
2255     Maxndv=MIN(Dum(*))           ! Largest negative deviation
2260     Maxdv=MAX(ABS(Maxpdv),ABS(Maxndv))    ! Largest largest deviation
2265     MAT Dum= Dum . Dum           ! Dum holds squares of deviations
2270     IF SIZE(P,1)>1.1 THEN        ! Check for single measurement
2275       Var=SUM(Dum)/(SIZE(P,1)-1) ! Variance
2280     ELSE
2285       Var=SUM(Dum)
2290     END IF
2295     Sd=SQR(Var)                  ! Standard deviation
2300     Max_al=3*Sd                  ! Maximum allowable standard deviation
2305     RETURN
2310     !
2315   SUBEND
2320   !
2325 Menu2:SUB Menu2                  !Post measurement soft keys
2330     OPTION BASE 1
2335     Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY")) !Determine system priority
2340     Lcl_prty=Sys_prty+1            !Set local priority 1 higher for ON KEY
2345     USER 1 KEYS                    !1st set of soft keys
2350     KEY LABELS ON                  !Turn on soft keys
2355     FOR N=0 TO 19                  !Clear keys
2360       ON KEY N LABEL "" GOTO Top   !Default destination
2365     NEXT N
2370     ON KEY 1 LABEL " MENU  ",Lcl_prty GOTO Exit
2375     ON KEY 2 LABEL " PRINT ",Lcl_prty GOSUB Print
2380    !
2385 Top:LOOP                         !Wait for input
2390     END LOOP
2395 Print:                           !Alpha dump
2400     KEY LABELS OFF                 !Turn off soft keys
2405     DUMP ALPHA                     !As it says
2410     KEY LABELS ON                  !Turn keys back on
2415     RETURN
2420 Exit:                            !
2425     KEY LABELS OFF
2430   SUBEND
2435  !
2440 Menu1:SUB Menu1(Nt,Quit)         !PRE measurement set up & soft keys
2445     OPTION BASE 1
2450     Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY")) !Determine system priority
2455     Lcl_prty=Sys_prty+1            !Set local priority 1 higher for ON KEY
2460     !
2465     COM /Wavetek/ Sn$[7]           !For the serial number
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2470     M_flag=1                      !To write menu
2475     USER 1 KEYS                   !1st set of soft keys
2480     KEY LABELS ON                 !Turn on soft keys
2485     FOR N=0 TO 19                 !Clear keys
2490       ON KEY N LABEL "" GOTO Top  !Default destination
2495     NEXT N
2500    !
2505     ON KEY 1 LABEL " SELECT   (1)",Lcl_prty GOSUB Help
2510     ON KEY 2 LABEL " SELECT   (2)",Lcl_prty GOSUB Sn
2515     ON KEY 3 LABEL " SELECT   (3)",Lcl_prty GOSUB Change
2520     ON KEY 4 LABEL " SELECT   (4)",Lcl_prty GOTO Exit
2525     ON KEY 5 LABEL " SELECT   (5)",Lcl_prty GOTO Quit
2530    !
2535 Top:LOOP                          !Wait for input
2540       IF M_flag=1 THEN GOSUB Menu
2545     END LOOP
2550     !
2555 Menu:CLEAR SCREEN
2560     PRINT TABXY(5,2),CHR$(129);" P W R _ M T R 1 ";CHR$(128)
2565     CLIP 10,110,24,88             !To draw a box
2570     FRAME
2575     PRINT TABXY(24,5),"- - - MEASUREMENT MENU - - -"
2580     PRINT TABXY(20,8),CHR$(129);"(1)";CHR$(128);"  WAVETEK OPERATING INSTRUCTIONS"
2585     PRINT TABXY(20,10),CHR$(129);"(2)";CHR$(128);"  INPUT WAVETEK SERIAL NUMBER"
2590     IF Sn$="" THEN
2595       PRINT TABXY(25,11),"(No S/N in memory)"
2600     ELSE
2605       PRINT TABXY(25,11),"(S/N ";Sn$;" in memory)"
2610     END IF
2615     PRINT TABXY(20,13),CHR$(129);"(3)";CHR$(128);"  CHANGE # OF MEASUREMENT POINTS"
2620     PRINT TABXY(25,14),"(Present setting =";Nt;")  "
2625     PRINT TABXY(20,16),CHR$(129);"(4)";CHR$(128);"  BEGIN MEASUREMENT"
2630     PRINT TABXY(20,18),CHR$(129);"(5)";CHR$(128);"  EXIT PROGRAM"
2635     M_flag=0
2640     RETURN
2645 Sn:                               !Input the WAVETEK serial number
2650     KEY LABELS OFF                !Turn off soft keys
2655     LINPUT "WAVETEK SERIAL NUMBER ?",Sn$[1,7]
2660     Sn$=TRIM$(Sn$)
2665     PRINT TABXY(25,11),"(S/N ";Sn$;" in memory)"
2670     KEY LABELS ON                 !Turn keys back on
2675     RETURN
2680 Change:                           !Change # of meas points
2685     KEY LABELS OFF                !Turn off soft keys
2690     INPUT "NUMBER OF MEASUREMENT POINTS ?",Nt
2695     Nt=MIN(Nt,100)
2700     Nt=MAX(Nt,1)
2705     PRINT TABXY(25,14),"(Present setting =";Nt;")  "
2710     KEY LABELS ON                 !Turn keys back on
2715     RETURN
2720 Help:                             !With operation of Wavetek
2725     CALL Help
2730     M_flag=1
2735     RETURN
2740 Quit:                             !Terminate program
2745     Quit=1
2750 Exit:                             !
2755     KEY LABELS OFF
2760   SUBEND
2765  !
2770 Help:SUB Help
2775     CLEAR SCREEN
2780     OPTION BASE 1
2785     Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY")) !Determine system priority
2790     Lcl_prty=Sys_prty+1           !Set local priority 1 higher for ON KEY
2795     USER 1 KEYS                   !1st set of soft keys
2800     KEY LABELS ON                 !Turn on soft keys
2805     FOR N=0 TO 19                 !Clear keys
2810       ON KEY N LABEL "" GOTO Top  !Default destination
2815     NEXT N
2820     ON KEY 1 LABEL "CONTINUE",Lcl_prty GOTO Exit
2825     GOSUB Text                    !Print info
2830    !
2835 Top:LOOP                          !Wait for input
2840     END LOOP
2845    !
2850 Text:PRINT TABXY(22,2),"CONTROLLING 8502A CALIBRATOR OUTPUT"
2855     PRINT TABXY(12,4),"Press the following 8502A front panel control keys in the"
2860     PRINT TABXY(12,5),"sequence indicated:"
```

```
2865     PRINT TABXY(14,7),"(1)-'CW',"
2870     PRINT TABXY(25,7),"(2)-'Menu',"
2875     PRINT TABXY(38,7),"(3)-'F3',"
2880     PRINT TABXY(49,7),"(4)-'F1'."
2885     PRINT TABXY(12,9),"Then, pressing the 8502A key '7' will turn the calibrator"
2890     PRINT TABXY(12,10),"output ON, and pressing the 8502A key 'CLEAR' will turn the"
2895     PRINT TABXY(12,11),"calibrator output OFF."
2900     PRINT TABXY(12,13),"For more detail see 'Calibrator Output Level Test' on page 6-2"
2905     PRINT TABXY(12,14),"of the 8502A manual."
2910     PRINT TABXY(12,17),"CAUTION: Do not press any UNITS key when the mount is"
2915     PRINT TABXY(12,18),"connected to the calibrator.  This will cause the"
2920     PRINT TABXY(12,19),"calibrator to output 100 mW which might damage the mount."
2925     RETURN
2930    !
2935 Exit:                          !
2940   SUBEND
```

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11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

An automated measurement system designed to measure power accurately at the level of 1 mW and at the frequency of 1 GHz is described. The system consists of commercial IEEE Std-488 bus-controlled instruments, a computer controller, and software. The results of a series of measurements are output to the computer display and, optionally, to a printer. The results are the mean of a measurement series and and estimate of the systematic and random uncertainty. The total estimated uncertainty for the average of six consecutive measurements of a nominal 1 mW, 1 GHz source is typically less than 1 percent. The system can measure any power from 0.1 to 10 mW at any microwave frequency by making appropriate changes to the software and possibly, the hardware.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

automated measurement; microwave; microwave power measurement; power; power measurement; power measurement system.

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