Power Measurement System for 1 mW at 1 GHz

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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 \(\pm 1.5\) 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.

\(^1\) 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 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.

Controlling 8502A Calibrator Output

Press the following 8502A front panel control keys in the sequence indicated:

1) 'CW'; 2) 'Menu'; 3) 'F3'; 4) 'F1'.

Then, pressing the 8502A key '7' will turn the calibrator output ON, and pressing the 8502A key 'CLEAR' will turn the calibrator output OFF.

For more detail see 'Calibrator Output Level Test' on page 6-2 of the 8502A manual.

Caution: Do not press any UNITS key when the mount is connected to the calibrator. This will cause the calibrator to output 100 mV which might damage the mount.

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.](image)

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

<table>
<thead>
<tr>
<th>Column Heading</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO.</td>
<td>Number of the power measurement.</td>
</tr>
<tr>
<td>POWER</td>
<td>Result of the power measurement in milliwatts.</td>
</tr>
<tr>
<td>PWR - 1 mW</td>
<td>Percent deviation of the measured power from 1 milliwatt.</td>
</tr>
<tr>
<td>V1</td>
<td>Power meter voltage with the rf off (see section 3.1).</td>
</tr>
<tr>
<td>Delta V</td>
<td>Change that occurs in the power meter voltage when the rf is turned on.</td>
</tr>
<tr>
<td>V1 Drift</td>
<td>Drift of $V_1$ in $\mu$V/s that occurred from the beginning of the measurement until it was complete. Note that if the drift is greater than 10 $\mu$V/s the measurement should be repeated after waiting a period of time for the mount temperature to further stabilize.</td>
</tr>
<tr>
<td>Ref. Offset</td>
<td>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.</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Column Heading</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG PWR</td>
<td>Average power in milliwatts computed from the measured data set.</td>
</tr>
<tr>
<td>AVG - 1mW</td>
<td>Percent deviation of the average power level from 1 milliwatt.</td>
</tr>
<tr>
<td>MAX DEV</td>
<td>The maximum positive and negative deviations from 1 milliwatt.</td>
</tr>
<tr>
<td>STD DEV</td>
<td>The standard deviation of the individual measurements.</td>
</tr>
<tr>
<td>SYS UNC</td>
<td>The total calculated systematic uncertainty in the measurement.</td>
</tr>
<tr>
<td>TOT UNC</td>
<td>Total uncertainty; the systematic uncertainty plus three times the standard deviation of the mean.</td>
</tr>
</tbody>
</table>
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

\[
P = \frac{1}{R_0} (V_1^2 - V_2^2),
\]

(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,

\[
P = \frac{1}{R_0} (2V_1 - \Delta V) \Delta V,
\]

(3.2)

where \( R_0 \) and \( V_1 \) were previously defined, and \( \Delta V \) 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 \( \Delta V \) 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 \( V_u \), 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.

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

\[
V_1 = V_{1f} + \left( \frac{t_3 - t_1}{t_5 - t_1} \right) (V_{2f} - V_{1f})
\]  

(3.3)

and,

\[
\Delta V = V_{2x} - \left[ V_{1xi} + \left( \frac{t_3 - t_2}{t_4 - t_2} \right) (V_{1xf} - V_{1xi}) \right].
\]  

(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.](image)

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),

\[ dP = \frac{2}{K_0} [ \Delta V dV_1 + (V_1 - \Delta V) d\Delta V ], \tag{4.1} \]

where, in terms of the measured parameters,

\[ dV_1 = (1 + T_{1f}) \delta V_{1i} + T_{1f} \delta V_{1f}, \tag{4.2} \]

\[ d\Delta V = \delta V_{2x} + (1 + T_{2f}) \delta V_{2xi} + T_{2f} \delta V_{2xf}, \tag{4.3} \]

\[ T_{1f} = \frac{t_5 - t_1}{t_5 - t_1}, \tag{4.4} \]
and,

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

The quantities \( \delta V_{1i} \), \( \delta V_{1f} \), \( \delta V_{1x,1} \), \( \delta V_{1x,f} \), and \( \delta V_{2x} \), are the uncertainties in the measured values of \( V_{1i} \), \( V_{1f} \), \( V_{1x,1} \), \( V_{1x,f} \), 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, \( \alpha \), and a fraction of full scale term, \( \beta \). The general expression for the voltmeter uncertainty is given by,

\[ \delta V = \alpha V_{\text{reading}} + \beta V_{\text{full scale}}. \tag{4.6} \]

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.](image-url)
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,

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

where $P_0$ is the power the source would deliver to a nonreflecting termination, $\Gamma_g$ is the generator reflection coefficient, and $\Gamma_t$ 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,

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

where $P_m$ is the bolometrically measured power, $\eta_m$ is the effective efficiency of the thermistor mount, $\Gamma_g$ is the generator reflection coefficient, and $\Gamma_m$ is the thermistor mount reflection coefficient. The denominator of eq (4.8) is the mount calibration factor,

$$C_f = \eta_m (1 - |\Gamma_m|^2). \quad (4.9)$$
so that eq (4.8) becomes,

\[
P_0 = \frac{P_m}{C_f} |1 - \Gamma_g\Gamma_m|^2.
\]

(4.10)

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

\[
(1 - |\Gamma_g||\Gamma_m|)^2 \leq |1 - \Gamma_g\Gamma_m|^2 \leq (1 + |\Gamma_g||\Gamma_m|)^2,
\]

(4.11)

so that \( P_0 \) is also only known within the limits,

\[
\frac{P_m}{C_f} (1 - |\Gamma_g||\Gamma_m|)^2 \leq P_0 \leq \frac{P_m}{C_f} (1 + |\Gamma_g||\Gamma_m|)^2.
\]

(4.12)

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

\[
\pm 2 |\Gamma_g||\Gamma_m|.
\]

(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 \cite{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.

![Diagram of waveguide mounts and power ratios](image)

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.](image)

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


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 = 30mW; maximum |T| < 0.025; NIST calibration at 1 GHz.

APPENDIX B
Software Listing

File$="PWRL" I Started:9001111632/FRC
Rev$="9011210805" I FRC
R0° I NTL author of the subprograms
ADDRESS
NIST
0.21%
HP3457A
mount
"Cf" calculated
"Mmu" | records coax
| total
the
**
If
HP2225A
Errors, "Cfu"
300
295
290
285
280
270
265
260
255
250
245
240
235
230
225
220
215
210
205
200

INSTRUMENTS CONTROLLED: ADDRESS
1. HP3457A DVM 722
2. HP2225A PRINTER 701

DESCRIPTION OF THE MAIN INITIAL VALUE VARIABLES:

The following are in the labeled common named "/Ovm/":

** "Ovm_name$" - the OVM identifier (ie, HP3457A)

* "PO" - power level in milliwatts. The measurement results are compared with this value. Default setting is 1 mW.

* "RO" - mount operating resistance in ohms. Normally 200 ohms for a coax mount and may be either 100 or 200 ohms for a waveguide mount. Default setting is 200 ohms.

The following are in the labeled common named "/Mount/":

* "Mount$" - bolometer mount identifier (manufacturer, model, and serial number).

* "Cf" - NIST measured mount calibration factor. Default setting is 0.9997 for the supplied mount. Value must be changed after mount replacement or recalibration.

The following are in the labeled common named "/Errs/":

* "Cfu" - total quoted uncertainty of the NIST measured mount calibration factor. Default setting is 0.5973% for the supplied mount.

* "Mmu" - calculated mismatch uncertainty. Default setting is 0.21% as indicated in the notes above.

The following is in the labeled common named "/Wavetek/":

* "Sn$" - records the serial number of the Wavetek meter being measured. It can be input before the measurement from an item on the initial menu.

CHANGING INITIAL VALUE OF VARIABLES

* These variables are initially defined in the subprogram "Set_up". To change them, move to the subprogram by executing, "EDIT S". Change the values as needed and "Re-store" the program if the changes are to be permanent.

** This variable is initially defined in the subprogram "Hp_3457".

If a different OVM is used, along with the name, the percent...
PROGRAMS

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 /Ovm/ PO,R0,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
535 | COM /Ovm/ Ovm_name[40] | OVM IO
540 | COM /Ovm/ Ovm_name[40] | OVM IO
545 | COM /Ovm/ Ovm_name[40] | OVM IO
550 | COM /Ovm/ Ovm_name[40] | OVM IO
555 | REAL P[100,1] | For the power measurements
560 | CONTROL 2,1:0 | Turn CRT ALL off
565 | KEY LABELS OFF | Turn off key labels
570 | |
575 | CALL Set_up | For mount & measurement parameters
580 | CALL Hp_3457 | Get OVM 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 | IScreen header
615 | REDIM P(Nt,1) | IRedimension
620 | FOR N=1 TO NT | IMeasurement loop
625 | DISP N
630 | CALL Meas(N,P1) | Do the measurement
635 | P(N,1)=P1 | IFill array for statistics
640 | WAIT 1 | IWait before measuring again
645 | NEXT N
650 | CALL Stats(P(*) | Calculate the statistics of the run
655 | OUTPUT 722;"TRIG AUTO" | Let OVM continue reading
660 | PRINT TABXY(30,1),CHR$(128),CHR$(136); | MEASUREMENT COMPLETE
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 priority
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 /Ovm/ PO,R0,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
740 | COM /Ovm/ Ovm_name[40] | OVM IO
745 | COM /Ovm/ Ovm_name[40] | OVM IO
750 | COM /Ovm/ Ovm_name[40] | OVM IO
755 | |
760 | CALL Ovm(V1x1,T1x1) | V1 before rf turn on
765 | OUTPUT 722;"CHAN 0" | Connect for delta V
770 | WAIT .2 | |
775 | CALL Ovm(V1x1,T1x1) | IInit delta V1 (V1x1) with rf off
780 | V1x1-V1i=V1i-SQR(V1i*2-9.0E-4*RF) | Calculate threshold for RF sub
785 | CALL RF(1,V1) | ICalls for rf ON and determines when
790 | WAIT 1 | IFor source to settle
795 | CALL Ovm(V2x2,T2x2) | IRead delta V2 (V2x2) with rf on
800 | CALL RF(0,Vt) | ICalls for rf OFF and determines when
805 | WAIT 1 | IWait again
810 | CALL Ovm(V1xf,T1xf) | IFinal delta V1 (V1x1) with rf off
815 | OUTPUT 722;"CHAN 1" | IReconnect for V1
820 | WAIT .2
825 | CALL Ovm(V1f,T1f) | IFinal V1 with rf off
830 |
835 | T1f=(T2x-T1x)/(T1f-T1i) | IFirst timing factor
840 | V1f=V1i+T1f*(V1f-V1i) | V1 corrections
845 |
850 | T2f=(T2x-T1x)/(T2f-T1f) | ISecound timing factor
855 | V1x=V1f+T2f*(V1x-V1f) | Delta V corrections
860 | V1=V1f+V1f*(V1-V1f) | Change in V1
865 | V1+V1f*(V1-V1f) | IDrift rate of V1 in mV/sec
870 | V2=V2x-V1x | IChange in V2 - (delta V)
875 |
880 | CALL Errors | ICalculate errors
885 |
P=1000/R0*(2*Vlc-(Dv2))*(0v2)  \| Power in mW
P=Pl/cf  \| Cal factor correction

GOSUB Printout  \| Print results

RETURN  \| Normal exit

Printout:  \| Printout

PRINT USING IMAGE 30,5x,Z.60,5x,S2Z.30,8x,Z.60,2X,30,30,5x,S20.0,8x,20.30
PRINT USING N,P1,100*(P1-P0)/P0,Vlc,0v2*l.E+3,0vl_dt,Vlx*l.E+3
PRINT USING IMAGE 30,5X,S2D.D,8X,20.3D

PRINT USING USING 925;N,Pl,100*(Pl-P0)/P0,Vlc,0v2*l.E+3,0vl_dt,Vlx*l.E+3
RETURN  \| Finished

Bail_out:  \| It says

OUTPUT 722;"TRIG AUTO"  \| VOM continue reading
PRINT TABXV(30,1),CHR$(128);CHR$(136);" MEASUREMENT STOPPED"
PAUSE

GOSUB Printout  \| Print results

OUTPUT 722;"CHAN 1"  \| Connect for VI, floating VOM
WAIT 1  \| Make sure everything is settled

GOSUB Header  \| Header

OPTION BASE 1  \| Option base 1
CLEAR SCREEN  \| Clear screen

COM /Ovm/ P0,R0,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
COM /Ovm/ Ovm.name$[40]  \| OVM 10
COM /Mount/ mount$[40],cf  \| Mount 10
COM /Wave/ snum[7]  \| For the serial number

PRINT TABXY(1,1),CHR$(137)&"P W R M T R 1"&CHR$(136)
PRINT TABXY(30,1),CHR$(136);CHR$(129);" MEASUREMENT IN PROGRESS ";CHR$(128)
1680 B4: DATA 20.  I fraction-of-FS error, counts, range R4
1685 B5: DATA 7.  I fraction-of-FS error, counts, range R5
1690 R1: DATA 0.0303 I lowest range (including overrange), volts
1695 R2: DATA 0.303 I next range up
1700 R3: DATA 3.03 I next range up
1705 R4: DATA 30.3 I next range up
1710 R5: DATA 300. I next range up
1715 READ Nc,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
1720 I
1725 Convert_fs_errs: I Normalize FS count errors to fractional errors
1730 B1=B1/Nc
1735 B2=B2/Nc
1740 B3=B3/Nc
1745 B4=B4/Nc
1750 B5=B5/Nc
1755 SUBEND
1760 I
1765 Select:SUB Select_v(V,Aa,Bb,ss)
1770 OPTION BASE 1
1775 COM /Dvm/ P0,R0,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
1780 COM /Dvm/ Dvm_name$[40] I IDVM 10
1785 SELECT ABS(V) I V may be of either polarity
1790 CASE <=R1 I Start at lowest range
1795 AA=A1 I Fraction of rdg error for V on range R1
1800 BB=B1 I Fraction of FS error for V on range R1
1805 SS=R1 I Fullscale reading for V, range R1
1810 Range=1 I Range_no number for plot
1815 CASE <=R2 I Up range if necessary
1820 AA=A2
1825 BB=B2
1830 SS=R2 I Etc. for range R2
1835 Range=2
1840 CASE <=R3 I 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 I
1950 S:SUB Set_up I 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$[40] I IDVM 10
1970 COM /Errs/ Op,Vic,Vi1,V1f,Vix,f,Vlx,v2x,T1fac,T2fac,Cfu,Mmu
1975 COM /Mount/ Mount$[40],Cf
1980 Mount$="HP 847BB, S/N 2106A20054"
1985 Cf=.997 I Mount calibration factor
1990 Cfu=.973 I Calibration factor uncertainty in %
1995 Mmu=.21 I Mismatch factor uncertainty in %
2000 P0=200 I Mount operating resistance in ohms
2005 P=1.0 I Comparison power in mW. Note that
2010 the following line limits this setting
2015 DATA I to a 0.1 mW resolution.
2020 P=ROUND(P0,2) I The following line limits this setting
2025 SUBEND
2030 I
2035 Stats:SUB Stats(REAL P(*))
2040 OPTION BASE 1
2045 COM /Dvm/ P0,R0,A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,R1,R2,R3,R4,R5
2050 COM /Dvm/ Dvm_name$[40] I IDVM 10
2055 COM /Errs/ Op,Vic,Vi1,V1f,Vix,f,Vlx,v2x,T1fac,T2fac,Cfu,Mmu
2060 ALLOCATE Dum(SIZE(P,1),1) I Use Dum(*) to preserve P(*)
2065 GOSUB Sd I Standard dev. of original set
2070 I
2075 Sys_err=Cfu**Mnu+100*Op/Mean  ISystematic error % (See header notes)
2080 Sdm=Sd/SQR(SIZE(P,1))  IStandard Deviation of the mean
2085 Tot_unc=Sys_err+300*(Sdm/Mean) ITotal uncertainty % with 3*SD mean
2090 I
2095 GOSUB Prt
2100 DEALLOCATE Qum(*)
2105 SUBEXIT
2110 I
2115 Prt:PRINT """"RESULTS:""""
2120 PRINT """"""""-----------------------------""""
2125 I
2130 DIM A$[128], B$[128], C$[128], D$[128], Scr$[128] IString variables to build IMAGE statement
2135 Imd:DATA ",", Bx,""""AVG_PWR"", 4X,""""AVG=""
2140 Imc:DATA ",", """"mW", """", MAX DEV ",", 3X,""""ST0 OEV", 3X,""""SYS UNC", 3X,""""TOT UNC"
2145 RESTORE Imd
2150 READ Scr$ IRead as IMAGE statement
2155 OUTPUT AS USING Scr$
2160 OUTPUT B$ USING ",", 20.0"";PO
2165 RESTORE Imc
2170 READ Scr$
2175 OUTPUT C$ USING Scr$
2180 Go=$AS8&Gs$
2185 PRINT Go
2190 I
2195 IMAGE Bx,"""" (mW)", 4X,"""" (%)", 7X,"""" (%)", 3X,"""" (%)", 3X,"""" (%)", 3X,"""" (%)", 3X,"""" (%)"
2200 PRINT USING 20.5
2205 IMAGE Bx,Z,60,5X,52,30,8X,5Z,30,8X,5Z,30,8X,30,5X,Z,30,5X,Z,30,5X,Z,30
2210 PRINT USING 2205;Mean,100*(Mean-P0)/P0,100*Maxpdv/Mean,""%;,100*Maxpdv/Mean,100*Sd/Mean,Sys_err,Tot_unc
2215 RETURN
2220 I
2225 Sd:
2230 MAT Qum+ P  ISum of the elements in P(*)
2235 Mean=SUM(Qum)/SIZE(P,1)  IMean of P(*)
2240 MAT Oum= P-Mean  IDum(*) contains deviations from mean
2245 MAXpdv=MAX(Oum(*))  ILargest positive deviation
2250 Maxndv=MIN(Oum(*))  ILargest negative deviation
2255 MAXpdv=MAX(Abs(Maxpdv),Abs(Maxndv)) I Largest largest deviation
2260 MAT Qum= Qum - Oum  IDum holds squares of deviations
2265 IF SIZE(P,1)>1 THEN ICheck for single measurement
2270 Var=SUM(Oum)/(SIZE(P,1)-1) I Variance
2275 ELSE
2280 Var=SUM(Oum)
2285 END IF
2290 Sd=SQR(Var) IStandard deviation
2300 MAXal=3*Sd I Maximum allowable standard deviation
2305 RETURN
2310 I
2315 SUBEND
2320 I
2325 Menu2:SUB Menu2 IPost measurement soft keys
2330 OPTION BASE 1 IPost measurement soft keys
2335 Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY")) I Determine system priority
2340 Lcl_prty=Sys_prty+1 ISet local priority 1 higher for ON KEY
2345 USER 1 KEYS ISet list of soft keys
2350 KEY LABELS ON ITurn on soft keys
2355 CLR=Keys IClear keys
2360 ON KEY N LABEL """" GO TO Top IDefault destination
2365 NEXT N
2370 ON KEY 1 LABEL """" MENU ",,Lcl_prty GOTO Exit
2375 ON KEY 2 LABEL """" PRINT ",,Lcl_prty GOSUB Print
2380 I
2385 Top:LOOP IWait for input
2390 END LOOP
2395 Print: IAlpha dump
2400 KEY LABELS OFF ITurn off soft keys
2405 DUMP ALPHA IAs it says
2410 KEY LABELS ON ITurn keys back on
2415 RETURN
2420 Exit: I
2425 KEY LABELS OFF I
2430 SUBEND
2435 I
2440 Menu1:SUB Menu1(Nt,Quit) IPre measurement set up & soft keys
2445 OPTION BASE 1 I
2450 Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY")) I Determine system priority
2455 Lcl_prty=Sys_prty+1 ISet local priority 1 higher for ON KEY
2460 I
2465 COM /wavetek/ Sn$[7] IFor the serial number
2470 M_flag=1
2475 USER 1 KEYS
2480 KEY LABELS ON
2485 FOR N=0 TO 19
2490 ON KEY N LABEL "" GOTO Top 1Default destination
2495 NEXT N
2500 I
2505 ON KEY 1 LABEL " SELECT (1)" Lcl_prty GOSUB Help
2510 ON KEY 2 LABEL " SELECT (2)" Lcl_prty GOSUB Sn
2515 ON KEY 3 LABEL " SELECT (3)" Lcl_prty GOSUB Change
2520 ON KEY 4 LABEL " SELECT (4)" Lcl_prty GOTO Exit
2525 ON KEY 5 LABEL " SELECT (5)" Lcl_prty GOTO Quit
2530 I
2535 Top: LOOP IWait for input
2540 IF M_flag=1 THEN GOSUB Menu
2545 END LOOP
2550 I
2555 Menu:
2560 PRINT TABXY(5,2),CHR$(129);" P W R _ M T R 1 ";CHR$(12B)
2565 CLIP 10,110,24,88 To draw a box
2570 FRAME
2575 PRINT TABXY(24,5)," -- MEASUREMENT MENU -- 
2580 PRINT TABXY(20,8),CHR$(129);" 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$(129);" (3)";CHR$(12B);" CHANGE # OF MEASUREMENT POINTS"  
2620 PRINT TABXY(25,14),"(Present setting =":Nt;") "  
2625 PRINT TABXY(20,16),CHR$(129);" (4)";CHR$(12B);" BEGIN MEASUREMENT"  
2630 PRINT TABXY(20,18),CHR$(129);" (5)";CHR$(12B);" EXIT PROGRAM"
2635 M_flag=0
2640 RETURN
2645 Sn:
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:
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:
2725 CALL Help
2730 M_flag=1
2735 RETURN
2740 Quit: ITerminate program
2745 Quit=1
2750 Exit:
2755 KEY LABELS OFF
2760 SUBEND
2765 I
2770 Help:SUB Help
2775 CLEAR SCREEN
2780 OPTION BASE 1
2785 Sys_prty=VAL(SYSTEM("SYSTEM PRIORITY")) IDetermine system priority
2790 Lcl_prty=Sys_prty+1 ISet local priority 1 higher for ON KEY
2795 USER 1 KEYS ISet list of soft keys
2800 KEY LABELS ON ITurn on soft keys
2805 FOR N=0 TO 19 IClear keys
2810 ON KEY N LABEL "" GOTO Top 1Default destination
2815 NEXT N
2820 ON KEY 1 LABEL "CONTINUE",Lcl_prty GOTO Exit
2825 GOSUB Text IPrint info
2830 I
2835 Top: LOOP IWait for input
2840 END LOOP
2845 I
2850 Text:PRINT TABXY(22,2),"CONTROLLING B502A CALIBRATOR OUTPUT"
2855 PRINT TABXY(12,4),"Press the following B502A front panel control keys in the"
2860 PRINT TABXY(12,5),"sequence indicated:"
PRINT TABXY(14,7), "(1) - 'CW', "
PRINT TABXY(25,7), "(2) - 'Menu', "
PRINT TABXY(36,7), "(3) - 'F3', "
PRINT TABXY(49,7), "(4) - 'F1'. "
PRINT TABXY(12,9), "Then, pressing the 8502A key '7' will turn the calibrator"
PRINT TABXY(12,10), "output ON, and pressing the 8502A key 'CLEAR' will turn the"
PRINT TABXY(12,11), "calibrator output OFF."
PRINT TABXY(12,13), "For more detail see 'Calibrator Output Level Test' on page 6-2"
PRINT TABXY(12,14), "of the 8502A manual."
PRINT TABXY(12,17), "CAUTION: Do not press any UNITS key when the mount is"
PRINT TABXY(12,18), "connected to the calibrator. This will cause the"
PRINT TABXY(12,19), "calibrator to output 100 mW which might damage the mount."
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 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.
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