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A CALIBRATION SERVICE FOR COAXIAL REFERENCE STANDARDS FOR MICROWAVE POWER

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CONTENTS

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Certain commercial components used in the calibration system are identified in this report in order to adequately document the design. Such use and identification do not imply recommendation or endorsement by NIST, nor do they imply that the identified items are necessarily the best available for the purpose.

A CALIBRATION SERVICE FOR COAXIAL REFERENCE STANDARDS FOR MICROWAVE POWER

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A calibration service at the National Institute of Standards and Technology (NIST) for coaxial microwave power reference standards is described. The service provides measurements of a reference standard's effective efficiency from 50 MHz to 18 GHz at a power of 10 mW. The NIST microwave power standards consist of both a microcalorimeter and an associated reference standard. The reference standard is a bolometric power detector (a thermistor mount). The only thermistor mounts accepted for measurement are those constructed to NIST specifications. These thermistor mounts and the automated microcalorimeter are described. A detailed error analysis with an estimate of the calibration uncertainties and their sources is included. The calibration uncertainty, which is quoted as a function of frequency, ranges from about 0.2 percent at 50 MHz to 0.4 percent at 18 GHz.

Key words: coaxial microwave power standard; microcalorimeter; microwave; microwave microcalorimeter; microwave power measurement; microwave power standard

1. INTRODUCTION

1.1 NIST Microwave Power Standards

The microwave power standards in use at the National Institute of Standards and Technology (NIST) consist of microcalorimeters and associated reference standards [1-4]. Each power standard is made up of both a microcalorimeter and a reference standard. The reference standards are substitution type bolometric power detectors. These detectors are generally called bolometer mounts or simply mounts. In this document the terms "reference standard," "bolometer mount," and "mount" are used interchangeably. Commercial bolometer mounts, especially coaxial units, are generally not suitable for use as a reference standard that is measured by the microcalorimeter. While they have been used by NIST in the past, the resulting calibration uncertainties were higher because of their use.

To meet the need in the microwave community for lower calibration uncertainty, a reference standard designed for use with the microcalorimeter is required. Figure 1.1 shows the coaxial microcalorimeter and the Type N thermistor mount used as the reference standard. This document includes a brief description of the microcalorimeter and the reference standard. Additional design and construction details for both the coaxial microcalorimeters and the bolometer mounts used as the reference standards are available as NIST Technical Notes [5, 6]. These references and those noted previously all include descriptions of the microcalorimeter and bolometer mount operation. However, for convenience a brief summary follows.

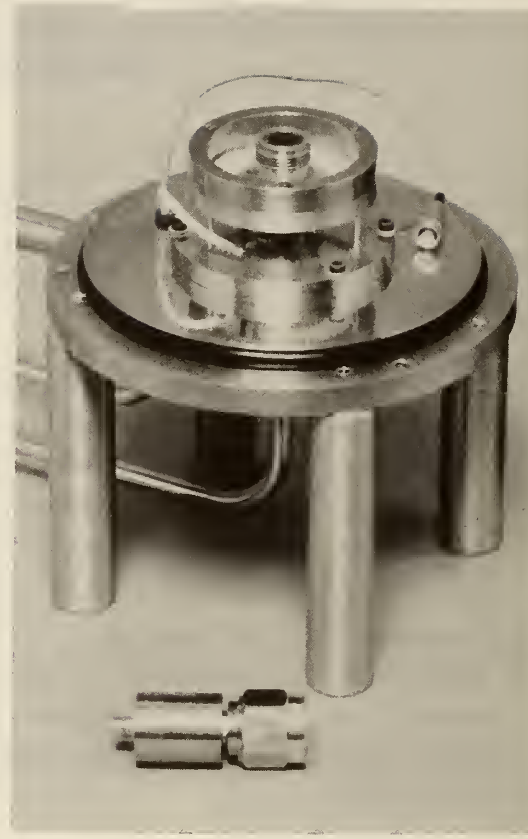


Figure 1.1 Coaxial microcalorimeter and coaxial reference standard.

1.2 Bolometer Mount-Microcalorimeter Operation

The bolometric power detector uses a heat sensitive resistor (bolometer) which terminates the transmission line and absorbs the microwave energy. Two types of bolometers are used: a platinum wire with a positive temperature coefficient called a barretter, and a thermistor bead with a negative temperature coefficient. The detectors are biased by an external source of dc current (power meter) to an operating resistance that produces a match with the characteristic impedance of the transmission line. Coaxial mounts typically use two bolometer elements which are connected in series for the dc bias, but are in parallel for the rf. Thus, to match the 50 Ω characteristic impedance of a coaxial transmission line, the pair is maintained at a series resistance of 200 Ω. When microwave energy is applied to the mount, the dc bias supplied by the power meter is automatically reduced to maintain a constant operating resistance [7]. If all the microwave energy incident on the mount were absorbed by the bolometer elements, and if the elements were heated identically by equal amounts of dc and rf power, then the microwave power would be equal to the amount by which the dc power is reduced. This is called a substitution type power meter, because the rf power replaces a portion of the dc bias power. The substituted dc power (also called the bolometric power) is calculated using the equation

$$P_{dc} = \frac{V_1^2 - V_2^2}{R_0}, \tag{1-1}$$

where V_1 is the power meter output voltage (the dc voltage across the bolometer elements) with no rf, V_2 is the power meter output voltage with rf, and R_0 is the dc operating resistance of the bolometer pair (200 Ω for a coaxial mount).

The microwave energy incident on a mount is not all absorbed by the bolometer elements. The dielectric and conductor losses in the input connector, the input transmission line, and the bolometer mounting structure, plus any leakage from the mount result in a measurement error characterized by a correction factor called the mount efficiency. This efficiency is always less than 1. In addition, the bolometer elements are not heated identically by equal amounts of rf and dc power. This is known as the rf-dc substitution error. The combination of these two effects, which is measured by the microcalorimeter, is a correction factor defined as the effective efficiency η_e. The rf power absorbed at the input of the mount is calculated by dividing the substituted dc power by the effective efficiency. The mount's effective efficiency is independent of mismatch corrections, which are treated separately at the time of calibration transfer to an unknown mount.

The bolometer elements used in the reference standards are thermistors. Thermistors are rugged and resist burnout in the event of an rf overload. They are available commercially as a conveniently usable subassembly. Disadvantages to using thermistors include a continuous drift in the bias current even in a constant temperature environment. Also, thermistors are not usable in an alternative efficiency measurement technique known as the impedance method [8].

The microcalorimeter essentially measures the temperature rise of the bolometer mount connected to it. In the coaxial microcalorimeter, the mount's temperature increase is measured with a thermopile. During the measurement, the microcalorimeter is immersed in a stable temperature-controlled water bath [9, 10] to minimize the effect of external temperature changes. The measurement procedure determines the following at each frequency of interest: the power meter and thermopile output voltages (V_1 and e_1) with only dc applied to the mount, and then again (V_2 and e_2) with both rf and dc applied. The effective efficiency η_e is calculated at each frequency using the equation

$$\eta_e = g \frac{1 - \left(\frac{V_2}{V_1}\right)^2}{\frac{e_2}{e_1} - \left(\frac{V_2}{V_1}\right)^2}. \tag{1-2}$$

The g term is a frequency dependent correction factor for the microcalorimeter-bolometer mount combination. It is also known as the calorimetric equivalence correction. The uncertainty of the η_e measurement is determined primarily by the uncertainty in g. The determination of g is a major effort that is described in section 6 of this document.

A typical reference standard calibration is done at approximately 125 frequencies from 50 MHz to 18 GHz. Even with the automated system described in section 4, the measurement takes about 40 h. Figure 1.2 shows a typical thermopile output at a few frequencies. The value of η_e for one the reference standards, measured at 125 frequencies, is shown in figure 1.3. The expanded uncertainty in the η_e measurement as a function of frequency is shown in figure 1.4. The basis for determining the uncertainty and the method for combining the different components are also described in section 6.

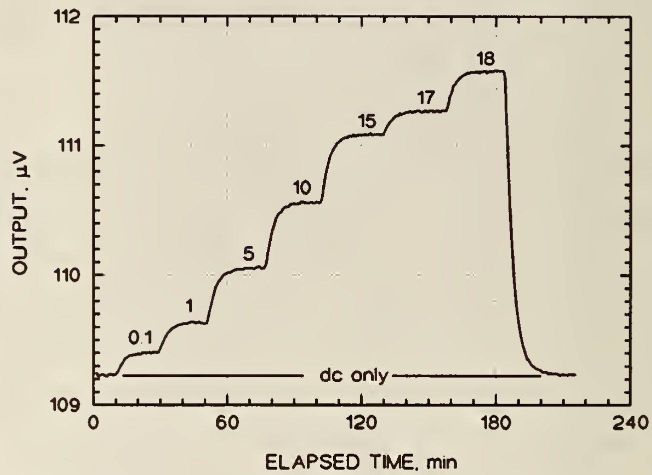


Figure 1.2 Thermopile output versus time for seven frequencies (in GHz).

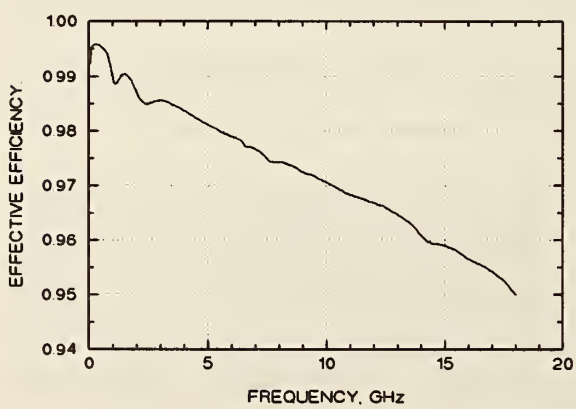


Figure 1.3 Effective efficiency of a Type N mount measured at 125 frequencies.

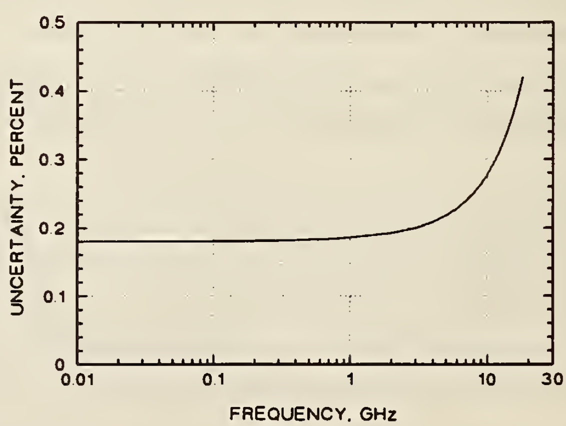


Figure 1.4 Expanded uncertainty for the Type N coaxial microcalorimeter when measuring the effective efficiency of a NIST Type N mount.

2. TYPE N AND APC-7 REFERENCE STANDARD DESIGN

The features of the bolometer mount described below are both desirable and necessary for the mount to be used as an optimum reference standard. The body of the mount and the internal thermistor bead assembly are both considered. Complete design and construction details are available in reference [5].

2.1 Mount Body Design

As noted in the introduction, the primary function of the microcalorimeter is to measure the effect of all microwave energy dissipated in the mount. To best accomplish this, there should be minimal thermal resistance between the heat sources and the measuring thermopile. Thus, the mount should be constructed of a material with a high thermal conductivity, and the thermal paths should be short as possible. Typical commercial mounts are constructed of nickel-plated or gold-plated brass and might also have stainless steel parts in the thermal path.

The transfer standard should have a high effective efficiency. This means a low rf-loss input transmission line made of high electrical conductivity material with low surface roughness ($\approx 0.5\ \mu m$).

To meet these requirements, the mount body is constructed of tellurium copper, while the parts of the mount that involve the input transmission line (the outer conductor) are made of electroformed copper. The electrical conductivity of copper is nearly 3 times higher than brass and 30 times higher than stainless steel. The thermal conductivity is about 2.5 times higher than either brass or beryllium copper and 26 times higher than stainless steel. The electroformed parts provide a better outer conductor surface finish than can be obtained by machining.

The disadvantage of these two materials is that they are softer than beryllium copper or brass. This is more of a liability for the Type N mount (because of the vulnerable outer conductor of the connector) than for the APC-7 design. With careful handling, it is not a major problem with either design. Experience with one of the Type N mounts reveals no visible connector damage after more than 100 connections. All parts of the mount are gold plated to prevent deterioration of the surface characteristics, primarily thermal emissivity and electrical conductivity.

Valid measurements of the thermopile output and the power meter voltage cannot be made until the microcalorimeter and mount are in thermal equilibrium with the water bath, a condition indicated by a stable thermopile output. The time to reach stability may be lengthy: an average of 50 min per measurement frequency (a typical calibration at 108 points can take about 90 h) on the commercial mounts because of their long thermal time constant. To minimize the effect of external temperature changes, all commercial mounts are typically massive and seek to thermally isolate the thermistor bead structures. Such design objectives are the opposite of those desired for use in the microcalorimeter. An effective way to speed the measurements is to minimize the thermal mass (heat capacity) of the bolometer mount by reducing the size and to eliminate the thermal isolation.

Both techniques are used in the mounts. For example, the mass of the new Type N mount is approximately one-third that of the commercial version previously used (53 g versus 142 g). The average measurement time per frequency for the new design is less than 30 min (see section 4).

The rf leakage from the bolometer mount is a first-order source of error in the measurement. The leakage energy, because it is not dissipated in the mount, is not detected by the bolometer elements or by the microcalorimeter thermopile. Leakage may radiate or conduct through mechanical joints in the mount body, the dc bias leads, or the rf input connector. Commercial mounts, which are adequate for their intended use, generally do not have low enough leakage for this application, where errors on the order of 0.01 percent are of concern.

The effort to minimize leakage has focused on rf containment by the mount body and the dc bias circuit. The shielding is accomplished by totally enclosing the mount and minimizing any gap that might allow leakage at a mechanical joint. Residual leakage from threaded joints can be further reduced by painting the seam with conductive epoxy or paint. Because of the thin wall of the mount body, the cap is not threaded. It is designed to be a tight press fit in the body; in fact, a special fixture is needed to remove the cap. Once it is determined that a newly constructed mount is operating properly, the cap seam can also be sealed with conductive epoxy or paint.

The internal rf bypass structure consists of a tubular pi-section (a pair of capacitors with a ferrite inductor) low-pass filter with an added external ferrite bead in each of four leads. A cross section of the dc feed-through structure is shown later as part of figure 2.1 and 2.2. The dc connection to the thermistor beads is through a miniature connector to allow the mount cap to be removed.

2.2 Thermistor Bead Assembly

As described earlier, the substitution type power meter measures power in terms of a change in the dc bias power. Any uncertainty in the bolometer dc resistance will be reflected as an error in the power calculation. Lead or contact resistance in the dc bias circuit will generate such an error. The solution to this problem is a four-wire connection from the bolometer elements to a power meter which uses external sense leads such as the NIST Type IV power meter (made commercially by several manufacturers). The thermistor bead assembly used in the mount does have the required four-wire connection.

Coaxial bolometer mounts typically use a dual bolometer configuration. The elements are connected in series for the dc bias and in parallel for the rf. This simplifies the dc bias connection and also provides a good rf match to the 50 Ω transmission line. However, if the electrical characteristics of the two elements are not identical, a dc-rf substitution error in the power measurement results. For thermistor mounts, the error increases nonlinearly with rf power. The error is restricted to coaxial mounts since, in general, waveguide designs use a single element. The effect can be minimized by proper matching of the element pair. The beads in the assembly used are matched to 0.05 Ω at 165°C. The details of the dual-element error are presented in reference [11].

Another performance parameter for the mount, which is a function of the bead assembly, is the input reflection coefficient. A low reflection coefficient (less than 0.1) is not necessary for the microcalorimeter measurement, but it is important for reducing the uncertainty in the calibration transfer and for reducing the minimum power requirement on the microwave source.

Another desirable feature of the mount is that the η_e be a smooth function of frequency. Most thermistor mounts display resonances, or sharp narrow dips in η_e. Because η_e is changing very rapidly with frequency at these points, the random uncertainty is greater and interpolation between measured points is not possible. The resonance effect is the result of microwave leakage past the thermistor beads into the space that forms a cavity behind the thermistor bulkhead. The effect can be reduced or eliminated by filling the cavity with two layers of magnetic microwave absorber. The filling material is fastened in place to prevent movement which could change the η_e.

The thermistor bead structure with its unique four-wire connection is a commercial product. This greatly simplifies the construction of the mount. The choice of the particular commercial part does not represent an endorsement of the vendor or the product or imply that it is the best in this application.

2.3 Final Design

The final mechanical and electrical design features are indicated in the following two figures. Figure 2.1 is a cross sectional view of the Type N mount with the major parts identified. The same view of the APC-7 mount design is shown in figure 2.2.

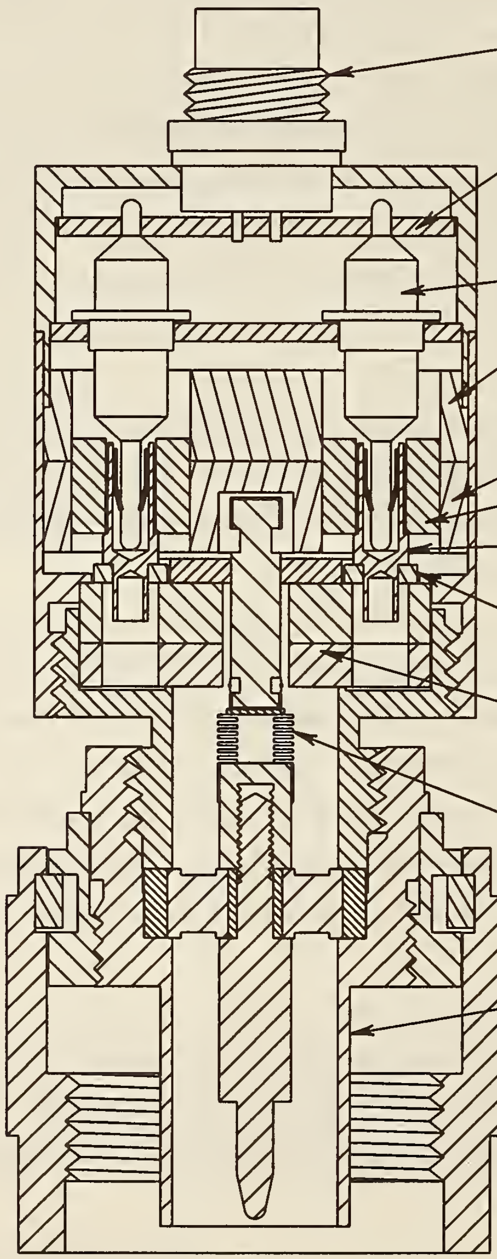


Figure 2.1. Cross section of the Type N thermistor mount.

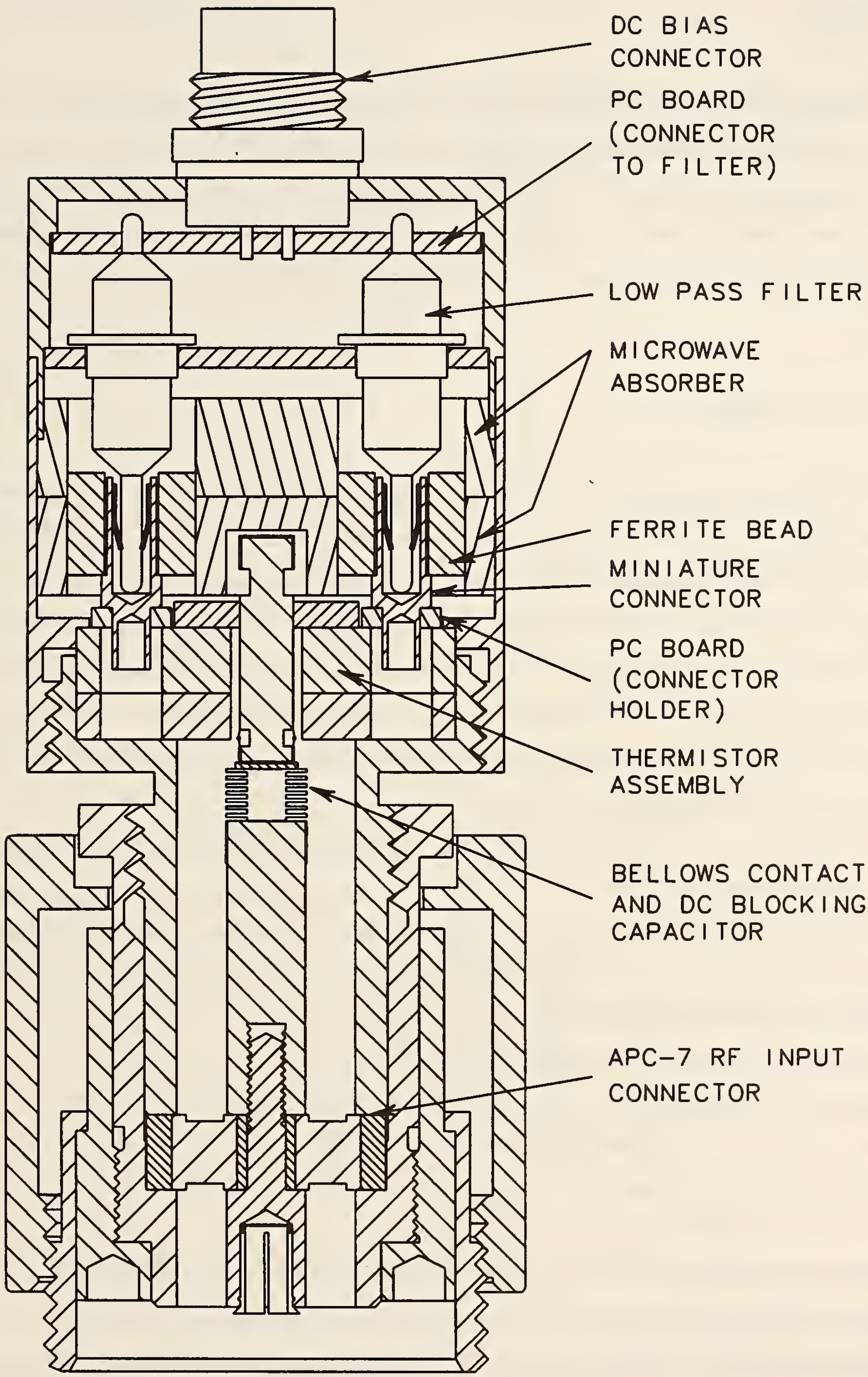


Figure 2.2 Cross section of the APC-7 mount.

2.4 Performance

Material presented in this section reports the measured performance of several samples of the Type N mount only. At the time of this publication, customer interest in an APC-7 service has not been sufficient to warrant constructing the mounts or evaluating the calorimeter. The parts, however, are in hand and can be assembled and evaluated if needed in the future. These measurements are thought to be typical and thus representative of future units. The basis of these performance measures was presented earlier in section 2.1.

2.4.1 Microwave Leakage

Detection of microwave leakage is relatively easy; accurate measurement of its magnitude is not. Development of special techniques and facilities such as the reverberation chamber and the TEM cell make such measurements potentially possible [12]. A reverberation chamber can be used to measure the energy above about 300 MHz (the low frequency limit is determined by the size of the available chamber) that is radiated from the mount and its connected dc bias cable. Energy that is conducted from the mount on the connecting dc bias cable can be measured using a vector voltmeter and a spectrum analyzer. Measurements on early prototype mounts show that most of the energy escaping from the mount is conducted away on the connecting cable, rather than radiated. Therefore, measurements were not made in the reverberation chamber.

Results shown in figure 2.3 were obtained from measurements on the mount using a vector voltmeter at the low frequencies and a spectrum analyzer above 1 GHz. The objective is to keep total leakage from the mount more than 40 dB below the input (less than 0.01 percent of the input). The figure indicates that this was achieved.

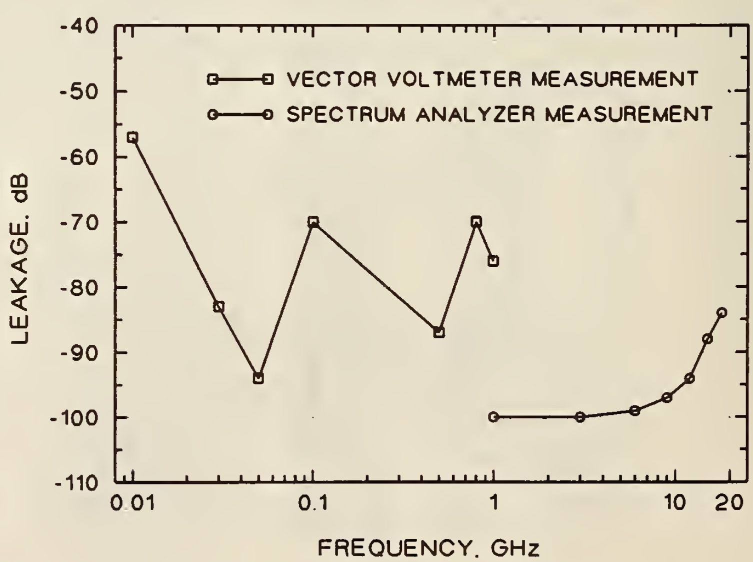


Figure 2.3. Microwave leakage in decibels below the input.

2.4.2 Input Reflection Coefficient

As previously indicated, it is desirable for the magnitude of the input reflection coefficient to be small. The measurements made by an automatic vector network analyzer (45 MHz to 18 GHz) and by a six-port network analyzer (10 MHz to 50 MHz) on a typical Type N mount are shown in figure 2.4. The magnitude is under 0.1 from about 20 MHz to 16.5 GHz.

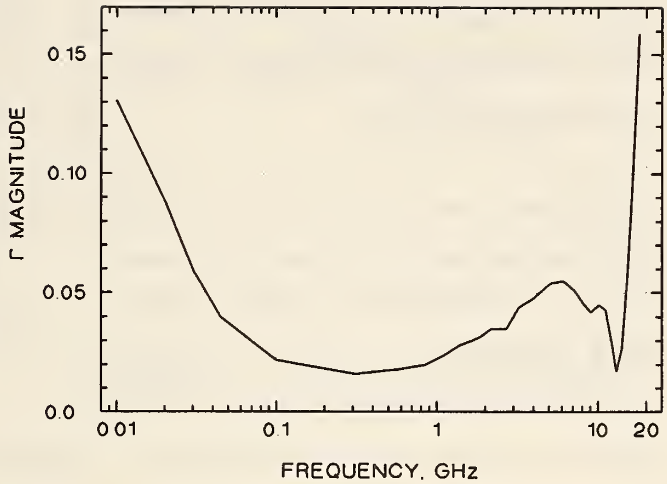


Figure 2.4. Type N mount reflection coefficient.

2.4.3 Dual Element Error

First, we note that if the mount is used at 10 mW, where it was calibrated, there is no error. However, if the mount is used as a reference standard to calibrate another system at a different power, say 1 mW, then there may well be an additional uncertainty in the measurement.

The only way to determine the magnitude of the dual-element error is by direct measurement. In theory, one possible measurement method is to connect the coaxial mount to one arm of a nominally equal power splitter (such as a 3 dB hybrid or a waveguide "magic tee"), and a single-element waveguide mount to the other arm. The ratio of the two bolometric powers is determined at 10 mW and again at a randomly selected power between 10 mW and 0.1 mW. The change in the ratios as determined at the two powers is a measure of the dual-element error. The process is repeated enough times to give a curve showing the nonlinearity as a function of power up to 10 mW.

The test of the procedure is to place identical model waveguide mounts on each arm of the power splitter to verify the linearity of the splitter and associated instrumentation. Figure 2.5 shows results of such a measurement with two identical model waveguide mounts at 9.1 GHz. The increased spread of the data as the power decreases is typical of bolometric measurements because of the small change in dc power that occurs at low microwave power.

The result for a commercial coaxial mount compared with one of the waveguide mounts is shown in figure 2.6. The error is very small at low power and increases to about 0.035 percent at 10 mW.

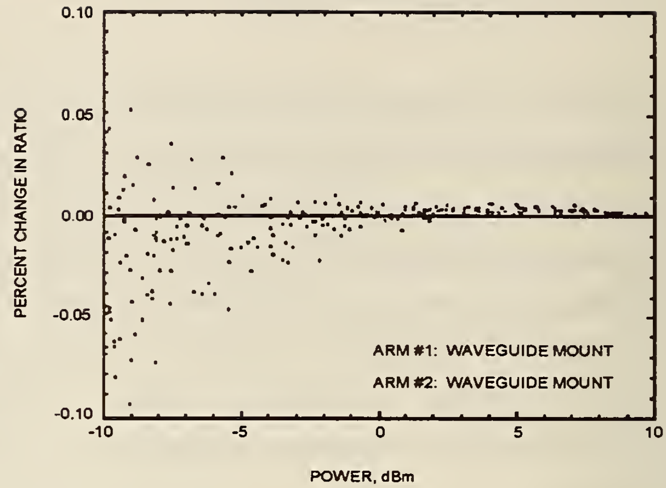


Figure 2.5. Change in the power ratio of two waveguide mounts versus power.

Unfortunately, most of the data taken using this technique do not give results comparable to figures 2.5 and 2.6. Considerable time has been put into the effort to reduce this approach to a reliable measurement technique. Thus far, it has not been successful. Generally, the results of the power splitter linearity tests have not provided the desired verification, so the comparisons between the coaxial mount and a waveguide mount are not too meaningful. The difficulty seems to be that when looking for deviations on the order of 0.01 percent, instrumentation problems such as the inability to locate the ground precisely where it should be in the dc measurement circuit are of the same order. At best, the comparison between the coaxial and waveguide mounts is in error by the amount of the apparent nonlinearity seen when comparing a waveguide mount to a waveguide mount.

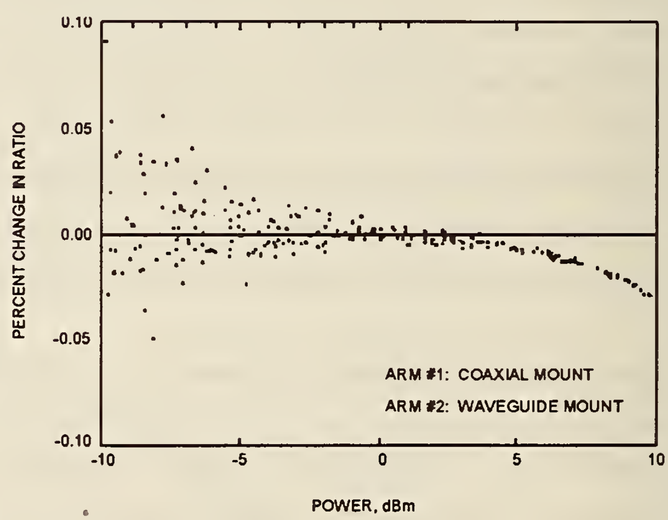


Figure 2.6. Change in the power ratio of a coaxial mount to a waveguide mount versus power.

Another way to determine the dual-element error is to measure the effective efficiency as a function of power. Figure 2.7 shows that measurement on a Type N mount. The significant nonlinearity above about 12 mW is largely due to the dual-element error. At the lower powers the measurement uncertainty becomes large, so the shape of the curve is not necessarily accurate. A line fitted to the measured data between 5 mW and 12 mW is shown in figure 2.8. Based on this linear fit, the change in efficiency for this mount between 10 mW and 1 mW is less than 0.01 percent. This is a better estimate of the dual-element error than the power splitter method provides.

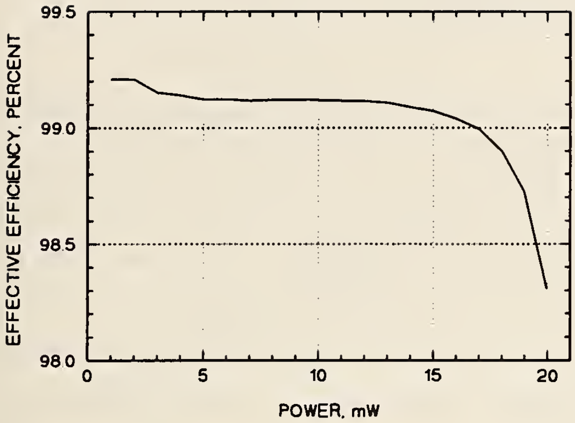


Figure 2.7. Effective efficiency as a function of power.

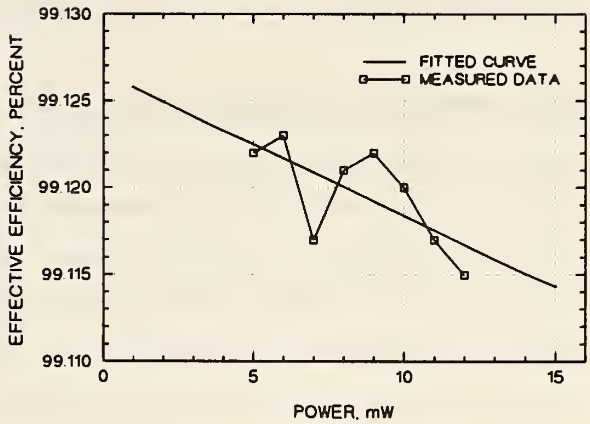


Figure 2.8. Linear fit to data of figure 2.7 from 5 to 12 mW.

2.4.4 Mount Settling Time

In figure 2.9, the upper trace is the output of a crystal detector monitoring a 10 GHz source as the rf is turned on for about 6 ms and then turned off. The lower trace is the power meter voltage of the coaxial thermistor mount as it measures the same output. Note the large "overshoot" excursions that occur for about 2 ms until a steady state is reached. These excursions may occur because the current distribution in the thermistor beads changes when rf is applied, so the heat distribution must also change. It takes a few milliseconds for a new thermal steady state to be reached. Thus the measurement of the power meter voltages should not be made until after the overshoot has subsided. The effect decreases with power and is independent of frequency.

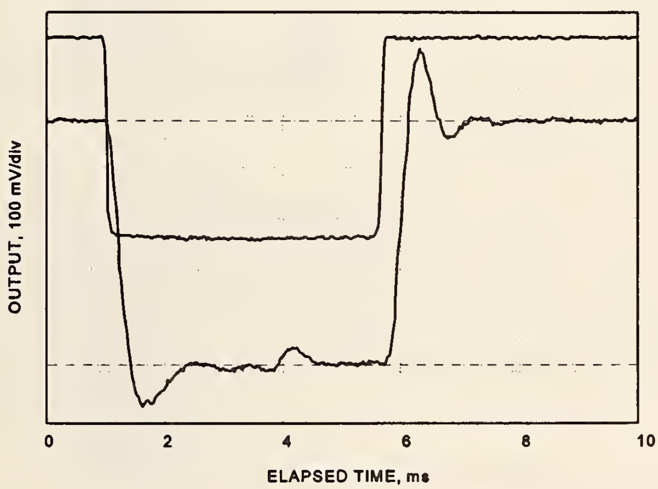


Figure 2.9. Crystal detector and mount output as rf power is switched on and off. The source output is 10 mW.

2.4.5 Effective Efficiency

A plot of the effective efficiency of one of the Type N mounts is shown in figure 1.3. The efficiency is well above 90 percent and decreases smoothly with frequency. Figure 2.10 is a plot of the effective efficiency of a mount before and after suppression of the resonant behavior with microwave absorber as described earlier.

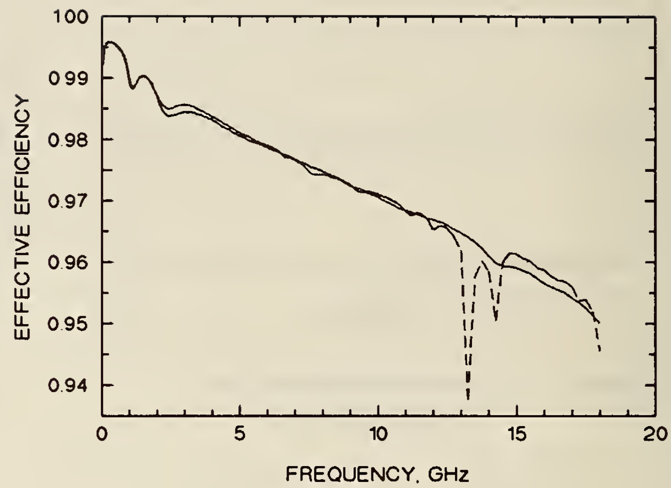


Figure 2.10. Effective efficiency of a Type N mount before (dashed line) and after resonance suppression.

3. MICROCALORIMETER DESIGN

As noted in section 1, the primary function of the microcalorimeter is to measure the effect of all microwave energy dissipated in the reference standard bolometer mount. This is accomplished by using a thermopile to measure the temperature rise of an attached bolometer mount with respect to a thermal reference ring under two conditions. The first condition is with dc only dissipated in the bolometer mount and the second condition is with both dc and rf dissipated in the mount. Because the temperature changes are very small (on the order of 0.05 °C), the microcalorimeter is also designed to be immersed in a stable temperature-controlled water bath [9, 10] during the measurement to minimize the effect of external temperature changes. The water bath is controlled to about ±20 μ°C at near room temperature. Figure 3.1 is a cross sectional view of the base of the microcalorimeter with the major parts labeled. Complete design and construction details are available as reference [6].

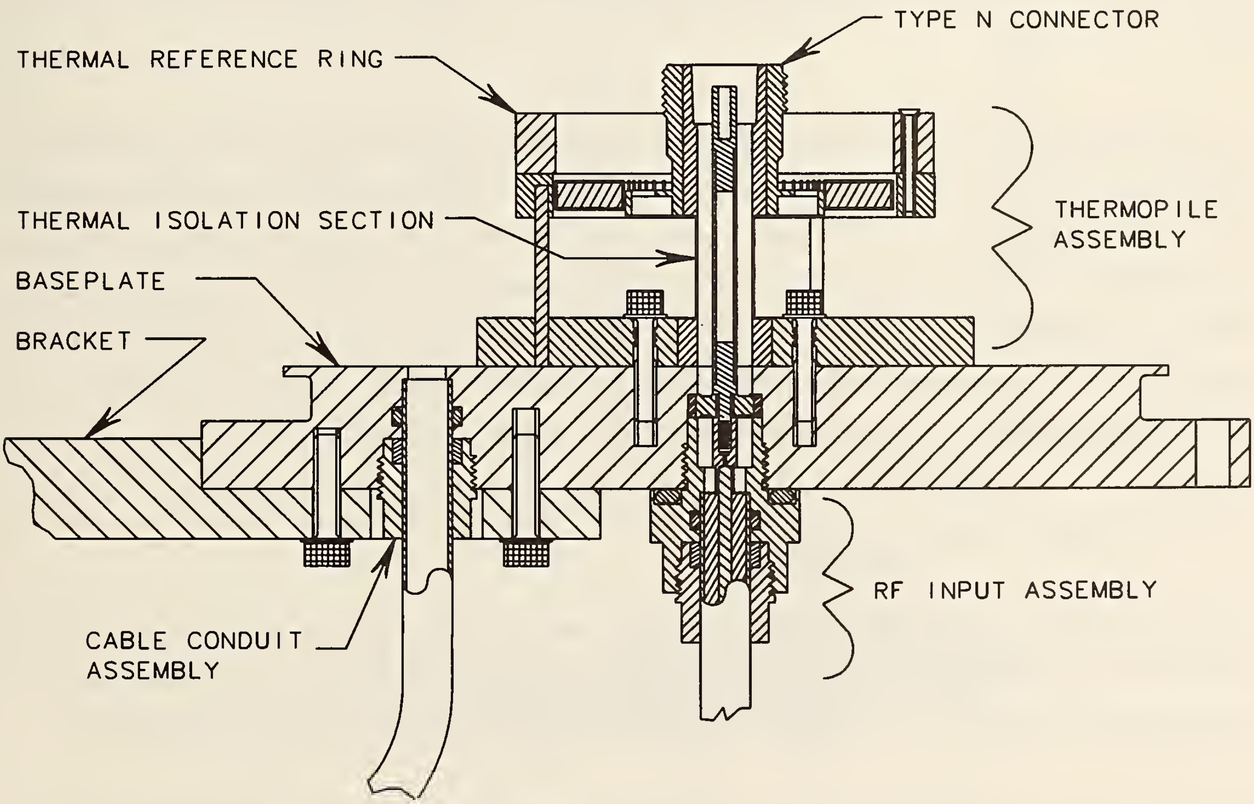


Figure 3.1. Cross section of the Type N microcalorimeter.

3.1 Thermopile Assembly

This part contains a thermal isolation section as well as the thermopile itself. The thermal isolation section, which is between the baseplate (in close contact with the water bath) and the bolometer mount, allows the mount temperature to rise with respect to the baseplate. The isolation section is a short length of coaxial transmission line made with a thin-wall copper outer conductor and a hollow thin-wall gold-plated stainless steel inner conductor.

The thermopile is a ring made of 66 equally spaced radial turns of Constantan wire; the lower half of the ring is copper plated giving 66 copper/Constantan junctions around both inner and outer circumferences. The ring of inner thermocouple junctions is in thermal contact with (but electrically insulated from) the 7 mm coaxial outer conductor just below the coaxial connector. The circle of outer thermocouple junctions is in contact with a thermal reference ring which approximates the thermal characteristics of the dummy reference standard used in the earlier twin-joule microcalorimeter design as described in references [1] and [2].

The thermocouples in the thermopile are connected in series, so the thermopile output can be increased by increasing the number of junctions. The number of thermocouples in the original thermopile was limited by the input range, 100 μV, of the potentiometer used to measure the thermopile output. Since the microcalorimeter described here uses the original thermopile assembly, it has less thermocouple junctions than it would otherwise. A thermopile with many more junctions and made of finer wire would be a better match to the 2 mV range of the modern electronic nanovoltmeter now used. A typical thermopile output at a few frequencies for one of the reference standards is shown in figure 1.2.

3.2 Other Design Features

The rf input leads, the mount's dc bias leads, and the thermopile's output leads are brought in through the bottom of the microcalorimeter. This provides a more convenient arrangement for removing the top cover and also keeps the leads in the water bath for a greater distance to provide better thermal tempering.

The entire assembly, including the cover, is gold plated for corrosion protection. The gold-plated interior of the cover is polished to provide a high infrared reflectivity. Figure 3.2 is a partial cross sectional view of the entire calorimeter with the cover raised. When in use the unit is suspended in the temperature-controlled water bath by the rod extending from the top of the cover. The actual water level when in the bath is indicated.

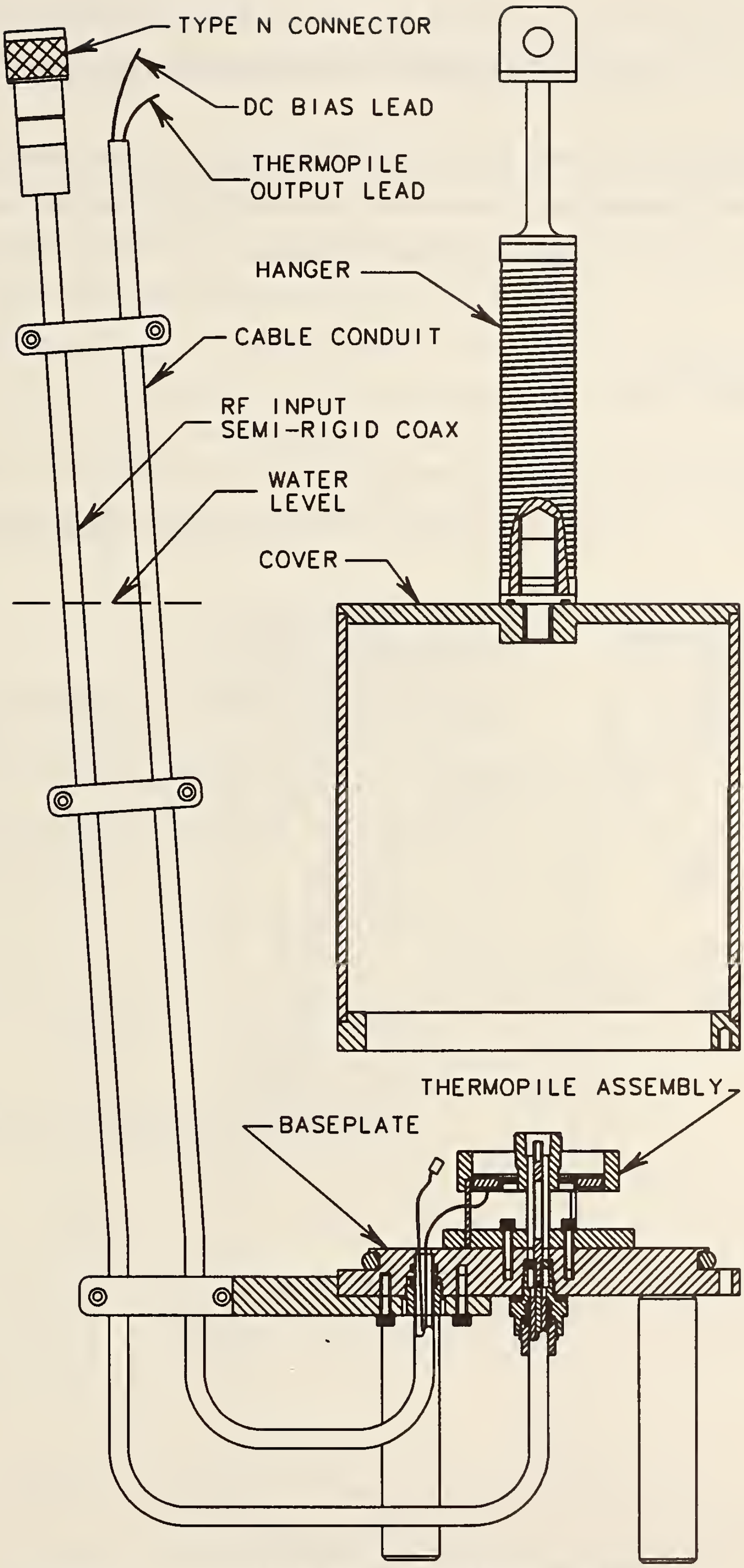


Figure 3.2. View of the entire microcalorimeter assembly.

4. AUTOMATED CALIBRATION SYSTEM

The automated system provides a completely unattended measurement of the effective efficiency once the reference standard and microcalorimeter are connected and placed in the temperature controlled water bath. The automation is accomplished using off-the-shelf computer controlled GPIB instrumentation and custom software.

4.1 SYSTEM HARDWARE

The measurement console containing two automated systems, one in each rack, is shown in figure 4.1. Except for items 7 and 9 each system has an identical set of instruments. The right-hand rack is intended

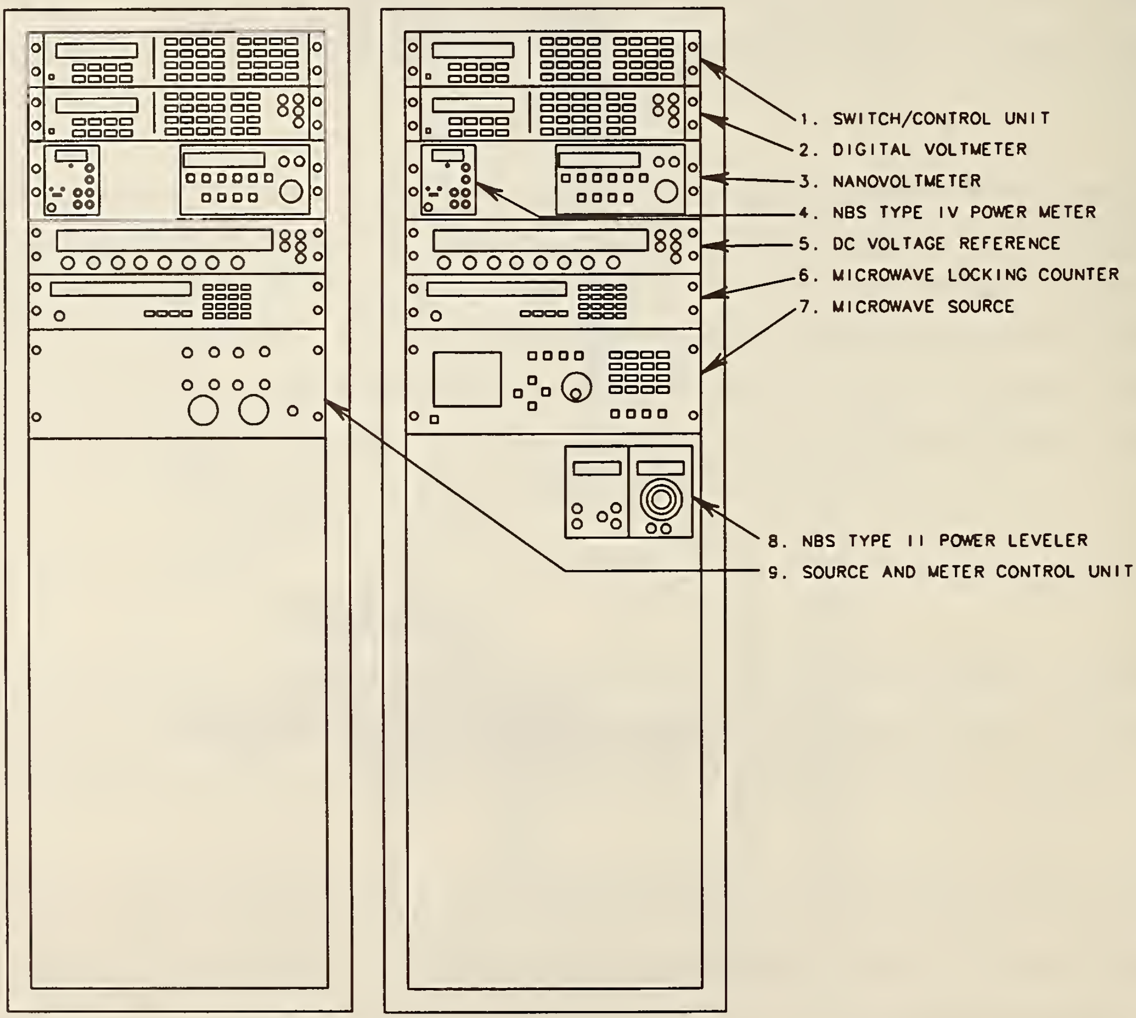


Figure 4.1. Automated calibration system instrument rack.

primarily for coaxial calibrations because the microwave source, item 6, has a 10 MHz to 20 GHz frequency range. The system in the left-hand rack is used with the waveguide microcalorimeters.

Item 1, the switch control unit, provides bus control for the different connections required as the measurement is made. Item 2, the digital voltmeter, measures the output from item 4, the Type IV power meter. Item 3 is a nanovoltmeter used to measure the thermopile output. A precision dc source, item 5, is used as the reference voltage for instrument 8, the NBS Type II power leveler. Item 6 is a locking counter which phase locks the microwave source, unit 7. Item 9 is a custom control unit for the individual YIG tuned FET oscillators used as sources for the waveguide microcalorimeters. Not shown in figure 4.1 are the two instrument controllers. The actual instruments used are identified by item in Appendix F.

A schematic diagram of the instrument connections is shown in figure 4.2.

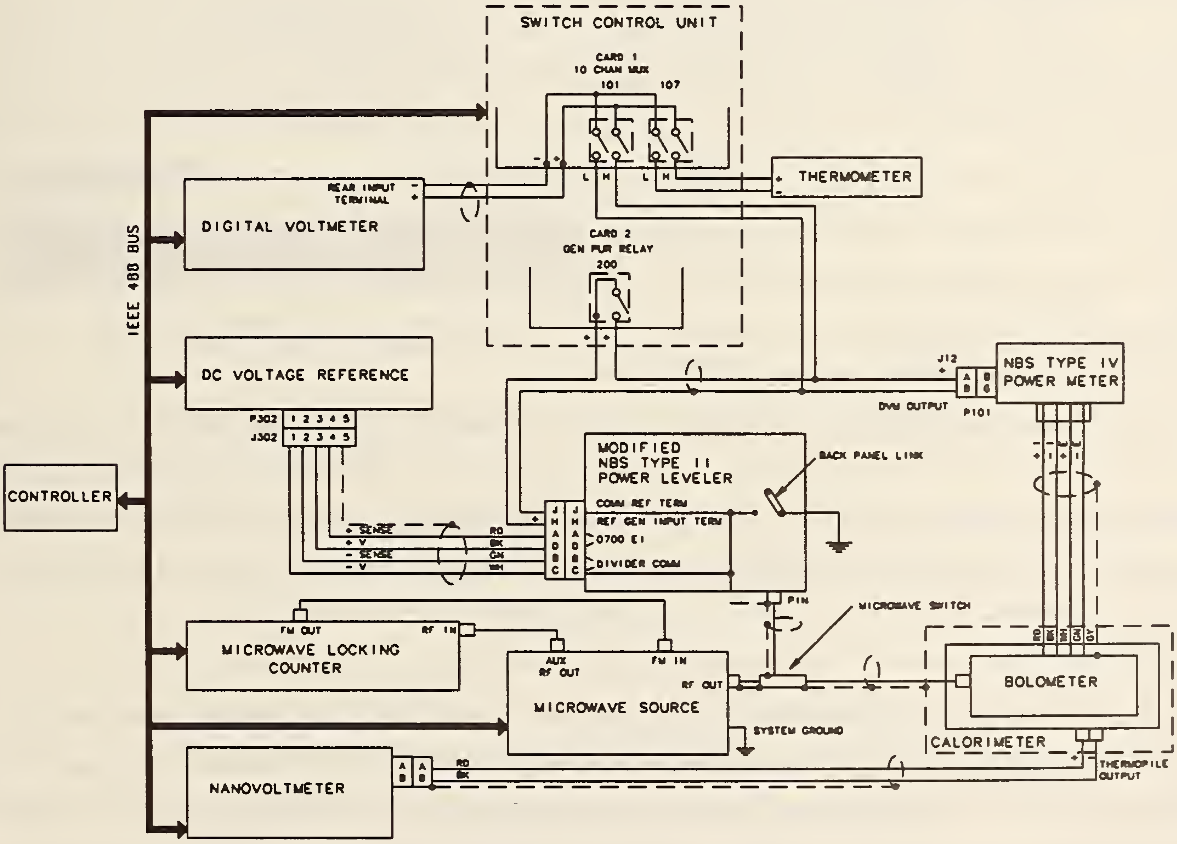


Figure 4.2. Automated calibration system schematic diagram.

4.2 SYSTEM SOFTWARE

The measurement program, called MICRO_CxAP, is written in HP BASIC (also known as Rocky Mountain BASIC or RMB). The program controls the measurement and does the post-measurement processing needed to compute the effective efficiency. A post-measurement computation is required because of the need to correct for the effect of drift in the reference standard bias voltage during the measurement.

4.2.1 Program Features

The program is menu driven, with soft keys used for much of the input. The first menu encountered in running the program is shown in figure 4.3. The reverse video items at the bottom of the screen are soft key definitions. When item 1 is selected, a series of screens is presented that set the initial conditions by asking for the measurement frequencies, the serial number of the reference standard, the scale factors for the real time graph, the desired time delay before starting the measurement, and whether a nanovoltmeter zero offset measurement will be included. One of the initial screens sets up the program to measure at five test frequencies when a mount is first connected to the microcalorimeter. After these results are entered into the program, the mount is removed, reconnected, and measured again at the five test frequencies. If the two sets of measurements agree within established limits, the program automatically continues the measurements over the full set of desired frequencies.

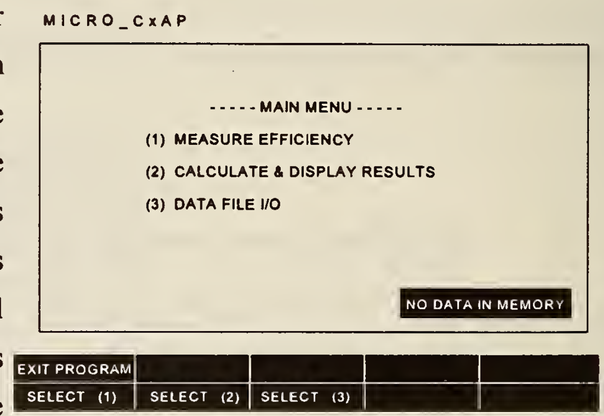


Figure 4.3. First program menu.

During the measurement a real-time graph is displayed on the monitor that shows the thermopile output and other information. Figure 4.4 is an example of the real-time display as the program is measuring the five test frequencies. Information about the program appears in the three windows at the top. The center and right windows can each be toggled to display additional information in another window. The information found in the left-hand window labeled "HEADER INFO" is self explanatory. The center window labeled "LAST READING" gives the total time since the measurement started, the elapsed time since switching to the frequency presently being measured, the total count of data points measured since the start, a countdown that gives the time remaining until the next reading and directions for switching to the alternate window. The right-hand window labeled "THERMOPILE OUTPUT & TEMP" shows the most recent nanovoltmeter reading of the thermopile output, the average of the last 18 thermopile voltage readings, two spaces for possible future readings of the room and water bath temperatures, and directions for switching to the alternate window. Figure 4.5 shows the real-time display with the alternate center and right windows. The center window labeled "SYSTEM PARAMETERS" shows the present measurement frequency, the last voltage reading from the power meter, the setting of the reference voltage for the power leveler, a calculated value for the substituted dc power in the reference standard, a countdown that gives the time remaining until the next reading, and directions for switching back to the original window. The alternate right window labeled "STATISTICS" shows variables related to the stability algorithm which is explained in section 4.2.2 and Appendix C.

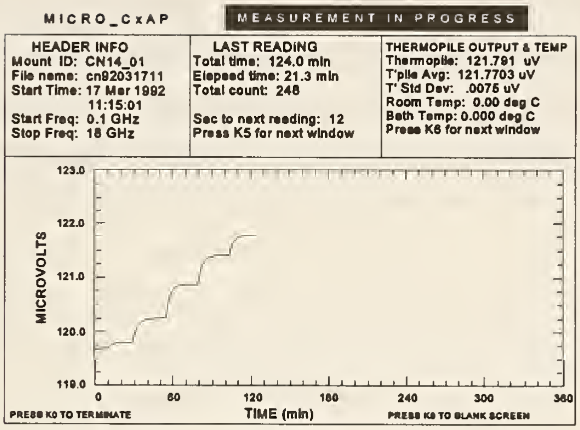


Figure 4.4. Real-time display.

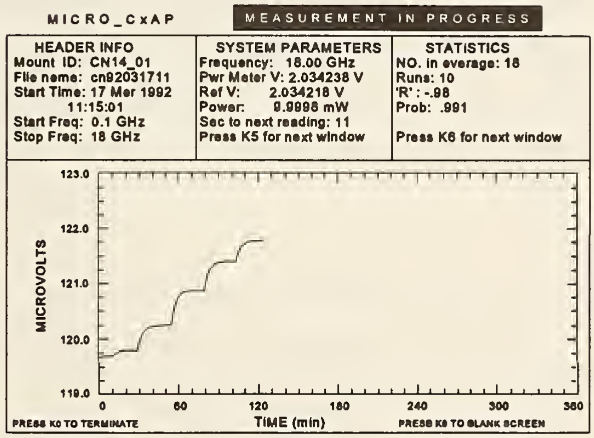


Figure 4.5. Alternate real-time display.

During the measurement the data are taken as the frequency is incremented (tests have shown no difference in results if the frequency is stepped incrementally, or if it is changed randomly) from 50 MHz to 18 GHz. The frequency range is broken into four segments: 50 MHz to 2 GHz in steps of 50 MHz, 2.1 to 4 GHz in steps of 100 MHz, 4.2 to 12.4 GHz in steps of 200 MHz, and 12.5 to 18 GHz in steps of 250 MHz. All of the measured data for each frequency segment are automatically saved to disk individually, with a name that includes the date and time at the beginning of the measurement. An example of the file name is shown under "HEADER INFO" in figure 4.4. The "cn" indicates the reference standard is a Model CN coax mount and "92031711" indicates the measurement was started between 1100 and 1200 h on Mar. 17, 1992. The program completes all four segments automatically without operator intervention.

After completing the entire measurement sequence, the program will return to the main menu. The data from the last set of measured frequencies will still be in memory. Item 2, "CALCULATE & DISPLAY

RESULTS", is selected. This produces the menu shown in figure 4.6 with options to plot the power meter voltage, plot the thermopile voltage, calculate the efficiency, plot the rf power, plot the temperature (if it had been measured), and calculate the standard deviation of any selected set of data points. The plots are useful to get a quick overview of the measurement results to see that the data looks reasonable before calculating the efficiency.

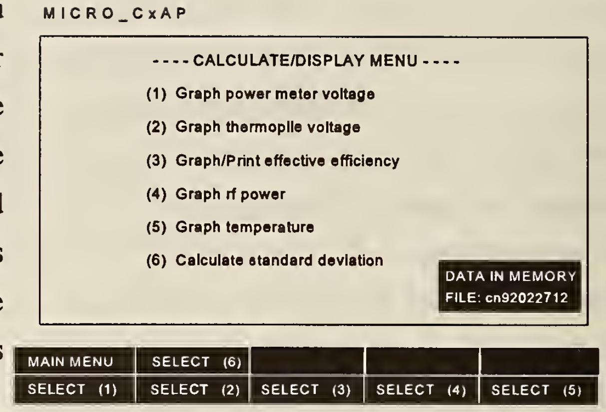


Figure 4.6. Calculation and display menu.

When the program calculates the effective efficiency, four plots at each frequency are optionally available. Examples of these plots for a measurement made at 15 GHz are shown in figures 4.7, 4.8, 4.9, and 4.10.

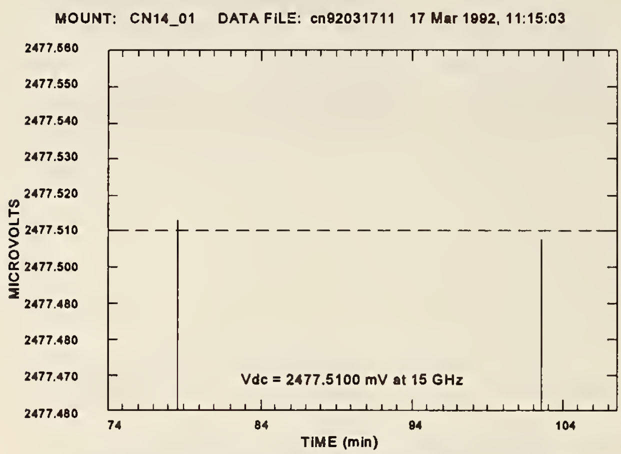


Figure 4.7. Power meter voltage with rf off.

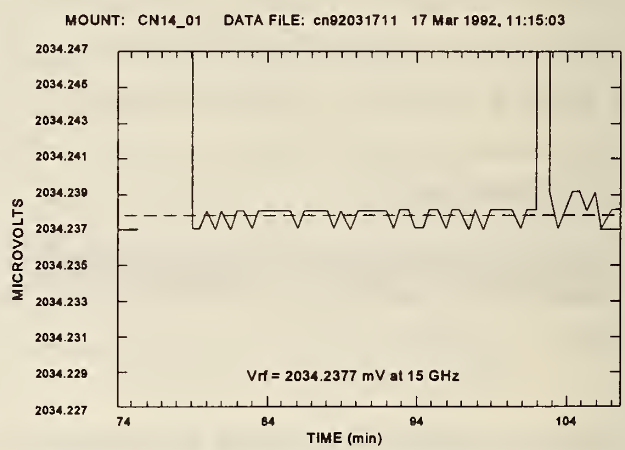


Figure 4.8. Power meter voltage with rf on.

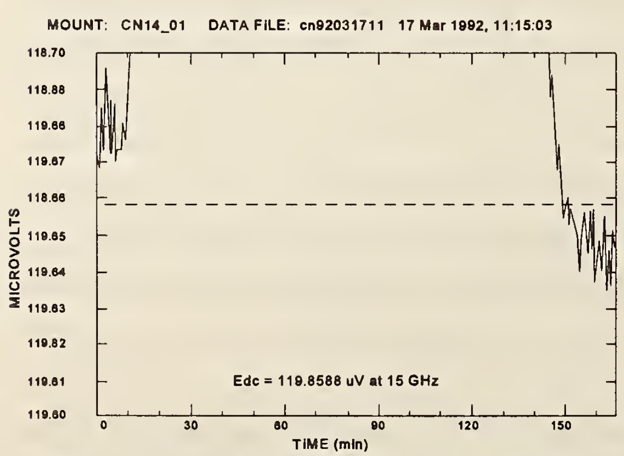


Figure 4.9. Thermopile output with rf off.

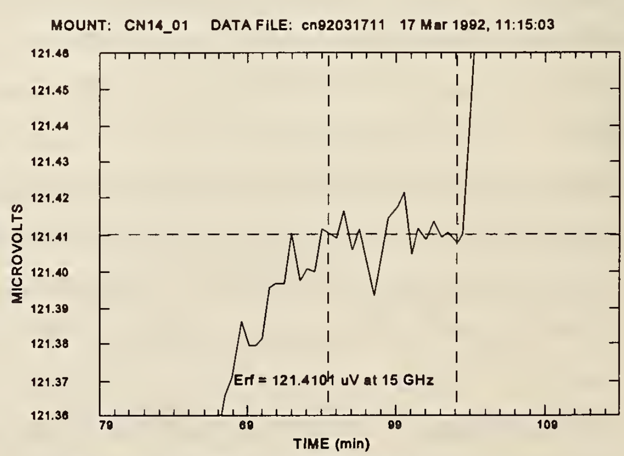


Figure 4.10. Thermopile output with rf on.

The horizontal dashed line in each plot shows the value calculated by the program for each variable. The exact numerical value is displayed at the bottom of the plot. Refer to section 6.1 for a description of the variables and equation used to calculate the effective efficiency. There is a change of variable between these figures and eq (6.1.20): Vdc, Vrf, Edc, and Erf in the figures equal V_1, V_2, e_1, and e_2, respectively, in the equation.

In figure 4.7, note that the rf is off only for the initial and final readings and the calculated Vdc is the average of the two readings. In figure 4.8, the calculated Vrf is the average of all the readings taken while the rf is on. Note that the power leveler keeps the power meter voltage constant within a single count of the DVM. In figure 4.9, the calculated Edc is taken from a linear fit between the average of the initial readings (taken while the rf is off) and the average of the final readings (again while the rf is off) at the time corresponding to the center of the stabilized thermopile output when the rf is on (about 99 min from figure 4.10). In figure 4.10, the value of Erf is the average of the 18 readings between the 2 vertical dashed lines. The decision that stability had been reached in the thermopile output was made by the stability algorithm described in section 4.2.2. The program determines these variables and then calculates and plots the effective efficiency for each frequency measured.

Figure 4.11 is an example how the screen looks when the effective efficiency is plotted. The X and Y axis can be changed to scale the graph and the numerical values can be listed to the screen or printed.

Figure 4.12 shows the screen listing (only a portion of the listing is shown, the rest can be scrolled). The effective efficiency values are now part of the original data file, and the file is saved to disk as described in the next paragraph.

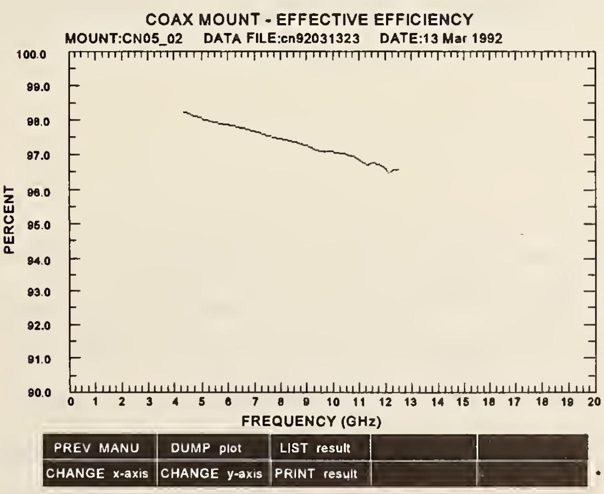
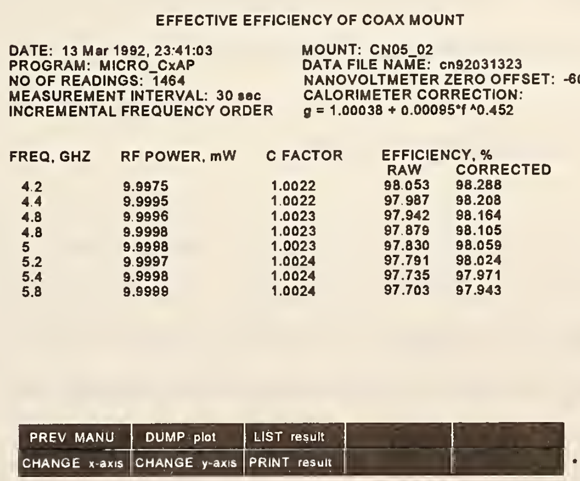


Figure 4.11. Effective efficiency plot.



EFFECTIVE EFFICIENCY OF COAX MOUNT

DATE: 13 Mar 1992, 23:41:03
PROGRAM: MICRO_CxAP
NO OF READINGS: 1464
MEASUREMENT INTERVAL: 30 sec
INCREMENTAL FREQUENCY ORDER

MOUNT: CN05_02
DATA FILE NAME: cn92031323
NANOVOLTMETER ZERO OFFSET: -60 nV
CALORIMETER CORRECTION:
g = 1.00038 + 0.00095*f ^0.452

FREQ, GHZ	RF POWER, mW	C FACTOR	EFFICIENCY, %	
			RAW	CORRECTED
4.2	9.9975	1.0022	98.053	98.288
4.4	9.9995	1.0022	97.987	98.208
4.8	9.9996	1.0023	97.942	98.164
4.8	9.9998	1.0023	97.879	98.105
5	9.9998	1.0023	97.830	98.059
5.2	9.9997	1.0024	97.791	98.024
5.4	9.9998	1.0024	97.735	97.971
5.8	9.9999	1.0024	97.703	97.943

PREV MANU | DUMP plot | LIST result
CHANGE x-axis | CHANGE y-axis | PRINT result

Figure 4.12. Screen listing.

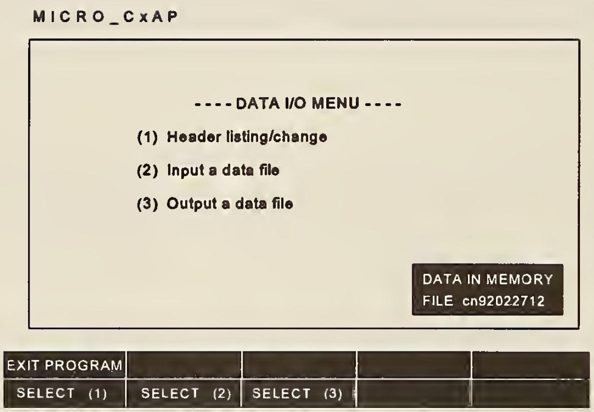


Figure 4.13. Data I/O menu.

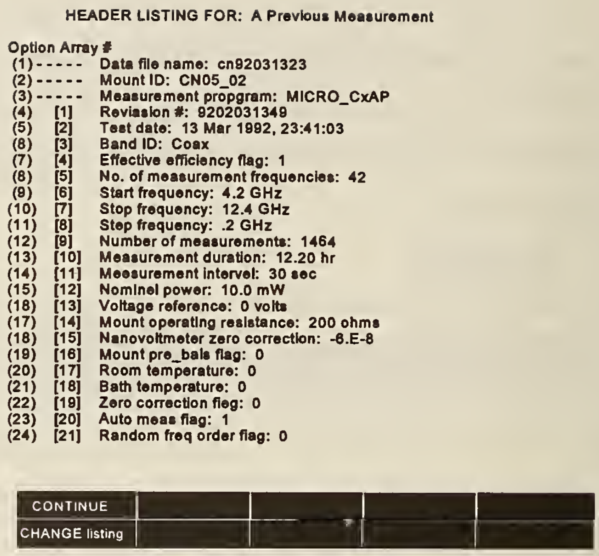


Figure 4.14. Header listing.

To save the data file (or input the data file for the next frequency segment), return to the main menu (figure 4.3), and select option 3, "DATA FILE I/O". This produces the screen shown in figure 4.13. The first item is an option to list the header that is part of each data file. The header, which contains information about the measurement, is shown as it lists to the screen in figure 4.14 (all of the header is shown in the figure, but the actual screen has to be scrolled). As indicated by the soft key options, it may be changed if needed. The item to input a data file also has the option to catalogue any mass storage unit on the system to obtain or check the file name if needed. Once the name is typed in, soft key options input the file from any mass storage unit connected to the controller. The data file output choice includes the option to change the file name, as well as save to any mass storage unit.

Once the efficiencies for all the measured frequencies have been calculated and saved, another program is used to collect them into a single file (which does not contain any of the raw data). This file is used to generate the final calibration report.

4.2.2 Stability Algorithm

One of the critical points in the measurement is the determination of when the thermopile output has reached equilibrium or stability. This is especially difficult because the bias voltage for the reference standard essentially never stops changing; in other words, an aging process is always going on. This means there is always a drift in the thermopile output, aside from the effect of the microwave loss. In addition, the nanovoltmeter reading is fairly noisy because the measurement is being made at about 100 μV, which is just 5 percent of the lowest range (2 mV) on the instrument. An algorithm to determine when stability has been reached under these conditions has been developed by the NIST Statistical Engineering Division. The algorithm is described in detail in Appendix C. Refer back to figure 4.10 as an example of the thermopile output when it was determined that stability had been achieved. The dashed line is taken to be the thermopile output and is the average of 18 successive measurements between the 2 vertical lines. The right vertical line is the point at which the algorithm decided the output was stable.

5. CALIBRATION PROCEDURES

This section describes the process followed in performing the effective efficiency measurement. Since the measurement is automated, the manual part of connecting the standard, setting up the software, and producing the measurement report are the primary things described. The description is appropriate for a new operator's training and thus detailed.

5.1 STEP-BY-STEP DESCRIPTION

The following steps are carried out in performing the calibration of a reference standard.

1. The Type N connector on the reference standard is inspected closely (under a microscope) for dirt and physical damage. The connector is cleaned if necessary. This is a precaution taken to avoid damaging the microcalorimeter connector, since the effective efficiency measurement is not affected to first order by the mount's reflection coefficient. The critical Type N connector dimension is measured (and compared with previous measurements if this is not the first calibration). This ensures that there will not be a destructive interference when the standard is mated to the microcalorimeter.

2. Any moisture retention by the reference standard or in the microcalorimeter has proven to give erroneous, nonrepeatable results in the efficiency measurement. Be sure your hands are clean and dry before handling the standard and that no water drops are in the microcalorimeter when the cover is replaced. An effective means of being certain that excess moisture is not present in the reference standard is to place the standard in a vacuum for a few hours.

3. The reference standard is connected to a power meter and biased with dc for a period of two to three days. This reduces the bias drift that occurs when the unit is placed in the microcalorimeter.

4. The reference standard is connected to the microcalorimeter using a Type N torque wrench (approximately 1.13 N · m (10 lbf · in)). The cover is placed on the microcalorimeter, the total unit is placed in the water bath, the Type IV power meter and nanovoltmeter leads are connected, the dc bias is turned on, and the entire unit is allowed to temperature stabilize for at least 1 h. If at that point the power meter and thermopile outputs are fairly stable (an operator's judgement call learned by experience–actually the program will not start the measurement if the drift rate is too high) the first of the measurements can be started. Section 6.4.1 describes a first-order drift correction made when the effective efficiency is calculated.

5. The program called "MICRO_CxAP" is loaded and set up to run the five check frequencies. Information about the program and how to use it can be found in section 4.2. When the program is run, a 3.5 in diskette with sufficient space must be in drive 0 (the left side) of the dual 3.5 in drive. The effective efficiency is measured at five check frequencies, 0.1, 3, 5, 10, 15, and 18 GHz. This takes four to five hours, and the data are saved to disk. The program is run again to compute the results.

6. The microcalorimeter is then disconnected from the power meter and nanovoltmeter, removed from the water bath, the cover removed, and the standard disconnected. The calorimeter is left open for at least 15 to 30 min and then the mount is replaced for a second connect, and the process described by step 5 is repeated, except the results from step 5 are entered into the program before it is run again.

7. If the second five-frequency check result repeats within ± 0.06 percent, the program automatically runs the full frequency set. (The measurement is made without disconnecting the mount.) Again, a 3.5 in diskette with sufficient space must be in drive 0 (the left side) of the dual 3.5 in drive. The effective efficiency is measured at 124 frequencies, 0.05 to 18 GHz. This takes about 40 h, with the data saved to disk in four files. As described in section 4.2, the program is run again to compute and save the results.

8. A program called "MICRO_DMA" is used to extract the effective efficiency from the four data files saved in the last step. The program combines the four segments and saves the results as a single ASCII file which is converted to a DOS file and used to produce the final test report.

9. As described in step 6, the microcalorimeter is removed from the water bath, and the mount removed. This completes the measurement.

5.2 MEASUREMENT RESULTS

The results in the Report of Calibration are listed in a table that gives the effective efficiency, Type B uncertainty, and expanded uncertainty for each frequency. An example of the report can be found in Appendix E.

6. MEASUREMENT CORRECTIONS AND EVALUATION OF UNCERTAINTIES

The factors listed below all contribute to the measurement uncertainty and are included or mentioned in the analysis. A correction is determined for the combined effect. The standard uncertainty for the correction factor and for the remaining uncertainty components is determined by either a Type A or a Type B evaluation [13] as appropriate.

1. Nonlinearity of thermopile and nanovoltmeter.
2. Instrumentation errors (voltmeters and dc-substitution power meter).
3. External temperature stability.
4. Microcalorimeter microwave transmission line loss.
5. Microcalorimeter microwave connector loss.
6. Bolometer mount microwave leakage.
7. Bolometer mount internal dc lead resistance.
8. Bolometer mount microwave transmission line loss.
9. Bolometer mount microwave connector loss.
10. Bolometer mount dc lead filter.
11. Microwave connector repeatability.

6.1 MICROCALORIMETER OPERATION THEORY

This section is based in part on formulations by both Engen [1] and Weidman [2]. Figure 6.1 is a cross section of the reference standard connected to the calorimeter isolation section and the thermopile. The figure may be helpful in understanding the following derivation and equations.

Recall that the thermopile measures the temperature rise of the attached bolometer mount when the mount is biased with dc alone, or with dc plus rf. The expression for the thermopile output voltage with only dc bias applied to the mount may be written as

$$e_1 = k_1 P_{dc1} = \frac{k_1 V_1^2}{R_0}, \qquad (6\text{-}1)$$

where k_1 is a proportionality factor characteristic of the thermal transfer path from the mount to the thermopile and is a constant unless the thermopile output is nonlinear. The other terms were originally defined in section 1.2. P_{dc1} is the dc bias power dissipated in the mount, V_1 is the power meter output voltage (equal to the voltage across the bolometer elements) when P_{dc1} is applied, and R_0 is the bolometer element dc operating resistance maintained by the power meter.

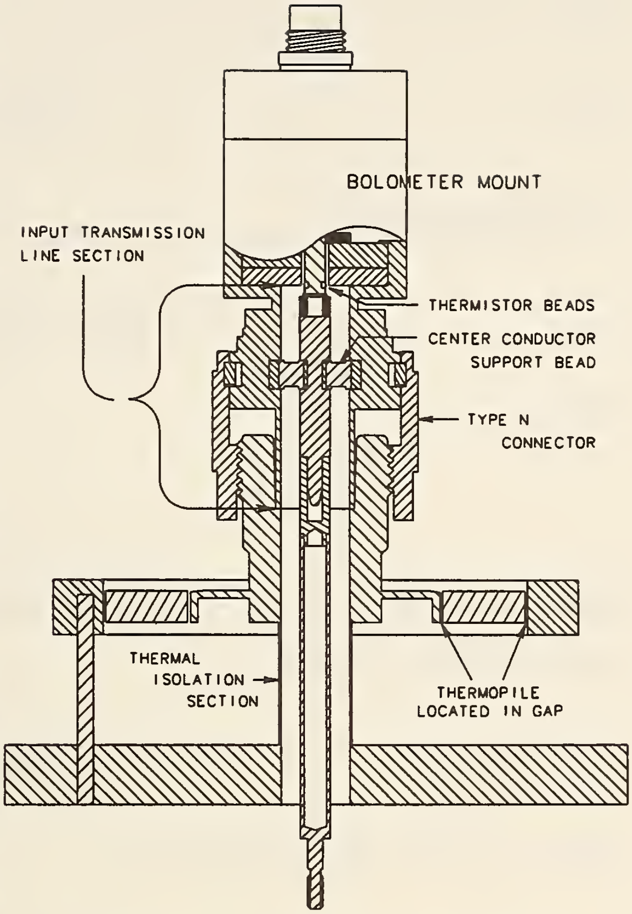


Figure 6.1 Cross section of mount and calorimeter.

With both dc and rf applied to the mount, the new thermopile output voltage is given by

$$e_2 = k_2 \left(P_{dc2} + aP_t + bP_{mi} + cP_{ci} + dP_{mb}\right), \tag{6-2}$$

where k_2 does not equal k_1 because of the thermopile nonlinearity, P_{dc2} is the dc bias power dissipated in the mount, P_t is the rf dissipation in and near the thermistor beads, P_{mi} is the rf loss in the mount input section transmission line including the connector, P_{ci} is the rf loss in the calorimeter isolation section transmission line including the connector, P_{mb} is the rf loss in the mount rf low-pass filters, and a, b, c, and d are constants that account for thermal paths that are different than the one described by k_2. Equation (6-2) may also be written as

$$e_2 = k_2 \left[P_{dc2} + P_{rf}\left(a\frac{P_t}{P_{rf}} + b\frac{P_{mi}}{P_{rf}} + c\frac{P_{ci}}{P_{rf}} + d\frac{P_{mb}}{P_{rf}}\right)\right], \tag{6-3}$$

where P_{rf} is the total rf power delivered to the mount. Letting

$$q = P_t / P_{rf}, \tag{6-4}$$

$$r = P_{mi} / P_{rf}, \tag{6-5}$$

$$s = P_{ci} / P_{rf}, \tag{6-6}$$

and

$$t = P_{mb} / P_{rf} , \tag{6-7}$$

we can write eq (6-3) as

$$e_2 = k_2[P_{dc2} + P_{rf}(aq + br + cs + dt)]. \tag{6-8}$$

Note that

$$q + r + t = 1 \tag{6-9}$$

because each term represents a fraction of the total rf power absorbed in the mount. Then eq (6-8) can be written as

$$e_2 = k_2(P_{dc2} + gP_{rf}), \tag{6-10}$$

where g is the correction factor given by

$$g = aq + br + cs + dt. \tag{6-11}$$

Writing eq (6-10) in terms of V_2 gives

$$e_2 = k_2 \left(\frac{V_2^2}{R_0} + g\,P_{rf} \right) . \tag{6-12}$$

Solving for P_{rf}, we find

$$P_{rf} = \frac{1}{g} \left(\frac{e_2}{k_2} - \frac{V_2^2}{R_0} \right) . \tag{6-13}$$

From eq (6-1), k_1 is given by

$$k_1 = \frac{e_1 R_0}{V_1^2} . \tag{6-14}$$

Let

$$k_2 = c_n k_1 = c_n \frac{e_1 R_0}{V_1^2}, \tag{6-15}$$

where c_n is a correction factor for the thermopile nonlinearity. Using eq (6-15), eq (6-13) becomes

$$P_{rf} = \frac{1}{g}\left[\left(\frac{e_2}{e_1}\right)\frac{V_1^2}{R_0 c_n} - \frac{V_2^2}{R_0}\right] \tag{6-16}$$

or

$$P_{rf} = \frac{1}{g}\left(\frac{V_1^2}{R_0}\right)\left[\left(\frac{e_2}{e_1}\right)\frac{1}{c_n} - \left(\frac{V_2}{V_1}\right)^2\right]. \tag{6-17}$$

The definition of effective efficiency is

$$\eta_e = \frac{P_b}{P_{rf}}, \tag{6-18}$$

where P_b is the bolometric substituted power given by

$$P_b = \frac{1}{R_0}\left(V_1^2 - V_2^2\right) = \frac{V_1^2}{R_0}\left[1 - \left(\frac{V_2}{V_1}\right)^2\right], \tag{6-19}$$

and P_{rf} is the total rf power delivered to the mount.

Using eqs (6-17) and (6-19), eq (6-18) becomes

$$\eta_e = g\,\frac{1 - \left(\frac{V_2}{V_1}\right)^2}{\frac{e_2}{e_1}\frac{1}{c_n} - \left(\frac{V_2}{V_1}\right)^2}. \tag{6-20}$$

Equation (6-20) can be simplified by letting

$$F_V = \frac{V_2}{V_1} \tag{6-21}$$

and

$$f_e = \frac{e_2}{e_1} \frac{1}{c_n}, \tag{6-22}$$

so eq (6-20) becomes

$$\eta_e = g \frac{1 - F_V^2}{f_e - F_V^2}. \tag{6-23}$$

Taking the total differential of eq (6-23) gives an expression for the uncertainty $\Delta\eta_e$ in η_e due to uncertainties in g, F_V, and f_e.

$$|\Delta\eta_e| = \frac{1 - F_V^2}{f_e - F_V^2} |\Delta g| + g \left| \frac{2 F_V (1 - f_e)}{(f_e - F_V^2)^2} \right| |\Delta F_V| + g \frac{1 - F_V^2}{(f_e - F_V^2)^2} |\Delta f_e|, \tag{6-24}$$

where the absolute value of each uncertainty term is used to obtain the maximum uncertainty. The relative uncertainty is given by

$$\left| \frac{\Delta\eta_e}{\eta_e} \right| = \left| \frac{\Delta g}{g} \right| + \frac{2 F_V^2 (f_e - 1)}{(1 - F_V^2)(f_e - F_V^2)} \left| \frac{\Delta F_V}{F_V} \right| + \frac{f_e}{f_e - F_V^2} \left| \frac{\Delta f_e}{f_e} \right|. \tag{6-25}$$

The determination of the terms g, F_V, and f_e, and their uncertainties, is described in the following sections.

6.2 DETERMINATION OF CORRECTION FACTOR g

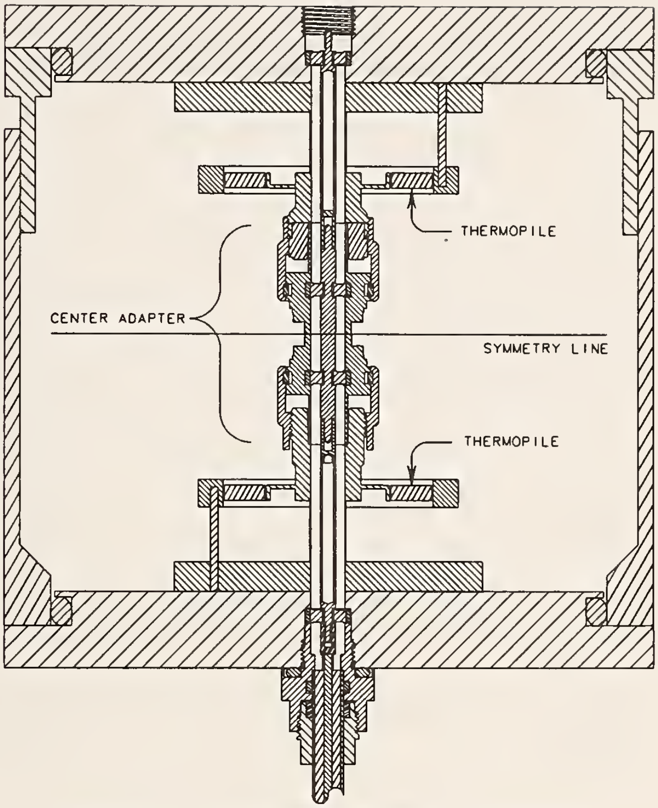


Figure 6.2 Arrangement used to determine the correction factor g.

Figure 6.2 is a cross section of a special measurement configuration used to determine g. The setup contains two thermopile assemblies and is symmetrical about the indicated horizontal center line. The microwave losses and the thermal conditions in each half are nearly equal, so the effect on the thermopiles is as if the other half were not present. (An analogy is the method of images employed with electromagnetic field problems.) Each half of the center adapter section is made of the same material and length as the input transmission line section of the mount (see figure 6.1), so that each half is thermally and electrically the same as a mount connector and input section. Although not shown, the transmission line is terminated (at the top of the figure) by one of the reference standards. The arrangement is fed by a nominal 10 mW (with the power leveled by the terminating mount) from the bottom, and the output of both thermopiles is noted. Assuming adequate symmetry, either thermopile reading is an indication of the heating due to loss in the calorimeter thermal isolation section and the mount input section. In the same way, then, as eqs (6-1) and (6-2) were developed, one of the thermopile outputs (say the lower) can be written as

$$e_B = k_B\left(b'P_{mi} + c'P_{ci}\right). \qquad (6\text{-}26)$$

As before, P_{mi} is the loss in the mount input section, and P_{ci} is the loss of the calorimeter thermal isolation section, and k_B, b', and c' are equivalent to k_1, b, and c, the constants characteristic of the different thermal transfer paths. Note that although the total loss in this measurement configuration is approximately double that of the configuration of figure 6.1, it does not result in added heating because there is also an additional identical thermal path to the temperature-controlled external environment.

In terms of the power ratios of eqs (6-5) and (6-6), eq (6-26) becomes

$$e_B = k_B P_{rf}(b'r + c's). \tag{6-27}$$

Because of the adapter material and size, we assume that

$$k_B \approx k_1. \tag{6-28}$$

The factor b' is associated with the loss in the mount input section. In the mount, the heat due to center conductor loss is transmitted to the thermopile primarily by the center conductor support bead rather than by the thermistor bead structure, because the dc blocking capacitor and bellows contact provide good thermal isolation. This was verified experimentally by measuring the thermopile output with the bellows and capacitor removed from a mount. For a representative mount with a dc bias of about 30 mW, the thermopile output with the bellows is 116 μV, and without the bellows the output is 118 μV, a less than 2 percent change. Thus the thermal effect should be nearly the same in the adapter and

$$b' \approx b. \tag{6-29}$$

The factor c' is associated with the loss of the calorimeter isolation section, and for the same reasons noted above,

$$c' \approx c. \tag{6-30}$$

With these substitutions eq (6-27) becomes

$$e_B \approx k_1 P_{rf}(br + cs), \tag{6-31}$$

so

$$br + cs \approx \frac{e_B}{k_1 P_{rf}}. \tag{6-32}$$

Recall that

$$g = aq + br + cs + dt. \tag{6-11}$$

The loss in the low pass filters is given by t. It will be zero only if there is no rf leakage past the internal thermistor bead structure. It is assumed that t is negligible, since its effect can be absorbed in the other loss term q, and it is not susceptible to direct measurement. The approximation that $a \approx 1$ can be made because q is the power ratio associated with the dissipation in the thermistor beads and k_1 is the thermal constant associated with that same heating. Then, with (6-32) substituted into (6-11), the expression for g becomes

$$g = q + \frac{e_B}{k_1 P_{rf}}. \tag{6-33}$$

From eq (6-9), with $t = 0$,

$$q = 1 - r. \tag{6-34}$$

Recall that r is the fractional loss in the input section and connector of the mount. An approximation for this is half the loss of the adapter section shown in figure 6.2. If the total loss is α_L, then

$$q \approx 1 - \frac{\alpha_L}{2}. \tag{6-35}$$

That loss is given by (see appendix A)

$$\alpha_L \approx 1 - |S_{21}|^2, \tag{6-36}$$

so the expression for g becomes

$$g \approx \frac{1 + |S_{21}|^2}{2} + \frac{e_B}{k_1 P_{rf}}. \tag{6-37}$$

Measured and calculated values for $|S_{21}|$ in decibels are shown in figure 6.3. The basis for the "theoretical plated line loss" curve is given in appendix B. The curve labeled "adjusted plated line loss" is a calculated loss obtained by changing the value of the conductivity of the gold plating and the joint loss factors (including the exponent of the frequency term) so the curve approximately fits the measured values. Table 6.1 lists the parameter values that were changed to obtain the adjusted curve

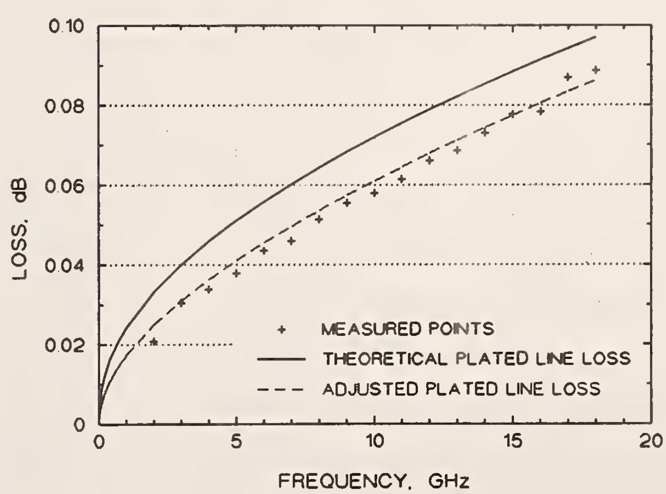


Figure 6.3 Type N male-to-male coax adapter loss.

Table 6.1 Values used in calculating the adjusted loss.

Parameter	Layer 1 (Au) thickness d μm	Layer 1 (Au) conductivity σ_1 S/m	Layer 2 (Cu) conductivity σ_2 S/m	Joint loss factors A_0	B dB/(GHz)^E	E
Inner conductor loss calculation	1.27 (nc)	2.5×10^7	8.00×10^6 (nc)	–	–	–
Outer conductor loss calculation	1.27 (nc)	2.5×10^7	5.75×107 (nc)	–	–	–
Type N joint loss calculation	–	–	–	0 (nc)	0.004	0.65
Bead joint loss calculation	–	–	–	0 (nc)	0.0022	0.65

(compare with table B1 in appendix B) using the equations derived in appendix B. An (nc) indicates the values have not changed from those listed in table B1.

The adjusted curve provides reasonable low frequency values for $|S_{21}|$ below 2 GHz where it was not possible to measure it. These values are used in eq (6-37) at all frequencies below 2 GHz. Above 2 GHz the measured values of $|S_{21}|$ are used.

Measurements of e_B, which were made over the frequency range of 10 MHz to 18 GHz, are shown in figure 6.4. The dashed line is a curve fitted to the bottom thermopile output. It shows that the output has a $\sqrt{f}$ dependence. The e_B values from the bottom thermopile are used in the calculation of g using eq (6-37).

The value used for P_{rf} in eq (6-37) can reasonably be the nominal 10 mW power at which e_B was measured.

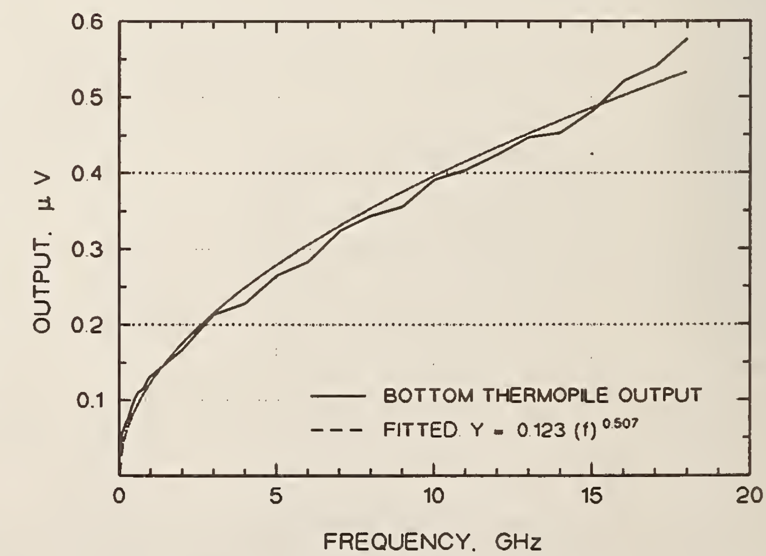


Figure 6.4 Measured thermopile output.

Values for g as a function of frequency from 10 MHz to 18 GHz are shown in figure 6.5. The fitted curve is proposed as the operational expression for g. A numerical listing of the values for g is included as table 6.2.

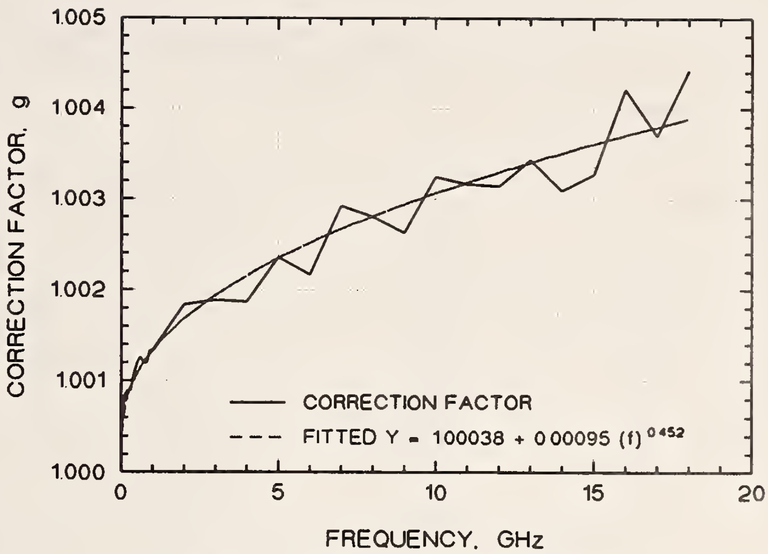


Figure 6.5 Microcalorimeter correction factor, g.

It is mathematically possible for g to be less than 1 if

$$\frac{\alpha_L}{2} > \frac{e_B}{k_1 P_{rf}}. \qquad (6\text{-}38)$$

Physically, this can happen because the heating effect of the center conductor loss is relatively isolated from the thermopile. In a waveguide calorimeter there is not an equivalent thermal path that is fairly well isolated from the thermopile, so g must always be 1 or greater.

Table 6.2 Tabulated values for g.

FREQ GHz	q	$\frac{e_B}{k_1 P_{rf}}$	g	g fitted
0.01	0.99983	0.00063	1.00046	1.00050
0.02	0.99975	0.00073	1.00048	1.00054
0.03	0.99969	0.00084	1.00052	1.00057
0.04	0.99964	0.00099	1.00063	1.00060
0.05	0.99960	0.00111	1.00071	1.00063
0.06	0.99955	0.00119	1.00074	1.00065
0.07	0.99951	0.00124	1.00075	1.00067

Table 6.2 (continued) Tabulated values for g.

FREQ GHz	q	$\frac{e_B}{k_1 P_{rf}}$	g	g fitted
0.08	0.99947	0.00129	1.00076	1.00068
0.09	0.99944	0.00134	1.00078	1.00070
0.10	0.99941	0.00142	1.00083	1.00072
0.20	0.99915	0.00175	1.00090	1.00084
0.30	0.99894	0.00195	1.00089	1.00093
0.40	0.99877	0.00230	1.00107	1.00101
0.50	0.99861	0.00258	1.00119	1.00107
0.60	0.99847	0.00278	1.00126	1.00113
0.70	0.99834	0.00286	1.00121	1.00119
0.80	0.99823	0.00296	1.00119	1.00124
0.90	0.99812	0.00322	1.00133	1.00129
1.00	0.99801	0.00332	1.00133	1.00133
2.00	0.99763	0.00423	1.00186	1.00186
3.00	0.99654	0.00539	1.00193	1.00194
4.00	0.99615	0.00577	1.00192	1.00216
5.00	0.99570	0.00671	1.00241	1.00235
6.00	0.99507	0.00716	1.00224	1.00252
7.00	0.99481	0.00820	1.00301	1.00267
8.00	0.99421	0.00871	1.00292	1.00281
9.00	0.99378	0.00901	1.00279	1.00294
10.0	0.99347	0.00990	1.00337	1.00307
11.0	0.99307	0.01023	1.00330	1.00319
12.0	0.99258	0.01073	1.00332	1.00330
13.0	0.99227	0.01132	1.00358	1.00341
14.0	0.99179	0.01147	1.00326	1.00351
15.0	0.99128	0.01218	1.00346	1.00361
16.0	0.99119	0.01319	1.00438	1.00371
17.0	0.99022	0.01367	1.00389	1.00380
18.0	0.99008	0.01461	1.00469	1.00389

6.3 UNCERTAINTY IN CORRECTION FACTOR g

From the preceding section

$$g \approx \frac{1 + |S_{21}|^2}{2} + \frac{e_B}{k_1 P_{rf}}. \tag{6-37}$$

Taking the total differential of eq (6-37) gives the following expression for the absolute uncertainty in g due to uncertainties in the independent variables.

$$|\Delta g| = |S_{21}|^2 \left| \frac{\Delta S_{21}}{S_{21}} \right| + \frac{1}{k_1 P_{rf}} |\Delta e_B| + \frac{e_B}{k_1 P_{rf}} \left| \frac{\Delta k_1}{k_1} \right| + \frac{e_B}{k_1 P_{rf}} \left| \frac{\Delta P_{rf}}{P_{rf}} \right|, \tag{6-39}$$

where the absolute value of each uncertainty term is used to obtain the maximum uncertainty.

In the measurement of both e_B and k_1 a correction for the zero offset is made. In terms of the measured quantities these are given by

$$e_B = (e_B)_1 - (e_B)_0 \tag{6-40}$$

and

$$k_1 = \frac{(e_{k_1})_1 - (e_{k_1})_0}{P_{dcl}}, \tag{6-41}$$

where the subscript $_0$ denotes the zero correction value and the subscript $_1$ the measured value. The variable P_{dcl} is the dc power dissipated in the thermistor mount. Thus the ratio of e_B to k_1 includes a ratio of zero-corrected nanovoltmeter readings.

$$\frac{e_B}{k_1} = \frac{(e_B)_1 - (e_B)_0}{(e_{k_1})_1 - (e_{k_1})_0} P_{dcl} \, . \tag{6-42}$$

As will be explained in the next section, under these circumstances only the random part of the nanovoltmeter error contributes to the uncertainty.

Rather than using analytical differentiation, the uncertainty in g has been evaluated numerically. The contribution of each variable is determined by first calculating g with no change in the variable, and then again with the variable at its uncertainty limit, all other variables held constant. The difference between these two values of g gives the uncertainty due to the effect of that variable. This process is repeated for each variable, with the total uncertainty given by the sum of these individual contributions. As eq (6-25) shows, the relative uncertainty in η_e due to g is just the relative uncertainty in g.

Table 6.3 gives the uncertainty used for each variable along with the basis for the choice. The value shown is either the equivalent of one standard deviation of a normal distribution (as indicated by an SD) or the half-width limit of a rectangular distribution (as indicated by an R).

Table 6.3. Variable uncertainty values.

<table>
<tr><th>Uncertainty</th><th>Value</th><th>Basis</th></tr>
<tr><td>$|\Delta e_B|$</td><td>6 nV (SD)</td><td>Random error of two e measurements
(each is average of 18, see section 6.4)</td></tr>
<tr><td>$\left|\frac{\Delta k_1}{k_1}\right|$</td><td>0.01 (R)</td><td>Approximation $k_1 \approx k_B$ plus measurement error</td></tr>
<tr><td>$\left|\frac{\Delta P_{rf}}{P_{rf}}\right|$</td><td>0.01 (R)</td><td>Bolometric power measurement plus
power level instability</td></tr>
<tr><td>$\left|\frac{\Delta S_{21}}{S_{21}}\right|$</td><td>1 (SD)</td><td>Below 0.2 GHz ($|S_{21}|$ from fitted curve)</td></tr>
<tr><td>$|\Delta S_{21}|$</td><td>0.0076 dB
(SD)</td><td>For 0.3 through 1 GHz ($|S_{21}|$ from fitted curve)</td></tr>
<tr><td>$|\Delta S_{21}|$</td><td>Function of
frequency (SD)
(see figure 6.6)</td><td>Above 1 GHz: 6-port measurement uncertainty given by:
$u_{S21} = \sqrt{\Delta^2/3 + S_{NIST}^2 + S_c^2/6}$
where
$\Delta = 0.0006\sqrt{f} + 0.0011$
$S_{NIST} = 10^{-2.17 + 0.024 f}$
$S_c = 10^{-3.22 + 0.034 f}$</td></tr>
</table>

The contribution of the individual factors to the uncertainty in g as a function of frequency is shown in figure 6.6. The contribution from the level instability is identical to that of k_1. That the end points of the curves seem to meet is only coincidence. By far the largest uncertainty is from the 6-port measurement of the adapter loss. These components are combined as part of the expanded uncertainty as described in section 6.9.

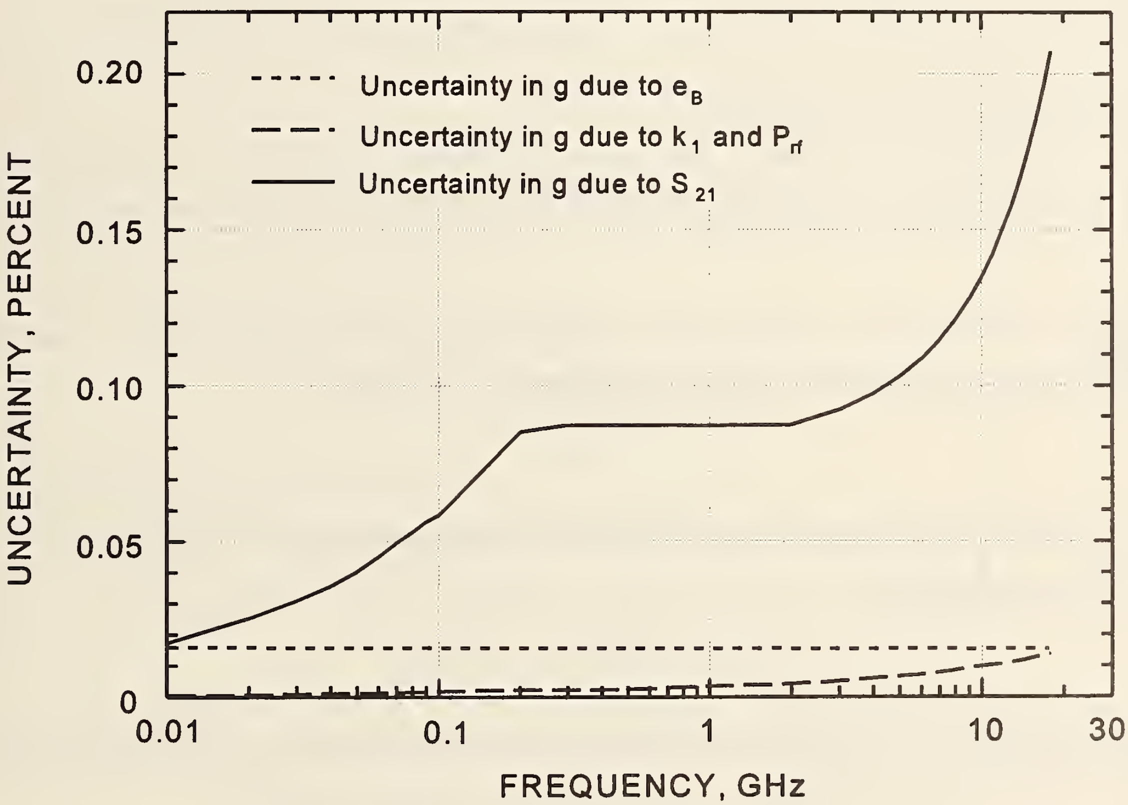


Figure 6.6 Contribution of each factor to the uncertainty in g.

6.4 UNCERTAINTY DUE TO VOLTAGE RATIOS

6.4.1 Power Meter Voltage Ratio

From section 6.1, the expression for F_V is

$$F_V = \frac{V_2}{V_1}. \tag{6-21}$$

The absolute value of the uncertainty in F_V is

$$|\Delta F_V| = \frac{V_2}{V_1^2}|\Delta V_1| + \frac{1}{V_1}|\Delta V_2|. \tag{6-43}$$

Because of mount drift, V_1 does not remain constant during the measurement, so V_1 is actually an interpolated value between two end point measurements. V_1 is given by

$$V_1 = V_{1i} + F(V_{1f} - V_{1i}), \tag{6-44}$$

where V_{1i} and V_{1f} are the initial and final values of the V_1 measurements and F is a fraction between 0 and 1. The uncertainty in V_1 is

$$|\Delta V_1| = (1-F)|\Delta V_{1i}| + F|\Delta V_{1f}|. \tag{6-45}$$

If both the initial and final values are measured on the same range, $|\Delta V_{1i}| \approx |\Delta V_{1f}|$. Then by eq (6-45), $|\Delta V_1| \approx |\Delta V_{1i}|$, so the uncertainty in V_1 is the same as for a single measurement.

For both the power meter voltages (V), and the nanovoltmeter readings (e), the desired quantity is a ratio. The error in a voltmeter reading is generally specified as a percent of reading factor (alpha) plus a percent of full scale (beta). The alpha factor comes from the error of the internal reference, while the beta factor is due to random and zero correction errors and nonlinearity. In a ratio measurement, if the two voltages are measured on the same scale, the alpha factor can be neglected. In addition, if the zero drift is explicitly corrected (as in the f_e case), the only contribution to the uncertainty is from the random part of the beta factor.

A calculation of the uncertainty in η_e due to ΔF_V, which is a function of η_e and P_{rf}, can be made using eqs (6-25) and (6-43). If the voltmeter manufacturer's one-year beta specification is used, the result is a value well under 0.001 percent for all reasonable values of η_e.

6.4.2 Thermopile Voltage Ratio

The expression for f_e is

$$f_e = \frac{e_2}{e_1}\frac{1}{c_n}. \tag{6-22}$$

In measuring f_e, a correction for the zero offset must be made. This involves measuring e_0 before measuring the dc bias term e_1 or the dc-plus-rf term e_2. When we take e_0 into consideration, eq (6.1.22) becomes

$$f_e = \frac{1}{c_n}\frac{e_2 - e_0}{e_1 - e_0}. \tag{6-46}$$

The absolute uncertainty in f_e is given by

$$|\Delta f_e| = \frac{e_2 - e_1}{c_n(e_1 - e_0)^2}|\Delta e_0| + \frac{e_2 - e_0}{c_n(e_1 - e_0)^2}|\Delta e_1| + \frac{1}{c_n(e_1 - e_0)}|\Delta e_2| + \frac{e_2 - e_0}{c_n^2(e_1 - e_0)}|\Delta c_n|. \tag{6-47}$$

Like V_1, e_1 is obtained by linear interpolation, so the uncertainty Δe_1 is also that of a single measurement.

The calculation of the uncertainty in η_e due to Δf_e is based on the applicable parts of eq (6-25) and eq (6-47). To determine the error in f_e it is necessary to know the random error in the nanovoltmeter measurement. This random error beta factor is determined by making repeated measurements on the actual setup and thus includes the effects of variations in the dc bias as supplied by the power meter, in the microwave power leveling, in the external temperature, and in the room air pressure. These measurements were made under three conditions: with no dc bias, with dc bias, and with dc bias plus rf at 18 GHz. The largest standard deviation seen was 3.65 nV for the dc-plus-rf case, and that result is shown in figure 6.7. The three-sigma limit is therefore about ± 11 nV.

In the actual efficiency measurement routine, each data point is the average of 18 separate measurements, so the value for Δf_e can be further decreased as a result of the averaging. This reduces the three-sigma limit by a factor of $1/\sqrt{18}$ to approximately ± 3 nV. Using a value of ± 3 nV for Δe_0 and Δe_1 in eq (6-47) and then using that result in eq (6-25) gives the uncertainty in η_e due to Δf_e shown in figure 6.8. The uncertainty is a function η_e and P_{rf} but not of frequency. The maximum is about 0.016 percent when η_e is 1. That value is used as the thermopile voltage ratio uncertainty.

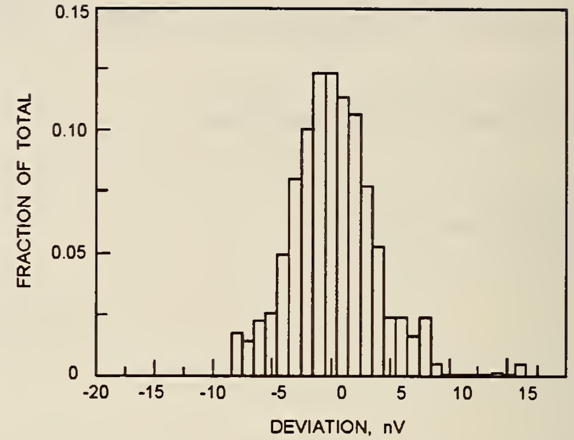


Figure 6.7. Histogram of the variation in 1000 nanovoltmeter readings. The average is 115.916 μV with a standard deviation of 3.65 nV.

An additional factor that may add to Δf_e is the uncertainty in knowing when the thermopile has reached equilibrium. This is a critical element in the measurement. A software algorithm determines when equilibrium has been reached at each measurement frequency. The algorithm is described in appendix C. It has been tested by letting the measurement continue for several minutes beyond the point the algorithm indicates stability has been reached and noting that the result essentially does not change. While it has not been possible to detect any systematic uncertainty in the process, there is a random component and that is included in the random uncertainty number.

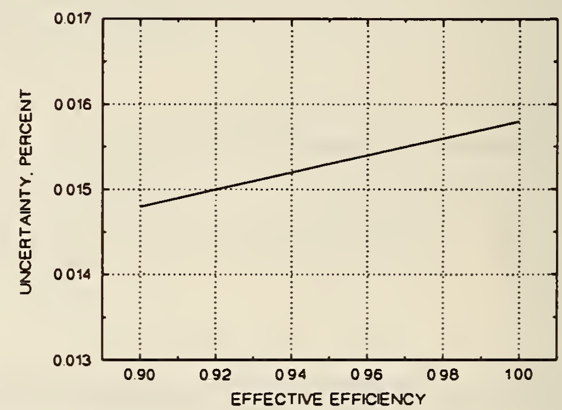


Figure 6.8. Uncertainty in η_e due to the thermopile voltage ratio uncertainty as a function of η_e.

6.4.3 Thermopile and Nanovoltmeter Nonlinearity

The linearity correction factor c_n has been determined from a series of measurements on the Type N microcalorimeter using a mount with a resistor in place of the thermistor beads. Figure 6.9 shows the measured k as a function of the thermopile output e. Note that these results include the effect of both thermopile and nanovoltmeter nonlinearity.

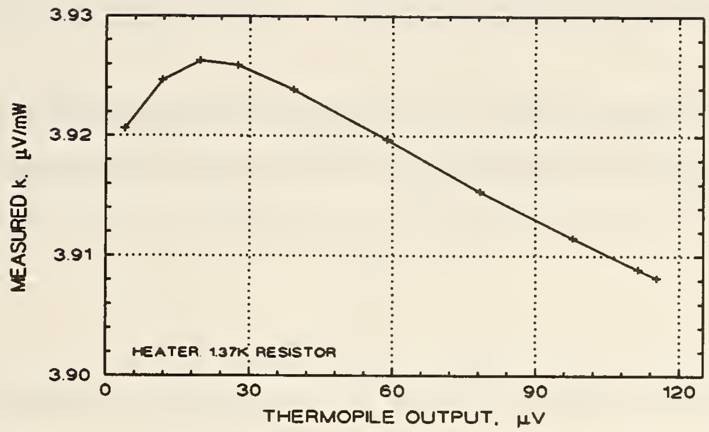


Figure 6.9. k factor vs thermopile output.

From equation (6-15),

$$k_2 = k_1 c_n. \tag{6-48}$$

k_2 can also be expressed as

$$k_2 = k_1 + \Delta k. \tag{6-49}$$

If S is the slope of the curve (from 30 μV and above) in figure 6.9,

$$\Delta k \approx S\,(e_2 - e_1). \tag{6-50}$$

Then

$$k_2 \approx k_1 \left(1 + \frac{S}{k_1}(e_2 - e_1) \right), \tag{6-51}$$

so

$$c_n \approx 1 + \frac{S}{k_1}(e_2 - e_1). \tag{6-52}$$

Based on experimental evidence ($e_2 - e_1 \leq 5$ μV and $k_1 \approx 3.90$) and figure 6.9 ($S \approx -0.00016$), c_n could vary between 1 and 0.9998. Thus the maximum correction would be on the order of 0.02 percent. Rather than make a correction, we will assume $c_n = 1$ and include the 0.02 percent as a Type B uncertainty.

6.5 MOUNT MICROWAVE POWER LEAKAGE

Microwave power leakage from the mount essentially reduces the effective efficiency because the leakage energy is not detected by the mount thermistor beads. The expression for effective efficiency is

$$\eta_e = \frac{P_b}{P_{rf}}, \tag{6-18}$$

where P_b is the dc bolometric power, and P_{rf} is the net rf power delivered to the mount. Since P_{rf} is the total power dissipated in the mount plus any microwave power leakage, η_e includes the effect of leakage. However the microcalorimeter measures only the effect of the total power dissipated in the mount because the thermopile does not sense the leakage power. Thus the microcalorimeter measurement of η_e is in error if there is any leakage. To account for leakage, let the measured η_e be denoted by η_{eL}. It is given by

$$\eta_{eL} = \frac{P_b}{P_{rf} - P_L}, \tag{6-53}$$

where P_L is the leakage power. Factoring out P_{rf} gives

$$\eta_{eL} = \frac{P_b}{P_{rf}\left(1 - \frac{P_L}{P_{rf}}\right)}. \tag{6-54}$$

Substituting from eq (6-18) and solving for η_e gives

$$\eta_e = \eta_{eL}\left(1 - \frac{P_L}{P_{rf}}\right), \tag{6-55}$$

so the error in η_e due to P_L is P_L/P_{rf}. The ratio P_L/P_{rf} for the prototype mount was measured as described in section 2.4.1. with the result shown in figure 2.3. The ratio is less than −40 dB from 5 MHz through 18 GHz. Thus the error is less than 0.0001 or 0.01 percent over that range.

6.6 BOLOMETER LEAD RESISTANCE

Lead resistance that is beyond the four-wire connection to the mount (in the form of any final short leads to the thermistor beads) does not cause an error in the measurement of efficiency, but does cause an error when the transfer standard is used to measure power. To determine the effect let r_L be the lead resistance. Then

$$R_0' = R_0 - r_L = R_0\left(1 - \frac{r_L}{R_0}\right), \tag{6-56}$$

and

$$V' = V\left(1 - \frac{r_L}{R_0}\right). \tag{6-57}$$

V' is the actual voltage across the beads, V is the power meter voltage (known), R_0' is the actual bead resistance, and R_0 is the resistance (known) being maintained by the power meter.

For the efficiency measurement the ratio of V_1' to V_2' is desired. In terms of V_1 and V_2 this is given by

$$\frac{V_1'}{V_2'} = \frac{V_1\left(1 - \frac{r_L}{R_0}\right)}{V_2\left(1 - \frac{r_L}{R_0}\right)} \tag{6-58}$$

which reduces to

$$\frac{V_1'}{V_2'} = \frac{V_1}{V_2} \tag{6-59}$$

and there is no error.

For the power measurement the desired expression is

$$P_b = \frac{1}{R_0'}\left(V_1'^2 - V_2'^2\right). \tag{6-60}$$

In terms of V_1 and V_2,

$$P_b = \frac{1}{R_0}\left(V_1^2 - V_2^2\right)\left(1 - \frac{r_L}{R_0}\right). \tag{6-61}$$

The measurement is in error by the factor $1 - r_L / R_0$. Values of r_L for a commercial mount have been measured as high as 400 mΩ (including connector contact resistance because the four leads are not brought through the connector), giving an uncertainty in the power measurement of about 0.2 percent. For the transfer standard, the residual lead resistance beyond the four-wire connection has not been measured, but is estimated as less than 10 mΩ. The error is less than 0.005 percent.

6.7 TYPE IV POWER METER ERRORS

The uncertainty due to the measurement of V_1 and V_2 was addressed in section 6.4. The additional uncertainty due to limitations of the operational amplifiers and reference resistor within the Type IV power meter is also very small. The uncertainty is under 0.001 percent and will be neglected.

6.8 RANDOM EFFECTS

The Type A evaluation of standard uncertainty for the measurement process reported in this document is based on repeated measurements of a single reference standard which will continue to be used as a check standard. Ideally, standard uncertainty for the bolometer mounts should be determined through repeat measurements for each individual mount. However, this is impractical due to the time required for a complete set of measurements. Therefore, we will assume that the standard uncertainty inherent in all mounts behaves in basically the same fashion so that the standard uncertainty we derive for the check standard mount will apply to the population of mounts as well. Although the actual measurements for the check standard mount are quite repeatable, the observed standard deviations are different for each frequency. Thus, a single value of standard uncertainty which is valid for all frequencies was calculated based on a "worst" case standard deviation.

The standard uncertainty, determined through Type A evaluation, in the measured effective efficiency for customer mounts at any individual frequency is 0.00014, which is the worst case (among frequencies) computed standard deviation based on ten degrees of freedom.

The Type A evaluation of standard uncertainty for the measured effective efficiency for the check standard mount CN05 at any individual frequency is 0.000041, which is the worst case (among frequencies) computed standard error of the mean effective efficiency, $0.00014/\sqrt{11}$ based on ten degrees of freedom.

6.9 COMBINED STANDARD AND EXPANDED UNCERTAINTY

Table 6.4 is a summary of the results at 18 GHz for all the uncertainty evaluations described earlier. The section describing the uncertainty is listed in the table. Definitions for the variables and terms used are found in reference [13]. The expanded uncertainty value is for a customer standard.

Table 6.4. Value of uncertainty components in percent at 18 GHz.

Uncertainty factor (evaluation type)		Section reference	Half-width interval (a)	Distribution	Conversion formula	Standard uncertainty
Adapter loss meas.	(B)	6.3	0.207	Normal	$u_j = a$	0.207
Nanovoltmeter, e_B	(A)	6.3	-	Normal	-	0.015
k_1	(B)	6.3	0.014	Rectangular	$u_j = a/\sqrt{3}$	8.1×10^{-3}
Power leveling & meas.	(B)	6.3	0.014	Rectangular	$u_j = a/\sqrt{3}$	8.1×10^{-3}
V ratio, F_V	(B)	6.4.1	0.001	Rectangular	$u_j = a/\sqrt{3}$	5.8×10^{-4}
e ratio, f_e	(A)	6.4.2	-	Normal	-	0.016
Linearity, c_n	(B)	6.4.3	0.02	Rectangular	$u_j = a/\sqrt{3}$	0.012
Mount leakage	(B)	6.5	0.01	Rectangular	$u_j = a/\sqrt{3}$	5.8×10^{-3}
Lead resistance	(B)	6.6	0.005	Rectangular	$u_j = a/\sqrt{3}$	2.9×10^{-3}
Type IV power meter	(B)	6.7	0.001	Rectangular	$u_j = a/\sqrt{3}$	5.8×10^{-4}
Random effects	(A)	6.8	-	Normal	-	0.014
Combined standard uncertainty (RSS)						0.209
Expanded uncertainty ($k = 2$)						0.419

The first factor on the list is the largest, and because of the RSS combination, dominates the combined uncertainty. It is also the only uncertainty that is a strong function of frequency.

Figure 6.10 shows the expanded uncertainty as a function of frequency. It also shows a fitted curve with the equation that is the operational expression for the expanded uncertainty. The uncertainty at any frequency is calculated using the equation. The higher value it gives in the range 50 to 200 MHz is intentional and accounts for low frequency dissipation in the mount that occurs in the low pass filter behind

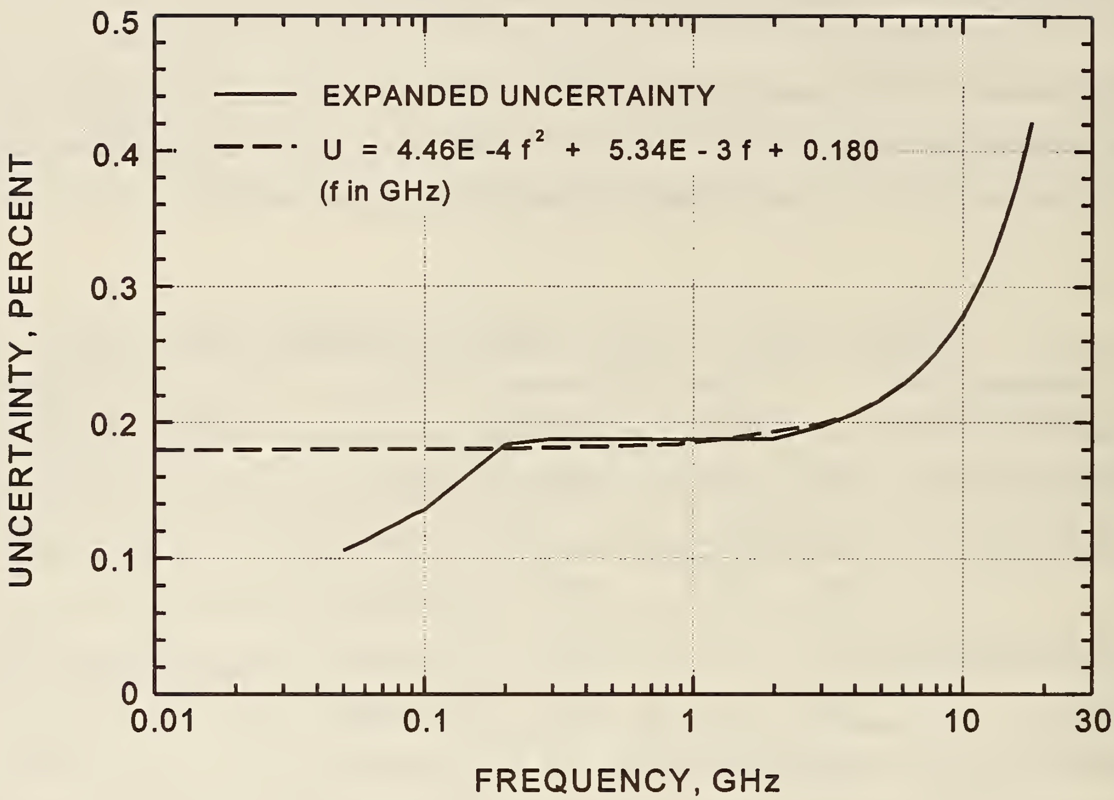


Figure 6.10 The expanded uncertainty ($k = 2$) for the Type N coaxial microcalorimeter when measuring the effective efficiency of a NIST CN coaxial transfer standard.

the thermistor beads. This process has become apparent in using and comparing the CN mount with other transfer standards, but we have not been able to come up with any way evaluate it directly.

A sample Report of Calibration is found in appendix E.

7. MEASUREMENT ASSURANCE

One of the most important aspects of maintaining the coaxial microcalorimeter system is measurement assurance. Since individual mounts cannot be measured repeatedly, it becomes even more important to ensure that the system is behaving as it should. Several techniques are currently being employed to monitor the system and assure measurement quality.

To monitor the long-term behavior of the microcalorimeter system, a check standard mount is measured on a regular basis at all 125 frequencies. Each new set of measurements is compared to the historical data to determine if the system is performing as expected. Figure 7.1 summarizes the behavior of the latest observation in relation to past data. The solid dots in Figure 7.1 represent the latest observation, the diamonds denote historical data, and three standard deviation limits are indicated by a solid, vertical line at each frequency.

A second chart is used to monitor system variability at each frequency through the use of moving ranges. A moving range is defined to be the absolute value of the difference between the two most recent observations. Figure 7.2 displays the moving range, indicated by a dot, and the associated control limits based on moving ranges for the historical data, represented by a solid vertical line. If the computed moving range for the latest observation is higher than the control limit, then the process variability is greater than the acceptable amount determined by the historical data, and the cause of the increased variability should be investigated. Figures 7.1 and 7.2 indicate that the system is behaving in a reasonable fashion relative to the historical data.

Although the control charts allow us to examine the behavior of new data in comparison to past data, other methods must be used to monitor the system over time. It is impractical to generate separate control charts to monitor all 125 frequencies; however, control charts for five check frequencies are used as an additional tool for signaling potential problems, such as drift [14]. An example of the type of control charts used to monitor a check frequency is shown in figure 7.3. The top chart, called an individuals chart, monitors the nominal effective efficiency, while the bottom chart, the moving range chart, monitors variability. Although it is possible to interpret patterns in the individuals control chart, patterns observed in the moving range chart are meaningless because adjacent points are related [15]. The variability observed in the moving range chart of figure 7.3 does not exceed the upper control limit, and the newest observation on the individuals chart lies within the control limits and does not reveal any patterns or drift, so we can conclude that the effective efficiency at a frequency of 0.1 GHz is "in control."

The five check frequencies are also used to determine the quality of mount connection before each measurement occasion using the following procedure. After each bolometer mount is connected to the coaxial calibration system, the five check frequencies are measured and the mount is disconnected. Then the same mount is reconnected to the system and the same five check frequencies are measured again. If the difference between the first and second set of measurements is small, then all 125 frequencies are measured before the mount is disconnected a second time, otherwise, the mount is disconnected, and the procedure is repeated until it can be determined that the connection is "good." The measurement assurance tools used to monitor this calibration system are quite extensive and provide confidence that the system is functioning properly.

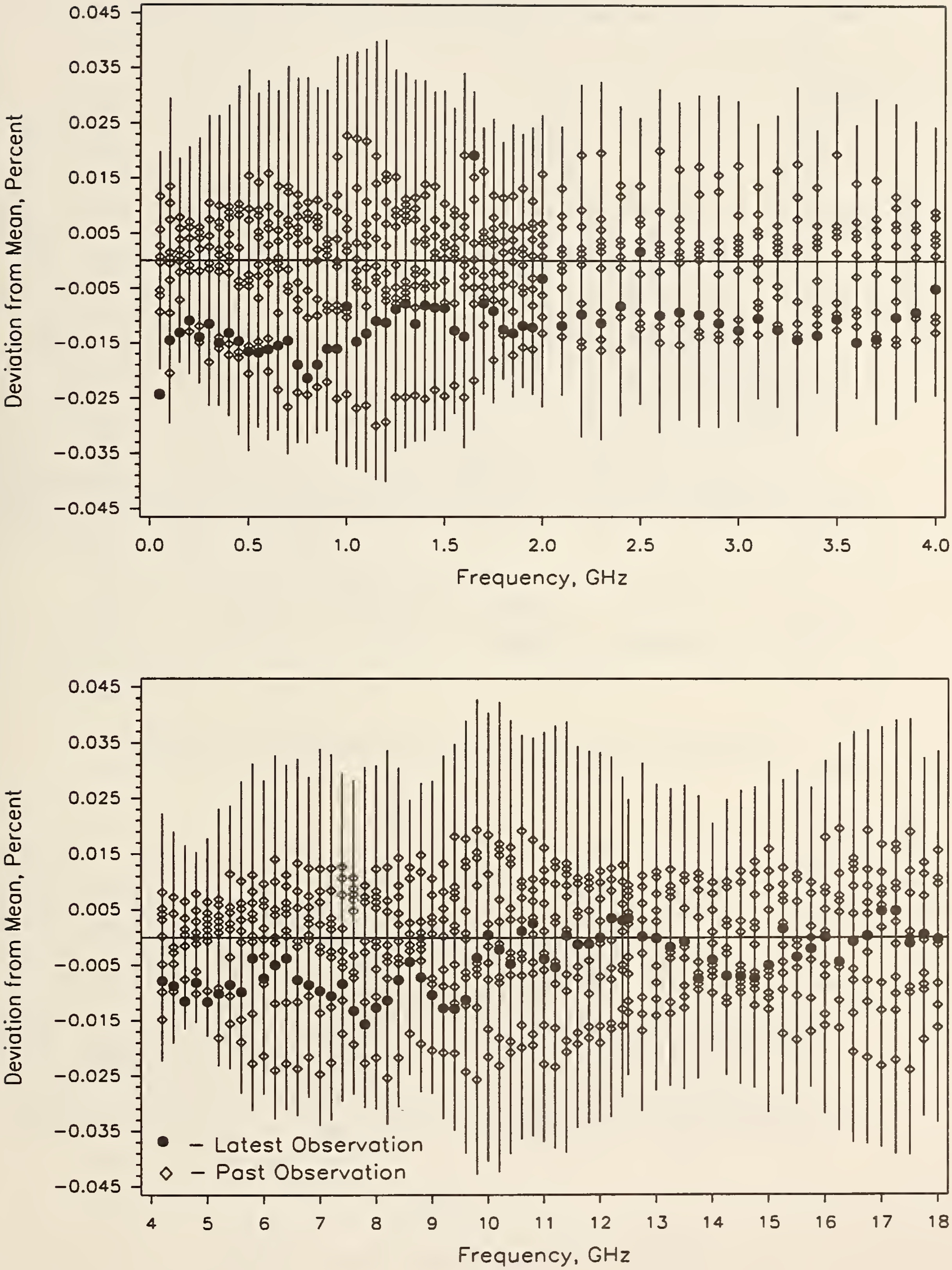


Figure 7.1. Three standard deviation limits for CN05.

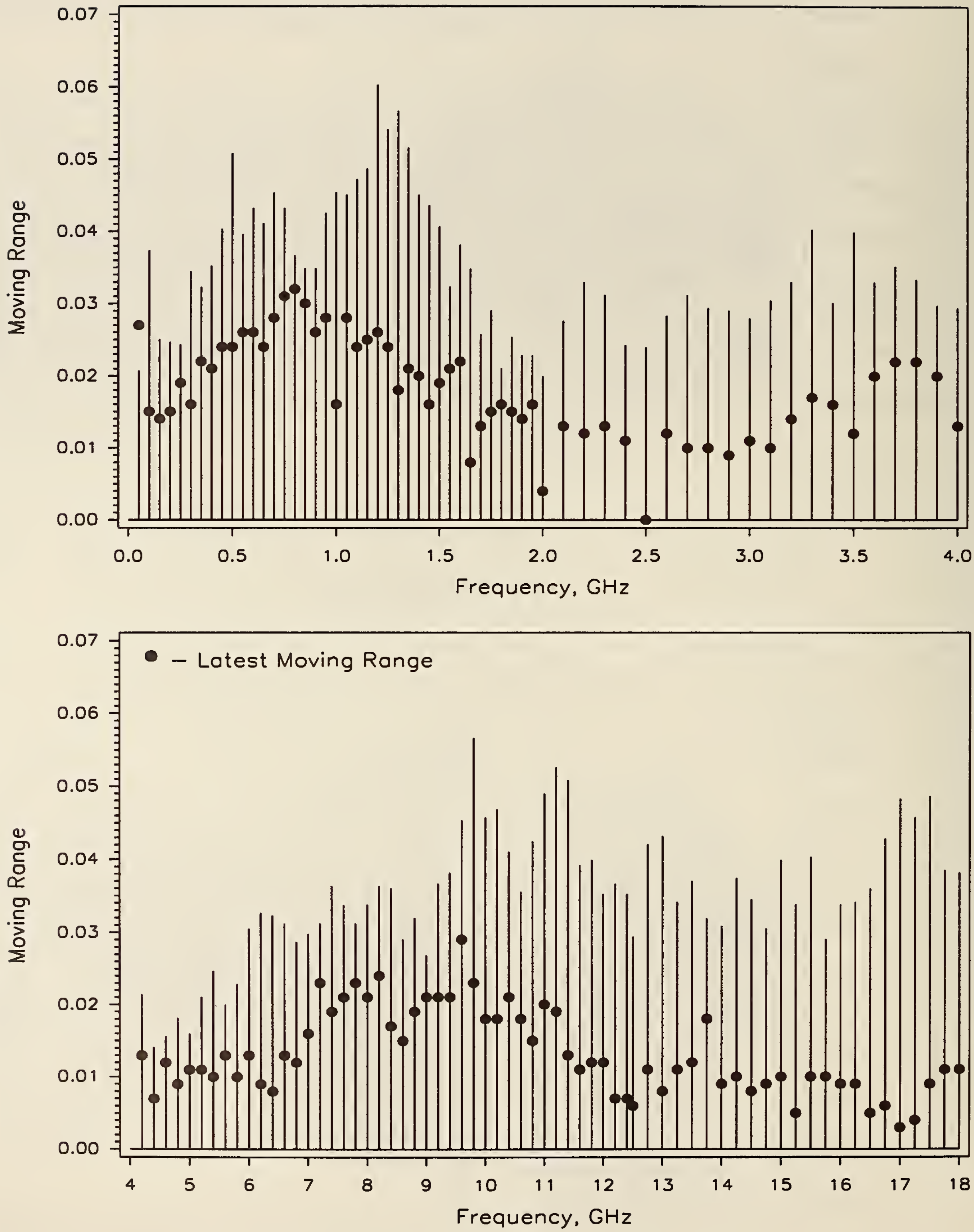


Figure 7.2. Moving range control chart for CN05.

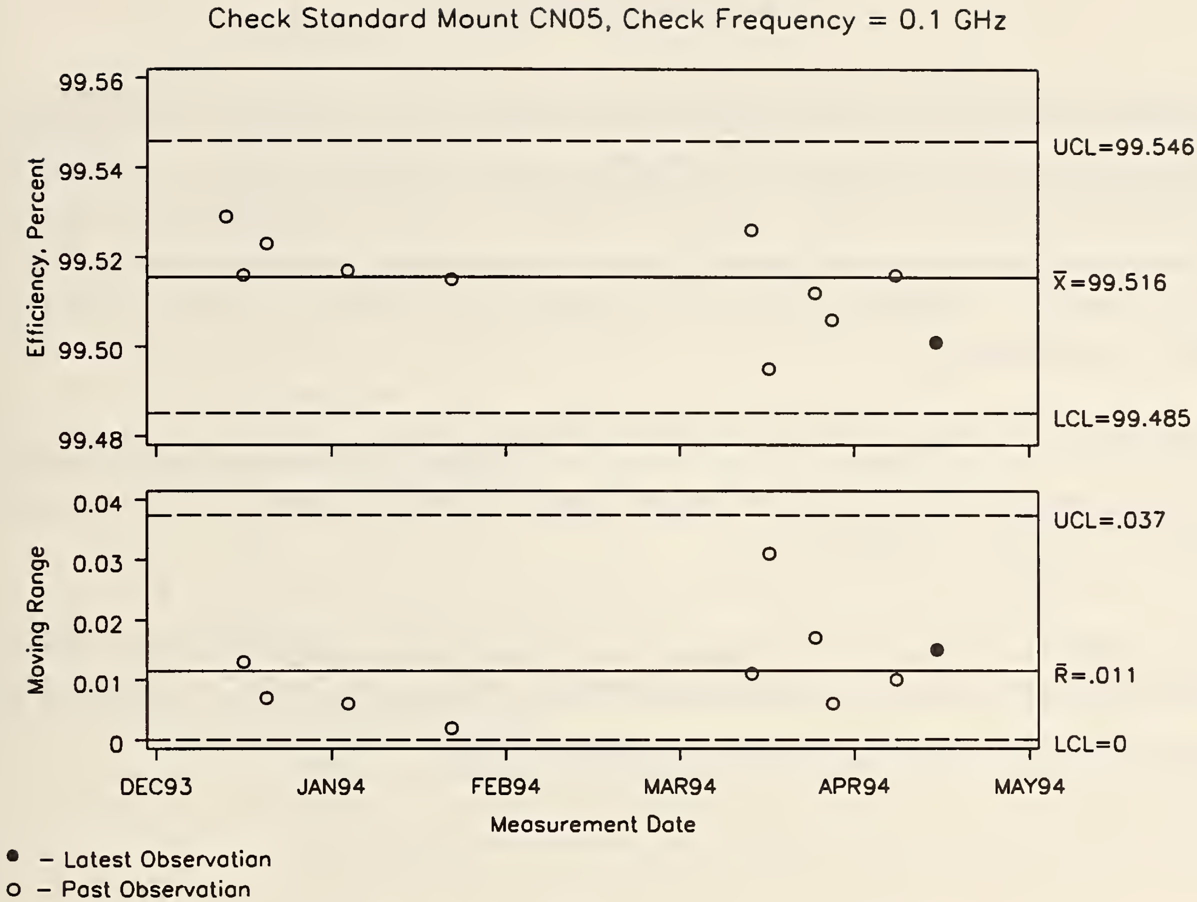


Figure 7.3. Control chart for the first of the five check frequencies.

8. FUTURE CHANGES

Inevitably, in the future the calibration system will not remain exactly as described in this document. Software will be modified or even completely rewritten to improve operating efficiency or implement new measurement requirements. Hardware changes will range from the simple replacement of an obsolete or defective microwave source to a completely new way of determining the temperature change of the reference standard. Additional uncertainty or measurement assurance factors may become apparent and will have to be addressed.

The majority of the modifications will be minor. The changes will be noted and kept in an active documentation file on the system. While the details may no longer be completely accurate, this report should still adequately describe the service.

Major changes, such as a new reference standard, a new microcalorimeter design, significantly different operating procedures, large changes in uncertainty (to say one-half the present value), or changes in the frequency range, may require the preparation of a new document.

If up-to-date information is critical, contact NIST for the current documentation.

9. ACKNOWLEDGEMENTS

The designs of both the coax reference standard and the coax microcalorimeter are based on the early work and ideas of Morris E. Harvey. Thanks also to Mr. Harvey for the review of his work plus his suggestions at the beginning of this project. The author is particularly indebted to Neil T. Larsen for his support, suggestions, and many helpful discussions. Special thanks to Dominic F. Veccia and Jolene D. Splett for help with the statistical analysis and experimental design contained in sections 6.8, 7, and appendix C, to Robert M. Judish for help with the uncertainty analysis and helpful comments on section 6, and also to Manly P. Weidman for his helpful suggestions on section 6.

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APPENDIX A. Measured Adapter Loss

Chapter 6 describes the determination of the calorimetric equivalence correction factor g for the microcalorimeter. The procedure uses a special type N male-to male adapter (made in the same way and of the same material as the reference standard bolometer mount) that connects two thermopile assemblies. The analysis requires a knowledge of the adapter loss (which is small). This appendix derives an expression for the loss in terms of the measurable S parameters.

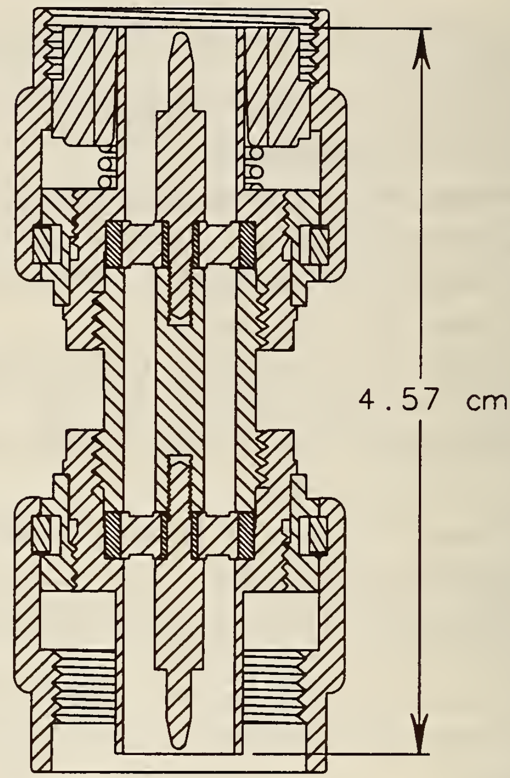

Figure A.1. Adapter cross section.

The adapter is gold plated with an electroformed copper outer conductor and a beryllium copper inner conductor supported by a pair of dielectric beads. Figure A.1 is a cross section view of the adapter. The connector on the bottom is a type N male while the top connector is a type N male modified to allow mating with the APC-7 connector on the top thermopile (see figure 6.2).

The desired result is the ratio of the total power dissipated in the adapter to the net power entering the adapter. The adapter is a 2-port junction as shown in figure A.2. The input incident and reflected powers at port 1 are P_{i1} and P_{r1}, the output incident and reflected powers at port 2 are P_{i2} and P_{r2}. The net input power P_1 at port 1 is

$$P_1 = P_{i1} - P_{r1}, \tag{A-1}$$

and the net output power P_2 at port 2 is

$$P_2 = P_{i2} - P_{r2}. \tag{A-2}$$

The total power, P_D, dissipated in the adapter is given by the change in the incident power plus the change in the reflected power

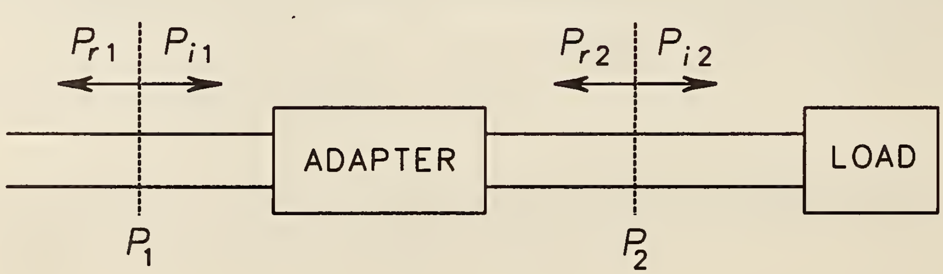

Figure A.2. The adapter as a 2-port junction.

$$P_D = (P_{i1} - P_{i2}) + (P_{r2} - P_{r1}). \tag{A-3}$$

Rearranging terms gives

$$P_D = (P_{i1} - P_{r1}) - (P_{i2} - P_{r2}), \tag{A-4}$$

which by eqs (A-1) and (A-2) is just the difference $P_1 - P_2$ in the net powers.
The desired fractional loss then is given by

$$\frac{P_D}{P_1} = \frac{P_1 - P_2}{P_1} = 1 - \frac{P_2}{P_1}. \tag{A-5}$$

The ratio of P_2 to P_1 is defined as the efficiency $_1\eta$ of the junction when energy is fed into port 1. Assuming unit normalization, it is given by reference [A1]

$$\eta_1 = \frac{|S_{21}|^2 (1 - |\Gamma_L|^2)}{|1 - S_{22}\Gamma_L|^2 - |(S_{12}S_{21} - S_{11}S_{22})\Gamma_L + S_{11}|^2}. \tag{A-6}$$

The S parameters are those of the adapter, and Γ_L is the reflection coefficient of the terminating load. If both Γ_L and S_{11} are sufficiently small, η_1 reduces to

$$\eta_1 \approx |S_{21}|^2, \tag{A-7}$$

and eq (A-5) becomes simply

$$\frac{P_D}{P_1} \approx 1 - |S_{21}|^2. \tag{A-8}$$

The S parameters of the adapter and Γ_L of the terminating load were measured using the NIST 6-port network analyzer, and the efficiency calculated. The result is shown in figure A.3. The curve labeled "exact" was obtained using eq (A-6) and the curve labeled "approximate" using eq (A-7). The differences are small, with the largest at 7 and 18 GHz. A change of just 2° in the phase of Γ_L (using eq (A-6)) eliminates the difference at either frequency. Because the amplitude of Γ_L is small, the uncertainty in the phase measurement is 20°. The "approximate" values are adequate in this case, and eq (A-8) is used as the expression for the adapter loss.

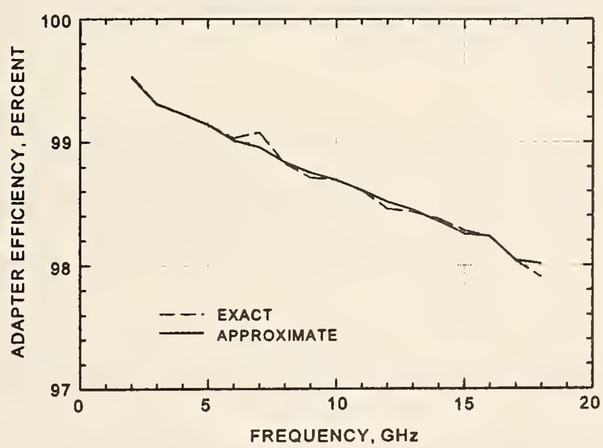

Figure A.3. Adapter efficiency.

References

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APPENDIX B. Theoretical Adapter Loss

Appendix A derives an expression for the loss of a special type N male-to-male adapter used in the determination of a correction factor g for the microcalorimeter. The result is in terms of measurable S parameters. The accuracy with which a small loss can be measured is limited at best, so additional support for the measurement in the form of a calculated result is useful.

The adapter is gold plated with an electroformed copper outer conductor and a beryllium copper inner conductor supported by a pair of dielectric beads. A cross sectional view of the adapter is shown in appendix A as figure A.1.

Calculation of the conductor loss for a plated coaxial transmission line is based on theory found in reference [B1]. Table 8.09 in the reference gives the attenuation due to the conductor as

$$\alpha_C = \frac{R}{2\,Z_0}, \tag{B-1}$$

where R is the conductor resistance and Z_0 is the transmission line characteristic impedance. R can be written in terms of the skin effect surface resistivity R_S as

$$R = \frac{R_S}{2\,\pi}\left(\frac{1}{a} + \frac{1}{b}\right). \tag{B-2}$$

The radius of the inner conductor is a and the inner radius of the outer conductor is b. The surface resistivity is given by

$$R_S = \frac{1}{\sigma\,\delta}, \tag{B-3}$$

where σ is the conductivity of the conductor and δ is the skin depth. The skin depth is

$$\delta = \frac{1}{\sqrt{\pi f \mu\,\sigma}}, \tag{B-4}$$

where f is the frequency and μ is the conductor permeability.

The conductors, being gold plated, are actually made up of two layers. Layer 1 is gold and layer 2 is beryllium copper for the inner conductor and copper for the outer conductor. Using the results found in section 5.19 of reference [B1] for two-layer conductors, the expression for the equivalent surface resistivity R_S of the combination for either the inner or outer conductor is

$$R_S = \Re\left(R_{S1}(1 + j)\left[\frac{\sinh \tau_1 d + (R_{S2}/R_{S1})\cosh \tau_1 d}{\cosh \tau_1 d + (R_{S2}/R_{S1})\sinh \tau_1 d}\right]\right). \tag{B-5}$$

The subscripts 1 and 2 refer to the layers, d is the thickness of layer 1,

$$\tau_1 = \frac{(1+j)}{\delta_1} = (1+j)\sqrt{\pi f \mu_1 \sigma_1}, \qquad \text{(B-6)}$$

$$R_{S1} = \sqrt{\frac{\pi f \mu_1}{\sigma_1}}, \qquad \text{(B-7)}$$

and

$$R_{S2} = \sqrt{\frac{\pi f \mu_2}{\sigma_2}}. \qquad \text{(B-8)}$$

Finally then, the total coaxial line conductor loss A_C (in dB) is

$$A_C = 20 \ln \frac{L}{4 \pi Z_0}\left(\frac{R_{Si}}{a} + \frac{R_{So}}{b}\right), \qquad \text{(B-9)}$$

where L is the total line length, and R_{Si} and R_{So} are the results of applying eq (B-5) to the inner and outer conductors, respectively.

The loss due to joints at the connector and at the center conductor support beads is calculated using the experimental results found in reference [B2]. (Loss in the dielectric of the center conductor support bead is not included.) A general expression for the joint loss in dB is

$$A_J = A_0 + B f^E, \qquad \text{(B-10)}$$

where f is the frequency in GHz, A_0 and B are small experimentally determined constants (≈ 0.01), and E is a constant with a value between 0.5 and 1. The work reported in reference [B2] gives A_0 a value of 0, B a value of 0.0088 for the type N joint and 0.0047 for a center conductor support bead joint, and E as 0.5 in both cases. Another investigator has found A_0 to be approximately 0.005, C approximately 0.007, and E very likely somewhat larger than 0.5.

Figure B.1 shows the calculated curves for the conductor (A_C), joint (A_J), and total adapter loss as a function of frequency. Table B.1 gives the values chosen for the different parameters used in the calculations.

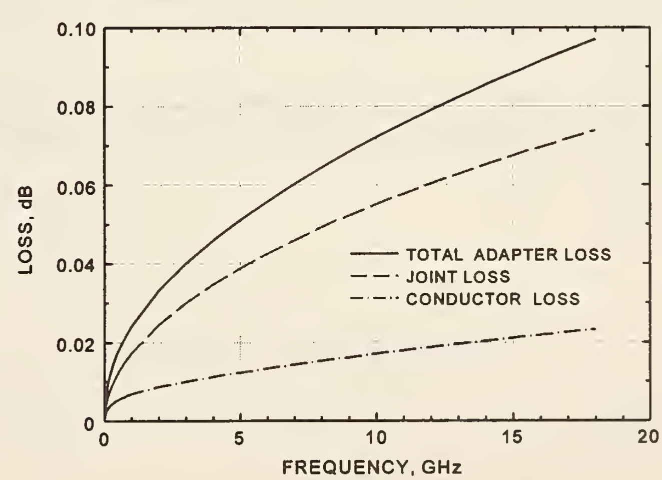

Figure B.1. Calculated adapter loss.

Table B.1. Values used in calculating adapter loss.

Fixed for all calculations:					
Parameter	Line length L cm	Layer 1 (Au) permeability μ_1 H/m	Layer 2 (Cu) permeability μ_2 H/m	Inner cond. radius a cm	Outer cond. radius b cm
Values	4.57	$4\pi \times 10^{-7}$	$4\pi \times 10^{-7}$	0.1521	0.3500

Changed in different calculations:						
				Joint loss factors		
Parameter	Layer 1 (Au) thickness d μm	Layer 1 (Au) conductivity σ_1 S/m	Layer 2 (Cu) conductivity σ_2 S/m	A_0	B dB/(GHz)^E	E
Inner conductor loss calculation	1.27	4.61×10^7	8.00×10^6	–	–	–
Outer conductor loss calculation	1.27	4.61×10^7	5.75×10^7	–	–	–
Type N joint loss calculation	–	–	–	0	0.008	0.5
Bead joint loss calculation	–	–	–	0	0.0047	0.5

REFERENCES

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APPENDIX C. Thermopile Stability Testing

This appendix describes statistical methods and algorithms for detecting "stable" periods in thermopile voltages as they evolve in time. The statistical methods that have been used essentially search for two types of instability: nonrandomness and trend. None of the statistical methods makes assumptions about the particular distributional properties of the data. Since they are not linked to variability, the methods should not have the shortcomings of variance-based criteria that cannot be successfully tuned to handle unpredictable changes in variability that may occur in the system. The methods that have been implemented are discussed briefly below.

RUNS TEST

A sequence of voltage readings $\{v_1, v_2, \ldots, v_n\}$ may be analyzed for randomness by considering the magnitude of each element relative to that of the immediately preceding element in the time sequence. If the next element is larger, a run up is started; if smaller, a run down. We observe when the sequence increases, and for how long, when it decreases, and for how long. A decision concerning randomness is then based on the number of runs, R. Long runs, leading to a small value of R, should not occur in a set of stable, random voltage readings. A runs analysis should be sensitive to either trends or other low frequency periodicities in the data.

The runs test calculation is a simple function of the difference sequence $d_j = v_{j+1} - v_j$, for $j = 1, \ldots, n - 1$. Under the assumption of randomness, the expected number of runs, μ_R, and the standard deviation, σ_R, of the number of runs for a sequence of length n are

$$\mu_R = \frac{2n - 1}{3}, \tag{C-1}$$

$$\sigma_R = \sqrt{\frac{16n - 29}{90}}. \tag{C-2}$$

If, for a given sequence of readings, R denotes the observed number of runs, the quantity

$$Z_R = \frac{R - \mu_R}{\sigma_R} \tag{C-3}$$

is used to test for nonrandomness. If the acceptable number of stable readings is n, then the value Z_R is calculated sequentially after each new voltage reading starting with the nth value obtained after a change of frequency. Successive values of Z_R each are based on the preceding n readings, ending with the latest value. A threshold (or critical value) of Z_R, denoted by R_{CV}, determines if Z_R passes the test for stability based on the runs analysis. The criterion for RUNS stability is that $Z_R \geq R_{CV}$ be satisfied. The particular value R_{CV} may be chosen to provide any desired sensitivity to detecting excessively long runs. Currently, the value $R_{CV} = -2.5$ is being used.

KENDALL'S TEST FOR TREND

The following test is useful to detect a particular type of nonrandomness: namely, a monotonic trend in the sequence $\{v_1, v_2, ..., v_n\}$. The procedure is complementary to the runs test. It seems to be more sensitive to the types of voltage drifts seen in the system, probably because it considers the relative magnitude of each voltage reading relative to every preceding measurement.

Kendall's test is derived from

$$\tau = \frac{S}{\sqrt{D n (n - 1)/2}}, \tag{C-4}$$

where

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\ (v_j - v_i), \tag{C-5}$$

$$D = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} [sign\ (v_j - v_i)]^2, \tag{C-6}$$

and ***sign(d)*** is simply the sign of the voltage difference, or 0 if $v_i = v_j$. The value of τ is a measure of association between the voltage sequence and "time," and hence is indicative of trend. Its interpretation is similar to the usual correlation coefficient, for instance, it takes values between -1 and 1.

To use Kendell's test for trend, we compute the test statistic

$$Z_S = \frac{S}{\sqrt{Var(S)}}, \tag{C-7}$$

where

$$Var(S) = [n(n-1)(2n+5) - T_v] / 18, \tag{C-8}$$

and $T_v = 0$ if there are no common voltages (i.e., ties) in the data sequence. Otherwise, T_v is computed by sorting the sequence and computing the multiplicity of each group of tied values. Then,

$$T_v = \sum t(t-1)(2t+5), \tag{C-9}$$

where the summation is over the number of sets of tied values. For a given set, t is the corresponding number of tied values ($t \geq 2$).

The software computes a probability (p) associated with Z_S, where a small value (say $p < 0.25$) would show an increasing trend and a large value (say $p > 0.75$) shows a significant decreasing trend. The particular values used to compare to p are arbitrary tuning constants that have been set by experience with the algorithm on the system. As the algorithm is refined and tested, the particular values of the tuning constants may be revised. Currently, the TREND criterion for accepting a sequence of n voltage readings as stable is that $0.25 < p < 0.75$.

STABILITY ALGORITHM

Suppose that n_a successive voltage readings are required for stability. Let μ_R and σ_R be the expected runs and standard deviation in equations (C-1) and (C-2) for sample size n_a. Following a change of frequency the algorithm is entered with an initial data set $\{v_1, v_2, \ldots, v_n\}$ such that $n \geq n_a$.

(A) $j \leftarrow n - n_a + 1$; Data $= \{v_j, v_{j+1}, \ldots, v_n\}$

(B) Compute: R, Z_R; S, Z_S, p from n_a readings in Data.

(C) If ($Z_R \geq -2.5$) and ($0.25 < p < 0.75$) then: compute $\overline{v}$ = Average (Data); S_V = Standard Deviation (Data); EXIT: Data is stable. Otherwise, GOTO (D).

(D) $n \leftarrow n+1$; $v_n \leftarrow$ {next voltage}; GOTO (A).

EXAMPLES

Figure C.1 shows the thermopile output for measurements at five frequencies on mount CN27_04. Graphical illustrations of the stability testing results at the first three frequencies are shown in figures C.2 - C.4. In each of the three figures, the vertical dashed lines represent endpoints of the region found to be acceptably stable, while the horizontal dashed line is plotted at the average voltage of readings in the stable region.

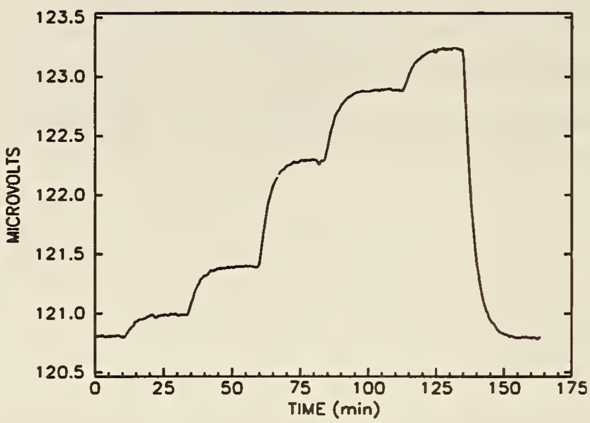

Figure C.1. Thermopile output versus time for CN27 at five check frequencies.

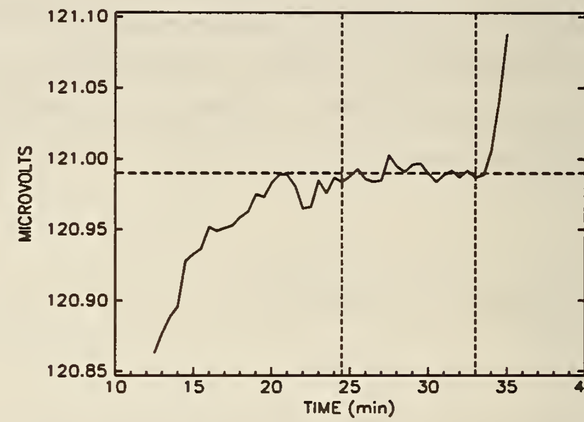

Figure C.2. Thermopile output versus time for CN27 at 100 MHz.

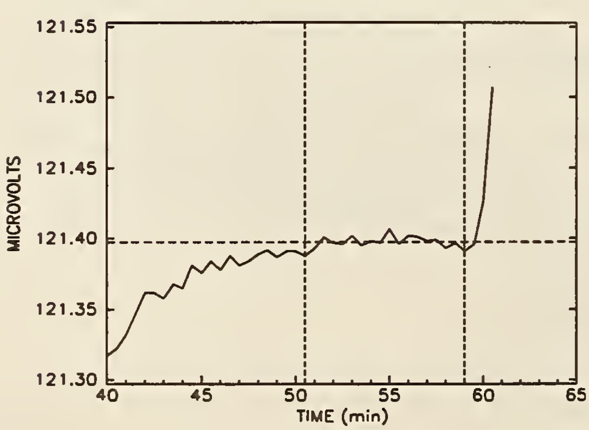

Figure C.3. Thermopile output versus time for CN27 at 3 GHz.

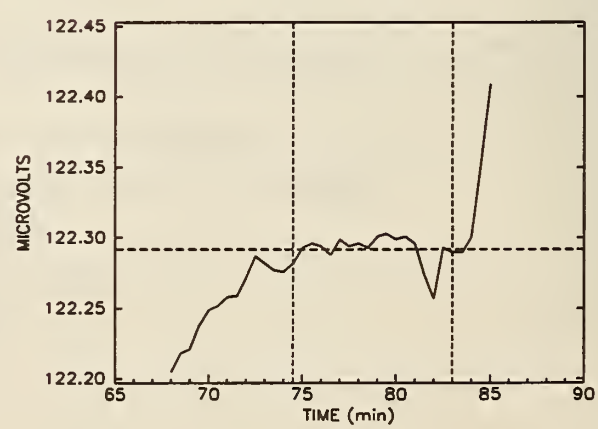

Figure C.4. Thermopile output versus time for CN27 at 10 GHz.

To illustrate the calculations, the sequence of numerical results at 10 GHz are listed in Tables C.1 and C.2. Since the required number of stable readings was n_a = 18, Table C.1 simply shows the sequential average and standard deviation calculated after each of the initial 17 readings. Stability checking (see Table C.2) began after the 18th reading, with the initial test results $Z_R = -6.29$ and $Z_S = 5.80$ with $p = 0.00$. The entries following Z_R and p show the respective test conclusions, indicating if the prior 18 readings passed (P) or failed (F) the RUNS and TREND stability tests, respectively, based on the criteria at step (C) of the algorithm. As the table shows, both procedures successfully passed tests after the 47th reading, thereby indicating that $\{v_{30}, v_{31}, \ldots, v_{47}\}$ was an acceptable data set. The resulting average, $\overline{v}$ = 122.2916 μV, was used in calculating the effective efficiency at 10 GHz.

Table C.1. Initial readings for mount CN27_04 at 10 GHz.

n	Time,s	μV	Average	S.D.
1	3600.1	121.426	121.4260	0.0000
2	3630.1	121.507	121.4665	0.0573
3	3660.1	121.598	121.5103	0.0860
4	3690.1	121.679	121.5525	0.1098
5	3720.1	121.764	121.5948	0.1341
6	3750.1	121.839	121.6355	0.1560
7	3780.1	121.912	121.6750	0.1766
8	3810.1	121.957	121.7103	0.1915
9	3840.1	122.004	121.7429	0.2042
10	3870.1	122.046	121.7732	0.2150
11	3900.1	122.081	121.8012	0.2241
12	3930.1	122.107	121.8267	0.2312
13	3960.1	122.132	121.8502	0.2370
14	3990.1	122.153	121.8718	0.2417
15	4020.1	122.177	121.8921	0.2458
16	4050.1	122.196	121.9111	0.2494
17	4080.1	122.205	121.9284	0.2517

Table C.2. Stability checking at 10 GHz: Average and S.D. of last 18 readings.

n	Time, s	μV	Average	S.D.	Z_R	Z_S	p
18	4110.1	122.218	121.9445	0.2536	-6.29 F	5.80	0.00 F
19	4140.1	122.221	121.9887	0.2257	-6.29 F	5.80	0.00 F
20	4170.1	122.238	122.0293	0.1980	-6.29 F	5.80	0.00 F
21	4200.1	122.249	122.0654	0.1723	-6.29 F	5.80	0.00 F
22	4230.1	122.252	122.0973	0.1480	-6.29 F	5.80	0.00 F
23	4260.1	122.258	122.1247	0.1268	-6.29 F	5.80	0.00 F
24	4290.1	122.259	122.1481	0.1084	-6.29 F	5.80	0.00 F
25	4320.1	122.272	122.1681	0.0947	-6.29 F	5.80	0.00 F
26	4350.1	122.287	122.1864	0.0826	-6.29 F	5.80	0.00 F
27	4380.1	122.282	122.2018	0.0717	-5.70 F	5.72	0.00 F
28	4410.1	122.277	122.2147	0.0623	-5.70 F	5.57	0.00 F
29	4440.1	122.276	122.2255	0.0541	-5.70 F	5.34	0.00 F
30	4470.1	122.282	122.2352	0.0467	-5.11 F	5.23	0.00 F
31	4500.1	122.293	122.2442	0.0409	-5.11 F	5.23	0.00 F
32	4530.1	122.296	122.2521	0.0357	-5.11 F	5.23	0.00 F
33	4560.1	122.294	122.2586	0.0316	-4.52 F	5.16	0.00 F
34	4590.1	122.288	122.2637	0.0281	-4.52 F	4.93	0.00 F
35	4620.1	122.299	122.2689	0.0251	-3.93 F	4.93	0.00 F
36	4650.1	122.294	122.2732	0.0223	-3.34 F	4.74	0.00 F
37	4680.1	122.296	122.2773	0.0187	-2.75 F	4.63	0.00 F
38	4710.1	122.293	122.2804	0.0162	-2.16 P	4.22	0.00 F
39	4740.1	122.301	122.2833	0.0149	-1.57 P	4.22	0.00 F
40	4770.1	122.303	122.2861	0.0134	-1.57 P	4.22	0.00 F
41	4800.1	122.299	122.2884	0.0117	-0.98 P	4.03	0.00 F
42	4830.1	122.301	122.2907	0.0094	-0.39 P	3.92	0.00 F
43	4860.1	122.296	122.2921	0.0083	-0.39 P	3.47	0.00 F
44	4890.1	122.274	122.2913	0.0092	-0.39 P	2.48	0.01 F
45	4920.1	122.257	122.2899	0.0121	-0.39 P	1.45	0.07 F
46	4950.1	122.293	122.2908	0.0117	-0.39 P	0.84	0.20 F
47	4980.1	122.290	122.2916	0.0111	0.20 P	0.00	0.50 P

APPENDIX D. Software Listing

```
7100   File$="MICRO_CxAP"              ! Started:8610231615/FRC
105    Rev$="9204061454" ! FRC,BFR
110    !
115    !
120    ! This program is a modification of MICRO_CAL. Its application is the
125    ! effective efficiency measurement of a thermistor mount using the
130    ! coax microcalorimeter.  Default menu choices and the correction factor
135    ! are set for coax; waveguide microcalorimeter measurements can also
140    ! can also be made by choosing the appropriate menu item and changing
145    ! the correction factor.  The correction factor is changed by changing
150    ! the four lines labeled G, G1, G2, and G3, and the RF subprogram.
155    ! Thermopile output (using the Kiethley 181 nanovoltmeter),
160    ! and power meter voltage are the measured parameters.
165    ! Provision for temperature measurement is made but not implemented in
170    ! this version.  It controls the instrumentation, does the calculations,
175    ! and outputs the results.
180    !
185     NOTES: This version can turn dc bias on & off, checking the nanovoltmeter
190    !         and thermopile zero.
195    !         This version is saving & looking for the temperature array, Tp,
200    !         even though it is not measured.
205    !         This version can run the entire frequency range of the coax
210    !         mounts, automatically.
215    !
220    ! INSTRUMENTS CONTROLLED:                              ADDRESS
225    !    1.  HP3457A  DVM                                    722
230    !    2.  HP3488A  SWITCH CONTROL UNIT                    709
235    !    3.  EIP 578  LOCKING COUNTER                        719
240    !    4.  KEITHLEY 181  DIGITAL NANOVOLTMETER             712
245    !    5.  EIP 931 0.01 - 18.6 GHz SOURCE                  720
250    !    6.  DATA PRECISION 8200 DC SOURCE                   714
255    !
260    ! DESCRIPTION OF THE MAIN VARIABLES:
265    !
270    !    These are in the labeled common  /Data/.
275    !
280    ! *  Dfile$ is the name of the data file (may include drive extension).
285    !    File name code example:
290    !                              9090060510
295    !                              /  \    /
300    !          Waveguide: WR-90    Date (year, mo, day, hour)
305    !    (Coax: Type N = cn, APC-7 = c7)
310    !
315    ! *  File1$ is the name of the program that generated the data file.
320    ! *  Mount_id$ is the identifier of the mount calibrated.
325    !
330    !--- The following are real arrays with TWO dimensions.  ---------------
335    ! *  V, an array containing in Col 1: the time of measurement;
340    !    in Col 2: the measured power meter voltages.
345    ! *  E, an array containing in Col 1: the time of measurement;
350    !    in Col 2: the measured thermopile output voltage.
355    ! *  AF, an array containing in each row of three columns the Start, Stop,
360    !    and Step sequences for each measurement set.
365    ! *  F, an array containing in Col 1: the frequencies; in Col 2:
370    !    the beginning measurement No. for that frequency.
375    ! *  Ne, an array containing in Col 1: the frequency; in Col 2:
380    !    the effective efficiency.
385    !
390    !--- The following is a real array with ONE dimension. ---------------
395    ! *  Header, an array with 27 elements, containing the housekeeping
400    !    information.
405    !    Each element is defined as follows:
410    !    (1)  - Rev$, revision No., yr-mo-day-hour-min-sec format.
415    !    (2)  - Test date, in "Timedate" format.
420    !    (3)  - Band Id, ie. "90" for WR-90.
425    !    (4)  - Efficiency flag, indicates data set includes Ne,
430    !              the effective efficiency result array.
435    !      (5)  - Total number of measurement frequencies
440    !      (6)  - Starting measurement frequency
445    !      (7)  - Final measurement frequency
450    !      (8)  - Step frequency size (the first step may be different)
455    !      (9)  - Total No. of measurements
460    !      (10) - Elapsed time for measurement series, sec
465    !      (11) - Measurement interval, sec
470    !      (12) - Nominal rf power level, mW
475    !      (13) - Reference voltage, volts
480    !      (14) - Mount operating resistance, ohms
485    !      (15) - Nanovoltmeter zero correction, volts
490    !      (16) - Pre-bias flag, mount dc biased before run
495    !      (17) - Room temperature
500    !      (18) - Bath temperature
505    !      (19) - Zero correction flag, data includes dc OFF
510    !      (20) - Auto measure flag, indicates full data set taken
515    !             and stored automatically
520    !      (21) - Random frequency order flag
525    !      (22) -
530    !      (23) -
535    !      (24) -
540    !      (25) -
545    !      (26) -
550    !      (27) -
555    !
560    !--- The following is an integer array with ONE dimension. -----------
565    ! *  Tp, an array containing the temperature measurements.
570    !
575    ! *******************  INITIALIZATION  ********************
580    !
585    OPTION BASE 1
590    KEY LABELS OFF
595    GINIT                                 !Default graphics parameters
600    PLOTTER IS CRT,"INTERNAL";COLOR MAP
605    CONTROL 1,15;1                        !Print color white
610    !
615 Common:                                  !Variables to put in common
620    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
625    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
630    COM /Data/ Af(10,3),INTEGER Tp(3000)
635    COM /Init_stats/ Tcv,Rcv,Enr,Sdnr,Volts(100),INTEGER Mode,Lss
640    COM /Flags/ Manual_freqs
645    COM /Xy_coordinates/ Timin,Timax,Vpmin,Vpmax
650    !
655    Timax=43200                           !Initial time maximum, in seconds.
660    Timin=0                               !  "      "  minimum,  "    "
665    Vpmax=1.21E-4                         !Initial voltage maximum, in volts.
670    Vpmin=1.17E-4                         !  "       "    minimum,  "   "
675    Lss=18                                !No in avg.
680      !
685 Mcontrol: !  ****************  MAIN MENU AND CONTROL ******************
690    !
695    IF V(1,2) OR E(1,2) THEN CALL New_size !If data still in common, re_dim
700    Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))    !Determine system priority
705    Lcl_prty=Sys_prty+1                   !Set local priority 1 higher for ON KEY
710    ! Softkey interrupts:
715    FOR N=0 TO 19
720      ON KEY N LABEL " " GOTO Top
725    NEXT N
730    ON KEY 0 LABEL " EXIT PROGRAM  ",Lcl_prty GOTO End
735    ON KEY 5 LABEL " SELECT  (1)  ",Lcl_prty GOSUB Measure
740    ON KEY 6 LABEL " SELECT  (2)  ",Lcl_prty GOSUB Calcdisp
745    ON KEY 7 LABEL " SELECT  (3)  ",Lcl_prty GOSUB Iodfile
750    ON KEY 9,Lcl_prty CALL Blank          !Turn CRT back on after meas
755    M_flg=1                               !Set flag to display menu
760    KEY LABELS ON
765 Top:LOOP
```

```
770      IF M_flg THEN GOSUB Main_menu
775    END LOOP
780    !
785 Measure:                        !
790    INTEGER Counter              !Local integer variables
795    CALL Soft_init(Z_flg)        !Initialize the software
800    File1$=File$                 !Put program file name into common
805    Header(1)=VAL(Rev$)          !Put program revision # in
810    IF Mount_id$="" THEN CALL Mount_id   !To get the mount identifier
815  ! CALL Hard_init               !Initialize the hardware
820    Counter=0                    !Start a counter for loop
825 Mk1:   !
830    LOOP                         !For auto meas
835    EXIT IF Nomore_f             !Stop if all freq meas
840      Counter=Counter+1          !Increment
845      IF Counter=1 THEN          !First time thru
850        CALL Generate_freq(Nomore_f,Counter)!Produces start, stop, step freq
855        CALL Freq_change_pts(1)      !Set up frequency list & display
860        CALL New_size                !Resize after any possible changes
865        CALL Display_data            !Init the voltage/time parameters
870      ELSE                           !After the first time
875        CALL Re_set                  !Partial software init
880        CALL Generate_freq(Nomore_f,Counter)!Produces start, stop, step freq
885        CALL New_size                !Resize arrays
890        CALL Freq_change_pts(0)      !Set up frequency list, no display
895      END IF
900      IF Counter=1 AND Header(16) THEN CALL Pre_bias(1)  !To set up for
         pre_bias
905      IF Counter=1 THEN CALL Delay_start   !Wait until start time
910      IF Counter=1 AND Header(16) THEN CALL Pre_bias(0)  !To do the pre_bias
915      CALL File_name                 !To set up the file name
920      CALL Meas_disp                 !To set up screen display for Meas
925      IF NOT Header(19) THEN CALL Dc(1,2)  !Be sure bias is on, if no zero
         check
930      CALL Meas                      !Do the measurement
935      IF Header(20) THEN CALL Save_data(1)   !If auto mode, save the meas
940    EXIT IF NOT Header(20)           !Once thru if manual or bail out
945    END LOOP
950    M_flg=1                          !To restore menu
955    RETURN
960    !
965 Calcdisp:                           !
970    IF V(1,2) OR E(1,2) THEN         !Check for data in the memory
975      CALL Calc_disp
980      M_flg=1                        !To restore menu
985    ELSE                             !Because no data in memory
990      CALL Flash(" NO DATA IN MEMORY ")
995      M_flg=1
1000   END IF
1005   RETURN
1010   !
1015 Iodfile:                           !
1020   CALL Io_dfile
1025   M_flg=1                          !To restore menu
1030   RETURN
1035   !
1040 Main_menu:                        !
1045   OUTPUT KBD;"K";                 !Clear screen
1050   PRINT TABXY(5,2),CHR$(137)&"M I C R O _ C x A P"&CHR$(136)
1055   Crt_id$=SYSTEM$("CRT ID")       !To find out the # of CRT col.
1060   IF Crt_id$[4,5]="80" THEN
1065     CLIP 10,117,24,84             !To draw a rectangle - small crt
1070   ELSE
1075     CLIP 4,74,62,92               !To draw a rectangle - large crt
1080   END IF
1085   PEN 5
1090   FRAME
1095   PRINT TABXY(25,7),"- - - - - - MAIN MENU - - - - - -"
1100   PRINT TABXY(25,10),"(1)  MEASURE EFFICIENCY"
1105   PRINT TABXY(25,12),"(2)  CALCULATE & DISPLAY RESULTS"
1110   PRINT TABXY(25,14),"(3)  DATA FILE I/O"
1115   IF V(1,2) OR E(1,2) THEN
1120     PRINT TABXY(59,18),CHR$(129)&" DATA IN MEMORY "&CHR$(128)
1125     IF Dfile$="" THEN
1130       PRINT TABXY(59,19),CHR$(129)&" (NO FILE NAME) "&CHR$(128)
1135     ELSE
1140       PRINT TABXY(59,19),CHR$(129)&" FILE:"&Dfile$&CHR$(128)
1145     END IF
1150   ELSE
1155     PRINT TABXY(56,19),CHR$(129)&" NO DATA IN MEMORY "&CHR$(128)
1160   END IF
1165   M_flg=0                          !Lower menu flag
1170   RETURN
1175   !
1180 End:CLEAR SCREEN
1185   END! MICRO_Cx??
1190!* * * * * * * * * * *  S U B    P R O G R A M S  * * * * * * * * * * * * *
1195 Io_dfile:!
1200   SUB Io_dfile
1205     OPTION BASE 1
1210     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
1215     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
1220     COM /Data/ Af(10,3),INTEGER Tp(3000)
1225     M_flg=1                        !Set flag to print menu
1230     No=Header(9)                   !Total measurement #
1235     Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
1240     Lcl_prty=Sys_prty+1            !Set local priority 1 higher for ON KEY
1245     FOR N=0 TO 19
1250       ON KEY N LABEL " " GOTO Top
1255     NEXT N
1260     ON KEY 0 LABEL " MAIN  MENU  ",Lcl_prty GOTO Exit
1265     ON KEY 5 LABEL " SELECT  (1) ",Lcl_prty GOSUB Disphdr
1270     ON KEY 6 LABEL " SELECT  (2) ",Lcl_prty GOSUB Get_data
1275     ON KEY 7 LABEL " SELECT  (3) ",Lcl_prty GOSUB Save_data
1280     KEY LABELS ON
1285 Top:LOOP
1290       IF M_flg THEN GOSUB Menu
1295     END LOOP
1300   !
1305 Disphdr:                           !
1310     IF Header(1) THEN              !Check for header data
1315       CALL Disp_hdr
1320       M_flg=1                      !To restore menu
1325     ELSE                           !Because no data in memory
1330       CALL Flash(" NO HEADER DATA IN MEMORY ")
1335       M_flg=1
1340     END IF
1345     RETURN
1350   !
1355 Save_data:                         !
1360     IF V(1,2) OR E(1,2) THEN       !Check for data in the memory
1365       CALL Save_data(0)            !Not an auto mode save
1370       M_flg=1                      !To restore menu
1375     ELSE                           !Because no data in memory
1380       CALL Flash(" NO DATA IN MEMORY ")
1385       M_flg=1
1390     END IF
1395     RETURN
1400     !
1405 Get_data:                          !Retrieve BDAT data file
1410     CALL Get_data
1415     M_flg=1
1420     RETURN
1425   !
```

```
1430 Menu:                              !
1435     OUTPUT KBD;"K";               !Clear screen
1440     PRINT TABXY(5,2),CHR$(137)&"M I C R O _ C x A P"&CHR$(136)
1445     PEN 1
1450     FRAME
1455     PRINT CHR$(138)
1460     PRINT TABXY(25,7),"- - - - DATA I/O MENU - - - -"
1465     PRINT TABXY(25,10),"(1)  Header listing/change"
1470     PRINT TABXY(25,12),"(2)  Input  a data file"
1475     PRINT TABXY(25,14),"(3)  Output a data file"
1480     IF V(1,2) OR E(1,2) THEN
1485       PRINT TABXY(59,18),CHR$(129)&" DATA IN MEMORY "&CHR$(128)
1490       IF Dfile$="" THEN
1495         PRINT TABXY(59,19),CHR$(129)&" (NO FILE NAME) "&CHR$(128)
1500       ELSE
1505         PRINT TABXY(59,19),CHR$(129)&" FILE:"&Dfile$&CHR$(128)
1510       END IF
1515     ELSE
1520       PRINT TABXY(56,19),CHR$(129)&" NO DATA IN MEMORY "&CHR$(128)
1525     END IF
1530     M_flg=0
1535     RETURN
1540     !
1545 Exit:OFF KEY
1550   SUBEND ! Io_dfile
1555   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
1560 Disp_hdr:  !
1565   SUB Disp_hdr
1570     OPTION BASE 1
1575     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
1580     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
1585     COM /Data/ Af(10,3),INTEGER Tp(3000)
1590     INTEGER Ans
1595 Disp_hdr:     !Print out the header items
1600     OUTPUT KBD;"K";                !Clear screen
1605     IF V(1,1) THEN
1610       PRINT TABXY(17,1),CHR$(138);CHR$(132);"HEADER LISTING
           FOR:";CHR$(128);CHR$(136);"  A Previous Measurement";CHR$(138)
1615     ELSE
1620       PRINT TABXY(17,1),CHR$(138);CHR$(132);"HEADER LISTING
           FOR:";CHR$(128);CHR$(136);"  A New Measurement";CHR$(138)
1625     END IF
1630     PRINT
1635     PRINT "Option  Array #"
1640     PRINT " (1) - - - - -  Data file name: ";CHR$(136);Dfile$;CHR$(138)
1645     PRINT " (2) - - - - -  Mount ID: ";CHR$(136);Mount_id$;CHR$(138)
1650     PRINT " (3) - - - - -  Measurement program: ";CHR$(136);File1$;CHR$(138)
1655     IMAGE " (4)     [1]     Revision #: ",A,ZZZZZZZZZZ,A
1660     PRINT USING 1655;CHR$(136);Header(1);CHR$(138)
1665     IF Header(2) THEN
1670       PRINT " (5)     [2]     Test date: ";CHR$(136);DATE$(Header(2));",
           ";TIME$(Header(2));CHR$(138)
1675     ELSE
1680       PRINT " (5)     [2]     Test date: ";CHR$(136);"NA";CHR$(138)
1685     END IF
1690     IF Header(3) THEN
1695       PRINT " (6)     [3]     Band ID: WR-";CHR$(136);Header(3);CHR$(138)
1700     ELSE
1705       PRINT " (6)     [3]     Band ID: ";CHR$(136);"Coax";CHR$(138)
1710     END IF
1715     PRINT " (7)     [4]     Effective efficiency flag:
         ";CHR$(136);Header(4);CHR$(138)
1720     PRINT " (8)     [5]     No. of measurement frequencies:
         ";CHR$(136);Header(5);CHR$(138)
1725     PRINT " (9)     [6]     Start frequency:
         ";CHR$(136);Header(6);CHR$(138);"GHz"
1730     PRINT "(10)     [7]     Stop frequency:
         ";CHR$(136);Header(7);CHR$(138);"GHz"
1735     PRINT "(11)     [8]     Step frequency:
         ";CHR$(136);Header(8);CHR$(138);"GHz"
1740     PRINT "(12)     [9]     Number of measurements:
         ";CHR$(136);Header(9);CHR$(138)
1745     IMAGE "(13)     [10]    Measurement duration: ",A,ZZ.DD,A," hr"
1750     PRINT USING 1745;CHR$(136);Header(10)/3600;CHR$(138)
1755     PRINT "(14)     [11]    Measurement interval:
         ";CHR$(136);Header(11);CHR$(138);"sec"
1760     IMAGE "(15)     [12]    Nominal power: ",A,DD.D,A," mW"
1765     PRINT USING 1760;CHR$(136);Header(12);CHR$(138)
1770     PRINT "(16)     [13]    Voltage reference:
         ";CHR$(136);Header(13);CHR$(138);"volts"
1775     PRINT "(17)     [14]    Mount operating resistance:
         ";CHR$(136);Header(14);CHR$(138);"ohms"
1780     PRINT "(18)     [15]    Nanovoltmeter zero correction:
         ";CHR$(136);Header(15);CHR$(138)
1785     PRINT "(19)     [16]    Mount pre_bias flag:
         ";CHR$(136);Header(16);CHR$(138)
1790     PRINT "(20)     [17]    Room temperature:
         ";CHR$(136);Header(17);CHR$(138)
1795     PRINT "(21)     [18]    Bath temperature:
         ";CHR$(136);Header(18);CHR$(138)
1800     PRINT "(22)     [19]    Zero correction flag:
         ";CHR$(136);Header(19);CHR$(138)
1805     PRINT "(23)     [20]    Auto meas flag: ";CHR$(136);Header(20);CHR$(138)
1810     PRINT "(24)     [21]    Random freq order flag:
         ";CHR$(136);Header(21);CHR$(138)
1815     PRINT CHR$(128)
1820     CONTROL CRT,12;2                 !Turn on key labels
1825     Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
1830     Lcl_prty=Sys_prty+1              !Set local priority 1 higher for ON KEY
1835     FOR N=0 TO 19
1840       ON KEY N LABEL "" GOTO Top
1845     NEXT N
1850     ON KEY 5 LABEL "CHANGE listing",Lcl_prty GOTO Edit
1855     ON KEY 0 LABEL " CONTINUE     ",Lcl_prty GOTO Disp_exit
1860 Top:LOOP
1865     END LOOP
1870 Edit:                               !
1875     CONTROL CRT,12;1                 !Turn off labels
1880     INPUT "Input item number to change: ",Ans
1885     SELECT Ans
1890     CASE 1
1895       INPUT "Input new data file name: ",Dfile$
1900     CASE 2
1905       INPUT "Input mount ID: ",Mount_id$
1910     CASE 3
1915       INPUT "Input measurement program name: ",File1$
1920     CASE 4
1925       INPUT "Input revision number: ",Header(1)
1930     CASE 5
1935       GOTO Disp_hdr
1940     CASE 6
1945       INPUT "Input band ID: ",Header(3)
1950     CASE 7
1955       INPUT "Effective efficiency flag:",Header(4)
1960     CASE 8
1965       INPUT "No. of measurement frequencies:",Header(5)
1970     CASE 9
1975       INPUT "Input Start frequency:",Header(6)
1980     CASE 10
1985       INPUT "Input Stop frequency:",Header(7)
1990     CASE 11
1995       INPUT "Input Step frequency:",Header(8)
2000     CASE 12
2005       INPUT "Input No. of measurements:",Header(9)
```

```
2010      CALL New_size
2015    CASE 14
2020      INPUT "Input measurement interval:",Header(11)
2025    CASE 15
2030      INPUT "Input power:",Header(12)
2035    CASE 16
2040      GOTO Disp_hdr
2045    CASE 17
2050      INPUT "Input mount resistance:",Header(14)
2055    CASE 18
2060      INPUT "Nanovoltmeter zero correction:",Header(15)
2065    CASE 19
2070      INPUT "Mount pre-bias flag:",Header(16)
2075    CASE 20
2080      INPUT "Room temperature:",Header(17)
2085    CASE 21
2090      INPUT "Bath temperature:",Header(18)
2095    CASE 22
2100      INPUT "Zero correction flag:",Header(19)
2105    CASE 23
2110      INPUT "Auto meas flag:",Header(20)
2115    CASE 24
2120      INPUT "Random freq order flag:",Header(21)
2125    CASE ELSE
2130      GOTO Disp_hdr
2135    END SELECT
2140    GOTO Disp_hdr
2145 Disp_exit:                      !
2150    OFF KEY
2155  SUBEND
2160  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
2165 Calc_disp:  !
2170  SUB Calc_disp                    !
2175    OPTION BASE 1
2180    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
2185    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
2190    COM /Data/ Af(10,3),INTEGER Tp(3000)
2195    COM /Grph_prt/ Pwr(100,2)         !Power array
2200    DIM B$[60]
2205    Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
2210    Lcl_prty=Sys_prty+1            !Set local priority 1 higher for ON KEY
2215    !
2220    FOR N=0 TO 19
2225      ON KEY N LABEL " " GOTO Top
2230    NEXT N
2235    ON KEY 0 LABEL " MAIN  MENU   ",Lcl_prty GOTO Exit
2240    ON KEY 5 LABEL " SELECT  (1) ",Lcl_prty GOSUB Grphv
2245    ON KEY 6 LABEL " SELECT  (2) ",Lcl_prty GOSUB Grphe
2250    ON KEY 7 LABEL " SELECT  (3) ",Lcl_prty GOSUB Grphn
2255    ON KEY 8 LABEL " SELECT  (4) ",Lcl_prty GOSUB Grphp
2260    ON KEY 9 LABEL " SELECT  (5) ",Lcl_prty GOSUB Grpht
2265    ON KEY 1 LABEL " SELECT  (6) ",Lcl_prty GOSUB Calc_sd
2270    M_flg=1                        !Set flag to print menu
2275 Top:LOOP
2280      IF M_flg THEN GOSUB Menu
2285    END LOOP
2290  !
2295 Grphv:                            !Graphs power meter voltage output
2300    IF V(1,1)=0 THEN               !If no power meter data
2305      CALL Flash("  NO DATA  ")
2310    ELSE
2315      Pltflg=1                     !To graph power meter
2320      B$="MOUNT VOLTAGE CHANGE VS TIME    "
2325      CALL Graph_v(Pltflg,B$)
2330    END IF
2335    M_flg=1                        !To restore menu
2340    RETURN
2345  !
2350 Grphe:                            !Graphs thermopile nanovolt output
2355     Pltflg=2                      !To graph thermopile
2360     B$="THERMOPILE VOLTAGE CHANGE VS TIME"
2365     CALL Graph_v(Pltflg,B$)
2370     M_flg=1                       !To restore menu
2375     RETURN
2380  !
2385 Grpht:                            !Graphs temperature probe output
2390     IF Tp(1)=0 THEN               !If no temp data
2395       CALL Flash("  NO DATA  ")
2400     ELSE
2405       Pltflg=3                    !To graph temperature
2410       B$="TEMPERATURE CHANGE VS TIME"
2415       CALL Graph_v(Pltflg,B$)
2420     END IF
2425     M_flg=1                       !To restore menu
2430     RETURN
2435  !
2440 Grphn:                            !Graphs calculated effective efficiency
2445     OUTPUT KBD;"K";              !Clear screen
2450     IF NOT Header(4) THEN CALL Eff_calc !Efficiency calculation if not done
2455     Pflg=0                        !For efficiency graph
2460     CALL Graph_n_p(Pflg)          !Graph efficiency
2465     M_flg=1                       !To restore menu
2470     RETURN
2475  !
2480 Grphp:                            !Graphs rf power level
2485     OUTPUT KBD;"K";              !Clear screen
2490     IF NOT Pwr(1,1) THEN CALL Eff_calc  !Do power calculation if not done
2495     Pflg=1                        !For power graph
2500     CALL Graph_n_p(Pflg)          !Graph power
2505     M_flg=1                       !To restore menu
2510     RETURN
2515  !
2520 Calc_sd:                          !Calculates standard deviations
2525     OUTPUT KBD;"K";              !Clear screen
2530     CALL Std_dev
2535     M_flg=1                       !To restore menu
2540     RETURN
2545 Menu:                            !
2550     OUTPUT KBD;"K";             !Clear screen
2555     PRINT TABXY(5,2),CHR$(137)&"M I C R O _ C x A P"&CHR$(136)
2560     Crt_id$=SYSTEM$("CRT ID")     !To find out the # of CRT col.
2565     IF Crt_id$[4,5]="80" THEN
2570       CLIP 10,117,24,84          !To draw a rectangle - small crt
2575     ELSE
2580       CLIP 4,74,62,92            !To draw a rectangle - large crt
2585     END IF
2590     PEN 1
2595     FRAME
2600     PRINT CHR$(140)               !Cyan characters
2605     PRINT TABXY(20,6),"- - - - CALCULATE/DISPLAY  MENU - - - -"
2610     PRINT TABXY(25,8),"(1)  Graph power meter voltage"
2615     PRINT TABXY(25,10),"(2)  Graph  thermopile voltage"
2620     PRINT TABXY(25,12),"(3)  Graph/Print effective efficiency"
2625     PRINT TABXY(25,14),"(4)  Graph Rf Power"
2630     PRINT TABXY(25,16),"(5)  Graph Temperature"
2635     PRINT TABXY(25,18),"(6)  Calculate standard deviation"
2640     IF V(1,2) OR E(1,2) THEN
2645       PRINT TABXY(59,18),CHR$(129)&" DATA IN MEMORY "&CHR$(128)
2650       IF Dfile$="" THEN
2655         PRINT TABXY(59,19),CHR$(129)&" (NO FILE NAME) "&CHR$(128)
2660       ELSE
2665         PRINT TABXY(59,19),CHR$(129)&" FILE:"&Dfile$&CHR$(128)
2670       END IF
2675     ELSE
```

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2680      PRINT TABXY(56,19),CHR$(129)&" NO DATA IN MEMORY "&CHR$(128)
2685    END IF
2690    M_flg=0
2695    RETURN
2700 Exit:OFF KEY
2705   SUBEND
2710   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
2715 Graph_v:      !
2720   SUB Graph_v(Pltflg,B$)           !Graphs voltage as a function of time
2725   ! For Pltflg=1 : Graph power meter voltage
2730   ! For Pltflg=2 : Graph thermopile output
2735   ! For Pltflg=3 : Graph temperature probe output
2740   ! B$ passes the plot title
2745    OPTION BASE 1
2750    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
2755    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
2760    COM /Data/ Af(10,3),INTEGER Tp(3000)
2765    No=Header(9)                   !Total # of measurements (array size)
2770    ALLOCATE A$[80]                  !String for title
2775    ALLOCATE P(No,2)                 !Plotting array
2780    Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
2785    Lcl_prty=Sys_prty+1              !Set local priority 1 higher for ON KEY
2790    G_flg=1                          !Set flag to display graph
2795    FOR N=0 TO 19
2800      ON KEY N LABEL " " GOTO Top
2805    NEXT N
2810    ON KEY 0 LABEL " PREV  MENU   ",Lcl_prty GOTO Exit
2815    ON KEY 1 LABEL " DUMP  plot   ",Lcl_prty GOSUB Dump
2820    ON KEY 5 LABEL "CHANGE x-axis ",Lcl_prty GOSUB Chg_x
2825    ON KEY 6 LABEL "CHANGE y-axis ",Lcl_prty GOSUB Chg_y
2830 Top:LOOP
2835      IF G_flg THEN GOSUB Graph
2840      IF Chg_flg THEN GOSUB Graph_xy
2845    END LOOP
2850   !
2855 Chg_x:                              !Change x axis range
2860    Ans$=""                          !Make sure dummy is empty
2865    DISP "New Tmin <";Timin/60;"> ";  !Ask if change for Tmin
2870    INPUT Ans$                       !Get response
2875    IF Ans$<>"" THEN Timin=60.*VAL(Ans$)
2880    Ans$=""                          !Make sure dummy is empty
2885    DISP "New Tmax <";Timax/60;"> ";  !Ask if change for Tmax
2890    INPUT Ans$                       !Get response
2895    IF Ans$<>"" THEN Timax=60.*VAL(Ans$)
2900    Ans$=""                          !Make sure dummy is empty
2905    Chg_flg=1                        !Indicate the change
2910    RETURN
2915   !
2920 Chg_y:                              !Graphs thermopile nanovolt output
2925    DISP "New Vmin <";Vpmin;"> ";    !Ask if change for Vmin
2930    INPUT Ans$                       !Get response
2935    IF Ans$<>"" THEN Vpmin=VAL(Ans$)
2940    Ans$=""                          !Make sure dummy is empty
2945    DISP "New Vmax <";Vpmax;"> ";    !Ask if change for Vmax
2950    INPUT Ans$                       !Get response
2955    IF Ans$<>"" THEN Vpmax=VAL(Ans$)
2960    Chg_flg=1                        !Indicate the change
2965    RETURN
2970   !
2975 Dump:                               !Graphs calculated effective efficiency
2980    OUTPUT KBD;"K";                 !Clear screen
2985    CONTROL 1,12;1                   !Turn off user soft key labels
2990    GOSUB Graph_xy                   !Go to alternate entry point
2995    OUTPUT KBD;"N";                 !Dump graphics
3000    CONTROL 1,12;0                   !Turn on user soft key labels
3005    RETURN
3010   !
3015 Graph:                                         !Main graph routine
3020     SELECT Pltflg
3025     CASE 1
3030       MAT P= V                                 !For power meter
3035     CASE 2
3040       MAT P= E                                 !For thermopile
3045     CASE 3
3050       MAT P= E                                 !For temperature - thermo time in Col 1
3055       FOR N=1 TO No
3060         P(N,2)=Tp(N)                           !Temp into Col 2
3065       NEXT N
3070     END SELECT
3075     IF P(No,1)>1.E+6 THEN                      !Check for elapsed or absolute time
3080       FOR N=1 TO No                            !Change to elapsed
3085         P(N,1)=P(N,1)-Header(2)
3090       NEXT N
3095     END IF
3100     Timax=P(No,1)                              !Find Max time
3105     Timin=0                                    !
3110     Vpmax=P(1,2)                               !Find the plot max/min
3115     Vpmin=P(1,2)
3120     FOR N=2 TO No
3125       IF Vpmax<P(N,2) THEN Vpmax=P(N,2)
3130       IF Vpmin>P(N,2) THEN Vpmin=P(N,2)
3135     NEXT N
3140     Vpmax=Vpmax+.05*ABS(Vpmax-Vpmin) !Find the plot max + 5%
3145     Vpmin=Vpmin-.05*ABS(Vpmax-Vpmin) !Find the plot min - 5%
3150 Graph_xy:                                      !Alternate entry point
3155     OUTPUT KBD;"K";                           !Clear screen
3160     GINIT
3165     LORG 6                                     !All labels ref. top center
3170     PEN 5
3175     MOVE 75,100                                !Move to top for title label
3180     CSIZE 3.0                                  !Smaller letters
3185     A$=DATE$(TIMEDATE)&", "&TIME$(TIMEDATE)
3190     A$=B$&"    "&A$                            !Add date to title
3195     LABEL A$                                   !Write title
3200     MOVE 75,95                                 !Move for sub title
3205     A$="MOUNT: "&Mount_id$&"   PROGRAM: "&File1$&"    DATA FILE: "&Dfile$
3210     LABEL A$                                   !Write title
3215     CSIZE 4.0                                  !Little larger letters
3220     MOVE 70,12                                 !For horizontal axes label
3225     LABEL "TIME (min)"                         !Write label
3230     MOVE 0,55                                  !For vertical axis label
3235     LDIR PI/2                                  !Rotate 90
3240     SELECT Pltflg
3245     CASE 1
3250       LABEL "MILLIVOLTS"                       !For power meter
3255     CASE 2
3260       LABEL "MICROVOLTS"                       !For thermopile
3265     CASE 3
3270       LABEL "DEGREES C "                       !For temperature
3275     END SELECT
3280     LDIR 0                                     !Back to horizontal
3285     PEN 1
3290     VIEWPORT 20,125,16,90                      !Subset of screen area
3295     MOVE 0,0                                   !Cure for WINDOW error
3300     WINDOW Timin,Timax,Vpmin,Vpmax !Scale factors
3305     ! Set up x+axis tic and label spacing
3310     Range=Timax-Timin                           !Horizontal scale range in seconds
3315     SELECT Range
3320     CASE <=5400                                 !For Range <= 90 min
3325       X=60                                      !X-tics every 1 min
3330       Xtic=10                                   !10 tics/major div
3335       Stp=600                                   !Labels every 10 min
3340     CASE <=18000                                !For 300 min >=Range> 120 min
3345       X=600                                     !X-tics every 10 min
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3350      Xtic=3                        !3 tics/major div
3355      Stp=1800                      !Label every 30 min
3360    CASE <=36000                    !For 600 min >=Range> 300 min
3365      X=600                         !H-tics every 10 min
3370      Xtic=6                        !6 tics/major div
3375      Stp=3600                      !Label every 60 min
3380    CASE >36000                     !For Range> 600 min
3385      X=600                         !H-tics every 10 min
3390      Xtic=12                       !12 tics/major div
3395      Stp=7200                      !Label every 120 min
3400    END SELECT
3405    Y=(Vpmax-Vpmin)/10             !Calculate vertical ticks
3410    AXES X,Y,Timin,Vpmin,Xtic,1,4  !Draw axes with ticks at the right place
3415    AXES X,Y,Timax,Vpmax,Xtic      !Same ticks on the other sides
3420    CLIP OFF                       !Allow labels outside viewport
3425    CSIZE 3.5                      !Smaller characters for axis labels
3430    FOR I=0 TO Timax-Timin STEP Stp       !Label every ? on X axis
3435      MOVE Timin+I,Vpmin-Y/10             !Just below x axis
3440      LABEL USING "#,DDDD";(Timin+I)/60   !No CR/LF
3445    NEXT I
3450    LORG 8                         !REf. center rt. end
3455    SELECT Pltflg
3460    CASE 1                         !Label for power meter output graph
3465      FOR I=Vpmin TO Vpmax STEP Y  !Label every Y on Y axis
3470        MOVE Timin-.01,I           !To the left of X axis
3475        LABEL USING "#,MDDDDD.DD";1.E+3*I !No CR/LF - millivolts
3480      NEXT I
3485    CASE 2                         !Label for thermopile output graph
3490      FOR I=Vpmin TO Vpmax STEP Y  !Label every Y on Y axis
3495        MOVE Timin-.01,I           !To the left of X axis
3500        LABEL USING "#,MDDD.DDD";1.E+6*I !No CR/LF - microvolts
3505      NEXT I
3510    CASE 3                         !Label for temperature graph
3515      FOR I=Vpmin TO Vpmax STEP Y  !Label every Y on Y axis
3520        MOVE Timin-.01,I           !To the left of X axis
3525        LABEL USING "#,MDD.DD";1.E-3*I !No CR/LF - degrees C
3530      NEXT I
3535    END SELECT
3540    PEN 2
3545    CLIP ON                        !Keep plot inside viewport
3550    FOR Count=1 TO No              !Loop to plot readings
3555      PLOT P(Count,1),P(Count,2)         !Plot the point
3560    NEXT Count
3565    PENUP
3570    G_flg=0                        !Don't replot
3575    Chg_flg=0                      !Don't replot
3580    RETURN
3585    !
3590 Exit:OFF KEY
3595    GINIT                          !Put graphics back to default
3600  SUBEND
3605  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
3610 Flash:  !
3615  SUB Flash(Msg$)                  !Sub to flash msg on screen
3620    OUTPUT KBD;"K";               !Clear screen
3625    BEEP 2000,.1
3630    FOR N=1 TO 4                   !Blinks the message red & white
3635      C=136
3640      C=C+2*FRACT(N/2)
3645      PRINT TABXY(28,13),CHR$(129)&CHR$(C)&Msg$&CHR$(128)
3650      WAIT .2
3655    NEXT N
3660  SUBEND
3665  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
3670 New_size:  !
3675  SUB New_size
3680    OPTION BASE 1
3685    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
3690    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
3695    COM /Data/ Af(10,3),INTEGER Tp(3000)
3700    No=Header(9)                        !No of measurements
3705    IF Header(5)=0 THEN Header(5)=1  !Default non zero
3710    No1=Header(5)                       !No. of frequencies + final rf off
3715    REDIM V(No,2)                       !New mount voltage & time
3720    REDIM E(No,2)                       !New thermopile reading & time
3725    REDIM Tp(No)                        !New temperature reading & time
3730    IF Header(19) THEN                  !Zero correction case
3735      REDIM F(No1+4,2)                  !Freq - meas no. array
3740    ELSE                                !No zero correction
3745      REDIM F(No1+2,2)                  !Freq - meas no. array
3750    END IF
3755    REDIM Ne(No1,2)                     !Effective efficiency array
3760  SUBEND
3765  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
3770 Save_data:     !
3775  SUB Save_data(Auto)                   !Writes BDAT file
3780    OPTION BASE 1
3785    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
3790    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
3795    COM /Data/ Af(10,3),INTEGER Tp(3000)
3800    No=Header(9)
3805    No1=Header(5)
3810    Msg_flg=1
3815    ALLOCATE N_name$[30]
3820    Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
3825    Lcl_prty=Sys_prty+1                 !Set local priority 1 higher for ON KEY
3830    !
3835    IF Auto THEN                        !For auto mode
3840      GOSUB D_3_5_0                     !Save on HD drive 0 on dual floppy
3845      GOTO Exit
3850    END IF
3855    !
3860    FOR N=0 TO 19
3865      ON KEY N LABEL " " GOTO Top
3870    NEXT N
3875    ON KEY 0 LABEL " PREV MENU    ",Lcl_prty GOTO Exit
3880    ON KEY 5 LABEL "CHANGE NAME    ",Lcl_prty GOSUB C_name
3885    ON KEY 6 LABEL "SAVE:  700,1 ",Lcl_prty GOSUB D_3_5
3890    ON KEY 7 LABEL "SAVE: 702,0  ",Lcl_prty GOSUB D_3_5_0
3895    ON KEY 8 LABEL "SAVE: 700,0,?",Lcl_prty GOSUB D_2
3900    ON KEY 9 LABEL "SAVE: 1400",Lcl_prty GOSUB D_1400
3905 Top:LOOP
3910      IF Msg_flg THEN GOSUB Msg1
3915      IF Dfile$="" THEN GOSUB C_name  !If no file name get one
3920    END LOOP
3925      !
3930 Msg1:                                  !Put message on screen
3935    OUTPUT KBD;"K";                    !Clear screen
3940    DISP "Select softkey for drive & other options.  The present file name
        is ";Dfile$
3945    Msg_flg=0
3950    RETURN
3955      !
3960 D_3_5:                                 !Save on 3.5" drive
3965    N_name$=Dfile$&":,700,1"
3970    GOSUB Save
3975    Msg_flg=1
3980    RETURN
3985      !
3990 D_3_5_0:                               !Save on drive 0 of dual 3.5" drive
3995    N_name$=Dfile$&":,702,0"
4000    GOSUB Save
4005    Msg_flg=1
4010    RETURN
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4015     !
4020 D_1400:                             !Save on 360 hard drive
4025     N_name$="/USERS/FRC/"&Dfile$&":,1400"
4030     GOSUB Save
4035     Msg_flg=1
4040     RETURN
4045     !
4050 D_2:                                !Save on vol ? of the hard drive
4055     INPUT "What hard volume ?",Vq$
4060     N_name$=Dfile$&":,700,0,"&Vq$
4065     GOSUB Save
4070     Msg_flg=1
4075     RETURN
4080     !
4085 C_name:                             !To change file name
4090     INPUT "Input the new file name",Dfile$
4095     Msg_flg=1
4100     RETURN
4105     !
4110 Save:                               !Save the data
4115     DISP "File name:";N_name$       !Print the name
4120     CALL New_size
4125     IF Header(4) THEN               !Indicates EE array to be saved
4130       Rec_no=(LEN(Test_date$)+LEN(File$)+8+8*27+34.*No+32*(No1+2))/256+1
4135       CREATE BDAT N_name$,Rec_no      !Create it
4140       ASSIGN @Path1 TO N_name$        !Open & set file pointer at beginning
4145  !           Output all test information and files
4150       OUTPUT @Path1;File1$,Mount_id$,Header(*)
4155       OUTPUT @Path1;E(*),V(*),F(*),Tp(*),Ne(*),END
4160     ELSE                            !EE array not saved
4165       Rec_no=(LEN(Test_date$)+LEN(File$)+8+8*27+34.*No+16*(No1+2))/256+1
4170       CREATE BDAT N_name$,Rec_no      !Create it
4175       ASSIGN @Path1 TO N_name$        !Open & set file pointer at beginning
4180  !           Output all test information and files
4185       OUTPUT @Path1;File1$,Mount_id$,Header(*)
4190       OUTPUT @Path1;E(*),V(*),F(*),Tp(*),END
4195     END IF
4200     ASSIGN @Path1 TO *              !Close file
4205     RETURN
4210 Exit:OFF KEY
4215   SUBEND
4220   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
4225 Get_data:         !
4230   SUB Get_data                      !Retrieve BDAT data file
4235     OPTION BASE 1
4240     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
4245     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
4250     COM /Data/ Af(10,3),INTEGER Tp(3000)
4255     Msg_flg=1
4260     ALLOCATE N_name$[20],D14file$[30]
4265     Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
4270     Lcl_prty=Sys_prty+1             !Set local priority 1 higher for ON KEY
4275     FOR N=0 TO 19
4280       ON KEY N LABEL " " GOTO Top
4285     NEXT N
4290     ON KEY 0 LABEL " PREV MENU    ",Lcl_prty GOTO Exit
4295     ON KEY 1 LABEL "  CAT  700,1  ",Lcl_prty GOSUB Cat_3_5
4300     ON KEY 2 LABEL "  CAT  702,0  ",Lcl_prty GOSUB Cat_3_5_0
4305     ON KEY 3 LABEL "  CAT  702,1  ",Lcl_prty GOSUB Cat_3_5_1
4310     ON KEY 4 LABEL "  CAT  1400   ",Lcl_prty GOSUB Cat_1400
4315     ON KEY 5 LABEL " INPUT  name  ",Lcl_prty GOSUB C_name
4320     ON KEY 6 LABEL " LOAD  700,1  ",Lcl_prty GOSUB Ld_3_5
4325     ON KEY 7 LABEL " LOAD  702,0  ",Lcl_prty GOSUB Ld_3_5_0
4330     ON KEY 8 LABEL " LOAD  702,1  ",Lcl_prty GOSUB Ld_3_5_1
4335     ON KEY 9 LABEL " LOAD  1400   ",Lcl_prty GOSUB Ld_1400
4340     KEY LABELS ON
4345 Top:LOOP
4350       IF Msg_flg THEN GOSUB Msg1
4355     END LOOP
4360       !
4365 Msg1:                               !Put message on screen
4370     OUTPUT KBD;"K";                 !Clear screen
4375     PRINT TABXY(30,14),"DATA FILE INPUT "
4380     IF Dfile$="" THEN
4385       PRINT TABXY(5,16),"File in memory: ";CHR$(136);"NONE";CHR$(138)
4390     ELSE
4395       PRINT TABXY(5,16),"File in memory: ";CHR$(136);Dfile$;CHR$(138)
4400     END IF
4405     IF N_name$="" THEN
4410       PRINT TABXY(5,18),CHR$(140);"Select softkey option.";CHR$(138)
4415     ELSE
4420       PRINT TABXY(5,18),"Requested file name: ";CHR$(136);N_name$;CHR$(140)
4425       PRINT TABXY(5,19),"(Select soft key option to load the file.)"
4430     END IF
4435     Msg_flg=0
4440     RETURN
4445       !
4450 Cat_3_5:                            !Cat 3.5" drive
4455     CAT ":,700,1"
4460     RETURN
4465       !
4470 Ld_3_5:                             !Load from 3.5" drive
4475     IF N_name$="" THEN
4480       DISP "Have not been given a file name."
4485       WAIT 1
4490       DISP ""
4495       GOTO R35
4500     END IF
4505     Dfile$=N_name$&":,700,1"
4510     N_name$=""
4515     GOSUB Get_data
4520     GOTO Exit
4525 R35:RETURN
4530     !
4535 Cat_3_5_0:                          !Cat dual 3.5", drive 0
4540     CAT ":,702,0"
4545     RETURN
4550       !
4555 Ld_3_5_0:                           !Load from dual 3.5", drive 0
4560     IF N_name$="" THEN
4565       DISP "Have not been given a file name."
4570       WAIT 1
4575       DISP ""
4580       GOTO R350
4585     END IF
4590     Dfile$=N_name$&":,702,0"
4595     N_name$=""
4600     GOSUB Get_data
4605     GOTO Exit
4610 R350:RETURN
4615     !
4620 Cat_3_5_1:                          !Cat dual 3.5", drive 1
4625     CAT ":,702,1"
4630     RETURN
4635       !
4640 Ld_3_5_1:                           !Load from dual 3.5", drive 1
4645     IF N_name$="" THEN
4650       DISP "Have not been given a file name."
4655       WAIT 1
4660       DISP ""
4665       GOTO R351
4670     END IF
4675     Dfile$=N_name$&":,702,1"
4680     N_name$=""
```

```
4685     GOSUB Get_data
4690     GOTO Exit
4695 R351:RETURN
4700     !
4705 Cat_1400:                         !Cat /USERS/FRC:,1400
4710     CAT "/USERS/FRC:,1400"
4715     RETURN
4720       !
4725       !
4730 Ld_1400:                          !Load from /USERS/FRC:,1400
4735     IF N_name$="" THEN
4740       DISP "Have not been given a file name."
4745       WAIT 1
4750       DISP ""
4755       GOTO R1400
4760     END IF
4765     D14file$="/USERS/FRC/"&N_name$&":,1400"
4770     N_name$=""
4775     GOSUB Get_14data
4780     GOTO Exit
4785 R1400:RETURN
4790       !
4795 C_name:                           !Change to another file name
4800     KEY LABELS OFF
4805     INPUT "Input the new file name",N_name$
4810     Msg_flg=1
4815     KEY LABELS ON
4820     RETURN
4825     !
4830 Get_data:                         !Retrieve data file
4835     MAT E= (0)                    !Clear the data arrays
4840     MAT V= (0)
4845     MAT F= (0)
4850     MAT Tp= (0)
4855     ASSIGN @Path1 TO Dfile$       !Open & set file pointer at beginning
4860  !           Input all test information and all files
4865     ENTER @Path1;File1$,Mount_id$,Header(*)
4870     CALL New_size                 !Redim arrays to fit data
4875     IF Header(4) THEN             !The EE array is present
4880       ENTER @Path1;E(*),V(*),F(*),Tp(*),Ne(*)
4885     ELSE                          !EE array not present
4890       ENTER @Path1;E(*),V(*),F(*),Tp(*)
4895     END IF
4900     ASSIGN @Path1 TO *            !Close file
4905     Dfile$=Dfile$[1,10]           !Strip off the drive extension
4910     Header(4)=0                   !Problem with Pwr(*) - force recalc
4915                                   !of EE & thus Pwr(*)
4920     RETURN
4925     !
4930 Get_14data:                     !Special Retrieve data file for 1400 drive
4935     MAT E= (0)                    !Clear the data arrays
4940     MAT V= (0)
4945     MAT F= (0)
4950     MAT Tp= (0)
4955     ASSIGN @Path1 TO D14file$      !Open & set file pointer at beginning
4960  !           Input all test information and all files
4965     ENTER @Path1;File1$,Mount_id$,Header(*)
4970     CALL New_size                 !Redim arrays to fit data
4975     IF Header(4) THEN             !The EE array is present
4980       ENTER @Path1;E(*),V(*),F(*),Tp(*),Ne(*)
4985     ELSE                          !EE array not present
4990       ENTER @Path1;E(*),V(*),F(*),Tp(*)
4995     END IF
5000     ASSIGN @Path1 TO *            !Close file
5005     Dfile$=D14file$[12,21]        !Strip off the drive extension
5010     Header(4)=0                   !Problem with Pwr(*) - force recalc
5015                                   !of EE & thus Pwr(*)
5020     RETURN
5025     !
5030 Exit:OFF KEY
5035   SUBEND
5040   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
5045 Ef:  !
5050 Eff_calc:     !
5055   SUB Eff_calc                      !Calculates effective efficiency
5060     OPTION BASE 1
5065     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
5070     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
5075     COM /Data/ Af(10,3),INTEGER Tp(3000)
5080     COM /Grph_prt/ P(100,2)         !Set up power array
5085     No_freq=Header(5)               !Get No. of frequencies
5090     Chk_e0=Header(19)               !Set flag if E0 check is in data set
5095     REDIM P(No_freq,2)              !Change size to match
5100     DISP "Do you wish to visually check the computed values of Vdc and Vrf
         ?"
5105     Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
5110     Lcl_prty=Sys_prty+1             !Set local priority 1 higher for ON KEY
5115   ! Softkey interrupts:
5120     FOR N=0 TO 19
5125       ON KEY N LABEL " " GOTO Top
5130     NEXT N
5135     ON KEY 0 LABEL " PREV MENU    ",Lcl_prty GOTO Exit
5140     ON KEY 5 LABEL "YES, all freq ",Lcl_prty GOTO Yes1
5145     ON KEY 6 LABEL " YES, 1 freq  ",Lcl_prty GOTO Yes2
5150     ON KEY 7 LABEL "     NO       ",Lcl_prty GOTO No
5155 Top:LOOP
5160     END LOOP
5165 Yes1:Chk_flg=1                      !Set the check flag (for visually
5170     GOTO Y_n_end                    !reasonable results-all freq)
5175 Yes2:Chk_flg=-1                     !Set single freq flag
5180     IF Chk_flg<0 THEN               !What frequency ?
5185       FOR N=1+Chk_e0 TO Header(5)+Chk_e0
5190         PRINT "No. ";N;" ";F(N,1);" GHz"
5195       NEXT N
5200       KEY LABELS OFF
5205       INPUT "Input the frequency you wish to see in GHz: ",Chk_freq
5210       KEY LABELS ON
5215     END IF
5220     GOTO Y_n_end                    !
5225 No: Chk_flg=0                       !Lower the check flag
5230 Y_n_end:                            !End of Y/N
5235     IF Chk_flg<=0 THEN              !
5240       KEY LABELS OFF                !Turn off key labels
5245       DISP ""                       !Clear display area
5250     END IF
5255     FOR N=1+Chk_e0 TO No_freq+Chk_e0         ! +1 if checking E0
5260       CALL V_avg(Chk_flg,Chk_freq,N,Vdc,Vrf)
5265       CALL E_avg(Chk_flg,Chk_freq,N,Edc,Erf)
5270       GOSUB Pwr_calc
5275       Freq=F(N,1)                   !Get the frequency
5280       P(N-Chk_e0,1)=Freq
5285       P(N-Chk_e0,2)=Pwr
5290       GOSUB Eff_calc                !Calculate EE
5295       Ne(N-Chk_e0,1)=Freq           !Fill array
5300       Ne(N-Chk_e0,2)=Eff
5305     NEXT N
5310     Header(4)=1                     !Set EE flag
5315     GOTO Exit
5320     !
5325 Pwr_calc:                           !Calculates rf power level
5330     Vref=Header(13)                 !Get the reference voltage (if any)
5335     R0=Header(14)                   !Get the mount operating resistance
5340     V1=Vref+Vdc                     !V1 for power calculation
5345     V2=Vref+Vrf                     !V2 for power calc
```

```
5350     Pwr=1000*(V1*V1-V2*V2)/R0       !Rf power in milliwatts
5355     RETURN
5360     !
5365 Eff_calc:                           !Calculates effective efficiency
5370 G:  G=1.00038+.00095*Freq^.452      !Calorimeter correction constant
5375     Ra2=(V2/V1)^2                   !Ratio of V2 to V1, squared
5380     Eff=G*(1-Ra2)/(Erf/Edc-Ra2)     !Effective efficiency
5385     PRINT Freq
5390     PRINT Ra2,Edc,Erf,Eff
5395     RETURN
5400     !
5405 Exit:CONTROL 1,12;0                 !Turn labels back on
5410   SUBEND
5415   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
5420 V_avg:     !
5425   SUB V_avg(Chk_flg,Chk_freq,Freq_no,Vdc,Vrf)  !Average V's from raw data
5430   !
5435   ! Chk_flg:  1  = Displays the data and results for a visual check
5440   !              at ALL frequencies.
5445   !    "   :  0  = Computes average without displaying result(s).
5450   !    "   : -1  = Displays the data and results for a visual check
5455   !              at ONE frequency.
5460   ! Chk_freq:  The single frequency for a visual check.
5465   ! Freq_no:  No. of freq (place in the series of frequencies) for which
5470   !           the average is to be determined.
5475   ! Vdc:  The returned calculated average value of Vdc.
5480   ! Vrf:  The returned calculated average value of Vrf.
5485   !
5490     OPTION BASE 1
5495     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
5500     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
5505     COM /Data/ Af(10,3),INTEGER Tp(3000)
5510     DIM B$[60]
5515     !
5520     Vdc=0                             !Zero out variable
5525     Vrf=0                             !Zero out variable
5530     Freq=INT(F(Freq_no,1)*1.E+3)/1.E+3   !Get the frequency in GHz
5535     N1=F(Freq_no,2)                   !Meas No. at start of freq
5540     Vst=V(N1-1,2)                     !Vdc at start of freq
5545     FOR N=N1 TO Header(9)             !Look for the next Rf-off reading
5550       IF V(N,2)>.9*Vst AND V(N,2)<1.1*Vst THEN GOTO Jump_out
5555       Vrf=Vrf+V(N,2)                  !Sum up the rf readings
5560     NEXT N
5565 Jump_out:N2=N                         !Meas No. at end of freq
5570     Vsp=V(N2,2)                       !Vdc at end of freq
5575     Vdc=(Vst+Vsp)/2                   !Avg the two end points
5580     Pltflg=1                          !Plot V
5585     Vflg=1                            !For Vdc
5590     OUTPUT Vdc$ USING "#,DDDD.DDDD";Vdc*1.E+3
5595     B$="Vdc="&Vdc$&" mV at "&VAL$(Freq)&" GHz"
5600     IF Chk_flg>0 THEN CALL Graph_check(Pltflg,Vflg,B$,Vdc,N1,N2,0,0,S_flg)
5605     IF Chk_flg<0 AND Freq=Chk_freq THEN CALL
         Graph_check(Pltflg,Vflg,B$,Vdc,N1,N2,0,0,S_flg)
5610     Vrf=Vrf/(N2-N1)                   !Vrf: compute the average
5615     Vflg=0                            !For Vrf
5620     OUTPUT Vrf$ USING "#,DDDD.DDDD";Vrf*1.E+3
5625     B$="Vrf="&Vrf$&" mV at "&VAL$(Freq)&" GHz"
5630     IF Chk_flg>0 THEN CALL Graph_check(Pltflg,Vflg,B$,Vrf,N1,N2,0,0,S_flg)
5635     IF Chk_flg<0 AND Freq=Chk_freq THEN CALL
         Graph_check(Pltflg,Vflg,B$,Vrf,N1,N2,0,0,S_flg)
5640     OFF KEY
5645   SUBEND
5650   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
5655 E_avg:     !
5660   SUB E_avg(Chk_flg,Chk_freq,Freq_no,Edc,Erf)      !Determine avg E's
5665   !
5670   ! Chk_flg:  1  = Displays the data and results for a visual check
5675   !              at ALL frequencies.
5680   !    "   :  0  = Computes average without displaying result(s).
5685   !    "   : -1  = Displays the data and results for a visual check
5690   !              at ONE frequency.
5695   ! S_flg: 1 =  step thru stability test routine
5700   ! Chk_e0:   1 if E0 check is in data set
5705   ! Chk_freq:  The single frequency for a visual check.
5710   ! Freq_no:  No. of freq (place in the series of frequencies) for which
5715   !           the average is to be determined.
5720   ! Edc:  The returned calculated average value of Edc.
5725   ! Erf:  The returned calculated average value of Erf.
5730   ! Lss:  The no. of data points averaged in Find_trend.
5735   !
5740   OPTION BASE 1
5745   INTEGER N
5750   COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
5755   COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
5760   COM /Data/ Af(10,3),INTEGER Tp(3000)
5765   COM /Init_stats/ Tcv,Rcv,Enr,Sdnr,Volts(100),INTEGER Mode,Lss
5770   COM /Flag/ S_flg
5775   DIM B$[60]
5780   !
5785   Chk_e0=Header(19)                 !Set flag if E0 check is in data set
5790   No_freq=Header(5)                 !Get the total # of freq measured
5795   E0=0                              !Zero out variable
5800   Edc=0                             !Zero out variable
5805   Erf=0                             !Zero out variable
5810   Freq=INT(F(Freq_no,1)*1.E+3)/1.E+3   !Get the frequency in GHz
5815   !
5820   !***************  E0 Average  ******************
5825   IF Chk_e0 THEN                    !Calculate E0
5830   !    *****     First end point for E0 average
5835     N1=F(1,2)                       !Meas No. at end of dc off
5840     Nst=N1-Lss                      !Start Lss points (Lss/2 min) back
5845     Nsp=N1-1                        !Stop point
5850     FOR N=Nst TO Nsp                !Avg points
5855       E01=E01+E(N,2)
5860     NEXT N
5865     E01=E01/(Nsp-Nst+1)             !Average
5870     X1=INT((Nsp+Nst)/2)             !X1 for linear thermopile correction
5875     Y1=E01                          !Y1 for linear thermopile correction
5880   !    *****     Second end point for E0 average
5885     Nf=Header(9)                    !Total No. of measurement points
5890     Nst=Nf-Lss                      !Start average back Lss/2 min from end
5895     Nsp=Nst+Lss-1                   !Average for Lss points (Lss/2 min)
5900     FOR N=Nst TO Nsp                !Start and stop as indicated above
5905       E02=E02+E(N,2)
5910     NEXT N
5915     E02=E02/(Nsp-Nst+1)             !Average
5920     X2=INT((Nsp+Nst)/2)             !X2 for linear thermopile correction
5925     Y2=E02                          !Y2 for linear thermopile correction
5930     E0=(Y1+Y2)/2                    !Avg without linear correction
5935     Header(15)=E0                   !Put avg value in header
5940     A0=(Y2-Y1)/(X2-X1)              !A0 - slope for linear correction
5945     B0=(X2*Y1-X1*Y2)/(X2-X1)        !B0 - intercept for a+bx correction
5950   END IF
5955   !
5960   !***************  Edc Average  ******************
5965   !    *****     First end point for Edc average
5970   N1=F(1,2)                         !Meas No. at start of rf (1st freq)
5975   IF Chk_e0 THEN N1=F(2,2)          !If E0 checked, jump that data
5980   Nst=N1-Lss                        !Start Lss points (Lss/2 min) back
5985   Nsp=N1-1                          !Stop point
5990   FOR N=Nst TO Nsp                  !Avg points
5995     Edc1=Edc1+E(N,2)
6000   NEXT N
6005   Edc1=Edc1/(Nsp-Nst+1)             !Average
```

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6010     X1=INT((Nsp+Nst)/2)              !X1 for linear thermopile correction
6015     Y1=Edc1                          !Y1 for linear thermopile correction
6020     !    *****     Second end point for Edc average
6025     Nf=Header(9)                     !Total No. of measurement points
6030     IF Chk_e0 THEN Nf=F(No_freq+3,2)      !Meas pts at end of rf_off
6035     Nst=Nf-Lss                       !Start average back Lss/2 min from end
6040     Nsp=Nst+Lss-1                    !Average for Lss points (Lss/2 min)
6045     FOR N=Nst TO Nsp                 !Start and stop as indicated above
6050       Edc2=Edc2+E(N,2)
6055     NEXT N
6060     Edc2=Edc2/(Nsp-Nst+1)            !Average
6065     X2=INT((Nsp+Nst)/2)              !X2 for linear thermopile correction
6070     Y2=Edc2                          !Y2 for linear thermopile correction
6075     Edc=(Y1+Y2)/2                    !Avg without linear correction
6080     A=(Y2-Y1)/(X2-X1)                !A - slope for linear correction
6085     B=(X2*Y1-X1*Y2)/(X2-X1)          !B - intercept for a+bx correction
6090     !   ***********    Get Erf value
6095     N1=F(Freq_no,2)                  !Meas No. at start of freq
6100     N2=F(Freq_no+1,2)                !Meas No. at end of freq
6105     CALL Settle_1(N1,N2,Erf,Nmid,Nst,Nsp,S_flg) !Rtrns avg Erf, mid, start, stop
6110     Nf=Header(9)                     !Total No. of measurement points
6115     Pltflg=0                         !Plot E
6120     Vflg=1                           !For Edc
6125     IF Chk_e0 THEN                   !For calculated E0
6130       E0=A0*Nmid+B0                  !Linear slope correction
6135       OUTPUT E0$ USING "#,DDD.DDDD";E0*1.E+6
6140       B$="E0="&E0$&" uV at "&VAL$(Freq)&" GHz"
6145       IF Chk_flg>0 THEN CALL Graph_check(Pltflg,Vflg,B$,E0,1,Nf,0,0,S_flg)
6150       IF Chk_flg<0 AND Freq=Chk_freq THEN CALL
           Graph_check(Pltflg,Vflg,B$,E0,1,Nf,0,0,S_flg)
6155     END IF
6160     Edc=A*Nmid+B                     !Linear correction for thermopile drift
6165     OUTPUT Edc$ USING "#,DDD.DDDD";Edc*1.E+6
6170     B$="Edc="&Edc$&" uV at "&VAL$(Freq)&" GHz"
6175     IF Chk_flg>0 THEN CALL Graph_check(Pltflg,Vflg,B$,Edc,1,Nf,0,0,S_flg)
6180     IF Chk_flg<0 AND Freq=Chk_freq THEN CALL
         Graph_check(Pltflg,Vflg,B$,Edc,1,Nf,0,0,S_flg)
6185     Vflg=0                           !For Erf
6190     OUTPUT Erf$ USING "#,DDD.DDDD";Erf*1.E+6
6195     B$="Erf="&Erf$&" uV at "&VAL$(Freq)&" GHz"
6200     IF Chk_flg>0 THEN CALL
         Graph_check(Pltflg,Vflg,B$,Erf,N1,N2,Nst,Nsp,S_flg)
6205     IF Chk_flg<0 AND Freq=Chk_freq THEN CALL
         Graph_check(Pltflg,Vflg,B$,Erf,N1,N2,Nst,Nsp,S_flg)
6210     E0=Header(15)                    !Get the 181 zero correction
6215     Edc=Edc-E0                       !Make the dc zero correction
6220     Erf=Erf-E0                       !Make the rf zero correction
6225     OFF KEY
6230   SUBEND
6235   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
6240 Graph_check:     !
6245   SUB Graph_check(Pltflg,Vflg,B$,Vavg,N1,N2,Nst,Nsp,S_flg)  !Visual check
6250   !
6255   ! Pltflg: set =  plot power meter voltages (Vdc & Vrf)
6260   !       : down = plot thermopile output (Edc & Erf)
6265   ! S_flg: set =  step thru stability test routine
6270   ! Vflg: set =  plot the dc values
6275   !     : down = plot the rf values
6280   ! B$: Title string
6285   ! Vavg: Average value of Vdc,Vrf,Edc, or Erf to be indicated on graph
6290   ! N1: Meas No. for start (left edge) of the plot
6295   ! N2: Meas No. for end (right edge) of the plot (+10 min)
6300   ! Nst: Meas No. for start of data points used in average
6305   ! Nsp: Meas No. for end of data points used in average
6310   !
6315     OPTION BASE 1
6320     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
6325     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
6330     COM /Data/ Af(10,3),INTEGER Tp(3000)
6335     No=Header(9)                     !Total # of measurements (array size)
6340     ALLOCATE A$[90]                  !String for title
6345     ALLOCATE P(No,2)                 !Plotting array
6350     Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
6355     Lcl_prty=Sys_prty+1              !Set local priority 1 higher for ON KEY
6360     G_flg=1                          !Set flag to display graph
6365     S_flg=0                          !Lower flag for stepping stability test
6370     CONTROL 1,12;0                   !Turn on user soft key labels
6375     !
6380     FOR N=0 TO 9
6385       ON KEY N LABEL " " GOTO Top
6390     NEXT N
6395     ON KEY 0 LABEL " CONTINUE       ",Lcl_prty GOTO Exit
6400     ON KEY 1 LABEL " STEP CONTINUE  ",Lcl_prty GOTO Sexit
6405     ON KEY 5 LABEL "CHANGE  x axis  ",Lcl_prty GOSUB Chg_x
6410     ON KEY 6 LABEL "CHANGE  y axis  ",Lcl_prty GOSUB Chg_y
6415     ON KEY 7 LABEL "CHANGE  V avg   ",Lcl_prty GOSUB Chg_v
6420     ON KEY 8 LABEL "  DUMP    plot  ",Lcl_prty GOSUB Dump
6425 Top:LOOP
6430       IF G_flg THEN GOSUB Graph_setup
6435       IF Chg_flg THEN GOSUB Graph_xy
6440     END LOOP
6445   !
6450 Vavg:                                !Show avg V
6455     Delt=Header(11)                  !Measurement interval in sec
6460     IF Pltflg THEN                   !For V
6465       Timin=N1*Delt-300              !Beginning point minus 5 min
6470       Timax=N2*Delt+300              !End point plus 5 min
6475       IF Vflg THEN                   !Sets up range for y axis
6480         Vpmin=Vavg-5.E-5             !Vdc minus 50 uV
6485         Vpmin=INT(Vpmin*1.E+6)*1.E-6    !Start at an integer division
6490         Vpmax=Vpmin+1.E-4            !Vpmin+100uV
6495       ELSE
6500         Vpmin=Vavg-1.E-5             !Vrf minus 10 uV
6505         Vpmin=INT(Vpmin*1.E+6)*1.E-6    !Start at an integer division
6510         Vpmax=Vpmin+2.E-5            !Vpmin+20uV
6515       END IF
6520     ELSE                             !For E
6525       Timin=INT(N1*Delt/60)*60       !Beginning point
6530       Timax=Timin+2100               !End point plus 30 min
6535       Vpmin=Vavg-5.E-8               !Edc minus 50 nV
6540       Vpmin=INT(Vpmin*1.E+8)*1.E-8 !Start at an integer division
6545       Vpmax=Vpmin+1.E-7              !Vmin+100nV (Edc plus 50 nV)
6550       IF Vflg THEN                   !Sets up range for y axis
6555         Timin=0                      !Beginning point
6560         Timax=N2*Delt                !End point
6565       END IF
6570     END IF
6575     Chg_flg=1                        !Indicate the change
6580     RETURN
6585     !
6590 Chg_x:                               !Change x axis range
6595     Ans$=""                          !Make sure dummy is empty
6600     DISP "New Tmin <";Timin/60;"> ";  !Ask if change for Tmin
6605     INPUT Ans$                       !Get response
6610     IF Ans$<>"" THEN Timin=60.*VAL(Ans$)
6615     Ans$=""                          !Make sure dummy is empty
6620     DISP "New Tmax <";Timax/60;"> ";  !Ask if change for Tmax
6625     INPUT Ans$                       !Get response
6630     IF Ans$<>"" THEN Timax=60.*VAL(Ans$)
6635     Ans$=""                          !Make sure dummy is empty
6640     Chg_flg=1                        !Indicate the change
6645     RETURN
6650   !
6655 Chg_y:                               !Change y axis range
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6660    DISP "New Vmin <";Vpmin;"> ";  !Ask if change for Vmin
6665    INPUT Ans$                     !Get response
6670    IF Ans$<>"" THEN Vpmin=VAL(Ans$)
6675    Ans$=""                        !Make sure dummy is empty
6680    DISP "New Vmax <";Vpmax;"> ";  !Ask if change for Vmax
6685    INPUT Ans$                     !Get response
6690    IF Ans$<>"" THEN Vpmax=VAL(Ans$)
6695    Chg_flg=1                      !Indicate the change
6700    RETURN
6705  !
6710 Chg_v:                            !Provision to input different V or E avg
6715    Ans$=""                        !Make sure dummy is empty
6720    DISP "New Vavg <";Vavg;"> ";   !Ask for changed value
6725    INPUT Ans$                     !Get response
6730    IF Ans$<>"" THEN Vavg=VAL(Ans$)
6735    B$[5,12]=VAL$(Vavg*1.E+6)      !Put new value in label
6740    G_flg=1                        !Indicate the change
6745    RETURN
6750 Dump:                             !Graphs calculated effective efficiency
6755    OUTPUT KBD;"K";               !Clear screen
6760    CONTROL 1,12;1                 !Turn off user soft key labels
6765    GOSUB Graph_xy                 !Go to alternate entry point
6770    OUTPUT KBD;"N";               !Dump graphics
6775    CONTROL 1,12;0                 !Turn on user soft key labels
6780    RETURN
6785  !
6790 Graph_setup:                      !Setup routine
6795    IF Pltflg THEN
6800      MAT P= V                     !For power meter
6805    ELSE
6810      MAT P= E                     !For thermopile
6815    END IF
6820    IF P(No,1)>1.E+6 THEN          !Check for elapsed or absolute time
6825      FOR N=1 TO No                !Change to elapsed
6830        P(N,1)=P(N,1)-Header(2)
6835      NEXT N
6840    END IF
6845    GOSUB Vavg                     !Setup Tmin, Tmax, Vmin, Vmax
6850    RETURN
6855    !
6860 Graph_xy:                         !Alternate entry point
6865    OUTPUT KBD;"K";               !Clear screen
6870    GINIT
6875    LORG 6                         !All labels ref. top center
6880    PEN 5
6885    !
6890    CSIZE 3.4                      !Size
6895    MOVE 64,98                     !Move for top label
6900    Timedate1=Header(2)            !Get time-date of measurement
6905    A$=DATE$(Timedate1)&","&TIME$(Timedate1)
6910    A$="MOUNT: "&Mount_id$&"    DATA FILE: "&Dfile$&"  "&A$
6915    LABEL A$                       !Write title
6920    !
6925    MOVE 73,25                     !Move for label giving V & Freq
6930    CSIZE 4.5                      !Larger size
6935    LABEL B$                       !Write title
6940    !
6945    CSIZE 4.0                      !Change size
6950    MOVE 10,12                     !Place to record Vmin
6955    MOVE 70,12                     !For horizontal axes label
6960    LABEL "TIME (min)"             !Write label
6965    MOVE 0,55                      !For vertical axis label
6970    LDIR PI/2                      !Rotate 90
6975    IF Pltflg=1 THEN
6980      LABEL "MILLIVOLTS"           !For power meter
6985    ELSE
6990      LABEL "MICROVOLTS"           !For thermopile
```

```
6995    END IF
7000    LDIR 0                         !Back to horizontal
7005    PEN 1
7010    VIEWPORT 20,125,16,90          !Subset of screen area
7015    MOVE 0,0                       !Cure for WINDOW error
7020    WINDOW Timin,Timax,Vpmin,Vpmax !Scale factors
7025    ! Set up x+axis tic and label spacing
7030    Range=Timax-Timin               !Horizontal scale range in seconds
7035    SELECT Range
7040    CASE <=5400                     !For Range <= 90 min
7045      X=60                          !X-tics every 1 min
7050      Xtic=10                       !10 tics/major div
7055      Stp=600                       !Labels every 10 min
7060    CASE <=18000                    !For 300 min >=Range> 120 min
7065      X=600                         !X-tics every 10 min
7070      Xtic=3                        !3 tics/major div
7075      Stp=1800                      !Label every 30 min
7080    CASE <=36000                    !For 600 min >=Range> 300 min
7085      X=600                         !H-tics every 10 min
7090      Xtic=6                        !6 tics/major div
7095      Stp=3600                      !Label every 60 min
7100    CASE >36000                     !For Range> 600 min
7105      X=600                         !H-tics every 10 min
7110      Xtic=12                       !12 tics/major div
7115      Stp=7200                      !Label every 120 min
7120    END SELECT
7125    Y=(Vpmax-Vpmin)/10             !Calculate vertical ticks
7130    AXES X,Y,Timin,Vpmin,Xtic,1,4  !Draw axes with ticks at the right place
7135    AXES X,Y,Timax,Vpmax,Xtic      !Same ticks on the other sides
7140    CLIP OFF                       !Allow labels outside viewport
7145    CSIZE 3.5                      !Smaller characters for axis labels
7150    FOR I=0 TO Timax-Timin STEP Stp       !Label every ? on X axis
7155      MOVE Timin+I,Vpmin-Y/10             !Just below x axis
7160      LABEL USING "#,DDDD";(Timin+I)/60  !No CR/LF
7165    NEXT I
7170    LORG 8                         !REf. center rt. end
7175    IF Pltflg THEN                 !Label for power meter output graph
7180      FOR I=Vpmin TO Vpmax STEP Y  !Label every Y on Y axis
7185        MOVE Timin-.01,I           !To the left of X axis
7190        LABEL USING "#,MDDDD.DDD";1.E+3*I !No CR/LF - millivolts
7195      NEXT I
7200    ELSE                           !Label for thermopile output graph
7205      FOR I=Vpmin TO Vpmax STEP Y  !Label every Y on Y axis
7210        MOVE Timin-.01,I           !To the left of X axis
7215        LABEL USING "#,MDDD.DD";1.E+6*I !No CR/LF - microvolts
7220      NEXT I
7225    END IF
7230    PEN 2
7235    CLIP ON                        !Keep plot inside viewport
7240    FOR Count=1 TO No              !Loop to plot readings
7245      PLOT P(Count,1),P(Count,2)          !Plot the point
7250    NEXT Count
7255    PENUP
7260    PEN 3                          !Plot yellow horizontal line for avg
7265    LINE TYPE 5                    !Dashed line
7270    PLOT Timin,Vavg
7275    PLOT Timax,Vavg
7280    PENUP
7285    PEN 1                          !White
7290    PLOT Nst*Delt,Vpmin            !Vertical, white, dashed at beginning
7295    PLOT Nst*Delt,Vpmax
7300    PENUP
7305    PLOT Nsp*Delt,Vpmin            !Vertical, white, dashed at end
7310    PLOT Nsp*Delt,Vpmax
7315    PENUP
7320    G_flg=0                        !Don't replot
7325    Chg_flg=0                      !Don't replot
```

```
7330     RETURN
7335     !
7340 Sexit:S_flg=1                      !Set the step flag
7345 Exit:OFF KEY
7350     KEY LABELS OFF                 !Turn off user soft key labels
7355     GINIT                          !Put graphics back to default
7360   SUBEND
7365   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
7370 Settle_2:  !
7375   SUB Settle_2(N1,N2,Erf,Nmid,Nst,Nsp,S_flg)
7380     !
7385     ! N1: Frequency starting point
7390     ! N2: Frequency stopping point
7395     ! Nst: Beginning of settled run
7400     ! Nsp: End of settled run
7405     ! Erf: is the final settled value
7410     ! Nmid: is the mid point of the array range from which Erf came
7415     ! S_flg: A flag to pause after every call to Find_trend subprogram
7420     !
7425     OPTION BASE 1
7430     INTEGER I,N
7435     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
7440     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
7445     COM /Data/ Af(10,3),INTEGER Tp(3000)
7450     COM /Init_stats/ Tcv,Rcv,Enr,Sdnr,Volts(100),INTEGER Mode,Lss
7455     !
7460     Erf=0                          !Initialize
7465     Mode=1                         !Initialize
7470     N=N1                           !Initialize
7475     WHILE N+Lss-1<N2 AND Stable_run=0  !Either
7480       FOR I=1 TO Lss               !Data for "Find_trend"
7485         Volts(I)=1.0E+6*E(I-1+N,2) !Data to microvolts
7490       NEXT I
7495       CALL Find_trend(Stable_run)  !Dom's routine
7500       IF S_flg THEN PAUSE          !So we can follow Find_trend variables
7505       N=N+1
7510     END WHILE
7515     Nst=N-1
7520     Nsp=N+Lss-2
7525     FOR N=Nst TO Nsp
7530       Erf=Erf+E(N,2)               !Sum
7535     NEXT N
7540     Erf=Erf/(Nsp-Nst+1)            !Average
7545     Nmid=INT((Nst+Nsp)/2)          !Mid-point
7550   SUBEND
7555   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
7560 Graph_n_p:       !
7565   SUB Graph_n_p(Pflg)              !Graph efficiency or power
7570     OPTION BASE 1
7575     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
7580     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
7585     COM /Data/ Af(10,3),INTEGER Tp(3000)
7590     COM /Grph_prt/ Pwr(100,2)         !Power array
7595     No=Header(5)                   !Total # of frequencies (array size)
7600     ALLOCATE A$[90]                !String for title
7605     ALLOCATE P(No,2)               !Plotting array
7610     REDIM Pwr(No,2)                !In case it hasn't been done
7615     Bid=Header(3)                  !Band ID
7620     Bid$=VAL$(Bid)
7625     Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
7630     Lcl_prty=Sys_prty+1            !Set local priority 1 higher for ON KEY
7635     G_flg=1                        !Set flag to display graph
7640     CONTROL 1,12;0                 !Turn on user soft key labels
7645     FOR N=0 TO 19
7650       ON KEY N LABEL " " GOTO Top
7655     NEXT N
7660     ON KEY 0 LABEL " PREV MENU    ",Lcl_prty GOTO Exit
7665     ON KEY 5 LABEL "CHANGE x-axis ",Lcl_prty GOSUB Chg_x
7670     ON KEY 6 LABEL "CHANGE y-axis ",Lcl_prty GOSUB Chg_y
7675     ON KEY 1 LABEL " DUMP  plot   ",Lcl_prty GOSUB Dump
7680     ON KEY 2 LABEL " LIST  result ",Lcl_prty GOSUB List
7685     ON KEY 7 LABEL " PRINT result ",Lcl_prty GOSUB Print
7690 Top:LOOP
7695       IF G_flg THEN GOSUB Graph_setup
7700       IF Chg_flg THEN GOSUB Graph_xy
7705     END LOOP
7710   !
7715 Chg_x:                                 !Change x axis range
7720     Ans$=""                            !Make sure dummy is empty
7725     DISP "New Xmin <";Xmin;"> ";       !Ask if change for Xmin
7730     INPUT Ans$                         !Get response
7735     IF Ans$<>"" THEN Xmin=VAL(Ans$)
7740     Ans$=""                            !Make sure dummy is empty
7745     DISP "New Xmax <";Xmax;"> ";       !Ask if change for Xmax
7750     INPUT Ans$                         !Get response
7755     IF Ans$<>"" THEN Xmax=VAL(Ans$)
7760     Ans$=""                            !Make sure dummy is empty
7765     Chg_flg=1                          !Indicate the change
7770     RETURN
7775   !
7780 Chg_y:                                 !Graphs thermopile nanovolt output
7785     DISP "New Ymin <";Ymin;"> ";       !Ask if change for Ymin
7790     INPUT Ans$                         !Get response
7795     IF Ans$<>"" THEN Ymin=VAL(Ans$)
7800     Ans$=""                            !Make sure dummy is empty
7805     DISP "New Ymax <";Ymax;"> ";       !Ask if change for Ymax
7810     INPUT Ans$                         !Get response
7815     IF Ans$<>"" THEN Ymax=VAL(Ans$)
7820     Chg_flg=1                          !Indicate the change
7825     RETURN
7830   !
7835 Dump:                                  !Graphs calculated effective efficiency
7840     OUTPUT KBD;"K";                   !Clear screen
7845     CONTROL 1,12;1                     !Turn off user soft key labels
7850     GOSUB Graph_xy                     !Go to alternate entry point
7855     OUTPUT KBD;"N";                   !Dump graphics
7860     CONTROL 1,12;0                     !Turn on user soft key labels
7865     RETURN
7870   !
7875 List:                                  !List effective efficiency to screen
7880     P_flg=0                            !
7885     CALL Print_ne(P_flg)
7890     RETURN
7895     !
7900 Print:                                 !Print effective efficiency
7905     P_flg=1                            !Set print flag
7910     CALL Print_ne(P_flg)
7915     RETURN
7920     !
7925 Graph_setup:                           !Setup routine
7930     IF Pflg THEN
7935       MAT P= Pwr                       !POWER
7940       IF Header(21) THEN MAT SORT P(*,1)  !If random freq order
7945       Xmin=0                           !Beginning point: x axis
7950       Xmax=20                          !End point: x axis
7955       Ymin=9.9                         !Beginning point: y axis
7960       Ymax=10.1                        !End point: y axis
7965     ELSE
7970       MAT P= Ne                        !EFFICIENCY
7975       IF Header(21) THEN MAT SORT P(*,1)  !If random freq order
7980       Xmin=0                           !Beginning point: x axis
7985       Xmax=20                          !End point: x axis
7990       Ymin=.90                         !Beginning point: y axis
7995       Ymax=1.0                         !End point: y axis
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8000     END IF
8005     Chg_flg=1                    !Indicate the change
8010     RETURN
8015     !
8020 Graph_xy:                        !Alternate entry point
8025     OUTPUT KBD;"K";             !Clear screen
8030     GINIT
8035     LORG 6                       !All labels ref. top center
8040     PEN 5
8045     !
8050     CSIZE 5.0                    !Size of title
8055     MOVE 64,100                  !Locate it
8060     IF Pflg THEN
8065       LABEL "COAX MOUNT -  RF POWER LEVEL"
8070     ELSE
8075       LABEL "COAX MOUNT - EFFECTIVE EFFICIENCY"
8080     END IF
8085     !
8090     CSIZE 3.5                    !Size of sub title
8095     MOVE 64,94                   !Move for sub title
8100     Timedate1=Header(2)          !Get time-date of measurement
8105     A$=DATE$(Timedate1)
8110     A$="MOUNT:"&Mount_id$&"    DATA FILE:"&Dfile$&"   DATE:"&A$
8115     LABEL A$                     !Write sub title
8120     !
8125     CSIZE 4.5                    !Change size
8130     MOVE 70,12                   !For horizontal axes label
8135     LABEL "FREQUENCY (GHz)"      !Write label
8140     MOVE 0,55                    !For vertical axis label
8145     LDIR PI/2                    !Rotate 90
8150     IF Pflg THEN
8155       LABEL "POWER (mW)"            !EFFICIENCY
8160     ELSE
8165       LABEL "PERCENT"            !EFFICIENCY
8170     END IF
8175     LDIR 0                       !Back to horizontal
8180     PEN 1
8185     IF Pflg THEN                 !POWER
8190       VIEWPORT 18,125,16,88      !Subset of screen area
8195     ELSE                         !EFFICIENCY
8200       VIEWPORT 14,125,16,88      !Subset of screen area
8205     END IF
8210     WINDOW Xmin,Xmax,Ymin,Ymax   !Scale factors
8215     ! Set up x-axis tic and label spacing
8220     X=.25                         !X-tics every 0.25
8225     Xtic=4                        !4 tics/major div
8230     Stpx=1                        !Label every 1 GHz
8235     Y=(Ymax-Ymin)/20             !Calculate vertical ticks
8240     AXES X,Y,Xmin,Ymin,Xtic,2,4  !Draw axes with ticks at the right place
8245     AXES X,Y,Xmax,Ymax,Xtic      !Same ticks on the other sides
8250     CLIP OFF                     !Allow labels outside viewport
8255     CSIZE 3.5                    !Smaller characters for axis labels
8260     FOR I=0 TO Xmax-Xmin STEP Stpx      !Label every ? on X axis
8265       MOVE Xmin+I,Ymin-Y/10             !Just below x axis
8270       LABEL USING "#,DD";(Xmin+I)       !No CR/LF
8275     NEXT I
8280     LORG 8                       !REf. center rt. end
8285     IF Pflg THEN                 !POWER
8290       FOR I=Ymin TO Ymax STEP 2*Y  !Label every ? on Y axis
8295         MOVE Xmin-.01,I            !To the left of X axis
8300         LABEL USING "#,DD.DDD";I   !Power -  mW
8305       NEXT I
8310     ELSE                         !EFFICIENCY
8315       FOR I=Ymin TO Ymax STEP 2*Y  !Label every ? on Y axis
8320         MOVE Xmin-.01,I            !To the left of X axis
8325         LABEL USING "#,DDD.D";100*I!No CR/LF - percent
8330       NEXT I
8335     END IF
8340     PEN 2
8345     CLIP ON                      !Keep plot inside viewport
8350     FOR Count=1 TO No            !Loop to plot readings
8355       PLOT P(Count,1),P(Count,2)       !Plot the point
8360     NEXT Count
8365     PENUP
8370     PEN 3
8375     G_flg=0                      !Don't replot
8380     Chg_flg=0                    !Don't replot
8385     RETURN
8390     !
8395 Exit:OFF KEY
8400     GINIT                        !Put graphics back to default
8405   SUBEND
8410   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
8415 Print_ne:     !
8420   SUB Print_ne(P_flg)
8425     OPTION BASE 1
8430     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
8435     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
8440     COM /Data/ Af(10,3),INTEGER Tp(3000)
8445     COM /Grph_prt/ Pwr(100,2)       !Power array
8450     No1=Header(5)                !No. of frequencies
8455     ALLOCATE Ne1(No1,2)          !Temp array for printing
8460     ALLOCATE Pwr1(No1,2)         !          "
8465     MAT Ne1= Ne                  !Copy to temp array
8470     MAT Pwr1= Pwr                !          "
8475     IF Header(21) THEN           !If random freq order
8480       MAT SORT Ne1(*,1)          !Sort by freq
8485       MAT SORT Pwr1(*,1)         !      "
8490     END IF
8495     FOR N=1 TO No1
8500       IF N=1 THEN
8505         GOSUB Print_e
8510       ELSE
8515         GOSUB Print_e2
8520       END IF
8525     NEXT N
8530     GOTO Exit
8535 Print_e:                         !Output TC calculation results
8540     OUTPUT KBD;"K";             !Clear screen
8545     IF P_flg THEN PRINTER IS PRT
8550     PRINT TAB(22),"EFFECTIVE EFFICIENCY OF COAX MOUNT"
8555     PRINT
8560     PRINT TAB(4),"DATE:  ";DATE$(Header(2));",";TIME$(Header(2));
8565     PRINT TAB(45),"MOUNT:  ";Mount_id$
8570 !
8575     PRINT TAB(4),"PROGRAM: ";File1$;
8580     PRINT TAB(45),"DATA FILE NAME: ";Dfile$
8585 !
8590     PRINT TAB(4),"NO OF READINGS:";Header(9);
8595     PRINT TAB(45),"NANOVOLTMETER ZERO OFFSET: ";
8600     PRINT USING "#,MDDD";Header(15)*1.E+9
8605     PRINT " nV"                  !Units
8610 !
8615     PRINT TAB(4),"MEASUREMENT INTERVAL: ";Header(11);" sec"; !4
8620     PRINT TAB(45),"CALORIMETER CORRECTION: "
8625     IF Header(21) THEN PRINT TAB(4),"RANDOM FREQUENCY ORDER";
8630     IF NOT Header(21) THEN PRINT TAB(4),"INCREMENTAL FREQUENCY ORDER";
8635 G1: PRINT TAB(48),"g = 1.00038 + 0.00095*f^0.452"
8640 !
8645 ! PRINT TAB(5),"BATH TEMPERATURE: N.A.";                   !5
8650 ! PRINT TAB(45),"ELAPSED TIME: "; !How long?               !10
8655 ! PRINT USING "#,DDD.DD";Header(10)/60            !Elapsed time in min.
8660 ! PRINT " min"                  !Units
8665     PRINT
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8670     PRINT
8675     PRINT TAB(4),"FREQ, GHz";
8680     PRINT TAB(20),"RF POWER, mW";
8685     PRINT TAB(38),"C  FACTOR";
8690     PRINT TAB(60),"EFFICIENCY, %"
8695     PRINT TAB(59),"RAW       CORRECTED"
8700 !   PRINT
8705 Print_e2:                                !Alternate entry point
8710 !   PRINT
8715     PRINT TAB(6),Ne1(N,1);               !Frequency
8720 !
8725     PRINT TAB(22),                       !Power in mW
8730     PRINT USING "#,DD.DDDD";Pwr1(N,2)
8735 !
8740     PRINT TAB(39),                       !Correction factor
8745 G2: PRINT USING "#,DD.DDDD";1.00038+.00095*Ne1(N,1)^.452
8750 !
8755     PRINT TAB(58),                       !Raw efficiency
8760 G3: PRINT USING "#,DD.DDD";100*Ne1(N,2)/(1.00038+.00095*Ne1(N,1)^.452)
8765 !
8770     PRINT TAB(70),                       !Corrected efficiency
8775     PRINT USING "DD.DDD";100*Ne1(N,2)
8780 !
8785     RETURN
8790 Exit:          !
8795     PRINTER IS CRT
8800   SUBEND
8805   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
8810 Soft_init:       !
8815   SUB Soft_init(Z_flg)
8820   !This is the "main" subprogram for sofware initialization.
8825   !The initial default entries for each calorimeter are in the subs,
8830   !Default1 thru Default6 (following this subprogram).
8835   !To change the initial menu default choices, goto label Default_sel,
8840   !(in the Menu subprogram).
8845     OPTION BASE 1
8850     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
8855     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
8860     COM /Data/ Af(10,3),INTEGER Tp(3000)
8865     COM /Menu/ INTEGER Men(17,20)
8870     COM /Init_stats/ Tcv,Rcv,Enr,Sdnr,Volts(100),INTEGER Mode,Lss
8875     COM /Screen_update/ Count,Cftime,Freq,Pwr
8880     COM /Screen_update2/ Avg,Sd
8885     COM /Stats_2/ R,Prob,INTEGER Nruns
8890     Dfile$=""                         !Clear data file name
8895     MAT V= (0)                        !Clear old data
8900     MAT E= (0)                        !
8905     MAT F= (0)                        !
8910     MAT Ne= (0)                       !
8915     MAT Header= (0)                   !Clear old header
8920     Count=0                           !Reset measurement counter
8925                                       !Then set some new defaults
8930     Header(9)=2400                    !No. of measurements
8935     Header(11)=30                     !Interval between meas (sec)
8940     Header(12)=10                     !Power in milliwatts
8945     Header(16)=0                      !Mount pre-bias
8950     Header(19)=0                      !Zero correction flag
8955     Header(20)=1                      !Set auto freq flag
8960     Header(21)=0                      !Set random freq order flag
8965                                       ! Stats init
8970     Lss=18                            !No. in avg
8975     Rcv=-2.5                          !Tuning constant
8980     Tcv=.25                           !Tuning constant
8985     Enr=(2.0*Lss-1.0)/3.0             !Expected No of runs
8990     Sdnr=SQR((16.0*Lss-29.0)/90.0)    !SD of No of runs
8995     Mode=1                            !For stats
9000     R=0                               !
9005     Prob=0                            !
9010     Nruns=0                           !
9015     Avg=0                             !Thermopile avg
9020     Sd=0                              !Thermopile std dev
9025     Pwr=0                             !
9030     !
9035     Menu_no=0                         !Call for the first menu
9040     No_rows=8                         ! Min=1, max=17
9045     No_cols=1                         ! Min=1, max=16 if No_rows >=6
9050     CALL Menu(Menu_no,No_rows,No_cols)
9055     FOR N=1 TO No_rows                !Find the option selected
9060       IF Men(N,1) THEN Menu_no=N
9065     NEXT N
9070     No_rows=8                         !For the second menu
9075     No_cols=1
9080     CALL Menu(Menu_no,No_rows,No_cols)
9085     Z_flg=Zero
9090   SUBEND
9095   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
9100 Default1:  !
9105   SUB Default1                      !Sets up defaults for coax
9110     OPTION BASE 1
9115     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
9120     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
9125     COM /Data/ Af(10,3),INTEGER Tp(3000)
9130     COM /Menu/ INTEGER Men(17,20)
9135     COM /Maxmin/ REAL Maxf,Minf
9140     Maxf=18
9145     Minf=.05
9150     Header(3)=0                       !Band ID
9155     Header(6)=1                       !Start frequency
9160     Header(7)=18                      !Stop frequency
9165     Header(8)=1                       !Step frequency
9170     Header(14)=200                    !Mount operating resistance
9175     !
9180     REDIM Af(4,3)                     !Set up Af array (auto freq mode)
9185     READ Af(*)                        !Read in Start,Stop,Step
9190     DATA .05,2,.05,2.1,4,.1,4.2,12.4,.2,12.5,18,.25  !Original
9195   SUBEND
9200   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
9205 Default2:  !
9210   SUB Default2                      !Sets up defaults for WR-90
9215     OPTION BASE 1
9220     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
9225     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
9230     COM /Data/ Af(10,3),INTEGER Tp(3000)
9235     COM /Menu/ INTEGER Men(17,20)
9240     COM /Maxmin/ REAL Maxf,Minf
9245     Maxf=12.4
9250     Minf=8.2
9255     Header(3)=90                      !Band ID
9260     Header(6)=8.2                     !Start frequency
9265     Header(7)=12.4                    !Stop frequency
9270     Header(8)=.2                      !Step frequency
9275     Header(14)=100                    !Mount operating resistance
9280   SUBEND
9285   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
9290 Default3:  !
9295   SUB Default3                      !Sets up defaults for WR-62
9300     OPTION BASE 1
9305     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
9310     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
9315     COM /Data/ Af(10,3),INTEGER Tp(3000)
9320     COM /Menu/ INTEGER Men(17,20)
9325     COM /Maxmin/ REAL Maxf,Minf
9330     Maxf=18
9335     Minf=12.4
```

```
9340    Header(3)=62              !Band ID
9345    Header(6)=12.4            !Start frequency
9350    Header(7)=18              !Stop frequency
9355    Header(8)=.25             !Step frequency
9360    Header(14)=100            !Mount operating resistance
9365  SUBEND
9370  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
9375 Default4:  !
9380  SUB Default4                !Sets up defaults for WR-42
9385    OPTION BASE 1
9390    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
9395    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
9400    COM /Data/ Af(10,3),INTEGER Tp(3000)
9405    COM /Menu/ INTEGER Men(17,20)
9410    COM /Maxmin/ REAL Maxf,Minf
9415    Maxf=26
9420    Minf=18
9425    Header(3)=42              !Band ID
9430    Header(6)=18              !Start frequency
9435    Header(7)=26              !Stop frequency
9440    Header(8)=.25             !Step frequency
9445    Header(14)=200            !Mount operating resistance
9450  SUBEND
9455  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
9460 Default5:  !
9465  SUB Default5                !Sets up defaults for WR-28
9470    OPTION BASE 1
9475    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
9480    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
9485    COM /Data/ Af(10,3),INTEGER Tp(3000)
9490    COM /Menu/ INTEGER Men(17,20)
9495    COM /Maxmin/ REAL Maxf,Minf
9500    Maxf=40
9505    Minf=26
9510    Header(3)=28              !Band ID
9515    Header(6)=37.5            !Start frequency
9520    Header(7)=41.5            !Stop frequency
9525    Header(8)=0               !Step frequency
9530    Header(14)=200            !Mount operating resistance
9535  SUBEND
9540  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
9545 Default6:  !
9550  SUB Default6                !Sets up defaults for WR-22
9555    OPTION BASE 1
9560    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
9565    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
9570    COM /Data/ Af(10,3),INTEGER Tp(3000)
9575    COM /Menu/ INTEGER Men(17,20)
9580    COM /Maxmin/ REAL Maxf,Minf
9585    Maxf=50
9590    Minf=33
9595    Header(3)=22              !Band ID
9600    Header(6)=33              !Start frequency
9605    Header(7)=50              !Stop frequency
9610    Header(8)=.25             !Step frequency
9615    Header(14)=200            !Mount operating resistance
9620  SUBEND
9625  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
9630 Default7:  !
9635  SUB Default7                !Sets up defaults for WR-15
9640    OPTION BASE 1
9645    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
9650    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
9655    COM /Data/ Af(10,3),INTEGER Tp(3000)
9660    COM /Menu/ INTEGER Men(17,20)
9665    COM /Maxmin/ REAL Maxf,Minf
9670    Maxf=75
9675    Minf=50
9680    Header(3)=15              !Band ID
9685    Header(6)=50              !Start frequency
9690    Header(7)=75              !Stop frequency
9695    Header(8)=.25             !Step frequency
9700    Header(14)=200            !Mount operating resistance
9705  SUBEND
9710  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
9715 Default8:  !
9720  SUB Default8                !Sets up defaults for WR-10
9725    OPTION BASE 1
9730    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
9735    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
9740    COM /Data/ Af(10,3),INTEGER Tp(3000)
9745    COM /Menu/ INTEGER Men(17,20)
9750    COM /Maxmin/ REAL Maxf,Minf
9755    Maxf=110
9760    Minf=75
9765    Header(3)=10              !Band ID
9770    Header(6)=75              !Start frequency
9775    Header(7)=110             !Stop frequency
9780    Header(8)=.25             !Step frequency
9785    Header(14)=200            !Mount operating resistance
9790  SUBEND
9795  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
9800 Scrn0:  !
9805  SUB Scrn0(Label$(*))
9810  ! Sets up the options of the first screen menu
9815    OPTION BASE 1
9820    DATA "   COAX "              !Label menu items
9825    DATA "   WR-90"              !
9830    DATA "   WR-62"              !
9835    DATA "   WR-42"              !
9840    DATA "   WR-28"              !
9845    DATA "   WR-22"              !
9850    DATA "   WR-15"              !
9855    DATA "   WR-10"              !
9860    READ Label$(*)
9865  SUBEND
9870  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
9875 Scrn1:  !
9880  SUB Scrn1(Label$(*))
9885  ! Sets up the options of the second screen menu
9890    OPTION BASE 1
9895    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
9900    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
9905    COM /Data/ Af(10,3),INTEGER Tp(3000)
9910    COM /Menu/ INTEGER Men(17,20)
9915    Startf=Header(6)          !Start frequency
9920    Stopf=Header(7)           !Stop frequency
9925    Stepf=Header(8)           !Step frequency
9930    Interval=Header(11)       !Measurement interval in sec
9935    Pwr=Header(12)            !Power level
9940    Zero=Header(19)           !Zero meas flag
9945    Prebias=Header(16)        !Pre-bias flag
9950    Label$(1,1)="    COMPLETE FREQ SET (auto)"
9955    Label$(2,1)="    START FREQ = "&VAL$(Startf)&" GHz      "
9960    Label$(3,1)="    STOP  FREQ = "&VAL$(Stopf)&" GHz      "
9965    Label$(4,1)="    STEP  FREQ = "&VAL$(Stepf)&" GHz      "
9970    Label$(5,1)="    POWER LEVEL = "&VAL$(Pwr)&" Mw     "
9975    Label$(6,1)="    MEAS. INTERVAL = "&VAL$(Interval)&" sec "
9980    IF Zero THEN
9985      Label$(7,1)="    ZERO DETERMINATION      "
9990    ELSE
9995      Label$(7,1)="    NO ZERO DETERMINATION  "
10000   END IF
10005   IF Prebias THEN
```

```
10010      Label$(8,1)="    MOUNT PRE-BIAS ON       "
10015    ELSE
10020      Label$(8,1)="    MOUNT PRE-BIAS OFF     "
10025    END IF
10030  SUBEND
10035  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
10040 Menu: !
10045  SUB Menu(Menu_no,No_rows,No_cols)
10050    Rev$="8609051427"! 8606240839, 8606121528, 8606111827, 8606100948
10055    Disk$=""
10060  ! General menu program written by NTL.
10065  ! 8606240839. Added 300 keyboard compatibility code.
10070  ! 8609051427. Added code to slow knob. (NTL)
10075  !      "      Removed 300 kbd compatibility and changed code to use 300
10080  !             softkey layout. (FRC)
10085    OPTION BASE 1
10090    COM /Menu/ INTEGER Men(17,20)
10095    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
10100    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
10105    COM /Data/ Af(10,3),INTEGER Tp(3000)
10110    COM /Flags/ Manual_freqs
10115    DIM A$[80],B$[90],C_sum(20),Screen$(17,20)[80]
10120 Para: !
10125    Spacing=2                        ! 1=single space, 2=double space, etc.
10130    Wrap=2                           ! Cursor wraparound; 1=no wrap (hard
10135    No_rows=MAX(1,No_rows)           ! limits), 1=wrap around, 3=raster.
10140    No_rows=MIN(17,No_rows)
10145    No_cols=MAX(1,No_cols)
10150    No_cols=MIN(40,No_cols)
10155    REDIM
         Screen$(1:No_rows,1:No_cols),Men(1:No_rows,1:No_cols),C_sum(1:No_cols)
10160    Ptr$=CHR$(129)&CHR$(136)&"=>"&CHR$(138)&CHR$(128)
10165    Clear$="  "
10170    GOSUB Defaults
10175    CLEAR SCREEN
10180    GOSUB Scrn_print
10185    Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
10190    Lcl_prty=Sys_prty+1            !Set local priority 1 higher for ON KEY
10195    ON KNOB .03,Lcl_prty GOSUB Knob_service
10200    WAIT .05
10205    FOR N=0 TO 19
10210      ON KEY N LABEL "",Lcl_prty GOTO Idle
10215    NEXT N
10220    ON KEY 0 LABEL " CONTINUE  ",Lcl_prty GOTO Exit
10225    IF Menu_no=0 THEN
10230      ON KEY 5 LABEL "SELECT OPTION",Lcl_prty GOSUB Check
10235    ELSE
10240      ON KEY 5 LABEL "CHANGE DEFAULT",Lcl_prty GOSUB Check
10245    END IF
10250    ON KBD,Lcl_prty GOSUB Kbd_service
10255    KEY LABELS ON
10260 Idle:LOOP
10265    END LOOP
10270    !
10275 Defaults:                       !Enter & set up default measurement params
10280    SELECT Menu_no
10285    CASE =1                      !Coax
10290      CALL Default1
10295    CASE =2                      !WR-90
10300      CALL Default2
10305    CASE =3                      !WR-62
10310      CALL Default3
10315    CASE =4                      !WR-42
10320      CALL Default4
10325    CASE =5                      !WR-28
10330      CALL Default5
10335    CASE =6                      !WR-22
10340      CALL Default6
10345    CASE =7                      !WR-15
10350      CALL Default7
10355    CASE =8                      !WR-10
10360      CALL Default8
10365    END SELECT
10370    RETURN
10375    !
10380 Scrn_print:                     !Print the menu's
10385    IF Menu_no>0 THEN
10390      CALL Scrn1(Screen$(*))
10395    ELSE
10400      CALL Scrn0(Screen$(*))
10405    END IF
10410    MAT Men= (0)
10415    IMAGE #,2Z
10420    IMAGE #,3Z
10425    Max_ctr=No_rows*No_cols
10430    IF Menu_no=0 THEN
10435      PRINT TABXY(28,1);CHR$(136);"SYSTEM INITIALIZATION MENU";CHR$(138)
10440    ELSE
10445      IF Header(3) THEN
10450        PRINT TABXY(30,1);CHR$(136);"WR-";Header(3);" DEFAULT
             PARAMETERS";CHR$(138)
10455      ELSE
10460        PRINT TABXY(31,1);CHR$(136);"COAX DEFAULT PARAMETERS";CHR$(138)
10465      END IF
10470    END IF
10475    Ctr=0
10480    FOR Col=1 TO No_cols
10485      FOR Row=1 TO No_rows
10490        Ctr=Ctr+1
10495        IF Max_ctr<100 THEN OUTPUT B$ USING 10415;Ctr
10500        IF Max_ctr>=100 THEN OUTPUT B$ USING 10420;Ctr
10505        B$=B$&Screen$(Row,Col)
10510        Screen$(Row,Col)=B$
10515        Stl=LEN(B$)
10520        CALL Sc(0,0,Spacing*(Row-1)+1,(Stl+2)*(Col-1)+3,B$)
10525      NEXT Row
10530    NEXT Col
10535 Default_sel:                    !Sets up initial menu defaults
10540    IF Menu_no>0 THEN            !Set up defaults for menu 1
10545      Col=1
10550      IF Header(20) THEN          !Auto freq setup
10555        Row=1
10560        Col=1
10565        GOSUB Accept
10570        FOR Row=5 TO No_rows
10575          GOSUB Accept
10580        NEXT Row
10585      ELSE                        !Start, Stop, & Step setup
10590        FOR Row=2 TO No_rows
10595          GOSUB Accept
10600        NEXT Row
10605      END IF
10610    ELSE                         !Set up default for menu 0
10615      Row=1
10620      Col=1
10625      GOSUB Accept
10630    END IF
10635    Col=1
10640    Old_col=1
10645    IF NOT Old_row THEN
10650      Row=1
10655      Old_row=1
10660    ELSE
10665      Row=Old_row                 !Keep pointer at old entry
```

```
10670    END IF
10675    CALL Sc(0,0,Spacing*(Row-1)+1,(Stl+2)*(Col-1)+1,Ptr$)
10680    RETURN
10685    !
10690 Knob_service:!
10695    Slowdown=10
10700    Kx=KNOBX+Kx
10705    Ky=KNOBY+Ky
10710    IF ABS(Kx)<Slowdown AND ABS(Ky)<Slowdown THEN 10775
10715    IF No_cols=1 THEN Ky=Kx
10720    IF Kx>0 THEN Col=Col+1
10725    IF Kx<0 THEN Col=Col-1
10730    IF Ky>0 THEN Row=Row+1
10735    IF Ky<0 THEN Row=Row-1
10740    GOSUB Rc_check
10745    CALL Sc(0,0,Spacing*(Old_row-1)+1,(Stl+2)*(Old_col-1)+1,Clear$) ! Clear
10750    CALL Sc(0,0,Spacing*(Row-1)+1,(Stl+2)*(Col-1)+1,Ptr$)            ! Print
10755    Old_row=Row
10760    Old_col=Col
10765    Kx=0
10770    Ky=0
10775    RETURN !


10780    !
10785 Kbd_service: !
10790    K$=KBD$
10795    CALL Sc(0,0,Spacing*(Old_row-1)+1,(Stl+2)*(Old_col-1)+1,Clear$)
10800    IF LEN(K$)<2 THEN 10935
10805    IF NUM(K$[1,1])<>255 THEN 10935
10810    SELECT NUM(K$[2,2])
10815    CASE =60                         ! LT arrow
10820      Col=Col-1
10825      GOSUB Rc_check
10830    CASE =62                         ! RT arrow
10835      Col=Col+1
10840      GOSUB Rc_check
10845    CASE =71                         ! Shift RT arrow
10850      Col=No_cols                    ! No check, wrap disregarded
10855    CASE =72                         ! Shift LT arrow
10860      Col=1                          ! No check
10865    CASE =84                         ! Shift DN arrow
10870      Row=No_rows                    ! No check
10875    CASE =86                         ! DN arrow
10880      Row=Row+1
10885      GOSUB Rc_check
10890    CASE =87                         ! Shift UP arrow
10895      Row=1                          ! No check
10900    CASE =94                         ! UP arrow
10905      Row=Row-1
10910      GOSUB Rc_check
10915    END SELECT
10920    CALL Sc(0,0,Spacing*(Row-1)+1,(Stl+2)*(Col-1)+1,Ptr$)
10925    Old_row=Row
10930    Old_col=Col
10935    RETURN !


10940 Rc_check: !
10945    SELECT Wrap
10950    CASE =1                          ! No wrap, hard limits
10955      IF Col<1 THEN Col=1
10960      IF Col>No_cols THEN Col=No_cols
10965      IF Row<1 THEN Row=1
10970      IF Row>No_rows THEN Row=No_rows
10975    CASE =2                          ! Wraparound on same row or col
10980      IF Col<1 THEN Col=No_cols
10985      IF Col>No_cols THEN Col=1
10990      IF Row<1 THEN Row=No_rows
10995      IF Row>No_rows THEN Row=1
11000    CASE =3                          ! Wrap to next row or col; raster
11005      IF Col<1 THEN
11010        Col=No_cols
11015        Row=Row-1
11020        IF Row<1 THEN Row=No_rows    ! Redundant test for completeness
11025      END IF
11030      IF Col>No_cols THEN
11035        Col=1
11040        Row=Row+1
11045        IF Row>No_rows THEN Row=1    ! Redundant test for completeness
11050      END IF
11055      IF Row<1 THEN
11060        Row=No_rows
11065        Col=Col-1
11070        IF Col<1 THEN Col=No_cols
11075      END IF
11080      IF Row>No_rows THEN
11085        Row=1
11090        Col=Col+1
11095        IF Col>No_cols THEN Col=1
11100      END IF
11105    END SELECT
11110    RETURN !


11115 Check:          !Check for disallowed selections before Accept is executed
11120    IF Menu_no>0 THEN                !
11125      CALL New_default(Row)          !Check for parameter change, do it
11130      GOSUB Scrn_print               !Redo the screen
11135    ELSE
11140      CALL Check0(Row,Orow,Rrow)     !Checks initial menu
11145      GOSUB Accept                   !Accept new selection
11150      Row=Rrow                       !Row to reject
11155      GOSUB Reject                   !Reject the old selection
11160      Row=Orow                       !Put the pointer back
11165    END IF
11170    RETURN
11175 Accept: !
11180    B$="ü"&Screen$(Row,Col)&"Ç"
11185    CALL Sc(0,0,Spacing*(Row-1)+1,(Stl+2)*(Col-1)+3,B$)! Inverse on
11190    Men(Row,Col)=1
11195    IF Array_printed THEN GOSUB Array_print
11200    RETURN !


11205 Reject: !
11210    B$="Ç"&Screen$(Row,Col)
11215    CALL Sc(0,0,Spacing*(Row-1)+1,(Stl+2)*(Col-1)+3,B$)! Inverse off
11220    Men(Row,Col)=0
11225    IF Array_printed THEN GOSUB Array_print
11230    RETURN !


11235 Set_wrap: !
11240    INPUT "No wrap with hard limits (1), normal wraparound (2), or raster
         (3)?",Wrap
11245    Wrap=MIN(3,Wrap)
11250    Wrap=MAX(1,Wrap)
11255    RETURN !


11260 Array_print: !
11265    FOR R=1 TO No_rows
11270      FOR C=1 TO No_cols
```

```
11275         PRINT TABXY(59+2*C,R);Men(R,C)
11280       NEXT C
11285     NEXT R
11290     Array_printed=1
11295     RETURN
11300 Exit:KEY LABELS OFF
11305   SUBEND
11310   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
11315   SUB Sc(Blank,Center,Row,Col,String$)
11320     IF Blank THEN OUTPUT KBD;CHR$(255)&CHR$(75);
11325     IF NOT Center THEN 11335
11330     Col=40-INT(LEN(String$)/2+.5)
11335     PRINT TABXY(Col+25,Row+2);String$;
11340   SUBEND
11345   ! * * * * * * * * * * * * * * * * * * * * * * * * * * *
11350 New_default: !
11355   SUB New_default(Row)            !Checks for parameter change, does it
11360     OPTION BASE 1
11365     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
11370     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
11375     COM /Data/ Af(10,3),INTEGER Tp(3000)
11380     COM /Menu/ INTEGER Men(17,20)
11385     COM /Maxmin/ REAL Maxf,Minf
11390     KEY LABELS OFF
11395     SELECT Row
11400     CASE =1                           !Row 1
11405       Header(20)=ABS(Header(20)-1)    !Toggle auto freq flag
11410     CASE =2
11415       DISP "What is the new starting frequency in GHz";
11420       INPUT Startf
11425       IF Startf<Minf THEN
11430         BEEP 2000,.1
11435         DISP "MINIMUM ALLOWED FREQ IS ";Minf;" GHz"
11440         WAIT 1.5
11445         GOTO 11415
11450       END IF
11455       IF Startf>Maxf THEN
11460         BEEP 2000,.1
11465         DISP "MAXIMUM ALLOWED FREQ IS ";Maxf;" GHz"
11470         WAIT 1.5
11475         GOTO 11415
11480       END IF
11485       IF Stopf<Startf AND Stepf>0 THEN Stepf=-Stepf
11490       Header(6)=Startf
11495     CASE =3
11500       DISP "What is the new stop frequency in GHz";
11505       INPUT Stopf
11510       IF Stopf<Minf THEN
11515         BEEP 2000,.1
11520         DISP "MINIMUM ALLOWED FREQ IS ";Minf;" GHz"
11525         WAIT 1.5
11530         GOTO 11500
11535       END IF
11540       IF Stopf>Maxf THEN
11545         BEEP 2000,.1
11550         DISP "MAXIMUM ALLOWED FREQ IS ";Maxf;" GHz"
11555         WAIT 1.5
11560         GOTO 11500
11565       END IF
11570       IF Stopf<Startf AND Stepf>0 THEN Stepf=-Stepf
11575       Header(7)=Stopf
11580     CASE =4
11585       DISP "What is the new step frequency in GHz";
11590       INPUT Stepf
11595       IF Stopf<Startf AND Stepf>0 THEN Stepf=-Stepf
11600       Header(8)=Stepf
11605     CASE =5
11610       DISP "What is the new power level in mW";
11615       INPUT Pwr
11620       Header(12)=Pwr
11625     CASE =6
11630       DISP "What is the new interval between samples (sec)";
11635       INPUT Interval
11640       Header(11)=Interval
11645     CASE =7
11650       Header(19)=ABS(Header(19)-1)    !Toggle zero flag
11655     CASE =8
11660       Header(16)=ABS(Header(16)-1)    !Toggle pre_bias flag
11665     END SELECT
11670     KEY LABELS ON
11675   SUBEND
11680   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
11685 Check0: !
11690   SUB Check0(Row,Orow,Rrow)       !Checks on excluded choices for menu 0
11695     OPTION BASE 1
11700     COM /Menu/ INTEGER Men(17,20)
11705     Orow=Row                      !Save the initial row in Orow (old row)
11710     FOR Row1=1 TO SIZE(Men,1)     !Step thru the array
11715       IF Men(Row1,1) THEN Rrow=Row1!Find the old selection
11720     NEXT Row1
11725   SUBEND
11730   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
11735 Hard_init: !
11740   SUB Hard_init                   !Initializes the system hardware
11745     CALL Init_dvm
11750     CALL Init_ndvm
11755     CALL Init_mux
11760     CALL Init_source
11765     CALL Init_eip
11770   SUBEND
11775   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
11780 Init_dvm: !
11785   SUB Init_dvm                    !Initialize the HP 3457
11790     CLEAR 722                     !Clear DVM
11795     OUTPUT 722;"NPLC 10"          !Sets integration time in # of PLCs
11800     OUTPUT 722;"DCV AUTO"         !DVM to autorange
11805     OUTPUT 722;"TERM REAR"        !Connects rear terminals of DVM
11810     OUTPUT 722;"TARM AUTO"        !Set up DVM to continually read
11815     OUTPUT 722;"TRIG AUTO"        !Start it off
11820   SUBEND
11825   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
11830 Init_ndvm: !
11835   SUB Init_ndvm                   !Initialize the Kiethly 181
11840     CLEAR 712                     !Clear DNVM
11845     REMOTE 712                    !Put 181 in remote mode
11850     OUTPUT 712;"B1"               !Display 6 1/2 digit resolution
11855     OUTPUT 712;"R1"               !2 mV range
11860     OUTPUT 712;"T0"               !Continuous readings
11865     OUTPUT 712;"P2"               !Filter on
11870     OUTPUT 712;"X"                !Do all of the above (execute)
11875   SUBEND
11880   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
11885 Init_mux: !
11890   SUB Init_mux                    !Initialize the HP 3488A MUX
11895     OUTPUT 709;"CMON 2"           !Turn on mux card monitor for card #2
11900     OUTPUT 709;"CHAN 101"         !Connects DVM to measurement element
11905     OUTPUT 709;"OPEN 200"         !Be sure power leveler not connected
11910   SUBEND
11915   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
11920 Init_eip: !
11925   SUB Init_eip                    !Set up the EIP 578
11930     OUTPUT 719;"PFG"              !Disable phase lock
11935   SUBEND
11940   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
11945 Init_source: !
11950  SUB Init_source                 !Set up the EIP 931
11955    OUTPUT 720;"RF OFF"           !Turn the RF off initially.
11960    OUTPUT 720;"CW"               !Set for CW operation
11965  SUBEND
11970  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
11975 File_name:     !
11980  SUB File_name                   !Sets up file name from date
11985    OPTION BASE 1
11990    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
11995    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
12000    COM /Data/ Af(10,3),INTEGER Tp(3000)
12005    ALLOCATE T$[11],Mo$[36]
12010    Mo$="JanFebMarAprMayJunJulAugSepOctNovDec"
12015    !
12020    IF Header(3) THEN             !To get prefix
12025      Pre$="w"&VAL$(Header(3))    !For waveguide
12030    ELSE                          !
12035      Pre$="cn"                   !Prefix for the coax type N
12040    END IF
12045    !
12050    D$=DATE$(TIMEDATE)            !For year, month, & day
12055    IF D$[1,1]=" " THEN D$[1,1]="0"
12060    M=POS((Mo$),(D$[4,6]))
12065    M=1+(M-1)/3
12070    OUTPUT M$ USING "#,2Z";M
12075    T$=TIME$(TIMEDATE)             !Time
12080    T$=T$[1,2]                     !Just the hour
12085    Dtg$=D$[10,11]&M$&D$[1,2]&T$
12090    Dfile$=Pre$&Dtg$
12095  SUBEND
12100  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
12105 Mount_id: !
12110  SUB Mount_id
12115    OPTION BASE 1
12120    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
12125    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
12130    COM /Data/ Af(10,3),INTEGER Tp(3000)
12135    CLEAR SCREEN
12140    CONTROL 1,12;1                !Turn off user soft key labels
12145    PRINT TABXY(25,16),"BOLOMETER MOUNT IDENTIFICATION"
12150    PRINT TABXY(25,18),"Maximum length: 16 characters."
12155    INPUT "Enter the mount identifier:",Mount_id$
12160  SUBEND
12165  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
12170 Meas:     !
12175  SUB Meas
12180    OPTION BASE 1
12185    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
12190    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
12195    COM /Data/ Af(10,3),INTEGER Tp(3000)
12200    COM /Init_stats/ Tcv,Rcv,Enr,Sdnr,Volts(100),INTEGER Mode,Lss
12205    COM /Pwr_lev_set_in/ P_rf,R_0
12210    COM /Io_path_names/ @Eip_578,@Eip_931,@Dp_8200,@Hp_3457
12215    COM /Initial_value/ V_ref_0,V_rf_off
12220    COM /Intr_parameters/ Desired_freq,INTEGER No_of_intrs
12225    COM /Window_flags/ Window_c$[1],Window_r$[1]
12230    COM /Screen_update/ Count,Cftime,Freq,Pwr
12235    COM /Stats_2/ R,Prob,INTEGER Nruns
12240    !
12245    INTEGER Hpib
12250    DIM New_window$[2]
12255    !
12260    Hpib=7                         !HPIB interface select code
12265    ASSIGN @Eip_578 TO 719         !EIP 578 - locking counter addr: 719
12270    ASSIGN @Eip_931 TO 720         !EIP 931 - uwave source addr: 720
12275    ASSIGN @Dp_8200 TO 714         !DP 8200 precision source addr: 714
12280    ASSIGN @Hp_3457 TO 722         !HP 3457 digital voltmeter addr: 722
12285    !
12290    P_rf=Header(12)                !RF Power, mW
12295    R_0=Header(14)                 !Mount resistance, Ohms
12300    Cycle_time=Header(11)          !Measurement interval
12305    Stop_freq=Header(7)            !Place to stop
12310    Max_count=Header(9)            !Another place to stop
12315    N=1                            !Counter for dc & freq
12320    Freq=0                         !Starting freq
12325    Rf_on=0                        !RF is off, initially.
12330    Desired_freq=0                 !Frequency set to DC
12335    New_window$="XX"               !Initialize to "don't care" state
12340    Window_c$="A"                  !Center window, "A" display
12345    Window_r$="A"                  !Right window, "A" display
12350                                   !(for interrupts from Window routines.)
12355    Na=Lss                         !No. of points to use in stability test
12360    !
12365    Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
12370    Lcl_prty=Sys_prty+1            !Set local priority 1 higher for ON KEY
12375    !
12380 Meas_control:                     !Measurement control block
12385    Header(2)=TIMEDATE             !Time at beginning (date & start time)
12390    Cftime=TIMEDATE                !Note the time for elapsed time disp
12395    Cycle_start=TIMEDATE           !Start time for wait until cycle_time
12400    !
12405 Set_interrupts:   !
12410    ON INTR Hpib,Lcl_prty CALL Intr7 !Turn on interrupt for EIP 578
12415    OUTPUT @Eip_578;"SRO2"           !Set bit 2 on the EIP 578 SRQ byte;
12420                                     !bit 2 = "counter searching"
12425!   ENABLE INTR Hpib;2
12430    ON CYCLE Cycle_time,Lcl_prty GOSUB E_meas    !Turn on meas interrupt
12435    !
12440    ON KEY 0 LABEL " ",Lcl_prty GOTO Bail_out       !Bail out if needed
12445    ON KEY 1 LABEL " ",Lcl_prty GOSUB Man_freq_chg  !Manual freq change
12450    ON KEY 5,Lcl_prty GOSUB View_c !Meas screen - change center section
12455    ON KEY 6,Lcl_prty GOSUB View_r !Meas screen - change right section
12460    ON KEY 9,Lcl_prty CALL Blank   !To blank CRT during measurement
12465    !
12470 Wait:                             !Wait for interrupt
12475    LOOP                           !Loop to wait
12480      GOSUB Time
12485      IF Count=Max_count THEN End_meas
12490!     IF Freq>Stop_freq THEN End_meas
12495    END LOOP
12500 !
12505 !The following 4 subroutines set flags that are used by the Window
12510 !subprograms to output the correct data displays; it was necessary
12515 !to accomplish that task using this code in order to avoid a problem
12520 !created during interrupt service while the display screens were
12525 !being updated.
12530 !
12535 View_c:  !
12540    IF Window_c$="A" THEN
12545      New_window$="CB"             !CB=center window, "B" display
12550    ELSE
12555      New_window$="CA"             !CA=center window, "A" display
12560    END IF
12565    RETURN
12570 View_r:     !
12575    IF Window_r$="A" THEN
12580      New_window$="RB"             !RB=right window, "B" display
12585    ELSE
12590      New_window$="RA"             !RA=right window, "A" display
12595    END IF
12600    RETURN
12605  !
12610  !  MAIN MEASUREMENT ROUTINE  ---------------------------------
```

```
12615  !
12620 E_meas:                              !Effective eff. measurement
12625    Count=Count+1                     !Count the measurements
12630    Cycle_start=TIMEDATE              !Start time for wait until cycle_time
12635    !
12640    !  ************ Change Frequency ? ******************
12645!   IF F(N,2)+119=Count THEN Next_freq=1  !Max time at any freq (60 min)
12650    IF Next_freq THEN                 !Frequency change requested
12655      CALL Rf(0,Freq,11,Rf_on)        !First, turn off rf
12660    END IF
12665    !
12670    !  ************  Power Meter
12675    CALL Dvm(Sread)                   !Read DVM (power meter)
12680    V(Count,1)=TIMEDATE               !Read clock & save
12685    V(Count,2)=Sread                  !Save DVM reading
12690    !  ************  Thermopile
12695    CALL Dnvm(Nread)                  !Read nanovoltmeter (thermopile)
12700    E(Count,1)=TIMEDATE               !Read clock & save
12705    E(Count,2)=Nread                  !Save DNVM reading
12710    IF NOT Rf_on THEN                 !When Rf off, set V_rf_off for pwr calc
12715      V_rf_off=Sread
12720    END IF
12725    IF Rf_on THEN                     !When Rf on, calc pwr & check pwr level
12730      CALL Power_lev_chk(V_ref,Sread,Pwr)
12735    END IF
12740    !  ************  Temperature
12745!   OUTPUT 709;"CHAN 107"             !Switch DVM to measure temperature
12750!   WAIT 1
12755!   CALL Dvm(Sread)                   !Read the temperature
12760!   Sread=Sread*1.E+5                 !Convert to integer
12765!   IF Sread>3.2E+4 THEN              !Trap too large spurious readings
12770!     Sread=2.6E+4                    !Set Max
12775!     BEEP 2200,.01
12780!   END IF
12785!   Tp(Count)=Sread                   !Save it in integer form
12790    !
12795!   OUTPUT 709;"CHAN 101"             !Switch DVM back to measure #2 Pwr Mtr
12800 !   ************ Finish freq change ? **********
12805 Next_freq:!
12810    IF Next_freq THEN                 !YES change frequency
12815      Freq=F(N,1)                     !New frequency
12820      Desired_freq=F(N,1)
12825      F(N,2)=Count+1                  !Put starting count into freq array
12830      SELECT Freq                     !Check for dc bias on/off, rf on/off
12835      CASE =-3                        !Measurement finished
12840        GOTO End_meas                 !Finished
12845      CASE =-2                        !Turn dc OFF
12850        CALL Dc(0,2)                  !Turn off #2 Type IV
12855      CASE =-1                        !Turn dc ON
12860        CALL Dc(1,2)                  !Turn on #2 Type IV
12865      CASE =0
12870        CALL Rf(0,Freq,15,Rf_on)      !Turn off rf
12875        Cftime=TIMEDATE               !Note the time
12880      CASE ELSE
12885        CALL Power_lev_set(V_ref,Sread)
12890        V_ref_0=V_ref                 ! Save the initial value of V_ref
12895        CALL Rf(1,Freq,15,Rf_on)      !Turn on rf at next freq
12900        Cftime=TIMEDATE               !Note the time
12905      END SELECT
12910      N=N+1                           !Increment counter
12915      Nruns=0                         !Reset some stats variables
12920      R=0                             !Reset stat
12925      Prob=0                          !Reset stat
12930      Next_freq=0                     !Lower flag after freq change
12935    END IF
12940    !
12945    CALL Screen_update                !Write current values to the screen.
12950    !
12955    PEN 1                             !Do the plotting
12960    PLOT E(Count,1)-Header(2),E(Count,2)
12965    PENUP                             !Lift pen between points - dotted line
12970    !
12975    IF Count=1 THEN Next_freq=1       !To reset a counter in Stats
12980    !
12985    !  *********  Check for Stability & Calculate Statistics **************
12990    CALL Stats(Na,E(Count,2),Next_freq)
12995    !
13000  !  END MAIN MEASUREMENT ROUTINE  ----------------------------------------
13005  !
13010 Time:                                !
13015    Cycle_stop=Cycle_start+Cycle_time
13020    T=TIMEDATE                        !Present time
13025    Count_down=INT(Cycle_stop-T)
13030    PRINT TABXY(49,8);                !Move cursor for time count-down
13035    IF Count_down<Cycle_time-1 THEN
13040      PRINT USING "#,ZZ,X";Count_down!
13045    END IF
13050    SELECT New_window$
13055    CASE "CA"
13060      CALL Window_c_a
13065      New_window$="XX"
13070    CASE "CB"
13075      CALL Window_c_b
13080      New_window$="XX"
13085    CASE "RA"
13090      CALL Window_r_a
13095      New_window$="XX"
13100    CASE "RB"
13105      CALL Window_r_b
13110      New_window$="XX"
13115    END SELECT
13120    RETURN
13125    !
13130 Man_freq_chg:                        !Changes with softkey K1
13135    Next_freq=1
13140    RETURN
13145  !
13150 Bail_out:                            !Housekeeping for bail out
13155    Header(20)=0                      !Set for manual
13160    CALL Rf(0,Freq,15,Rf_on)          !Be sure RF is off
13165    OUTPUT 722;"TRIG AUTO"            !Let DVM continue reading
13170    !
13175 End_meas:                            !End measurement loop
13180    Header(9)=Count                   !Up-date new total measurements
13185    CALL New_size                     !Redimension the arrays
13190    !
13195    OFF CYCLE                         !Turn off interrupts
13200    Stop_time=TIMEDATE                !Read clock at end
13205    Header(10)=Stop_time-Header(2)     !Calculate elapsed time
13210    OUTPUT 722;"TRIG AUTO"            !Let DVM continue reading
13215    GOSUB Dvm_status                  !Get DVM measurement parameters
13220    CALL Rf(0,Freq,15,Rf_on)          !Be sure RF is off
13225    VIEWPORT 0,128,0,100              !Back to default
13230    WINDOW 0,128,0,100                !Units = GDU's
13235    !
13240    IF Header(20) THEN SUBEXIT        !Exit for auto mode
13245    !
13250    CSIZE 3.4                         !Smaller letters
13255    MOVE 115,3
13260    LABEL "PROGRAM PAUSED"
13265    PAUSE                             !Time for look at data
13270    STATUS 1,20;Bl                    !Check for screen blanked
13275    IF Bl=0 THEN CALL Blank           !Turn screen back on
13280    !
```

```
13285 Exit:                                !Finished
13290    GINIT                             !Put graphics back to default
13295    KEY LABELS ON                     !
13300  SUBEND ! SUB Meas
13305  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
13310 Delay_start: !
13315  SUB Delay_start
13320    Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
13325    Lcl_prty=Sys_prty+1               !Set local priority 1 higher for ON KEY
13330    OUTPUT KBD;"K";                  !Clear screen
13335 Enter:KEY LABELS OFF                 !Turn off user soft key labels
13340    PRINT TABXY(27,16),"DELAYED  PROGRAM  START"
13345    T$=TIME$(TIMEDATE)                !Present time
13350    PRINT TABXY(27,18),"Present time:  ";T$
13355    INPUT "Enter the desired starting time. (1832 for 6:32 PM, 0215 for 2:15
         AM, etc).",Start$[1,4]
13360    St$=Start$[1,2]&":"&Start$[3,4]&":00"
13365    PRINT TABXY(27,18),"                    "
13370    ON KEY 0 LABEL " START  meas   ",Lcl_prty GOTO Exit
13375    ON KEY 1 LABEL " CHANGE  time  ",Lcl_prty GOTO Enter
13380    FOR N=2 TO 8
13385      ON KEY N LABEL " " GOTO Top
13390    NEXT N
13395    ON KEY 9 LABEL " BLANK CRT ",Lcl_prty CALL Blank    !To blank CRT
13400    !
13405    KEY LABELS ON
13410 Top:LOOP                             !Wait until time to start
13415      T$=TIME$(TIMEDATE)              !Get the time
13420      Ts$=T$[1,2]&T$[4,5]             !Format to compare with Start$
13425      DISP "     Starting time:  ";St$,"              Present time:  ";T$
13430      IF Ts$>=Start$ THEN Exit
13435    END LOOP
13440 Exit:                                !
13445  SUBEND
13450  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
13455 Rf: !
13460  SUB Rf(On,Freq,Pwr,Rf_on)           !Turn rf on,off, & set frequency
13465    OFF CYCLE                         !Temporarily suspend ON CYCLE
13470    OFF KEY                           !Temporarily suspend ON KEY.
13475    IF On THEN
13480 Rf_on:                               !To turn ON the RF
13485      DISABLE INTR 7
13490      BEEP 1500,.01                   !To let everyone know
13495      Rf_on=1                         !Set flag for status of RF signal
13500      OUTPUT 709;"CLOSE 200"          !Connect power meter to leveler
13505      IF Freq<1 THEN                  !1st set counter to correct band
13510        OUTPUT 719;"B2"
13515      ELSE
13520        OUTPUT 719;"B3"
13525      END IF
13530      OUTPUT 720;"FR "&VAL$(Freq)&" GH,PO "&VAL$(Pwr)&" DB" !Set 931 f & p
13535      OUTPUT 720;"RF ON"              !Turn on the source
13540      WAIT 4                          !Wait for source to settle
13545!     ENTER 719;F                     !Meas 931 output freq
13550!     Delt=Freq-F*1.E-9               !Correction is desired minus actual
13555!     Nfreq=Freq+Delt                 !Correction for source
13560!     OUTPUT 720 USING "2A,X,2D.2D,X,2A";"FR",Nfreq,"GH" !Correct it
13565!     WAIT 2
13570      OUTPUT 719;"PF "&VAL$(Freq)&" G"  !Set EIP to lock at desired freq.
13575      WAIT 6                          !Wait for mount to settle
13580      ENABLE INTR 7;2
13585    ELSE
13590 Rf_off:                              !To turn OFF the RF
13595      DISABLE INTR 7
13600      OUTPUT 720;"RF OFF"             !Turn off rf source
13605      OUTPUT 719;"PFG"                !Disable EIP phase lock
13610      OUTPUT 709;"OPEN 200"           !Disconnect power meter from leveler
13615      WAIT 2                          !Wait for mount to settle
13620      Rf_on=0
13625      Freq=0                          !Frequency is now zero
13630!     ENABLE INTR 7;2
13635    END IF                            !Back to wait for next interrupt
13640  SUBEND
13645  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
13650 Rtime_graph: !
13655  SUB Rtime_graph
13660    OPTION BASE 1
13665    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
13670    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
13675    COM /Data/ Af(10,3),INTEGER Tp(3000)
13680    COM /Xy_coordinates/ Timin,Timax,Vpmin,Vpmax
13685    No=Header(9)                      !Total # of measurements (array size)
13690    ALLOCATE A$[60]                   !String for title
13695  !
13700    CSIZE 2.6                         !Smaller letters
13705    LORG 6                            !Labels ref. top center
13710    MOVE 29,4                         !Place to put bail out msg
13715    PEN 1                             !White
13720    LABEL "PRESS K0 TO TERMINATE"     !To bail out
13725    !
13730    MOVE 101,4                        !Place to put blank screen msg
13735    LABEL "PRESS K9 TO BLANK SCREEN"  !To Blank the screen
13740    !
13745    CSIZE 3.4                         !Change size again
13750    PEN 5                             !Cyan
13755    MOVE 64,5                         !For horizontal axes label
13760    LABEL "TIME (min)"                !Write label
13765    MOVE 1,35                         !For vertical axis label
13770    LDIR PI/2                         !Rotate 90
13775    LABEL "MICROVOLTS"                !For thermopile
13780    LDIR 0                            !Back to horizontal
13785    VIEWPORT 13,125,8,60              !Subset of screen area
13790    WINDOW Timin,Timax,Vpmin,Vpmax    !Scale factors
13795    !
13800    ! Set up x-axis tic and label spacing
13805    Range=Timax-Timin                  !Horizontal scale range in seconds
13810    SELECT Range
13815    CASE <=5400                        !For Range <= 90 min
13820      X=60                             !X-tics every 1 min
13825      Xtic=10                          !10 tics/major div
13830      Stp=600                          !Labels every 10 min
13835    CASE <=18000                       !For 300 min >=Range> 120 min
13840      X=600                            !X-tics every 10 min
13845      Xtic=3                           !3 tics/major div
13850      Stp=1800                         !Label every 30 min
13855    CASE <=36000                       !For 600 min >=Range> 300 min
13860      X=600                            !H-tics every 10 min
13865      Xtic=6                           !6 tics/major div
13870      Stp=3600                         !Label every 60 min
13875    CASE >36000                        !For Range> 600 min
13880      X=600                            !H-tics every 10 min
13885      Xtic=12                          !12 tics/major div
13890      Stp=7200                         !Label every 120 min
13895    END SELECT
13900    Y=(Vpmax-Vpmin)/16                !Calculate vertical ticks
13905    AXES X,Y,Timin,Vpmin,Xtic,4,4     !Draw axes with ticks at the right place
13910    AXES X,Y,Timax,Vpmax,Xtic,4       !Same ticks on the other sides
13915    CLIP OFF                          !Allow labels outside viewport
13920    CSIZE 3.0                         !Smaller characters for axis labels
13925    FOR I=0 TO Timax-Timin STEP Stp        !Label every ? on X axis
13930      MOVE Timin+I,Vpmin-Y/10              !Just below x axis
13935      LABEL USING "#,DDDD";(Timin+I)/60    !No CR/LF
13940    NEXT I
13945    LORG 8                                 !REf. center rt. end
```

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13950    FOR I=Vpmin TO Vpmax STEP 4*Y         !Label every 10*Y on Y axis
13955      MOVE Timin-.01,I                    !To the left of X axis
13960      LABEL USING "#,DDD.D";1.E+6*I       !No CR/LF - microvolts
13965    NEXT I
13970    PEN 2
13975    CLIP ON                               !Keep plot inside viewport
13980    PENUP
13985  SUBEND ! Rtime_graph
13990  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
13995 Stats: !
14000  SUB Stats(Na,E,Next_freq)        !Statistics to determine when to change
14005                                   !to next frequency
14010    OPTION BASE 1
14015    COM /Stats/ Eavg(100,2),Ecal(100),INTEGER N
14020    COM /Init_stats/ Tcv,Rcv,Enr,Sdnr,Volts(100),INTEGER Mode,Lss
14025    COM /Window_flags/ Window_c$[1],Window_r$[1]
14030    COM /Screen_update2/ Avg,Sd
14035    INTEGER Ta
14040   !
14045   ! Na - number of data points in the average & SD calculation
14050   ! E - latest thermopile reading (recieved parameter)
14055   ! Next_freq - flag indicating switch to next frequency (returned
14060   !           parameter) and flag to reset average counter
14065   ! Eavg - In Col 1: freq; in Col 2: Avg thermopile V
14070   ! Ecal - scratch array for avg
14075   ! N - keep track of No. of measurement values added
14080   ! Ecal - scratch array for avg
14085   !
14090    REDIM Ecal(Na)                 !Make it the right size
14095    ALLOCATE D(Na)                 !Temp for calculation
14100    IF Next_freq THEN              !Reset counter-This loop for count=1
14105      N=0                          !Reset counter
14110      MAT Ecal= (0)                !Zero out calc array
14115      Next_freq=0                  !Reset freq flag
14120    END IF
14125    N=N+1                          !Increment counter
14130    SELECT N                       !Check for sufficient data
14135    CASE <Na                       !If not
14140      Ecal(N)=E                    !Fill array
14145      GOTO Exit                    !No calculation until all data in
14150    CASE =Na                       !Last point
14155      Ecal(Na)=E                   !Last reading added
14160    CASE >Na                       !Normal operation
14165      FOR K=1 TO Na-1
14170        Ecal(K)=Ecal(K+1)          !Drop off bottom the first reading
14175      NEXT K
14180    END SELECT
14185    Ecal(Na)=E                     !Last reading added at top
14190    MAT Volts= Ecal                !Transfer Ecal to Find_trend array Volts
14195    CALL Find_trend(Next_freq)     !Stability check
14200    IF Next_freq THEN              !If stable then reset for next series
14205      N=0                          !Reset counter
14210      MAT Ecal= (0)                !Zero out calc array
14215    END IF
14220    GOSUB Calc_sd                  !Avg & SD
14225    GOTO Exit                      !Finished
14230 Calc_sd:                          !Sub to calculate average & SD
14235    Avg=SUM(Ecal)/Na               !New average
14240    MAT D= Ecal-(Avg)              !Subtract mean from each element
14245    MAT D= D . D                   !Square each element
14250    Sd=SQR(SUM(D)/(Na-1))          !Standard Deviation
14255    IF Sd<3.E-9 THEN BEEP 2200,.01 !Signal when SD below threshold
14260    RETURN
14265 Exit:        !
14270  SUBEND
14275  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
14280 Dnvm: !
14285  SUB Dnvm(Nread)                    !Obtain reading(s) from nanovoltmeter
14290    ENTER 712;Nread                  !Actually get reading
14295  SUBEND
14300  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
14305 Dvm: !
14310  SUB Dvm(Sread)
14315    ENTER 722;Sread
14320  SUBEND
14325  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
14330 Dc: !
14335  SUB Dc(On,Unit)                    !Turn Type IV (dc) on,off for power
14340                                     !meter #1 or #2
14345    DISABLE                          !Temporarily suspend ON CYCLE
14350    SELECT Unit                      !Choose #1 or #2
14355    CASE =1
14360      IF On THEN
14365        OUTPUT 709;"CLOSE 207"       !Turn on #1 Type IV (110 VAC)
14370      ELSE
14375        OUTPUT 709;"OPEN 207"        !Turn off #1 Type IV (110 VAC)
14380      END IF                         !Back to wait for next interrupt
14385    CASE =2
14390      IF On THEN
14395        OUTPUT 709;"CLOSE 209"       !Turn on #2 Type IV (110 VAC)
14400      ELSE
14405        OUTPUT 709;"OPEN 209"        !Turn off #2 Type IV (110 VAC)
14410      END IF                         !Back to wait for next interrupt
14415    END SELECT
14420    ENABLE                           !Turn interrupts back on
14425  SUBEND
14430  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
14435 Std_dev: !
14440  SUB Std_dev                        !To calculate the std dev of subsets of
14445                                     !thermopile array, E
14450    OPTION BASE 1
14455    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
14460    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
14465    COM /Data/ Af(10,3),INTEGER Tp(3000)
14470    INTEGER N,Na,N1,N2
14475    N1=1                             !Default
14480    N2=100                           !Default
14485  !
14490    Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
14495    Lcl_prty=Sys_prty+1              !Set local priority 1 higher for ON KEY
14500  ! Softkey interrupts:
14505    CONTROL 2,2;1                   !Turn on user menu #1
14510    CONTROL 1,12;0                  !Turn on user soft key labels
14515    FOR N=0 TO 19
14520      ON KEY N LABEL " " GOTO Top
14525    NEXT N
14530    ON KEY 0 LABEL "  PREV MENU   ",Lcl_prty GOTO Exit
14535    ON KEY 5 LABEL "  CHANGE N1   ",Lcl_prty GOSUB N_one
14540    ON KEY 6 LABEL "  CHANGE N2   ",Lcl_prty GOSUB N_two
14545    ON KEY 7 LABEL " CALCULATE SD ",Lcl_prty GOSUB Calc_sd
14550    S_flg=1
14555 Top:LOOP
14560      IF S_flg THEN GOSUB Screen
14565    END LOOP
14570  !
14575    GOTO Exit                        !Finished
14580  !
14585 N_one:                              !Calculation starting point
14590    INPUT "Calculation starting point # ?",N1
14595    S_flg=1
14600    RETURN
14605  !
14610 N_two:                              !Calculation stoping point
14615    INPUT "Calculation stopping point # ?",N2
```

```
14620    S_flg=2
14625    RETURN
14630 !
14635 Calc_sd:                          !Sub to calculate average & SD
14640    Na=N2-N1+1
14645    ALLOCATE Ecal(Na),D(Na)         !Temporary for calculation
14650    MAT Ecal= (0)                   !Reset array
14655    MAT D= (0)                      !Reset array
14660    FOR N=N1 TO N2
14665      Ecal(N+1-N1)=E(N,2)           !Move the data into calc array
14670    NEXT N
14675    Avg=SUM(Ecal)/Na                !Average
14680    MAT D= Ecal-(Avg)               !Subtract mean from each element
14685    MAT D= D . D                    !Square each element
14690    Sd=SQR(SUM(D)/(Na-1))           !Standard Deviation
14695    PRINT TABXY(20,14);CHR$(136);   !Move cursor for average
14700    PRINT USING "6D.1D,X,2A";Avg*1.E+9,"nV"   !Erf
14705    PRINT TABXY(30,16);             !Move cursor for SD
14710    PRINT USING "4D.2D,X,2A";Sd*1.E+9,"nV"
14715    DEALLOCATE Ecal(*),D(*)
14720    RETURN
14725 Screen:                           !
14730    T1=(E(N1,1)-Header(2))/60       !Starting elapsed time, min
14735    T2=(E(N2,1)-Header(2))/60       !Stoping elapsed time, min
14740    OUTPUT KBD;"K";               !Clear screen
14745    PRINT TABXY(5,2),CHR$(137)&"M I C R O _ S D T"&CHR$(136)
14750    CLIP 0,80,62,100                !To draw a rectangle
14755    PEN 1
14760    FRAME
14765    PRINT CHR$(140)                 !Cyan characters
14770    PRINT TABXY(18,6),"- - - - CALCULATE STANDARD DEVIATION - - - -"
14775    PRINT TABXY(10,8),"Starting point (N1):  ";CHR$(136);N1;CHR$(140)
14780    PRINT TABXY(45,8),"Time: ";CHR$(136);
14785    OUTPUT CRT USING "3Z.D,3A,3A";T1;CHR$(140);"min"
14790    PRINT TABXY(10,10),"Stopping point (N2):  ";CHR$(136);N2;CHR$(140)
14795    PRINT TABXY(45,10),"Time: ";CHR$(136);
14800    OUTPUT CRT USING "3Z.D,3A,3A";T2;CHR$(140);"min"
14805    PRINT TABXY(10,12),"Total points: ";CHR$(136);N2-N1+1;CHR$(140)
14810    PRINT TABXY(10,14),"Average: "
14815    PRINT TABXY(10,16),"Standard Deviation:"
14820    IF V(1,2) OR E(1,2) THEN
14825      PRINT TABXY(59,17),CHR$(129)&" DATA IN MEMORY "&CHR$(128)
14830      IF Dfile$="" THEN
14835        PRINT TABXY(59,18),CHR$(129)&" (NO FILE NAME) "&CHR$(128)
14840      ELSE
14845        PRINT TABXY(59,18),CHR$(129)&" FILE:"&Dfile$&CHR$(128)
14850      END IF
14855    ELSE
14860      PRINT TABXY(56,18),CHR$(129)&" NO DATA IN MEMORY "&CHR$(128)
14865    END IF
14870    S_flg=0
14875    RETURN
14880 Exit:          !
14885  SUBEND
14890  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
14895 Freq_change_pts: !
14900  SUB Freq_change_pts(Display)
14905    OPTION BASE 1
14910    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
14915    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
14920    COM /Data/ Af(10,3),INTEGER Tp(3000)
14925    COM /Matrix_var/ Insert_matrix(50),Choice$[1]
14930    COM /Matrix_var/ INTEGER Lower_index,No_of_inserts
14935    !
14940    INTEGER N,No1,Start,Finish,X,Y,Z
14945    !
14950    IF NOT Display THEN             !No display or manual input
14955      GOSUB Update_screen           !For auto mode
14960      IF Header(21) THEN            !Random freq flag
14965        CALL Random_f               !Put freq in random order
14970      END IF
14975      SUBEXIT
14980    ELSE
14985      CLEAR SCREEN
14990      GOSUB Update_screen
14995      IF Header(21) THEN            !Random freq flag
15000        CALL Random_f               !Put freq in random order
15005        GOSUB Update_screen
15010      END IF
15015    END IF
15020    !
15025 Update_values:  !
15030    Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))
15035    Lcl_prty=Sys_prty+1
15040    !
15045    FOR Nn=0 TO 19
15050      ON KEY Nn LABEL " ",Lcl_prty GOTO Wait_loop
15055    NEXT Nn
15060    ON KEY 5 LABEL " CHANGE FREQ  ",Lcl_prty GOSUB Change_freq
15065    ON KEY 6 LABEL " ADD FREQ'S ",Lcl_prty GOSUB Add_freqs
15070    ON KEY 0 LABEL " CONTINUE ",Lcl_prty GOTO Sub_exit
15075    !
15080!   GOSUB Update_screen
15085!   IF Header(21) THEN              !Random freq flag
15090!     CALL Random_f                 !Put freq in random order
15095!     GOSUB Update_screen
15100!   END IF
15105    KEY LABELS ON
15110    !
15115 Wait_loop:                        ! Wait for ON KEY interrupt
15120    GOTO Wait_loop
15125    !
15130 Update_screen:!
15135    No1=Header(5)                   !# of meas frequencies + final rf off
15140    IF Header(19) THEN              !For zero correction
15145      F(1,1)=-1                     !To turn ON dc
15150      F(No1+2,1)=0                  !To turn OFF rf
15155      F(No1+3,1)=-2                 !To turn OFF dc
15160      F(No1+4,1)=-3                 !To terminate the measurement
15165      Start=2
15170      Finish=No1+1
15175    ELSE                            !No zero correction measurement
15180      F(No1+1,1)=0                  !To turn OFF rf
15185      F(No1+2,1)=-3                 !To terminate the measurement
15190      Start=1
15195      Finish=No1
15200    END IF
15205    X=1
15210    Y=3
15215    Z=3
15220    PRINT TABXY(X,1),"No.",TABXY(X+5,1),"Freq (GHz)"
15225    FOR N=Start TO Finish           !Input freq. & starting points
15230      IF F(N,1)<1 AND N<=No_elements THEN
15235        OUTPUT F$ USING "XX,Z.DDD";F(N,1)
15240      ELSE
15245        OUTPUT F$ USING "3D.DDD";F(N,1)
15250      END IF
15255      IF Start=1 THEN
15260        PRINT TABXY(X,Y);N;TABXY(X+5,Y);F$
15265      ELSE
15270        PRINT TABXY(X,Y);N-1;TABXY(X+5,Y);F$
15275      END IF
15280      Y=Y+1
15285      SELECT Y
```

```
15290     CASE =19,=39,=59
15295       X=X+20
15300       Y=Z
15305       PRINT TABXY(X,1),"No.",TABXY(X+5,1),"Freq (GHz)"
15310     END SELECT
15315   NEXT N
15320   RETURN ! Update_screen
15325   !
15330 Add_freqs:   !
15335   Lcl_prty_2=VAL(SYSTEM$("SYSTEM PRIORITY"))+2
15340   MAT Insert_matrix= (0)
15345   !
15350   FOR M=1 TO 7
15355     ON KEY M LABEL " ",Lcl_prty_2 GOTO Wait_loop_2
15360   NEXT M
15365   ON KEY 5 LABEL "BEFORE FREQ #1",Lcl_prty_2 GOSUB Insert_before
15370   ON KEY 6 LABEL "AFTER LAST FRQ",Lcl_prty_2 GOSUB Insert_after
15375   ON KEY 7 LABEL "INSERT BETWEEN",Lcl_prty_2 GOSUB Insert_between
15380   ON KEY 0 LABEL " CONTINUE ",Lcl_prty_2 GOTO Update_values
15385   !
15390 Wait_loop_2:   ! Wait for ON KEY interrupt.
15395   GOTO Wait_loop_2
15400   !
15405 Insert_before:   !
15410   KEY LABELS OFF
15415   INPUT "No. of frequencies to be added:",No_of_inserts
15420   FOR I=1 TO No_of_inserts
15425     INPUT "New frequency:",Insert_matrix(I)
15430   NEXT I
15435   Choice$="B"  ! Flag for "Before first frequency"
15440   CALL Insert_array
15445   GOSUB Update_screen
15450   KEY LABELS ON
15455   RETURN ! Insert_before
15460   !
15465 Insert_between:   !
15470   KEY LABELS OFF
15475   INPUT "No. of frequencies to be added:",No_of_inserts
15480   INPUT "No. of lower frequency (from display):",Lower_index
15485   FOR I=1 TO No_of_inserts
15490     INPUT "New frequency:",Insert_matrix(I)
15495   NEXT I
15500   Choice$="I"  ! Flag for "In-between frequencies"
15505   CALL Insert_array
15510   GOSUB Update_screen
15515   KEY LABELS ON
15520   RETURN ! Insert_between
15525   !
15530 Insert_after:   !
15535   KEY LABELS OFF
15540   INPUT "No. of frequencies to be added:",No_of_inserts
15545   FOR I=1 TO No_of_inserts
15550     INPUT "New frequency:",Insert_matrix(I)
15555   NEXT I
15560   Choice$="A"  ! Flag for "After last frequency"
15565   CALL Insert_array
15570   GOSUB Update_screen
15575   KEY LABELS ON
15580   RETURN ! Insert_after
15585   !
15590   RETURN ! Add_freqs
15595   !
15600 Change_freq:!
15605   KEY LABELS OFF
15610   INPUT "No. of frequency to be changed:",N_screen
15615   INPUT "Frequency (GHz)?",New_freq
15620   IF Header(19) THEN
15625     GOSUB Zero_flag_on
15630   ELSE
15635     GOSUB Zero_flag_off
15640   END IF
15645   KEY LABELS ON
15650   RETURN ! Change_freq
15655   !
15660 Zero_flag_off:   !
15665   N=N_screen
15670   F(N,1)=New_freq
15675   IF F(N,1)<1 THEN
15680     OUTPUT F$ USING "XX,Z.DD";F(N,1)
15685   ELSE
15690     OUTPUT F$ USING "3D.DD";F(N,1)
15695   END IF
15700   SELECT N
15705   CASE <=16
15710     X=1
15715     Y=N+2
15720   CASE <=32
15725     X=21
15730     Y=N-14
15735   CASE <=48
15740     X=41
15745     Y=N-30
15750   END SELECT
15755   PRINT TABXY(X,Y);N;TABXY(X+5,Y);F$
15760   RETURN ! Zero_flag_off
15765   !
15770 Zero_flag_on:   !
15775   N=N_screen+1
15780   F(N,1)=New_freq
15785   IF F(N,1)<1 THEN
15790     OUTPUT F$ USING "XX,Z.DD";F(N,1)
15795   ELSE
15800     OUTPUT F$ USING "3D.DD";F(N,1)
15805   END IF
15810   SELECT N_screen
15815   CASE <=16
15820     X=1
15825     Y=N_screen+2
15830   CASE <=32
15835     X=21
15840     Y=N_screen-14
15845   CASE <=48
15850     X=41
15855     Y=N_screen-30
15860   END SELECT
15865   PRINT TABXY(X,Y);N_screen;TABXY(X+5,Y);F$
15870   RETURN ! Zero_flag_on
15875!
15880 Sub_exit:KEY LABELS OFF           !
15885  SUBEND ! Freq_change_pts
15890  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
15895 Runs: !
15900  SUB Runs(X(*),INTEGER N,Nruns)
15905    !This subroutine Runs determines the number of successive "runs"
15910    !that occurs in the data array "X", and returns the result in "Nruns".
15915    !
15920    OPTION BASE 1
15925    INTEGER I,J
15930    Nruns=0
15935    I=1
15940 Segment_1:!
15945    IF (I+1)>=N THEN GOTO Segment_2
15950    Oldiff=X(I+1)-X(I)
15955    IF (Oldiff<>0.) THEN
```

```
15960      Oldiff=FNSign(1.0,Oldiff)
15965      GOTO Segment_2
15970    END IF
15975    I=I+1
15980    GOTO Segment_1
15985 Segment_2:!
15990    FOR J=I+1 TO N-1
15995      Diff=X(J+1)-X(J)
16000      IF (Diff<>0.) THEN
16005        Diff=FNSign(1.0,Diff)
16010        IF (Diff<>Oldiff) THEN
16015          Nruns=Nruns+1
16020          Oldiff=Diff
16025        END IF
16030      END IF
16035    NEXT J
16040    Nruns=Nruns+1
16045  SUBEND    ! Runs
16050  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
16055 Taub: !
16060  SUB Taub(X(*),INTEGER N,REAL Tau,Prob)
16065    !This subroutine Taub computes the probability "Prob" from the data
16070    !array contained in "X".
16075    !
16080    OPTION BASE 1
16085    INTEGER I,J
16090    REAL U,S,Susq,Tx,Tiechk,Xtmp,T,Vars
16095    !
16100    S=0.
16105    Susq=0.
16110    FOR I=1 TO N-1
16115      FOR J=I+1 TO N
16120        U=X(J)-X(I)
16125        IF (U<>0.) THEN U=FNSign(1.,U)
16130        S=S+U
16135        Susq=Susq+U*U
16140      NEXT J
16145    NEXT I
16150    Tau=S/SQR(Susq*N*(N-1)/2)
16155    Tx=0.
16160    Tiechk=Susq-(N*(N-1))/2
16165    IF Tiechk<0. THEN
16170      MAT SORT X(*)
16175      Xtmp=X(1)
16180      T=1.
16185      FOR I=2 TO N
16190        IF X(I)=Xtmp THEN
16195          T=T+1.
16200          GOTO End_of_taubloop
16205        ELSE
16210          Xtmp=X(I)
16215        END IF
16220        IF T>1.0 THEN
16225          Tx=Tx+T*(T-1)*(2.*T+5.)
16230          T=1.0
16235        END IF
16240 End_of_taubloop:!
16245      NEXT I
16250    END IF
16255    Vars=(N*(N-1)*(2*N+5)-Tx)/18.0
16260    Z=S/SQR(Vars)
16265    CALL Errf(Z,Prob)
16270  SUBEND   ! Taub
16275  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
16280 Fnsign: !
16285  DEF FNSign(A,B)
16290    !This function "SIGN" returns:
16295    !    ABS(A) if B>=0
16300    !   -ABS(A) if B<0
16305    !
16310    IF B<0 THEN
16315      RETURN -ABS(A)
16320    ELSE
16325      RETURN ABS(A)
16330    END IF
16335  FNEND   ! Sign
16340  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
16345 Errf: !
16350  SUB Errf(X,P)
16355    ! From FORTRAN code supplied by D. Vecchia,870929.
16360    ! This subroutine computes the error function for the value X,
16365    ! and returns the answer in the variable P. The answer is not
16370    ! the standard result, but is computed on the basis of the last
16375    ! three conditional statements at the end of the subroutine.
16380    !
16385    DATA
         0.319381530,-0.356563782,1.781477937,-1.8212515978,1.330274429,0.2316419
16390    READ B1,B2,B3,B4,B5,P
16395    Z=ABS(X)
16400    T=1/(1+P*Z)
16405    Cdf=1-((.39894228040143)*EXP(-.5*Z*Z))*
         (B1*T+B2*T*T+B3*T*T*T+B4*T*T*T*T+B5*T*T*T*T*T)
16410    IF X<0 THEN P=1-Cdf
16415    IF X=0 THEN P=.5
16420    IF X>0 THEN P=Cdf
16425  SUBEND    ! errf
16430  ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
16435 Find_trend: !
16440  SUB Find_trend(Stable_run)
16445 ! The purpose of this of subroutine is to determine if
16450 ! stability exist in a given set of data points. This
16455 ! is determined by computing two statistical values,
16460 ! denoted by R and Prob, and comparing these values to
16465 ! pre-determined constants. A decision is based on the
16470 ! results of this comparison as follows:
16475 !      R > Rcv or Prob > (1 - Tcv)
16480 ! If either of these conditions are met, then the sub-
16485 ! routine returns Stable_run=1 , which means stability
16490 ! exist. If stability does not exist, then Stable_run=0.
16495 !
16500    OPTION BASE 1
16505    COM /Init_stats/ Tcv,Rcv,Enr,Sdnr,Volts(100),INTEGER Mode,Lss
16510    COM /Stats_2/ R,Prob,INTEGER Nruns
16515    REAL Vwork(100)
16520    INTEGER I,N
16525 !
16530 !Compute the statistics of the number of runs, R:
16535    CALL Runs(Volts(*),Lss,Nruns)
16540    R=(Nruns-Enr)/Sdnr
16545 !
16550 !Copy vector Volts into vector Vwork for use in SUB Taub;
16555 !Taub computes the probability Prob:
16560    MAT Vwork= Volts
16565    CALL Taub(Vwork(*),Lss,Tau,Prob)
16570 !
16575 ! - - -Nruns,R,Prob printed by Screen_update
16580 !
16585 ! Check for monotonically increasing/decreasing data.
16590    IF R>=Rcv AND Prob>Tcv AND Prob<(1-Tcv) THEN
16595      Stable_run=1
16600    ELSE
16605       !Data is not stable; fetch new data point and re-compute the
16610       !statistics.
16615      GOTO Sub_exit
```

```
16620     END IF
16625 Sub_exit:!
16630   SUBEND  ! Find_trend
16635   ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
16640 Settle_1: !
16645   SUB Settle_1(N1,N2,Erf,Nmid,Nst,Nsp,S_flg)
16650     !
16655     ! N1: Frequency starting point
16660     ! N2: Frequency stopping point
16665     ! Nst: Beginning of settled run
16670     ! Nsp: End of settled run
16675     ! Erf: is the final settled value
16680     ! Nmid: is the mid point of the array range from which Erf came
16685     ! S_flg: A flag to pause after every call to Find_trend subprogram
16690     !
16695     OPTION BASE 1
16700     INTEGER I,N
16705     COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
16710     COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
16715     COM /Data/ Af(10,3),INTEGER Tp(3000)
16720     COM /Init_stats/ Tcv,Rcv,Enr,Sdnr,Volts(100),INTEGER Mode,Lss
16725     !
16730     Erf=0                           !Initialize
16735     Nst=N2-Lss                      !
16740     Nsp=Nst+Lss-1
16745     FOR N=Nst TO Nsp
16750       Erf=Erf+E(N,2)                !Sum
16755     NEXT N
16760     Erf=Erf/(Nsp-Nst+1)             !Average
16765     Nmid=INT((Nst+Nsp)/2)           !Mid-point
16770   SUBEND
16775 !
16780 Dp_8200:!
16785 !****************************
16790   SUB Dp_8200(Value_0,Mode_0$)
16795 !****************************
16800 !
16805 !Rev: 880503 BFR
16810 !
16815 !INPUT(S):         Value_0 - the numerical value of the desired
16820 !                            voltage or current setting.
16825 !                  Mode$_0 - a single character specifying the mode;
16830 !                            "V" = voltage  "A" = current.
16835 !                  @Dp_8200 - IO path name for HPIB address of the
16840 !                             Data Precision source; addr: 713
16845 !                             (through COM /Io_path_names/).
16850 !                  V_ref_0 - initial value of the voltage setting when a
16855 !                            new frequency is requested; the subroutine
16860 !                            will not allow a setting lower than this
16865 !                            value, and will re-set the DP 8200 to this
16870 !                            value if Value_0 is less than V_ref_0.
16875 !
16880 !OUTPUT(S):        Output voltage or current setting on the DP 8200.
16885 !
16890 !Maximum available output settings:
16895 !               Voltage
16900 !                  100 mV range - 104.8575 mV
16905 !                    10 V range - 10.48575 V
16910 !                   100 V range - 104.8575 V
16915 !               Current
16920 !                  100 mA range - 100 mA
16925 !
16930 !Software lockouts (maximum output allowed):
16935 !               Max_voltage (or Min_voltage)
16940 !               Max_current  (set at the line labelled "Sftware_lockout")
16945 !
16950     OPTION BASE 1
16955 !
16960     COM /Io_path_names/ @Eip_578,@Eip_931,@Dp_8200,@Hp_3457
16965     COM /Initial_value/ V_ref_0,V_rf_off
16970 !
16975     DIM Sign$[1],Range$[1]
16980     INTEGER No_dec_digits
16985 !
16990 Sftware_lockout:!
16995     Min_voltage=1.6! 1.9 V originally
17000     Max_current=100! 100 mA
17005 !
17010 !Copy initial values into reference variables:
17015     Value=ABS(Value_0)  ! Absolute value required.
17020     Mode$=UPC$(Mode_0$) ! Force uppercase letters.
17025 !
17030     IF Mode$="V" THEN
17035       IF Value<Min_voltage THEN
17040         Present_max=Min_voltage
17045         Unit$=" V"
17050         GOSUB Error_lockout
17055         BEEP 1500,.05
17060         Value_0=V_ref_0
17065         Value=ABS(V_ref_0)
17070       END IF
17075     END IF ! Mode$="V"
17080     IF Mode$="A" THEN
17085       IF Value>Max_current THEN
17090         Present_max=Max_current
17095         Unit$=" mA"
17100         GOSUB Error_lockout
17105         Value=Max_current
17110       END IF
17115     END IF ! Mode$="A"
17120 !
17125     IF Value_0<0 THEN
17130       Sign$="-"
17135     ELSE
17140       Sign$="+"
17145     END IF!  Value_0<0
17150 !
17155     IF Mode$="V" THEN
17160       SELECT Value
17165       CASE <=1.048575E-1
17170         Range$="0"      ! 100 mV range; max value= 104.8575 mV
17175         No_dec_digits=4 ! Format required: NNNDDDD
17180                         ! N = integer numbers  D = decimal numbers
17185       CASE <=10.48575
17190         Range$="1"      ! 10 V range; max value= 10.48575 V
17195         No_dec_digits=5 ! Format required: NNDDDDD
17200       CASE <=104.8575
17205         Range$="2"      ! 100 V range; max value= 104.8575 V
17210         No_dec_digits=5 ! Format required: NNNDDDD
17215       END SELECT!  Value
17220     END IF!  Mode$="V"
17225 !
17230     IF Mode$="A" THEN
17235       Range$=""
17240       No_dec_digits=3   ! Format required: NNNDDD
17245     END IF!  Mode$="A"
17250 !
17255     New_value=Value*10^No_dec_digits! Move decimal point over.
17260 !
17265 !The following code writes alphanumeric data into the string
17270 !variable "Dp_output$":
17275     IF Mode$="V" THEN
17280       OUTPUT Dp_output$ USING "3A,7Z";Mode$&Range$&Sign$,New_value
17285     ELSE
```

```
17290      OUTPUT Dp_output$ USING "2A,6Z";Mode$&Sign$,New_value
17295    END IF! Mode$="V"
17300 !
17305    GOTO Set_output! Set output of DP 8200 and SUBEND.
17310 !
17315 Error_lockout:!
17320    BEEP
17325    PRINT
17330    PRINT USING "K";"Output requested ",Value,Unit$," exceeds maximum
         allowed."
17335    PRINT USING "K";"Present maximum: ",Present_max,Unit$
17340    PRINT "Program is PAUSEd in subroutine DP_8200_source."
17345    PRINT
17350    PAUSE
17355    RETURN ! Error_lockout
17360 !
17365 Set_output:!
17370    BEEP 1500,.05
17375    OUTPUT @Dp_8200;Dp_output$
17380 !
17385  SUBEND !  Dp_8200
17390 !
17395 Power_lev_set:!
17400 !*****************************
17405  SUB Power_lev_set(V_ref,Sread)
17410 !*****************************
17415 !
17420 ! INPUT(S) : Sread - power meter voltage, RF is off.
17425 ! OUTPUT(S): V_ref - reference voltage for the DP 8200.
17430 !
17435    COM /Pwr_lev_set_in/ P_rf,R_0
17440    COM /Initial_value/ V_ref_0,V_rf_off
17445 !
17450    V_rf_off=Sread           ! Power meter voltage, RF is off.
17455    V_ref=SQR(V_rf_off*V_rf_off-(P_rf/1000*R_0))
17460    CALL Dp_8200(V_ref,"V")  ! Set the voltage reference to initial value.
17465 !
17470  SUBEND ! Power_lev_set
17475 !
17480 Intr7:!
17485 !********
17490  SUB Intr7
17495 !********
17500 !
17505    COM /Io_path_names/ @Eip_578,@Eip_931,@Dp_8200,@Hp_3457
17510    COM /Intr_parameters/ Desired_freq,INTEGER No_of_intrs
17515 !
17520    No_of_intrs=No_of_intrs+1
17525    Source_freq=Desired_freq
17530 !
17535 !
17540    OUTPUT @Eip_931 USING "2A,X,2D.2D,X,2A";"FR",Source_freq,"GH"
17545    WAIT 2
17550 !
17555    OUTPUT @Eip_578;"RS"     ! Reset the counter to allow a measurement.
17560    WAIT 2
17565    ENTER @Eip_578;Freq_m    ! Measure the EIP uWave Source frequency with
17570                             ! the EIP counter.
17575 !
17580    Measured_freq=Freq_m/1.E+9                ! Convert to GHz.
17585    Offset=DROUND(Desired_freq-Measured_freq,5)! Units are GHz.
17590    IF Offset>=.2*Desired_freq THEN Offset=.2*Desired_freq
17595    Source_freq=Source_freq+Offset
17600 !
17605    OUTPUT @Eip_931 USING "2A,X,2D.2D,X,2A";"FR",Source_freq,"GH"
17610    WAIT 2
17615    OUTPUT @Eip_578;"PF "&VAL$(Desired_freq)&" G"
17620 !
17625    OUTPUT @Eip_931;"CLEARST"! Clear the status register of the 931
17630                             ! source to prevent an interrupt from it.
17635    ENABLE INTR 7;2          ! Re-enable the interrupts (2=SRQ bit).
17640    OUTPUT @Eip_578;"SR02"   ! SRQ on bit 2, "counter searching", enabled.
17645 !
17650  SUBEND !  SUB Intr7
17655 !
17660 Power_lev_chk:!
17665 !*****************************
17670  SUB Power_lev_chk(V_ref,V_rf_on,Pwr)
17675 !*****************************
17680 !
17685 ! INPUT(S)  : V_ref   - reference voltage for DP 8700.
17690 !             V_rf_on - power meter voltage, RF is on.
17695 ! OUTPUT(S) : V_ref   - may be changed as determined by code.
17700 !             Pwr     - calculated from last V_rf_off & V_rf_on
17705    COM /Pwr_lev_set_in/ P_rf,R_0
17710    COM /Initial_value/ V_ref_0,V_rf_off
17715 !
17720    Delta_v=DROUND(V_ref-V_rf_on,5)  !Difference: Ref-present reading
17725    SELECT Delta_v
17730    CASE <-.0001                     !Leveler out of control - reset
17735      V_ref=DROUND(V_rf_on,5)+.0001!Compute new value
17740      CALL Dp_8200(V_ref,"V")       !Set 8200 to new value
17745    CASE >.05                       !8200 has probably set itself to zero
17750      CALL Dp_8200(V_ref_0,"V")     !Reset 8200 to orginal value
17755    END SELECT
17760    !
17765    Pwr=1000*(V_rf_off*V_rf_off-V_rf_on*V_rf_on)/R_0        !Power calc
17770 !
17775  SUBEND! Power_lev_chk
17780 !
17785 Display_data:!
17790 !****************
17795  SUB Display_data
17800 !****************
17805 !
17810    COM /Xy_coordinates/ T_min,T_max,V_min,V_max
17815 !
17820    CLEAR SCREEN
17825 !
17830    PRINT CHR$(136)
17835    PRINT TABXY(15,4),"The current real-time graph parameters are:"
17840    PRINT CHR$(138)
17845    PRINT TABXY(15,7),"(1) Minimum Time  (hours)"
17850    PRINT TABXY(50,7),CHR$(136);T_min/3600;CHR$(138)
17855    PRINT TABXY(15,10),"(2) Maximum Time  (hours)"
17860    PRINT TABXY(50,10),CHR$(136);T_max/3600;CHR$(138)
17865    PRINT TABXY(15,13),"(3) Mimimum Voltage (microvolts)"
17870    PRINT TABXY(50,13),CHR$(136);V_min*10^6;CHR$(138)
17875    PRINT TABXY(15,16),"(4) Maximum Voltage (microvolts)"
17880    PRINT TABXY(50,16),CHR$(136);V_max*10^6;CHR$(138)
17885    !
17890    Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))
17895    Lcl_prty=Sys_prty+1
17900    FOR N=0 TO 19
17905      ON KEY N LABEL " ",Lcl_prty GOTO Wait_loop
17910    NEXT N
17915    ON KEY 5 LABEL "CHANGE DEFAULT",Lcl_prty GOSUB Change_param
17920    ON KEY 0 LABEL " CONTINUE ",Lcl_prty GOTO Sub_exit
17925    KEY LABELS ON
17930    !
17935 Wait_loop:         ! Wait for ON KEY interrupt.
17940    GOTO Wait_loop
17945 !
17950 Change_param: !
```

```
17955   KEY LABELS OFF
17960   INPUT "Number of parameter to be changed:",Parameter_no
17965 !
17970   PRINT CHR$(136)
17975   SELECT Parameter_no
17980   CASE =1
17985     INPUT "Minimum Time (hours)=",T_min
17990     PRINT TABXY(50,7),T_min,"      "
17995     T_min=T_min*3600              !Convert to seconds
18000   CASE =2
18005     INPUT "Maximum Time (hours)=",T_max
18010     PRINT TABXY(50,10),T_max,"      "
18015     T_max=T_max*3600              !Convert to seconds
18020   CASE =3
18025     INPUT "Minimum Voltage (microvolts)=",V_min_uv
18030     PRINT TABXY(50,13),V_min_uv,"      "
18035     V_min=V_min_uv/10^6           ! Convert from microvolts to volts.
18040   CASE =4
18045     INPUT "Maximum Voltage (microvolts)=",V_max_uv
18050     PRINT TABXY(50,16),V_max_uv,"      "
18055     V_max=V_max_uv/10^6           ! Convert from microvolts to volts.
18060   END SELECT
18065   PRINT CHR$(138)
18070   KEY LABELS ON
18075   RETURN ! Change_param
18080   !
18085 Sub_exit:KEY LABELS OFF           !
18090  SUBEND! Display_data
18095 !
18100 Generate_freq:!
18105 !**************
18110  SUB Generate_freq(Nomore_f,INTEGER Row)
18115 !**************
18120 !
18125   OPTION BASE 1
18130   COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
18135   COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
18140   COM /Data/ Af(10,3),INTEGER Tp(3000)
18145 !
18150   INTEGER I,No_of_freqs,Rowm
18155   Rowm=SIZE(Af,1)                 !For auto freq mode
18160 !
18165   IF Header(20) THEN              !Auto freq mode
18170     Min_freq=Af(Row,1)            !Start
18175     Header(6)=Min_freq            !Put in header
18180     Max_freq=Af(Row,2)            !Stop
18185     Header(7)=Max_freq            !Put in header
18190     Delta_freq=Af(Row,3)          !Step
18195     Header(8)=Delta_freq          !Put in header
18200     IF Row=Rowm THEN Nomore_f=1   !Last freq set
18205   ELSE                            !Manual mode
18210     Min_freq=Header(6)            !Start
18215     Max_freq=Header(7)            !Stop
18220     Delta_freq=INT(1.E+3*Header(8))/1.E+3 !Step, integer based
18225     Nomore_f=1                    !Single set of frequencies
18230   END IF
18235 !
18240   IF Delta_freq>0 THEN            !Positive for regular freq set
18245     No_of_freqs=(Max_freq-Min_freq)/Delta_freq+1
18250     Header(5)=No_of_freqs
18255     Next_freq=Min_freq
18260 !
18265     IF Header(19) THEN            !Zero correction flag (meas E0)
18270       Start=2
18275       Finish=No_of_freqs+1
18280     ELSE
18285       Start=1                     !Without zero correction
18290       Finish=No_of_freqs
18295     END IF
18300 !
18305     REDIM F(Finish+2,2)           !Be sure F is large enough
18310 !
18315     FOR I=Start TO Finish
18320       F(I,1)=Next_freq            !Fill array, interger based #'s
18325       Next_freq=Next_freq+Delta_freq
18330     NEXT I
18335   ELSE                            !Neg. for special freq list
18340     No_of_freq=7                  !Number in list
18345     Header(5)=No_of_freq          !Put in header
18350     REDIM F(No_of_freq+2,2)       !Be sure F is right size
18355     FOR I=1 TO No_of_freq         !Read the data
18360       READ F(I,1)                 !
18365     NEXT I
18370     DATA .1,1,5,10,15,17,18       !Freq list
18375   END IF
18380 !
18385  SUBEND ! Generate_freq
18390  !
18395 Insert_array: !
18400 !***************
18405  SUB Insert_array
18410 !***************
18415 !
18420 !This subroutine inserts a subarray into a larger array. It is designed
18425 !specifically for the program MICRO_Cx??, and the large array is a two
18430 !dimensional array with inserted items in the first column.
18435 !
18440 !INPUT(S):  Dest_matrix - the array that receives the inserted items
18445 !           Insert_matrix - the array that is to be inserted into
18450 !                     Dest_matrix
18455 !           Choice$ - A character variable that flags a need to insert
18460 !                     data before the first frequency ("B"), in-between
18465 !                     two frequencies ("I"), or after the last frequency
18470 !                     ("A").
18475 !           Lower_index - the lower index number of Dest_matrix
18480 !           Upper_index - the upper index number of Dest_matrix
18485 !         (e.g., if Insert_array needed to be inserted between items
18490 !          3 and 4 of Dest_matrix, then  Lower_index=3 and Upper_index=4)
18495 !           No_elements - total No. of elements in Dest_matrix (before
18500 !                     Insert_array is inserted)
18505 !           No_of_inserts - No. of elements in Insert_array to be inserted
18510 !                     into Dest_matrix
18515 !           (All variables are in COM /Matrix_var/)
18520 !
18525 !OUTPUT(S): Elements in Insert_array are inserted in the proper place
18530 !           in the array Dest_matrix, and elements in Dest_matrix are
18535 !           moved up accordingly (no elements are deleted).
18540 !           Variable "No_elements" updated to the size of the new, ex-
18545 !           panded array.
18550 !
18555   OPTION BASE 1
18560   COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
18565   COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
18570   COM /Data/ Af(10,3),INTEGER Tp(3000)
18575 !
18580   COM /Matrix_var/ Insert_matrix(50),Choice$
18585   COM /Matrix_var/ INTEGER Lower_index,No_of_inserts
18590 !
18595   ALLOCATE Temp_matrix(250),Dest_matrix(500)
18600   INTEGER A,B,Z
18605 !
18610   Total=Header(5)+No_of_inserts! Total No. of elements for new array.
18615   No_elements=Header(5)
18620 !
```

```
18625   MAT Dest_matrix= (0)
18630   MAT Temp_matrix= (0)
18635 !
18640   IF Header(19) THEN
18645     MAT Dest_matrix(1:No_elements+1)= F(1:No_elements+1,1)
18650   ELSE
18655     MAT Dest_matrix(1:No_elements)= F(1:No_elements,1)
18660   END IF
18665 !
18670   SELECT Choice$
18675   CASE ="B"! Before first frequency
18680     IF Header(19) THEN
18685       A=2
18690       Z=No_elements+1
18695       Tot=Total+1
18700     ELSE
18705       A=1
18710       Z=No_elements
18715       Tot=Total
18720     END IF
18725     B=A+No_of_inserts
18730     MAT Temp_matrix= Dest_matrix(A:Z)
18735     MAT Dest_matrix(A:B-1)= Insert_matrix(1:No_of_inserts)
18740     MAT Dest_matrix(B:Tot)= Temp_matrix
18745   !
18750   CASE ="I"! In-between frequencies
18755     IF Header(19) THEN
18760       A=Lower_index+2
18765       B=Lower_index+No_of_inserts+1
18770       Z=No_elements+1
18775       Tot=Total+1
18780     ELSE
18785       A=Lower_index+1
18790       B=Lower_index+No_of_inserts
18795       Z=No_elements
18800       Tot=Total
18805     END IF
18810     MAT Temp_matrix= Dest_matrix(A:Z)
18815     MAT Dest_matrix(A:B)= Insert_matrix(1:No_of_inserts)
18820     MAT Dest_matrix(B+1:Tot)= Temp_matrix
18825   !
18830   CASE ="A"! After last frequency
18835     IF Header(19) THEN
18840       A=2
18845       Q=No_elements+2
18850       Tot=Total+1
18855     ELSE
18860       A=1
18865       Q=No_elements+1
18870       Tot=Total
18875     END IF
18880     MAT Dest_matrix(Q:Tot)= Insert_matrix(1:No_of_inserts)
18885   END SELECT
18890 !
18895   MAT F(A:Tot,1)= Dest_matrix(A:Tot)
18900   Header(5)=Total          ! Update variable for new matrix size.
18905 !
18910   DEALLOCATE Temp_matrix(*),Dest_matrix(*)
18915 !
18920  SUBEND! Insert_array
18925  !
18930 Window_left: ! Left window
18935  !**************
18940  SUB Window_left
18945  !**************
18950  !
18955   OPTION BASE 1
18960  !
18965   COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
18970   COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
18975   COM /Data/ Af(10,3),INTEGER Tp(3000)
18980  !
18985   PRINT TABXY(7,3),"HEADER INFO"
18990   PRINT TABXY(1,4),"Mount ID: ";CHR$(136);" ";Mount_id$;" ";CHR$(140)
18995   PRINT TABXY(1,5),"File name:  ";CHR$(136);Dfile$;CHR$(140)
19000   PRINT TABXY(1,6),"Start Time: ";CHR$(136);DATE$(TIMEDATE)
19005   PRINT TABXY(14,7),CHR$(136);TIME$(TIMEDATE);CHR$(140)
19010   PRINT TABXY(1,8),"Start Freq: ";CHR$(136);Header(6);"GHz ";CHR$(140)
19015   PRINT TABXY(1,9),"Stop  Freq: ";CHR$(136);Header(7);"GHz ";CHR$(140)
19020  !
19025  SUBEND ! Window_left
19030  !
19035 Window_c_a: ! Center window
19040  !*************
19045  SUB Window_c_a
19050  !*************
19055  !
19060   OPTION BASE 1
19065   COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
19070   COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
19075   COM /Data/ Af(10,3),INTEGER Tp(3000)
19080   COM /Window_flags/ Window_c$,Window_r$
19085   COM /Screen_update/ Count,Cftime,Freq,Pwr
19090  !
19095   Window_c$="A"                    !Flags which header info is displayed.
19100   FOR Row=3 TO 7
19105     PRINT TABXY(28,Row);"                          " !Clear previous info.
19110   NEXT Row
19115  !
19120   PRINT TABXY(34,3),CHR$(140);"LAST READING"
19125   PRINT TABXY(28,4),"Total time:"
19130   PRINT TABXY(28,5),"Elapsed time:"
19135   PRINT TABXY(28,6),"Total count:"
19140   PRINT TABXY(28,9),CHR$(136);"Press K5 for next window";CHR$(128)
19145   PRINT CHR$(136)
19150   CALL Screen_update
19155  !
19160  SUBEND ! Window_c_a
19165  !
19170 Window_r_a: ! Right window
19175  !*************
19180  SUB Window_r_a
19185  !*************
19190  !
19195   OPTION BASE 1
19200   COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
19205   COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
19210   COM /Data/ Af(10,3),INTEGER Tp(3000)
19215   COM /Window_flags/ Window_c$,Window_r$
19220  !
19225   Window_r$="A"                    !Flags which header info is displayed.
19230   FOR Row=3 TO 8
19235     PRINT TABXY(55,Row);"                          " !Clear previous info.
19240   NEXT Row
19245  !
19250   PRINT TABXY(56,3),CHR$(140);"THERMOPILE OUTPUT & TEMP"
19255   PRINT TABXY(55,4),"Thermopile:"
19260   PRINT TABXY(55,5),"T'pile Avg:"
19265   PRINT TABXY(55,6),"T' Std Dev:"
19270   PRINT TABXY(55,7),"Room Temp:"
19275   PRINT TABXY(55,8),"Bath Temp:"
19280   PRINT TABXY(55,9),CHR$(136);"Press K6 for next window";CHR$(128)
19285   PRINT CHR$(136)
19290   CALL Screen_update
```

```
19295  !
19300  SUBEND ! Window_r_a
19305  !
19310 Window_c_b: !
19315  !*************
19320  SUB Window_c_b
19325  !*************
19330  !
19335    OPTION BASE 1
19340    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
19345    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
19350    COM /Data/ Af(10,3),INTEGER Tp(3000)
19355    COM /Window_flags/ Window_c$,Window_r$
19360  !
19365    Window_c$="B"                  !Flags which header info is displayed.
19370    FOR Row=3 TO 7
19375      PRINT TABXY(28,Row);"                            " !Clear previous info.
19380    NEXT Row
19385  !
19390    PRINT TABXY(32,3),CHR$(140);"SYSTEM PARAMETERS"
19395    PRINT TABXY(28,4),"Frequency:"
19400    PRINT TABXY(28,5),"Pwr Meter V:"
19405    PRINT TABXY(28,6),"Ref V:"
19410    PRINT TABXY(28,7),"Power:"
19415    PRINT TABXY(28,9),CHR$(136);"Press K5 for next window";CHR$(128)
19420    PRINT CHR$(136)
19425    CALL Screen_update
19430  !
19435  SUBEND ! Window_c_b
19440  !
19445 Window_r_b: !
19450  !*************
19455  SUB Window_r_b
19460  !*************
19465  !
19470    OPTION BASE 1
19475    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
19480    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
19485    COM /Data/ Af(10,3),INTEGER Tp(3000)
19490    COM /Window_flags/ Window_c$,Window_r$
19495  !
19500    Window_r$="B"                  !Flags which header info is displayed.
19505    FOR Row=3 TO 8
19510      PRINT TABXY(55,Row);"                              "!Clear previous info
19515    NEXT Row
19520    PRINT TABXY(64,3),CHR$(140);"STATISTICS"
19525    PRINT TABXY(55,4),"NO. in average:"
19530    PRINT TABXY(55,5),"Runs:"
19535    PRINT TABXY(55,6),"'R' :"
19540    PRINT TABXY(55,7),"Prob:"
19545    PRINT TABXY(55,9),CHR$(136);"Press K6 for next window";CHR$(128)
19550    PRINT CHR$(136)
19555    CALL Screen_update
19560  !
19565  SUBEND ! Window_r_b
19570  !
19575 Meas_disp: !
19580  !************
19585  SUB Meas_disp
19590  !************
19595  !
19600    OPTION BASE 1
19605    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
19610    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
19615    COM /Data/ Af(10,3),INTEGER Tp(3000)
19620    COM /Window_flags/ Window_c$[1],Window_r$[1]
19625    COM /Screen_update/ Count,Cftime,Freq,Pwr
19630    !
19635    KEY LABELS OFF                    !
19640    OUTPUT KBD;"K";                  !Clear screen
19645    PRINT TABXY(1,1),CHR$(137)&"M I C R O _ C c x"&CHR$(136)
19650    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$(128)
19655    PEN 3                            !Line color: Yellow
19660    CLIP 0,128,63,92                 !To draw a rectangle
19665    FRAME                            !Draw the rectangle
19670    VIEWPORT 0,100*RATIO,0,100       !Map x,y to default GDU's
19675    PLOT 41,63                       !Draw a vertical line
19680    PLOT 41,92                       !         "
19685    PLOT 83,92                       !Draw a vertical line
19690    PLOT 83,63                       !         "
19695    CLIP 0,128,1,63                  !To draw a rectangle
19700    PEN 2
19705    FRAME
19710    PRINT CHR$(140)                  !Set PEN color to Cyan.
19715    !
19720    CALL Window_left                 !Left header information
19725    CALL Window_c_a                  !Center header information
19730    CALL Window_r_a                  !Right header information
19735    !
19740    PRINT TABXY(28,8),CHR$(140);"Sec to next reading:";CHR$(136)
19745    !
19750    CALL Rtime_graph
19755  SUBEND ! Meas_disp
19760  !
19765 Screen_update: !
19770  !****************
19775  SUB Screen_update
19780  !****************
19785  !
19790    OPTION BASE 1
19795  !
19800    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
19805    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
19810    COM /Data/ Af(10,3),INTEGER Tp(3000)
19815    COM /Initial_value/ V_ref_0,V_rf_off
19820    COM /Init_stats/ Tcv,Rcv,Enr,Sdnr,Volts(100),INTEGER Mode,Lss
19825    COM /Stats_2/ R,Prob,INTEGER Nruns
19830    COM /Window_flags/ Window_c$[1],Window_r$[1]
19835    COM /Screen_update/ Count,Cftime,Freq,Pwr
19840    COM /Screen_update2/ Avg,Sd
19845  !
19850    IF Window_c$="A" THEN            !LAST READING
19855      Total_time=(TIMEDATE-Header(2))/60 !Total time elasped.
19860      IF Count<1 THEN Total_time=0 !Special first time thru
19865      PRINT TABXY(41,4),CHR$(136); !Move cursor for total time.
19870      PRINT USING "#,4D.D,X,3A";Total_time,"min"
19875      E_time=(TIMEDATE-Cftime)/60  !Elapsed time since last freq change
19880      IF Count<1 THEN E_time=0     !Special first time thru
19885      PRINT TABXY(41,5);           !Move cursor for Elapsed time
19890      PRINT USING "#,4D.D,X,3A";E_time,"min"
19895      PRINT TABXY(42,6),Count;     !Display the count
19900!     GOTO Sub_exit
19905    END IF ! Window_c$="A"
19910       !
19915    IF Window_c$="B" THEN            !SYSTEM PARAMETERS
19920      PRINT TABXY(41,4);             !Move cursor for Freq
19925      PRINT USING "#,2D.2D,X,3A";Freq,"GHz"
19930      PRINT TABXY(40,5);             !Move cursor for power meter voltage
19935      Cnt=Count
19940      IF Count=0 THEN Cnt=1
19945      PRINT USING "#,MZ.6D,X,1A";V(Cnt,2),"V"
19950      PRINT TABXY(40,6);             !Move cursor for reference voltage
19955      PRINT USING "#,MZ.6D,X,1A";V_ref_0,"V"
```

```
19960     PRINT TABXY(40,7);            !Move cursor for power
19965     PRINT USING "#,2D.4D,X,2A";Pwr,"mW"
19970   END IF ! Window_c$="B"
19975   !
19980   IF Window_r$="A" THEN          !THERMOPILE OUTPUT & TEMPS
19985     PRINT TABXY(70,4);           !Move cursor for thermopile voltage
19990     Cnt=Count
19995     IF Count=0 THEN Cnt=1        !Special first time thru
20000     PRINT USING "#,3D.3D,X,3A";E(Cnt,2)*1.E+6," uV"
20005     PRINT TABXY(70,5);           !Move cursor for average
20010     PRINT USING "3D.4D,X,2A";Avg*1.E+6,"uV" !Erf
20015     PRINT TABXY(69,6);           !Move cursor for SD
20020     PRINT USING "4D.4D,X,2A";Sd*1.E+6,"uV"
20025     PRINT TABXY(66,7);           !Move cursor for room temperature
20030     Cnt=Count
20035     IF Count=0 THEN Cnt=1        !Special first time thru
20040     PRINT USING "#,2D.2D,X,6A";Tp(Cnt)*1.E-3," deg C"
20045     PRINT TABXY(66,8);           !Move cursor for bath temperature.
20050     PRINT USING "#,2D.3D,X,5A";Header(18),"deg C"
20055   END IF ! Window_r$="A"
20060  !
20065      !
20070   IF Window_r$="B" THEN          !STATISTICS
20075     PRINT TABXY(70,4),Lss        !Print readings in average
20080     PRINT TABXY(61,5);           !Move cursor for runs
20085     PRINT USING "#,2D";Nruns     !No of runs
20090     PRINT TABXY(61,6);           !Move cursor for R
20095     PRINT USING "#,2D.2D";R      !R
20100     PRINT TABXY(62,7);           !Move cursor for Prob
20105     PRINT USING "#,D.3D";Prob    !Prob
20110   END IF ! Window_r$="B"
20115 Sub_exit:   !
20120  SUBEND  ! Screen_update
20125  !
20130 Blank:SUB Blank                  !To blank or unblank crt
20135   COM /Blank/ INTEGER Off        !To keep track of CRT
20140   IF Off THEN
20145     SET DISPLAY MASK 15          !Turn all 4 planes on
20150     Off=0                        !Indicate CRT is ON
20155   ELSE
20160     SET DISPLAY MASK 0           !Turn all 4 planes off
20165     Off=1                        !Indicate CRT is OFF
20170   END IF
20175  SUBEND  ! Blank
20180  !
20185 Pre_bias:SUB Pre_bias(Setup)     !To bias the mount for a time
20190                                  !before the run
20195   OPTION BASE 1
20200   COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
20205   COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
20210   COM /Data/ Af(10,3),INTEGER Tp(3000)
20215   COM /Init_stats/ Tcv,Rcv,Enr,Sdnr,Volts(100),INTEGER Mode,Lss
20220   COM /Stats_2/ R,Prob,INTEGER Nruns
20225   COM /Screen_update2/ Avg,Sd
20230   COM /Prebias/ On_dur           !Keep track of previous setting
20235   !
20240   Sys_prty=VAL(SYSTEM$("SYSTEM PRIORITY"))  !Determine system priority
20245   Lcl_prty=Sys_prty+1            !Set local priority 1 higher for ON KEY
20250   CLEAR SCREEN                   !
20255   KEY LABELS OFF                 !Turn off user soft key labels
20260   !
20265   IF Setup THEN                  !To set up defaults
20270     IF Header(19) THEN On_dur=1      !Default, zero flag ON
20275     IF NOT Header(19) THEN On_dur=0  !Default, zero flag OFF
20280   END IF
20285   Cycle_time=Header(11)          !Measurement interval
20290   Na=Lss                         !No. of points to use in stability test
20295   !
20300   GOSUB Print
20305   !
20310   IF Setup THEN                  !For setup
20315     ON KEY 0 LABEL " Continue      ",Lcl_prty GOTO Exit
20320     ON KEY 1 LABEL " Chng ON time ",Lcl_prty GOSUB Change_on
20325     FOR N=2 TO 9
20330       ON KEY N LABEL " " GOTO Top1
20335     NEXT N
20340   ELSE                           !For measurement
20345     ON KEY 0 LABEL " Start meas    ",Lcl_prty GOTO Bailout
20350     FOR N=1 TO 8
20355       ON KEY N LABEL " " GOTO Top2
20360     NEXT N
20365     ON KEY 9 LABEL " BLANK CRT ",Lcl_prty CALL Blank  !To blank CRT
20370   END IF
20375   !
20380   KEY LABELS ON
20385   IF Setup THEN
20390 Top1:LOOP                        !Wait for input
20395     END LOOP
20400   ELSE
20405     Start$=TIME$(TIMEDATE)       !Start time now
20410     GOSUB Calc
20415     IF On_dur>0 THEN             !If On_dur=0 skip this
20420       CALL Dc(1,2)               !Turn on the dc bias
20425       ON DELAY On_dur*3600,Lcl_prty GOSUB Dc_off !Turn off bias after delay
20430     ELSE
20435       GOSUB Dc_off               !If NO bias be sure dc off
20440     END IF
20445 Top2:LOOP                        !Wait for interrupts
20450       T$=TIME$(TIMEDATE)         !Get the time
20455       Ts$=T$[1,2]&T$[4,5]        !Format to compare with Stp$
20460       DISP "Pre-bias off: ";Stop1$,"              Present time:  ";T$
20465       IF Stable THEN Exit1       !Finished
20470     END LOOP
20475   END IF
20480   !
20485 Calc:                            !Calculations
20490   Stop1$=TIME$(TIME(Start$)+On_dur*3600)  !Time to shut off bias
20495   Stop1$=Stop1$[1,5]&":00"       !Eliminate seconds
20500   Stp1$=Stop1$[1,2]&Stop1$[4,5]  !Convert
20505   RETURN
20510   !
20515 Change_on:                       !To change duration
20520   KEY LABELS OFF
20525   INPUT "New ON time in hours?",On_dur
20530   GOSUB Print
20535   KEY LABELS ON
20540   RETURN
20545   !
20550 Dc_off:                          !Turn off the dc bias
20555   CALL Dc(0,2)
20560   ON CYCLE Cycle_time,Lcl_prty GOSUB E0_meas    !Turn on meas interrupt
20565   RETURN
20570     !
20575 E0_meas:                         !To determine E0
20580   CALL Dnvm(Nread)               !Read nanovoltmeter (thermopile)
20585   Avg1=Avg                       !Save avg from previous meas
20590   CALL Stats(Na,Nread,Stable)    !Check for stablity of thermopile
20595   IF Stable THEN
20600     Nruns=0                      !Reset some stats variables
20605     R=0                          !Reset stat
20610     Prob=0                       !Reset stat
20615     IF ABS(Nread)<1.E-6 THEN     !If less than 1 uV, the bias is off
20620       Header(15)=Avg1            !Put E0 in Header (Avg=E0)
20625       IF NOT Header(19) THEN     !No zero correction, then
```

```
20630          Stable=0                  !not finished and
20635          CALL Dc(1,2)              !turn bias back on & wait for stability
20640        END IF
20645      END IF
20650    END IF
20655    RETURN
20660    !
20665 Print:                             !Print screen
20670    PRINT TABXY(27,4),"   MOUNT PRE-BIAS   "
20675    PRINT TABXY(27,6),"DC Bias ON for:  ";On_dur;" hrs.  "
20680    RETURN
20685    !
20690 Bailout:                           !
20695    IF Header(19) THEN CALL Dc(0,2)!Be sure bias is off if zero correction
20700 Exit1:                             !
20705    OFF DELAY                       !Disable any interrupts left on
20710    OFF CYCLE                       !Disable any interrupts left on
20715 Exit:                              !
20720  SUBEND    !Pre_bias
20725  !
20730 Re_set:SUB Re_set                  !To do a partial software init
20735    OPTION BASE 1
20740    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
20745    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
20750    COM /Data/ Af(10,3),INTEGER Tp(3000)
20755    COM /Init_stats/ Tcv,Rcv,Enr,Sdnr,Volts(100),INTEGER Mode,Lss
20760    COM /Screen_update/ Count,Cftime,Freq,Pwr
20765    COM /Screen_update2/ Avg,Sd
20770    COM /Stats_2/ R,Prob,INTEGER Nruns
20775    Dfile$=""                       !Clear data file name
20780    MAT V= (0)                      !Clear old data
20785    MAT E= (0)                      !
20790    MAT F= (0)                      !
20795    MAT Ne= (0)                     !
20800    Count=0                         !Reset measurement counter
20805                                    !Then set some new defaults
20810    Header(9)=2400                  !No. of measurements
20815                                    ! Stats init
20820    Lss=18                          !No. in avg
20825    Rcv=-2.5                        !Tuning constant
20830    Tcv=.25                         !Tuning constant
20835    Enr=(2.0*Lss-1.0)/3.0           !Expected No of runs
20840    Sdnr=SQR((16.0*Lss-29.0)/90.0)  !SD of No of runs
20845    Mode=1                          !For stats
20850    R=0                             !
20855    Prob=0                          !
20860    Nruns=0                         !
20865    Avg=0                           !Thermopile avg
20870    Sd=0                            !Thermopile std dev
20875    Pwr=0                           !
20880    !
20885  SUBEND    !Re_set
20890  !
20895 Random_f:SUB Random_f              !Sub to randomize freq list
20900    OPTION BASE 1
20905    COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
20910    COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
20915    COM /Data/ Af(10,3),INTEGER Tp(3000)
20920    !
20925    INTEGER Nr,No1
20930    No1=Header(5)                   !# of meas frequencies + final rf off
20935    !
20940    DIM Rm(50)                      !Set up array for random nos
20945    DIM Rv(50)                      !Set up vector array for sort
20950   !
20955    RANDOMIZE
20960    FOR Nr=1 TO 50                  !Fill array with random nos
20965      Rm(Nr)=INT(1000*RND)
20970    NEXT Nr
20975    IF Header(19) THEN              !For account for zero correction
20980      REDIM Rm(No1+4)
20985      REDIM Rv(No1+4)
20990      Rm(1)=0                       !To maintain original value
20995      Rm(No1+2)=1100                !          "
21000      Rm(No1+3)=1200                !          "
21005      Rm(No1+4)=1300                !          "
21010      MAT SORT Rm TO Rv             !Sort order to vector
21015      MAT REORDER F BY Rv,1         !Reorder freq list by vector
21020    ELSE                            !No zero correction measurement
21025      REDIM Rm(No1+2)
21030      REDIM Rv(No1+2)
21035      Rm(No1+1)=1100                !To maintain original value
21040      Rm(No1+2)=1200                !          "
21045!     Rm(No1+3)=1300                !          "
21050      MAT SORT Rm TO Rv             !Sort order to vector
21055      MAT REORDER F BY Rv,1         !Reorder freq list by vector
21060    END IF
21065    !
21070 Sub_exit:                          !
21075  SUBEND ! Random_f
```

APPENDIX E. Calibration Report

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY
Boulder, Colorado

REPORT OF CALIBRATION

COAXIAL THERMISTOR MOUNT
NIST Model CN, Serial No. 05

Submitted by:

Customer's Name
Customer's Address
Customer's City, State and Zip

The measurements were performed under ambient environmental conditions of approximately 23°C and 40 percent relative humidity. The uncertainty of the calibration frequency is 1 ppm. The thermistor mount is operated at its designated resistance and is allowed to attain thermal equilibrium before beginning the test.

Effective efficiency η_e is defined as the ratio of the bolometrically substituted dc power in the thermistor mount to the net rf or microwave power delivered to the thermistor mount.

The effective efficiency of the thermistor mount was measured using the NIST automated coaxial microcalorimeter. Two connect-disconnect measurements were made in the microcalorimeter. On the first connect, measurements were made at five test frequencies. The frequencies are 0.1, 3, 10, 15 and 18 GHz. On the second connect the measurements at the five test frequencies were repeated. The results of the second series were compared with the first and found to agree to better than ±0.1 percent. Then with the device still connected, the measurements were done at the full set of desired frequencies and these results are reported in Table 1. All the measurements were made at a power of 10 mW. Detailed descriptions of the calibration procedure, the system hardware, and the uncertainty evaluation process are found in references [1 - 3].

Test No. cn05_84
Date of Test: March 28, 1994
Reference:

Coaxial Thermistor Mount
Model CN, Serial No. 05

The uncertainties associated with the measurement of η_e are grouped in two categories according to the method used to estimate their numerical values [4]. The Type A evaluations of standard uncertainty are based on a statistical analysis of measurement results. The Type B evaluations of standard uncertainty are based on other methods. The standard uncertainties obtained by either the Type A or the Type B evaluations are expressed as a standard deviation.

The Type A evaluation of standard uncertainty in the measurement process is based on repeated measurements of another identical Model CN used as a check standard. The random effects are due to voltmeter resolutions, connector nonrepeatability, long term system variations, and system noise. This standard uncertainty is estimated to be 0.032 percent, independent of frequency. The estimate is subject to change in the future as additional measurements are made on the check standard.

The Type B evaluation accounts for uncertainties in the microcalorimeter correction factor and the associated measurement instrumentation. These estimates of standard uncertainty are based on measurement results and manufacturer's instrument specifications.

A combined standard uncertainty is calculated as the RSS (square root of the sum of the squares) combination of all the uncertainty components from both categories. The expanded uncertainty given in Table 1 is obtained by multiplying the combined standard uncertainty by a coverage factor of 2 and can be calculated using the equation,

$$U = 4.46 \times 10^{-4} f^2 + 5.34 \times 10^{-3} f + 0.180,$$

where U is the uncertainty in percent and f is the frequency in GHz.

For the Director,
National Institute of
Standards and Technology

Approved by:

Robert M. Judish, Group Leader
Microwave Metrology Group
Electromagnetic Fields Division

Fred R. Clague
(303) 497-5778

Test No. cn05_84
Date of Test: March 28, 1994
Reference:

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[1] Fred R. Clague, and Paul G. Voris, "Coaxial reference standard for microwave power," NIST Technical Note 1357, 1993. (U.S. Government Printing Office, Washington DC 20402-9325 or NTIS, Springfield, VA 22161).

[2] Fred R. Clague, "Microcalorimeter for 7 mm coaxial transmission line," NIST Technical Note 1358, 1993. (U.S. Government Printing Office, Washington DC, 20402-9325 or NTIS, Springfield, VA 22161).

[3] Fred R. Clague, "A calibration service for coaxial reference standards for microwave power," NIST Technical Note 1374, May 1995. (U. S. Government Printing Office, Washington DC 20402-9325 or NTIS, Springfield, VA 22161).

[4] Barry N. Taylor and Chris E. Kuyatt, "Guidelines for evaluating and expressing the uncertainty of NIST measurement results," NIST Technical Note 1297, 1993. (U.S. Government Printing Office, Washington DC 20402-9325 or NTIS, Springfield, VA 22161).

Coaxial Thermistor Mount
Model CN, Serial No. 05

Table 1.

Frequency (GHz)	Effective Efficiency	Type B Uncertainty (Percent)	Expanded Uncertainty (Percent)
0.05	0.9922	0.11	0.21
0.10	0.9951	0.13	0.23
0.15	0.9957	0.14	0.24
0.20	0.9959	0.16	0.26
0.25	0.9959	0.17	0.27
0.30	0.9959	0.18	0.28
0.35	0.9959	0.19	0.29
0.40	0.9958	0.20	0.30
0.45	0.9957	0.21	0.31
0.50	0.9956	0.22	0.32
0.55	0.9955	0.22	0.32
0.60	0.9953	0.23	0.33
0.65	0.9951	0.23	0.33
0.70	0.9949	0.24	0.34
0.75	0.9947	0.25	0.35
0.80	0.9942	0.25	0.35
0.85	0.9936	0.25	0.35
0.90	0.9926	0.25	0.35
0.95	0.9916	0.25	0.35
1.00	0.9905	0.25	0.35
1.05	0.9895	0.25	0.35
1.10	0.9889	0.25	0.35
1.15	0.9889	0.25	0.35
1.20	0.9892	0.25	0.35
1.25	0.9896	0.25	0.35
1.30	0.9900	0.25	0.35
1.35	0.9903	0.25	0.35
1.40	0.9906	0.25	0.35
1.45	0.9907	0.25	0.35
1.50	0.9907	0.25	0.35
1.55	0.9907	0.25	0.35
1.60	0.9906	0.25	0.35
1.65	0.9903	0.25	0.35
1.70	0.9901	0.25	0.35
1.75	0.9898	0.25	0.35
1.80	0.9894	0.25	0.35

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Table 1. (con't)

Frequency (GHz)	Effective Efficiency	Type B Uncertainty (Percent)	Expanded Uncertainty (Percent)
1.85	0.9889	0.25	0.35
1.90	0.9884	0.25	0.35
1.95	0.9879	0.25	0.35
2.00	0.9873	0.25	0.35
2.10	0.9863	0.25	0.35
2.20	0.9855	0.25	0.35
2.30	0.9851	0.25	0.35
2.40	0.9849	0.25	0.35
2.50	0.9849	0.25	0.35
2.60	0.9851	0.25	0.35
2.70	0.9852	0.25	0.35
2.80	0.9854	0.25	0.35
2.90	0.9855	0.25	0.35
3.00	0.9856	0.25	0.35
3.10	0.9855	0.25	0.35
3.20	0.9855	0.25	0.35
3.30	0.9853	0.25	0.35
3.40	0.9851	0.25	0.35
3.50	0.9849	0.25	0.35
3.60	0.9847	0.25	0.35
3.70	0.9845	0.25	0.35
3.80	0.9843	0.25	0.35
3.90	0.9840	0.25	0.35
4.00	0.9837	0.25	0.35
4.20	0.9831	0.26	0.36
4.40	0.9826	0.26	0.36
4.60	0.9821	0.26	0.36
4.80	0.9816	0.26	0.36
5.00	0.9811	0.26	0.36
5.20	0.9807	0.26	0.36
5.40	0.9802	0.26	0.36
5.60	0.9798	0.26	0.36
5.80	0.9793	0.26	0.36
6.00	0.9789	0.26	0.36
6.20	0.9785	0.26	0.36
6.40	0.9780	0.26	0.36

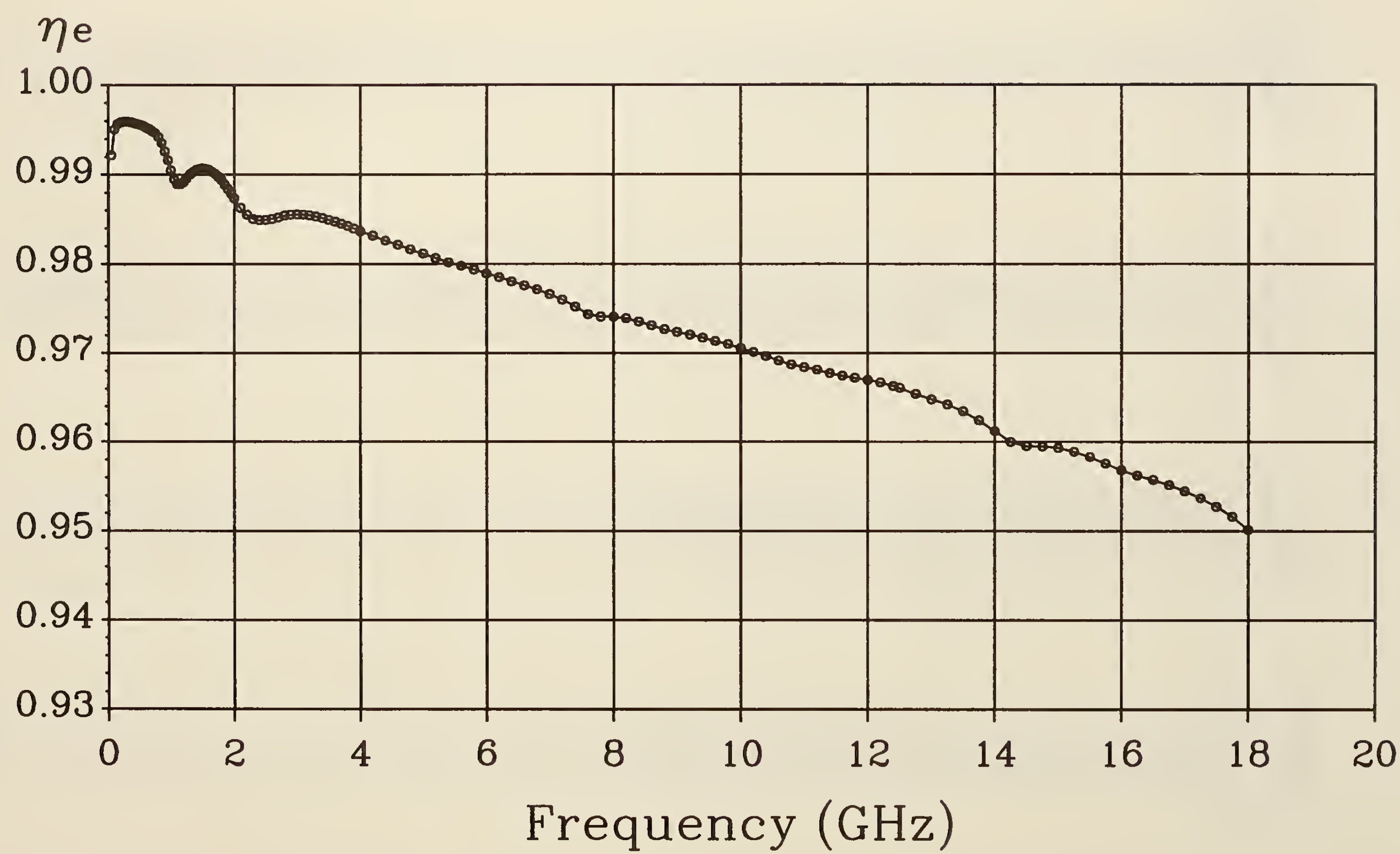
Table 1. (con't)

Frequency (GHz)	Effective Efficiency	Type B Uncertainty (Percent)	Expanded Uncertainty (Percent)
6.60	0.9776	0.26	0.36
6.80	0.9771	0.26	0.36
7.00	0.9766	0.26	0.36
7.20	0.9760	0.26	0.36
7.40	0.9752	0.26	0.36
7.60	0.9743	0.26	0.36
7.80	0.9741	0.26	0.36
8.00	0.9741	0.26	0.36
8.20	0.9739	0.26	0.36
8.40	0.9735	0.26	0.36
8.60	0.9731	0.26	0.36
8.80	0.9727	0.26	0.36
9.00	0.9724	0.26	0.36
9.20	0.9721	0.26	0.36
9.40	0.9717	0.26	0.36
9.60	0.9713	0.26	0.36
9.80	0.9710	0.26	0.36
10.00	0.9705	0.27	0.36
10.20	0.9701	0.27	0.37
10.40	0.9697	0.27	0.37
10.60	0.9691	0.27	0.37
10.80	0.9687	0.27	0.37
11.00	0.9684	0.27	0.37
11.20	0.9681	0.27	0.37
11.40	0.9677	0.27	0.37
11.60	0.9674	0.27	0.37
11.80	0.9672	0.27	0.37
12.00	0.9670	0.27	0.37
12.20	0.9667	0.27	0.37
12.40	0.9663	0.27	0.37
12.50	0.9661	0.27	0.37
12.75	0.9654	0.27	0.37
13.00	0.9648	0.27	0.37
13.25	0.9642	0.27	0.37
13.50	0.9634	0.27	0.37
13.75	0.9624	0.27	0.37

Table 1. (con't)

Frequency (GHz)	Effective Efficiency	Type B Uncertainty (Percent)	Expanded Uncertainty (Percent)
14.00	0.9612	0.27	0.37
14.25	0.9600	0.27	0.37
14.50	0.9595	0.27	0.37
14.75	0.9595	0.27	0.37
15.00	0.9593	0.27	0.37
15.25	0.9589	0.27	0.37
15.50	0.9583	0.27	0.37
15.75	0.9576	0.27	0.37
16.00	0.9568	0.28	0.38
16.25	0.9562	0.28	0.38
16.50	0.9557	0.28	0.38
16.75	0.9552	0.28	0.38
17.00	0.9545	0.28	0.38
17.25	0.9537	0.28	0.38
17.50	0.9527	0.28	0.38
17.75	0.9516	0.28	0.38
18.00	0.9501	0.28	0.38

Coaxial Power Standard
Microcalorimeter Measurements



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APPENDIX F. Instrument Identification

Table F1 identifies the commercial instruments used in the automated calibration system at the time this report was prepared. Items are listed as shown in figure 4.1. This 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.

Table F.1. Commercial instrument identification.

Item	Manufacturer	Model
1. Switch/Control Unit	Hewlett-Packard	3488A
2. Digital Voltmeter	Hewlett-Packard	3457A
3. Nanovoltmeter	Keithley	181
4. NBS Type IV Power Meter	-	-
5. DC Voltage Reference	Data Precision	8200
6. Microwave Locking Counter	EIP	578
7. Microwave Source	EIP	931
8. NBS Type II Power Leveler	-	-
9. Source and Meter Control Unit	-	-
Microwave Switch (See figure 4.2)	Hewlett Packard	P/N 33102A

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