Design, Evaluation, and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements

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The research described in this report represents the culmination of over 3 years of work at the National Bureau of Standards (NBS), Electromagnetic Fields Division, Boulder, Colorado, to carefully evaluate, develop (when necessary), describe, and document the methodology for performing radiated susceptibility/vulnerability (EMS/V) measurements using a reverberation chamber. This effort was jointly funded by the Naval Surface Weapons Center (NSWC), Dahlgren, Virginia; Rome Air Development Center (RADC), Griffiss Air Force Base, Rome, New York; and the NBS. Three major tasks were outlined. These were to:

1. Determine how well a shielded enclosure could be made to operate as a reverberation chamber to establish time averaged (statistically determined), randomly polarized, uniform EM fields as a function of spatial position, frequency and chamber quality factor (Q);

2. Evaluate interaction effects between the chamber and equipment under test (EUT) placed inside the chamber to determine:
   a. The range of applications of the measurement techniques (i.e., where the technique could or should not be used),
   b. Whether measurement results obtained using the reverberation chamber could be correlated with results obtained using anechoic chambers or open field sites, and
   c. To identify pertinent chamber calibration parameters;

3. Develop a technique applications and use manual.

These tasks were addressed sequentially in three major phases. The first phase was to design, construct, assemble and evaluate an empty (without the presence of an EUT inside) reverberation chamber with associated instrumentation and software to evaluate its electrical performance characteristics. This phase of the work began in January 1982 and was completed by the end of 1983. Results of this effort are contained in Section 2 of this report. Section 2 discusses the modification of a 2.74 m x 3.05 m x 4.57 m welded steel shielded enclosure located at NBS into a reverberation chamber. Information given includes theoretical concepts, physical design and construction details, and the evaluation of the empty chamber's electrical parameters. These parameters are excitation and reference receiving antennas voltage standing wave ratio (VSWR), loss, Q factor, wave impedance, spatial E-field distribution versus frequency, and determination of the test field level.

The second phase of the work was to evaluate the interaction effects between the chamber and the EUT placed in the chamber. This effort occupied the latter part of 1983 through 1984. The results are contained in Section 3 of this report. The third phase was to develop methodology and evaluate the use of the reverberation chamber for susceptibility measurements and compare the results to other more conventional measurements techniques such as anechoic chambers and other reverberation chambers. This study included the selection and susceptibility evaluation of four samples of EUTs: a one centimeter dipole probe, a ridged horn antenna, a series of rectangular TEM transmission cells with apertures and a modified 7.0 cm (2.75") diameter folded fin aircraft rocket (FFAR). The first three "reference standard" EUT's were selected because they could be characterized theoretically. The fourth EUT (FFAR) was more typical of an operational EUT which is more indicative of the actual type of equipment routinely tested for EM susceptibility. Results were obtained for this phase of the effort during 1984 and 1985. Details of how the measurements were performed, including setups, approaches, and instrumentation and software requirements are contained in Section 4. The final task was to document these results, presented in Section 5, and to produce a reverberation measurement technique applications and use manual. This, of course, is one of the purposes of this report. Section 6 gives a brief summary and conclusions drawn from this study. Some of the more significant are: 1) the NBS chamber lower useful frequency limit is 200 MHz; 2) the spatial variation in the statistically determined E-field established in the chamber is approximately 8 dB at 200 MHz and decreases to 2 dB at 2 GHz; 3) the preferred measurement approaches are mode tuned (explained in section 4.3.2) at frequencies below 2 GHz and mode stirred (also explained in section 4.3.2) at frequencies above 2 GHz; 4) the loading effect, of lowering the chamber's Q by inserting the EUT, should be limited to an increase in chamber loss ± 2 dB or a minimum tuner effectiveness ± 20 dB; 5) the average wave impedance in the chamber is approximately 120 ohms; 6) the maximum E-field is approximately 7-8 dB greater than the average E-field established in the chamber; 7) scattering from EUT does not significantly influence the E-field statistical, spatial distribution; 8) the directional characteristics of antenna or EUT placed inside the chamber are effectively lost; 9) the response of EUT measured inside a reverberation chamber is less than when measured inside an anechoic chamber (open space) in proportion to the EUT open space gain; 10) the response of EUT to an interference...
field after it has penetrated the EUT's shield appears to be equivalent in both reverberation and anechoic chambers; and 11) the experimental error analysis suggests that Root Square Sum (RSS) errors in establishing the test field inside a reverberation chamber range from approximately ± 10 dB at 200 MHz to ± 4 dB at 18 GHz.

Section 7 provides suggestions for future research and Section 8 acknowledges the significant contribution of others to this project. References cited are given in Section 9.
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Design, Evaluation, and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements

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This report presents the results of work at the National Bureau of Standards, Boulder, Colorado, to carefully evaluate, document, develop (when necessary), and describe the methodology for performing radiated susceptibility/vulnerability measurements using a reverberation chamber. The report describes the reverberation chamber theory of operation, construction, evaluation, functional operation, and use for performing immunity measurements. It includes an estimate of measurement uncertainties derived empirically from test results and from comparisons with anechoic chamber measurements. Finally, it discusses the limitations and advantages of the measurement technique to assist potential users in determining the applicability for this technique to their electromagnetic compatibility (EMC) measurement needs.

Key Words: electromagnetic susceptibility/vulnerability; estimated uncertainty; evaluation; measurement procedures; reverberation chamber

1. Background and Introduction

The use of mode tuned or stirred reverberation chambers for performing EMC measurements is a relatively new method which appears to have considerable potential for electromagnetic susceptibility/vulnerability testing [1-7]. The idea of reverberating a shielded enclosure as a way to improve the EMC measurement results obtained using the enclosure was first proposed in 1968 [1]. Since then measurement procedures have been developed for implementing the technique for both radiated susceptibility and emission testing, but with considerable skepticism and a general lack of acceptance on the part of many EMC engineers. Reasons given include: 1) a lack of information about interaction effects between the EUT, reverberation chamber, and sources used to excite the chamber, 2) significant unanswered questions concerning the interpretation and accuracy of the measurement results, and 3) the lack of clear correlation of test results with other more conventional measurement techniques. Emphases for performing the work described in this report result from numerous advantages suggested for use of a reverberation chamber. These include:

1. Electrical isolation from or to the external environment;
2. Accessibility (indoor test facility);
3. The ability to generate high level fields efficiently over large test volumes;
4. Broad frequency coverage;
5. Cost effectiveness;
6. Potential use for both radiated susceptibility and emission testing with minor instrumentation changes; and
7. No requirement of physical rotations of the equipment under test (EUT).

These advantages are somewhat offset by limitations which include loss of polarization and directivity information relative to the EMC/EMI profile of the EUT and reduced measurement accuracy. However, this technique does offers a time efficient, cost effective way to evaluate EMC performance of large equipment using existing shielded enclosures with only minor modifications. The concept utilizes the shielded, high-Q, multimoded environment to obtain uniform (time averaged) fields that may simulate "real world", near field environments.

This report describes efforts to answer some of the questions referred to above and outlines an approach using this technique for EMS/V testing. It also describes efforts to identify a "correlation factor" between reverberation chamber and anechoic chamber obtained results, and outlines a detailed, step by step procedure for performing EMS/V tests. An experimental error analysis is given to provide insight into the magnitude of the measurement uncertainties expected for tests performed using this method.
2. Development of an Operational Reverberation Chamber

2.1 Theoretical Concepts

A reverberation chamber is a large (in terms of wavelength) high quality (Q) cavity whose boundary conditions are continuously and randomly perturbed by means of a rotating conductive tuner or stirrer. The time averaged field inside such a cavity, when a sufficient number of modes are excited, is formed by uniformly distributed plane waves coming from all directions. This property causes the polarization of the field to vary randomly hence eliminating the need, or the utility of physical rotation of test objects in the field. This has its obvious advantages and disadvantages as is apparent from the results and conclusions given in this report.

Two analytical approaches can be used to provide basic knowledge for designing a reverberation chamber. One involves the direct solution of Maxwell's equations with time varying boundary conditions. A formal solution using this direct approach is rather difficult to obtain. In the second approach, suitable linear combinations of basic eigenmodes of the unperturbed cavity (without mode stirrer or tuner) with time-dependent expansion coefficients are taken to represent the field and to satisfy approximately the boundary condition on the surface of the rotating mode stirrer or tuner [8]. The main advantage of this latter approach is that the unperturbed eigenfrequencies and eigenmodes are much easier to calculate, and the problem can be reduced to a more familiar one under special conditions. A necessary condition for the validity of this method is, however, that the total number of eigenmodes which can exist inside a chamber be large for a specified frequency and chamber size. Thus, the measurement technique using reverberating chambers is good for high frequency application. Typical frequencies of operation are from a few hundred MHz to 18 GHz and above.

The frequencies at which particular modes can exist inside a shielded, rectangular enclosure of dimensions a, b, and d are given as [9]

\[ f_{mnp} = 150 \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{d}\right)^2} \]  

(MHz)

where m, n, and p are integers.

Figure 2.1 gives the distinct frequencies of resonances of the first few modes for the NBS reverberation chamber. There are 26 resonant modes at distinct frequencies below 150 MHz and 63 resonant modes at distinct frequencies below 200 MHz.

As expected, the total possible number of eigenmodes, \( N(f) \), inside an unperturbed, lossless, rectangular chamber increases in steps with frequency. A smooth approximation to \( N(f) \) has been given by [8,10,11]:

\[ N_s(f) = \frac{8\pi}{3} \text{abd} \left(\frac{f}{c}\right)^3 - (a + b + d) \frac{f}{c} + \frac{1}{2}, \]

where \( \text{abd in m}^3 \) represents the chamber volume, \( f \) is the operating frequency in Hz, and \( c \) is the speed of wave propagation in the chamber medium (usually air) in m/s. Note that the first term in (2) is identical to the well-known Weyl's formula derived originally for the same problem by a different approach, and is proportional to the chamber volume and the third power of frequency. The second term is the edge term, which is proportional to the sum of the linear dimensions of the chamber. This term may be used to modify Weyl's result, especially in the lower frequency range. Also, the inner surface area of the chamber, \( 2(ab + bd + da) \), is not involved in (2). An example is given in figure 2.2 showing \( N(f) \) as curve 1, \( N_s(f) \) as curve 2, and Weyl's formula as curve 3 for the NBS chamber. Note that none of the dimensions of the NBS chamber (2.74 m x 3.05 m x 4.57 m) are equal. Equivalent examples for a square-based chamber (2.17 m x 4.19 m x 4.19 m) and a cubic chamber (3.37 m)^3, both of which have the same volume as that of the NBS chamber, are shown respectively in figures 2.3 and 2.4 for comparison purposes. Clearly, wider steps for curve 1 in figures 2.3 and 2.4 as compared with figure 2.2 are observed. This is true even though the smooth approximation \( N_s(f) \) remains almost identical for all the three chambers. The main reason for this is due to the increased mode degeneracy for the last two chambers, under which the total number of distinct eigenmodes with respect to a given operating frequency and chamber size decreases.
While the total number of eigenmodes inside an unperturbed chamber is an important design criterion, another equally important factor to consider is the mode density function, \( \frac{dN}{df} \), which represents the change in number of modes in a given frequency interval. Ideally, the chamber should be designed, if possible, so that the distribution of the modes is uniform. To determine the exact shape of \( \frac{dN}{df} \) involves using impulse functions since they are the derivatives of step functions. It is not difficult to see that within a given frequency interval, the average distance between the different impulses for the NBS chamber is shorter than that for the other two chambers having the same volume. An alternative quantity to examine for exhibiting this property is

\[
\Delta N = \int \Delta f \frac{dN}{df} df,
\]

which represents the increase or decrease in mode number within a frequency interval of \( \Delta f \).

Results of \( \Delta N \) when \( \Delta f = 1 \text{ MHz} \) are presented respectively in figures 2.5 through 2.7 for the NBS chamber, the square-based chamber, and the cubic chamber. The uniformity of mode distribution in the frequency interval of 1 MHz is better for the NBS chamber (figure 2.7). This is the reason that the NBS chamber was designed with unequal dimensions. As a consequence, more uniformity for the electromagnetic field is expected within the NBS chamber than for chambers that have two equal sides or that are cubic, with the same volume and frequency of operation. Or, the NBS chamber should be capable of being operated with an extended lower frequency limit than other chambers of the same volume, in order to meet a given degree of uniformity for the final, expected field distribution. Thus, one of the general design criteria for a reverberating chamber is to make the volume as large as possible and the ratio of squares of linear dimensions as nonrational as possible.

A third design criterion, namely, the quality or Q factor, must also be considered in designing a reverberation chamber. Since there are so many eigenmodes which may exist in an unperturbed chamber with each mode carrying its own Q value [8,10,11], it is not always trivial to define a quality factor for the chamber as a whole. A composite quality factor for an unloaded chamber (without an EUT in it) within a specified frequency range can be obtained approximately from the equation [8],

\[
\bar{Q} = \frac{3}{2} \left( \frac{V}{2 \delta_S^2} \right) \left( \frac{1}{1 + \frac{3k}{16(a + b + c)}} \right)
\]

where \( V \) is the chamber’s volume in cubic meters, \( S \) is the internal surface area in square meters, and \( \delta_S = \sqrt{\frac{2}{\mu \sigma}} \) is the skin depth in meters, \( \lambda \) is the wavelength in meters, and \( a, b, \) and \( d \), are the chamber’s internal dimensions in meters.

The physical meaning of (4) may be interpreted by comparing it with the individual Q values of all the modes in the form of a cumulative distribution. Since \( V/(S \delta_S) \) is a common factor whether the composite quality factor defined above or the quality factor for individual modes is considered, it is more convenient to present the results in terms of \( 1/Q \) values normalized with respect to \( S \delta_S/V \). Thus, the variable used herein is

\[
\alpha = \frac{1}{Q} \left( \frac{V}{S \delta_S} \right).
\]

Examples of the cumulative distribution of \( \alpha \) for the NBS chamber are given respectively in figures 2.8 - 2.10 for three different frequency bands. For the frequency band of 180 to 200 MHz in figure 2.8, the total number of modes existing in this band of 20 MHz is 69, with each mode having its own Q-value. The probability of having a high upper-bound value of \( \alpha \leq 0.80 \) (or a lower-bound for Q) is almost 100%, and that for a low value of \( \alpha \leq 0.48 \) (or a high value for Q) is only about 10%. This implies that almost all of the 69 modes in this frequency band have \( \alpha \leq 0.80 \). The arithmetic mean of 0.623 and the standard deviation of 0.090 are also indicated in the figure. The probability of having \( \alpha \leq 0.623 \) (arithmetic mean) is 50%, meaning that at least one half of the 69 modes have \( \alpha \leq 0.623 \).
For the case presented in figure 2.9, where the frequency band is from 330 to 350 MHz, also of a bandwidth of 20 MHz, there are 261 modes, an increase in number of modes relative to that in figure 2.8. This is because of higher frequency. A similar interpretation of the \( \alpha \) values (or Q values) carried by these modes in terms of probability applies. There are now a small number of modes (low probability) carrying a value of \( \alpha \) as low as 0.43 (high Q). The arithmetic mean and standard deviation are, respectively 0.630 (higher than the corresponding value in figure 2.8) and 0.085 (lower than the corresponding value of figure 2.8). A higher value of arithmetic mean implies that one half or more of the 261 modes carry a higher value of \( \alpha \) (lower Q) compared to the frequency band considered in figure 2.8. A decrease in standard deviation reveals that a greater number of modes have \( \alpha \)-values closer to the arithmetic mean.

If we consider a still higher frequency band 480 to 500 MHz such as that illustrated in figure 2.10, 534 possible modes will exist in the same bandwidth of 20 MHz. The arithmetic mean increases further to 0.646 while the standard deviation decreases further to 0.074, indicating that a greater number of modes will have still higher \( \alpha \) values near the arithmetic mean. This tendency, increasing in arithmetic mean and decreasing in standard deviation with increased frequency, yields a limiting mean of \( \alpha \leq 0.667 \) with a 50% probability, which also agrees precisely with the limiting value for composite \( \alpha \) derived from (4) and (5).

Thus, even though there are a large number of possible modes existing in a specified operating frequency band for a reverberating chamber, with each mode carrying its own value of \( \alpha \) or Q, the probability that \( \alpha \leq 0.667 \) (or Q \( \leq 1.5 \) V/\( S \)a) is 50%. This implies that one half of the modes have \( \alpha \)-values less than 0.667. Preliminary estimation of a quality factor to characterize the reverberating chamber as a whole, based on the simple expression of Q in (4), for the purpose of predicting the field strength level to be generated in the test zone is indeed very useful.

Finite Q values also imply that more than 1 mode can be excited at a single frequency. The extent to which modes not specifically resonant at a given frequency are excited is, of course, dependant upon the particular modes' Q, and how close the modes' resonant frequencies are to the given frequency.

The composite \( Q' \) estimated from (4) is considered an upper-bound value because it does not take into account losses other than that due to wall conductivity. In reality, some loss will also occur due to leakage from the chamber, loss in antenna support structures, etc., and loss in the chamber's wall coatings. Hence an alternative means of determining chamber Q can be achieved from measuring the chamber's loss. Chamber loss is determined experimentally by measuring the difference between the net input power, \( P_t \), delivered to the chamber's transmitting antenna, and the power available, \( P_r \), at the reference antenna terminals. A photograph showing the interior of the NBS reverberation chamber is shown in figure 2.11. If the energy is uniformly distributed over the volume of the chamber, an empirical value \( Q' \) can be obtained [6] using the equation,

\[
Q' = 16 \pi^2 \frac{V}{A \lambda} \frac{P_r}{P_t} ,
\]

where \( V \) and \( A \) are as previously defined.

Typical losses for the NBS chamber are shown in figure 2.12. The two curves show the average and minimum loss as a function of frequency. These results were determined statistically by rotating the chamber's tuner through 200 increments of 1.8 degrees and measuring the chamber's loss at each position for all test frequencies. The smooth curves are an estimated curve fit for the data.

Results obtained using (4) to calculate the composite \( Q \) and by using the data shown in figure 2.12 and (6) to calculate the experimental \( Q' \) are shown in figure 2.13. Figure 2.13a gives the curves for the calculated values of \( Q \) and \( Q' \) and figure 2.13b shows the ratio of \( Q \) to \( Q' \). At frequencies above approximately 1 GHz the ratio approaches a constant value approximately equal to 3 or a loss equivalent of approximately 5 dB.
The Q factor of the chamber, of course, influences the rf input power requirements to generate the EM field levels inside the chamber for performing susceptibility tests. The average power received by the reference antenna, \( \overline{P_r} \) in watts, is related to the average power density, \( \overline{P_d} \) in watts per square meter, of the EM field inside the chamber by the equation,

\[
\overline{P_d} = \frac{\overline{P_r}}{A_r} \text{ (W/m)}^2,
\]

where \( A_r \) is the average effective aperture in square meters of the receiving antenna.

If the receiving antenna is subjected to EM energy coming from all aspect angles and random polarizations, the average gain of the antenna over \( 4\pi \) solid angle is unity. (i.e., the field distribution at each point in the antenna aperture plane is assumed to be a composite of randomly polarized plane waves. This implies that the orientation of the receiving antenna will not influence the measured response and hence the effective gain of the antenna is unity.) The effective aperture of the antenna then is given as, \( A_r = \lambda^2/8\pi \) [12].

However, data obtained, as shown later in this report, indicates that these conditions are not achieved ideally (the field is not completely randomly polarized and incident at all aspect angles and the assumption that the average gain for the antenna is one is not exact). Hence, a more practical value to use for the effective aperture appears to be \( \lambda^2/4\pi \). This value has been suggested previously for use in reverberation chambers for determining the "equivalent" average power density, \( \overline{P_d} \) [4]. Equation (7) then becomes,

\[
\overline{P_d} = \frac{4\pi \overline{P_r}}{\lambda^2} \text{ (W/m)}^2.
\]

Combining (6) and (8), we can obtain an expression for comparing the average, equivalent power density inside chambers of different size, assuming equal net input power, or

\[
\frac{\overline{P_d}_1}{\overline{P_d}_2} = \frac{V_1 Q_1^2}{V_2 Q_2^2} = \frac{S_2 \delta_2}{S_1 \delta_1},
\]

where the subscripts 1 and 2 refer to the two different enclosures, #1 and #2. For example, assume the #1 enclosure is the NBS enclosure with \( S_1 = 69.63 \text{ m}^2 \) and the #2 enclosure is a larger chamber constructed of the same metal (\( \delta_1 = \delta_2 \)) with dimensions, 3.51 m x 5.18 m x 10.82 m, or \( S_2 = 224.42 \text{ m}^2 \); this would give a ratio in average power densities (assuming the same net input power) of \( \overline{P_d}_1 / \overline{P_d}_2 = 3.22 \) (i.e., the average power density inside the larger enclosure would be approximately \( 1/\overline{3.22} \) or 0.311 times as much as that in the NBS enclosure). Note that the validity of (9) is dependent upon a number of assumptions alluded to in its derivation.

2.2 Physical Design Considerations

A number of criteria should be considered in physically designing a reverberation chamber EM susceptibility/vulnerability measurement system. They can be addressed under the following categories:

1. Chamber physical shape and volume,
2. Chamber quality factor (Q),
3. Chamber auxiliary needs (venting, electrical power, EUT visual monitoring, EUT operational and functional monitoring requirements),
4. Tuner/stirrer(s) design, and
5. Chamber excitation and field monitoring.
2.2.1 Chamber Physical Shape and Volume

This criterion was addressed in Section 2.1. For optimum chamber performance (i.e., spatial field uniformity and accuracy in determining the test field level), especially at the low end of the frequency intended for use, the volume of the chamber should be as large as possible and the ratio of the squares of the chamber's linear dimensions should be as nonrational as possible. Choice of chamber size would be dictated by test volume size requirements, lowest test frequency, and budget considerations.

2.2.2 Chamber Quality Factor, \( Q \)

The second criterion, that of chamber \( Q \), is established by carefully considering trade-off options. If one has the option of designing and constructing a new shielded chamber, it is advantageous to use solid welded aluminum or copper construction since this will result in a higher \( Q \) than if sheet steel is used. Presumably one can always lower the \( Q \) of the chamber, if desired, by inserting material such as lossy wall coatings or a limited amount of rf anechoic material. The reason for lowering the chamber \( Q \) is to increase the bandwidth of the chamber's modes, thus improving mode overlap and smoothing the EM field uniformity vs. frequency response characteristics, especially at the lower test frequencies. Doing this, however, increases the rf input power needed to generate the required field strengths and reduces the effectiveness of the chamber's tuner to redistribute energy uniformly into modes in all three axes of the chamber. In addition, the time required for the chamber test field to arrive at its steady state condition, after the input power to the chamber is applied, is a function of chamber \( Q \). The higher the \( Q \) the longer the settling or charging time. This could have significant implications if the reverberation chamber is to be used for pulsed rf susceptibility testing. Regardless of the metal used in the chamber's construction (aluminum, copper or steel) it should be standard practice to keep the chamber clear of lossy material such as wood or absorbing materials except for special purposes.

2.2.3 Chamber Auxiliary Needs

The third criterion, chamber auxiliary needs, must be established based upon the intended use and the upper test frequency for use. Venting panels should use screens with apertures significantly smaller than waveguide below cutoff at the maximum intended test frequency. Electrical power supplied to outlets inside the chamber, EUT visual monitoring, and EUT operational and functional monitoring requirements are similar to conventional shielded enclosure requirements. A bulkhead panel similar to that shown for the NBS reverberation chamber in figure 2.14 can be used to access the excitation and reference receiving antennas, and the EUT. Care must be taken to ensure that the shielding integrity of the enclosure is not compromised by access holes or cables, etc. This may require the use of high resistance (carbon impregnated) lines [13] or fiber optic links for monitoring the EUT. In addition, waveguides below cutoff access ports can be very useful.

2.2.4 Tuner Design

The fourth criterion is to design the tuner to ensure its effectiveness to redistribute the energy inside the enclosure and hence to tune the field. To achieve this, the tuner must be electrically large (>\( \lambda/2 \)) at the lowest frequency of operation) and be shaped or oriented to distribute energy into all possible modes. Three such tuners are shown in figures 2.15a, 2.15b, and 2.15c. The first tuner (figure 2.15a) was developed by McDonnell Douglas Corp. [2,14,15] after extensive testing to optimize the design for use in their translational electromagnetic environment chamber (TEMEC) facility. The second tuner (figure 2.15b) is used by the Naval Surface Weapons Center in their reverberation chamber [16]. The third tuner (figure 2.15c) is used in the NBS reverberation chamber. The tuner is mounted as shown in figure 2.16, with the blades bent at an angle of approximately 45 degrees to the ceiling to improve its scattering of the field evenly in all directions. The tuner mounting includes a shielded housing with internal metal wipers to prevent rf leakage from the chamber via the tuner shaft to the stepping motor. Details of the housing and motor mounting arrangement are shown in figure 2.17. The tuner controller system which includes the stepping motor and a computer accessed controller, allows movement of the tuner in increments as small as 0.113 degrees (3200 steps per revolution) at rates from seconds up to hours per revolution. The motion was optimized for as smooth a motion of the tuner as possible.

A test to determine how effectively the tuner is functioning is to measure the ratio of the maximum to minimum received power of the receiving antenna as a function of tuner position. This is done while maintaining a constant net input power to the enclosure's
transmitting antenna. The results of such measurements made with the NBS tuner are shown in figures 2.18a and 2.18b. The magnitude of the ratio is dependent upon a number of factors including tuner shape, size, orientation, and the Q of the enclosure. The average value of the maximum to minimum ratio is higher in the empty chamber. (Data for figure 2.18b were obtained with 4 pieces of 66 cm x 61 cm x 61 cm rf absorber placed in the center of the chamber 0.5 meter above the floor). The purpose for inserting the absorber was to simulate a gross loading effect of an EUT placed in the enclosure. A lower loss (ratio) is indicative of a higher Q and more effective mode tuning. This influences the spatial uniformity of the test field (statistically) as is shown in section 2.3. A reasonable guideline for proper operation of the tuner is a minimum tuning ratio of 20 dB.

Multiple tuners have been used in some reverberation chambers [3,6]. Typically they are mounted on opposite walls to improve the stirring of the fields in the chamber. This is especially important if the tuners are flat, thus acting as scatterers in only one plane. The tuner controller system used in the NBS system allows for control of several tuners simultaneously. This may be particularly advantageous if the reverberation chamber is especially large or is compartmentalized (multiple sections). Examples of compartmentalized chambers are a large chamber divided into two sections by a separating wall or a small chamber placed inside a large chamber. Both arrangements have been proposed for using the reverberation chamber method for measuring shielding effectiveness of materials and enclosures [17].

2.2.5 Chamber Excitation and Field Monitoring

The fifth consideration in designing a reverberation chamber EMC measurement system is in the selection and mounting of appropriate antennas for exciting and monitoring the EM fields inside the chamber. The following parameters are used in selecting the antennas:

a) frequency range of interest,

b) input power rating (>200 watts),

c) bandwidth (>10:1 if possible),

d) minimum VSWR (low as possible),

e) efficiency for exciting modes inside chamber,

f) minimum size, and

g) durability.

The typical frequency range of application is from 200 MHz to 18 GHz or higher. A number of candidate antennas could be used in this range. No single antenna has sufficient bandwidth to cover the full range with the possible exception of the long wire antenna. Based upon the above and, to a certain extent, the antennas available at the Electromagnetic Fields Division of NBS, the following were selected for evaluation.

a) Long wire antenna (200 MHz - 18 GHz),
b) Log periodic antenna (200 MHz - 2 GHz),
c) Monopole antenna (200 MHz - 1 GHz),
d) Bow-tie antenna (200 MHz - 1 GHz),
e) Leaky 50 ohm coaxial cable (200 MHz - 1 GHz),
f) Ridged horn (1.0 GHz - 12 GHz),
g) Double ridged circular horn (2.0 GHz - 18 GHz).

The efficiency with which energy can be injected into or coupled out of the chamber via transmitting or receiving antennas is determined by: 1) the voltage standing wave ratio (VSWR) of the antennas (i.e., the impedance match between the rf source and the transmitting antenna or between the receiving antenna and its output detector), and 2) the ability of the antennas to couple energy into or out of the particular modes that exist at the test frequencies of interest. Rotating the tuner changes the chamber's boundary conditions and hence, shifts the mode excitation frequencies. This, of course, changes the characteristics of the field inside the enclosure which in turn influences the effective VSWR of the antennas. The Q factor of the enclosure as a resonant cavity also has considerable effect upon the VSWR of the antenna. This is particularly true at frequencies below a few GHz.

The placement and orientation of the transmitting and receiving antennas can also influence the operation of the chamber [16]. Two positions or orientations are recommended: 1) position the transmitting and receiving antennas in different corners of the chamber, oriented toward the corners as shown in figure 2.19, or 2) position one of the antennas in a corner oriented toward the corner, for example the reference receiving antenna, with the other antenna (transmitting antenna) sufficiently far away and oriented toward the tuner. The first
arrangement was selected for use in the NBS chamber. The purpose for these configurations is to couple energy into and out of all chamber modes as efficiently and uniformly as possible without significantly favoring particular modes or favoring a direct path coupled signal between the transmitting and receiving antennas.

Installation of a long wire antenna inside the chamber is different from other antennas because it uses the chamber wall as its ground plane to obtain as close to a 50 ohm impedance as possible. Details for designing the taper transition region of the long wire antenna are shown in figure 2.20. A photograph of the long wire antenna installed inside the NBS chamber is shown in figure 2.21. The long wire extends around two surfaces of the chamber. This is done to achieve, however somewhat limited, the purpose of the locations and orientation configurations referred to above for other conventional antennas.

Based upon the results of data obtained for various antenna pairs selected from the above list, the following four antennas were chosen for use in the NBS chamber in the following frequency ranges:

1) Long wire (200 MHz - 1000 MHz), receiving mode,
2) Log Periodic (200 MHz - 1000 MHz), transmitting mode,
3) Ridged horn (1.0 GHz - 10 GHz), transmitting and receiving modes,
4) Double ridged circular horn (2.0 GHz - 18 GHz), transmitting and receiving modes.

Within the recommended frequency bands of operation, the long wire and log periodic antennas can accommodate up to 1000 watts input power, and the ridged horns and double ridged circular horns can accommodate up to 200 watts input power.

A number of preliminary tests were performed to determine the operational parameters of the NBS reverberation chamber using these antennas and to evaluate the interactions between EUT, the chamber, and the rf sources used in performing these measurements. Some of these tests and their results were previously published [19]. The VSWRs and coupling efficiency of these four antennas placed inside the empty NBS chamber are given in figures 2.22 and 2.23. Figure 2.22 shows the maximum, average, and minimum VSWR obtained statistically by measuring return loss from the antennas, operating in the transmitting mode, as a function of tuner position at discrete frequencies from 200 MHz to 18 GHz. The tuner was stepped at 1.8 degree increments (200 steps) through a complete revolution. Figure 2.22a is for the long wire antenna operating over the complete frequency range. Figure 2.22b, is the composite VSWR of three antennas (#2, #3, and #4) used within the frequency bands shown in the figure's caption. In the past a long wire antenna has been used quite extensively as a reference receiving antenna across the full frequency range [4,14,17]. Its input VSWR is not as low, especially at frequencies above 1 GHz, as for the composite of the three antennas. Also, at frequencies above approximately 2 GHz, rotation of the tuner appears to have a minor influence on the VSWR of the antennas. This feature can have considerable impact upon the decision as to what approach to use in performing susceptibility measurements as discussed in section 4.1 of this report. Figure 2.23 shows the coupling efficiency or loss between the long wire antenna transmitting (200 MHz - 18 GHz), and a composite of the three antennas receiving. This figure is provided for comparison with figure 2.12. The long wire antenna is not as efficient in coupling energy into the chamber and hence, the loss is greater, particularly above 1 GHz.

The quality factor of the chamber as a resonant cavity also has considerable effect upon the VSWR and coupling efficiency of the antenna placed inside, especially at frequencies below a few GHz. This is shown in figures 2.22c and 2.24. These data were obtained with four pieces of 66 cm x 61 cm x 61 cm rf absorber placed in the center of the chamber's test zone. Note the significant reduction in the VSWR variations of the transmitting antenna associated with the substantially lower Q in the enclosure and the significant increase in the chamber loss.

2.3 Determination of Wave Impedance and E-Field Amplitude Distribution Inside Reverberation Chamber

2.3.1 Determining the Test Field and Wave Impedance Amplitudes

The field strength in the chamber can be determined in two ways. The first is to measure the power received by the reference antennas, and then determine the equivalent power density in the enclosure from (8). The equivalent electric field, $E_a'$, is then found using the expression,
where \( \eta' \) is the statistically averaged wave impedance in the chamber. This averaged wave impedance is assumed to be approximately equal to 120\( \Omega \). Obviously, the wave impedance inside the reverberation chamber will have large variations as a function of tuner orientation and chamber location. To test the validity of (10), independent measurements were made of the maximum, average, and minimum magnetic and electric fields in the chamber. These measurements were made using a one centimeter diameter loop probe and a one-centimeter long dipole probe. The probes were rotated through three orthogonal orientations aligned with the chamber axes and located at the center of the test zone. The magnitudes of the total magnetic and electric fields were then determined as the square root of the sum of the squared values of each of the three components respectively for both the magnetic and electric fields. The corresponding ratios of the electric-field and magnetic-field amplitudes for a data base of 200 positions of the tuner were then used to determine an "equivalent" wave impedance. The results are shown in figure 2.25. Four curves are given. Three curves show the maximum, average and minimum wave impedance determined as a function of frequency. The fourth curve shows the wave impedance calculated from the ratio of E to H when the electric-field was a maximum. Even though the wave impedance varies widely as expected with frequency, the average wave impedance at frequencies above 200 MHz (the lower frequency limit recommended for this chamber) is approximately 120\( \Omega \). This then, provides evidence that (10) is valid, at least for determining the average E-field in the chamber. The fourth curve was included because, as will be discussed later in this report, the convenient parameter for comparing reverberation chamber with anechoic chamber obtained EUT susceptibility data is the EUT's peak response. This typically corresponds to a maximum electric field in the reverberation chamber. Note that the wave impedance corresponding with the maximum E-field typically is greater than 120\( \Omega \) and was found to be as large as 1600\( \Omega \) thus contributing to an error as large as 6 dB in determining the maximum E-field if (10) is used.

The second method used to determine the field strength in the reverberation chamber is to measure the electric field using an electrically small dipole probe that has been previously calibrated in a standard uniform field. This is the same dipole probe, referred to above, that was used to determine the chamber's wave impedance. The assumption made in using the probe is that since it is electrically small, the fields measured in the reverberation chamber over the aperture of the dipole will be uniform (i.e., "equivalent" to the standard uniform field used in the probe's calibration); and hence the probe's response will give an accurate measurement of the "equivalent" field strength in the chamber. Results of the measurements comparing the electric-field strength generated in the chamber based upon these two methods are shown in figure 2.26. The maximum and average E-field strength data were normalized to one watt net input power. The agreement shown is typical of the random variations in the data used to determine the field in a reverberation chamber. The systematic offset difference between the field determined using the reference antenna and that determined using the probe is, however, less than 3 dB. This result also strengthens the validity of (10).

2.3.2 Maximum Versus Average Amplitude Responses

Another important observation from figure 2.26 is the approximate 7-8 dB difference in signal amplitude between the maximum and average field strengths. This can be explained simply in terms of the structure of the cavity modes in the chamber [20]. For a cavity of dimensions, a, b, and d, modes in all three dimensions can be represented as

\[
\phi_{mnp}(x,y,z) = \sin \frac{m\pi x}{a} \sin \frac{n\pi y}{b} \sin \frac{p\pi z}{d},
\]

where x, y, and z correspond to the three orthogonal axes of the chamber and m, n, and p are the associated mode numbers.

An antenna typically responds to a specific field component, or in the reverberation chamber case, to the composite field impinging upon its aperture. However, measured power is related to \( \phi_{mnp}^2 \). The maximum value of \( \phi_{mnp}^2 \) occurs when each component is a maximum or

\[
\text{Max} (\phi_{mnp}^2 (x,y,z)) \leq 1.
\]

The average value of \( \phi_{mnp}^2 (x,y,z) \) is given by
The ratio of $\text{Max} \left( \phi_{\text{mp}}^2 (x,y,z) \right) / \text{Ave} \left( \phi_{\text{mp}}^2 (x,y,z) \right)$ in the limit then is 8 which corresponds to 9 dB (i.e., this is the theoretical maximum difference that can exist between the maximum and average responses of an antenna or EUT measured in a reverberation chamber). In practice, the mode mixing is not 100 percent efficient to achieve a perfect average nor does one obtain a perfect maximum in all three dimensions. Hence the average difference of 7 to 8 dB shown in figure 2.26 is expected.

In the past, a question regarding the validity of maximum or "peak" reverberation chamber results has been raised. However, this question seems to be resolved as apparent by examining the relationship between maximum and average measurements in the reverberation chamber exhibited in figure 2.26 and from the implications of (12) and (13). These results suggest one can extract one set of data (e.g., average) from the other (e.g., maximum) quite accurately (within ± 2 dB), assuming of course, that the response of the EUT is linear.

### 2.4 Spatial E-Field Distribution

Tests were made to determine the uniformity of the maximum and average values of the E-field in the chamber as a function of spatial position and frequency. Seven NBS isotropic probes [21] designed to operate at frequencies up to 2 GHz were placed inside the enclosure as shown in figures 2.19 and 2.21. Each probe has three orthogonally oriented dipoles aligned with the enclosure axes. Measurements were made of the field strength of each orthogonal component at the seven locations for each tuner position (200 steps of 1.8 degree increments). The maximum and average values for each component and the corresponding amplitudes were then determined from the complete data set for a normalized net input power to the chamber of 1 watt. The results of these measurements are shown in figure 2.27. These measurements were made in 50 MHz increments from 100 MHz to 2.0 GHz. The spread of the data points show the spatial field variation inside the enclosure at the indicated frequencies. Note at 200-300 MHz the spread and potential errors in determining E-field amplitude is as great as ±8 dB, decreasing to approximately ±2 dB at 2.0 GHz. Note also the large difference in the three orthogonal components at frequencies below 150 MHz. This is especially apparent from inspecting figure 2.26 which shows the average values of the seven statistically determined average and maximum E-fields for each component and their composite total determined from figure 2.27. Strong mode structure is indicated in the chamber at frequencies below 150 MHz (i.e., the presence of a dominant mode with its associated directional properties). Hence, there are insufficient modes for proper operation at these frequencies. At frequencies above 150 MHz, the relative amplitudes of the field components are approximately the same and the composite total of the average E-field components is approximately 4.8 dB greater than the individual components. This indicates that the measured value of the average of each component is independent of polarization of the dipole. (i.e., $E_x(\text{ave})$ is independent of $E_y(\text{ave})$, etc.). Thus,

$$E_{T(\text{ave})} = \sqrt{(E_x(\text{ave}))^2 + (E_y(\text{ave}))^2 + (E_z(\text{ave}))^2} = \sqrt{3} (E_{x,y,or z}(\text{ave})).$$

The composite total however, of the E-field components' maxima (figure 2.28b) is less than 4.8 dB. This indicates that the maximum measured values for each component are not independent. (i.e., $E_x(\text{total})$ is a function of $E_y(\text{total})$, etc.). The implication is that if multiple receptors are involved in establishing the maximum susceptibility of an EUT (or for example in measuring the E-field in the chamber by using an isotropic probe with 3 orthogonal dipoles), the difference between the maximum and average response may be less than the typical 7 to 8 dB referred to in section 2.3.

### 2.5 Multiple Excitation of the Chamber

Electromagnetic fields were generated inside the chamber using two separate antennas simultaneously excited in the frequency ranges, (200-400) MHz, and (1000-2000) MHz. The antennas used for the frequency range (200-400) MHz were a log periodic and a long wire described previously. Two ridged horns were used in the frequency range (1.0-2.0) GHz. The spatial, statistical, E-field uniformity did not improve significantly over using a single antenna excitation in the 200-400 MHz frequency range; however, it did improve slightly (from approximately ± 2 dB to ± 1.5 dB variations) in the frequency range (1.0-2.0) GHz.
The E-field amplitude in the chamber decreased when using two excitation antennas, in both frequency ranges, assuming the same net input power as for a single antenna. The decrease was approximately 1 dB in the frequency range (200-400) MHz and approximately 1.5 dB in the frequency range (1.0-2.0) GHz. This loss however, can be accounted for in the losses in the additional rf transmission line cables and the second excitation antenna (i.e., the antennas are not 100% efficient in converting input rf power to radiated power).

3. Interaction Effects Between Chamber, Source and Reference Antennas, and EUT.

3.1 Placement Constraints of EUT

Constraints on the placement of EUT inside the reverberation chamber are a result of the proximity effect of the chamber walls on the test field and upon the EUT. Measurements were made of the E-field close to the chamber's walls for comparison with measurements made of the E-field within the test zone outlined by the matrix of seven probes shown in figure 2.21. Two locations were selected: 1) 0.5 m from the chamber's side and back wall, 1.0 m above the floor; and 2) 0.12 m from the side wall approximately mid-way between the chamber's ends and 0.5 m above the floor. Location 1 was selected so the EUT test zone would be clear of obstructions but also with the probe far enough from the chamber's walls, hopefully, to avoid significant proximity effects. Location 1 measurements were consistent with the measurements made at the 7 probe locations. Location 2 was selected to determine just how significant the proximity effect is at distances less than one third wavelength (<800 MHz). The average E-field measured at location 2 was approximately 2 dB lower at frequencies from 200 to 400 MHz than the E-field measured in the test zone. The field close to the chamber wall then increased as a function of frequency, approaching the test zone measured field strength at frequencies above 1 GHz. These results indicate a need to maintain a minimum spacing for the reference antenna, field measurement probe(s), and/or EUT of at least 1/3 from the chamber's walls at the lowest test frequency. This equates to approximately 1/2 meter at 200 MHz for the NBS chamber. An exception to this guideline may be a desired spacing between the EUT and the chamber floor or walls. This spacing may be dictated by the test plan. If the EUT is electrically large (many wavelengths) it may be necessary to have a separation distance from the chamber walls greater than 1/3 at frequencies where 1/3 is less than 1/2 meter or greater than 1/2 meter under some test conditions to prevent shadowing effects from influencing the spatial distribution of the test field. Results of scattering effects measurements discussed in section 3.2 suggest shadowing is not a significant problem, if the EUT is placed in the center of the test zone as far from the walls as possible.

3.2 Scattering Effects of Metal Objects upon E-field Distribution

Two test objects were selected to simulate an EUT placed in the chamber to evaluate their scattering effect upon the field distribution inside the chamber. The first object was a solid welded aluminum box 30 cm x 50 cm x 60 cm in size. The second was an electronic equipment rack 56 cm x 67 cm x 114 cm in size. Tests were made to determine the E-field uniformity or distribution over the test zone matrix defined earlier using 6 isotropic probes (figure 2.19) with each of the two test objects placed at the center of the test zone. (The probe at the center of the test zone was removed to accommodate the test objects.) Figures 3.1a and 3.1b show the two test objects placed inside the enclosure. The mean value of the maximum and average values for each E-field component (vertical, longitudinal, and transverse) and their composite total were determined for each of the 6 probes. The results, shown in figure 3.2, give a comparison with the empty chamber E-field distribution measurements shown in figure 2.28. Little or no difference was noted in the statistical (average and maximum) values measured.

3.3 Loading Effects of EUT on Chamber

One of the concerns expressed about using a reverberation chamber for EMC measurements was the realization that if the EUT absorbed energy from the chamber (i.e., demonstrates susceptibility) it would reduce the Q of the chamber and thus affect the measurement results. Typically this is compensated for by simply increasing the net input power to the chamber transmitting antennas as required. This may not be sufficient if inserting the EUT lowers the chamber's Q to the extent that the chamber no longer reverberates or the tuner will no longer sufficiently stir the modes, (i.e., the chamber no longer functions properly). Recall that the absolute amplitude of the test field level inside the chamber is determined from the reference antenna received power measurements. The assumption is that this measurement is unaffected by the loading effect of the EUT. Two simple tests were used to evaluate the loading effect: the first was to insert a 500 MHz, half-wave, resonant dipole near the center of the chamber's test zone to determine if energy coupled from the chamber to the dipole would
reduce the field strength in the chamber. This test was intended to simulate the loading effect of a simple resonant EUT. Field strength measurements were made again using the seven probe matrix and the long wire antenna as a reference receiving antenna to determine the level of the test field, before and after inserting the resonant dipole. A constant normalized input power of 1 watt was applied at the input of the chamber log periodic transmitting antenna to establish the field in the chamber. The following observations were made:

1) Energy is conserved (i.e., power coupled from the chamber via the dipole results in a proportional decrease in the E-field in the room).
2) The 500 MHz resonant dipole and the long wire receiving antenna coupled approximately the same amount of power from the room.

The seven probe matrix used to determine the spatial distribution of the E-field inside the chamber, also load or reduces the Q factor in a similar fashion to the resonant dipole. Each of these probes couple a small amount of energy out of the test field. In addition, they have lossy transmission lines made up of carbon loaded teflon that serve to convey their detected dc signals to their instrumentation located outside the chamber. These lossy transmission lines increase the chamber's loss up to 5 dB at 2.0 GHz. However, this amount of loss did not seem to significantly influence the ability to determine the field level in the chamber, with or without the presence of the probes by using the reference receiving antenna. The field level simply was lower for the same net input power due to the loading effect of the probes in the chamber.

The second test used to evaluate the loading effect was to place varying amounts of rf absorbing material inside the chamber. This was done to get an indication of just how much loading the chamber could tolerate before it fails to operate properly and/or large errors existed in determining test field level and EUT response. Progressively greater amounts of absorber were added until approximately 90 percent of the net input power was being absorbed (i.e., the chamber loss was increased by approximately 10 dB). The amount of rf absorber required was four pieces of 66 cm pyramidal high performance absorber 61 cm x 61 cm square. Results for tuner effectiveness, VSWR and chamber loss with absorber loading were shown in figures 2.18b, 2.22c, and 2.24. As indicated earlier, lowering the chamber Q reduces the test field level in the chamber for a given net input power. Inserting the 4 pieces of absorber in the chamber lowers the field considerably as shown in figure 3.3. This figure compares the maximum E-field strength in the test volume defined by the 7 probe matrix inside the empty chamber with the field strength after the chamber is loaded with the 4 pieces of absorber.

In summary, the following observations can be made from the data obtained (figures 2.18b, 2.22c, 2.24 and 3.3). Lowering the chamber Q:

1) decreases the effectiveness of the tuner (lower Max/ in ratio),
2) improves the VSWR of the transmitting and receiving antennas,
3) increases the chamber loss and hence increases the rf power required to obtain test fields of the same level,
4) increases the uncertainty in determining the test field level and EUT response (indicated by the larger variations in the E-field data obtained with absorber, figure 3.3), and
5) decreases the spatial, statistical E-field uniformity.

In conclusion, the following guidelines are suggested. Inserting the EUT should not lower the maximum or average received power from the chamber's reference antenna for the same net input power into the chamber (before and after inserting the EUT) excessively. If these ratios, net input power/received power(max or ave), increase more than 6 dB, or if the tuner's average effectiveness decreases to less than 20 dB, use of the reverberation chamber is not recommended.

4.0 Performing Immunity Measurements

4.1 Planning the Measurements

A number of considerations are important in planning the measurements, writing the test plan, and documenting the test results. One is the amount of data required to accurately
characterize the EUT. Equipment susceptibility to EMI is primarily determined by the degree to which the interference field couples into and interacts with the equipment's components. This undesired coupling is influenced by a number of equipment parameters such as: input/output, power line, and circuit lead impedances and lead lengths; impedances of circuit components (especially those terminating lead wires); type of circuit components (particularly active components); and amount and type of EMI shielding and filtering used. The susceptibility of any particular equipment is usually a function of frequency, suggesting resonance effects within the equipment with its input/output leads and other interconnected equipment. These resonances may be caused, for example, by the reactance of the connecting leads acting as an antenna, coupling with the input impedance of the terminating circuit components. The quality factor (Q) of such a resonant circuit determines the maximum spacing or increment between frequencies at which susceptibility tests must be performed. Automated systems such as required by the reverberation chamber test methods are (by their digital nature) discrete frequency systems. The number of test points one can obtain using such a system are limited by the memory or storage capacity of the computer, the measurement system bandwidth, and the measurement time constraints. Thus, care must be exercised in choosing frequency and amplitude measurement intervals compatible with the test system and the number of test points required.

A second consideration is the test-field time duration versus reaction time of the EUT. Some EUTs have components with relatively slow thermal time constants. This equipment must be exposed to test fields with sufficient duration to allow reaction and interaction; otherwise susceptibility tests may not be true indicators of the equipment's vulnerability. For example, thermocouple devices used to simulate electro-explosive devices may require one to two seconds exposure time for maximum response. EUT soak time requirements influence the approach (section 4.2) selected for performing the tests using the reverberation chamber method.

Another important consideration relates to the need to simulate as closely as possible "real world" operating conditions. Ideally, susceptibility tests should be performed with the EUT connected and operated in its operational environment. Since this, most likely, is not possible, these operational conditions should be carefully simulated. This normally includes making certain the EUT is tested with its wiring harness in the same configuration (as nearly as possible) as when in actual use. (Actually, one of the advantages of the reverberation chamber method is that the test results are independent of EUT wiring harness, input/output and power lead orientation.) In addition, all connecting leads should be terminated with equivalent impedances as when in actual use. Failure to simulate these conditions can result in data that are misleading. An additional problem is the EUT-antenna-enclosure interaction that exists inside any shielded enclosure. Antenna radiation or receiving characteristics are altered when enclosed inside a shielded environment. One should realize that the EUT always interacts somewhat with the exposure field in any environment. What is difficult is sorting out the normal open-field scattering effect from the unknown perturbation effects of the EUT-antenna-enclosure interaction that is typically ignored in shielded room susceptibility testing. Efforts to quantify this effect for reverberation chamber obtained results are discussed in section 5.

How to sense and telemeter the performance of the EUT from the test environment without disturbing the EUT, the test environment or sensitive test equipment is another important consideration. This is usually done by using either fiber optics lines or "invisible" wire [13] (carbon impregnated Teflon) with appropriate readout devices.

Finally, one obvious purpose for performing susceptibility tests is to determine EUT compliance with pre-established performance criteria. For production item sampling, a worst case EMI exposure environment with pass-fail criteria may be appropriate. However, for engineering development of EMI-hardened equipment or for correcting EMI problems discovered in existing equipment, diagnostic testing is needed. This type of testing requires knowledge of the exposure field parameters, such as: frequency, repetition rates, and wave shape of test signal; type and percent of modulation imposed; and polarization, amplitude and signal waveform time variations. These parameters must be carefully selected, as part of the test plan, controlled, and (for some tests) statistically characterized for the testing to be meaningful. One obvious limitation of the reverberation chamber method for susceptibility testing is the loss of polarization information. However, this is in part compensated for because worst case response characteristics of the EUT can be determined without repositioning or orienting the EUT in the reverberation chamber since the test field is rotated around the EUT. If carefully controlled tests are performed, resonances and susceptible EUT circuit components can be determined, from which cause and effect relationships can be established. These can then be modified or eliminated to improve the immunity of the EUT. Another
important consideration in performing diagnostic testing is the desirability of determining how the EMI is coupled into the EUT. This requires separating, if possible, the sources of interference reception, such as EUT input/output and power line leads, leakage through the EUT case housing, or internally generated and coupled EMI. This can be achieved by a systematic process of shielding and filtering various leads and functional sections of the EUT’s circuit, etc., while conducting the susceptibility tests.

4.2 Measurement Approach (Tuned vs. Stirred)

Two approaches are used for performing EMC measurements using the reverberation chamber. The first approach, mode tuned, steps the tuner at selected, uniform increments, permitting measurements of the net input power, reference antenna received power, field measuring probe response and the EUT response at each tuner position. This allows corrections and normalization of the received power, field measurements and EUT response to be made for variations in the net input power to the chamber. These variations are due to changes in the input VSWR of the transmitting antenna as a function of the tuner position. The number of tuner steps per revolution that must be used is a function of frequency and chamber Q. Typically, at least 200 steps or more are required to provide sufficient sampling to accurately determine the statistical parameters of the test field and EUT response (maximum and average amplitudes). If the sample size is too small, the fidelity of the measurements suffers and true maxima, minima, etc. are not recorded. The mode tuned approach also allows the operator to select long test field exposure times as needed to accommodate some EUT response times.

The second approach, mode stirred, rotates (steps) the tuner continuously while sampling the reference antenna received power, field probe response and EUT response at rates much faster than the tuner revolution rate. These measurements are made using a spectrum analyzer, diode detectors, and “smart” voltmeters with their own microprocessors capable of data storage and calculation of statistical functions such as mean values and standard deviations. The mode stirred approach allows large data samples (up to 9,999) for a single tuner revolution. Tuner revolution rates are adjusted to meet EUT response time and output monitor response time requirements. Typical revolution periods are from 1 to 12 minutes. This large sample, as compared to mode tuned, improves the accuracy in determining the statistics of the measured parameters, however, at the expense of increased uncertainty due to failure to correct for net input power variations.

Hence a trade-off exists between mode tuned and mode stirred operation. An examination of figure 2.22 suggests this trade-off occurs approximately between 1-2 GHz. (i.e., The mode tuned approach would be more accurate below 1-2 GHz where the mode density is not as great and corrections can be made for variations in the net input power caused by large variations in the input VSWR of the transmitting antennas. Mode stirring is more accurate at frequencies above 1-2 GHz where VSWR variations in the transmit antenna as a function of tuner position are small and large data samples of the test field and EUT response can be taken.)

4.3 Measurement System

4.3.1 Measurement Setup and Instrumentation Requirements

A block diagram of the basic NBS reverberation chamber EMC measurement system is shown in figure 4.1. The test field is established by means of rf source(s) connected to transmitting antenna(s) placed inside the chamber. Antennas used are discussed in section 2.2.5. Modes excited inside the chamber are then tuned or stirred by rotating the mode tuner which functions as a field-perturbing device. The EUT may be placed anywhere convenient within the chamber provided no point on the EUT is closer than 1/2 meter to any wall, or ceiling. Placement relative to the floor is dependent upon a number of factors including intended use configuration relative to ground-planes etc., and should be specified by the test plan. Test, power, and control cables are routed to appropriate monitors, etc., outside the chamber via shielded or filtered cables and feed-through connectors, high resistance lines, and fiber optic lines as required to prevent leakage of fields to the outside environment. Note that a precision 10 dB attenuator is used with the power detector or spectrum analyzer, whenever possible, to measure the receiving antenna power. This is done to minimize impedance mismatch with the receiving antenna. The calibrated bidirectional coupler at the input to the transmitting antenna allows measurements of the net input power so corrections can be made for changes in net input power resulting from antenna-rf generator impedance mismatch and rf generator output variations that occur during the rotation of the tuner. As referred to earlier, these corrections are made when using the mode tuned measurements approach for each incremental change in tuner rotation. For mode stirred, the net input power is measured only.
at the beginning of the measurement cycle. Details of how the measurement cycle proceeds under computer control, how the data are managed, recorded, and processed for presentation are contained in the next section describing the software used for these functions.

### 4.3.2 Software Requirements and Measurement Procedures

The computer code used in the evaluation of the reverberating chamber has evolved from simple routines that record only the measurement data to the present complex programs that have abilities to recover from many common system failures and operator errors. The more sophisticated programming is made possible by using modern laboratory computers containing large amounts of memory. The primary function of recording the measurement data however, remains unchanged and is outlined in this section, with some discussion of the supporting activities and refinements.

A general overview of the software is shown in figure 4.2. The major tasks of accumulating data using the two primary methods (mode tuned and mode stirred), saving the measured results, and preparing the data graphics are shown. The measurement routines are supported by the module entitled System Calibrations. The data library is not actually program code, rather it indicates data storage that is available to the Data Graphics program and is added to by the measurement programs. Two major programs, detailed below, are used to implement the measurement approaches. They are quite different in how the instrumentation is programmed and the data managed and will be discussed separately. The basic computer code defining these measurements is listed in appendix A. The listings contain the details of the measurements as shown in figures 4.3 and 4.4. The instrument control modules have been omitted to avoid excessive detail.

#### Mode-Tuned Approach

The flow diagram for the mode-tuned measurement program is given in figure 4.3. This diagram is used to assist in guiding the operator systematically through the measurement procedure.

**Step 1.** Place the EUT inside the chamber and access at as required for operation and performance monitoring.

Details for placement of the EUT and accessing it are contained in sections 3.1, 4.1, and 4.3.1. The EUT should be placed at least one half meter away from the outer walls of the chamber unless specified in the test plan to simulate proximity to a ground plane.

**Step 2.** Connect the measurement system as shown in figure 4.1.

**Step 3.** Specify measurement and calibration parameters.

Calibration factors for the cables and directional couplers used must first be tabulated and stored in the computer for later access. All parameters used in the measurements are then specified using a menu of items from which the operator may select the values for the experiment. These parameters include: frequency range and increments, number of tuner steps, signal generator output level as required to obtain the desired field strength inside the chamber, the EUT output voltage considered as an upper bound for maximum safe EUT operation, and an estimate of the response time of the EUT. The experiment description, operator's name, and the system clock can be accessed in the menu also. When the operator is satisfied with the parameter values and exits the menu, these values plus all calibration values (e.g., cable loss, coupling factors, etc.) are tabulated for reference. The measurement hardware is then initialized and the measurement begins.

**Step 4.** Perform the measurement (automated measurement sequence).

The measurement sequence can be traced in figure 4.3. At the beginning of each test all the instruments are set to zero (if there is an internal auto-zeroing feature) or a reading is taken to determine the offset from zero with the field removed. These offset readings are then used to adjust the readings taken with the field applied. This should be done as often as needed to minimize errors resulting from zero drift.

It is important to have reached both mechanical and electrical stability at each step of the tuner before reading the instruments. As the mechanical time constant of the stepping motor and the chamber's tuner blades is typically much longer than the electrical response time of the measurement instrumentation or the EUT, the most efficient manner with which to
collect the data is to minimize the movements of the tuner. Any given measurement usually involves a sequence of frequencies at which to measure the response of the device. This routine is designed to collect the data for all frequencies at each tuner step before moving the tuner to another location. The data is then rearranged at the conclusion of the measurements such that data from all tuner positions for a given frequency is together before it is processed for final graphic presentation.

After the instruments are zeroed and their offset voltages recorded, the rf power is applied and the response of all devices which could be damaged by excessive field strength is measured. This checking is done as rapidly as possible for each frequency and provides one level of protection for the system. Typically, the operator should specify power levels that are appropriate for the EUT(s) being tested. Then this test will detect only those conditions which cause an unusually high response.

With the initial checking done, the program then proceeds to read the remaining instruments in the system. These include power meters, digital voltmeters, spectrum analyzer, specialized data acquisition systems, and/or any other monitoring device being used.

As mentioned above, all frequencies of interest are measured before the tuner is moved to the next position. There are many possible ways to group this data and save it on a mass storage device. The approach used here is to maintain all the data for a given tuner step (or several steps) together in one file. This file can then be recalled and the data rearranged such that all the information for a given frequency is together. Saving the data frequently allows the measurement to be continued, without starting over, should the system lose power or a fatal error occur.

The routines necessary for operation of the instruments are, of course, unique to the device but some general concepts are useful to discuss:

a). The program should exercise some care to insure the validity of the readings. Most instruments will allow access to a status byte that will indicate many failures common to the device. This can be monitored during the read cycle and action taken if the measurement is not valid. Action is also necessary if the device fails to respond or hangs the interface bus. These situations may require operator assistance, but the program should be able to recover and repeat the operation if the condition is temporary.

b). Readings taken within the limits of the instrument yet too quickly for the rest of the system to respond, for instance the tuner may still be vibrating or the sensor may be slow to respond, will cause erroneous results. For these measurements where the field being monitored is generated by a cw signal of constant amplitude, the response of a device should settle to a constant value, provided the tuner has stabilized and the device has had enough time to respond. The computer should be able to determine when to accept the reading based on the factors mentioned. One method is to install fixed wait statements that guarantee steady conditions. A more dynamic approach is to monitor the device and compare readings until steady conditions are reached. This optimizes the already lengthy measurement by avoiding long idle times that may not be necessary. A refinement to simply comparing readings is to compare the averages of several readings grouped together, referred to as a running average. This has a tendency to smooth noise that may be on the signal and also to make comparisons of low level readings (near the noise floor) more stable.

Step 5. Correct the data by applying the system calibration values and zero field offset readings.

The correction factors are applied to the measured quantities at the time the data are taken and key items are calculated. These items are then stored in the memory for later use in compiling the data. Items may include incident and reflected powers to the transmitting antenna corrected for cable loss and coupling factors, power received from the reference antenna (corrected), etc. Care must be taken at the beginning of the measurement to assure that calibration factors and cable loss correction to be used match the physical setup.

At the completion of the last tuner position, with all the data residing in mass storage, the measurement routine is complete. The remaining tasks are independent programs, freeing the measurement system for other measurements.

Step 6. Compile the corrected data by frequency, normalize to a constant net input power (for example, 1 watt), perform the statistical calculations and present final results.
Normalization of the corrected measurement data for determining: a) the E-field in the chamber, and b) the EUT response, for a constant net input power is done for each tuner position. First the corrected net input power is determined and compared to the desired normalized value. The difference is then used to shift the corrected received power measurements and EUT response measurements as if the actual net input power had been the desired normalized value. This may involve a simple linear extrapolation as is the case for linear detectors, or it may require calibration of the nonlinear response characteristics of the received power detectors and/or EUT monitors thus resulting in appropriate corresponding nonlinear corrections.

The statistical calculations are performed using the corrected, normalized data. These calculations include the maximum, average, and minimum values as appropriate, of the desired parameters (net input power, received power, EUT output response, etc.). The calculations are made using data sets obtained by using the corrected normalized data at the selected number of discrete tuner positions for one complete revolution of the tuner, at each frequency of interest. These result are then, typically, presented in graphs as a function of frequency.

Mode Stirred Approach

The mode-stirred measurement (figure 4.4) begins in a similar manner to the mode-tuned discussed above. The automated measurements sequence of events is somewhat different and hence some of the parameters necessary for performing mode-stirred measurements differ from mode-tuned.

Step 1. Place EUT inside the chamber and access it as required for operation and performance monitoring.

This is the same as for mode tuned.

Step 2. Connect the measurement system as shown in figure 4.1

This step is similar to the setup for mode tuned except the spectrum analyzer is used to measure the reference antenna received power and the EUT monitors must be fast sampling devices such as "smart" voltmeters referred to earlier.

Step 3. Specify measurement and calibration parameters.

These parameters are similar to the mode tuned case with the following two exceptions:

a) The specification of revolution time for the tuner determines the sample size and sampling parameters associated with the EUT monitoring equipment. Tuner steps (sampling size) are now given as a function of time for one complete revolution of the tuner from which the number of samples that will be taken during that single revolution, for each of the sampling instruments, is determined. These numbers require careful timing trials prior to automating a mode-stirred measurement. The instruments used for the tests detailed in this report, "smart" digital voltmeters, are capable of performing statistical operations on a large number of samples (up to 9999) using a single trigger command. This feature is very convenient for this type of measurement but requires that the number of samples needed to synchronize rotation time of the tuner and total sampling time of the voltmeter be known prior to triggering the measurement. The time required for taking each sample voltage varies slightly with the amplitude of the signal measured. This makes it difficult to estimate accurately the total time required for any given number of samples. Approximations are used and the program adjusts the sample count to insure the correct sampling time for a complete revolution. The sampling should be completed as near to the end of the tuner revolution as possible to avoid weighting the statistics with an incomplete data set or data taken as the tuner begins a second revolution. Typical rates for tuner rotation are in the range of 1 to 12 minutes per single revolution.

b) The signal generator output level is now a range of values because this program has the ability to search for an optimum response of the device. The range of response values is also accessible in the mode-stirred menu and gives the operator control over minimum readable output from the EUT and also the level considered as the upper safe limit. The program will attempt to keep power levels adjusted such that the response is at some point above the minimum and never above a maximum.
Sometimes it is advantageous to monitor the EUT response using analog devices such as an xy recorder. If care is taken to insure that the response time of the recorder is short compared to the sampling rate or rotation rate of the tuner, the EUT output can be monitored in real time, thus allowing optimization of the sample rate to correspond to the EUT response time. Care must be taken to insure adequate sample time, otherwise the EUT response will be clipped yielding inaccurate results. This condition is easy to detect from the analog output plots and hence avoid.

When the operator is satisfied with the parameter values and exits the menu, these values plus all calibration values (e.g., cable loss, coupling factors, etc.) are tabulated for reference. The measurement hardware is then initialized and the measurement begins.

Step 4. Perform the measurement (automated measurement sequence)

The measurement sequence is shown in figure 4.4. At the beginning of each test all the instruments are set to zero (rf power is off), if possible, or the zero offset is recorded the same as for the mode-tuned approach. The rf power is then applied at the lowest specified level, the tuner motion is activated, and the EUT response is monitored. This first measurement attempt, at each specified frequency, results in a search for a threshold response from the EUT. If the EUT's response is below the preselected level, the rf power is increased in 1 dB increments and held constant allowing the tuner to rotate a few degrees, while searching for the threshold level. If the threshold value for the EUT's response is not reached, the generator level is increased again and the searching process repeated until the threshold level is reached or the maximum range selected for the generator output is achieved. Upon finding an acceptable power level, the instruments are triggered to begin a measurement cycle. Typically the instruments used include "smart" digital voltmeters as mentioned earlier and a spectrum analyzer looking for a peak response from the reference antenna. Any specialized detecting device would also be included. The response of the EUT is constantly monitored via a second fast sampling voltmeter (in addition to the "smart" voltmeter doing the statistics) to protect it from overload. If, during the test, the response should exceed the maximum safe value so that the power level is decreased or any other error condition is detected, the program will remember the correct power level to be used as the measurement is restarted.

At the time all the instruments are done sampling, the program checks to see if the tuner completed a full revolution before the measurements (sample) were finished. A comparison of the times taken for the tuner revolution and each meter's total sampling time is made. If these values agree to within a given tolerance and no other errors were detected, then the numbers are assumed to represent a valid measurement. On the other hand, if these conditions are not met, the sampling parameters are adjusted and the entire measurement process is repeated for the same frequency. Special care taken in the preparation of these sample parameters, as mentioned earlier, will minimize the need for repeat measurements.

The results from all the instruments are now read into the computer, corrected using the appropriate calibration factors and the necessary calculations are made. This includes the statistical parameters for the EUT monitored data, as determined by the "smart" voltmeters, and the peak value of the received power from the reference antenna as measured using the spectrum analyzer. Caution must be exercised if the test field is modulated since this may influence the accuracy of the measurement results depending upon the detector(s) response characteristics. The reference antenna received power data can be used to determine a normalized response for the EUT based upon a constant test field level as a function of frequency if desired. The net input power delivered to the chamber is measured after the acceptable power level is established at the beginning of the measurement cycle, just prior to triggering the "smart" voltmeters. These measurements may then be used to normalize the data to an equivalent constant input power level preselected for all test frequencies if desired. The entire process is then repeated until all frequencies have been measured.

The process by which the statistics are derived for the parameters monitored by the "smart voltmeters" consists of the following steps: 1) the measured analog data is converted to digital form; 2) the first data value is stored for future reference; 3) the second and subsequence data values are compared to the previous data values to determine maximum, minimum, and the running total values; 4) at the conclusion of the data collection, (completion of the data sample) the running total is divided by the sample size to calculate an average value for the data set; and 5) finally, the maximum, minimum, and average values stored in the "smart" voltmeter are transferred upon command to the computer for mass storage and future use as required.
Step 5. Compile the corrected data and present final results.

Data obtained using the mode stirring approach is not normalized at each tuner position. Corrections applied to this data to normalize it to a specified value of net input power must be applied to the maximum, average, and minimum values as determined by the "smart" voltmeters (EUT and other monitored responses) or the maximum value (reference received power) as determined by the spectrum analyzer. Correction made to the data for cable loss, etc., must also be made in a similar way. After these corrections are made, the data is compiled by frequency and presented typically in graph form usually showing only the maximum values as a function of frequency. For example see figures 5.15 and 5.16.

5. Experimental Test Results

5.1 Correlation of Results to Anechoic Chamber Tests - Some Examples

This section describes efforts to estimate a "correlation factor" between reverberation chamber and anechoic chamber obtained results. This was done first for reference standard EUTs and then for an EUT more typical of operational equipment. Tests were performed using the NBS reverberation chamber and a 4.9 m x 6.7 m x 8.5 m anechoic chamber also located at NBS. The EUTs included in this study are: 1) a one centimeter dipole probe antenna (200 MHz to 18 GHz), 2) a ridged horn antenna (800 MHz to 10 GHz), 3) a series of rectangular coaxial transmission line (TEM) cells with apertures (200 MHz to 4000 MHz), and 4) a modified 7.0 cm (2.75") folded fin aircraft rocket, (FFAR) (200 MHz to 12.0 GHz).

5.1.1 Description of Anechoic Chamber Measurement System

A block diagram of the NBS anechoic chamber EMC measurement system is shown in figure 5.1. The test field is established inside the chamber by means of an rf source connected to a standard gain transmitting antenna. This "standard field" is computed from [22]

\[ E = \sqrt{\frac{30 P_{\text{net}} G}{D}} \]  (14)

where \( P_{\text{net}} \) is the net power in watts delivered to the transmitting antenna, \( G \) is the effective gain for the transmitting antenna, and \( D \) is the separation distance in meters. Equation (14) assumes far-field conditions for a field point on axis of the transmitting antenna so that \( G \) is the maximum power gain.

The net power, \( P_{\text{net}} \), is determined using calibrated power meters and bidirectional couplers from the expression

\[ P_{\text{net}} = P_{\text{inc}} CR_F - P_{\text{ref}} CR_R \]  (15)

where \( P_{\text{inc}} \) is the forward incident power, \( P_{\text{ref}} \) is the reverse reflected power measured on the sidearm of the coupler, and \( CR_F \) and \( CR_R \) are the forward and reverse coupling ratios for the coupler referenced to its output port.

The transmitting antennas used are open ended waveguides (200 to 500 MHz) and standard gain horns (500 MHz to 18 GHz).

Comparisons of the response or susceptibility characteristics of EUT (or antennas) obtained using an anechoic chamber and a reverberation chamber are typically made in terms of peak values. The main reasons for this are that typically the EUT's worst case performance or susceptibility is desired, and the practical consideration of the difficulty in obtaining a true average response for an EUT from anechoic chamber data. Even determining the EUT's peak response in an anechoic chamber (depending of course upon how well behaved the EUT radiation pattern characteristic is) can require considerable measurements involving complete pattern measurements.

5.1.2 Measurement of the Peak Response of a 1 cm Dipole and a Ridged Horn

A comparison of the peak output response data obtained for the 1.0 cm dipole using the NBS reverberation and anechoic chambers is given in figure 5.2. Note that the probe output response in the anechoic chamber is greater, in general, by about 2.5 dB than its output in
the reverberation chamber. This suggests that the correlation between the results may be related to the EUT's gain characteristics in the two chambers (i.e., the gain of the dipole probe in free space is approximately 2.5 dB). Determination of a far-field gain for a complex receptor (for example the EUT described in section 4.3.4) is extremely difficult. Therefore, a simple, well defined broadband receiving antenna (a ridged horn) was used as an EUT to repeat similar tests performed for the 1 cm dipole. The horn is designed to operate in the frequency range 800 MHz - 10 GHz. For these measurements in the anechoic chamber, the peak response (peak received power) of the horn occurs when the horn is bore-site aligned and polarization matched with the source antenna. These measurement results were then compared with the horn's peak received power in the reverberation chamber with the same level exposure field. The results are shown in figure 5.3a. Note that the horn's response is greater in the anechoic chamber. To see if this difference corresponded to the difference in the gain characteristics of the horn in the anechoic chamber, as compared to that in the reverberation chamber, the horn was calibrated to determine its far-field gain in the frequency range 800 MHz - 10 GHz. These results are shown in figure 5.3b. Again, note the general agreement between the difference in the horn's response measured in the two facilities and the horn's far-field gain.

5.1.3 Measurement of RF Coupling Through Apertures in TEM Lines

Measurements were made using the reverberation and anechoic chambers to evaluate the rf coupling through apertures cut into a series of TEM cells or transmission lines. Three TEM cells were used. Similar models (EUTs) have been used for evaluating shielding effectiveness of connector assemblies [23]. Electromagnetic energy coupled through the aperture in the TEM cell when exposed to the test field excites the fundamental TEM mode inside the cell. These results in rf power conducted to the cell's output ports which can then be measured. These results are compared with the theoretically predicted values based upon a planar field exposure to determine degree of correlation. The results obtained for one of the TEM cells, shown in the photograph of figure 5.4, are given in figure 5.5. The dimensions for this cell are 12 cm x 18 cm x 36 cm with a 5.1 cm x 5.1 cm aperture centered in the top of the outer conductor. The theoretically predicted peak coupling for a uniform field exposure is also shown on figure 5.5 [24]. Measurements were not made in the anechoic chamber at frequencies below 500 MHz because of the limitations of the anechoic chamber measurement system. The theoretical peak values should be essentially the same as the measured values in the anechoic chamber. Again, the anechoic chamber peak data are generally higher than the peak reverberation chamber data. Also, the average reverberation chamber data are approximately 7-8 dB lower than the peak data, similar to both the 1 cm dipole and ridged horn results.

Results obtained for the second cell, shown in figure 5.6, are given in figure 5.7. The dimensions for this cell are 12 cm x 12 cm x 24 cm with a 3.1 cm diameter aperture. The results are similar to those shown for the larger cell. Results obtained for the third cell, shown in figure 5.8, are given in figure 5.9. The dimensions for this cell are 3.0 cm x 6.0 cm x 11.4 cm with a 1.4 cm diameter aperture centered in the top of the outer conductor. Again the results are similar.

5.1.4 Measurements of the EM Susceptibility of a Modified 7.0 cm Folding Fin Aircraft Rocket (FFAR) [25].

A 7.0 cm diameter FFAR was modified with a thermocouple element to sense the response of the rocket's inserted electro-explosive device (EED). This was done to allow measurement of the rf current coupling into the EED's bridge wire circuit when the rocket is exposed to an rf field. The rocket was also modified with a 1.27 cm plastic spacer at the base of its fin (on the tail section) to increase the rf coupling to the bridge wire circuit. This lessened the requirements for high rf power to generate fields sufficient to perform these measurements. This modification was justified, realizing the purpose of this study was to compare susceptibility results obtained for the rocket in different environments and not to simply evaluate an EUT's susceptibility to EMI. Photographs showing the rocket placement inside the NBS reverberation chamber and the NBS anechoic chamber are shown in figures 5.10 and 5.11. Measurement results of the rocket's thermocouple peak output current resulting from rf coupling as a function of frequency are shown in figures 5.12a and 5.12b. These data were obtained using exposure fields normalized to 10 mW/cm² in each of the chambers. The anechoic chamber data were obtained by rotating the rocket in azimuth in a planar far-field using both vertical and horizontal polarizations. The rocket was rolled a few degrees around its axis before each azimuth cut. Sufficient roll angles were used to determine the peak response. Examples of pattern data obtained in the anechoic chamber at three selected frequencies are shown in figure 5.13. A total of 719 patterns were obtained in the anechoic chamber from
which the peak response at each frequency was determined. These data were then used to plot curve A of figure 5.12a. Curve A (anechoic chamber data) indicated greater response or more susceptibility, except at one frequency (1800 MHz), than curve B (reverberation chamber peak response). Again, the proposed explanation for this is the difference between the gain characteristics of the rocket's response in the anechoic chamber (for example see figure 5.13) and its gain characteristics in the reverberation chamber. The rocket gain is lost in the reverberation chamber. Figure 5.12b shows the difference between curves A and B for figure 5.12a.

5.2 Comparison of Results Between Reverberation Chambers

Measurements were made of the EM susceptibility response of three different EUTs, using two additional, similar, but different size reverberation chambers. These measurements were made to give an indication of the repeatability in measurement results obtained using the same technique (reverberation chamber methods) but with totally different facilities. The second and third reverberation chambers are located at the Naval Surface Weapons Center, Dahlgren, Virginia. These chambers were made from a single large shielded enclosure partitioned into two compartments with a removable center panel. The two chambers consist of: 1) the half chamber, 3.51 m x 5.18 m x 5.86 m in size using a little over half of the full enclosure, and 2) the full chamber, 3.51 m x 5.18 m x 10.82 m in size, using the full enclosure. The NSWC enclosure was constructed of continuously welded steel sheeting similar to the NBS enclosure. Two basic insights are provided by a comparison of results obtained from the evaluation of these different enclosures. First, that the input power requirements of a chamber is a function of its size and can be estimated based upon the calibration of a chamber of similar construction. Second, susceptibility test results obtained for the same EUT in different reverberation chambers are comparable. These conclusions are demonstrated in figures 5.14 to 5.17. Figure 5.14 shows a comparison of the fields inside the NBS and NSWC chambers calculated from the chamber's reference antenna received power measurements and then measured by a calibrated 1 cm dipole probe. The net input power was normalized to one watt for all three chambers. Note that the field inside the NBS chamber is approximately 4 dB stronger than the NSWC half chamber and 6 dB stronger than the NSWC full chamber. Recall that the power density inside a second chamber can be estimated from a calibrated chamber by using (9). The ratio of the average power densities for the NBS to NSWC full size chamber for the same net input power (see section 2.1) was 3.22. This is equal to approximately 5 dB, a little less than that indicated by comparing figures 5.14a and 5.14c, but still within reason.

The second point of obtaining comparable susceptibility results using different chambers is demonstrated in figures 5.15 to 5.17. These graphs show the comparison in measuring the responses of the NBS 1 cm dipole probe and a rectangular single ridged horn to a normalized 37 dB V/m field inside the three different chambers and the peak response of the 7.0 cm FFAR to a normalized 10 mW/cm² power density inside the NBS and the NSWC half size reverberation chambers. In general, the agreement is within measurement tolerances except at 200 MHz for the FFAR. This frequency approaches the lower limit for using the reverberation chambers and is also where the FFAR is most susceptible and hence where one would expect the greatest difference.

6. Summary and Conclusions

6.1 Conclusions Drawn From Study

1. The practical lower frequency limit for using the NBS enclosure as a reverberation chamber is approximately 200 MHz. This lower limit is due to a number of factors including insufficient mode density, limited tuner effectiveness, and ability to uniformly excite all modes in the chamber. These factors are a function of both chamber geometry and size. Increasing the inside dimensions of the chamber will lower the useful frequency limit in an approximately proportional manner.

2. Spatial variations in the E-field maximum and average values determined in the chamber's test volume are:

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Variation in Measured E-Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>± 8 dB</td>
</tr>
<tr>
<td>500</td>
<td>± 5 dB</td>
</tr>
<tr>
<td>1000</td>
<td>± 3 dB</td>
</tr>
<tr>
<td>2000</td>
<td>± 2 dB</td>
</tr>
</tbody>
</table>
These data were determined using the mode tuned approach with 200 tuner increments for one complete tuner revolution. The limitation for determining the spatial E-field variation is most likely due to the increasing mode density and hence field complexity in the chamber as a function of frequency and the insufficient sampling of the field resulting from the limited number of tuner positions used. The spatial E-field variations should decrease less than 2 dB at frequencies above 2 GHz if sufficiently large data samples are taken.

3. Using a combination of antennas within their specified design frequency ranges for transmitting and as reference receiving antennas inside the chamber is preferred to the use of a long wire antenna. This is apparent because of the lower VSWR and greater efficiency in exciting the chamber and coupling energy from the chamber.

4. E-field data obtained using the mode stirred approach with the chamber empty have significantly less amplitude variations with frequency than data obtained using the mode tuned approach, particularly at frequencies above 1-2 GHz (e.g., <3 dB rather than <6 dB. Compare figure 2.26 to figure 3.3.) This implies that the mode stirring method is superior for some applications above these frequencies. This is significant since the stirred method is much simpler and faster to use. In comparing the two methods it is interesting to note the difference in the amplitude of the maximum fields at frequencies below 1-2 GHz. The mode tuned method is more accurate at these frequencies for determining the absolute amplitude of the test field since it allows for corrections due to changes in antenna VSWR. Because of these observations and other supporting data, the best results (accuracy versus measurement time considerations) for the NBS reverberation chamber can be obtained using the following approaches and tuner positions for susceptibility testing:

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>Method</th>
<th># Tuner Positions or Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2-1.0 GHz</td>
<td>Mode Tuned</td>
<td>200</td>
</tr>
<tr>
<td>1.0-2.0 GHz</td>
<td>Mode Tuned</td>
<td>400</td>
</tr>
<tr>
<td>&gt;2.0 GHz</td>
<td>Mode Stirred</td>
<td>5000</td>
</tr>
</tbody>
</table>

5. Lowering the Q of the enclosure: a) increases the rf power required to obtain the test field, b) increases the uncertainty in determining the test field level, and c) decreases the spatial, statistical field uniformity.

6. The statistically determined average wave impedance of the EM field in the chamber is approximately that of free space (377 ohms), thus confirming the validity of (10).

7. The maximum E-field is approximately 7 to 8 dB greater than the average E-field.

8. Scattering from the EUT does not seem to influence the statistical, spatial E-field distribution within the chamber.

9. Multiple source excitation (from more than one location) improves the spatial E-field distribution slightly, but not enough to justify additional hardware requirements and the additional rf power needed to compensate for the loss in the additional input transmission line required.

10. Energy is conserved in the chamber (i.e., power coupled from the chamber via loss in transmission lines, antennas, EUT, physical support materials, etc., reduce the power density in the chamber. Thus it is good practice to remove all that are not essential to the tests from the chamber.

11. The chamber (NBS) continues to operate (as a reverberation chamber) with loading that reduces the Q significantly (up to 90% of the total energy absorbed), however, with significant loss in measurement accuracy.

6.2 Summary of Measurement Uncertainties

6.2.1 Determining the Field Strength Inside the Chamber

Recall from section 2.3.1 that the susceptibility/vulnerability test field established inside the chamber can be expressed either in terms of an "equivalent" power density (8) or an "equivalent" E-field strength (10). An estimate of the uncertainties in each of these quantities can be obtained by analyzing the contributing parameters involved in each
mode-tuned and mode stirred approaches respectively, within their appropriate frequency bands. Five major categories are identified. The first is the uncertainty in determining the received power from the chamber's reference antenna. This is broken up into four components: namely, cable loss, attenuator calibration, reference antenna efficiency and power meter or spectrum analyzer measurements uncertainties. Values shown are typical of estimated uncertainties stated for these type of measurements and instruments.

The second category is the impedance mismatch error that can occur between the reference receiving antenna(s) (source) and the power detector(s) (load). The actual power delivered to the load is a function of the impedance match between the source and load, with maximum power transfer occurring when a conjugate impedance match exists.

\[
P_f = \frac{\text{fraction of maximum available power absorbed}}{\text{by the load}} = \frac{(1 - |r_S|^2)(1 - |r_L|^2)}{|1 - r_S r_L|^2}
\]

(16)

where \(r_S\) and \(r_L\) denote complex reflection coefficients. The magnitudes, \(|r_S|\) and \(|r_L|\) can be obtained from the appropriate VSWR by the expressions

\[
|r_i| = \frac{\text{VSWR} - 1}{\text{VSWR} + 1}, \quad i = S \text{ or } L
\]

The VSWRs for the reference antennas (sources) and power detectors (loads) used in the NBS reverberation chamber are given in table 6.3. These values were used to calculate the estimated uncertainties shown for the mismatch error in tables 6.1 and 6.2. Note that different average and maximum values are given.

The third category of error, referred to as mixing or sampling efficiency, is divided into two parts. The first part relates to the ability to obtain a uniform spatial field distribution (statistically) inside the chamber and to effectively destroy the polarization characteristics of the exposure field. (i.e., the statistically determined response characteristics of the EUT and chamber reference antenna are independent of their directional properties.) The second part is the uncertainty due to limiting the number of tuner positions per revolution when performing the measurement. This source of uncertainty is different when determining the average as compared to the maximum field as shown in the tables. Data shown in figure 2.27 and table 6.4 were used in obtaining these estimates.

The fourth category of uncertainty relates only to determining the equivalent E-field strength in the chamber from the equivalent power density. Recall that (10) assumes that the equivalent wave impedance inside the chamber is 120\(\Omega\) ohms. In reality this is not true as was shown in figure 2.25. This figure was then used to provide an estimate for this error taking into account that a significant amount of data obtained to date indicates that peak fields are approximately 7-8 dB greater than the average field strength inside the chamber (see section 2.3.2). i.e., An examination of figure 2.25 shows values of wave impedance as large as 1600 ohms at frequencies below 500 MHz when the maximum E-field was measured. This would require a large correction, up to 6.3 dB. However, experience indicates that a well behaved relationship (7-8 dB difference) exists between the measured peak and average values of the E-field. This suggests that the peak value of the wave impedance for maximum E-field inside the chamber decreases as the frequency increases thus lowering this source of error. These observations are reflected in the uncertainty estimates shown in the tables.

The fifth source of error occurs if one fails to correct for net input power variations due to the loading effect of the chamber on the VSWR of the source antennas. (See section 4.2 for more details.) Note that these corrections are made typically when using the mode tuned approach and hence are not included in the total or root-sum-square error estimates of table 6.1. They are shown on the table to provide insight to the estimated magnitude of error expected if this correction were not made. The basis for these estimates are the data shown in figures 6.1a and 6.1b. These figures show the average and maximum E-field strength measured inside the NBS reverberation chamber using an array of seven NBS isotropic probes. A comparison is shown between results obtained before and after the measurements were corrected for net input power variations and normalized for an equivalent constant net input power. Note from table 6.1 this error is the same order of magnitude as 2), the mismatch error between the receiving antennas and power detectors. This is as expected since the source and
receiving antennas used in the chamber have similar VSWRs and the power detector (load) and generator VSWRs are also similar. This error is included in table 6.2 and estimated to be the same as for the receiving mismatch error.

The total (worst-case) uncertainties for each approach (mode-tuned, and mode-stirred) are shown at the bottom of each table. This uncertainty should be regarded as a conservative estimate. The probability of the true value of $E_a$ being near the extreme of such worst-case uncertainty is small. This is because the probability of every error source being at its extreme value and in the worst possible combination is almost zero.

A more realistic method of combining uncertainties is the root-sum-of-the-squares (rss) method. The rss uncertainty is based on the fact that most of the errors are independent of each other and hence are random with respect to each other and combine like random variables. The rss method of combining random variables is justified by statistical considerations (beyond the scope of this report) which are also inherent in the reverberation chamber measurement methods.

Finding the rss uncertainty requires that each individual uncertainty be expressed in fractional form. The method of calculation follows the name - square the components, sum those squares and then take the square root. The results are shown at the bottom of tables 6.1 and 6.2.

6.2.2 General Comments on Error Analysis.

Some general comments on interpreting immunity measurement results uncertainties based upon the above experimental error analysis are appropriate.

1) The mismatch error at frequencies below 2 GHz, (particularly if corrections are not made for either the transmitting antennas or the receiving antennas mismatch looking into their source or load), will cause the field determination inside the chamber to be low. This also causes the EUT response results to be lower than they actually are. For example, the low frequency data of figures 5.15, 1 cm dipole, and 5.16, ridged horn, should be corrected (response increased) proportionally to the systematic offset error estimates show in tables 6.1 and 6.2. (i.e., 3.46 dB at 1.0 GHz and 1.66 dB at 2.0 GHz).

2) The wave impedance, when the peak response of an EUT is measured, appears to be higher than 120 ohms. This means that if the free space wave impedance of 120 ohms is used in determining the corresponding peak amplitude of the exposure field, there will be a systematic offset error resulting in too low a calculated E-field exposure value, or, since the actual E-field is higher than the calculated value this results in too high a EUT response indication for a specified E-field exposure.

3) The spatial variation in the measured, statistically determined E-field in the chamber resulting from a complete revolution of the tuner decreases from as great as ± 8 dB at 200 MHz down to less than ± 2 dB at 2.0 GHz. (See figure 2.27.) Logically, it is expected that this variation will continue to decrease as the frequency increases. However, high variations exist in the response data obtained for EUT at frequencies where the spatial E-field variations are small. This is probably due to the relatively large variations in the wave impedance as a function of tuner position. Some additional influence may be due to the mismatch characteristics of the antennas vs source and load as a function of frequency. A way to reduce this problem is to increase the number of frequencies at which data are taken (clustered around a particular frequency of interest) or increase the number of reference receiving antennas or probes used to determine the exposure field (for example see figure 2.27) and then average the data.

6.3 Measurement Technique Advantages and Limitations

Significant advantages do exist, as alluded to in the introduction, for using a reverberation chamber for EMC measurements. Specific advantages and limitations for which insight was obtain from this study include:

a) The ability to generate high level fields efficiently. For example, 1 watt net input power into the NBS reverberation chamber results in electric fields of approximately 70 V/m. This is approximately 1/10 the input power required to generate the same level field in the NBS anechoic chamber, assuming far-field separation distances.
b) Large test zones, for example up to 2/3 of the volume inside a reverberation chamber can be available excluding an area approximately 1/2 meter spacing to the walls.

c) Broad frequency coverage (from 200 MHz to at least 18 GHz in the NBS chamber).

d) Testing is cost effective. This is especially true in comparison to anechoic chamber testing. Significant savings are realized in two major ways. First, the facility installation and measurement system procurement costs for a reverberation chamber are significantly less than for an anechoic chamber. Second, the time required to perform a complete EMC analysis of an EUT should be much less using a reverberation chamber. Again, from our experience in evaluating the susceptibility of the 7.0 cm FFAR, it required approximately 1/10 the test time to obtain the reverberation chamber results as compared to the anechoic chamber results shown on figure 5.13.

e) The directional characteristics of antenna or EUT placed inside a reverberation chamber are lost resulting in an equivalent gain of unity.

f) The response of an antenna or EUT measured inside a reverberation chamber is less than when measured inside an anechoic chamber (open space) in proportion to its gain. Hence, it appears that the EUT's gain is the desired correlation factor. This implies that susceptibility criteria determined for an EUT using a reverberation chamber must include an additional factor proportional to the EUT's estimated maximum gain as a function of frequency.

g) The response of EUT to an electromagnetic field after it has penetrated the EUT's shield, appears to be equivalent in both the reverberation and anechoic chambers.

The advantages indicated above may well outweigh the disadvantages implied in items e and f, at least for some applications. The obvious trade off is one of measurement uncertainty that one can tolerate in determining the EMC/EMI characteristics of specific EUT and the inherent measurement uncertainties associated with determining the amplitude of the test fields inside the reverberation chamber.

7. Suggestions for Future Research Efforts

Because of the significant potential of the reverberation chamber method for performing immunity measurements, considerable interest has been expressed to further evaluate this technique with the intent of extending its range of applications. Specifically, the following suggestions are offered.

1) Evaluate the reverberation chamber measurement method for pulsed rf (down to 1 μs pulse duration) immunity testing, (i.e., experimentally investigate pulse dispersion characteristics of the chamber). Measurement studies are in progress at NBS under the sponsorship of the NSWC and RADC to complete this task.

2) Determine the feasibility of extending the use of the chamber from 18 GHz to 40 GHz. A plan exists to undertake such an effort in late 1985 at NBS under sponsorship of RADC.

3) Evaluate reverberation chamber excited as a TEM transducer, (i.e., determine the feasibility of consolidating a TEM cell and reverberation chamber into a single facility for testing from 10 kHz to 18 GHz and beyond). This item is suggested because of the unique potential of developing a single, shielded facility that could be used for EMC/EMV testing over the complete frequency range listed above. This task is also planned at NBS under RADC sponsorship.

4) Investigate the feasibility of using the reverberation chamber for multiple frequency immunity testing. This is of interest because such complex fields of multiple frequencies can exist in typical operational environments.

5) Investigate the use of the reverberation chamber technique for measuring shielding effectiveness of connectors (evaluate MIL STD 1344 measurement technique), shielding materials, and enclosures in comparison to other techniques. This suggestion is included with the objective of improving the state of art in shielding measurements and to determine if correlation or agreement exists between results obtained using the reverberation chamber method and other established techniques.
8.0 Acknowledgments

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9.0 References


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- \(a = 2.18 \text{ m}\)
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TRHSN MAXIMUM E-FIELD MEASURED WITH 7 PROBES

E-FIELD (dB V/m)

FREQUENCY (GHz)

AVG OF MEAS MAX OF 7 PROBES

VERT MAXIMUM E-FIELD MEASURED WITH 7 PROBES

E-FIELD (dB V/m)

FREQUENCY (GHz)

AVG OF MEAS MAX OF 7 PROBES

LONGIT MAXIMUM E-FIELD MEASURED WITH 7 PROBES

E-FIELD (dB V/m)

FREQUENCY (GHz)

AVG OF MEAS MAX OF 7 PROBES

TOTAL MAXIMUM E-FIELD MEASURED WITH 7 PROBES

E-FIELD (dB V/m)

FREQUENCY (GHz)

AVG OF MEAS MAX OF 7 PROBES

(a)
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Figure 5.11 Photograph of modified 7.0 cm Folding Fin Aircraft Rocket inside NBS anechoic chamber.
Figure 5.12 Comparison of 7.0 cm modified FFAR thermocouple responses to EM field established inside NBS reverberation and anechoic chambers. Data normalized to exposure power density of 10 mW/cm$^2$. a) Thermocouple output vs frequency. b) Difference in thermocouple output measured in NBS reverberation and anechoic chambers.
Figure 5.13 Examples of azimuth patterns of 7.0 cm modified FFAR thermocouple response taken in NBS anechoic chamber.
Figure 5.14 Comparison of the average and maximum E-field strengths inside the NBS and NSWC reverberation chambers determined for 1 W net input power using 1) reference antenna received power measurements, and 2) calibrated 1 cm dipole probe measurements. (a) NBS chamber, (b) NSWC half chamber, and (c) NSWC full chamber.
Figure 5.15  Comparison of 1 cm dipole probe's peak response to normalized E-field of 37 dB V/m using NBS and NSWC reverberation chambers.

Figure 5.16  Comparison of ridged horn's peak responses to normalized exposure E-field of 37 dB V/m using NBS and NSWC reverberation chambers.
Figure 5.17 Comparison of 7.0 cm modified FFAR thermocouple responses to EM field established inside NBS and NSWC half reverberation chambers. Data normalized to exposure power density of 10 $^{2}$ mW/cm$^2$. a) Thermocouple output vs frequency. b) Difference in thermocouple output measured in NBS and NSWC reverberation chambers.
Figure 6.1 Sheet 1 of 2
Figure 6.1 E-field strength measured inside NBS reverberation chamber using array of 7 NBS isotropic probes: (a) average, and (b) maximum. Comparison shown between results obtained before and after normalization of measurements to correct for changes in net input power. Normalized data corrected for net input power of 1.0 Watt. Chamber excitation antenna is log periodic. E is average field strength determined from 7 probes.
Table 6.1 Summary and estimates of measurement uncertainties for determining field strength inside NBS reverberation chamber - Mode Tuned (200 MHz - 2.0 GHz)

<table>
<thead>
<tr>
<th>Source of Error</th>
<th>200 MHz</th>
<th>500 MHz</th>
<th>1.0 GHz</th>
<th>2.0 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Measuring Received Power</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cable Loss</td>
<td>± 0.05</td>
<td>± 0.05</td>
<td>± 0.05</td>
<td>± 0.10</td>
</tr>
<tr>
<td>Attenuator Calibration</td>
<td>± 0.10</td>
<td>± 0.10</td>
<td>± 0.10</td>
<td>± 0.10</td>
</tr>
<tr>
<td>Antenna Efficiency</td>
<td>± 0.05</td>
<td>± 0.05</td>
<td>± 0.05</td>
<td>± 0.10</td>
</tr>
<tr>
<td>Power Meter Calibration</td>
<td>± 0.20</td>
<td>± 0.20</td>
<td>± 0.20</td>
<td>± 0.20</td>
</tr>
<tr>
<td>Total</td>
<td>± 0.40</td>
<td>± 0.40</td>
<td>± 0.40</td>
<td>± 0.50</td>
</tr>
<tr>
<td>2) Receiving Power Mismatch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(See Figure 6.1)</td>
<td>-2.8</td>
<td>-5.1</td>
<td>-1.5</td>
<td>-3.4</td>
</tr>
<tr>
<td></td>
<td>-0.7</td>
<td>-1.5</td>
<td>-0.3</td>
<td>-0.7</td>
</tr>
<tr>
<td>3) Mixing/Sampling Efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Field Uniformity</td>
<td>± 8.0</td>
<td>± 5.0</td>
<td>± 3.0</td>
<td>± 2.0</td>
</tr>
<tr>
<td>Limited Sample Size</td>
<td>±0.2 ±0.5</td>
<td>±0.2 ±0.5</td>
<td>±0.2 ±1.5</td>
<td>±0.3 ±1.0</td>
</tr>
<tr>
<td>Total</td>
<td>±8.2 ±8.5</td>
<td>±5.2 ±5.5</td>
<td>±3.2 ±4.5</td>
<td>±2.3 ±3.0</td>
</tr>
<tr>
<td>4) Wave Impedance * 120m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(see Figure 2.25)</td>
<td>-2.8</td>
<td>-2.8</td>
<td>-2.0</td>
<td>-2.0</td>
</tr>
<tr>
<td></td>
<td>+2.0</td>
<td>+6.0</td>
<td>+2.0</td>
<td>+4.5</td>
</tr>
<tr>
<td></td>
<td>+2.0</td>
<td>+2.0</td>
<td>+2.0</td>
<td>+3.0</td>
</tr>
<tr>
<td></td>
<td>-14.2</td>
<td>-16.8</td>
<td>-9.1</td>
<td>-11.3</td>
</tr>
<tr>
<td></td>
<td>-6.3</td>
<td>-8.4</td>
<td>-5.1</td>
<td>-6.2</td>
</tr>
<tr>
<td>Total Worst Case Error</td>
<td>+10.6</td>
<td>+14.9</td>
<td>+7.6</td>
<td>+11.9</td>
</tr>
<tr>
<td></td>
<td>+5.6</td>
<td>+9.4</td>
<td>+4.8</td>
<td>+6.5</td>
</tr>
<tr>
<td>RSS Error</td>
<td>-9.1</td>
<td>-10.3</td>
<td>-5.8</td>
<td>-6.8</td>
</tr>
<tr>
<td></td>
<td>-3.9</td>
<td>-5.2</td>
<td>-3.1</td>
<td>-3.7</td>
</tr>
<tr>
<td></td>
<td>+6.5</td>
<td>+10.4</td>
<td>+5.6</td>
<td>+8.1</td>
</tr>
<tr>
<td></td>
<td>+3.8</td>
<td>+6.4</td>
<td>+3.1</td>
<td>+4.3</td>
</tr>
<tr>
<td>5) Failure to Correct for</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Power Variations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Transmit Mismatch Error)</td>
<td>-4.0</td>
<td>-3.0</td>
<td>-2.0</td>
<td>-1.0</td>
</tr>
</tbody>
</table>
Table 6.2  Summary and estimates of measurement uncertainties for determining field strength inside NBS reverberation chamber - Mode Stirred (2.0 GHz - 18.0 GHz)

<table>
<thead>
<tr>
<th>Source of Error</th>
<th>2.0 GHz Ave.</th>
<th>2.0 GHz Max.</th>
<th>4.0 GHz Ave.</th>
<th>4.0 GHz Max.</th>
<th>8.0 GHz Ave.</th>
<th>8.0 GHz Max.</th>
<th>12.0 GHz Ave.</th>
<th>12.0 GHz Max.</th>
<th>18.0 GHz Ave.</th>
<th>18.0 GHz Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Measuring Received Power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cable Loss</td>
<td>± 0.10</td>
<td>± 0.10</td>
<td>± 0.15</td>
<td>± 0.15</td>
<td>± 0.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attenuator Calibration</td>
<td>± 0.10</td>
<td>± 0.15</td>
<td>± 0.15</td>
<td>± 0.20</td>
<td>± 0.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antenna Efficiency</td>
<td>± 0.10</td>
<td>± 0.15</td>
<td>± 0.15</td>
<td>± 0.20</td>
<td>± 0.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectrum Analyzer Cal.</td>
<td>± 1.50</td>
<td>± 1.50</td>
<td>± 1.50</td>
<td>± 1.50</td>
<td>± 1.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub Total</td>
<td>± 1.80</td>
<td>± 1.90</td>
<td>± 1.95</td>
<td>± 2.05</td>
<td>± 2.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) Receiving Power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mismatch</td>
<td>-0.8</td>
<td>-0.8</td>
<td>-0.8</td>
<td>-1.0</td>
<td>-1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) Mixing/Sampling Efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Field Var.</td>
<td>± 2.0</td>
<td>± 1.0</td>
<td>± 0.5</td>
<td>± 0.2</td>
<td>± 0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited Sample Size</td>
<td>± 0.1 ± 0.3</td>
<td>± 0.2 ± 0.5</td>
<td>± 0.3 ± 0.7</td>
<td>± 0.3 ± 1.0</td>
<td>± 0.3 ± 1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub Total</td>
<td>± 2.1 ± 2.3</td>
<td>± 1.2 ± 1.5</td>
<td>± 0.8 ± 1.5</td>
<td>± 0.5 ± 1.2</td>
<td>± 0.5 ± 1.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) Wave Imped = 120π</td>
<td>Average ≤ ±2.0, -2.0 &amp; Maximum ≤ +3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5) Failure to Correct</td>
<td>-0.8</td>
<td>-0.8</td>
<td>-0.8</td>
<td>-1.0</td>
<td>-1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total(Worst Case)Error          -7.5 -7.7 -7.6 -7.6 -6.6 -6.7 -6.6 -6.2 -9.4 +5.9 +7.1 +5.1 +6.4 +4.8 +6.6 +4.6 +6.3 +4.6 +6.8

RSS Error                       -3.6 -3.7 -3.1 -3.1 -3.1 -3.2 -3.2 -3.4 -3.9 -4.2 +3.4 +4.2 +3.0 +3.9 +2.9 +3.8 +2.9 +3.8 +2.9 +4.0
Table 6.3 Estimates of impedance mismatch uncertainties for received power measurements

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Source VSWR Ave</th>
<th>Source VSWR Max</th>
<th>Load Max</th>
<th>Mismatch Error (dB) Ave</th>
<th>Mismatch Error (dB) Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>5.0</td>
<td>10.0</td>
<td>1.10</td>
<td>-2.83</td>
<td>-5.15</td>
</tr>
<tr>
<td>0.5</td>
<td>3.0</td>
<td>6.0</td>
<td>1.10</td>
<td>-1.46</td>
<td>-3.40</td>
</tr>
<tr>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
<td>1.10</td>
<td>-0.66</td>
<td>-1.46</td>
</tr>
<tr>
<td>2.0</td>
<td>1.5</td>
<td>2.0</td>
<td>1.10</td>
<td>-0.27</td>
<td>-0.66</td>
</tr>
<tr>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>1.20</td>
<td>-0.81</td>
<td>-0.81</td>
</tr>
<tr>
<td>4.0</td>
<td>2.0</td>
<td>2.0</td>
<td>1.20</td>
<td>-0.81</td>
<td>-0.81</td>
</tr>
<tr>
<td>8.0</td>
<td>2.0</td>
<td>2.0</td>
<td>1.20</td>
<td>-0.81</td>
<td>-0.81</td>
</tr>
<tr>
<td>12.0</td>
<td>2.0</td>
<td>2.0</td>
<td>1.30</td>
<td>-0.95</td>
<td>-0.95</td>
</tr>
<tr>
<td>18.0</td>
<td>2.5</td>
<td>2.5</td>
<td>1.50</td>
<td>-1.77</td>
<td>-1.77</td>
</tr>
</tbody>
</table>

Table 6.4 Estimates of uncertainties due to limiting number of tuner positions (sample size).

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Number of Tuner Positions</th>
<th>Error due to limiting Sample Size Ave/Max (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>0.2</td>
<td>0.2/0.8</td>
<td>0.2/0.5</td>
</tr>
<tr>
<td>0.5</td>
<td>0.6/3.6</td>
<td>0.5/2.0</td>
</tr>
<tr>
<td>1.0</td>
<td>--</td>
<td>1.0/4.0</td>
</tr>
<tr>
<td>2.0</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>4.0</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>8.0</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
APPENDIX

Computer Programs for
Reverberation Chamber Immunity Measurements
This measurement routine will operate the REVERBERATION CHAMBER using MODE TUNED techniques. The tuner is stepped in discrete steps and measurements are performed at each step. In this version ALL frequencies are measured at each tuner step before proceeding to the next step. Both the case of susceptibility (power supplied by a signal generator) and emissions (power supplied by EUT) can be handled. This program will handle EUT emissions by not measuring the net input power and recording the received power as detected by the reference antenna. Duplicate measurements are required to inject an 'equivalent' (will be normalized later) power to set up the same response using the transmit antenna as was measured with the EUT only. This method will determine the total power radiated by the EUT.

The program will also handle the case where the tuner is not stepped, as in a TEM cell or ANECHOIC chamber where a single measurement is needed. The data is condensed for this case.

Coupler, cable loss, and Power meter head corrections are applied immediately to the measured data. These computations must be verified by examining program lines that begin with the line label App, merely execute the EDIT command as shown.

The measurement data are saved on disk for processing. It may also be tabulated as the measurement proceeds by toggling a print flag that is shown at the start of each tuner step.

Features: 1) NBS multiprobe system 2) HP 436 and/or HP 438 power meters 3) HP 3456 or 3478 DVMs 4) HP 8566 Spectrum Analyzer (Power only) 5) HP relay actuator for RF switching 6) Superior Electric Stepping motor control 7) Either of HP8660A or HP8672A signal source.

Current Configuration

Perform preliminary emissions experiments in the chamber.

Standard items: 1) Incident Power to transmit antenna 2) Reflected power from transmit antenna 3) Received power from reference antenna

Measure output of: 4) Any number of NBS probes via system. [not used for emission tests]

Special Notes
OPTION BASE 1

DEG

OUTPUT 2 USING "K.8"; "SCRATCH KEY"

CALL Wipe_clean

GOSUB Dim_variables ! Dimension all variables, set selected values.
GOSUB Load_cal_data ! Load all calibration data for pads & cables.

New_measurement:

PRINTER IS CRT
DISP CHR$(129)
GOSUB Initial_values ! Preset all parameters and access menu.
GOSUB Sig_gen_sub ! Load selected Signal Generator subs
GOSUB Fill_calibration ! Fill lookup table for calibration values.
GOSUB Do_measurements ! Delete signal generator subs from memory

PRINTER IS CRT
DISP " ;TIME$(TIMEDATE); " ;DATE$(TIMEDATE); " ....PROGRAM FINISHED,";
DISP " 'CONTINUE' to repeat."
PAUSE

GOTO New_measurement
STOP

DIMENSION VARIABLES

Dim_variables:

COM /Parameters/ REAL Fstart,Fstop,Fstep
COM /Parameters/ REAL Min_eut,Max_eut,Min_pwr,Max_pwr
COM /Parameters/ INTEGER Low_dbm,High_dbm,Step_dbm
COM /Parameters/ INTEGER Search_eut,Search_pwr,Re_run
COM /Parameters/ INTEGER Begin_step,Total_steps,Total_meters
COM /Parameters/ Run_id$(160),Measmt_id$(160),Time_date$(30)
COM /Parameters/ Meter_defns$(40),Operator_name$(28),Test_type$[20]
COM /Parameters/ Coupler_id$(10),Generator_id$(10)
COM /Parameters/ INTEGER Sys_size,Total_chans,Probe_addr(30,3)
COM /Parameters/ INTEGER Top_probe,Fcal_pts,Pr_avgs
COM /Parameters/ INTEGER Probe_vols(30),Overrange(30)
COM /Parameters/ INTEGER Probe_zero(30),REAL Probe_v_m(30)
COM /Parameters/ REAL Amplitude_cal(11,3,5),Freq_cal(11,3,13,2)
COM /Parameters/ REAL Readtime(30),Freq_crib(13,2)
COM /Interrupts/ INTEGER Intr_prt
COM /Motor_menu/ Motion_type$(10),Rev_rate,INTEGER Tuner_steps
COM /Bugs/ INTEGER Bug1,Bug2,Bug3,Printer
COM /Files/ Sourcedisk$(20),Outdisk$(20),Filename$(80)

DIM Baddata_id$(15)[40]
DIM Coup_inc(205,2),Coup_refl(205,2)
INTEGER Inc_pts,Refl_pts
REAL Coupinc,Coupref1

DIM Cable6_1(180,2),Cable6_2(180,2),Cable4_2(180,2),Cable4_4(180,2)
INTEGER C6_npts,C6_npts,C4_4pts
REAL C6_1loss,C6_2loss,C4_2loss,C4_4loss

DIM Cable10_3(180,2),Cable10_5(180,2),Cable6_7(180,2)
INTEGER C10_3pts,C10_5pts,C5_7pts
REAL C10_3loss,C10_5loss,C5_7loss

DIM Cable12_4(80,2),Cable_r12(80,2)
INTEGER Cr4pts,Cr12pts
REAL Cr4loss,Cr12loss

DIM Pad_s6a(180,2),Pad_s6770(180,2),Pad_f5530(180,2)
INTEGER Pads_npts,Pads_npts,Pads_npts
REAL Pada_loss,Pada_loss,Pada_loss

DIM H_jct(77,2) !Anzac Hybrid Junction
INTEGER Jct_pts
REAL Jct_loss

!.................Other useful variables......................

DIM Cal_id#140,Pwr_id#2,Test#160
INTEGER Baddata,Dbm,Rf_on_off,Fileszie,I,J,K,P
INTEGER Valid,Total,File20steps,Beginstep,Endstep
INTEGER Printflag,Fcount,Too_hot,Printflag2,Steps
INTEGER Local_prty,Probe

INTEGER Fp436a1,Fp436a2,Fp438a1,Fp438a2,Fsa0566b
INTEGER Fv3456a1,Fv3456a2,Fv3478a1,Fv3478a2,Fv3478a1
REAL Z3456a1,Z3456a2,Z3478a1
REAL V3456a1,V3456a2,V3478a1

!...... we need these initial values ...................

Print=701
Sourcedisk$=":INTERNAL,4,0"
Outdisk$=":INTERNAL,4,1" ! or ":HP9133,700,0"
Intr_prty=6
Local_prty=Intr_prty

BUGS:
PRINTflag=1 ! Print all setup parameters and calibration values.
PRINTflag2=1 ! Print raw data if both Printflag and Printflag 2
Bug1=0
Bug2=0
Bug3=0

RETURN

! ///////////////////////////////////////////////////////////////////****INITIALIZE VARIABLES & I/O****///////////////////////////////////////////////////////////////////
ASSIGN @Sig_gen TO 719
ASSIGN @Dvm1 TO 722
ASSIGN @Dvm2 TO 723
ASSIGN @Dvm3 TO 724
ASSIGN @Gpio TO 12
ASSIGN @Relayl TO 717
ASSIGN @Spec_altr TO 718

! Signal generator HP8660a or HP8672a
! HP3456A Dvm.
! HP3456A Dvm.
! HP3478A Dvm.
! NBS Multiprobe system
! HP relay actuator
! HP 8566 Spectrum Analyzer

Calib_items=15  ! 15 files for cables, coupler, and pad calcs.
Pr_avg=3       ! Read Multiprobe 3 times and average.
Motion_type="STEP" ! or "CONTINUOUS" for MODE STIRRING.
Rev_rate=1.0   ! used only if MODE STIRRING operation.
Rf_on_off=1    !

CALL Measure_menu  ! Go and set up measurement parameters.
GOSUB Configure_instr  ! Turn on/off instruments as per menu
GOSUB Configure_instr  ! Set up the 30 probe system.
GOSUB Configure_instr  ! Use above info to define data.
GOSUB Configure_instr  ! To assure clean start.
GOSUB Configure_instr  ! Initialize the Generator Level
GOSUB Configure_instr  ! Initialize the motor control

!----------------ALLOCATE THE RAW DATA MATRIX-------------------
Ftotal=INT((Fstop-Fstart)/Fstep)+1
IF Test_type="OTHER (NO STEPS)" THEN
  File20steps=Ftotal
ELSE
  File20steps=20*Ftotal
END IF
ALLOCATE Rawdata(Total_meters+Total_chans+1,File20steps)

!----------------------
DISP "INSERT OUTPUT DATA DISK IN ";
SELECT Outdisk:
CASE ": INTERNAL,4,0"
  DISP "RIGHT DRIVE, ";
CASE ": INTERNAL,4,1"
  DISP "LEFT DRIVE, ";
END SELECT
DISP "and hit 'Continue-kS'.";
BEEP
ON KEY 5 LABEL "Continue",Local prt_key GOTO Zippity
Zippity:GOTO Zippity
Datasaver:OFF KEY
GOSUB Save_configure
IF Printer<>CRT THEN
  PRINTER IS Printer
  PRINT RPT"("_,80)
PRINT
PRINTER IS CRT
END IF
GOSUB Print_vitals
DISP CHR\n(12)
RETURN

! //**********************************************************************************

Configure_instr!!
SELECT Test_type
579  CASE "MODE TUNE REGULAR"
580       Fp436a1=0  ! Power meter HP436a at addr 09
581      Fp436a2=0  ! Power meter HP436a at addr 10
582       Fp439a1=0  ! Power meter HP439a at addr 11
583      Fp439a2=0  ! Power meter HP439a at addr 12
584      Fv3456a1=0  ! HP3456A Dvm at addr 22
585      Fv3456a2=0  ! HP3456A Dvm at addr 23
586      Fv3478a1=0  ! HP3478A Dvm at addr 24
587      Fr59306a=0  ! HP relay actuator at addr 17
588      Fsa8566b=1  ! HP 8566 Spectrum Analyzer at addr 18
589  CASE "MODE TUNE EMISSIONS"
590       Fp436a1=0  ! Power meter HP436a at addr 09
591      Fp436a2=0  ! Power meter HP436a at addr 10
592       Fp439a1=0  ! Power meter HP439a at addr 11
593      Fp439a2=0  ! Power meter HP439a at addr 12
594      Fv3456a1=0  ! HP3456A Dvm at addr 22
595      Fv3456a2=0  ! HP3456A Dvm at addr 23
596      Fv3478a1=0  ! HP3478A Dvm at addr 24
597      Fr59306a=0  ! HP relay actuator at addr 17
598      Fsa8566b=1  ! HP 8566 Spectrum Analyzer at addr 18
599  CASE "OTHER (NO STEPS)"
600     Fp436a1=0  ! Power meter HP436a at addr 09
601    Fp436a2=0  ! Power meter HP436a at addr 10
602     Fp439a1=0  ! Power meter HP439a at addr 11
603    Fp439a2=0  ! Power meter HP439a at addr 12
604    Fv3456a1=0  ! HP3456A Dvm at addr 22
605    Fv3456a2=0  ! HP3456A Dvm at addr 23
606    Fv3478a1=0  ! HP3478A Dvm at addr 24
607    Fr59306a=0  ! HP relay actuator at addr 17
608    Fsa8566b=1  ! HP 8566 Spectrum Analyzer at addr 18
609  END SELECT
610  !
611  RETURN
612  !
613  !  ///////////////////////////////////////////////////////////////////****DATA DEFINITION****/////////////////////////////////////////////////////////////////////////////////
614  !
615  ! Data_definition:  ! Set up the definitions of each meter reading,
616      ! these are used later when processing
617      ! SO be sure these are correct.
618  ! The index corresponds to the Rawdata matrix row+1
619      ! Frequency is always in row 1
620      ! Meter 1 is in row 2, etc.
621  !
622  SELECT Test_type
623  CASE "MODE TUNE REGULAR"
624     Total_meters=3
625     Meter_defs$(1)="Incident Power (Watts)"
626     Meter_defs$(2)="Reflected Power (Watts)"
627     Meter_defs$(3)="Received Power (Watts)"
628  CASE "MODE TUNE EMISSIONS"
629     Total_meters=1
630     Meter_defs$(1)="Received Power (Watts)"
631  CASE "OTHER (NO STEPS)"
632     Total_meters=3
633     Meter_defs$(1)="Incident Power (Watts)"
698   Meter_defns$(2) = "Reflected Power (Watts)"
700   Meter_defns$(3) = "Probe Output (Volts)"
702   END SELECT
704
706   FOR P=1 TO Total_chans
708   Test#="Amp # " & VAL$(Proben addr(P,1)) & ", 5cm Probe # "
710   Test#="Test# & VAL$(Proben addr(P,2)) & ""
712   SELECT Proben addr(P,3)
714   ! CASE 1
716   Test# = Test# & "X"
718   CASE 2
720   Test# = Test# & "Y"
722   CASE 3
724   Test# = Test# & "Z"
726   CASE 4
728   Test# = Test# & "Single"
730   CASE ELSE
732   Test# = Test# & "Error!"
734   END SELECT
736   IF LEN(Test#) > 40 THEN
738   BEEP
740   DISP "ERROR in probe definitions"
742   PAUSE
744   Test# = Test#[1,40]
746
748   Meter_defns$(P+Total_meters) = Test#
750   END IF
752   NEXT P
754   RETURN
756
758   !----------------------------------------------------------------------------
760   !
762   Die_gracefully:
764   IF Bug1 THEN
766   PRINT TIME$(TIMEDATE);
768   PRINT RPT$("\",15); " DIE GRACEFULLY \"RPT$("]",15)
770   END IF
772   ON ERROR GOTO Delete_done1
774   SELECT Generator_id#
776   CASE "HP 8660A"
778   DELSUB Set_freq,Set_dbm,FNdigit10$,FNdigit3$,FNRev$
780   CASE "HP 8672A"
782   DELSUB Set_freq,Set_dbm
784   END SELECT
786   Delete_done1:
788   OFF ERROR
790   ON ERROR GOTO Delete_done2
792   DEALLOCATE Rawdata(*),Adjust(*)
794   Delete_done2:
796   OFF ERROR
798   RETURN
800
802   !----------------------------------------------------------------------------
804
806   Sig_gen_sub:
808   PRINT TABXY(1,18); RPT$("\",15);
810   PRINT "LOAD SUB PROGRAMS & Coupler Calibrations \"RPT$("]",15)
814   Filename$= Generator_id$ & Sourceid$ & Sourceid$
816   DISP "Put 'CALIBRATION DATA & SUB Program' disk in " ;
SELECT Sourcedisk$;
CASE ":::INTERNAL,4,0"
DISP "RIGHT DRIVE, ";
CASE ":::INTERNAL,4,1"
DISP "LEFT DRIVE, ";
END SELECT
DISP "hit 'Continue-1':".
BEEP
ON KEY S LABEL "Continue",Local_prty GOTO Subloads
LOOP
END LOOP
Subloads:OFF KEY
DISP Chr$(12)
DISP " Signal Generator SUB PROGRAMS NOW LOADING ",
ON ERROR CALL Error-trap
LOADSUB ALL FROM Filename$
OFF ERROR
DISP " Signal Generator SUB PROGRAMS LOADED ",
WAIT 1
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938 PRINT TABXY(1,18);RFT(" "","80");
940 RETURN
942 !
944 ! /'/-------------------------'/-----------------------------'/
946 !
948 Load_cal_date:
950 PRINT TABXY(1,18);RFT("="",20);" LOAD CALIBRATION DATA ";RFT("="",20)
952 DISP "Put 'CALIBRATION DATA & SUB Program' disk in ";
954 SELECT Sourcedisk$
956 CASE ":INTERNAL,4,0"
958 DISP "RIGHT DRIVE,";
960 CASE ":INTERNAL,4,1"
962 DISP "LEFT DRIVE,";
964 END SELECT
966 DISP "hit 'Continue-k5'.";
968 BEEP
970 ON KEY 5 LABEL "Continue",Local_prty GOTO Calloads
972 LOOP
974 END LOOP
976 Calloads:OFF KEY
978 DISP " Calibration DATA for Cables, Couplers, Pads, etc. now LOADING ".
980 ! 'Install new calibration files here!'
982 ! '-----------------------------------------------'
984 !
986 IF Printflag THEN PRINTER IS Printer
988 IF Printflag THEN PRINT "CALIBRATION DATA FOR THE FOLLOWING IS LOADED:");
990 !
992 !
994 !
996 Filename$="Cable6FT_1";Sourcedisk$
998 CALL Enter_caldata(Filename$,Cable6_1(*),Cal_id$,C6_1pts)
1000 Baddata_id$(3)=Cal_id$
1002 IF Printflag THEN PRINT Cal_id$
1004 !
1006 Filename$="Cable6FT_6";Sourcedisk$
1008 CALL Enter_caldata(Filename$,Cable6_6(*),Cal_id$,C6_6pts)
1010 Baddata_id$(4)=Cal_id$
1012 IF Printflag THEN PRINT Cal_id$
1014 !
1016 Filename$="Cable4FT_2";Sourcedisk$
1018 CALL Enter_caldata(Filename$,Cable4_2(*),Cal_id$,C4_2pts)
1020 Baddata_id$(5)=Cal_id$
1022 IF Printflag THEN PRINT Cal_id$
1024 !
1026 Filename$="Cable4FT_4";Sourcedisk$
1028 CALL Enter_caldata(Filename$,Cable4_4(*),Cal_id$,C4_4pts)
1030 Baddata_id$(6)=Cal_id$
1032 IF Printflag THEN PRINT Cal_id$
1034 !
1036 Filename$="Cable10F_3";Sourcedisk$
1038 CALL Enter_caldata(Filename$,Cable10_3(*),Cal_id$,C10_3pts)
1040 Baddata_id$(7)=Cal_id$
1042 IF Printflag THEN PRINT Cal_id$
1044 !
1046 Filename$="Cable10F_5";Sourcedisk$
1048 CALL Enter_caldata(Filename$,Cable10_5(*),Cal_id$,C10_5pts)
1050 Baddata_id$(8)=Cal_id$
1052 IF Printflag THEN PRINT Cal_id$
1054 !
1056 Filename$="Cable5FT_7";Sourcedisk$
CALL Enter Caldwell(Filename$, Cable5_7(*), Cal_id#, C5_7pts)
BADDATA(id$(9)=Cal_id#
IF Printflag THEN PRINT Cal_id#
!
FILENAME="FAD_S6770"%Sourcedisk:
CALL Enter Caldwell(Filename$, Pad_s6770(*), Cal_id#, Pads_pts)
BADDATA(id$(10)=Cal_id#
IF Printflag THEN PRINT Cal_id#
!
FILENAME="FAD_5530"%Sourcedisk:
CALL Enter Caldwell(Filename$, Pad_f5530(*), Cal_id#, Pads_pts)
BADDATA(id$(11)=Cal_id#
IF Printflag THEN PRINT Cal_id#
!
FILENAME="FAD56A1466"%Sourcedisk:
CALL Enter Caldwell(Filename$, Pad_as6a(*), Cal_id#, Pads_pts)
BADDATA(id$(12)=Cal_id#
IF Printflag THEN PRINT Cal_id#
!
FILENAME="ANZAC_JCT"%Sourcedisk:
CALL Enter Caldwell(Filename$, H_jct(*), Cal_id#, Jct_pts)
BADDATA(id$(13)=Cal_id#
IF Printflag THEN PRINT Cal_id#
!
FILENAME="Rcable4ft"%Sourcedisk:
CALL Enter Caldwell(Filename$, Cable_r4(*), Cal_id#, Cr4pts)
BADDATA(id$(14)=Cal_id#
IF Printflag THEN PRINT Cal_id#
!
FILENAME="Rcable12ft"%Sourcedisk:
CALL Enter Caldwell(Filename$, Cable_r12(*), Cal_id#, Cr12pts)
BADDATA(id$(15)=Cal_id#
IF Printflag THEN PRINT Cal_id#
!
IF Printflag THEN
PRINT RPT$("", 80)
PRINT USING ";/"
END IF
! DISP " Calibration DATA LOADED 
! WAIT 1
PRINTER IS CRT
CALL Wipe_clean
RETURN
!
! /////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

! Fillcalibration: ! Determine the cable, couple and pad calibration values for each frequency.
! ! Save these in the adjust(*) file for use by the measurement routine.
!
IF Bug1 THEN
PRINT TIME$(TIMEDETECTION);
PRINT RPT$("<", 15); " FILL CALIBRATION MATRIX "; RPT$(">", 15)
END IF
! DISP "NOW Filling Calibration matrix."
! ALLOCATE Adjust(Ftotal, Calib_items)
! Fcount=1
! FOR Frequency=start TO Fstop STEP Fstep
CALL Get cal_value(Frequency, Coupinc, Coup_inc(*), Baddata, Inc_pts)
IF Baddata THEN
    Cal_id$=Baddata_id$(1)
    GOSUB Flagbaddata
END IF
Adjust(Fcount,1)=Coup1nc
!
CALL Get_cal_value(Frequency,Couplnc,Couplnc Refl (*) ,Baddata,Ref1_pts)  
IF Baddata THEN
    Cal_id$=Baddata_id$(2)
    GOSUB Flagbaddata
END IF
Adjust(Fcount,1)=Coup1nc
!
CALL Get_cal_value(Frequency,C6_1loss,Cable6_1(*) ,Baddata,C6_1pts)
IF Baddata THEN
    Cal_id$=Baddata_id$(3)
    GOSUB Flagbaddata
END IF
Adjust(Fcount,2)=C6_1loss
!
CALL Get_cal_value(Frequency,C6_6loss,Cable6_6(*) ,Baddata,C6_6pts)
IF Baddata THEN
    Cal_id$=Baddata_id$(4)
    GOSUB Flagbaddata
END IF
Adjust(Fcount,3)=C6_6loss
!
CALL Get_cal_value(Frequency,C4_2loss,Cable4_2(*) ,Baddata,C4_2pts)
IF Baddata THEN
    Cal_id$=Baddata_id$(5)
    GOSUB Flagbaddata
END IF
Adjust(Fcount,4)=C4_2loss
!
CALL Get_cal_value(Frequency,C4_4loss,Cable4_4(*) ,Baddata,C4_4pts)
IF Baddata THEN
    Cal_id$=Baddata_id$(6)
    GOSUB Flagbaddata
END IF
Adjust(Fcount,5)=C4_4loss
!
CALL Get_cal_value(Frequency,C10_3loss,Cable10_3(*) ,Baddata,C10_3pts)
IF Baddata THEN
    Cal_id$=Baddata_id$(7)
    GOSUB Flagbaddata
END IF
Adjust(Fcount,6)=C10_3loss
!
CALL Get_cal_value(Frequency,C10_5loss,Cable10_5(*) ,Baddata,C10_5pts)
IF Baddata THEN
    Cal_id$=Baddata_id$(8)
    GOSUB Flagbaddata
END IF
Adjust(Fcount,7)=C10_5loss
!
CALL Get_cal_value(Frequency,C5_7loss,Cable5_7(*) ,Baddata,C5_7pts)
IF Baddata THEN
    Cal_id$=Baddata_id$(9)
    GOSUB Flagbaddata
END IF
Adjust(Fcount,8)=C5_7loss
!
1298 Adjust(Fcount,9)=CS_71loss
1300
1302 CALL Get_cal_value(Frequency,Pads_loss,Pad_s6770(*),Baddata,Pads_pts)
1304 IF Baddata THEN
1306 Cal_id#=Baddata_id#(10)
1308 GOSUB Flagbaddata
1310 END IF
1312 Adjust(Fcount,10)=Pads_loss
1314
1316 CALL Get_cal_value(Frequency,Pads_loss,Pad_f5530(*),Baddata,Pads_pts)
1318 IF Baddata THEN
1320 Cal_id#=Baddata_id#(11)
1322 GOSUB Flagbaddata
1324 END IF
1326 Adjust(Fcount,11)=Pads_loss
1328
1330 CALL Get_cal_value(Frequency,Pads_loss,Pad_s66a(*),Baddata,Pads_pts)
1332 IF Baddata THEN
1334 Cal_id#=Baddata_id#(12)
1336 GOSUB Flagbaddata
1338 END IF
1340 Adjust(Fcount,12)=Pads_loss
1342
1344 CALL Get_cal_value(Frequency,Jct_loss,H_jct(*),Baddata,Jct_pts)
1346 IF Baddata THEN
1348 Cal_id#=Baddata_id#(13)
1350 GOSUB Flagbaddata
1352 END IF
1354 Adjust(Fcount,13)=Jct_loss
1356
1358 CALL Get_cal_value(Frequency,CR12loss,Cable_r4(*),Baddata,CR4pts)
1360 IF Baddata THEN
1362 Cal_id#=Baddata_id#(14)
1364 GOSUB Flagbaddata
1366 END IF
1368 Adjust(Fcount,14)=CR12loss
1370
1372 CALL Get_cal_value(Frequency,CR12loss,Cable_r12(*),Baddata,CR12pts)
1374 IF Baddata THEN
1376 Cal_id#=Baddata_id#(15)
1378 GOSUB Flagbaddata
1380 END IF
1382 Adjust(Fcount,15)=CR12loss
1384
1386 Fcount=Fcount+1
1388 NEXT Frequency
1390 DISP "NOW tabulating calibration values."
1392 GOSUB Printcalvalues
1394 DISP CHR$(12)
1396 RETURN
1398
1400 !~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
1402 ! Flagbaddata: !Inform the operator that there is wrong data being brought back from Enter_cal_data
1404 !~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
1406 Printer IS Printer
1408 PRINT RPT$("*",5);" NO CAL DATA at ";Frequency;
1410 PRINT " MHz: ";Cal_id#
PRINTER IS CRT
RETURN

PRINT RPT$("*",24);" CALIBRATION / LOSS VALUES (dB) ";RPT$("*",24)
PRINT
PRINT
PRINT "Frequency Coupler ----------------- BLUE CABLES -----";
PRINT "-------------------"
PRINT " MHz Foward Ref1 6ft#1 6ft#6 4ft#2 4ft#4 10ft#3 ";
PRINT "10ft#5 5ft#7"
PRINT USING Lossfmt1;Frequency,Coupler,Colpref,C6_1loss,C6_6loss
PRINT USING Lossfmt2;C4_2loss,C4_4loss,C10_3loss,C10_5loss,C5_7loss
Fcount=1
FOR Frequency=Fstart TO Fstop STEP Fstep
Coupinc=10*LGTCAdjust(Fcount,1) !Coupler incident
Couprefl=10*LGTCAdjust(Fcount,2) !Coupler reflected
C6_1loss=10*LGTCAdjust(Fcount,3) !6 foot BLUE cable #1
C6_6loss=10*LGTCAdjust(Fcount,4) !6 foot BLUE cable #6
C4_2loss=10*LGTCAdjust(Fcount,5) !4 foot BLUE cable #2
C4_4loss=10*LGTCAdjust(Fcount,6) !4 foot BLUE cable #4
C10_3loss=10*LGTCAdjust(Fcount,7) !10 foot BLUE cable #3
C10_5loss=10*LGTCAdjust(Fcount,8) !10 foot BLUE cable #5
C5_7loss=10*LGTCAdjust(Fcount,9) !4 foot BLUE cable #4
PRINT USING Lossfmt3;Frequency,Pads_loss,Padf_loss,Pada_1oss
PRINT USING Lossfmt4;Jct_loss,Cre.loss,Cr12loss
Fcount=Fcount+1
NEXT Frequency
PRINT "Frequency S6770 F5530 AS6A Hjct Semi-Rigid"
PRINT " MHz pad pad pad pad loss 4ft 12ft"
PRINT USING Lossfmt3;Frequency,Pads_loss,Padf_loss,Pada_1oss
PRINT USING Lossfmt4;Jct_loss,Cre.loss,Cr12loss
Fcount=1
FOR Frequency=Fstart TO Fstop STEP Fstep
Pads_loss=10*LGTCAdjust(Fcount,10) !Weinschel S6770 10dB pad
Padf_loss=10*LGTCAdjust(Fcount,11) !Weinschel F5530 10dB pad
Pada_loss=10*LGTCAdjust(Fcount,12) !Weinschel AS6A-1466 10dB
Jct_loss=10*LGTCAdjust(Fcount,13) !Anzac Hybrid Junction
Cr12loss=10*LGTCAdjust(Fcount,14) ! 4ft Rigid coax
Cr12loss=10*LGTCAdjust(Fcount,15) ! 12ft Rigid coax
PRINT USING Lossfmt3;Frequency,Pads_loss,Padf_loss,Pada_loss
PRINT USING Lossfmt4;Jct_loss,Cre.loss,Cr12loss
Fcount=Fcount+1
NEXT Frequency
PRINT RPT$("*",80)
PRINT
PRINTER IS CRT
RETURN
Extract_caldata: 'Get all calibration data for this frequency. 
 Calibration data for all cables, probes, & power heads.

Pwrmcrcal1=FPwrmcrcal1((Frequency)) ! 18 GHz HEAD. 
Pwrmcrcal2=FPwrmcrcal2((Frequency)) ! 26 GHz HEAD.

Coupling=Adjust(Fcount,1) !Coupler incident 
Couplerf1=Adjust(Fcount,2) !Coupler reflected 
C6_1loss=Adjust(Fcount,3) !6 foot BLUE cable #1 
C6_6loss=Adjust(Fcount,4) !6 foot BLUE cable #6 rcvr. 
C4_2loss=Adjust(Fcount,5) !4 foot BLUE cable #2 
C4_4loss=Adjust(Fcount,6) !4 foot BLUE cable #4 
C10_3loss=Adjust(Fcount,7) !10 foot BLUE cable #3 
C10_5loss=Adjust(Fcount,8) !10 foot BLUE cable #5 
C5_7loss=Adjust(Fcount,9) !5 foot BLUE cable #7 
Pads_loss=Adjust(Fcount,10) !Weinschel S6770 10dB pad 
Pads_loss=Adjust(Fcount,11) !Weinschel Fs530 10dB pad 
Pada_loss=Adjust(Fcount,12) !Weinschel AS6A-1466 10dB 
Jct_loss=Adjust(Fcount,13) !Anzac Hybrid Junction 
Cr4loss=Adjust(Fcount,14) !4ft Semi-rigid coax lines 
Cr12loss=Adjust(Fcount,15) !12ft Semi-rigid coax lines 
RETURN

Flip_printflag: ' 
DIsF "Toggle PRINTING of measurement data. 
Waittime=TIMEDATE 
LOOP

IF Printflag2 THEN 
ON KEY O LABEL "Print is ON",Local_prty GOSUB Toggleprint 
ELSE 
ON KEY O LABEL "Print is OFF",Local_prty GOSUB Toggleprint 
END IF
EXIT IF TIMEDATE-Waittime>4 
END LOOP
DISP CHR$(12) 
OFF KEY 
RETURN

Do_measurements:!!

PRINT TIME*(TIMEDATE);RPT*"(";20);" DO MEASUREMENTS ";RPT*("";20)
END IF
! ..........................Initialize instruments ......................
1660 REMOTE @Sig_gen
1662 IF Fp436al OR Fp436a2 THEN CALL Menu_pwr436a ' Set up 436A pwr mtrs
1664 IF Fv3456a1 THEN CALL Setdvm_3456a(@Dvm1)
1666 IF Fv3456a2 THEN CALL Setdvm_3456a(@Dvm2)
1668 IF Fv3479a1 THEN CALL Setdvm_3479a(@Dvm3)
1670 IF Fsa8566b THEN CALL Spec_alzr_setup(@Spec_alzr)
1672 IF Test_type$<>"OTHER (NO STEPS)" THEN
1674 CALL InitializeMotor(@Motor)
1676 CALL Zeromotor(@Motor)
1678 END IF
1680 IF Test_type$="MODE TUNE EMISSIONS" THEN
1682 CALL Set_dbm(-140,0,@Sig_gen) ! EUT is the source
1684 END IF
1686 !
1688 Column=1
1690 Beginstep=Begin_step
1692 Steps=Begin_step-1
1694 REPEAT ! measurements for all steps or once for non-stepping type.
1696 Steps=Steps+1
1700 !
1702 IF (Steps-1)/40. = INT((Steps-1)/40.) OR Steps=Begin_step THEN
1704 IF Test_type$="MODE TUNE EMISSIONS" THEN
1706 GOSUB Flip_printflag ! includes WAIT action.
1708 ELSE
1710 GOSUB Read_zero_field ! for all enabled instruments.
1712 END IF
1714 ELSE
1716 GOSUB Flip_printflag
1718 END IF
1720 !
1722 ! ........................ ZERO Readings or WAIT complete ............
1724 !
1726 IF Total_chans<1 THEN ! Print single header for all frequencies
1728 IF Printflag AND Printflag2 THEN GOSUB Print_headinfo
1730 END IF
1732 IF Test_type$<>"MODE TUNE EMISSIONS" THEN ! Restore power
1734 CALL Set_freq(Frequency),@Sig_gen)
1736 CALL Set_dbm(Dbm,1,@Sig_gen)
1738 END IF
1740 !
1742 ! ........................ Measure all frequencies .................
1744 !
1746 Fcount=1
1748 FOR Frequency=Fstart TO Fstop STEP Fstep
1750 DISP CHR$(129)
1752 DISP " TIME: ";TIME$(DATE);
1754 IF Test_type$="OTHER (NO STEPS)" THEN
1756 DISP " Now Testing: FREQUENCY =";Frequency;" MHz. "
1758 ELSE
1760 DISP " TUNER STEP ";Steps;, FREQUENCY =";Frequency;" MHz. "
1762 END IF
1764 GOSUB Extract_caldata ! Get all calibration data for this
1766 ! frequency.
1768 Rawdata(1,Column)=Frequency
1770 IF Test_type$<>"MODE TUNE EMISSIONS" THEN
1772 CALL Set_freq(Frequency),@Sig_gen)
1774 END IF
1776 IF Search_eut THEN GOSUB Level_eut_out
1778 IF Search_pwr THEN GOSUB Level_net_input
1780 GOSUB Read_meters ! Read all enabled instruments.
1782 ! See Configure_instr for changes.
1784 ! Calibration data is applied there
1786 ! via Apply_cal_data.
1788
1789 ! .................FILL the DATA file .....................
1790
1792 !
1794 Fill_data_file: ! **** Make sure this assignment matches defns.
1796 SELECT Test_type#
1798 CASE "MODE TUNE REGULAR"
1800 Rawdata(2,Column)=P1
1802 Rawdata(3,Column)=P2
1804 Rawdata(4,Column)=Sa_pwr
1806 CASE "MODE TUNE EMISSIONS"
1808 Rawdata(1,Column)=Sa_pwr
1810 CASE "OTHER (NO STEPS)"
1812 Rawdata(2,Column)=P1
1814 Rawdata(3,Column)=P2
1816 Rawdata(4,Column)=V1
1818 END SELECT
1820
1822 IF Total_chans>0 THEN
1824 FOR P=Total_meters+2 TO Total_chans+Total_meters+1
1826 Rawdata(P,Column)=Probe_v_m(P-Total_meters-1)
1828 NEXT P
1830 END IF
1832 !
1834 IF Printflag AND Printflag2 THEN
1836 IF Total_chans>0 THEN GOSUB Print_headinfo
1838 GOSUB Print_rawdata
1840 END IF
1842 Column=Column+1
1844 Fcount=Fcount+1
1846 NEXT Frequency
1848 !
1850 ! .................. ALL frequencies measured ..................
1852 !
1854 IF Test_type$="OTHER (NO STEPS)" THEN
1856 GOSUB Save_data
1858 ELSE
1860 PRINT TIME$(TIMEDATE);" ...Step number";Steps;" completed....."
1862 IF (Column+Total-1>File20steps) OR (Steps=Tuner_steps) THEN
1864 Endstep=Steps
1866 GOSUB Save_data
1868 Beginstep=Endstep+1
1870 Column=1
1872 MAT Rawdata= Rawdata*(0.)
1874 END IF
1876 CALL Movemotor(@Motor)
1878 END IF
1880 UNTIL Steps>=Tuner_steps OR Test_type$="OTHER (NO STEPS)"
1882 !
1884 IF Test_type$="MODE TUNE EMISSIONS" THEN
1886 CALL Set_dbm(-140,0,@Sig_gen)
1888 END IF
1890 LOCAL 7
1892 RETURN ! ALL Measurements complete.
1894 !
1896 ! //////////////////////////////////////////////////////////////////
1898 !
1900 Read_zero_field: !
1902 PRINT TIME$(TIMEDATE);" Step number";Steps;", zero meters."
1904 !
1906 ! ............... Measure all zero field values .............
1908 !
1910 CALL Set_dbm(-140,0,@Sig_gen)
1912 IF Fp436a1 AND Fp436a2 THEN
1914 CALL Zero_pwr_mtrs(@Sig_gen,@Pwr1,@Pwr2)
1916 ELSE
1918 IF Fp436a1 THEN CALL Zero_pwr_mtrs(@Sig_gen,@Pwr1)
1920 IF Fp436a2 THEN CALL Zero_pwr_mtrs(@Sig_gen,@Pwr2)
1922 END IF
1924 IF Fp438a1 THEN
1926 Ab$="AB"
1928 CALL Zero_438a(@Dual_pwr1,Ab$)
1930 END IF
1932 IF Fp438a2 THEN
1934 Ab$="A"
1936 CALL Zero_438a(@Dual_pwr2,Ab$)
1938 END IF
1940 IF Fv3456a1 THEN CALL Readdv(Z3456a1,@Dvm1)
1942 IF Fv3456a2 THEN CALL Readdv(Z3456a2,@Dvm2)
1944 IF Fv3478a1 THEN CALL Readdv(Z3478a1,@Dvm3)
1946 IF Bug1 THEN
1948 PRINTER IS Printer
1950 PRINT "Zeros DVM1=";Z3456a1","; DVM2=";Z3456a2"," DVM3=";Z3478a1
1952 PRINTER IS CRT
1954 END IF
1956 !
1958 ! Fill Probe_volts(30) using Probe_addr(*) and Total_chans
1960 !
1962 IF Total_chans>=0 THEN
1964 MAT Probe_zero= (0)
1966 CALL Read_probes(@Gpio)
1968 MAT Probe_zero= Probe_volts
1970 IF MAX(Probe_zero(*))>10 OR MIN(Probe_zero(*))<-10 THEN
1972 PRINT TIME$(TIMEDATE);" ... ";
1974 PRINT " WARNING ... Check Multiprobe zero ******** "
1976 END IF
1978 END IF
1980 RETURN
1982 !
1984 ! ////////////////////////////////////////////////////////////////// APPLY CALIBRATION TO MEASUREMENT DATA //////////////////////////////////////////////////////////////////
1986 !
1988 Apply_cal_data: ! For listing of valid variable names
1990 ! see Extract_caldata. Values are in ratio form.
1992 Cal_power_1_2:
1994 P1=Power1*Coupling*Pwrmtrcall*Padf_loss*(C10_3loss*Fads_loss)
1996 P2=Power2*Coupref1*Pwrmtcall*C10_3loss*Fads_loss
1998 RETURN
2000 !---------------------------------------------------------------
2002 Cal_power_3_4:
2004 P3=Power3
2006 P4=Power4
2008 RETURN
2010 !---------------------------------------------------------------
2012 Cal_power_5:
2014 P5=Power5
2016 RETURN

101
2018 !------------------------------------------------------------
2020 Cal_power_6:
2022 P6=Power6
2024 RETURN
2026 !------------------------------------------------------------
2028 Cal_ea_power:
2030 Sa_pwr=Sa_power*C10_Sloss*C4_2loss*C4_4loss
2032 RETURN
2034 !------------------------------------------------------------
2036 ! //////////////////////////////////////////////////////////////////
2038 ! //////////////////////////////////////////////////////////////////
2040 !
2042 Read_meters: Control module for all instrument reads.
2044 Too_hot=0
2046 P1=0
2048 P2=0
2050 Checktime=TIMEDATE
2052 !------------------------------------------------------------
2054 Hp438a_1:
2056 IF Fp438a1 THEN
2058 GOSUB Power_1_2  ! HP438A both channels
2060 ! returns Power1, Power2 (watts)
2062 IF Too_hot THEN GOTO Read_meters
2064 GOSUB Cal_power_1_2! correct for losses and return P1,P2
2066 Min_power:IF (P1-P2)(Min"pwr THEN
2068 BEEP
2070 PRINTER IS Printer
2072 PRINT TIME$(TIMEDATE);" "
2074 PRINT "Raw P1=";Power1;" ** Cal P1=";P1
2076 PRINT "Raw P2=";Power2;" ** Cal P2=";P2
2078 PRINT "Net input power (P1-P2)=";P1-P2
2080 PRINT RPT$("-",40)
2082 PRINT PRINT "Min power (P1-P2)"<Min_pwr THEN
2084 PRINTER IS CRT
2086 GOSUB Adjust_power
2088 GOTO Read_meters
2090 END IF
2092 END IF
2094 !------------------------------------------------------------
2096 Hp438a_2:
2098 IF Fp438a2 THEN
2100 GOSUB Power_3_4 ! Set for channel A (Power3) only, Power4=0
2102 ! returns Power3, Power4 (watts)
2104 IF Too_hot THEN GOTO Read_meters
2106 GOSUB Cal_power_3_4! correct for losses and return P3,P4
2108 END IF
2110 !------------------------------------------------------------
2112 Hp436a_1:
2114 IF Fp436a1 THEN
2116 GOSUB Power_5  ! HP 436A
2118 ! returns Power5
2120 IF Too_hot THEN GOTO Read_meters
2122 GOSUB Cal_power_5 ! correct for losses and return P5
2124 END IF
2126 !------------------------------------------------------------
2128 Hp436a_2:
2130 IF Fp436a2 THEN
2132 GOSUB Power_6  ! HP 436A
2134 ! returns Power6
2136 IF Too_hot THEN GOTO Read_meters

102
2138 GOSUB Cal_power_6  ! correct for losses and return P6
2140 END IF
2142 !-----------------------------------------------------
2144 Mds_probes:
2146 IF Total_chans>0 THEN GOSUB Probe_rd     ! Multiprobe system
2148 IF Too_hot THEN GOTO Read_meters    ! returns corrected V/m.
2150 !-----------------------------------------------------
2152 Wait_loop:!
2154 LOOP
2156 EXIT IF (TIMEDATE-Checktime)>Time_eut
2158 END LOOP
2160 !-----------------------------------------------------
2162 Hp3456a_1: == EUT connected to this dvm. ==
2164 IF Fv3456a1 THEN
2166 CALL Readvdm(Volt1,@Dvm1)  ! HP digital voltmeter
2168 ! returns Volts (DC volts)
2170 V1=Volt1-Z3456a1  ! correct for zero, yields V1
2172 IF V1>Max_eut THEN
2174 PRINTER IS Printer
2176 PRINT TIME#(TIMEDATE);"...DVM1 error / EUT overload."
2178 PRINT "Set max=";Max_eut;", Reading=";Volt1;", Zero=";Z3456a1;
2180 PRINT ", Adjusted reading=";V1
2182 PRINTER IS CRT
2184 GOSUB Reduce_power
2186 GOTO Read_meters
2188 END IF
2190 END IF
2192 !-----------------------------------------------------
2194 Hp3456a_2:    
2196 IF Fv3456a2 THEN
2198 CALL Readvdm(Volt2,@Dvm2)  ! HP digital voltmeter
2200 ! returns Volts (DC volts)
2202 V2=Volt2-Z3456a2  ! correct for zero, yields V2
2204 END IF
2206 !-----------------------------------------------------
2208 Hp3478a_1:    
2210 IF Fv3478a1 THEN
2212 CALL Readvdm(Volt3,@Dvm3)  ! HP digital voltmeter
2214 ! returns Volts (DC volts)
2216 V3=Volt3-Z3478a1  ! correct for zero, yields V3
2218 END IF
2220 !-----------------------------------------------------
2222 Hp59306a_relay:    An example of using the relay to measure multiple quantities. This requires additional instrument to actually do the measurements, as the relay only controls a system of rf switches.
2224 ! In this example, turn off the Spectrum Analyzer flag.
2226 IF Fr59306a THEN
2228 OUTPUT @fly1;"A123"  ! Toggle to SUM port
2230 CALL Spec_alzr_start(Frequency,@Spec_alzr)
2232 CALL Spec_alzr_read(Sa_power,Frequency,@Spec_alzr)
2234 Sa_power=10.0^((Sa_power/10.0)-3.0)  ! dBm -> watts
2236 GOSUB Cal_sa_power! correct for losses and return Sa_pwr
2238 Sum_power=Sa_pwr
2240 !
2242 OUTPUT @fly1;"B123"  ! Toggle to DIFFERENCE port
2244 CALL Spec_alzr_start(Frequency,@Spec_alzr)
2246 CALL Spec_alzr_read(Sa_power,Frequency,@Spec_alzr)
2248 Sa_power=10.0^((Sa_power/10.0)-3.0)  ! dBm -> watts
2250 GOSUB Cal.sa_power! correct for losses and return Sa_pwr


Specalr

IF Fsa8566b AND NOT Fr59306a THEN ! HP8566B Spectrum analyzer
CALL Spec_alzr_start(Frequency,@Spec_alzr)
CALL Spec_alzr_read(Sa_power,Frequency,@Spec_alzr)
Sa_power=10.0^((Sa_power/10.0)-3.0) ! dBm -> watts
GOSUB Cal_sa_power! correct for losses and return Sa_pwr
END IF
RETURN

Specalr::!

END IF

Read instrument subroutines

HP 438A Dual power meter - @Dual_pwr1 ...........

Power_1_2:Ab$="AB"
CALL Read_dual_pwr(Ab$,Apower,Bpower,Too_hot,Valid,@Dual_pwr1)
IF Too_hot THEN
GOSUB Reduce_power
RETURN
END IF

HP 438A Dual power meter - @Dual_pwr2 ...........

Power_3_4:Ab$="A" or Ab$="AB" if you want both channels.
CALL Read_dual_pwr(Ab$,Apower,Bpower,Too_hot,Valid,@Dual_pwr2)
IF Too_hot THEN
GOSUB Reduce_power
RETURN
END IF

HP 436A Power meter - @Pwr1 ............

Power detectors are not sources

Power detectors are not sources

Power detectors are not sources

Power detectors are not sources

Return
Power. 5: Pwr_id$="P1"
CALL Read_pwr_meter(Power,Pwr_id$,Valid,@Pwr1,@Sig_gen)
IF NOT Valid THEN
    DISP "ERROR IN 436a POWER METER 1"
    BEEP
    PAUSE
    Power=0.
    Too_hot=1
END IF
IF Power<0. THEN Power=0.
Power5=Power
RETURN

Power. 6: Pwr_id$="P6"
CALL Read_pwr_meter(Power,Pwr_id$,Valid,@Pwr2,@Sig_gen)
IF NOT Valid THEN
    DISP "ERROR IN 436a POWER METER 2"
    BEEP
    PAUSE
    Power=0.
    Too_hot=1
END IF
IF Power<0. THEN Power=0.
Power6=Power
RETURN

PROBE rd:
IF Total_chans>0 THEN
    CALL Read_probes(@Gpio)
    Too_hot=0
    FOR P=1 TO Total_chans
        Too_hot=Too_hot OR Overrange(P)
    NEXT P
    IF Too_hot THEN
        GOSUB Reduce_power
    ELSE
        CALL Apply_probe_cal(Frequency) ! Amplitude correction.
        ! Frequency correction.
    END IF
END IF
RETURN

Level.eut_out: This routine will adjust the signal generator
! output to cause the EUT output (tied to @Dvm1)
! to fall within the limits of Min_eut and Max.eut.
! All the while within the bounds of Low_dbm to High_dbm.
RETURN

END
Level_net_input: This routine will adjust the signal generator output to cause the corrected net input power to fall within the limits of Min_pwr and Max_pwr. All the while within the bounds of Low_dbm to High_dbm.

RETURN

Adjust_power: !

On KEY 5 LABEL "Continue","Local_prt" GOTO Tryitagain

On KEY 0 LABEL "Reduce Power","Local_prt" GOSUB Reduce_power

On KEY 2 LABEL "Increase Pwr","Local_prt" GOSUB Increase_power

Myself:ON KEY 6 LABEL "DBm"="VAL$(Dbm)" ,Local_prt" GOTO Myself

END LOOP

Tryitagain:OFF KEY

DISP CHR$(12)

RETURN

Dual_power_error:

CALL Set_dbm(-140,0,@Sig_gen) ! Kill power

IF Printflag THEN

PRINTER IS Printer

PRINT TIME$(TIMEDATE);": Step#";Steps;" Freq=";Frequency;

PRINT RPT$('*',10);" NEW GENERATOR LEVEL =";Dbm

PRINTER IS CRT

END IF

RETURN

Dual_power_error:

CALL Set_dbm(-140,0,@Sig_gen) ! Kill power

IF Printflag THEN

PRINTER IS Printer

PRINT TIME$(TIMEDATE);": Step#";Steps;" Freq=";Frequency;

PRINT RPT$('*',10);" ERROR IN DUAL POWER METER !!!

PRINTER IS CRT

END IF

DISP " ERROR in DUAL POWER METER, correct and \"CONTINUE\" 

BEEP
SET_dbm(Dbm,1, Sig_gen)  ! Restore power.
RETURN
!
! //!!!PRINT HEADING FOR RAW DATA///!!!
PRINT_heading:  ! Values in order of insertion into matrix.
PRINTER IS Printer
PRINT
SELECT Test_type$
CASE "MODE TUNE REGULAR"
    PRINT RPT$ ("-", 15); "Identifier: "; Run_id$
    PRINT " STEP NUMBER "; Steps; RPT$ ("-", 15)
    PRINT "FREQUENCY INC-PWR REFL-PWR ";
    PRINT " REC-PWR"
    PRINT ", MHz Watts Watts "
    PRINT " Watts"
CASE "MODE TUNE EMISSIONS"
    PRINT RPT$ ("-", 15); "Identifier: "; Run_id$
    PRINT " STEP NUMBER "; Steps; RPT$ ("-", 15)
    PRINT "FREQUENCY REC-PWR ";
    PRINT " MHz Watts "
CASE "OTHER (NO STEPS)"
    PRINT RPT$ ("="; 80)
    PRINT "Measurement Identifier: "; Run_id$
    PRINT Measmt_id$
    PRINT RPT$ ("-", 80)
    PRINT "FREQUENCY INC-PWR REFL-PWR ";
    PRINT " Probe OUTPUT"
    PRINT " MHz Watts Watts "
    PRINT " Volts"
END SELECT
PRINTER IS CRT
RETURN
!
! //!!!PRINT RAW DATA///!!!
PRINTrawdata:
Rawimage1: IMAGE 6D.2D,X,#
Rawimage2: IMAGE #,MD.DDDE,X
PRINTER IS Printer
PRINT USING Rawimage1; Rawdata(I,Column)
FOR I=2 TO Total_meters+1
PRINT USING Rawimage2; Rawdata(I,Column)
NEXT I
PRINT
IF Total_chans>1 THEN GOSUB Print_probes
PRINTER IS CRT
RETURN
!  ! //!!!PRINT probes///!!!
PRINT Probes:
PRINT RPT$ (" ", 80)
PRINT "Amp# Probe# Amp is Zero Output Or not?"
PRINT " Volts/mtr"
PRINT IMAGE M3D,2X,M3D,3X,A,3X,2(M4D,2X),MDD,2X,M4D,2D
FOR I=1 TO Total_chans
Amp=Probe_addr(I,1)
Probe=Probe_addr(I,2)
SELECT Probe_addr(I,3)
CASE 1
   A$="X"
CASE 2
   A$="Y"
CASE 3
   A$="Z"
CASE 4
   A$="S"
CASE ELSE
   A$="E"
END SELECT
Org=Overrange(I)
Zer=ProbE_zero(I)
A_d=Probe_volts(I)
V_m=Rawdata(Total_meters+I+1,Column)
PRINT USING Pimage1;Amp,Probe,A$;Zer,A_d,Org,V_m
NEXT I
PRINT RPT$('_",80)
PRINT
PRINT
RETURN
\11111111111111111111****SAVE DATA****11111111111111111111
ON ERROR CALL Errortrap
IF Test_type$="OTHER (NO STEPS)" THEN
   Filename$=Run_id$
ELSE
   Filename$=SIGNAL$(Beginstep) & "_" & SIGNAL$(Endstep)
END IF
Filename$=Filename$ & Outdisk$
Filesize=INT((Total_chans+Total_meters+1) * File20steps * 8) / 256 + 2
CREATE BDAT Filename$, Filesize, 256
ASSIGN @Datapath TO Filename$
OUTPUT @Datapath;Rawdata(*)
ASSIGN @Datapath TO
PRINTER IS Printer
IF Test_type$="OTHER (NO STEPS)" THEN
   PRINT TIME$(TIMEDATE);" \11111111111111111111
   DATA STORED ON FILE ";Filename$
ELSE
   Filename$="S" & SIGNAL$(Beginstep) & "_" & SIGNAL$(Endstep)
   PRINT TIME$(TIMEDATE);" .... DATA FOR STEPS ";
   PRINT Beginstep; TO ";Endstep;" STORED ON FILE ";Filename$
END IF
OFF ERROR
PRINTER IS CRT
RETURN
\11111111111111111111****SAVE CONFIGURE ****11111111111111111111
ON ERROR CALL Errortrap
Filename$="CONFIGURE"
Filename$=Filename$ & Outdisk$
CREATE BDAT Filename$, 16, 256
ASSIGN @Datapath TO Filename$
OUTPUT @Datapath;Run_id$
OUTPUT @Datapath;Measmt_id$
OUTPUT @Datapath;Time_date$
OUTPUT @Datapath;Fstart,Fstop,Fstep
IF Test_type$="OTHER (NO STEPS)" THEN
    OUTPUT @Datapath;1
ELSE
    OUTPUT @Datapath;Total_steps
END IF
OUTPUT @Datapath;Total_meters
OUTPUT @Datapath;Total_chans
OUTPUT @Datapath;Probe_addr
(*>)
OUTPUT @Datapath;Meter_defs$
(*>)
OUTPUT @Datapath;File20steps
ASSIGN @Datapath TO *
OFF ERROR
PRINTER IS CRT
PRINT TIME$(TIME_DATE);" CONFIGURE file for ";Run_id$;" SAVED."
RETURN
! ////////////////////////////////////////////////////////////
Print_vitals: !
PRINTER IS Printer
PRINT RPT$(" ",80)
PRINT "THIS DATA SET IS IDENTIFIED AS: ";Run_id$
PRINT "MEASUREMENT date: ";Time_date$
PRINT RPT$(" ",80)
PRINT Measmt_id$
PRINT RPT$(" ",80)
PRINT "FREQUENCIES ";Fstart;" TO ";
PRINT Fstop;" STEP ";Fstep; MHz."
PRINT "THE TUNER STEPPED ";Total_steps;" increments."
PRINT Total_meters;" PWR METERS and DVMs, along with ";Total_chans;
PRINT " channels of the NBS multiprobe system."
PRINT
PRINT "The measured DATA are defined as follows:"
PRINT RPT$(" ",80)
PRINT "Data slot # Description";
PRINT TAB(40);"Data slot # Description"
J=INT((Total_chans+Total_meters)/2)+1
IF J<>(Total_chans+Total_meters)/2+1 THEN J=J+1
I=1
K=J
! J is starting point of second column.
REPEAT
PRINT I; ";Meter_defs$(I);
IF I<Total_chans+Total_meters THEN
    PRINT TAB(40);K; ";Meter_defs$(K)
ELSE
    PRINT
END IF
I=I+1
K=K+1
UNTIL I>=J
PRINT RPT$(" ",80)
PRINT USING "2/
PRINTER IS CRT
RETURN
! ////////////////////////////////////////////////////////////
This routine will facilitate setting up the measurement by providing MENU access to the parameters.

**COM** /Parameters/ REAL Fstart, Fstop, Fstep
**COM** /Parameters/ REAL Min_eut, Max_eut, Min_pwr, Max_pwr, Time_eut
**COM** /Parameters/ INTEGER Low_dbm, High_dbm, Step_dbm
**COM** /Parameters/ INTEGER Search_eut, Search_pwr, Re_run
**COM** /Parameters/ INTEGER Begin_step, Total_steps, Total_meters
**COM** /Parameters/ Run_id#, Measmt_id#, Time_date#
**COM** /Parameters/ Meter_defns#(*), Operator_name#, Test_type#
**COM** /Parameters/ Coupler_id#, Generator_id#

**COM** /Filesl Sourceldisk#, Outdisk#, Filename#
**COM** /Files/ SOURCeldisk#, Outdisk#, Filename#
**COM** /Files/ SOURCeldisk#, Outdisk#, Filename#

IF Printer=701 THEN
   ON TIMEOUT 7,.5 GOSUB Printerdead
   PRINT
   OFF TIMEOUT
END IF

IF Bug1 THEN
   PRINT TIME$(TIMEDATE);RPT$("*",10);" ENTER Measure_menu"
END IF

CALL Wipe_clean ! Clear the CRT.
PRINTER IS CRT
GOSUB Write_backgnd ! Format menu area.
IF NOT Re_run THEN
   GOSUB Start_up_values ! Initial values
   GOSUB Fill_in_values ! Put initial values in menu
ELSE
   GOSUB Fill_in_values ! Put current values in menu
END IF

! Make any changes or corrections.
GOSUB Define_keys
GOSUB Define_keys

LOOP
   IF Interrupted THEN GOSUB Define_keys
   ON KEY 5 LABEL "EXIT ""RESET", Local_prty GOTO Exit_sub
   ON KEY 15,Local_prty GOSUB Start_up_values
   PRINT TABXY(69,3);TIME$(TIMEDATE)
END LOOP
Exit_sub:
SUB Measure_menu

Original: 5 May 1984
Revision: 24 Jan 1986
This routine will facilitate setting up the
measurement by providing MENU access to the
parameters.

COM /Parameters/ REAL Fstart,Fstop,Fstep
COM /Parameters/ REAL Min_eul,Max_eul,Min_pwr,Max_pwr,Time_eul
COM /Parameters/ INTEGER Low_dbm,High_dbm,Step_dbm
COM /Parameters/ INTEGER Search_eul,Search_pwr,Re_run
COM /Parameters/ INTEGER Begin_step,Total_steps,Total_meters
COM /Parameters/ Run_id#,Measmt_id#,Time_date#
COM /Parameters/ Meter_defns#(),Operator_name#,Test_type#
COM /Parameters/ Coupler_id#,Generator_id#

COM /Files/ Source_,disk#,Outdisk#,Filename#
COM /Bugs/ INTEGER Bug1,Bug2,Bug3 Printer
COM /Interrupts/ INTEGER Intr_prtv
DIM Test#[160]
INTEGER Local_prtv,Asci_num,Interrupted
Local_prtv=Intr_prtv
DISP CHR$(129)

IF Printer=701 THEN
  ON TIMEOUT 7,.5 GOSUB Printerdead
  PRINT
  OFF TIMEOUT
END IF
IF Bug1 THEN
  PRINT TIME$(TIMEDATE);RPT#("","10");" ENTER Measure_menu"
END IF

CALL Wipe_clean
PRINT IS CRT
GOSUB Write_backgnd
IF NOT Re_run THEN
  GOSUB Start_up_values
  GOSUB Fill_in_values
ELSE
  GOSUB Fill_in_values
END IF

Make any changes or corrections.
GOSUB Define_keys
PRINT TABXY(56,3);DATE$(TIMEDATE)
LOOP
IF Interrupted THEN GOSUB Define_keys
ON KEY 5 LABEL "EXIT "RESET",Local_prtv GOTO Exit_sub
ON KEY 15,Local_prtv GOSUB Start_up_values
PRINT TABXY(69,3);TIME$(TIMEDATE)
END LOOP
END

Exit_sub:!
3098 OFF KEY
3100 DISP CHR$(12)
3102 Time_date=$1TIME$(TIMEDATE)$","$DATE$(TIMEDATE)
3104 PRINTER IS Printer
3106 IF Printer=701 THEN DUMP ALPHA
3108 IF Bug$ THEN
3110 PRINT TIME$(TIMEDATE);$RPT$("*",10);" EXIT Measure_menu"
3112 END IF
3114 CALL Wipe_clean
3116 PRINTER IS CRT
3118 SUBEXIT
3120 !
3122 !-------------------------------------------------------------------------------------------------------
3124 !
3126 Define_keys:!
3128 OFF KEY
3130 Interrupted=0
3132 DISP RPT$(">",15);" SELECT PARAMETER TO CHANGE ";
3134 DISP "("shift key) "RPT$(">",15)
3136 ON KEY 0 LABEL "TEST ID "TYPE",Local_prty GOSUB Change_euid
3138 ON KEY 10,Local_prty GOSUB Change_type
3140 ON KEY 1 LABEL "FREqs SIG GEN",Local_prty GOSUB Change_freqs
3142 ON KEY 11,Local_prty GOSUB Change_levels
3144 ON KEY 2 LABEL "INPUT MIN MAX",Local_prty GOSUB Change_pwr_min
3146 ON KEY 12,Local_prty GOSUB Change_pwr_max
3148 ON KEY 3 LABEL "LEVEL SEARCH",Local_prty GOSUB Change_search_p
3150 ON KEY 13,Local_prty GOSUB Change_search_e
3152 ON KEY 4 LABEL "EUT MIN MAX",Local_prty GOSUB Change_eut_min
3154 ON KEY 14,Local_prty GOSUB Change_eut_max
3156 ON KEY 5 LABEL "DATE NAME",Local_prty GOSUB Call_time_date
3158 ON KEY 15,Local_prty GOSUB Enter_name
3160 ON KEY 7 LABEL "Response Time",Local_prty GOSUB Change_response
3162 IF Test_type$="OTHER (NO STEPS)" THEN
3164 ON KEY 8 LABEL "TUNER BEGIN",Local_prty GOSUB Change_tuner
3166 ON KEY 10,Local_prty GOSUB Change_beginstep
3168 END IF
3170 ON KEY 9 LABEL "DISK DRIVE",Local_prty GOSUB Change_diskdrive
3172 RETURN
3174 !
3176 !-------------------------------------------------------------------------------------------------------
3180 Start_up_values: ! Define the initial values for all parameters.
3182 Re_run=1
3184 Fstart=100 ! Frequency range in MHz.
3186 Fstop=1000
3188 Fstep=50
3190 Low_dbm=-40 ! Signal generator level in dBm.
3192 High_dbm=-10
3194 Step_dbm=1
3196 Search_eut=0 ! 0= DO NOT auto search for EUT response
3198 Search_pwr=0 ! 1= DO
3200 ! 0= DO NOT auto level the Net Input power.
3202 ! 1= DO
3204 Min_eut=1.0E-6 ! Minimum output of EUT in volts.
3206 Max_eut=10.0
3208 Min_pwr=1.0E-6 ! Maximum output of EUT in volts.
3210 Max_pwr=10.0
3212 Time_eut=0.0 ! Minimum net input power in watts.
3214 Begin_step=1 ! Time for EUT to respond after field is set.
3216 Total_steps=200 !An integer division of 3200

112
Test_type$="MODE TUNE REGULAR" : or "MODE TUNE EMISSIONS"

Run_id$="Run_1"

Operator_name$="Galen Kopeke"

Measmt_id$="Evaluate the susceptibility of a device"

Measmt_id$="Measmt_id$" in the NBS Reverberating Chamber."

Coupler_id$="HP_778D"

Generator_id$="HP_B660A"

GOSUB Fill_in_values! Put initial values in menu

RETURN


GOSUB Change_euid! Fill in the values

GOSUB Print_type

GOSUB Print_freqs

GOSUB Print_gen_level

GOSUB Print_beginstp

GOSUB Print_tuner

GOSUB Print_name

GOSUB Print_search_p

GOSUB Print_search_e

GOSUB Print_eut_min

GOSUB Print_eut_max

GOSUB Print_pwr_min

GOSUB Print_pwr_max

GOSUB Print_wait

GOSUB Print_diskdrive

RETURN


Write_backgrnd! Format menu area.

PRINT CHR$(129)

PRINT TABXY(16,1);"***MEASUREMENT PARAMETERS - *** "

PRINT TABXY(1,3);" TEST ID:"

PRINT TABXY(23,3);" TYPE:"

PRINT TABXY(41,3);" DATE / TIME:"

PRINT CHR$(132);

PRINT TABXY(1,5);RPT$(" ",160)

PRINT CHR$(129);

PRINT TABXY(1,8);" FREQUENCY (MHz)"

PRINT TABXY(1,9);" LOW:"

PRINT TABXY(1,10);" HIGH:"

PRINT TABXY(1,11);" STEP:"

PRINT TABXY(21,8);" GENERATOR (dBm)"

PRINT TABXY(41,8);" NET INPUT POWER (W)"

PRINT TABXY(41,9);" MIN:"

PRINT TABXY(41,10);" MAX:"

PRINT TABXY(41,11);" LEVEL INPUT?"

PRINT TABXY(65,8);" EUT RESPONSE"

PRINT TABXY(65,11);" SEARCH?"

PRINT CHR$(129);

PRINT TABXY(62,9);"..."
PRINT TABXY(42,10);"...
PRINT CHR$(128);
PRINT TABXY(1,13);" ESTIMATE EUT RESPONSE TIME 
PRINT TABXY(41,13);" seconds. ":RPT$(" ",30)
PRINT TABXY(41,15);" COUPLER/SIG GEN:");
PRINT TABXY(1,15);" BEGIN TUNER POSITION 
PRINT TABXY(29,15);" END 
PRINT TABXY(1,17);" OPERATOR: ";
PRINT TABXY(41,17);" OUTPUT DISK DRIVE: 
PRINT CHR$(128)
RETURN
! ///////////////////////////////////////////////////!
Printhead:DISP "NO PRINTER at HPIB address 701 !! ";
DISP " Please correct situation and hit 'CONTINUE' ";
BEEP
PAUSE
RETURN
!
! ///////////////////////////////////////////////////!
Call_time_date:Interrupted=1
CALL Time_date
RETURN
!
! ///////////////////////////////////////////////////!
Change_eut_max:Interrupted=1
IF Test_type$t="MODE TUNE EMISSIONS" THEN RETURN
DISP " ENTER the UPPER LIMIT for the EUT RESPONSE (your units) ";
INPUT Max_eut
IF Max_eut<Min_eut THEN
Min_eut=Max_eut
GOSUB Print_eut_min
END IF
Print_eut_max:
PRINT TABXY(66,10);
IF Test_type$t="MODE TUNE EMISSIONS" THEN
PRINT USING "9A"; Not used
ELSE
PRINT USING "MD.2DE";Max_eut
END IF
RETURN
!
! ///////////////////////////////////////////////////!
Change_eut_min:Interrupted=1
IF NOT Search_eut OR Test_type$t="MODE TUNE EMISSIONS" THEN RETURN
DISP " ENTER the LOWER LIMIT for the EUT RESPONSE (your units) ";
INPUT Min_eut
IF Min_eut<Max_eut THEN Min_eut=Max_eut
Print_eut_min:
PRINT TABXY(66,9);
IF NOT Search_eut OR Test_type$t="MODE TUNE EMISSIONS" THEN
PRINT USING "9A"; Not used
ELSE
PRINT USING "MD.2DE";Min_eut
END IF
RETURN
Change_pwr_max:Interrupted=1

IF NOT Search_pwr OR Test_type$="MODE TUNE EMISSIONS" THEN RETURN

DISP "ENTER the Maximum NET Input Power ";

INPUT Max_pwr

IF Max_pwr<0, THEN Max_pwr=0.

IF Max_pwr<Min_pwr THEN

Min_pwr=Max_pwr

GOSUB Print_pwr_min

END IF

Print_pwr_max:

PRINT TABXY(50,10);

IF NOT Search_pwr OR Test_type$="MODE TUNE EMISSIONS" THEN

PRINT USING "9A";" Not used"

ELSE

PRINT USING "MD.2DE";Max_pwr

END IF

RETURN

!

Change_pwr_min:Interrupted=1:

IF Test_type$="MODE TUNE EMISSIONS" THEN RETURN

DISP " ENTER the Minimum NET Input Power ";

INPUT Min_pwr

IF Min_pwr<0, THEN Min_pwr=0.

IF Min_pwr>Max_pwr THEN Min_pwr=Max_pwr

Print_pwr_min:

PRINT TABXY(50,10);

IF Test_type$="MODE TUNE EMISSIONS" THEN

PRINT USING "9A";" Not used"

ELSE

PRINT USING "MD.2DE";Min_pwr

END IF

RETURN

!

Change_search_p:

IF Search_pwr=0 AND Search_eut=0 THEN

Search_pwr=1

ELSE

Search_pwr=0

END IF

GOSUB Print_gen_level

GOSUB Print_pwr_max

Print_search_p:

PRINT TABXY(56,11);

IF Test_type$="MODE TUNE EMISSIONS" THEN

PRINT "OFF"

ELSE

IF Search_pwr THEN

PRINT " ON" 

ELSE

PRINT " OFF"

END IF

END IF

RETURN
IF Search_eut=0 AND Search_pow=0 THEN
    Search_eut=1
ELSE
    Search_eut=0
END IF
GOSUB Print_gen_level
GOSUB Print_eut_min
PRINT TABXY(75,11);
IF Test_type$="MODE TUNE EMISSIONS" THEN
    PRINT "OFF"
ELSE
    IF Search_eut THEN
        PRINT "ON "
    ELSE
        PRINT "OFF"
    END IF
END IF
RETURN

GOSUB Print_eutid
GOTO New_type

Source_eut: Regular MODE TUNED TESTS with transmitting antenna
Test_type$="MODE TUNE REGULAR"
Measmt_id$="Evaluate the susceptibility of a device"
Measmt_id$=Measmt_id$%" in the NBS Reverberating Chamber."
GOSUB Print_eutid
GOTO New_type

Source_eut: Emissions using MODE TUNED sequence, EUT is source
Test_type$="MODE TUNE EMISSIONS"
Measmt_id$="Measure the radiated emissions of a device"
Measmt_id$=Measmt_id$%" in the NBS Reverberating Chamber."
GOSUB Print_eutid
GOTO New_type

Notunerstep: Other measurements that require no TUNER stepping
Test_type$="OTHER (NO STEPS)"
Measmt_id$="Measure the response of a device to a field"
Measmt_id$=Measmt_id$%" in the NBS 1.2 meter TEM CELL."
GOSUB Print_eutid
GOTO New_type

New_type:OFF KEY
! Update all the menu items affected by TYPE change.
GOSUB Print_gen_level
GOSUB Print_beginstep
GOSUB Print_tuner
GOSUB Print_search_e
GOSUB Print_search_p
GOSUB Print_gen_id
3693  GOSUB Print_pwr_min
3700  GOSUB Print_pwr_max
3702  GOSUB Print_out_min
3704  GOSUB Print_out_max
3706  PRINT type: !
3708  PRINT CHR$(129);
3710  PRINT TABXY(45,1);
3712  SELECT Test_type$
3714  CASE "MODE TUNE REGULAR", "MODE TUNE EMISSIONS"
3716     PRINT "MODE TUNED TESTS";
3718  CASE "OTHER (NO STEPS)"
3720     PRINT "TEM CELL TESTS ";
3722  CASE ELSE
3724     PRINT "?????????????????";
3726  END SELECT
3728  PRINT CHR$(129);
3730  PRINT TABXY(31,3);
3732  SELECT Test_type$
3734  CASE "MODE TUNE REGULAR"
3736     PRINT "REGULAR "
3738  CASE "MODE TUNE EMISSIONS"
3740     PRINT "EMISSIONS"
3742  CASE "OTHER (NO STEPS)"
3744     PRINT "OTHER 
3746  CASE ELSE
3748     PRINT "?????????"
3750  END SELECT
3752  RETURN
3754  !
3756  ! /----------------------------------------------------------------------
3758  !
3760  Change_beginstp: Interrupted=1
3762  IF Test_type$="OTHER (NO STEPS)" THEN GOTO Print_beginstep
3764  DISP " ENTER THE BEGINNING TUNER STEP NUMBER ";
3766  INPUT Begin_step
3768  IF Begin_step>Total_steps THEN Begin_step=Total_steps
3770  Print_beginstep:
3772  PRINT TABXY(24,15);
3774  IF Test_type$="OTHER (NO STEPS)" THEN
3776      PRINT USING "4D";Begin_step
3778  ELSE
3780      PRINT USING "4A";"N/A 
3782  END IF
3784  RETURN
3786  !
3788  ! /----------------------------------------------------------------------
3790  !
3792  Change_tuner:
3794  IF Test_type$="OTHER (NO STEPS)" THEN GOTO Print_tuner
3796  SELECT Total_steps
3798  CASE 3200
3800     Total_steps=3200
3802  CASE 1600
3804     Total_steps=1600
3806  CASE 800
3808     Total_steps=800
3810  CASE 400
3812     Total_steps=400
3814  CASE 200
3816     Total_steps=200
3818  Total_steps=400
CASE 100
    Total_steps=200
CASE ELSE
    Total_steps=400
END SELECT

Print_t recognizer:
PRINT TABXY(35,15);
IF Test_type<>"OTHER (NO STEPS)" THEN
    PRINT USING "4D";Total_steps
ELSE
    PRINT USING "4A";"N/A"
END IF
IF Begin_step>Total_steps THEN
    Begin_step=Total_steps
GOSUB Print_beginstp
END IF
RETURN

CHANGE_FILE: Interrupted=1
DISP " ENTER the TEST ID# (LEGAL FILE NAME) ";
OUTPUT 2 USING "K,";Run_id$
INPUT Test$
IF LEN(Test$)=0 THEN Change_fileid
IF LEN(Test$)>10 THEN
    BEEP
    DISP " ERROR in NAME ENTRY--TOO MANY CHARACTERS, TRY AGAIN. "
    WAIT 1.8
    OUTPUT 2 USING "K,";Filename$
    GOTO Change_fileid
END IF
FOR I=1 TO LEN(Test$)
    ASCII_num=NUM(Test$[I])
    SELECT Ascii_num
        CASE 65 TO 90,95,97 TO 122,48 TO 57
            ! Allowed characters
        CASE ELSE
            BEEP
            DISP " ERROR in NAME ENTRY--ILLEGAL CHARACTERS, TRY AGAIN."
            WAIT 1.8
            GOTO Change_fileid
    NEXT I
Run_id$=Test$
DISP " DESCRIPTION of the EUT and PURPOSE for test?? (<2 lines) ":
OUTPUT 2 USING "K,";Measmt_id$
LINPUT Measmt_id$
PRINT_fileid:
PRINT TABXY(12,3);RPT$(" ",10)
PRINT TABXY(12,3);Run_id$
PRINT CHR$(132);" ";
PRINT TABXY(11,5);RPT$(" ",160)
PRINT TABXY(11,5);Measmt_id$
PRINT CHR$(128);
RETURN
Enter_freq_er: ' 
DISP " ERROR in numeric entry or ILLEGAL value. " 
BEEP 
WAIT 1.8 
Change_freqs: Interrupted=1 
DISP " ENTER Start, Stop, Step frequencies (MHz). "; 
DISP " [Ranges: 1-30, 30-2000, 2000-18000]";
LINPUT Test#
ON ERROR GOTO Enter_freq_er 
Fstart=VAL(Test#) 
Fstop=VAL((POS(Test#, ",") +1))
Test#=Test#[POS(Test#,",",)+1,LEN(Test#)] 
Fstop=VAL((POS(Test#,",",)+1))
OFF ERROR 
IF Fstop<Fstart THEN GOTO Enter_freq_er 
Fstart=MAX(MIN(Fstart,18000),1)
Fstop=MAX(MIN(Fstop,18000),1) 
Fstep=MAX(MIN(Fstep,18000),.01)
SELECT Fstart+(Fstop-Fstart)/2 !Mid point in the range of freq. 
CASE (=30 ! Set limits to 1-30 range 
  IF Fstop>30 THEN Fstop=30 
  Generator_id$="HP_8660A"
  Coupler_id$="CH_130_4"
CASE (=2000 ! Set limits to 30-2000 range 
  IF Fstart<30 THEN Fstart=30 
  IF Fstop>2000 THEN Fstop=2000 
  Coupler_id$="HP_778D"
  Generator_id$="HP_8660A"
CASE )=2000 ! Set limits to 2000-18000 range 
  IF Fstart(2000 THEN Fstart=2000 
  Coupler_id$="HF_11692D"
  Generator_id$="HP_8672A"
END SELECT 
Print_freqs: 
PRINT TABXY(9,9); PRINT USING "5D.2D";Fstart
PRINT TABXY(9,10); PRINT USING "5D.2D";Fstop
PRINT TABXY(9,11); PRINT USING "5D.2D";Fstep
Print_gen_id: 
PRINT TABXY(59,15);RPT$(" ",21);
IF Test_type$="MODE TUNE EMISSIONS" THEN 
  PRINT TABXY(59,15);"Not used"
ELSE 
  PRINT TABXY(59,15);Coupler_id$;" ";Generator_id#
END IF 
RETURN

! ///////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
! 4038 Change_levels: Interrupted=1 
4042 IF Test_type$="MODE TUNE EMISSIONS" THEN RETURN 
4044 IF Search_sut OR Search_pwr THEN 
  DISP " ENTER the LOW, HIGH, STEP Signal generator LEVEL (dBm) "; 
  DISP " ...integers only! "; 
4050 INPUT Low_dbm,High_dbm,Step_dbm 
4052 IF Low_dbm>=High_dbm THEN Low_dbm=High_dbm ! capped by high_dbm 
4054 IF Step_dbm<1 THEN Step_dbm=1 
4056 ELSE
04058 DISP " ENTER Signal generator LEVEL (dBm) ";
04059 DISP " ...integers only! ";
04060 INPUT Low_dbm
04061 IF High_dbm<Low_dbm THEN High_dbm=Low_dbm  ! capped by low_dbm
04062 END IF
04063 Print_gen_level:
04064 PRINT CHR$(129);
04065 SELECT Test_type$
04066 CASE "MODE TUNE REGULAR","OTHER (NO STEPS)"
04067 IF Search_eut OR Search_pwr THEN
04068 PRINT TABXY(21,9);" LOW: "
04069 PRINT TABXY(21,10);" HIGH: "
04070 PRINT TABXY(21,11);" STEP: "
04071 ELSE
04072 PRINT TABXY(21,9);" FIXED: "
04073 PRINT TABXY(21,10);" 
04074 PRINT TABXY(21,11);" 
04075 END IF
04076 CASE "MODE TUNE EMISSIONS"
04077 PRINT TABXY(21,9);" NOT "
04078 PRINT TABXY(21,10);" USED "
04079 PRINT TABXY(21,11);" .... "
04080 CASE ELSE
04081 PRINT TABXY(21,9);" ERROR "
04082 PRINT TABXY(21,10);" DETECTED"
04083 PRINT TABXY(21,11);" IN TYPE!"
04084 END SELECT
04085 PRINT CHR$(128);
04086 PRINT TABXY(30,9);
04087 PRINT USING "4A";
04088 PRINT TABXY(30,10);
04089 PRINT USING "4A";
04090 PRINT TABXY(30,11);
04091 PRINT USING "4A";
04092 IF Test_type$<"MODE TUNE EMISSIONS" THEN
04093 PRINT TABXY(30,9);
04094 PRINT USING "4D";Low_dbm
04095 IF Search_eut OR Search_pwr THEN
04096 PRINT TABXY(30,10);
04097 PRINT USING "4D";High_dbm
04098 PRINT TABXY(30,11);
04099 PRINT USING "4D";Step_dbm
04100 END IF
04101 END IF
04102 RETURN
04103
04104 Change_response: Interrupted=1
04105 DISP " ENTER time for EUT to respond after field is set. (seconds) ";
04106 INPUT Time_eut
04107 Print_wait:
04108 PRINT TABXY(30,13);
04109 IF Time_eut<9999 THEN
04110 PRINT USING "X,5D.3D";Time_eut
04111 ELSE
04112 PRINT USING "MD.3DE";Time_eut
04113 END IF
04114 RETURN
04115

4178  ! /////////////////////////////////////////////////////////////
4180 !
4182 Enter_name: Interrupted=1
4184 DISP "PLEASE TYPE IN YOUR NAME ";
4186 LINPUT Test$
4188 Operator_name$=Test$(1,28)
4190 Print_name:
4192 PRINT TABXY(13,17);RFT$(" ",28);
4194 PRINT TABXY(13,17);Operator_name$
4196 RETURN
4198 !
4200 ! /////////////////////////////////////////////////////////////
4202 !
4204 Change_diskdrive:
4206 OFF KEY
4208  Interrupted=1
4210 DISP "$ SELECT DISK DRIVE for DATA OUTPUT. "
4212 ON KEY 0 LABEL "$LEFT Internal",Local_prty+1 GOTO Left_internal
4214 ON KEY 2 LABEL "$9133 HARD DISK",Local_prty+1 GOTO Hard9133
4216 ON KEY 4 LABEL "$RIGHT Internal",Local_prty+1 GOTO Right_internal
4218 ON KEY 7 LABEL "$9133 floppy",Local_prty+1 GOTO Floppy9133
4220 LOOP
4222 END LOOP
4224 Left_internal:Outdisk$="INTERNAL,4,1"
4226 GOTO Disk_selected
4228 Right_internal:Outdisk$="INTERNAL,4,0"
4230 GOTO Disk_selected
4232 Hard9133:Outdisk$="HP9133,700,0"
4234 GOTO Disk_selected
4236 Floppy9133:Outdisk$="HP9133,702,0"
4238 Disk_selected:OFF KEY
4240 Print_diskdrive:
4242 PRINT TABXY(62,17);Outdisk$
4244 RETURN
4246 !
4248 ! /////////////////////////////////////////////////////////////
4250 !
4252 SUBEND
4254 !
4256 ! ***************************************************************
4258 !
The program is currently configured as follows:

1) Read diode detector on DVM 1 [722] (Horn antenna)
   Calibrate this reading via diode calibration
   and normalize to 10 mW/cm^2 referenced to the
   energy calculated via reference antenna as read
   on the spectrum analyzer.

2) Read 1cm dipole output on DVM 2 [723] and DVM 3 [724]
   This is the EUT for the measurement.
   Calibrate via calibration curve and
   normalize to 37 dB V/m as calculated from
   reference received power.

3) In the event of failure to complete revolution
   the program will modify sample count to compensate.

4) Parameters set for NBS chamber.

5) Save data is disabled, needs to be updated for GRAPH_DATA

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This measurement routine will operate the REVERBERATION CHAMBER
using MODE STIRRED techniques. The tuner is stepped continuously
and measurements are performed asynchronously. In this version each
frequency is measured completely before proceeding
to the next frequency.
Coupler, cable loss, and Power meter head corrections are applied
immediately to the measured data.

The statistical results are saved for graphing.

OPTION BASE 1
DEG
PRINTER IS 1
OUTPUT 2 USING "K, #"; "SCRATCH KEYX"
DISP CHR$(129)

Die_gracefully
!For a clean slate.
Dim variables
Dim Initial_values
GOSUB Fillcalibration
DO measurements
Dim Die_gracefully

DIMENSION VARIABLES

Dim variables:
COM /Parameters/ Startf,Stopf,Stepf,Slow_down,Coupler_idf(10]
COM /Parameters/ Generator_idf(10),Dvm_integrate(3]
COM /Parameters/ INTEGER Low_dbm,High_dbm,Step_dbm,Dvm_samples
COM /Parameters/ Upperlimit,Threshold,Rev_time
COM /Motor_menu/ Motion_type(!0$2),INTEGER Jog_wait
222 COM /Bugs/ INTEGER Bug1,Bug2,Bug3,Printer
224 COM /Interrupts/ INTEGER Intr_prtty
226 COM /Files/ Source:disk$:1(20),Outdisk$:1(20),Filename$:1(90)
228
230 DIM Coup_inc(100,2),Coup_ref(100,2),Baddata_id$:1(100180)
232 DIM Cable6a(180,2),Cable6b(180,2),Cable4(180,2),Cable10ft(180,2)
234 DIM Pad_e6a(180,2),Pad_e670(180,2),Pad_e530(180,2)
236 DIM Newc(180,2) !NSWC CABLE DATA
238
240 DIM Cal_id$:180,Ab$:1(2),Pwr_id$:12),Test$:1(40)
242
244 INTEGER Baddata,Dbm,Rf_on_off
246 INTEGER Failflag
248 INTEGER Valid,Totdfreqs,Totalcurves,Ser_poll
250 INTEGER Printflag,Readiflag,Readzflag,Movingflag,Fad10db
252
254 INTEGER Newc_pts
256 INTEGER Inc_pts,Rel_pts,C6a_pts
258 INTEGER C6b pts,C4 pts,C10 pts,Pada pts,Pad pts,Padf pts
260 INTEGER Fcount,Too_hot,Printflag2
262 INTEGER Local_prtty,P_sams,P,Dvm1_sams,Dvm2_sams
264
266 RETURN
268
270 !-----------------------------------------------------------------------------------------
272
274 Initial_values: !
276
278 ASSIGN @Motor TO 706
280 ASSIGN @Pwrl TO 709
282 ASSIGN @Pwr2 TO 710
284 ASSIGN @Dual_pwr1 TO 711
286 ASSIGN @Spectrum TO 718
288 ASSIGN @Dvm1 TO 722
290 ASSIGN @Dvm2 TO 723
292 ASSIGN @Dvm3 TO 724
294 ASSIGN @Sig_gen TO 719
296
298 Intr_prtty=6
300 Local_prtty=Intr_prtty
302 Printer=701
304 Source:disk$:"INTERNAL,4,0"
306 Outdisk$:"INTERNAL,4,1"
308
310 Printflag=0
312 Bug1=O
314 Bug2=O
316 Bug3=O
318
320 Motion_type="CONTINUOUS" !or "STEP" for MODE TUNED.
322
324 Rf_on_off=1
326 ! 1=on, 0=off
328 CALL Measure_menu
330 GOSUB Die_gracefully !Go and set up the measurement parameters.
332)
334 CALL Menu_pwr436
336 !Set up all power meters
338 !For a clean slate.
!----------------------------------ALLOCATION THE RAW DATA MATRIX----------------------------------!
Totalfreqs=INT((Stopf-Startf)/Stepf)+1
Totalcurves=#
ALLOCAE Savedata(Totalfreqs,Totalcurves+1)
ALLOCAE Adjust(Totalfreqs,10)
PRINCF CTR
PRINT TABXY(1,18);RPT$(*",20);" LOAD SUB PROGRAMS ";RPT$(*",20)
Filename$=Generator_id$&Sourcedisk$
DISP "Insert 'SUB Program/Support DATA' disk in ";
SELECT Sourcedisk$
CASE ":INTERNAL",4,0"
DISP "RIGHT DRIVE, ";
CASE ":INTERNAL",4,1"
DISP "LEFT DRIVE, ";
END SELECT
DISP "and hit 'CONTINUE' ".
BEEP
ON KEY 5 LABEL "CONTINUE",Local_prty GOTO Subloads
Zippy:GOTO Zippy
Subloads:OFF KEY
DISP CHR$(12)
DISP U Signal
ON ERROR CALL Errortrap
LOADSUB ALL FROM Filename$
OFF ERROR
DISP "Signal Generator SUB PROGRAMS LOADED 
WAIT 1
PRINT TABXY(1,18);RPT$(*",20);" LOAD CALIBRATION DATA ";RPT$(*",20)
DISP " Calibration DATA for Cables, Couplers, Pads, etc. now LOADING 
I
Install cal fl:.... Install new calibration files here....!
ELSE
IF Printflag THEN PRINTER IS Printer
IF Printflag THEN PRINT "CALIBRATION DATA FOR THE FOLLOWING IS LOADED:"
SELECT Coupler_id$
CASE "HP_778D"
Filename$="HP_778D_f"&Sourcedisk$
Enter_calidata(Filename$,Coup_inc(*),Cal_id#,Inc_pts)
Baddata_id#(1)=Cal_id$
IF Printflag THEN PRINT Cal_id#
Filename$="HP_778D_r"&Sourcedisk$
Enter_calidata(Filename$,Coup_ref1(*),Cal_id#,Ref1_pts)
Baddata_id#(2)=Cal_id#
IF Printflag THEN PRINT Cal_id#
CASE "HP_11692D"
Filename$="HP_11692D_f"&Sourcedisk$
Enter_calidata(Filename$,Coup_inc(*),Cal_id#,Inc_pts)
Baddata_id#(1)=Cal_id$
IF Printflag THEN PRINT Cal_id#
Filename$="HP_11692D_r"&Sourcedisk$
Enter_calidata(Filename$,Coup_ref1(*),Cal_id#,Ref1_pts)
Baddata_id#(2)=Cal_id#
IF Printflag THEN PRINT Cal_id#
CASE ELSE
PRINT "COUPLER CALIBRATION DATA ERROR.....NOT DEFINED."
BEEP
PAUSE
END SELECT

FILENAME="Cable6FT_1"&Sourcedisk$
ENTER_CALDATA(FILENAME$,Cable6a(*),Cal_id$,C6a_pts)
Baddata_id$(3)=Cal_id$
IF Printflag THEN PRINT Cal_id$

FILENAME="Cable6FT_6"&Sourcedisk$
ENTER_CALDATA(FILENAME$,Cable6b(*),Cal_id$,C6b_pts)
Baddata_id$(4)=Cal_id$
IF Printflag THEN PRINT Cal_id$

FILENAME="Cable4FT_2"&Sourcedisk$
ENTER_CALDATA(FILENAME$,Cable4(*),Cal_id$,C4_pts)
Baddata_id$(5)=Cal_id$
IF Printflag THEN PRINT Cal_id$

FILENAME="Cable10F_5"&Sourcedisk$
ENTER_CALDATA(FILENAME$,Cable10f(*),Cal_id$,C10_pts)
Baddata_id$(6)=Cal_id$
IF Printflag THEN PRINT Cal_id$

FILENAME="PAD_S6770"&Sourcedisk$
ENTER_CALDATA(FILENAME$,Pad_s6770(*),Cal_id$,Pad_pts)
Baddata_id$(7)=Cal_id$
IF Printflag THEN PRINT Cal_id$

FILENAME="PAD_S5530"&Sourcedisk$
ENTER_CALDATA(FILENAME$,Pad_s5530(*),Cal_id$,Padf_pts)
Baddata_id$(8)=Cal_id$
IF Printflag THEN PRINT Cal_id$

FILENAME="PdAS6A1466"&Sourcedisk$
ENTER_CALDATA(FILENAME$,Pd_s6a(*),Cal_id$,Pda_pts)
Baddata_id$(9)=Cal_id$
IF Printflag THEN PRINT Cal_id$

FILENAME="PdAS6A1466"
FILENAME=FILENAME&Sourcedisk$
ENTER_CALDATA(FILENAME$,Nswe(*),Cal_id$,Nswe_pts)
Baddata_id$(10)=Cal_id$
IF Printflag THEN PRINT Cal_id$

DISP "Caliberation DATA LOADED 
WAIT 1
PRINT "OUT DISK IN ";
SELECT Outdisk$
CASE ":INTERNAL,4,0"
    DISP "RIGHT DRIVE, ";
CASE ":INTERNAL,4,1"
    DISP "LEFT DRIVE, ";
END SELECT
DISP "and hit 'CONTINUE'."
ON KEY 5 LABEL "CONTINUE",Local_prty GOTO Datasaver
Zippity:G010 Zippity
Datasaver:OFF KEY
DISP CHR$(12)
RETURN

!///////////////////////////////////////////////////////////////////////****DIE GRACEFULLY****///////////////////////////////////////////////////////////////////////
!

Die_gracefully:  
IF Bug1 THEN
PRINT TIME$(TIMEDATE); 
PRINT RPT$("<",15);" DIE GRACEFULLY ";RPT$(">",15)
END IF
ON ERROR GOTO Delet_done1
SELECT Generator_id$
CASE "HP_8660A"
DELSUB Set_freq,Set_dbm,FNDigit10$,FNDigit3$,FNRev$
CASE "HP_8672A"
DELSUB Set_freq,Set_dbm
END SELECT
Delet_done1:  
OFF ERROR
RETURN

!///////////////////////////////////////////////////////////////////////
!

Fillcalibration:  !Determine the cable, coupler and pad calibration
!values for each frequency.
!Save these in the adjust(*) file for use by the
!measurement routine.
!
IF Bug1 THEN
PRINT TIME$(TIMEDATE); 
PRINT RPT$("<",15);" FILL CALIBRATION MATRIX ";RPT$(">",15)
END IF
Fcount=1
FOR Frequency=Startf TO Stopf STEP Stepf
Get_cal_value(Frequency,Coupinc,Coup_inc(*),Baddata,Inc_pts)
IF Baddata THEN
Cal_id$=Baddata_id$(1)
GOSUB Flagbaddata
END IF
Adjust(Fcount,1)=Coupinc
!
Get_cal_value(Frequency,Couprefl,Coup_refl(*),Baddata,Refl_pts)
IF Baddata THEN
Cal_id$=Baddata_id$(2)
GOSUB Flagbaddata
END IF
Adjust(Fcount,2)=Couprefl
!
Get_cal_value(Frequency,C6a_loss,Cable6a(*),Baddata,C6a_pts)
IF Baddata THEN
Cal_id$=Baddata_id$(3)
GOSUB Flagbaddata

!///////////////////////////////////////////////////////////////////////
700  END IF
702  Adjust(Fcount,3)=C6b_loss
704  !
706  Get_cal_value(Frequency,C6b_loss,Cable6b(*),Baddata,C6b_pts)
708  IF Baddata THEN
710      Cal_id$=Baddata_id$(4)
712      GOSUB Flagbaddata
714  END IF
716  Adjust(Fcount,3)=C6b_loss
718  !
720  Get_cal_value(Frequency,C4_loss,Cable4(*),Baddata,C4_pts)
722  IF Baddata THEN
724      Cal_id$=Baddata_id$(5)
726      GOSUB Flagbaddata
728  END IF
730  Adjust(Fcount,4)=C4_loss
732  !
734  Get_cal_value(Frequency,CI0_loss,Cable10ft(*),Baddata,CI0_pts)
736  IF Baddata THEN
738      Cal_id$=Baddata_id$(6)
740      GOSUB Flagbaddata
742  END IF
744  Adjust(Fcount,5)=CI0_loss
746  !
748  Get_cal_value(Frequency,Pad_loss,Pad_s6770(*),Baddata,Pad_pts)
750  IF Baddata THEN
752      Cal_id$=Baddata_id$(7)
754      GOSUB Flagbaddata
756  END IF
758  Adjust(Fcount,6)=Pad_loss
760  !
762  Get_cal_value(Frequency,Padf_loss,Pad_f5530(*),Baddata,Padf_pts)
764  IF Baddata THEN
766      Cal_id$=Baddata_id$(8)
768      GOSUB Flagbaddata
770  !
772  Adjust(Fcount,7)=Padf_loss
774  !
776  Get_cal_value(Frequency,Pada_loss,Pad_a56a(*),Baddata,Pada_pts)
778  IF Baddata THEN
780      Cal_id$=Baddata_id$(9)
782      GOSUB Flagbaddata
784  END IF
786  Adjust(Fcount,8)=Pada_loss
788  !
790  Get_cal_value(Frequency,Nswc_loss,Nswc(*),Baddata,Nswc_pts)
792  IF Baddata THEN
794      Cal_id$=Baddata_id$(10)
796      GOSUB Flagbaddata
798  END IF
800  Adjust(Fcount,9)=Nswc_loss
802  !
804      Fcount=Fcount+1
806  NEXT Frequency
808  GOSUB Printcalvalues
810  RETURN
812  !
814  ! //////////////////////////////////////////////////////////////////****FLAG BAD DATA****///////////////////////////////////////////////
816  !
818  Flagbaddata:   !Inform the operator that there is wrong data
PRINT "FREQUENCY COUPLER ----- BLUE CABLES -----";
PRINT "MHZ INC REF 6FT#1 6FT#6 4FT 10FT";
PRINT "PAD PAD PAD PAD CBL";
PRINT USING Lossfmt1;Frequenc,Fcount,Fcount,Fcount,Fcount,Fcount;
PRINT USING Lossfmt2;C4_loss,C10_loss,Pad_loss,Padf_loss,Pada_loss;
PRINT USING Lossfmt3;Nswc_loss;
Fcount=Fcount+1
NEXT Frequency
PRINT
PRINT "PERFORM MEASUREMENTS"******
Do_measurements:

F'RUN1ER IS 1

Fcount=1

Dbm=Low_dbm !Initialize the Generator Level
Frequency=Startf !Initialize first frequency.

! BEEP

INPUT "ENTER THE RANGE SET ON THE 1 cm DIPOLE AMPLIFIER",Picm_scale

Picm_scale=1

InitializeMotor(@Motor)

ZeroMotor(@Motor)

!

REPEAT

! Initial values and zeroing

! Calibration data for all cables, probes, & power heads.

Pwrmtcal1=FNFWrmtrcal1((Frequency)) !18 GHz HEAD.
Pwrmtcal2=FNFWrmtrcal2((Frequency)) !26 GHz HEAD.

Couplnc=Adjust(Fcount,1) !Coupler incident
Couplref1=Adjust(Fcount,2) !Coupler reflected
C6a_loss=Adjust(Fcount,3) !6 foot BLUE cable #1
C6b_loss=Adjust(Fcount,4) !6 foot BLUE cable #6 rcvr.
C4_loss=Adjust(Fcount,5) !4 foot BLUE cable
C10_loss=Adjust(Fcount,6) !10 foot BLUE cable
Pad_loss=Adjust(Fcount,7) !Weinschel S6770 10dB pad
Pdfl_loss=Adjust(Fcount,8) !Weinschel F5530 10dB pad
Pad2_loss=Adjust(Fcount,9) !Weinschel AB6A-1466 10dB

Nswe_loss=Adjust(Fcount,10) !NSWC input cable

Dvm1_sams=Dvm_samples !The measurement will be attempted at
Dvm2_sams=Dvm_samples !the predicted number of samples first.

Failflag=0

Restart: !Any failure on this measurement causes branch to here.

Set_dbm(-140,Rf_on_off,@Sig_gen)

Set_freq(Frequency,@Sig_gen)

InitializeMotor(@Motor)

!

Disp Chr\$(12)

!

Setdcv3456a(@Dvm1)
Readvm(Eut_zero,@Dvm1)
Setdcv3456a(@Dvm2)
Readvm(Picm_zero,@Dvm2)

Setdvm_3456a(@Dvm1,Dvm_integrat#,Dvm1_sams)
Setdvm_3456a(@Dvm2,Dvm_integrat#,Dvm2_sams)
Setdvm_3478a(@Dvm3)

Spec_alzr_setup(@Spectrum)

!

Zero_pwr_mtrs(@Fwr1,@Fwr2)

!

Ab$="AB"

CALL Zero_438a(@Dual_pwr1,Ab$)

!

IF NOT Failflag THEN

Dbm=Low_dbm
Movemotor(@Motor)
PRINT CHR$(12)
PRINT TABXY(1,3); TIME$(TIMEDATE); "***************"
PRINT "FREQUENCY" "MHz. " **************
PRINT TABXY(1,5); "FINDING THRESHOLD VALUE dBm=
PRINT TABXY(36,5); " Average EUT RESPONSE="
LOOP
  Set_dbm(Dbm,Rf_on_off,@Sig_gen)
  Vave=0.
  FOR Sams=1 TO 30
    Readdvm_3478a(@Dvm3,V)
    V=V-P1cn_zero
    Vave=Vave+V
  NEXT Sams
  Vave=Vave/40
  Print using "50"; Dbm
  PRINT USING "30.80"; Vave
  EXIT IF Vave>=Thresh_or(Db);=High_dbm
  Dbm=Dbm+Step_dbm
END LOOP
Stop_motor(@Motor)
ELSE
  Set_dbm(Dbm,Rf_on_off,@Sig_gen)
END IF
Failflag=1
! Trigger measurement ........................................
! DISP CHR$(12)
! Restart_point2: !
Ab$="AB"
CALL Read_dual_pwr(Ab$,Apower,Bpower,Too_hot,Valid,@Dual_pwr1)
IF Too_hot THEN
  GOSUB Reduce_power
  ! GOTO Restart_point2
END IF
IF NOT Valid AND NOT Too_hot THEN GOSUB Dual_pwr_error
IF Apower<0. THEN Apower=0.
IF Bpower<0. THEN Bpower=0.
Incpwr_raw=Apower
Refpwr_raw=Bpower
! ....Sequence for reading 436a Power meters...............  
! Pwr_id$="P1"
! Read_pwr_meter(Power,Pwr_id$,Valid,@Pwr1,@Sig_gen)
! IF NOT Valid THEN
!  DISP "ERROR IN 436a POWER METER 1"
! BEEP
! FAUSE
! END IF
! Incpwr=Incpwr_raw
! Refpwr=Refpwr_raw*Coupinc*Pwrnin/(C6b_loss) !Inc power at ANT
! Refpwr=Refpwr_raw*Couprefl*Pwrnin/(C6b_loss) !Ref pwr at ANT
! Netpower=(Incpwr-Refpwr)
! PRINT TIME$(TIMEDATE);
PRINT "**** START NEW MEASUREMENT AT FREQUENCY = ";Frequency
ON INTR 7 GOSUB Check_dvm_done
ENABLE INTR 7;2
MoveMotor(@Motor)
IF Bug1 THEN PRINT "DVM1 trigger ";TIME$(TIMEDATE);" ";
Trig1_time=TIMEDATE
Trigger_3456a(@Dvm1)
IF Bug1 THEN PRINT "DVM2 trigger ";TIME$(TIMEDATE);" ";
Trig2_time=TIMEDATE
Trigger_3456a(@Dvm2)
Spec_alr_start(Frequency,@Spectrum)
IF Bug1 THEN PRINT "TRIGGER ANALYZER ";TIME$(TIMEDATE)
Read1flag=0
Read2flag=0
Vpeak=0
LOOP
  Readdvm_3478a(@Dvm3,V)
  V=V-Ptc_m_zero
  IF V>Upperlimit THEN
    Stop_motor(@Motor)
  REPEAT
    Dbm=Dbm-Step_dbm
    Set_dbm(Dbm,Rf_on_off,@Sig_gen)
    WAIT Slow_down
    Readdvm_3478a(@Dvm3,V)
    V=V-Ptc_m_zero
    BEEP
    PRINT "EUT MAXIMUM EXCEEDED **** POWER DECREASED TO ",
    PRINT Dbm;" dBm."
  UNTIL V<Upperlimit
  OFF INTR 7
  GOTO Restart
END IF
CheckMotor(@Motor,Movingflag)
IF NOT Movingflag THEN
  PRINT "MOTOR NOT MOVING********DATA BAD"
  GOTO Restart
END IF
IF V>Vpeak THEN Vpeak=V
Countdown=Rev_time-(TIMEDATE-Trig1_time)
IMAGE M4D.D," Seconds left, EUT mV="M6D.2D," / ",M6D.2D," 
DISP USING Spy;Countdown,V*1000,Vpeak*1000
EXIT IF Read1flag AND Read2flag
EXIT IF Read1flag AND Read2flag
END LOOP
!=======================================================
! Make sure that the correct voltmeters are connected for this test!
! IF (Vpeak+Eut_zero) >High2 THEN High2=Vpeak+Eut_zero
!=======================================================
OFF INTR 7
Failflag=0
!
! Insure successful (synchronized tuner and dvms) measurement.
!
IF (Read1_time<.98*Rev_time) OR (Read1_time>1.02*Rev_time) THEN
  Dvm1_sams=INT((Rev_time/Read1_time)*Dvm1_sams)
  PRINT "Dvm 1 NOT synchronized with TUNER REVOLUTION. ";
  PRINT "Changing samples to ";Dvm1_sams
  Failflag=1
END IF
!
IF (Read2_time<.98*Rev_time) OR (Read2_time>1.02*Rev_time) THEN
  Dvm2_sams=INT((Rev_time/Read2_time)*Dvm2_sams)
PRINT "Dvm 2 NOT synchorized with TUNER REVOLUTION. ";
PRINT "Changing samples to ";Dvm2_sams
Failflag=1
END IF
IF Failflag THEN
Stop_motor(@Motor)
GOTO Restart
END IF
Spec_alzr_read(Power,Frequency,@Spectrum)
PRINT "SPECTRUM ANALYZER READS ";Power;" AT FREQUENCY ";Frequency
Stop_motor(@Motor)
Set_dbm(-140,Rf_on_off,@Sig_gen)
!
GOSUB Process_data
GOSUB Print_alldata
!
Frequency=Frequency+Stepf
Fcount=Fcount+1
UNTIL Frequency>Stopf
Set_dbm(-140,0,@Sig_gen)
! GOSUB Save_data
RETURN
Freq=";FreqLlency;
GENERATOR LEVEL =";Dbm
////////////////////////////////////////////////////////////
Dual-pwr_error: 
Set_dbm(-140,0,@Sig_gen)
IF Printflag THEN
PRINTER IS Printer
PRINT TIME$(TIMEDATE); ": Freq=";Frequency;
PRINT RPT$(*",10);" ERROR IN DUAL POWER METER !!!!"
END IF
RETURN
CHECK DVM DONE: 
Enter an INTERRUPT on the HPIB generated by one of
two HP3456a DVMs. Meaning that the data is ready.
Ser_poll=SPOLL(@Dvm1)
ENABLE INTR 7
IF Ser_poll=66 THEN
Read1_time=TIMEDATE-Trig1_time
IF Bug1 THEN PRINT "DVM1 total sample time = ";Read1_time;" ";
IF Bug1 THEN PRINT TIME$(TIMEDATE)
1420
1422
1424
1426
1428
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! Since the output of the detector is negative, Low and High are ! swapped.
Read_dvm_stat(@Dvm1, High1, Low1, Mean1, Var1, Sam1) ! Low and High swapped!

Low1=-1*Low1  ! Crystal detector has negative output
High1=-1*High1
Mean1=-1*Mean1

PRINT " DVM 1===",Low1,High1,Mean1,Var1,Sam1
Read1flag=1
END IF
Ser_poll=SFOLL(@Dvm2)
ENABLE INTR 7
IF Ser_poll=66 THEN
Read2_time=TIMEDATE-Trig2_time
IF Bug1 THEN PRINT "DVM2 total sample time = ";Read2_time;" ";
IF Bug1 THEN PRINT TIME$(TIMEDATE)
Read_dvm_stat(@Dvm2, Low2, High2, Mean2, Var2, Sam2)
PRINT " DVM 2===",Low2,High2,Mean2,Var2,Sam2
Read2flag=1
END IF
RETURN
Process_data:
! Calculations for power read from spectrum analyzer.
Power= (.001)*10^(Power/10.) ! Convert dBm to watts.
Cor_power=Power*C10_loss*C6a_loss*Pada_loss

Norm_pwr=SQR(10/Ref_pwr_den)
Normal_pwr=37 dB V/m
Ref_pwr_den=(.4*PI*Frequency*Frequency*Cor_power)/9.0E+4
Normal_field=(((10.0^37/20))/Ref_e_field)

! Calculations for CRYSTAL detector with 6 ft cable.
Cor_high1=(High1-Eut_zero)
Cor_mean1=(Mean1-Eut_zero)
IF Cor_high1<1.0E-50 THEN Cor_high1=1.0E-50
IF Cor_mean1<1.0E-50 THEN Cor_mean1=1.0E-50

IF Cor_high1<.1 THEN
Cor_high1=.00304939*Cor_high1/(1.1195) ! Convert to WATTS
ELSE
Cor_high1=.0135056*Cor_high1^(1.7488) ! Convert to WATTS
END IF

Cor_high1=Cor_high1*C10_loss
1540 Cor_high1=Cor_high1*Normal_pwr*Normal_pwr
1542 Cor_high1=10*LGT(Cor_high1/1.0E-3) !Convert to dBm
1544 !
1546 IF Cor_mean1=1. THEN
1548 Cor_mean1=0.0004939*Cor_mean1^((1.1195)) !Convert to WATTS
1550 ELSE
1552 Cor_mean1=.0135056*Cor_mean1^((1.7488)) !Convert to WATTS
1554 END IF
1556 !
1558 Cor_mean1=Cor_mean1*C10_loss
1560 Cor_mean1=Cor_mean1*Normal_pwr*Normal_pwr
1562 Cor_mean1=10*LGT(Cor_mean1/1.0E-3) !Convert to dBm
1564 !
1566 !Calculations for 1 cm DIPOLE with super amp.!
1568 !
1570 Cor_high2=(High2-F1cm_zero)
1572 Return_field(Cor_high2,F1cm fld_high)
1574 F1cm fld_high=F1cm fld_high*Normal fld
1576 New_volts(F1cm fld_high,Cor_high2)
1578 !
1580 Cor_mean2=(Mean2-F1cm_zero)
1582 Return_field(Cor_mean2,F1cm fld_mean)
1584 F1cm fld_mean=F1cm fld_mean*Normal fld
1586 New_volts(F1cm fld_mean,Cor_mean2)
1588 !
1590 IF Cor_high2<1.0E-50 THEN Cor_high2=1.0E-50
1592 IF Cor_mean2<1.0E-50 THEN Cor_mean2=1.0E-50
1594 Cor_high2=20*LGT(Cor_high2*1000) !dB mV
1596 Cor_mean2=20*LGT(Cor_mean2*1000) !dB mV
1598 !
1600 Savedata(Fcount,1)=Frequency !MHz
1602 Savedata(Fcount,2)=Netpower !Watts
1604 Savedata(Fcount,3)=Ref_e_field !V/m
1606 Savedata(Fcount,4)=Cor_high1 !dBm
1608 Savedata(Fcount,5)=Cor_mean1 !dBm
1610 Savedata(Fcount,6)=Cor_high2 !dB mV
1612 Savedata(Fcount,7)=Cor_mean2 !dB mV
1614 !
1616 RETURN
1618 !
1620 !\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\

134
1660 PRINT USING Spyraw2;High1*1000,Mean1*1000
1662 PRINT
1664 PRINT "1 cm PRB ZERO  1 cm PRB PEAK  1 cm PRB MEAN  Signal Gen Level"
1666 PRINT " mV  mV  mV  dBm"
1670 Spyraw3:IMAGE 6D.2D,6X,7D.2D,6X,7D.2D,10X,5D
1672 PRINT USING Spyraw3;P1cm_zero*1000,High2*1000,Mean2*1000,Dbm
1674 PRINT
1676 PRINT "PROCESSED DATA:"
1678 PRINT "HORN normalized to 10 mW/cm², 1 cm DIPOLE normalized to 37";
1680 PRINT "  db V/m."
1682 PRINT "NET INPUT POWER  NET REF INPUT POWER"
1684 PRINT "HORN PEAK     HORN MEAN"
1686 PRINT "dbm     Watts mW/cm²  V/m"
1688 Spyraw6:IMAGE MD.4DE,5X,M4D.2D,3X,#
1690 PRINT USING Spyraw6;Cor_power,Cor_high1
1692 PRINT USING Spyraw7;Cor_mean1,Cor_high2,Cor_mean2
1694 PRINT "Field V/m     Field V/m"
1696 Spyraw8:IMAGE X,M4D.2D,10X,MD.4DE,6X,M2D.4D,5X,M4D.4D
1700 PRINT "Field V/m     Field V/m"
1702 PRINT "HORN PEAK     HORN MEAN"
1704 PRINT "Watts mW/cm²  V/m"
1706 PRINT "dbm     Watts mW/cm²  V/m"
1708 Spyraw8:IMAGE X,M4D.2D,10X,MD.4DE,6X,M2D.4D,5X,M4D.4D
1710 PRINT "Watts mW/cm²  V/m"
1712 PRINT "REC PWR CORR. NET INPUT POWER  NET REF PWR DENSITY  REF FIELD"
1714 PRINT "Watts mW/cm²  V/m"
1716 PRINT "Watts mW/cm²  V/m"
1718 Spyraw8:IMAGE X,M4D.2D,10X,MD.4DE,6X,M2D.4D,5X,M4D.4D
1720 POWER_dbm=10*LOG10(COR_power)
1722 PRINT USING Spyraw8;Power_dbm,Netpower,Ref_pwr_den,Ref_field
1724 PRINT "CHRS/NUMS ONLY) "
1726 PRINT "FILE NAME FOR THIS DATA"
1728 PRINT "FILE NAME FOR THIS DATA"
1730 PRINT "FILE NAME FOR THIS DATA"
1732 PRINT "FILE NAME FOR THIS DATA"
1734 PRINT "FILE NAME FOR THIS DATA"
1736 PRINT "FILE NAME FOR THIS DATA"
1738 PRINT "FILE NAME FOR THIS DATA"
1740 PRINT "FILE NAME FOR THIS DATA"
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1768 PRINT "FILE NAME FOR THIS DATA"
1770 PRINT "FILE NAME FOR THIS DATA"
1772 PRINT "FILE NAME FOR THIS DATA"
1774 PRINT "FILE NAME FOR THIS DATA"
1776 PRINT "FILE NAME FOR THIS DATA"
1778 PRINT "FILE NAME FOR THIS DATA"
SUB Measure_menu

!This routine will facilitate setting up the
!measurement.

DIM Eut_identity$[160], Operator_name$[60]

PRINTER IS 1
Wipe_clean
!Clear the CRT.

!Define the choices at start-up.

Operator_name$="Mike Crawford"

Startf=2000
Stopf=4000
Stepf=200
!
Low_dbm=-30
High_dbm=-10
Step_dbm=1
!
Eut_identity$="Evaluate use of NSWC Reverberating Chamber"
Eut_identity$=Eut_identity$~(lfor
measuring response of EUT."
Threshold=50.0
Upperlimit=1200.0
Slow_down=.02
!
Jog_wait=10
!
Coupler_id$="HP_11692D"
Generator_id$="HP_8672A"
!
PRINT CHR$(129)
PRINT TABXY(16,1);" MEASUREMENT PARAMETERS FOR MODE STIRRED TESTS."
PRINT TABXY(1,3);" TEST DESCRIPTION:"
PRINT TABXY(1,7);" FREQUENCY RANGE "
PRINT TABXY(30,7);"TO"
PRINT TABXY(42,7);"STEP"
PRINT TABXY(56,7);"MHz."
PRINT TABXY(1,9);" SIG-GEN RANGE "
1900 PRINT TABXY(22,9);"TO"
1902 PRINT TABXY(29,9);"/
1904 PRINT TABXY(37,9);"dBm."
1906 PRINT TABXY(44,9);" EUT RESPONSE TIME"
1908 PRINT TABXY(70,9);"Sec."
1910 PRINT TABXY(45,11);" EUT LOWER THRESHOLD RESPONSE mV"
1912 PRINT TABXY(1,11);"EST. TIME/Tuner rev"
1914 PRINT TABXY(33,13);" DVM SAMPLES"
1916 PRINT TABXY(53,13);"LINE CYCLES/SAMPLE"
1918 PRINT TABXY(40,15);"COUPLER/SIG GEN"
1920 PRINT TABXY(70,15);" DATE/TIME"
1922 PRINT TABXY(45,17);"FAIL LIMIT mV"
1924 PRINT TABXY(1,17);"OPERATOR'S NAME"
1926 PRINT CHR$(128)
1928 !Fill in the default choices.
1930 !Make any changes or corrections.
1932 !
1934 GOSUB Print_eutid
1936 GOSUB Print_freqs
1938 GOSUB Print_gen_level
1940 GOSUB Print_eufail
1942 GOSUB Print_slowdown
1944 GOSUB Print_thresh
1946 GOSUB Print_tuner
1948 GOSUB Print_name
1950 !
1952 !
1954 !
1956 OFF KEY
1958 ON KEY 0 LABEL "TEST ID",5 GOSUB Change_eutid
1960 ON KEY 1 LABEL "Frequency",5 GOSUB Change_freqs
1962 ON KEY 2 LABEL "GEN Levels ",5 GOSUB Change_levels
1964 ON KEY 3 LABEL "THRESHOLD",5 GOSUB Change_thresh
1966 ON KEY 4 LABEL "FAIL LIMIT",5 GOSUB Change_eufail
1968 ON KEY 8 LABEL "TUNER REV's",5 GOSUB Change_tuner
1970 ON KEY 5 LABEL "CONTINUE",5 GOSUB Exit_sub
1972 ON KEY 6 LABEL "YOUR NAME",5 GOSUB Enter_name
1974 ON KEY 7 LABEL "RESPONSE tm",5 GOSUB Change_respond
1976 ON KEY 9 LABEL "TUNER REV's",5 GOSUB Change_tuner
1978 ON KEY 5 LABEL "CONTINUE",5 GOSUB Exit_sub
1980 ON KEY 9 LABEL " DATE ",5 CALL Time_date
1982 BEEP
1984 PRINT TABXY(14,15);DATE$(TIMEDATE)
1986 Spin:
1988 DISP "<<<<<<<<<<< SELECT PARAMETER TO CHANGE >>>>>>>>>>>>>"
1990 PRINT TABXY(29,15);TIME$(TIMEDATE)
1992 GOTO Spin
1994 Exit_sub:
1996 Upperlimit=Upperlimit/1000!Convert to volts
1998 Threshold=Threshold/1000!Convert to volts
2000 OFF KEY
2002 DISP CHR$(12)
2004 PRINTER IS Printer
2006 IF Printer=70 THEN DUMP ALPHA
2008 CALL Wipe_clean
2010 SUBEXIT
2012 !
2014 !
2016 !
2018 Change_tuner: !
2020 Jog_wait=Jog_wait+1
2022 Print_tuner: !
2024 Rev_time=38.37068*Jog_wait+4.92406
2026 !
2028 Dvm_samples=INT(1.15*(38.9729+23.60383*(Rev_time))) ! .1 cycle
2030 Dvm_integrat$="1"
2032 !
2034 IF Dvm_samples>9999 THEN
2036 Dvm_samples=INT(1.15*(3.970658+12.8621757*(Rev_time))) ! .1 cycle
2038 Dvm_integrat$="1"
2040 END IF
2042 IF Dvm_samples>9999 THEN
2044 Jog_wait=0
2046 GOTO Change_tuner
2048 END IF
2050 Hh=Rev_time DIV 3600
2052 Mm=(Rev_time-Hh*3600) DIV 60
2054 Ss=INT(Rev_time-Hh*3600) MOD 60
2056 PRINT TABXY(23,13);
2058 PRINT USING "DD,A,ZZ,A,ZZ";Hh,"":Mm,"";Ss
2060 PRINT TABXY(47,13);Dvm_samples
2062 PRINT TABXY(74,13);
2064 PRINT TABXY(74,13);Dvm_integrat$
2066 RETURN
2068 !
2070 !
2072 !
2074 Change_eutid: !
2076 DISP "DESCRIPTION of the EUT and PURPOSE for test?? (<2 lines)"
2078 OUTPUT 2 USING "K,#";Eut_identity$
2080 LINPUT Eut_identity$
2082 !
2084 PRINT_eutid: !
2086 PRINT TABXY(1,4);RPTS(" ",160)
2088 PRINT TABXY(1,4);Eut_identity$
2090 RETURN
2092 !
2094 !
2096 Change_freqs: !
2098 DISP "ENTER the START, STOP, and STEP frequencies (MHz) "
2100 INPUT Startf,Stopf,Stepf
2102 IF Startf<100 THEN Startf=100
2104 IF Startf>18000 THEN Startf=18000
2106 SELECT Startf
2108 CASE <2000
2110 IF Stopf>2000 THEN Stopf=2000
2112 Coupler_id$="HP_778D"
2114 Generator_id$="HP_8660A"
2116 CASE >=2000
2118 IF Stopf>18000 THEN Stopf=18000
2120 Coupler_id$="HP_11692D"
2122 Generator_id$="HP_8672A"
2124 END SELECT
2126 PRINT_freqs: !
2128 PRINT TABXY(21,7);
2130 PRINT USING "5D.2D";Startf
2132 PRINT TABXY(33,7);
2134 PRINT USING "5D.2D";Stopf
2136 PRINT TABXY(47,7);
2138 PRINT USING "5D.2D";Stepf

138
2140 PRINT TABXY(58,15);RF'T(" ",10)
2141 PRINT TABXY(69,15);RF'T(" ",10)
2142 PRINT TABXY(58,15);Coupler_id$
2143 PRINT TABXY(69,15);Generator_id$
2144 RETURN
2145
2146 !________________________________________________________________________________________________________________________________________________________________
2147 !
2148 ! Change_levels: !
2149 DISF' "ENTER Signal generator LEVEL (dBm) ";
2150 ! INPUT Dbm
2151 ! Low_dbm=INT(Dbm)
2152 DISF "LOW, HIGH, STEP Signal generator LEVEL (dBm) ";
2153 INPUT Low_dbm,High_dbm,Step_dbm
2154 RETURN
2155 !
2156 !////////////////////////////////////////////////////////////
2157 ! Change_eLltfail: !
2158 DISF "ENTER the UPPER LIMIT for the EUT RESPONSE (mV) ";
2159 INPUT Upper_limit
2160 PRINT_eLltfail:
2161 PRINT TABXY(60,11);Upper_limit
2162 RETURN
2163 !
2164 !////////////////////////////////////////////////////////////
2165 ! Change_thresh: !
2166 DISF "LOWER LIMIT EUT RESPONSE for initially setting field. (mV) ";
2167 INPUT Threshold
2168 Print_thresh:
2169 PRINT TABXY(35,11);Threshold
2170 RETURN
2171 !
2172 !////////////////////////////////////////////////////////////
2173 ! Change_respond: !
2174 DISF "WAIT TIME FOR EUT TO RESPOND AFTER FIELD IS SET.");
2175 INPUT Slow_down
2176 Print_slowdown:
2177 PRINT TABXY(64,9);RFT(" ",6)
2178 PRINT TABXY(64,9);Fast_down
2179 RETURN
2180 !
2181 !////////////////////////////////////////////////////////////
2182 ! Enter_name: !
2183 DISF "PLEASE TYPE IN YOUR NAME ";
2184 ! INPUT Operator_name$
2185 Print_name:
2186 PRINT TABXY(20,17);Clear_opname$
2187 PRINT TABXY(20,17);Operator_name$
2188 RETURN
2189 !
2190 ! SUBEND
2191 !-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
2192 !
**4. TITLE AND SUBTITLE**

Design, Evaluation, and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements

**5. AUTHOR(S)**

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**11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)**

This report presents the results of work at the National Bureau of Standards, Boulder, Colorado, to carefully evaluate, document, develop (when necessary), and describe the methodology for performing radiated susceptibility/vulnerability measurements using a reverberation chamber. The report describes the reverberation chamber theory of operation, construction, evaluation, functional operation, and use for performing immunity measurements. It includes an estimate of measurement uncertainties derived empirically from test results and from comparisons with anechoic chamber measurements. Finally, it discusses the limitations and advantages of the measurement technique to assist potential users in determining the applicability for this technique to their electromagnetic compatibility (EMC) measurement needs.

**12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)**

electromagnetic susceptibility/vulnerability; estimated uncertainty; evaluation; measurement procedures; reverberation chamber

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