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A RADIAL TRANSMISSION LINE MATERIAL MEASUREMENT APPARATUS

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ABSTRACT

A radial transmission line material measurement apparatus has been proposed, analyzed, designed, constructed, and tested. The purpose of the apparatus is to obtain accurate surface impedance measurements of lossy, possibly anisotropic, samples at low and intermediate frequencies (VHF and low UHF). The samples typically take the form of sections of the material coatings on conducting objects. Such measurements thus provide the key input data for predictive numerical scattering codes. Prediction of the sample surface impedance from the coaxial input impedance measurement is carried out by two techniques. The first is an analytical model for the coaxial-to-radial transmission line junction. The second is an empirical determination of the bilinear transformation model of the junction by the measurement of three full standards. The standards take the form of three offset shorts (and an additional lossy Salisbury load), which have also been constructed. The accuracy achievable with the device appears to be near one percent.

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SUMMARY

Surface impedance is a fundamental quantity in characterizing, coatings on conducting objects. This quantity is often the necessary input parameter for numerical scattering codes. However, the measurement of surface impedance, using standard microwave measurement techniques, is often difficult. For example, the materials are often too lossy to use resonant material measurement techniques. Alternatively, standard nonresonant impedance techniques typically use inconvenient sample shapes, such as coaxial sample holders. Furthermore, the materials could be anisotropic, confounding the interpretation of results when such sample holders are used.

This report introduces a different type of sample holder, which exhibits several advantages for this type of measurement. The concept is to use a junction of coaxial and radial transmission lines. The measurements are performed at the coaxial port, while the sample is placed in the radial port. Typically a sample, in the form of a coating material, would be placed around the circumference of the radial transmission line against a terminating short circuit. Measurement of the coaxial input impedance can then be used to infer the surface impedance at the surface of the sample.

The advantages of such a sample holder are: the technique can measure lossy samples, the incident wave is linearly polarized and normally incident allowing anisotropic samples to be measured, there is no low frequency cutoff, convenient sample shapes are used (for certain applications), and relatively simple coaxial cable to sample holder transformations are available.

Practical considerations along with sensitivity calculations are used to choose a set of dimensions for the apparatus. For example, use of a standard 7 mm coaxial connector dictates the dimensions of the coaxial port. Reasonable sample size and higher order radial mode cutoff constraints were used to choose the dimensions of the radial port. A design to obtain highly idealized junction geometry, but using commercially available 7 mm air lines,

refined the radial port dimensions. Sensitivity analyses confirmed that these dimensions were compatible with the desired electrical design of the device (yield reasonably good accuracies with the types of load impedances envisioned).

The model for the coaxial-to-radial transmission line junction is a bilinear transformation. Accurate analytical approximate solutions for this idealized junction exist. These approximations typically assume a radial electric field at the end of the coax which varies inversely with radial distance. However, a correction to this approximation exists, and its small magnitude provides convincing evidence of the accuracy of the analytical model. An alternative empirical approach has been used to determine the bilinear transformation model. This approach makes use of three full standards with the same junction geometry as the sample holder. If there were deviations of the junction from idealized geometry this approach would include the effect if the standards were constructed identical to the sample holder. In any event, a comparison of this empirical approach with the analytical approach indicates the accuracy of the junction model.

The analytical model of the coaxial-to-radial junction was used to carry out a sensitivity analysis of the device. It was found that for typical maximum expected uncertainties in the measured reflection coefficient, uncertainties in the inferred sample surface impedance were acceptably small.

Sample holders and four standards were constructed. Drawings of the hardware are included in the report. Three of the standards are offset shorts (terminating shorts in the radial transmission line occur at different radial locations). A fourth standard was a Salisbury load. The Salisbury load provides an alternative lossy standard. The Salisbury load was constructed by placing a cylindrical resistive sheet at the sample radius, with an offset short terminating the radial transmission line. A step height discontinuity was placed at the sample radius to allow mounting of the resistive sheet. Analysis of the expected surface impedance for both the offset shorts and the Salisbury load (including step height discontinuity) were carried out. Radial slots were cut in the radial transmission line top and

bottom cover plates of both the Salisbury load and the largest offset short, for suppression of higher order circumferential modes.

Software was written for a Hewlett Packard QS/20 Vectra computer to allow automated measurements on a Hewlett Packard model 8753C vector automatic network analyzer. The computer and network analyzer were procured. Descriptions of the instrumentation and the software are given in the report. A listing of the software is included.

The Salisbury load was used as a canonical test sample; the measured surface impedance was thus compared with its "known" value. When the resistive sheet was removed from the Salisbury load, the measured results for the surface impedance agreed with the expected results to within one percent. Unfortunately, several iterations were needed with the resistive sheet present. At first, contact problems prevented a DC calibration measurement of the resistive sheet impedance. Contact problems are thought to have caused problems with the dynamic measurements as well. The final iteration used an elastically stressed plastic tape to secure the resistive sheet to the step discontinuity in the Salisbury load. Furthermore, vapor deposited gold edges were incorporated on the resistive sheet to allow repeatable DC calibration measurements to be made. Note that, because of 50% variations in this DC calibration measurement, a dozen such resistive sheets were treated in this way, and three (each covering 120° of circumference) with relatively close (7%) resistance values were chosen to be inserted into the Salisbury load. The final measured results were within seven percent of the expected surface impedance results. But, more importantly, the analytical junction model and the empirical junction model (based on the three offset shorts) yielded results within one percent of each other in all cases. It is thought that this is the achievable accuracy of the device if an ideally seated, uniform, sample is used. The Salisbury load is not yet suitable for use as a standard because of the remaining uncertainty in its surface impedance value. However, measurements of the Salisbury load do indicate that reasonably accurate measurements of lossy samples (even with uniformity and

possible contact concerns remaining) can be made.

In conclusion we believe the radial transmission line measurement apparatus is capable of yielding surface impedance measurements with accuracies approaching one percent. A complete system, including sample holders, offset short standards, measurement software and instrumentation, is available to make surface impedance measurements on lossy, possibly anisotropic samples in the frequency range of 50 to 250 MHz (the sample holder and analytical junction model can be used perhaps up to 500 MHz). This frequency range can be extended at least to 1 GHz by reducing the size of the offset shorts and sample holder. Future work should include considerations of an alternative, more accurate, lossy reference standard design.

I. INTRODUCTION

Standard microwave material measurement techniques fall into two general categories: resonant techniques and nonresonant impedance techniques.

Resonant techniques typically involve the insertion of a small sample of material into a resonant cavity and subsequent measurement of the change in cavity quality factor and resonant frequency. Next, either cavity perturbation theory or, in special geometries, exact field descriptions of the cavity-sample geometry are used to infer the sample electrical properties. However, if the sample is sufficiently lossy, the determination of the resonant properties of the cavity becomes difficult as well as inaccurate.

Nonresonant impedance techniques involve the measurement of the impedance properties of a sample holder containing the sample. A field description of the sample holder (with sample) is then used to infer the sample electrical properties. The most common sample holder is the coaxial sample holder. However, in cases where the samples are anisotropic, use of such a sample holder yields some combination of elements of the tensor electrical properties of the sample. Furthermore, for certain sample types such as thin layers or coatings, the coaxial sample geometry may be inconvenient and in addition force such large deformations of the sample from its intended geometry that the results become questionable. Impedance measurements may of course also be performed on other sample holders, such as rectangular waveguides. However, drawbacks still exist such as: the transformation from coaxial cable to rectangular waveguide is far from simple, the angle of incidence of the exciting waves depend on frequency, and, because of the cutoff frequency of the waveguide, low frequency measurements are either eliminated or require very large waveguide structures and samples. An alternative sample holding structure, which is the subject of this report, has certain advantages, including: no cutoff, normally incident linearly polarized excitation, convenient sample shapes (for certain applications), and relatively simple coaxial cable to sample holder transformations.

A radial transmission line measurement apparatus has been proposed by the authors as a means to obtain accurate surface impedance measurements of very lossy, possibly anisotropic, samples. Figure I.1 shows the geometry of the apparatus. Figure I.2 shows a cross sectional view. The apparatus is rotationally symmetric. The sample lines the outer radial backing conductor as shown in Figure I.2. Measurement of the input impedance at the coaxial port is used to determine the surface impedance of the sample.

Section II discusses the choices of geometrical parameters for the device.

Appendix I reviews the theory of a coaxial to radial transmission line junction when the simple assumption of a radial electric field inversely proportional to the radial distance is placed at the junction. Appendix II reviews a junction capacitance correction which can be incorporated in the model or used to estimate the accuracy of the previous simple assumption of the radial electric field dependence at the junction. Section III gives results for the apparent admittance at the junction as well as the coaxial reflection coefficient.

Section IV uses the theoretical model of the device in addition to estimated maximum errors in the measurement of the reflection coefficient in the coax, to predict uncertainties in the predicted sample surface impedance. These results give a feel for the accuracy achievable by use of the apparatus.

Appendix III reviews the experimental approach of constructing a bilinear transformation model of the apparatus from the measurement of three full (complex) standards. Section V briefly gives the results in the appropriate notation.

Appendix IV reviews the impedance transformation formula in a radial transmission line. Section VI uses this result to determine the offset short impedances at the appropriate radial location.

Section VII discusses a fourth reference standard, the Salisbury load. Appendix V provides a formula for lumped capacitance representing a step discontinuity in the radial line at the location of the impedance sheet load. Appendix VI provides an estimate of the effective impedance of the Salisbury load impedance sheet in the limit of high impedance.

Section VIII discusses the transformation of the sample impedance to different radial reference locations. Appendix VII discusses the detailed philosophy of the application of this transformation. Section IX gives the coaxial impedance transformation required to transform from the coaxial connector to the coaxial to radial transmission line junction.

Section X gives a brief description of the instrumentation layout. Appendix VIII gives mechanical drawings of the apparatus.

Section XI gives a brief description of the computer software for the apparatus. This computer software implements both the theoretical and experimentally determined models of the device. Appendix IX gives listings of the software.

Section XII gives measurements made with the apparatus on the Salisbury load. Appendix X estimates the effect of airgaps at the terminations of the Salisbury load impedance sheet.

Section XIII gives conclusions.

The notation used in Appendices I through IV has been chosen to conform to the source references. The notation in the main text, however, has been modified where necessary so as to be self consistent and to avoid confusion. Harmonic time dependence $e^{j\omega t}$ will be suppressed throughout. (Note that $e^{-i\omega t}$ time dependence was originally used in the theoretical calculations. Rather than replotting the figures of Sections III and IV, minus signs were simply introduced in the labels of the imaginary parts of the impedance and admittance quantities.)

II. CHOICE OF DIMENSIONS

The dimensions chosen for the apparatus, shown in Figure I.1, will now be given and very briefly discussed. The coaxial region is chosen as the standard 50 ohm 7 millimeter airline with inner and outer diameters

$$2a = 0.11970 \text{ inches} \quad (\text{II.1})$$

$$2b = 0.27560 \text{ inches} \quad (\text{II.2})$$

(Note that original considerations involved 50 ohm GR900 airline with $2a = 0.244$ inch and $2b = 0.5625$ inch. When consideration shifted to a 7 mm airline, these dimensions were simply divided by a factor of two. These values were used in the figures of Sections III and IV. Although these dimensions are not identical to the exact values given above, they are very close. It was therefore decided not to replot these figures.)

The radial line dimensions are height h and radius $\rho = c$ at the sample surface. It is desirable to have the higher order modes cutoff in the operating frequency range. The frequency range of interest is below, say, 200 MHz. The higher order modes with variations in the h dimension are cutoff if $h < \lambda/2$ [1]. The higher order circumferential modes are cutoff if the circumference is roughly smaller than a wavelength $2\pi c < \lambda$ [1]. A set of dimensions consistent with these cutoff requirements, which also lead to reasonably sized samples, are

$$h = 1.861 \text{ inches} \quad (\text{II.3})$$

$$c = 4 \text{ inches} \quad (\text{II.4})$$

(Note that original considerations used the value $h = 2$ inches, which was a convenient choice for material sample sizes and also satisfied the cutoff constraints. The figures of Sections III and IV have not been replotted with the final choice of h given above, because the sensitivities of the apparatus will not change in any significant manner as a result of this change.) The height (II.3) results from the use of standard 7 mm airline lengths of 5 cm and 10 cm to form the inner coaxial conductor in the radial transmission line section as shown in Figure II.1. Also included is a 0.1 inch wall thickness so that $h = (9.9771 \text{ cm} - 4.9967 \text{ cm} -$

0.1 inch = 1.861 inch), where 9.9771 cm and 4.9967 cm are the exact lengths of the 10 cm and 5 cm lines, respectively. Note that the choices of height (II.3), and sample radius (II.4), result in considerable decay of the higher order modes, which have variations in the h dimension, from the coaxial-to-radial junction to the sample load. (Higher order modes in a planar parallel plate waveguide, of height two inches, decay by approximately $e^{-2\pi}$ over a four inch length.) This is important because the model for the device assumes the junction and load only interact through the fundamental radial transmission line mode.

Four standard reference fixtures are also required, in addition to the above defined sample measurement fixture. Three of these fixtures are simple offset shorts. Offset short #1 has the same dimensions as the above sample fixture except that a short circuit condition exists at

$$\rho = d = 4 \text{ inches} = c \quad (\text{II.5})$$

rather than the surface of a lossy sample of material. Offset short #2 has the same set of dimensions except that a short circuit condition exists at radius $\rho = d$ where

$$d = 9 \text{ inches} \quad (\text{II.6})$$

Offset short #3 has a short circuit condition at

$$d = 15 \text{ inches} \quad (\text{II.7})$$

We note that the radius (II.6) is near the cutoff radius of the first higher order circumferential mode. Thus offset short #3, with outer radius (II.7), exceeds this limit. This first higher order circumferential mode is supported by circumferential currents as well as the usual radial currents associated with the transmission line mode. Thus to suppress

the circumferential currents associated with this higher order mode, nine radial slots were cut in the top and bottom plates of the radial transmission line from radius (II.6) to radius (II.7).

The fourth reference standard is a Salisbury load depicted in Figure II.2. The purpose of this standard is to provide a known lossy impedance reference in contrast to the three approximately lossless standards. A lossy sheet impedance Z_{sS}

$$Z_{sS} \approx \eta_o \quad (II.8)$$

where $\eta_o = \sqrt{\mu_o/\epsilon_o} \approx 120\pi$ ohms is the impedance of free space, is placed at $\rho = c$. We cannot place a short circuit boundary condition directly behind the lossy sheet because current will then primarily flow on the short. Thus displacement of the short a significant electrical distance behind the sheet is desired. The short is placed at $\rho = d$, given by (II.7). Again radial slots are cut in the walls of the radial transmission line from radial distance (II.6) to (II.7) to suppress the circumferential currents associated with the higher order circumferential modes. The attachment of the lossy impedance sheet at $\rho = c$, is accomplished by placing a step in the height of the radial transmission line at this radius. Thus for $\rho < c$ the height is h given by (II.3), and for $\rho > c$ the height is h'

$$h' = 2.341 \text{ inches} \quad (II.9)$$

This value results from a 0.24 inch wall thickness forming each side of the step transition.

Thin resistive sheets are commercially available with advertised impedance per square values of free space given by (II.8), and 50 ohms. Thus an alternative value to (II.8) is

$$Z_{sS} \approx 50 \text{ ohms} \quad (II.10)$$

The geometries of the sample holder and four reference standards have now been described.

III. THEORY OF COAXIAL TO RADIAL TRANSMISSION LINE JUNCTION

The typical analysis of the coaxial to radial transmission line junction of Figure I.1 leads to a value of the apparent admittance Y at the end of the coaxial line in terms of the surface impedance Z_s at the radial transmission line boundary $\rho = c$. Appendix I gives the relationship between Y and Z_s when the simple inverse radial distance form is assumed for the radial electric field at the coaxial to radial line junction. Appendix II gives an additional small parallel capacitance C_T , which serves to correct the apparent admittance for the true radial electric field distribution at the junction (the effect of this capacitance is typically negligible). From Appendices I and II, this relationship can be written as

$$Y = \frac{A'Z_s + B'}{C'Z_s + D'} E' + F' \quad (\text{III.1})$$

where

$$F' = j B_1 + j B_2 + \left[\frac{2\pi j \gamma_0}{kh\eta_o \ln(b/a)} \right] \frac{H_0^{(2)}(kb)}{H_0^{(2)}(ka)} + j\omega C_T \quad (\text{III.2})$$

$$E' = \left[\frac{2\pi j \gamma_0}{kh\eta_o \ln(b/a)} \right] \quad (\text{III.3})$$

$$D' = \eta_o H_0^{(2)}(ka) \{J_0(ka)Y_0(kc) - J_0(kc)Y_0(ka)\} \quad (\text{III.4})$$

$$C' = j H_0^{(2)}(ka) \{J_0(ka)Y_1(kc) - J_1(kc)Y_0(ka)\} \quad (\text{III.5})$$

$$B' = \eta_o H_0^{(2)}(kc) \{J_0(kb)Y_0(ka) - J_0(ka)Y_0(kb)\} \quad (\text{III.6})$$

$$A' = j H_1^{(2)}(kc) \{J_0(kb)Y_0(ka) - J_0(ka)Y_0(kb)\} \quad (\text{III.7})$$

where $\eta_o = \sqrt{\mu_o/\epsilon_o}$ is the impedance of free space, γ_o is given by (AI.9), B_1 is given by (AI.3), B_2 is given by (AI.4), (AI.5), and (AI.10), and C_T is given by (AII.2) and for 50 ohm coax by (AII.3).

Figures III.1 to III.4 give contour plots of the real and imaginary parts of the apparent admittance Y (the scale is limited to values less than 0.04 Siemens in magnitude) in terms of the real and imaginary parts of Z_s in the range $0 \leq \text{Re}(Z_s) \leq 500$ ohms, -500 ohms $\leq \text{Im}(Z_s) \leq 500$ ohms. These figures give a feel for typical expected variations in the admittance (and reflection coefficient in the 50 ohm coax) with respect to variations in the surface impedance at $\rho = c$. We note that if we had set $C_T = 0$ in these figures, there would be little effect on the graphical results since this term is a small contribution to the admittance. Figures III.5 to III.8 give the corresponding real and imaginary values of the reflection coefficient

$$R = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \quad (\text{III.8})$$

where for the coax

$$Z_0 = 50 \text{ ohms} \quad (\text{III.9})$$

and the input impedance to the radial transmission line at the end of the coax is

$$Z_{\text{in}} = 1/Y \quad (\text{III.10})$$

The desired form of the theory is the inverse of (III.1) which can be written as

$$Z_s = \frac{AZ_{\text{in}} + B}{CZ_{\text{in}} + 1} \quad (\text{III.11})$$

Comparing (III.1), (III.10), and (III.11) we obtain

$$A = (B'E' + F'D')/C' \quad (\text{III.12})$$

$$B = -D'/C' \quad (\text{III.13})$$

$$C = -(A'E' + F'C')/C' \quad (\text{III.14})$$

IV. SENSITIVITY OF THE SURFACE IMPEDANCE TO UNCERTAINTIES IN THE REFLECTION COEFFICIENT

One important consideration before building such an apparatus is: how accurate a value for the surface impedance do we expect to be able to deduce from a measurement of input impedance to the device? The typical way this question is posed is: given an estimated maximum uncertainty ΔR in the measurement of the reflection coefficient R in the coax what is the uncertainty in the value of surface impedance Z_s ?

An estimate of the maximum uncertainty expected in the reflection coefficient was taken to be [2]

$$|\Delta R| = \pm 0.007 \quad (\text{IV.1})$$

$$\arg(\Delta R) = \pm 1 \text{ degree} \quad (\text{IV.2})$$

where (IV.1) are uncertainties in magnitude and (IV.2) represent phase uncertainties. These uncertainty estimates were deduced by assuming the reflection coefficient magnitude had a mid value $|R| = 0.4$ at a frequency of 100 MHz [2]. They were nevertheless used as reasonable values for the entire range of frequencies about 100 MHz as well as the entire range of surface impedances.

An incremental uncertainty analysis was carried out by writing

$$\Delta Z_s \approx \left(\frac{\partial Z_s}{\partial R} \right) \Delta R \quad (\text{IV.3})$$

where it is convenient for current purposes to evaluate the derivative in (IV.3) by finding $\frac{\partial R}{\partial Z_s}$ as a function of Z_s by use of (III.1), (III.8), and (III.10). Given that $R = |R| e^{j \arg(R)}$ we can write for the magnitude uncertainty (IV.1)

$$\Delta R = \pm 0.007 e^{j \arg(R)} \quad (\text{IV.4})$$

or for the phase uncertainty (IV.2)

$$\Delta R \approx \pm j \frac{\pi}{180} R \quad (\text{IV.5})$$

The value (IV.3), for a given value of Z_s , is added to Z_s for each of the values (IV.4) and a line segment is drawn between them. Similarly the value (IV.3), for a given value of Z_s , is added to Z_s for each of the values (IV.5) and a line segment is drawn between them. Figures IV.1 to IV.4 show these line segments at the same frequencies and range of values of Z_s discussed in Section III. These figures thus give a feel for the uncertainties one would

obtain in the surface impedance Z_s given the expected maximum uncertainties in the reflection coefficient (IV.1) and (IV.2).

As a check on this incremental uncertainty analysis, which used the approximate formula (IV.3), an exact uncertainty analysis was also carried out. A given value of Z_s was used to obtain a value of R via (III.1), (III.8), and (III.10). The uncertainties (IV.4) or (IV.5) were added to R and Z_s was determined by means of (III.8) and (III.11). There was essentially no graphical difference in the exact results from the approximate results in Figures IV.1 to IV.4.

V. EXPERIMENTAL APPROACH OF CHARACTERIZING COAXIAL TO RADIAL TRANSMISSION LINE TRANSITION

Appendix III discusses in a general setting the determination of a bilinear transformation model by measuring three full (complex) standards. The appropriate notation here is given by (III.11). Using (AIII.4) to (AIII.8), we can write the A, B, and C parameters of (III.11) as

$$\tilde{A} = (Z_s^{(1)} - Z_s^{(2)})Z_s^{(3)}(Z_{in}^{(2)} - Z_{in}^{(3)}) - (Z_s^{(2)} - Z_s^{(3)})Z_s^{(1)}(Z_{in}^{(1)} - Z_{in}^{(2)}) \quad (V.1)$$

$$\tilde{B} = Z_{in}^{(3)}(Z_{in}^{(1)} - Z_{in}^{(2)})(Z_s^{(2)} - Z_s^{(3)})Z_s^{(1)} - Z_{in}^{(1)}(Z_{in}^{(2)} - Z_{in}^{(3)})(Z_s^{(1)} - Z_s^{(2)})Z_s^{(3)} \quad (V.2)$$

$$\tilde{C} = (Z_{in}^{(2)} - Z_{in}^{(3)})(Z_s^{(1)} - Z_s^{(2)}) - (Z_{in}^{(1)} - Z_{in}^{(2)})(Z_s^{(2)} - Z_s^{(3)}) \quad (V.3)$$

$$\tilde{D} = Z_{\text{in}}^{(3)}(Z_{\text{in}}^{(1)} - Z_{\text{in}}^{(2)})(Z_s^{(2)} - Z_s^{(3)}) - Z_{\text{in}}^{(1)}(Z_{\text{in}}^{(2)} - Z_{\text{in}}^{(3)})(Z_s^{(1)} - Z_s^{(2)}) \quad (\text{V.4})$$

$$A = \tilde{A}/\tilde{D}; B = \tilde{B}/\tilde{D}; C = \tilde{C}/\tilde{D} \quad (\text{V.5})$$

where $Z_{\text{in}}^{(i)}$ are the input impedance measurements of the known standards $Z_s^{(i)}$ at $\rho = c$, the sample surface location. Values for $Z_s^{(i)}$ for the three offset shorts are discussed in the next Section and for the Salisbury load are discussed in Section VII. These values are denoted simply by Z_{sR} (R for reference load impedance) in the next two sections.

VI. REFERENCE OFFSET SHORT STANDARD IMPEDANCES

Three of the standards are reference offset shorts. Short #1 has a short circuit condition at $\rho = d = c$ (II.5) and thus for this reference load

$$Z_{\text{sR}} = 0 \quad (\text{VI.1})$$

Offset shorts #2 and #3 have short circuit conditions placed at $\rho = d$ given by (II.6) and (II.7). Appendix IV discusses the impedance transformations in a radial transmission line. Setting $Z_L = 0$ in (AIV.14), and changing the sign because $Z_{\text{sR}} = -E_z(\rho = c)/H_\varphi(\rho = c)$ (where E_z is the electric field in the h direction and H_φ is the magnetic field in the azimuthal direction) for a wave impinging from $\rho < c$, gives

$$Z_{\text{sR}} = -Z_0(kc) j \sin[\theta(kc) - \theta(kd)]/\cos[\psi(kc) - \theta(kd)] \quad (\text{VI.2})$$

where the radial line characteristic impedance is a function of $k\rho$

$$Z_0(k\rho) = \eta_0 \frac{G_0(k\rho)}{G_1(k\rho)} \quad (\text{VI.3})$$

and we define the real functions G_0 , G_1 , θ , and ψ by means of

$$H_0^{(2)}(x) = J_0(x) - j Y_0(x) = G_0(x) e^{-j\theta(x)} \quad (\text{VI.4})$$

$$j H_1^{(2)}(x) = Y_1(x) + j J_1(x) = -G_1(x) e^{-j\psi(x)} \quad (\text{VI.5})$$

Formula (VI.2) provides the offset short standard surface impedance at the $\rho = c$ reference location.

VII. SALISBURY LOAD STANDARD IMPEDANCE

The fourth standard, a Salisbury load, is shown in Figure II.2. A load impedance sheet with impedance per square Z_{sS} , given by (II.8) or (II.10), is placed at $\rho = c$ and an offset short is placed at $\rho = d$, given by (II.7). However there is a step discontinuity in the height of the radial guide at $\rho = c$ from h , given by (II.3), to h' , given by (II.9). Let us denote by Z'_{sR} the value determined from (VI.2) for $\rho = c + 0$. Let us also denote by Z_{sR} the value of the wave impedance for $\rho = c - 0$. Continuity of the voltage $V = -E_z h$ (or $V = -E'_z h'$) and current $I = 2\pi\rho H_\varphi$ (ignoring for the moment the parasitic capacitance associated with the junction) means that the effective wave impedance can be continued across the junction as

$$Z_{sR} = \frac{h'}{h} Z'_{sR} \quad (\text{VII.1})$$

An added capacitance associated with the junction is determined from conformal

mapping in Appendix V. This capacitance, from (AV.26), is

$$\Delta C_{\text{tot}} = c\epsilon_o \left[-\frac{1}{p} (1-p)^2 \ln(1-p) + \frac{1}{p} (1+p)^2 \ln(1+p) - 2 \ln(2) - 2 \ln(2p) \right] \quad (\text{VII.2})$$

where

$$p = h/h' \quad (\text{VII.3})$$

Converting to an effective wave impedance $1/(j\omega\Delta C)$ this becomes

$$\Delta C = \frac{h\epsilon_o}{2\pi} \left[-\frac{1}{p} (1-p)^2 \ln(1-p) + \frac{1}{p} (1+p)^2 \ln(1+p) - 2 \ln(2) - 2 \ln(2p) \right] \quad (\text{VII.4})$$

Of course the small capacitance (VII.4) typically has negligible effect.

Thus the parallel combination

$$Z_{sR} \approx \frac{1}{(h/h')/Z_{sR} + j\omega\Delta C + 1/Z_{sS}} \quad (\text{VII.5})$$

is the effective wave impedance at the reference location $\rho = c$ in this case. Note that, adding the offset short (including parasitic step capacitance) in parallel with the reference load sheet impedance represents an approximation. Strictly speaking, there is an interaction between the step discontinuity and the reference load sheet impedance. Because the step will be relatively small with respect to h , it appears reasonable to use this approximation.

The accuracy of this approximation can be assessed by the following consideration.

First consider the case of an impedance sheet with $Z_{sS} \rightarrow 0$. The region with height h' plays little role and the total impedance $\frac{h}{2\pi c} Z_{sS}$ (derived from assuming a uniform electric field in the height) is a good approximation. This of course corresponds to an effective wave impedance Z_{sS} as assumed in (VII.5).

Next consider the case of an impedance sheet with $Z_{sS} \rightarrow \infty$. The electric field in this case assumes its value when the impedance sheet is not present. An effective conductance for the sheet can be estimated by the equivalence of power

$$P = \frac{1}{2} G_{\text{eff}} |V_{\text{tot}}|^2 = \frac{1}{2} \frac{2\pi c}{Z_{sS}} \int_{-h/2}^{h/2} |E_z|^2 dz \quad (\text{VII.6})$$

where Z_{sS} is a purely real quantity here, and the effective wave impedance of the sheet is $Z_{sS}^{\text{eff}} = \frac{2\pi c}{hG_{\text{eff}}}$. In principle the conformal mapping solution of Appendix V could be used in this integral for E_z . However because the integration is off the conductor surface, this is difficult to carry out directly (Appendix VI gives an alternative approach). Using (VII.6), as h approaches h' , Z_{sS}^{eff} approaches Z_{sS} . Appendix VI gives the value

$$Z_{sS}^{\text{eff}}/Z_{sS} \approx 0.940 \quad (\text{VII.7})$$

in the high impedance limit with parameters (II.3) and (II.9). This represents a 6% decrease in the value of the sheet impedance. The impedance values (II.8) and (II.10) are expected to result in values of $Z_{sS}^{\text{eff}}/Z_{sS}$ closer to unity. Of course, in the limit of high impedance, the offset short behind the sheet will typically dominate anyway. Although these corrections are not totally negligible, and they are typically larger than the capacitive correction (VII.4), they are nevertheless small enough that the device should be a useful standard. Because we

do not have the value of the effective impedance for arbitrary (midrange) values of Z_{sS} , we have taken $Z_{sS}^{\text{eff}} = Z_{sS}$ in (VII.5) as an approximation.

VIII. TRANSFORMATION OF SAMPLE SURFACE IMPEDANCE TO OTHER RADIAL REFERENCE LOCATIONS

It may not always be desirable for the free surface of the sample to be required to end up at radius $\rho = c$. For example, this requires removal of an exact thickness of metal from a fixed set of sample holders with inner radii $\rho = c$ so that the addition of the samples then results in $\rho = c$ being the inner surface of the samples. It is probably more convenient to allow the free surface of the sample to vary from $\rho = c$ to say

$$\rho = c' \neq c \quad (\text{VIII.1})$$

The above procedures are then followed (either the experimental calibration technique or the analytical model technique) to obtain a fictitious surface impedance Z_s at $\rho = c$ from (III.11). Next the appropriate surface impedance Z'_s at $\rho = c'$ is determined by applying the radial transformation formula (AIV.14). This becomes

$$-Z'_s = Z_0(kc') \left[\frac{(-Z_s) \cos(\theta(kc') - \psi(kc)) + j Z_0(kc) \sin(\theta(kc') - \theta(kc))}{Z_0(kc) \cos(\psi(kc') - \theta(kc)) + j (-Z_s) \sin(\psi(kc') - \psi(kc))} \right] \quad (\text{VIII.2})$$

where the appropriate sign changes have been introduced for Z_s and Z'_s , because these wave impedances are defined as $-E_z/H_\varphi$ (the wave impinges from smaller ρ values). The reason this transformation approach is valid is discussed in Appendix VII.

IX. COAXIAL AIR LINE OFFSET IMPEDANCE TRANSFORMATION

Figure II.1 shows the 7 mm airline junction. There is a well calibrated offset between the connector on the air line and the radial transmission line junction. The transformation from Z_{in} , at the radial transmission line – coaxial transmission line junction, to Z_{in}^{conn} , referenced to the coaxial 7 mm connector, is accomplished by an impedance transformation [1]

$$Z_{in} = Z_0 \left[\frac{Z_{in}^{conn} \cos(\beta\ell) - j Z_0 \sin(\beta\ell)}{Z_0 \cos(\beta\ell) - j Z_{in}^{conn} \sin(\beta\ell)} \right] \quad (IX.1)$$

where Z_0 is given by (III.9) for the 7 mm airline, and

$$\ell = (4.9967 \text{ cm} + 0.1 \text{ inches}) \quad (IX.2)$$

and $\beta = \omega \sqrt{\mu_o \epsilon_o}$ where $\mu_o = 4\pi \times 10^{-7} \text{ H/m}$ and $1/\sqrt{\mu_o \epsilon_o} \approx 2.997925 \times 10^8 \text{ m/sec}$. The transformation (IX.1) is applied to all data Z_{in}^{conn} in order to transform them to the radial transmission line junction.

X. INSTRUMENTATION LAYOUT

Figure X.1 gives a block diagram of the hardware configuration used. A typical sequence for measuring the radial line devices (shown at the bottom of the figure) is as follows:

1. Initialize the HP8753C network analyzer system at the 7 mm test port, at the frequencies of interest, using an HP85031B calibration kit.

2. Measure the radial line reference short #1, offset short #2 and offset short #3 in order to determine the A, B, C parameters of the coax-to-radial-line transition section of the sample fixture.
3. Measure the reference/unknown Salisbury load and compare the results with the theoretical value for the Salisbury load in order to assess the quality of the determination in step 2.
4. Measure a loaded sample fixture to determine the impedance of a radial load of interest.

In practice, it is best to measure offset short, #3 and the reference/unknown Salisbury load in the vertical position to eliminate problems due to sag in the top plate of the radial line.

In principle the Salisbury load can also be substituted for one of the three calibration standards if confidence develops in its measured effective surface impedance properties.

Figure X.2 is a photograph of the reference short, two offset shorts, and the Salisbury load (step discontinuity in top plate is evident in the photograph). Figure X.3 shows the HP 8753C network analyzer and the reference short. Figure X.4 shows the system consisting of the HP 8753C network analyzer, HP QS/20 Vectra computer, printer, and reference short.

XI. DESCRIPTION OF MEASUREMENT SOFTWARE

The BASIC 5.1 program RLMS_a1 (see listing in Appendix IX) consists of a main program and 32 subprograms and functions as shown in Figure XI.1. (Three additional subprogram stubs are included for ease of future expansion.) The functional purpose of each subprogram/function is given in comments at the beginning of its source code.

The major purpose of the code is to determine the total and surface impedances of a

radial load as viewed looking outward from the radial line port of a radial–line/coaxial–line junction (RL/CL J). The desired impedances are computed from measurements made at the coax port of the junction by a Hewlett Packard model 8753C vector automatic network analyzer (VANA). In order to compute the total and surface radial line impedances, the network parameters of the RL/CL J must be known. RLMS_a1 utilizes a bilinear fraction characterization of the transition section viz.

$$Z_s = \frac{A Z_m + B}{C Z_m + 1} \quad (\text{XI.1})$$

where Z_s is the surface impedance as observed by looking outward from the radial line port of the RL/CL J; Z_m is the impedance measured looking into the RL/CL J from the interface between the coaxial line and the radial line; A, B, and C are frequency dependent complex network parameters which characterize the RL/CL J. These parameters are determined by the geometry of the section and the frequency of interest.

A Functional Walk–Thru of the Code RLMS_a1

The following paragraphs give a narrative of the functions performed by the code as guided by the options offered on the main menu of RLMS_a1. See Figure XI.2.

Option 1 invokes subprogram Meas_abc_par which directs the process of determining the A, B, and C parameters of a RL/CL J. It makes use of the anharmonic ratio (in subprogram Abc_anharm) to compute the ABC values from (1) the computed impedances (using subprogram Radial_line and function FNZi) of three well–characterized radial line offset short standards at the radial line port of the RL/CL J and (2) the 3 corresponding measured impedances (from subprogram Acq_dat_abc_par) at the coax–radial line interface. The code then generates a hardcopy report (using subprogram

Type_abc_rept) of the ABC parameters and a file of the same on a diskette in HP BDAT format and, optionally in DOS format. The report is shown at the top of Figure XI.3 and a print out of the DOS file is at the bottom.

The file of A, B, C parameters is subsequently used under option 2. (Digressing a moment, a Salisbury load (see Section VII) can be substituted for one of the offset short standards. Subprogram Salis_ld_z and function FNstep_cap_w (see Section VII) are used to compute its impedance from its dimensions, space cloth film resistivity and the frequency.) Optionally, the ABC parameters can also be recorded in an MS-DOS (henceforth referred to as DOS) text file by using subprogram Abc_dos_dat_file.

Option 2 invokes subprogram Z_via_abc which uses the network method (henceforth referred to as the "ABC method") to determine the surface impedance, Z_s . Z_via_abc uses the ABC parameters (as determined by use of option 1) and Z_m (from subprogram Acqdat_zmeas) in equation (XI.1) (in function FNBilinear) to compute Z_s . Subprogram Type_lod_z_rept is called to print a hardcopy report of the values of Z_s . A typical report appears in Figure XI.4. Here also, one has the option of using subprogram Z_dos_dat_fil to record the results in a DOS text file. Subprogram Type_lod_z_rept (which is utilized in both options 2 and 3) allows the operator to specify that the surface impedances, Z_s , be reported at terminal cylinders of either greater or smaller radius than that of RL/CL J. This feature, embodied in subprogram Z_r_xform, is of obvious utility if the inner radius of the radial load being measured is not identically equal to the radius of the radial line port of the RL/CL J.

Option 3 invokes subprogram Z_via_will which uses the "Williamson method" based on the field theory of Section III to compute Z_s from the frequency, transition section dimensions, and Z_m . Z_via_will employs FORTRAN executable code WILL.EXE to compute the values of Z_s . The source for WILL.EXE, WILL.FOR, was written in FORTRAN (before RLMS_al was written) in order to utilize library routines for Bessel functions which are not readily available in a BASIC environment. A listing of WILL.FOR

is included in Appendix IX (note that WILL.FOR was originally written using time dependence $e^{-i\omega t}$ and thus conjugates of both the input impedance and the output surface impedance, to convert to $e^{j\omega t}$, can be found in the listing.) The use of WILL.EXE proceeds as follows:

1. When the operator chooses to use the Williamson method, the measurement frequencies and the impedance measurements, Z_m , made on the loaded coax-to-radial-line transition section (as well as its dimensions) are written (from BASIC) into a DOS text file named DOSIN.DAT. Utilizing compiled subprograms (FNB1p_lock, B1p_enable, FNB1p_background, B1p_send, and B1p_send_key) from the HP BASIC Multi-Com library, the BASIC code then places the BASIC language coprocessor into background mode and calls for execution of the DOS batch file SEQ.BAT.
2. The first command in SEQ.BAT calls for the execution of WILL.EXE which, in turn, reads file DOSIN.DAT. WILL.EXE then computes the surface impedances at the radial line port, and writes them along with their corresponding frequencies into DOS text file DOSOUT.DAT.
3. When execution of WILL.EXE is completed, SEQ.BAT issues a command to place the BASIC language processor back into foreground mode. Z_via__will then reads file DOSOUT.DAT and prints out a report of the surface and total impedance results. The report shown in Figure XI.5 shows a set of Z_s values as determined by Williamson from the same input data that was used to produce the report in Figure XI.4 using the ABC method. As before, the results can also be written to a DOS text file.

Option 4 displays (on the CRT) the theoretical surface impedances looking into a Salisbury load from its radial line input port. Of course, before this display, the operator is prompted to enter the mechanical dimensions of the Salisbury load, the properties of its resistive film, and the frequencies of interest. Figure XI.6 is a copy from the CRT that resulted after invoking option 4 for the case when the surface resistivity of the film is 363.26 ohms per square.

Miscellaneous Comments about RLMS_a1

1. Instructions for use of RLMS_a1, its required environment, etc. appear in a user's guide which is listed as comments at the beginning of the source code. During execution, the operator is guided by menu choices and prompts on the CRT.
2. Several subprograms and functions included in RLMS_a1 were not mentioned in the above discussion of the options offered by the code. These are discussed briefly in the paragraphs which follow.
3. Subprogram Acq_meas_par sets up the measurement parameters of any measurement performed under main menu options 1, 2, or 3. These measurement parameters include the measurement frequencies, identities of the radial transmission line components involved, setup of the HP 8753 VANA, etc. This information may be entered from the keyboard then saved in an HP BDAT SUPport file, or it may be read from an already existing SUPport file. Subprogram Sup_fil_id is used during specification and validation of the appropriate SUPport file. Subprogram Mf_gen sets up the desired list of measurement frequencies. Subprogram Choose_cals allows the operator to select the appropriate calibration set for the HP8753 VANA and subprogram Mf_vf_fit verifies that the HP8753 VANA is calibrated to measure at

all the desired measurement frequencies.

4. Subprogram Acq_8753_dat acquires the raw measured impedances at the APC-7 coaxial connector of a RL/CL J. Since the APC-7 connector port is approximately 5.25 cm from the interface between the coaxial line and the radial line, Acq_8753_dat transforms the raw impedance to the interface plane; this transformed impedance is Z_m . Acq_8753_dat gives the operator the option to record in a DOS text file (by use of subprogram Raw_z_dos_dat) the values of Z_m at each frequency.

5. While measuring Z_s by the ABC method (under main menu option 2), one must utilize a file of ABC parameters previously measured under option 1. If Z_s measurements are being made at a subset of the frequencies for which the ABC parameters were determined, subprogram Fmatch_abc_file extracts the correct set of ABC parameters to use during the Z_s measurements.

6. Function FNAng2 computes the angle determined by an x, y coordinate and places that angle in the correct quadrant. It is analagous to the FORTRAN function ATAN2.

7. Function FNStp_cap_wk is a (unused) function for computing the step capacitance associated with a change in separation of the plates of a radial transmission line. It is based on an iterative technique described in [3]. Its results are virtually identical to those from subprogram FNStep_cap_w.

8. Dummy subprogram Comdef gives the definitions of all variables appearing in COM.

XII. STANDARDS MEASUREMENTS

The testing of the apparatus was carried out by using the Salisbury load as the test object and the three offset shorts as the three complex standards.

The first test series made use of the Salisbury load with the resistive sheet removed ($Z_{SS} = \infty$). This is not a trivial test case, however, because the combination of large offset short and step discontinuity results in a different surface impedance (at the step radius) than any of the offset short standards. The expected values of the Salisbury load surface impedance are determined from (VI.2), (VI.3), (VI.4), (VI.5), (VII.4), and (VII.5), with $Z_{SS} = \infty$ and the dimensions given by (II.3), (II.4), (II.7), and (II.9). Figure XII.1 shows the magnitude and phase of the surface impedance at the radius (II.4). Four curves are shown. The long dashed curve represents the expected result, the short dashed curve represents the measured result using the Williamson theory to theoretically determine the surface impedance from the measured coaxial impedance, the dotted curve (nearly overlays the short dashed curve) represents the Williamson theory measured result with the junction capacitance correction included, and the solid curve represents the empirical ABC technique (using the three offset shorts as standards) to determine the surface impedance from the measured coaxial impedance. The agreement is excellent: the maximum deviation of the three curves for the magnitude is less than one percent, the maximum deviation in phase of the three curves is less than one degree. We believe these test results indicate the type of accuracy achievable with the apparatus.

The fact that the Williamson results, and the Williamson results with the capacitive junction correction included, nearly overlay, gives us confidence in the accuracy of the model (the assumption of junction radial electric field inversely proportional to radial distance is not contributing to any significant discrepancies). Another possible source of error in the model is the fact that the radial load and coaxial-radial junction are assumed to interact only through the fundamental radial transmission line mode (of course higher order modes

are incorporated at the junction as well as at the load, Appendix V). However, the choice of the height of the radial transmission line results in large decay of the higher order modes (in addition, the empirical ABC technique assumes there is interaction only through the fundamental radial mode). The fact that the empirical ABC technique gives results closer to the expected results is thus thought to be the result of small but unquantified differences between the measurement system and the assumed model.

Several iterations were carried out when the resistive impedance sheet was inserted into the device. We briefly describe the sequence of iterations before presenting the final results.

The resistive sheet was made up of three strips, each covering 120° of the circumference at the (II.4) radius. This was done because of the limited lengths that could be obtained from the manufacturer. A DC calibration measurement was carried out on the resistive strips before they were inserted in the apparatus. The procured resistive strips were slightly longer than required, and had a conductive silver edge deposited on the ends. (The resistive material consists of a 0.001 inch thick mylar backing with vapor deposited Nichrome resistive material.) Unfortunately, this DC measurement could only be made in the length direction of the strips, using this silver edge coating to provide contact. Contact problems prevented accurate DC measurements in the transverse direction, which is of course the direction of current flow in the apparatus. The average of the three strip resistance per square values was used for Z_{SS} to give the expected surface impedance result in the apparatus. Scotch tape was used to secure the resistive strips to the midpoint in the step of the Salisbury load fixture. Discrepancies of the measured surface impedance with the expected result were as large as thirty percent. The expected result was smaller than the measurements yielded, however, the phase was more accurate than the magnitude. (Note that the Williamson and ABC measurement techniques agreed to about one percent.) Contact problems at the resistive sheet attachment were suspected.

Appendix X considers the effect of an air gap beneath the resistive sheet and the step

in the Salisbury load height. Because the resistive strip was only secured by tape at the outer edge, it was possible for an approximately linear air gap to form if the height of the fixture decreased slightly after mounting. Appendix X indicates, however, that if the air gap is small enough, say, small compared to the thickness of the sheet (0.001 inches), then the capacitance is large enough that conductive contact is not necessary (above 100 MHz) to eliminate contact problems.

A second iteration thus made use of a plastic tape elastically loaded (elastic over 1 inch circumference) to place pressure on a new set of resistive strips and thus attempt to minimize or eliminate the air gaps. A new set of resistive strips was used because the first set was slightly damaged in an attempted post-test DC evaluation of their transverse resistance per square. Discrepancies of the measured values of the surface impedance relative to the expected surface impedance were less than about fifteen percent. Again the expected value was less than the measured results indicated. (Again the Williamson and ABC measurement techniques agreed to about one percent.)

The final iteration involved better DC calibration measurements of the resistive strips. Questions about the isotropy of the resistive strips could not be eliminated without calibrating the resistance per square in the direction of interest. To obtain reliable measurements of the transverse resistance per square, gold contacts were vapor deposited on the edges of the strips. These contacts allowed repeatable measurements of the transverse DC resistance per square to be obtained. These contacts also remain in place when the strips are inserted into the apparatus, reducing contact problems. Unfortunately, the first set of gold edged strips showed wide variations in the transverse resistance per square (one having nearly twice the free space impedance value). It was thus decided to treat a total of twelve strips and pick three with the closest resistance per square values. Fortunately, three strips were identified with similar resistance per square values, and furthermore, these three values were near the free space value. The three values were

$$Z_{sS}^{(1)} \approx 383.60 \text{ ohms/sq}$$

$$Z_{sS}^{(2)} \approx 357.07 \text{ ohms/sq} \quad (\text{XII.1})$$

$$Z_{sS}^{(3)} \approx 359.64 \text{ ohms/sq}$$

The average of the three values (XII.1) is

$$Z_{sS} \approx 366.77 \text{ ohms/sq} \quad (\text{XII.2})$$

Of course, the average is the appropriate quantity to use for calculations with the axisymmetric mode. These three strips were again secured by the elastically stressed plastic tape to reduce or eliminate air gap problems. Figure XII.2 shows the amplitude and phase of the surface impedance at radius (II.4) (the small junction capacitance correction is now left out). The fourth curve (dash-dot) shows the "expected result" if the sheet impedance (XII.2) is increased to obtain a better fit of the magnitude with the measured results. Discrepancies of the measured results with the expected result (with $Z_{sS} \approx 366.77 \text{ ohms}$) are less than seven percent in magnitude and two degrees in phase.

The final results of the Salisbury load tests are greatly improved over the initial results. The remaining discrepancies, although perhaps acceptable as errors in an unknown sample, are not sufficiently small to allow the Salisbury load to be used as a standard itself. It must be noted however, that the agreement in Figure XII.2 between the Williamson theoretically interpreted results and the ABC empirically interpreted results is excellent (less than one percent in magnitude and less than one degree in phase). The comparison between these two interpretation techniques is believed to be an indication of the accuracy to which the coax-to-radial transmission line junction is being modeled. Thus the remaining discrepancies are believed to be associated with remaining uncertainties in the

resistive sheet impedance (note that the DC calibrations only yield average values for each strip), possible higher order circumferential modes generated by the remaining azimuthal nonuniformity of the load (these may not decay rapidly with radial distance), or remaining contact problems. It is thus believed that the accuracy achievable with an ideally seated and uniform sample is approximately one percent in magnitude and one degree in phase.

Figures XII.3 and XII.4 give listings of the expected results, measurements using Williamson theory, and measurements using the ABC technique, for the Salisbury load both without the resistive sheet and with the resistive sheet (final iteration).

XIII. CONCLUSIONS

A coaxial-to-radial transmission line sample holder, three offset shorts, and a Salisbury load were constructed. The Salisbury load was used as a canonical test sample.

An analytical approximation (Williamson), and an empirical experimental technique (ABC) with three standards, were used to model the coaxial-to-radial junction. Either technique is used to transform the measured coaxial input impedance to the sample surface impedance. Both techniques yielded answers within one percent of one another when used on the Salisbury load test sample (with the three offset shorts used as standards in the ABC technique). It is believed that this small discrepancy is an indication of the accuracy achievable by the apparatus.

The Salisbury load measurements were within one percent of the expected surface impedance values when the resistive sheet in the Salisbury load was removed. The measurements with the resistive sheet present were within seven percent of the expected surface impedance values. These expected values were predicted using radial transmission line theory and DC calibration measurements of the sheet resistance. It is possible that remaining contact problems and remaining uncertainties about the resistive sheet are responsible for the discrepancies. These discrepancies, although perhaps acceptable as a

practical sample error, render the Salisbury load unusable as a reference standard.

The current apparatus, with the offset short reference standards is applicable for the frequency range below, say, 250 MHz. The sample holder and analytical model are applicable to the frequency range below about 500 MHz. It appears possible to extend the range to at least 1 GHz by reducing the dimensions of the sample holder and reference standards. Future work should include considerations of an alternative, more accurate, lossy reference standard design.

REFERENCES

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- [2] Private communication, R. D. Moyer, Sandia National Laboratories, August 1991.
- [3] Electromagnetic Theory for Engineering Applications, W. L. Weeks, John Wiley & Sons, Inc., New York, 1964, p. 431.

APPENDIX I. THEORY OF COAXIAL TO RADIAL TRANSMISSION LINE APPARATUS

There have been several theoretical investigations of the transition between coaxial and radial transmission lines. We will summarize the results in [A.1] with an arbitrary terminating load impedance Z_L in the radial transmission line. The formulas for apparent admittance in the coaxial line Y will be evaluated by use of the typical approximation for the radial electric field at the junction

$$E_\rho = V/[\rho \ln(b/a)] \quad (\text{AI.1})$$

where V is the voltage from the center conductor of the coax, of radius a , to the outer conductor, of radius b , the distance between parallel plates in the radial line is h , and $Y_{1/\rho}$ is used to denote this apparent admittance when the approximation (AI.1) is used. Note that the case of an infinite radial line, which includes discussions of how to improve the approximate junction field (AI.1) is given in [A.2].

The apparent admittance from [A.1] is given by

$$Y_{1/\rho} = j B_1 + j B_2 + Y' \quad (\text{AI.2})$$

where

$$B_1 = -\frac{2\pi}{\eta_o \ln(b/a)} \cot(kh) \quad (\text{AI.3})$$

$$B_2 = -\frac{4\pi}{kh\eta_o \ln(b/a)} \sum_{m=1}^{\infty} \frac{1}{q_m} \frac{K_0(q_m kb)}{K_0(q_m ka)} \gamma_m \quad (\text{AI.4})$$

$$q_m = \sqrt{\left(\frac{m\pi}{kh}\right)^2 - 1} \quad (\text{AI.5})$$

$$\begin{aligned} Y' / \left[\frac{2\pi j}{kh\eta_o} \ln(b/a) \gamma_0 \right] &= \frac{H_0^{(2)}(kb)}{H_0^{(2)}(ka)} + \{J_0(kb)Y_0(ka) - J_0(ka)Y_0(kb)\} \\ &\quad \{j(\frac{2\pi c}{h} Z_L)H_1^{(2)}(kc) + \eta_o H_0^{(2)}(kc)\} \\ &\quad \left[j(\frac{2\pi c}{h} Z_L)H_0^{(2)}(ka) \{J_0(ka)Y_1(kc) - J_1(kc)Y_0(ka)\} \right. \\ &\quad \left. + \eta_o H_0^{(2)}(ka) \{J_0(ka)Y_0(kc) - J_0(kc)Y_0(ka)\} \right]^{-1} \end{aligned} \quad (\text{AI.6})$$

$$\gamma_0 = \frac{\pi}{2} \int_a^b \{J_1(k\rho')Y_0(ka) - J_0(ka)Y_1(k\rho')\} k\rho' E_\rho(\rho')/V d\rho' \quad (\text{AI.7})$$

$$\gamma_m = \int_a^b \{I_0(q_m ka)K_1(q_m k\rho') + I_1(q_m k\rho')K_0(q_m ka)\} q_m k\rho' E_\rho(\rho')/V d\rho' \quad (\text{AI.8})$$

Note that in the above form E_ρ , at the junction, is arbitrary. Inserting (AI.1) into (AI.7) and (AI.8) yields

$$\gamma_0 = \frac{\pi}{2 \ln(b/a)} \{J_0(ka)Y_0(kb) - J_0(kb)Y_0(ka)\} \quad (\text{AI.9})$$

$$\gamma_m = \frac{1}{\ln(b/a)} \{I_0(q_m kb)K_0(q_m ka) - I_0(q_m ka)K_0(q_m kb)\} \quad (\text{AI.10})$$

The quantity Z_L is the total load impedance at $\rho = c$. The wave impedance or surface impedance Z_s at $\rho = c$ is

$$Z_s = \frac{2\pi c}{h} Z_L \quad (\text{AI.11})$$

APPENDIX II. COAXIAL TO INFINITE MONOPOLE JUNCTION CAPACITANCE CORRECTION

The usual assumption for the radial electric field at the end of the coaxial transmission line $E_\rho = V/[\rho \ln(b/a)]$, discussed in the previous section, is assumed to be a very good approximation although it is of course not exact. The correction to this field distribution, in the case where there is no plate at $z = +h/2$, that is an infinite monopole antenna ($h \rightarrow \infty$), will be tabulated in this appendix. This correction can be applied to the case of finite h provided that $h \gg b$.

The correction to the apparent admittance of the junction can be written as [A.3]

$$Y = Y_{1/\rho} + j\omega C_T \quad (\text{AII.1})$$

where $Y_{1/\rho}$ is the apparent admittance assuming $E_\rho = V/[\rho \ln(b/a)]$, given in Appendix I, and C_T is a correcting capacitance resulting from deviations of the exact E_ρ distribution from this simple assumed form. This capacitance can be written in the form [A.3]

$$C_T = \frac{4\pi a \epsilon_0}{A(a/b)} \quad (\text{AII.2})$$

where the value of the function $A(x)$ for a 50 ohm coax is [A.3]

$$-A(0.43421624) \approx 11.466824 \quad (\text{AII.3})$$

The value of the function $A(x)$ at unity from a conformal mapping approximation [A.3] is

$$-A(1) = -\pi/[\ln(\pi/4)] \approx 13.005193 \quad (\text{AII.4})$$

We also note [A.4]

$$-A'(1) = 0 \quad (\text{AII.5})$$

Furthermore a perturbation method for small x yielded the asymptotic form [A.4]

$$-A(x) \sim 5x \ln^2(x) - 14x \ln(x) + 7x, \quad x \rightarrow 0 \quad (\text{AII.6})$$

Thus the accurate approximate fit [A.5]

$$-A(x) \approx 5x \ln^2(x) - 14x \ln(x) + 7x + A_2 x^2 + A_3 x^3 + A_4 x^4 \quad (\text{AII.7})$$

can be used for $0 \leq x \leq 1$. Using (AII.3), (AII.4), and (AII.5) we obtain the coefficients

$$A_2 \approx 13.97311535 \quad (\text{AII.8})$$

$$A_3 \approx -10.92545814 \quad (\text{AII.9})$$

$$A_4 \approx 2.957535929 \quad (\text{AII.10})$$

APPENDIX III. BILINEAR TRANSFORMATION AND ANHARMONIC RATIO

The bilinear transformation

$$Z = \frac{aW + b}{cW + 1} \quad (\text{AIII.1})$$

occurs frequently as a model for reflectometer systems [A.6]. The three complex constants (which are of course frequency dependent) a , b , and c can be determined from the measurement of impedances Z_i of three complex (full) standards W_i . (Of course we can also take Z_i to represent the standard values and W_i to be the measured impedances.) Invariance of the "anharmonic ratio" [A.6] (or "cross ratio") gives

$$\frac{(Z_1 - Z_2)(Z_3 - Z_4)}{(Z_2 - Z_3)(Z_4 - Z_1)} = \frac{(W_1 - W_2)(W_3 - W_4)}{(W_2 - W_3)(W_4 - W_1)} \quad (\text{AIII.2})$$

Solving (AIII.2) for Z_4 gives [A.6]

$$Z_4 = \frac{AW_4 + B}{CW_4 + D} \quad (\text{AIII.3})$$

where

$$A = (Z_1 - Z_2)Z_3(W_2 - W_3) - (Z_2 - Z_3)Z_1(W_1 - W_2) \quad (\text{AIII.4})$$

$$B = W_3(W_1 - W_2)(Z_2 - Z_3)Z_1 - W_1(W_2 - W_3)(Z_1 - Z_2)Z_3 \quad (\text{AIII.5})$$

$$C = (W_2 - W_3)(Z_1 - Z_2) - (W_1 - W_2)(Z_2 - Z_3) \quad (\text{AIII.6})$$

$$D = W_3(W_1 - W_2)(Z_2 - Z_3) - W_1(W_2 - W_3)(Z_1 - Z_2) \quad (\text{AIII.7})$$

Comparing (AIII.3) and (AIII.1) we see that [A.6]

$$a = A/D; b = B/D; c = C/D \quad (\text{AIII.8})$$

APPENDIX IV. RADIAL TRANSMISSION LINE IMPEDANCE TRANSFORMATIONS

The radial transmission line mode has field components E_z and H_φ [A.7]. The electric field E_z satisfies the Helmholtz equation and is independent of φ and z . Thus it has the form [A.7]

$$E_z = A H_0^{(1)}(k\rho) + B H_0^{(2)}(k\rho) \quad (\text{AIV.1})$$

where $k = \omega \sqrt{\mu_o \epsilon_o}$ and μ_o and ϵ_o are the magnetic permeability and electric permittivity of free space. The corresponding magnetic field is given by

$$H_\varphi = \frac{1}{j\omega\mu_o} \frac{\partial}{\partial \rho} E_z = \frac{j}{\eta_o} [A H_1^{(1)}(k\rho) + B H_1^{(2)}(k\rho)] \quad (\text{AIV.2})$$

where $\eta_o = \sqrt{\mu_o/\epsilon_o} \approx 120\pi$ ohms.

Defining amplitude and phase by means of [A.7]

$$H_0^{(1)}(x) = J_0(x) + j Y_0(x) = G_0(x) e^{j\theta(x)} \quad (\text{AIV.3})$$

$$H_0^{(2)}(x) = J_0(x) - j Y_0(x) = G_0(x) e^{-j\theta(x)} \quad (\text{AIV.4})$$

$$j H_1^{(1)}(x) = -Y_1(x) + j J_1(x) = G_1(x) e^{j\psi(x)} \quad (\text{AIV.5})$$

$$j H_1^{(2)}(x) = Y_1(x) + j J_1(x) = -G_1(x) e^{-j\psi(x)} \quad (\text{AIV.6})$$

where

$$G_0(x) = \sqrt{J_0^2(x) + Y_0^2(x)} \quad (\text{AIV.7})$$

$$\theta(x) = \text{Arctan}[Y_0(x)/J_0(x)] \quad (\text{AIV.8})$$

$$G_1(x) = \sqrt{J_1^2(x) + Y_1^2(x)} \quad (\text{AIV.9})$$

$$\psi(x) = \text{Arctan}[J_1(x)/\{-Y_1(x)\}] \quad (\text{AIV.10})$$

The fields can thus be written as [A.7]

$$E_z = G_0(k\rho) [Ae^{j\theta(k\rho)} + Be^{-j\theta(k\rho)}] \quad (\text{AIV.11})$$

$$H_\varphi = \frac{G_0(k\rho)}{Z_0(k\rho)} [Ae^{j\psi(k\rho)} - Be^{-j\psi(k\rho)}] \quad (\text{AIV.12})$$

where the characteristic impedance is

$$Z_0(k\rho) = \eta_o \frac{G_0(k\rho)}{G_1(k\rho)} \quad (\text{AIV.13})$$

Defining input wave impedance at reference location $\rho = c$ as $Z_i = E_z(c)/H_\varphi(c)$ and load wave impedance at radial location $\rho = d$ as $Z_L = E_z(d)/H_\varphi(d)$ we can write the impedance transformation formula as [A.7]

$$Z_i = Z_{0i} \left[\frac{Z_L \cos(\theta_i - \psi_L) + j Z_{0L} \sin(\theta_i - \theta_L)}{Z_{0L} \cos(\psi_i - \theta_L) + j Z_L \sin(\psi_i - \psi_L)} \right] \quad (\text{AIV.14})$$

where $Z_{0i} = Z_0(kc)$, $Z_{0L} = Z_0(kd)$, $\theta_i = \theta(kc)$, $\theta_L = \theta(kd)$, $\psi_i = \psi(kc)$, and $\psi_L = \psi(kd)$.

APPENDIX V. STEP CAPACITANCE IN RADIAL TRANSMISSION LINE

We will apply a planar solution of the step discontinuity problem as an approximation to the cylindrical geometry. We use a perfect electric conductor symmetry plane in between the two plates and denote the two half heights by $s = h/2$ and $s' = h'/2$.

A cartesian coordinate system is chosen so that the x axis is aligned with the symmetry plane and $x = 0$ placed at the location of the step. Thus $y = 0$ corresponds to the symmetry plane and $y = s$ ($x < 0$), $y = s'$ ($x > 0$) is the upper plate. Let us take the top plate to be at potential V and the bottom symmetry plane to be at potential 0. The electric field $\underline{E}$ is found from a scalar potential ϕ by means of

$$\underline{E} = -\nabla\phi \quad (\text{AV.1})$$

where ϕ satisfies Laplace's equation

$$\nabla^2\phi = 0 \quad (\text{AV.2})$$

The potential can be taken as the imaginary part of a complex potential W

$$\phi = \text{Im}(W) \quad (\text{AV.3})$$

The Schwarz—Christoffel transformation which maps the region interior to the conducting plates in the complex $z = x + iy$ plane to the upper half of a complex z_1 plane is

$$\begin{aligned} \frac{dz}{dz_1} &= C_1 (z_1 + 1)^{\frac{\pi/2}{\pi} - 1} (z_1 + p^2)^{\frac{3\pi/2}{\pi} - 1} z_1^{\frac{0}{\pi} - 1} \\ &= C_1 \frac{1}{z_1} \sqrt{\frac{z_1 + p^2}{z_1 + 1}} \end{aligned} \quad (\text{AV.4})$$

where $0 < p < 1$. Integrating and noting that $z_1 = -1$ maps to $z = is'$ gives

$$z = C_1 \int_{-1}^{z_1} \sqrt{\frac{z_1 + p^2}{z_1 + 1}} \frac{dz_1}{z_1} + is' \quad (\text{AV.5})$$

Note that $z_1 \rightarrow +\infty$ maps into $z \rightarrow +\infty$ if C_1 is real and positive.

The solution for the parameters C_1 and p is accomplished simply by means of the following procedure [A.8]. When the magnitude of z_1 , $|z_1| = R_1$, is large (and the real part of z , $\text{Re}(z) = R$, is large and positive) we can expand (AV.4) as

$$dz \sim \frac{C_1}{z_1} dz_1 \quad (\text{AV.6})$$

Integrating from one plate to the other yields

$$\int_{R+i0}^{R+is'} dz \sim C_1 \int_{R_1 e^{i0}}^{R_1 e^{i\pi}} \frac{dz_1}{z_1} \quad (\text{AV.7})$$

which gives

$$s' = \pi C_1 \quad (\text{AV.8})$$

Similarly for z_1 small, $|z_1| = \epsilon_1$, (and the real part of z , $\text{Re}(z) = -R$, large and negative) we can expand (AV.4) as

$$dz \sim C_1 p \frac{dz_1}{z_1} \quad (\text{AV.9})$$

Integrating from one plate to the other yields

$$\int_{-R+i0}^{-R+is} dz = C_1 p \int_{\epsilon_1 e^{i0}}^{\epsilon_1 e^{i\pi}} \frac{dz_1}{z_1} \quad (\text{AV.10})$$

which gives

$$s = \pi C_1 p \quad (\text{AV.11})$$

Solving (AV.8) and (AV.11) gives

$$C_1 = s'/\pi \quad (\text{AV.12})$$

$$p = s/s' \quad (\text{AV.13})$$

Note that the point $z_1 = -p^2$ maps to $z = is$.

The complex potential can be taken as (insulated hinge problem)

$$W = \frac{V}{\pi} \ln(z_1) \quad (\text{AV.14})$$

Because we ultimately intend to compute net charge on a conductor, it is convenient to use the electric vector potential $\underline{A}_e$, where

$$\underline{D} = -\nabla \times \underline{A}_e = \epsilon_o \underline{E} \quad (\text{AV.15})$$

where $\underline{D}$ is the electric displacement vector, ϵ_o is the electric permittivity of free space, and for this two-dimensional static problem we only require the component A_{ez} to be nonzero. This component can be taken as

$$A_{ez} = -\epsilon_o \operatorname{Re}(W) \quad (\text{AV.16})$$

The electric surface charge Q , on a conductor, can thus be written as (by Stokes theorem)

$$Q = \int_S \underline{D} \cdot \underline{n} \, dS = - \oint_C \underline{A}_e \cdot d\ell \quad (\text{AV.17})$$

where the contour C bounds the surface S on the conductor. The charge on the top conductor between $z = -R + is$ and $z = R + is'$ ($R \rightarrow +\infty$) will be denoted by Q_R . Thus using (AV.17) we obtain

$$\begin{aligned}
Q_R &= A_{ez}(z = R + is') - A_{ez}(-R + is) \\
&= \epsilon_o \frac{V}{\pi} \ell n \left| \frac{z_1(z = R + is')}{z_1(z = -R + is)} \right| = \epsilon_o \frac{V}{\pi} \ell n(R_1/\epsilon_1) \quad (AV.18)
\end{aligned}$$

where $z_1 = -R_1$ ($R_1 \rightarrow +\infty$) when $z = R + is'$ and $z_1 = -\epsilon_1$ ($\epsilon_1 \rightarrow +0$) when $z = -R + is$.

The conformal transformation (AV.5) must be expanded to obtain the relation between R and R_1 or ϵ_1 . Letting $z_1 = -R_1$ (and $z_1 = -t$ in the integrand) we obtain

$$\begin{aligned}
R &= \frac{s'}{\pi} \int_1^{R_1} \sqrt{\frac{t - p^2}{t - 1}} \frac{dt}{t} \\
&= \frac{2}{\pi} s' \int_{u_1}^{\infty} \left(\frac{1}{u^2 - 1} - \frac{p^2}{u^2 - p^2} \right) du \quad (AV.19)
\end{aligned}$$

where $u^2 = \frac{t - p^2}{t - 1}$, $u_1^2 = \frac{R_1 - p^2}{R_1 - 1}$, and partial fractions have been used. Evaluation using partial fractions yields

$$\begin{aligned}
R &= \frac{s'}{\pi} \left[\ell n \left(\frac{u_1 + 1}{u_1 - 1} \right) - p \ell n \left(\frac{u_1 + p}{u_1 - p} \right) \right] \\
&\sim \frac{s'}{\pi} \left[\ell n \left(\frac{4R_1}{1 - p^2} \right) - p \ell n \left(\frac{1 + p}{1 - p} \right) \right] \quad (AV.20)
\end{aligned}$$

Letting $z_1 = -\epsilon_1$ (changing the lower limit in (AV.5) from -1 to $-p^2$, changing $+is'$ on the right of (AV.5) to $+is$, and changing the integration variable to $z_1 = -t$) we obtain

$$\begin{aligned}
R &= \frac{s'}{\pi} \int_{\epsilon_1}^{p^2} \sqrt{\frac{p^2 - t}{1 - t}} \frac{dt}{t} \\
&= -\frac{2}{\pi} s' \int_0^{u_1} \left(\frac{1}{1 - u^2} - \frac{p^2}{p^2 - u^2} \right) du \quad (\text{AV.21})
\end{aligned}$$

where $u^2 = \frac{p^2 - t}{1 - t}$, $u_1^2 = \frac{p^2 - \epsilon_1}{1 - \epsilon_1}$, and partial fractions have been used. Evaluation using partial fractions yields

$$\begin{aligned}
R &= \frac{s'}{\pi} \left[p \ln\left(\frac{p + u_1}{p - u_1}\right) - \ln\left(\frac{1 + p}{1 - p}\right) \right] \\
&\sim \frac{s'}{\pi} \left[p \ln\left(\frac{4p^2/\epsilon_1}{1 - p^2}\right) - \ln\left(\frac{1 + p}{1 - p}\right) \right] \quad (\text{AV.22})
\end{aligned}$$

Solving (AV.20) for $\ln(R_1)$ and (AV.22) for $\ln(1/\epsilon_1)$ gives

$$\ln(R_1) \sim \frac{\pi}{s'} R + p \ln\left(\frac{1 + p}{1 - p}\right) + \ln\left(\frac{1 - p^2}{4}\right) \quad (\text{AV.23})$$

$$\ln(1/\epsilon_1) \sim \frac{\pi}{s'} R + \frac{1}{p} \ln\left(\frac{1 + p}{1 - p}\right) + \ln\left(\frac{1 - p^2}{4p^2}\right) \quad (\text{AV.24})$$

Now from (AV.18) we obtain

$$Q_R \sim \epsilon_o V \left(\frac{1}{s} + \frac{1}{s'} \right) R + \frac{\epsilon_o}{\pi} V \left[\frac{1}{p} (1+p)^2 \ln(1+p) - \frac{1}{p} (1-p)^2 \ln(1-p) - 2 \ln(4p) \right] \quad (\text{AV.25})$$

The first term in (AV.25) represents the charge per unit length resulting from uniform fields in both sections of the structure out to a distance R from the origin. The second term is thus the voltage V times the step capacitance per unit length. The length in this case is the circumference $2\pi c$ at which the junction is placed. However, because we are interested in the full problem extending from $-h/2 < z < h/2$ rather than the planar geometry with symmetry plane extending from $0 < y < h/2$, the result in (AV.25) must also be divided by two (the two identical capacitances are in series). Thus the total step capacitance of interest is

$$\Delta C_{\text{tot}} = \epsilon_o c \left[\frac{1}{p} (1+p)^2 \ln(1+p) - \frac{1}{p} (1-p)^2 \ln(1-p) - 2 \ln(4p) \right] \quad (\text{AV.26})$$

where $p = h/h'$.

APPENDIX VI. EFFECTIVE IMPEDANCE OF SALISBURY LOAD IMPEDANCE SHEET

The power absorbed in the impedance sheet, with real Z_{sS} , can be written as

$$P = \frac{1}{2} G_{\text{eff}} |V_{\text{tot}}|^2 = \frac{1}{2} \frac{2\pi c}{Z_{sS}} \int_{-h/2}^{h/2} |E_z|^2 dz \quad (\text{AVI.1})$$

where G_{eff} is an effective sheet conductance, V_{tot} is the voltage between the top and bottom plates, and we can take

$$Z_{\text{sS}}^{\text{eff}} = \frac{2\pi c}{hG_{\text{eff}}} \quad (\text{AVI.2})$$

where $Z_{\text{sS}}^{\text{eff}}$ is the effective sheet impedance, leading to the same absorbed power when the electric field has a uniform distribution.

If the sheet impedance is sufficiently large then the electric field distribution E_z approaches its form without the sheet present. This form was solved for by means of conformal mapping in the previous appendix. Note that the variable y replaces z in the conformal mapping solution. Here also we will make that replacement and write

$$Z_{\text{sS}}^{\text{eff}}/Z_{\text{sS}} = \frac{V^2/s}{\int_0^s E_y^2 dy} \quad (\text{AVI.3})$$

where $V_{\text{tot}} = 2V$ and V is the voltage from the top plate to the symmetry plane, $h/2 = s$, and symmetry of E_y about the symmetry plane has been used. Unfortunately, it is difficult to directly use the conformal mapping solution to carry out the integration in (AVI.3), because the integration contour is not on the conductors. Let us instead introduce the modal expansion

$$\phi = \frac{y}{s} V + \sum_{n=1}^{\infty} A_n e^{\frac{n\pi x}{s}} \sin\left(\frac{n\pi y}{s}\right) \quad (\text{AVI.4})$$

where

$$\underline{E} = -\nabla\phi \quad (\text{AVI.5})$$

The expansion (AVI.4) is to be used only in the region $x < 0$, $0 < y < s$. The change in height occurs at $x = 0$. The vertical electric field is given by

$$E_y = -\frac{V}{s} - \sum_{n=1}^{\infty} A'_n e^{\frac{n\pi}{s}x} \cos\left(\frac{n\pi}{s}y\right) \quad (\text{AVI.6})$$

where

$$A'_n = A_n \left(\frac{n\pi}{s}\right) \quad (\text{AVI.7})$$

Setting $x = 0$, inserting (AVI.6) into (AVI.3), and using the orthogonality of the modes yields

$$Z_{sS}^{\text{eff}}/Z_{sS} = \frac{1}{1 + \frac{1}{2} \sum_{n=1}^{\infty} A_n''^2} \quad (\text{AVI.8})$$

where

$$A_n'' = A'_n s/V \quad (\text{AVI.9})$$

The conformal mapping solution, from Appendix V yields

$$E_y = -\text{Re}\left(\frac{dW}{dz}\right) \quad (\text{AVI.10})$$

$$W = \frac{V}{\pi} \ln(z_1) \quad (\text{AVI.11})$$

$$z = \frac{s'}{\pi} \int_{-p^2}^{z_1} \sqrt{\frac{z_1 + p^2}{z_1 + 1}} \frac{dz_1}{z_1} + is \quad (\text{AVI.12})$$

where $p = s/s'$. Taking $y = s$ in (AVI.6) and in the above conformal mapping solution taking $z = x + is$ and $z_1 = x_1$ gives

$$E_y = -\frac{V}{s} - \sum_{n=1}^{\infty} A'_n (-1)^n e^{\frac{n\pi}{s}x} = -\frac{V}{s'} \sqrt{\frac{1 + x_1}{p^2 + x_1}} \quad (\text{AVI.13})$$

and from (AVI.12)

$$x = \frac{s'}{\pi} \int_{-p^2}^{x_1} \sqrt{\frac{x_1 + p^2}{x_1 + 1}} \frac{dx_1}{x_1} \quad (\text{AVI.14})$$

Multiplying (AVI.14) by $1/p$ and letting

$$u^2 = \frac{p^2 + x_1}{1 + x_1} \quad (\text{AVI.15})$$

gives

$$\begin{aligned}
x \frac{\pi}{s} &= -\frac{1}{p} \int_0^u \frac{(1-p^2) 2u^2}{(1-u^2)(p^2-u^2)} du \\
&= \int_0^u \left(-\frac{1}{p-u} - \frac{1}{p+u} + \frac{1/p}{1-u} + \frac{1/p}{1+u} \right) du \\
&= \ln\left(\frac{p-u}{p+u}\right) + \frac{1}{p} \ln\left(\frac{1+u}{1-u}\right)
\end{aligned} \tag{AVI.16}$$

Taking the exponential of both sides yields

$$e^{\frac{\pi}{s}x} = \left(\frac{p-u}{p+u}\right) \left(\frac{1+u}{1-u}\right)^{1/p} \tag{AVI.17}$$

Equation (AVI.13) can be written as

$$E_y = -\frac{Vp}{su} = -\frac{V}{s} - \sum_{n=1}^{\infty} A'_n (-1)^n (e^{\frac{\pi}{s}x})^n \tag{AVI.18}$$

If we take $z = \frac{p}{u}$ and $w = e^{\frac{\pi}{s}x}$, then these two equations take the form

$$w = q(z) = \left(\frac{z-1}{z+1}\right) \left(\frac{z+p}{z-p}\right)^{1/p} \tag{AVI.19}$$

$$z = g(w) = 1 + \sum_{n=1}^{\infty} A''_n (-1)^n w^n \tag{AVI.20}$$

The Lagrange inversion formula [A.9] can be used to determine the coefficients as

$$n! A_n'' (-1)^n = \frac{1}{(n-1)!} \frac{d^{n-1}}{d\zeta^{n-1}} \left[\frac{(\zeta-1)^n}{\{q(\zeta)\}^n} \right]_{\zeta=1} \quad (\text{AVI.21})$$

Inserting the function (AVI.19) thus yields

$$n! A_n'' (-1)^n = \frac{d^{n-1}}{d\zeta^{n-1}} \left[(\zeta+1)^n \left(\frac{\zeta-p}{\zeta+p} \right)^{n/p} \right]_{\zeta=1} \quad (\text{AVI.22})$$

The coefficients provided by (AVI.22) and (AVI.8) thus yields the effective sheet impedance.

Unfortunately the slow convergence of the resulting series, and the tedious nature of (AVI.22) for large n , forces one to consider the asymptotic nature of the coefficients for large n . The slow convergence results from the singular nature of the field as one approaches the edge at $x = 0$, $y = s$.

We can obtain the asymptotic form of the field E_y as $y \rightarrow s$ from the conformal mapping solution. As $z_1 \rightarrow -p^2$ in (AVI.12) we can use the approximations

$$\frac{1}{\sqrt{1+z_1}} \approx \frac{1}{\sqrt{1-p^2}} \left[1 - \frac{1}{2} \frac{(z_1 + p^2)}{(1-p^2)} + O((z_1 + p^2)^2) \right] \quad (\text{AVI.23})$$

$$\frac{1}{z_1} \approx -\frac{1}{p^2} \left[1 + \frac{(z_1 + p^2)}{p^2} + O((z_1 + p^2)^2) \right] \quad (\text{AVI.24})$$

Thus from (AVI.12)

$$\begin{aligned}
z - is &\sim -\frac{s'}{\pi p^2 \sqrt{1-p^2}} \int_{-p^2}^{z_1} \sqrt{z_1 + p^2} \left[1 + \frac{(1-3p^2/2)}{p^2(1-p^2)} (z_1 + p^2) + O((z_1 + p^2)^2) \right] dz_1 \\
&\sim -\frac{s'}{\pi p^2 \sqrt{1-p^2}} \frac{2}{3} (z_1 + p^2)^{3/2} \left[1 + \frac{3}{5} \frac{(1-3p^2/2)}{p^2(1-p^2)} (z_1 + p^2) + O((z_1 + p^2)^2) \right]
\end{aligned} \tag{AVI.25}$$

where $0 < \arg(z_1 + p^2) < \pi$. Therefore setting $z = iy$ and solving for $\sqrt{z_1 + p^2}$ gives

$$\begin{aligned}
\sqrt{z_1 + p^2} &\sim e^{i\pi/6} \left[\frac{3\pi}{2s'} p^2 \sqrt{1-p^2} (s-y) \right]^{1/3} \left[1 - \frac{1}{5} \frac{(1-3p^2/2)}{p^2(1-p^2)} e^{i\pi/3} \right. \\
&\quad \left. \left[\frac{3\pi}{2s'} p^2 \sqrt{1-p^2} (s-y) \right]^{2/3} + O((s-y)^{4/3}) \right]
\end{aligned} \tag{AVI.26}$$

From (AVI.11), (AVI.12), and (AVI.23)

$$\begin{aligned}
\frac{dW}{dz} &= \frac{V}{s'} \sqrt{\frac{z_1 + 1}{z_1 + p^2}} \\
&\sim \frac{V}{s'} \sqrt{1-p^2} \frac{1}{\sqrt{z_1 + p^2}} \left[1 + \frac{1}{2} \frac{(z_1 + p^2)}{(1-p^2)} + O((z_1 + p^2)^2) \right]
\end{aligned} \tag{AVI.27}$$

Using (AVI.26) in (AVI.27) gives

$$\begin{aligned} \frac{dW}{dz} \sim e^{-i\pi/6} \frac{V}{s} \sqrt{1-p^2} \left[\frac{3\pi}{2s} p^2 \sqrt{1-p^2} (s-y) \right]^{-1/3} \left[1 + \frac{1}{5} \frac{(1+p^2)}{p^2(1-p^2)} e^{i\pi/3} \right. \\ \left. \left[\frac{3\pi}{2s} p^2 \sqrt{1-p^2} (s-y) \right]^{2/3} + O((s-y)^{4/3}) \right] \end{aligned} \quad (\text{AVI.28})$$

Thus the asymptotic form of the electric field at the edge from (AVI.10) is

$$E_y(x=0) \sim -E_0 (s-y)^{-1/3} - E_1 (s-y)^{1/3} + O(s-y) \quad (\text{AVI.29})$$

where $y \rightarrow s$ and

$$E_0 = \frac{V}{s} \sqrt{\frac{3}{2}} \sqrt{1-p^2} \left[\frac{3\pi}{2s} p^2 \sqrt{1-p^2} \right]^{-1/3} \quad (\text{AVI.30})$$

$$E_1 = \frac{V}{s} \sqrt{\frac{3}{10}} \frac{(1+p^2)}{p^2 \sqrt{1-p^2}} \left[\frac{3\pi}{2s} p^2 \sqrt{1-p^2} \right]^{1/3} \quad (\text{AVI.31})$$

Using orthogonality to invert (AVI.6), at $x=0$, we obtain

$$A_n'' = -\frac{2}{V} \int_0^s E_y(x=0) \cos\left(\frac{n\pi}{s}y\right) dy \quad (\text{AVI.32})$$

where (AVI.9) has been used. Noting the asymptotic form of $E_y(x=0)$ as $y \rightarrow s$ (AVI.29), the asymptotic form of A_n'' as $n \rightarrow \infty$ is given by [A.10]

$$A_n'' \sim \frac{2}{V} \left[\Gamma\left(\frac{2}{3}\right) \cos\left(-\frac{\pi}{3} + n\pi\right) E_0 \left(\frac{n\pi}{s}\right)^{-2/3} + \Gamma\left(\frac{4}{3}\right) \cos\left(-\frac{2\pi}{3} + n\pi\right) E_1 \left(\frac{n\pi}{s}\right)^{-4/3} + O(n^{-2}) \right] \quad (\text{AVI.33})$$

Note that the $O(n^{-2})$ results only from the end point $y = s$. Inserting (AVI.31) and (AVI.32) gives

$$A_n'' (-1)^n \sim \frac{3^{1/6}}{2^{2/3} \pi} \Gamma\left(\frac{2}{3}\right) (1 - p^2)^{1/3} n^{-2/3} - \frac{\Gamma\left(\frac{1}{3}\right)}{3^{1/6} 2^{1/3} 10 \pi (1 - p^2)^{1/3}} n^{-4/3} + O(n^{-2}) \quad (\text{AVI.34})$$

Evaluating the constants in (AVI.34) gives

$$A_n'' (-1)^n \sim 0.32609201 (1 - p^2)^{1/3} n^{-2/3} - 0.05635719 \frac{(1 + p^2)}{(1 - p^2)^{1/3}} n^{-4/3} + O(n^{-2}) \quad (\text{AVI.35})$$

Inserting the value

$$p = h/h' = 0.79495942 \quad (\text{AVI.36})$$

from (II.3) and (II.9) gives

$$A_n'' (-1)^n \sim 0.23368902 n^{-2/3} - 0.12833964 n^{-4/3} + O(n^{-2}) \quad (\text{AVI.37})$$

Table AVI.1 gives the evaluation of (AVI.22) for A_n'' from $n = 1$ to $n = 23$. This table was created by using the symbolic manipulation software Mathematica. The structure of the table is as follows: first the expression for A_n'' from (AVI.22) is given for general parameter p ; next n is given followed by the value of A_n'' with the value (AVI.36); finally the value of the sum $\sum_{k=1}^n A_k''^2$ is given. Using (AVI.37) for $n = 23$ we obtain

$$A_{23}'' \sim -0.02693269 \quad (\text{AVI.38})$$

The last value of n in the table gives

$$A_{23}'' = -0.026939469 \quad (\text{AVI.39})$$

The sum from the last entry in the table is

$$\sum_{n=1}^{23} A_n''^2 = 0.071904653 \quad (\text{AVI.40})$$

If we let $O(n^{-2}) = D/n^2$ and estimate D from the difference between (AVI.38) and (AVI.39) we obtain $D \approx 0.0035848$. This empirical term will be used as a gauge of the error. We first note the Euler–Maclaurin sum formula [A.11] can be written as

$$S_N = \sum_{n=N}^{\infty} f(n) \sim \int_N^{\infty} f(x) dx + \frac{1}{2} f(N) - \sum_{m=1}^{\infty} \frac{B_{2m}}{(2m)!} f^{(2m-1)}(N), \quad N \rightarrow \infty \quad (\text{AVI.41})$$

where B_{2m} are the Bernoulli numbers. Applying this formula gives

$$S_N = \sum_{n=N}^{\infty} n^{-\alpha} \sim N^{1-\alpha} \left[\frac{1}{\alpha-1} + \frac{1}{2} N^{-1} + \sum_{m=1}^{\infty} \frac{B_{2m}}{(2m)!} (\alpha)_{2m-1} N^{-2m} \right], N \rightarrow \infty \quad (\text{AVI.42})$$

where $(\alpha)_{2m-1} = \alpha(\alpha+1) \dots (\alpha+2m-2)$. This can be written as

$$S_N \sim N^{1-\alpha} \left[\frac{1}{\alpha-1} + \frac{1}{2} N^{-1} + \frac{\alpha}{12} N^{-2} + O(N^{-4}) \right], N \rightarrow \infty \quad (\text{AVI.43})$$

Using (AVI.37) we can write

$$S_{24}'' = \sum_{n=24}^{\infty} A_n''^2 \sim (0.23368902)^2 \sum_{n=24}^{\infty} n^{-4/3} \left[1 - 2(0.54918985) n^{-2/3} + \{(0.54918985)^2 + 2(0.01534004)\} n^{-4/3} \right] \quad (\text{AVI.44})$$

where the last numerical value results from the empirical term D/n^2 . Using (AVI.43), this can be written as

$$S_{24}'' \approx (0.05461056) \left[1.04733130 - 0.04673252 + \{0.30160949 + 0.03068009\} 0.00311095 \right] \quad (\text{AVI.45})$$

It appears possible to calculate S_{24}'' to approximately four significant figures. Therefore, from (AVI.45), we obtain

$$S_{24}'' \approx 0.05470 \quad (\text{AVI.46})$$

Adding (AVI.40) and (AVI.46) gives

$$S = \sum_{n=1}^{\infty} A_n''^2 \approx 0.1266 \quad (\text{AVI.47})$$

From (AVI.8) the effective impedance is thus

$$Z_{sS}^{\text{eff}}/Z_{sS} = \frac{1}{1 + S/2} \approx 0.940 \quad (\text{AVI.48})$$

Thus there is a 6% decrease in the value of the impedance sheet in the high impedance limit with the dimension (AVI.36).

APPENDIX VII. POST TRANSFORMATION OF SAMPLE IMPEDANCE REFERENCE CYLINDERS

Section VIII gave the transformation to be applied to the surface impedance Z_s at reference location $\rho = c$ to obtain the surface impedance Z_s' at reference location $\rho = c'$. The purpose of this final transformation is to obtain the surface impedance at the actual radial location of the sample free surface. The original analysis, in general, yields a fictitious surface impedance Z_s , because $\rho = c$ may be either less than or greater than the actual sample free surface at $\rho = c'$. This appendix discusses the rationale behind this procedure.

Consider the two networks in Figure AVII.1. The first network is characterized by the transformation

$$Z_{i1} = \frac{PZ_{l2} + Q}{RZ_{l2} + 1} \quad (\text{AVII.1})$$

where Z_{i1} is the input impedance at port 1 and Z_{l2} is the load impedance at port 2. The second network is characterized by the transformation

$$Z_{i3} = \frac{EZ_{l4} + F}{GZ_{l4} + 1} \quad (\text{AVII.2})$$

where Z_{i3} is the input impedance at port 3 and Z_{l4} is the load impedance at port 4. We have in mind that the first port (Z_{i1}) represents the coaxial port on the radial transmission line measurement apparatus, that the location of the second and third ports ($Z_{l2} = Z_{i3}$) will be specified below, and that port 4 represents the reference surface of the calibration loads. Attaching the two networks together ($Z_{l2} = Z_{i3}$) gives the overall transformation

$$Z_{i1} = \frac{AZ_{l4} + B}{CZ_{l4} + 1} \quad (\text{AVII.3})$$

where

$$A = \frac{PE + QG}{1 + RF}; B = \frac{PF + Q}{1 + RF}; C = \frac{RE + G}{1 + RF} \quad (\text{AVII.4})$$

Now suppose A, B, and C are determined experimentally by measuring three full standards as discussed previously. Let us further assume that E, F, and G can be easily calculated (radial transmission line theory). However let P, Q, and R be unknown or at least difficult to calculate (coax to radial transmission line junction). Next let an unknown structure X (the sample to be measured) be inserted into the E, F, G network such that the second and third ports ($Z_{l2} = Z_{i3}$) represent the actual surface of the sample, and let Z_{i1x}

be measured. If P, Q, and R were known we can invert (AVII.1) to give

$$Z_{i3x} = Z_{l2x} = \frac{Z_{i1x} - Q}{P - RZ_{i1x}} \quad (\text{AVII.5})$$

Instead let us invert (AVII.3) (even though it no longer characterizes the complete network) to obtain the fictitious load

$$Z_{l4f} = \frac{Z_{i1x} - B}{A - CZ_{i1x}} \quad (\text{AVII.6})$$

Note that if the load (AVII.6) were applied to port 4 with the structure X removed, we would measure the same input impedance Z_{i1x} at port 1. Now we apply (AVII.2) (with the original calculable parameters E, F, G) to (AVII.6)

$$Z_{i3f} = \frac{EZ_{l4f} + F}{GZ_{l4f} + 1} = Z_{i3x} \quad (\text{AVII.7})$$

where the second identity follows by inserting (AVII.6) and the definitions (AVII.4) to show that (AVII.7) is identical to (AVII.5). Of course we could have also carried through the above analysis with the beginning bilinear transformations, (AVII.1), (AVII.2), and (AVII.3), inverted to correspond more closely with the main body of the report. The conclusions are obviously the same.

APPENDIX VIII. MECHANICAL DRAWINGS OF APPARATUS

Figures AVIII.1 through AVIII.3 show the assembly and detail drawings of the radial line reference short and two offset shorts which may be used to characterize the

radial-line/coaxial-line junction (RL/CL J). (The reference shorts were discussed in sections II, VI, and IX.) Due to the mechanical similarity of the three shorts, the tabular definition system appearing on sheet 1 of drawing R36877 was used to describe the three shorts.

The terminal cylinder at the radial port of the coax-to-radial-line transition was defined by the 4 inch inner radius of the reference shorting barrel (PN R36297-009) as embodied in assembly R36297-200. Replacing the reference shorting barrel by a radial load of interest constitutes a terminated RL/CL J.

In the absence of a repeatable, reliable connector at the radial port of the transition, each offset short was constructed with its own, built-in RL/CL J. (See assemblies R36297-000 and R36297-100.) As justified by the small tolerances on the critical dimensions of each assembly, the following measurement assumption was made: The actual impedance, Z_9 , measured at the coax port of, say, the 9-inch radius offset short assembly was assumed to be identical to the impedance, $Z_{4,5}$, that would be measured at the coax port of the actual RL/CL J which was terminated at its (4-inch radius) radial line port by a radial short 5 inches away. Of course this would require that a PERFECT radial line connector exist at the 4 inch radius port.

Figures AVIII.4 through AVIII.6 are the assembly and detail drawings of the radial Salisbury load which was discussed in Sections II, VII, and IX. The Salisbury load also incorporated its own built-in RL/CL J for the same reasons discussed above.

Items 6, 7, and 8 (as defined on drawing R36877) facilitate mounting the resistive film to the outer peripheries of items 3 and 4. The assembly procedure is outlined as follows:

1. The radial load is fully assembled as shown at the bottom of sheet 1 EXCEPT that the resistive film is not mounted and the six plugs (item 6) are not installed.
2. Three of item 8 are fully threaded into the three .25-20 holes in item 3.

3. Using item 5, the outer conductor of a 5 (4.9967) cm air line is assembled on item 4.
4. The center conductor from a 10 (9.9771) cm air line is inserted through the 5 (4.9967) cm air line outer conductor and seated in the .043 diameter hole in item 3.
5. Two .25–20 nuts are screwed fully onto each item 7.
6. Each item 7 is then threaded into a .25–20 hole in item 4.
7. The three item 7's are adjusted until the end of the fully seated center conductor is flush with the end of the outer conductor of the 5 cm air line.
8. The two nuts on each item 7 are tightened to lock each item 7 into the adjusted position.
9. Item 1 is carefully removed from the assembly and temporarily set aside.
10. Three strips of resistive film (of the user's choice — typically 377 ohms per square) are cut to be 8.38 inches long and approximately $2 \frac{7}{32}$ inch wide.
11. The three strips are then mounted (with the conductive side facing the center of the assembly) to the peripheries of items 3 and 4 to form a closed cylinder of 8 inch diameter. (Small pieces of removable Scotch tape may be used to hold the film strips in place until step 12 is completed.)

12. Secure the films to the peripheries of items 3 and 4 with 7 by 1/8 inch elastic bands.
13. Carefully re-install item 1 to the assembly.
14. Stand the assembly on edge and remove items 7 and 8 from the assembly.
15. Install each item 6 into its marked .25–20 hole.
16. Keep the assembly on edge as much as possible – particularly during measurements.

All parts of the radial shorts and radial load (except for the resistive film and air lines) were constructed of brass to facilitate possible silver plating to reduce the effects of parasitic losses in the reference shorts and load.

APPENDIX IX. COMPUTER SOFTWARE LISTINGS

This appendix includes listings of RLMS_a1 (see listing AIX.1), the auxiliary code SEQ.BAT, and the source code WILL.FOR (see listing AIX.2).

RLMS_a1 was written in HP BASIC 5.0 to run on an HP QS/20 Vectra computer equipped with an HP 82300C language processor co-processor board. It occupies 170 kilobytes of memory on the co-processor board. Further details of the environment required by RLMS_a1 are given in the user's guide which appears as comments at the beginning of the source code listing of RLMS_a1.

SEQ.BAT is a two-line MS-DOS batch file which calls executable file WILL.EXE (whose source is written in FORTRAN) then places HP BASIC back into foreground mode.

The two commands in SEQ.BAT are:

C:\ DOS\WILL.EXE

C:\ BLP\BASIC

APPENDIX X. EFFECT OF AIR GAPS AT SALISBURY LOAD IMPEDANCE SHEET TERMINATIONS

Figure AX.1 shows the upper half of the step region of the Salisbury load. Note that the impedance sheet Z_{sS} was originally attached by dielectric tape at the midpoint of the step (it is assumed, however, that no contact is made at this attachment point, but, of course, the capacitance is large here). Figure AX.1 also shows this step region expanded with an assumed linear air gap of maximum dimension g , minimum dimension Δ , and extent $w = (s' - s)/2$. Figure AX.2 shows an R-L-C ladder network transmission line model of this region. The capacitance and resistance per unit length can be written as

$$C = \frac{2\pi c \epsilon_0}{g(1 - z/w) + \Delta(z/w)} \quad (\text{AX.1})$$

$$R = \frac{Z_{sS}}{2\pi c} \quad (\text{AX.2})$$

where c is the radius of the step and $0 < z < w$. The inductance per unit length is determined by (AX.1) and $LC = \mu_0 \epsilon_0$. The propagation constant along the transmission line $e^{-j\gamma z}$ (assuming L and C are independent of z or slowly varying) is

$$\gamma = \sqrt{-j\omega C(R + j\omega L)} \approx (1 - j) \sqrt{\omega CR/2}, \quad R \gg \omega L \quad (\text{AX.3})$$

The decay length (this is being used even with varying C to obtain a feel for the size of the decay length) is thus

$$\sqrt{\frac{2}{\omega CR}} = \sqrt{\frac{2[(1 - z/w)g + \Delta(z/w)]}{\omega \epsilon_o Z_{sS}}} \quad (\text{AX.4})$$

Taking average parameters $f = (100 + 200)/2 = 150$ MHz, $z = w/2$, and assuming values $Z_{sS} = \eta_o \approx 120\pi$ ohms, $w = 1/8$ inches, $g = 0.01$ inches, and $\Delta = 0.001$ inches (equal to the sheet thickness), gives

$$\sqrt{\frac{2}{\omega CR}} \approx 0.37 \text{ inches} \quad (\text{AX.5})$$

Because this decay length is several times larger than w , it is reasonable to ignore the decay and take the voltage along the R-C transmission line to be approximately uniform.

The transmission line equations (ignoring ωL compared to L) are

$$\frac{dV}{dz} = -RI \quad (\text{AX.6})$$

$$\frac{dI}{dz} = -j\omega C(z)V \quad (\text{AX.7})$$

Eliminating I gives the second order equation

$$\left[\frac{d^2}{dz^2} - j\omega C(z)R \right] V = 0 \quad (\text{AX.8})$$

The boundary conditions are

$$I(w) = 0 \quad (\text{AX.9})$$

$$V(0) = A \quad (\text{AX.10})$$

Because the decay length is large compared to w , we can regard the term $j\omega C(z)R$ as a small perturbation. Expanding V and I in asymptotic series

$$V = V_0 + V_1 + V_2 + \dots \quad (\text{AX.11})$$

$$I = I_0 + I_1 + I_2 + \dots \quad (\text{AX.12})$$

we obtain

$$\frac{d^2}{dz^2} V_n = j\omega C(z)R V_{n-1} = -R \frac{d}{dz} I_n \quad (\text{AX.13})$$

where for $n = 0$ we take $V_{-1} = 0$. Thus, using (AX.9) and (AX.10), the leading term is

$$V_0 = A \quad (\text{AX.14})$$

and from (AX.6)

$$I_0 = 0 \quad (\text{AX.15})$$

From (AX.14), (AX.13), and from (AX.9) noting that $I_n(w) = 0$, the next term of the current is

$$I_1 = -j\omega A \int_w^z C(z') dz' \quad (\text{AX.16})$$

Using (AX.16) in (AX.13), and noting from (AX.10) that $V_n(0) = 0$ for $n = 1, 2, \dots$, gives

$$V_1 = j\omega R A \int_0^z \int_w^{z'} C(z'') dz'' dz' \quad (\text{AX.17})$$

Integration by parts yields

$$\begin{aligned} V_1 &= -j\omega R A \left[z \int_z^w C(z') dz' + \int_0^z z' C(z') dz' \right] \\ &= -j\omega R A \int_0^w z_{<} C(z') dz' \end{aligned} \quad (\text{AX.18})$$

where $z_{<} = \min(z, z')$. From (AX.13) with $n = 2$, we obtain

$$I_2 = -\omega^2 R A \int_w^z C(z') \int_0^w z_{<} C(z'') dz'' dz' \quad (\text{AX.19})$$

where $z_{<} = \min(z', z'')$ in this equation. Integration by parts yields

$$I_2 = \omega^2 R A \left[\int_z^w C(z') dz' \int_0^w z_{<} C(z') dz' + \int_z^w \left[\int_{z'}^w C(z'') dz'' \right]^2 dz' \right] \quad (\text{AX.20})$$

where here again $z_{<} = \min(z, z')$. Taking $z = 0$ we obtain

$$Y_{\text{tot}} = I(0)/A = [I_1(0) + I_2(0) + \dots]/A$$

$$\approx j\omega C_{\text{tot}} + G_{\text{tot}} \quad (\text{AX.21})$$

where

$$C_{\text{tot}} = \int_0^w C(z) dz \quad (\text{AX.22})$$

$$G_{\text{tot}} = R \omega^2 \int_0^w \left[\int_z^w C(z') dz' \right]^2 dz \quad (\text{AX.23})$$

Note that (AX.23) could have been obtained from the dissipated power

$$P_{\text{diss}} = \frac{1}{2} G_{\text{tot}} |V(0)|^2 \approx \frac{1}{2} R \int_0^w |I_1(z)|^2 dz \quad (\text{AX.24})$$

Considering the case where $C(z) = C = \text{constant}$ we obtain

$$C_{\text{tot}} = Cw \quad (\text{AX.25})$$

$$G_{\text{tot}} = (\omega C w)^2 \left(\frac{1}{3} R w\right) \quad (\text{AX.26})$$

The equivalent series circuit can be written as in Figure AX.2 with total series resistance

$$R_{\text{tot}} = \frac{1}{3} R w \quad (\text{AX.27})$$

If the capacitance per unit length increases with increasing z as truly expected then for a given total capacitance C_{tot} there will be a greater dissipation and therefore a greater R_{tot} (of course $R_{\text{tot}} \leq R w$). This increase is to some extent offset by the expected decrease in the effective sheet impedance $Z_{\text{SS}}^{\text{eff}}$ resulting from the step change in the height, as discussed in Appendix AVI. Note that the total capacitance from (AX.22) of the linear profile (AX.1) is $C_{\text{tot}} = 2\pi c(w/g_{\text{eff}})\epsilon_o$ where $g_{\text{eff}} = (g - \Delta)/\ln(g/\Delta)$. The capacitance with a uniform profile of gap g is $C_{\text{tot}} = 2\pi c(w/g)\epsilon_o$.

Let us therefore use this constant C case to see what the size of $1/(\omega C_{\text{tot}})$ is compared to the one half (because we are only considering the geometry above the symmetry plane) the total resistive sheet impedance

$$Z_{\text{tot}} = \left(\frac{s}{2\pi c}\right) Z_{\text{SS}} \quad (\text{AX.28})$$

Taking $Z_{\text{SS}} \approx \eta_o \approx 377$ ohms (the nominal manufacturers value), midpoint frequency 150 MHz, $w \approx 1/8$ inches, $s = h/2 = 1.861/2$ inches, and assuming a uniform gap $g \approx 0.001$ inches (thickness of resistive sheet) gives $1/(\omega C_{\text{tot}}) = \left(\frac{s}{2\pi c}\right)\left(\frac{g/w}{\omega \epsilon_o s}\right) \approx \left(\frac{s}{2\pi c}\right)$ (40 ohms). Note that the resistive component from (AX.2) and (AX.27) is $R_{\text{tot}} = \left(\frac{s}{2\pi c}\right) Z_{\text{SS}} \left(\frac{w}{3s}\right) \approx \left(\frac{s}{2\pi c}\right)$ (17 ohms). Thus, if g is substantially larger than the thickness of the resistive sheet, this capacitance substantially increases the surface impedance of the sheet load. Alternatively, if g is substantially less than the thickness of the resistive sheet, this capacitance can be

treated as a short.

The addition of the elastically loaded plastic tape should reduce this gap to the point where either contact is made or the capacitance is so large that contact is not essential. Furthermore the addition of the vapor deposited gold edges, which are placed exactly dimension h apart, fix the total resistance of the sheet at twice the value (AX.28).

APPENDIX REFERENCES

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Figure I.1. Three dimensional view of radial transmission line material measurement apparatus.

Figure I.2. Cross section of radial transmission line material measurement apparatus.

Figure II.1. Geometry of mechanical junction between coaxial air line and radial line.

Figure II.2. Cross section of Salisbury load.

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 50$ MHz, $\text{Re}(Y)$ (Siemens)

(a)

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 50$ MHz, $-\text{Im}(Y)$ (Siemens)

(b)

Figure III.1. Analytical predictions of input coaxial admittance as a function of radial load surface impedance for 50 MHz. a) Real part of admittance. b) Imaginary part of admittance.

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 100$ MHz, $\text{Re}(Y)$ (Siemens)

(a)

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 100$ MHz, $-\text{Im}(Y)$ (Siemens)

(b)

Figure III.2. Analytical predictions of input coaxial admittance as a function of radial load surface impedance for 100 MHz. a) Real part of admittance. b) Imaginary part of admittance.

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 150$ MHz, $\text{Re}(Y)$ (Siemens)

(a)

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 150$ MHz, $\text{Im}(Y)$ (Siemens)

(b)

Figure III.3. Analytical predictions of input coaxial admittance as a function of radial load surface impedance for 150 MHz. a) Real part of admittance, b) Imaginary part of admittance.

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 200$ MHz, $\text{Re}(Y)$ (Siemens)

(a)

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 200$ MHz, $\text{Im}(Y)$ (Siemens)

(b)

Figure III.4. Analytical predictions of input coaxial admittance as a function of radial load surface impedance for 200 MHz. a) Real part of admittance, b) Imaginary part of admittance.

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 50$ MHz, $\text{Re}(R)$

(a)

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 50$ MHz, $-\text{Im}(R)$

(b)

Figure III.5. Analytical predictions of input coaxial reflection coefficient as a function of radial load surface impedance for 50 MHz. a) Real part of reflection coefficient, b) Imaginary part of reflection coefficient.

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 100$ MHz, $\text{Re}(R)$

(a)

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 100$ MHz, $-\text{Im}(R)$

(b)

Figure III.6. Analytical predictions of input coaxial reflection coefficient as a function of radial load surface impedance for 100 MHz. a) Real part of reflection coefficient, b) Imaginary part of reflection coefficient.

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 150$ MHz, $\text{Re}(R)$

(a)

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 150$ MHz, $\text{Im}(R)$

(b)

Figure III.7. Analytical predictions of input coaxial reflection coefficient as a function of radial load surface impedance for 150 MHz. a) Real part of reflection coefficient, b) Imaginary part of reflection coefficient.

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 200$ MHz, $\text{Re}(R)$

(a)

$2a = 0.244/2$ inch, $2b = 0.5625/2$ inch, $c = 4$ inch, $h = 2$ inch
 $f = 200$ MHz, $-\text{Im}(R)$

(b)

Figure III.8. Analytical predictions of input coaxial reflection coefficient as a function of radial load surface impedance for 200 MHz. a) Real part of reflection coefficient, b) Imaginary part of reflection coefficient.

$2a = 0.244/2$ inches, $2b = 0.5625/2$ inches, $c = 4$ inches, $h = 2$ inches

$f = 50$ MHz, $|\Delta R| = \pm 0.007$, $\arg(\Delta R) = \pm 1$ degree

Figure IV.1. Maximum uncertainties (assuming maximum uncertainties in the coaxial reflection coefficient) in the real and imaginary parts of the radial surface impedance as a function of the radial load surface impedance for 50 MHz.

$$2a = 0.244/2 \text{ inches}, 2b = 0.5625/2 \text{ inches}, c = 4 \text{ inches}, h = 2 \text{ inches}$$

$$f = 100 \text{ MHz}, |\Delta R| = \pm 0.007, \arg(\Delta R) = \pm 1 \text{ degree}$$

Figure IV.2. Maximum uncertainties (assuming maximum uncertainties in the coaxial reflection coefficient) in the real and imaginary parts of the radial surface impedance as a function of the radial load surface impedance for 100 MHz.

$2a = 0.244/2$ inches, $2b = 0.5625/2$ inches, $c = 4$ inches, $h = 2$ inches

$f = 150$ MHz, $|\Delta R| = \pm 0.007$, $\arg(\Delta R) = \pm 1$ degree

Figure IV.3. Maximum uncertainties (assuming maximum uncertainties in the coaxial reflection coefficient) in the real and imaginary parts of the radial surface impedance as a function of the radial load surface impedance for 150 MHz.

$$2a = 0.244/2 \text{ inches}, 2b = 0.5625/2 \text{ inches}, c = 4 \text{ inches}, h = 2 \text{ inches}$$

$$f = 200 \text{ MHz}, |\Delta R| = \pm 0.007, \arg(\Delta R) = \pm 1 \text{ degree}$$

Figure IV.4. Maximum uncertainties (assuming maximum uncertainties in the coaxial reflection coefficient) in the real and imaginary parts of the radial surface impedance as a function of the radial load surface impedance for 200 MHz.

RADIAL LINE MEASUREMENT SYSTEM

DGAL CJS U1 RADLINE.GAL

Figure X.1. Block diagram of measurement system hardware.

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

2 of 2

Figure A.2. Photograph of three out of six metal and plastic discs for the step height measurement of the film surface.

Figure X.3 Photograph of the Hewlett-Packard 8753C vector network analyzer and the 4 inch offset short

Figure N.4. Photograph of the Hewlett Packard 8753C vector network analyzer, HP QS/20

Vectra computer, printer, and 1 inch offset short.

```

RLMS_a1:,1500,1
NAME                               SIZE  TYPE
=====
MAIN                               10652 BASIC
Meas_abc_par                       4016 BASIC
Acq_meas_p                        10450 BASIC
Sup_fil_id                        5118 BASIC
Mf_gen                            4820 BASIC
Mf_vf_fit                         3070 BASIC
Acq_8753_dat                      3794 BASIC
Choose_cals                      4172 BASIC
Acq_dat_abc_par                   8496 BASIC
Comdef                           7584 BASIC
Radial_line                       4702 BASIC
FNZi                              2564 BASIC
Abc_anharm                        2224 BASIC
FNBilinear                        976 BASIC
FNStp_cap_wk                     1736 BASIC
Salis_ld_z                       4952 BASIC
FNStep_cap_w                     1234 BASIC
Type_abc_rept                    4232 BASIC
Z_via_abc                       4114 BASIC
Acqdat_zmeas                     2984 BASIC
Fmatch_abc_file                  3384 BASIC
Type_lod_z_rept                  4450 BASIC
Z_dos_dat_fil                   5496 BASIC
FNAng2                           686 BASIC
Z_via_will                       7202 BASIC
Abc_dos_dat_fil                  4378 BASIC
Raw_z_dos_dat                   4366 BASIC
Z_r_xform                       3794 BASIC
Dum_sub1                         234 BASIC
Dum_sub2                         284 BASIC
Dum_sub3                         344 BASIC
Code_list                       1458 BASIC
FNBlp_lock                       2024 COMPILED UTILITY
Blp_enable                       1494 COMPILED UTILITY
FNBlp_background                 984 COMPILED UTILITY
Blp_send                         2120 COMPILED UTILITY
Blp_send_key                     1652 COMPILED UTILITY
AVAILABLE ENTRIES = 0

```

Figure XI.1. Directory of BASIC 5.1 program RLMS_a1.

ENTER CODE OF YOUR CHOICE

CODE OPERATION TO BE PERFORMED

1. For the model $Z_s = (a*Z_m + b)/(c*Z_m + 1)$, determine the a,b,c parameters of a coax-to-radial line transition at frequencies of choice and store in BDAT format on a HP LIF volume and, optionally, on a DOS format volume. (Z_m is measured impedance at the coax/radial line (C/RL) interface; Z_s is the surface impedance at the radial port.)
2. Measure surface and total impedance seen by radial line test port, at frequencies of choice, using a,b,c parameters.
3. Measure surface impedance seen by radial line test port, at frequencies of choice, using Williamson theory.
4. Compute the theoretical impedances looking outward from the radial line port into a radial line Salisbury screen at the frequencies of choice.

Figure XI.2. Main menu options of BASIC 5.1 program RLMS_a1.

DATA SHEET

Test Fixture Serial Number: 1

Property Number: 00000

Owner: 4342

Measured: 11 May 1992

Measured abc parameters of transformation $Z_s = (a*Z_m + b)/(c*Z_m + 1)$ are:

Frequency	a		b		c	
100.00	.1959E+02	-.4150E+00	-.1139E+02	-.4950E+03	-.1141E-02	-.1775E-01
110.00	.1937E+02	-.3891E+00	-.1194E+02	-.5393E+03	-.9770E-03	-.1612E-01
120.00	.1948E+02	-.3515E+00	-.1168E+02	-.5930E+03	-.8331E-03	-.1550E-01
130.00	.1945E+02	-.4515E-01	-.3020E+01	-.6451E+03	-.2155E-03	-.1485E-01
140.00	.1940E+02	-.2221E+00	-.9492E+01	-.6939E+03	-.5183E-03	-.1423E-01
150.00	.1952E+02	-.8971E-01	-.5307E+01	-.7497E+03	-.2542E-03	-.1403E-01
160.00	.1963E+02	-.3182E+00	-.1536E+02	-.8069E+03	-.6028E-03	-.1391E-01
170.00	.1980E+02	.4611E-01	-.4191E+00	-.8681E+03	-.3288E-04	-.1395E-01
180.00	.1998E+02	-.1714E-01	-.2981E+01	-.9314E+03	-.9499E-04	-.1401E-01
190.00	.2036E+02	-.5334E-01	-.4488E+01	-.1005E+04	-.1447E-03	-.1442E-01
200.00	.2081E+02	-.6713E-01	-.5548E+01	-.1085E+04	-.1487E-03	-.1496E-01

C:\BLP>type A:ABCPMA11.DAT

11, 1 ! No. Freqs, Measurement option

1, 00000 ! SN, Prop No.

4342, 11 May 1992 ! Owner, Meas. date

100.0,	19.593,	-.415,	-11.394,	-494.998,	-.001,	-.018
110.0,	19.367,	-.389,	-11.938,	-539.325,	-.001,	-.016
120.0,	19.478,	-.352,	-11.682,	-592.966,	-.001,	-.016
130.0,	19.454,	-.045,	-3.020,	-645.091,	-0.000,	-.015
140.0,	19.399,	-.222,	-9.492,	-693.861,	-.001,	-.014
150.0,	19.515,	-.090,	-5.307,	-749.689,	-0.000,	-.014
160.0,	19.626,	-.318,	-15.356,	-806.886,	-.001,	-.014
170.0,	19.799,	.046,	-.419,	-868.091,	-0.000,	-.014
180.0,	19.982,	-.017,	-2.981,	-931.435,	-0.000,	-.014
190.0,	20.363,	-.053,	-4.488,	-1005.416,	-0.000,	-.014
200.0,	20.814,	-.067,	-5.548,	-1085.361,	-0.000,	-.015
Freq	REAL(a)	IMAG(a)	REAL(b)	IMAG(b)	REAL(c)	IMAG(c)

C:\BLP>

Figure XI.3. Hard-copy report and DOS file printout of ABC parameters.

DATA SHEET

Item: Salisbury Load #2 w/o space cloth in vertical position

Item Serial Number: 2

Measured: 9 May 1992

The impedances (as measured by the abc technique) are as follows:

Frequency	Z _t		Z _{p_sq}	
	Mag.	Ang.	Mag.	Ang.
100.00	10.61	89.80	143.25	89.80
110.00	11.82	89.83	159.69	89.83
120.00	13.11	89.79	177.11	89.79
130.00	14.45	89.84	195.11	89.84
140.00	15.86	89.86	214.17	89.86
150.00	17.38	89.87	234.73	89.87
160.00	18.97	89.93	256.24	89.93
170.00	20.73	89.97	279.90	89.97
180.00	22.62	89.97	305.52	89.97
190.00	24.71	89.96	333.68	89.96
200.00	27.02	89.97	364.89	89.97

Figure XI.4. Typical output of measured surface impedances using the ABC parameter method.

DATA SHEET

Item: Salisbury Load #2 w/o space cloth in vertical position

Item Serial Number: 2

Measured: 9 May 1992

The impedances (as measured by the Williamson technique) are as follows:

Frequency	Z _t		Z _{p_sq}	
	Mag.	Ang.	Mag.	Ang.
100.00	10.71	89.51	144.61	89.51
110.00	11.94	89.54	161.20	89.54
120.00	13.22	89.63	178.58	89.63
130.00	14.69	89.45	198.42	89.45
140.00	16.10	89.52	217.38	89.52
150.00	17.61	89.50	237.79	89.50
160.00	19.24	89.50	259.89	89.50
170.00	21.03	89.54	284.06	89.54
180.00	22.95	89.65	309.92	89.65
190.00	25.02	89.70	337.93	89.70
200.00	27.32	89.73	368.96	89.73

Figure XI.5. Typical output of measured surface impedances using the Williamson method.

For Salisbury Load parameters as follow:

Test port radius = 4 ; Short radius = 15 ; Height = 2.341 inch
 Top step = .24 ; Bottom step = .24 inch
 Film surface resistivity = 363.2585 Ohms per square

Frequency (MHz)	Total Z of Salisbury Load		Surface Z of Salisbury Load	
	Magnitude (ohms)	Angle (deg.)	Magnitude (ohms/sq)	Angle (deg.)
100.00	9.80	68.63	132.37	68.63
110.00	10.76	66.41	145.37	66.41
120.00	11.72	64.17	158.28	64.17
130.00	12.67	61.90	171.11	61.90
140.00	13.61	59.60	183.84	59.60
150.00	14.55	57.26	196.45	57.26
160.00	15.47	54.89	208.94	54.89
170.00	16.39	52.47	221.29	52.47
180.00	17.29	50.01	233.46	50.01
190.00	18.17	47.49	245.45	47.49
200.00	19.05	44.92	257.22	44.92

Press CONTINUE to continue.

Figure XI.6. Typical (CRT displayed) "expected" or theoretical values of the surface impedance of a Salisbury load.

(a)

(b)

Figure XII.1. Measured surface impedances, using both the ABC technique (with three offset shorts as standards), the Williamson method, the Williamson method with capacitive junction correction, and the expected results for the Salisbury load with resistive sheet removed. a) Magnitude of surface impedance, b) Phase of surface impedance.

(a)

(b)

Figure XII.2. Measured surface impedances, using both the ABC technique (with three offset shorts as standards) and Williamson method, and the expected results (366.77 ohms is the average DC calibration measurement of the resistive sheet, 420 ohms is an artificial resistive sheet value obtained by fitting the magnitude of the measured surface impedance).

a) Magnitude of the surface impedance, b) Phase of surface impedance.

For Salisbury Load parameters as follow:

Test port radius = 4 ; Short radius = 15 ; Height = 2.341 inch

Top step = .24 ; Bottom step = .24 inch

Film surface resistivity = $1.E+15$ Ohms per square

Frequency (MHz)	Total Z of Salisbury Load Magnitude (ohms)	Angle (deg.)	Surface Z of Salisbury Load Magnitude (ohms/sq)	Angle (deg.)
100.00	10.53	90.00	142.15	90.00
110.00	11.75	90.00	158.62	90.00
120.00	13.02	90.00	175.85	90.00
130.00	14.36	90.00	193.98	90.00
140.00	15.78	90.00	213.15	90.00
150.00	17.29	90.00	233.55	90.00
160.00	18.91	90.00	255.42	90.00
170.00	20.66	90.00	279.03	90.00
180.00	22.56	90.00	304.73	90.00
190.00	24.65	90.00	332.95	90.00
200.00	26.97	90.00	364.26	90.00

Press CONTINUE to continue.

(a)

Figure XII.3. Listings of surface impedance data for the Salisbury load with resistive sheet removed. a) Expected values of surface impedance, b) Measured values of surface impedance using ABC technique (with three offset shorts as standards), c) Measured values of surface impedance using Williamson method.

DATA SHEET

Item: Salisbury Load #2 w/o space cloth in vertical position

Item Serial Number: 2

Measured: 9 May 1992

The impedances (as measured by the abc technique) are as follows:

Frequency	Z _t		Z _{p_sq}	
	Mag.	Ang.	Mag.	Ang.
100.00	10.61	89.80	143.25	89.80
110.00	11.82	89.83	159.69	89.83
120.00	13.11	89.79	177.11	89.79
130.00	14.45	89.84	195.11	89.84
140.00	15.86	89.86	214.17	89.86
150.00	17.38	89.87	234.73	89.87
160.00	18.97	89.93	256.24	89.93
170.00	20.73	89.97	279.90	89.97
180.00	22.62	89.97	305.52	89.97
190.00	24.71	89.96	333.68	89.96
200.00	27.02	89.97	364.89	89.97

(b)

Figure XII.3. Listings of surface impedance data for the Salisbury load with resistive sheet removed. a) Expected values of surface impedance, b) Measured values of surface impedance using ABC technique (with three offset shorts as standards), c) Measured values of surface impedance using Williamson method.

DATA SHEET

Item: Salisbury Load #2 w/o space cloth in vertical position

Item Serial Number: 2

Measured: 9 May 1992

The impedances (as measured by the Williamson technique) are as follows:

Frequency	Z _t		Z _{p_sq}	
	Mag.	Ang.	Mag.	Ang.
100.00	10.71	89.51	144.61	89.51
110.00	11.94	89.54	161.20	89.54
120.00	13.22	89.63	178.58	89.63
130.00	14.69	89.45	198.42	89.45
140.00	16.10	89.52	217.38	89.52
150.00	17.61	89.50	237.79	89.50
160.00	19.24	89.50	259.89	89.50
170.00	21.03	89.54	284.06	89.54
180.00	22.95	89.65	309.92	89.65
190.00	25.02	89.70	337.93	89.70
200.00	27.32	89.73	368.96	89.73

(c)

Figure XII.3. Listings of surface impedance data for the Salisbury load with resistive sheet removed. a) Expected values of surface impedance, b) Measured values of surface impedance using ABC technique (with three offset shorts as standards), c) Measured values of surface impedance using Williamson method.

For Salisbury Load parameters as follow:

Test port radius = 4 ; Short radius = 15 ; Height = 2.341 inch
 Top step = .24 ; Bottom step = .24 inch
 Film surface resistivity = 366.77 Ohms per square

Frequency (MHz)	Total Z of Salisbury Load Magnitude (ohms)	Angle (deg.)	Surface Z of Salisbury Load Magnitude (ohms/sq)	Angle (deg.)
100.00	9.81	68.82	132.54	68.82
110.00	10.78	66.61	145.59	66.61
120.00	11.74	64.38	158.57	64.38
130.00	12.70	62.13	171.47	62.13
140.00	13.65	59.84	184.29	59.84
150.00	14.59	57.51	197.00	57.51
160.00	15.52	55.15	209.60	55.15
170.00	16.44	52.74	222.07	52.74
180.00	17.36	50.28	234.39	50.28
190.00	18.25	47.77	246.52	47.77
200.00	19.14	45.20	258.46	45.20

Press CONTINUE to continue.

For Salisbury Load parameters as follow:

Test port radius = 4 ; Short radius = 15 ; Height = 2.341 inch
 Top step = .24 ; Bottom step = .24 inch
 Film surface resistivity = 420 Ohms per square

Frequency (MHz)	Total Z of Salisbury Load Magnitude (ohms)	Angle (deg.)	Surface Z of Salisbury Load Magnitude (ohms/sq)	Angle (deg.)
100.00	9.97	71.30	134.64	71.30
110.00	10.99	69.31	148.39	69.31
120.00	12.01	67.28	162.21	67.28
130.00	13.04	65.21	176.10	65.21
140.00	14.07	63.09	190.07	63.09
150.00	15.11	60.92	204.12	60.92
160.00	16.16	58.69	218.24	58.69
170.00	17.21	56.40	232.42	56.40
180.00	18.26	54.04	246.65	54.04
190.00	19.32	51.59	260.91	51.59
200.00	20.38	49.07	275.19	49.07

Press CONTINUE to continue.

(a)

Figure XII.4. Listings of surface impedance data for the Salisbury load with resistive sheet present. a) Expected values of surface impedance (DC calibration yielded 366.77 ohms/sq, artificial fit yielded 420 ohms/sq), b) Measured values of surface impedance using ABC technique (with three offset shorts as standards), c) Measured values of surface impedance using Williamson method.

DATA SHEET

Item: Salis. Load 2 w/ films 41, 42 & 72 (RF Ind.) w/ Au contacts

Item Serial Number: 2

Measured: 7 Jan 1993

Impedance at 4 inch radius as measured by abc technique:

Frequency	Zt		Z_p_sq	
	Mag.	Ang.	Mag.	Ang.
100.00	10.12	70.80	136.72	70.80
110.00	11.15	68.69	150.64	68.69
120.00	12.18	66.48	164.44	66.48
130.00	13.19	64.22	178.16	64.22
140.00	14.25	61.98	192.38	61.98
150.00	15.26	59.72	206.10	59.72
160.00	16.23	57.39	219.21	57.39
170.00	17.26	54.98	233.08	54.98
180.00	18.28	52.49	246.90	52.49
190.00	19.28	49.95	260.34	49.95
200.00	20.29	47.31	274.05	47.31

(b)

Figure XII.4. Listings of surface impedance data for the Salisbury load with resistive sheet present. a) Expected values of surface impedance (DC calibration yielded 366.77 ohms/sq, artificial fit yielded 420 ohms/sq), b) Measured values of surface impedance using ABC technique (with three offset shorts as standards), c) Measured values of surface impedance using Williamson method.

DATA SHEET

Item: Salis. Load 2 w/ films 41, 42 & 72 (RF Ind.) w/ Au contacts

Item Serial Number: 2

Measured: 7 Jan 1993

Impedance at 4 inch radius as measured by Williamson technique:

Frequency	Zt		Z_p_sq	
	Mag.	Ang.	Mag.	Ang.
100.00	10.19	69.90	137.62	69.90
110.00	11.21	67.91	151.41	67.91
120.00	12.24	65.90	165.30	65.90
130.00	13.37	63.71	180.56	63.71
140.00	14.39	61.55	194.28	61.55
150.00	15.40	59.29	207.95	59.29
160.00	16.43	57.03	221.84	57.03
170.00	17.46	54.76	235.84	54.76
180.00	18.47	52.40	249.44	52.40
190.00	19.45	49.90	262.71	49.90
200.00	20.42	47.31	275.80	47.31

(c)

Figure XII.4. Listings of surface impedance data for the Salisbury load with resistive sheet present. a) Expected values of surface impedance (DC calibration yielded 366.77 ohms/sq, artificial fit yielded 420 ohms/sq), b) Measured values of surface impedance using ABC technique (with three offset shorts as standards), c) Measured values of surface impedance using Williamson method.

Table AVI.1. Modal coefficients determined from the conformal mapping solution for use in evaluating the decrease in effective resistive sheet impedance.

$$\begin{aligned}
 & -2 \frac{1 - p^{1/p}}{1 + p} \\
 & 1, -0.13055504 \\
 & 0.017044618 \\
 & 2 \frac{1 - p^{2/p}}{1 + p} \frac{(-5 + p^2)}{(-1 + p^2)} \\
 & 2, 0.10114615 \\
 & 0.027275162 \\
 & -2 \frac{1 - p^{3/p}}{1 + p} \frac{(29 - 14p^2 + p^4)}{(-1 + p^2)^2} \\
 & 3, -0.084408182 \\
 & 0.034399903 \\
 & 2 \frac{1 - p^{4/p}}{1 + p} \frac{(-539 + 425p^2 - 81p^4 + 3p^6)}{3(-1 + p)^3(1 + p)^3} \\
 & 4, 0.073333041 \\
 & 0.039777638 \\
 & -2 \frac{1 - p^{5/p}}{1 + p} \frac{(3467 - 3828p^2 + 1258p^4 - 132p^6 + 3p^8)}{3(-1 + p)^4(1 + p)^4} \\
 & 5, -0.065351876 \\
 & 0.044048506 \\
 & 2 \frac{1 - p^{6/p}}{1 + p} \frac{(-38081 + 54265p^2 - 25834p^4 + 4850p^6 - 325p^8 + 5p^{10})}{5(-1 + p)^5(1 + p)^5} \\
 & 6, 0.059271609 \\
 & 0.047561629 \\
 & (-2 \frac{1 - p^{7/p}}{1 + p} \frac{(2297425 - 4018178p^2 + 2526955p^4 - 704652p^6 + 86775p^8 - 4050p^{10} + 45p^{12})}{(45(-1 + p)^6(1 + p)^6)}) / \\
 & 7, -0.054454077 \\
 & 0.050526876 \\
 & (2 \frac{1 - p^{8/p}}{1 + p} \frac{(-109167851 + 226527581p^2 - 177836743p^4 + 66701329p^6 - 12436641p^8 + 1088535p^{10} - 37485p^{12} + 315p^{14})}{(315(-1 + p)^7(1 + p)^7)}) /
 \end{aligned}$$

8, 0.050523727
0.053079523

$$(-2 \frac{1-p^9/p}{1+p}) (83141299 - 199746920 p^2 + 188457892 p^4 - 89450168 p^6 + 22757954 p^8 - 3061912 p^{10} + 200900 p^{12} - 5320 p^{14} + 35 p^{16}) / (35 (-1+p)^8 (1+p)^8)$$

9, -0.047243654
0.055311485

$$(2 \frac{1-p^{10}/p}{1+p}) (-9303339907 + 25407243183 p^2 - 28036799148 p^4 + 16164396172 p^6 - 5262913530 p^8 + 977595858 p^{10} - 99812412 p^{12} + 5100732 p^{14} - 107163 p^{16} + 567 p^{18}) / (567 (-1+p)^9 (1+p)^9)$$

10, 0.044456285
0.057287847

$$(-2 \frac{1-p^{11}/p}{1+p}) (1616609002771 - 4947190723130 p^2 + 6256557176643 p^4 - 4255226730520 p^6 + 1698017766086 p^8 - 407424279420 p^{10} + 57992226750 p^{12} - 4658494680 p^{14} + 190866375 p^{16} - 3260250 p^{18} + 14175 p^{20}) / (14175 (-1+p)^{10} (1+p)^{10})$$

11, -0.042052332
0.059056245

$$(2 \frac{1-p^{12}/p}{1+p}) (-4601669466615 + 15599947025157 p^2 - 22256690205585 p^4 + 17470568556331 p^6 - 8284449342950 p^8 + 2454873476562 p^{10} - 454944072770 p^{12} + 51367857750 p^{14} - 3336472755 p^{16} + 112121625 p^{18} - 1588125 p^{20} + 5775 p^{22}) / (5775 (-1+p)^{11} (1+p)^{11})$$

12, 0.039953377
0.060652518

$$(-2 \frac{1-p^{13}/p}{1+p}) (2615671472444983 - 9731245377590668 p^2 + 15467228096736966 p^4 - 13777514582728204 p^6 + 7586414230374529 p^8 - 2688359880172248 p^{10} + 619331740216692 p^{12} - 91665587538360 p^{14} + 8427526132905 p^{16} - 452220296220 p^{18} + 12695725350 p^{20} - 151559100 p^{22} + 467775 p^{24}) / (467775 (-1+p)^{12} (1+p)^{12})$$

13, -0.038101547

0.062104246

$$(2 \frac{1 - p^{14/p}}{1 + p}) (-34216519493594561 + 138612327277811985 p^2 -$$

$$> 242945659626296302 p^4 + 242291240440242422 p^6 -$$

$$> 152179712141408523 p^8 + 62955811620076531 p^{10} -$$

$$> 17440289677973364 p^{12} + 3227135582212932 p^{14} - 391210420507335 p^{16} +$$

$$> 29893973793255 p^{18} - 1348466566590 p^{20} + 32110971750 p^{22} -$$

$$> 327509325 p^{24} + 868725 p^{26}) / (868725 (-1 + p)^{13} (1 + p)^{13})$$

14, 0.036453112
0.063433075

$$(-2 \frac{1 - p^{15/p}}{1 + p}) (5850843487524849 - 25638474077357946 p^2 +$$

$$> 49133276992806279 p^4 - 54265714980881716 p^6 + 38329689475061985 p^8 -$$

$$> 18169824037715350 p^{10} + 5903940910775679 p^{12} - 1320062690751000 p^{14} +$$

$$> 201065190426555 p^{16} - 20362878750214 p^{18} + 1314949817181 p^{20} -$$

$$> 50585018484 p^{22} + 1034884851 p^{24} - 9123114 p^{26} + 21021 p^{28}) /$$

$$> (21021 (-1 + p)^{14} (1 + p)^{14})$$

15, -0.034974347
0.06465628

$$(2 \frac{1 - p^{16/p}}{1 + p}) (-1259425185539653127243 + 5935978400818730012485 p^2 -$$

$$> 12349388658230081037251 p^4 + 14968711750056008063405 p^6 -$$

$$> 11753827469470943846119 p^8 + 6290718556993758050345 p^{10} -$$

$$> 2351762420612696158287 p^{12} + 619349099706931414305 p^{14} -$$

$$> 114480949290179004225 p^{16} + 14631905101723972335 p^{18} -$$

$$> 1257956654546817225 p^{20} + 69599603268570375 p^{22} -$$

$$> 2311214028648525 p^{24} + 41068083931875 p^{26} - 316063873125 p^{28} +$$

$$> 638512875 p^{30}) / (638512875 (-1 + p)^{15} (1 + p)^{15})$$

16, 0.03363879
0.065787848

$$(-2 \frac{1 - p^{17/p}}{1 + p}) (8947252437797093332235 - 451360890711363362384 p^2 +$$

$$\begin{aligned}
&> 101319842164753454618440 p^4 - 133756948464607101321648 p^6 + \\
&> 115652708729932520013140 p^8 - 69049308017415550566352 p^{10} + \\
&> 29248086608384685590200 p^{12} - 8894522534486357943216 p^{14} + \\
&> 1943715252789321489570 p^{16} - 302635432044737996400 p^{18} + \\
&> 32965150237717010040 p^{20} - 2438017194185773200 p^{22} + \\
&> 116918909067460500 p^{24} - 3386404624402800 p^{26} + 52758190485000 p^{28} - \\
&> 357567210000 p^{30} + 638512875 p^{32} \big) / (638512875 (-1 + p)^{16} (1 + p)^{16}) \\
&17, -0.032425356 \\
&0.066839252 \\
&(2 \frac{1 - p^{18/p}}{1 + p}) (-1485547554992474914367 + 7986764129380780753987 p^2 - \\
&> 19242838553127386429432 p^4 + 27488876773944334776184 p^6 - \\
&> 25963491513871213241012 p^8 + 17121038234382254734276 p^{10} - \\
&> 8115303802608921578792 p^{12} + 2805199985361820484968 p^{14} - \\
&> 710199992501647957642 p^{16} + 131171171526005335490 p^{18} - \\
&> 17465693724022681480 p^{20} + 1642346643346365320 p^{22} - \\
&> 105660848098105300 p^{24} + 4435852253732900 p^{26} - 113069589232600 p^{28} + \\
&> 1557242687000 p^{30} - 9365731375 p^{32} + 14889875 p^{34} \big) / \\
&> (14889875 (-1 + p)^{17} (1 + p)^{17}) \\
&18, 0.031317016 \\
&0.067820007 \\
&(-2 \frac{1 - p^{19/p}}{1 + p}) (69532546869173713149501223 - \\
&> 396897818084037294130495770 p^2 + 1021664822872624087045269723 p^4 - \\
&> 1570489636006023643132377776 p^6 + 1609340571717933973018958988 p^8 - \\
&> 1162390495153452452422299672 p^{10} + 610225387032090388307241388 p^{12} - \\
&> 236709370291940965118787408 p^{14} + 68316424797332526630261858 p^{16} - \\
&> 14661483970093220447366364 p^{18} + 2322807872070985880626890 p^{20} - \\
&> 267824701591980787895760 p^{22} + 21977184152662309787580 p^{24} - \\
&26 \qquad \qquad \qquad 28
\end{aligned}$$

$$\begin{aligned}
&> 1241765634497302114200 p + 46030839440501015100 p - \\
&> 1040727416363434800 p^{30} + 12763032726819375 p^{32} - \\
&> 68580113852250 p^{34} + 97692469875 p^{36} \big) / \\
&> (97692469875 (-1 + p)^{18} (1 + p)^{18}) \\
&19, -0.030299855 \\
&0.068738089 \\
&(2 \frac{1 - p^{20/p}}{1 + p}) (-75532307157884600895184261 + \\
&> 456214894616152508169818279 p^2 - 1249612271989878670970337495 p^4 + \\
&> 2056972446417842792474478245 p^6 - 2273529200010244207279507636 p^8 + \\
&> 1785899790448574891894466876 p^{10} - 1029445360956187965509362124 p^{12} + \\
&> 443392234149382099895852420 p^{14} - 143974319003250978742299702 p^{16} + \\
&> 35316427969158506521847730 p^{18} - 6518956926262942367361090 p^{20} + \\
&> 896806924224408254213190 p^{22} - 90489629173153229556516 p^{24} + \\
&> 6540078465264060822924 p^{26} - 327239249652638134812 p^{28} + \\
&> 10791618722676972180 p^{30} - 217920322177162605 p^{32} + \\
&> 2395051256108511 p^{34} - 11567569972959 p^{36} + 14849255421 p^{38} \big) / \\
&> (14849255421 (-1 + p)^{19} (1 + p)^{19}) \\
&20, 0.029362375 \\
&0.069600238 \\
&(-2 \frac{1 - p^{21/p}}{1 + p}) (9459879575530132540188189 - 60278565712462056028195740 p^2 + \\
&> 175061056861340715755939454 p^4 - 307266508983927363165324780 p^6 + \\
&> 364444971417290280007859329 p^8 - 309447879082354596441547440 p^{10} + \\
&> 194423017050280227193382824 p^{12} - 92155989248484000321495600 p^{14} + \\
&> 33303109083549495651149354 p^{16} - 9212763215395525831345160 p^{18} + \\
&> 1948397949062679602621300 p^{20} - 313064047797356161466280 p^{22} + \\
&> 37783863455542159841850 p^{24} - 3366508521729298470000 p^{26} + \\
&> 216028118339227420200 p^{28} - 9641772994983558000 p^{30} + \\
&> 284756707764725625 p^{32} - 5167479154909500 p^{34} + 51190980018750 p^{36} -
\end{aligned}$$

$$\begin{aligned}
& > \quad 223439287500 p^{38} + 259813125 p^{40} / (259813125 (-1 + p)^{20} (1 + p)^{20}) \\
& 21, -0.02849499 \\
& 0.070412202 \\
& (2 \frac{1 - p^{22/p}}{1 + p}) (-4624490049448078178643779575415 + \\
& > \quad 31003273410234093098692557020879 p^2 - \\
& > \quad 95162900923033453889630549116350 p^4 + \\
& > \quad 177429507340421407527576968224054 p^6 - \\
& > \quad 224825485373853531415993349731735 p^8 + \\
& > \quad 205255597704656196519944131540839 p^{10} - \\
& > \quad 139676124578901852618487133825480 p^{12} + \\
& > \quad 72310061187923889640713364443944 p^{14} - \\
& > \quad 28817507632398980201684820161550 p^{16} + \\
& > \quad 8890982670078862573725986632734 p^{18} - \\
& > \quad 2125168483645052415923169477780 p^{20} + \\
& > \quad 392099400424650079868331032100 p^{22} - \\
& > \quad 55396611681879210703389773190 p^{24} + \\
& > \quad 5917349461503640547986518150 p^{26} - 469204747879448786558661000 p^{28} + \\
& > \quad 26920957315542920699869800 p^{30} - 1078658933098757503822875 p^{32} + \\
& > \quad 28698801369665108101875 p^{34} - 470601057467318982750 p^{36} + \\
& > \quad 4223879141580393750 p^{38} - 16743379194871875 p^{40} + 17717861581875 p^{42} \\
& > \quad / (17717861581875 (-1 + p)^{21} (1 + p)^{21}) \\
& 22, 0.027689634 \\
& 0.071178918 \\
& (-2 \frac{1 - p^{23/p}}{1 + p}) (4016551943902862119978017069801911 - \\
& > \quad 28261930478012123112629618616281886 p^2 + \\
& > \quad 91421936895026127762093364838612725 p^4 - \\
& > \quad 180459816825662628386682016014015556 p^6 +
\end{aligned}$$

> 243325428403175337171999448545115005 p ⁸ -
 > 237744827292987565765980814132460726 p ¹⁰ +
 > 174268804773434274170902731311385335 p ¹² -
 > 97896461201451522124509879728842416 p ¹⁴ +
 > 42691891122387079370555163063253750 p ¹⁶ -
 > 14553634482143304353462999140616796 p ¹⁸ +
 > 3887368136127544675700068694520834 p ²⁰ -
 > 812237015658426186534231799710360 p ²² +
 > 13203877972134663458709783577290 p ²⁴ -
 > 16544729718176819550771303984060 p ²⁶ +
 > 1576092120414101908973191648350 p ²⁸ -
 > 111981444918435911260608289200 p ³⁰ +
 > 5780541378211068981529692675 p ³² - 209116118060845286212671750 p ³⁴ +
 > 5038830079179033441929625 p ³⁶ - 75033715130102687458500 p ³⁸ +
 > 613042127182715855625 p ⁴⁰ - 2216752533954708750 p ⁴² +
 > 2143861251406875 p ⁴⁴) / (2143861251406875 (-1 + p) ²² (1 + p) ²²)
 23 , -0.026939469
 0.071904653

Figure AVII.1. The coaxial-to-radial transmission line apparatus is decomposed into two cascaded two-port networks. One network represents the junction and the other represents a section of the radial transmission line attached to the load.

Figure AVIII.1. Mechanical drawing of radial transmission line assembly.

Figure AVIII.2. Top and bottom cover plates on radial line for offset shorts.

▶

Figure AVIII.5. a) Top and bottom annular cover plates for Salisbury load. b) Central top disc plate for Salisbury load. c) Central bottom plate for Salisbury load.

Figure AVIII.6. a) Terminating short for Salisbury load. b) Mounting flange for millimeter coaxial air line. c) Shorting plugs for central disc assembly fixture. d) and e) Fixture assembly positioning bolts.

Listing AIX.1. The BASIC 5.1 program RLMS_al.

```

10  ! RLMS_al
20  OPTION BASE 1
30  ! Master program making impedance measurements in radial lines.
40  ! Written by Robert D. Moyer, Sandia National Laboratories
50  ! Electrical Standards Division 4342.
60  !
70  ! Upgraded from RLMS_a0 to RLMS_al on 5/31/92 by RDM. Changes are:
80  ! 1. FORMAT ON added to path ASSIGN statements in lines U1, U2 & U3 in
90  !    SUBS Z_dos_dat_fil, Abc_dos_dat_fil & Raw_z_dos_dat, respectively.
100 ! 2. SUB Acq_8753_dat sends HP8753 test port impedance to CRT now instead
110 !    of coax/radial line interface impedance.
120 !
130 ! ***** User's Guide *****
140 !
150 ! User's guide to RLMS_*/# program.
160 !
170 ! This program is menu/prompt driven so very few auxiliary instructions
180 ! are required to run it; however, the following specifies the resources
190 ! which will be required during a measurement run.
200 ! A. RLMS_*/# will run on an HP Vectra Personal computer with HP model
210 !    82300C Coprocessor (BASIC Language Processor) with BASIC 5.0.
220 !    Operating System DOS 5.0 is used. Files SEQ.BAT and WILL.EXE must
230 !    reside on the DOS system disc.
240 ! B. Configuration information is as follows:
250 !    1. COM1:9600,N,8,1,P
260 !    2. COM2:9600,N,8,1,P
270 !    3. LPT1:=COM2
280 !    4. LPT1: rerouted to COM2:
290 !
300 !    5. HP-IB (Meas. Coproc.) at : 7
310 !    6. Serial (COM1) at: 9
320 !    7. Disk Drives (LIF) at : 15
330 !    8. DOS port at : 19
340 !    9. Serial (COM2) at: 23
350 !
360 !    An HP model 3630A Paint Jet printer is used at serial COM2 port 23.
370 !    The HP8753 VANA has HP-IB address 716.
380 !
390 ! C. The Master program, RLMS_*/#, appears on the Bernoulli disc
400 !    of the same name.
410 ! D. A "SUPport" microfloppy (HP LIF format), with the label "SUP", is
420 !    sometimes required & is usually loaded from drive :,1500,0. It
430 !    receives and/or contains files which store a,b,c constants in BDAT
440 !    FORMAT for various 7mm to radial line transitions. ( To label a disc
450 !    in drive 0, use command PRINT LABEL "SUP" TO ":",1500,0")
460 ! E. All files on the SUPport disc are both generated and accessed as
470 !    directed by prompts in the program, RLMS_*/#.
480 ! F. If the operator chooses - in response to prompts - the results of:
490 !
500 !    a. raw impedance measurements at the coax line/radial line interface;
510 !    b. abc parameter measurements and
520 !    c. measured radial load impedance results
530 !
540 !    may be stored on microfloppy disc in DOS format. This allows
550 !    subsequent machine analysis of results at many frequencies.
560 ! G. All variables in COM are defined in a subsequent dummy SUBprogram
570 !    named Comdef.
580 !
590 ! *****

```

```

600  !
610  COM /Misc/ In$(25),@Nwa,@Nwa_data1,@Nwa_data2
620  COM /Freq/ Meas_freq(101),INTEGER To_no_mf
630  COM /Abc_freq/ Abc_file_freq(101),INTEGER To_no_abc_f,Indx_abc(101)
640  COM /Rawdat/ Rz(101,3,2),Qz(101,3,2),COMPLEX Mw(101,3),Tsz(101,4)
650  COM /Abc/ COMPLEX A_par(101),B_par(101),C_par(101)
660  COM /Stds/ Std_name$(4)[25],Nom_std_radius(4)
670  COM /Short_dims/ Rad4,Height4,Rad9,Height9,Rad15,Height15
680  COM /Salis/ O_rad_salis,I_rad_salis,Hite_salis,Topdisk_thk,Botdisk_thk
690  COM /Salis2/ Rs_film
700  COM /Sysid/ Serial_8753$(10),Model_ts$(5),Serial_ts$(10)
710  COM /Ctorlt/ Ser_ctorlt$(12),Prop_ctorlt$(8),Own_ctorlt$(15)
720  COM /Vana/ INTEGER If_avg_factor,If_band_width
730  COM /Meas_param/ Tech_cons$(25),Jet,Sim,INTEGER No_copies,Meas_option
740  COM /Progid/ Version_date$(18),Prog_name$(10)
750  COM /Rad4_p/ Z0s4(101),Theta4(101),Psi4(101)
760  COMPLEX T_salis(101),S_salis(101)
770  INTEGER I,J,K,L,M,N
780  !
790  !! NOTE: To list the code, or sections of it, on an HP Desk Jet at select
800  !!       code 9, with top, bottom and left margins, follow these steps:
810  !! 1. Temporarily replace the exclamation point in line List by a space.
820  !! 2. RUN the program.
830  !! 3. Type LIST or LIST F1,L1 (where F1 and L1 are the first and last line
840  !!    numbers, respectively, to be listed.)
850  !! 4. After the listing is complete, CONTINUE the program.
860  !! 5. Follow the instructions in the prompts.
870  !
880  List: CALL Code_list
890  !
900  Mem$=SYSTEM$("AVAILABLE MEMORY")
910  DISP "Available memory = ";Mem$
920  ! Write to HP8753 HP-IB
930  ASSIGN @Nwa TO 716
940  ! Read ASCII Data to/from HP8753 HP-IB
950  ASSIGN @Nwa_data1 TO 716;FORMAT ON
960  ! Read non-ASCII data to/from 8753 HP-IB
970  ASSIGN @Nwa_data2 TO 716;FORMAT OFF
980  REMOTE 7
990  OUTPUT @Nwa;"MARKDISC;" ! Sets 8753 markers to discrete
1000 Prog_name$="RLMS_al"
1010 Version_date$="31-May-1992"
1020 Sim=0
1030 Serial_8753$="3135A01643"
1040 Serial_ts$="3033A04720"
1050 Model_ts$="85046"
1060 Jet=23 ! Selects PaintJet
1070 No_runs=1
1080 No_copies=1
1090 If_avg_factor=32
1100 If_band_width=300
1110 Ser_ctorlt$="2"
1120 Prop_ctorlt$="00000"
1130 Own_ctorlt$="4342"
1140 Tech_cons$="R. D. Moyer - 4342"
1150 G:SYSTEM KEYS
1160 CLEAR SCREEN
1170 PRINT "Measurement date is ";DATE$(TIMEDATE)
1180 WAIT 1
1190 CLEAR SCREEN

```

```

1200 IF Rad4>0 THEN
1210   PRINT " Enter 1 to retain current hardware dimensions and values stored
in COM"
1220   PRINT "           OR"
1230   PRINT " Enter 0 to work with default hardware dimensions and values in c
ode. ";
1240   BEEP
1250   INPUT Com_dim
1260   PRINT Com_dim
1270 ELSE
1280   Com_dim=0
1290 END IF
1300 IF Com_dim=0 THEN
1310   Rad4=4.
1320   Height4=1.861
1330   Rad9=9.
1340   Height9=1.861
1350   Rad15=15.
1360   Height15=1.861
1370   O_rad_salis=15.
1380   I_rad_salis=4.
1390   Hite_salis=2.341
1400   Topdisk_thk=.240
1410   Botdisk_thk=.240
1420   Rs_film=363.2585      ! Surface resistivity of space cloth in ohms/square
1430 END IF
1440 H: CLEAR SCREEN
1450 BEEP
1460 PRINT " ENTER CODE OF YOUR CHOICE"
1470 PRINT ""
1480 PRINT "CODE      OPERATION TO BE PERFORMED"
1490 PRINT " "
1500 PRINT " 1. For the model  $Z_s = (a \cdot Z_m + b) / (c \cdot Z_m + 1)$ , determine the a,b,c p
arameters of"
1510 PRINT "      a coax-to-radial line transition at frequencies of choice and s
tore in BDAT"
1520 PRINT "      format on a HP LIF volume and, optionally, on a DOS format volu
me. (Zm is "
1530 PRINT "      measured impedance at the coax/radial line (C/RL) interface; Zs
is the "
1540 PRINT "      surface impedance at the radial port.)"
1550 PRINT " 2. Measure surface and total impedance seen by radial line test po
rt, at"
1560 PRINT "      frequencies of choice, using a,b,c parameters."
1570 PRINT " 3. Measure surface impedance seen by radial line test port, at fre
quencies of"
1580 PRINT "      choice, using Williamson theory."
1590 PRINT " 4. Compute the theoretical impedances looking outward from the rad
ial line port"
1600 PRINT "      into a radial line Salisbury screen at the frequencies of choic
e."
1610 C: INPUT Meas_option
1620 PRINT Meas_option
1630 IF Meas_option>0 AND Meas_option<5 THEN
1640   SELECT Meas_option
1650   CASE 1
1660     CALL Meas_abc_par
1670   CASE 2
1680     CALL Z_via_abc
1690   CASE 3

```

```

1700     CALL Z_via_will
1710     CASE 4
1720     CLEAR SCREEN
1730     IF Com_dim=0 THEN
1740         PRINT " "
1750         PRINT "Enter 1 to MODIFY default hardware dimensions and values spec
ified in code;"
1760         PRINT "Enter 0 otherwise.";
1770         INPUT Mod_def_dim
1780         PRINT Mod_def_dim
1790     END IF
1800     CALL Mf_gen
1810     FOR Jf=1 TO To_no_mf
1820         CALL Salis_ld_z(Jf,Com_dim,Mod_def_dim,T_salis(Jf),S_salis(Jf))
1830     NEXT Jf
1840     CLEAR SCREEN
1841 !     PAUSE
1843     PRINT "For Salisbury Load parameters as follow:"
1844     PRINT " "
1852     PRINT "Test port radius =";I_rad_salis;"; Short radius =";O_rad_salis;
"; Height =";Hite_salis;" inch"
1853     PRINT "Top step =";Topdisk_thk;"; Bottom step =";Botdisk_thk;" inch"
1854     PRINT "Film surface resistivity =";Rs_film;" Ohms per square"
1855     PRINT " "
1859     PRINT "Frequency      Total Z of Salisbury Load      Surface Z of Salisbury
Load"
1860     PRINT "      (MHz)          Magnitude          Angle          Magnitude          Angle
"
1870     PRINT "              (ohms)          (deg.)          (ohms/sq)          (deg.
)"
1880     PRINT " "
1890     FOR Jf=1 TO To_no_mf
1900         PRINT USING Fmt1;Meas_freq(Jf),ABS(T_salis(Jf)),FNAng2(T_salis(Jf)),
ABS(S_salis(Jf)),FNAng2(S_salis(Jf))
1910 Fmt1:  IMAGE 5D.2D,5X,5D.2D,6X,4D.2D,9X,5D.2D,6X,4D.2D
1920     NEXT Jf
1930     PRINT " "
1940     PRINT " "
1950     PRINT " Press CONTINUE to continue."
1960     BEEP
1970     PAUSE
1980     END SELECT
1990 ELSE
2000     BEEP
2010     PRINT " "
2020     PRINT " INVALID ENTRY; PLEASE TRY AGAIN"
2030     GOTO C
2040 END IF
2050 GOTO G
2060 END
2070 !
2080 !*****
2090 !
2100 Meas_abc_par:SUB Meas_abc_par
2110 ! LEAD SUBPROGRAM FOR MEASURING a,b,c PARAMETERS OF COAX TO RADIAL LINE
2120 ! TRANSITION.
2130 !
2140 !
2150     OPTION BASE 1
2160     COM /Misc/ In$(25),@Nwa,@Nwa_data1,@Nwa_data2

```

```

2170 COM /Freq/ Meas_freq(*),INTEGER To_no_mt
2180 COM /Abc_freq/ Abc_file_freq(*),INTEGER To_no_abc_f,Indx_abc(*)
2190 COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
2200 COM /Abc/ COMPLEX A_par(*),B_par(*),C_par(*)
2210 COM /Vana/ INTEGER If_avg_factor,If_band_width
2220 COM /Sysid/ Serial_8753$(10),Model_ts$(5),Serial_ts$(10)
2230 COM /Ctorl/ Ser_ctorlt$(12),Prop_ctorlt$(8),Own_ctorlt$(15)
2240 COM /Meas_param/ Tech_cons$(25),Jet,Sim,INTEGER Nc_copies,Meas_option
2250 COM /Progid/ Version_date$(18),Prog_name$(10)
2260 INTEGER I,J,K,L,M,N
2270 DEG
2280 CLEAR SCREEN
2290 E: PRINT ""
2300 IF Sim=0 THEN
2310 PRINT "Do you want to re-process previous measurement data in Computer
"
2320 PRINT "COM? (Y or N)"
2330 BEEP
2340 LINPUT In$
2350 PRINT In$
2360 IF In$="Y" OR In$="y" THEN GOTO C
2370 END IF
2380 ! DEFINE PARAMETERS OF CALIBRATION
2390 PRINT " "
2400 CLEAR SCREEN
2410 PRINT "Place Measurement Parameter SUPPORT disc (HP LIF format) in drive
0 then press"
2420 PRINT "CONTINUE"
2430 BEEP
2440 PAUSE
2450 B: CALL Acq_meas_p
2460 CLEAR SCREEN
2470 IF Sim=0 THEN
2480 ! Acquire measurement data to determine a,b,c parameters
2490 CALL Acq_dat_abc_par
2500 ELSE
2510 ! CALL Abc_meas_sim
2520 END IF
2530 ! Process data to get a,b,c parameters.
2540 C: FOR Jf=1 TO To_no_mf
2550 CALL Abc_anharm(Jf)
2560 NEXT Jf
2570 ! Output the Results
2580 CALL Type_abc_rept
2590 D: SUBEND ! Meas_abc_par
2600 !
2610 !*****
2620 !
2630 Acq_meas_p: SUB Acq_meas_p
2640 ! SUBPROGRAM TO ACCESS OR GENERATE MEASUREMENT PARAMETERS FILE ON SUPPORT
2650 ! DISC.
2660 !
2670 OPTION BASE 1
2680 COM /Misc/ In$(25),@Nwa,@Nwa_data1,@Nwa_data2
2690 COM /Freq/ Meas_freq(*),INTEGER To_no_mf
2700 COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
2710 COM /Vana/ INTEGER If_avg_factor,If_band_width
2720 COM /Sysid/ Serial_8753$(10),Model_ts$(5),Serial_ts$(10)
2730 COM /Ctorl/ Ser_ctorlt$(12),Prop_ctorlt$(8),Own_ctorlt$(15)
2740 COM /Meas_param/ Tech_cons$(25),Jet,Sim,INTEGER No_copies,Meas_option

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2750 COM /Progid/ Version_date${18},Prog_name${10}
2760 DIM New_file${1},Mp_f_nam${10},First_3let${3},Id${1},Learn_string${3000}
2770 DIM Mod_rep${1}
2780 INTEGER I,J,K,L,M,N,Size,File_size,Flag,Temp
2790 INTEGER Prob,L1,L2
2800 G: First_3let$="MP_" ! First 3 letters of Measurement Parameter
2810 ! support file name.
2820 REMOTE 7
2830 Id$="N"
2840 Mod_rep$=" "
2850 CALL Sup_fil_id(New_file$,Mp_f_nam$,First_3let$,Id$)
2860 IF New_file$="N" OR New_file$="n" THEN
2870 ! Acquire Measurement Parameter file from SUPport disc.
2880 ASSIGN @Path_2 TO Mp_f_nam$&"":,1500,0"
2890 ENTER @Path_2;Ser_ctorlt$
2900 ENTER @Path_2;Prop_ctorlt$
2910 ENTER @Path_2;Own_ctorlt$
2920 ENTER @Path_2;Tech_cons$
2930 ENTER @Path_2;Serial_8753$
2940 ENTER @Path_2;Serial_ts$
2950 ENTER @Path_2;If_avg_factor,If_band_width
2960 ENTER @Path_2;To_no_mf,No_copies,Learn_string$
2970 FOR I=1 TO To_no_mf
2980 ENTER @Path_2;Meas_freq(I)
2990 NEXT I
3000 ASSIGN @Path_2 TO * ! Closes I/O path
3010 ! Output INSTRUMENT STATE to 8753
3020 PRINT " "
3030 PRINT "Setting up 8753 INSTRUMENT STATE "
3040 PRINT " "
3050 OUTPUT @Nwa;"HOLD;INPULEAS";Learn_string$
3060 ! Assure that 8753 frequencies are compatible with measurement
3070 ! frequencies.
3080 REMOTE 7
3090 CALL Mf_vf_fit(Flag)
3100 IF Flag=1 THEN
3110 BEEP
3120 GOTO G
3130 END IF
3140 CLEAR SCREEN
3150 PRINT "Do you wish to merely LOOK AT operating parameters ON 8753 CRT?
(Y or N)"
3160 LINPUT In$
3170 PRINT In$
3180 IF In$="Y" OR In$="y" THEN
3190 OUTPUT @Nwa;"OPEP;"
3200 PRINT " "
3210 PRINT "Press CONTINUE to see second page on 8753 CRT and other CALIB
RATION parameters"
3220 PRINT "on computer screen."
3230 BEEP
3240 PAUSE
3250 OUTPUT @Nwa;"NEXP;"
3260 PRINT " "
3270 CLEAR SCREEN
3280 PRINT "C/RL transition S/N: ";Ser_ctorlt$; Property No.: ";P
rop_ctorlt$
3290 PRINT "Owner: ";Own_ctorlt$; Consultant: ";Tech_cons$
3300 PRINT ""
3310 PRINT To_no_mf;" Frequencies (MHz) of measurement are:"

```



```

3320      ALLOCATE Dum(1:To_no_mf)
3330      FOR L=1 TO To_no_mf
3340          Dum(L)=Meas_freq(L)
3350      NEXT L
3360      PRINT Dum(*)
3370      DEALLOCATE Dum(*)
3380      PRINT " "
3390      PRINT "8753 Serial no. is ";Serial_8753$
3400      PRINT "Test Set is model ";Model_ts$;";      Serial no. ";Serial_ts$
3410      PRINT "IF AVERAGING FACTOR IS";If_avg_factor;"and IF BANDWIDTH is";I
f_band_width;"Hz."
3420      PRINT No_copies;"copy(s) of the report will be printed."
3430      PRINT " "
3440      PRINT " "
3450      PRINT "Press CONTINUE to continue"
3460      BEEP
3470      PAUSE
3480      OUTPUT @Nwa;"RESD;"      ! Restore 8753 CRT display (pg. 11A-4 of
3490                          ! HP "Operating and Programming Reference").
3500      END IF
3510      CLEAR SCREEN
3520      PRINT "Do you wish to MODIFY & REPLACE file ";Mp_f_nam$;" on SUPport d
isc? (Y or N)"
3530      LINPUT Mod_rep$
3540      PRINT Mod_rep$
3550      IF Mod_rep$="Y" OR Mod_rep$="y" THEN GOSUB Constr_mp2
3560      ELSE
3570          GOSUB Constr_mp2
3580      END IF
3590      PRINT " "
3600      CLEAR SCREEN
3610      GOTO B
3620 Constr_mp2: CLEAR SCREEN
3630      PRINT "The default value of the IF AVERAGING FACTOR is ";If_avg_factor
3640      PRINT "Enter new value ( < 1000 ) or press CONTINUE to continue."
3650 Ab: BEEP
3660      LINPUT In$
3670      IF NOT LEN(In$) THEN GOTO Gg
3680      ON ERROR GOTO Hh
3690      ENTER In$;T
3700      PRINT In$
3710      OFF ERROR
3720      IF T<1000 THEN
3730          If_avg_factor=T
3740      ELSE
3750 Hh: PRINT "In-valid entry; please try again."
3760      GOTO Ab
3770      END IF
3780 Gg: OUTPUT @Nwa;"AVERFACT";If_avg_factor;";AVEROON;"
3790      PRINT " "
3800      PRINT "Default IF BANDWIDTH = ";If_band_width;" Hz. Enter new value or C
ONTINUE."
3810      PRINT "(Allowable values are 300, 1000 or 3000 Hz.)"
3820      LINPUT In$
3830      IF NOT LEN(In$) THEN GOTO Gm
3840      ENTER In$;If_band_width
3850      PRINT In$
3860 Gm: OUTPUT @Nwa;"IFBW";If_band_width;";"
3870      ! Specify measurement frequencies
3880      IF Mod_rep$="y" OR Mod_rep$="Y" THEN

```

```

3890     PRINT " "
3900     PRINT To_no_mf;" Frequencies (MHz) of measurement are:"
3910     ALLOCATE Dum(1:To_no_mf)
3920     FOR L=1 TO To_no_mf
3930         Dum(L)=Meas_freq(L)
3940     NEXT L
3950     PRINT Dum(*)
3960     PRINT " "
3970     PRINT "Do you want to specify new frequencies? (Y or N)"
3980     LINPUT In$
3990     PRINT In$
4000     IF In$<>"y" AND In$<>"Y" THEN GOTO Inst_st
4010     END IF
4020     CALL Mf_gen
4030 Inst_st:PRINT " "
4040     PRINT " "
4050     PRINT "If necessary, manually or via a cassette file, place the 8753 int
o the"
4060     PRINT "INSTRUMENT STATE for which its measurement performance is certifi
ed."
4070     PRINT "If you wish instructions on what is required, enter I. Otherwise,
"
4080     PRINT "after the correct instrument state is set, press CONTINUE."
4090     PRINT " "
4100     BEEP
4110     LOCAL 7
4120     LINPUT In$
4130     IF In$="I" OR In$="i" THEN GOSUB Tutor
4140         ! Assure that 8753 frequencies are compatible with measurement
4150         ! frequencies.
4160     REMOTE 7
4170     CALL Mf_vf_fit(Flag)
4180     IF Flag=1 THEN
4190         BEEP
4200         GOTO G
4210     END IF
4220     PRINT " "
4230     PRINT "C/RL transition owner is ";Own_ctorlt$;"; Enter new owner. [<15]
or CONTINUE."
4240     BEEP
4250     LINPUT In$
4260     IF NOT LEN(In$) THEN GOTO Lm
4270     Own_ctorlt$=In$
4280     PRINT Own_ctorlt$
4290 Lm:PRINT " "
4300     PRINT "Prop. no. of C/RL transition ";Prop_ctorlt$;"; Enter new prop. no
. [<8] or CONTINUE."
4310     BEEP
4320     LINPUT In$
4330     IF NOT LEN(In$) THEN GOTO Ls
4340     Prop_ctorlt$=In$
4350     PRINT Prop_ctorlt$
4360 Ls:PRINT " "
4370     PRINT "S/N of C/RL transition is ";Ser_ctorlt$;"; Enter new serial no. [
<13] or CONTINUE."
4380     BEEP
4390     LINPUT In$
4400     IF NOT LEN(In$) THEN GOTO Lc
4410     Ser_ctorlt$=In$
4420     PRINT Ser_ctorlt$

```

```

4430 Lc:PRINT " "
4440 PRINT "Present consultant is ";Tech_cons$;"; Enter new consultant [<26]"
4450 PRINT "or CONTINUE."
4460 BEEP
4470 LINPUT In$
4480 IF NOT LEN(In$) THEN GOTO De
4490 Tech_cons$=In$
4500 PRINT Tech_cons$
4510 De:PRINT " "
4520 PRINT "Default 8753 serial no. is ";Serial_8753$;"; Enter new number or
CONTINUE."
4530 BEEP
4540 LINPUT In$
4550 IF NOT LEN(In$) THEN GOTO Cc
4560 Serial_8753$=In$
4570 PRINT Serial_8753$
4580 Cc: CLEAR SCREEN
4590 A: BEEP
4600 PRINT " Default test set is ";Model_ts$;"; Enter new model or CONTINUE"
4610 LINPUT In$
4620 IF NOT LEN(In$) THEN D
4630 ON ERROR GOTO E
4640 ENTER In$;Temp$
4650 PRINT In$
4660 OFF ERROR
4670 IF Temp$<>"85044" AND Temp$<>"85046" THEN
4680 GOTO E
4690 ELSE
4700 Model_ts$=Temp$
4710 END IF
4720 GOTO D
4730 E: BEEP
4740 PRINT " "
4750 PRINT " IN-VALID ENTRY; PLEASE TRY AGAIN"
4760 GOTO A
4770 D: PRINT " "
4780 PRINT "Default test set serial no. is ";Serial_ts$;"; Enter new no. or C
ONTINUE."
4790 BEEP
4800 LINPUT In$
4810 IF NOT LEN(In$) THEN GOTO Dd
4820 Serial_ts$=In$
4830 PRINT Serial_ts$
4840 Dd:PRINT " "
4850 PRINT "Default number of report copies is ";No_copies
4860 Bb:PRINT "Enter different number of copies desired or CONTINUE."
4870 BEEP
4880 LINPUT In$
4890 IF NOT LEN(In$) THEN GOTO H
4900 ON ERROR GOTO Aa
4910 PRINT In$
4920 ENTER In$;No_copies
4930 OFF ERROR
4940 GOTO H
4950 Aa:PRINT "In-valid entry; Please try again."
4960 BEEP
4970 GOTO Bb
4980 ! Obtain LEARN STRING from 8753
4990 H: OUTPUT @Nwa;"OUTPLEAS;"
5000 ENTER @Nwa USING "-K";Learn_string$

```

```

5010      ! Store Measurement Parameters in file Mp_f_nam$ on SUPport disc
5020      ! in drive 0.
5030      IF Mod_rep$="Y" OR Mod_rep$="y" THEN PURGE Mp_f_nam$&"",1500,0"
5040      PRINT " "
5050      PRINT "Storing Measurement Parameter file on disc ..."
5060      File_size=144+((To_no_mf-1)/3)+12
5070      CREATE BDAT Mp_f_nam$&"",1500,0",File_size,24
5080      ASSIGN @Path_2 TO Mp_f_nam$&"",1500,0"
5090      OUTPUT @Path_2;Ser_ctorlt$
5100      OUTPUT @Path_2;Prop_ctorlt$
5110      OUTPUT @Path_2;Own_ctorlt$
5120      OUTPUT @Path_2;Tech_cons$
5130      OUTPUT @Path_2;Serial_8753$
5140      OUTPUT @Path_2;Serial_ts$
5150      OUTPUT @Path_2;If_avg_factor,If_band_width
5160      OUTPUT @Path_2;To_no_mf,No_copies,Learn_string$
5170      FOR I=1 TO To_no_mf
5180          OUTPUT @Path_2;Meas_freq(I)
5190      NEXT I
5200      ASSIGN @Path_2 TO *
5210      RETURN
5220 Tutor:      !
5230      CLEAR SCREEN
5240      PRINT "You need to set up the Instrument State for which the measurement
"
5250      PRINT "performance of the HP8753 is certified."
5260      PRINT " "
5270      PRINT "You need to specify:"
5280      PRINT " "
5290      PRINT "1. START and STOP frequencies, NUMBER OF POINTS and SWEEP TYPE -
LIN or LOG or"
5300      PRINT "      LIST (or equivalent) - in such a way that the 8753 measurement
frequency set"
5310      PRINT "      includes all desired measurement frequencies."
5320      PRINT "2. SOURCE POWER"
5330      PRINT "3. IF AVERAGING FACTOR."
5340      PRINT "4. IF BANDWIDTH - 300 Hz or more."
5350      PRINT "5. CAL KIT i.e. N 50 or 7mm or etc."
5360      PRINT "6. CHANNEL 1 must be selected."
5370      PRINT "7. SMOOTHING must be OFF."
5380      PRINT "8. AVERAGING must be ON."
5390      PRINT "9. Set up any other conditions unique to your requirement."
5400      PRINT " "
5410      PRINT "Press CONTINUE to continue after you have set up the INSTRUMENT S
TATE."
5420      LOCAL 7
5430      BEEP
5440      PAUSE
5450      REMOTE 7
5460      RETURN
5470 B:SUBEND ! Acq_meas_p
5480      !
5490      !*****
5500      !
5510 Sup_fil_id:SUB Sup_fil_id(New_file$,Sup_f_nam$,First_3let$,Id$)
5520      ! SUBPROGRAM TO IDENTIFY AND ACCESS PROPER SUPport & DATA DISCS & FILES ON
5530      ! THEM.
5540      !
5550      !ARGUMENT DEFINITIONS:
5560      !

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5570 ! New_file$="N" (output argument) is a flag indicating that no new file
5580 !           is needed. An existing one can be used.
5590 ! New_file$=" " indicates that no decision has yet been made.
5600 ! Sup_f_nam$=(input argument) is the name of the desired file on the
5610 !           SUPport disc.
5620 ! First_3let$="DAT" (input argument) identifies a file where measurement
5630 !           results are stored.
5640 !           "MP_" identifies a file of measurement parameter data.
5650 ! Id$="Y" (input argument) is a flag which requests that the LABEL on the
5660 !           SUPport disc be verified.
5670 !
5680 OPTION BASE 1
5690 DIM Catalog$(50)[80],Temp$(10]
5700 COM /Misc/ In$(25),@Nwa,@Nwa_data1,@Nwa_data2
5710 COM /Freq/ Meas_freq(*),INTEGER To_no_mf
5720 COM /Abc_freq/ Abc_file_freq(*),INTEGER To_no_abc_f,Indx_abc(*)
5730 COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
5740 COM /Vana/ INTEGER If_avg_factor,If_band_width
5750 COM /Sysid/ Serial_8753$(10],Model_ts$(5],Serial_ts$(10]
5760 COM /Ctorl/ Ser_ctorl$(12],Prop_ctorl$(8],Own_ctorl$(15]
5770 COM /Meas_param/ Tech_cons$(25],Jet,Sim,INTEGER No_copies,Meas_option
5780 COM /Progid/ Version_date$(18],Prog_name$(10]
5790 INTEGER I,J,K,L,M,N
5800 CLEAR SCREEN
5810 ! If Id$ = Y or y, then disc LABEL is checked for proper identity.
5820 IF Id$="y" OR Id$="Y" THEN
5830 A: BEEP
5840 IF First_3let$="MP_" OR First_3let$="ABC" THEN
5850 PRINT " Place SUPport disc (HP LIF format) in drive 0 then CONTINUE"
5860 PAUSE
5870 ON ERROR GOTO B
5880 READ LABEL Label$ FROM ":",1500,0"
5890 IF Label$<>"SUP" THEN GOTO B
5900 OFF ERROR
5910 GOTO F
5920 END IF
5930 G: BEEP
5940 IF First_3let$="DAT" THEN
5950 PRINT " Place DATA disc (DAT) in drive 0 then CONTINUE"
5960 PAUSE
5970 ON ERROR GOTO B
5980 READ LABEL Label$ FROM ":",1500,0"
5990 IF Label$<>"DAT" THEN GOTO B
6000 OFF ERROR
6010 GOTO F
6020 END IF
6030 B: PRINT " "
6040 BEEP
6050 PRINT " WRONG DISC; PLEASE TRY AGAIN! Press CONTINUE to continue."
6060 BEEP
6070 PAUSE
6080 PRINT " "
6090 GOTO A
6100 END IF
6110 OFF ERROR
6120 F: CLEAR SCREEN
6130 IF First_3let$="MP_" THEN
6140 PRINT "The CATalog of Measurement Parameter files on the SUPport disc
is:"
6150 END IF

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6160 IF First_3let$="ABC" THEN
6170     PRINT "The CATalog of abc parameter files on the SUPport disc is:"
6180 END IF
6190 IF First_3let$="DAT" THEN
6200     PRINT "The CATalog of DATA files on the DATA disc is:"
6210 END IF
6220 CAT ":",1500,0" TO Catalog$(*);SELECT First_3let$,COUNT No_lines
6230 FOR J=7 TO No_lines
6240     K=J-6
6250     Temp$=Catalog$(J)[1,10]
6260     PRINT K,Temp$
6270 NEXT J
6280 PRINT " "
6290 BEEP
6300 PRINT "Enter number of file you desire or CONTINUE to generate a new fil
e."
6310 LINPUT In$
6320 PRINT In$
6330 IF NOT LEN(In$) THEN
6340     New_file$="Y"
6350 E: BEEP
6360     PRINT " "
6370     PRINT " Enter name for new file - 10 characters or less."
6380     PRINT " NOTE: The first 3 letters of the file name must be ";First_3
let$
6390     LINPUT Sup_f_nam$
6400     PRINT Sup_f_nam$
6410 ELSE
6420     ON ERROR GOTO C
6430     ENTER In$;Number
6440     OFF ERROR
6450     Sup_f_nam$=Catalog$(6+Number)[1,10]
6460     New_file$="N"
6470 END IF
6480 GOTO D
6490 C: BEEP
6500 PRINT " "
6510 PRINT " INVALID ENTRY; PLEASE TRY AGAIN"
6520 GOTO E
6530 D: SUBEND ! Sup_fil_id
6540 !
6550 !*****
6560 !
6570 Mf_gen: SUB Mf_gen
6580     OPTION BASE 1
6590 ! This subprogram allows the operator to generate the list of frequencies
6600 ! for measurement.
6610     INTEGER Prob,Num_cfreqs,Istart,Istep
6620     INTEGER I,J,K,L,M,N,L1,L2
6630     COM /Misc/ In$[25],@Nwa,@Nwa_data1,@Nwa_data2
6640     COM /Freq/ Meas_freq(*),INTEGER To_no_mf
6650     COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
6660     COM /Vana/ INTEGER If_avg_factor,If_band_width
6670     COM /Sysid/ Serial_8753$[10],Model_ts$[5],Serial_ts$[10]
6680     COM /Ctorl/ Ser_ctorlt$[12],Prop_ctorlt$[8],Own_ctorlt$[15]
6690     COM /Meas_param/ Tech_cons$[25],Jet,Sim,INTEGER No_copies,Meas_option
6700     COM /Progid/ Version_date$[18],Prog_name$[10]
6710     MAT Meas_freq= (0)
6720     To_no_mf=0
6730 G: CLEAR SCREEN

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```

6740 PRINT "Option      Measurement Frequency Selection Mode"
6750 PRINT " "
6760 PRINT "   1      Start, Stop, Step"
6770 PRINT "   2      One-at-a-time"
6780 PRINT "   3      Terminate entire frequency selection process"
6790 PRINT " "
6800 PRINT " Enter option of your choice"
6810 PRINT " "
6820 PRINT " "
6830 PRINT " "
6840 BEEP
6850 ON ERROR GOTO A
6860 INPUT I
6870 PRINT I
6880 OFF ERROR
6890 IF I>0 OR I<4 THEN GOTO B
6900 A: PRINT " "
6910 PRINT "In-valid entry; please try again"
6920 BEEP
6930 GOTO G
6940 B: SELECT I
6950 CASE 1
6960     CLEAR SCREEN
6970 C: PRINT "Please enter desired Start, Stop, Step frequencies in whole MHz
      ."
6980     BEEP
6990     INPUT Start,Stop,Step
7000     PRINT Start,Stop,Step
7010     Scrch=(Stop-Start)/Step
7020     Num_cfreqs=INT(Scrch)+1
7030     IF FRACT(Scrch)>.5 THEN Num_cfreqs=Num_cfreqs+1
7040     IF Num_cfreqs<102 THEN GOTO D
7050     PRINT "Too many frequencies; please try again"
7060     BEEP
7070     GOTO C
7080 D: Istart=INT(Start)
7090     IF FRACT(Start)>.5 THEN Istart=Istart+1
7100     Istep=INT(Step)
7110     IF FRACT(Step)>.5 THEN Istep=Istep+1
7120     K=0
7130     FOR M=To_no_mf+1 TO To_no_mf+Num_cfreqs
7140         Meas_freq(M)=Istart+K*Istep
7150         K=K+1
7160     NEXT M
7170     PRINT " "
7180     PRINT "You have chosen the following frequencies:"
7190     PRINT " "
7200     N=To_no_mf+Num_cfreqs
7210     ON ERROR GOTO 7240
7220     DEALLOCATE Dum(*)
7230     OFF ERROR
7240     ALLOCATE Dum(1:N)
7250     FOR L=1 TO N
7260         Dum(L)=Meas_freq(L)
7270     NEXT L
7280     PRINT Dum(*)
7290     PRINT " "
7300     PRINT "Is this list OK? (Y or N)"
7310     BEEP
7320     LINPUT In$

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```

7330     PRINT In$
7340     IF In$="Y" OR In$="y" THEN
7350         To_no_mf=To_no_mf+Num_cfreqs
7360     END IF
7370     GOTO G
7380     CASE 2
7390         Num_cfreqs=0
7400         CLEAR SCREEN
7410         PRINT " Enter desired frequency in whole MHz; enter 0 to stop entering
single freqs."
7420         FOR M=To_no_mf+1 TO 101
7430             INPUT K
7440             PRINT K
7450             IF K=0 THEN GOTO E
7460             Num_cfreqs=Num_cfreqs+1
7470             Meas_freq(M)=K
7480         NEXT M
7490 E:    PRINT "You have chosen the following frequencies:"
7500         PRINT " "
7510         N=To_no_mf+Num_cfreqs
7520         PRINT "N = ";N
7530         ON ERROR GOTO H
7540         DEALLOCATE Dum(*)
7550 H:    ALLOCATE Dum(1:N)
7560         OFF ERROR
7570         FOR L=1 TO N
7580             Dum(L)=Meas_freq(L)
7590         NEXT L
7600         PRINT Dum(*)
7610         PRINT " "
7620         PRINT "Is this list OK? (Y or N)"
7630         BEEP
7640         LINPUT In$
7650         PRINT In$
7660         IF In$="Y" OR In$="y" THEN
7670             To_no_mf=To_no_mf+Num_cfreqs
7680         END IF
7690         GOTO G
7700     CASE 3
7710     END SELECT
7720     GOTO F
7730 F: SUBEND ! Mf_gen
7740 !
7750 !*****
7760 !
7770 Mf_vf_fit: SUB Mf_vf_fit(INTEGER Flag)
7780     OPTION BASE 1
7790     ! This subprogram assures that the 8753 VANA is measuring at the
7800     ! frequencies of measurement.
7810     !
7820     ! ARGUMENT DEFINITION:
7830     !
7840     ! Flag is an output argument set to 1 if the 8753 is not measuring at a
7850     ! desired measurement frequency.
7860     !
7870     COM /Misc/ In$[25],@Nwa,@Nwa_data1,@Nwa_data2
7880     COM /Freq/ Meas_freq(*),INTEGER To_no_mf
7890     COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
7900     COM /Vana/ INTEGER If_avg_factor,If_band_width
7910     COM /Sysid/ Serial_8753$[10],Model_ts$[5],Serial_ts$[10]

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```

7920 COM /Ctorl/ Ser_ctorlt$(12),Prop_ctorlt$(8),Own_ctorlt$(15]
7930 COM /Meas_param/ Tech_cons$(25),Jet,Sim,INTEGER No_copies,Meas_option
7940 COM /Progid/ Version_date$(18),Prog_name$(10]
7950 INTEGER I,J,K,L,M,N,Freq
7960 Flag=0
7970 REMOTE 7
7980 PRINTER IS CRT
7990 OUTPUT @Nwa;"DEBUON;MARK1;WAIT;"
8000 FOR I=1 TO To_no_mf
8010     OUTPUT @Nwa;"MARK1";Meas_freq(I);" MHZ;WAIT;"
8020     OUTPUT @Nwa;"OUTPACTI;"
8030     ENTER @Nwa;Scrch
8040     Scrch=Scrch/1.E+6
8050     IF Scrch<Meas_freq(I) THEN
8060         PRINT " "
8070         PRINT "The 8753 is not measuring at measurement frequency ";Meas_freq(I)
8080         Flag=1
8090     END IF
8100 NEXT I
8110 IF Flag=1 THEN
8120     PRINT " "
8130     PRINT " Press CONTINUE to continue"
8140     BEEP
8150     PAUSE
8160     PRINT " "
8170 END IF
8180 SUBEND ! Mf_vf_fit
8190 !
8200 !*****
8210 !
8220 Acq_8753_dat:SUB Acq_8753_dat(INTEGER K,I)
8230 ! Subprogram to acquire measurement data from the 8753.
8240 !
8250 !ARGUMENT DEFINITIONS:
8260 !
8270 ! K (input argument) is the integer index of the measurement being
8280 !   acquired.
8290 ! I (input argument) is the identity of the test port at which the
8300 !   impedance is being measured.
8310 !
8320 OPTION BASE 1
8330 COM /Misc/ In$(25),@Nwa,@Nwa_data1,@Nwa_data2
8340 COM /Freq/ Meas_freq(*),INTEGER To_no_mf
8350 COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
8360 COM /Abc/ COMPLEX A_par(*),B_par(*),C_par(*)
8370 COM /Stds/ Std_name$(*),Nom_std_radius(*)
8380 COM /Vana/ INTEGER If_avg_factor,If_band_width
8390 COM /Sysid/ Serial_8753$(10],Model_ts$(5],Serial_ts$(10]
8400 COM /Ctorl/ Ser_ctorlt$(12],Prop_ctorlt$(8],Own_ctorlt$(15]
8410 COM /Meas_param/ Tech_cons$(25],Jet,Sim,INTEGER No_copies,Meas_option
8420 COM /Progid/ Version_date$(18],Prog_name$(10]
8430 COMPLEX M
8440 RAD
8450 REMOTE 7
8460 IF I=1 THEN OUTPUT @Nwa;"S11;WAIT;"
8470 IF I=2 THEN OUTPUT @Nwa;"S22;WAIT;"
8480 OUTPUT @Nwa;"SMIMRX;"
8490 PRINT " "
8500 PRINT "           Impedance at HP8753 Test Port"

```

```

8510 PRINT "Freq          REAL(Z)          IMAG(Z)"
8520 PRINT " "
8530 FOR Jf=1 TO To_no_mf
8540   OUTPUT @Nwa;"MARK1 ",Meas_freq(Jf);" MHZ;WAIT;"
8550   OUTPUT @Nwa;"OUTPMARK;WAIT;"
8560   ENTER @Nwa_data1;R,Q,Dum
8570   M=CMPLX(R,Q)
8580   PRINT Meas_freq(Jf),R,Q
8590 !   Correct impedance to that at the input of the radial line. See p 91
8600 !   of Weeks.
8610   Ang=2*PI*Meas_freq(Jf)*1.E+6*(4.997+.254)/2.997925E+10
8620 !   PRINT Meas_freq(Jf),Ang
8630   Cbl=COS(Ang)
8640   Sbl=SIN(Ang)
8650   Mw(Jf,K)=50*(M*Cbl-CMPLX(0,50*Sbl))/(50*Cbl-CMPLX(0,1)*M*Sbl)
8660   Rz(Jf,K,1)=REAL(Mw(Jf,K))
8670   Qz(Jf,K,1)=IMAG(Mw(Jf,K))
8680 NEXT Jf
8690 PRINT ""
8700 PRINT "Enter D to save measured impedances (at coax/radial line interfac
e) on DOS disc;"
8710 PRINT "Press ENTER otherwise.  "
8720 INPUT Ans$
8730 IF LEN(Ans$)<>0 THEN CALL Raw_z_dos_dat(K)
8740 SUBEND ! Acq_8753_dat
8750 !
8760 !*****
8770 !
8780 Choose_cals:SUB Choose_cals
8790 ! Subprogram to choose the desired CAL SET from 8753 non-volatile memory.
8800 OPTION BASE 1
8810 COM /Misc/ In$[25],@Nwa,@Nwa_data1,@Nwa_data2
8820 COM /Freq/ Meas_freq(*),INTEGER To_no_mf
8830 COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
8840 COM /Vana/ INTEGER If_avg_factor,If_band_width
8850 COM /Sysid/ Serial_8753$[10],Model_ts$[5],Serial_ts$[10]
8860 COM /Ctorl/ Ser_ctorlt$[12],Prop_ctorlt$[8],Own_ctorlt$[15]
8870 COM /Meas_param/ Tech_cons$[25],Jet,Sim,INTEGER No_copies,Meas_option
8880 COM /Progid/ Version_date$[18],Prog_name$[10]
8890 INTEGER I,J,K,L,M,N,Cal_set_no,Flag
8900 CLEAR SCREEN
8910 Cal_set_no=5
8920 D: PRINT "Default CAL SET is ";Cal_set_no;"; You may do one of the followin
g:"
8930 PRINT " "
8940 PRINT " "
8950 PRINT "* Press CONTINUE to use the default CAL SET."
8960 PRINT " "
8970 PRINT "* Enter the number of a different existing CAL SET you wish to u
se."
8980 PRINT " "
8990 PRINT "* (a) Perform a new S11 1-PORT CAL on the 8753."
9000 PRINT " (b) Store it in the 8753 under the CAL SET number of your choi
ce."
9010 PRINT " (c) Enter that number on the computer keyboard."
9020 PRINT " "
9030 PRINT " CAUTION 1.! Remember that the CAL SET you choose must include th
e CALIBRATION"
9040 PRINT " frequencies you have already chosen."
9050 PRINT " "

```

```

9060    LOCAL 7
9070    BEEP
9080    LINPUT In$
9090    REMOTE 7
9100    IF NOT LEN(In$) THEN GOTO B
9110    ON ERROR GOTO C
9120    PRINT In$
9130    ENTER In$;N
9140    OFF ERROR
9150    IF N>0 AND N<9 THEN
9160        Cal_set_no=N
9170        GOTO B
9180    ELSE
9190 C:    PRINT " "
9200        PRINT "In-valid entry; Please try again."
9210        BEEP
9220        GOTO D
9230    END IF
9240    PRINT "Entering CAL SET into 8753 and assuring compatibility of Measurem
ent and "
9250    PRINT "CAL SET frequencies ..."
9260 B:    SELECT Cal_set_no
9270    CASE 1
9280        OUTPUT @Nwa;"RECA1;"
9290    CASE 2
9300        OUTPUT @Nwa;"RECA2;"
9310    CASE 3
9320        OUTPUT @Nwa;"RECA3;"
9330    CASE 4
9340        OUTPUT @Nwa;"RECA4;"
9350    CASE 5
9360        OUTPUT @Nwa;"RECA5;"
9370    END SELECT
9380    ! Assure that CALIBRATION frequencies are a subset of the chosen CAL
9390    ! SET frequencies.
9400    CALL Mf_vf_fit(Flag)
9410    IF Flag=1 THEN
9420        PRINT " "
9430        PRINT "The CALIBRATION frequencies are not a subset of the 8753 measur
ement"
9440        PRINT "frequencies in the CAL SET you have chosen. Please select anothe
r CAL SET."
9450        BEEP
9460        PRINT " "
9470        GOTO D
9480    END IF
9490    CLEAR SCREEN
9500    SUBEND ! Choose_cals
9510    !
9520    !*****
9530    !
9540    Acq_dat_abc_par:SUB Acq_dat_abc_par
9550    ! Subprogram directing the acquisition of data for determining the abc
9560    ! parameters of coax to radial line transitions. The parameters describe
9570    ! the transition from the impedance at the coaxial port to the TOTAL
9580    ! impedance at the radial line port.
9590    !
9600    OPTION BASE 1
9610 Gc:COM /Misc/ In$(25),@Nwa,@Nwa_data1,@Nwa_data2
9620    COM /Freq/ Meas_freq(*),INTEGER To_no_mf

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```

9630 COM /Abc_freq/ Abc_file_freq(*),INTEGER To_no_abc_f,Indx_abc(*)
9640 COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
9650 COM /Abc/ COMPLEX A_par(*),B_par(*),C_par(*)
9660 COM /Std/ Std_name$(*),Nom_std_radius(*)
9670 COM /Short_dims/ Rad4,Height4,Rad9,Height9,Rad15,Height15
9680 COM /Salis/ O_rad_salis,I_rad_salis,Hite_salis,Topdisk_thk,Botdisk_thk
9690 COM /Salis2/ Rs_film
9700 COM /Vana/ INTEGER If_avg_factor,If_band_width
9710 COM /Sysid/ Serial_8753$(10),Model_ts$(5),Serial_ts$(10)
9720 COM /Ctorl/ Ser_ctorlt$(12),Prop_ctorlt$(8),Own_ctorlt$(15)
9730 COM /Meas_param/ Tech_cons$(25),Jet,Sim,INTEGER No_copies,Meas_option
9740 COM /Progid/ Version_date$(18),Prog_name$(10)
9750 COM /Rad4_p/ Z0s4(*),Theta4(*),Psi4(*)
9760 DIM Z0s9(101),Z0s15(101)
9770 DIM Theta9(101),Psi9(101),Theta15(101),Psi15(101)
9780 INTEGER I,J,K,L,M,N
9790 COMPLEX Czero,Ttz
9800 DEG
9810 CLEAR SCREEN
9820 CALL Choose_cals
9830 CLEAR SCREEN
9840 REMOTE 7
9850 Czero=CMPLX(0,0)
9860 PRINT " The available standards are as follows:"
9870 Std_name$(1)="4 Inch Radius Short"
9880 Nom_std_radius(1)=4.0
9890 Std_name$(2)="9 Inch Radius Short"
9900 Nom_std_radius(2)=9.0
9910 Std_name$(3)="15 Inch Radius Short"
9920 Nom_std_radius(3)=15.0
9930 Std_name$(4)="15 Inch Salisbury Screen"
9940 Nom_std_radius(4)=15.0
9950 PRINT " "
9960 PRINT "Code           Standard Name           Standard Radius (Inches)"
9970 PRINT " "
9980 FOR I=2 TO 4
9990 PRINT USING Fmt1;I,Std_name$(I),Nom_std_radius(I)
10000 Fmt1:IMAGE 2X,D,3X,25A,15X,DD.DDD
10010 NEXT I
10020 PRINT " "
10030 PRINT "The first standard you use must be the 4 Inch Radius Short."
10040 Std_code(1)=1
10050 PRINT "Enter code numbers for the other two standards you wish to use."
10060 INPUT Std_code(2),Std_code(3)
10070 PRINT Std_code(2);" ";Std_code(3)
10080 CLEAR SCREEN
10090 IF Rad4>0 THEN
10100 PRINT " Enter 1 to retain current hardware dimensions and values store
d in COM"
10110 PRINT " OR"
10120 PRINT " Enter 0 to work from default hardware dimensions and values in
code. ";
10130 BEEP
10140 INPUT Com_dim
10150 PRINT Com_dim
10160 ELSE
10170 Com_dim=0
10180 END IF
10190 IF Com_dim=0 THEN

```

```

10200 PRINT " "
10210 PRINT "Enter 1 to MODIFY default hardware dimensions and values in code;"
10220 PRINT "Enter 0 otherwise.";
10230 INPUT Mod_def_dim
10240 PRINT Mod_def_dim
10250 IF Mod_def_dim=1 THEN
10260 PRINT " "
10270 PRINT " "
10280 PRINT "Default RADIUS of the 4 Inch Radius Short in inches is";
10290 PRINT Rad4
10300 PRINT "Enter new value or press ENTER to accept default value.";
10310 BEEP
10320 LINPUT Rad4$
10330 IF LEN(Rad4$)<>0 THEN
10340 ENTER Rad4$;Rad4
10350 PRINT Rad4
10360 END IF
10370 PRINT " "
10380 PRINT " "
10390 PRINT "Default HEIGHT (inches) of the 4 Inch Radius Short is";
10400 PRINT Height4
10410 PRINT "Enter new value or press ENTER to accept default value.";
10420 BEEP
10430 LINPUT Height4$
10440 IF LEN(Height4$)<>0 THEN
10450 ENTER Height4$;Height4
10460 PRINT Height4
10470 END IF
10480 END IF
10490 END IF
10500 FOR Jf=1 TO To_no_mf
10510 CALL Radial_line(Meas_freq(Jf),Rad4,Height4,Z0s4(Jf),Theta4(Jf),Psi4(Jf))
10520 Tsz(Jf,1)=Czero
10530 NEXT Jf
10540 FOR I=2 TO 3
10550 SELECT Std_code(I)
10560 CASE 2
10570 IF Com_dim=0 AND Mod_def_dim=1 THEN
10580 PRINT " "
10590 PRINT "Default RADIUS (inches) of the 9 Inch Radius Short is";
10600 PRINT Rad9
10610 PRINT "Enter new value or press ENTER to accept default value.";
10620 BEEP
10630 LINPUT Rad9$
10640 IF LEN(Rad9$)<>0 THEN
10650 ENTER Rad9$;Rad9
10660 PRINT Rad9
10670 END IF
10680 PRINT " "
10690 PRINT " "
10700 PRINT "Default HEIGHT (inches) of the 9 Inch Radius Short is";
10710 PRINT Height9
10720 PRINT "Enter new value or press ENTER to accept default value.";
10730 BEEP
10740 LINPUT Height9$
10750 IF LEN(Height9$)<>0 THEN
10760 ENTER Height9$;Height9
10770 PRINT Height9

```

```

10780      END IF
10790      END IF
10800      FOR Jf=1 TO To_no_mf
10810          CALL Radial_line(Meas_freq(Jf),Rad9,Height9,Z0s9(Jf),Theta9(Jf),Ps
19(Jf))
10820          Tsz(Jf,I)=FNZi(Z0s4(Jf),Theta4(Jf),Psi4(Jf),Z0s9(Jf),Theta9(Jf),Ps
19(Jf),Czero)
10830      NEXT Jf
10840      CASE 3
10850          IF Com_dim=0 AND Mod_def_dim=1 THEN
10860              PRINT " "
10870              PRINT "Default RADIUS (inches) of the 15 Inch Radius Short is";
10880              PRINT Rad15
10890              PRINT "Enter new value or press ENTER to accept default value.";
10900              BEEP
10910              LINPUT Rad15$
10920              IF LEN(Rad15$)<>0 THEN
10930                  ENTER Rad15$;Rad15
10940                  PRINT Rad15
10950              END IF
10960              PRINT " "
10970              PRINT " "
10980              PRINT "Default HEIGHT (inches) of the 15 Inch Radius Short ";
10990              PRINT Height15
11000              PRINT "Enter new value or press ENTER to accept default value.";
11010              BEEP
11020              LINPUT Height15$
11030              IF LEN(Height15$)<>0 THEN
11040                  ENTER Height15$;Height15
11050                  PRINT Height15
11060              END IF
11070          END IF
11080          FOR Jf=1 TO To_no_mf
11090              CALL Radial_line(Meas_freq(Jf),Rad15,Height15,Z0s15(Jf),Theta15(Jf
),Psi15(Jf))
11100              Tsz(Jf,I)=FNZi(Z0s4(Jf),Theta4(Jf),Psi4(Jf),Z0s15(Jf),Theta15(Jf),
Psi15(Jf),Czero)
11110          NEXT Jf
11120          CASE 4
11130              FOR Jf=1 TO To_no_mf
11140                  CALL Salis_ld_z(Jf,Com_dim,Mod_def_dim,Ttz,Tsz(Jf,I))
11150              NEXT Jf
11160          END SELECT ! Std_code(I)
11170      NEXT I
11180      FOR K=1 TO 3
11190          PRINT " "
11200          PRINT "      a. Connect ";Std_name$(Std_code(K));" to port 1 of the VANA
."
11210          PRINT "      b. Press CONTINUE when done."
11220          LOCAL 716
11230          BEEP
11240          PAUSE
11250          GOSUB Setup
11260      NEXT K
11270      PRINT " "
11280      CLEAR SCREEN
11290      GOTO A
11300      Setup: ! Subroutine to acquire needed impedance measurements
11310      PRINT " "
11320      PRINT "      8753 measurements in progress..."

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11330 PRINT " "
11340 REMOTE 716
11350! OUTPUT 716;"S11;POLA;S21;POLA;S12;POLA;S22;POLA;"
11360 OUTPUT 716;"SMIC;"
11370 OUTPUT 716;"OPC?;NUMG";If_avg_factor;";"
11380 ENTER 716;Reply
11390 CALL Acq_8753_dat(K,1)
11400 RETURN
11410 A:SUBEND! Acq_dat_abc_par
11420 !
11430 !*****
11440 !
11450 Comdef:SUB Comdef
11460 ! Dummy SUBprogram to define variables in COM
11470 !
11480 ! In$ is a scratch string variable which is used in many places.
11490 ! @Nwa is an IO path for HPIB command transfer to the HP8753 VANA.
11500 ! @Nwa_data1 is an IO path for ASCII HPIB data transfer (FORMAT ON) with
11510 ! the HP8753 VANA.
11520 ! @Nwa_data2 is an IO path for non-ASCII HPIB data transfer (FORMAT OFF)
11530 ! with the HP8753 VANA.
11540 ! Meas_freq(Jf) is the Jf'th measurement frequency in MHz.
11550 ! To_no_mf is the total number of frequencies at which measurements are
11560 ! currently being made.
11570 ! Abc_file_freq(L) is the frequency in MHz of the L'th frequency for which
11580 ! abc parameters are stored in the A_par, B_par & C_par
11590 ! arrays.
11600 ! To_no_abc_f is the total number of frequencies for which abc parameters
11610 ! are stored in the A_par, B_par & C_par arrays.
11620 ! Indx_abc(Jf) is the index - in the A_par, B_par and C_par vectors - of
11630 ! the abc parameters for the Jf'th frequency at which
11640 ! measurements are currently being made.
11650 ! Rz(Jf,I,K) + jQz(Jf,I,K) = Mw(Jf,I) is the measured complex impedance
11660 ! (in rectangular form) at the coaxial port of radial line
11670 ! impedance standard I at the Jf'th frequency. K (always =1
11680 ! in this application) is the test port of the test set where
11690 ! the measurement was made.
11700 ! Tsz(Jf,I) is the true complex surface impedance (in rectangular form)
11710 ! at the radial port of radial line impedance standard (I) at
11720 ! the Jf'th frequency.
11730 ! A_par(L), B_par(L) & C_par(L) are the complex a, b, c parameters,
11740 ! respectively, of a coax/radial line transition as defined by
11750 ! the model  $Z_s = (a*Z_m + b)/(c*Z_m + 1)$ . Zm is the measured
11760 ! impedance at the L'th frequency at the coax/radial line
11770 ! interface & Zs is the surface impedance at the radial port.
11780 ! Std_name$(I) & Nom_std_radius(I) are the name & nominal radius (inches),
11790 ! respectively, of the I'th standard used during the
11800 ! experimental measurements of the abc parameters of a
11810 ! coax/radial line transition.
11820 ! Rad4 & Height4 are the outer radius & height, respectively, in inches
11830 ! of the 4 inch radius radial line reference short.
11840 ! Rad9 & Height9 are the outer radius & height, respectively, in inches
11850 ! of the 9 inch radius radial line offset short.
11860 ! Rad15 & Height15 are the outer radius & height, respectively, in inches
11870 ! of the 15 inch radius radial line offset short.
11880 ! O_rad_salis, I_rad_salis & Hite_salis are the outer radius, inner radius
11890 ! and height, respectively, in inches of the outer section of
11900 ! the Salisbury load.
11910 ! Topdisk_thk & Botdisk_thk are the thicknesses in inches of the top &
11920 ! bottom central disks, respectively, used in the Salisbury

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11930 !          load.
11940 ! Rs_film is the surface resistivity (ohms per square) of the film used
11950 !          in the Salisbury load.
11960 ! Serial_8753$ specifies the serial number of the HP8753 VANA used to
11970 !          make the measurements.
11980 ! Model_ts$ & Serial_ts$ specify the model & serial number, respectively,
11990 !          of the test set used to make the measurements.
12000 ! Ser_ctorlt$, Prop_ctorlt$ & Own_ctorlt$ specify the serial number,
12010 !          property number and owner, respectively, of the
12020 !          characterized coax to radial line (C/RL) transition.
12030 ! If_avg_factor is the number of IF measurements averaged by the HP8753
12040 !          VANA.
12050 ! If_band_width is the bandwidth in Hz used in the HP8753 VANA.
12060 ! Tech_cons$ is the name of the metrologist making the measurements.
12070 ! Jet is the port number of the serial port driving the HP 3630A Paint Jet
12080 !          printer.
12090 ! Sim is an (unused) flag set to 1 if simulated data is being processed.
12100 ! No_copies specifies how many copies of the reports will be printed.
12110 ! Meas_option specifies which measurement option has been selected using
12120 !          the codes below:
12130 ! 1. For the model  $Z_s = (a \cdot Z_m + b) / (c \cdot Z_m + 1)$ , determine the a,b,c
12140 !          parameters of a coax-to-radial line transition at frequencies of
12150 !          choice and store in BDAT format on a HP LIF volume and, optionally,
12160 !          on a DOS format volume. ( $Z_m$  is measured impedance at the coax/radial
12170 !          line interface;  $Z_s$  is the surface impedance at the radial port.)
12180 ! 2. Measure surface and total impedance seen by radial line test port,
12190 !          at frequencies of choice, using a,b,c parameters."
12200 ! 3. Measure surface impedance seen by radial line test port, at
12210 !          frequencies of choice, using Williamson theory."
12220 ! 4. Compute the theoretical impedances, at the frequencies of choice
12230 !          looking into a Salisbury screen.
12240 ! Version_date$ is the date of the current version of program RLMS_*.
12250 ! Prog_name$ is the name of the current version of RLMS_*.
12260 ! Z0s4(Jf) is the characteristic surface impedance of the radial line at
12270 !          its test port at radius Rad4.
12280 ! Theta4(Jf) =  $\arctan(Y0(x)/J0(x))$  as defined in section 8.12 of RW&VD
12290 !          where  $x = k \cdot \text{Rad4}$  and  $k = 2 \cdot \text{Pi} \cdot \text{Fmhz}(Jf) / c$ .
12300 ! Psi4(Jf) =  $\arctan(J1(x)/(-Y1(x)))$ .
12310 !
12320 SUBEND ! Comdef
12330 !
12340 !*****
12350 !
12360 Radial_line:SUB Radial_line(Fmhz,Radius,Height,Z0s,Theta,Psi)
12370 !
12380 ! SUB to compute Z0s(x), Theta(x) and Psi(x) of radial line as
12390 !          defined in section 8.12 of RW&VD. x is computed as  $x = k \cdot \text{Radius}$ 
12400 !          where  $k = 2 \cdot \text{Pi} \cdot \text{Fmhz} / c$ .
12410 !
12420 ! INPUT ARGUMENT DEFINITIONS:
12430 !
12440 ! Fmhz is the frequency in Mhz;
12450 ! Radius is the radius in inches;
12460 ! Height is the height of the radial line in inches.
12470 !
12480 ! OUTPUT ARGUMENT DEFINITIONS:
12490 !
12500 ! Z0s is the surface characteristic impedance of the radial line at Radius
12510 !          inches.
12520 ! Theta is the ratio  $Y0(x)/J0(x)$  evaluated at Radius inches.

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12530 ! Psi is the ratio J1(x)/(-Y1(x)) evaluated at Radius inches.
12540 !
12550 OPTION BASE 1
12560 RAD
12570 C=2.997925E+10 ! Speed of light in cm/sec.
12580 Rad_cm=Radius*2.54 ! Radius in cm
12590 X=2.E+6*PI*Fmhz*Rad_cm/C
12600 IF ABS(X)<=3 THEN
12610     R=(X/3)*(X/3)! (x/3)^2
12620     S=R
12630 ! Compute J0(x), Y0(x), J1(x) & Y1(x) from equations 9.4.1, 9.4.2,
12640 ! 9.4.4 & 9.4.5, respectively, of Abramowitz & Stegun for cases when x<=3.
12650     J0=1-2.2499997*S
12660     Y0=.36746691+.60559366*S
12670     J1ox=.5-.56249985*S
12680     Y1x=-.6366198+.2212091*S
12690     S=S*R ! S now equal R^2
12700     ! Now, S=R^2
12710     J0=J0+1.2656208*S
12720     Y0=Y0-.74350384*S
12730     J1ox=J1ox+.21093573*S
12740     Y1x=Y1x+2.1682709*S
12750     S=S*R
12760     ! Now, S=R^3
12770     J0=J0-.3162866*S
12780     Y0=Y0+.25360117*S
12790     J1ox=J1ox-.03954289*S
12800     Y1x=Y1x-1.3164827*S
12810     S=S*R
12820     ! Now, S=R^4
12830     J0=J0+.0444479*S
12840     Y0=Y0-.04261214*S
12850     J1ox=J1ox+.00443319*S
12860     Y1x=Y1x+.3123951*S
12870     S=S*R
12880     ! Now, S=R^5
12890     J0=J0-.0039444*S
12900     Y0=Y0+.00427916*S
12910     J1ox=J1ox-.00031761*S
12920     Y1x=Y1x-.0400976*S
12930     S=S*R
12940     ! Now, S=R^6
12950     J0=J0+.0002100*S
12960     Y0=Y0-.00024846*S+2*LOG(X/2)*J0/PI
12970     J1ox=J1ox+.00001109*S
12980     J1=J1ox*X
12990     Y1x=Y1x+.0027873*S+2*X*LOG(X/2)*J1/PI
13000     Y1=Y1x/X
13010 ELSE
13020 ! Compute J0(x), Y0(x), J1(x) & Y1(x) from equations 9.4.3 & 9.4.6,
13030 ! respectively, of Abramowitz & Stegun for cases when x>3.
13040     T=3./X
13050     U=T! Now U=(3/X)
13060     F0=.79788456-.00000077*U
13070     Theta_0=X-.78539816-.04166397*U
13080     F1=.79788456+.00000156*U
13090     Theta_1=X-2.35619449+.12499612*U
13100     U=U*T! Now, U=T^2
13110     F0=F0-.00552740*U
13120     Theta_0=Theta_0-.00003954*U

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13130      F1=F1+.01659667*U
13140      Theta_1=Theta_1+.00005650*U
13150      U=U*T! Now U=T^3
13160      F0=F0-.00009512*U
13170      Theta_0=Theta_0+.00262573*U
13180      F1=F1+.00017105*U
13190      Theta_1=Theta_1-.00637879*U
13200      U=U*T! Now, U=T^4
13210      F0=F0+.00137237*U
13220      Theta_0=Theta_0-.00054125*U
13230      F1=F1-.00249511*U
13240      Theta_1=Theta_1+.00074348*U
13250      U=U*T! Now, U=T^5
13260      F0=F0-.00072805*U
13270      Theta_0=Theta_0-.00029333*U
13280      F1=F1+.00113653*U
13290      Theta_1=Theta_1+.00079824*U
13300      U=U*T! Now, U=T^6
13310      F0=F0+.00014476*U
13320      Theta_0=Theta_0+.00013558*U
13330      J0=F0*COS(Theta_0)/SQRT(X)
13340      Y0=F0*SIN(Theta_0)/SQRT(X)
13350      F1=F1-.00020033*U
13360      Theta_1=Theta_1-.00029166*U
13370      J1=F1*COS(Theta_1)/SQRT(X)
13380      Y1=F1*SIN(Theta_1)/SQRT(X)
13390      END IF
13400      ! Compute polar form of Hankel functions. (See eqn's 8.12-7
13410      !           & 8.12-8 of RW&VD.)
13420      G0=SQRT(J0*J0+Y0*Y0)
13430      IF J0<0 THEN
13440          Theta=ATN(Y0/J0)
13450          IF J0<0 THEN Theta=Theta+PI
13460      ELSE
13470          IF Y0<0 THEN
13480              Theta=(PI/2)*Y0/ABS(Y0)
13490          ELSE
13500              Theta=0
13510          END IF
13520      END IF
13530      G1=SQRT(J1*J1+Y1*Y1)
13540      IF Y1<0 THEN
13550          Psi=ATN(J1/(-1*Y1))
13560          IF (-1*Y1)<0 THEN Psi=Psi+PI
13570      ELSE
13580          IF J1<0 THEN
13590              Psi=(PI/2)*J1/ABS(J1)
13600          ELSE
13610              Psi=0
13620          END IF
13630      END IF
13640      ! Compute wave impedance Z0(x) per eqn 8.12-11 of RW&VD
13650      Z0s=SQRT(4.E-7*PI/8.8542E-12)*G0/G1
13660      ! PRINT " "
13670      ! PRINT " "
13680      ! PRINT "X=";X;"; J0=";J0;"; Y0=";Y0
13690      ! PRINT "X=";X;"; J1=";J1;"; Y1=";Y1
13700      ! PRINT "G0=";G0;"; G1=";G1
13710      ! PRINT "Theta=";Theta;" radians or ";Theta*180/PI;"degrees"
13720      ! PRINT "Psi=";Psi;" radians or ";Psi*180/PI;"degrees"

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```

13730 ! PRINT "Z0s=";Z0s
13740 SUBEND ! Radial_line
13750 !
13760 !
13770 Zi:DEF FNZi(Z0i,Theta_i,Psi_i,Z0l,Theta_l,Psi_l,COMPLEX Zl)
13780 !
13790 ! Function to compute the (total or surface) impedance looking into a
13800 !   radial line from the input parameters specified below.
13810 !
13820 ! INPUT PARAMETER DEFINITIONS:
13830 !
13840 ! Z0i is the characteristic surface impedance, in ohms, (looking outward)
13850 !   of the radial line as computed at the input port of the line.
13860 !   Z0i is defined by equations 8.12-11, 8.12-16 and 8.12-18 in RW&VD.
13870 ! Theta_i is the argument (radians) of the Hankel function of the first
13880 !   kind of order 0 at the input port. See eqn 8.12-7 of RW&VD.
13890 ! Psi_i is the argument (radians) of j times the Hankel function of the
13900 !   first kind of order 1 at the input port. See eqn 8.12-8 of RW&VD.
13910 ! Z0l is the characteristic surface impedance, in ohms, (looking outward)
13920 !   of the radial line as computed at the load port of the radial line.
13930 ! Theta_l is the argument (radians) of the Hankel function of the first
13940 !   kind of order 0 at the load port. It is defined in eqn 8.12-7 of
13950 !   RW&VD.
13960 ! Psi_l is the argument (radians) of j times the Hankel function of the
13970 !   first kind of order 1 at the load port. It is defined in equation
13980 !   8.12-8 of RW&VD.
13990 ! Zl is the complex surface impedance (ohms) terminating the radial line
14000 !   at the load end. The load port is assumed to be at a greater radius
14010 !   than the input port.  $Zl = Ez/Hphi$  as defined by RW&VD.
14020 !
14030   COMPLEX Ans,Numer,Denom,Cnl
14040   RAD
14041   Cnl=CMPLX(-1,0)
14050   Ctp=COS(Theta_i-Psi_l)
14060   Stt=SIN(Theta_i-Theta_l)
14070   Cpt=COS(Psi_i-Theta_l)
14080   Spp=SIN(Psi_i-Psi_l)
14090   Numer=(Cnl*Zl)*CMPLX(Ctp,0)+CMPLX(0.,Z0l*Stt) ! Cnl*Zl is "positive"
14100   Denom=CMPLX(Z0l*Cpt,0)+CMPLX(0.,1.)*(Cnl*Zl)*CMPLX(Spp,0)
14110   Ans=CMPLX(-Z0i,0)*Numer/Denom
14120   ! See last paragraph on page 457 of RW&VD for origin of - sign in
14130   ! preceding line.
14140   PRINT "Z0i=";Z0i;" Theta_i=";Theta_i;" Psi_i=";Psi_i
14150   PRINT "Z0l=";Z0l;" Theta_l=";Theta_l;" Psi_l=";Psi_l
14160   PRINT "Zl=";Zl;" FNZi=";Ans
14170   PRINT " "
14180   RETURN Ans
14190 FNEND ! FNZi
14200 !
14210 !
14220 Abc_anharm:SUB Abc_anharm(Jf)
14230 !
14240 ! SUB Abc_anharm computes complex a,b,c parameters of the bilinear
14250 !   transformation using the anharmonic ratio.
14260 !
14270 !   The model used is  $Tsz(Jf,I)=(a*Mw(Jf,I)+b)/(c*Mw(Jf,I)+1)$  where
14280 !    $Tsz(Jf,I)$  is the True value of standard I and
14290 !    $Mw(Jf,I)$  is the corresponding measured value. The complex a, b & c
14300 !   values are placed into COM variables A_par(Jf), B_par(Jf) &
14310 !   C_par(Jf), respectively.

```

```

14320 !
14330 !      Reference is NBS Tech Note 623 by R.W. Beatty.
14340 !
14350 ! INPUT ARGUMENT DEFINITIONS:
14360 !
14370 ! Jf is the index of the frequency Meas_freq(Jf) (MHz) under consideration
14380 !
14390      OPTION BASE 1
14400      COM /Abc/ COMPLEX A_par(*),B_par(*),C_par(*)
14410      COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
14420      COMPLEX A,B,C,S,S1,S2,S3,Z1mz2,W2mw3,Z2mz3,W1mw2
14430      COMPLEX Z1z2w2w3,Z2z3w1w2,A4,B4,C4,D4
14440      Z1mz2=Tsz(Jf,1)-Tsz(Jf,2)
14450      W2mw3=Mw(Jf,2)-Mw(Jf,3)
14460      PRINT "Tsz(";Jf;" ,1)=";Tsz(Jf,1);";   Tsz(";Jf;" ,2)=";Tsz(Jf,2)
14470      PRINT "Mw(";Jf;" ,2)=";Mw(Jf,2);";   Mw(";Jf;" ,3)=";Mw(Jf,3)
14480      Z1z2w2w3=Z1mz2*W2mw3
14490      Z2mz3=Tsz(Jf,2)-Tsz(Jf,3)
14500      W1mw2=Mw(Jf,1)-Mw(Jf,2)
14510      Z2z3w1w2=Z2mz3*W1mw2
14520      A4=Z1z2w2w3*Tsz(Jf,3)
14530      B4=-A4*Mw(Jf,1)
14540      S2=Z2z3w1w2*Tsz(Jf,1)
14550      A4=A4-S2
14560      S3=Mw(Jf,3)*S2
14570      B4=B4+S3
14580      C4=Z1z2w2w3-Z2z3w1w2
14590      D4=Z2z3w1w2*Mw(Jf,3)
14600      S1=Z1z2w2w3*Mw(Jf,1)
14610      PRINT "D4=";D4;";   S1=";S1
14620      D4=D4-S1
14630      A_par(Jf)=A4/D4
14640      B_par(Jf)=B4/D4
14650      C_par(Jf)=C4/D4
14660      PRINT "a=";A_par(Jf);"; b=";B_par(Jf);"; c=";C_par(Jf)
14670 SUBEND ! Abc_anharm
14680 !
14690 !
14700 Bilinear:DEF FNBilinear(COMPLEX A,B,C,Mw)
14710 !      Function to compute the surface impedance Tsz from the measured valu
e Mw and
14720 !      the a,b,c parameters.
14730 !      The model used is  $Tsz=(a*Mw+b)/(c*Mw+1)$  where Tsz is the True value
14740 !      of complex variable Z and Mw is the Measured value of complex
14750 !      variable W(i).
14760 !
14770 ! INPUT ARGUMENT DEFINITIONS:
14780 !
14790 !      A,B,C are the complex a,b,c parameters, in rectangular form, as
14800 !      defined in the model above.
14810 !      Mw is the complex measured value in rectangular form.
14820 !
14830      RETURN (A*Mw+B)/(C*Mw+1)
14840 FNEND ! Bilinear
14850 !
14860 !
14870 Stp_cap_wk:DEF FNStp_cap_wk(Bb,Sa,Radius)
14880 ! Function to compute the capacitance at the junction (at Radius inches)
14890 ! of two radial line waveguides which have heights of Bb and Sb,
14900 ! respectively. See eqn 39c on p 431 of Electromagnetic Theory for

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14910 ! Engineering Application by Weeks.
14920 !
14930 ! INPUT ARGUMENT DEFINITIONS:
14940 !
14950 !   Bb is the height of the tall waveguide in inches.
14960 !   Sa is the height of the small waveguide in inches.
14970 !   Radius is the radius of the junction in inches.
14980 !
14990   RAD
15000   Piaob=PI*Sa/Bb
15010   EO=8.8542E-12! farads per meter
15020   Twocpm=0
15030   N=1
15040   Rel_change=10
15050   REPEAT ! until Rel_change <1E-6
15060     Npiaob=N*Piaob
15070     Kernel=SIN(Npiaob)/Npiaob
15080     Twocpm=Twocpm+Kernel*Kernel/N
15090     IF N>1 THEN
15100       Rel_change=(Twocpm-Last_twocpm)/Last_twocpm
15110     END IF
15120     Last_twocpm=Twocpm
15130     DISP "N=";N
15140     N=N+1
15150   UNTIL Rel_change<1.E-6
15160   Cpm=(Twocpm/2)*(2*EO/PI)
15170   Delt_c_tot=Radius*.0254*Cpm
15180   RETURN Delt_c_tot
15190 FNEND ! Stp_cap_wk
15200 !
15210 !
15220 Salis_ld_z:SUB Salis_ld_z(Jf,Com_dim,Mod_def_dim,COMPLEX T_salis_z,S_salis
_z)
15230 !
15240 ! ARGUMENT DEFINITIONS:
15250 !
15260 ! Jf (input argument) is the index of the frequency for which the total &
15270 !   surface impedances of the Salisbury load is desired.
15280 ! Com_dim (input argument) is set to 1 if radial line dimensions specified
15290 !   in COM are to be used; otherwise, it is set to 0.
15300 ! Mod_def_dim (input argument) is set to 1 if default dimensions specified
15310 !   in code are to be modified; otherwise, it is set to 0.
15320 ! T_salis_z (output argument) is the total complex impedance presented by
15330 !   the Salisbury load at the Jf'th frequency.
15340 ! S_salis_z (output argument) is the surface complex impedance presented
15350 !   by the Salisbury load at the Jf'th frequency.
15360 !
15370   OPTION BASE 1
15380   DIM Z0s_i_salis(101),Z0s_o_salis(101)
15390   DIM Theta_o_salis(101),Theta_i_salis(101),Psi_i_salis(101),Psi_o_salis(1
01)
15400   COM /Freq/ Meas_freq(*),INTEGER To_no_mf
15410   COM /Short_dims/ Rad4,Height4,Rad9,Height9,Rad15,Height15
15420   COM /Salis/ O_rad_salis,I_rad_salis,Hite_salis,Topdisk_thk,Botdisk_thk
15430   COM /Salis2/ Rs_film
15440   COMPLEX Czero,Tsz_sal_offshrt,Tys,C_hite_ratio,C_one,Yos,Yfilm,Ycap
15450   DIM O_rad_salis$(6),I_rad_salis$(6),Hite_salis$(6),Topdisk_thk$(6)
15460   DIM Botdisk_thk$(6),Rs_film$(9)
15470   Czero=CMPLX(0,0)
15480   C_one=CMPLX(1,0)

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```

15490 PRINT " "
15500 IF Jf=1 AND Com_dim=0 AND Mod_def_dim=1 THEN
15510 PRINT "Default outer RADIUS (inches) of the Salisbury screen load is "
;
15520 PRINT O_rad_salis
15530 PRINT "Enter new value or press ENTER to accept default value. ";
15540 BEEP
15550 LINPUT O_rad_salis$
15560 IF LEN(O_rad_salis$)<>0 THEN
15570 ENTER O_rad_salis$;O_rad_salis
15580 END IF
15590 PRINT O_rad_salis
15600 PRINT " "
15610 PRINT "Default inner RADIUS (inches) of the Salisbury screen load is "
;
15620 PRINT I_rad_salis
15630 PRINT "Enter new value or press ENTER to accept default value. ";
15640 BEEP
15650 LINPUT I_rad_salis$
15660 IF LEN(I_rad_salis$)<>0 THEN
15670 ENTER I_rad_salis$;I_rad_salis
15680 END IF
15690 PRINT I_rad_salis
15700 PRINT " "
15710 PRINT "I_rad_salis - Rad4 = ";I_rad_salis-Rad4
15720 PRINT " "
15730 PRINT "Default HEIGHT (inches) of the Salisbury screen load is ";
15740 PRINT Hite_salis
15750 PRINT "Enter new value or press ENTER to accept default value. ";
15760 BEEP
15770 LINPUT Hite_salis$
15780 IF LEN(Hite_salis$)<>0 THEN
15790 ENTER Hite_salis$;Hite_salis
15800 END IF
15810 PRINT Hite_salis
15820 PRINT " "
15830 PRINT "Default thickness (in.) of TOP central disc of Salisbury load i
s ";
15840 PRINT Topdisk_thk
15850 PRINT "Enter new value or press ENTER to accept default value. ";
15860 BEEP
15870 LINPUT Topdisk_thk$
15880 IF LEN(Topdisk_thk$)<>0 THEN
15890 ENTER Topdisk_thk$;Topdisk_thk
15900 END IF
15910 PRINT Topdisk_thk
15920 PRINT " "
15930 PRINT "Default thickness (in.) of BOTTOM central disc of Salisbury loa
d is ";
15940 PRINT Botdisk_thk
15950 PRINT "Enter new value or press ENTER to accept default value. ";
15960 BEEP
15970 LINPUT Botdisk_thk$
15980 IF LEN(Botdisk_thk$)<>0 THEN
15990 ENTER Botdisk_thk$;Botdisk_thk
16000 END IF
16010 PRINT Botdisk_thk
16020 PRINT " "
16030 PRINT "Default surface resistivity of space cloth is ";Rs_film;" ohms
per square."

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16040     PRINT "Enter new value or press ENTER to accept default value.  ";
16050     BEEP
16060     LINPUT Rs_film$
16070     IF LEN(Rs_film$) <> 0 THEN
16080         ENTER Rs_film$;Rs_film
16090     END IF
16100     PRINT Rs_film
16110     END IF
16120     CALL Radial_line(Meas_freq(Jf),O_rad_salis,Hite_salis,Z0s_o_salis(Jf),Th
eta_o_salis(Jf),Psi_o_salis(Jf))
16130 !
16140 ! PRINT Meas_freq(Jf),O_rad_salis,Hite_salis,Z0s_o_salis(jf),Theta_o_salis
(Jf),Psi_o_salis(Jf)
16150 !
16160     CALL Radial_line(Meas_freq(Jf),I_rad_salis,Hite_salis,Z0s_i_salis(Jf),Th
eta_i_salis(Jf),Psi_i_salis(Jf))
16170 !
16180 ! PRINT Meas_freq(Jf),I_rad_salis,Hite_salis,Z0s_i_salis(jf),Theta_i_salis
(Jf),Psi_i_salis(Jf)
16190 !
16200 ! Compute Surface Salisbury impedance
16210     Film_hite=Hite_salis-(Topdisk_thk+Botdisk_thk)
16220     Tsz_sal_offshrt=FNZI(Z0s_i_salis(Jf),Theta_i_salis(Jf),Psi_i_salis(Jf),Z
0s_o_salis(Jf),Theta_o_salis(Jf),Psi_o_salis(Jf),Czero)
16230 !
16240     C_hite_ratio=CMPLX(Film_hite/Hite_salis,0)
16250     Total_cap=FNStep_cap_w(Hite_salis,Film_hite,I_rad_salis)
16260     Cap_per_square=Total_cap*Film_hite/(2*PI*I_rad_salis)
16270     Yos=C_hite_ratio/Tsz_sal_offshrt
16280     Yfilm=CMPLX(1./Rs_film,0)
16290     Ycap=CMPLX(0,(2.E+6)*PI*Meas_freq(Jf)*Cap_per_square)
16300     PRINT "Freq=";Meas_freq(Jf)
16310     PRINT "Yos=";Yos;" "; Yfilm="";Yfilm;" "; Ycap="";Ycap
16320     Tys=Yos+Yfilm+Ycap
16330     S_salis_z=C_one/Tys
16340 !
16350 ! Compute Total Salisbury impedance from Surface Salisbury impedance.
16360     T_salis_z=S_salis_z*Film_hite/(2*PI*I_rad_salis)
16370 !
16380 SUBEND                ! Salis_ld_z
16390 !
16400 !
16410 Step_cap_w:DEF FNStep_cap_w(Bh,Sh,Radius)
16420 ! Function to compute the total step capacitance at the junction (at
16430 ! Radius inches) of two radial line waveguides which have heights of Bh
16440 ! and Sh, respectively). Reference is Schwartz-Christoffel transformation
16450 ! by Larry Warne of 2753.
16460 !
16470 ! INPUT ARGUMENT DEFINITIONS:
16480 !
16490 !     Bh is the height of the tall waveguide in inches.
16500 !     Sh is the height of the small waveguide in inches.
16510 !     Radius is the radius (in inches) at which the Bh,Sh junction occurs.
16520 !
16530     Q=Sh/Bh
16540     E0=8.8542E-12! Farads per meter
16550     Delt_c_tot=(1+Q)*(1+Q)*LOG(1+Q)/Q-(1-Q)*(1-Q)*LOG(1-Q)/Q
16560     Delt_c_tot=Radius*.0254*E0*(Delt_c_tot-2*LOG(2)-2*LOG(2*Q))
16570     RETURN Delt_c_tot
16580 FNEND                ! FNStep_cap_w

```

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16590 !
16600 !
16610 !*****
16620 Type_abc_rept:SUB Type_abc_rept
16630 !*****
16640 !
16650 ! Subprogram for printing out abc measurement results
16660 !
16670 !ARGUMENT DEFINITIONS:
16680 !
16690   OPTION BASE 1
16700   COM /Misc/ In$(25),@Nwa,@Nwa_data1,@Nwa_data2
16710   COM /Freq/ Meas_freq(*),INTEGER To_no_mf
16720   COM /Abc_freq/ Abc_file_freq(*),INTEGER To_no_abc_f,Indx_abc(*)
16730   COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
16740   COM /Abc/ COMPLEX A_par(101),B_par(101),C_par(101)
16750   COM /Vana/ INTEGER If_avg_factor,If_band_width
16760   COM /Sysid/ Serial_8753$(10),Model_ts$(5),Serial_ts$(10)
16770   COM /Ctorl/ Ser_ctorlt$(12),Prop_ctorlt$(8),Own_ctorlt$(15)
16780   COM /Meas_param/ Tech_cons$(25),Jet,Sim,INTEGER No_copies,Meas_option
16790   COM /Progid/ Version_date$(18),Prog_name$(10)
16800   INTEGER J,Ret_flag,Initial
16810   CLEAR SCREEN
16820   PRINT "Printing Data Sheet ...."
16830   PRINT " "
16840   Form_feed$=CHR$(12)
16850   !
16860   PRINTER IS Jet
16870   FOR I=1 TO No_copies
16880     PRINT Form_feed$
16890     PRINT TAB(33);"DATA SHEET"
16900     PRINT " "
16910     PRINT ""
16920     PRINT ""
16930     PRINT USING "28A,12A";"C/RL transition Ser Number: ";Ser_ctorlt$
16940     PRINT ""
16950     PRINT USING "17A,8A,20X,7A,15A";"Property Number: ";Prop_ctorlt$;"Owne
r: ";Own_ctorlt$
16960     PRINT " "
16970     PRINT USING "10A,11A,23X,9A,11A";"Measured: ",DATE$(TIMEDATE)
16980     PRINT " "
16990     PRINT " "
17000     PRINT " "
17010     PRINT "Measured abc parameters of transformation  $Z_s = (a*Z_m + b)/(c*Z_m + 1)$  are:"
17020     PRINT " "
17030     PRINT "Frequency          a          b
c"
17040     PRINT " "
17050     FOR Jf=1 TO To_no_mf
17060       PRINT USING Fmt1;Meas_freq(Jf),A_par(Jf),B_par(Jf),C_par(Jf)
17070 Fmt1: IMAGE 5D.2D,3(2X,M.DDDDESZZ,1X,M.DDDDESZZ)
17080     NEXT Jf
17090   NEXT I
17100 ! PRINT Form_feed$
17110   PRINTER IS CRT
17120   PRINT " "
17130     ! Store Measurement Results in file Data_file_name$ on SUPport disc
17140     ! in drive 0.
17150   Id$="Y"

```



```

17160 First_3let$="ABC"
17170 CALL Sup_fil_id(New_file$,Data_file_name$,First_3let$,Id$)
17180 IF New_file$="N" THEN PURGE Data_file_name$&"",1500,0"
17190 File_size=1+3+To_no_mf+1
17200 PRINT "Storing data on disc..."
17210 CREATE BDAT Data_file_name$&"",1500,0",File_size,88
17220 ASSIGN @Path_3 TO Data_file_name$&"",1500,0"
17230 OUTPUT @Path_3;To_no_mf,Meas_option
17240 OUTPUT @Path_3;Ser_ctorlt$,Prop_ctorlt$
17250 OUTPUT @Path_3;Own_ctorlt$,TIMEDATE
17260 FOR J=1 TO To_no_mf
17270     OUTPUT @Path_3;Meas_freq(J),A_par(J),B_par(J),C_par(J)
17280     Indx_abc(J)=J
17290 NEXT J
17300 ASSIGN @Path_3 TO *
17310 PRINT " "
17320 PRINT "Do you wish to record the abc parameters on a DOS format disc? (Y
or N) ";
17330 INPUT Yorn$
17340 Yorn$=UPC$(Yorn$)
17350 PRINT Yorn$
17360 IF Yorn$="Y" THEN CALL Abc_dos_dat_fil
17370 A:SUBEND ! Type_abc_rept
17380 !
17390 !*****
17400 !
17410 Z_via_abc:SUB Z_via_abc
17420 ! LEAD SUBPROGRAM FOR MEASURING TERMINATING IMPEDANCE OF A RADIAL LINE
17430 ! TRANSITION VIA THE abc PARAMETER METHOD
17440 !
17450 !
17460 OPTION BASE 1
17470 COM /Misc/ In${25},@Nwa,@Nwa_data1,@Nwa_data2
17480 COM /Freq/ Meas_freq(*),INTEGER To_no_mf
17490 COM /Abc_freq/ Abc_file_freq(*),INTEGER To_no_abc_f,Indx_abc(*)
17500 COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
17510 COM /Abc/ COMPLEX A_par(*),B_par(*),C_par(*)
17520 COM /Vana/ INTEGER If_avg_factor,If_band_width
17530 COM /Short_dims/ Rad4,Height4,Rad9,Height9,Rad15,Height15
17540 COM /Sysid/ Serial_8753${10},Model_ts${5},Serial_ts${10}
17550 COM /Ctorl/ Ser_ctorlt${12},Prop_ctorlt${8},Own_ctorlt${15}
17560 COM /Meas_param/ Tech_cons${25},Jet,Sim,INTEGER No_copies,Meas_option
17570 COM /Progid/ Version_date${18},Prog_name${10}
17580 DIM Technique${10}
17590 COMPLEX Zt(101),Z_p_sq(101)
17600 INTEGER I,J,K,L,M,N,Aborted
17610 DEG
17620 ! DEFINE PARAMETERS OF CALIBRATION
17630 CLEAR SCREEN
17640 PRINT "Place Measurement Parameter SUPport disc (HP LIF format) in drive
0 then press"
17650 PRINT "CONTINUE"
17660 BEEP
17670 PAUSE
17680 B:CALL Acq_meas_p
17690 IF To_no_abc_f>0 THEN
17700     PRINT " "
17710     PRINT "Enter C to utilize abc parameters stored in COM or"
17720     PRINT "Enter D to utilize abc parameters stored in a Disc file. ";
17730     LINPUT Cord$

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17740     PRINT Cord$
17750     ELSE
17760         Cord$="D"
17770     END IF
17780 Ta: IF Cord$="d" OR Cord$="D" THEN
17790     PRINT " "
17800     ! Read abc values from file Data_file_name$ on SUPport disc in drive 0
.
17810     Id$="Y"
17820     First_3let$="ABC"
17830     CALL Sup_fil_id(New_file$,Data_file_name$,First_3let$,Id$)
17840     PRINT "Reading data from disc..."
17850     ASSIGN @Path_3 TO Data_file_name$&":1500,0"
17860     ENTER @Path_3;To_no_abc_f,Meas_option
17870     ENTER @Path_3;Ser_ctorlt$,Prop_ctorlt$
17880     ENTER @Path_3;Own_ctorlt$,Meas_date_ctime
17890     FOR J=1 TO To_no_abc_f
17900         ENTER @Path_3;Abc_file_freq(J),A_par(J),B_par(J),C_par(J)
17910     NEXT J
17920     ASSIGN @Path_3 TO *! Close I/O path
17930     PRINT " "
17940 ! Find indices of the abc values for the current set of measurement freqs
17950     FOR J=1 TO To_no_mf
17960         CALL Fmatch_abc_file(Meas_freq(J),Indx_abc(J),Aborted)
17970         IF Aborted=1 THEN GOTO Ta
17980     NEXT J
17990     END IF
18000     CLEAR SCREEN
18010     IF Sim=0 THEN
18020         PRINT "Do you want to re-process previous measurement data in Computer
"
18030         PRINT "COM? (Y or N)"
18040         BEEP
18050         INPUT In$
18060         PRINT In$
18070         IF In$="Y" OR In$="y" THEN GOTO C
18080     END IF
18090     IF Sim=0 THEN
18100         ! Acquire measurement data to measure Z
18110         CALL Acqdat_zmeas
18120     ELSE
18130 ! CALL Z_via_abc_sim
18140     END IF
18150 C:FOR Jf=1 TO To_no_mf
18160     Z_p_sq(Jf)=FNBilinear(A_par(Indx_abc(Jf)),B_par(Indx_abc(Jf)),C_par(In
dx_abc(Jf)),Mw(Jf,1))
18170 ! Compute total Zt(Jf) from Z_p_sq(Jf) where
18180     Zt(Jf)=Z_p_sq(Jf)*Height4/(2*PI*Rad4)
18190     NEXT Jf
18200     ! Output the Results
18210     Technique$="abc"
18220     CALL Type_lod_z_rept(Technique$,Zt(*),Z_p_sq(*))
18230 D: SUBEND ! Z_via_abc
18240 !
18250 !
18260 !*****
18270 !
18280 Acqdat_zmeas: SUB Acqdat_zmeas
18290 ! Subprogram directing the acquisition of data for measuring the impedance
18300 ! at the coaxial input of a coax-to-radial-line-transition which is

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18310 ! loaded by a total impedance of Zt(Jf).
18320 !
18330 OPTION BASE 1
18340 COM /Misc/ In$(25),@Nwa,@Nwa_data1,@Nwa_data2
18350 COM /Freq/ Meas_freq(*),INTEGER To_no_mf
18360 COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
18370 COM /Vana/ INTEGER If_avg_factor,If_band_width
18380 COM /Meas_param/ Tech_cons$(25),Jet,Sim,INTEGER No_copies,Meas_option
18390 INTEGER I,J,K,L,M,N
18400 DEG
18410 CLEAR SCREEN
18420 CALL Choose_cals
18430 CLEAR SCREEN
18440 REMOTE 7
18450 PRINT " "
18460 PRINT "      a. Connect the loaded coax-to-radial-line-transition to port
1 of the VANA."
18470 PRINT "      b. Press CONTINUE when done."
18480 LOCAL 716
18490 BEEP
18500 PAUSE
18510 GOSUB Setup
18520 PRINT " "
18530 CLEAR SCREEN
18540 GOTO A
18550 Setup: ! Subroutine to acquire needed Impedance measurements
18560 PRINT " "
18570 PRINT "                        8753 measurements in progress..."
18580 PRINT " "
18590 REMOTE 716
18600! OUTPUT 716;"S11;POLA;S21;POLA;S12;POLA;S22;POLA;"
18610 OUTPUT 716;"SMIC;"
18620 OUTPUT 716;"OPC?;NUMG";If_avg_factor;";"
18630 ENTER 716;Reply
18640 CALL Acq_8753_dat(1,1)
18650 RETURN
18660 A:SUBEND! Acqdat_zmeas
18670 !
18680 !
18690 Fmatch_abc_file:SUB Fmatch_abc_file(F,INTEGER J_abc,Aborted)
18700 ! Sub to find the index of the frequency F in the array of abc values.
18710 !
18720 ! INPUT ARGUMENT DEFINITIONS:
18730 !
18740 ! F (input argument) is the frequency whose index is needed.
18750 ! J_abc (output argument) is the index of the frequency F in the
18760 !      array of abc values.
18770 ! Aborted = 1 indicates that the certification process has been aborted.
18780 !
18790 OPTION BASE 1
18800 COM /Freq/ Meas_freq(*),INTEGER To_no_mf
18810 COM /Abc_freq/ Abc_file_freq(*),INTEGER To_no_abc_f,Indx_abc(*)
18820 !
18830 INTEGER I,J,K,L,M,N
18840 DEG
18850 FOR I=1 TO To_no_abc_f
18860     IF F=Abc_file_freq(I) THEN
18870         J_abc=I
18880         GOTO A
18890     END IF

```

```

18900 NEXT I
18910 PRINT "abc values aren't available at ";F;" MHz! Load new file or measur
e abc values."
18920 BEEP
18930 Aborted=1
18940 A:SUBEND !Fmatch_abc_file
18950 !
18960 !
18970 Type_lod_z_rept:SUB Type_lod_z_rept(Technique$,COMPLEX Zt(*),Z_p_sq(*))
18980 !
18990 ! Subprogram for printing results of measuring load Z on a radial line.
19000 !
19010 ! INPUT ARGUMENT DEFINITIONS:
19020 !
19030 ! Technique$ is either "Williamson" or "abc"; it describes the technique
19040 ! used to measure the load.
19050 ! Zt(J) is the measured total complex impedance (in rectangular form) of
19060 ! the load terminating a radial line at the Jth frequency.
19070 ! Z_p_sq(J) is the measured complex surface impedance (in rectangular form
19080 ! in ohms per square) of the load terminating the radial line.
19090 !
19100 OPTION BASE 1
19110 COM /Misc/ In$(25),@Nwa,@Nwa_data1,@Nwa_data2
19120 COM /Freq/ Meas_freq(*),INTEGER To_no_mf
19130 COM /Short_dims/ Rad4,Height4,Rad9,Height9,Rad15,Height15
19140 COM /Ctorl/ Ser_ctorlt$(12),Prop_ctorlt$(8),Own_ctorlt$(15)
19150 COM /Meas_param/ Tech_cons$(25),Jet,Sim,INTEGER No_copies,Meas_option
19160 COM /Progid/ Version_date$(18),Prog_name$(10)
19170 COMPLEX Zt_z_rad(101),Z_p_sq_z_rad(101)
19180 DIM Ztm(101),Zta(101),Z_p_sqm(101),Z_p_sqa(101),Descrip$(64)
19190 INTEGER J,Ret_flag,Initial
19200 Z_rad=Rad4
19210 A: CLEAR SCREEN
19220 PRINT "Enter a description of the measured load in 64 characters or less
."
19230 LINPUT Descrip$
19240 PRINT " "
19250 PRINT Descrip$
19260 B:PRINT " "
19270 PRINT " "
19280 PRINT "Enter serial number of the measured load or enter 0 to correct pr
ior entry.";
19290 INPUT Unk_sn
19300 IF Unk_sn=0 THEN GOTO A
19310 PRINT Unk_sn
19320 PRINT " "
19330 PRINT " "
19340 PRINT "Enter 0 to correct prior entry or enter 1 to proceed."
19350 INPUT Corp
19360 IF Corp=0 THEN GOTO B
19370 C:PRINT " "
19380 PRINT " "
19390 PRINT "The impedance looking outward from a radius of ";Z_rad;" inches w
ill be printed."
19400 PRINT "If desired, enter a different radius or press ENTER to continue."
19410 LINPUT Rad$
19420 IF LEN(Rad$)>0 THEN
19430 ENTER Rad$;Z_rad
19440 PRINT Z_rad
19450 PRINT " "

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```

19460     PRINT " "
19470     PRINT "Enter 0 to correct prior entry or enter 1 to proceed."
19480     INPUT Corp
19490     IF Corp=0 THEN GOTO C
19500     CALL Z_r_xform(Z_rad,Z_p_sq(*),Zt_z_rad(*),Z_p_sq_z_rad(*))
19510     END IF
19520     Form_feed$=CHR$(12)
19530     !
19540     PRINT "Printing Data Sheet ...."
19550     PRINTER IS Jet
19560     FOR I=1 TO No_copies
19570         PRINT Form_feed$
19580         PRINT TAB(33);"DATA SHEET"
19590         PRINT " "
19600         PRINT " "
19610         PRINT " "
19620         PRINT "Item: ";Descrip$
19630         PRINT ""
19640         PRINT ""
19650         PRINT "Item Serial Number: ";Unk_sn
19660         PRINT ""
19670         PRINT " "
19680         PRINT USING "10A,11A,23X,9A,11A";"Measured: ",DATE$(TIMEDATE)
19690         PRINT " "
19700         PRINT " "
19710         PRINT " "
19720         PRINT "Impedance at ";Z_rad;" inch radius as measured by ";TRIM$(Techn
ique$);" technique:"
19730         PRINT " "
19740         PRINT "Frequency                                Zt
19750         PRINT "                                Mag.      Ang.      Z_p_sq "
19760         PRINT "                                Mag.      Ang.      Ang. "
19770         FOR Jf=1 TO To_no_mf
19780             IF LEN(Rad$)=0 THEN
19790                 Ztm(Jf)=ABS(Zt(Jf))
19800                 Zta(Jf)=FNAng2(Zt(Jf))
19810                 Z_p_sqm(Jf)=ABS(Z_p_sq(Jf))
19820                 Z_p_sqa(Jf)=FNAng2(Z_p_sq(Jf))
19830             ELSE
19840                 Ztm(Jf)=ABS(Zt_z_rad(Jf))
19850                 Zta(Jf)=FNAng2(Zt_z_rad(Jf))
19860                 Z_p_sqm(Jf)=ABS(Z_p_sq_z_rad(Jf))
19870                 Z_p_sqa(Jf)=FNAng2(Z_p_sq_z_rad(Jf))
19880             END IF
19890             PRINT USING Fmt1;Meas_freq(Jf),Ztm(Jf),Zta(Jf),Z_p_sqm(Jf),Z_p_sqa(J
f)
19900 Fmt1: IMAGE 1X,5D.DD,2(7X,DDDD.DD,1X,DDDD.DD)
19910         NEXT Jf
19920     NEXT I
19930     PRINTER IS CRT
19940     PRINT " "
19950     PRINT "Do you want to record these results on a 3 1/2 disc in DOS format
? (Y or N)";
19960     LINPUT In$
19970     PRINT In$
19980     IF In$="y" OR In$="Y" THEN
19990         CALL Z_dos_dat_fil(Descrip$,Unk_sn,Technique$,Z_rad,Ztm(*),Zta(*),Z_p_
sqm(*),Z_p_sqa(*))
20000     END IF
20010     PRINT " "

```

```

20020 SUBEND ! Type_lod_z_rept
20030 !
20040 !
20050 !*****
20060 Z_dos_dat_fil:SUB Z_dos_dat_fil(Descrip$,Unk_sn,Technique$,Z_rad,Ztm(*),Zt
a(*),Z_p_sqm(*),Z_p_sqa(*))
20070 !*****
20080 !
20090 ! Subprogram Z_dos_dat_fil will write measured radial load impedance
20100 ! (looking outward from the radial line input port cylinder)
20110 ! results into an ASCII file on a DOS formatted disc.
20120 !
20130 ! INPUT ARGUMENT DEFINITIONS:
20140 !
20150 ! Descrip$ is a text description (<65 characters) of the measured radial
20160 ! load.
20170 ! Unk_sn is the numeric serial number of the measured radial load.
20180 ! Technique$ identifies the technique - abc or Williamson - used to
20190 ! measure the radial load.
20200 ! Z_rad is the radius in inches at which the radial load surface impedance
20210 ! is measured.
20220 ! Ztm(Jf), Zta(Jf) are the magnitude and angle (degrees), respectively, of
20230 ! the total impedance of the radial load at the Jf'th
20240 ! frequency.
20250 ! Z_p_sqm(Jf), Z_p_sqa(Jf) are the magnitude and angle (degrees),
20260 ! respectively, of the surface impedance
20270 ! of the measured radial load at the Jf'th
20280 ! frequency.
20290 !
20300 OPTION BASE 1
20310 DEG
20320 !
20330 COM /Misc/ In$(25),@Nwa,@Nwa_data1,@Nwa_data2
20340 COM /Freq/ Meas_freq(*),INTEGER To_no_mf
20350 COM /Ctorl/ Ser_ctorlt$(12),Prop_ctorlt$(8),Own_ctorlt$(15)
20360 COM /Meas_param/ Tech_cons$(25),Jet,Sim,INTEGER No_copies,Meas_option
20370 !
20380 DIM Meas_param5$(80),File_name$(18)
20390 !
20400 File_name$="ZDAT.DAT"
20410 St:PRINT " "
20420 PRINT " Insert a DOS formatted disc into drive A, then press CONTINUE."
20430 BEEP
20440 PAUSE
20450 PRINT " "
20460 MASS STORAGE IS ":DOS,A"
20470 PRINT " "
20480 PRINT " Enter the filename (<9 characters + optional 3 character extensi
on)"
20490 PRINT " OR"
20500 PRINT " Press ENTER to accept the default which is ";File_name$
20510 BEEP
20520 LINPUT In$
20530 !
20540 IF LEN(In$)<>0 THEN
20550 ENTER In$;File_name$
20560 PRINT File_name$
20570 END IF
20580 !

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```

20590 PRINT " "
20600 !
20610 ON ERROR GOTO Proceed
20620 !
20630 ASSIGN @Tape5 TO * ! If TAPE5 is open then close it.
20640 Proceed:N_hdr_recs=4 ! 3 records for header + 1 extra
20650 OFF ERROR
20660 N_rec_per_freq=1 ! 1 records for each frequency
20670 N_recs_in_5=N_hdr_recs+N_rec_per_freq*to_no_mf
20680 PRINT "Storing data on DOS disc..."
20690 ON ERROR GOTO Message
20700 CREATE File_name$&":DOS,A",N_recs_in_5
20710 Ul:ASSIGN @Tape5 TO File_name$&":DOS,A";FORMAT ON
20720 OFF ERROR
20730 !
20740 OUTPUT Meas_param5$ USING Format1;To_no_mf,"",Meas_option," ! No. Freqs
, Measurement option"
20750 Format1:IMAGE X,DDD,A,X,DD,32A
20760 OUTPUT @Tape5;Meas_param5$
20770 !
20780 OUTPUT Meas_param5$ USING Format2;Unk_sn,"",Descrip$," !SN, Des"
20790 Format2:IMAGE X,DD,A,X,64A,9A
20800 OUTPUT @Tape5;Meas_param5$
20810 !
20820 OUTPUT Meas_param5$ USING Format3;TRIM$(Technique$),"",Z_rad,"",TRIM$(
DATE$(TIMEDATE))," ! Technique, Z_rad, Meas. date"
20830 Format3:IMAGE X,10A,A,X,DD.4D,A,X,11A,31A
20840 OUTPUT @Tape5;Meas_param5$
20850 !
20860 FOR J=1 TO To_no_mf
20870 OUTPUT Meas_param5$ USING Format4;Meas_freq(J),"",Ztm(J),"",Zta(J),"
",Z_p_sqm(J),"",Z_p_sqa(J)," ! Freq(MHz) Ztm Zta Zsm Zsa"
20880 Format4:IMAGE 5D.2D,4(A,X,5D.2D),28A
20890 OUTPUT @Tape5;Meas_param5$
20900 NEXT J
20910 !
20920 ASSIGN @Tape5 TO *
20930 MASS STORAGE IS ":,1500,1"
20940 SUBEXIT
20950 Message:PRINT " "
20960 BEEP
20970 PRINT "Something is wrong! Check for WRONG disc, duplicate file name, et
c."
20980 PRINT
20990 GOTO St
21000 RETURN
21010 !
21020 SUBEND ! Z_dos_dat_fil
21030 !
21040 !
21050 !*****
21060 Ang2:DEF FNAng2(COMPLEX Z)
21070 !*****
21080 !
21090 ! Function to determine the angle in degrees of the complex input
21100 ! argument Z which is given in rectangular form.
21110 !
21120 DEG
21130 X=REAL(Z)
21140 Y=IMAG(Z)

```

```

21150 IF X<>0 THEN
21160   Ang=ATN(Y/X)
21170   IF X<0 THEN Ang=Ang+180
21180 ELSE
21190   IF Y<>0 THEN
21200     Ang=90*Y/ABS(Y)
21210   ELSE
21220     Ang=0
21230   END IF
21240 END IF
21250 RETURN Ang
21260 FNEND ! Ang2
21270 !
21280 !
21290 Z_via_will:SUB Z_via_will
21300 !
21310 ! SUB to compute the surface and total impedance at a radial line port
21320 ! from the measured impedance, Mw(Jf), at the coax line/radial line
21330 ! interface at the Jf'th frequency. Reference is:
21340 ! A.G. Williamson, "Radial-line/coaxial-line junctions: analysis and
21350 ! equivalent circuits", INT. J. ELECTRONICS, 1985, VOL. 58, NO.1, 91-104
21360 !
21370 OPTION BASE 1
21380 COM /Freq/ Meas_freq(*),INTEGER To_no_mf
21390 COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
21400 COM /Short_dims/ Rad4,Height4,Rad9,Height9,Rad15,Height15
21410 DIM R(101),Q(101),Meas_param5$(80),Technique$(10)
21420 COMPLEX Zt(101),Z_p_sq(101)
21430 INTEGER Siz
21440 DEG
21450 Sim=0
21460 CLEAR SCREEN
21470 IF Sim=0 THEN
21480   PRINT "Do you want to re-process previous measurement data in Computer
21490   PRINT "COM? (Y or N)"
21500   BEEP
21510   LINPUT In$
21520   PRINT In$
21530   IF In$="Y" OR In$="y" THEN GOTO C
21540 END IF
21550 ! DEFINE PARAMETERS OF CALIBRATION
21560 PRINT " "
21570 CLEAR SCREEN
21580 PRINT "Place Measurement Parameter SUPport disc (HP LIF format) in drive
21590 PRINT "CONTINUE"
21600 BEEP
21610 PAUSE
21620 B:CALL Acq_meas_p
21630 PRINT " "
21640 CLEAR SCREEN
21650 IF Rad4>0 THEN
21660   PRINT "Enter 1 to retain current hardware dimensions and values stored
21670   PRINT " OR"
21680   PRINT "Enter 0 to work from default hardware dimensions and values in
21690   PRINT " code. ";
21700   INPUT Com_dim

```



```

21710     PRINT Com_dim
21720 ELSE
21730     Com_dim=0
21740 END IF
21750 IF Com_dim=0 THEN
21760     PRINT " "
21770     PRINT " "
21780     PRINT "Enter 1 to MODIFY default hardware dimensions and values in code;"
21790     PRINT "          OR"
21800     PRINT "Enter 0 otherwise.";
21810     BEEP
21820     PRINT " "
21830     INPUT Mod_def_dim
21840     PRINT Mod_def_dim
21850     IF Mod_def_dim=1 THEN
21860         PRINT "Default RADIUS of the 4 Inch Radius Load in inches is";
21870         PRINT Rad4
21880         PRINT "Enter new value or press ENTER to accept default value.";
21890         BEEP
21900         LINPUT Rad4$
21910         IF LEN(Rad4$)<>0 THEN
21920             ENTER Rad4$;Rad4
21930             PRINT Rad4
21940         END IF
21950         PRINT " "
21960         PRINT " "
21970         PRINT "Default HEIGHT (inches) of the 4 Inch Radius Load is";
21980         PRINT Height4
21990         PRINT "Enter new value or press ENTER to accept default value.";
22000         BEEP
22010         LINPUT Height4$
22020         IF LEN(Height4$)<>0 THEN
22030             ENTER Height4$;Height4
22040             PRINT Height4
22050         END IF
22060     END IF
22070 END IF
22080 IF Sim=0 THEN
22090 ! Acquire measurement data to measure Z
22100     CALL Acqdat_zmeas
22110 ELSE
22120 ! CALL Z_via_wil_sim
22130 END IF
22140 !
22150 ! Specify co-ax dimensions for Williamson:
22160 C:Two_a=.1197 ! ODIC of 7mm line in inches
22170 Two_b=.2756! IDOC of 7mm line in inches
22180 !
22190 ! PRINT " Insert a DOS formatted disc into drive A, then press CONTINUE."
22200 ! BEEP
22210 ! PAUSE
22220 E1: CLEAR SCREEN
22230 PRINT " Make NO keyboard entries until you are returned to HP BASIC!"
22240 PRINT " "
22250 PRINT " Sit back and relax!"
22260 ON ERROR GOTO Proceed1
22270 ASSIGN @Di TO * ! If Di is open then close it.
22280 PURGE "\BLP\DOSIN.DAT:DOS,C"
22290 OFF ERROR

```

```

22300 !
22310 Proceed1:Siz=To_no_mf+2
22320 CREATE "\BLP\DOSIN.DAT:DOS,C",Siz! Create file for DOS app to read
22330 ASSIGN @Di TO "\BLP\DOSIN.DAT:DOS,C";FORMAT ON
22340 !
22350 ! Fill DOS file for DOS application to read
22360 OUTPUT Meas_param5$ USING Format1;To_no_mf
22370 Format1:IMAGE DDD,#
22380 OUTPUT @Di;Meas_param5$
22390 OUTPUT Meas_param5$ USING Format2;Two_a,"",Two_b,"",Rad4,"",Height4
22400 Format2:IMAGE DD.5D,3(A,X,DD.5D),#
22410 OUTPUT @Di;Meas_param5$
22420 FOR Jf=1 TO To_no_mf
22430 OUTPUT Meas_param5$ USING Format3;Meas_freq(Jf),"",REAL(Mw(Jf,1)),"",
,IMAG(Mw(Jf,1))
22440 Format3:IMAGE 5D.6D,2(A,X,6D.3D),#
22450 OUTPUT @Di;Meas_param5$
22460 NEXT Jf
22470 ASSIGN @Di TO *
22480 !
22490 ON ERROR GOTO Proceed2
22500 ASSIGN @Do TO * ! If Do is open then close it.
22510 PURGE "\BLP\DOSOUT.DAT:DOS,C"
22520 OFF ERROR
22530 !
22540 Proceed2:CREATE "\BLP\DOSOUT.DAT:DOS,C",To_no_mf! Create file for BASIC to
read
22550 X=FNBlp_lock(0) ! Lock DOS to accept input from BLP only
22560 CLEAR SCREEN
22570 OUTPUT 19;"BACKGROUND"! Put RLMS_*/# in background mode
22580 WAIT 3
22590 Blp_send(0," ") ! Press any key to run DOSSHELL
22600 WAIT 1
22610 Blp_send_key(0,92) ! Send SHIFT F9 to DOS to invoke DOS command line.
22620 WAIT 3
22630 ! See page B-3 of HP's "Integrating HP BASIC with
22640 ! MS-DOS Applications".
22650 Blp_send(0,"C:\DOS\SEQ.BAT"&CHR$(13)) ! Send request to DOS command line
22660 ! to execute BATCH file SEQ.BAT
22670 Blp_enable(0) ! Enable BLP to receive information from DOS
22680 !
22690 ! Tread water until BLP returns to foreground
22700 Az:I=FNBlp_background
22710 IF I=1 THEN GOTO Az
22720 !
22730 ! Read surface impedance results produced by WILL
22740 ASSIGN @Do TO "\BLP\DOSOUT.DAT:DOS,C";FORMAT ON
22750 !
22760 PRINT "Surface Impedances in Rectangular Form:"
22770 PRINT " "
22780 FOR Jf=1 TO To_no_mf
22790 ENTER @Do;Meas_freq(Jf),R(Jf),Q(Jf)
22800 Z_p_sq(Jf)=CMPLX(R(Jf),Q(Jf))
22810 PRINT Meas_freq(Jf),R(Jf),Q(Jf)
22820 ! Compute total impedances
22830 ! Rad4=C_radius
22840 ! Height4=H_height
22850 Zt(Jf)=Z_p_sq(Jf)*Height4/(2*PI*Rad4)
22860 NEXT Jf
22870 WAIT 2

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```

22880 ! Output the Results
22890 Technique$="Williamson"
22900 CALL Type_lod_z_rept(Technique$,Zt(*),Z_p_sq(*))
22910 SUBEND ! Z_via_will
22920 !
22930 !
22940 !*****
22950 Abc_dos_dat_fil:SUB Abc_dos_dat_fil
22960 !*****
22970 !
22980 ! SUBprogram Abc_dos_dat_fil will write abc measurement results into an
22990 ! ASCII file on a DOS formatted disc.
23000 !
23010 OPTION BASE 1
23020 DEG
23030 !
23040 Gc:COM /Misc/ In$[25],@Nwa,@Nwa_data1,@Nwa_data2
23050 COM /Freq/ Meas_freq(*),INTEGER To_no_mf
23060 COM /Abc_freq/ Abc_file_freq(*),INTEGER To_no_abc_f,Indx_abc(*)
23070 COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
23080 COM /Abc/ COMPLEX A_par(*),B_par(*),C_par(*)
23090 COM /Stds/ Std_name$(*),Nom_std_radius(*)
23100 COM /Short_dims/ Rad4,Height4,Rad9,Height9,Rad15,Height15
23110 COM /Salis/ O_rad_salis,I_rad_salis,Hite_salis,Topdisk_thk,Botdisk_thk
23120 COM /Salis2/ Rs_film
23130 COM /Vana/ INTEGER If_avg_factor,If_band_width
23140 COM /Sysid/ Serial_8753$[10],Model_ts$[5],Serial_ts$[10]
23150 COM /Ctorl/ Ser_ctorlt$[12],Prop_ctorlt$[8],Own_ctorlt$[15]
23160 COM /Meas_param/ Tech_cons$[25],Jet,Sim,INTEGER No_copies,Meas_option
23170 COM /Progid/ Version_date$[18],Prog_name$[10]
23180 COM /Rad4_p/ ZO4(*),Theta4(*),Psi4(*)
23190 DIM Meas_param5$[80],File_name$[18]
23200 !
23210 File_name$="ABCP.DAT"
23220 St:PRINT " "
23230 PRINT " Insert a DOS formatted disc into drive A, then press CONTINUE."
23240 BEEP
23250 PAUSE
23260 PRINT " "
23270 MASS STORAGE IS ":DOS,A"
23280 PRINT " "
23290 PRINT " Enter the filename (<9 characters + optional 3 character extensi
on)"
23300 PRINT " OR"
23310 PRINT " Press ENTER to accept the default which is ";File_name$
23320 BEEP
23330 LINPUT In$
23340 !
23350 IF LEN(In$)<>0 THEN
23360 ENTER In$;File_name$
23370 PRINT File_name$
23380 END IF
23390 !
23400 PRINT " "
23410 !
23420 ON ERROR GOTO Proceed
23430 !
23440 ASSIGN @Tape5 TO * ! If TAPE5 is open then close it.
23450 Proceed:N_hdr_recs=4 ! 3 records for header + 1 extra
23460 OFF ERROR

```

```

23470 N_rec_per_freq=1      ! 1 records for each frequency
23480 N_recs_in_5=N_hdr_recs+N_rec_per_freq*To_no_mf
23490 PRINT "Storing data on DOS disc..."
23500 ON ERROR GOTO Message
23510 CREATE File_name$&" :DOS,A",N_recs_in_5
23520 U2:ASSIGN @Tape5 TO File_name$&" :DOS,A";FORMAT ON
23530 OFF ERROR
23540 !
23550 OUTPUT Meas_param5$ USING Format1;To_no_mf,"",Meas_option;" ! No. Freqs
, Measurement option"
23560 Format1:IMAGE X,DDD,A,X,DD,32A
23570 OUTPUT @Tape5;Meas_param5$
23580 !
23590 OUTPUT Meas_param5$ USING Format2;Ser_ctorlt$,"",Prop_ctorlt$," ! SN, P
rop No."
23600 Format2:IMAGE X,12A,A,X,8A,15A
23610 OUTPUT @Tape5;Meas_param5$
23620 !
23630 OUTPUT Meas_param5$ USING Format3;Own_ctorlt$,"",DATE$(TIMEDATE)," ! Ow
ner, Meas. date"
23640 Format3:IMAGE X,15A,A,X,11A,21A
23650 OUTPUT @Tape5;Meas_param5$
23660 !
23670 FOR J=1 TO To_no_mf
23680   Ra=REAL(A_par(J))
23690   Qa=IMAG(A_par(J))
23700   Rb=REAL(B_par(J))
23710   Qb=IMAG(B_par(J))
23720   Rc=REAL(C_par(J))
23730   Qc=IMAG(C_par(J))
23740   OUTPUT Meas_param5$ USING Format4;Meas_freq(J),"",Ra,"",Qa,"",Rb,"
",Qb,"",Rc,"",Qc
23750 Format4:IMAGE 5D.D,6(A,M.4DESZZ)
23760   OUTPUT @Tape5;Meas_param5$
23770 NEXT J
23780 OUTPUT Meas_param5$;" Freq    REAL(a)    IMAG(a)    REAL(b)    IMAG(b)
    REAL(c)    IMAG(c)"
23790 OUTPUT @Tape5;Meas_param5$
23800 !
23810 ASSIGN @Tape5 TO *
23820 MASS STORAGE IS ":,1500,1"
23830 SUBEXIT
23840 Message:PRINT " "
23850 BEEP
23860 PRINT "Something is wrong! Check for WRONG disc, duplicate file name, et
c."
23870 PRINT
23880 GOTO St
23890 RETURN
23900 SUBEND ! Abc_dos_dat_fil
23910 !
23920 !
23930 !*****
23940 Raw_z_dos_dat:SUB Raw_z_dos_dat(INTEGER K)
23950 !*****
23960 !
23970 ! Subprogram Raw_z_dos_dat will write raw impedance measurements into an
23980 ! ASCII file on a DOS formatted disc. The impedance values are at the
23990 ! plane defined by the interface between the coaxial line and the radial
24000 ! transmission line.

```

```

24010 !
24020 ! INPUT ARGUMENT DEFINITION:
24030 ! K is the measurement number for which impedance measurements at all
24040 !   To_no_mf measurement frequencies will be recorded.
24050 !
24060   OPTION BASE 1
24070   DEG
24080 !
24090 Gc:COM /Misc/ In$[25],@Nwa,@Nwa_data1,@Nwa_data2
24100   COM /Freq/ Meas_freq(*),INTEGER To_no_mf
24110   COM /Abc_freq/ Abc_file_freq(*),INTEGER To_no_abc_f,Indx_abc(*)
24120   COM /Rawdat/ Rz(*),Qz(*),COMPLEX Mw(*),Tsz(*)
24130   COM /Abc/ COMPLEX A_par(*),B_par(*),C_par(*)
24140   COM /Stds/ Std_name$(*),Nom_std_radius(*)
24150   COM /Short_dims/ Rad4,Height4,Rad9,Height9,Rad15,Height15
24160   COM /Salis/ O_rad_salis,I_rad_salis,Hite_salis,Topdisk_thk,Botdisk_thk
24170   COM /Salis2/ Rs_film
24180   COM /Vana/ INTEGER If_avg_factor,If_band_width
24190   COM /Sysid/ Serial_8753$[10],Model_ts$[5],Serial_ts$[10]
24200   COM /Ctorl/ Ser_ctorlt$[12],Prop_ctorlt$[8],Own_ctorlt$[15]
24210   COM /Meas_param/ Tech_cons$[25],Jet,Sim,INTEGER No_copies,Meas_option
24220   COM /Progid/ Version_date$[18],Prog_name$[10]
24230   COM /Rad4_p/ ZO4(*),Theta4(*),Psi4(*)
24240   DIM Meas_param5$[80],File_name$[18]
24250 !
24260   File_name$="RAWZDAT.DAT"
24270 St:PRINT " "
24280   PRINT " Insert a DOS formatted disc into drive A, then press CONTINUE."
24290   BEEP
24300   PAUSE
24310   PRINT " "
24320   MASS STORAGE IS ":DOS,A"
24330   PRINT " "
24340   PRINT " Enter the filename (<9 characters + optional 3 character extensi
on)"
24350   PRINT " OK "
24360   PRINT " Press ENTER to accept the default which is ";File_name$
24370   BEEP
24380   LINPUT In$
24390 !
24400   IF LEN(In$)<>0 THEN
24410     ENTER In$;File_name$
24420     PRINT File_name$
24430   END IF
24440 !
24450   PRINT " "
24460 !
24470   ON ERROR GOTO Proceed
24480 !
24490   ASSIGN @Tape5 TO *           ! If TAPE5 is open then close it.
24500 Proceed:N_hdr_recs=4         ! 3 records for header + 1 extra
24510   OFF ERROR
24520   N_rec_per_freq=1           ! 1 records for each frequency
24530   N_recs_in_5=N_hdr_recs+N_rec_per_freq*To_no_mf
24540   PRINT "Storing data on DOS disc..."
24550   ON ERROR GOTO Message
24560   CREATE File_name$&" :DOS,A",N_recs_in_5
24570 U3:ASSIGN @Tape5 TO File_name$&" :DOS,A";FORMAT ON
24580   OFF ERROR
24590 !

```

```

24600  OUTPUT Meas_param5$ USING Format1;To_no_mf,"",Meas_option;" ! No. Freqs
, Measurement option"
24610  Format1:IMAGE X,DDD,A,X,DD,32A
24620  OUTPUT @Tape5;Meas_param5$
24630  !
24640  OUTPUT Meas_param5$ USING Format2;Ser_ctorlt$,"",Prop_ctorlt$," ! SN, P
rop No."
24650  Format2:IMAGE X,12A,A,X,8A,15A
24660  OUTPUT @Tape5;Meas_param5$
24670  !
24680  OUTPUT Meas_param5$ USING Format3;Own_ctorlt$,"",DATE$(TIMEDATE)," ! Ow
ner, Meas. date"
24690  Format3:IMAGE X,15A,A,X,11A,21A
24700  OUTPUT @Tape5;Meas_param5$
24710  !
24720  FOR J=1 TO To_no_mf
24730  OUTPUT Meas_param5$ USING Format4;Meas_freq(J),"",Rz(J,K,1),"",Qz(J,
K,1)," ! Freq, REAL(Z), IMAG(Z)"
24740  Format4:IMAGE 5D.D,2(A,X,9D.9D),25A
24750  OUTPUT @Tape5;Meas_param5$
24760  NEXT J
24770  !
24780  ASSIGN @Tape5 TO *
24790  MASS STORAGE IS ":,1500,1"
24800  SUBEXIT
24810  Message:PRINT " "
24820  BEEP
24830  PRINT "Something is wrong! Check for WRONG disc, duplicate file name, et
c."
24840  PRINT
24850  GOTO St
24860  RETURN
24870  SUBEND ! Raw_z_dos_dat
24880  !
24890  !
24900  Z_r_xform:SUB Z_r_xform(Z_rad,COMPLEX Z_p_sq(*),Zt_z_rad(*),Z_p_sq_z_rad(*
))
24910  !SUB Z_r_xform transforms a surface impedance Z_p_sq(Jf) at radius
24920  ! Rad4 to the corresponding surface impedance Z_p_sq_z_rad(Jf) at
24930  ! radius Z_rad where Z_rad is near Rad4. It then computes the
24940  ! corresponding total impedance Zt_z_rad(Jf) at radius Z_rad.
24950  !
24960  ! Reference is the inversion of eqn (16) in the light of eqn (18) on
24970  ! pages 456, 457 of RW&VD i.e. Zl & Zi are negatives of RW&VD terms.
24980  !
24990  !INPUT ARGUMENT DEFINITIONS:
25000  !
25010  ! Z_rad is the radius in inches at which the input surface impedance
25020  ! (looking outward) is desired.
25030  ! Z_p_sq(Jf) is the surface impedance (at the Jf'th frequency) seen
25040  ! looking outward from radius Rad4 inches.
25050  !
25060  !OUTPUT ARGUMENT DEFINITIONS:
25070  !
25080  ! Zt_z_rad(Jf) is the total impedance (at the Jf'th frequency) seen
25090  ! looking outward from radius Z_rad inches.
25100  ! Z_p_sq_z_rad(Jf) is the surface impedance (at the Jf'th frequency)
25110  ! seen looking outward from radius Z_rad inches.
25120  !
25130  OPTION BASE 1

```

```

25140 COM /Misc/ In$(25),@Nwa,@Nwa_data1,@Nwa_data2
25150 COM /Freq/ Meas_freq(*),INTEGER To_no_mf
25160 COM /Short_dims/ Rad4,Height4,Rad9,Height9,Rad15,Height15
25170 COM /Rad4_p/ Z0s4(*),Theta4(*),Psi4(*)
25180 COMPLEX Czero,Numer,Denom
25190 DIM Z0s_z_rad(101),Theta_z_rad(101),Psi_z_rad(101)
25200 RAD
25210 Czero=CMPLX(0,0)
25220 !
25230 FOR Jf=1 TO To_no_mf
25240 CALL Radial_line(Meas_freq(Jf),Rad4,Height4,Z0s4(Jf),Theta4(Jf),Psi4(J
f))
25250 CALL Radial_line(Meas_freq(Jf),Z_rad,Height4,Z0s_z_rad(Jf),Theta_z_rad
(Jf),Psi_z_rad(Jf))
25260 Ctp=COS(Theta4(Jf)-Psi_z_rad(Jf))
25270 Stt=SIN(Theta4(Jf)-Theta_z_rad(Jf))
25280 Cpt=COS(Psi4(Jf)-Theta_z_rad(Jf))
25290 Spp=SIN(Psi4(Jf)-Psi_z_rad(Jf))
25300 Numer=Z_p_sq(Jf)*CMPLX(Cpt,0)+CMPLX(0.,Z0s4(Jf)*Stt)
25310 Denom=CMPLX(Z0s4(Jf)*Ctp,0)+CMPLX(0.,1.)*Z_p_sq(Jf)*CMPLX(Spp,0)
25320 Z_p_sq_z_rad(Jf)=CMPLX(Z0s_z_rad(Jf),0)*Numer/Denom
25330 Zt_z_rad(Jf)=Z_p_sq_z_rad(Jf)*Height4/(2*PI*Z_rad)
25340 NEXT Jf
25350 SUBEND ! Z_r_xform
25360 !
25370 !
25380 Dum_sub1:SUB Dum_sub1
25390 ! stub for a new SUB (because of CSUBs later)
25400 SUBEND
25410 !
25420 !
25430 Dum_sub2:SUB Dum_sub2
25440 ! stub for a new SUB (because of CSUBs later)
25450 SUBEND
25460 !
25470 !
25480 Dum_sub3:SUB Dum_sub3
25490 ! stub for a new SUB (because of CSUBs later)
25500 SUBEND
25510 !
25520 !
25530 Code_list:SUB Code_list
25540 ! SUBprogram to list source code on an HP Desk Jet with top, left and
25550 ! bottom margins.
25560 ! CLEAR SCREEN
25570 PRINTER IS 9
25580 Reset_default$=CHR$(27)&CHR$(69)
25590 ! Desk Jet Escape Sequence to reset printer to default condition.
25600 PRINT Reset_default$
25610 Pitch_12$=CHR$(27)&CHR$(40)&CHR$(115)&CHR$(49)&CHR$(50)&CHR$(72)
25620 ! Desk Jet Escape Sequence for pitch = 12 cpi.
25630 PRINT Pitch_12$
25640 Left_marg$=CHR$(27)&CHR$(38)&CHR$(97)&CHR$(49)&CHR$(50)&CHR$(76)
25650 ! Desk Jet Escape Sequence for 1 inch left margin.
25660 PRINT Left_marg$
25670 Perf_skip_on$=CHR$(27)&CHR$(38)&CHR$(108)&CHR$(49)&CHR$(76)
25680 ! Desk Jet Escape Sequence for Perforation Skip on.
25690 PRINT Perf_skip_on$
25700 PAUSE
25710!

```

```

25720  Form_feed$=CHR$(12)
25730  PRINT Form_feed$
25740  PRINT Reset_default$
25750  PRINTER IS CRT
25760  PRINT " "
25770  PRINT "To list another segment of code, press RUN and enter desired LIST
      command."
25780  PRINT "  OR"
25790  PRINT "To return to normal program operation, you must edit line List by
      "
25800  PRINT "inserting an exclamation point immediately after the colon."
25810  BEEP
25820  STOP
25830  SUBEND ! Code_list
25840  !
25850  ! CSUB's from HP Multi-Com software BLPLIB and ADVLIB libraries follow:
25860  !
25870  CDEF FNBlp_lock(INTEGER Blp,OPTIONAL Nowait,Ecode)
25880  CSUB Blp_enable(INTEGER Blp,OPTIONAL Ecode)
25890  CDEF FNBlp_background
25900  CSUB Blp_send(INTEGER Blp,S$,OPTIONAL Ecode)
25910  CSUB Blp_send_key(INTEGER Blp,Keycode,OPTIONAL Ecode)

```


Listing AIX.2. The FORTRAN program will.for. This program implements the Williamson analytical model of the junction. It is called as an executable from RLMS_a1.

```

      PROGRAM will
c
c-----1-----2-----3-----4-----5-----6-----7---+
c
c      Written by Terry E. Koontz
c              Sandia National Laboratories, SNLA
c              Division 2753, Electromagnetic Analysis Group
c              Albuquerque, NM 87185
c              (505) 844-5688
c
c      Original: May 18, 1991
c      Revised:  Wed 02-17-1993
c
c Description:
c
c      Radial-line/coaxial-line junction analysis.
c
c       $Y = 1 / Z_{in}$ 
c
c      This code is a special version of my MEMLKW1 code.
c      It was modified for Bob Moyer to use on an HP Vectra without a 387 chip.
c      It was compiled with Microsoft Fortran 5.1.
c
c      Based on the paper:
c      Radial-line/coaxial-line junctions:analysis and equivalent circuits
c      by A.G. Williamson
c      Int. J. Electronics, 1985, vol. 58, no. 1,91-104
c
c      Includes a correction calculation in subroutine jc.
c      Correction provided by Marvin Morris of SNLA.
c
c NOTES:
c
c      It uses the following Slatec library files:
c      BESI BESJ BESK BESY ALNGAM ASYIK ASYJY BESKO BESK1 BESKNU BESYO
c      BESY1 BESYNU JAIRY BESIO BESI1 BESJO BESJ1 BESKOE BESK1E CSEVL
c      GAMMA INITS R9LGMC YAIRY GAMLIM BESIOE BESI1E
c      XERROR XERRWV XGETUA XERCTL XERABT XERSAV FDUMP XERPRT J4SAVE
c
c      Input data is read from dosin.dat.
c      Format:
c          number of freqs.
c          2a , 2b , c , h
c          freq1 , Real(Zin) , Imag(Zin)
c
c          freqn , Real(Zin) , Imag(Zin)
c
c      Output data is written to dosout.dat and dosoutm.dat.
c      Format:
c          Freq1 , Real(Zs) , Imag(Zs)
c
c          Freqn , Real(Zs) , Imag(Zs)
c
c      NOTE: all freqs. are in MHz.
c
c      Output file abc.dat contains the bilinear transformation coefficients.
c
c          
$$Z = \frac{AY + B}{CY + D} = \frac{aZ + b}{cZ + 1}$$


```

```

c
c-----1-----2-----3-----4-----5-----6-----7---+
c

```

```

      IMPLICIT NONE

```

```

      REAL a, b, c, h, r, pi, n0, s, u0, e0
      REAL ka, kb, kc
      REAL j0ka(1), j0kb(1), j0kc(1), j0kr(1), j1kc(1)
      REAL y0ka(1), y0kb(1), y0kc(1), y0kr(1), y1kc(1)
      REAL k0qmka(1), k0qmkb(1), k0qmkr(1)
      REAL k0ka(1), k0kc(1)
      REAL b1, b2, k, y0, sum, qm, ym, kr
      REAL alpha0, alpha1, fnu0, fnu1
      REAL qmka, qmkb, qmkr
      REAL i0qmka(1), i0qmkr(1), i0qmkb(1)
      REAL ainch, binch, cinch, hinch, f
      REAL zinr, zini, zsr, zsi

```

```

      INTEGER inf, m, nz, kode, n
      INTEGER i, nf

```

```

      COMPLEX ci
      COMPLEX p1, p2, p3, p4, p5, p6, p7, p8, p9
      COMPLEX y1p, y
      COMPLEX h01ka, h01kb, h01kc, h11kc
      COMPLEX z, zs
      COMPLEX biga, bigb, bigc, bigd

```

```

      DATA ci /(0.0, 1.0)/
      DATA pi /3.1415926535/
      DATA s /2.997925E+8/

```

```

      u0 = 4.0E-7 * pi
      e0 = 1.0 / (u0 * s * s)
      n0 = sqrt(u0 / e0)

```

```

      inf = 10

```

```

      OPEN (UNIT=1, FILE='dosin.dat')
      OPEN (UNIT=2, FILE='dosout.dat')
      OPEN (UNIT=3, FILE='dosoutm.dat')
      OPEN (UNIT=4, FILE='abc.dat')

```

```

      READ (1, *) nf
      READ (1, *) ainch, binch, cinch, hinch

```

```

      ainch = ainch / 2.0
      binch = binch / 2.0

```

```

      a = ainch * 0.0254
      b = binch * 0.0254
      c = cinch * 0.0254
      h = hinch * 0.0254

```

```

      r = c

```

```

      alpha0 = 0.0
      alpha1 = 1.0

```

```

      n = 1

```

```

fnu0 = 0.0
fnu1 = 1.0

DO 20 i = 1, nf

    READ (1, *) f, zinr, zini

    z = cmplx(zinr, zini)
    z = conjg(z)
    y = 1.0 / z

    f = f * 1.0E+6

    k = 2.0 * pi * f / s
    ka = k * a
    kb = k * b
    kc = k * c

    CALL besj(ka, alpha0, n, j0ka, nz)
    CALL besj(kb, alpha0, n, j0kb, nz)
    CALL besj(kc, alpha0, n, j0kc, nz)
    CALL besj(kc, alpha1, n, j1kc, nz)

    CALL besy(ka, fnu0, n, y0ka)
    CALL besy(kb, fnu0, n, y0kb)
    CALL besy(kc, fnu0, n, y0kc)
    CALL besy(kc, fnu1, n, y1kc)

    kode = 1
    CALL besk(ka, fnu0, kode, n, k0ka, nz)
    CALL besk(kc, fnu0, kode, n, k0kc, nz)

    h01ka = j0ka(1) + ci * y0ka(1)
    h01kb = j0kb(1) + ci * y0kb(1)
    h01kc = j0kc(1) + ci * y0kc(1)
    h11kc = j1kc(1) + ci * y1kc(1)

    p1 = j0ka(1) * y0kc(1) - j0kc(1) * y0ka(1)
    p2 = n0 * h01ka
    p3 = j0ka(1) * y1kc(1) - j1kc(1) * y0ka(1)
    p4 = h01ka

    p5 = h11kc
    p6 = n0 * h01kc
    p7 = j0kb(1) * y0ka(1) - j0ka(1) * y0kb(1)
    p8 = h01kb / h01ka

    kr = k * r
    CALL besj(kr, alpha0, n, j0kr, nz)
    CALL besy(kr, fnu0, n, y0kr)

    * y0 = 0.5 * pi * ( -y0ka(1) * j0kb(1) +
                        j0ka(1) * y0kb(1) ) / alog(b / a)

    p9 = -2.0 * pi * ci * y0 / (k * h * n0 * alog(b / a))

    b1 = -2.0 * pi / (tan(k * h) * n0 * alog(b / a))

    sum = 0.0

```

```

DO 10 m = 1, inf

  qm = sqrt((m * pi) / (k * h)) ** 2 - 1.0)
  qmka = qm * ka
  qmkb = qm * kb

  kode = 2
  CALL besi(qmka, alpha0, kode, n, i0qmka, nz)
  i0qmka(1) = i0qmka(1) * exp(qmka)

  CALL besi(qmkb, alpha0, kode, n, i0qmkb, nz)
  i0qmkb(1) = i0qmkb(1) * exp(qmkb)

  CALL besk(qmka, fnu0, kode, n, k0qmka, nz)
  k0qmka(1) = k0qmka(1) * exp(-qmka)

  CALL besk(qmkb, fnu0, kode, n, k0qmkb, nz)
  k0qmkb(1) = k0qmkb(1) * exp(-qmkb)

  ym = (-i0qmka(1) * k0qmkb(1) + k0qmka(1) *
*      i0qmkb(1)) / alog(b / a)

  sum = sum + k0qmkb(1) * ym / (qm * qm * k0qmka(1))

10  CONTINUE

  b2 = -4.0 * pi * sum / (k * h * n0 * alog(b / a))

  biga = ci * p1 * p2

  bigb = -ci * p6 * p7 * p9 - ci * p1 * p2 * p8 * p9
*      - p1 * p2 * b1 - p1 * p2 * b2

  bigc = -p3 * p4

  bigd = p5 * p7 * p9 + p3 * p4 * p8 * p9
*      - ci * p3 * p4 * b1 - ci * p3 * p4 * b2

  zs = (biga * y / bigd + bigb / bigd) / (bigc * y / bigd + 1.0)
  zs = conjg(zs)

  zsr = real(zs)
  zsi = aimag(zs)

  f = f / 1.0E+6

  WRITE (2, *) f, ",", zsr, ",", zsi

  ylp = y
  CALL jc(ylp, a, b, pi, ci, ka, n0, y)

  zs = (biga * y / bigd + bigb / bigd) / (bigc * y / bigd + 1.0)
  zs = conjg(zs)

  zsr = real(zs)
  zsi = aimag(zs)

  WRITE (3, *) f, ",", zsr, ",", zsi

  WRITE (4, 5000) f,

```

```

*          real(bigb / bigc), aimag(bigb / bigc),
*          real(biga / bigc), aimag(biga / bigc),
*          real(bigd / bigc), aimag(bigd / bigc)

20 CONTINUE

      CLOSE (UNIT=1)
      CLOSE (UNIT=2)
      CLOSE (UNIT=3)
      CLOSE (UNIT=4)
5000 FORMAT (7(E13.6,', '))

      END

      SUBROUTINE jc(y1p, a, b, pi, ci, ka, n0, y)

      IMPLICIT NONE

      REAL a2, a3, a4, e, ba
      REAL a, b, pi, ka, n0

      COMPLEX ci, y1p, y

      DATA a2 /13.97311535/
      DATA a3 / -10.92545814/
      DATA a4 /2.957535929/

      e = a / b

      ba = -1.0 * (5.0 * e * alog(e) ** 2 - 14.0 * e * alog(e)
*          + 7.0 * e + a2 * e * e + a3 * e ** 3 + a4 * e ** 4)

      y = y1p + ci * (ka / n0) * ( 4.0 * pi / ba)

      RETURN
      END

```

(a)

(b)

Figure AX.1. Original geometry (first iteration with assumed bowing of sheet) of the attachment of the resistive sheet to the step height change in the Salisbury load. a) Top half (above center symmetry plane) of the step height change, b) Magnified view of attachment of resistive sheet edges.

(a)

$$R_{\text{tot}} = R_w/3$$

(b)

Figure AX.2. Circuit models of the resistive sheet attachment region. a) RLC transmission line, b) Low frequency equivalent circuit when transmission line parameters are constant.

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