(2)

NSWC TR 86-46

AUTOMATED MICROWAVE DIELECTRIC CONSTANT MEASUREMENT SYSTEM

BY B. C. GLANCY A. KRALL

RESEARCH AND TECHNOLOGY DEPARTMENT

9 MARCH 1987

NAVAL SURFACE WEAPONS CENTER

Dahlgren, Virginia 22448-5000 • Silver Spring, Maryland 20903-5000

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release, distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NSWC TR 86-46	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Surface Weapons Center 6b. OFFICE SYMBOL (If applicable) R13	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) 10901 New Hampshire Avenue, White Oak Silver Spring, Maryland 20903-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Naval Surface Weapons Center 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) 10901 New Hampshire Avenue, White Oak Silver Spring, Maryland 20903-5000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 61152N; PROJECT NO. ZR00001; TASK NO. ZR01301; WORK UNIT ACCESSION NO. R01AA290

11. TITLE (Include Security Classification)

AUTOMATED MICROWAVE DIELECTRIC CONSTANT MEASUREMENT SYSTEM

12. PERSONAL AUTHOR(S)

Glancy, B. C. and Krall, A.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Progress	FROM 2/85 TO 1/86	1987 March 9	43

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Dielectric constant, Dielectric constant measurement, Porous bed, Slotted line, Waveguide, Permittivity
20	14		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The tedious and often difficult measurement of dielectric constants as a function of microwave frequency has been simplified using an automated testing apparatus. This automated procedure is based on the use of a slotted line to take measurements. It also includes the automatic application of a numeric solution to a transcendental equation to determine the dielectric constant. The computer program for automation of data acquisition and the overall experimental setup are fully discussed. Experimental data taken using this apparatus are presented in graphic form for porous beds of inerts (including aluminized inerts) and explosives. An equation previously derived in the literature, describing the variation of dielectric constant with density, is used to fit the data. Also, additional applications of this automated apparatus are proposed including the use of this system, and the equation describing the variation of dielectric material mixtures, to estimate the dielectric constant of conductive materials.

keywords included!

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Brian C. Glancy	22b. TELEPHONE (Include Area Code) (202)394-1612 22c. OFFICE SYMBOL R13

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

FOREWORD

A microwave interferometer has been developed at both the Naval Surface Weapons Center (NSWC) and the Sandia National Laboratories (SNL) for the specific purpose of investigating the shock-to-detonation transition and the deflagration-to-detonation transition in porous energetic materials. For this technique to be successful, the dielectric constant of the test material at various densities is required.

This report discusses a device developed to perform automated dielectric property investigations and some preliminary measurements that have been taken using this system. The slotted-line waveguide method is well suited to dielectric constant measurements and uses widely available equipment. The mechanical movement of the slotted line is controlled and scaled by an automated digital micropositioner. A bench-top computer, used to automate the data acquisition procedure, and a previously developed program, used to calculate the dielectric parameters, were combined to develop this system. The computer program for data acquisition automation and the overall experimental setup are fully discussed here. In addition, some data are presented from the initial evaluation of this apparatus, as well as some preliminary results from tests run on porous inert and energetic materials. A possible useful supplemental application of this system is discussed within for the determination of the dielectric constant of conductive or other very high dielectric constant materials.

The development of the microwave dielectric parameters measurement apparatus was carried out as a Junior Professional Training Rotation under the direction and tutelage of Albert D. Krall for the Independent Research program, Task ZR01301.

Approved by:

KURT F. MUELLER, Head
Energetic Materials Division

CONTENTS

ILLUSTRATIONS

TABLES

CHAPTER 1

INTRODUCTION

This report discusses the setup and operation of a computerized apparatus, shown in Figure 1, for use in measuring dielectric properties of selected materials under investigation. These measurements are directly applicable to microwave interferometeric measurements where the microwave wavelength in the material under investigation is a variable dependent on its dielectric constant, the microwave test frequency and the boundary conditions of the material. The procedure discussed here is based on the use of a slotted line to measure the parameters necessary for the computation of the dielectric properties whose boundary conditions are a rectangular waveguide. The accuracy of the dielectric constant computation is to a large extent dependent on the measurement of the location of a null, or voltage standing wave ratio (VSWR) minimum, of the interference pattern resultant from the incident signal and the reflected wave from the sample. A stepper motor with movement accuracy of ±1 micrometer was applied to improve the precision of the spatial measurements compared to the manual technique previously used to locate the voltage minima. This use of the stepper motor also improved the VSWR dramatically and, coupled with the improvement in minima location, enhanced the accuracy of both the real and imaginary parts of the dielectric constant computation.

In November of 1972, the Agricultural Research Service of the U. S. Department of Agriculture published a report[1] outlining a computer program that had been developed for calculating dielectric properties. This program, originally written in FORTRAN, had been adapted to run in HP-BASIC on an HP 9845B computer. With the computer program and a precision stepper motor available, it was possible to incorporate these resources into a single apparatus capable of automated dielectric property measurements. The initial objective of these automated measurements was to facilitate research into the development of a material with equal permittivity (dielectric constant) and permeability for dielectric antennas. However, the procedures that have been developed should be suitable for use wherever dielectric constant measurements are needed.

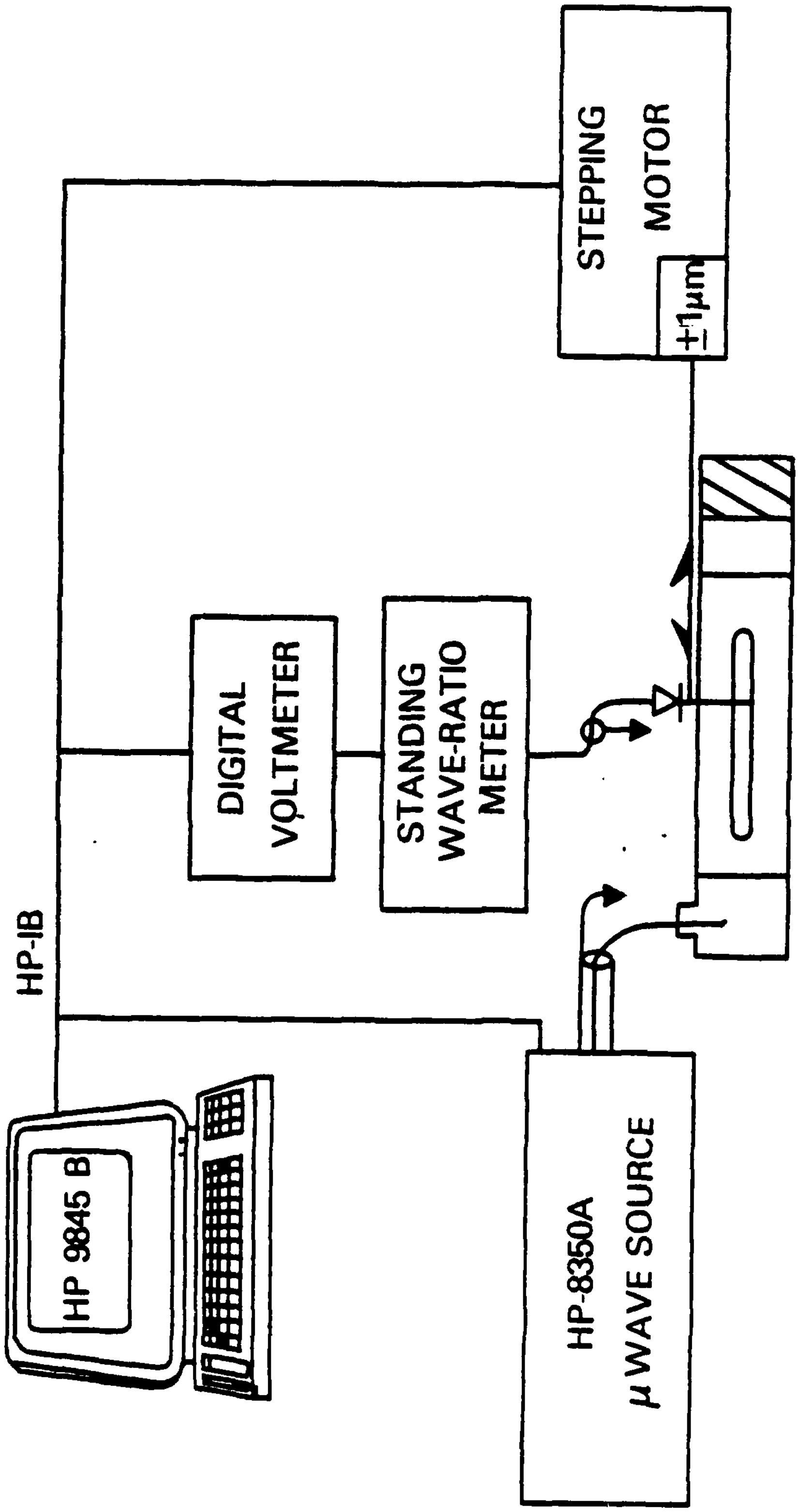

FIGURE 1. AUTOMATED DIELECTRIC CONSTANT MEASUREMENT APPARATUS

CHAPTER 2

EXPERIMENTAL ARRANGEMENT

The dielectric-properties computerized setup is based on the use of a slotted-line probe carriage and a two-point method for measuring the dielectric constant involving the solution of a transcendental equation.[2,3] A tuned probe mounted in the carriage is connected to an HP-415D SWR meter. The carriage allows for the positioning of the probe to locate the standing wave minima while the probe slides along a relative scale. The carriage scale gives position measurements which are used in the calculation of the microwave parameters and allows measurements to be taken to within ±.1 mm over a range of 130 mm. This measurement can be improved by mounting a dial gage onto the carriage which enables measurements to be taken to within ±.01 mm, but only over a range of approximately 25 mm. This small range is inconvenient for the determination of complete dielectric properties. In place of this, a stepper motor was connected to the probe carriage which would drive the probe over a 120 mm range with an accuracy of ±.001 mm. The addition of the stepper motor, with a controller allowing a computer to regulate its movements via an IEEE-488 interface bus, made it possible to automate the measurement acquisition process.

An HP-8350A sweep oscillator with an IEEE-488 interface was available as the microwave source. This source provides the option of square wave modulation of the signal, which is necessary to obtain gain from the narrow band amplifier of the standing wave ratio (SWR) meter used. Other necessary features of this source are frequency control and power level control via the IEEE-488 interface. The frequency range with the available sweep oscillator plug-in was .01 to 8.4 GHz initially, so when working in X-band (8.2-12.4 GHz) waveguide as we did, the usable frequency range was then only 8.2 to 8.4 GHz. A plug-in that will totally cover the X-band frequency range has been employed only recently and was used in some measurements that are reported here.

An HP-3438A digital multimeter with IEEE-488 interface was connected to the voltage output of the SWR meter. A voltage reading is sent to the computer corresponding to the power level measured by the SWR meter. A full-scale reading outputs 500 mV to the voltmeter with 0 mv output for a minimum scale reading. This remains constant for any scale used on the SWR meter, although the SWR meter remained only on its most sensitive scale. A voltage reading received from the SWR meter on the multimeter is output to the computer and then checked before the power of the source is adjusted. This way, the power seen by the tuned probe can be held low with the voltage reading maintained below 100 mV, thus keeping the probe's crystal operating in its square-law (linear) region. This also avoids a temperature change or humidity bake-out due to high power dissipation in the crystal detector. When the probe is located at a standing wave minimum, for example, a reading of 100 mV will correspond to the power level of the source being raised to its highest level. The concept of having maximum power output from the source when the probe is located at a standing wave minimum is a concept that is very important for the understanding of the automated program shown in Appendix A. The principle of operating in the square law region of the probe's crystal is a basis upon which this program is developed.

CHAPTER 3

PROGRAM DISCUSSION

The program is begun with the empty sample holder mounted in place on the microwave circuit. This is done to obtain a base-line measurement for the circuit with the sample holder to be used. The program asks for the initial room conditions of temperature and relative humidity as well as the frequency to be used. The sweep oscillator is then set at the assigned frequency by the computer and the power output level is set to its lowest possible point. The waveguide wavelength is calculated for the assigned frequency and a search process is begun to find the standing wave minimum nearest the sample. The search is a four-part iteration process.

With the probe positioned at its initial location, the microwave power is set very low, to less than 70 dBm. Each iteration commands the source to increase the power of the microwave signal in increments while the SWR meter outputs a voltage to the multimeter. When the multimeter detects a reading of 100 mV or more, the power level of the source is recorded and then reset low, again less than 70 dBm. The stepper motor is then commanded to move the probe one increment (a step). The power is again increased until the 100 mV can be read from the multimeter, the power level is recorded and the power is set low, and the probe is again moved. The third power reading is compared to the first two to see how the power level has changed before the probe is moved again. The program looks for the position where the power level decreases after two consecutive rises in recorded power level. The highest power level reading is assumed to be the estimate of SWR minimum for that iteration.

In the first iteration, the wavelength is divided into 10° step sizes. Since there are two standing waves for each waveguide wavelength or 360°, at most twenty steps would be necessary for the first iteration. This would only be necessary in the case that the probe started at or less than 20° to the left of a standing wave minimum, thereby requiring a search over 200°. The probe is placed half of the initial step (5°) before the maximum power reading location - the first estimate of the standing wave minimum from the first iteration. A new step size is calculated for steps of 1°, and again, after the power has increased for two steps and then drops off, the probe is located a half step (.5°) before the maximum power reading. A new step size of .1° is calculated and used in the next iteration using the same process as above. A final step size of .05° is used in the last iteration to locate the best estimate of the minimum position. The probe is then located at that position.

A new process is begun to locate the "3 dBm locations." These are the points on either side of the standing wave minimum where the SWR meter power reading would be 3 dBm greater than at the SWR minimum. The program finds these points by turning the power level of the source down 3 dBm from the maximum power reading at the standing wave minimum. The probe is moved away from the minimum, both positively and negatively, using step sizes of .025° until the 3 dBm positions are located. This occurs on either side of the minimum position where the voltage reading returns to the level obtained when the probe was located at the standing wave minimum. This completes the baseline measurement without the sample in place. The probe carriage is then returned to its original starting location.

The computer at this point prompts the user to load the sample in place in the sample holder. If a porous sample is being tested, a known weight of material is loaded and then pressed, if required, to achieve a higher density. After the sample in its sample holder is attached to the circuit, the process is begun anew to locate the first new standing wave minimum to the left of the starting position. The locations of the "3 dBm points", both with and without the sample in place, are sent to the portion of the program that calculates the dielectric properties (lines 1870 to 3170 of program shown in Appendix A). The original program, as adapted by R. Watkins of this Center, is shown in Appendix B. That program takes manually input values, previously determined from the adjustment of the probe carriage, to calculate the dielectric parameters. See Reference 2 if further details are needed regarding this program.

When the calculation of the dielectric properties is complete, the first three calculations of possible property values are printed out. The computer then asks if more values are desired; if so press "Y", if not press "N" and the program will stop. If an estimate of the dielectric constant is not known, then the process will need to be repeated with a different sample length. The intersection of the two data sets is the correct dielectric constant value.

CHAPTER 4

FUTURE WORK

The frequency source plug-in used for early studies had a frequency range of 0.1 to 8.4 GHz and, therefore, only had a usable range of 8.2 to 8.4 GHz in X-band waveguide. A C-band setup could be developed to better utilize the frequency capabilities of the available plug-in. For the C-band system, the program would be adapted to make automated measurements over the entire C-band range of frequencies at specific intervals. Then the variation of dielectric properties over a range of frequencies for a specific sample could readily be seen. Recently, a frequency source plug-in became available, covering the entire X-band range. For this plug-in, the program will be changed to make measurements automatically over the entire X-band range at specific frequency intervals. Then, with porous samples, dielectric constants can be determined at various frequencies and sample densities.

Temperature could also be introduced as an additional variable. The sample holder could be placed into an oven arrangement to allow the temperature to be increased incrementally as required by the program. The temperature measurement of the sample could be accomplished with the use of a thermocouple to measure the temperature and an IEEE-488 controllable power supply to control the temperature of the oven. Both of these could be easily added to the existing program. It would be possible at that time to acquire data as the frequency varies in conjunction with changes in temperature for each specific sample density under test.

The original developmental use for this setup was to tailor a material with equal permittivity and permeability for dielectric antennas; this research will continue. It is also possible for the magnetic properties of the materials to be calculated using the type of procedure used here. This requires a different equation to be solved in the calculation of magnetic permeability and dielectric constant, and the measurement of the sample at two different positions in the waveguide.

CHAPTER 5

VARIATIONS OF DIELECTRIC PROPERTIES WITH VARIATIONS OF TEMPERATURE AND HUMIDITY

A porous sample is considered to be a mixture of solid material and air where the solid material is diluted from its theoretical maximum density (TMD). Its electrical permeability or relating dielectric constant is then calculated using the Lichtenecker-Rother and the Landau-Lifshitz-Looyenga formulas for combining materials of variable volume percentages.

No adequate theory is available to predict the effect of temperature change on the dielectric constant, and measured materials have exhibited both positive and negative temperature coefficients. Fortunately, at microwave frequencies, most of the molecular resonances have occurred and the temperature effects are small. Changes of less than .01 percent/°C in the dielectric constant are normally expected, however, temperature coefficients should be measured for each new material used.

The effects of humidity or absorbed water in the sample represent a potentially large variation in dielectric constant because water has a high relative dielectric constant (~55 at 10 GHz). To add to this, its temperature coefficient[4] near room temperature is about 1 percent/°C and its frequency variation[4] is about 3 percent/GHz. Fortunately, in a sealed waveguide system, such as is used in the experiments, the external environment is of little concern. Our samples were prepared in a room with a controlled temperature and low relative humidity. For these reasons, the effects of temperature and humidity have been neglected in our analysis, though are reported for future considerations.

CHAPTER 6

RESULTS AND DISCUSSION

Although this technique gives good values for the real part of the dielectric constant, it is known to be less accurate for the determination of values for loss factor or loss tangent. To obtain more accurate values for the loss parameters, other methods of testing could be used, but they, in turn are less accurate in determining the real values of dielectric constant. Some data printouts are shown in Appendix C as an illustration of the performance of this program. The first two examples were run to show that this procedure would return a dielectric constant value of 1.0 for an air filled sample holder. For the two sample holder lengths used, the dielectric constant data intersects at the value of 1.000 and the accepted value for air is in fact 1.00064.

The next example of data printout is for a sample of ceramic foam with a dielectric constant known to be near 1.5. Our procedure confirmed this by calculating the most likely value of dielectric constant to be 1.507. A further demonstration of the effectiveness of this procedure to find the correct value of dielectric constant was shown when a sample of polysulfone was tested. Polysulfone has been extensively measured by the Massachusetts Institute of Technology (MIT), Laboratory for Insulation Research and their findings show the variation of dielectric constant with temperature and incident microwave frequency. The temperature and frequency parameters which most closely matched our test parameters occurred at 25°C (77°F) and 8.515 GHz. The MIT value for dielectric constant was given as 2.980. Our procedure determined the dielectric constant at a temperature of 79°F and an incident microwave frequency of 8.40 GHz to be 2.971.

The automated testing apparatus was used as a research tool to determine the dielectric properties of a porous inert material. The material chosen for investigation was Teflon 7C. Samples were tested at a constant frequency of 8.30 GHz in a well controlled environment, where temperature and humidity were kept constant. A variety of loading densities were tried to give the variation of the dielectric constant with loading density. This data for Teflon 7C is plotted in Figure 2. It was observed from the plot that the data follows the empirical exponential formula

$$e_r = e_1^{v_1} e_2^{v_2}$$

where e_r = relative dielectric constant
e_1 = dielectric constant of the material at TMD
v_1 = solid fraction of the material. Percent TMD/100

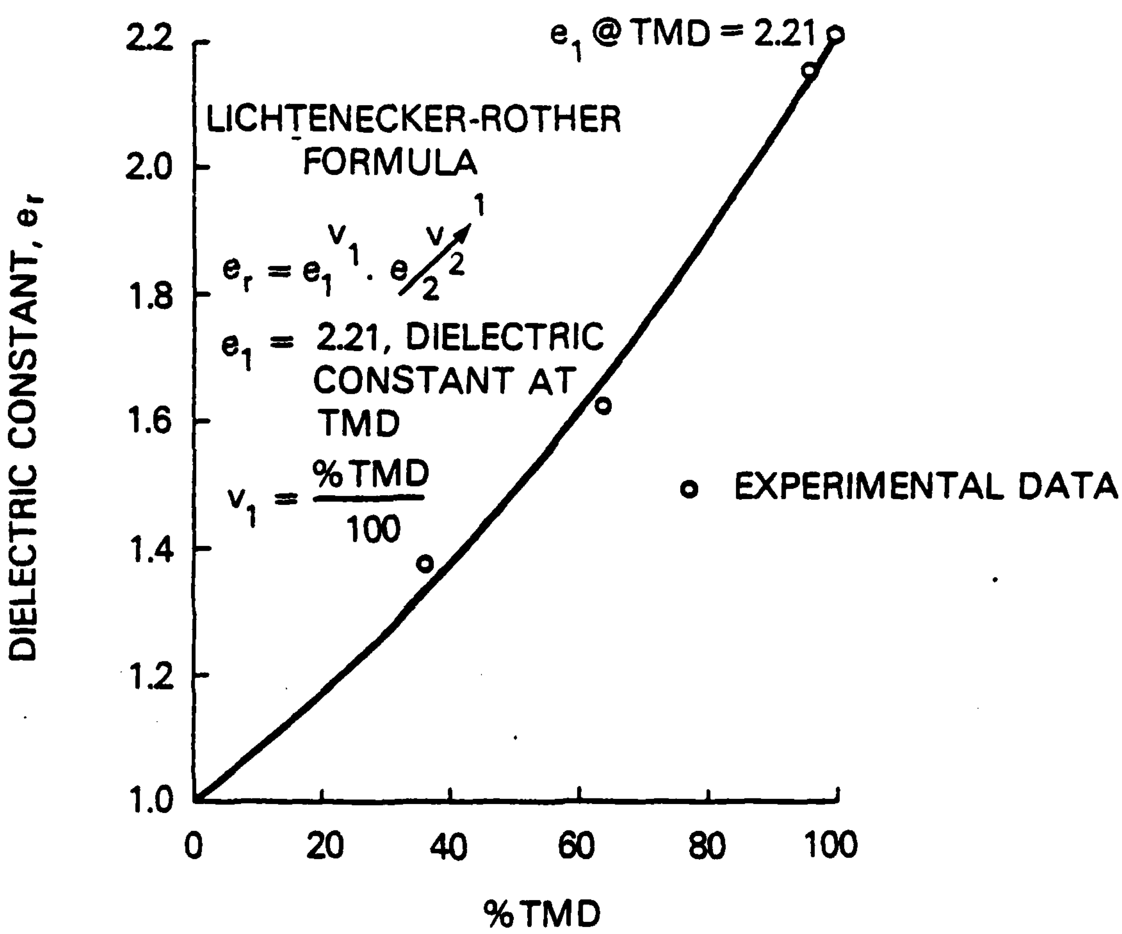

FIGURE 2. VARIATION OF DIELECTRIC CONSTANT WITH PERCENT TMD FOR TEFLON 7C POWDER AT 8.3 GHz

e_2 = dielectric constant of mixing material, air, in this simple case
$v_2 = 1 - v_1$ = volume fraction of mixing material

This formula was derived previously by Lichtenecker-Rother[5] in the early 1930's to describe the dielectric constant resulting from the mixture of various components. In the simple case where e_2 and v_2 are for air, its dielectric constant is 1.0, therefore e_2 raised to the v_2 power is still one, and can be neglected.

The apparatus again was used to evaluate the same dielectric constant variation for Class D HMX. The data for this testing is shown in Figure 3. Since most of our testing is done with Class D HMX porous beds initially loaded at 73 percent theoretical maximum density (percent TMD), a large number of trials were run at that density to obtain an average dielectric constant for the frequency of 8.30 GHz. After determining that the empirical exponential equation fit the data well, the number of tests run on any particular density need only be one, assuming a range of densities are tested.

The given formula and the automated dielectric constant measurement apparatus were again used to describe the variation of dielectric constant with density for various mixtures of melamine (inert) and aluminized powders. The mixtures contained 50μ particle size melamine. Measurements were made of melamine alone, for use as a base line, and for 10, 20 and 30 percent of aluminum by weight in the melamine. The dielectric constant of aluminum, a conductor, is not readily known, but the dielectric constant of the mixture can be easily measured, thus allowing the use of the Lichtenecker-Rother formula, only now the variables are slightly changed. Now, e_1 is the dielectric constant at TMD for the mixture of melamine and aluminum as determined empirically from experimental data, e_r is the relative dielectric constant of the mixture and v_1 is now the solid fraction of the entire mixture. This data is shown graphically in Figure 4. All data for Figures 2, 3, and 4 are given in Table 1.

Once the value of relative dielectric constant at TMD for each mixture has been computed, these TMD values can be replotted as the dielectric constant versus the percentage of aluminum from 0 to 100 percent. The values at low percentages can be reinserted into the mixture formula to calculate the dielectric constant of 100 percent aluminum or a curve can be fitted through the points and extrapolated to 100 percent. Either method yields a value of the relative dielectric constant of aluminum to be approximately 12.0. This is the first reporting of the experimental value of the dielectric constant of such a highly conductive material known to the author. Normally, the conductivity and associated losses of aluminum or other conductors preclude such a measurement. Not only can this mixture method be used for the measurement of metals and semiconductors, it can also be used to measure any other material with a very high dielectric constant.

This automatic apparatus for the measurement of the dielectric constant has given us a necessary tool, enabling the measurement of a wide variety of porous and solid materials, to be practically done in a modest amount of time. Further, this has allowed the use of impedance matching techniques which had previously been used only in broad band ranges.

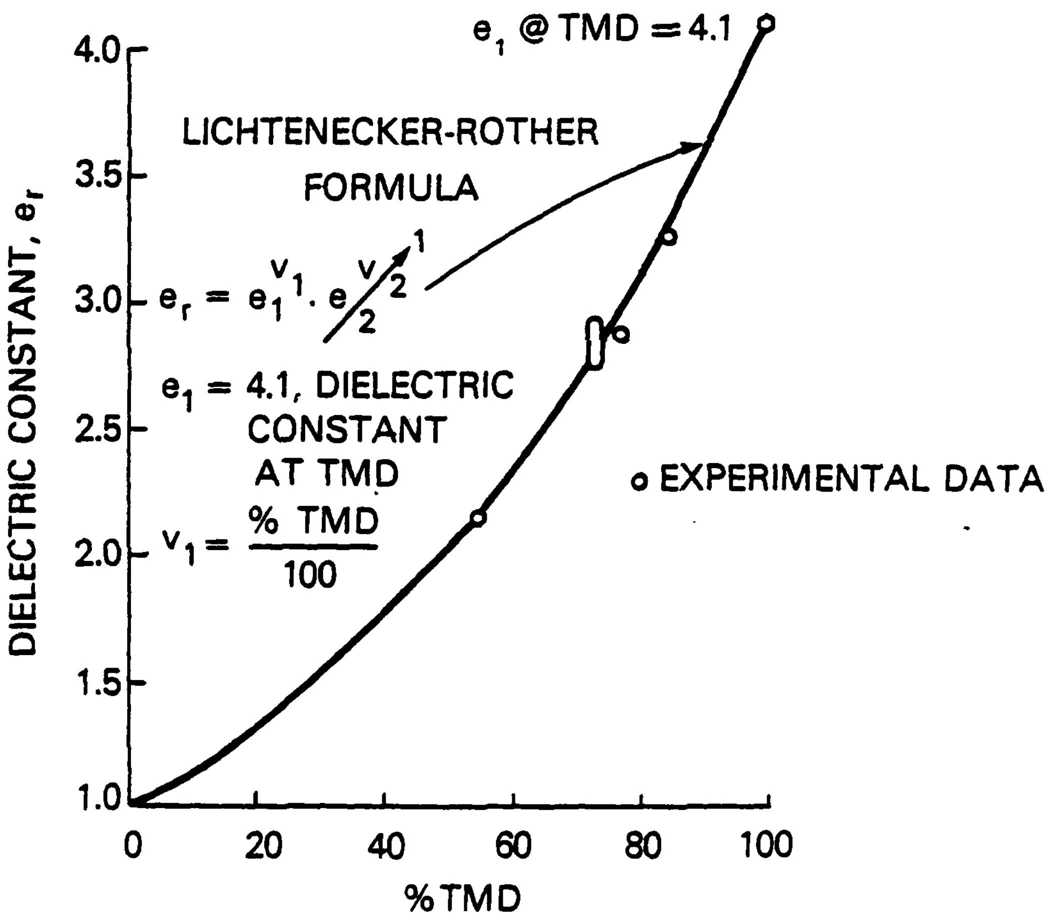

FIGURE 3. VARIATION OF DIELECTRIC CONSTANT WITH PERCENT TMD FOR CLASS D HMX AT 8.3 GHz

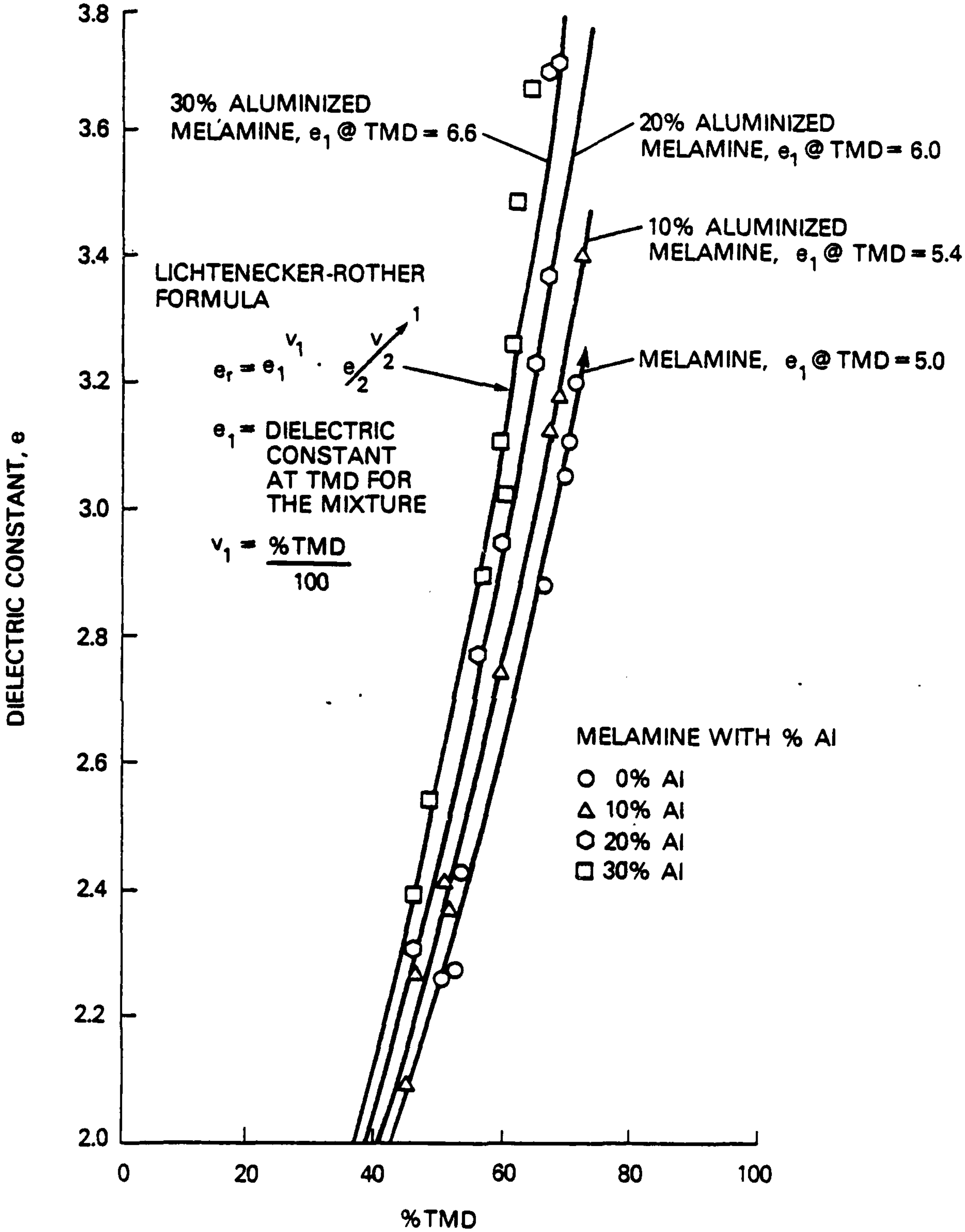

FIGURE 4. VARIATION OF DIELECTRIC CONSTANT WITH PERCENT TMD FOR VARIOUS MIXTURES OF MELAMINE AND ALUMINUM AT 10GHz

TABLE 1. EXPERIMENTAL DIELECTRIC CONSTANT DATA

Sample	Length (mm)	Density (g/cc)	% TMD	Dielectric Constant	Temp (°F)	Relative Humidity (%)
Teflon 7C	25.05	.842	36.5	1.375	76	35
"	12.70	1.448	62.8	1.632	75	46
"	8.28	2.222	96.4	2.141	76	44
Class D HMX	25.05	1.043	54.9	2.148	76	46
"	12.70	1.387	73.0	2.902	80	45
"	6.40	1.387	73.0	2.768	77	50
"	6.40	1.387	73.0	2.807	78	45
"	6.40	1.387	73.0	2.801	76	46
"	12.70	1.387	73.0	2.894	77	46
"	12.70	1.457	76.7	2.870	81	46
"	11.04	1.599	84.2	3.255	79	46
Melamine	12.06	0.799	50.8	2.259	77	70
with	6.22	0.823	52.3	2.275	76	69
no	12.06	0.823	52.3	2.275	76	69
Aluminum	6.22	0.823	52.3	2.276	76	69
	22.58	0.843	53.6	2.431	76	66
	12.06	1.053	66.9	2.881	77	73
	12.06	1.099	69.9	3.055	77	74
	10.03	1.107	70.4	3.108	76	67
	9.98	1.121	71.3	3.201	76	68
Melamine	6.22	0.740	45.1	2.096	77	66
with	12.14	0.760	46.3	2.271	76	65
10%	12.06	0.842	51.3	2.410	76	69
Aluminum	6.22	0.851	51.9	2.371	75	69
by	6.39	0.984	60.0	2.743	75	69
weight	9.47	1.113	67.9	3.125	76	69
	12.14	1.135	69.2	3.180	77	66
	7.29	1.193	72.7	3.404	76	69

TABLE 1. (Cont.) EXPERIMENTAL DIELECTRIC CONSTANT DATA (Cont)

Sample	Length (mm)	Density (g/cc)	% TMD	Dielectric Constant	Temp (F)	Relative Humidity (%)
Melamine	12.14	0.791	46.1	2.307	75	62
with	12.14	0.894	52.1	2.538	70	69
20%	6.22	0.906	52.8	2.455	71	69
Aluminum	12.14	0.945	56.2	2.774	74	60
by	6.39	1.030	60.0	2.948	75	66
weight	12.14	1.064	62.0	2.922	74	67
	12.14	1.124	65.5	3.236	74	67
	12.14	1.156	67.4	3.372	74	67
	10.50	1.160	67.6	3.697	75	63
	9.45	1.184	69.0	3.709	75	62
Melamine	12.14	0.831	46.2	2.393	75	61
with	12.14	0.876	48.7	2.542	75	62
30%	12.14	1.036	57.6	2.897	75	61
Aluminum	6.39	1.079	60.0	3.108	75	65
by	12.14	1.095	60.9	3.023	75	62
weight	6.39	1.115	62.0	3.264	75	66
	7.72	1.126	62.6	3.487	75	62
	6.39	1.169	65.0	3.667	76	65
	5.59	1.395	77.6	4.493	75	61

REFERENCES

1. Computer Program for Calculating Dielectric Properties of Low or High-Loss Materials From Short-Circuited Waveguide Measurements, ARS-NC-4, Agricultural Research Service, U.S. Department of Agriculture, Nov 1972.

2. Sucher, M., and Fox, J., Handbook of Microwave Measurements, Vol. II, 1963, pp. 495-548.

3. Complex Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials at Microwave Frequencies and Temperatures to 1650°C, ANSI/ASTM D 2520-77, ASTM, 1961 Race St., Philadelphia, PA 19103.

4. Von Hippel, A., Dielectric Materials and Applications, (New York: John Wiley & Sons, Inc., 1954), p. 361

5. Lichtenecker, K., and Rother, K., Physics Z., Vol. 32, 1931, p. 225.

APPENDIX A

AUTOMATED DIELECTRIC CONSTANT MEASUREMENT PROGRAM

```
10      ! THIS PROGRAM IS STORED AS "AUTO-E"
20      !  ON THE TAPE LABELED  "BC 85"
30      !
40      ! APRIL 1985,  Brian Glancy and Al Krall
50      !
60      ! THE SAMPLE IS INSERTED IN THE END OF A SECTION OF WAVEGUIDE AFTER
70      !   THE PROGRAM IS BEGUN, WHEN IT IS INDICATED THAT YOU DO SO.
80      !   A SLOT IN THE TRANSMISSION LINE ALLOWS THE VSWR AND MINIMUM
90      !   POSITION OF THE RESULTING STANDING WAVE TO BE MEASURED.
100     !
110     ! THIS PROGRAM IS FOR AN HP 9845B COMPUTER AND THE INSTRUMENTATION FOR
120     ! AN EXPERIMENT TO DETERMINE THE DIELECTRIC PARAMETERS OF ANY MATERIAL.
130     !   THIS PROGRAM IS DESIGNED TO KEEP THE POWER LOW SO THAT THE SLOTTED
140     !   LINE'S PROBE CRYSTAL IS ALWAYS OPERATING IN ITS SQUARE LAW REGION.
150     !
160     !  THE PROGRAM ADJUSTS THE POWER TO KEEP THE VOLTAGE LOW, THEREFORE,
170     !   THE PROBE WILL BE LOCATED AT A MINIMUM WHEN THE POWER IS HIGHEST.
180     !
190     ! ADDITIONAL INSTRUMENTATION:
200     !       Klinger Stepper Motor Controller, CC-1 and Micro-Controle Motor
210     !       HP 8350A Sweep Oscillator with 83525A RF plug-in, .01-8.4 GHz
220     !       HP 3438A Digital Multimeter connected to an HP 415D SWR Meter
230     !       Appropriate Slotted line probe carriage and Associated
240     !         Waveguide for the Frequency Range of Interest
250   ! -----------------------------------------------------------------------
260     ! IF THE TRANSMISSION LINE IS CHANGED FROM RECTANGULAR X-BAND, CHECK
270     !  TO MAKE SURE THE PROGRAM LINES CONTAINING RECTANGULAR X-BAND DATA
280     !  HAVE BEEN CHANGED TO REFLECT THE NEW TRANSMISSION LINE SIZE and/or
290     !  WAVE VELOCITY!
300     !
310     ! IF THE PROGRAM IS NOT CONVERGING TO A POWER MAXIMUM, PRESS STOP ON
320     ! COMPUTER, PRESS COUNTER RESET ON THE KLINGER, THEN RUN ON COMPUTER.
330     !  THIS WILL RESTART THE PROGRAM AT A DIFFERENT POSITION
340   ! -----------------------------------------------------------------------
350   PRINTER IS 16     ! PRINTER 16 IS THE CRT SCREEN OF THE 9845B
360    OPTION BASE 1
370   DIM Dbm(40),Volts(40),Pos(40),Sampl$[80],Xx(9,2),Dc(9),Epp(9),Tad(9)
380   DIM F(3,30)
390    DEF FNSinh(X)=.5*(EXP(X)-EXP(-X))  ! USED IN DIELECTRIC CONST. CALC.
400    DEF FNCosh(X)=.5*(EXP(X)+EXP(-X))  ! USED IN DIELECTRIC CONST. CALC.
410   A1=22.86     ! Width of Rectangular Waveguide in mm  (X Band)
420   B1=10.16     ! Height of Rectangular Waveguide in mm (X Band)
430   Slot=3.2     ! Rectangular Slotted line slot width (mm) (X Band
440   OUTPUT 9;"Request time" ! FROM THE 98035A REAL TIME CLOCK
450   ENTER 9;Month,Day,Hour,Minute,Second
460   GOSUB 3910  ! SENDS US TO A SUBROUTINE TO HELP US PRINT OUT DATE & TIME
470   BEEP        !BELL
480   PRINT "IS THE SLOTTED SECTION'S PROBE NEAR THE RIGHT SIDE OF CARRIAGE?"
490   PRINT "     RESET THE KLINGER BY PRESSING THE COUNTER RESET BUTTON"
500   INPUT "What Year is it now?  Enter only the last two digits",Year
510   INPUT "Room Temperature is what at this time? (Deg. F)",Temp
520   INPUT "Relative Humidity in the room is what at this time? (%)",Rh
530   PRINT CHR$(12)     ! FORM FEED TO CLEAR THE CRT SCREEN
540   Count=1
550   IF Count=1 THEN GOTO 740
560   INPUT "Is the sample in place on the set-up? (Y or N) CAPS",Samp$
570   IF Samp$="Y" THEN GOTO 630
580   BEEP            ! BELL
590   PRINTER IS 16
600   PRINT "PUT SAMPLE IN PLACE. NOW!"
610   PRINTER IS 0
620   GOTO 550
630   BEEP             ! BELL
640   PRINTER IS 16
650   PRINT CHR$(12) ! FORM FEED TO CLEAR THE CRT SCREEN
660   PRINTER IS 0
```

```
670   INPUT "SAMPLE DESIGNATION (less than 80 characters)",Sampl$
680   PRINT
690   PRINT Sampl$
700   INPUT "LENGTH OF SAMPLE (mm)",Le
710   PRINT "Length of Sample is: ";Le;"(mm)"
720   PRINT
730   GOTO 760
740   INPUT "FREQUENCY (GHz)",F       ! DEFINES THE FREQUENCY TO BE USED
750   OUTPUT 7,19;"CW",F,"GZ"         ! SETS THE FREQUENCY ON THE HP 8350A SOURCE
760   Dbm=-40.0                       ! DEFINE THE dBm LEVEL TO BE -40.0 dBm
770   OUTPUT 7,19;"PL",Dbm,"DM"       ! SETS dBm LEVEL ON THE 8350A SOURCE
780   EOL 7;CHR$(13)       ! ADDRESS 7 IS THE KLINGER STEPPER MOTOR CONTROLLER
790     ! THE EOL FUNCTION DEFINES A NEW END OF LINE CHARACTER, IN THIS CASE
800     !  CHR$(13) DEFINES A CARRIAGE RETURN WITH NO LINE FEED, AS NECESSARY
810     !  FOR THE KLINGER STEPPER MOTOR CONTROLLER.
820     ! THE NEW END OF LINE STRING IS STORED AS IMAGE "L".
830     ! THE "USING "#,K,L", IS USED TO DEFINE THE USE OF THE NEW EOL STRING,
840     ! THE "#" DISABLES THE CARRIAGE RETURN AND LINE FEED (OLD EOL STRING),
850     ! THE "L" ALLOWS US TO USE OUR EOL STRING STORED AS IMAGE "L".
860   Lamda0=299.6966/F    ! 2.997E8 M/SEC IS THE SPEED OF E-M RAD. IN AIR @ STP
870     !  THIS LAST EQUATION CALCULATES THE FREE AIR WAVELENGTH OF ANY
880     !    FREQUENCY OF ELECTROMAGNETIC RADIATION.
890   Lamdac=2*A1          ! THE CUTOFF FREQ. FOR RECTANGULAR WAVEGUIDE (TE10 MODE)
900   Lamdag=Lamda0/(1-(Lamda0/Lamdac)^2)^.5     ! WAVEGUIDE WAVELENGTH
910   PRINTER IS 0       ! PRINTER 0 IS THE HARD COPY PRINTER OF THE 9845B
920   IF Count=2 THEN GOTO 1070
930   PRINT
940   PRINT
950   IMAGE "Date: ",ZZ,A,ZZ,A,ZZ
960   PRINT USING 950;Month,Slash$,Day,Slash$,Year
970   IMAGE "Time: ",ZZ,A,ZZ,A,ZZ,"   At start of test"
980   PRINT USING 970;Hour,Col$,Minute,Col$,Second
990   PRINT
1000  PRINT "Relative Humidity=";Rh;"%","Temperature=";Temp;"Deg. F"
1010  PRINT
1020  IMAGE "Frequency selected for this test is",DDD.DDD," (GHz)"
1030  PRINT USING 1020;F
1040  IMAGE "Waveguide Wavelength =",DDD.DDD,"(mm)"
1050  PRINT USING 1040;Lamdag
1060  PRINT
1070  Step=INT(Lamdag/36*1000)   ! READINGS TAKEN EVERY 10 DEGREES OF WAVELENGTH
1080  GOSUB 3700          ! DEFINE THE MOVE COMMAND FOR THE KLINGER   "N Step"
1090  Lstep=Step          ! Lstep = LAST STEP SIZE
1100  Pm$="+"             ! SET DIRECTION OF NEXT MOVE
1110  Dstep1=2            ! THESE THREE Dstep VALUES ARE USED TO ADJUST THE 8350A
1120  Dstep2=1            !     dBm LEVEL IN THE SUBROUTINE THAT ZEROS IN ON dBm
1130  Dstep3=.7           !
1140  Dbless=20.0
1150  GOSUB 4040          ! SUBROUTINE THAT FINDS THE NEXT ESTIMATE OF MINIMUM
1160  Step=INT(Lstep/2)
1170  GOSUB 3700          ! DEFINE THE MOVE COMMAND FOR THE KLINGER   "N Step"
1180  Dbm=Dbm-7
1190  OUTPUT 7,19;"PL -20 DM"
1200  GOSUB 3600          ! MOVE PROBE TO POSITION 1/2 STEP BEFORE MINIMUM ESTIMATE
1210  Pm$="+"
1220  Dstep1=1
1230  Dstep2=.5
1240  Dstep3=.1
1250  Dbless=10
1260  Step=INT(Lamdag/360*1000)     ! EACH STEP IS 1 DEGREE
1270  Lstep=Step
1280  Dbm=Dbm-10
1290  OUTPUT 7,19;"PL -5 DM"
1300  GOSUB 3700          ! DEFINE THE MOVE COMMAND FOR THE KLINGER  "N Step"
1310  GOSUB 4040          ! FIND NEXT ESTIMATE OF MINIMUM POSITION
1320  Step=INT(Lstep/2)
```

```
1330  GOSUB 3680        ! DEFINE THE MOVE COMMAND FOR THE KLINGER  "N Step"
1340  GOSUB 3600         ! MOVE THE PROBE TO A POSITION 1/2 STEP BEFORE MIN. EST.
1350  Pms="+"            ! SET DIRECTION OF NEXT MOVE
1360  Dstep1=.5
1370  Dstep2=.1
1380  Dstep3=.02
1390  Dbless=1
1400  Step=INT(Lamdag/3600*1000)    ! EACH STEP = .1 DEGREE
1410  GOSUB 3700         ! DEFINES THE MOVE COMMAND FOR THE KLINGER  "N Step"
1420  Lstep=Step
1430  Dbm=Dbm-10
1440  OUTPUT 7,19;"PL 0.0 DM"
1450  GOSUB 4040         ! FIND THE NEXT ESTIMATE OF MINIMUM POSITION
1460  Step=Step*2
1470  GOSUB 3700         ! DEFINES THE MOVE COMMAND FOR THE KLINGER  "N Step"
1480  GOSUB 3600         ! MOVE TO POSITION 2 STEPS BEFORE MINIMUM ESTIMATE
1490  Pms="+"            ! SET DIRECTION OF NEXT MOVE
1500  Dstep1=.2
1510  Dstep2=.08
1520  Dstep3=.04
1530  Dbless=.5
1540  Step=INT(Lamdag/7200*1000)    ! EACH STEP IS .05 DEGREE
1550  IF Step=0 THEN Step=1
1560  GOSUB 3700         ! DEFINES THE MOVE COMMAND FOR THE KLINGER  "N Step"
1570  Lstep=Step
1580  Dbm=Dbm-1
1590  OUTPUT 7,19;"PL",Dbm,"DM"
1600  GOSUB 4040         ! FIND THE NEXT ESTIMATE OF MINIMUM
1610  Dbm=Dbm-3          ! SET THE dBm POWER DOWN 3 dBm FROM LAST READING
1620  OUTPUT 7,19;"PL",Dbm,"DM"
1630  WAIT 1000          ! WAIT 1 SECOND UNTIL VOLTMETER HAS TIME TO SETTLE
1640 ! Lstep=Step
1650  Step=INT(Lstep/2)
1660  Lstep=Step
1670  IF Step=0 THEN Step=1
1680  GOSUB 3700         ! DEFINES THE MOVE COMMAND FOR THE KLINGER  "N Step"
1690  GOSUB 3750         ! MOVE KLINGER TO FIND THE 3 dBm POSITION
1700  GOSUB 3860         ! ASK THE KLINGER THE POSITION OF THE PROBE
1710  Pt3db1=Pos         ! POINT OF FIRST 3 dBm POSITION
1720  Step=I             ! FIGURE STEP TO MOVE BACK TO THIRD MINIMUM EST.
1730  GOSUB 3700         ! DEFINE THE MOVE COMMAND FOR THE KLINGER
1740  Pms="+"            ! SET DIRECTION OF NEXT MOVE
1750  GOSUB 3600         ! MOVE PROBE BACK TO THIRD EST. OF MINIMUM
1760  Step=Lstep
1770  WAIT 2000          ! WAIT 2 SECONDS BEFORE SEARCHING FOR 2nd 3 dBm POSITION
1780  GOSUB 3700         ! DEFINE THE MOVE COMMAND FOR THE KLINGER  "N Step"
1790  GOSUB 3750         ! MOVE KLINGER TO FIND THE 3 dBm POSITION
1800  GOSUB 3860         ! ASK THE KLINGER THE POSITION OF THE PROBE
1810  Pt3db2=Pos         ! POINT OF SECOND 3 dBm POSITION
1820  OUTPUT 7,19;"PL -72 DM"  ! SET POWER LEVEL OF 8350A BACK LOW
1830  Step=Pos
1840  GOSUB 3700
1850  Pms="-"
1860  GOSUB 3600
1870 ! -----------------------------------------------------------------------
1880     !   THIS PORTION OF THE PROGRAM IS BASED ON THE NOV. 1972 REPORT
1890     ! ARS-NC-4 FROM THE AGRICULTURAL RESEARCH SERVICE.  IT WILL FIND
1900     ! DIELECTRIC CONSTANT, LOSS TANGENT, AND LOSS FACTOR.
1910 ! -----------------------------------------------------------------------
1920    IF Count=2 THEN GOTO 1980
1930    Lza=Pt3db1/1000   ! Lza IS ONE 3 dBm POSITION W/O SAMPLE
1940    Rza=Pt3db2/1000   ! Rza IS ONE 3 dBm POSITION W/O SAMPLE
1950    PRINT "Positions of 3 dBm pts w/o sample are ";Lza;Rza;"mm"
1960    Count=Count+1
1970    GOTO 550
1980    Rzs=Pt3db1/1000   ! Rzs IS ONE 3 dBm POSITION WITH SAMPLE IN PLACE
```

```
1990  Lzs=Pt3db2/1000   ! Lzs IS ONE 3 dBm POSITION WITH SAMPLE IN PLACE
2000  PRINT "Positions of 3 dBm pts with sample are";Rzs;Lzs;"mm"
2010  Sd=3
2020  Db=3
2030  W1=-2
2040  W1=W1+2             ! ASSIGN AN INITIAL VALUE FOR SHIFT
2050  M=X=0
2060  Sc=1+(Slot*Lamdag)^2/(8*PI*B1*A1^3) ! SLOTTED LINE WAVELENGTH CORRECTION
2070  Za=.5*(Lza+Rza)                ! MINIMUM POSITION WITHOUT SAMPLE
2080  Z1=Za                          ! REDEFINE MINIMUM
2090  Q=1
2100  IF ABS(Q*(Lamdag/2)-(Za+Lamdag/2))<Lamdag/4 THEN 2130
2110  Q=Q+1
2120  GOTO 2100
2130  Za=Q*(Lamdag/2)                ! MIN POS W/O SAMPLE IS INTEGRAL # Lamdag/2'S
2140  Zs=.5*(Lzs+Rzs)                ! MINIMUM POSITION WITH SAMPLE IN PLACE
2150  Dza=ABS(Lza-Rza)/Sc            ! CORRECTED SEPERATION BTW 3dB PTS W/O SAMPLE
2160  Dzs=ABS(Lzs-Rzs)/Sc            ! CORRECTED SEPERATION BTW 3dB PTS WITH SAMPLE
2170  St=(Z1-Zs)/Sc                  ! CORRECTED SEPERATION BTW MINIMUMS
2180  Swr=(1.9952623-COS(PI*Dza/Lamdag)^2)^.5/SIN(PI*Dza/Lamdag)
2190  Arg=(.9952623/(Swr^2-1))^.5
2200  Dza=Lamdag*ASN(Arg)/PI
2210  R=(Za-Le-St)/Za
2220  Ppr=PI*(Dzs-R*Dza)/Lamdag
2230  Swr=(1.9952623-COS(Ppr)^2)^.5/SIN(Ppr)
2240  Phi=1/Swr
2250  N=0
2260  IF -(Le+St)+.5*Lamdag*N>0 THEN 2290
2270  N=N+1
2280  GOTO 2260
2290  Z0=-(St+Le)+.5*Lamdag*N
2300  U=2*PI*Z0/Lamdag
2310  A=TAN(U)*(Phi^2-1)
2320  B=Phi*(1+TAN(U)^2)
2330  C=(A^2+B^2)^.5*(Lamdag/(2*PI*Le*(1+(Phi*TAN(U))^2)))
2340  C=C*(A/ABS(A))
2350  IF C<1 THEN K=2
2360  FOR Y=K+1+W1*2 TO 6+K+W1*2 STEP 2
2370  M1=Y*PI/2
2380  M2=(Y-2)*PI/2
2390  IF M2<0 THEN M2=0
2400  X2=(M1-M2)/2+M2
2410  Fu=TAN(X2)/X2-C
2420  IF Fu>0 THEN M1=X2
2430  IF Fu<=0 THEN M2=X2
2440  IF M1-M2<.000000001 THEN 2460
2450  GOTO 2400
2460  M=M+1
2470  Xx(M,1)=X2
2480  Ad=Xx(M,1)*Lamdag*Phi*(1+TAN(U)^2)
2490  Den=2*PI*Le*(1+TAN(Xx(M,1))^2-TAN(Xx(M,1))/Xx(M,1))
2500  Xx(M,2)=Ad/Den
2510  NEXT Y
2520  Q=Lamdag/(2*PI*Le)
2530  Den=Q/(1+(Phi*TAN(U))^2)
2540  U0=A*Den
2550  V0=-B*Den
2560  FOR X=1 TO 3
2570  J=0
2580  X6=Xx(X,2)
2590  X7=Xx(X,1)
2600  D=.01
2610  GOSUB 3950
2620  Di1=((U0-Ua)^2+(V0-Va)^2)^.5
2630  IF Di1<.00001 THEN 2920
2640  K=0
```

```
2650    X6=Xx(X,2)+D
2660    X7=Xx(X,1)
2670    GOSUB 3950
2680    Di2=((U0-Ua)^2+(V0-Va)^2)^.5
2690    K=K+1
2700    IF Di2>=Di1 THEN 2740
2710    Xx(X,2)=X6
2720    Di1=Di2
2730    GOTO 2630
2740    IF K>1 THEN 2770
2750    X6=Xx(X,2)-D
2760    GOTO 2670
2770    K=0
2780    X7=Xx(X,1)+D
2790    X6=Xx(X,2)
2800    GOSUB 3950
2810    Di2=((U0-Ua)^2+(V0-Va)^2)^.5
2820    K=K+1
2830    IF Di2>=Di1 THEN 2860
2840    Xx(X,1)=X7
2850    GOTO 2720
2860    IF K>1 THEN 2890
2870    X7=Xx(X,1)-D
2880    GOTO 2800
2890    D=D/2
2900    J=J+1
2910    IF J<>15 THEN 2640
2920    P=(Lamda0/Lamdac)^2
2930    Ss=(Lamda0/(2*PI*Le))^2
2940    Dc(X)=P-Ss*(Xx(X,2)^2-Xx(X,1)^2) ! Dc IS THE DIELECTRIC CONSTANT
2950    Epp(X)=Ss*2*Xx(X,2)*Xx(X,1)      ! Epp IS THE LOSS FACTOR
2960    Ta=Epp(X)/Dc(X)
2970    Tad(X)=Ta                        ! Tad IS THE LOSS TANGENT
2980    Tadw=Dza*(1-P)/Za
2990    Cg=A1/(2*B1)
3000    Taws=Tadw*((Cg+P/Dc(X))/(Cg+P))
3010    Tad(X)=Ta-Taws
3020    Epp(X)=Dc(X)*Tad(X)
3030    NEXT X
3040    IF E1=2 THEN 3070
3050    IF E>0 THEN 2350
3060    PRINTER IS 0
3070    PRINT
3080    PRINT
3090    PRINT "DIELECTRIC CONSTANT";"   LOSS FACTOR","    LOSS TANGENT"
3100    PRINT
3110    FOR X=1+E TO 3+E
3120    IMAGE 4X,DDDD.DDD,10X,MD.DDE,10X,MD.DDE
3130    PRINT USING 3120;Dc(X),Epp(X),Tad(X)
3140    NEXT X
3150    PRINTER IS 16
3160    INPUT "DO YOU WANT SOME OTHER POSSIBLE VALUES [Y OR N]",Y$
3170    IF Y$="Y" THEN 2040
3180    OUTPUT 9;"Request time"     ! FROM THE 98035A REAL TIME CLOCK
3190    ENTER 9;Month,Day,Hour,Minute,Second
3200    PRINTER IS 0
3210    PRINT
3220    GOSUB 3910       ! SUBROUTINE TO HELP PRINT OUT THE TIME UNDERSTANDABLY
3230    PRINT
3240    IMAGE "The time at the end of the test is: ",ZZ,A,ZZ,A,ZZ
3250    PRINT USING 3240;Hour,Col$,Minute,Col$,Second
3260    PRINT
3270    PRINTER IS 16           ! RETURN PRINTER CONTROL TO CRT SCREEN
3280    LOCAL 719
3290    CLEAR 7
3300    END     ! END OF MAIN PROGRAM
```

```
3310 ! ------------------------------------------------------------------
3320  ! THIS SUBROUTINE ZEROS IN ON THE VALUE OF dBm THAT CORRESPONDS
3330  !     TO A VOLTAGE READING GREATER THAN 100 mV
3340   OUTPUT 7,19;"PL",Dbm,"DM"     ! SET POWER ON HP-8350A SWEEP OSCILLATOR
3350   TRIGGER 7,23                  ! ASK HP-3438A METER TO OUTPUT ITS READING
3360   ENTER 7,23;Volts              ! READ VOLTS FROM METER
3370   LOCAL 7,23
3380   IF Volts>.08 THEN GOTO 3450
3390   Dbm=Dbm+Dstep1
3400   OUTPUT 7,19;"PL",Dbm,"DM"
3410   TRIGGER 7,23
3420   ENTER 7,23;Volts
3430   LOCAL 7,23
3440   GOTO 3380
3450   IF Volts>.095 THEN GOTO 3520
3460   Dbm=Dbm+Dstep2
3470   OUTPUT 7,19;"PL",Dbm,"DM"
3480   TRIGGER 7,23
3490   ENTER 7,23;Volts
3500   LOCAL 7,23
3510   GOTO 3450
3520   IF Volts>=.1 THEN GOTO 3590
3530   Dbm=Dbm+Dstep3
3540   OUTPUT 7,19;"PL",Dbm,"DM"
3550   TRIGGER 7,23
3560   ENTER 7,23;Volts
3570   LOCAL 7,23
3580   GOTO 3520
3590    RETURN
3600  ! SUBROUTINE TO MOVE THE PROBE BY COMMANDING THE KLINGER
3610  EOL 7;CHR$(13)                      ! SET-UP NEW END OF LINE STRING
3620  OUTPUT 7,7 USING "#,K,L";"R 253"  !
3630  OUTPUT 7,7 USING "#,K,L";"S 2"    ! R,S,F SET MOVE SPEED OF PROBE
3640  OUTPUT 7,7 USING "#,K,L";"F 20"   !
3650  OUTPUT 7,7 USING "#,K,L";Nstep$   ! MOVE THIS NUMBER OF STEPS
3660  OUTPUT 7,7 USING "#,K,L";Pm$      ! DIRECTION OF MOVE
3670  OUTPUT 7,7 USING "#,K,L";"G"      ! GO...EXECUTE MOVE
3680  LOCAL 7,7
3690  RETURN
3700  ! THIS SUBROUTINE DEFINES THE STEP SIZE MOVE COMMAND FOR THE KLINGER
3710  N$=VAL$(Step)
3720  Q$="N "
3730  Nstep$=Q$&N$
3740  RETURN
3750    ! THIS ROUTINE FINDS THE 3 dBm POSITION, STARTING AT A MINIMUM
3760    I=Step
3770    GOSUB 3600         ! MOVE PROBE
3780    WAIT 500
3790    TRIGGER 7,23
3800    ENTER 7,23;Volts
3810    IF (Volts=.1) OR (Volts>.1) THEN GOTO 3840
3820    I=I+Step
3830    GOTO 3770
3840    LOCAL 7,23
3850    RETURN
3860 ! SUBROUTINE TO ASK THE KLINGER TO OUTPUT THE POSITION OF THE PROBE
3870  EOL 7;CHR$(13)
3880  OUTPUT 7,7 USING "#,K,L";"V 0"  ! OUTPUT POSITION FROM KLINGER
3890  ENTER 7,29;Pos                  ! READ POSITION
3900  RETURN
3910    ! THIS SUROUTINE HELPS US PRINT OUT THE DATE & TIME IN GOOD FORM
3920     Slash$="/"
3930     Col$=":"
3940     RETURN
3950  ! THIS IS A SUBROUTINE FOR THE DIELECTRIC CONSTANT PART OF THE PROGRAM
3960  S=X6*2
```

```
3970 T=X7*2
3980 V1=X6*FNSinh(S)+X7*SIN(T)
3990 V2=X6*SIN(T)-X7*FNSinh(S)
4000 Bot=(X6^2+X7^2)*(FNCosh(S)+COS(T))
4010 Ua=V1/Bot
4020 Va=V2/Bot
4030 RETURN
4040   ! SUBROUTINE TO FIND THE NEXT ESTIMATE OF MINIMUM POSITION
4050   N=1
4060   GOSUB 3320              ! ZERO IN ON THE dBm LEVEL
4070   OUTPUT 7,19;"OPPL"      ! ASK SWEEP OSCILLATOR ITS POWER LEVEL
4080   ENTER 7,19;Dbm(N)       ! READ POWER LEVEL IN dBm
4090   GOSUB 3860              ! ASK THE KLINGER THE POSITION OF THE PROBE
4100   Pos(N)=Pos
4110   Volts(N)=Volts
4120   Dbm=Dbm-Dbless          ! SET POWER LOWER BEFORE NEXT MOVE
4130 !  PRINT LINES ARE COMMENTED OUT BUT ARE AVAILABLE FOR USE IF NEEDED
4140 ! PRINT N;"  Position =";Pos(N);"(um)","dBm = ";Dbm(N),"Volts =";Volts(N)
4150   OUTPUT 7,19;"PL",Dbm,"DM"
4160   IF N>=2 THEN GOTO 4210
4170   N=N+1
4180   GOSUB 3600 .             ! MOVE PROBE
4190   WAIT 1000                ! WAIT 1 SECOND FOR PROBE TO SETTLE
4200   GOTO 4060
4210   L=N
4220   N1=N-1
4230   N=N+1
4240   Dbm=Dbm(L)-Dbless
4250   OUTPUT 7,19;"PL",Dbm,"DM"
4260   GOSUB 3600               ! MOVE PROBE
4270   WAIT 1000.               ! WAIT 1 SECOND FOR PROBE TO SETTLE
4280   GOSUB 3320               ! ZERO IN ON dBm LEVEL
4290   OUTPUT 7,19;"OPPL"
4300   ENTER 7,19;Dbm(N)
4310   GOSUB 3860               ! ASK THE KLINGER THE PROBE'S NEW POSITION
4320   Pos(N)=Pos
4330   Volts(N)=Volts
4340 ! PRINT N;"  Position =";Pos(N);"(um)","dBm = ";Dbm(N),"Volts =";Volts
4350   IF Dbm(N)<-25.0 THEN GOTO 4210
4360   IF (Dbm(N)<=Dbm(L)) AND (Dbm(L)>=Dbm(N1)) THEN GOTO 4380
4370   GOTO 4210
4380   Pm$="-"
4390   GOSUB 3600               ! MOVE PROBE BACK TO LOCATION OF MINIMUM ESTIMATE
4400   Dbm=Dbm(L)
4410 ! PRINT
4420   RETURN
```

APPENDIX B

DIELECTRIC CONSTANT CALCULATION PROGRAM

```
10   !  JULY, 1983             R. WATKINS
11   !
20   !   THIS PROGRAM IS BASED ON THE NOV. 1972 REPORT ARS-NC-4 FROM THE
30   !  AGRICULTURAL RESEARCH SERVICE.  IT WAS REVISED FROM THE PREVIOUS
40   !  VERSION WRITTEN IN 1980 AND NOW IS ACCURATE FOR ALL CASES.
50   !  IT WILL FIND DIELECTRIC CONSTANT, LOSS TANGENT,
60   !  AND LOSS FACTOR AND WILL PRINT THEM ON THE PRINTER OR THE SCREEN.
70   !  AVG. RUNNING TIME: 1-3 MIN.
80    ! DETAILED INSTRUCTIONS ARE OBTAINED BY TYPING 'EDIT 1680'.
90    ! MAKE SURE THAT WAVEGUIDE DIMENSIONS (LINES 1640-1660) ARE CORRECT
100   ! BEFORE RUNNING PROGRAM.
110  DEF FNSinh(X)=.5*(EXP(X)-EXP(-X))
120 DEF FNCosh(X)=.5*(EXP(X)+EXP(-X))
130  DIM Xx(9,2),Dc(9),Epp(9),Tad(9),F(3,30),Sampl$[60]
140 GOSUB 1640
150 LINPUT "SAMPLE DESIGNATION",Sampl$
160 INPUT "FREQUENCY(GHz)",F
170 INPUT "LENGTH OF SAMPLE(mm)",Le
180 INPUT "2 ()dB POINTS WITH SAMPLE(mm)",Lzs,Rzs
190  INPUT "SAMPLE Db",Sd
200 INPUT "2 ()dB POINTS WITHOUT SAMPLE(mm)(IF NONE, INPUT 0,0",Lza,Rza
210  INPUT "dB LEVEL WITHOUT SAMPLE",Db
220  INPUT "ENTER SHIFT",W1
230  M=X=0
240  Lamo=299.6966/F
250  Lamc=2*A1
260  Lamg=Lamo/(1-(Lamo/Lamc)^2)^.5
270  IF Lza<>0 THEN 300
280  Lza=Lamg/2
290  Rza=Lamg/2
300  Sc=1+(W*Lamg)^2/(8*PI*B1*A1^3)
310  Za=.5*(Lza+Rza)
320  Z1=Za
330  Q=0
340  Q=Q+1
350  IF ABS(Q*(Lamg/2)-(Za+Lamg/2))<Lamg/4 THEN 370
360  GOTO 340
370  Za=Q*(Lamg/2)
380  Zs=.5*(Lzs+Rzs)
390  Dza=ABS(Lza-Rza)/Sc
400  Dzs=ABS(Lzs-Rzs)/Sc
410  St=(Z1-Zs)/Sc
420  IF Dza=0 THEN 460
430  Arg=.2302585*Db
440  Po=EXP(Arg)
450  Swr=(Po-COS(PI*Dza/Lamg)^2)^.5/SIN(PI*Dza/Lamg)
460  Arg=.2302585*Sd
470  Po=EXP(Arg)
480  IF Dza=0 THEN 520
490  Arg=((Po-1)/(Swr^2-1))^.5
500  Dza=Lamg*ASN(Arg)/PI
510  R=(Za-Le-St)/Za
520  Ppr=PI*(Dzs-R*Dza)/Lamg
530  Swr=(Po-COS(Ppr)^2)^.5/SIN(Ppr)
540 Phi=1/Swr
550  N=0
560  IF -(Le+St)+.5*Lamg*N>0 THEN 590
570  N=N+1
580 GOTO 560
590  Z0=-(St+Le)+.5*Lamg*N
600  U=2*PI*Z0/Lamg
610  A=TAN(U)*(Phi^2-1)
620  B=Phi*(1+TAN(U)^2)
630  C=(A^2+B^2)^.5*(Lamg/(2*PI*Le*(1+(Phi*TAN(U))^2)))
640  C=C*(A/ABS(A))
650  IF C<1 THEN K=2
```

```
660  FOR Y=K+1+W1*2 TO 6+K+W1*2 STEP 2
670 M1=Y*PI/2
680  M2=(Y-2)*PI/2
690  IF M2<0 THEN M2=0
700  X2=(M1-M2)/2+M2
710  Fu=TAN(X2)/X2-C
720  IF Fu>0 THEN M1=X2
730  IF Fu<=0 THEN M2=X2
740  IF M1-M2<.000000001 THEN 760
750  GOTO 700
760  M=M+1
770 Xx(M,1)=X2
780  Ad=Xx(M,1)*Lamg*Phi*(1+TAN(U)^2)
790  Den=2*PI*Le*(1+TAN(Xx(M,1))^2-TAN(Xx(M,1))/Xx(M,1))
800  Xx(M,2)=Ad/Den
810  NEXT Y
820  Q=Lamg/(2*PI*Le)
830  Den=Q/(1+(Phi*TAN(U))^2)
840  U0=A*Den
850  V0=-B*Den
860  FOR X=1 TO 3
870  J=0
880  X6=Xx(X,2)
890  X7=Xx(X,1)
900 D=.01
910  GOSUB 1560
920  Di1=((U0-Ua)^2+(V0-Va)^2)^.5
930  IF Di1<.00001 THEN 1220
940 K=0
950  X6=Xx(X,2)+D
960  X7=Xx(X,1)
970  GOSUB 1560
980  Di2=((U0-Ua)^2+(V0-Va)^2)^.5
990  K=K+1
1000 IF Di2>=Di1 THEN 1040
1010 Xx(X,2)=X6
1020 Di1=Di2
1030 GOTO 930
1040 IF K>1 THEN 1070
1050 X6=Xx(X,2)-D
1060 GOTO 970
1070 K=0
1080 X7=Xx(X,1)+D
1090 X6=Xx(X,2)
1100 GOSUB 1560
1110 Di2=((U0-Ua)^2+(V0-Va)^2)^.5
1120 K=K+1
1130 IF Di2>=Di1 THEN 1160
1140 Xx(X,1)=X7
1150 GOTO 1020
1160 IF K>1 THEN 1190
1170 X7=Xx(X,1)-D
1180 GOTO 1100
1190 D=D/2
1200 J=J+1
1210 IF J<>15 THEN 940
1220 P=(Lamo/Lamc)^2
1230 Ss=(Lamo/(2*PI*Le))^2
1240 Dc(X)=P-Ss*(Xx(X,2)^2-Xx(X,1)^2)
1250 Epp(X)=Ss*2*Xx(X,2)*Xx(X,1)
1260 Ta=Epp(X)/Dc(X)
1270 Tad(X)=Ta
1280 Tadw=Dza*(1-P)/Za
1290 Cg=A1/(2*B1)
1300 Taus=Tadw*((Cg+P/Dc(X))/(Cg+P))
1310 Tad(X)=Ta-Taus
```

```
1320 Epp(X)=Dc(X)*Tad(X)
1330 NEXT X
1340 IF E1=2 THEN 1360
1350 IF E>0 THEN 650
1360 INPUT "PRINTER OR SCREEN(P OR S)",Y$
1370 IF Y$="P" THEN PRINTER IS 0
1380  PRINT
1390  PRINT "SAMPLE DESIGNATION:  ";Sampl$
1400  PRINT
1410  PRINT "FREQUENCY IN GIGAHERTZ:  ";F
1420  PRINT
1430  PRINT "SAMPLE LENGTH IN MILLIMETERS:  ";Le
1440  PRINT
1441  PRINT
1450  PRINT "SHIFT=";W1
1460  PRINT
1470 PRINT "DIELECTRIC CONSTANT";"   LOSS FACTOR","    LOSS TANGENT"
1480 FOR X=1+E TO 3+E
1490 PRINT Dc(X),Epp(X),Tad(X)
1500 NEXT X
1510  PRINT
1520 PRINTER IS 16
1530 INPUT "ANOTHER VALUE OF SHIFT(Y OR N)",Y$
1540 IF Y$="Y" THEN 220
1550 STOP
1560 S=X6*2
1570 T=X7*2
1580 V1=X6*FNSinh(S)+X7*SIN(T)
1590 V2=X6*SIN(T)-X7*FNSinh(S)
1600 Bot=(X6^2+X7^2)*(FNCosh(S)+COS(T))
1610 Ua=V1/Bot
1620 Va=V2/Bot
1630 RETURN
1640 A1=22.8600   ! WIDTH OF WAVEGUIDE  IN MILLIMETERS
1650 B1=10.16   ! HEIGHT OF  WAVEGUIDE  IN MILLIMETERS
1660 W=3.2  ! SLOT WIDTH IN MILLIMETERS OF THE WAVEGUIDE SLOTTED LINE
1670 RETURN
1680  !      INSTRUCTIONS FOR USE OF DIELECTRIC CONSTANT PROGRAM
1690  !
1700  !              R. Watkins
1710  !
1720  !   1.  If you don't need to enter waveguide cross sectional
1721  !       dimensions, go to 2.
1721  !       dimensions, go to 2.
1722  !
1730  !         a. Push  EDIT 1640 if you need to change waveguide dimensions
1740  !         b. Use cursor controls to position cursor on
1750  !            the line that needs to be changed.
1760  !         c. Use cursor controls to position cursor on
1770  !            the number that needs to be changed
1780  !         d. Enter changes.
1790  !         e. When line is correct, push  STORE  and go on to next line.
1800  !         f. When all is correct, push  PAUSE  to exit the edit mode.
1810  !
1820  ! 2.  Push  RUN
1830  !
1831  ! 3.  Enter the Sample Designation (description of sample), then CONTINUE
1832  !
1840  ! 4.  Enter frequency in gigahertz, then  CONTINUE.
1850  !
1860  ! 5.  Enter sample length in mm, then  CONTINUE.
1870  !
1880  ! 6.  Enter two positions along the slotted line in mm where the
1881  !     power is up a given number of dB from the minimum dB value
1890  !     with the sample in.  These points should be measured relative to
```

```
1900  !      the short.  Separate values by a comma, then CONTINUE.
1910  !
1920  ! 7.   Enter the dB level of the measurements in step 6.(usually 3)
1921  !      and then CONTINUE
1930  !
1940  ! 8.   Same as step 6. but with the waveguide empty. Then CONTINUE.
1950  !
1960  ! 9.   dB level of measurement in step 8.  Then CONTINUE.
1970  !
1980  ! 10. Enter shift.  This is a positive whole number that determines
1990  !       what 3 possible values of dielectric constant will be examined.
2000  !       Then CONTINUE.  If you have no idea what value to use try 0,
2001  !       then 1, etc.
2010  !
2020  ! 11.   Wait
2030  !
2040  ! 12.   When asked, enter P (printer) or S (screen) to determine
2041  !       where data will be displayed.
2050  !
2060  ! 13.   When asked, enter Y (yes) if another value of shift is desired.
```

APPENDIX C

SAMPLE COMPUTER OUTPUT

Date: 04/10/85
Time: 11:55:27 At start of test

Relative Humidity = 50 percent Temperature = 75 Deg. F

Frequency selected for this test is: 8.400 (GHz)
Waveguide Wavelength = 57.055 (mm)

THIS IS A TEST OF THIS PROGRAM TO SEE IF IT WILL GIVE DC=1 FOR AIR
Length of Sample is: 25.4 (mm)

DIELECTRIC CONSTANT	LOSS FACTOR	LOSS TANGENT
1.000	-1.72E-04	-1.72E-04
2.207	-2.28E-03	-1.03E-03
4.297	-3.22E-03	7.49E-04

The time at the end of the test is: 12:05:58

Date: 04/10/85
Time: 14:49:38 At start of test

Relative Humidity = 50 percent Temperature = 80 Deg. F

Frequency selected for this test is: 8.400 (GHz)
Waveguide Wavelength = 57.055 (mm)

THIS IS A TEST OF THIS PROGRAM TO SEE IF IT WILL GIVE DC=1 FOR AIR
Length of Sample is: 12.7 (mm)

DIELECTRIC CONSTANT	LOSS FACTOR	LOSS TANGENT
1.000	2.06E-04	2.06E-04
4.950	-5.67E-03	-1.15E-03
12.843	-1.70E-02	-1.32E-03

The time at the end of the test is: 15:01:11

Date: 04/01/85
Time: 15:4 At start of program

Relative Humidity = 56 percent Temperature = 82 Deg. F

Frequency selected for this test is: 8.3 (GHz)
Waveguide Wavelength = 58.864 (mm)

WHITE CERAMIC FOAM

Length of Sample is: 9/32 (mm)

DIELECTRIC CONSTANT	LOSS FACTOR	LOSS TANGENT
1.507	2.11E-03	1.40E-03
9.012	-8.32E-03	-9.23E-04
24.02	-2.89E-02	-1.20E-03

The time at the end of the test is: 15:25

Date: 04/19/85
Time: 14:27:40 At start of test

Relative Humidity = 43 percent Temperature = 79 Deg. F

Frequency selected for this test is: 8.400 (GHz)
Waveguide Wavelength = 57.055 (mm)

POLYSULFONE POLYMER SAMPLE

Length of Sample is: 12.903 (mm)

DIELECTRIC CONSTANT	LOSS FACTOR	LOSS TANGENT
2.971	2.97E-02	1.00E-02
9.856	8.44E-02	8.57E-03
20.942	1.27E-01	6.05E-03

The time at the end of the test is: 14:44:46

DISTRIBUTION

	Copies
Commander	
Naval Air Systems Command	
Attn: Library	1
AIR-932H	1
AIR-932T	1
AIR-932F (B. Sobers)	1
Department of the Navy	
Washington, DC 20361	
Commander	
Naval Sea Systems Command	
Attn: SEA-99612	1
SEA-62D	1
SEA-62D31	1
SEA-06G42	1
Department of the Navy	
Washington, DC 20362	
Director	
Strategic Systems Program Office (PM-1)	
Attn: SP2731 (J. Culver)	1
SP273 (E. Throckmorton)	1
Department of the Navy	
Washington, DC 20376	
Commanding Officer	
Naval Propellant Plant	
Attn: Technical Library	1
Indian Head, MD 20640	
Office of Naval Technology	
Attn: ONT-21 (E. Zimet)	1
ONT-213 (D. Siegel)	1
ONT-23 (A. Faulstich)	1
ONT-232 (D. Houser)	1
Department of the Navy	
800 North Quincy Street	
Arlington, VA 22217	

	Copies
Commander	
Naval Weapons Center	
Attn: Technical Library	1
Code 326B (L. Josephson)	1
Code 3266 (D. Lind)	1
Code 326B (G. Greene)	1
Code 3891 (M. Chan)	1
Code 3858 (R. Yee)	1
Code 3264 (H. Gollmar)	1
Code 385 (R. Atkins)	1
Code 3265 (J. Pakulak)	1
Code 38 (R. Derr)	1
Code 389 (T. Boggs)	1
Code 3891 (C. Price)	1
Code 3891 (K. Graham)	1
China Lake, CA 93555	
Director	
Naval Research Laboratory	
Attn: Technical Information Section	2
Washington, DC 20375	
Director	
Defense Advanced Research Projects Agency	1
Washington, DC 20301	
Commanding Officer	
Naval Weapons Station	
Attn: R & D Division	1
Code 50, NEDED	1
Code 505, NEDED	1
Yorktown, VA 23691	

DISTRIBUTION LIST (CONT.)

	Copies
Air Force Office of Scientific Research Attn: Library Bolling Air Force Base Washington, DC 20332	1
Department of the Air Force AFRPL/DY, Stop 24 Attn: C. Merrill Edwards AFB, CA 93523	1
Georgia Institute of Tech. Attn: Prof. E. Price School of Aerospace Eng. Atlanta, GA 91125	1
Commanding Officer Naval Weapons Evaluation Facility Attn: Code AT-7 Kirtland Air Force Base Albuquerque, NM 87117	1
Superintendent Naval Academy Attn: Library Annapolis, MD 21402	1 1
Naval Plant Representative Office Lockheed Missiles and Space Co. Attn: SPL-332 P. O. Box 504 Sunnyvale, CA 94088	1
AMCRD 5001 Eisenhower Avenue ALexandria, VA 22302	1
Hercules Incorporated Allegany Ballistics Laboratory Attn: Library P. O. Box 210 Cumberland, MD 21502	1
Redstone Scientific Information Center U. S. Army Missile Command Attn: Chief, Documents Redstone Arsenal, AL 35809	1
Commanding Officer Army Armament Research and Development Command Energetic Materials Division Attn: DRSMC-LCE (N. Slagg) DRSMC-LCE (J. Alster) Dover, NJ 07801	1 1
Commanding Officer Harry Diamond Laboratories Attn: Library DELHD-DE-OM (K. Warner) George Simmonis J. W. McCorkle 2800 Powder Mill Road Adelphi, MD 20783	1 1 1 1
Army Ballistic Research Laboratories Attn: DRDAR-BLT (P. Howe) DRDAR-BLT (R. Frey) Aberdeen Proving Ground Aberdeen, MD 21005	1 1
Armament Development & Test Center Attn: DLOSL/Technical Library AFATL/MNE (G. Parsons) AFATL/MNE (T. Floyd) Eglin Air Force Base, FL 32542	1 1 1
Commanding Officer Naval Ordnance Station Louisville, KY 40124	
U. S. Department of Energy Attn: OMA Washington, DC 20545	1

DISTRIBUTION (CONT.)

	Copies
Director Applied Physics Laboratory Attn: Library Johns Hopkins Road Laurel, MD 20707	1
Research Director Pittsburgh Mining and Safety Research Center U. S. Bureau of Mines 4800 Forbes Avenue Pittsburgh, PA 15213	1
Director Defense Technical Information Center Cameron Station Alexandria, VA 22304-6145	12
Goddard Space Flight Center NASA Glenn Dale Road Greenbelt, MD 20771	1
Lawrence Livermore National Laboratory University of California Attn: Library	1
M. Costantino	1
L. Green	1
E. Lee	1
P. Studt	1
P. Urtiew P. O. Box 808 Livermore, CA 94550	1
Sandia National Laboratories Attn: M. Baer	1
P. Stanton	1
E. Venturini P. O. Box 5800 Albuquerque, NM 87115	1

	Copies
Library of Congress Attn: Gift & Exchange Division Washington, DC 20540	4
Director Los Alamos National Laboratory Attn: Library	1
B. Dobratz	1
L. Stretz	1
A. Bowman	1
J. McAfee	1
J. J. Dick P. O. Box 1663 Los Alamos, NM 87544	1
Chairman DOD Explosives Safety Board Attn: J. Ward 2461 Eisenhower Avenue Alexandria, VA 22331	1
Aerojet Ordnance and Manufacturing Co. 9236 East Hall Road Downey, CA 90241	1
CETR New Mexico Tech. Attn: P. Anders Persson Socorro, NM 87801	1
University of California at Santa Barbara Attn: Richard Watkins c/o 286 Spruce Drive Goleta, CA	1
Supercomputing Research Center Attn: D. Jablonski 4380 Forbes Blvd. Lanham, MD 20706	1
Thiokol/Huntsville Division Attn: Technical Library Huntsville, AL 35807	1

DISTRIBUTION (CONT.)

	Copies
Zernow Technical Service Center Attn: Dr. L. Zernow 425 W. Bonita Ave., Suite 208 San Dimas, CA 91773	2
Commanding Officer Naval Underwater Systems Center Attn: LA 151 - Technical Library Newport, RI 02840	1
Superintendent Naval Postgraduate School Attn: Library Monterey, CA 93940	1
RARDE/Ft. Halstead Attn: Dr. John Connor, NP1 Sevenoaks, Kent TN13 7BP England	1
Defense Research Establishment, Valcartier Attn: Dr. Conrad Belanger P. O. Box 8800 Courcelette, Quebec GOA 1RO Canada	1

Internal Distribution

	Copies
E231	2
E323	15
R04	1
R10	1
R101	1
R10B	1
R10C	1
R10D	1
R10F	1
R	1
R11	1
R11 (T. Hall)	1
R11 (C. Gotzmer)	1
R12	1
R12 (P. Spahn)	1
R13	1
R13 (B. Glancy)	10
R13 (D. Demske)	1
R13 (S. Jacobs)	1
R13 (D. Price)	1
R13 (S. Coffey)	1
R13 (W. Elban)	1
R13 (J. Forbes)	1
R13 (K. Kim)	1
R13 (R. Lee)	1
R13 (E. Lemar)	1
R13 (D. Tasker)	1
R14	1
R15	1
R15 (W. Smith)	1
R30	1
R31	1
R31 (I. Talmy)	1
R31 (C. Martin)	1
R40	1
R43	1
R43 (J. Choe)	1
R43 (H. Crosby)	1
R45 (A. Clark)	1
E35 (GIDEP Office)	1