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AUTOMATED MICROWAVE DIELECTRIC CONSTANT MEASUREMENT SYSTEM

BY B. C. GLANCY A. KRALL

RESEARCH AND TECHNOLOGY DEPARTMENT

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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. <i>Key words included!</i>					
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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:

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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 interferometric 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 report¹ 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.

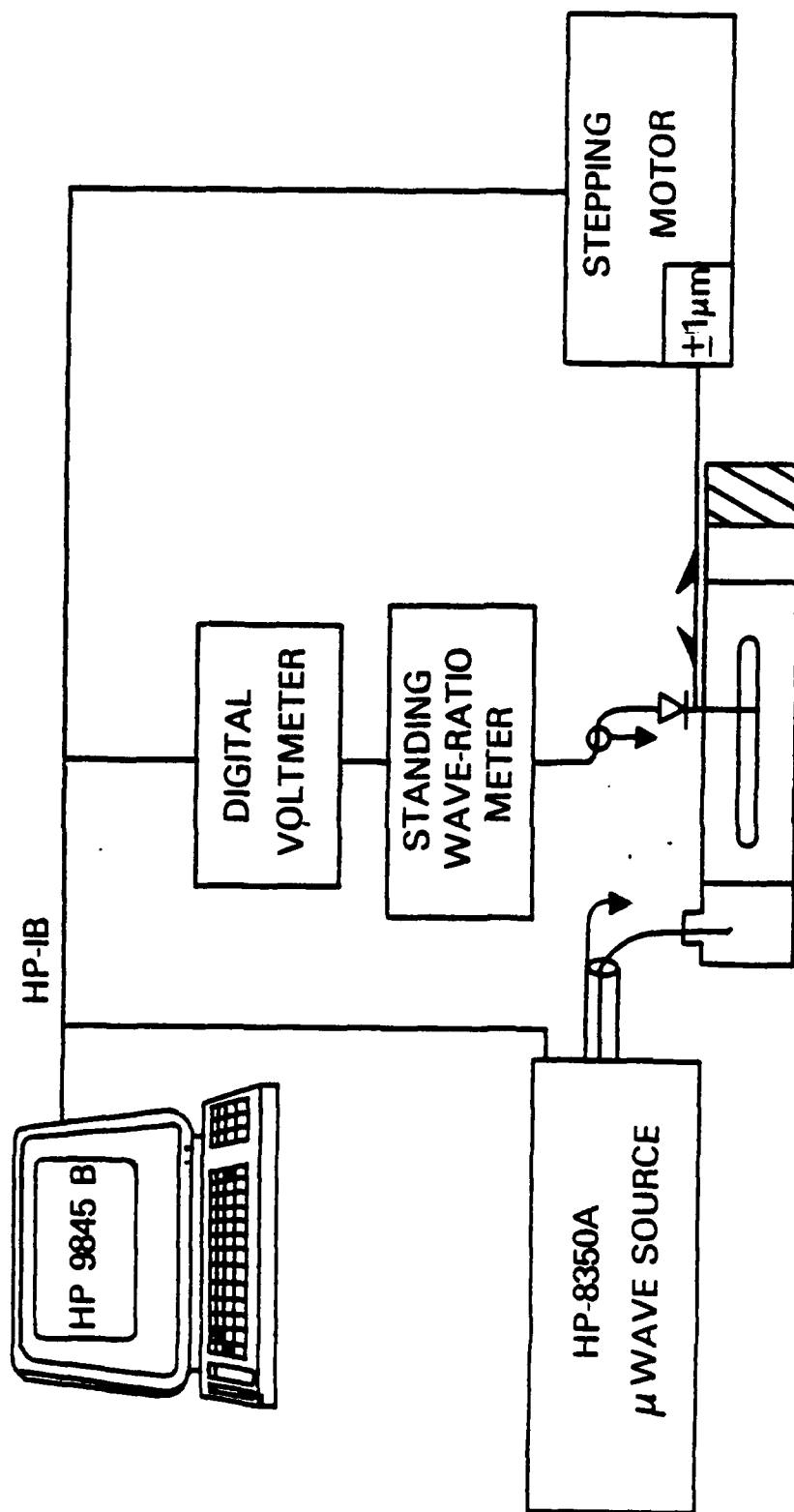


FIGURE 1. AUTOMATED DIELECTRIC CONSTANT MEASUREMENT APPARATUS

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 ± 0.01 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 ± 0.001 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 ($.5^\circ$) before the maximum power reading. A new step size of $.1^\circ$ is calculated and used in the next iteration using the same process as above. A final step size of $.05^\circ$ 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 $.025^\circ$ 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 coefficient⁴ near room temperature is about 1 percent/°C and its frequency variation⁴ 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

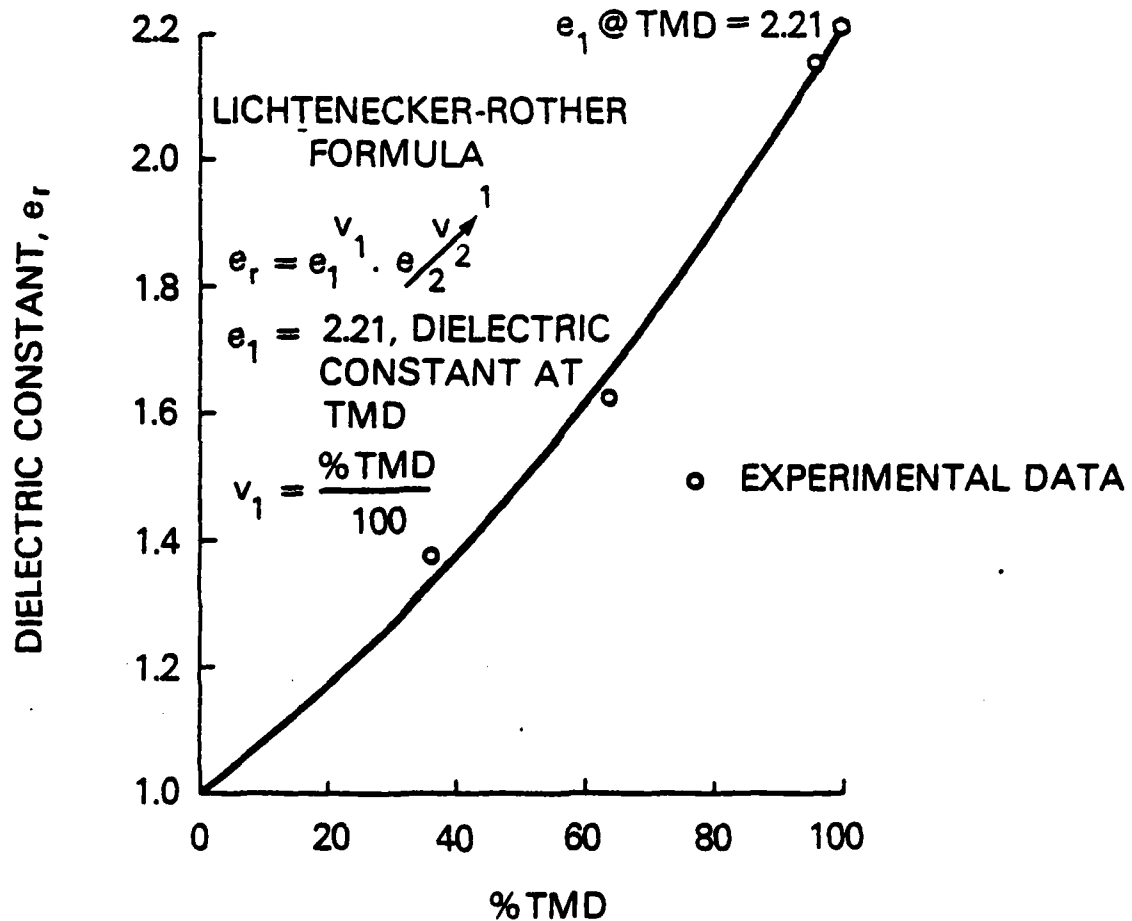


FIGURE 2. VARIATION OF DIELECTRIC CONSTANT WITH PERCENT TMD FOR TEFLON 7C POWDER AT 8.3 GHz

ϵ_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-Rother⁵ in the early 1930's to describe the dielectric constant resulting from the mixture of various components. In the simple case where ϵ_2 and v_2 are for air, its dielectric constant is 1.0, therefore ϵ_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 50 μ 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, ϵ_1 is the dielectric constant at TMD for the mixture of melamine and aluminum as determined empirically from experimental data, ϵ_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.

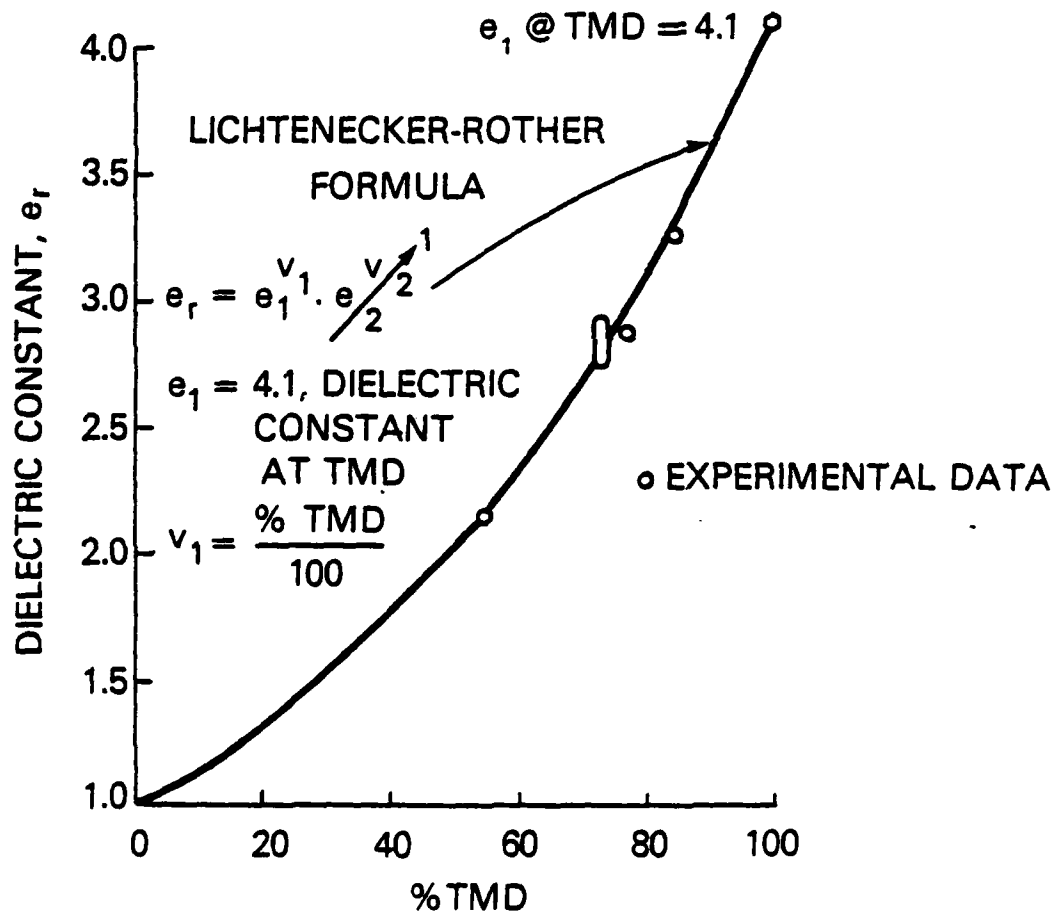


FIGURE 3. VARIATION OF DIELECTRIC CONSTANT WITH PERCENT TMD FOR CLASS D HMX AT 8.3 GHz

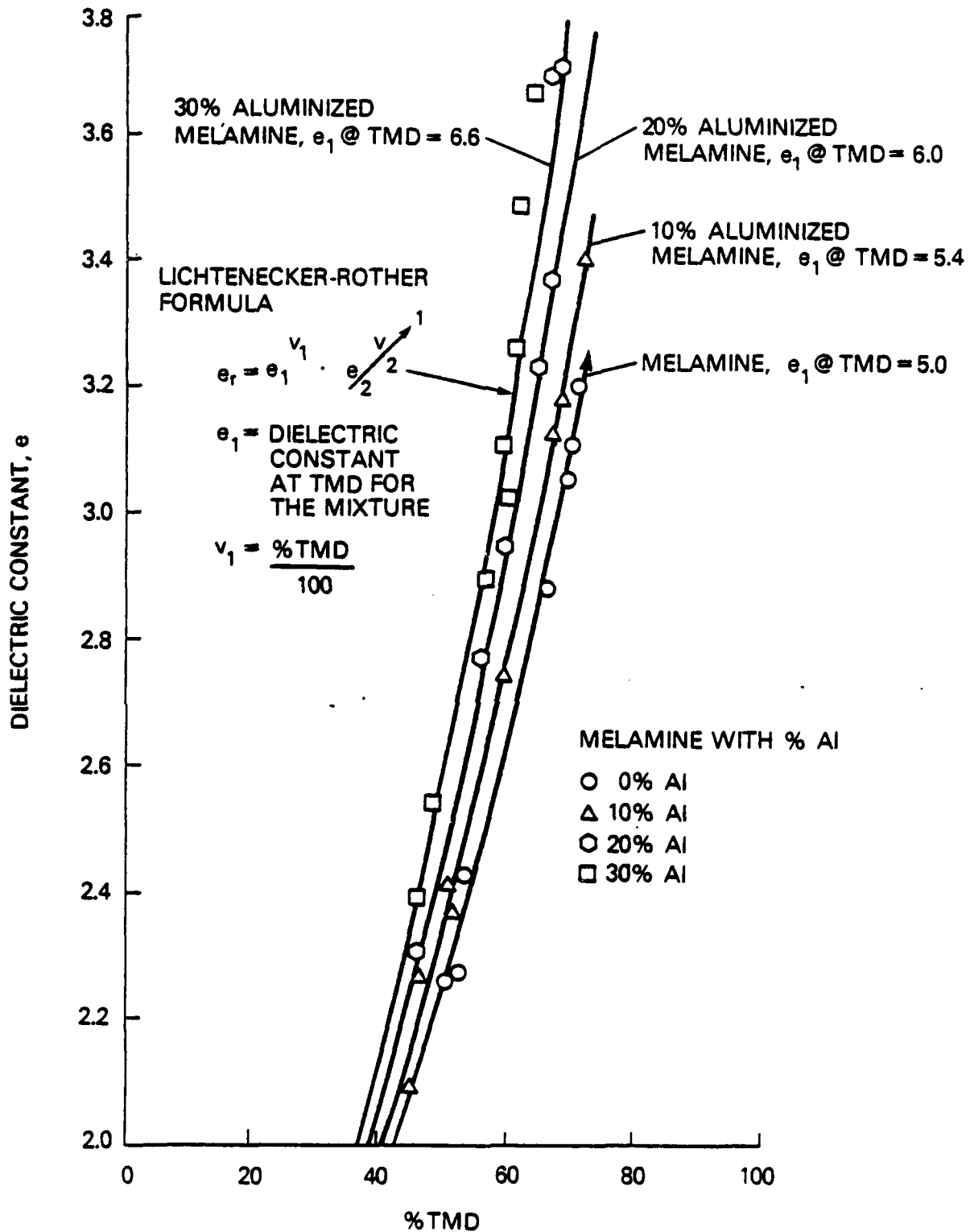


FIGURE 4. VARIATION OF DIELECTRIC CONSTANT WITH PERCENT TMD FOR VARIOUS MIXTURES OF MELAMINE AND ALUMINUM AT 10GHz

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 with no Aluminum	12.06	0.799	50.8	2.259	77	70
	6.22	0.823	52.3	2.275	76	69
	12.06	0.823	52.3	2.275	76	69
	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 with 10% Aluminum by weight	6.22	0.740	45.1	2.096	77	66
	12.14	0.760	46.3	2.271	76	65
	12.06	0.842	51.3	2.410	76	69
	6.22	0.851	51.9	2.371	75	69
	6.39	0.984	60.0	2.743	75	69
	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)

<u>Sample</u>	<u>Length (mm)</u>	<u>Density (g/cc)</u>	<u>% TMD</u>	<u>Dielectric Constant</u>	<u>Temp (F)</u>	<u>Relative Humidity (%)</u>
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

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APPENDIX A

AUTOMATED DIELECTRIC CONSTANT MEASUREMENT PROGRAM

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10  ! THIS PROGRAM IS STORED AS "AUTO-E"
20  !   ON THE TAPE LABELED  "BG 05"
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-Control 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),Samples(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$(12)  ! FORM FEED TO CLEAR THE CRT SCREEN
540 ! Count=1
550 ! IF Count=1 THEN GOTO 740
560 ! INPUT "Is the sample in place on the set-up? (Y or N) CAPS",Samps
570 ! IF Samps="Y" THEN GOTO 630
580 ! BEEP  ! BELL
590 ! PRINTER IS 16
600 ! PRINT "PUT SAMPLE IN PLACE. NOW!"
610 ! PRINTER IS 0
620 ! GOTO 550
630 ! BEEP  ! BELL
640 ! PRINTER IS 16
650 ! PRINT CHR$(12) ! FORM FEED TO CLEAR THE CRT SCREEN
660 ! PRINTER IS 0

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```

670 INPUT "SAMPLE DESIGNATION (less than 80 characters)", Sample
680 PRINT
690 PRINT Sample
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 Lambda=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 Lambda0=2*Pi ! THE CUTOFF FREQ. FOR RECTANGULAR WAVEGUIDE (TE10 MODE)
900 Lambda0=Lambda0/(1-(Lambda0/Lambda0)^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,Slashes,Day,Slashes,Year
970 IMAGE "Time: ",ZZ,A,ZZ,A,ZZ," At start of test"
980 PRINT USING 970;Hour,Cols,Minute,Cols,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;Lambda0
1060 PRINT
1070 Step=INT(Lambda0/36+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 Pms="+" ! 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 Pms="+"
1220 Dstep1=1
1230 Dstep2=.5
1240 Dstep3=.1
1250 Dbless=10
1260 Step=INT(Lambda0/360+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)

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```

1330 GOSUB 3600      ! 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(Landag/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(Landag/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=1          ! 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

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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 Sur=(1.9952623-COS(PI*Dza/Lamdag)^2)^.5/SIN(PI*Dza/Lamdag)
2190 Arg=(1.9952623-(Sur^2-1))^2)^.5
2200 Dza=Lamdag*ASN(Arg)/PI
2210 R=(Za-Le-St)/Za
2220 Ppr=PI*(Dzs-R*Dza)/Lamdag
2230 Sur=(1.9952623-COS(Ppr)^2)^.5/SIN(Ppr)
2240 Phi=1/Sur
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 D1=((U0-Ua)^2+(V0-Va)^2)^.5
2630 IF D1<.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=(Landa0/Landac)^2
2930 Ss=(Landa0/(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 Tadu=D+a*(1-P)/Za
2990 Cg=A1/(2*B1)
3000 Taus=Tadu*((Cg+P/Dc(X))/(Cg+P))
3010 Tad(X)=Ta-Taus
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

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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$(13) ! SET-UP NEW END OF LINE STRING
3620 OUTPUT 7,7 USING "#,K,L";"R 253" !
3630 OUTPUT 7,7 USING "#,K,L";"S 2" ! R,S,F SET MOVE SPEED OF PROBE
3640 OUTPUT 7,7 USING "#,K,L";"F 20" !
3650 OUTPUT 7,7 USING "#,K,L";Nsteps ! MOVE THIS NUMBER OF STEPS
3660 OUTPUT 7,7 USING "#,K,L";Pms ! DIRECTION OF MOVE
3670 OUTPUT 7,7 USING "#,K,L";"G" ! GO...EXECUTE MOVE
3680 LOCAL 7,7
3690 RETURN
3700 ! THIS SUBROUTINE DEFINES THE STEP SIZE MOVE COMMAND FOR THE KLINGER
3710 N$=VAL$(Step)
3720 Q$="N "
3730 Nsteps=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$(13)
3880 OUTPUT 7,7 USING "#,K,L";"V 0" ! OUTPUT POSITION FROM KLINGER
3890 ENTER 7,29;Pos ! READ POSITION
3900 RETURN
3910 ! THIS SUBROUTINE HELPS US PRINT OUT THE DATE & TIME IN GOOD FORM
3920 Slash$="/"
3930 Col$=":"
3940 RETURN
3950 ! THIS IS A SUBROUTINE FOR THE DIELECTRIC CONSTANT PART OF THE PROGRAM
3960 S=X6*2

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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 Pns="--"
4390 GOSUB 3600 ! MOVE PROBE BACK TO LOCATION OF MINIMUM ESTIMATE
4400 Dbm=Dbm(L)
4410 ! PRINT
4420 RETURN

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NSWC TR 86-46

APPENDIX B

DIELECTRIC CONSTANT CALCULATION PROGRAM

```

10  !   JULY, 1983                R. WATKINS
11  !
12  !   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),Sample$(60)
140 GOSUB 1640
150 INPUT "SAMPLE DESIGNATION",Sample$
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*..1
260 Lang=Lamo/(1-(Lamo/Lamc)^2)^.5
270 IF Lza<>0 THEN 300
280 Lza=Lang/2
290 Rza=Lang/2
300 Sc=1+(W+Lang)^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*(Lang/2)-(Za+Lang/2))<Lang/4 THEN 370
360 GOTO 340
370 Za=Q*(Lang/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 Sur=(Po-COS(PI*Dza/Lang)^2)^.5/SIN(PI*Dza/Lang)
460 Arg=.2302585*Sd
470 Po=EXP(Arg)
480 IF Dza=0 THEN 520
490 Arg=((Po-1)/(Sur^2-1))^.5
500 Dza=Lang*ASN(Arg)/PI
510 R=(Za-Le-St)/Za
520 Ppr=PI*(Dzs-R*Dza)/Lang
530 Sur=(Po-COS(Ppr)^2)^.5/SIN(Ppr)
540 Phi=1/Sur
550 N=0
560 IF -(Le+St)+.5*Lang+N>0 THEN 590
570 N=N+1
580 GOTO 560
590 Z0=-(St+Le)+.5*Lang+N
600 U=2*PI+Z0/Lang
610 A=TAN(U)*(Phi^2-1)
620 B=Phi*(1+TAN(U)^2)
630 C=(A^2+B^2)^.5*(Lang^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 1150
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 Tadu=Dza+(1-P)*Ca
1290 Cg=A1/(2*B1)
1300 Taus=Tadu+((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)",Ys
1370 IF Ys="P" THEN PRINTER IS 0
1380 PRINT
1390 PRINT "SAMPLE DESIGNATION: ";Sample
1400 PRINT
1410 PRINT "FREQUENCY IN GIGAHERTZ: ";F
1420 PRINT
1430 PRINT "SAMPLE LENGTH IN MILLIMETERS: ";Ls
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)",Ys
1540 IF Ys="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.
1722 !           dimensions, go to 2.
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

```

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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

1.000
4.950
12.843

LOSS FACTOR

2.06E-04
-5.67E-03
-1.70E-02

LOSS TANGENT

2.06E-04
-1.15E-03
-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

1.507
9.012
24.02

LOSS FACTOR

2.11E-03
-8.32E-03
-2.89E-02

LOSS TANGENT

1.40E-03
-9.23E-04
-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

2.971
9.856
20.942

LOSS FACTOR

2.97E-02
8.44E-02
1.27E-01

LOSS TANGENT

1.00E-02
8.57E-03
6.05E-03

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

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