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Measurement of the Properties of Lossy Materials Inside a Finite Conducting Cylinder

by

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(NASA-CR-182560) MEASUREMENT OF THE PROPERTIES OF LOSSY MATERIALS INSIDE A FINITE CONDUCTING CYLINDER Final Report (Ohio State Univ.) 30 p CSCL 20N

N89-10223

Unclas
G3/32 0168980

Final Report No. 719300-4
Grant No. NAG3-784
October 1988

National Aeronautics and Space Administration
Lewis Research Center
21000 Brookpark Rd.
Cleveland, OH 44135

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Chapter 1

Introduction

A novel approach to the observation of temperature effects of material was developed for NASA Lewis Research Center. Their need was to characterize the electromagnetic behavior of material coatings in an existing high temperature fixture. The characterization would ideally include the determination of the electromagnetic constitutive parameters, ε and μ. This aspect would involve the accurate measurement of both reflection and transmission properties of the material. It was decided not to attempt this goal with this fixture at this time. Other fixtures were investigated to obtain wide band constitutive parameters [1,2]. The main goal for the present fixture was to characterize the electromagnetic behavior of coated samples at elevated temperatures by a relative reflection coefficient.

Chapter 2

Measurement Fixture

The existing test rig at NASA Lewis Research Center was designed to monitor the mechanical and chemical behavior of material coatings in the presence of jet exhaust gases up to 1800° F. A section of the test rig was replaced with one that had a wide band AEL 2-18 GHz horn [3] oriented normal to the sample plate. Figure 2.1 conceptually illustrates the fixture built by Tanksley Engineering [4]. The fixture could accommodate both reflection and transmission measurements, however, only the means to obtain reflection measurements were actually incorporated.

The anticipated performance for reflection measurements was shown in [5]. Other measurements were performed to demonstrate the feasibility of transmissions measurements. Figures 2.2 and 2.3 demonstrate the coupling of a surface wave between two coaxial probes mounted through a surface. The probe consisted of a semi-rigid cable press fitted through a hole in the sample plate with its inner conductor extending approximately .1 inch above the conducting surface of the sample plate. As anticipated, the coupling increased as the probe separation distance decreased and the presence of lossy material decreased the coupled field. High temperature cable to withstand the operating conditions can be produced by Whittaker Corporation [6].

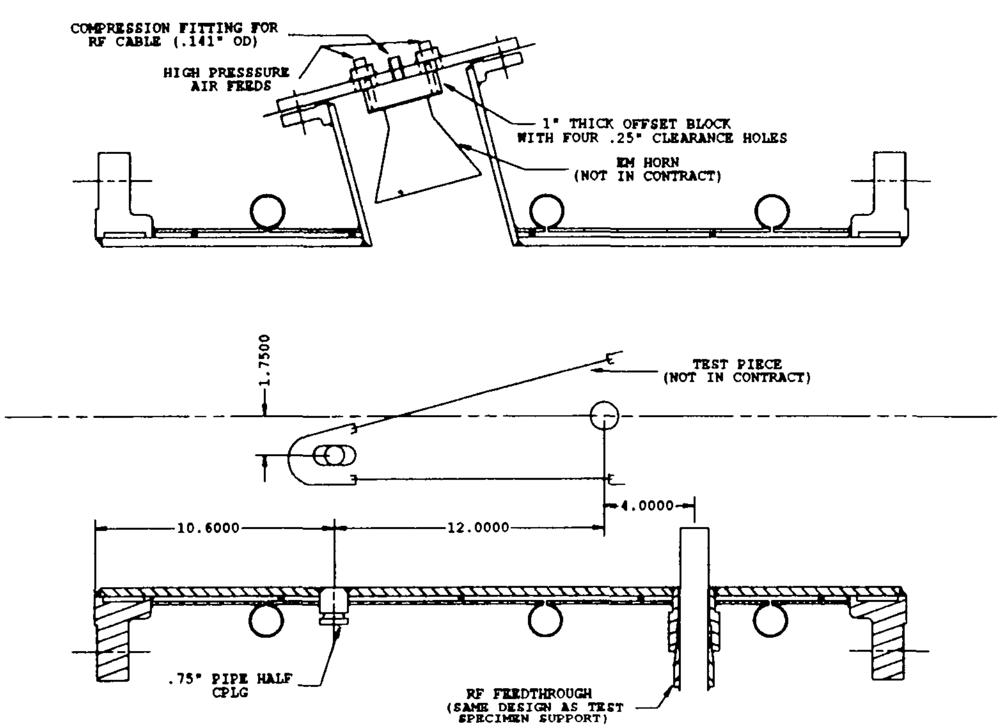

Figure 2.1: Illustration of test fixture for reflection and transmission measurements.

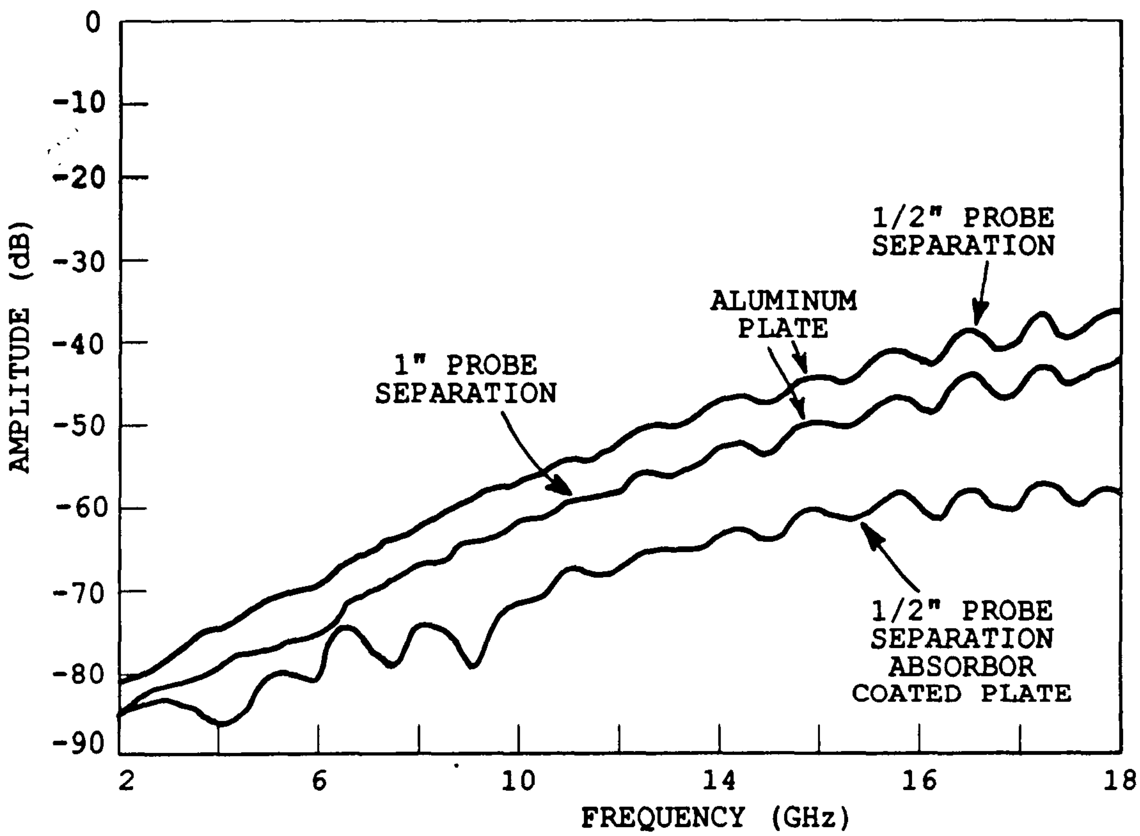

Figure 2.2: Measured frequency response for probe coupling via a surface wave mechanism.

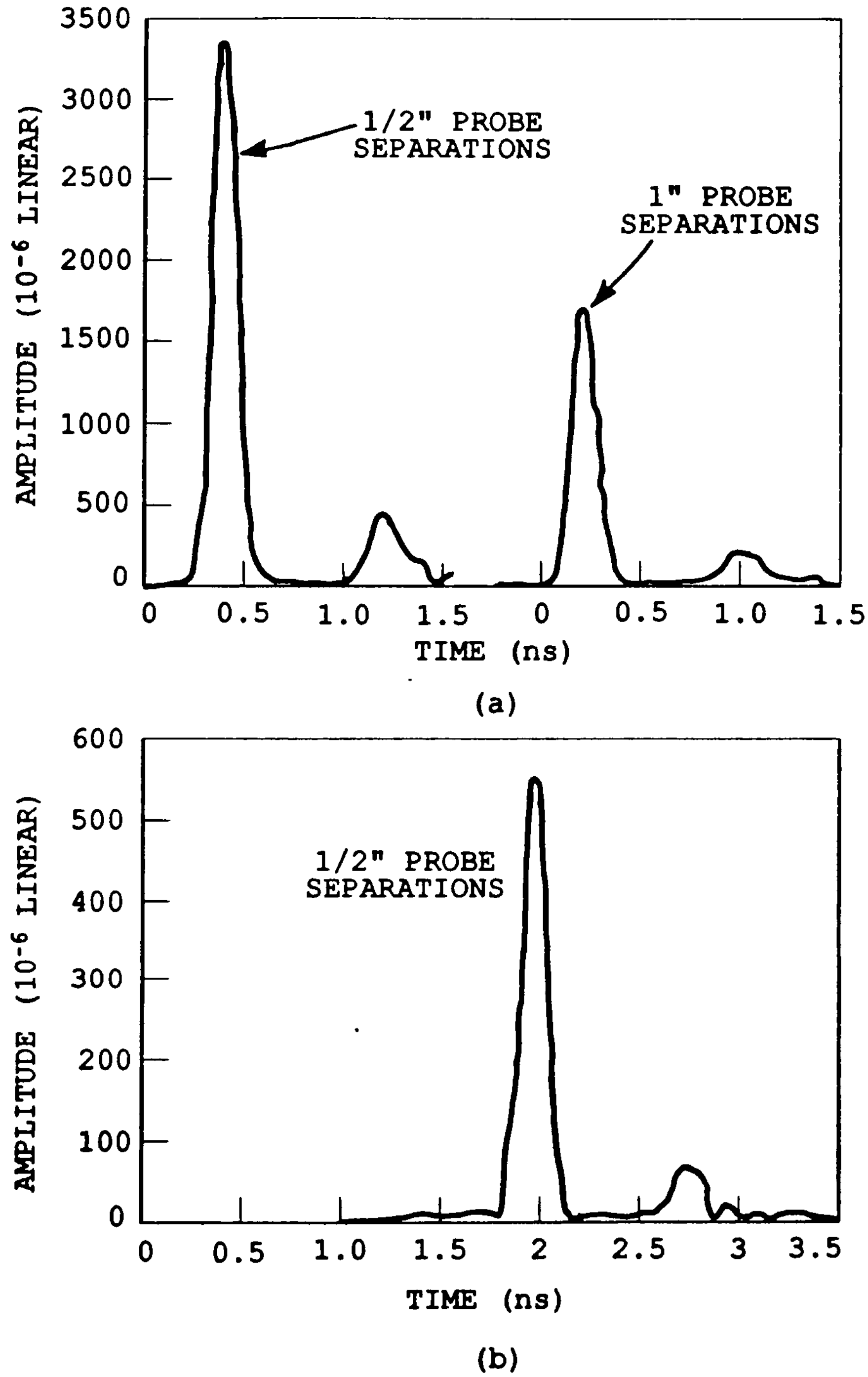

Figure 2.3: Time domain representation of measured frequency response for probe coupling via a surface mechanism.

Chapter 3

Measurement Technique

The performance of the material can be monitored by measuring the reflected field. The instrumentation chosen to perform these measurements was the HP 8510B Network Analyzer. This instrument can perform measurements between 2 and 18 GHz and process data to eliminate the effects of undesired reflections that occur at different time periods from the desired time period. The network analyzer is controlled with a HP 300 Series computer. The program description is given in the next chapter and is capable of performing the necessary tasks.

The reflected field measurements from the various samples require a minimal amount of processing. It is assumed that the samples will be positioned at the same place in the fixture and be of the same surface dimensions. All measurements should be made with the HP 8510B software time gate on with the window set at the appropriate time to receive the desired signal and narrow enough to remove most of the other undesired signals without perturbing the desired signal significantly. The measured reflected field spectrum ideally should be calibrated as follows:

$$\mathrm{CSD} = \left(\frac{\mathrm{MSD} - \mathrm{MBD}}{\mathrm{MRD} - \mathrm{MBD}}\right) \mathrm{CRD} \tag{3.1}$$

where CSD is calibrated sample data, MSD is measured sample data, MBD is measured background data, MRD measured reference data and CRD is calculated (exact) reference data. The subtraction process in the above equation minimizes the influence of other scattering centers that are not sample dependent. The system response is normalized from the measurement through the scaling of the sample response with the measured and calculated response for the reference. The background data is simply a measurement with no sample present in the sample holder. The reference data is a measurement of a metal plate of the same surface dimensions in the sample holder. A value of -1 can be used for the exact reference data when a conducting metal plate is used for the reference.

The validity of this calibration equation is dependent upon the physical stability of the fixture during a testing period. The background and reference measurements have to be performed before the start of the test. They could also be performed after the test to test the stability of the fixture. If the stability of the fixture is not sufficient for reliable background subtraction, only relative reflection measurements can be obtained. It is known that the performance of background subtraction is very essential in this fixture to obtain the most reliable measurement possible. Subtraction of sequential measurements at different temperatures during a continuous test may be useful to observe changes in the performance of the material.

The material performance can be referenced by the normalized reflected field either in the frequency or time domain as a function of temperature. The performance is most accurately portrayed in the frequency domain since the response at each frequency is given. This information can be reduced to a single number if the magnitude of the peak return in the time domain is used. The value of the peak return is somewhat an average of the frequency domain data.

Chapter 4

Measurement Program Description

The program is designed to be interactive, command-oriented and flexible. The network analyzer is operated and the data processed and stored by a series of individual commands. However, when particular measurement sequences are to be repeated a number of times the commands may be entered in command procedure files. The file name may then be entered as a single command rather than entering each individual command separately.

Many errors of syntax are trapped by the program and appropriate error messages issued. However, the commands are designed to be entered in any desired sequence and it is up to the user to ensure that the results of that sequence are meaningful.

I INSTRUMENT CONNECTIONS

The program assumes that an 8511A frequency converter will be used to connect the measuring system to the network analyzer. It further assumes that input a1 on the frequency converter will be used to sample the source signal, b1 the reflected signal, b2 a transmitted signal (referred to as transmission mode 1 in the program), and a2 a second transmitted signal (referred to as transmission mode 2).

II PROGRAM STARTUP

The program and operating system are stored on the same floppy disc, labeled 8510 NETWORK ANALYZER CONTROL PROGRAM. The program file has been given the name AUTOST. This name is looked for automatically at boot up and if found will be run. Thus when the system is booted from this disc it will respond with the program prompt <>. A list of the available commands with brief descriptions may then be displayed by typing a question mark followed by a carriage return (CR). This may be done any time the command prompt is displayed. The commands are described below. If the user requires further information about the individual commands one should refer to the program listing.

III COMMAND INPUT

The commands consist of two or three characters. For immediate execution the command is followed by a carriage return. Some commands require additional input, e.g. the SF (set frequency) command requires a start and stop frequency. These will be prompted for. A user familiar with the program may enter the frequencies (in GHz) after the command and before the (CR) separated by commas. Thus: <>SF,8,18(CR) would set the 8510 sweep to between 8 and 18 GHz. Additional commands may also be entered on the same line. <>SF,8,18,SP,201(CR) would set the number of points in the sweep to 201 in addition to setting the frequency limits.

The user may also perform some functions from the 8510 program keys by pressing the LOCAL key first to get control of the instrument. However, one should realize that the program will be unaware of the changes made.

For example, changing the start or stop frequency from the 8510 keys rather than via the program will result in incorrect frequencies being stored in any data files written.

IV SPECIAL COMMANDS

There are four special commands designed to increase the flexibility of the program.

Since the 8510 vocabulary is very extensive it is not practical to incorporate all possibilities into the program directly. Therefore, if the user wishes to send some special sequence of 8510 commands, one starts the program command with a percent sign (%). Everything following the sign will be passed through directly to the 8510. It should therefore conform to the 8510 command syntax; multiple commands are separated by semicolons. The final semicolon is optional; it will be supplied by the program if absent. Quotation marks are not used around the 8510 command string. An example is <>%CHAN1;GATEOFF(CR) which would select channel 1 and then turn off the time gate on that channel. A direct 8510 command may follow other program commands on the same line, separated from them by a comma. However, once the percent sign is found it is assumed that the entire remainder of the line is a direct 8510 command.

Another special form of command is that used to execute a command procedure file. (The format of these files is described below.) These commands begin with a pound sign #. Thus #MYFILE(CR) would execute the procedure file named MYFILE. A procedure file command may also follow other program commands separated from them by a comma. However, like the direct 8510 commands, it must be the last (or only) thing on the command input line.

A special command used with command procedure files is the END command. It is normally the last command in the file and serves to close the file and return input to the keyboard. It may also be used from the keyboard, in response to the command prompt when in a PAUSE (see below), to close a file before it is completed.

The final special command is PAUSE. It may only be used in a command file and must be on a line by itself. It is used when some input is required from the keyboard while executing a procedure file. PAUSE is inserted at the point in the file where some input is to be supplied by the user. The user will be prompted for one input item and execution of the file will then resume. If multiple inputs are required from the user a separate PAUSE must be placed in the file for each one, even though they are consecutive. The PAUSE may also be used in conjunction with the MS (message) and CO (continue) commands to request the user to perform some action, such as inserting a test sample, before execution of the file resumes. Examples of this appear in the demonstration command procedure files (REFUNCAL, REFCAL and MEASURE) included on the program disc.

V COMMAND PROCEDURE FILES

These must be in ASCII format, that is they are written to the disc using the Basic SAVE or RE-SAVE commands and retrieved (for further editing) with the GET command. Files are created using the Basic editor. Because the editor checks all lines for correct Basic syntax immediately on entry, it is necessary to lull its suspicions by making all lines comments. Thus each line begins with the Basic comment symbol (an exclamation point) following the line number. The program command is entered immediately after the exclamation point exactly as it would be if given from the keyboard. The file may be commented if desired. A comment is added to a line by entering a second exclamation point followed by the comment. This second exclamation point and what follows it is stripped off by the program when the line is read. PAUSE may be used in the file to solicit input from the keyboard. The last command in the file must be the END command. An alternative to this is for the last line to be a command to execute another procedure file. Examples of procedure files may be found on the program disc under the names REFUNCAL, REFCAL and MEASURE. Listings of these files may be found at the back of this manual.

VI ERROR TRAPPING

Many errors are trapped by the program such as invalid commands, numerical input which is out of range or non-existent file names. When an error is detected processing of the command line stops and a command procedure file is closed if one is being used. An appropriate error message is then printed and the program will expect the next input from the keyboard. It is not practical to trap all errors in the program. If an error is detected by the operating system it will print a message and the program will pause. If the user then presses the STOP key followed by the RUN key it is usually possible to resume execution with the data in the program intact. Typing SCRATCH C before RUN will reset all program variables to their intial state (any data stored in the program will be lost). SCRATCH (without the C) deletes the program from memory. It must then be reloaded from the disc.

VII BUILT-IN PROGRAM COMMANDS

These are of several types. They include commands to perform the more common network analyzer operations, to perform various processing operations on data read from the network analyzer and, to plot and store on disc files the raw or processed data.

General Commands

CL Clear the network analyzer HPIB interface and go to LOCAL. This will normally clear most I/O hangups between the computer and the network analyzer caused by command syntax and similar errors.

UV Generate a unit vector in the main data array. This command is intended for program testing purposes. It fills the complex array with data of unit magnitude and with a phase angle rotating through 360 degrees over the number of points to which the array size is currently set. The array size is 51 points at program start up.

CS Catalog system disc files. This performs a system CATalog command for the left disc drive. The program assumes that the program disc with any procedure files is in the left drive and that any data files will be written or read on the right drive.

CD Catalog the data files. i.e. the files on the right disc drive.

EX Exit from the program back to the BASIC operating system.

Network Analyzer Set Up Commands

PR Perform an 8510 preset command. This restores the network analyzer back to the power up condition.

SF Set the start and stop frequencies on the 8510. This command will request the two frequencies in GHz. These may be supplied from the keyboard or a command procedure file.

SP Set the number of points in the sweep. The number will be requested by the program. It must be 51, 101, 201, 401 or 801.

SG Set time gate. This command sets channel 2 to the time domain with the time gate off. Channel 1 is set to the frequency domain with the time gate on. The program will request four times (in nanoseconds): the start and stop times for the time domain display and the start and stop times for the actual gate window.

SR Set reflection mode for both network analyzer channels. Both channels are set to display the reflected signal, S11 or b1/a1. If the reflection mode was previously calibrated using either the CRO or CRS commands the calibration set is also recalled in the 8510.

ST1 Both channels are set to display transmission mode 1, i.e. S21 or b2/a1. If transmission mode 1 was previously calibrated using the CT1 command the calibration set will be recalled in the 8510.

ST2 Both channels are set to display a2/a1. If transmission mode 2 was previously calibrated using the CT2 command the calibration set will be recalled in the 8510.

Calibration Commands

CRO Calibrate channel 1 in the reflection mode using an open circuit. This command performs a calibration using the current signal response assuming the termination to be an open circuit. This is the simplest 8510 calibration procedure, requiring no connection changes during the calibration sequence. Any connection changes must be made before the program command is given. With a set up employing an antenna looking at a test sample, this might be done by disconnecting the cable at the antenna terminals.

CRS Calibrate channel 1 in the reflection mode using a short circuit. In the above example a similar procedure might be followed by connecting a short to the disconnected antenna cable.

CT1 Calibrate channel 1 in direct transmission mode 1. This calibrates the transmission path to input b2 using the current signal response. The source and receive cable must be disconnected as close to the test region as possible and connected directly to each other before the command is given.

CT2 Calibrate channel 2 in direct transmission mode 2. This calibrates the transmission path to input a2 using the current signal response. The procedure is similar to the CT1 command.

Data Processing Commands

R8 Read a channel from the 8510. The program will request the channel number and the number of points currently set in the 8510 will be read into the main data array in the program. The number of points read will be displayed and this number will replace the number presently stored in the program as the size of the main array. This is an array of complex numbers and all processing operations are performed on it.

W8 Writes the main array stored in the program back to an 8510 channel. The program will request a channel number. The only function of this command is to display data on the 8510 screen. It cannot be processed in the 8510 as scanning must be stopped to prevent the data from immediately being written over by new data.

SV Save the main program array in one of six temporary storage arrays within the program. The temporary array number will be requested. Data parameters (see PP command) are also saved.

RC Recall one of the six temporary storage arrays to the main array. The temporary array number will be requested. The data parameters are also recalled.

ML Multiply the main array by one of the six temporary storage arrays. The number of the temporary array will be requested. Afterwards the main array will contain the complex product, element by element, of its original contents and the contents of the storage array. The contents of the storage array will be unchanged. The program checks to see that the arrays are of the same size and contain compatible data types before performing the operation.

DV Similar to the ML command but the contents of the main array is divided by that of one of the six temporary storage arrays.

AD Similar to the ML command but the contents of one of the six temporary storage arrays is added to the main array.

SB Similar to the ML command but the contents of one of the six temporary storage arrays is subtracted from the main array.

IF Perform an inverse Fourier transform on the data in the main array. Frequency domain data is converted to time domain. This is a relatively slow algorithm since a compiled fast Fourier transform compatible with Version 5 of Basic was not available. In order to save time only the time window of interest and enough points to give the desired resolution need be used. The program will request the start and stop time of the transform time window and the number of points required in the output. A counter on the screen indicates the progress of the transformation.

TH Thin the main array; even numbered elements are discarded. This is intended as an aid to speeding up the the IF command. A large frequency domain array may be read from the 8510 and stored in a file. The array may then be thinned and transformed to get a quick look at the time domain without losing the original full data set. The command may be used repeatedly down to a limit of 51 points.

FM Calculate a figure of merit for the data in the main array. In the frequency domain this is the mean square of the magnitudes of the data points. In the time domain it is an equivalent quantity. It is intended to indicate a measure of the performance of an absorber panel in the following situation. Two arrays are recorded, one with an antenna looking at a metal plate and one with the same antenna looking at an absorber panel. The arrays are saved and that from the metal plate is divided by that from the absorber. The FM command may then be used on the quotient array to provide a measure of the absorber performance over a band of frequencies.

Input-Output Commands

WF Write a data file to the right hand disc drive. This is a binary file to speed writing and reading and to save disc space. The contents of the main array is written to the file together with the data parameters (see PP command) and a plain language description. The program will request three lines of description. Each line should be terminated with (CR) or short lines may be typed together separated by commas. Note that a comma is a delimiter and may not be used as part of the description text.

RF Read a data file from the right disc drive. This must be a file previously written by the WF command. The data will be read into the main array and the data parameters in the program will be replaced by those read from the file.

PD Print the current file description on the CRT terminal. This will be the three description lines from the most recently read or written file.

PP Print parameters. The current data parameters are displayed on the CRT terminal. These include the number of points in the array, the data type (frequency or time domain or time domain generated by the IF command), start and stop frequencies, start and stop times for the time domain display and gate, and window times used by the IF command if applicable.

PL Plot the main array on the CRT terminal. The user may choose to plot the real or imaginary part of the data or the magnitude or phase. Except for the phase a choice of linear or dB scales may be made. The user may also select the upper and lower scale limits. The plot is shown in the same format as that used on the screen of the 8510. If the appropriate scale limits are chosen the plots will look identical.

DP Dump the plot on the CRT terminal screen to the printer. In the case of a terminal which does not have separate graphics and alphanumeric storage this command prints the entire contents of the screen.

Program Control Commands

MS This command is used in a procedure file to send a message to the operator. The message should follow the command separated from it by a comma. It might for example request the operator to make some change in the hardware set up. It would then be followed by a PAUSE command in the file so that the program would wait for the action to be performed.

CO Continue with a procedure file. This is actually a dummy command. It performs no function except that it may be given from the keyboard to terminate a PAUSE (for example after a message to the operator) when no numerical or other data input is required.

VIII THE SUBROUTINES

A number of subroutines are used within the program. Their functions and calling parameters are described in the following paragraphs.

Comd(String$)

This is the command processing routine. String$ is a command mnemonic. When a command is entered from the keyboard or read from a command procedure file, the program is searched for a Comd call with a matching mnemonic. If one is found execution resumes at that point in the program. If no match is found an error message is issued and a new command requested. Only as many characters as appear in String$ will be tested. Extra characters in the command input in excess of the number in String$ or in excess of eight, whichever is less, are ignored. Thus if String$ is the characters ABC any of the following command inputs will be considered a match: ABC ABCD abc AbCd, etc. To restrict the match to only ABC (upper or lower case characters) String$ should be terminated with a period mark thus ABC. – the period is not typed in the command input. String$ may also contain a comment. This is indicated by placing an exclamation point (!) immediately after the command mnemonic. Anything after the ! is considered a comment. It is ignored in command matching but will be shown when a list of available commands is requested by typing a question mark (?) in response to the command prompt (<>).

Every call to Comd must be followed on the next line by the statement:
IF Hunt THEN Label
where Label is a label pointing to the next Comd call or the first such call if this IF statement follows the last Comd call. Calls must be linked in a closed loop. There may be more than one loop in a program module, which may be the main program or a subroutine. Command searches will only be

conducted within the loop including the call which generated the prompt.

The Comd routine uses variables stored in the common block /Comdh/. This block must appear in the main program and any subroutine which calls Comd. Two variables in this block are worth noting. Hunt is a flag which is set when Comd is searching for a command. When Hunt is not set then a call to Comd issues the command prompt. Cbuf$ is a buffer in which the command input is stored. An input line may contain additional input beyond a single command, the items being separated by commas. Unused items are stored in Cbuf$ for future use. The buffer is shared with the Rqrel and Rqchr routines so input to these may be intermixed with commands on a single input line.

<u>Rqrel(Prompt$,Rel)</u>

Rqrel is used to request input of a real number. This routine shares the input buffer Cbuf$ with the Comd routine. If data is available in the buffer it is read from there. Otherwise the prompt message contained in the character variable Prompt$ is issued and the routine waits for input from the keyboard or reads an input line from a command procedure file. The routine recognizes the special command PAUSE if read from a file. In this case the prompt message is issued and the program waits for keyboard input. Since this routine shares the command input buffer with Comd$ the common block /Comdh/ must appear in any routine which calls Rqrel. The real variable read is returned in Rel.

<u>Rqchr(Prompt$,String$)</u>

This routine is the same as Rqrel in all respects except that it reads a character variable into String$ rather than a real variable into Rel.

<u>Trim(Temp$)</u>

This routine is used to remove the line number, the initial ! and any comment from a line read from an ASCII command procedure file. The command input line is in Temp$

Getitem(Nc)

This routine extracts one item from Cbuf$, up to the next comma or the end of the line, and returns it in the character variable Item$ which is in the common block /Chrara/. If Cbuf$ begins with % or # then the entire contents of Cbuf$ is returned. Nc is the number of characters returned in Item$.

Enter_data(@N,INTEGER N,COMPLEX Z(*))

Reads a complex data array from the 8510 into the computer using the computer's internal floating point format. Z is the complex data array. N is the number of points read. This is returned to the calling program and overrides any previous point count. @N is the I/O path to the network analyzer.

Load_data(_@N,INTEGER N,COMPLEX Z(_*))

Reverses the process of Enter_data. N points from the array Z are transferred back to the 8510. The 8510 is put into a HOLD state, otherwise the data will immediately be written over by a new scan.

Wfile

Writes a data file to the right-hand disc drive. The file includes the main data array Z, which is stored in the common block /Cmpara/, a three-line description, which is entered from the keyboard, the size of the array, a data type code (indicating whether the data is frequency domain, time domain, time domain generated with the IF command, or undefined), the start and stop frequencies, the start and stop times for the time domain display, the start and stop times for the time domain gate, and the start and stop times for the time window used by the IF command if applicable. The file is binary to minimize the amount of disc space used and to make the access time as fast as possible.

Wfile

Reads a data file written with Wfile. The parameters read replace any previously stored in the program.

Crtplot

This routine implements the PL command. See PL for further information. The type of plot and scale limits are requested.

Sintab

Generates a sine table for use by the IF command. It is called only at program startup. Sines are calculated at intervals of 1/800th of a full circle. Values are generated for five quadrants so that the table may also be used for cosines by offsetting the index by 200. The table is stored in the array S in the common block /Stable/.

Sumzq(INTEGER Nsize,REAL Sm)

Calculates the sum of the squares of the magnitudes of the first Nsize points in the main complex array Z (stored in the common block /Cmpara/). The result is returned in Sm.

Pkparms

Packs the parameters described under the PP command into a single real array Parms (stored in the common block /Arrays/) for use by the WF (write file) and SV (Save) commands.

Upkparms

Reverses the process of the Pkparms routine. The parameters unpacked replace those previously stored in the program.

Clrbuf

Clears the command input buffer Cbuf (stored in the common block /Comdh/) and closes the command input file if one is open. This routine is called after an error is detected to prevent the program from trying to execute additional commands in improper sequence.

Bells

This routine rings the bell on the terminal three times to get the operator's attention. It is used after an error is detected or in response to the PAUSE or END commands.

IX SAMPLE COMMAND PROCEDURE FILES

The following three files are intended to set up the network analyzer and make reflection measurements on absorber samples placed on a ground plane viewed by an antenna. Either of the files REFUNCAL or REFCAL may be used to initialize the 8510 and to measure the first absorber sample. The file MEASURE may then be used repeatedly to measure additional samples. REFUNCAL does not use any of the 8510's internal calibration procedures. It simply measures the reflection from the uncovered ground-plane and uses this as a reference. The zero time reference point is at the 8510 terminals. The gate times in the file are therefore dependent on cable length and must be adjusted if the cable length is changed so that the time gate covers the sample region and excludes other reflections, such as the antenna. REFCAL goes a step further. It uses an open circuit at the end of the cable leading to the antenna as the reference. The gate times in the file are therefore independent of cable length. They are, however, still dependent on the spacing between the antenna and the test region and must be adjusted if that is changed.

File REFUNCAL

```
10    !PR! Preset 8510
20    !SF,8,18! Set start and stop frequencies (GHz)
30    !SP,801! Set the number of points in the 8510
40    !SR! Set both channels to reflection mode
50    !SG,15,20,17.5,18.8! Time domain display start, stop, gate
                                                  start and stop
60    !CHAN1;REFP10! Adjust the frequency display reference point
70    !%CHAN2;SCAL.02;GATEON! Adjust time display scale and gate
                                                              it
80    !MS,Uncover metal plate and type COntinue! Operator request
90    !PAUSE! Wait for operator response
100   !R8,1! Read the gated frequency domain data
110   !SV,1! Save it
120   !MS,Reference measurement completed. Will now run sample
                                                    measurement.
130   !#MEASURE! File to run sample measurement
```

File REFCAL

```
10    !PR! Preset 8510
20    !SF,8,18! Set start and stop frequencies (GHz)
30    !SP,801! Set the number of points in the 8510
40    !SR! Set both channels to reflection mode
50    !MS,Disconnect antenna cable at antenna. Leave it open.
```

```
                                                    Type COntinue.
60     !PAUSE! Wait for operator response
70     !CRO! Do an open circuit reflected response calibration
80     !SG,0,10,5.8,6.8! Time domain display start, stop, gate
                                                    start and stop
90     !CHAN1;REFP10! Adjust the frequency display reference point
100    !%CHAN2;SCAL.02;GATEON! Adjust time display scale and gate
                                                                it
110    !MS,Reconnect cable! Operator request
120    !MS,Uncover metal plate and type COntinue! Operator request
130    !PAUSE! Wait for operator response
140    !R8,1! Read the gated frequency domain data
150    !SV,1! Save it
160    !MS,Reference measurement completed. Will now run sample
                                                      measurement.
170    !#MEASURE! File to run sample measurement
```

File MEASURE

```
10     !Place absorber sample on metal plate. Type COntinue.
20     !PAUSE! Wait for operator response
30     !R8,1! Read frequency spectrum
40     !SV,2! Save it
50     !RC,1! Recall the reference spectrum
60     !DV,2! Divide by the absorber spectrum
70     !FM! Calculate the figure of merit
80     !MS,=Total power reflected from metal/total power from
                                                         absorber.
90     !MS,To measure another sample type #MEASURE
100    !END! Close command input file
```

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50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No

4. Title and Subtitle MEASUREMENT OF THE PROPERTIES OF LOSSY MATERIALS INSIDE A FINITE CONDUCTING CYLINDER	5. Report Date October 1988
	6.
7. Author(s) R. Caldecott, A. Dominek and A. Park	8. Performing Organization Rept No 719300-4
9. Performing Organization Name and Address THE OHIO STATE UNIVERSITY ELECTROSCIENCE LABORATORY 1320 Kinnear Road Columbus, Ohio 43212	10. Project/Task/Work Unit No
	11. Contract(C) or Grant(G) No (C) (G) NAG3-784
12. Sponsoring Organization Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	13. Type of Report & Period Covered Final
	14

15. Supplementary Notes

16. Abstract (Limit 200 words)

A computer code was developed to automatically perform swept frequency reflection and transmission measurements using a HP5510B Network Analyzer and computer. This software is used in conjunction with a modified high temperature test rig to obtain reflection measurements from a flat material sample. The software allows data processing to eliminate measurement errors and to obtain a reflection coefficient in the frequency or time domain. A description of the program is presented.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) Unclassified	21. No of Pages 26
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI–Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4–77) (Formerly NTIS–35) Department of Commerce