

AFML-TR-74-250

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EXPLORATORY DEVELOPMENT ON DIELECTRIC CONSTANT AND LOSS  
MEASUREMENTS ON POTENTIAL ELECTROMAGNETIC WINDOW MATERIALS

AD-A955 671

by

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Final Report for the Period February 1, 1971 to June 30, 1974

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Prepared for

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Materials are listed for which dielectric constant and loss tangent data have been determined. Equipment developed under the program is discussed as are some of the computer programs used to analyze the data.		

Final Report

The work reported herein concerns research carried on under Contract F33615-71-C-1274 between February 1, 1971 and June 30, 1973. This document

MATERIALS MEASURED

(February 1, 1974 to July 1, 1974)

<u>Material</u>	<u>Source</u>	<u>Manufacturer</u>
Noryl SE-1	Alford	General Electric
Borosilicate coating	Rockwell	
Organic Foam	"	
RTV	"	
Nomex felt	"	
Honeycomb	"	
Foam	"	
Viton	G.E.	Dupont
Shale rocks	Raytheon	
Polyurethane sealant P/N 596927	"	
Kevlar reinforced polybutadiene (Firestone PM502)	Whittaker	
Astroquartz reinforced polybutadiene (3164-11) (Firestone PM 502)	"	
Polyphenylquinoxaline (PPQ 401) resin	"	
Cyanurate ester resin (XSR-10500)	"	
IRTRAN 2, 4, 5, 6, 8	Kodak	

Earlier measurements and/or data are listed in the following reports:

1. AFML-TR-72-39, April 1972 - data
2. Interim Report, July 31, 1972 - listing only
3. Annual Report, February 1, 1973 - data

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4. Interim Report, August 1, 1973 - listing only
5. Interim Report, February 1, 1974 - listing only

A technical report covering data obtained since April 1972 and an updated index to all data will be issued on the succeeding contract.

#### EQUIPMENT DEVELOPMENT

##### Low-Frequency Precision Bridge

Work has continued intermittently on the low-frequency (0.5 Hz - 1 kHz) bridge described in our Report AFML-TR-71-66 on a previous contract. The capacitance network is complete and the bridge has been used with a temporary G network for manual operation. The useful frequency range is 1/8 Hz to 10 kHz with typical laboratory samples. The capacitance voltage selector switch has double contacts connected by a 5-ohm resistor and staggered in rotation, so the transformer is never open circuited or shorted. For the G network, not yet completed, each transformer tap connects to two reed switches operated by a bar magnet which turns on a second adjacent switch before turning off the first. A total of 1000 reed switches are used and their lack of uniformity was a major problem. At present all units have been tested and are ready for assembly.

##### Sample Holders for Wide-Range Bridge

Two sample holders were added to this bridge covering the frequency range 1 Hz to 20 MHz. Both are for samples with diameters to 2 inches with thicknesses to 1/2 inch. The first allows measurement in a vacuum from -190 to +200°C. The second allows samples to be measured in equilibrium with moist air (or other atmosphere) circulated through the sample holder. Together they are useful for studying the effect of special atmosphere on the electrical properties of surfaces and intergrain boundaries in sintered materials.

##### Signal Sources

During the last 3-1/2 years the laboratory has acquired, on another contract, two signal generators with leveled outputs and with frequency stability and accuracy of 1 ppm. The instruments are listed below:

Rockland Model 5100 programmable synthesizer, .001 Hz to 2 MHz, 2 volts into 50 ohms.

Hewlett-Packard Model 8640B signal generator, 500 kHz to 512 MHz, 1 volt into 50 ohms.

During this contract period an oscillator-multiplier combination capable of simultaneously providing 1 watt at 300 MHz and 200 mW at 900 MHz was constructed.

The 8640B replaces two older sources described in Tech. Rep. 36, July 1950, pp. 35-37. These were used for our susceptance variation circuit. The 8640B also replaces General Radio Unit Oscillators and previous\* oscillator multiplier combinations for feeding our standing-wave equipment in the range 150 to 1000 MHz.

#### PROGRAMMING

##### 1. Temperature Runs on Standing-Wave Equipment

We have recently combined many correction terms used in temperature runs, especially on plastics, into the final program. A review of the measurement procedure will indicate the parameters involved.

The empty holder is calibrated for node shift and change in node width with temperature. The change in length of a coax holder is identical with node shift; for hollow waveguide a separate measurement with depth gauge is made. In the temperature range reported here the node shift of empty holder is linear; in line 31 of Program 1 in the Appendix the correction is made in sample node (with reversal of sign) instead of air node. The sample length is determined by combining the change in depth gauge readings (DDO-DD) with the known thermal change in length of the holder (line 32 of the program). For TE modes cutoff wavelength and guide wavelength vary with temperature (lines 39 and 40). The change in loss of the air-filled section of holder appears in line 43. Finally corrections are made for sample fit using separately determined values of sample diameters (lines 181-185 or 210) and for wall losses in the sample filled section which is also temperature dependent (lines 188 or 192).

##### 2. Radome Analysis for Perpendicular Incidence

The nomenclature for this analysis is given in Fig. I. Wave propagation

\* See, for example, M.S. Thesis of S. I. Kramer, Elec. Eng. Department, MIT, 1946, and early progress reports of this laboratory.

$\gamma_8$	$\gamma_7$	$\gamma_6$	$\gamma_5$	$\gamma_4$	$\gamma_3$	$\gamma_2$	$\gamma_1$
$T_8$	$T_7$	$T_6$	$T_5$	$T_4$	$T_3$	$T_2$	$T_1$
$Z_8$	$Z_7$	$Z_6$	$Z_5$	$Z_4$	$Z_3$	$Z_2$	$Z_1$
B9	B8	B7	B6	B5	B4	B3	B2
E9	E8	E7	E6	E5	E4	E3	E2
							B1

Fig. 1. Nomenclature for multiple-layer radome.

is from left to right. From the mathematics developed by Kennelly<sup>1)</sup> and reiterated by Hartig,<sup>2)</sup> the field strength at boundary 1 is defined as  $1 + j0$  and serves as the reference field. The impedance at this boundary is that of free space  $Z_0$ .

At boundary 2

$$E_2 = E_1 \sinh(\gamma_1 T_1 + \rho_{B1}) / \sinh \rho_{B1}, \quad (1)$$

where  $\rho_{B1} = \tanh^{-1}(Z_0/Z_{01})$ . In more general terms:

$$Z_{B(n+1)} = Z_n \tanh(\gamma_n T_n + \rho_{Bn}), \quad (2)$$

$$\rho_{Bn} = \tanh^{-1}(Z_{Bn}/Z_n), \quad (3)$$

and

$$E_{(n+1)} = E_n \sinh(\gamma_n T_n + \rho_{Bn}) / \sinh \rho_{Bn}. \quad (4)$$

The power level at each boundary is  $E_B^2 \times G$ , where  $G$  is the real part of the admittance  $Y = 1/ZB$ .

In the Program (2) given in the Appendix, the DO LOOP 10 computes the propagation function and intrinsic impedance for each layer from the given values of dielectric constant ( $K_l$ ) and loss (TAN). Lines 36 through 41 define initial conditions. The relation

$$\tanh(A + jB) = C + jD, \quad (5)$$

with  $C$  and  $D$  given by THRB, is solved for  $A$  and  $B$  through lines to 64. The values are further refined in the DO 400 LOOP from an initial precision of

- 
1. A. E. Kennelly, Chart Atlas of Complex Hyperbolic and Circular Functions, Harvard University Press, Cambridge, Mass. 1924, pp. 28-33.
  2. H. E. Hartig, Charts for Transmission Line Problems, Physics 1, No. 6, December 1931, pp. 380-387.

$10^{-6}$  to  $10^{-12}$ . Then with  $\rho_{Bn}$  known,  $ZB_{(n+1)}$  can be calculated (line 114), as well as voltage ratios (line 120), and power levels (line 124). This procedure is repeated for each layer (DO LOOP 13). Finally the magnitude of the impedance of the last boundary is used to calculate the standing-wave ratio and input reflection loss (lines 143-146), and an equivalent single-layer dielectric is defined (lines 148-152). It is obvious that a single-layer dielectric cannot necessarily have the same phase shift and attenuation of the composite and at the same time match in input impedance.

A few examples of a single-layer radome are given to illustrate how the equivalent dielectric differs from the real as a function of thickness.

Five-Layer Analysis

<u>Layer No.</u>	<u>Material</u>	<u>Thickness (inches)</u>
1	Boro-Silicate coating	.0209
2	Alumina foam (Reusable Surface Insulation) RSI	2.0000
3	Nomex felt with RTV coating both sides (Strain Insulation Pad), SIP	.1435
4	Reinforced polyimide sandwich with phenolic honeycomb cell (Carrier panel)	.5350
5	Moisture avoidance pad, MAP, flexible foam	.1260

Nine-Layer Analysis

1	Boro-Silicate coating	.0209
2	RSI	2.0
3	RTV	.0197
4	Nomex felt mat	.1040
5	RTV	.0197
6	Honeycomb skin, fiberglass laminate	.0260
7	Honeycomb core	.4830
8	Honeycomb skin, fiberglass laminate	.0260
9	MAP foam	.1260

### 3. Open-Circuit and Short-Circuit Measurements

In measuring a completely unknown material, it is common practice to make measurements with sample against the short and a quarter-wavelength away. We normally calculate the results of both measurements independently. The last program of the Appendix uses the value of propagation function obtained in the first measurement as the initial value in the iteration costs and data typing.

## APPENDIX

- 7 -

PROGRAM 1. SAMPLE AGAINST SHORT, TEMPERATURE RUN WITH INCORPORATED  
THERMAL CORRECTIONS

FORTRAN IV G1 RELEASE 2.0

```

0001      INTEGER*4 I,J,K,N,NX
0002      REAL*8 K3,Y,XE,AN,SN,LW,DX,DS,DA,X,A,B,A2,B2,Z14RE,Z14IM,
2BOLD,Z14IGC,Z14FC0,ERRCR1,ERCLD,ACLC,AIM,RE,TAM,Z11RE,Z11IM,HE,
9KAPPA,KAPPAC,L1,L2,L3,R,TAND,TANDC,D2,D,D3,SNC,TCL,T,T0,TC2,TC3,
3COSINE,FC,W,ZF,YL,TAHA,TANB,PII,PII2,ZRD,CNE,STEP(22)/1.5D-2,
41.2D-2,
41.D-2,7.D-3,5.D-3,2.D-3+1.D-3,5.D-4,2.D-4,1.D-4,5.D-5,2.D-5,
51.D-5,
55.D-6,2.D-6,1.D-6,1.D-7,1.D-8,1.D-1C,1.D-11,1.D-12/,NC3,
6F(2)/1.00,-1.00/,SCLD,RA,TANH,DC,CCJ,CC,TC4,TC5,WC1,WC2,TC6,LW02,
7WL2,CCA,A5,A6,C1,C2,C1C,C2C,FCC
0003      COMPLEX*16 Z1,Z2,Z3,Z5,Z10,Z11,Z12,Z13,Z14R,Z14I,Z16,
2Z14,Z12NEH,Z12PE,Z12IM,Z12SC,G,H,Z15,Z2A,ZCNE,ZCNE
0004      REAL*8 SILLY(2),FAKE(2)
0005      EQUIVALENCE (SILLY(1),Z11),(FAKE(1),Z15)
0006      DIMENSION DS(30),SN(30),C(30),D2(30),D3(30),N(30),DATE(19),
2T(30),CC(30)
0007      NAMELIST/IN/DS,SN,A,NX,C,C2,D3,T,CC/CCNST/CA,AN,FC,LW,TANH,TC1,
2TC2,TC3,TC,CCC,TC4,TC5,A5,A6,C1,C2,TC6
0008      200 FORMAT(1X,15A4)
0009      201 FORMAT(1HC,20X,15A4)
0010      220 FORMAT(1H5,5X,2HDS,7X,2HSN,6X,1HD,7X,2HD2,7X,2HD3,6X,1HN,
26X,2HDC,4X,1HTENF,CC,C..)
0011      230 FORMAT(2X,FF.4,1X,FF.4,2X,FF.4,2X,FC.4,2X,FF.5,2X,12,2X,FD.4,
22X,FF.2)
0012      100 FORMAT(1HC,5X,2HNS,6X,2HD5,4X,7HC,CCRR,4X,2HFC,6X,1HB,6X,2HK1,
29X,2HK2,6X,3HTAN,15X,7HZ11/Z14//)
0013      300 FORMAT(2X,FF.4,2X,FF.4,1X,FF.4,1X,FF.4,1Y,FF.4,1X,FF.4,3XF9.6,
23A,FS.6,3X,E13.6,2X,E13.6)
0014      77 READ(5,200,END=99) DATE
0015      WRITE(6,201) DATE
0016      READ(5,IN)
0017      READ(5,CCNST)
0018      WRITE(6,220)
0019      WRITE(6,230)(CS(I),SN(I),D(I),D2(I),D3(I),N(I),DD(I),T(I),I=1,NX)
0020      WRITE(6,CCNST)
0021      WRITE(6,100)
0022      ZONE=11.0..0.001
0023      ZCCNE=0.00,1.001
0024      PII=31416.D-4
0025      PII2=1.2E32.D-4
0026      ZFC=C.00
0027      CNE=1.00
0028      DO 10 I=1,NX
0029      IF(SN(I).EQ.AN) GO TO 10
0030      XF=-D(I)+1Y
0031      SLC=SN(I)+TC1*(T(I)-TC)*TC2*(T(I)-TC)**TC3
0032      DC=D(I)+(CCJ-CC(I))*2.54D+TC4*(T(I)-TJ)+T05*(T(I)-TC)**2
0033      A=CNE*FC
0034      LNS2=LW**2/W
0035      IF(FC.GT.0.0) GO TO 33
0036      H12=LX
0037      G7 TC 30

```

0033        33  $WC1 = 3.4125 \cdot e^{Cx} + 1.27Cj \cdot C2$   
0039         $WC2 = WC1^2 \cdot (CNE + TCC^2 \cdot (T(I) - TC))$   
0040         $WL2 = DSCRT(L \cdot KC2 - KC2^2 \cdot 2 / (KC2^2 - LW02))$   
0041        35  $K3 = \sqrt{L2 / (PI12 \cdot CC)}$   
0042         $Y = PI12 \cdot (XF - AN + SNC) / LW$   
0043         $DCA = CA = (CNE + A5 \cdot (T(I) - TJ) + A6 \cdot (T(I) - TJ))^2$   
0044         $DX = DS(I) - CCA$   
0045        IF(DX, LE, ZRC) GC TO 10  
0046        COSINE = DCOS(PI12 \* CX / LW)^2  
0047        X = DSIN(PI12 \* DX / LW) / CSQRT(Z, DJ - COSINE)  
0048        YI = CTAN(Y)  
0049        Z1 = ZCNE \* YI  
0050        Z2A = ZCNE \* X  
0051        Z2 = Z2A - Z1  
0052        Z3 = ZCNE - Z2A \* Z1  
0053        Z9 = Z2 / Z3  
0054        Z10 = ZCNE \* (-K3)  
0055        Z11RE = SILLY(1)  
0056        Z11IM = SILLY(2)  
0058        ZM = DSCRT(Z11RE^2 + Z11IM^2)  
0059        IF(N(I), EC, 1) CC TC 141  
0060        IF(N(I), GE, 2) GO TO 142  
0061        141 IF(ZM, LE, AND, Z11RE, GE, ZRC) GC TC 150  
0062        IF(ZM, LE, AND, Z11RE, LT, ZRJ) GC TC 151  
0063        IF(ZM, GT, CNE, AND, Z11RE, GE, ZRJ) GO TO 152  
0064        IF(ZM, GT, CNE, AND, Z11RE, LT, ZRJ) GO TO 153  
0065        142 IF(ZM, LE, AND, Z11RE, GE, ZRJ) GC TC 170  
0066        IF(ZM, LE, CNE, AND, Z11RE, LT, ZRJ) GC TC 171  
0067        IF(ZM, GT, CNE, AND, Z11RE, GE, ZRJ) GC TC 172  
0068        IF(ZM, GT, CNE, AND, Z11RE, LT, ZRJ) GO TO 173  
0069        150 B=CNE  
0070        A=42, C=1 \* CX / LW  
0071        GC TC 160  
0072        151 B=22, C=1  
0073        A=2, CC \* CX / LW  
0074        GC TC 160  
0075        152 B=CNE  
0076        A=6, CC \* DX / LW  
0077        GO TC 160  
0078        153 B=19, C=1  
0079        A=DX / LW  
0080        GO TC 160  
0081        170 NDC=N(I)  
0082        B=(N09 - CNE) \* PI12 + 7E54, C=4  
0083        A=4, CC \* DX / LW  
0084        GO TO 160  
0085        171 NDC=N(I)  
0086        B=N10 \* PI12 - 7E54, C=4  
0087        A=4, CC \* CX / LW  
0088        GC TC 160  
0089        172 NDC=N(I)  
0090        B=(2, CC \* N09 - 1, CC) \* 15700, D=4 - 2, C=1 / NCD

L091 A=DX/LW  
J092 GL TC 160  
L093 173 NDR=1(1)  
J094 B=(2.0C\*NDE-1.0C)\*15708.C-4+2.D-1/NDR  
C095 A=DX/LW  
J096 160 TAHA=CTANH(A)  
J097 TANB=DTAN(B)  
C098 A2=TAHA\*\*2/(CNE+TAHA\*\*2+TANB\*\*2)  
C099 B2=TANB\*\*2/(CNE+TAHA\*\*2+TANB\*\*2)  
0100 Z14RE=(A\*A2+B\*B2)/(A\*\*2+B\*\*2)  
0101 Z14IM=(A\*B2-B\*A2)/(A\*\*2+B\*\*2)  
0102 EPRDR1=CSQRT((Z14RE-Z11RE)\*\*2+(Z14IM-Z11IM)\*\*2)  
0103 DC 40 K=1,22  
J104 SCLD=STEP(K)  
0105 TAHA=CTANH(A)  
C106 DC 600 J=1,2  
0107 420 WE=CNE+STEP(K)\*F(J)  
J108 KCOUNT=0  
C109 401 KCOUNT=KCOUNT+1  
0110 IF(KCLNT.GT.10) GC TC 411  
0111 GO TO 425  
0112 411 STEP(K)=STEP(K)\*10.00  
0113 GO TO 420  
0114 425 BCLD=0  
0115 Z14ICO=Z14IV  
0116 Z14RDC=Z14FE  
0117 ERCLD=ERRCFL  
B=R\*WE  
0119 TANB=DTAN(B)  
C120 A2=TAHA\*(CNE+TAHB\*\*2)/(CNE+TAHA\*\*2+TANB\*\*2)  
B2=TANB\*(CNE-TAHA\*\*2)/(CNE+TAHA\*\*2+TANB\*\*2)  
Z14RE=(A\*A2+B\*B2)/(A\*\*2+B\*\*2)  
Z14IM=(A\*B2-B\*A2)/(A\*\*2+B\*\*2)  
EPRDR1=CSQRT((Z14RE-Z11RE)\*\*2+(Z14IM-Z11IM)\*\*2)  
0125 IF(ERRCFL.LE.ERCLD) GC TC 401  
0126 Z14IM=Z14ICO  
0127 Z14RE=Z14FCC  
0128 R=BCLD  
0129 ERRCFL=ERCLD  
0130 STEP(K)=SCLD  
0131 600 CONTINUE  
0132 TAHB=DTAN(B)  
0133 DC 700 J=1,2  
0134 421 WE=CNE+STEP(K)\*F(J)  
0135 KOLAT=0  
0136 402 KCOUNT=KCLNT+1  
0137 IF(KCOUNT.GT.10) GC TC 412  
0138 GO TO 420  
0139 412 STEP(K)=STEP(K)\*10.00  
0140 GO TC 421  
0141 420 BCLD=0  
0142 Z14FCC=Z14RE  
0143 Z14ICO=Z14IV

0144 ER01D=EF RUE1  
0145 A=A\*\*WE  
0146 TAHA=CTANH(1)  
0147 A2=TAHA\*(CNE+TANB\*\*2)/(CNE+TAHA\*\*2+TANB\*\*2)  
0148 B2=TANB\*(CNE-TAHA\*\*2)/(CNE+TAHA\*\*2+TANB\*\*2)  
0149 Z14RF=(A\*\*2+B\*\*2)/((A\*\*2+B\*\*2)\*\*2)  
0150 Z14IM=(A\*\*2-B\*\*2)/((A\*\*2+B\*\*2)\*\*2)  
0151 ERFOR1=DSQRT((Z14RE-Z11RE)\*\*2+(Z14IM-Z11IM)\*\*2)  
0152 IF(ERFOR1.LE.ERCLC) GC TC 402  
0153 Z14RE=Z14RCC  
0154 Z14IM=Z14IMC  
0155 A=AO1D  
0156 ERRCR1=ERCLC  
0157 STEP(K)=SCLD  
0158 700 CONTINUE  
0159 IF(ERPCF1.LE.1.E-6) GC TC 430  
0160 400 CONTINUE  
0161 450 Z12RF=ZCNE\*A  
0162 Z12IM=ZCNE\*B  
0163 Z12REH=(Z12RE+Z12IM)\*.52  
0164 Z13=-Z12AEW\*K3\*\*2  
0165 FCC=WL2\*\*2/WC2\*\*2  
0166 W=JNE+FCC  
0167 G=ZCNE+FCC  
0168 H=ZCNE\*B  
0169 Z15=(G+Z13)/H  
0170 Z14R=ZCNE=Z14RE  
0171 Z14I=ZCNE+Z14IM  
0172 Z14=Z14R+Z14I  
0173 Z16=Z11/Z14  
0174 RA=FAKE(1)  
0175 AIM=-FAKE(2)  
0176 C1C=C1\*(CNE+(T(1)-TC)\*TC6)  
0177 C2C=C2\*(CNE+(T(1)-TC)\*TC6)  
0178 IF(FPC.GT.3.00) GC TC 210  
0179 KAPPA=FAKE(1)  
0180 TANC=AIM/RA  
0181 L1=DLCG10(C2(1))/C1C\*DLOG10(C2C/03(1))  
0182 L2=DLCG10(C2(1))/D2(1)  
0183 L3=DLCG10(C2C/C1C)  
0184 R=CNE-L1\*KAPPA\*(CNE+TANC\*\*2)/L3  
0185 KPPAC=R\*KAPPA/((L3/L2)-2.05\*L1\*KAPPA/L2\*(CNE-R)\*L1/L2)  
0186 TANOC=TANC/R  
0187 RF=KAPPA\*C  
0188 TAN=TANOC-TANR\*(CFA/C)  
0189 AIM=RF\*TAN  
0190 GC TO 15  
0191 210 RF=RA\*(36H.0-4\*(RA\*\*2-FA)\*(C2-C3(1))/C2  
0192 15 TAN=AIM/RF-TANR\*KCAP(4.2D-1\*(RF)/(4.2D-1\*N)\*\*04)  
0193 AIM=RF\*TAN  
0194 15 KAPPA(6,34C) SAC,FX,FC,FCC,R,RF,AIM,TAN,Z16  
0195 10 CONTINUE  
0196 GC TC 77  
0197 89 CALL EXIT  
0198 END

WHITTAKER FPC-401, 8.5 GHZ, AT 74,154,238,303,402,505,158 DEG.F.

DS	SN	D	D2	D3	N	DD	TEMP.DEG.C.
0.0281	5.3289	2.5440	1.0000	0.99980	3	4.8830	23.50
0.0339	5.2951	2.5440	1.0000	1.00000	3	4.8840	68.00
0.0369	5.2775	2.5440	1.0000	1.00100	3	4.8846	87.80
0.0403	5.2562	2.5440	1.0000	1.00250	3	4.8842	150.70
0.0399	5.2383	2.5440	1.0000	1.00250	3	4.8847	206.10
0.0366	5.2352	2.5440	1.0000	1.00250	3	4.8862	263.00
0.0313	5.3239	2.5440	1.0000	0.99980	3	4.8840	70.00

&CCNST  
 DA= .519999999999999760-02,AN= 6.088CCCCCCCCCCCC010 ,  
 FC= 1.99399999999999991 ,LW= 6.000000000000000000 ,TANW=  
     .6699999999999999890-04,TC1= .3699999999999995D-03,  
 TC2= .536599999999999950-05,TC3= 1.5000000000000000 ,TO=  
     23.500000000000000000 ,DD0= 4.8836CCCCCCCC0001 ,  
 TC4= .6299999999999999990-04,TC5= .1120000000000000020-07,A5=  
     .40000000000000019D-03,A6= .0  
 C1= .3745000000000000 ,C2= 1.00380000000000003 ,TC6=  
     .19429999999999860-04  
 &END

NS	DS	D,CORR.	FC	B	K1	K2	TAN
5.3289	0.0229	2.5440	1.8985	6.9981	3.0516	0.014469	0.004741
5.3132	0.0286	2.5443	1.8890	7.0262	3.0683	0.017504	0.005706
5.3041	0.0316	2.5440	1.8848	7.0422	3.0742	0.018966	0.006169
5.3110	0.0348	2.5491	1.8716	7.0277	3.0451	0.021141	0.006443
5.3191	0.0343	2.5516	1.8602	7.0114	3.0280	0.021123	0.006476
5.3437	0.0309	2.5516	1.8465	6.9639	2.9943	0.019933	0.006657
5.3428	0.0260	2.5444	1.8886	6.9767	3.0308	0.016681	0.005570

ZI/Z14

0.9999990+00	-0.6835020-08
0.1000000+01	-0.1729810-07
0.1000000+01	0.1512950-05
0.1000000+01	-0.1371360-07
0.1000000+01	0.5532940-07
0.1000010+01	0.1273520-06
0.9999920+00	-0.7755670-07

## PROGRAM 2. MULTILAYER RADOME ANALYSIS

FORTRAN IV G1 RELEASE 2.0

```

0001 INTEGER*4 I,J,JJ,K,N,KCUNT
0002 REAL*8 T,TA,ALP,BET,K2,PII3,ONE,WL,FAKE(2),B,C,D,AB,AA,RR,AR,BR,
0003 2ERROR1,WE,BOLD,ERCLD,AOLC,TAATAB,DEN,ARC,ABD,K1,TAN,CDM,SOLD,
0004 7STEP(22)/1.5D-2,1.2D-2,1.D-2,7.D-3,5.D-3,2.D-3,1.D-3,5.D-4,2.D-4,
0005 81.D-4,5.D-5,2.D-5,1.D-5,5.D-6,2.D-6,1.D-6,1.D-7,1.D-8,1.D-9,
0006 91.D-10,1.D-11,1.D-12/,F(2)/1.,-1./,P,DB,EV2,SILLY(2),FUN(2),
0007 6R,RR,FR,GR,THETA,TGH2A,TG2B,B2,AAA,ZETAM,VSWR,REFL,KEFF,DA,TANEF
0008 COMPLEX*16 ZCNE,ZZONE,ALPC,BETC,GAMMA,K1C,K2C,KC,Z0,Z,THRIB,RB,
0009 2TH,ZB,SHGRR,SHGRI,SHGR,SHGI,E,EV,YB,ZETA
0010 DIMENSION DATE(19),ALP(10),BET(10),GAMMA(1C),Z(10),P(10),DBS(10),
0011 2AR(10),BR(10),RB(10),TH(10),E(10),ZB(10),K1(10),TAN(10),T(10)
0012 EQUIVALENCE (FAKE(1),THRIB),(SILLY(1),EV1),(FUN(1),YB)
0013 NAMELIST/IN/K1,TAN,T,N,WL/OUT/GAMMA,Z,ZB/OUT1/A,B,ERROR1,C,
0014 2D/OUT3/C,D/OUT2/RB,TH,ZB,SHGRR,SHGRI,SHGR,SHGI,A,B,E,THRIB,THETR,
0015 3ERROR1
0016 200 FORMAT(1X,19A4)
0017 201 FORMAT(1H0,20X,19A4)
0018 202 FORMAT(1HG,23X,9HLAYER NO.,4X,2HK1,6X,9HTAN DELTA,1X,
0019 212HTHICKNESS,CM,2X,2DHACCUMULATIVE LOSS,DB,2X,13HLAYER LOSS,DB,
0020 32X,16HPHASE SHIFT,DEG.)
0021 ,300 FORMAT(28X,12,2X,F9.5,2X,F11.7,2X,F8.4,10X,F11.7,6X,F11.7,9X,F8.3)
0022 ,302 FORMAT(25X,1·NPUT VSHR=,1X,F9.6,4X,2DHREFLECTION LOSS,DB=,1X,
0023 2F8.5)
0024 303 FORMAT(25X,12HEFFECTIVE K=,1X,F9.6,3X,21HEFFECTIVE TAN DELTA =,
0025 21X,F10.7)
0026 77 READ(5,200,END=88) DATE
0027 WRITE(6,201) DATE
0028 READ(5,IN)
0029 PII=3.141592653600
0030 PII2=6.283185307200
0031 PII3=PII2/WL
0032 ONE=1.00
0033 ZZONE=(1.00,0.00)
0034 ZO=377.00*ZONE
0035 DO 10 J=1,N
0036 TA=DSQRT(ONE+TAN(J)**2)
0037 ALP(J)=PII3*DSQRT(K1(J)*5.D-1*(TA-CNE))*T(J)
0038 BET(J)=PII3*DSQRT(K1(J)*5.D-1*(TA+CNE))*T(J)
0039 ALPC=7CNE*ALP(J)
0040 BETC=ZZONE*BET(J)
0041 GAMMA(J)=ALPC+BETC
0042 K2=K1(J)*TAN(J)
0043 K2C=7CNE*K2
0044 K1C=K1(J)*ZONE
0045 KC=K1C+K2C
0046 Z(J)=ZO/DSQRT(KC)
0047 10 CONTINUE
0048 SUM=0.00
0049 E(1)=ZCNE
0050 P(1)=CNE/377.00
0051 Z(N+1)=ZO
0052 ZB(1)=ZO

```

```
0041      THRB=Z0/Z(1)
0042      WRITE(6,202)
0043      DO 13 J=1,N
0044      C=FAKE(1)
0045      D=FAKE(2)
0046      R=DSQRT(C**2+D**2)
0047      IF(R .GT. CNE) GO TO 33
0048      FR=2.D0*R/(CNE+R**2)
0049      GR=2.D0*R/(CNE-R**2)
0050      THETA=DATAN(D/C)
0051      TGH2A=FR*DCCS(TH-ETA)
0052      TG2B=GR*DSIN(THETA)
0053      GO TO 34
0054 33  RR=ONE/R
0055      FR=2.DC*RR/(ONE+RR**2)
0056      GR=-2.D0*RR/(CNE-RR**2)
0057      THETA=DATAN(D/C)
0058      TGH2A=FR*DCOS(THETA)
0059      TG2B=GR*DSIN(THETA)
0060 34  B2=DATAN(TG2B)
0061      IF(R .GT. CNE) B2=PII+B2
0062      B=DTAN(0.5D0*B2)
0063      AAA=C.25D0*DLOG((ONE+TGH2A)/(ONE-TGH2A))
0064      A=DTANH(AAA)
0065 50  AB=ONE+(A*B)**2
0066      ABC=(A*(ONE+B**2)/AB-C)**2
0067      ABD=(B*(ONE-A**2)/AB-D)**2
0068      ERROR1=DSQRT(ABC+ABD)
0069      DO 400 K=1,22
0070      SOLD=STEP(K)
0071      DO 600 JJ=1,2
0072      420 WE=ONE+STEF(K)*F(JJ)
0073      KOUNT=0
0074 401  KOUNT=KOUNT+1
0075      425 BOLD=B
0076      EROLD=ERROR1
0077      B=B*WE
0078      AB=ONE+(A*B)**2
0079      ABC=(A*(ONE+B**2)/AB-C)**2
0080      ABD=(B*(ONE-A**2)/AB-D)**2
0081      ERROR1=DSQRT(ABC+ABD)
0082      IF(ERROR1.LE.ERCLD) GO TO 401
0083      B=BOLD
0084      ERROR1=EROld
0085      STEP(K)=SOLD
0086 600  CONTINUE
0087      DO 700 JJ=1,2
0088      421 WE=ONE+STEF(K)*F(JJ)
0089      KOUNT=0
0090 402  KOUNT=KOUNT+1
0091      428 AOLD=A
0092      EROLD=ERROR1
0093      A=A*WE
```

```
0094      AB=ONE+(A*B)**2
0095      ABC=(A*(ONE+B**2),AB-C)**2
0096      ABD=(B*(ONE-A**2)/AB-C)**2
0097      ERROR1=DSQRT(ABC+ABD)
0098      IF(ERROR1.LE.ERCLD) GO TO 402
0099      A=AOLD
0100      ERROR1=ERCLD
0101      STEP(K)=SOLD
0102      700 CONTINUE
0103      IF(ERROR1.LE.1.D-12) GO TO 450
0104      400 CONTINUE
0105      450 AR(J)=0.5DC*DLOG((1+A)/(1-A))
0106      BR(J)=DATAN(B)
0107      RB(J)=ZCNE*AR(J)+ZOOONE*BR(J)
0108      AA=ALP(J)+AR(J)
0109      BB=BET(J)+BR(J)
0110      TAA=DTANH(AA)
0111      TAB=DTAN(BB)
0112      DEN=CNE+(TAA*TAB)**2
0113      TH(J)=ZONE*(TAA*(CNE+TAB**2)/DEN)+ZOOONE*(TAB*(ONE-TAA**2)/DEN)
0114      ZB(J+1)=Z(J)*TH(J)
0115      THRR=ZB(J+1)/?(J+1)
0116      SHGRR=ZC *(DSINH(AA)*DCOS(BB))
0117      SHGRI=ZOOONE*(DCCSH(AA)*DSIN(BB))
0118      SHGR=ZONE*(DSINH(AR(J))*DCOS(BR(J)))
0119      SHGI=ZOOONE*(DCCSH(AR(J))*DSIN(BR(J)))
0120      E(J+1)=E(J)*(SHGRR+SHCR)/ (SHGR+SHGI)
0121      YE=ZCNE/ZB(J+1)
0122      EV=E(J+1)
0123      EV2=SILLY(1)**2+SILLY(2)**2
0124      P(J+1)=EV2*FUN(1)
0125      THETR=DATAN(SILLY(2)/SILLY(1))
0126      IF(SILLY(2) .LT. 0.00 .AND. SILLY(1) .GT. 0.00) THETR=THETR+PI/2
0127      IF(SILLY(2) .LT. 0.00 .AND. SILLY(1) .LT. 0.00) THETR=THETR+PI
0128      IF(SILLY(2) .GT. 0.00 .AND. SILLY(1) .LT. 0.00) THETR=THETR+PI
0129      SUM=T(J)+SUM
0130      X=2.00*SUM/WL
0131      Q=0.00
0132      IF(X .GT. 0) GO TO 12
0133      GO TO 14
0134      12 Q=Q+ONE
0135      IF(X .GT. C) GO TO 12
0136      14 Q=Q-ONE
0137      THETD=57.2957795C0*THETR+Q*180.00-360.00*SUM/WL
0138      IF(THETD .GT. 180.00) THETD=THETD-180.00
0139      DBS(J)=10.00*DLOG10(P(J+1)/P(J)),
0140      DB=10.00*DLOG10(P(J+1)/P(1'))
0141      WRITE(6,300) J,K1(J),TAN(J),T(J),DB,DBS(J),THETD
0142      13 CONTINUE
0143      ZETA=(ZB(N+1)-ZC)/(ZB(N+1)+ZC)
0144      ZETAM=CCARS(ZETA)
0145      VSWR=(CNE+ZETAM)/(CNE-ZETAM)
0146      REFL=10.00*DLOG10(ONE/(CNE-ZETAM**2))
0147      WRITE(6,302) VSWR,REFL
0148      KEFF=(WL*THETD/(360.00*SUM)+ONE)**2
0149      DA=8.686DC*38.61DC*SUM*DSORT(KEFF)/(DB*WL)
0150      TANEF=DSQRT(2.00/DA**2+CNE/DA**4)
0151      WRITE(6,303) KEFF,TANEF
0152      GO TO 77
0153      88 CALL EXIT
0154      END
```

## FIVE-LAYER ANALYSIS

3 GHZ 74 DEG F.

LAYER NO.	K1	TAN DELTA	THICKNESS, CM	ACCUMULATIVE LOSS, DB	LAYER LOSS, DB	PHASE SHIFT, DEG.
1	2.44000	0.0668000	0.0530	0.0009846	0.0009846	0.001
2	1.11550	0.0000900	5.0800	0.0023020	0.0013174	9.743
3	1.81000	0.0083900	0.3640	0.0113003	0.0059983	10.495
4	1.42460	0.0064300	1.3600	0.0438699	0.0325696	26.664
5	1.30400	0.0045300	0.3200	0.0496189	0.0057490	31.925
INPUT VSHR =	1.452168	REFLECTION LOSS, DB =	0.15024			
EFFECTIVE K =	1.262393	EFFECTIVE TAN DELTA =	0.0302595			

## NINE-LAYER ANALYSIS

3 GHZ 74 DEG F.

LAYER NO.	K1	TAN DELTA	THICKNESS, CM	ACCUMULATIVE LOSS, DB	LAYER LOSS, DB	PHASE SHIFT, DEG.
1	2.44000	0.0668000	0.0530	0.0009846	0.0009846	0.001
2	1.11550	0.0000900	5.6800	0.0023020	0.0013174	9.743
3	3.59000	0.0125000	0.0500	0.0040788	0.0017768	9.800
4	1.21500	0.0033930	0.2640	0.0367270	0.0026482	10.382
5	3.59000	0.0125000	0.0500	0.0086609	0.0019339	10.558
6	4.14000	0.0103000	0.0660	0.0108214	0.0021605	10.840
7	1.12500	0.0027020	1.2280	0.0236838	0.0128623	27.576
8	4.14000	0.0160000	0.6600	0.0262639	0.0025801	28.559
9	1.30400	0.0045300	0.3200	0.0317474	0.0054834	32.756
INPUT VSHR =	1.391847	REFLECTION LOSS, DB =	0.11815			
EFFECTIVE K =	1.269634	EFFECTIVE TAN DELTA =	0.0001655			

PROGRAM 3. OPEN-CIRCUIT AND SHORT-CIRCUIT MEASUREMENTS

FORTRAN IV G1 RELEASE 2.0

```
0001      INTEGER*4 I,J,K,N,NX
0002      REAL*8 K3,Y,XE,AN,SN,LW,DX,DS,DA,X,A,B,A2,B2,Z14RE,Z14IM,
29ULD,Z14I0C,Z14R0D,ERR0R1,ER0LD,ACLD,AIM,RE,TAM,Z11RE,Z11IM,WE,
9KAPPA,KAPPAC,L1,L2,L3,R,TAND,TANDC,D2,D,D3,
3COSINE,FC,W,ZM,Y1,TAHA,TANB,PII,PII2,ZR0,LNE,STEP(22)/1.5D-2,
41.2D-2,
41.D-2,7.D-3,5.D-3,2.D-3,1.D-3,5.D-4,2.D-4,1.D-4,5.D-5,2.D-5,
51.D-5,
55.D-6,2.D-6,1.D-6,1.D-7,1.D-8,1.D-9,1.D-10,1.D-11,1.D-12/,ND8,
6F(2)/1.D),-1.D0/,SCLD,RA,TANW,AG,KG,C1,C2
0003      COMPLEX*16 Z1,Z2,Z3,Z5,ZL,Z11,Z12,Z13,Z14R,Z14I,Z4,
2Z14,Z12NEW,Z12RE,Z12IM,Z12SC,G,H,Z15,Z2A,ZONE,ZQNE
0004      REAL*8 SILLY(2),FAKE(2)
0005      EQUIVALENCE (SILLY(1),Z11),(FAKE(1),Z15)
0006      DIMENSION DS(30),SN(30),D(30),D2(30),D3(30),N(30),DATE(19),
2AG(30),BG(30)
0007      NAMELIST/IN/DS,SN,N,NX,D,D2,D3/CONST/DA,AN,FC,W,LW,
2TANW,C1,C2
0008      200 FORMAT(1X,19A4)
0009      201 FORMAT(1H0,2GX,19A4)
0010      220 FORMAT(1H0,5X,2HDS,8X,2HSN,6X,1HD,7X,2HD2,7X,2HD3,6X,1HN)
0011      230 FORMAT(2X,F8.4,1X,F3.4,2X,F7.4,2X,F5.4,2X,F8.5,2X,I2)
0012      100 FORMAT(1H0,5X,2HNS,6X,2HDS,6X,1H8,6X,2HK1,9X,2HK2,9X,3HTAN,
21BX,3HZ11,28X,3HZ14//)
0013      300 FORMAT(2X,F7.4,2X,F7.4,1X,F7.3,1X,F7.4,3X,F9.6,3X,F9.6,3X,E13.6,
22X,E13.6,3X,E13.6,2X,E13.6)
0014      77 READ(5,200,END=88) DATE
0015      WRITE(6,201) DATE
0016      READ(5,IA)
0017      READ(5,CONST)
0018      WRITE(6,220)
0019      WRITE(6,230)(CS(I),SN(I),D(I),D2(I),D3(I),N(I),I=1,NX)
0020      WRITE(6,CONST)
0021      WRITE(6,100)
0022      ZONE=(1.00,0.00)
0023      ZQNE=(0.00,1.00)
0024      PII=31416.D-4
0025      PII2=62832.D-4
0026      ZR0=0.00
0027      ONE=1.00
0028      DO 10 I=1,NX
0029      IF(SN(I).EQ.AN) GO TO 10
0030      XE=-D(I)+LW
0031      K3=LW/(PII2*D(I))
0032      Y=PII2*(XE-AN+SN(I))/LW
0033      DX=DS(I)-DA
0034      IF(DX.LE.ZR0) GO TO 10
0035      CCSINE=CCOS(PII*DX/LW)**2
0036      X=DSIN(PII*DX/LW)/DSQR(2.00-CCSINE)
0037      Y1=DTAN(Y)
0038      Z1=ZCNE*Y1
0039      Z2A=ZQNE*X
0040      Z2=Z2A-Z1
```

0041 Z3=ZONE-Z2A\*Z1  
0042 Z9=72/Z3  
0043 Z10=ZCCNE\*(-K3)  
0044 Z11=Z10\*Z9  
0045 Z11RE=SILLY(1)  
0046 Z11IM=SILLY(2)  
0047 ZM=DSQRT(Z11RE\*\*2+Z11IM\*\*2)  
0048 IF(N(I) .EQ. 1) GO TO 141  
0049 IF(N(I) .GE. 2) GO TO 142  
0050 141 IF(ZM.LE.CNE.AND.Z11RE.GE.ZR0) GO TO 150  
0051 IF(ZM.LE.CNE.AND.Z11RE.LT.ZR0) GO TO 151  
0052 IF(ZM.GT.CNE.AND.Z11RE.GE.ZR0) GO TO 152  
0053 IF(ZM.GT.CNE.AND.Z11RE.LT.ZR0) GO TO 153  
0054 142 IF(ZM.LE.CNE.AND.Z11RE.GE.ZR0) GO TO 170  
0055 IF(ZM.LE.CNE.AND.Z11RE.LT.ZR0) GO TO 171  
0056 IF(ZM.GT.CNE.AND.Z11RE.GE.ZR0) GO TO 172  
0057 IF(ZM.GT.CNE.AND.Z11RE.LT.ZR0) GO TO 173  
0058 150 B=ONE  
0059 A=42.D-1\*DX/LW  
0060 GO TO 160  
0061 151 B=22.D-1  
0062 A=2.DC\*DX/LW  
0063 GO TO 160  
0064 152 B=CNE  
0065 A=6.DC\*DX/LW  
0066 GO TO 160  
0067 153 B=19.D-1  
0068 A=DX/LW  
0069 GO TO 160  
0070 170 NDB=N(I)  
0071 B=(NDB-CNE)\*PII+7854.D-4  
0072 A=4.DC\*DX/LW  
0073 GO TO 160  
0074 171 NDB=N(I)  
0075 B=NDB\*PII-7854.D-4  
0076 A=4.DC\*DX/LW  
0077 GO TO 160  
0078 172 NDB=N(I)  
0079 B=(2.DC\*NDB-1.DC)\*15708.D-4-2.D-1/NDB  
0080 A=DX/LW  
0081 GO TO 160  
0082 173 NDB=N(I)  
0083 B=(2.DD\*NDB-1.DC)\*15709.D-4+2.D-1/NDB  
0084 A=DX/LW  
0085 160 TAHAA=DTANH(A)  
0086 TANB=DTAN(B)  
0087 A2=TAHAA\*(CNE+TANB\*\*2)/(CNE+TAHAA\*\*2+TANB\*\*2)  
0088 B2=TANB\*(CNE-TAHAA\*\*2)/(CNE+TAHAA\*\*2+TANB\*\*2)  
0089 Z14RE=(A\*A2+B\*B2)/(A\*\*2+B\*\*2)  
0090 Z14IM=(A\*B2-B\*A2)/(A\*\*2+B\*\*2)  
0091 EXPDR1=DSQRT((Z14RE-Z11RE)\*\*2+(Z14IM-Z11IM)\*\*2)  
0092 DO 400 K=1,22  
0093 SOLD=STEP(K)

```
0094      TAHA=DTANH(A)
0095      DO 600 J=1,2
0096      420 WE=CNE+STEP(K)*F(J)
0097      KCOUNT=0
0098      401 KCOUNT=KCOUNT+1
0099      IF(KCOUNT.GT.10) GO TO 411
0100      GO TO 425
0101      411 STEP(K)=STEP(K)*10.00
0102      GO TO 420
0103      425 BCOLD=B
0104      Z14ICD=Z14IM
0105      Z14ROD=Z14RE
0106      EROLD=ERRCF1
0107      B=B*WE
0108      TANB=DTAN(B)
0109      A2=TAHA*(CNE+TANB**2)/(CNE+TAHA**2*TANB**2)
0110      B2=TANB*(CNE-TAHA**2)/(CNE+TAHA**2*TANB**2)
0111      Z14RE=(A*A2+B*B2)/(A**2+B**2)
0112      Z14IM=(A*B2-B*A2)/(A**2+B**2)
0113      ERROR1=CSQRT((Z14RE-Z11RE)**2+(Z14IM-Z11IM)**2)
0114      IF(ERROR1.LE.ERRCLD) GO TO 401
0115      Z14IM=Z14ICD
0116      Z14RE=Z14ROD
0117      B=BCOLD
0118      EPROR1=ERCLD
0119      STEP(K)=SOLD
0120      600 CONTINUE
0121      TAND=DTAN(B)
0122      DO 700 J=1,2
0123      421 WE=CNE+STEP(K)*F(J)
0124      KCOUNT=0
0125      402 KCOUNT=KCOUNT+1
0126      IF(KCOUNT.GT.10) GO TO 412
0127      GO TO 428
0128      412 STEP(K)=STEP(K)*10.00
0129      GO TO 421
0130      428 AOLD=A
0131      Z14ROD=Z14RE
0132      Z14ICD=Z14IM
0133      EROLD=ERROR1
0134      A=A*WE
0135      TAHA=DTANH(A)
0136      A2=TAHA*(CNE+TANB**2)/(CNE+TAHA**2*TANB**2)
0137      B2=TANB*(CNE-TAHA**2)/(CNE+TAHA**2*TANB**2)
0138      Z14RE=(A*A2+B*B2)/(A**2+B**2)
0139      Z14IM=(A*B2-B*A2)/(A**2+B**2)
0140      ERROR1=CSQRT((Z14RE-Z11RE)**2+(Z14IM-Z11IM)**2)
0141      IF(ERROR1.LE.ERRCLD) GO TO 402
0142      Z14RE=Z14ROD
0143      Z14IM=Z14ICD
0144      A=AOLD
0145      EPROR1=EPCLD
0146      STEP(K)=SOLD
```

```
0147 700 CONTINUE
0148  IF(ERRCR1.LE.1.C-6) GO TC 450
0149 400 CONTINUE
0150 450 Z12RE=ZCNE*A
0151  Z12IM=ZCNE*B
0152  AG(I)=A
0153  BG(I)=B
0154  Z12NEW=(Z12RE+Z12IM)**2
0155  Z14R=Z14RE*ZCNE
0156  Z14I=Z14IM*ZCNE
0157  Z14=Z14R+Z14I
0158  Z13=-Z12NEW*K3**2
0159  G=ZCNE*FC
0160  H=ZCNE*W
0161  Z15=(G+Z13)/H
0162  RA=FAKE(1)
0163  AIM=-FAKE(2)
0164  IF(FC.GT.C.DC) GO TC 210
0165  KAPPA=FAKE(1)
0166  TAND=AIM/RA
0167  L1=DLOG10(D2(I)/C1)+DLCG10(C2/D3(I))
0168  L2=DLOG10(D3(I)/D2(I))
0169  L3=DLCG10(C2/C1)
0170  R=1.-L1*KAPPA*(1.+TAND**2)/L3
0171  KAPPAC=R*KAPPA/((L3/L2)-2.*L1*KAPPA/L2+(1.-R)*L1/L2)
0172  TANCC=TAND/R
0173  RE=KAPPAC
0174  TAM=TANDC-TANW
0175  AIM=RE*TAM
0176  GO TO 15
0177 210 IF(LW.GT.5.00.AND.LW.LT.7.00) GO TC 211
0178  IF(LW.GT.3.400.AND.LW.LT.4.00) GO TO 212
0179  IF(LW.GT.2.00.AND.LW.LT.3.00) GO TO 213
0180 211 RE=RA+8368.0-4*(RA**2-RA)*(C2-D3(I))/C2
0181  GO TO 18
0182 212 RE=RA+8368.0-4*(RA**2-RA)*(6250.0-4-D3(I))/6250.0-4
0183  GO TO 18
0184 213 RE=RA+8368.0-4*(RA**2-RA)*(3750.0-4-D3(I))/3750.0-4
0185 18 TAM=AIM/RE-TANW
0186  AIM=RE*TAM
0187 15 WRITE(6,300) SN(I),DS(I),E,RE,AIM,TAM,Z11,Z14
0188 10 CONTINUE
0189 66 READ(5,IN)
0190  READ(5,CONST)
0191  WRITE(6,220)
0192  WRITE(6,230)(DS(I),SN(I),D(I),D2(I),D3(I),N(I),I=1,NX)
0193  WRITE(6,CONST)
0194  WRITE(6,100)
0195 11 DO 20 I=L,NX
0196  IF(SN(I).EQ.AN) GO TO 21
0197  XE=SN(I)+25.C-2*LW-AN-C(I)
0198  Y=PI12*XE/LW
0199  DX=DS(I)-CA
```

```
0200      IF(DX.LE.ZRC) GO TO 21
0201      COSINE=DCOS(PII*DX/LW)**2
0202      X=DSIN(PII*DX/LW)/DSQRT(2.00-COSINE)
0203      Y1=DTAN(Y)
0204      Z1=ZONE*X1
0205      Z2A=ZCNE*X
0206      Z2=Z2A-Z1
0207      Z3=ZONE-Z2A**Z1
0208      Z4=Z2/Z3
0209      K3=LW/(PII2*C(I))
0210      Z1C=ZCNE/K3
0211      Z1I=Z1O/Z4
0212      Z1IRE=SILLY(1)
0213      Z1IIM=SILLY(2)
0214      A=AG(I)
0215      B=BG(I)
0216      TAHA=DTANH(A)
0217      TANB=DTAN(B)
0218      A2=TAHA*(CNE+TANB**2)/(CNE+TAHA**2*TANB**2)
0219      B2=TANB*(CNE-TAHA**2)/(CNE+TAHA**2*TANB**2)
0220      Z14RE=A*A2-B*B2
0221      Z14IM=A*B2+B*A2
0222      ERROR1=DSQRT((Z14RE-Z1IRE)**2+(Z14IM-Z1IIM)**2)
0223      DO 410 K=1,22
0224      TAHA=DTANH(A)
0225      DO 610 J=1,2
0226      WE=CNE+STEP(K)*F(J)
0227      525  BOLD=A
0228      Z14ICD=Z14IM
0229      Z14RCD=Z14RE
0230      EROLD=ERROR1
0231      B=R*WE
0232      TANB=DTAN(B)
0233      A2=TAHA*(CNE+TANB**2)/(CNE+TAHA**2*TANB**2)
0234      B2=TANB*(CNE-TAHA**2)/(CNE+TAHA**2*TANB**2)
0235      Z14RE=A*A2-B*B2
0236      Z14IM=A*B2+B*A2
0237      ERROR1=DSQRT((Z14RE-Z1IRE)**2+(Z14IM-Z1IIM)**2)
0238      IF(ERROR1.LE.FRCLO) GO TO 525
0239      Z14IM=Z14ICD
0240      Z14RF=Z14RCD
0241      B=BOLD
0242      ERROR1=EROld
0243      610  CONTINUE
0244      TANB=DTAN(B)
0245      DO 710 J=1,2
0246      WE=CNE+STEP(K)*F(J)
0247      528  ACLO=A
0248      Z14RCD=Z14RE
0249      Z14ICD=Z14IM
0250      EROLD=ERROR1
0251      A=A*WE
0252      TAHA=DTANH(A)
```

```
0253      A2=TAHA*(CNE+TANB**2)/(CNE+TAHA**2*TANB**2)
0254      B2=TANB*(CNE-TAHA**2)/(CNE+TAHA**2*TANB**2)
0255      Z14RE=A*A2-B*B2
0256      Z14IM=A*B2+B*A2
0257      ERPCR1=DSQRT((Z14RE-Z11RE)**2+(Z14IM-Z11IM)**2)
0258      IF(ERPCR1.LE.ERCLD) GO TO 528
0259      Z14RE=Z14RCC
0260      Z14IM=Z14ICD
0261      A=ACLD
0262      ERRORP1=ERCLD
0263    710 CCNTINIE
0264      IF(ERRORP1.LE.1.D-6) GO TO 460
0265    410 CONTINUE
0266    460 Z12RE=ZCNE*A
0267      Z12IM=ZCNE*B
0268      Z12NEW=(Z12RE+Z12IM)**2
0269      Z13=-Z12NEW*K3**2
0270      Z14R=Z14RE*ZCNE
0271      Z14I=Z14IM*ZCNE
0272      Z14=Z14R+Z14I
0273      G=ZCNE*FC
0274      H=ZONE**W
0275      Z15=(G+Z13)/H
0276      RA=FAKE(1)
0277      A1M=-FAKE(2)
0278      IF(FC.GT.0.00) GO TO 310
0279      KAPPA=FAKE(1)
0280      TAND=A1M/KAPPA
0281      L1=DLOG10(C2(I)/C1)+DLOG10(C2/D3(I))
0282      L2=DLOG10(C3(I)/D2(I))
0283      L3=DLOG10(C2/C1)
0284      R=1.-L1*KAPPA*(1.+TAND**2)/L3
0285      KAPPAC=R*KAPPA/((L3/L2)-2.*L1*KAPPA/L2+(1.-R)*L1/L2)
0286      TANDC=TAND/R
0287      RE=KAPPAC
0288      TAM=TANDC-TANW
0289      AIM=RE*TAM
0290      GO TO 16
0291    310 IF(LW.GT.5.00.AND.LW.LT.7.00) GO TO 311
0292      IF(LW.GT.3.400.AND.LW.LT.4.00) GO TO 312
0293      IF(LW.GT.2.00.AND.LW.LT.3.00) GO TO 313
0294    311 RE=RA+8368.0-1*(RA**2-RA)*(C2-D3(I))/C2
0295      GO TO 28
0296    312 RE=RA+8368.0-4*(RA**2-RA)*(6250.0-4-D3(I))/6250.0-4
0297      GO TO 28
0298    313 RE=RA+6368.0-4*(RA**2-RA)*(3750.0-4-D3(I))/3750.0-4
0299    28 TAM=A1M/RE-TANW
0300      AIM=RE*TAM
0301    16 WRITE(6,30C) SN(I),DS(I),B,RE,AIM,TAM,Z11,Z14
0302      GO TO 20
0303    21 WRITE(6,110)
0304    110 FORMAT(11H,5X,20HMEASUREMENT NOT MADE//)
0305    20 CCNTINUE
```

U306        GL TO 77  
U307        89 CALL EXIT  
U309        END

WHITTAKER DD3164-10\*4,3164-11\*2,0PO-401\*2,ASR-1050J\*2 8.5GHZ, 22 DEG C

DS	SN	D	D2	D3	N
0.1555	5.7375	2.5575	1.0000	1.00030	3
0.1624	5.7428	2.5575	1.0000	1.00030	3
0.1582	5.7437	2.5575	1.0000	1.00030	3
0.1495	5.7467	2.5575	1.0000	1.00030	3
0.0356	5.7335	2.5800	1.0000	0.99730	3
0.0461	5.7126	2.6800	1.0000	0.99730	3
0.0215	5.9288	2.5440	1.0000	0.99980	3
0.0197	5.9579	2.5440	1.0000	0.99980	3
0.0398	5.8805	2.5415	1.0000	1.00000	3
0.0395	5.8813	2.5415	1.0000	1.00000	3

&CONST

DA= .149999999999999998D-02,AN= 6.709400000000003  
6.000000000000000 ,TANW= .44999999999999940-04,

&END

ECT.

NS	DS	B	K1	K2	TAN
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5.7375	0.1555	7.328	3.2613	0.058525	0.017945
5.7428	0.1624	7.323	3.2576	0.061820	0.018977
5.7437	0.1582	7.321	3.2567	0.060351	0.018532
5.7467	0.1495	7.317	3.2537	0.057426	0.017649
5.7335	0.0356	7.422	3.1049	0.009344	0.003009
5.7126	0.0461	7.440	3.1168	0.011813	0.003790
5.9288	0.0215	7.035	3.0840	0.012168	0.003926
5.9579	0.0197	6.981	3.0467	0.011685	0.003835
5.8805	0.0398	7.113	3.1429	0.021131	0.006723
5.8813	0.0395	7.112	3.1420	0.021003	0.006684

DS	SN	D	D2	D3	N
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0.0795	7.8979	2.5575	1.0000	1.00030	3
0.0761	7.8991	2.5575	1.0000	1.00030	3
0.0803	7.8951	2.5575	1.0000	1.00030	3
0.0765	7.8955	2.5575	1.0000	1.00030	3
0.0112	7.9691	2.5800	1.0000	0.99730	3
0.0194	7.9845	2.6800	1.0000	0.99730	3
0.0281	5.0660	2.5440	1.0000	0.99980	3
0.0276	5.0358	2.5440	1.0000	0.99980	3
0.0368	7.9771	2.5415	1.0000	1.00000	3
0.0369	7.9769	2.5415	1.0000	1.00000	3

&CONST

DA= .1840000000000000-02,AN= 6.622000000000011  
6.000000000000000 ,TANW= .44999999999999940-04,

&END

ECT.

NS	DS	B	K1	K2	TAN
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7.8979	0.0795	7.285	3.2311	0.054786	0.016956
7.8991	0.0761	7.283	3.2296	0.052219	0.016109
7.8951	0.0803	7.291	3.2350	0.055780	0.017242
7.8955	0.0765	7.291	3.2348	0.053026	0.016392
7.9691	0.0112	7.373	3.0723	0.056370	0.02073
7.9845	0.0194	7.383	3.0789	0.012090	0.003927
5.0660	0.0281	6.991	3.0537	0.011496	0.003764
5.0358	0.0276	7.031	3.0819	0.012170	0.003949
7.9771	0.0368	7.115	3.1439	0.019229	0.006116
7.9769	0.0369	7.115	3.1441	0.019294	0.006137