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Part IV

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DIELECTRIC CONSTANT AND LOSS DATA

Laboratory for Insulation Research  
Massachusetts Institute of Technology  
Cambridge, MA 02139

December 1980

FINAL REPORT AFML-TR-74-250, PART IV  
INTERIM REPORT FOR PERIOD JANUARY 1977 - MAY 1980

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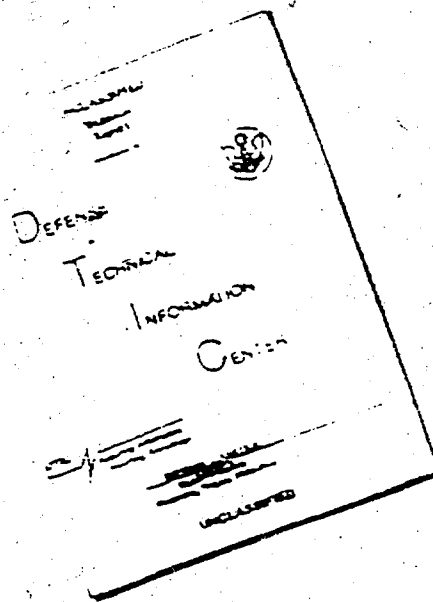
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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>The main body of this report lists dielectric constant and loss data on materials measured in this laboratory in the period 1 July 1977 through 15 May 1980 together with measurements techniques and calculations.<br><br>The index following the data section is intended to be a complete reference to dielectric measurement data of this laboratory to date. ← |                                                                                           |                                             |

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# PREFACE

The dielectric constant and loss data presented in this report were measured at the Laboratory for Insulation Research of the Massachusetts Institute of Technology, Cambridge, Massachusetts, by W. B. Westphal. This work was performed between 1 January 1977 and 15 May 1980 under Contract F33615-77-C-5063, Project No. 7514, Task No. 24230104 for the Materials Laboratory of the Air Force Wright Aeronautical Laboratories.

This report was submitted by the author for publication in August 1980.

The work was administered under direction of the AF Materials Laboratory, with Mr. John C. Olson (AFWAL/MLPJ) acting as project engineer.



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## SUMMARY

The first sections of this report describe changes in measurement techniques and programming of calculations.

A technical report dated December 1975 presents data on materials measured in the early part of this contract. A later data report is dated May 1977. The index following the data section refers to early data reports and uses the prefix 10- for pages of the present report.

The data section does not generally include measurements on research samples under development by or for the Air Force Materials Laboratory.

## MEASUREMENT TECHNIQUE

The basic measurement techniques using bridges, reentrant cavities, standing waves, and dielectric-filled cavities have been discussed in previous reports.<sup>1-7\*</sup> During the present contract period the only new type of measurements has been for high loss liquids: the use of a glass or plastic capillary tube mounted in a plane one-quarter wavelength from the short in the standing wave system. The tube axis is parallel to the electric field in either rectangular or circular hollow waveguide. This method was used for water-acid solutions, liquid ammonia and sulfur.

## PROGRAMMING

Program 1, in the following section, is used for calculating the dielectric constant and loss of a sample in a capillary tube. The input data:

|      |                                                                                           |
|------|-------------------------------------------------------------------------------------------|
| DS   | node width, sample in                                                                     |
| SN   | node position, sample in                                                                  |
| CONC | specified acid concentration                                                              |
| NC   | number of measurements                                                                    |
| DG   | node width, empty capillary                                                               |
| GN   | node position, empty capillary                                                            |
| R    | inner radius of capillary                                                                 |
| FGH  | frequency, GHz                                                                            |
| C    | conversion factor between capillary admittance and waveguide admittance at the same plane |
| Cl   | initial guess for correction term in K1 due to loss, Iteration finds exact correction     |
| WLG  | wavelength in air filled waveguide                                                        |
| SMF  | conversion factor to calculate conductivity from loss factor                              |

### \*References

1. Tech. Rep. 182 Lab. Ins. Res., Contract AF33(616)-8353, October 1963.
2. " " 201 " " " " " " October 1966.
3. AFML-TR-66-28, " " " " AF33(615)-2199, January 1966.
4. AFML-TR-70-138, " " " " F33615-67C-1612, July 1970.
5. AFML-TR-71-66, " " " " F33615-70C-1220, April 1971.
6. AFML-TR-74-250, Pt. II, Lab. Ins. Res., Contract F33615-71-C-1274, December 1975
7. AFML-TR-74-250, Pt. III, " " " " Contract F33615-75-C-5020, May 1977

# Program 1 High Loss Liquid in Capillary

FORTRAN IV G1 RELEASE 2.0

```

0001      REAL*8 TWO,WL,FGH,PII3,PII4,WLG,XOG,DELN,TANG,EG,DG,XOS,GN,SN,
          2TANS,THETA,DS,ES,K1M,K2M,K1,K2,C1,KM,KMA,KMB,K1CAL,K2CAL,ERROR,
          3WE,K1OLD,K2OLD,EROLD,SMF,SIGMA,CONC,R,C,STEP(4)/.03D0,.01D0,
          4.003D0,.001D0/,F(2)/1.D0,-1.D0/FAKE(2),FUN(2),ONE
0002      COMPLEX*16 ZONE,ZOONE,TWOC,YG,YT,KMAC,KMBC,GR,D2C,D3C,D4C,D5C,
          2D6C,D7C,J11,J12,J13,J14,J1,J01,J02,J03,J04,J0,RATIO,K1C,K2C,KCOR,
          3YG1,YG2,YG3,YG4,YT2,YT3,YT4,Y5,KC
0003      EQUIVALENCE (FAKE(1),YS),(FUN(1),KCOR)
0004      DIMENSION DS(40),SN(40),CONC(40),DATE(39)
0005      NAMELIST/IN/DS,SN,CONC,NC/CONST/DG,GN,DELN,R,FGH,C,C1,WLG,SMF
0006      200 FORMAT (1X,39A2)
0007      201 FORMAT(1H0,20X,39A2,/)
0008      100 FORMAT(1X,7HWT%ACID,5X,2HK1,3X,9HUNCOR,K1,5X,2HK2,3X,
          29HUNCOR,K2,3X,12HS%GMA,MHO/CM,1X,5HERROR,10X,3HJ04,10X,3HJ14)
0009      101 FORMAT(F7.3,1X,F8.2,1X,F8.2,3X,F8.2,2X,F8.2,3X,F9.5,1X,
          2E9.2,1X,E9.2,1X,E9.2,1X,E9.2,1X,E9.2)
0010      102 FORMAT(5X,2HDS,10X,2HSN,10X,4HCONC,8X,1HI)
0011      103 FORMAT(1X,F10.4,1X,F10.4,1X,F10.4,8X,I2)
0012      104 FORMAT(3X,13HKOUNT FOR K1=,1X,I2)
0013      105 FORMAT(3X,13HKOUNT FOR K2=,1X,I2)
0014      77 READ(5,200,END=88) DATE
0015      WRITE(6,201) DATE
0016      READ(5,IN)
0017      READ(5,CONST)
0018      WRITE(6,102)
0019      DO 8 I=1,NC
0020      WRITE(6,103) DS(I),SN(I),CONC(I),I
0021      8 CONTINUE
0022      ZONE=(1.D0,0.D0)
0023      ZOONE=(0.D0,1.D0)
0024      ONE=1.D0
0025      TWO=2.D0
0026      TWOC=ZONE*TWO
0027      WL=2.997924562D1/FGH
0028      PII3=6.2831853072D0/WL
0029      PII4=6.28318D0/WLG
0030      WRITE(6,CONST)
0031      WRITE(6,100)
0032      XOG=WLG/4.D0-DELN
0033      TANG=DTAN(PII4*XOG)
0034      EG=PII4*DG/TWO
0035      YG=(ZOONE*(-C))*(ZONE-ZOONE*(EG*TANG))/((ZONE*EG)-(ZOONE*YANG))
0036      DO 10 I=1,NC
0037      XOS=XOG-(GN-SN(I))
0038      TANS=DTAN(PII4*XOS)
0039      THETA=PII4*DS(I)/TWO
0040      ES=DSIN(THETA)/DSQRT(TWO-(DCOS(THETA))*2)
0041      YT=(ZOONE*(-C))*(ZONE-ZOONE*(ES*TANS))/((ZONE*ES)-(ZOONE*TANS))
0042      YS=YT-YG
0043      K1M=FAKE(1)
0044      K2M=-FAKE(2)
0045      K1M=K1M+ONE
0046      K1=K1M+C1*K2M
0047      K2=K2M
0048      KM=DSQRT(K1**2+K2**2)
0049      KMA=DSQRT((KM-K1)/TWO)*PII3*R
0050      KMB=DSQRT((KM+K1)/TWO)*PII3*R
0051      KMAC=ZONE*KMA
0052      KMBC=ZOONE*KMB
0053      GR=KMBC+KMAC
0054      D2C=ZONE*16.D0
0055      D3C=ZONE*384.D0
0056      D4C=ZONE*1.8432D4
0057      D5C=ZONE*4.D0
0058      D6C=ZONE*64.D0
0059      D7C=ZONE*2304.D0
0060      J11=GR/TWOC
0061      J12=GR**3/D2C
0062      J13=GR**5/D3C
0063      J14=GR**7/D4C

```

Program 1, continued

```

0064      J1=J11+J12+J13+J14
0065      J01=ZONE
0066      J02=GR**2/D5C
0067      J03=GR**4/D6C
0068      J04=GR**6/D7C
0069      J0=J01+J02+J03+J04
0070      RATIO=(TWOC/GR)*J1/J0
0071      K1C=ZONE*K1
0072      K2C=ZONE*(-K2)
0073      KC=K1C+K2C
0074      KCOR=KC*RATIO
0075      K1CAL=FUN(1)
0076      K2CAL=-FUN(2)
0077      ERROR=DSQRT((K1M-K1CAL)**2+(K2M-K2CAL)**2)
0078      DO 400 K=1,4
0079      DO 600 J=1,2
0080      WE=ONE+STEP(K)*F(J)
0081      KOUNT=0
0082      401 K1OLD=K1
0083      KOUNT=KOUNT+1
0084      EROLD=ERROR
0085      K1=K1*WE
0086      KM=DSQRT(K1**2+K2**2)
0087      KMA=DSQRT((KM-K1)/TWO)*PII3*R
0088      KMB=DSQRT((KM+K1)/TWO)*PII3*R
0089      KMAC=ZONE*KMA
0090      KMBC=ZONE*KMB
0091      GR=KMBC+KMAC
0092      D2C=ZONE*16.D0
0093      D3C=ZONE*384.D0
0094      D4C=ZONE*1.8432D4
0095      D5C=ZONE*4.D0
0096      D6C=ZONE*64.D0
0097      D7C=ZONE*2304.D0
0098      J11=GR/TWOC
0099      J12=GR**3/D2C
0100      J13=GR**5/D3C
0101      J14=GR**7/D4C
0102      J1=J11+J12+J13+J14
0103      J01=ZONE
0104      J02=GR**2/D5C
0105      J03=GR**4/D6C
0106      J04=GR**6/D7C
0107      J0=J01+J02+J03+J04
0108      RATIO=(TWOC/GR)*J1/J0
0109      K1C=ZONE*K1
0110      K2C=ZONE*(-K2)
0111      KC=K1C+K2C
0112      KCOR=KC*RATIO
0113      K1CAL=FUN(1)
0114      K2CAL=-FUN(2)
0115      ERROR=DSQRT((K1M-K1CAL)**2+(K2M-K2CAL)**2)
0116      IF(KOUNT.GT.20) GO TO 601
0117      IF(ERROR.LE.EROLD) GO TO 401
0118      K1=K1OLD
0119      ERROR=EROLD
0120      600 CONTINUE
0121      GO TO 602
0122      601 WRITE(6,104) KOUNT
0123      602 DO 700 J=1,2
0124      WE=ONE+STEP(K)*F(J)
0125      KOUNT=0
0126      421 K2OLD=K2
0127      KOUNT=KOUNT+1
0128      EROLD=ERROR
0129      K2=K2*WE
0130      KM=DSQRT(K1**2+K2**2)
0131      KMA=DSQRT((KM-K1)/TWO)*PII3*R
0132      KMB=DSQRT((KM+K1)/TWO)*PII3*R

```

Program 1, continued

```

0133      GR=KMBC+KMAC
0134      D2C=ZONE*16.D0
0135      D3C=ZONE*384.D0
0136      D4C=ZONE*1.8432D4
0137      D5C=ZONE*4.D0
0138      D6C=ZONE*64.D0
0139      D7C=ZONE*2304.D0
0140      J11=GR/TWOC
0141      J12=GR**3/D2C
0142      J13=GR**5/D3C
0143      J14=GR**7/D4C
0144      J1=J11+J12+J13+J14
0145      J01=ZONE
0146      J02=GR**2/D5C
0147      J03=GR**4/D6C
0148      J04=GR**6/D7C
0149      J0=J01+J02+J03+J04
0150      RATIO=(TWOC/GR)*J1/J0
0151      K1C=ZONE*K1
0152      K2C=ZONE*(-K2)
0153      KC=K1C+K2C
0154      KCOR=KC*RATIO
0155      K1CAL=FUN(1)
0156      K2CAL=-FUN(2)
0157      ERROR=DSQRT((K1M-K1CAL)**2+(K2M-K2CAL)**2)
0158      IF(KOUNT.GT.20) GO TO 701
0159      IF(ERROR.LE.EROLD) GO TO 421
0160      K2=K2OLD
0161      ERROR=EROLD
0162      700 CONTINUE
0163      GO TO 702
0164      701 WRITE(6,105) KOUNT
0165      702 IF(ERROR.LE.1.D-4) GO TO 450
0166      400 CONTINUE
0167      450 SIGMA=SMF*K2
0168      WRITE(6,101) CONC(I),K1,K1M,K2,K2M,SIGMA,ERROR,J04,J14
0169      10 CONTINUE
0170      GO TO 77
0171      88 CALL EXIT
0172      END

```

Output

3GHZ 21.3 DEG.C.

```

DS      SN      CONC      I
0.0679  0.3032  0.0      1
0.2009  0.3159  1.1090  2
0.6445  0.3835  5.0434  3
1.1360  0.5070  10.0760  4

&CONST
DG= .120000000000000002D-01,GN= .47999999999999996 ,DELN= .219700000000000006
R= .321730000000000002D-01,FGH= 3.0000000000000000 ,C= 938.39999999999977
C1= .157000000000000004D-01,WLG= 13.8550000000000000 ,SMF= .16666599999999998D-02
&END

```

| WT%ACID | K1     | UNCOR. K1 | K2     | UNCOR. K2 | SIGMA MHQ/CM | ERROR    |
|---------|--------|-----------|--------|-----------|--------------|----------|
| 0.0     | 77.45  | 77.73     | 12.24  | 12.34     | 0.02041      | 0.24D-01 |
| 1.109   | 71.70  | 71.84     | 41.14  | 41.43     | 0.06856      | 0.33D-01 |
| 5.043   | 40.68  | 39.82     | 134.86 | 135.40    | 0.22477      | 0.19D-01 |
| 10.076  | -12.93 | -15.64    | 231.21 | 230.75    | 0.38534      | 0.11D+00 |

| J04       |           | J14       |           |
|-----------|-----------|-----------|-----------|
| -0.13D-07 | 0.65D-08  | -0.17D-09 | -0.27D-09 |
| -0.11D-09 | 0.17D-07  | -0.37D-09 | 0.97D-10  |
| 0.64D-07  | -0.53D-07 | 0.24D-08  | 0.59D-09  |
| -0.62D-07 | -0.37D-06 | 0.79D-08  | -0.12D-07 |

Program 2 is used for calculating the results for a temperature run on a thin sample (in coax or hollow waveguide) located on a quarter-wavelength spacer. The variations in data with temperature of the empty sample holder with, and without, the spacer are expressed as a power series of temperature change from room temperature. Corrections can then be made for the change in electrical length of the spacer with temperature. Partial notation follows:

DXQC node width for holder with spacer only, corrected for temperature effects  
 DAC node width for empty holder corrected for temperature  
 ANC node position for empty holder versus temperature  
 QNC node position for holder with spacer only corrected for changes with temperature  
 DQC spacer length versus temperature  
 THC sample thickness corrected for linear thermal expansion

#### Program 2 Thin Sample temp. run

FORTRAN IV G1 RELEASE 2.0

```

0001      INTEGER*4 I,J,K,N,NX
0002      REAL*8 P11,P112,ONE,TWO,W,FC,W1,TANW1,DA,DT,THC,D,T,TO,TCO,LW02,
      2LW,WL2,WC2,WC1,C2,TC6,K3,TANW2,TCW,DQC,DQ,TCQ,DAC,A5,A6,DXQC,
      3DXQ,AQ,AQQ,DXQCC,QN,AN,TC1,TC2,TC3,ANC,QNC,TC7,TC8,TC9,IXOQ,
      4W2,P113,U,TA1,DC,DX,SN,COSINE,IXOS,Z11RE,Z11IM,SILLY(2),AZ11,
      5AZ16,A,B,FUN(2),TAHA,TANB,A2,B2,Z14RE,Z14IM,ERROR1,WE,BOLD,
      6STEP(5)/1.D-2,1.D-3,1.D-4,1.D-5,1.D-6/,F(2)/1.D0,-1.D0/,Z141OD,
      7Z14ROD,EROLD,AOLD,FCC,FAKE(2),RA,AIM,C1,TC6,C2C,C2,KAPPA,TAND,L1,
      8L2,L3,R,KAPPAC,TANDC,RE,TAM,SIGMA,PUN(2),DS,C1C,D2,D3,AX,WL1
0003      COMPLEX*16 ZONE,ZOONE,X,Y,ZJ2,AL1O2,BE1O2,G1D2,Z4,Z10,Z11,Z16,
      2Z12SQ,THG2D2,Z14,Z12RE,Z12IM,Z12NEW,Z13,G,H,Z15,Z17,G2D2,K3C,Z14R,
      3Z14I
0004      DIMENSION DS(30),SN(30),D2(30),D3(30),DATE(39),AX(30),T(30)
0005      EQUIVALENCE (SILLY(1),Z4),(FAKE(1),Z15),(FUN(1),Z14),
      2(PUN(1),Z12SQ)
0006      NAMELIST/CONST/DA,DXQ,DQ,FC,LW,DT,TCW,TCQ,A5,A6,AQ,AQQ,TC1,TC2,TO,
      2TC3,TC7,TC8,TC9,TCO,TC6,C1,C2,D,AN,QN/IN/DS,SN,1,D2,D3,AX,
      3NX/OUT/A,B,AZ11,AZ16,Z12SQ,Z11,Z16
0007      200 FORMAT(1X,39A2)
0008      201 FORMAT(1H0,20X,39A2)
0009      220 FORMAT(1H0,5X,2HDS,8X,2HSN,6X,2HD2,7X,2HD3,7X,2HX,8X,
      24HTEMP,6X,1HI)
0010      230 FORMAT(2X,F8.4,1X,F8.4,2X,F7.4,2X,F6.4,2X,F8.5,2X,F8.2,2X,I2)
0011      100 FORMAT(1H0,5X,2HNS,6X,2HDS,4X,7HD,CORR.,4X,2HFC,6X,1HB,6X,2HK1,
      29X,2HK2,9X,3HTAN,15X,6HZ4/Z14//)
0012      300 FORMAT(2X,F7.4,2X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,3X,F9.6,
      23X,F9.6,3X,E13.6,2X,E13.6)
0013      301 FORMAT(10X,6HTEMP=,F7.1,1X,6HDEG.C.,4X,6HSIGMA=,E11.4,6HMH0/CM,
      25X,19HSAMPLE HOLDER DIA.=,F8.5)
0014      77 READ(5,200,END=88) DATE
0015      WRITE(6,201) DATE
0016      READ(5,CONST)
0017      READ(5,IN)
0018      WRITE(6,220)
0019      WRITE(6,230)(DS(I),SN(I),D2(I),D3(I),AX(I),T(I),I,I=1,NX)
0020      WRITE(6,CONST)
0021      WRITE(6,100)
0022      ZONE=(1.D0,0.D0)
0023      ZOONE=(0.D0,1.D0)
0024      ONE=1.D0
  
```

Program 2, continued

```

0025      TWO=2.D0
0026      PII=3.1415926536D0
0027      PII2=TWO*PII
0028      W=ONE+FC
0029      W1=W
0030      TANW1=DA/(DT*W1)
0031      WL1=LW
0032      LW02=LW**2/W
0033      DO 10 I=1,NX
0034      THC=D*(ONE+(T(I)-T0)*TCD)
0035      IF(FC.GT.0.D0) GO TO 33
0036      WL2=LW
0037      WC2=1.D30

0038      GO TO 35
0039      33 WC1=3.412586D0+1.27D0*C2
0040      WC2=WC1*(ONE+TC6*(T(I)-T0))
0041      WL2=DSQRT(LW02*WC2**2/(WC2**2-LW02))
0042      35 K3=WL2/(PII2*THC)
0043      W2=(WL2/WC2)**2+ONE
0044      TANW2=TANW1*DSQRT(ONE+TCW*(T(I)-T0))*W1/W2
0045      DQC=DQ*(ONE+TCQ*(T(I)-T0))
0046      DAC=DA*(ONE+AS*(T(I)-T0)+A6*(T(I)-T0)**2)
0047      DXQC=DXQ*(ONE+AQ*(T(I)-T0)+AQQ*(T(I)-T0)**2)
0048      DXQCC=DXQC-DAC-(QN-AN)*W1*TANW1+DQC*W2*TANW2
0049      ANC=AN-TC1*(T(I)-T0)-TC2*(T(I)-T0)**TC3
0050      QNC=QN-TC7*(T(I)-T0)-TC8*(T(I)-T0)**TC9
0051      TXDQ=DTAN(PII2*((QNC-ANC)/WL1-DQC/WL2))
0052      X=ZONE*(DXQCC*PII/WL2)
0053      Y=ZQONE*(-TXDQ)
0054      ZB2=(X+Y)/(ZONE+X*Y)
0055      PII3=PII2/WL2
0056      U=W2-ONE
0057      TA1=DSQRT(ONE+(TANW2/(ONE-U/(1.00054D0+W2))))**2)
0058      AL1D2=ZONE*(PII3*DSQRT(5.D-1*(1.00054*W2-U)*(TA1-ONE))*THC)
0059      BE1D2=ZQONE*(PII3*DSQRT(5.D-1*(1.00054*W2-U)*(TA1+ONE))*THC)
0060      G1D2=AL1D2+BE1D2
0061      DC=DQC+THC
0062      DX=DS(I)-DXQC-(SN(I)-QN)*W1*TANW1+DC*W2*TANW2
0063      COSINE=DCOS(PII*DX/WL2)**2
0064      X=DSIN(PII*DX/WL2)/DSQRT(AX(I)-COSINE)
0065      TXOS=DTAN(PII2*((SN(I)-ANC)/WL1-DC/WL2))
0066      Y=ZQONE*(-TXOS)
0067      Z4=(X+Y)/(ZONE+X*Y)
0068      Z10=ZQONE/K3
0069      Z11=Z10/Z4
0070      Z11RE=SILLY(1)
0071      Z11IM=SILLY(2)
0072      Z16=(1.D0/3.D0)*Z11**2
0073      Z12SQ=CDSQRT(Z11+Z16)
0074      AZ11=CDABS(Z11)
0075      AZ16=CDABS(Z16)
0076      A=PUN(1)
0077      B=PUN(2)
0078      IF(0.D0.LT.B) GO TO 160
0079      WRITE(6,OUT)
0080      B=1.D0
0081      160 TAHA=DTANH(A)
0082      TANB=DTAN(B)
0083      A2=TAHA*(ONE+TANB**2)/(ONE+TAHA**2*TANB**2)
0084      B2=TANB*(ONE+TAHA**2)/(ONE+TAHA**2*TANB**2)
0085      THG2D2=ZONE*A2+ZQONE*B2
0086      G2D2=ZONE*A+ZQONE*B
0087      Z14=(ZONE+G1D2*THG2D2/(ZB2*G2D2))/(ZONE/ZB2+G2D2*THG2D2/G1D2)
0088      Z14RE=FUN(1)
0089      Z14IM=FUN(2)
0090      ERROR1=DSQRT((Z14RE-Z11RE)**2+(Z14IM-Z11IM)**2)

```

Program 2, continued

```

0091      DO 400 K=1,5
0092      TAHA=DTANH(A)
0093      DO 600 J=1,2
0094      WE=ONE+STEP(K)*F(J)
0095      401 BOLD=B
0096      Z14IOD=Z14IM
0097      Z14ROD=Z14RE
0098      EROLD=ERROR1
0099      B=B*WE
0100      TANB=DTAN(B)
0101      A2=TAHA*(ONE+TANB**2)/(ONE+TAHA**2*TANB**2)
0102      B2=TANB*(ONE-TAHA**2)/(ONE+TAHA**2*TANB**2)
0103      THG2D2=ZONE*A2+ZOONE*B2
0104      G2D2=ZONE*A+ZOONE*B
0105      Z14=(ZONE+G1D2*THG2D2/(ZB2*G2D2))/(ZONE/ZB2+G2D2*THG2D2/G1D2)
0106      Z14RE=FUN(1)
0107      Z14IM=FUN(2)
0108      ERROR1=DSQRT((Z14RE-Z11RE)**2+(Z14IM-Z11IM)**2)
0109      IF(ERROR1.LE.EROLD) GO TO 401
0110      Z14IM=Z14IOD
0111      Z14RE=Z14ROD
0112      B=BOLD
0113      ERROR1=EROLD
0114      600 CONTINUE
0115      TANB=DTAN(B)
0116      DO 700 J=1,2
0117      WE=ONE+STEP(K)*F(J)
0118      402 AOLD=A
0119      Z14ROD=Z14RE
0120      Z14IOD=Z14IM
0121      EROLD=ERROR1
0122      A=A*WE
0123      TAHA=DTANH(A)
0124      A2=TAHA*(ONE+TANB**2)/(ONE+TAHA**2*TANB**2)
0125      B2=TANB*(ONE-TAHA**2)/(ONE+TAHA**2*TANB**2)
0126      THG2D2=ZONE*A2+ZOONE*B2
0127      G2D2=ZONE*A+ZOONE*B
0128      Z14=(ZONE+G1D2*THG2D2/(ZB2*G2D2))/(ZONE/ZB2+G2D2*THG2D2/G1D2)
0129      Z14RE=FUN(1)
0130      Z14IM=FUN(2)
0131      ERROR1=DSQRT((Z14RE-Z11RE)**2+(Z14IM-Z11IM)**2)
0132      IF(ERROR1.LE.EROLD) GO TO 402
0133      Z14RE=Z14ROD
0134      Z14IM=Z14IOD
0135      A=AOLD
0136      ERROR1=EROLD
0137      700 CONTINUE
0138      IF(ERROR1.LE.1.D-6) GO TO 450
0139      400 CONTINUE
0140      450 Z12RE=ZONE*A
0141      Z12IM=ZOONE*B
0142      Z12NEW=(Z12RE+Z12IM)**2
0143      K3C=K3*ZONE
0144      Z13=-Z12NEW*K3C**2
0145      FCC=U
0146      G=ZONE*FCC
0147      H=ZONE*W2
0148      Z15=(G+Z13)/H
0149      Z14R=ZONE*Z14RE
0150      Z14I=ZOONE*Z14IM
0151      Z14=Z14R+Z14I
0152      Z17=Z4/Z14
0153      RA=FAKE(1)
0154      AIM=-FAKE(2)
0155      C1C=C1*(ONE+(T(I)-T0)*TC6)
0156      C2C=C2*(ONE+(T(I)-T0)*TC6)
0157      KAPPA=FAKE(1)
0158      TAND=AIM/RA
0159      IF(FC.GT.0.D0) GO TO 210

```

# Program 2, continued

```

0160      L1=DLOG10(D2(I)/C1C)+DLOG10(C2C/D3(I))
0161      L2=DLOG10(D3(I)/D2(I))
0162      L3=DLOG10(C2C/C1C)
0163      R=ONE-L1*KAPPA*(ONE+TAND**2)/L3
0164      KAPPAC=R*KAPPA/((L3/L2)-TWO*L1*KAPPA/L2+(ONE-R)*L1*KAPPA/L2)
0165      TANDC=TAND/R
0166      RE=KAPPAC
0167      TAM=TANDC-TANW2
0168      AIM=RE*TAM
0169      GO TO 15
0170
210 RE=RA+9368.D-4*(RA**2-RA)*(C2C-D3(I))/C2C
18 TAM=AIM/RE-TANW2*(4.2D-1+W2/RA)/(4.2D-1+W2)
0171      AIM=RE*TAM
0172
15 WRITE(6,300) ANC,DX,THC,FCC,B,RE,AIM,TAM,Z17
0173      SIGMA=1.6669198D-2*AIM/DSQRT(LW02)
0174      WRITE(6,301) T(I),SIGMA,C2C
0175
10 CONTINUE
0176      GO TO 77
0177
88 CALL EXIT
0178      END
0179

```

## Output

RAYTHEON POLYIMIDE LAMINATE (OAK) TEMP. RUN 8-3-79

| DS     | SN     | D2  | D3     | AX      | TEMP   | I |
|--------|--------|-----|--------|---------|--------|---|
| 0.0233 | 5.4206 | 0.0 | 0.9948 | 2.00000 | 24.00  | 1 |
| 0.0263 | 5.3965 | 0.0 | 0.9951 | 2.00000 | 52.00  | 2 |
| 0.0251 | 5.3842 | 0.0 | 0.9953 | 2.00000 | 77.00  | 3 |
| 0.0280 | 5.3681 | 0.0 | 0.9956 | 2.00000 | 100.00 | 4 |

&CONST

DA= .600000000000000012D-02,DXQ= .719999999999999980D-02,  
5.99269999999999992 ,DT= 21.0000000000000000 ,  
.4000000000000000019D-03,A6= .0  
.482759999999999993D-03,TC2= .353300000000000000D-08,  
.620900000000000001D-04,TC8= -.5851900000000000023D-09,  
.194299999999999986D-04,C1= .374500000000000000 ,  
6.15979999999999994 ,QN= 5.95910000000000006  
&END

DQ= 1.28760000000000008 ,FC= 1.90060000000000007 ,LW=  
TCW= .400000000000000008D-02,TCQ= .54000000000000005D-06,A5=  
AQ= .150000000000000000D-03,AQQ= .0 ,TC1=  
TC= 24.0000000000000000 ,TC3= 2.5000000000000000 ,TC7=  
TC9= 3.0000000000000000 ,TCD= .9999999999999997D-05,TC6=  
C2= 1.00279999999999991 ,D= .665000000000000036D-01,AN=

| NS     | DS     | D,CORR.      | FC     | B                | K1     | K2       |
|--------|--------|--------------|--------|------------------|--------|----------|
| 6.1586 | 0.0166 | 0.0665       | 1.9025 | 0.2238           | 4.2987 | 0.059233 |
|        | TEMP.= | 24.0 DEG.C.  | SIGMA= | 0.2806D-03MHO/CM |        |          |
| 6.1463 | 0.0196 | 0.0665       | 1.8965 | 0.2286           | 4.4583 | 0.072164 |
|        | TEMP.= | 52.0 DEG.C.  | SIGMA= | 0.3419D-03MHO/CM |        |          |
| 6.1341 | 0.0194 | 0.0665       | 1.8912 | 0.2306           | 4.5282 | 0.071714 |
|        | TEMP.= | 77.0 DEG.C.  | SIGMA= | 0.3397D-03MHO/CM |        |          |
| 6.1229 | 0.0213 | 0.0666       | 1.8863 | 0.2336           | 4.6312 | 0.080035 |
|        | TEMP.= | 100.0 DEG.C. | SIGMA= | 0.3792D-03MHO/CM |        |          |

TAN

Z4/Z14

|                     |              |               |
|---------------------|--------------|---------------|
| 0.013779            | 0.100000D+01 | 0.166215D-07  |
| SAMPLE HOLDER DIA.= | 1.00280      |               |
| 0.016187            | 0.999999D+00 | -0.248313D-08 |
| SAMPLE HOLDER DIA.= | 1.00335      |               |
| 0.015837            | 0.100000D+01 | 0.804382D-09  |
| SAMPLE HOLDER DIA.= | 1.00383      |               |
| 0.017282            | 0.100000D+01 | 0.402349D-08  |
| SAMPLE HOLDER DIA.= | 1.00428      |               |

Program 3 is the latest version for calculating a temperature run for a sample at the bottom of the sample holder. It includes a correction for the fact that a node shift in the hot zone of hollow waveguide does not result in an equal shift in the cold slotted section because the guide wavelengths are different in the two zones. The changes appear in statements 43-47, and 174 in the following program.

### Program 3 Shorted Line Temperature Run

FORTRAN IV G1 RELEASE 2.0

```

0001      INTEGER*4 I,J,K,N,NX,KOUNT,COUNT
0002      REAL*8 K3,Y,XE,AN,SN,LW,DX,DS,DA,X,A,B,A2,B2,Z14RE,Z14IM,TWO,
      2BOLD,Z14IOD,Z14ROD,ERROR1,EROLD,AOLD,AIM,RE,TAM,Z11RE,Z11IM,WE,
      9KAPPA,KAPPAC,L1,L2,L3,R,TAND,TANDC,D2,D,D3,SNC,TC1,T,T0,TC2,TC3,
      3COSINE,FC,W,ZM,YI,TAHA,TANB,PII,PII2,ZRC,ONE,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.D0,-1.D0/SOLD,RA,TANW,DC,DD0,DD,TC4,TC5,WC1,WC2,TC6,LW02,
      7WL2,DOA,A5,A6,C1,C2,C1C,C2C,FCC,SIGMA,AX,TC0
0003      COMPLEX*16 Z1,Z2,Z3,Z9,Z10,Z11,Z12,Z13,Z14R,Z14I,Z16,K3C,
      2Z14,Z12NEW,Z12RE,Z12IM,Z12SQ,G,H,Z15,Z2A,ZONE,ZOONE
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(39),
      2T(30),DD(30),AX(30),SIGMA(30),C2C(30)
0007      NAMELIST/IN/DS,SN,N,NX,D,D2,D3,T,DD,AX/CONST/DA,AN,FC,LW,TANW,
      2TC2,TC3,T0,DD0,TC4,TC5,A5,A6,C1,C2,TC6,TC1,TC0
0008      200 FORMAT(1X,39A2)
0009      201 FORMAT(1H0,20X,39A2)
0010      220 FORMAT(11X,5X,2HDS,6X,2HNS,6X,1HD,7X,2HD2,7X,2HD3,6X,1HN,
      26X,2HDD,4X,11HTEMP,DEG.C.)
0011      230 FORMAT(2X,F8.4,1X,F8.4,2X,F7.4,2X,F6.4,2X,F8.5,2X,I2,2X,F8.4,
      22X,F8.2)
0012      100 FORMAT(1H0,5X,2HNS,6X,2HDS,4X,7HD,CORR.,4X,2HFC,6X,1HB,6X,2HK1,
      29X,2HK2,9X,3HTAN,15X,7HZ11/(14//))
0013      300 FORMAT(2X,F7.4,2X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,3X,F9.6,
      23X,F9.6,3X,E13.6,2X,E13.6)
0014      301 FORMAT(2X,6HDEG.C. 4X,8HSIGMA IN,1X,6HMH0/CM,1X,
      220HSAMPLE HOLDER DIA.'')
0015      302 FORMAT(10X,F7.1,4X,E11.4,10X,F8.5)
0016      77 READ(5,200,END=98) DATE
0017      WRITE(6,201) DATE
0018      READ(5,IN)
0019      READ(5,CONST)
0020      WRITE(6,220)
0021      WRITE(6,230)(DS(I),SN(I),D(I),D2(I),D3(I),N(I),DD(I),T(I),I=1,NX)
0022      WRITE(6,CONST)
0023      WRITE(6,100)
0024      ZONE=(1.D0,0.D0)
0025      ZOONE=(0.D0,1.D0)
0026      ONE=1.D0
0027      TWO=2.D0
0028      PII=3.1415926536D0
0029      PII2=PII*TWO
0030      ZRO=0.D0
0031      DO 10 I=1,NX
0032      IF(DD(I).EQ.DD0) GO TO 22
0033      DC=D(I)+(DD0-DD(I))*2.54D0+TC4*(T(I)-T0)+TC5*(T(I)-T0)**2
0034      GO TO 23
0035      22 DC=D(I)*(ONE+(T(I)-T0)*TCD)
0036      23 SNC=SN(I)+(TC1*(T(I)-T0)+TC2*(T(I)-T0)**TC3)

```

Program 3, continued

```

0037      W=ONE+FC
0038      LW02=LW**2/W
0039      IF(FC.GT.0.D0) GO TO 33
0040      WL2=LW
0041      WC2=1.D30
0042      GO TO 35
0043      33 WC1=3.412586D0*1.27D0*C2
0044      WC2=WC1*(ONE+TC6*(T(I)-T0))
0045      WL2=DSQRT(LW02*WC2**2/(WC2**2-LW02))
0046      35 K3=WL2/(PII2*DC)
0047      Y=PII2*((SNC-AN)/LW-DC/WL2)
0048      DDA=DA*(ONE+A5*(T(I)-T0)+A6*(T(I)-T0)**2)
0049      DX=DS(I)-DDA
0050      IF(DX.LE.ZRO) GO TO 10
0051      COSINE=DCOS(PII*DX/LW)**2
0052      X=DSIN(PII*DX/LW)/DSQRT(AX(I)-COSINE)
0053      Y1=DTAN(Y)
0054      Z1=ZQONE*Y1
0055      Z2A=ZONE*X
0056      Z2=Z2A-Z1
0057      Z3=ZONE-Z2A*Z1
0058      Z9=Z2/Z3
0059      Z10=ZQONE*(-K3)
0060      Z11=Z10*Z9
0061      Z11RE=SILLY(1)
0062      Z11IM=SILLY(2)
0063      ZM=DSQRT(Z11RE**2+Z11IM**2)
0064      IF(N(1).EQ.1) GO TO 141
0065      IF(N(1).GE.2) GO TO 142
0066      141 IF(ZM.LE.ONE.AND.Z11RE.GE.ZRO) GO TO 150
0067      IF(ZM.LE.ONE.AND.Z11RE.LT.ZRO) GO TO 151
0068      IF(ZM.GT.ONE.AND.Z11RE.GE.ZRO) GO TO 152
0069      IF(ZM.GT.ONE.AND.Z11RE.LT.ZRO) GO TO 153
0070      142 IF(ZM.LE.ONE.AND.Z11RE.GE.ZRO) GO TO 170
0071      IF(ZM.LE.ONE.AND.Z11RE.LT.ZRO) GO TO 171
0072      IF(ZM.GT.ONE.AND.Z11RE.GE.ZRO) GO TO 172
0073      IF(ZM.GT.ONE.AND.Z11RE.LT.ZRO) GO TO 173
0074      150 B=ONE
0075      A=42.D-1*DX/LW
0076      GO TO 160
0077      151 B=22.D-1
0078      A=2.D0*DX/LW
0079      GO TO 160
0080      152 B=ONE
0081      A=6.D0*DX/LW
0082      GO TO 160
0083      153 B=18.D-1
0084      A=DX/LW
0085      GO TO 160
0086      170 NDB=N(I)
0087      B=(NDB-ONE)*PII+7854.D-4
0088      A=4.D0*DX/LW
0089      GO TO 160
0090      171 NDB=N(I)
0091      B=NDB*PII-7854.D-4
0092      A=4.D0*DX/LW
0093      GO TO 160
0094      172 NDB=N(I)
0095      B=(2.D0*NDB-1.D0)*15708.D-4-2.D-1/NDB
0096      A=DX/LW
0097      GO TO 160
0098      173 NDB=N(I)
0099      B=(2.D0*NDB-1.D0)*15708.D-4+2.D-1/NDB
0100      A=DX/LW
0101      160 TAHA=DTANH(A)
0102      TANB=DTAN(B)
0103      A2=TAHA*(ONE+TANB**2)/(ONE+TAHA**2*TANB**2)
0104      B2=TANB*(ONE-TAHA**2)/(ONE+TAHA**2*TANB**2)
0105      Z14RE=(A*A2+B*B2)/(A**2+B**2)
0106      Z14IM=(A*B2-B*A2)/(A**2+B**2)

```

Program 3, continued

```

0107      ERROR1=DSQRT((Z14RE-Z11RE)**2+(Z14IM-Z11IM)**2)
0108      COUNT=0
0109      440 COUNT=COUNT+1
0110          DO 400 K=1,22
0111              SOLD=STEP(K)
0112              TAHA=DTANH(A)
0113              DO 600 J=1,2
0114      420 WE=ONE+STEP(K)*F(J)
0115              KOUNT=0
0116      401 KOUNT=KOUNT+1
0117              IF(KOUNT.GT.10.AND.STEP(K).LE.1.D-3) GO TO 411
0118              GO TO 425
0119      411 STEP(K)=STEP(K)*1C.D0
0120              GO TO 420
0121      425 BOLD=B
0122              Z14IOD=Z14IM
0123              Z14ROD=Z14RE
0124              EROLD=ERROR1
0125              B=B*WE
0126              TANB=DTAN(B)
0127              A2=TAHA*(ONE+TANB**2)/(ONE+TAHA**2*TANB**2)
0128              B2=TANB*(ONE-TAHA**2)/(ONE+TAHA**2*TANB**2)
0129              Z14RE=(A*A2+B*B2)/(A**2+B**2)
0130              Z14IM=(A*B2-B*A2)/(A**2+B**2)
0131              ERROR1=DSQRT((Z14RE-Z11RE)**2+(Z14IM-Z11IM)**2)
0132              IF(ERROR1.LE.EROLD) GO TO 401
0133              Z14IM=Z14IOD
0134              Z14RE=Z14ROD
0135              B=BOLD
0136              ERROR1=EROLD
0137              STEP(K)=SOLD
0138      600 CONTINUE
0139              TANB=DTAN(B)
0140              DO 700 J=1,2
0141      421 WE=ONE+STEP(K)*F(J)
0142              KOUNT=0
0143      402 KOUNT=KOUNT+1
0144              IF(KOUNT.GT.10.AND.STEP(K).LE.1.D-3) GO TO 412
0145              GO TO 428
0146      412 STEP(K)=STEP(K)*10.D0
0147              GO TO 421
0148      428 AOLD=A
0149              Z14ROD=Z14RE
0150              Z14IOD=Z14IM
0151              EROLD=ERROR1
0152              A=A*WE
0153              TAHA=DTANH(A)
0154              A2=TAHA*(ONE+TANB**2)/(ONE+TAHA**2*TANB**2)
0155              B2=TANB*(ONE-TAHA**2)/(ONE+TAHA**2*TANB**2)
0156              Z14RE=(A*A2+B*B2)/(A**2+B**2)
0157              Z14IM=(A*B2-B*A2)/(A**2+B**2)
0158              ERROR1=DSQRT((Z14RE-Z11RE)**2+(Z14IM-Z11IM)**2)
0159              IF(ERROR1.LE.EROLD) GO TO 402
0160              Z14RE=Z14ROD
0161              Z14IM=Z14IOD
0162              A=AOLD
0163              ERROR1=EROLD
0164              STEP(K)=SOLD
0165      700 CONTINUE
0166              IF(ERROR1.LE.1.D-7) GO TO 450
0167      400 CONTINUE
0168              IF(ERROR1.GT.1.D-7.AND.COUNT.LE.2) GO TO 440
0169      450 Z12RE=ZONE+A
0170              Z12IM=ZDONE*B
0171              Z12NEW=(Z12RE+Z12IM)**2
0172              K3C=K3*ZONE
0173              Z13=-Z12NEW*K3C**2
0174              FCC=WL2**2/WC2**2
0175              W=ONE+FCC
0176              G=ZONE+FCC

```

Program 3, continued

```

0177      H=ZONE*W
0178      Z15=(G+Z13)/H
0179      Z14R=ZONE*Z14RE
0180      Z14I=ZOOONE*Z14IM
0181      Z14=Z14R+Z14I
0182      Z16=Z11/Z14
0183      RA=FAKE(1)
0184      AIM=-FAKE(2)
0185      C1C=C1*(ONE+(T(I)-T0)*TC6)
0186      C2C(I)=C2*(ONE+(T(I)-T0)*TC6)
0187      KAPPA=FAKE(1)
0188      TAND=AIM/RA
0189      IF(FC.GT.0.D0) GO TO 210
0190      L1=DLOG10(D2(I)/C1C)+DLOG10(C2C(I)/D3(I))
0191      L2=DLOG10(D3(I)/D2(I))
0192      L3=DLOG10(C2C(I)/C1C)
0193      R=ONE-L1*KAPPA*(ONE+TAND**2)/L3
0194      KAPPAC=R*KAPPA/((L3/L2)-TWO*L1*KAPPA/L2+(ONE-R)*L1*KAPPA/L2)
0195      TANDC=TAND/R

0196      RE=KAPPAC
0197      TAM=TANDC-TANW*DDA/DA
0198      AIM=RE*TAM
0199      GO TO 15
0200      210 RE=RA+8368.D-4*(RA**2-RA)*(C2C(I)-D3(I))/C2C(I)
0201      18 TAM=AIM/RE-TANW*DDA*(4.2D-1+W/RA)/((4.2D-1+W)*DA)
0202      AIM=RE*TAM
0203      15 WRITE(6,300) SNC,DX,DC,FCC,B,RE,AIM,TAM,Z16
0204      SIGMA(I)=1.6669198D-2*AIM/DSORT(LW02)
0205      10 CONTINUE
0206      WRITE(6,301)
0207      DO 11 I=1,NX
0208      WRITE(6,302) T(I),SIGMA(I),C2C(I)
0209      11 CONTINUE
0210      GO TO 77
0211      88 CALL EXIT
0212      END

```

In the latter part of this report period we have investigated the possibility of using derivatives in the shorted line (also corresponding relations in the open circuited line) calculations for finding a and b in the expression

$$\tanh(a + jb) / (a + jb) = C + jD$$

when C and D are known. In principle the use of derivatives to extrapolate to the solution could provide faster, more efficient programs than the blind stepping method we have used. In practice we found that the damping required (in a general use program) because of large changes in values of the derivatives resulted in little or no improvement.

If approximately correct initial values of a and b are obtained from charts (or in the case of thin samples at the quarter wave plane, from algebraic expressions) iteration using derivatives is useful, as in our programs for the HP9810A calculator. These are available on request.

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## DIELECTRIC PARAMETERS

Dielectric parameters in this series of reports have the variables in one of the following notations:

- $\kappa'$ ,  $\epsilon'/\epsilon_0$ , K, K1, dielectric constant relative to vacuum
- $\kappa''$ ,  $\epsilon''/\epsilon_0$ , K2, dielectric loss factor relative to vacuum
- $\tan \delta$ ,  $\tan \delta_d$ , TAN DELTA, D.F., dielectric loss tangent (dissipation-factor)
- $\kappa'_m$ ,  $\mu'/\mu_0$ , magnetic permeability relative to vacuum
- $\kappa''_m$ ,  $\mu''/\mu_0$ , magnetic loss factor relative to vacuum
- $\tan \delta_m$ , magnetic loss tangent
- $\sigma$ , a.c. volume conductivity in mho/cm
- $\rho$ , a.c. volume resistivity in ohm-cm

# MATERIALS INDEX

## I. Inorganic Compounds

Aluminum nitrides General Electric/RSD Measurements made under AMMRC contract DAAG46-79-C-0096, reference AMMRC report AMMRC-TR81-45 (March 1982)

| CVD-AlN-3 24 GHz, E parallel to deposition plane |      |       | Hot-pressed (HP-21) 2.64 gm/cc (81%) |       |        |
|--------------------------------------------------|------|-------|--------------------------------------|-------|--------|
| T°C                                              | K    | tan δ | T°C                                  | K     | tan δ  |
| 30                                               | 7.47 | .0020 | 27.5                                 | 5.963 | .00216 |
| 96                                               | 7.56 | .0019 | 136                                  | 6.038 | .00243 |
| 205                                              | 7.68 | .0026 | 222                                  | 6.090 | .00275 |
| 300                                              | 7.83 | .0122 | 311                                  | 6.144 | .00239 |
| 401                                              | 7.98 | .0225 | 408                                  | 6.202 | .00234 |
| 518                                              | 8.21 | .0606 | 507                                  | 6.285 | .00276 |
| 589                                              | 8.36 | .110  | 607                                  | 6.380 | .00320 |
| 672                                              | 8.59 | .181  | 708                                  | 6.457 | .00372 |
| 723                                              | 8.74 | .248  | 738                                  | 6.492 | .00395 |
| 800                                              | 9.0  | .35   | 800                                  | 6.549 | .00435 |

Aluminum oxide

Single crystal, sapphire

Unknown

E ⊥ to optic axis, 8.5 GHz

|          | K    | tan δ           |
|----------|------|-----------------|
| Sample 1 | 9.42 | .00006 ± .00004 |
| 2        | 9.38 | <.00002         |

Ceramic, Wesgo 4078

Western Gold & Pt.

8.5 GHz, 24°C

| K    | tan δ  |
|------|--------|
| 9.31 | .00034 |

Aluminum oxynitride crystal

AMMRC

| T°C | Freq., Hz | 10 <sup>2</sup> | 10 <sup>3</sup> | 10 <sup>4</sup> | 10 <sup>5</sup> | 10 <sup>6</sup> | 10 <sup>7</sup> |
|-----|-----------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 25  | K'        | 8.56            | 8.56            | 8.56            | 8.56            | 8.56            | 8.56            |
|     | tan δ     | .0015           | .0011           | .0006           | .0005           | .0005           | .0004           |
|     | σ         | 7.1E-13         |                 |                 |                 |                 |                 |
| 150 | K'        | 8.62            | 8.60            | 8.60            | 8.60            | 8.60            | 8.60            |
|     | tan δ     | .0033           | .0037           | .0024           | .0018           | .0010           | .0006           |
|     | σ         | 1.6E-12         |                 |                 |                 |                 |                 |
| 300 | K'        | 8.97            | 8.79            | 8.72            | 8.65            | 8.64            | 8.64            |
|     | tan δ     | .0270           | .0108           | .0044           | .0029           | .0026           | .0021           |
|     | σ         | 1.343E-11       |                 |                 |                 |                 |                 |
| 400 | K'        | 10.0            | 9.40            | 9.13            | 8.95            | 8.76            | 8.72            |
|     | tan δ     | .0709           | .0495           | .0229           | .0078           | .0037           | .0031           |
|     | σ         | 3.94E-11        |                 |                 |                 |                 |                 |
| 500 | K'        | 14.0            | 11.7            | 9.92            | 9.18            | 8.95            | 8.87            |
|     | tan δ     | 1.014           | .212            | .0941           | .0370           | .0136           | .0070           |
|     | σ         | 7.89E-10        | 1.38E-9         |                 |                 |                 |                 |

# Beryllium oxide

## Ceramics

418S

Ceradyne

K150

Unknown

23°C, 8.5 GHz

Density = 2.842 g/cm<sup>3</sup>

$\kappa' = 6.60$ ;  $\tan \delta = .00030$

23°C, 8.5 GHz

| Sample | Density<br>(g/cm <sup>3</sup> ) | $\kappa$ | $\tan \delta$ |
|--------|---------------------------------|----------|---------------|
| 1      | 2.891                           | 6.715    | .00037        |
| 2      | 2.882                           | 6.688    | .00039        |

# Boron nitride

Cubic, CVD Specimen No. 1025(3)

24°C, 24 GHz

$\kappa' = 7.01$ ;  $\tan \delta = .0048$

General Electric/RSD measured under  
AMMRC Contract No. DAAG46-79-C-0047;  
reference AMMRC TR79-45(August, 1979)

Hot-pressed, 8.5 GHz, 24°C

| Grade HP |                                 | Carborundum |               | Grade HBC |                                 | Union Carbide |               |
|----------|---------------------------------|-------------|---------------|-----------|---------------------------------|---------------|---------------|
| Sample   | Density<br>(g/cm <sup>3</sup> ) | $\kappa$    | $\tan \delta$ | Sample    | Density<br>(g/cm <sup>3</sup> ) | $\kappa$      | $\tan \delta$ |
| 1        | 1.895                           | 4.28        | .00078        | 1         | 1.943                           | 4.10          | .00015        |
| 2        | 1.879                           | 4.27        | .00078        | 2         | 1.944                           | 4.08          | .00013        |

# Woven fiber

BN-3DX 59-1-1.74

14 GHz

Ford Aerospace

24°C

Face 1, rotation 0°

| Face | Rotation,° | $\kappa$ | $\tan \delta$ | T°C | $\kappa$ | $\tan \delta$ |
|------|------------|----------|---------------|-----|----------|---------------|
| 1    | 0          | 3.775    | .00111        | 200 | 3.796    | .00105        |
|      | 90         | 3.683    | .00047        | 400 | 3.797    | .00114        |
| 2    | 0          | 3.706    | .00066        | 600 | 3.805    | .00092        |
|      | 90         | 3.720    | .00148        | 800 | 3.818    | .00135        |

# Cordierite ceramics

Brunswick 2, 8.5 GHz

Brunswick

Against short

$\lambda/4$  away

| Sample | Face | $\kappa$ | $\tan \delta$ | $\kappa$ | $\tan \delta$ | Density<br>(g/cm <sup>3</sup> ) |
|--------|------|----------|---------------|----------|---------------|---------------------------------|
| 1      | 1    | 4.735    | .00050        |          |               | 2.4472                          |
|        | 2    | 4.729    | .00047        |          |               |                                 |
| 2      | 1    | 4.730    | .00050        | 4.69     | .00047        | 2.5521                          |
|        | 2    | 4.722    | .00047        |          |               |                                 |
| 3      | 1    | 4.717    | .00051        |          |               | 2.4372                          |
|        | 2    | 4.711    | .00056        |          |               |                                 |

## Cordierite ceramics (cont.)

Brunswick 2 (1+2+3) stacked  
Silver paint + silver foil

Brunswick 2-2

Resonant-cavity method TE114

| T°C   | K      | tan δ  |
|-------|--------|--------|
| 25    | 4.7237 | .00050 |
| 81    | 4.7410 | .00054 |
| 103   | 4.7484 | .00054 |
| 133.5 | 4.7585 | .00057 |
| 162   | 4.7664 | .00058 |
| 200   | 4.781  | .00066 |
| 232   | 4.7936 | .00081 |
| 261   | 4.806  | .00114 |
| 372   | 4.8464 | .0023  |
| 409   | 4.8606 | .0033  |
| 418   | 4.865  | .0035  |
| 457   | 4.886  | .0046  |
| 500   | 4.937  | .0061  |

Standing-wave method

| T°C | K     | tan δ  |
|-----|-------|--------|
| 23  | 4.729 | .00052 |
| 100 | 4.754 | .00054 |
| 200 | 4.790 | .00062 |
| 300 | 4.829 | .00137 |
| 400 | 4.863 | .00283 |
| 500 | 4.890 | .00570 |
| 600 | 4.935 | .0115  |
| 700 | 4.980 | .0228  |
| 900 | 5.09  | .080   |

$$\frac{\Delta K/K}{\Delta T} \text{ at } 300^{\circ}\text{C} = \frac{4.8205 - 4.7237}{4.7237 \times 275} = 7.45\text{E-5};$$

$$\frac{\Delta K/K}{\Delta T} \text{ at } 900^{\circ}\text{C} = 8.70\text{E-5}$$

Coor CD1

Coors

| Sample | Against short |       |        | $\lambda/4$ away |        | Density<br>(g/cm <sup>3</sup> ) |
|--------|---------------|-------|--------|------------------|--------|---------------------------------|
|        | Face          | K     | tan δ  | K                | tan δ  |                                 |
| 1      | 1             | 4.858 | .00133 | 4.857            | .00122 | 2.4709                          |
|        | 2             | 4.859 | .00129 | 4.856            | .00120 |                                 |
| 2      | 1             | 4.885 | .00122 | 4.872            | .00120 | 2.4816                          |
|        | 2             | 4.881 | .00122 | 4.871            | .00121 |                                 |
| 3      | 1             | 4.894 | .00134 | 4.884            | .00121 | 2.4862                          |
|        | 2             | 4.894 | .00124 | 4.883            | .00120 |                                 |

Coor CD1-1, silver paint + silver foil

Resonant-cavity method

| T°C   | K      | tan δ  |
|-------|--------|--------|
| 26.3  | 4.8593 | .00130 |
| 88    | 4.8772 | .00145 |
| 119   | 4.888  | .00157 |
| 131   | 4.891  | .00164 |
| 166.7 | 4.905  | .0018  |
| 210.5 | 4.919  | .00229 |
| 243   | 4.928  | .00243 |
| 265   | 4.935  | .0025  |
| 287   | 4.941  | .0035  |
| 308   | 4.955  | .0039  |
| 327   | 4.962  | .0045  |
| 346   | 4.971  | .0050  |
| 373   | 4.983  | .0072  |

Standing-wave method

| T°C | K     | tan δ  |
|-----|-------|--------|
| 23  | 4.857 | .00130 |
| 100 | 4.881 | .00146 |
| 200 | 4.913 | .00200 |
| 300 | 4.943 | .00307 |
| 400 | 4.975 | .00538 |
| 500 | 5.009 | .0111  |
| 600 | 5.046 | .0189  |
| 700 | 5.092 | .034   |
| 800 | 5.142 | .060   |
| 900 | 5.202 | .110   |

$$\frac{\Delta K/K}{\Delta T} \text{ at } 300^{\circ}\text{C} = \frac{.0917}{4.859 \times 273.7} = 6.89\text{E-5};$$

$$\frac{\Delta K/K}{\Delta T} \text{ at } 900^{\circ}\text{C} = \frac{.345}{4.857 \times 877} = 8.10\text{E-5}$$

## Cordierite ceramics (cont.)

"Rayceram" QNP 2102

Raytheon

Resonant-cavity method

| 4.17 GHz (TE111 mode) |        |              | 8.73 GHz (TE113 mode) |        |              |
|-----------------------|--------|--------------|-----------------------|--------|--------------|
| T°C                   | K      | tan $\delta$ | T°C                   | K      | tan $\delta$ |
| 20.5                  | 4.7448 | .0018        | 20.5                  | 4.7439 | .00165       |
| 64                    | 4.7600 | .0019        | 74.7                  | 4.7633 | .0019        |
| 104.5                 | 4.7767 | .0022        | 100.5                 | 4.7761 | .0020        |
| 255.3                 | 4.837  | .0034        | 254                   | 4.8335 | .0034        |
| 334                   | 4.869  | -            | 295                   | 4.8492 | .0041        |
| 368                   | 4.880  | -            | 374                   | 4.9018 | .0052        |
|                       |        |              | 414                   | 4.9145 | .0057        |

Standing-wave method"Rayceram" QNP 2102 in room-  
temperature holder

At 8.515 GHz

|            | K     |        | T°C | K     | tan $\delta$ |
|------------|-------|--------|-----|-------|--------------|
| Pc. 1      | 4.734 | .00154 | 23  | 4.736 | .00154       |
| Pc. 2      | 4.701 | .00157 | 100 | 4.769 | .0020        |
| Pc. 3      | 4.714 | .00155 | 200 | 4.809 | .0033        |
| Pcs. 1/2/3 | 4.736 | .99157 | 300 | 4.852 | .0047        |
|            |       |        | 400 | 4.897 | .0063        |
|            |       |        | 500 | 4.944 | .0082        |
|            |       |        | 600 | 4.992 | .0102        |
|            |       |        | 700 | 5.040 | .0124        |
|            |       |        | 800 | 5.096 | .0152        |

Cordierite + 10% TiO<sub>2</sub>

Raytheon

8.515 GHz, standing-wave method

| T°C | Face | K | tan $\delta$ |
|-----|------|---|--------------|
| 24  | RTH  | 1 | 6.277        |
| 24  |      | 2 | 6.272        |
| 28  | HTH  | 2 | 6.252        |
| 100 |      |   | 6.252        |
| 200 |      |   | 6.280        |
| 300 |      |   | 6.292        |
| 400 |      |   | 6.314        |
| 500 |      |   | 6.353        |
| 600 |      |   | 6.391        |
| 700 |      |   | 6.425        |
| 800 |      |   | 6.443        |

Ferrites

Transtech

TT-1-105

2.45 GHz

| T°C | $\epsilon'/\epsilon_0$ | $\tan \delta$ | Conductivity<br>(mho-cm) | $\mu'/\mu_0$ | $\tan \delta_m$ | Attenuation<br>(db/cm) |
|-----|------------------------|---------------|--------------------------|--------------|-----------------|------------------------|
| 25  | 12.8                   | .0008+.0005   | 1.4E-5                   | -.160        | -10.03          | 13.6                   |
| 50  | 12.8                   | .001          | 1.7E-5                   | -.141        | - 8.60          | 11.4                   |
| 75  | 12.8                   | .0012         | 2.E-5                    | -.081        | -11.0           | 9.36                   |
| 100 | 12.8                   | .0015         | 2.6E-5                   | .023         | 23.8            | 6.47                   |
| 125 | 12.9                   | .0015         | 2.6E-5                   | .162         | 1.34            | 2.64                   |
| 150 | 12.9                   | .0011         | 1.8E-5                   | .48          | .035            | .160                   |
| 175 | 13.0                   | .0015         | 2.65E-5                  | .80          | .0086           | .0623                  |
| 200 | 13.1                   | .0025         | 4.46E-5                  | 1.053        | .0062           | .073                   |
| 250 | 13.3                   | .0067         | 1.21E-4                  | 1.036        | .0072           | .117                   |
| 300 | 13.4                   | .0139         | 2.53E-4                  | 1.031        | .0080           | .184                   |
| 350 | 13.6                   | .0314         | 5.81E-4                  | 1.019        | .0094           | .344                   |
| 400 | 13.8                   | .070          | 1.31E-3                  | 1.014        | .0124           | .707                   |
| 500 | 14.1                   | .392          | 7.5E-3                   | 1.00         | .028            | 3.71                   |

1 GHz

|    |      |             |        |       |       |     |
|----|------|-------------|--------|-------|-------|-----|
| 25 | 12.8 | .0005+.0003 | 3.6E-6 | 2.097 | 2.097 | 7.7 |
|----|------|-------------|--------|-------|-------|-----|

"Ferrimag" 5 (BaO-6F<sub>2</sub>O<sub>3</sub>)

Permag

24°C, 14 GHz

$$\kappa' = 20.\pm 5, \tan \delta_d = .009\pm 4, \mu'/\mu_0 = 1.37\pm .1, \tan \delta_m = .024\pm .01$$

Germanium mullite

General Electric

24 GHz

| T°C | $\kappa$ | $\tan \delta$ | T°C | $\kappa$ | $\tan \delta$ |
|-----|----------|---------------|-----|----------|---------------|
| 25  | 6.92     | .0003         | 450 | 7.54     | .0071         |
| 77  | 7.00     | .0002         | 540 | 7.67     | .0128         |
| 100 | 7.03     | .0003         | 606 | 7.76     | .0152         |
| 180 | 7.16     | .0011         | 674 | 7.85     | .0180         |
| 300 | 7.33     | .0031         | 734 | 7.93     | .022          |
| 375 | 7.44     | .0048         | 800 | 8.04     | .026          |

Lithium Niobate

MIT Lincoln Lab.

24 GHz

|                     |        |
|---------------------|--------|
| E    Y              | E    X |
| $\kappa$ 27.9       | 39.    |
| $\tan \delta$ .0122 | .0054  |

Magnesium fluoride, ITRAN 1

Eastman Kodak

8.5 GHz 23°C

$$\kappa = 5.276 \quad \tan \delta = .00017$$

## Magnesium fluoride, IRTRAN 1 (cont.)

Eastman

24 GHz

| T°C  | K    | tan δ  | T°C | K    | tan δ |
|------|------|--------|-----|------|-------|
| 25.3 | 5.29 | .0001  | 367 | 5.78 | .0006 |
| 53   | 5.33 | .0001  | 451 | 5.93 | .0007 |
| 104  | 5.39 | .0001  | 517 | 6.06 | .0009 |
| 146  | 5.45 | .0002  | 597 | 6.23 | .0013 |
| 194  | 5.52 | .00025 | 654 | 6.36 | .0022 |
| 239  | 5.57 | .00035 | 722 | 6.6  | .060  |
| 293  | 5.66 | .0005  |     |      |       |

## Sialons and Silicon nitride

AFML (Ruh)

 $\text{Si}_3\text{N}_4 + 6\% \text{CeO}_2 + 15\% \text{BN}$ 1800°C vacuum hot-pressed,  
20 Dec. 1977, density=2.866 g/cm<sup>3</sup>1900°C vacuum hot-pressed, Jan. 1978,  
density=2.848 g/cm<sup>3</sup>

14 GHz

| Face | Rotation<br>(degrees) | T°C | K     | tan δ  | Face | Rotation<br>(degrees) | T°C | K     | tan δ |
|------|-----------------------|-----|-------|--------|------|-----------------------|-----|-------|-------|
| 1    | 0                     | 22  | 7.175 | .00966 | 1    | 0                     | 22  | 7.166 | .0131 |
|      | 90                    | 22  | 7.157 | .00931 |      | 90                    | 22  | 7.131 | .0138 |
| 2    | 0                     | 22  | 7.159 | .00935 | 2    | 0                     | 22  | 7.144 | .0133 |
|      | 90                    | 22  | 7.148 | .00875 |      | 90                    | 22  | 7.173 | .0134 |
| 1    | 0                     | 100 | 7.25  | .0125  | 1    | 0                     | 100 | 7.22  | .0154 |
|      |                       | 200 | 7.35  | .0180  |      |                       | 200 | 7.32  | .0210 |
|      |                       | 300 | 7.45  | .0247  |      |                       | 300 | 7.42  | .0249 |
|      |                       | 400 | 7.58  | .0357  |      |                       | 400 | 7.53  | .0415 |
|      |                       | 500 | 7.72  | .0475  |      |                       | 500 | 7.65  | .0548 |
|      |                       | 600 | 7.88  | .059   |      |                       | 600 | 7.78  | .070  |

## G.E. 128-2

General Electric

Resonant-cavity measurements  
at approx. 8.5 GHz

Standing-wave measurements at 24 GHz

| T°C  | K    | tan δ | T°C | K    | tan δ |
|------|------|-------|-----|------|-------|
| 25   | 7.67 | .0014 | 25  | 7.65 | .0028 |
| 100  | 7.72 | .0014 | 100 | 7.67 | .0022 |
| 200  | 7.78 | .0015 | 200 | 7.69 | .0024 |
| 300  | 7.85 | .0015 | 300 | 7.73 | .0025 |
| 400  | 7.91 | .0015 | 400 | 7.78 | .0026 |
| 500  | 7.97 | .0015 | 500 | 7.84 | .0027 |
| 600  | 8.05 | .0015 | 600 | 7.89 | .0027 |
| 700  | 8.13 | .0016 | 700 | 7.95 | .0026 |
| 800  | 8.21 | .0017 | 800 | 8.02 | .0025 |
| 900  | 8.30 | .0018 | 25  | 7.76 | .0019 |
| 1000 | 8.40 | .0021 |     |      |       |
| 1100 | 8.51 | .0026 |     |      |       |
| 1150 | 8.57 | .0030 |     |      |       |
| 1200 | 8.62 | .0037 |     |      |       |
| 1220 | 8.65 | .0040 |     |      |       |
| 1250 | 8.70 | .0050 |     |      |       |
| 1270 | 8.75 | .0098 |     |      |       |

# Sialons and Silicon nitride (cont.)

G.E. 129-1

Resonant-cavity measurements  
at approx. 8.5 GHz

| T°C  | K     | tan δ |
|------|-------|-------|
| 25   | 7.79  | .0015 |
| 100  | 7.815 | .0016 |
| 200  | 7.86  | .0017 |
| 300  | 7.91  | .0017 |
| 400  | 7.97  | .0018 |
| 500  | 8.03  | .0019 |
| 600  | 8.09  | .0020 |
| 700  | 8.16  | .0021 |
| 800  | 8.22  | .0022 |
| 900  | 8.30  | .0023 |
| 1000 | 8.37  | .0026 |
| 1100 | 8.46  | .0030 |
| 1150 | 8.50  | .0033 |
| 1200 | 8.57  | .0038 |
| 1260 | 8.67  | .014  |

General Electric

Standing-wave measurements at 24 GHz

| T°C | K    | tan δ |
|-----|------|-------|
| 25  | 7.67 | .0016 |
| 100 | 7.68 | .0022 |
| 200 | 7.70 | .0028 |
| 300 | 7.73 | .0031 |
| 400 | 7.77 | .0031 |
| 500 | 7.82 | .0032 |
| 600 | 7.87 | .0033 |
| 700 | 7.94 | .0035 |
| 800 | 8.01 | .0040 |

G.E. 130-1

| T°C  | K    | tan δ |
|------|------|-------|
| 25   | 7.44 | .0014 |
| 100  | 7.48 | .0014 |
| 200  | 7.53 | .0015 |
| 300  | 7.58 | .0015 |
| 400  | 7.62 | .0016 |
| 500  | 7.66 | .0017 |
| 600  | 7.71 | .0018 |
| 700  | 7.75 | .0019 |
| 800  | 7.81 | .0020 |
| 900  | 7.87 | .0022 |
| 1000 | 7.93 | .0025 |
| 1100 | 8.02 | .0040 |
| 1150 | 8.08 | .0057 |
| 1200 | 8.18 | .0100 |

| T°C | K    | tan δ  |
|-----|------|--------|
| 25  | 7.55 | .00182 |
| 100 | 7.58 | .00225 |
| 200 | 7.62 | .00266 |
| 300 | 7.65 | .00274 |
| 400 | 7.69 | .00272 |
| 500 | 7.72 | .00268 |
| 600 | 7.77 | .00276 |
| 700 | 7.81 | .00292 |
| 800 | 7.87 | .0031  |

## Silica

Corning 7940 (1979), 8.5 GHz

Corning

In room-temperature sample holder

| Samples        | K     | tan δ             |
|----------------|-------|-------------------|
| 1 pc.          | 3.825 | .00012 ± .00003   |
| 2 pcs. stacked | 3.816 | .00010 ± .00002   |
| 3 pcs. "       | 3.815 | .00010 ± .00003   |
| 4 pcs. "       | 3.820 | .000122 ± .000012 |

## Silica (cont.)

## Corning 7940 (cont.)

## Temperature run, 2 pcs. stacked

| T°C | K     | tan $\delta$              |
|-----|-------|---------------------------|
| 22  | 3.815 | .0001 + .0001<br>- .00005 |
| 104 | 3.819 |                           |
| 165 | 3.823 |                           |
| 222 | 3.829 |                           |
| 326 | 3.837 |                           |
| 410 | 3.843 |                           |
| 510 | 3.853 |                           |
| 611 | 3.862 |                           |
| 699 | 3.879 |                           |
| 751 | 3.882 |                           |

## Corning

## Temperature run, 3 pcs. stacked

| T°C  | K      | tan $\delta$        |
|------|--------|---------------------|
| 19.6 | 3.812* | .00014 $\pm$ .00005 |
| 100  | 3.816  | .00012              |
| 207  | 3.822  | .00010              |
| 300  | 3.829  | .00011              |
| 422  | 3.829  | .00010              |
| 488  | 3.847  | .00011              |
| 572  | 3.847  | .00011              |
| 656  | 3.862  | .00011              |
| 722  | 3.879  | .00010              |
| 750  | 3.882  | .00013              |

\* Not corrected for stacking error.

## Temperature run, 4 pcs. stacked

| T°C  | K**   | tan $\delta$       |
|------|-------|--------------------|
| 25.3 | 3.822 | .00014 $\pm$ .0003 |
| 100  | 3.827 | .00011             |
| 200  | 3.835 | .00010             |
| 297  | 3.844 | .00010             |
| 400  | 3.855 | .00010             |
| 493  | 3.866 | .00012             |
| 600  | 3.878 | .00013             |
| 725  | 3.894 | .00014             |
| 760  | 3.900 | .00014             |
| 800  | 3.905 | .00014             |
| 25.0 | 3.823 | .00014             |

Previous resonant-cavity data<sup>†</sup>

| T°C | K     | tan $\delta$        |
|-----|-------|---------------------|
| 25  | 3.823 | .00015 $\pm$ .00007 |
| 100 | 3.829 | .00014              |
| 200 | 3.836 | .00012              |
| 300 | 3.845 | .00012              |
| 400 | 3.855 | .00012              |
| 500 | 3.866 | .00012              |
| 600 | 3.878 | .00012              |
| 700 | 3.890 | .00012              |
| 800 | 3.904 | .00013              |

\*\* Corrected for stacking error.

<sup>†</sup> Corrected for thermal expansion and frequency shift from 4 to 8.5 GHz.

## Slip cast with moisture proofing, 8.5 GHz

| T°C | K     | tan $\delta$ |
|-----|-------|--------------|
| 22  | 3.224 | .00075       |
| 100 | 3.233 | .00095       |
| 200 | 3.242 | .00092       |
| 300 | 3.247 | .00090       |
| 400 | 3.257 | .00140       |
| 500 | 3.268 | .00180       |

## Harbison-Walker

| T°C | K     | tan $\delta$ |
|-----|-------|--------------|
| 600 | 3.281 | .00250       |
| 700 | 3.293 | .00335       |
| 800 | 3.304 | .0042        |
| 900 | 3.317 | .0050        |
| 22  | 3.198 | .00054       |

# Silica (cont.)

Slip cast, Brunswick 201B (1978), 8.5 GHz

Brunswick

| T°C | K     | tan δ  | T°C | K     | tan δ  |
|-----|-------|--------|-----|-------|--------|
| 22  | 3.460 | .00104 | 650 | 3.481 | .00042 |
| 100 | 3.471 | .00080 | 700 | 3.480 | .00049 |
| 200 | 3.475 | .00050 | 750 | 3.479 | .00058 |
| 300 | 3.475 | .00035 | 800 | 3.482 | .00068 |
| 400 | 3.474 | .00028 | 900 | 3.490 | .00090 |
| 500 | 3.477 | .00030 | 171 | 3.456 | .00016 |
| 600 | 3.481 | .00037 | 57  | 3.450 | .00024 |

Silica Composite ADL-4D6 (1.59gm/cc)

General Electric/RSD measured under  
AMMRC Contract No. DAAG46-79-C-0047;  
reference AMMRC TR79-45(August, 1979)

After preheat to 700°C

| 8.5 GHz, Mode 1 |       |        | ---continued |       |        | 24 GHz As received |       |       |
|-----------------|-------|--------|--------------|-------|--------|--------------------|-------|-------|
| T°C             | K     | tan δ  | T°C          | K     | tan δ  | T°C                | K     | tan δ |
| 22              | 2.656 | .00153 | 503          | 2.673 | .00062 | 24                 | 2.878 | .0072 |
| 1 hour          |       |        | 587          | 2.684 | .00092 | 117                | 2.878 | .0055 |
| 22              | 2.660 | .00218 | 735          | 2.703 | .00120 | 217                | 2.856 | .0039 |
| 67.5            | 2.658 | .00202 | 790          | 2.709 | .00132 | 271                | 2.841 | .0023 |
| 83.5            | 2.657 | .00185 | 835          | 2.714 | .0016  | 320                | 2.833 | .0016 |
| 116.6           | 2.655 | .00093 | 973          | 2.726 | .0028  | 404                | 2.823 | .0018 |
| 123             | 2.654 | .00083 | 1100         | 2.736 | .0032  | 496                | 2.813 | .0020 |
| 190             | 2.650 | .00079 | 1178         | 2.741 | .0036  | 546                | 2.809 | .0021 |
| 252             | 2.649 | .00061 | 1234         | 2.746 | .0040  | 698                | 2.797 | .0022 |
| 300             | 2.652 | .00061 | 1290         | 2.77  | .0045  | 750                | 2.793 | .0023 |
| 411             | 2.663 | .00120 | 1321         | 2.79  | .0048  | 800                | 2.790 | .0023 |
| 429             | 2.665 | .00086 | 1400         | 2.82  | .0057  | 95                 | 2.822 | .0020 |

8.5 GHz, Mode 2

|     |        |        |      |       |        |
|-----|--------|--------|------|-------|--------|
| 22  | 2.8295 | .00196 | 623  | 2.832 | .00079 |
| 130 | 2.8284 | .00122 | 731  | 2.835 | .00126 |
| 189 | 2.826  | .00086 | 1016 | 2.860 | .00302 |

## Silicates

Corning 9754 glass

Corning

8.515 GHz

24 GHz

| T°C | K     | tan δ | T°C | K     | tan δ |
|-----|-------|-------|-----|-------|-------|
| 22  | 8.72  | .0069 | 23  | 8.69  | .0089 |
| 100 | 8.91  | .0069 |     | 8.83  | .0090 |
| 200 | 9.18  | .0070 |     | 9.05  | .0093 |
| 300 | 9.47  | .0072 |     | 9.29  | .0097 |
| 400 | 9.78  | .0074 |     | 9.55  | .0103 |
| 500 | 10.08 | .0079 |     | 9.83  | .0108 |
| 600 | 10.4  | .0085 |     | 10.14 | .0116 |

Silicates (cont.)

"Cervit" Glass-1, 8.515 GHz

Owens-Illinois

| T°C | K    | tan δ | T°C | K    | tan δ |
|-----|------|-------|-----|------|-------|
| 22  | 6.38 | .050  | 400 | 8.52 | .145  |
| 100 | 6.87 | .066  | 444 | 8.88 | .184  |
| 200 | 7.37 | .081  | 538 | 9.12 | .346  |
| 300 | 7.85 | .097  |     |      |       |

Silicon carbide

Vesuvius Crucible

Four-terminal measurements on samples  
of various conductivities

| Sample<br>designation | Resistivity in ohm-cm |         |         |
|-----------------------|-----------------------|---------|---------|
|                       | 100 Hz                | 1 kHz   | 10 kHz  |
| NR2                   | .661                  | .660    | .658    |
| NH1                   | .06414                | .06385  | .06377  |
| LR1                   | .004593               | .004592 | .004509 |
| LH1                   | .003604               | .003598 | .003587 |

Silicon carbide + glass matrix

ITT Gilfillan

May stone .25, 2.45 GHz

| T°C | K    | tan δ | T°C | K    | tan δ |
|-----|------|-------|-----|------|-------|
| 25  | 25.6 | .247  | 300 | 29.5 | .0983 |
| 100 | 26.2 | .275  | 400 | 29.7 | .108  |
| 150 | 27.2 | .239  | 450 | 29.6 | .109  |
| 200 | 28.7 | .115  | 500 | 29.4 | .127  |
| 250 | 29.4 | .0956 |     |      |       |

Repeat run

|     |      |      |     |      |       |
|-----|------|------|-----|------|-------|
| 25  | 25.6 | .190 | 250 | 29.3 | .0955 |
| 100 | 26.2 | .154 | 300 | 29.7 | .0984 |
| 200 | 28.7 | .101 | 400 | 29.8 | .107  |

Silicon nitride

Samples from AMMRC

sintered, 8.515 GHz

| Sample   | Face | Rotation<br>(degrees) | T°C | K     | tan δ  |
|----------|------|-----------------------|-----|-------|--------|
| HP-X-214 | 1    | 0                     | 25  | 8.653 | .00744 |
|          |      | 90                    |     | 8.646 | .00735 |
|          | 2    | 0                     |     | 8.586 | .00655 |
|          |      | 90                    |     | 8.590 | .00654 |
| 7-24     | 1    | 0                     |     | 7.787 | .0229  |
|          |      | 90                    |     | 7.742 | .0214  |
|          | 2    | 0                     |     | 7.455 | .0226  |
|          |      | 90                    |     | 7.511 | .0262  |
| 8-3A     | 1    | 0                     |     | 7.840 | .467   |
|          |      | 90                    |     | 7.828 | .440   |

Silicon nitride (cont.)

Hot-pressed, sample HP-X-214, 8.515 GHz

AMMRC

| T°C  | $\kappa$ | $\tan \delta$ | T°C | $\kappa$ | $\tan \delta$ |
|------|----------|---------------|-----|----------|---------------|
| 23.5 | 8.63     | .0064         | 493 | 9.17     | .0067         |
| 100  | 8.70     | .0066         | 596 | 9.30     | .0065         |
| 207  | 8.81     | .0065         | 679 | 9.40     | .0064         |
| 290  | 8.92     | .0065         | 700 | 9.44     | .0066         |
| 395  | 9.06     | .0070         | 752 | 9.50     | .0067         |

Ceralloy 147Y-1, 24 GHz

Ceradyne

Measurements in room-temperature sample holder

| Sample | Face | Rotation<br>(degrees) | $\kappa$ | $\tan \delta$ |
|--------|------|-----------------------|----------|---------------|
| A      | 1    | 0                     | 8.79     | .00363        |
|        | 2    | 0                     | 8.73     | .00894        |
|        | 2    | 45                    | 8.83     | .00354        |
|        | 2    | 135                   | 8.72     | .00746        |
| B      | 1    | 0                     | 8.26     | .00166        |
|        | 1    | 45                    | 8.27     | .00452        |
|        | 1    | 135                   | 8.42     | .00385        |
|        | 2    | 0                     | 8.25     | .0015         |
|        | 2    | 90                    | 8.39     | .0093         |

Temperature runs

| A, Face 1, 0° |          |               | B, Face 1, 0° |          |               |
|---------------|----------|---------------|---------------|----------|---------------|
| T°C           | $\kappa$ | $\tan \delta$ | T°C           | $\kappa$ | $\tan \delta$ |
| 25            | 8.79     | .0036         | 25            | 8.26     | .0016         |
| 100           | 8.84     | .0041         | 100           | 8.30     | .0017         |
| 200           | 8.90     | .0047         | 200           | 8.38     | .0019         |
| 300           | 8.97     | .0056         | 300           | 8.47     | .0023         |
| 400           | 9.05     | .0061         | 400           | 8.56     | .0024         |
| 500           | 9.14     | .0063         | 500           | 8.66     | .0023         |
| 600           | 9.23     | .0061         | 600           | 8.77     | .0031         |
| 700           | 9.33     | .0062         | 700           | 8.88     | .0048         |
| 750           | 9.38     | .0075         | 750           | 8.93     | .0057         |
| 800           | 9.44     | .0091         | 800           | 8.99     | .0067         |

# Silicon nitride

Chemical vapor deposition, specimen No. 231

General Electric/RSD

Measured at 24GHz under AMMRC Contract No. DAAG46-79-C-0096; reference  
AMMRC TR-81-45(March 1982) 24 GHz

| T°C  | $\kappa$ | $\tan \delta$ | T°C | $\kappa$ | $\tan \delta$ |
|------|----------|---------------|-----|----------|---------------|
| 28.5 | 8.07     | .0003         | 495 | 8.64     | .0004         |
| 99   | 8.13     | <.0003        | 460 | 8.73     | .0004         |
| 208  | 8.24     |               | 624 | 8.82     | .0004         |
| 294  | 8.34     |               | 650 | 8.87     | .0004         |
| 358  | 8.44     |               | 696 | 8.95     | .0005         |
| 414  | 8.53     | <.0004        | 733 | 6.01     | .0005         |

## Silicon nitride plus BN fibers

AVCO

Sample 1 at room temperature

Against short  $\kappa' = 9.40$ ;  $\tan \delta = .118$

$\lambda/4$  away  $\kappa' = 9.00$ ;  $\tan \delta = .144$

Temperature run, average

| T°C | $\kappa$ | $\tan \delta$ | T°C | $\kappa$ | $\tan \delta$ |
|-----|----------|---------------|-----|----------|---------------|
| 25  | 9.15     | .131          | 500 | 9.33     | .137          |
| 100 | 9.18     | .132          | 600 | 9.38     | .137          |
| 200 | 9.21     | .135          | 700 | 9.53     | .138          |
| 300 | 9.25     | .136          | 800 | 9.47     | .139          |
| 400 | 9.30     | .137          |     |          |               |

Sample 2 at room temperature

Against short  $\kappa' = 9.25$ ;  $\tan \delta = .125$

$\lambda/4$  away  $\kappa' = 8.69$ ;  $\tan \delta = .144$

Calculated as a magnetic sample:

$\kappa' = 8.04$ ;  $\tan \delta_d = .9215$ ;  $\mu'/\mu_0 = 1.12$ ;  $\tan \delta_m = .121$

## Silicon mullite, ceramic

General Electric

8.5 GHz, density = 3.15 g/cm<sup>3</sup>

24 GHz, 3.12 g/cm<sup>3</sup>

| T°C | $\kappa$ | $\tan \delta$ | T°C  | $\kappa$ | $\tan \delta$     |
|-----|----------|---------------|------|----------|-------------------|
| 23  | 7.02     | .0004         | 23.5 | 6.98     | .0002 $\pm$ .0001 |
| 83  | 7.09     | .0005         | 111  | 7.04     | .0003             |
| 207 | 7.21     | .0008         | 2.3  | 7.14     | .0004             |
| 357 | 7.40     | .0023         | 276  | 7.22     | .0012             |
| 440 | 7.55     | .0043         | 374  | 7.34     | .0032             |
| 534 | 7.60     | .0062         | 460  | 7.46     | .0070             |
| 573 | 7.75     | .0067         | 554  | 7.59     | .0138             |
| 632 | 7.84     | .0072         | 607  | 7.66     | .0177             |
| 698 | 7.95     | .0073         | 660  | 7.73     | .023              |
| 740 | 8.01     | .0073         | 719  | 7.82     | .030              |
| 800 | 8.12     | .0072         | 740  | 7.86     | .033              |

## Sulfur

Merck Chemical

8.5 GHz

|                                | T°C   | Density<br>(g/cm <sup>3</sup> ) | $\kappa$ | $\tan \delta$       |
|--------------------------------|-------|---------------------------------|----------|---------------------|
| Pressed pellet                 | 23    | 1.683                           | 3.28     | .00005 $\pm$ .00001 |
| Fast cooled from<br>liquid     | 23    | 1.976                           | 3.78     | .00005 $\pm$ .00001 |
| Pressed pellet<br>(m.p. 120°C) | 23    |                                 | 3.379    | .000046             |
|                                | 48    |                                 | 3.378    | .000062             |
|                                | 65    |                                 | 3.378    | .000052             |
|                                | 88    |                                 | 3.379    | .000008             |
|                                | 101   |                                 | 3.375    | .00012              |
|                                | 126.7 |                                 | 3.289    | .00038              |
| Liquid<br>(b.p. 447°C)         | 125   |                                 | 3.38     | .0004               |
|                                | 140   |                                 | 3.38     | .0007               |
|                                | 160   |                                 | 3.38     | .0005               |
|                                | 180   |                                 | 3.39     | .0006               |
|                                | 200   |                                 | 3.40     | .0006               |
|                                | 220   |                                 | 3.40     | .0007               |
|                                | 240   |                                 | 3.40     | <.002               |
|                                | 260   |                                 | 3.41     |                     |
|                                | 280   |                                 | 3.41     |                     |
|                                | 300   |                                 | 3.38     | <.004               |
|                                | 320   |                                 | 3.33     |                     |
|                                | 340   |                                 | 3.28     |                     |
|                                | 360   |                                 | 3.24     |                     |
|                                | 380   |                                 | 3.20     |                     |
|                                | 400   |                                 | 3.17     |                     |
|                                | 444   |                                 | 3.14     | <.005               |

## Zinc sulfide

Eastman Kodak

(IRTRAN 2), 8.5 GHz, 24°C, density = 4.081 g/cm<sup>3</sup> $\kappa' = 8.43$ ;  $\tan \delta = .00160$ 

24 GHz

| T°C | $\kappa$ | $\tan \delta$ | T°C | $\kappa$ | $\tan \delta$ |
|-----|----------|---------------|-----|----------|---------------|
| 25  | 8.32     | .00170        | 600 | 9.32     | .0069         |
| 100 | 8.44     | .00172        | 650 | 9.56     | .0148         |
| 200 | 8.61     | .00175        | 700 | 9.75     | .0244         |
| 300 | 8.79     | .0019         | 730 | 9.92     | .033          |
| 400 | 9.00     | .0025         | 750 | 10.03    | .037          |
| 500 | 9.24     | .0029         |     |          |               |

## Zirconia fiber products

Zircoa

24 GHz, 24°C

|                       | $\kappa$ | $\tan \delta$ |
|-----------------------|----------|---------------|
| "ZIRCAR" Type ZYW-30A | 2.63     | .0082         |
| "ZIRCAR" Type ZYF-100 | 1.474    | .0014         |

## II. Miscellaneous Inorganics

"Pyroceram" 9606

Corning

Measurements on a group of 12 samples received in December 1977 from  
General Dynamics and one sample from Raytheon

Standing-wave measurements at 8.515 GHz, 24°C

| Sample No. | Diameter (inches) | Face 1 |        | Face 2            |        |        | Density (g/cm <sup>3</sup> ) |
|------------|-------------------|--------|--------|-------------------|--------|--------|------------------------------|
|            |                   | κ      | tan δ  | Diameter (inches) | κ      | tan δ  |                              |
| 1 BH       | .9993             | 5.5426 | .00023 | .9996             | 5.5418 | .00022 |                              |
| 1 OP       |                   | 5.5457 | .00020 |                   | 5.5436 | .00022 |                              |
| 2 BH       | 1.0005            | 5.5382 | .00018 | 1.0007            | 5.5389 | .00018 |                              |
| 3          | 1.0004            | 5.5430 | .00020 | 1.0003            | 5.5431 | .00019 |                              |
| 4          | .9992             | 5.5395 | .00021 | .9994             | 5.5405 | .00021 |                              |
| 5          | .9998             | 5.5456 | .00020 | .9998             | 5.5465 | .00020 | 2.5933                       |
| 6.         | .9993             | 5.5481 | .00022 | .9993             | 5.5457 | .00020 |                              |
| 7          | .9996             | 5.5396 | .00021 | .9997             | 5.5414 | .00022 |                              |
| 8          | 1.0000            | 5.5421 | .00021 | 1.0003            | 5.5415 | .00021 | 2.5914                       |
| 9          | .9998             | 5.5446 | .00021 | 1.0000            | 5.5442 | .00021 | 2.5929                       |
| 10         | 1.0003            | 5.5428 | .00021 | 1.0005            | 5.5448 | .00021 | 2.5927                       |
| 11         | .9987             | 5.5359 | .00023 | .9992             | 5.5362 | .00022 | 2.5898                       |
| 12         | .9997             | 5.5469 | .00021 | .9997             | 5.5461 | .00020 | 2.5922                       |

BH - Sample measured against bottom of sample holder.

OP - Sample measured a quarter wavelength from end using a polystyrene tube spacer.

Resonant-cavity measurements at approx. 8.5 GHz

| #1   |          |               | #2   |          |               | #3       |               | #4   |          |               |
|------|----------|---------------|------|----------|---------------|----------|---------------|------|----------|---------------|
| T°F  | $\kappa$ | $\tan \delta$ | T°F  | $\kappa$ | $\tan \delta$ | $\kappa$ | $\tan \delta$ | T°F  | $\kappa$ | $\tan \delta$ |
| 67   | 5.542    | .00023        | 69   | 5.539    | .00020        | 5.543    | .00020        | 74   | 5.540    | .00021        |
| 300  | 5.586    | .0003         | 300  | 5.581    | .00029        | 5.585    | .00030        | 300  | 5.584    | .0004         |
| 600  | 5.643    | .0007         | 600  | 5.635    | .0008         | 5.639    | .0008         | 600  | 5.636    | .0010         |
| 900  | 5.714    | .0021         | 900  | 5.701    | .0014         | 5.712    | .0016         | 900  | 5.713    | .0018         |
| 1200 | 5.80     | .0052         | 1200 | 5.784    | .0045         | 5.79     | .0045         | 1200 | 5.785    | .0054         |

| #5   |          |               | #7   |          |               | #8       |               | #9   |          |               |
|------|----------|---------------|------|----------|---------------|----------|---------------|------|----------|---------------|
| T°F  | $\kappa$ | $\tan \delta$ | T°F  | $\kappa$ | $\tan \delta$ | $\kappa$ | $\tan \delta$ | T°F  | $\kappa$ | $\tan \delta$ |
| 72   | 5.546    | .0002         | 72   | 5.541    | .0002         | 5.542    | .0002         | 72   | 5.544    | .0002         |
| 300  | 5.588    | .0004         | 300  | 5.586    | .0003         | 5.584    | .0004         | 300  | 5.589    | .0004         |
| 600  | 5.646    | .0010         | 600  | 5.647    | .0006         | 5.643    | .00115        | 600  | 5.649    | .0012         |
| 900  | 5.710    | .0015         | 900  | 5.709    | .0014         | 5.710    | .0023         | 900  | 5.713    | .0028         |
| 1200 | 5.793    | .0045         | 1200 | 5.781    | .0052         | 5.790    | .0043         | 1200 | 5.786    | .0056         |

"Pyroceram" 9606 (cont.)

Resonant-cavity measurements at approx. 8.5 GHz (cont.)

| #10  |       |       | #12  |       |       |
|------|-------|-------|------|-------|-------|
| T°F  | κ     | tan δ | T°F  | κ     | tan δ |
| 72   | 5.544 | .0002 | 70   | 5.546 | .0002 |
| 300  | 5.589 | .0004 | 300  | 5.589 | .0004 |
| 600  | 5.649 | .0008 | 600  | 5.646 | .0010 |
| 900  | 5.715 | .0018 | 900  | 5.714 | .0021 |
| 1200 | 5.792 | .0059 | 1200 | 5.798 | .0058 |

| #11  |       |            | #6    |            | Raytheon |            |
|------|-------|------------|-------|------------|----------|------------|
| T°F  | κ     | tan δ      | κ     | tan δ      | κ        | tan δ      |
| 74   | 5.536 | .00022 ± 5 | 5.547 | .00022 ± 5 | 5.661    | .0003 ± 1  |
| 300  | 5.581 | .00028 ± 5 | 5.587 | .00030 ± 5 | 5.697    | .0005 ± 1  |
| 600  | 5.643 | .0007 ± 2  | 5.642 | .00053 ± 7 | 5.751    | .0010 ± 2  |
| 900  | 5.718 | .0018 ± 4  | 5.708 | .0014 ± 2  | 5.808*   | .0019* ± 4 |
| 1200 | 5.81  | .0041 ± 5  | 5.79  | .0042 ± 4  |          |            |

Error in right digit shown for tan δ

Error in κ ± .002 except at 1200°F ± .03

\* Extrapolated from run to 752°F

Average values for 12 samples from Gen. Dynamics

Dec. 1977, densities: 2.5898 to 2.5933 gm/cm<sup>3</sup>

From Raytheon Nov. 1979:

| 8.5 GHz |     |       |        | 8.5 GHz |      |       |        |
|---------|-----|-------|--------|---------|------|-------|--------|
| T°F     | T°C | K     | D.F.   | T°F     | T°C  | K     | D.F.   |
| 73      | 23  | 5.542 | .00021 | 73      | 22.6 | 5.619 | .00028 |
|         |     |       |        | 212     | 100  | 5.649 | .00033 |
| 300     | 149 | 5.586 | .0003  | 392     | 200  | 5.683 | .00060 |
|         |     |       |        | 572     | 300  | 5.720 | .00105 |
| 600     | 316 | 5.643 | .0009  | 752     | 400  | 5.760 | .00165 |
|         |     |       |        | 932     | 500  | 5.804 | .00263 |
| 900     | 482 | 5.711 | .0018  | 1112    | 600  | 5.847 | .00388 |
|         |     |       |        | 1292    | 700  | 5.888 | .00567 |
| 1200    | 649 | 5.79  | .0049  | 1400    | 760  | 5.915 | .0070  |
|         |     |       |        | 1472    | 800  | 5.932 | .0082  |

"Pyroceram" 9606, continued

From Gen. Dynamics July 1978:

| 8.5 GHz |       |        |
|---------|-------|--------|
| T°C     | K     | D.F.   |
| 22.3    | 5.419 | .00030 |
| 100     | 5.453 | .00047 |
| 200     | 5.501 | .00069 |
| 299     | 5.549 | .00097 |
| 400     | 5.601 | .00139 |
| 500     | 5.661 | .00197 |
| 600     | 5.725 | .00294 |
| 700     | 5.781 | .00469 |
| 750     | 5.814 | .00569 |
| 810     | 5.864 | .00734 |

"Pyroceram" 960Q      Corning  
Sample from Gen. Dynamics July 1978  
8.5 GHz

| T°F  | T°C | K     | D.F.   |
|------|-----|-------|--------|
| 73   | 23  | 6.268 | .00024 |
| 122  | 50  | 6.259 | .00022 |
| 176  | 80  | 6.254 | .00022 |
| 212  | 100 | 6.257 | .00024 |
| 248  | 120 | 6.262 | .00026 |
| 284  | 140 | 6.270 | .00029 |
| 338  | 170 | 6.282 | .00033 |
| 392  | 200 | 6.296 | .00042 |
| 572  | 300 | 6.334 | .00050 |
| 752  | 400 | 6.377 | .00098 |
| 932  | 500 | 6.424 | .00236 |
| 1112 | 600 | 6.477 | .0044  |
| 1292 | 700 | 6.542 | .0074  |
| 1472 | 800 | 6.615 | .0113  |
| 1517 | 825 | 6.638 | .0124  |

Pyroceram 960Q      Sample from General Dynamics 1980

| 8.515 GHz |       |        | 24 GHz |       |        |
|-----------|-------|--------|--------|-------|--------|
| T°C       | K     | tan δ  | T°C    | K     | tan δ  |
| 25        | 6.228 | .00027 | 21     | 6.173 | .00032 |
| 100       | 6.209 | .00025 |        | 6.157 | .0004  |
| 200       | 6.206 | .00041 |        | 6.164 | .0005  |
| 300       | 6.215 | .00070 |        | 6.179 | .0006  |
| 400       | 6.236 | .00140 |        | 6.198 | .0010  |
| 500       | 6.265 | .00295 |        | 6.227 | .0020  |
| 600       | 6.296 | .0060  |        | 6.275 | .0050  |
| 700       | 6.321 | .0112  |        | 6.338 | .013   |
| 800       | 6.35  | .018   |        | 6.40  | .020   |

"Pyroceram" 960Z

Corning

Sample from Gen. Dynamics July 1978

Samples from Gen. Dynamics 1980

| 8.5 GHz |       |        | 8.5 GHz |       |        | 24 GHz |        |  |
|---------|-------|--------|---------|-------|--------|--------|--------|--|
| T°C     | K     | D.F.   | T°C     | K     | D.F.   | K      | D.F.   |  |
| 23.1    | 5.732 | .00026 | 21      | 5.688 | .00024 | 5.663  | .00062 |  |
| 90      | 5.771 | .00038 | 100     | 5.737 | .00052 | 5.695  | .0005  |  |
| 150     | 5.811 | .00053 | 200     | 5.795 | .00097 | 5.743  | .0008  |  |
| 231     | 5.861 | .00074 | 300     | 5.853 | .00208 | 5.790  | .0012  |  |
| 297     | 5.901 | .00095 | 400     | 5.919 | .00305 | 5.843  | .0017  |  |
| 350     | 5.938 | .00118 | 500     | 5.987 | .0054  | 5.900  | .0028  |  |
| 435     | 5.999 | .00169 | 600     | 6.054 | .0105  | 5.960  | .0048  |  |
| 525     | 6.064 | .00278 | 700     | 6.132 | .0162  | 6.030  | .0076  |  |
| 585     | 6.107 | .00370 | 800     | 6.19  | .034   | 6.11   | .012   |  |
| 653     | 6.164 | .00550 |         |       |        |        |        |  |
| 690     | 6.188 | .00655 |         |       |        |        |        |  |
| 730     | 6.218 | .00805 |         |       |        |        |        |  |
| 765     | 6.242 | .00966 |         |       |        |        |        |  |
| 800     | 6.272 | .0115  |         |       |        |        |        |  |

Pipe Insulating Compound, fresh mix

Lebanon Steel Foundry

2.15 GHz

| T°F                  | K    | D.F.  | T°F  | K    | D.F.  | Composition: |          |
|----------------------|------|-------|------|------|-------|--------------|----------|
| 77                   | 14.3 | .15   | 500  | 1.22 | .0096 | Perlite      | 82 grams |
| 100                  | 14.3 | .18   | 600  | 1.23 | .012  | SSF          | 5 grams  |
| 150                  | 14.0 | .22   | 700  | 1.24 | .016  | Water        | 23 ml    |
| 200                  | 13.6 | .24   | 800  | 1.26 | .021  | Silicate     | 87 grams |
|                      |      |       | 900  | 1.28 | .028  | ZnO          | 13 grams |
| water lost, unstable |      |       | 1000 | 1.30 | .040  |              |          |
| 300                  | 2.8  | .026  | 1100 | 1.33 | .056  |              |          |
| 350                  | 1.21 | .0074 | 1200 | 1.38 | .081  |              |          |
| 400                  | 1.21 | .0079 |      |      |       |              |          |

Chimney Flue Liner

Sample from MIT, Melcher

D.C. conductivity (one-minute) versus temperature

| T°C   | Sigma, mho/cm | T°C            | Sigma, mho/cm | T°C | Sigma, mho/cm |
|-------|---------------|----------------|---------------|-----|---------------|
| 22.5  | 4.40E-13      | 217.5          | 2.45E-10      | 583 | 5.53E-6       |
| 33    | 3.94E-14      | 232.6          | 4.88E-10      | 653 | 1.19E-5       |
| 55    | 1.33E-13      | 281            | 2.64E-9       | 704 | 1.88E-5       |
| 85    | 5.44E-13      | 302.5          | 5.11E-9       | 751 | 2.95E-5       |
| 103.5 | 1.22E-12      | 411            | 1.21E-7       | 793 | 4.37E-5       |
| 137   | 5.19E-12      | 495            | 5.44E-7       | 841 | 6.83E-5       |
| 161   | 1.53E-11      | 12hrs at 245°C |               | 907 | 1.24E-4       |
| 192   | 7.42E-11      | 439            | 2.08E-7       | 969 | 1.90E-4       |
| 199   | 1.13E-10      | 576            | 5.04E-6       | 982 | 2.05E-4       |

# CHIMNEY FLUE LINER

| 1000/T | T, DEG.C | FREQ., HZ | K1      | K2         | TAN DELTA | SIGMA, MHO/CM |
|--------|----------|-----------|---------|------------|-----------|---------------|
| 3.3824 | 22.5     | 100.      | 5.254   | 0.793128   | 0.150943  | 0.44063E-10   |
| 3.3824 | 22.5     | 1000.     | 5.013   | 0.190604   | 0.038022  | 0.10589E-09   |
| 3.3824 | 22.5     | 10000.    | 4.902   | 0.076039   | 0.015511  | 0.42244E-09   |
| 3.3824 | 22.5     | 100000.   | 4.728   | 0.048433   | 0.010244  | 0.26907E-08   |
| 3.3824 | 22.5     | 1000000.  | 4.677   | 0.038693   | 0.008273  | 0.21496E-07   |
| 3.3824 | 22.5     | 9500000.  | 4.586   | 0.037590   | 0.008196  | 0.19839E-06   |
| 2.6799 | 100.0    | 100.      | 5.831   | 0.634580   | 0.108831  | 0.35254E-10   |
| 2.6799 | 100.0    | 1000.     | 5.316   | 0.236510   | 0.063298  | 0.18695E-09   |
| 2.6799 | 100.0    | 10000.    | 5.041   | 0.157745   | 0.031295  | 0.87636E-09   |
| 2.6799 | 100.0    | 100000.   | 4.892   | 0.093367   | 0.019087  | 0.51870E-08   |
| 2.6799 | 100.0    | 1000000.  | 4.767   | 0.067494   | 0.014160  | 0.37497E-07   |
| 2.6799 | 100.0    | 9500000.  | 4.703   | 0.054057   | 0.011495  | 0.28530E-06   |
| 2.1135 | 200.0    | 100.      | 11.029  | 8.651924   | 0.784484  | 0.48066E-09   |
| 2.1135 | 200.0    | 1000.     | 7.353   | 2.188744   | 0.297670  | 0.12160E-08   |
| 2.1135 | 200.0    | 10000.    | 5.963   | 0.751230   | 0.125976  | 0.41735E-08   |
| 2.1135 | 200.0    | 100000.   | 5.377   | 0.330298   | 0.061433  | 0.18350E-07   |
| 2.1135 | 200.0    | 1000000.  | 5.041   | 0.176863   | 0.035083  | 0.98257E-07   |
| 2.1135 | 200.0    | 9500000.  | 4.872   | 0.105227   | 0.021619  | 0.55589E-06   |
| 1.7447 | 300.0    | 100.      | 45.871  | 216.696243 | 4.724037  | 0.12399E-07   |
| 1.7447 | 300.0    | 1000.     | 18.303  | 30.440948  | 1.663164  | 0.16912E-07   |
| 1.7447 | 300.0    | 10000.    | 9.921   | 5.454198   | 0.549772  | 0.30301E-07   |
| 1.7447 | 300.0    | 100000.   | 6.811   | 1.675701   | 0.246042  | 0.93094E-07   |
| 1.7447 | 300.0    | 1000000.  | 5.654   | 0.607396   | 0.107423  | 0.33744E-06   |
| 1.7447 | 300.0    | 9500000.  | 5.025   | 0.275409   | 0.054803  | 0.14535E-05   |
| 1.4856 | 400.0    | 100.      | 203.086 | 3021.52686 | 14.878033 | 0.16786E-06   |
| 1.4856 | 400.0    | 1000.     | 55.502  | 314.027588 | 5.657909  | 0.17446E-06   |
| 1.4856 | 400.0    | 10000.    | 20.490  | 39.550461  | 1.930255  | 0.21972E-06   |
| 1.4856 | 400.0    | 100000.   | 10.048  | 7.160682   | 0.712662  | 0.39782E-06   |
| 1.4856 | 400.0    | 1000000.  | 6.826   | 1.731097   | 0.253602  | 0.96172E-06   |
| 1.4856 | 400.0    | 9500000.  | 5.554   | 0.569652   | 0.102563  | 0.30065E-05   |
| 1.2934 | 500.0    | 1000.     | 146.175 | 1804.77759 | 12.346718 | 0.10027E-05   |
| 1.2934 | 500.0    | 10000.    | 45.371  | 232.481750 | 5.124066  | 0.12916E-05   |
| 1.2934 | 500.0    | 100000.   | 18.036  | 33.052612  | 1.832572  | 0.18363E-05   |
| 1.2934 | 500.0    | 1000000.  | 9.184   | 6.321146   | 0.688289  | 0.35117E-05   |
| 1.2934 | 500.0    | 9500000.  | 6.103   | 1.639059   | 0.268581  | 0.86506E-05   |

8.5GHz 24°C as received, K=4.95, D.F.=.026; dry, K=4.81, D.F.=.012

New Jersey Sand #2, initial H<sub>2</sub>O 4.25%

M.I.T., Melcher

Sigma, d.c. conductivity mho/cm

| T°C | Sigma    | T°C             | Sigma    | T°C | Sigma   |
|-----|----------|-----------------|----------|-----|---------|
| 28  | 2.11E-10 | 48 hours drying |          | 475 | 2.02E-9 |
| 50  | 3.93E-10 | 63              | 2.09E-13 | 490 | 4.18E-9 |
| 79  | 1.01E-11 | 143             | 1.02E-13 | 549 | 2.20E-8 |
| 95  | 4.73E-12 | 229             | 7.99E-13 | 609 | 1.14E-7 |
| 127 | 5.97E-13 | 269             | 2.61E-12 | 705 | 8.65E-7 |
| 146 | 7.21E-13 | 328             | 1.84E-11 | 747 | 2.73E-6 |
| 216 | 1.11E-12 | 395             | 1.25E-10 | 831 | 4.56E-6 |
| 270 | 5.28E-12 |                 |          |     |         |

### III. Organics

#### "Laminac" 4123

American Cyanamid

| 25°C | Freq., MHz | $\kappa'$ | $\tan \delta$ |
|------|------------|-----------|---------------|
|      | 10         | 3.71      | .0167         |
|      | 30         | 3.64      | .0166         |

#### IL-T001 Absorber

TDK Industries

Sample from Army Materials and Mechanics  
Research Center (AMMRC)

| Frequency, GHz        | 1    | 1.685 | 2.45 | 3     | 5     | 8.5  |
|-----------------------|------|-------|------|-------|-------|------|
| $\kappa'$             | 47.  | 43.   | 41.2 | 39.   | 36.   | 35.  |
| $\tan \delta$         | .104 | .091  | .102 | .1445 | .125  | .085 |
| $\mu'/\mu_0$          | 4.03 | 2.84  | 2.11 | 1.785 | 1.064 | .85  |
| $\tan \delta_m$       | .687 | .937  | 1.20 | 1.218 | 1.585 | 1.29 |
| $\alpha$ , att. db/cm | 9.56 | 16.28 | 24.5 | 28.2  | 41.5  | 51.6 |

#### Ferrite-Epoxy Resin Mixtures

AMMRC

##### FP-4 50 wt% ferrite

| GHz             | 1     | 1.685 | 2.45  | 3     | 5     | 8.5   | 14    | 24   |
|-----------------|-------|-------|-------|-------|-------|-------|-------|------|
| $\kappa$        | 4.469 | 4.328 | 4.178 | 3.153 | 4.119 | 3.950 | 3.92  | 3.90 |
| $\tan \delta$   | .0947 | .0883 | .0874 | .0825 | .0819 | .0620 | .0512 | .046 |
| $\mu'/\mu_0$    | 1.294 | 1.219 | 1.160 | 1.121 | .979  | .963  | .989  | 1.00 |
| $\tan \delta_m$ | .0669 | .1703 | .1858 | .1984 | .190  | .0528 | .0163 | .005 |

##### MAG-20 50 wt% 20 mesh magnetite

|                 |      |      |      |      |      |       |      |      |
|-----------------|------|------|------|------|------|-------|------|------|
| $\kappa'$       | 25.7 | 25.4 | 24.2 | 23.6 | 23.1 | 13.1  | 17.2 | 23.9 |
| $\tan \delta$   | .111 | .109 | .116 | .114 | .101 | .0475 | .03  | .03  |
| $\mu'/\mu_0$    | 1.75 | 1.57 | 1.44 | 1.37 | 1.12 | .937  | .897 | 1.03 |
| $\tan \delta_m$ | .276 | .325 | .378 | .423 | .515 | .579  | .49  | .30  |

##### MAG-65 50 wt% 65 mesh magnetite

|                 |       |       |       |       |       |       |        |
|-----------------|-------|-------|-------|-------|-------|-------|--------|
| $\kappa'$       | 16.84 | 16.5  | 16.46 | 16.3  | 16.25 | 16.16 | 18.8*  |
| $\tan \delta$   | .0624 | .0633 | .0624 | .0656 | .075  | .091  | .0593* |
| $\mu'/\mu_0$    | 1.765 | 1.611 | 1.495 | 1.453 | 1.242 | .985  | 2.149* |
| $\tan \delta_m$ | .203  | .254  | .309  | .326  | .36   | .419  | .0979* |

\*freq. = 300 MHz

#### "Nylon" 66

E. I. Dupont de Nemours and Co.

As Received, .559% water

| Time, sec. | Freq., Hz | $\sigma$ mho/cm |
|------------|-----------|-----------------|
|            | 1000      | 4.96E-11        |
|            | 100       | 3.84E-12        |
| 60         | .00265    | 6.95E-15        |
| 300        | .0053     | 4.15E-15        |
| 778        | .00020    | 2.59E-15        |
| 2400       | .000066   | 1.66E-15        |

After vacuum drying, 2 days, 68°C

| Time, sec. | Freq., Hz | $\sigma$ mho/cm |
|------------|-----------|-----------------|
|            | 1000      | 2.61E-11        |
|            | 100       | 2.14E-12        |
|            | 20        | 3.17E-13        |
| 60         | .00265    | 7.31E-17        |
| 120        | .00133    | 5.41E-17        |
| 180        | .00098    | 3.90E-17        |
| 300        | .00053    | 2.98E-17        |

Frequencies less than 20 Hz calculated as  $1/(2\pi\tau)$ ; this assumes charging current is negligible at these times.

"Nylon" 66

E. I. Dupont de Nemours and Co.  
Sample molded by AMP

Water Content = .13%

| T, DEG.C | FREQ., HZ | K1    | K2       | TAN DELTA | SIGMA, MHO/CM |
|----------|-----------|-------|----------|-----------|---------------|
| 25.0     | 10.       | 3.662 | 0.017556 | 0.004794  | 0.97532E-13   |
| 25.0     | 20.       | 3.647 | 0.019707 | 0.005404  | 0.21896E-12   |
| 25.0     | 30.       | 3.642 | 0.021817 | 0.005990  | 0.36362E-12   |
| 25.0     | 50.       | 3.633 | 0.023715 | 0.006528  | 0.65876E-12   |
| 25.0     | 100.      | 3.618 | 0.027065 | 0.007480  | 0.15036E-11   |
| 25.0     | 200.      | 3.575 | 0.038884 | 0.010875  | 0.43204E-11   |
| 25.0     | 300.      | 3.566 | 0.042309 | 0.011863  | 0.70515E-11   |
| 25.0     | 500.      | 3.563 | 0.048911 | 0.013727  | 0.13586E-10   |
| 25.0     | 1000.     | 3.546 | 0.053687 | 0.015141  | 0.29826E-10   |
| 25.0     | 2000.     | 3.514 | 0.064390 | 0.018323  | 0.71545E-10   |
| 25.0     | 3000.     | 3.483 | 0.067870 | 0.019484  | 0.11312E-09   |
| 25.0     | 5000.     | 3.443 | 0.073324 | 0.021296  | 0.20368E-09   |
| 25.0     | 10000.    | 3.403 | 0.076979 | 0.022619  | 0.42766E-09   |
| 25.0     | 20000.    | 3.388 | 0.078724 | 0.023238  | 0.87472E-09   |
| 25.0     | 50000.    | 3.370 | 0.075890 | 0.022521  | 0.21081E-08   |
| 25.0     | 100000.   | 3.338 | 0.073176 | 0.021923  | 0.40653E-08   |
| 25.0     | 200000.   | 3.305 | 0.069027 | 0.020888  | 0.76697E-08   |
| 25.0     | 300000.   | 3.295 | 0.067828 | 0.020585  | 0.11305E-07   |
| 25.0     | 500000.   | 3.272 | 0.067459 | 0.020620  | 0.18739E-07   |
| 25.0     | 1000000.  | 3.247 | 0.063208 | 0.019468  | 0.35115E-07   |
| 25.0     | 2000000.  | 3.218 | 0.065476 | 0.020345  | 0.72752E-07   |
| 25.0     | 3500000.  | 3.200 | 0.067161 | 0.020990  | 0.13059E-06   |
| 25.0     | 6000000.  | 3.181 | 0.066853 | 0.021019  | 0.22284E-06   |
| 25.0     | 9500000.  | 3.154 | 0.066478 | 0.021075  | 0.35086E-06   |
| 25.0     | 30000000. | 3.145 | 0.067829 | 0.021566  | 0.11305E-05   |

Water Content = .23%

| T, DEG.C | FREQ., HZ | K1    | K2       | TAN DELTA | SIGMA, MHO/CM |
|----------|-----------|-------|----------|-----------|---------------|
| 25.0     | 5.        | 4.413 | 0.108300 | 0.024539  | 0.30083E-12   |
| 25.0     | 10.       | 4.364 | 0.102985 | 0.023598  | 0.57214E-12   |
| 25.0     | 20.       | 4.316 | 0.098521 | 0.022126  | 0.10947E-11   |
| 25.0     | 30.       | 4.285 | 0.098263 | 0.022932  | 0.16377E-11   |
| 25.0     | 50.       | 4.229 | 0.098553 | 0.023304  | 0.27376E-11   |
| 25.0     | 100.      | 4.208 | 0.101789 | 0.024190  | 0.56549E-11   |
| 25.0     | 200.      | 4.119 | 0.123972 | 0.030094  | 0.13775E-10   |
| 25.0     | 300.      | 4.117 | 0.127763 | 0.031036  | 0.21294E-10   |
| 25.0     | 500.      | 4.067 | 0.135682 | 0.033354  | 0.37684E-10   |
| 25.0     | 1000.     | 4.014 | 0.143965 | 0.035868  | 0.79981E-10   |
| 25.0     | 2000.     | 3.957 | 0.148788 | 0.037600  | 0.16532E-09   |
| 25.0     | 3000.     | 3.918 | 0.154694 | 0.039479  | 0.25782E-09   |
| 25.0     | 5000.     | 3.868 | 0.155900 | 0.040306  | 0.43306E-09   |
| 25.0     | 10000.    | 3.795 | 0.160411 | 0.042272  | 0.89117E-09   |
| 25.0     | 20000.    | 3.724 | 0.158407 | 0.042539  | 0.17601E-08   |
| 25.0     | 50000.    | 3.635 | 0.151328 | 0.041682  | 0.42035E-08   |
| 25.0     | 100000.   | 3.574 | 0.141872 | 0.039696  | 0.78818E-08   |
| 25.0     | 200000.   | 3.507 | 0.128033 | 0.038510  | 0.14226E-07   |
| 25.0     | 300000.   | 3.477 | 0.121737 | 0.035016  | 0.20290E-07   |
| 25.0     | 500000.   | 3.450 | 0.113173 | 0.032808  | 0.31437E-07   |
| 25.0     | 1000000.  | 3.378 | 0.103135 | 0.030535  | 0.57297E-07   |
| 25.0     | 2000000.  | 3.358 | 0.091325 | 0.027190  | 0.10147E-06   |
| 25.0     | 3000000.  | 3.324 | 0.085876 | 0.025836  | 0.16898E-06   |
| 25.0     | 6000000.  | 3.297 | 0.083500 | 0.025323  | 0.27833E-06   |
| 25.0     | 9500000.  | 3.275 | 0.078912 | 0.024063  | 0.41595E-06   |
| 25.0     | 30000000. | 3.259 | 0.072724 | 0.022316  | 0.12121E-05   |

## AL-300, polyimide laminate

## Atlantic Laminates

8.5 GHz

| T°C | K    | D.F.  | T°C | K    | D.F.  |
|-----|------|-------|-----|------|-------|
| 26  | 4.65 | .0192 | 179 | 4.64 | .0238 |
| 48  | 4.71 | .0203 | 212 | 4.64 | .0238 |
| 71  | 4.69 | .0212 | 237 | 4.57 | .0220 |
| 96  | 4.70 | .0230 | 259 | 4.58 | .0229 |
| 123 | 4.72 | .0235 | 279 | 4.58 | .0229 |
| 148 | 4.65 | .0228 | 26  | 4.39 | .0103 |

## "Avcoat" 8029

## AVCO

8.5 GHz

| Thickness<br>(cm) | T°C  | K     | D.F.   | Thickness<br>(cm) | T°C                 | K     | D.F.   |
|-------------------|------|-------|--------|-------------------|---------------------|-------|--------|
| 3.189             | 25   | 2.267 | .00079 | 3.228             | 25                  |       |        |
| 3.202             | 60.5 | 2.257 | .00079 |                   | reheated            |       |        |
| 3.210             | 108  | 2.244 | .00101 | 3.469             | 348                 | 2.019 | .0022  |
| 3.215             | 136  | 2.234 | .00116 | 3.949             | 406                 | 1.896 | .00235 |
| 3.241             | 189  | 2.214 | .00130 | 4.197             | 450                 | 1.805 | .00218 |
| 3.276             | 224  | 2.198 | .00148 | 4.415             | 485                 | 1.756 | .00200 |
| 3.377             | 278  | 2.160 | .00172 | 5.037             | 509                 | 1.44  | .0027  |
| 3.432             | 300  | 2.142 | .00188 |                   | liquid with bubbles |       |        |
| 3.771             | 343  | 2.055 | .0021  |                   |                     |       |        |

## AVCO K96 sample one

## AVCO

8.5 GHz

| E perpendicular to<br>hot pressing dir. |       |              |                   | E parallel to<br>hot pressing dir. |              |  |
|-----------------------------------------|-------|--------------|-------------------|------------------------------------|--------------|--|
| T°C                                     | K     | tan $\delta$ | Thickness<br>(cm) | K                                  | tan $\delta$ |  |
| 20.3                                    | 2.464 | .00207       | 1.9350            | 2.383                              | .00160       |  |
| 64.3                                    | 2.453 | .00203       | 1.9424            | 2.375                              | .00187       |  |
| 101                                     | 2.441 | .00210       | 1.9504            | 2.362                              | .00173       |  |
| 148                                     | 2.432 | .00212       | 1.9559            | 2.351                              | .00165       |  |
| 203                                     | 2.406 | .00221       | 1.9711            | 2.326                              | .00091       |  |
| 250                                     | 2.347 | .00239       | 2.0239            | 2.265                              | .00115       |  |
| 303                                     | 2.056 | .00250       | 2.3077            | 1.980                              | .00133       |  |
| 347                                     |       |              | ~ 2.56            |                                    |              |  |

## sample two, E perpendicular to hot pressing direction

| T°C  | K     | tan $\delta$ | Thick, cm | T°C | K     | tan $\delta$ | Thick, cm |
|------|-------|--------------|-----------|-----|-------|--------------|-----------|
| 20.2 | 2.448 | .00150       | 2.2110    | 288 | 2.368 | .00143       | 2.3187    |
| 57   | 2.443 | .00136       | 2.2200    | 325 | 2.345 | .00145       | 2.3522    |
| 84   | 2.436 | .00140       | 2.2295    | 350 | 2.033 | .00133       | 2.8405    |
| 101  | 2.431 | .00132       | 2.2356    | 380 | 1.951 | .00204       | 2.9830    |
| 130  | 2.424 | .00130       | 2.2452    | 400 | 1.431 | .00201       | 3.3168    |
| 148  | 2.418 | .00127       | 2.2533    | 431 | 1.879 | .00190       | 3.3124    |
| 188  | 2.399 | .00100       | 2.2682    | 474 | 1.843 | .00208       | 3.4829    |
| 208  | 2.390 | .00112       | 2.2797    | 509 | 1.645 | .00273       | 3.7028    |
| 248  | 2.385 | .00136       | 2.2909    |     |       |              |           |

## Dielectric insulation boards

23°C

Cincinnati Milacron

| Sample designation | Freq., Hz    | 1 M   | 10 M  | 100 M | 300 M | 1 G   | 3 G    | 8.5 G        | 14 G   | 24 G  |
|--------------------|--------------|-------|-------|-------|-------|-------|--------|--------------|--------|-------|
| PC-75              | $\kappa$     | 4.14  | 3.94  | 3.68  | 3.64  | 3.61  | 3.59   | 3.568 ± .02  | 3.556  | 3.54  |
|                    | tan $\delta$ | .0272 | .0358 | .0378 | .0370 | .0324 | .0289  | .0245        | .0250  | .026  |
| 65M62              | $\kappa$     | 4.40  | 4.22  | 3.96  | 3.89  | 3.81  | 3.755  | 3.715 ± .01  | 3.700  | 3.685 |
|                    | tan $\delta$ | .0305 | .0377 | .0415 | .0394 | .0358 | .0304  | .0256        | .0269  | .029  |
| HP424              | $\kappa$     | 4.49  | 4.22  | 3.95  | 3.89  | 3.82  | 3.76   | 3.710 ± .2   | 3.692  | 3.68  |
|                    | tan $\delta$ | .0399 | .044  | .0455 | .0449 | .0394 | .0337  | .0300        | .0312  | .040  |
| FR-4*              | $\kappa$     | 4.58  | 4.46  | 4.33  | 4.53  | 4.48  | 4.46   | 4.445 ± .02  | 4.42   | 4.38  |
|                    | tan $\delta$ | .0200 | .0202 | .0187 | .0155 | .0146 | .0143  | .0146        | .0150  | .016  |
| MILCLAD            | $\kappa$     | 4.11  | 4.02  | 3.94  | 3.93  | 3.92  | 3.92   | 3.914 ± .01  | 3.912  | 3.90  |
| CA7FR              | tan $\delta$ | .0118 | .0130 | .0132 | .0127 | .0115 | .0105  | .0099        | .00985 | .011  |
| CIMCLAD            | $\kappa$     | 3.86  | 3.78  | 3.69  | 3.76  | 3.71  | 3.675  | 3.645 ± .01  | 3.635  | 3.625 |
| MA*                | tan $\delta$ | .0126 | .0114 | .0110 | .0109 | .0105 | .00928 | .00888       | .0095  | .0105 |
| CIMCLAD            | $\kappa$     | 4.17  | 4.09  | 3.99  | 3.98  | 3.96  | 3.94   | 3.929 ± .02  | 3.917  | 3.91  |
| MA7FR              | tan $\delta$ | .0115 | .0131 | .0133 | .0126 | .0116 | .0110  | .0106        | .0105  | .0108 |
| CIMCLAD            | $\kappa$     | 4.10  | 4.01  | 3.92  | 3.89  | 3.85  | 3.85   | 3.839 ± .006 | 3.83   | 3.82  |
| ACA7FR             | tan $\delta$ | .0122 | .0135 | .0142 | .0137 | .0114 | .0104  | .00995       | .0103  | .0109 |

1, 10, 100 M  $\Sigma$  sheet; higher frequencies,  $\Sigma$  H.\*These are not isotropic within 1% in  $\kappa$ ."Ethofoam" .0381 gm/cm<sup>3</sup>Dart Industries  
Sample from Sperry

| Freq., GHz | K     | D.F.            |
|------------|-------|-----------------|
| 3          | 1.042 | <.0001          |
| 8.5        | 1.042 | .00001 ± .00001 |

"Rulon" II

Dixon Industries

| Freq., Hz     |         | 24°C, Freq. run |          |          |          |          |         |         |         |         |
|---------------|---------|-----------------|----------|----------|----------|----------|---------|---------|---------|---------|
| DC, 1 minute  |         | 60              | 100      | 1 K      | 10 K     | 100 K    | 1 M     | 10 M    | 1 G     | 2.45 G  |
| $\kappa'$     |         | 3.00            | 3.00     | 2.99     | 2.99     | 2.98     | 2.98    | 2.97    | 2.863   | 2.850   |
| $\kappa''$    |         | .0103           | .0103    | .00703   | .00526   | .00462   | .00343  | .00285  | .00472  | .00485  |
| tan $\delta$  |         | .00344          | .00342   | .00235   | .00176   | .00135   | .00115  | .00096  | .00165  | .00170  |
| $\rho$ ohm/cm | 1.3E-16 | 3.44E-13        | 3.78E-13 | 3.90E-12 | 2.92E-11 | 2.57E-10 | 1.90E-9 | 1.58E-8 | 2.62E-6 | 6.6E-6  |
| $\rho$ ohm/cm | 6.6E-15 |                 |          |          |          |          |         |         |         | 3.61E-6 |

Temperature run

| Freq., GHz |  | Temperature run |            |              |                |                 |              |                |                 |              |                |
|------------|--|-----------------|------------|--------------|----------------|-----------------|--------------|----------------|-----------------|--------------|----------------|
|            |  | 1.              | 2.45       |              |                |                 | 3.           |                |                 |              |                |
| T°C        |  | $\kappa'$       | $\kappa''$ | tan $\delta$ | $10^6 \kappa'$ | $10^6 \kappa''$ | tan $\delta$ | $10^6 \kappa'$ | $10^6 \kappa''$ | tan $\delta$ | $10^6 \kappa'$ |
| 26         |  | 2.863           | .00472     | .00165       | 2.62           | 2.850           | .00485       | .00170         | 6.60            | 2.840        | .00517         |
| 74         |  | 2.858           | .00503     | .00176       | 2.79           | 2.839           | .00520       | .00183         | 7.07            | 2.832        | .00586         |
| 109        |  | 2.854           | .00605     | .00212       | 3.36           | 2.835           | .00641       | .00226         | 8.72            | 2.827        | .00732         |
| 136        |  | 2.852           | .00695     | .00321       | 5.9            | 2.833           | .00904       | .00319         | 12.5            | 2.824        | .0105          |
| 173        |  | 2.851           | .0131      | .00531       | 8.41           | 2.829           | .0151        | .00533         | 20.5            | 2.819        | .0164          |
| 205        |  | 2.855           | .0225      | .00787       | 12.5           | 2.827           | .0216        | .00765         | 29.4            | 2.817        | .0228          |
| 250        |  | 2.868           | .0280      | .00975       | 15.5           | 2.829           | .0274        | .00969         | 37.3            | 2.819        | .0290          |
| 22         |  | 2.844           | .00435     | .00153       | 2.42           | 2.836           | .00400       | .00141         | 5.45            |              | .0103          |

"Kevlar" laminates

E. I. Dupont de Nemours and Co.  
Samples from Sperry

8.5 GHz 22°C

After 21-1/2 days 95% R.H.

|    |        | K | tan $\delta$ | wt. % |
|----|--------|---|--------------|-------|
| #1 | Face 1 | 0 | 4.16         | .113  |
| #2 | Face 1 | 0 | 3.93         | .0772 |
| #3 | Face 1 | 0 | 4.19         | .103  |
| #4 | Face 1 | 0 | 3.78         | .0799 |

"Kevlar" laminates, continued As Received  
Against short

Over  $\lambda/4$

| Sample |        | Rotation<br>(degrees) | $\kappa$ | $\tan \delta$ | %H <sub>2</sub> O | $\kappa$ | $\tan \delta$ |
|--------|--------|-----------------------|----------|---------------|-------------------|----------|---------------|
| #1     | Face 1 | 0                     | 4.24     | .0534         | 3.505             | 4.098    | .0707         |
|        |        | 90                    | 4.08     | .0756         |                   |          | .0736         |
|        | Face 2 | 0                     | 4.05     | .084          |                   | 4.176    |               |
|        |        | 90                    | 4.11     | .0819         |                   |          |               |
| #2     | Face 1 | 0                     | 3.65     | .0369         | 2.613             |          |               |
|        |        | 90                    | 3.72     | .0357         |                   |          |               |
| #3     | Face 1 | 0                     | 4.17     | .0886         | 3.677             |          |               |
|        |        | 90                    | 4.24     | .0895         |                   |          |               |
| #4     | Face 1 | 0                     | 3.59     | .0478         | 2.784             |          |               |
|        |        | 90                    | 3.72     | .0451         |                   |          |               |

Dried 2-1/2 days 80°C vac. oven

|    |    |      |       |  |
|----|----|------|-------|--|
| #1 | 0  | 3.35 | .0092 |  |
|    | 90 | 3.38 | .0083 |  |
| #2 | 0  | 3.37 | .0109 |  |
|    | 90 | 3.44 | .0089 |  |
| #3 | 0  | 3.43 | .0110 |  |
|    | 90 | 3.47 | .0099 |  |
| #4 | 0  | 3.20 | .0103 |  |
|    | 90 | 3.29 | .0087 |  |

45 hours 95% R.H. Desiccator

|    |    |      |       |       |
|----|----|------|-------|-------|
| #1 | 0  | 3.84 | .0661 | 3.039 |
|    | 90 | 3.92 | .0672 |       |
| #2 | 0  | 3.62 | .0318 | 2.019 |
|    | 90 | 3.70 | .0311 |       |
| #3 | 0  | 3.79 | .0500 | 2.575 |
|    | 90 | 3.84 | .0503 |       |
| #4 | 0  | 3.60 | .0465 | 2.637 |
|    | 90 | 3.73 | .0448 |       |

Intermediate desiccation

| for Sample #3 | Hours | Rotation<br>(degrees) | $\kappa$ | $\tan \delta$ | wt. % |
|---------------|-------|-----------------------|----------|---------------|-------|
|               | 69    | 0                     | 3.88     | .0583         | 2.931 |
|               |       | 90                    | 3.93     | .0585         |       |
|               | 100   |                       |          |               | 3.228 |
|               | 139   |                       |          |               | 3.465 |

"Kevlar" Ropes

E. I. Dupont de Nemours and Co.

FR is frequency in Hz

Rope A, 24°C, 50% R.H.

| FR        | K1     | K2       | TAN DELTA | SIGMA       |
|-----------|--------|----------|-----------|-------------|
| 50.       | 6.6255 | 0.528094 | 0.079706  | 0.14669E-10 |
| 100.      | 5.9849 | 0.411533 | 0.068762  | 0.22863E-10 |
| 1000.     | 5.7568 | 0.334317 | 0.058074  | 0.18573E-09 |
| 10000.    | 5.2008 | 0.266940 | 0.051268  | 0.14830E-08 |
| 100000.   | 4.7625 | 0.300517 | 0.063100  | 0.16695E-07 |
| 1000000.  | 4.4191 | 0.303765 | 0.068739  | 0.16876E-06 |
| 9500000.  | 4.3046 | 0.316421 | 0.073507  | 0.16700E-05 |
| 30000000. | 3.6555 | 0.304161 | 0.083207  | 0.50694E-05 |

Rope A, 120°C

| FR       | K1     | K2       | TAN DELTA | SIGMA       |
|----------|--------|----------|-----------|-------------|
| 50.      | 21.033 | 53.21245 | 2.52997   | 0.17737E-08 |
| 100.     | 15.918 | 29.27719 | 1.83929   | 0.16265E-08 |
| 1000.    | 6.407  | 5.25332  | 0.81997   | 0.29105E-08 |
| 10000.   | 4.772  | 0.85355  | 0.17885   | 0.47419E-08 |
| 100000.  | 4.560  | 0.19611  | 0.04301   | 0.10895E-07 |
| 1000000. | 4.209  | 0.15851  | 0.03766   | 0.88062E-07 |
| 9500000. | 4.025  | 0.16402  | 0.04075   | 0.86569E-06 |

Rope B, 24°C, 50% R.H.

| FR        | K1     | K2       | TAN DELTA | SIGMA       |
|-----------|--------|----------|-----------|-------------|
| 50.       | 7.6933 | 0.875021 | 0.113738  | 0.24306E-10 |
| 100.      | 7.5078 | 0.640551 | 0.085318  | 0.35586E-10 |
| 1000.     | 6.9986 | 0.444717 | 0.063543  | 0.24706E-09 |
| 10000.    | 6.0960 | 0.323063 | 0.053128  | 0.17992E-08 |
| 100000.   | 5.5494 | 0.346957 | 0.062522  | 0.19275E-07 |
| 1000000.  | 5.1731 | 0.392599 | 0.075892  | 0.21811E-06 |
| 9500000.  | 4.8283 | 0.406893 | 0.084272  | 0.21475E-05 |
| 30000000. | 4.1279 | 0.411350 | 0.099650  | 0.68558E-05 |

Rope B, 120°C

| FR       | K1     | K2       | TAN DELTA | SIGMA       |
|----------|--------|----------|-----------|-------------|
| 50.      | 26.353 | 66.87852 | 2.53784   | 0.18577E-08 |
| 60.      | 23.345 | 57.07666 | 2.44490   | 0.19026E-08 |
| 100.     | 16.986 | 39.67288 | 2.33562   | 0.22040E-08 |
| 1000.    | 5.527  | 6.04871  | 1.09446   | 0.33604E-08 |
| 10000.   | 4.982  | 0.78675  | 0.15793   | 0.43708E-08 |
| 100000.  | 4.783  | 0.17227  | 0.03602   | 0.95707E-08 |
| 1000000. | 4.691  | 0.11827  | 0.02521   | 0.65705E-07 |
| 9500000. | 4.588  | 0.14783  | 0.03222   | 0.78019E-06 |

"Kevlar" Ropes, continued

Rope C, 24°C, 50% R.H.

| FR        | K1      | K2       | TAN DELTA | SIGMA       |
|-----------|---------|----------|-----------|-------------|
| 50.       | 12.3266 | 1.799829 | 0.146012  | 0.49995E-10 |
| 100.      | 11.6037 | 1.436832 | 0.123825  | 0.79824E-10 |
| 1000.     | 9.5361  | 1.285998 | 0.134856  | 0.71444E-09 |
| 10000.    | 8.0059  | 0.964711 | 0.120500  | 0.53595E-08 |
| 100000.   | 6.8165  | 0.687531 | 0.100863  | 0.39196E-07 |
| 1000000.  | 5.6022  | 0.653690 | 0.116684  | 0.36316E-06 |
| 9500000.  | 4.9611  | 0.742388 | 0.149642  | 0.39182E-05 |
| 30000000. | 3.9680  | 0.689153 | 0.173678  | 0.11486E-04 |

Rope C, 120°C

| FR       | K1     | K2        | TAN DELTA | SIGMA       |
|----------|--------|-----------|-----------|-------------|
| 50.      | 36.390 | 160.49568 | 4.41044   | 0.44582E-08 |
| 60.      | 27.560 | 128.04948 | 4.64614   | 0.42693E-08 |
| 100.     | 23.815 | 89.23180  | 3.74686   | 0.49573E-08 |
| 1000.    | 7.197  | 12.34859  | 1.71576   | 0.68603E-09 |
| 10000.   | 5.520  | 1.78799   | 0.32393   | 0.99333E-08 |
| 100000.  | 4.989  | 0.39323   | 0.07881   | 0.21846E-07 |
| 1000000. | 4.886  | 0.22794   | 0.04665   | 0.12663E-06 |
| 9500000. | 4.441  | 0.27151   | 0.06114   | 0.14329E-05 |

Rope D, 24°C, 50% R.H.

| FR        | K1      | K2       | TAN DELTA | SIGMA       |
|-----------|---------|----------|-----------|-------------|
| 50.       | 10.3523 | 1.177239 | 0.113718  | 0.32701E-10 |
| 100.      | 10.1137 | 0.912032 | 0.090178  | 0.50668E-10 |
| 1000.     | 9.4470  | 0.800575 | 0.084744  | 0.44476E-09 |
| 10000.    | 8.0265  | 0.950508 | 0.118422  | 0.52806E-08 |
| 100000.   | 6.4204  | 0.921320 | 0.143320  | 0.51184E-07 |
| 1000000.  | 5.0137  | 0.617431 | 0.123148  | 0.34302E-06 |
| 9500000.  | 4.5359  | 0.532482 | 0.117392  | 0.28103E-05 |
| 30000000. | 3.6717  | 0.476469 | 0.129768  | 0.79412E-05 |

Rope D, 120°C

| FR       | K1     | K2        | TAN DELTA | SIGMA       |
|----------|--------|-----------|-----------|-------------|
| 50.      | 34.260 | 127.21927 | 3.71333   | 0.35339E-08 |
| 60.      | 30.668 | 110.98825 | 3.61901   | 0.36996E-08 |
| 100.     | 22.945 | 87.83615  | 3.82816   | 0.48798E-08 |
| 1000.    | 7.334  | 10.14525  | 1.38328   | 0.56362E-08 |
| 10000.   | 5.576  | 1.54414   | 0.27692   | 0.85786E-08 |
| 100000.  | 5.013  | 0.33321   | 0.06646   | 0.18512E-07 |
| 1000000. | 4.956  | 0.19092   | 0.03853   | 0.10607E-06 |
| 9500000. | 4.625  | 0.24093   | 0.05209   | 0.12716E-05 |

"Mylar" 2-ply, corrugated

E. I. Dupont de Nemours and Co.

| Frequency, MHz | K     | D.F.   |
|----------------|-------|--------|
| 1              | 1.114 | .00507 |
| 10             | 1.107 | .00512 |
| 20             | 1.106 | .00480 |
| 30             | 1.106 | .00380 |

"Riston", exposed film

E. I. Dupont de Nemours and Co.

| Freq., MHz | 1    | 10   | 100   | 1000  | 8515  |
|------------|------|------|-------|-------|-------|
| K          | 3.31 | 3.12 | 2.97  | 2.85  | 2.77  |
| D.F.       | .042 | .039 | .0326 | .0272 | .0182 |

"Sclair" polyethylene  
#8307-UV#5

Dupont of Canada

24 GHz 22°C

K = 2.33 ± .02 D.F. = .00027 ± .00008

After 1500 hours in Atlas Weatherometer:

K = 2.30 ± .02 D.F. = .00041 ± .00003

"Tefzel"

E. I. Dupont de Nemours and Co.

8.5 GHz 23°C K = 2.328 ± .011 D.F. = .0117

"Eccofloat"

Emerson and Cuming

8.5 GHz 24 °C

EF38A, .6002 gm/cm<sup>3</sup> K = 1.8605 D.F. = .0128

EF38B, .4833 gm/cm<sup>3</sup> K = 1.8401 D.F. = .0121

"Eccofoam" H1K 625

Emerson and Cuming

24 GHz 24°C K = 6.0 D.F. = .045

"Stycast" 1.9

Emerson and Cuming

Sample from MIT, RLE

8.5 GHz 24°C K = 1.71 D.F. = .0055

"Esscolam" VI 8166

ESSCO

Sample from Raytheon

The temperature run was made with stacked disks at 8.5 GHz. The thickness shown is the stack height divided by the number of pieces and includes expansion due to trapped decomposition gases.

| T°C | K     | D.F.  | Thick., cm | Atten., db | Insertion loss, db | Excess phase shift (deg.) |
|-----|-------|-------|------------|------------|--------------------|---------------------------|
| 25  | 2.943 | .0158 | .063       | .00789     | .0587              | .058                      |
| 49  | 2.843 | .0216 | .0664      | .0114      | .0621              | .065                      |
| 73  | 2.835 | .0292 | .0669      | .0155      | .0665              | .067                      |
| 107 | 2.84  | .047  | .0677      | .0252      | .0779              | .071                      |
| 129 | 3.032 | .0304 | .0696      | .0169      | .0743              | .086                      |
| 163 | 3.129 | .0764 | .0676      | .0410      | .1112              | .088                      |
| 179 | 2.744 | .0723 | .0754      | .0432      | .1018              | .090                      |
| 198 | 2.748 | .0569 | .0784      | .0355      | .0988              | .103                      |
| 233 | 1.664 | .0283 | .1139      | .0253      | .0446              | .091                      |
| 245 | 2.165 | .0251 | .0909      | .0180      | .0559              | .096                      |
| 258 | 2.817 | .0426 | .0760      | .0258      | .0900              | .098                      |
| 272 | 3.02  | .0527 | .0731      | .0307      | .1042              | .102                      |
| 300 | 3.09  | .0418 | .0735      | .0246      | .1040              | .107                      |

"Lexan" General Purpose Grade, clear

General Electric

| Freq., Hz    | Frequency Run at 25°C |                 |                 |                 |                 |                 |                 |                   |                 |                   |                     |
|--------------|-----------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-------------------|-----------------|-------------------|---------------------|
|              | 10 <sup>2</sup>       | 10 <sup>3</sup> | 10 <sup>4</sup> | 10 <sup>5</sup> | 10 <sup>6</sup> | 10 <sup>7</sup> | 10 <sup>8</sup> | 3x10 <sup>8</sup> | 10 <sup>9</sup> | 3x10 <sup>9</sup> | 8.5x10 <sup>9</sup> |
| Lexan, clear |                       |                 |                 |                 |                 |                 |                 |                   |                 |                   |                     |
| K            | 3.004                 | 3.004           | 3.003           | 2.996           | 2.971           | 2.922           | 2.797           | -                 | 2.780           | 2.773             | -                   |
| tan δ        | .00056                | .00083          | .00132          | .00403          | .00649          | .0111           | .0103           | -                 | .00643          | .00515            | -                   |

"Lexan" 500, polycarbonate

| R.T. 8.5 GHz |        | T°C  | 24 GHz |        |
|--------------|--------|------|--------|--------|
| K            | D.F.   |      | K      | D.F.   |
| 2.921        | .00568 | 24.4 | 2.881  | .00625 |
|              |        | 62.3 | 2.872  | .00734 |
|              |        | 68.3 | 2.871  | .00739 |

"Noryl" (S)

General Electric

| Freq., Hz   | Frequency Run at 25°C |                 |                 |                 |                 |                 |                 |                   |                 |                   |                     |
|-------------|-----------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-------------------|-----------------|-------------------|---------------------|
|             | 10 <sup>2</sup>       | 10 <sup>3</sup> | 10 <sup>4</sup> | 10 <sup>5</sup> | 10 <sup>6</sup> | 10 <sup>7</sup> | 10 <sup>8</sup> | 3x10 <sup>8</sup> | 10 <sup>9</sup> | 3x10 <sup>9</sup> | 8.5x10 <sup>9</sup> |
| Noryl N300  |                       |                 |                 |                 |                 |                 |                 |                   |                 |                   |                     |
| K           | 2.791                 | 2.779           | 2.767           | 2.751           | 2.736           | 2.717           | 2.71            | 2.73              | 2.726           | 2.723             | 2.720               |
| tan δ       | .00324                | .00337          | .00388          | .00367          | .00342          | .00252          | .00241          | .00266            | .00356          | .00436            | .00573              |
| Noryl RN300 |                       |                 |                 |                 |                 |                 |                 |                   |                 |                   |                     |
| K           | 3.044                 | 3.017           | 3.081           | 3.048           | 3.020           | 2.982           | 2.976           | 3.065             | 3.062           | 3.057             | 3.050               |
| tan δ       | .00637                | .00669          | .00697          | .00673          | .00573          | .00409          | .00418          | .00479            | .00578          | .00644            | .00691              |
| Noryl RM240 |                       |                 |                 |                 |                 |                 |                 |                   |                 |                   |                     |
| K           | 3.059                 | 3.034           | 3.002           | 2.981           | 2.960           | 2.938           | 2.927           | 3.062             | 3.057           | 3.052             | 3.046               |
| tan δ       | .00702                | .00649          | .00581          | .00469          | .00385          | .00289          | .00280          | .00320            | .00380          | .00365            | .00324              |

Note: Electric field is perpendicular to faces of injection molded Noryl disks in the frequency range 10<sup>2</sup> to 10<sup>8</sup> Hz; at higher frequencies electric field is parallel to faces of disks.

"Noryl" undesignated

G.E. Sample from Sperry

| Freq., GHz | 24 °C |        |       |        |       |
|------------|-------|--------|-------|--------|-------|
|            | 1     | 3      | 5     | 8.5    | 14    |
| K          | 2.66  | 2.65   | 2.65  | 2.652  | 2.648 |
| D.F.       | .0020 | .00313 | .0036 | .00396 | .0058 |

PPO-534-8G1, polyphenylene oxide

General Electric

| R.T. 8.5 GHz |        | T°C   | 24 GHz |        |
|--------------|--------|-------|--------|--------|
| K            | D.F.   |       | K      | D.F.   |
| 2.635        | .00181 | 25    | 2.628  | .00251 |
|              |        | 62.2  | 2.622  | .00257 |
|              |        | 102.6 | 2.616  | .00246 |
|              |        | 139.7 | 2.599  | .00253 |
|              |        | 145.5 | 2.598  | .00256 |
|              |        | 184.5 | 2.515  | .00269 |
|              |        | 25    | 2.564  | .00231 |

RTV's

General Electric

| 24°C 8.5 GHz |             |
|--------------|-------------|
| K            | D.F.        |
| #60, red     | 3.736 .0172 |
| #630, grey   | 3.016 .0199 |

Marco 28C

R.T. 8.5 GHz  
K D.F.

Sample #1 2.929 .0164  
Sample #2 2.880 .0114

Grace Industries  
Sample from Sperry

Polyethylene with olive drab pigment

Hardigg Industries

24 GHz 23°C K = 2.29 D.F. = .00062

Radome fabrics

Hoover Industries

22 °C 8.5 GHz

Averages for three samples:

|       | K     | D.F.  | Thickness, cm |
|-------|-------|-------|---------------|
| Grey  | 2.889 | .0172 | .059          |
| White | 2.895 | .0174 | .056          |

Polyethylene with 20 wt% gamma ferric oxide (<1μ) R.T. Hellerbond

| Frequency, GHz          | 1      | 1.685 | 2.45   | 3      |
|-------------------------|--------|-------|--------|--------|
| Dielectric Constant     | 2.6605 |       | 2.6576 | 2.6520 |
| Dielectric Loss Tangent | .0025  |       | .0018  | .0015  |
| Magnetic Permeability   | 1.1163 | 1.113 | 1.1099 | 1.0860 |
| Magnetic Loss Tangent   | .01287 | .0389 | .0684  | .0821  |

Hercules PC-072-2 polypropylene

Hercules

| R.T. 8.5 GHz  | 24 GHz | T°C   | K     | D.F.   |
|---------------|--------|-------|-------|--------|
| K = 2.532     |        | 25    | 2.525 | .00206 |
| D.F. = .00217 |        | 62.1  | 2.511 | .00222 |
|               |        | 97.8  | 2.483 | .00232 |
|               |        | 133.2 | 2.441 | .00246 |
|               |        | 25    | 2.532 | .00208 |

"Hycar" E4109

Hycar  
Samples from Raytheon

| 8.5 GHz     |       |       |                |        |
|-------------|-------|-------|----------------|--------|
| T°C         | K     | D.F.  | K              | D.F.   |
| Sample A 22 | 1.191 | .0020 | Sample B 1.178 | .00196 |
| 125         | 1.201 | .0062 | 1.186          | .0054  |
| 25          | 1.190 | .0021 | 1.175          | .0020  |

"Thermocomp" DF1008

Liquid Nitrogen Proc. Corp.

40% glass fiber reinforced polycarbonate 23°C

| Freq. MHz | 1      | 10    | 100    |
|-----------|--------|-------|--------|
| K         | 3.81   | 3.79  | 3.73   |
| D.F.      | .00704 | .0084 | .00864 |

LNP-OF-1006 polyphenylene sulfide

LNP

| R.T. 8.5 GHz | 24 GHz      |       |
|--------------|-------------|-------|
| K D.F.       | T°C K       | D.F.  |
| 3.762 .00406 | 25 3.709    | .0055 |
|              | 58.6 3.722  | .0058 |
|              | 85.8 3.715  | .0063 |
|              | 107.5 3.712 | .0067 |
|              | 135.8 3.677 | .0078 |
|              | 25 3.706    | .0053 |

## LNP-GF-1006 polysulfone

LNP

| R.T.<br>K | 8.5 GHz<br>D.F. | T°C   | 24 GHz<br>K | D.F.  |
|-----------|-----------------|-------|-------------|-------|
| 3.613     | .00763          | 25    | 3.532       | .0087 |
|           |                 | 61.8  | 3.529       | .0102 |
|           |                 | 83.8  | 3.526       | .0107 |
|           |                 | 112.  | 3.516       | .0112 |
|           |                 | 126.8 | 3.506       | .0105 |
|           |                 | 138.3 | 3.494       | .0104 |

## "Loctite" LI-260

24°C

Loctite Corp.

| Freq., Hz            | 100      | 1 k      | 10 k     | 100 k   | 1 M     | 10 M    | 8.5 G   | 14 G    | 24 G    |
|----------------------|----------|----------|----------|---------|---------|---------|---------|---------|---------|
| $\kappa'$            | 4.568    | 4.459    | 4.319    | 4.093   | 3.716   | 3.356   | 2.409   | 2.404   | 2.394   |
| $\kappa''$           | .0851    | .0888    | .127     | .200    | .243    | .230    | .072    | .0683   | .0645   |
| $\tan \delta$ (D.P.) | .0186    | .0199    | .0295    | .0489   | .0653   | .0684   | .0299   | .0284   | .02695  |
| $\sigma$ mho/cm      | 4.74E-12 | 4.94E-12 | 7.09E-10 | 1.11E-8 | 1.35E-7 | 1.28E-6 | 3.41E-4 | 5.31E-4 | 8.31E-4 |

## Bondex 420

Loctite Corp.

Samples from Sperry

| Sample #1<br>T°F | 8.5 GHz<br>K | D.F.  | Sample #2<br>Freq. GHz | R.T.<br>3 | 5    | 8.5   | 14    |
|------------------|--------------|-------|------------------------|-----------|------|-------|-------|
| 74               | 2.855        | .0128 | K                      | 3.07      | 3.05 | 3.027 | 2.958 |
| 139              | 2.90         | .0168 | D.F.                   | .025      | .026 | .027  | .0263 |
| 204              | 2.89         | .0191 |                        |           |      |       |       |

## "Merlon" 1799 polycarbonate

Mobay Chemical Corp.

oven dry

| 1000/T | T, DEG.C | FREQ., HZ  | K1    | K2       | TAN DELTA | SIGMA, MHO/CM |
|--------|----------|------------|-------|----------|-----------|---------------|
| 3.3653 | 24.0     | 20.        | 2.873 | 0.001810 | 0.000630  | 0.20113E-13   |
| 3.3653 | 24.0     | 50.        | 2.877 | 0.001600 | 0.000556  | 0.44455E-13   |
| 3.3653 | 24.0     | 100.       | 2.895 | 0.001456 | 0.000503  | 0.80886E-13   |
| 3.3653 | 24.0     | 200.       | 2.897 | 0.001821 | 0.000629  | 0.20235E-12   |
| 3.3653 | 24.0     | 500.       | 2.894 | 0.002099 | 0.000725  | 0.58299E-12   |
| 3.3653 | 24.0     | 1000.      | 2.905 | 0.002241 | 0.000771  | 0.12450E-11   |
| 3.3653 | 24.0     | 2000.      | 2.904 | 0.002507 | 0.000863  | 0.27854E-11   |
| 3.3653 | 24.0     | 5000.      | 2.904 | 0.003329 | 0.001146  | 0.92465E-11   |
| 3.3653 | 24.0     | 10000.     | 2.904 | 0.004523 | 0.001558  | 0.25128E-10   |
| 3.3653 | 24.0     | 20000.     | 2.895 | 0.005672 | 0.001960  | 0.63022E-10   |
| 3.3653 | 24.0     | 50000.     | 2.867 | 0.008290 | 0.002891  | 0.23027E-09   |
| 3.3653 | 24.0     | 100000.    | 2.839 | 0.010191 | 0.003590  | 0.56618E-09   |
| 3.3653 | 24.0     | 1000000.   | 2.835 | 0.022129 | 0.007807  | 0.12294E-07   |
| 3.3653 | 24.0     | 3000000.   | 2.876 | 0.015637 | 0.005438  | 0.26061E-08   |
| 3.3653 | 24.0     | 30000000.  | 2.845 | 0.026918 | 0.009462  | 0.44864E-07   |
| 3.3653 | 24.0     | 60000000.  | 2.893 | 0.027568 | 0.009529  | 0.91894E-07   |
| 3.3653 | 24.0     | 95000000.  | 2.904 | 0.029700 | 0.010228  | 0.15675E-06   |
| 3.3653 | 24.0     | 300000000. | 2.899 | 0.029737 | 0.010256  | 0.49562E-06   |

"Merlon 1799 polycarbonate .15% water

Mobay

| 1000/T | T, DEG.C | FREQ., HZ  | K1    | K2       | TAN DELTA | SIGMA, MHO/CM |
|--------|----------|------------|-------|----------|-----------|---------------|
| 3.3653 | 24.0     | 5.         | 2.939 | 0.003736 | 0.001271  | 0.10378E-13   |
| 3.3653 | 24.0     | 10.        | 2.941 | 0.002830 | 0.000962  | 0.15721E-13   |
| 3.3653 | 24.0     | 20.        | 2.934 | 0.002222 | 0.000757  | 0.24685E-13   |
| 3.3653 | 24.0     | 50.        | 2.935 | 0.001623 | 0.000553  | 0.45090E-13   |
| 3.3653 | 24.0     | 100.       | 2.933 | 0.001461 | 0.000498  | 0.81140E-13   |
| 3.3653 | 24.0     | 300.       | 2.930 | 0.001685 | 0.000575  | 0.28082E-12   |
| 3.3653 | 24.0     | 1000.      | 2.931 | 0.002294 | 0.000783  | 0.12743E-11   |
| 3.3653 | 24.0     | 3000.      | 2.931 | 0.003168 | 0.001081  | 0.52803E-11   |
| 3.3653 | 24.0     | 10000.     | 2.927 | 0.004844 | 0.001655  | 0.26908E-10   |
| 3.3653 | 24.0     | 20000.     | 2.925 | 0.006437 | 0.002200  | 0.71524E-10   |
| 3.3653 | 24.0     | 50000.     | 2.922 | 0.009453 | 0.003235  | 0.26260E-09   |
| 3.3653 | 24.0     | 100000.    | 2.920 | 0.012359 | 0.004233  | 0.68661E-09   |
| 3.3653 | 24.0     | 1000000.   | 2.896 | 0.024580 | 0.008489  | 0.13655E-07   |
| 3.3653 | 24.0     | 3000000.   | 2.916 | 0.017691 | 0.006066  | 0.29485E-08   |
| 3.3653 | 24.0     | 9500000.   | 2.875 | 0.029417 | 0.010233  | 0.49029E-07   |
| 3.3653 | 24.0     | 30000000.  | 2.848 | 0.032089 | 0.011265  | 0.16936E-06   |
| 3.3653 | 24.0     | 300000000. | 2.837 | 0.028328 | 0.009984  | 0.47214E-06   |

"Merlon 1799 polycarbonate .40% water

Mobay

| 1000/T | T, DEG.C | FREQ., HZ | K1    | K2       | TAN DELTA | SIGMA, MHO/CM |
|--------|----------|-----------|-------|----------|-----------|---------------|
| 3.3653 | 24.0     | 30000000. | 2.831 | 0.035201 | 0.012434  | 0.58668E-06   |
| 3.3653 | 24.0     | 9500000.  | 2.878 | 0.038360 | 0.013329  | 0.20245E-06   |
| 3.3653 | 24.0     | 6000000.  | 2.889 | 0.038060 | 0.013172  | 0.12687E-06   |
| 3.3653 | 24.0     | 16000000. | 2.868 | 0.036307 | 0.012657  | 0.32273E-06   |
| 3.3653 | 24.0     | 3000000.  | 2.907 | 0.037947 | 0.013053  | 0.63245E-07   |
| 3.3653 | 24.0     | 300000.   | 2.952 | 0.023151 | 0.007842  | 0.38585E-08   |
| 3.3653 | 24.0     | 1000000.  | 2.928 | 0.032768 | 0.011191  | 0.18205E-07   |
| 3.3653 | 24.0     | 100000.   | 2.973 | 0.015012 | 0.005049  | 0.83403E-09   |
| 3.3653 | 24.0     | 50000.    | 2.951 | 0.011321 | 0.003837  | 0.31447E-09   |
| 3.3653 | 24.0     | 20000.    | 2.979 | 0.007393 | 0.002482  | 0.82140E-10   |
| 3.3653 | 24.0     | 10000.    | 2.987 | 0.005536 | 0.001853  | 0.30754E-10   |
| 3.3653 | 24.0     | 5000.     | 2.987 | 0.004109 | 0.001376  | 0.11414E-10   |
| 3.3653 | 24.0     | 2000.     | 2.982 | 0.003129 | 0.001049  | 0.34762E-11   |
| 3.3653 | 24.0     | 1000.     | 2.985 | 0.002618 | 0.000877  | 0.14544E-11   |
| 3.3653 | 24.0     | 500.      | 2.987 | 0.002519 | 0.000843  | 0.69976E-12   |
| 3.3653 | 24.0     | 500.      | 2.989 | 0.002411 | 0.000806  | 0.66963E-12   |
| 3.3653 | 24.0     | 200.      | 2.983 | 0.001958 | 0.000656  | 0.21751E-12   |
| 3.3653 | 24.0     | 100.      | 2.988 | 0.001946 | 0.000651  | 0.10814E-12   |
| 3.3653 | 24.0     | 100.      | 2.989 | 0.001831 | 0.000612  | 0.10170E-12   |
| 3.3653 | 24.0     | 50.       | 2.988 | 0.001829 | 0.000612  | 0.50805E-13   |
| 3.3653 | 24.0     | 20.       | 2.990 | 0.002070 | 0.000692  | 0.23000E-13   |

Napthalene C<sub>10</sub>H<sub>8</sub>

MIT Material Science

|             | Freq., GHz | 1     | 1.7    | 3      | 8.5    | 14     |
|-------------|------------|-------|--------|--------|--------|--------|
| 23°C solid  | K          |       |        |        | 2.76   | 2.75   |
|             | D.F.       |       |        |        | .00016 | .00025 |
| 82°C liquid | K          | 2.53  | 2.53   | 2.53   |        | 2.47   |
|             | D.F.       | .0001 | .00022 | .00052 |        | .00115 |

## Laminated polypropylene

24 GHz 24°C

MIT, Lincoln

| Thickness, cm | K    | D.F.  |
|---------------|------|-------|
| .415          | 2.27 | .0010 |
| .751          | 2.28 | .0016 |
| .866          | 2.27 | .0037 |

## RX-18 polymethylpentene

Samples from Naval Underwater Sys. Cen

Mitsui

| Color      | Freq., MHz | 400    | 1000   | 3000   | 8515   | 21°C |
|------------|------------|--------|--------|--------|--------|------|
| None, 1977 | K          | 2.132  | 2.130  | 2.127  | 2.125  |      |
|            | D.F.       | .00041 | .00041 | .00043 | .00054 |      |
| None, 1978 | K          |        |        |        | 2.133  |      |
|            | D.F.       |        |        |        | .00063 |      |
| Yellow     | K          |        |        |        | 2.132  |      |
|            | D.F.       |        |        |        | .00062 |      |
| Red        | K          |        |        |        | 2.1325 |      |
|            | D.F.       |        |        |        | .00062 |      |
| Dark Blue  | K          |        |        |        | 2.134  |      |
|            | D.F.       |        |        |        | .00064 |      |
| Light Blue | K          |        |        |        | 2.130  |      |
|            | D.F.       |        |        |        | .00063 |      |

## TPX Natural

Mitsui

| T°C | Freq., GHz | 1      | 1.685  | 2.45   | 3      | 5      | 8.5     |
|-----|------------|--------|--------|--------|--------|--------|---------|
| 25  | K          | 2.122  | 2.122  | 2.121  | 2.121  | 2.120  | 2.120   |
|     | D.F.       | .00059 | .00061 | .00063 | .00063 | .00061 | .000595 |
| 75  | K          |        |        | 2.092  |        |        |         |
|     | D.F.       |        |        | .00067 |        |        |         |
| 125 | K          |        |        | 2.060  |        |        |         |
|     | D.F.       |        |        | .00071 |        |        |         |
| 175 | K          |        |        | 2.024  |        |        |         |
|     | D.F.       |        |        | .00076 |        |        |         |

## "Texin" 355D, natural, polyurethane

Mobay Chemical Corp.

Oven Dry

| 1000/T | T, DEG.C | FREQ., HZ  | K1    | K2       | TAN DELTA | SIGMA, MHO/CM |
|--------|----------|------------|-------|----------|-----------|---------------|
| 3.3653 | 24.0     | 5.         | 5.827 | 0.493223 | 0.084651  | 0.13701E-11   |
| 3.3653 | 24.0     | 10.        | 5.720 | 0.321775 | 0.056253  | 0.17876E-11   |
| 3.3653 | 24.0     | 20.        | 5.624 | 0.233114 | 0.041447  | 0.25902E-11   |
| 3.3653 | 24.0     | 50.        | 5.562 | 0.177018 | 0.031828  | 0.49172E-11   |
| 3.3653 | 24.0     | 100.       | 5.498 | 0.158494 | 0.028829  | 0.88052E-11   |
| 3.3653 | 24.0     | 200.       | 5.466 | 0.172873 | 0.031628  | 0.19208E-10   |
| 3.3653 | 24.0     | 500.       | 5.325 | 0.170832 | 0.032080  | 0.47453E-10   |
| 3.3653 | 24.0     | 1000.      | 5.258 | 0.170086 | 0.032350  | 0.94492E-10   |
| 3.3653 | 24.0     | 2000.      | 5.204 | 0.169613 | 0.032595  | 0.18846E-09   |
| 3.3653 | 24.0     | 5000.      | 5.106 | 0.174394 | 0.034156  | 0.48443E-09   |
| 3.3653 | 24.0     | 10000.     | 5.026 | 0.169712 | 0.033764  | 0.94284E-09   |
| 3.3653 | 24.0     | 20000.     | 4.951 | 0.186249 | 0.037615  | 0.20694E-08   |
| 3.3653 | 24.0     | 50000.     | 4.892 | 0.197352 | 0.040345  | 0.54820E-08   |
| 3.3653 | 24.0     | 100000.    | 4.765 | 0.207658 | 0.043581  | 0.11537E-07   |
| 3.3653 | 24.0     | 1000000.   | 4.446 | 0.248577 | 0.055915  | 0.13810E-06   |
| 3.3653 | 24.0     | 3000000.   | 4.624 | 0.223435 | 0.048325  | 0.37239E-07   |
| 3.3653 | 24.0     | 30000000.  | 4.238 | 0.261347 | 0.061662  | 0.43558E-06   |
| 3.3653 | 24.0     | 95000000.  | 4.059 | 0.285754 | 0.070401  | 0.15081E-05   |
| 3.3653 | 24.0     | 300000000. | 3.825 | 0.329739 | 0.086210  | 0.54957E-05   |

| "Texin" 355D |          |           | .24% water |          | Mobay     |               |
|--------------|----------|-----------|------------|----------|-----------|---------------|
| 1000/T       | T, DEG.C | FREQ., HZ | K1         | K2       | TAN DELTA | SIGMA, MHO/CM |
| 3.3653       | 24.0     | 1000.     | 5.529      | 0.197005 | 0.035632  | 0.10945E-09   |
| 3.3653       | 24.0     | 300.      | 5.653      | 0.199805 | 0.035343  | 0.33301E-10   |
| 3.3653       | 24.0     | 100.      | 5.821      | 0.226719 | 0.038952  | 0.12595E-10   |
| 3.3653       | 24.0     | 3000.     | 5.409      | 0.200310 | 0.037031  | 0.33385E-09   |
| 3.3653       | 24.0     | 10000.    | 5.252      | 0.209153 | 0.039825  | 0.11620E-08   |
| 3.3653       | 24.0     | 20000.    | 5.157      | 0.215246 | 0.041739  | 0.23916E-08   |
| 3.3653       | 24.0     | 50000.    | 5.041      | 0.235391 | 0.046699  | 0.65386E-08   |
| 3.3653       | 24.0     | 100000.   | 4.946      | 0.236061 | 0.047723  | 0.13114E-07   |
| 3.3653       | 24.0     | 1000000.  | 4.569      | 0.270618 | 0.059230  | 0.15034E-06   |
| 3.3653       | 24.0     | 3000000.  | 4.771      | 0.249592 | 0.052311  | 0.41599E-07   |
| 3.3653       | 24.0     | 3000000.  | 4.354      | 0.278557 | 0.063980  | 0.46426E-06   |
| 3.3653       | 24.0     | 9500000.  | 4.159      | 0.298530 | 0.071771  | 0.15756E-05   |
| 3.3653       | 24.0     | 100.      | 5.744      | 0.198500 | 0.034555  | 0.11028E-10   |
| 3.3653       | 24.0     | 50.       | 5.865      | 0.240356 | 0.040982  | 0.66766E-11   |
| 3.3653       | 24.0     | 20.       | 5.990      | 0.358001 | 0.059769  | 0.39778E-11   |
| 3.3653       | 24.0     | 10.       | 6.088      | 0.432141 | 0.070988  | 0.24008E-11   |

| "Texin" 355D |          |           | 1.14% water |          | Mobay     |               |
|--------------|----------|-----------|-------------|----------|-----------|---------------|
| 1000/T       | T, DEG.C | FREQ., HZ | K1          | K2       | TAN DELTA | SIGMA, MHO/CM |
| 3.3653       | 24.0     | 30000000. | 4.044       | 0.396381 | 0.098006  | 0.66063E-05   |
| 3.3653       | 24.0     | 95000000. | 4.328       | 0.378195 | 0.087390  | 0.19960E-05   |
| 3.3653       | 24.0     | 60000000. | 4.471       | 0.369416 | 0.082618  | 0.12314E-05   |
| 3.3653       | 24.0     | 30000000. | 4.603       | 0.359783 | 0.078168  | 0.59964E-06   |
| 3.3653       | 24.0     | 4000000.  | 5.151       | 0.317665 | 0.061671  | 0.70592E-07   |
| 3.3653       | 24.0     | 2000000.  | 5.151       | 0.292836 | 0.056847  | 0.32537E-07   |
| 3.3653       | 24.0     | 1000000.  | 5.708       | 0.280082 | 0.049068  | 0.15560E-07   |
| 3.3653       | 24.0     | 500000.   | 5.379       | 0.261052 | 0.048534  | 0.72515E-08   |
| 3.3653       | 24.0     | 200000.   | 5.573       | 0.244764 | 0.043922  | 0.27136E-08   |
| 3.3653       | 24.0     | 100000.   | 5.673       | 0.239800 | 0.042267  | 0.13322E-08   |
| 3.3653       | 24.0     | 50000.    | 6.185       | 0.242461 | 0.039204  | 0.67350E-09   |
| 3.3653       | 24.0     | 20000.    | 5.883       | 0.272124 | 0.046255  | 0.30236E-09   |
| 3.3653       | 24.0     | 10000.    | 5.964       | 0.325954 | 0.054652  | 0.18109E-09   |
| 3.3653       | 24.0     | 5000.     | 6.095       | 0.425658 | 0.069834  | 0.11824E-09   |
| 3.3653       | 24.0     | 2000.     | 6.246       | 0.691620 | 0.110727  | 0.76847E-10   |
| 3.3653       | 24.0     | 1000.     | 6.407       | 1.150263 | 0.179529  | 0.63903E-10   |
| 3.3653       | 24.0     | 1000000.  | 4.987       | 0.346178 | 0.070842  | 0.19232E-06   |
| 3.3653       | 24.0     | 50.       | 6.660       | 1.667348 | 0.250363  | 0.46315E-10   |
| 3.3653       | 24.0     | 50.       | 6.640       | 1.947284 | 0.293261  | 0.54091E-10   |
| 3.3653       | 24.0     | 20.       | 7.157       | 4.148470 | 0.579605  | 0.46094E-10   |
| 3.3653       | 24.0     | 10.       | 7.634       | 7.581223 | 0.967773  | 0.42118E-10   |

Polysulfone board

Norplex Division, UOP Inc.

| T°C | Freq., GHz | 1      | 2.45   | 3      | 5      | 8.5    | 16     | 24     |
|-----|------------|--------|--------|--------|--------|--------|--------|--------|
| 23  | "          | 2.981  | 2.978  | 2.977  | 2.975  | 2.960  | 2.950  | 2.945  |
|     | tan δ      | .00393 | .00459 | .00469 | .00524 | .00539 | .00560 | .00573 |
| 50  | "          | 2.983  | 2.976  | 2.975  | 2.973  | 2.954  | 2.946  | 2.940  |
|     | tan δ      | .00412 | .00484 | .00523 | .00568 | .00595 | .00623 | .00669 |
| 100 | "          | 2.984  | 2.982  | 2.980  | 2.976  | 2.953  | 2.945  | 2.940  |
|     | tan δ      | .00458 | .00548 | .00585 | .00634 | .00704 | .00734 | .00760 |
| 150 | "          | 2.965  | 2.963  | 2.961  | 2.958  | 2.948  | 2.943  | 2.935  |
|     | tan δ      | .00428 | .00552 | .00603 | .00664 | .00766 | .00812 | .00877 |
| 175 | "          | 2.948  | 2.946  | 2.945  | 2.941  | 2.934  | 2.928  | 2.921  |
|     | tan δ      | .00370 | .00500 | .00546 | .00623 | .00762 | .00872 | .00968 |
| 150 | "          | 2.952  | 2.952  | 2.951  | 2.950  | 2.946  | 2.940  | 2.934  |
|     | tan δ      | .00362 | .00474 | .00526 | .00594 | .00695 | .00725 | .00784 |
| 100 | "          | 2.953  | 2.952  | 2.951  | 2.949  | 2.942  | 2.936  | 2.931  |
|     | tan δ      | .00357 | .00458 | .00489 | .00547 | .00649 | .00660 | .00680 |
| 50  | "          | 2.959  | 2.957  | 2.957  | 2.955  | 2.940  | 2.935  | 2.928  |
|     | tan δ      | .00352 | .00431 | .00456 | .00501 | .00562 | .00570 | .00574 |
| 23  | "          | 2.959  | 2.958  | 2.956  | 2.954  | 2.937  | 2.935  | 2.930  |
|     | tan δ      | .00321 | .00408 | .00419 | .00467 | .00524 | .00518 | .00510 |

Temperature Runs to the Liquid State at 2.45 Ghz on ten materials  
Phillips Petroleum Co.

#52263

Type R-4 glass filled  
polyphenylene sulfide

| T°C  | K    | D.F.   | Thick.,cm |
|------|------|--------|-----------|
| 24.5 | 4.12 | .00438 | 1.506     |
| 47   | 4.11 | .00464 | 1.510     |
| 85   | 4.10 | .00505 | 1.517     |
| 112  | 4.05 | .0057  | 1.523     |
| 155  | 4.04 | .0083  | 1.528     |
| 205  | 4.00 | .0106  | 1.545     |
| 242  | 3.95 | .0128  | 1.591     |

#52265

Type R-10 glass & mineral filled  
polyphenylene sulfide color compd.

|     |      |        |       |
|-----|------|--------|-------|
| 22  | 4.88 | .0037  | 1.513 |
| 55  | 4.89 | .0040  | 1.517 |
| 76  | 4.90 | .0042  | 1.519 |
| 99  | 4.92 | .00514 | 1.522 |
| 118 | 4.91 | .0059  | 1.521 |
| 152 | 4.90 | .0076  | 1.528 |
| 171 | 4.90 | .00816 | 1.531 |
| 210 | 4.88 | .00936 | 1.547 |
| 240 | 4.83 | .0105  | 1.573 |

#52267

polysulfone

|      |      |       |       |
|------|------|-------|-------|
| 23   | 3.06 | .0049 | 1.678 |
| 50.4 | 3.07 | .0055 | 1.680 |
| 89.6 | 3.04 | .0060 | 1.690 |
| 113  | 3.00 | .0057 | 1.700 |
| 157  | 2.91 | .0060 | 1.735 |
| 174  | 2.62 | .0084 | 1.884 |
| 204  | 2.30 | .0209 | 2.34  |

#52269

polybutylene terephthalate

|       |      |       |       |
|-------|------|-------|-------|
| 21.7  | 2.97 | .0050 | 1.707 |
| 55.4  | 2.98 | .0102 | 1.721 |
| 80.4  | 2.96 | .0189 | 1.737 |
| 118.5 | 2.96 | .0435 | 1.770 |
| 139   | 2.99 | .0596 | 1.771 |
| 165   | 3.14 | .0836 | 1.768 |
| 199   | 3.58 | .1172 | 1.778 |
| 230   | 3.90 | .1383 | 1.849 |

#52264

Type R-8 Glass and mineral filled  
polyphenylene sulfide

| T°C | K    | D.F.  | Thick.,cm |
|-----|------|-------|-----------|
| 24  | 4.33 | .0059 | 1.574     |
| 64  | 4.35 | .0088 | 1.379     |
| 92  | 4.38 | .0112 | 1.578     |
| 112 | 4.34 | .0126 | 1.579     |
| 143 | 4.29 | .0132 | 1.590     |
| 178 | 4.26 | .0134 | 1.599     |
| 209 | 4.11 | .0134 | 1.654     |
| 229 | 3.97 | .0128 | 1.732     |

#52266

Mineral filled polysulfone

|       |      |        |       |
|-------|------|--------|-------|
| 23    | 3.37 | .00517 | 1.670 |
| 67    | 3.38 | .00595 | 1.676 |
| 93    | 3.38 | .0064  | 1.680 |
| 120.6 | 3.33 | .0062  | 1.683 |
| 153   | 3.23 | .0065  | 1.709 |
| 176.5 | 2.91 | .0097  | 1.908 |
| 206   | 2.55 | .0224  | 2.377 |

#52268

Glass filled polybutylene  
terephthalate

|     |      |        |       |
|-----|------|--------|-------|
| 24  | 3.49 | .00645 | 1.664 |
| 54  | 3.47 | .0110  | 1.676 |
| 87  | 3.47 | .0203  | 1.688 |
| 114 | 3.48 | .0352  | 1.705 |
| 145 | 3.50 | .0448  | 1.726 |
| 175 | 3.65 | .0772  | 1.776 |
| 197 | 3.94 | .0937  | 1.772 |
| 235 | 4.24 | .1152  | 1.818 |

#52270

Glass filled polyacetal

|       |      |       |       |
|-------|------|-------|-------|
| 21.6  | 3.26 | .0292 | 1.723 |
| 49.5  | 3.49 | .0309 | 1.761 |
| 87    | 3.61 | .0649 | 1.785 |
| 118.5 | 3.75 | .0563 | 1.799 |
| 146   | 3.99 | .0511 | 1.812 |
| 179   | 4.24 | .0491 | 1.943 |
| 199   | 4.04 | .0445 | 2.098 |

Phillips' plastics, continued

#52271 polyacetal

| T°C  | K    | D.F.  | Thick.,cm |
|------|------|-------|-----------|
| 21   | 3.08 | .0338 | 1.679     |
| 51.4 | 3.21 | .0623 | 1.685     |
| 75   | 3.39 | .0805 | 1.700     |
| 111  | 3.60 | .0741 | 1.713     |
| 142  | 3.82 | .0605 | 1.728     |
| 184  | 3.99 | .0489 | 1.980     |
| 196  | 4.08 | .046  | 1.755     |

#52272 polypropylene

| T°C   | K     | D.F.   | Thick.,cm |
|-------|-------|--------|-----------|
| 24.2  | 2.242 | .00041 | 1.684     |
| 40.3  | 2.240 | .00045 | 1.684     |
| 56    | 2.233 | .00051 | 1.685     |
| 96    | 2.195 | .00054 | 1.702     |
| 130.7 | 2.159 | .00069 | 1.729     |
| 158   | 2.014 | .00079 | 1.846     |
| 187   | 1.779 | .00077 | 2.559     |

Cross-linked polyethylene CL-100

Phillips

Sample molded by Hardigg

24 GHz 23°C K = 2.229 D.F. = .00056

Ferrite Absorber Mixes  
with Dow Corning 184

2.45 GHz

Raytheon

R-153 Ferrite, 60 wt%,

Q-1 2.5:1 ratio

| T°C | $\kappa'$ | $\tan \delta$ | $\mu'/\mu_0$ | $\tan \delta_m$ | T°C  | $\kappa'$ | $\tan \delta$ | $\mu'/\mu_0$ | $\tan \delta_m$ |
|-----|-----------|---------------|--------------|-----------------|------|-----------|---------------|--------------|-----------------|
| 22* | 4.47      | .0127         | .9985        | .491            | 22*  | 5.79      | .0129         | 1.553        | .8996           |
| 24  | 4.35      | .0123         | 1.014        | .483            | 23   | 5.72      | .0117         | 1.554        | .894            |
| 65  | 4.27      | .0110         | .940         | .498            | 62   | 5.63      | .0112         | 1.502        | .881            |
| 88  | 4.20      | .0110         | .901         | .432            | 92   | 5.60      | .0109         | 1.397        | .903            |
| 113 | 4.15      | .0111         | .837         | .454            | 95   | 5.60      | .0109         | 1.386        | .902            |
| 127 | 4.12      | .0117         | .822         | .391            | 120  | 5.56      | .0129         | 1.323        | .911            |
| 156 | 4.09      | .0129         | .817         | .295            | 128  | 5.53      | .0137         | 1.309        | .902            |
| 179 | 4.05      | .0138         | .813         | .232            | 153  | 5.50      | .0150         | 1.211        | .924            |
| 210 | 4.00      | .0152         | .840         | .1535           | 184  | 5.46      | .0159         | 1.130        | .926            |
| 241 | 3.95      | .0180         | .891         | .052            | 220  | 5.41      | .0195         | 1.027        | .941            |
| 259 | 3.92      | .0190         | .913         | .033            | 239  | 5.37      | .0214         | 1.012        | .944            |
| 290 | 3.87      | .0212         | .984         | .0081           | 272  | 5.33      | .0265         | .896         | .944            |
| 22  | 4.37      | .0114         | 1.012        | .494            | 298  | 5.30      | .0285         | .797         | 1.060           |
|     |           |               |              |                 | 21.7 | 5.90      | .0127         | 1.480        | .997            |

\* in room temp. sample holder, other values in high temp. holder

"Plexiglass" V811-100, polymethylmethacrylate, oven dry Rhom & Haas Co.

| 1000/T | T, DEG.C | FREQ.,HZ  | K1    | K2       | TAN DELTA | SIGMA,MHO/CM |
|--------|----------|-----------|-------|----------|-----------|--------------|
| 3.3653 | 24.0     | 30000000. | 2.607 | 0.025432 | 0.009755  | 0.42388E-06  |
| 3.3653 | 24.0     | 9500000.  | 2.596 | 0.015776 | 0.006078  | 0.83264E-07  |
| 3.3653 | 24.0     | 3000000.  | 2.639 | 0.035585 | 0.013484  | 0.59308E-07  |
| 3.3653 | 24.0     | 300000.   | 2.681 | 0.051897 | 0.019354  | 0.86496E-08  |
| 3.3653 | 24.0     | 1000000.  | 2.664 | 0.040346 | 0.015143  | 0.22415E-07  |
| 3.3653 | 24.0     | 100000.   | 2.705 | 0.057965 | 0.021432  | 0.32203E-08  |
| 3.3653 | 24.0     | 50000.    | 2.742 | 0.067078 | 0.024462  | 0.18633E-08  |
| 3.3653 | 24.0     | 20000.    | 2.782 | 0.076921 | 0.027652  | 0.85468E-09  |
| 3.3653 | 24.0     | 10000.    | 2.849 | 0.082731 | 0.029037  | 0.45962E-09  |
| 3.3653 | 24.0     | 10000.    | 2.849 | 0.084718 | 0.029735  | 0.47065E-09  |
| 3.3653 | 24.0     | 5000.     | 2.889 | 0.096873 | 0.033535  | 0.26909E-09  |
| 3.3653 | 24.0     | 3000.     | 2.921 | 0.105489 | 0.036117  | 0.17582E-09  |
| 3.3653 | 24.0     | 1000.     | 3.000 | 0.127622 | 0.042541  | 0.70901E-10  |
| 3.3653 | 24.0     | 500.      | 3.032 | 0.142581 | 0.047028  | 0.39606E-10  |
| 3.3653 | 24.0     | 200.      | 3.109 | 0.159903 | 0.051582  | 0.17767E-10  |
| 3.3653 | 24.0     | 100.      | 3.168 | 0.147102 | 0.046427  | 0.81723E-11  |
| 3.3653 | 24.0     | 50.       | 3.255 | 0.157021 | 0.048238  | 0.43617E-11  |
| 3.3653 | 24.0     | 20.       | 3.408 | 0.168988 | 0.049002  | 0.18554E-11  |
| 3.3653 | 24.0     | 10.       | 3.494 | 0.172959 | 0.049503  | 0.96088E-12  |
| 3.3653 | 24.0     | 5.        | 3.569 | 0.174577 | 0.048921  | 0.48494E-12  |
| 3.3653 | 24.0     | 3.        | 3.636 | 0.138368 | 0.038050  | 0.23061E-12  |
| 3.3653 | 24.0     | 2.        | 3.731 | 0.143764 | 0.038530  | 0.15974E-12  |

"Plexiglass" continued

.27% water

Rhom & Haas

Molded by Eastman, from MIT ME

| 1000/T | T, DEG.C | FREQ., HZ | K1    | K2       | TAN DELTA | SIGMA, MHO/CM |
|--------|----------|-----------|-------|----------|-----------|---------------|
| 3.3653 | 24.0     | 9500000.  | 2.596 | 0.034817 | 0.013414  | 0.18376E-06   |
| 3.3653 | 24.0     | 3000000.  | 2.654 | 0.041893 | 0.015783  | 0.69822E-07   |
| 3.3653 | 24.0     | 300000.   | 2.731 | 0.059684 | 0.021858  | 0.99473E-08   |
| 3.3653 | 24.0     | 1000000.  | 2.673 | 0.050151 | 0.018762  | 0.27862E-07   |
| 3.3653 | 24.0     | 100000.   | 2.755 | 0.067682 | 0.024566  | 0.37601E-08   |
| 3.3653 | 24.0     | 50000.    | 2.799 | 0.072824 | 0.026018  | 0.20229E-08   |
| 3.3653 | 24.0     | 20000.    | 2.843 | 0.079186 | 0.027854  | 0.87984E-09   |
| 3.3653 | 24.0     | 10000.    | 2.844 | 0.085537 | 0.030081  | 0.47520E-09   |
| 3.3653 | 24.0     | 3000.     | 2.910 | 0.103130 | 0.035441  | 0.17188E-09   |
| 3.3653 | 24.0     | 1000.     | 3.014 | 0.122055 | 0.040498  | 0.67808E-10   |
| 3.3653 | 24.0     | 1000.     | 3.014 | 0.121073 | 0.040165  | 0.67263E-10   |
| 3.3653 | 24.0     | 300.      | 3.001 | 0.143380 | 0.046533  | 0.23897E-10   |
| 3.3653 | 24.0     | 100.      | 3.220 | 0.171322 | 0.053137  | 0.95179E-11   |
| 3.3653 | 24.0     | 50.       | 3.289 | 0.150950 | 0.045894  | 0.41931E-11   |
| 3.3653 | 24.0     | 20.       | 3.407 | 0.161970 | 0.047547  | 0.17907E-11   |
| 3.3653 | 24.0     | 10.       | 3.539 | 0.172468 | 0.048727  | 0.95815E-12   |
| 3.3653 | 24.0     | 5.        | 3.632 | 0.172526 | 0.047507  | 0.47924E-12   |
| 3.3653 | 24.0     | 3.        | 3.658 | 0.147920 | 0.040435  | 0.27390E-12   |
| 3.3653 | 24.0     | 2.        | 3.797 | 0.140221 | 0.036928  | 0.15580E-12   |

1.5% water

| 1000/T | T, DEG.C | FREQ., HZ  | K1    | K2       | TAN DELTA | SIGMA, MHO/CM |
|--------|----------|------------|-------|----------|-----------|---------------|
| 3.3653 | 24.0     | 10.        | 4.117 | 0.241926 | 0.058758  | 0.13440E-11   |
| 3.3653 | 24.0     | 10.        | 4.147 | 0.222634 | 0.053684  | 0.12369E-11   |
| 3.3653 | 24.0     | 20.        | 4.029 | 0.218649 | 0.054270  | 0.24294E-11   |
| 3.3653 | 24.0     | 50.        | 3.871 | 0.206526 | 0.053346  | 0.57368E-11   |
| 3.3653 | 24.0     | 100.       | 3.768 | 0.194061 | 0.051509  | 0.10781E-10   |
| 3.3653 | 24.0     | 200.       | 3.672 | 0.178341 | 0.048567  | 0.19816E-10   |
| 3.3653 | 24.0     | 500.       | 3.532 | 0.187601 | 0.053107  | 0.52111E-10   |
| 3.3653 | 24.0     | 1000.      | 3.454 | 0.169185 | 0.048989  | 0.93992E-10   |
| 3.3653 | 24.0     | 2000.      | 3.421 | 0.149799 | 0.043784  | 0.16644E-09   |
| 3.3653 | 24.0     | 5000.      | 3.341 | 0.129041 | 0.038624  | 0.35845E-09   |
| 3.3653 | 24.0     | 10000.     | 3.290 | 0.116235 | 0.035327  | 0.64575E-09   |
| 3.3653 | 24.0     | 20000.     | 3.243 | 0.107560 | 0.033162  | 0.11951E-08   |
| 3.3653 | 24.0     | 50000.     | 3.191 | 0.098730 | 0.030953  | 0.27439E-08   |
| 3.3653 | 24.0     | 100000.    | 3.162 | 0.095400 | 0.030169  | 0.53000E-08   |
| 3.3653 | 24.0     | 500000.    | 3.008 | 0.085860 | 0.027987  | 0.23850E-07   |
| 3.3653 | 24.0     | 1000000.   | 3.029 | 0.078446 | 0.025898  | 0.43581E-07   |
| 3.3653 | 24.0     | 3000000.   | 3.095 | 0.088521 | 0.028603  | 0.14754E-07   |
| 3.3653 | 24.0     | 9500000.   | 2.976 | 0.068226 | 0.022924  | 0.11371E-06   |
| 3.3653 | 24.0     | 30000000.  | 2.935 | 0.056405 | 0.019220  | 0.29769E-06   |
| 3.3653 | 24.0     | 300000000. | 2.874 | 0.046728 | 0.016257  | 0.77880E-06   |

Richo 31001 polyurethane

Richo Plastics

Sample from Sperry

8.5 GHz 23°C K = 2.979 D.F. = .0186

"Duroid" 5650 M-5

Rogers

8.5 GHz 21 °C

E perpendicular hot pressing direction K = 2.660 D.F. = .00242

E parallel " " " K = 2.558 D.F. = .00206

"Duroid" 5870

Rogers

8.5 GHz 21 °C E parallel to sheet

| Thickness, inch | K    | D.F.  |
|-----------------|------|-------|
| 1/16            | 2.42 | .0019 |
| .010            | 2.33 | .0019 |

"Duroid" 5870M-1

Rogers

E perpendicular HPD 2.443 .00207

E parallel HPD 2.317 .00138

"Duroid" 5870M

Rogers

In Room Temperature Sample Holder

|                      |              | Rotation<br>(degrees) | K     | tan $\delta$ |           |
|----------------------|--------------|-----------------------|-------|--------------|-----------|
| 1 pc. full thickness | Face 1       | 0                     | 2.630 | .00287       | E $\perp$ |
|                      |              | 90                    | 2.495 | .00237       | E //      |
|                      | 2            | 0                     | 2.632 | .0031        | E $\perp$ |
|                      |              | 90                    | 2.484 | .00207       | E //      |
|                      | pc. 1/ pc. 2 | 0                     | 2.592 | .00283       | E $\perp$ |
|                      |              | 90                    | 2.452 | .00213       | E //      |

Temperature run pc. 2/pc. 1

| T °C | E $\perp$<br>K | tan $\delta$ | Thickness<br>(cm) | E //<br>K | tan $\delta$ |
|------|----------------|--------------|-------------------|-----------|--------------|
| 23.1 | 2.594          | .00287       | 1.8583            | 2.462     | .00256       |
| 50   | 2.592          | .00306       | 1.8619            | 2.464     | .00226       |
| 97   | 2.593          | .00229       | 1.8670            | 2.460     | .00203       |
| 160. | 2.591          | .00209       | 1.8681            | 2.452     | .00199       |
| 205  | 2.597          | .00159       | 1.8722            | 2.425     | .00129       |
| 246  | 2.571          | .00182       | 1.8734            | 2.419     | .00131       |
| 300  | 2.563          | .00186       | 1.8805            | 2.405     | .00131       |
| 350  | 2.395          | .00239       | 2.0639            | 2.258     | .00130       |
| 395  | 2.242          | .00251       | 2.2581            | 2.159     | .00100       |
| 468  | 2.088          | .00289       | 2.5177            | 1.989     | .00112       |
| 504  | 1.828          | .00396       | 3.2300            | 1.722     | .00339       |
| 528  | 1.095          | .00155       | 4.7506            | 1.017     | .0195        |

## Polybutylenes

Shell

| Material # | Freq., GHz | Room Temperature |        |        |         |
|------------|------------|------------------|--------|--------|---------|
|            |            | .4               | 1      | 3      | 8.5     |
| 0200       | K          | 2.265            | 2.265  | 2.264  | 2.264   |
|            | D.F.       | .00029           | .00026 | .00025 | .000275 |
| 8240       | K          | 2.247            | 2.247  | 2.246  | 2.246   |
|            | D.F.       | .00029           | .00029 | .00029 | .00027  |

"Epon" 828

100 pts resin, 80 pts hardener, 1 pt accelerator  
(ATC-3)Shell  
Sample from Brunswick

|                                               | 2.45 GHz | 23°C | K     | D.F.  |
|-----------------------------------------------|----------|------|-------|-------|
| Sample #1, 30 min. after mixing, some bubbles |          |      | 3.873 | .198  |
| 5 hrs at 23°C, no bubbles                     |          |      | 3.907 | .214  |
| 47 hrs " " "                                  |          |      | 3.710 | .152  |
| Then 95 hrs at 40°C                           |          |      | 3.310 | .0756 |
| Then 80 hrs at 60°C                           |          |      | 3.165 | .0533 |
| Sample #2 Cured 1 hour at 105°C               |          |      | 3.14  | .054  |

## Various Plastics

All at 8.5 GHz, R.T.

Samples formed by Sperry

|                            | K     | tan δ  |
|----------------------------|-------|--------|
| Cycloaliphatic resin       | 2.850 | .0209  |
| Polyester, coating, face 1 | 2.861 | .010   |
| face 2                     | 2.850 | .0086  |
| " , Laminac                | 2.911 | .0128  |
| "Epon" 815, clear          | 2.60  | .0074  |
| white                      | 13.9  | .007   |
| Ciba 2790, clear           | 2.87  | .0135  |
| HY 917                     | 12.9  | .0095  |
| Dow 7521                   | 13.0  | .0045  |
| Hetron 92FS                | 13.5  | .0095  |
| "Stafoam"                  | 1.035 | .00103 |
| Richo 90-578 + 34-841      | 1.042 | .00073 |
| Rigid polyurethane foam    | 1.036 | .00055 |
| (Same at 1 GHz)            | 1.039 | .00060 |

## Rigid polyurethane foams:

| Sample Designation | Length, cm | K      | D.F.   | gm/cm <sup>3</sup> | (K-1)/den. |
|--------------------|------------|--------|--------|--------------------|------------|
| V6                 | 2.35       | 1.1224 | .00145 | -                  | -          |
|                    | 3.55       | 1.1225 | .00155 | .096               | 1.28       |
| V8                 | 2.10       | 1.1580 | .00214 | -                  | -          |
|                    | 3.12       | 1.1591 | .00229 | .1189              | 1.34       |
| V12                | 2.30       | 1.2872 | .00390 | -                  | -          |
|                    | 3.37       | 1.2906 | .00362 | .2056              | 1.41       |
| V16                | 2.32       | 1.3271 | .00456 | -                  | -          |
|                    | 3.45       | 1.3252 | .00460 | .2398              | 1.35       |
| V20                | 2.13       | 1.3948 | .00455 | -                  | -          |
|                    | 3.21       | 1.3895 | .00445 | .2941              | 1.32       |

"Tellite" RCP

Tellite

8.5 GHz R.T.

| Thickness, inch | K    | D.F.   |
|-----------------|------|--------|
| 1/32            | 2.35 | .0004  |
| 1/16            | 2.34 | .00033 |

"Mindel" Stabilized basic polysulfone

1976

Union Carbide Corp.

| 1000/T | T, DEG.C | FREQ.,HZ  | K1    | K2       | TAN DELTA | SIGMA,MHO/CM |
|--------|----------|-----------|-------|----------|-----------|--------------|
| 3.3484 | 25.5     | 1000000.  | 3.607 | 0.013891 | 0.003851  | 0.77170E-08  |
| 3.3484 | 25.5     | 9500000.  | 3.584 | 0.014416 | 0.004022  | 0.76082E-07  |
| 3.3484 | 25.5     | 30000000. | 3.579 |          |           |              |
| 3.3484 | 25.5     | 100000.   | 3.627 | 0.008946 | 0.002466  | 0.49697E-09  |
| 3.3484 | 25.5     | 10000.    | 3.639 | 0.008157 | 0.002242  | 0.45315E-10  |
| 3.3484 | 25.5     | 1000.     | 3.651 | 0.010085 | 0.002762  | 0.56027E-11  |
| 3.3484 | 25.5     | 100.      | 3.671 | 0.012933 | 0.003523  | 0.71852E-12  |
| 3.3484 | 25.5     | 50.       | 3.683 | 0.014043 | 0.003613  | 0.39008E-12  |
| 3.0945 | 50.0     | 50.       | 3.626 | 0.019363 | 0.005340  | 0.53787E-12  |
| 3.0945 | 50.0     | 100.      | 3.614 | 0.016199 | 0.004482  | 0.89995E-12  |
| 3.0945 | 50.0     | 1000.     | 3.590 | 0.011298 | 0.003147  | 0.62767E-11  |
| 3.0945 | 50.0     | 10000.    | 3.572 | 0.008738 | 0.002446  | 0.48544E-10  |
| 3.0945 | 50.0     | 100000.   | 3.558 | 0.007548 | 0.002121  | 0.41932E-09  |
| 3.0945 | 50.0     | 1000000.  | 3.538 | 0.010719 | 0.003030  | 0.59551E-08  |
| 3.0945 | 50.0     | 9500000.  | 3.520 | 0.013302 | 0.003779  | 0.70207E-07  |
| 3.0945 | 50.0     | 30000000. | 3.512 |          |           |              |
| 2.6799 | 100.0    | 30000000. | 3.387 |          |           |              |
| 2.6799 | 100.0    | 9500000.  | 3.390 | 0.009495 | 0.002801  | 0.50114E-07  |
| 2.6799 | 100.0    | 1000000.  | 3.425 | 0.006362 | 0.001858  | 0.35345E-08  |
| 2.6799 | 100.0    | 100000.   | 3.431 | 0.006911 | 0.002014  | 0.38395E-09  |
| 2.6799 | 100.0    | 10000.    | 3.441 | 0.008783 | 0.002843  | 0.54349E-10  |
| 2.6799 | 100.0    | 1000.     | 3.461 | 0.015383 | 0.004444  | 0.85459E-11  |
| 2.6799 | 100.0    | 100.      | 3.510 | 0.025626 | 0.007301  | 0.14237E-11  |
| 2.6799 | 100.0    | 50.       | 3.528 | 0.030249 | 0.008574  | 0.84025E-12  |
| 2.3632 | 150.0    | 50.       | 3.557 | 0.046422 | 0.013050  | 0.12895E-11  |
| 2.3632 | 150.0    | 100.      | 3.550 | 0.037887 | 0.010671  | 0.21049E-11  |
| 2.3632 | 150.0    | 1000.     | 3.504 | 0.022269 | 0.006356  | 0.12372E-10  |
| 2.3632 | 150.0    | 10000.    | 3.497 | 0.013270 | 0.003795  | 0.73723E-10  |
| 2.3632 | 150.0    | 100000.   | 3.458 | 0.008736 | 0.002526  | 0.48531E-09  |
| 2.3632 | 150.0    | 1000000.  | 3.456 | 0.005919 | 0.001712  | 0.32885E-08  |
| 2.3632 | 150.0    | 9500000.  | 3.436 | 0.006981 | 0.002032  | 0.36846E-07  |
| 2.3632 | 150.0    | 30000000. | 3.424 |          |           |              |
| 2.2314 | 175.0    | 30000000. | 3.434 |          |           |              |
| 2.2314 | 175.0    | 9500000.  | 3.444 | 0.006878 | 0.001997  | 0.36303E-07  |
| 2.2314 | 175.0    | 1000000.  | 3.458 | 0.007112 | 0.002056  | 0.39510E-08  |
| 2.2314 | 175.0    | 100000.   | 3.480 | 0.009930 | 0.002854  | 0.55169E-09  |
| 2.2314 | 175.0    | 10000.    | 3.492 | 0.016847 | 0.004825  | 0.93595E-10  |
| 2.2314 | 175.0    | 1000.     | 3.522 | 0.027321 | 0.007758  | 0.15178E-10  |
| 2.2314 | 175.0    | 100.      | 3.570 | 0.054329 | 0.015217  | 0.30183E-11  |
| 2.2314 | 175.0    | 50.       | 3.596 | 0.076612 | 0.021303  | 0.21281E-11  |

At 25°C after temperature run:

| Freq., MHz | .5     | 1      | 2      | 3.5    | 6      | 9.5    |
|------------|--------|--------|--------|--------|--------|--------|
| Tan delta  | .00336 | .00370 | .00369 | .00350 | .00339 | .00326 |

Microwave data:

| Freq., GHz | .15    | .3     | 1      | 2.45   | 3      | 8.5    |
|------------|--------|--------|--------|--------|--------|--------|
| K          | 3.63   | 3.63   | 3.63   | 3.626  | 3.624  | 3.618  |
| Tan delta  | .00300 | .00320 | .00362 | .00405 | .00414 | .00477 |

"Radel" polyphenylsulfone

1976

Union Carbide

| 1000/T | T, DEG.C | FREQ., HZ | K1    | K2       | TAN DELTA | SIGMA, MHO/CM |
|--------|----------|-----------|-------|----------|-----------|---------------|
| 3.3428 | 26.0     | 1000000.  | 3.090 | 0.015613 | 0.005053  | 0.86739E-08   |
| 3.3428 | 26.0     | 9500000.  | 3.067 | 0.013474 | 0.004393  | 0.71113E-07   |
| 3.3428 | 26.0     | 30000000. | 3.054 | 0.011929 | 0.003906  | 0.19881E-06   |
| 3.3428 | 26.0     | 100.      | 3.138 | 0.003346 | 0.001066  | 0.18588E-12   |
| 3.3428 | 26.0     | 60.       | 3.138 | 0.003189 | 0.001016  | 0.10630E-12   |
| 3.3428 | 26.0     | 50.       | 3.139 | 0.003530 | 0.001124  | 0.98045E-13   |
| 3.3428 | 26.0     | 1000.     | 3.130 | 0.003654 | 0.001167  | 0.20299E-11   |
| 3.3428 | 26.0     | 10000.    | 3.119 | 0.004841 | 0.001584  | 0.27451E-10   |
| 3.3428 | 26.0     | 100000.   | 3.111 | 0.009492 | 0.003051  | 0.52733E-09   |
| 3.0945 | 50.0     | 30000000. | 3.034 | 0.016283 | 0.005366  | 0.27139E-06   |
| 3.0945 | 50.0     | 9500000.  | 3.056 | 0.014325 | 0.004687  | 0.75605E-07   |
| 3.0945 | 50.0     | 1000000.  | 3.070 | 0.012026 | 0.003917  | 0.66812E-08   |
| 3.0945 | 50.0     | 100000.   | 3.082 | 0.006560 | 0.002161  | 0.37002E-09   |
| 3.0945 | 50.0     | 10000.    | 3.088 | 0.004375 | 0.001417  | 0.24303E-10   |
| 3.0945 | 50.0     | 1000.     | 3.092 | 0.003760 | 0.001216  | 0.20886E-11   |
| 3.0945 | 50.0     | 100.      | 3.114 | 0.003895 | 0.001251  | 0.21641E-12   |
| 3.0945 | 50.0     | 50.       | 3.116 | 0.004514 | 0.001449  | 0.12538E-12   |
| 2.6799 | 100.0    | 50.       | 3.069 | 0.010899 | 0.003551  | 0.30274E-12   |
| 2.6799 | 100.0    | 100.      | 3.063 | 0.008544 | 0.002769  | 0.47466E-12   |
| 2.6799 | 100.0    | 1000.     | 3.064 | 0.004451 | 0.001453  | 0.24730E-11   |
| 2.6799 | 100.0    | 10000.    | 3.060 | 0.003849 | 0.001258  | 0.21385E-10   |
| 2.6799 | 100.0    | 100000.   | 3.032 | 0.004239 | 0.001398  | 0.23549E-09   |
| 2.6799 | 100.0    | 1000000.  | 3.025 | 0.006789 | 0.002244  | 0.37714E-08   |
| 2.6799 | 100.0    | 9500000.  | 3.022 | 0.011622 | 0.003346  | 0.61341E-07   |
| 2.6799 | 100.0    | 30000000. | 2.986 | 0.014829 | 0.004967  | 0.24715E-06   |
| 2.3632 | 150.0    | 30000000. | 2.997 | 0.011814 | 0.003943  | 0.19651E-06   |
| 2.3632 | 150.0    | 9500000.  | 3.003 | 0.008740 | 0.002910  | 0.46126E-07   |
| 2.3632 | 150.0    | 1000000.  | 3.002 | 0.005359 | 0.001785  | 0.29770E-08   |
| 2.3632 | 150.0    | 100000.   | 2.985 | 0.004182 | 0.001401  | 0.23236E-09   |
| 2.3632 | 150.0    | 10000.    | 3.008 | 0.004254 | 0.001414  | 0.23634E-10   |
| 2.3632 | 150.0    | 1000.     | 3.017 | 0.006471 | 0.002145  | 0.35949E-11   |
| 2.3632 | 150.0    | 100.      | 3.030 | 0.017789 | 0.005871  | 0.98825E-12   |
| 2.3632 | 150.0    | 50.       | 3.027 | 0.029222 | 0.009655  | 0.81172E-12   |
| 2.2314 | 175.0    | 1000.     | 2.996 | 0.010348 | 0.003454  | 0.57488E-11   |
| 2.2314 | 175.0    | 10000.    | 2.989 | 0.005134 | 0.001734  | 0.28802E-10   |
| 2.2314 | 175.0    | 100000.   | 2.985 | 0.004093 | 0.001371  | 0.22737E-09   |
| 2.2314 | 175.0    | 1000000.  | 2.983 | 0.004754 | 0.001594  | 0.26410E-08   |
| 2.2314 | 175.0    | 9500000.  | 2.981 | 0.007016 | 0.002354  | 0.37027E-07   |
| 2.2314 | 175.0    | 30000000. | 2.959 | 0.009583 | 0.003239  | 0.15972E-06   |
| 2.2314 | 175.0    | 100.      | 3.001 | 0.047240 | 0.015739  | 0.26245E-11   |
| 2.2314 | 175.0    | 50.       | 3.016 | 0.078053 | 0.025882  | 0.21681E-11   |

At 25°C after temperature run:

| Freq., MHz | .1     | .5     | 1      | 2      | 3.5    | 6      | 9.5    | 16     |
|------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Tan delta  | .00355 | .00502 | .00539 | .00562 | .00553 | .00513 | .00489 | .00446 |

Microwave data, as received, 26°C:

| Freq., GHz | .15    | .3     | 1      | 2.45   | 3      | 8.5    |
|------------|--------|--------|--------|--------|--------|--------|
| K          | 3.15   | 3.15   | 3.15   | 3.145  | 3.14   | 3.13   |
| Tan delta  | .00422 | .00466 | .00535 | .00583 | .00590 | .00637 |

"Radel" 5000, batch 6

1977

Union Carbide

| 1000/T | T, DEG.C | FREQ., HZ | K1    | K2       | TAN DELTA | SIGMA, MHO/CM |
|--------|----------|-----------|-------|----------|-----------|---------------|
| 3.3462 | 25.7     | 30000000. | 3.225 | 0.015655 | 0.004855  | 0.26091E-08   |
| 3.3462 | 25.7     | 9500000.  | 3.249 | 0.017758 | 0.005468  | 0.93720E-07   |
| 3.3462 | 25.7     | 1000000.  | 3.280 | 0.019903 | 0.006068  | 0.11057E-07   |
| 3.3462 | 25.7     | 500000.   | 3.289 | 0.018275 | 0.005556  | 0.50765E-08   |
| 3.3462 | 25.7     | 3500000.  | 3.273 | 0.019114 | 0.005840  | 0.37166E-07   |
| 3.3462 | 25.7     | 6000000.  | 3.267 | 0.018102 | 0.005540  | 0.60341E-07   |
| 3.3462 | 25.7     | 2000000.  | 3.278 | 0.020383 | 0.006217  | 0.22647E-07   |
| 3.3462 | 25.7     | 100000.   | 3.314 | 0.012325 | 0.003719  | 0.68470E-09   |
| 3.3462 | 25.7     | 10000.    | 3.324 | 0.006728 | 0.002024  | 0.37377E-10   |
| 3.3462 | 25.7     | 1000.     | 3.333 | 0.005138 | 0.001542  | 0.28547E-11   |
| 3.3462 | 25.7     | 100.      | 3.337 | 0.004497 | 0.001347  | 0.24983E-12   |
| 3.3462 | 25.7     | 50.       | 3.340 | 0.004390 | 0.001315  | 0.12194E-12   |
| 3.3462 | 25.7     | 10.       | 3.344 | 0.004597 | 0.001375  | 0.25536E-13   |
| 3.0945 | 50.0     | 10.       | 3.373 | 0.003845 | 0.001140  | 0.21362E-13   |
| 3.0945 | 50.0     | 50.       | 3.367 | 0.004292 | 0.001275  | 0.11922E-12   |
| 3.0945 | 50.0     | 100.      | 3.365 | 0.004294 | 0.001276  | 0.23854E-12   |
| 3.0945 | 50.0     | 1000.     | 3.365 | 0.004493 | 0.001335  | 0.24961E-11   |
| 3.0945 | 50.0     | 10000.    | 3.361 | 0.005586 | 0.001662  | 0.31031E-10   |
| 3.0945 | 50.0     | 100000.   | 3.349 | 0.008392 | 0.002506  | 0.46620E-09   |
| 3.0945 | 50.0     | 1000000.  | 3.330 | 0.016008 | 0.004808  | 0.88935E-08   |
| 3.0945 | 50.0     | 3500000.  | 3.308 | 0.018926 | 0.005720  | 0.36800E-07   |
| 3.0945 | 50.0     | 6000000.  | 3.304 | 0.019846 | 0.006007  | 0.56154E-07   |
| 3.0945 | 50.0     | 9500000.  | 3.257 | 0.019724 | 0.006056  | 0.10410E-06   |
| 3.0945 | 50.0     | 30000000. | 3.230 | 0.017414 | 0.005391  | 0.29023E-06   |
| 2.6799 | 100.0    | 30000000. | 3.277 | 0.017188 | 0.005246  | 0.28647E-06   |
| 2.6799 | 100.0    | 9500000.  | 3.303 | 0.016053 | 0.004861  | 0.84724E-07   |
| 2.6799 | 100.0    | 6000000.  | 3.312 | 0.014460 | 0.004366  | 0.48201E-07   |
| 2.6799 | 100.0    | 3500000.  | 3.316 | 0.013026 | 0.003928  | 0.25327E-07   |
| 2.6799 | 100.0    | 1000000.  | 3.322 | 0.009055 | 0.002726  | 0.50305E-08   |
| 2.6799 | 100.0    | 100000.   | 3.320 | 0.005697 | 0.001711  | 0.31651E-09   |
| 2.6799 | 100.0    | 10000.    | 3.344 | 0.004510 | 0.001349  | 0.25054E-10   |
| 2.6799 | 100.0    | 1000.     | 3.346 | 0.003191 | 0.000954  | 0.17728E-11   |
| 2.6799 | 100.0    | 100.      | 3.346 | 0.004024 | 0.001202  | 0.22355E-12   |
| 2.6799 | 100.0    | 50.       | 3.348 | 0.004350 | 0.001299  | 0.12082E-12   |
| 2.6799 | 100.0    | 10.       | 3.352 | 0.004761 | 0.001421  | 0.26432E-13   |
| 2.3632 | 150.0    | 10.       | 3.337 | 0.008127 | 0.002436  | 0.45151E-13   |
| 2.3632 | 150.0    | 50.       | 3.326 | 0.005039 | 0.001515  | 0.13997E-12   |
| 2.3632 | 150.0    | 100.      | 3.325 | 0.004616 | 0.001388  | 0.25643E-12   |
| 2.3632 | 150.0    | 1000.     | 3.324 | 0.004200 | 0.001264  | 0.23331E-11   |
| 2.3632 | 150.0    | 10000.    | 3.318 | 0.005729 | 0.001726  | 0.31828E-10   |
| 2.3632 | 150.0    | 100000.   | 3.312 | 0.004871 | 0.001471  | 0.27064E-09   |
| 2.3632 | 150.0    | 1000000.  | 3.299 | 0.008096 | 0.002454  | 0.44980E-08   |
| 2.3632 | 150.0    | 9500000.  | 3.304 | 0.012436 | 0.003764  | 0.65635E-07   |
| 2.3632 | 150.0    | 30000000. | 3.235 | 0.018230 | 0.005016  | 0.27050E-06   |
| 2.1135 | 200.0    | 30000000. | 3.204 | 0.017966 | 0.005608  | 0.29944E-06   |
| 2.1135 | 200.0    | 9500000.  | 3.259 | 0.013099 | 0.004019  | 0.69133E-07   |
| 2.1135 | 200.0    | 1000000.  | 3.257 | 0.008395 | 0.002578  | 0.46642E-08   |
| 2.1135 | 200.0    | 100000.   | 3.274 | 0.011336 | 0.003463  | 0.62976E-09   |
| 2.1135 | 200.0    | 10000.    | 3.292 | 0.006291 | 0.001911  | 0.34950E-10   |
| 2.1135 | 200.0    | 1000.     | 3.312 | 0.007955 | 0.002402  | 0.44192E-11   |
| 2.1135 | 200.0    | 100.      | 3.314 | 0.022555 | 0.006806  | 0.12530E-11   |
| 2.1135 | 200.0    | 50.       | 3.318 | 0.037448 | 0.011285  | 0.10402E-11   |
| 2.1135 | 200.0    | 10.       | 3.335 | 0.129655 | 0.038878  | 0.72030E-12   |
| 2.0074 | 225.0    | 10.       | 4.254 | 1.648727 | 0.387569  | 0.91596E-11   |
| 2.0074 | 225.0    | 50.       | 3.708 | 0.455797 | 0.122933  | 0.12661E-10   |
| 2.0074 | 225.0    | 100.      | 3.579 | 0.345433 | 0.096506  | 0.19191E-10   |
| 2.0074 | 225.0    | 1000.     | 3.401 | 0.104960 | 0.030863  | 0.58311E-10   |
| 2.0074 | 225.0    | 10000.    | 3.312 | 0.044307 | 0.013377  | 0.24615E-09   |
| 2.0074 | 225.0    | 100000.   | 3.268 | 0.021754 | 0.006656  | 0.12085E-08   |
| 2.0074 | 225.0    | 1000000.  | 3.240 | 0.017423 | 0.005378  | 0.96792E-08   |
| 2.0074 | 225.0    | 9500000.  | 3.202 | 0.018617 | 0.005815  | 0.98257E-07   |
| 2.0074 | 225.0    | 30000000. | 3.148 | 0.019601 | 0.006226  | 0.32668E-08   |

"Radel" 5000, continued

| T°C | Freq.,GHz | 1      | 1.685  | 2.45   | 3      | 5      | 8.515  |
|-----|-----------|--------|--------|--------|--------|--------|--------|
| 25  | K         | 3.195  | 3.190  | 3.186  | 3.182  | 3.170  | 3.155  |
|     | D.F.      | .00547 | .00533 | .00594 | .00618 | .00646 | .00654 |
| 75  | K         | 3.200  | 3.193  | 3.187  | 3.183  | 3.171  | 3.157  |
|     | D.F.      | .0065  | .00646 | .0067  | .0074  | .0080  | .00757 |
| 125 | K         | 3.197  | 3.191  | 3.182  | 3.178  | 3.169  | 3.155  |
|     | D.F.      | .0074  | .0072  | .0077  | .0086  | .0094  | .00875 |
| 175 | K         | 3.194  | 3.190  | 3.181  | 3.177  | 3.166  | 3.141  |
|     | D.F.      | .00805 | .00795 | .00835 | .0092  | .010   | .0098  |
| 200 | K         | 3.199  | 3.193  | 3.180  | 3.175  | 3.161  | 3.120  |
|     | D.F.      | .0084  | .0083  | .0088  | .0096  | .0103  | .0102  |

"Udell" P1700, Blend 63-72

1977

Union Carbide

| 1000/T | T, DEG.C | FREQ.,HZ  | K1    | K2       | TAN DELTA | SIGMA,MHO/CM |
|--------|----------|-----------|-------|----------|-----------|--------------|
| 3.3653 | 24.0     | 10.       | 3.157 | 0.003836 | 0.001215  | 0.21313E-13  |
| 3.3653 | 24.0     | 50.       | 3.154 | 0.003579 | 0.001135  | 0.99417E-13  |
| 3.3653 | 24.0     | 100.      | 3.153 | 0.003723 | 0.001181  | 0.20683E-12  |
| 3.3653 | 24.0     | 100.      | 3.153 | 0.003624 | 0.001149  | 0.20131E-12  |
| 3.3653 | 24.0     | 1000.     | 3.139 | 0.004013 | 0.001279  | 0.22296E-11  |
| 3.3653 | 24.0     | 10000.    | 3.129 | 0.005502 | 0.001759  | 0.30567E-10  |
| 3.3653 | 24.0     | 100000.   | 3.119 | 0.010105 | 0.003240  | 0.56139E-09  |
| 3.3653 | 24.0     | 1000000.  | 3.095 | 0.015610 | 0.005043  | 0.86721E-08  |
| 3.3653 | 24.0     | 9500000.  | 3.080 | 0.015480 | 0.005025  | 0.81701E-07  |
| 3.3653 | 24.0     | 30000000. | 3.070 | 0.009535 | 0.003106  | 0.15892E-06  |
| 3.0945 | 50.0     | 30000000. | 3.076 | 0.009711 | 0.003157  | 0.16185E-06  |
| 3.0945 | 50.0     | 95000000. | 3.085 | 0.015347 | 0.004075  | 0.80997E-07  |
| 3.0945 | 50.0     | 1000000.  | 3.096 | 0.011903 | 0.003144  | 0.66125E-08  |
| 3.0945 | 50.0     | 100000.   | 3.102 | 0.005793 | 0.001868  | 0.32186E-09  |
| 3.0945 | 50.0     | 10000.    | 3.109 | 0.003908 | 0.001157  | 0.21711E-10  |
| 3.0945 | 50.0     | 1000.     | 3.116 | 0.002879 | 0.000724  | 0.15996E-11  |
| 3.0945 | 50.0     | 100.      | 3.123 | 0.002834 | 0.000907  | 0.15742E-12  |
| 3.0945 | 50.0     | 50.       | 3.126 | 0.002814 | 0.000900  | 0.78171E-13  |
| 3.0945 | 50.0     | 10.       | 3.127 | 0.002999 | 0.000959  | 0.16659E-13  |
| 2.6799 | 100.0    | 10.       | 3.116 | 0.005021 | 0.001611  | 0.27895E-13  |
| 2.6799 | 100.0    | 50.       | 3.110 | 0.003440 | 0.001106  | 0.95564E-13  |
| 2.6799 | 100.0    | 100.      | 3.108 | 0.003318 | 0.001068  | 0.18434E-12  |
| 2.6799 | 100.0    | 1000.     | 3.103 | 0.000283 | 0.000091  | 0.15746E-12  |
| 2.6799 | 100.0    | 10000.    | 3.098 | 0.003210 | 0.001016  | 0.17833E-10  |
| 2.6799 | 100.0    | 100000.   | 3.093 | 0.004087 | 0.001312  | 0.22706E-09  |
| 2.6799 | 100.0    | 1000000.  | 3.084 | 0.006812 | 0.002209  | 0.37843E-08  |
| 2.6799 | 100.0    | 9500000.  | 3.076 | 0.015220 | 0.004948  | 0.90328E-07  |
| 2.6799 | 100.0    | 30000000. | 3.064 | 0.014844 | 0.004844  | 0.24740E-06  |
| 2.3632 | 150.0    | 30000000. | 3.065 | 0.007800 | 0.002545  | 0.13000E-06  |
| 2.3632 | 150.0    | 9500000.  | 3.070 | 0.009555 | 0.003113  | 0.50431E-07  |
| 2.3632 | 150.0    | 1000000.  | 3.078 | 0.005506 | 0.001789  | 0.30586E-08  |
| 2.3632 | 150.0    | 100000.   | 3.085 | 0.003295 | 0.001068  | 0.18304E-09  |
| 2.3632 | 150.0    | 10000.    | 3.089 | 0.003178 | 0.001029  | 0.17657E-10  |
| 2.3632 | 150.0    | 1000.     | 3.092 | 0.003490 | 0.001129  | 0.19390E-11  |
| 2.3632 | 150.0    | 100.      | 3.105 | 0.004438 | 0.001430  | 0.24657E-12  |
| 2.3632 | 150.0    | 50.       | 3.101 | 0.005444 | 0.001756  | 0.15121E-12  |
| 2.3632 | 150.0    | 10.       | 3.107 | 0.008402 | 0.002704  | 0.46679E-13  |
| 2.2314 | 175.0    | 10.       | 3.123 | 0.024379 | 0.007807  | 0.13544E-12  |
| 2.2314 | 175.0    | 50.       | 3.113 | 0.012030 | 0.003865  | 0.33417E-12  |
| 2.2314 | 175.0    | 100.      | 3.097 | 0.010603 | 0.003424  | 0.58908E-12  |
| 2.2314 | 175.0    | 1000.     | 3.089 | 0.004452 | 0.001441  | 0.24735E-11  |
| 2.2314 | 175.0    | 10000.    | 3.086 | 0.005330 | 0.001727  | 0.29611E-10  |
| 2.2314 | 175.0    | 100000.   | 3.075 | 0.002816 | 0.000916  | 0.15645E-09  |
| 2.2314 | 175.0    | 1000000.  | 3.065 | 0.003813 | 0.001244  | 0.21184E-08  |
| 2.2314 | 175.0    | 9500000.  | 3.033 | 0.010316 | 0.003401  | 0.54445E-07  |
| 2.2314 | 175.0    | 30000000. | 3.023 | 0.012438 | 0.004114  | 0.20730E-06  |
| 2.1135 | 200.0    | 30000000. | 3.066 | 0.018076 | 0.005895  | 0.30127E-06  |
| 2.1135 | 200.0    | 9500000.  | 3.079 | 0.016358 | 0.005312  | 0.86331E-07  |
| 2.1135 | 200.0    | 1000000.  | 3.102 | 0.019015 | 0.006130  | 0.10564E-07  |
| 2.1135 | 200.0    | 100000.   | 3.132 | 0.040219 | 0.012840  | 0.22344E-08  |
| 2.1135 | 200.0    | 10000.    | 3.211 | 0.105181 | 0.032752  | 0.58434E-09  |
| 2.1135 | 200.0    | 1000.     | 3.413 | 0.253232 | 0.074187  | 0.14068E-09  |
| 2.1135 | 200.0    | 100.      | 3.939 | 0.517254 | 0.131319  | 0.28736E-10  |
| 2.1135 | 200.0    | 50.       | 4.216 | 0.636457 | 0.150959  | 0.17679E-10  |
| 2.1135 | 200.0    | 10.       | 4.978 | 0.980310 | 0.196988  | 0.54462E-10  |

"Udell" P1700, continued

| T°C | Freq.,GHz | 1      | 1.685 | 2.45   | 3      | 5      | 8.515  |
|-----|-----------|--------|-------|--------|--------|--------|--------|
| 25  | K         | 2.995  | 2.993 | 2.991  | 2.990  | 2.986  | 2.980  |
|     | D.F.      | .00435 | .0047 | .0050  | .00515 | .0056  | .00608 |
| 75  | K         | 2.993  | 2.991 | 2.988  | 2.987  | 2.982  | 2.976  |
|     | D.F.      | .00497 | .0053 | .00495 | .00584 | .00618 | .00661 |
| 125 | K         | 2.984  | 2.983 | 2.979  | 2.977  | 2.973  | 2.969  |
|     | D.F.      | .00526 | .0056 | .00517 | .00637 | .00676 | .00737 |
| 175 | K         | 3.003  | 2.998 | 2.983  | 2.974  | 2.930  | 2.856  |
|     | D.F.      | .0080  | .0083 | .00732 | .00902 | .0087  | .00816 |

"Udell" P8000 (formerly "Mindel")

1977

Union Carbide

| 1000/T | T, DEG.C | FREQ.,HZ  | K1    | K2       | TAN DELTA | SIGMA,MHO/CM |
|--------|----------|-----------|-------|----------|-----------|--------------|
| 3.3597 | 24.5     | 9500000.  | 3.650 | 0.015715 | 0.004306  | 0.82939E-07  |
| 3.3597 | 24.5     | 30000000. | 3.620 | 0.013623 | 0.003763  | 0.22705E-06  |
| 3.3597 | 24.5     | 1000000.  | 3.680 | 0.016830 | 0.004573  | 0.93498E-08  |
| 3.3597 | 24.5     | 100000.   | 3.701 | 0.011566 | 0.003125  | 0.64255E-09  |
| 3.3597 | 24.5     | 10000.    | 3.722 | 0.009637 | 0.002589  | 0.53540E-10  |
| 3.3597 | 24.5     | 1000.     | 3.735 | 0.012112 | 0.003242  | 0.67286E-11  |
| 3.3597 | 24.5     | 100.      | 3.756 | 0.014206 | 0.003782  | 0.78920E-12  |
| 3.3597 | 24.5     | 50.       | 3.764 | 0.015360 | 0.004081  | 0.42667E-12  |
| 3.3597 | 24.5     | 10.       | 3.773 | 0.017836 | 0.004727  | 0.99091E-13  |
| 3.0945 | 50.0     | 10.       | 3.778 | 0.022700 | 0.006009  | 0.12611E-12  |
| 3.0945 | 50.0     | 50.       | 3.760 | 0.017612 | 0.004684  | 0.48922E-12  |
| 3.0945 | 50.0     | 100.      | 3.753 | 0.016253 | 0.004331  | 0.90296E-12  |
| 3.0945 | 50.0     | 1000.     | 3.745 | 0.012819 | 0.003423  | 0.71214E-11  |
| 3.0945 | 50.0     | 10000.    | 3.727 | 0.009887 | 0.002653  | 0.54927E-10  |
| 3.0945 | 50.0     | 100000.   | 3.710 | 0.008623 | 0.002324  | 0.47904E-09  |
| 3.0945 | 50.0     | 1000000.  | 3.695 | 0.010598 | 0.002868  | 0.58876E-08  |
| 3.0945 | 50.0     | 9500000.  | 3.651 | 0.015408 | 0.004220  | 0.81320E-07  |
| 3.0945 | 50.0     | 30000000. | 3.623 | 0.011837 | 0.003267  | 0.19729E-06  |
| 2.6799 | 100.0    | 30000000. | 3.631 | 0.012888 | 0.003549  | 0.21481E-06  |
| 2.6799 | 100.0    | 9500000.  | 3.666 | 0.012966 | 0.003537  | 0.68429E-07  |
| 2.6799 | 100.0    | 1000000.  | 3.695 | 0.008235 | 0.002229  | 0.45748E-08  |
| 2.6799 | 100.0    | 100000.   | 3.705 | 0.008922 | 0.002408  | 0.49569E-09  |
| 2.6799 | 100.0    | 10000.    | 3.726 | 0.012396 | 0.003327  | 0.68866E-10  |
| 2.6799 | 100.0    | 1000.     | 3.742 | 0.016426 | 0.004390  | 0.91257E-11  |
| 2.6799 | 100.0    | 100.      | 3.764 | 0.024341 | 0.006467  | 0.13523E-11  |
| 2.6799 | 100.0    | 50.       | 3.774 | 0.031256 | 0.008282  | 0.86823E-12  |
| 2.6799 | 100.0    | 10.       | 3.803 | 0.054660 | 0.014374  | 0.30367E-12  |
| 2.3632 | 150.0    | 10.       | 3.839 | 0.092246 | 0.024028  | 0.51248E-12  |
| 2.3632 | 150.0    | 50.       | 3.790 | 0.044838 | 0.011829  | 0.12455E-11  |
| 2.3632 | 150.0    | 100.      | 3.778 | 0.032946 | 0.008719  | 0.18303E-11  |
| 2.3632 | 150.0    | 1000.     | 3.744 | 0.020960 | 0.005598  | 0.11644E-10  |
| 2.3632 | 150.0    | 10000.    | 3.727 | 0.015101 | 0.004052  | 0.83693E-10  |
| 2.3632 | 150.0    | 100000.   | 3.706 | 0.012757 | 0.003442  | 0.70872E-09  |
| 2.3632 | 150.0    | 1000000.  | 3.677 | 0.008623 | 0.002345  | 0.47904E-08  |
| 2.3632 | 150.0    | 9500000.  | 3.652 | 0.013743 | 0.003763  | 0.72534E-07  |
| 2.3632 | 150.0    | 30000000. | 3.614 | 0.017161 | 0.004749  | 0.28601E-06  |
| 2.2314 | 175.0    | 30000000. | 3.603 | 0.009362 | 0.002599  | 0.15603E-06  |
| 2.2314 | 175.0    | 9500000.  | 3.633 | 0.013707 | 0.003772  | 0.72341E-07  |
| 2.2314 | 175.0    | 1000000.  | 3.682 | 0.017783 | 0.004830  | 0.98792E-08  |
| 2.2314 | 175.0    | 100000.   | 3.697 | 0.020848 | 0.005639  | 0.11582E-08  |
| 2.2314 | 175.0    | 10000.    | 3.726 | 0.026165 | 0.007022  | 0.14536E-09  |
| 2.2314 | 175.0    | 1000.     | 3.761 | 0.025904 | 0.006888  | 0.14391E-10  |
| 2.2314 | 175.0    | 100.      | 3.799 | 0.041062 | 0.010809  | 0.22812E-11  |
| 2.2314 | 175.0    | 50.       | 3.812 | 0.053381 | 0.014004  | 0.14828E-11  |
| 2.2314 | 175.0    | 10.       | 3.865 | 0.092537 | 0.023944  | 0.51409E-12  |
| 2.1135 | 200.0    | 10.       | 6.776 | 1.172523 | 0.173032  | 0.65140E-11  |
| 2.1135 | 200.0    | 50.       | 5.528 | 0.987350 | 0.178601  | 0.27426E-10  |
| 2.1135 | 200.0    | 100.      | 5.088 | 0.858599 | 0.168743  | 0.47700E-10  |
| 2.1135 | 200.0    | 1000.     | 4.221 | 0.401071 | 0.095028  | 0.22282E-09  |
| 2.1135 | 200.0    | 10000.    | 3.892 | 0.161689 | 0.041549  | 0.89827E-09  |
| 2.1135 | 200.0    | 100000.   | 3.767 | 0.073601 | 0.019537  | 0.40889E-08  |
| 2.1135 | 200.0    | 1000000.  | 3.683 | 0.036921 | 0.010025  | 0.20512E-07  |
| 2.1135 | 200.0    | 9500000.  | 3.617 | 0.030299 | 0.008377  | 0.15991E-06  |
| 2.1135 | 200.0    | 30000000. | 3.571 | 0.022495 | 0.006300  | 0.37491E-06  |

"Udell" P-8000, continued

| T°C | Freq., GHz | 1      | 1.685  | 2.45   | 3      | 5      | 8.515  |
|-----|------------|--------|--------|--------|--------|--------|--------|
| 25  | K          | 3.590  | 3.569  | 3.556  | 3.550  | 3.538  | 3.527  |
|     | D.F.       | .00410 | .00420 | .00428 | .00432 | .00438 | .00435 |
| 75  | K          | 3.575  | 3.558  | 3.547  | 3.542  | 3.527  | 3.515  |
|     | D.F.       | .00471 | .0049  | .00503 | .00504 | .00496 | .00480 |
| 125 | K          | 3.562  | 3.545  | 3.532  | 3.527  | 3.511  | 3.486  |
|     | D.F.       | .00495 | .00518 | .00538 | .00555 | .00582 | .00576 |
| 175 | K          | 3.543  | 3.523  | 3.517  | 3.510  | 3.495  | 3.472  |
|     | D.F.       | .00520 | .0056  | .0060  | .0063  | .0067  | .0069  |

Printed Circuit Boards

Union Carbide

Polyimide laminate, 11848-12-3

| T°C  | Freq., Hz | 10     | 100    | 10 <sup>3</sup> | 10 <sup>4</sup> | 10 <sup>5</sup> | 10 <sup>6</sup> | 10 <sup>7</sup> | 10 <sup>8</sup> | 10 <sup>9</sup> | 10 <sup>10</sup> |
|------|-----------|--------|--------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|
| 24.2 | K         | 5.141  | 5.122  | 5.075           | 5.044           | 4.972           | 4.898           | 4.789           | 4.68            | 4.65            | 4.57             |
|      | tan δ     | .00577 | .00510 | .00459          | .00553          | .00994          | .0136           | .0194           | .022            | .0124           | .0147            |
| 50   | K         |        |        |                 |                 |                 |                 |                 |                 | 4.67            | 4.58             |
|      | tan δ     |        |        |                 |                 |                 |                 |                 |                 | .0138           | .0196            |
| 100  | K         |        |        |                 |                 |                 |                 |                 |                 | 4.60            | 4.59             |
|      | tan δ     |        |        |                 |                 |                 |                 |                 |                 | .0144           | .0229            |
| 150  | K         |        |        |                 |                 |                 |                 |                 |                 | 4.66            | 4.593            |
|      | tan δ     |        |        |                 |                 |                 |                 |                 |                 | .0144           | .0263            |
| 175  | K         |        |        |                 |                 |                 |                 |                 |                 | 4.65            | 4.577            |
|      | tan δ     |        |        |                 |                 |                 |                 |                 |                 | .0143           | .0319            |
| 200  | K         | 7.560  | 5.797  | 5.191           | 4.988           | 4.929           | 4.830           | 4.759           | 4.71            | 4.64            | 4.516            |
|      | tan δ     | .422   | .1488  | .0525           | .0182           | .00994          | .00736          | .00820          | .0108           | .0138           | .0346            |
| 175  | K         | 5.519  | 5.149  | 4.971           | 4.874           | 4.815           | 4.75            | 4.717           | 4.68            | 4.63            | 4.54             |
|      | tan δ     | .110   | .0510  | .0215           | .0112           | .00792          | .0065           | .00939          | .0114           | .0136           | .0314            |
| 150  | K         | 5.325  | 4.983  | 4.884           | 4.814           | 4.765           | 4.730           | 4.675           | 4.63            | 4.61            | 4.55             |
|      | tan δ     | .0534  | .0265  | .0127           | .00835          | .00624          | .0070           | .00924          | .0113           | .0130           | .0255            |
| 100  | K         | 4.951  | 4.850  | 4.793           | 4.750           | 4.717           | 4.671           | 4.624           | 4.60            | 4.58            | 4.514            |
|      | tan δ     | .0121  | .00844 | .0067           | .00529          | .00476          | .0066           | .0104           | .0108           | .0117           | .0212            |
| 50   | K         | 4.823  | 4.725  | 4.709           | 4.684           | 4.660           | 4.609           | 4.544           | 4.50            | 4.55            | 4.451            |
|      | tan δ     | .00547 | .00691 | .00429          | .00411          | .00557          | .00795          | .0109           | .0098           | .0097           | .0169            |
| 25   | K         | 4.786  | 4.695  | 4.682           | 4.659           | 4.621           | 4.547           | 4.503           | 4.46            | 4.51            | 4.413            |
|      | tan δ     | .00322 | .00389 | .00396          | .00456          | .0069           | .00841          | .0108           | .0110           | .0086           | .0133            |

Polyolefin, crosslinked, 11848-12-2

| T°C | Freq., Hz | 10     | 100    | 10 <sup>3</sup> | 10 <sup>4</sup> | 10 <sup>5</sup> | 10 <sup>6</sup> | 10 <sup>7</sup> | 10 <sup>8</sup> | 10 <sup>9</sup> | 10 <sup>10</sup> |
|-----|-----------|--------|--------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|
| 24  | K         | 2.91   | 2.89   | 2.869           | 2.845           | 2.814           | 2.777           | 2.761           | 2.757           | 2.847           | 2.842            |
|     | tan δ     | .00322 | .00455 | .0053           | .00644          | .00668          | .01704          | .00735          | .0076           | .00754          | .00664           |
| 50  | K         |        |        |                 |                 |                 |                 |                 |                 | 2.860           | 2.828            |
|     | tan δ     |        |        |                 |                 |                 |                 |                 |                 | .0103           | .00807           |
| 100 | K         |        |        |                 |                 |                 |                 |                 |                 | 2.845           | 2.796            |
|     | tan δ     |        |        |                 |                 |                 |                 |                 |                 | .0163           | .0117            |
| 150 | K         |        |        |                 |                 |                 |                 |                 |                 | 2.877           | 2.778            |
|     | tan δ     |        |        |                 |                 |                 |                 |                 |                 | .0236           | .0170            |
| 175 | K         |        |        |                 |                 |                 |                 |                 |                 | 2.861           | 2.759            |
|     | tan δ     |        |        |                 |                 |                 |                 |                 |                 | .0276           | .0205            |
| 200 | K         | 3.229  | 3.046  | 3.002           | 2.884           | 2.790           | 2.755           | 2.688           | 2.59            | 2.778           | 2.756            |
|     | tan δ     | .438   | .0633  | .0265           | .0310           | .0134           | .0132           | .0212           | .0272           | .0309           | .0216            |
| 175 | K         | 3.226  | 3.216  | 3.045           | 2.923           | 2.872           | 2.812           | 2.731           | 2.65            | 2.779           | 2.757            |
|     | tan δ     | .1324  | .0334  | .0345           | .0183           | .0133           | .0177           | .0211           | .0232           | .0248           | .0200            |
| 150 | K         | 3.219  | 3.067  | 2.967           | 2.936           | 2.883           | 2.824           | 2.740           | 2.69            | 2.781           | 2.782            |
|     | tan δ     | .0467  | .0345  | .0165           | .0117           | .0134           | .0166           | .0188           | .0211           | .0225           | .0165            |
| 100 | K         | 3.012  | 3.005  | 2.978           | 2.931           | 2.874           | 2.821           | 2.766           | 2.72            | 2.805           | 2.801            |
|     | tan δ     | .00247 | .00417 | .00859          | .0115           | .0128           | .0137           | .0139           | .0136           | .0130           | .0104            |
| 50  | K         | 2.817  | 2.807  | 2.796           | 2.773           | 2.767           | 2.704           | 2.708           | 2.695           | 2.806           | 2.802            |
|     | tan δ     | .00650 | .00645 | .00554          | .00554          | .00557          | .00658          | .00742          | .0084           | .00815          | .00686           |
| 25  | K         | 2.824  | 2.820  | 2.814           | 2.805           | 2.789           | 2.767           | 2.743           | 2.73            | 2.804           | 2.802            |
|     | tan δ     | .00200 | .00251 | .00294          | .00336          | .00403          | .00510          | .00618          | .0066           | .00632          | .00536           |

## Printed Circuit Boards, continued

Union Carbide

## Polysulfone P-1700, 11848-12-1

| T°C | Freq., Hz | 10     | 100    | 10 <sup>3</sup> | 10 <sup>4</sup> | 10 <sup>5</sup> | 10 <sup>6</sup> | 10 <sup>7</sup> | 10 <sup>8</sup> | 10 <sup>9</sup> | 10 <sup>10</sup> |
|-----|-----------|--------|--------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|
| 24  | κ         | 3.203  | 3.186  | 3.173           | 3.157           | 3.152           | 3.141           | 3.094           | 3.06            | 3.043           | 3.025            |
|     | tan δ     | .00111 | .00132 | .00157          | .00240          | .00448          | .00810          | .0106           | .0197           | .0063           | .00652           |
| 50  | κ         |        |        |                 |                 |                 |                 |                 |                 | 3.05            | 3.031            |
|     | tan δ     |        |        |                 |                 |                 |                 |                 |                 | .00702          | .00749           |
| 100 | κ         |        |        |                 |                 |                 |                 |                 |                 | 3.05            | 3.029            |
|     | tan δ     |        |        |                 |                 |                 |                 |                 |                 | .00785          | .00878           |
| 150 | κ         |        |        |                 |                 |                 |                 |                 |                 | 3.06            | 3.016            |
|     | tan δ     |        |        |                 |                 |                 |                 |                 |                 | .0087           | .01154           |
| 175 | κ         |        |        |                 |                 |                 |                 |                 |                 | 3.03            | 2.983            |
|     | tan δ     |        |        |                 |                 |                 |                 |                 |                 | .0095           | .0122            |
| 200 | κ         | 5.48   | 4.30   | 3.59            | 3.35            | 3.21            | 3.16            | 3.13            | 3.08            | 3.02            | 2.977            |
|     | tan δ     | .293   | .186   | .0923           | .0413           | .0199           | .0094           | .0087           | .010            | .0148           | .0132            |
| 175 | κ         | 3.22   | 3.22   | 3.20            | 3.14            | 3.12            | 3.10            | 3.09            | 3.07            | 3.01            | 2.977            |
|     | tan δ     | .00929 | .00756 | .00720          | .00952          | .00342          | .00371          | .00411          | .0064           | .04962          | .0139            |
| 150 | κ         | 3.21   | 3.18   | 3.14            | 3.11            | 3.10            | 3.09            | 3.08            | 3.06            | 3.03            | 2.993            |
|     | tan δ     | .00371 | .00787 | .00853          | .00407          | .00317          | .00270          | .00333          | .0052           | .00182          | .0108            |
| 100 | κ         | 3.09   | 3.08   | 3.08            | 3.08            | 3.08            | 3.07            | 3.07            | 3.05            | 3.01            | 2.977            |
|     | tan δ     | .00073 | .00064 | .00057          | .00065          | .00094          | .00158          | .00303          | .0042           | .0055           | .00783           |
| 50  | κ         | 3.09   | 3.08   | 3.08            | 3.08            | 3.07            | 3.07            | 3.06            | 3.05            | 3.00            | 2.969            |
|     | tan δ     | .00041 | .00054 | .00068          | .00095          | .00141          | .00223          | .00352          | .0043           | .0046           | .00609           |
| 25  | κ         | 3.097  | 3.088  | 3.085           | 3.080           | 3.073           | 3.063           | 3.056           | 3.03            | 3.00            | 2.966            |
|     | tan δ     | .00046 | .00066 | .00096          | .00134          | .00160          | .00256          | .00384          | .0039           | .0041           | .00519           |

At 24°C, 30 MHz, tan δ = .016

## Polysulfone P-1720, 11848-12-2

| T°C | Freq., Hz | 10     | 100    | 10 <sup>3</sup> | 10 <sup>4</sup> | 10 <sup>5</sup> | 10 <sup>6</sup> | 10 <sup>7</sup> | 10 <sup>8</sup> | 10 <sup>9</sup> | 10 <sup>10</sup> |
|-----|-----------|--------|--------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|
| 24  | κ         | 3.252  | 3.238  | 3.233           | 3.222           | 3.197           | 3.159           | 3.141           | 3.08            | 3.044           | 3.032            |
|     | tan δ     | .00119 | .00144 | .00226          | .00306          | .00446          | .00774          | .00764          | .0061           | .00366          | .00660           |
| 50  | κ         | 3.23   | 3.22   | 3.21            | 3.20            | 3.20            | 3.17            | 3.13            | 3.08            | 3.050           | 3.034            |
|     | tan δ     | .00127 | .00098 | .00125          | .00162          | .00272          | .00555          | .00795          | .0077           | .00656          | .01757           |
| 100 | κ         | 3.19   | 3.18   | 3.17            | 3.17            | 3.15            | 3.15            | 3.14            | 3.07            | 3.05            | 3.015            |
|     | tan δ     | .00221 | .00263 | .00193          | .00170          | .00181          | .00287          | .00546          | .0073           | .0078           | .00726           |
| 150 | κ         | 3.27   | 3.22   | 3.19            | 3.15            | 3.13            | 3.11            | 3.10            | 3.07            | 3.04            | 3.006            |
|     | tan δ     | .00491 | .00827 | .00777          | .00518          | .00433          | .00379          | .00451          | .0068           | .0086           | .0111            |
| 24  | κ         | 3.11   | 3.11   | 3.10            | 3.10            | 3.09            | 3.08            | 3.07            |                 |                 |                  |
|     | tan δ     | .00061 | .00081 | .00103          | .00160          | .00237          | .00326          | .00389          |                 |                 |                  |
| 50  | κ         | 3.12   | 3.09   | 3.09            | 3.09            | 3.09            | 3.08            | 3.07            |                 |                 |                  |
|     | tan δ     | .00051 | .00069 | .00081          | .00111          | .00175          | .00284          | .00375          |                 |                 |                  |
| 100 | κ         | 3.11   | 3.09   | 3.09            | 3.08            | 3.08            | 3.08            | 3.07            |                 |                 |                  |
|     | tan δ     | .00111 | .00083 | .00073          | .00084          | .00119          | .00196          | .00319          |                 |                 |                  |
| 150 | κ         | 3.24   | 3.20   | 3.15            | 3.13            | 3.11            | 3.08            | 3.08            |                 |                 |                  |
|     | tan δ     | .00513 | .00958 | .00714          | .00403          | .00371          | .00332          | .00404          |                 |                 |                  |
|     | Freq., Hz |        |        |                 |                 |                 |                 |                 |                 |                 |                  |
| 150 | tan δ     | .00612 | .00926 |                 |                 |                 |                 |                 |                 |                 |                  |
| 175 | κ         |        |        |                 |                 |                 |                 |                 |                 | 3.01            | 2.962            |
|     | tan δ     |        |        |                 |                 |                 |                 |                 |                 | .0093           | .0129            |
| 200 | κ         | 4.84   | 3.84   | 3.46            | 3.28            | 3.20            | 3.16            | 3.13            | 3.08            | 3.02            | 2.942            |
|     | tan δ     | .234   | .1285  | .0575           | .0302           | .01147          | .00700          | .00713          | .0079           | .0150           | .0137            |
| 175 | κ         | 3.26   | 3.22   | 3.19            | 3.15            | 3.14            | 3.11            | 3.10            | 3.06            | 2.95            | 2.917            |
|     | tan δ     | .00679 | .00703 | .01132          | .00551          | .00306          | .00338          | .00396          | .0060           | .00946          | .0123            |
| 150 | κ         | 3.23   | 3.19   | 3.14            | 3.13            | 3.10            | 3.10            | 3.09            | 3.05            | 3.00            | 2.938            |
|     | tan δ     | .00617 | .0104  | .00581          | .00319          | .00360          | .00251          | .00311          | .0056           | .00792          | .0102            |
| 100 | κ         | 3.11   | 3.11   | 3.10            | 3.10            | 3.10            | 3.09            | 3.09            | 3.04            | 2.99            | 2.935            |
|     | tan δ     | .00078 | .00062 | .00058          | .00066          | .00088          | .00151          | .00271          | .0042           | .00362          | .00785           |
| 50  | κ         | 3.11   | 3.10   | 3.10            | 3.10            | 3.09            | 3.08            | 3.06            | 3.02            | 2.98            | 2.932            |
|     | tan δ     | .00050 | .00055 | .00068          | .00094          | .00144          | .00228          | .00334          | .0039           | .00452          | .00634           |
| 24  | κ         | 3.110  | 3.104  | 3.100           | 3.100           | 3.098           | 3.087           | 3.081           | 3.04            | 2.98            | 2.931            |
|     | tan δ     | .00045 | .00073 | .00098          | .00135          | .00195          | .00269          | .00348          | .0035           | .00408          | .00517           |

At 200°C, 30 Hz, κ = 4.25, tan δ = .1796

## Epoxy 2795/2793 with UV stabilizers

Union Carbide

Samples from MIT Lincoln Laboratory

3 GHz R.T.

| Stabilizer                | K    | tan $\delta$ |
|---------------------------|------|--------------|
| None                      | 3.11 | .0365        |
| Benzotriazole             | 2.98 | .0327        |
| Substituted acrylonitrile | 3.09 | .0327        |
| Benzidine malonate        | 3.14 | .039         |
| Benzophenone              | 3.10 | .031         |

## Polymer with tungsten wire reinforcement

AFML

25°C

Temperature run 8.5 GHz

| Freq., Hz | K     | tan $\delta$ | T°C | K     | tan $\delta$ |
|-----------|-------|--------------|-----|-------|--------------|
| 100       | 8.91  | .0117        | 23  | 3.032 | .0241        |
| 1K        | 8.31  | .0459        | 94  | 3.142 | .049         |
| 3K        | 8.02  | .0400        | 101 | 3.222 | .077         |
| 10K       | 7.72  | .0487        | 130 | 3.294 | .106         |
| 300K      | 6.10  | .141         | 150 | 3.344 | .137         |
| 1M        | 5.71  | .160         | 170 | 3.376 | .156         |
| 3.5M      | 4.69  | .168         | 208 | 3.428 | .184         |
| 30M       | 3.75  | .110         |     |       |              |
| 8.5G      | 3.034 | .0253        |     |       |              |

## Polyurethane Foam CPR 1057-6.24

Upjohn

8.5 GHz R.T. K = 1.122 D.F. = .00241

## IV. Liquids

## Crude oil, low viscosity

MIT

| T°C | T°F | Freq., Hz    | 10 <sup>2</sup> | 10 <sup>3</sup> | 10 <sup>4</sup> | 10 <sup>5</sup> | 10 <sup>6</sup> | 5x10 <sup>6</sup> | 1.6x10 <sup>7</sup> | 10 <sup>8</sup> | 2.45x10 <sup>9</sup> | 3x10 <sup>9</sup> |
|-----|-----|--------------|-----------------|-----------------|-----------------|-----------------|-----------------|-------------------|---------------------|-----------------|----------------------|-------------------|
| 58  | 136 | K            | 2.667           | 2.456           | 2.363           | 2.327           | 2.306           | 2.281             | 2.278               | 2.256           | 2.256                | 2.238             |
|     |     | tan $\delta$ | 2.63            | .332            | .0341           | .0102           | .0038           | .0030             | .0073               | .0074           | .00495               | .0052             |
|     |     | $\sigma$     | 3.9E-10         | 4.5E-10         | 7.1E-10         | 1.33E-9         | 4.87E-9         | 3.2E-8            | 1.5E-7              | 9.3E-6          | 1.5E-5               | 1.9E-5            |
| 22  | 72  | K            | 2.643           | 2.494           | 2.407           | 2.376           | 2.360           | 2.333             | 2.309               | 2.292           | 2.290                | 2.272             |
|     |     | tan $\delta$ | .408            | .0742           | .0172           | .0061           | .0076           | .0106             | .0115               | .0035           | .0028                | .0029             |
|     |     | $\sigma$     | 6.1E-11         | 1.1E-10         | 2.3E-10         | 8.1E-10         | 1.1E-8          | 6.9E-8            | 2.3E-7              | 4.45E-6         | 8.7E-6               | 1.1E-5            |
| -20 | -4  | K            | 2.563           | 2.481           | 2.402           | 2.392           | 2.336           | 2.330             | 2.318               | 2.310           | 2.31                 | 2.31              |
|     |     | tan $\delta$ | .0287           | .0146           | .0118           | .0118           | .00909          | .00535            | .00361              | .0007           | .0008                | .0010             |
|     |     | $\sigma$     | 4.1E-12         | 2.1E-11         | 1.5E-10         | 1.5E-9          | 1.2E-8          | 3.5E-8            | 7.4E-8              | 1.1E-6          | 2.5E-6               | 3.8E-6            |

## Crude oil, high viscosity

MIT

C536 (Alaskan type) 2%

| T°C | T°F | Freq., Hz    | 10 <sup>2</sup> | 10 <sup>3</sup> | 10 <sup>4</sup> | 10 <sup>5</sup> | 10 <sup>6</sup> | 5x10 <sup>6</sup> | 1.6x10 <sup>7</sup> | 10 <sup>8</sup> | 2.45x10 <sup>9</sup> | 3x10 <sup>9</sup> |
|-----|-----|--------------|-----------------|-----------------|-----------------|-----------------|-----------------|-------------------|---------------------|-----------------|----------------------|-------------------|
| 60  | 140 | K            | 3.277           | 2.903           | 2.673           | 2.578           | 2.548           | 2.473             | 2.464               | 2.333           | 2.330                | 2.330             |
|     |     | tan $\delta$ | .285            | .37             | .0705           | .0104           | .0169           | .019              | .0173               | .0080           | .00584               | .0076             |
|     |     | $\sigma$     | 5.2E-10         | 5.9E-10         | 1.1E-9          | 1.9E-9          | 2.4E-8          | 1.3E-7            | 3.8E-7              | 1.1E-5          | 1.85E-5              | 2.95E-5           |
| 28  | 82  | K            | 3.129           | 2.820           | 2.669           | 2.606           | 2.511           | 2.488             | 2.467               | 2.396           | 2.394                | 2.393             |
|     |     | tan $\delta$ | .397            | .092            | .0304           | .0110           | .0190           | .0154             | .0116               | .0050           | .0040                | .0047             |
|     |     | $\sigma$     | 6.9E-11         | 1.4E-10         | 4.5E-10         | 2.1E-9          | 2.7E-8          | 1.1E-7            | 2.5E-7              | 6.65E-6         | 1.3E-5               | 1.9E-5            |
| -18 | 0   | K            | 2.811           | 2.670           | 2.591           | 2.535           | 2.495           | 2.492             | 2.489               | 2.37            | 2.37                 | 2.37              |
|     |     | tan $\delta$ | .0421           | .0275           | .0178           | .0115           | .0076           | .0050             | .0032               | .0022           | .0021                | .0025             |
|     |     | $\sigma$     | 6.6E-12         | 4.1E-11         | 2.6E-10         | 1.6E-9          | 1.1E-8          | 3.4E-8            | 7.1E-8              | 2.9E-6          | 6.8E-6               | 1.1E-5            |

## Carbon tetrabromide

MIT Materials Science

|        | T°C | K     | D.F.   |
|--------|-----|-------|--------|
| Liquid | 94  | 2.584 | .00069 |
|        | 102 | 2.563 | .00091 |
| Solid  | 25  | 2.468 | .0002  |

Diethylphthalate  $C_{10}H_{10}O_4$ 

MIT, Melcher

At 1 to 100 Hz, 23°C  $\kappa = 5.15$   $\sigma = 5.74E-12$  mho/cm

## Water-Hydrochloric Acid Solutions

MIT for JPL

8.515 GHz 24.1°C

| Wt% Acid | $\kappa'$ | $\kappa''$ | $\sigma$ | Wt% Acid | $\kappa'$ | $\kappa''$ | $\sigma$ |
|----------|-----------|------------|----------|----------|-----------|------------|----------|
| 0        | 63.5      | 63.7       | .131     | 25       | 1.3       | 151        | .713     |
| 5        | 39.5      | 119        | .562     | 29       | 2.8       | 145        | .685     |
| 10       | 12.0      | 162        | .765     | 32       | 5.8       | 132        | .625     |
| 18       | -4.8      | 164        | .777     | 37       | 9.4       | 124        | .586     |

## Water-Sulfuric Acid Solutions

MIT for JPL

8.515 GHz 24.9 ± .5°C

8.515 GHz 22.8°C

| Wt% Acid | $\kappa'$ | $\kappa''$ | $\sigma$ | Wt.% Acid | $\kappa'$ | $\kappa''$ | $\sigma$ |
|----------|-----------|------------|----------|-----------|-----------|------------|----------|
| 0        | 67.2      | 28.3       | .134     | 0         | 67.0      | 29.4       | .139     |
| 1.11     | 64.0      | 37.3       | .177     | 31.72     | 1.3       | 153        | .7225    |
| 5.04     | 50.1      | 65.9       | .312     | 33.7      | 2         | 153.4      | .726     |
| 10.08    | 32.0      | 97.7       | .462     | 35.23     | 3.2       | 153.3      | .725     |
| 15.09    | 18.1      | 122        | .579     | 38.06     | 3.2       | 149        | .704     |
| 20.15    | 6.4       | 140.5      | .665     | 40.80     | 6.4       | 145        | .687     |
| 25.32    | -0.4      | 152        | .720     | 43.66     | 9.8       | 140.4      | .664     |
| 30.15    | -4.1      | 157.5      | .745     | 47.22     | 11.3      | 130.8      | .619     |
| 35.24    | -0.2      | 157.4      | .7445    | 50.38     | 16.7      | 122        | .578     |
| 40.38    | 3.8       | 150.7      | .713     | 52.74     | 21.8      | 119        | .564     |
| 45.31    | 6.5       | 137.4      | .650     | 58.37     | 22.3      | 106        | .502     |
| 50.38    | 17.3      | 127.3      | .602     | 64.69     | 32.0      | 78.6       | .372     |
| 55.43    | 23.4      | 111.4      | .527     | 73.33     | 30.2      | 52.6       | .249     |
| 60.39    | 25.5      | 91.9       | .435     | 84.59     | 29.8      | 32.7       | .155     |
| 65.55    | 29.6      | 76.4       | .362     | 91.94     | 28.45     | 34.5       | .163     |
| 70.61    | 24.2      | 56.2       | .266     | 95.87     | 26.4      | 34.6       | .164     |
| 75.61    | 28.4      | 44.4       | .210     | 96.26     | 24.5      | 32.9       | .159     |
| 80.49    | 29.0      | 36.1       | .171     | 96.61     | 23.4      | 31.1       | .147     |
| 85.52    | 26.8      | 33.7       | .159     | 97.1      | 22.0      | 29.6       | .140     |
| 90.55    | 28.0      | 35.6       | .168     | 97.22     | 21.8      | 29.9       | .141     |
| 96.26    | 23.7      | 33.6       | .159     |           |           |            |          |

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