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MICROWAVE PROPERTIES OF GERMANIUM AND
SILICON WINDOWS

Robert W. Lothrop

Naval Weapons Laboratory
Dahlgren, Virginia

September 1972

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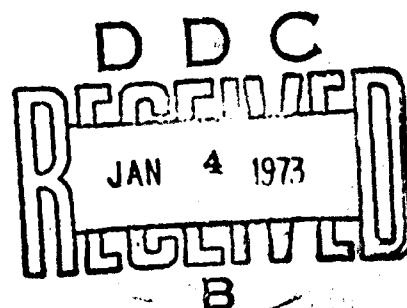
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NAVAL WEAPONS LABORATORY
DAHLGREN, VIRGINIA



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NAVAL WEAPONS LABORATORY
Dahlgren, Virginia
22448

R. F. Schniedwind, Capt., USN
Commander

Bernard Smith
Technical Director

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13. ABSTRACT

Theoretical Analysis and on-the-bench tests were performed to determine the required doping levels for germanium and silicon to produce infrared windows with large attenuations to microwave energy in the 1 to 10 GHz range. An optimum doping level was determined where infrared signals were attenuated by only 3% above that for a higher purity sample, while microwave signals were attenuated by over 100 dB with over 60% of this attenuation resulting from reflections on the window surface and not absorption within the doped window. Results, conclusions and potentialities are discussed.

NWL Technical Report No. TR-2815
September 1972

MICROWAVE PROPERTIES OF GERMANIUM AND SILICON WINDOWS

by

Robert W. Lothrop

Advanced Systems Department

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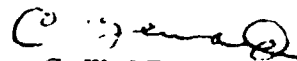
FOREWORD

Microwave attenuation measurements were made on samples of arsenic-doped germanium and phosphorus-doped silicon (each of three different resistivities supplied by the Naval Weapons Center, China Lake, California. These microwave measurements are compared to infrared transmission measurements made by Victor Rehn at China Lake to determine an optimum doping level for strong microwave energy attenuation and limited infrared attenuation.

This work was performed by R. W. Lothrop as a training assignment in the Electromagnetic Vulnerability Division at the Naval Weapons Laboratory, Dahlgren, Virginia.

This report was reviewed by R. L. Schmidt, Head of the Electromagnetic Vulnerability Division.

Released by:



C. W. BERNARD

Head, Advanced Systems Department

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I. INTRODUCTION

Many semiconductors are almost indistinguishable in physical appearance from metals. In the visible region of the spectrum, like metals, they generally absorb strongly, having coefficients of absorption on the order of 10^5 cm^{-1} . In the pure state, the absorption coefficients of many semiconductors, such as silicon and germanium, drop off rapidly in the near or intermediate infrared region and become fairly transparent at longer infrared and RF wavelengths. The transparency of semiconductors at wavelengths beyond the absorption edge is frequently apparent only when they are purified to such an extent that absorption due to free carriers is small enough to show up the fundamental absorption. In an impure state, they are generally opaque from ultraviolet right up to radio frequency wavelengths.

The problem is to find doping levels for both silicon and germanium which will make them effectively transparent in the infrared region but opaque in the microwave region.

II. DOPED SEMICONDUCTOR PHYSICS

The quantum mechanized model of a semiconductor explains electrical conduction in terms of electrons which have been moved from their natural bond states within the atom to non-localized energy states. There are two varieties of these states -- the donor and acceptor states. In the donor state, an electron is localized around an impurity from which it can be released into the conduction band with a rather small expenditure of energy. This makes the electron from the impurity atom available for electrical conduction. Similarly, an acceptor state is an available electron state around an impurity which can accept an electron from the valence band. When this transition occurs an electron is taken from the valence band, or a hole is produced. An electrical current can now be carried by the valence band. Since the energies involved in these processes are of the order of 0.01 to 0.1 eV, they are much smaller than the energy required to excite an electron directly from the valence band into the conduction band. These states exist in continuous bands which are separated by regions where no energy level states exist (forbidden bands). When the semiconductor material is doped with an impurity, energy levels are created which lie within the forbidden band.

An optical absorption arises from the promotion of a free electron from the valence band to the conduction band, accompanied by the absorption of a photon. For the photon $h\nu \geq E_g$ (forbidden band energy gap), strong optical absorption may occur. If the photon energy is less than the gap energy, the absorption is usually much weaker. By their basic nature semiconducting materials have small energy gaps which correspond to cut-on wavelengths in the infrared region.

When radiation is applied to a solid, electrons are displaced from their equilibrium position by a self produced electric field (E). The equation for the motion of a free electron in the presence of this electric field is:

$$m \frac{d^2 x}{dt^2} + m\gamma \frac{dx}{dt} = eEe^{j\omega t} \quad (1)$$

where

γ is the damping constant which is related to the relaxation time (τ) by

$$\gamma = \frac{1}{\tau} = \frac{e}{m\mu} \quad (2)$$

and where

m = free carrier mass

e = electronic charge (1.6×10^{-19} C)

μ = free carrier mobility

Solving for X ,

$$X = C_1 + C_2 e^{-\gamma t} + \frac{eE}{m} \frac{1}{(-\omega^2 + j\gamma\omega)} e^{j\omega t} \quad (3)$$

As t gets very large, $C_2 e^{-\gamma t}$ approaches zero and if it is assumed that at $t = 0$, $E = 0$ and $X = 0$, then

$$C_1 = -C_2$$

Therefore let

$$C_1 = -C_2 = 0$$

So the solution becomes

$$X = \frac{eE}{m} \frac{1}{(-\omega^2 + j\gamma\omega)} e^{j\omega t} \quad (4)$$

The net polarization caused by the displacement of electrons a distance X is,

$$P = Ne(X) = \frac{Ne^2 E}{m(-\omega^2 + j\gamma\omega)} \quad (5)$$

where

N is the total number of electrons per unit volume.

The complex index of refraction $(n - jk)^2$ can be defined as

$$(n - jK)^2 = 1 + (P/\epsilon_0 E) \quad (6)$$

where

n equals 4.0 for germanium and 3.42 for silicon (real part of the index of refraction).

Substituting in the polarization calculated above,

$$n^2 - K^2 - 2jnK = 1 + \frac{Ne^2}{m\epsilon_0(-\omega^2 + j\gamma\omega)} \quad (7)$$

where

K is equal to the imaginary part of the index of refraction.

The basic wave equation for a E field in a lossy material is,

$$\nabla^2 \vec{E} + k^2 \vec{E} = 0 \quad (8)$$

The wave number k is, in general, complex and may be written,

$$k = k' - jk'' \quad (9)$$

where

k' is the intrinsic phase constant, and
k'' is the intrinsic attenuation constant.

The k'' term causes an exponential attenuation of the wave amplitude. The solution to the wave equation is

$$\vec{E} = \vec{E}_0 e^{-k''z} e^{-jk'z} \quad (10)$$

The absorption coefficient α can be determined by equating the imaginary parts of equation (7),

$$2nK\omega = 2cn\alpha = \frac{\gamma Ne^2}{m\epsilon_0(\omega^2 + \gamma^2)} \quad (11)$$

Substituting in for γ ,

$$\alpha = \frac{Ne\mu}{\epsilon_0 cn} \left[1 + \omega^2 \tau^2 \right]^{-1} \quad (12)$$

Values for α are calculated in Program One in Appendix A for frequencies from the infrared range to the RF range for both silicon and germanium doped at three different levels. For these calculations, three different doping levels were used: $2.5 \times 10^{13}/\text{cm}^3$, $1 \times 10^{15}/\text{cm}^3$, and $1 \times 10^{17}/\text{cm}^3$. Three different thicknesses were used: 0.058 in. (0.1473 cm), 0.127 in. (0.5 cm), and 0.70 in. (1.778 cm). The frequency range used went from 1 GHz to 3.7 μm . The equations were evaluated for both silicon and germanium. There are two regions of interest in this equation. The first is the relaxation region where $1/\tau \ll \omega$. In this region, the absorption coefficient is proportional to the wavelength squared and the transmission of infrared radiation is fairly high. In the second region (low frequency region), where $\omega \ll 1/\tau$, the absorption coefficient is fairly high for RF radiation.

Knowing the absorption coefficient, the transmission percentage can be calculated by solving a parallel plate type of problem. At every interface there is an incident and a reflected wave.

$$\begin{array}{c} \text{incident wave} \rightarrow e^{jk_0 X} \rightarrow \left\{ \begin{array}{l} A e^{jk X} \rightarrow \\ R e^{-jk_0 X} \leftarrow \end{array} \right. \left\{ \begin{array}{l} T e^{jk_0 X} \\ B e^{-jk X} \leftarrow \end{array} \right. \end{array}$$

The constants R, A, B, and T can be evaluated by solving,

$$1 + R = A + B \quad (13)$$

$$jk_0(1 - R) = jk(A - B) \quad (14)$$

$$Te^{jk_0a} = Ae^{jka} + Be^{-jka} \quad (15)$$

$$jk_0Te^{jk_0a} = jk(Ae^{jka} - Be^{-jka}) \quad (16)$$

therefore

$$T = e^{-jk_0a} \frac{2j\mu}{(1 + \mu^2)\sin ka + 2j\mu \cos ka} \quad (17)$$

where

a = thickness

$k = \beta + j\alpha$

$\mu = \frac{k}{k_0}$

$\beta = \frac{\omega n}{c}$

therefore

$$T = \frac{2j(\beta + j\alpha)}{\frac{1}{k} (k_0^2 + (\beta + j\alpha)^2) \sin (\beta + j\alpha)a + 2j(\alpha + j\beta) \cos (\alpha + j\beta)a} \quad (18)$$

The values for the absolute transmission through different samples can be found in Program One (and plotted in Figures B-1 through B-4) in Appendix B. Transmission percentages were found as high as 98.5% in the infrared region. Large variations within the infrared region are caused by cancellation or enforcement of the incoming signal with the reflected signal.

The amplitudes of the waves reflected from each surface will reinforce each other when

$$n(t) = (2m + 1) \frac{\lambda}{4} \quad (19)$$

where

m is an integer and
t is the thickness.

Destructive interference will occur at wavelengths when

$$n(t) = m \frac{\lambda}{4} \quad (20)$$

Transmission percentages below 10^{-150} in the radio frequency range were considered as zero.

The reflection coefficient for different samples can be calculated from

$$R = \frac{1 - n^*}{1 + n^*} \quad (21)$$

where

$$n^* = \frac{c}{\omega} (\beta + j\alpha)$$

Therefore,

$$1 - R = \frac{\frac{2c}{\omega} (\beta + j\alpha)}{1 + \frac{2c}{\omega} \beta + j \frac{c}{\omega} \alpha} \quad (22)$$

The absolute values of $1 - R$ can also be found in Program One in Appendix A.

III. TEMPERATURE VARIATIONS

An increase in temperature above room temperature causes an increase in free carrier concentration because electrons from the valence band begin to enter the conduction band and thereby create hole-carrier pairs. There is a cross-over point called the intrinsic range where the concentration of electrons in the conduction band becomes greater than that due to the donor impurities. For germanium, the free carrier concentration increases as,

$$n_i(T) = 1.76 \times 10^{16} T^{3/2} e^{-4550/T} \text{ cm}^{-3} \quad (23)$$

and for silicon as

$$n_i(T) = 3.88 \times 10^{16} T^{3/2} e^{-7000/T} \text{ cm}^{-3} \quad (24)$$

The values for the free carrier concentration from 200° to 800° K are listed on pages A-12 through A-18. These new free carrier concentrations were substituted into Equations (12) and (17) to calculate the absolute signal transmitted at frequencies ranging from 2×10^{13} Hz (15 μm) to 11×10^{14} (0.27 μm). When the transmission percentage is high, the germanium samples do not show a noticeable drop in transmission to about 500° K. The silicon does not show a drop until about 650° K. Plots of this data can be found in Appendix B (Figures B-5 and B-6).

To test the actual RF transmittance of both silicon and germanium, samples were made to fit a jig that mated with precision 7mm connectors, (APC-7). The samples were cut and polished to a donut shape, with a hole diameter of 0.121 in. and outside diameter of 0.2745 in. Plane surfaces were polished with 6mm diamond grit. Two different length samples were available; 0.127 in. and 0.058 in. The three different doping levels were; 7.5, 0.4, and 0.1 Ωcm for germanium, and 10, 1, and 0.4 Ωcm for silicon. When a sample is placed in a line, the impedance of the line at the point may be calculated.

$$Z_{\text{Sample}} = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \quad (25)$$

where

$$L = \frac{\mu_0}{2\pi} \ln (b/a) \quad (26)$$

$$C = \frac{2\pi\sigma}{\ln b/a} \epsilon = n^2 \quad (27)$$

$$G = \frac{2\pi\sigma}{\ln b/a} \quad (28)$$

and

$$R = \frac{\rho}{\pi(b^2 - a^2)} \quad (29)$$

The computed values of Z (impedance) at different frequencies for the various resistivities are listed on pages A-19 through A-24.

Using these values of calculated impedance, the theoretical transmittance through the sample at various RF frequencies can be calculated. From two-port theory, the transmittance is found to be,

$$T = \frac{V \text{ TRANSMITTED}}{V \text{ INCIDENT}} = \frac{Z_T}{Z_0 \sinh \gamma L + Z_T \cosh \gamma L} \quad (30)$$

where

$$\begin{aligned} Z_T &= 50 \Omega \\ \gamma &= \gamma + j\beta \end{aligned}$$

The calculated transmittance is listed on pages A-25 through A-36 (and plotted in Figures B-8, B-9, B-11 and B-13 in Appendix B) for frequencies from 0.5 GHz to 12.5 GHz.

IV. SAMPLE MEASUREMENTS

The setup used to make actual measurements on the samples is shown in Figure 1. The samples were held in the test jigs with silver conductive paint. Data were taken from 0.25 Hz to 11.5 GHz in 0.5 GHz steps. Figures B-7, B-10 and B-12 show the results of these tests. Test data follow fairly close to predicted data to about 50 dB of attenuation, the sensitivity limit of the Hewlett Packard (HP) network analyzer. The measured data are given in Tables 1 and 2.

A test was run to prove the importance of a good conductive seal between the sample and the test jig (see Table 3). The first test was run without the use of conductive silver paint between the sample and the jig and between the sample and the center pin. Tolerances were better than 1/10,000 in., but leakage was still quite high. A second run was made with only the center pin painted and leakage was decreased. In the third test, both the center pin and the sample-to-test-jig joint were painted and leakage was further reduced. The limiting factor in attenuation for any doped semiconductor will be the seals between metal and the semiconductor. The only sure way of preventing leakage is to solder the gaps with low-temperature solder. Measurements made with the test setup shown in Figure 1 show as much as a 30 dB reduction in attenuation when no silver conductive paint is used in the gaps between the test jig and the semiconductor sample. The placement of the test sample in the test jig is shown in Figure 2.

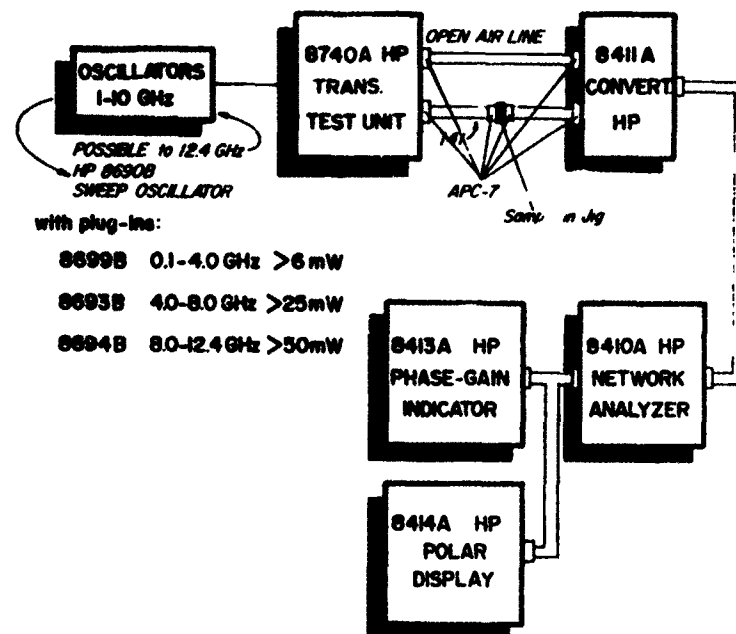


FIGURE 1

Test Setup for RF Measurements

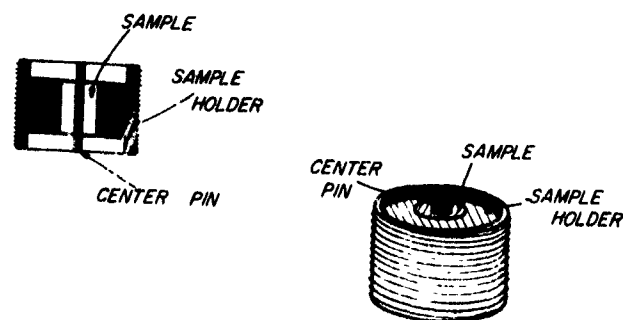


FIGURE 2

Positioning of Sample within Jig

TABLE 1

MEASURED ATTENUATION (dB) OF SILICON

Freq. (GHz)	Resistivity (Ω cm)					
	10	1 0.127-in	0.4	10	1 0.058-in	0.4
0.25	34.6	19.5	37.8	4.0	8.8	18.1
0.5	16.0	24.1	26.8	7.2	14.9	23.5
1.0	16.2	27.2	27.8	8.4	18.3	26.1
1.5	16.7	27.0	29.9	9.5	19.9	27.2
2.0	16.95	28.95	31.65	10.25	21.15	28.45
2.5	17.1	30.6	34.0	10.7	21.8	28.2
3.0	16.9	32.1	36.4	10.6	22.2	29.6
3.5	17.2	34.1	39.0	10.9	23.0	30.5
4.0	17.7	36.2	41.4	11.4	23.9	32.0
4.5	17.7	37.2	43.5	11.3	23.9	32.8
5.0	17.8	38.8	45.7	11.4	24.8	33.7
5.5	17.7	39.9	47.3	11.1	25.8	34.4
6.0	17.6	41.6	49.2	11.5	26.2	35.2
6.5	18.4	43.3	50.4	11.7	26.3	36.2
7.0	18.1	44.3	51.3	11.6	26.4	36.8
7.5	18.2	45.2	52.0	11.9	26.7	37.5
8.0	18.8	46.1	52.2	11.7	27.2	38.5
8.5	19.7	48.2	52.1	12.5	27.8	39.8
9.0	20.0	49.7	52.5	12.7	28.3	40.9
9.5	19.7	50.3	53.2	12.2	28.4	41.0
10.0	19.9	50.5	53.1	11.5	29.1	40.8
10.5	20.6	51.6	53.4	12.2	30.4	42.2
11.0	20.3	51.8	53.2	12.8	30.7	42.7
11.5	20.7	52.4	52.8	12.1	30.6	44.6

TABLE 2
MEASURED ATTENUATION (dB) OF GERMANIUM

Freq. (GHz)	Resistivity (Ω cm)			
	7.5	0.4 0.127-in.	0.1	7.5 0.058-in.
0.25	15.6	22.8	21.8	1.7
0.5	17.0	28.3	28.0	4.6
1.0	17.5	30.3	32.2	8.1
1.5	17.9	33.9	37.5	9.5
2.0	18.15	37.55	39.25	10.25
2.5	18.3	40.1	41.7	10.8
3.0	18.0	43.0	43.8	11.3
3.5	18.2	44.7	46.0	11.7
4.0	18.5	48.7	49.1	12.2
4.5	18.4	49.6	48.5	12.3
5.0	18.6	51.5	51.8	12.4
5.5	18.5	53.1	52.9	12.7
6.0	18.9	54.0	54.0	13.2
6.5	19.3	54.7	54.1	13.1
7.0	19.1	55.2	55.7	12.9
7.5	19.1	55.4	55.6	12.8
8.0	19.2	55.5	55.8	13.4
8.5	19.8	56.4	56.4	13.4
9.0	20.4	56.5	56.4	13.3
9.5	20.3	56.5	56.5	13.0
10.0	20.1	56.4	56.6	13.3
10.5	20.8	56.7	57.0	13.6
11.0	21.0	56.6	56.8	13.4
11.5	21.0	56.0	56.0	13.4

TABLE 3
EFFECT OF CONDUCTIVE PAINTING BETWEEN
SAMPLE AND TEST JIG AND
SAMPLE AND CENTER PIN ON ATTENUATION
(dB) OF 0.127-in. GERMANIUM WITH
RESISTIVITY OF 0.4 Ω cm

Freq. (GHz)	Unpainted	Painted Pin	Both Painted
0.2	6.4	12.1	22.8
0.5	12.0	19.2	28.3
1.0	16.2	23.9	30.0
1.5	19.9	27.7	33.9
2.0	21.85	30.25	37.55
2.5	23.0	32.7	40.1
3.0	24.4	34.0	43.0
3.5	25.6	35.4	44.7
4.0	26.3	35.1	48.7
4.5	25.1	35.5	49.6
5.0	25.8	35.3	51.5
5.5	27.1	35.9	53.1
6.0	27.8	37.0	54.0
6.5	29.0	37.4	54.7
7.0	29.4	37.5	55.2
7.5	29.9	38.2	55.4
8.0	30.7	39.2	55.5
8.5	33.0	40.0	56.4
9.0	34.0	40.8	56.5
9.5	34.0	41.5	56.5
10.0	34.1	43.0	56.4
10.5	35.5	44.7	56.7
11.0	35.5	45.0	56.6

V. INFRARED MEASUREMENTS

Infrared transmission measurements performed at the Naval Weapons Center at China Lake, California were made on a Perkin-Elmer Model 137, covering the 2.5 to 15 μm range. The samples were polished with 1 μm diamond polish before the measurements were made. These China Lake measurements led to a recommendation specifying a silicon window of $2 \pm .5 \Omega \text{ cm}$ resistivity and polish with 1/4 μm diamond grit.

VI. CONCLUSIONS AND RECOMMENDATIONS

The RF measurements show that the microwave absorption in doped semiconductors increases with increasing resistivity until about $100\ \Omega\text{ cm}$ where the absorption drops to almost zero. A $2\ \Omega\text{ cm}$ sample at four GHz has about a 17% absorption rate. This means that 83% of the over 100 dB loss at microwave frequencies is caused by reflections and not by absorption within the sample which could cause heating. Infrared transmission in a $2\ \Omega\text{ cm}$ sample is 51%. This value improves only to 54% in a higher-purity sample.

It is recommended that a silicon window of $2(+3 - 0.5 + 3.0)\ \Omega\text{ cm}$ resistivity polished with $1/4\ \mu\text{m}$ diamond grit would be the best possible filter for microwave frequencies from 0.25 GHz to 12.5 GHz. This resistivity is small enough to produce a fairly large reflectance of microwave energy to reduce the possibility of heating of the window by absorbed microwave energy. This window shows only a 3% reduction of infrared energy over the intrinsic material while attenuating microwave energy by more than 100 dB. Due to the high likelihood of leakage around the window, it is recommended that the window be soldered to its frame with a V-shape metal band to take up changes in size of the window due to temperature variation.

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APPENDIX A

Test Set-Up

A-i

PROGRAM ONE

```

PROGRAM LOH (INPUT, OUTPUT, OPL, TAPL6=ROPL)
COMPLEX T, T1, T2, T3, T4, T5, T6
COMPLEX T11, T41, RHON, STICK1, P2, P3, P4
REAL KO, MUO
DIMENSION AMU(2), AM(2), C(2), C(3), LABEL(2)
DIMENSION Z(4), WIDTH(3)
DATA Z/1., 2., 4., 8./
DATA WIDTH/.127, .008, .7/
PI=3.14159265358932
E=1.E-19
AMU(1)=.38
AMU(2)=.136
EO=8.E-12
CO=3.E+8
AMASS=9.11E-31
AM(1)=.12
AM(2)=.26
DO 230 M=1, 3
WRITE(6, 125) WIDTH(L-M)
125 FORMAT(1H1, *THICKNESS= *F10.6, * INCHES*)
A=WIDTH(4-M)*.0054
D(1)=1.0
D(2)=3.42
COO=1./CO
C(1)=2.5E+19
C(2)=1.E+21
C(3)=1.E+23
DATA LABEL(1)/9HGGERMANIUM/
DATA LABEL(2)/7HSILICON/
DO 230 LP=1, 2
MUO=AMU(LP)*AM(LP)
TAU=(MUO*AMASS)/E
DN = C(LP)
ALPHA1=E*AMU(LP)/(2.*PO*CO*PI)
BETA1= DN*COO
391 WRITE(6, 110) LABEL(LP)
395 DELF=1.0
DO 230 LM=1, 3
WRITE(6, 111) C(LM)
115 FORMAT(10X, *DOPTING LEVEL*, F10.3)

```

```

      F0=.37+Q
      WRITE(6,1213)
1219  FORMAT(5X,*F*,12X,*ALPHA*,12X,*REFLECT*,15X,*TARS*)
      CN=C(LM)
119   FORMAT(30X,A10)
      DO 230 II=1,5
      DO 230 JJ=1,4
      F=7(JJ)*10.** (II+9)
      W=2.*PI*F
      ALPHA=(ALPHA1*CN)/(1.+(.*TA1)**2)
      BETA =BETA1*W
      RAT=CO/W
      PAT=CMPLX(RAT,0.)
      SIM=CMPLX(BETA,ALPHA)
      PHON=PAT*SIM
      IF (PHON.GT.1.0) 2,1
2      RARS=1.
      GO TO 4
4      P1=1.-PHON
      R2=CMPLX(1.,0.)
      R3=R2 + PHON
      P4=P1/R3
      RARS=(ABS(R4)
7(1826 IF(ALPHA.GT..10)117,119
117   TOT=0.
      GO TO 119
118   K0=K*COO
      AA=ALPHA*AA
      AB=A*TA
      A1=(K0**2+BETA**2-ALPHA**2)/K0
      B1=(2.*AB)/K0
      T1=CMPLX(A1,B1)
      T11=CMPLX(AB,AA)
      T2=CSIN(T11)
      TN1=+2.*BETA
      TN2=-2.*ALPHA
      TN11=-TN1
      T3=CMPLX(TN2,TN1)
      T41=CMPLX(AB,AA)
      T4=CCOS(T41)
      TC = T1*T2 + T3*T4
      TN=CMPLX(TN2,TN11)
      T=TN/TC
      TOT=CCOS(T)
119  WRITE(6,120) F,ALPHA,TARS,TOT
120  FORMAT(4(5X,F11.5))
230  CONTINUE
      EN)

```

TRANSMISSION FROM R. F. To I. R. (ANSWERS)

THICKNESS= .700000 INCHES

GERMANIUM

DOPING LEVEL .250E+20

FREQUENCY (Hz)	ALPHA	ABSORPTION COEFF. cm^{-1}	REFLECTION COEFF.	TRANSMISSION COEFF.
.10000E+10		.71563E+02	.75082E+00	.40675E+00
.20000E+10		.71562E+02	.65338E+00	.22107E+00
.40000E+10		.71560E+02	.61494E+00	.19150E+00
.80000E+10		.71551E+02	.60385E+00	.18222E+00
.10000E+11		.71544E+02	.60247E+00	.17992E+00
.20000E+11		.71487E+02	.60062E+00	.17501E+00
.40000E+11		.71260E+02	.60015E+00	.18550E+00
.80000E+11		.70365E+02	.60004E+00	.18817E+00
.10000E+12		.69750E+02	.60002E+00	.18607E+00
.20000E+12		.64078E+02	.60001E+00	.20596E+00
.40000E+12		.50192E+02	.60000E+00	.25314E+00
.80000E+12		.26473E+02	.60000E+00	.37813E+00
.10000E+13		.19546E+02	.60000E+00	.50810E+00
.20000E+13		.61454E+01	.60000E+00	.53639E+00
.40000E+13		.16421E+01	.60000E+00	.46594E+00
.80000E+13		.41772E+00	.60000E+00	.91908E+00
.10000E+14		.26790E+00	.60000E+00	.52292E+00
.20000E+14		.67164E-01	.60000E+00	.52401E+00
.40000E+14		.16803E-01	.60000E+00	.52429E+00
.80000E+14		.42014E-02	.60000E+00	.52436E+00

DOPING LEVEL .100E+22

F	ALPHA	REFLECT	TA3S
.10000E+10	.28625E+04	.99957E+00	.23091E-23
.20000E+10	.28625E+04	.99829E+00	.46432E-23
.40000E+10	.28624E+04	.99327E+00	.94899E-23
.80000E+10	.28620E+04	.97442E+00	.20728E-22
.10000E+11	.28618E+04	.96147E+00	.27722E-22
.20000E+11	.28595E+04	.88122E+00	.10296E-21
.40000E+11	.28504E+04	.75004E+00	.13640E-21
.80000E+11	.28140E+04	.65185E+00	.14289E-21
.10000E+12	.27883E+04	.63433E+00	.21251E-21
.20000E+12	.25871E+04	.60796E+00	.69229E-20
.40000E+12	.20577E+04	.60122E+00	.20193E-15
.80000E+12	.10589E+04	.60009E+00	.42603E-08
.10000E+13	.78184E+03	.60003E+00	.58752E-06
.20000E+13	.24582E+03	.60000E+00	.80919E-02
.40000E+13	.65684E+02	.60000E+00	.19250E+00
.80000E+13	.16709E+02	.60000E+00	.57818E+00
.10000E+14	.10716E+02	.60000E+00	.46280E+00
.20000E+14	.26860E+01	.60000E+00	.50947E+00
.40000E+14	.67211E+00	.60000E+00	.52070E+00
.80000E+14	.16806E+00	.60000E+00	.52346E+00

DOPING LEVEL .100E+24			
FREQUENCY (Hz) ALPHA	ABSORPTION COEFF. CM ⁻¹	REFLECTION COEFF.	TRANSMISSION COEFF.
.10000E+10	.28025E+06	.10000E+01	0.
.20000E+10	.28625E+06	.10000E+01	0.
.40000E+10	.28624E+06	.10000E+01	0.
.80000E+10	.28620E+06	.10000E+01	0.
.10000E+11	.28618E+06	.10000E+01	0.
.20000E+11	.28595E+06	.99998E+00	0.
.40000E+11	.28504E+06	.99993E+00	0.
.80000E+11	.28140E+06	.99972E+00	0.
.10000E+12	.27883E+06	.99955E+00	0.
.20000E+12	.25871E+06	.99791E+00	0.
.40000E+12	.20077E+06	.98656E+00	0.
.80000E+12	.10589E+06	.86812E+00	0.
.10000E+13	.78184E+05	.76750E+00	0.
.20000E+13	.24582E+05	.60720E+00	0.
.40000E+13	.65684E+04	.60013E+00	0.
.80000E+13	.16709E+04	.60000E+00	.12206E-50
.10000E+14	.10716E+04	.60000E+00	.80204E-13
.20000E+14	.26860E+03	.60000E+00	.34003E-08
.40000E+14	.67211E+02	.60000E+00	.53912E-02
.80000E+14	.16800E+02	.60000E+00	.19051E+00

DOPING LEVEL .250E+20			
F ALPHA	REFLECT	TABS	
.10000E+10	.60510E+00	.48160E+00	
.20000E+10	.56359E+00	.42986E+00	
.40000E+10	.55165E+00	.38237E+00	
.80000E+10	.54855E+00	.41533E+00	
.10000E+11	.54818E+00	.45706E+00	
.20000E+11	.54768E+00	.44743E+00	
.40000E+11	.54755E+00	.41957E+00	
.80000E+11	.54752E+00	.37737E+00	
.10000E+12	.54752E+00	.37603E+00	
.20000E+12	.54751E+00	.46970E+00	
.40000E+12	.54751E+00	.49126E+00	
.80000E+12	.54751E+00	.50064E+00	
.10000E+13	.54751E+00	.49353E+00	
.20000E+13	.54751E+00	.64876E+00	
.40000E+13	.54751E+00	.53525E+00	
.80000E+13	.54751E+00	.93567E+00	
.10000E+14	.54751E+00	.79558E+00	
.20000E+14	.54751E+00	.60341E+00	
.40000E+14	.54751E+00	.57707E+00	
.80000E+14	.54751E+00	.63861E+00	

DOPING LEVEL .10JE+22			
FREQUENCY (Hz) ALPHA	ABSORPTION COEFF. cm^{-3}	REFLECTION COEFF.	TRANSMISSION COEFF.
.10000E+10	.11982E+04	.99792E+J0	.39383E-10
.20000E+10	.11982E+04	.99180E+J0	.80439E-10
.40000E+10	.11982E+04	.96900E+J0	.17580E-C9
.80000E+10	.11981E+04	.89801E+00	.51237E-09
.10000E+11	.11980E+04	.85920E+00	.85697E-C9
.20000E+11	.11975E+04	.71154E+J0	.79456E-09
.40000E+11	.11952E+04	.60484E+J0	.49362E-09
.80000E+11	.11861E+04	.56328E+J0	.50797E-C9
.10000E+12	.11794E+04	.55763E+J0	.56330E-C9
.20000E+12	.11261E+04	.54986E+J0	.14198E-08
.40000E+12	.95397E+J3	.54794E+00	.30157E-07
.80000E+12	.59197E+03	.54755E+00	.18805E-04
.10000E+13	.46082E+03	.54753E+J0	.19362E-03
.20000E+13	.16190E+03	.54751E+00	.39365E-01
.40000E+13	.45040E+02	.54751E+J0	.29687E+00
.80000E+13	.11587E+02	.54751E+J0	.68991E+00
.10000E+14	.74413E+01	.54751E+J0	.68314E+00
.20000E+14	.18690E+01	.54751E+J0	.59010E+00
.40000E+14	.46781E+00	.54751E+J0	.57417E+00
.80000E+14	.11699E+J0	.54751E+J0	.63763E+00

DOPING LEVEL .100E+24			
F	ALPHA	REFLECT	TRANS
.10000E+10	.11982E+06	.10000E+01	0.
.20000E+10	.11982E+06	.10000E+01	0.
.40000E+10	.11982E+06	.10000E+01	0.
.80000E+10	.11981E+06	.99999E+00	0.
.10000E+11	.11980E+06	.99998E+00	0.
.20000E+11	.11975E+06	.99992E+00	0.
.40000E+11	.11952E+06	.99966E+00	0.
.80000E+11	.11861E+06	.99864E+00	0.
.10000E+12	.11794E+06	.99785E+00	0.
.20000E+12	.11261E+06	.99074E+00	0.
.40000E+12	.95397E+05	.95306E+00	0.
.80000E+12	.59197E+05	.75680E+00	0.
.10000E+13	.46082E+05	.66244E+00	0.
.20000E+13	.16190E+05	.55234E+00	0.
.40000E+13	.45040E+04	.54761E+00	.11653E-34
.80000E+13	.11587E+04	.54751E+00	.79128E-C9
.10000E+14	.74413E+03	.54751E+00	.12566E-C5
.20000E+14	.18690E+03	.54751E+00	.25231E-C1
.40000E+14	.46781E+02	.54751E+00	.29389E+00
.80000E+14	.11699E+02	.54751E+00	.53904E+00

THICKNESS= .058000 INCHES

GERMANIUM

DOPING LEVEL .250E+20

FREQUENCY (Hz) ALPHA	ABSORPTION COEFF. cm^{-1}	REFLECTION COEFF.	TRANSMISSION COEFF.
.10000E+10	.71563E+02	.75082E+00	.99792E+00
.20000E+10	.71562E+02	.65338E+00	.93167E+00
.40000E+10	.71560E+02	.61494E+00	.74837E+00
.80000E+10	.71551E+02	.60385E+00	.52385E+00
.10000E+11	.71544E+02	.60247E+00	.47446E+00
.20000E+11	.71487E+02	.60062E+00	.58162E+00
.40000E+11	.71260E+02	.60015E+00	.45335E+00
.80000E+11	.70360E+02	.60004E+00	.68248E+00
.10000E+12	.69708E+02	.60002E+00	.77158E+00
.20000E+12	.64678E+02	.60001E+00	.68575E+00
.40000E+12	.50192E+02	.60000E+00	.53458E+00
.80000E+12	.26473E+02	.60000E+00	.47067E+00
.10000E+13	.19546E+02	.60000E+00	.55288E+00
.20000E+13	.61454E+01	.60000E+00	.47759E+00
.40000E+13	.16421E+01	.60000E+00	.77638E+00
.80000E+13	.41772E+00	.60000E+00	.56626E+00
.10000E+14	.26790E+00	.60000E+00	.76771E+00
.20000E+14	.67164E-01	.60000E+00	.55633E+00
.40000E+14	.16803E-01	.60000E+00	.48442E+00
.80000E+14	.42014E-02	.60000E+00	.71732E+00

DOPING LEVEL .100E+22

F	ALPHA	REFLECT	TRANS
.10000E+10	.28625E+04	.99957E+00	.43225E-03
.20000E+10	.28625E+04	.99829E+00	.86884E-03
.40000E+10	.28624E+04	.99327E+00	.17730E-02
.80000E+10	.28620E+04	.97442E+00	.38486E-02
.10000E+11	.28618E+04	.96147E+00	.51239E-02
.20000E+11	.28595E+04	.88122E+00	.18345E-01
.40000E+11	.28504E+04	.75004E+00	.20947E-01
.80000E+11	.28145E+04	.65185E+00	.12240E-01
.10000E+12	.27883E+04	.63433E+00	.11862E-01
.20000E+12	.25871E+04	.60796E+00	.14528E-01
.40000E+12	.20077E+04	.60122E+00	.33362E-01
.80000E+12	.10589E+04	.60009E+00	.13264E+00
.10000E+13	.78184E+03	.60003E+00	.20067E+00
.20000E+13	.24582E+03	.60000E+00	.38407E+00
.40000E+13	.65684E+02	.60000E+00	.68777E+00
.80000E+13	.16709E+02	.60000E+00	.55693E+00
.10000E+14	.10716E+02	.60000E+00	.75302E+00
.20000E+14	.26866E+01	.60000E+00	.55492E+00
.40000E+14	.67211E+00	.60000E+00	.48418E+00
.80000E+14	.16806E+00	.60000E+00	.71713E+00

JOPING LEVEL .100E+24			
FREQUENCY (Hz) ALPHA	ABSORPTION COEFF. cm^{-3}	REFLECTION COEFF.	TRANSMISSION COEFF.
.10000E+10	.28625E+06	.10000E+01	0.
.20000E+10	.28625E+06	.10000E+01	0.
.40000E+10	.28624E+06	.10000E+01	0.
.80000E+10	.28620E+06	.10000E+01	0.
.10000E+11	.28618E+06	.10000E+01	0.
.20000E+11	.28595E+06	.99998E+00	0.
.40000E+11	.28504E+06	.99993E+00	0.
.80000E+11	.28146E+06	.99972E+00	0.
.10000E+12	.27883E+06	.99955E+00	0.
.20000E+12	.25871E+06	.99791E+00	0.
.40000E+12	.20077E+06	.98656E+00	0.
.80000E+12	.10589E+06	.86812E+00	0.
.10000E+13	.78184E+05	.76750E+00	0.
.20000E+13	.24582E+05	.60720E+00	0.
.40000E+13	.65684E+04	.60013E+00	.40167E-04
.80000E+13	.16709E+04	.60000E+00	.54567E-01
.10000E+14	.10716E+04	.60000E+00	.13322E+00
.20000E+14	.26860E+03	.60000E+00	.40810E+00
.40000E+14	.67211E+02	.60000E+00	.45935E+00
.80000E+14	.16800E+02	.60000E+00	.69808E+00

SILICON			
DOPING LEVEL .250E+20			
F	ALPHA	REFLECT	TA3S
.10000E+10	.29956E+02	.60510E+00	.99073E+00
.20000E+10	.29955E+02	.56359E+00	.95257E+00
.40000E+10	.29955E+02	.55165E+00	.83925E+00
.80000E+10	.29953E+02	.54855E+00	.64187E+00
.10000E+11	.29951E+02	.54818E+00	.58283E+00
.20000E+11	.29936E+02	.54768E+00	.57704E+00
.40000E+11	.29879E+02	.54755E+00	.57203E+00
.80000E+11	.29652E+02	.54752E+00	.58998E+00
.10000E+12	.29484E+02	.54752E+00	.56260E+00
.20000E+12	.28154E+02	.54751E+00	.61618E+00
.40000E+12	.23849E+02	.54751E+00	.53589E+00
.80000E+12	.14799E+02	.54751E+00	.82686E+00
.10000E+13	.11520E+02	.54751E+00	.54850E+00
.20000E+13	.40476E+01	.54751E+00	.76473E+00
.40000E+13	.11260E+01	.54751E+00	.57895E+00
.80000E+13	.28967E+00	.54751E+00	.63046E+00
.10000E+14	.18603E+00	.54751E+00	.88265E+00
.20000E+14	.46726E-01	.54751E+00	.70712E+00
.40000E+14	.11695E-01	.54751E+00	.54521E+00
.80000E+14	.29247E-02	.54751E+00	.87212E+00

DOPING LEVEL .100E+22

FREQUENCY (Hz) ALPHA	ABSORPTION COEFF. cm^{-3}	REFLECTION COEFF.	TRANSMISSION COEFF.
.10000E+13	.11982E+04	.99792E+00	.12402E-01
.20000E+10	.11982E+04	.99180E+00	.25262E-01
.40000E+10	.11982E+04	.96900E+00	.54466E-01
.80000E+10	.11981E+04	.89801E+00	.15187E+00
.10000E+11	.11980E+04	.85920E+00	.24927E+00
.20000E+11	.11975E+04	.71154E+00	.23935E+00
.40000E+11	.11952E+04	.60484E+00	.14095E+00
.80000E+11	.11861E+04	.56328E+00	.12678E+00
.10000E+12	.11794E+04	.55763E+00	.12625E+00
.20000E+12	.11261E+04	.54986E+00	.13366E+00
.40000E+12	.95397E+03	.54794E+00	.16920E+00
.80000E+12	.59197E+03	.54755E+00	.30333E+00
.10000E+13	.46082E+03	.54753E+00	.33301E+00
.20000E+13	.16190E+03	.54751E+00	.59101E+00
.40000E+13	.45040E+02	.54751E+00	.55524E+00
.80000E+13	.11587E+02	.54751E+00	.62269E+00
.10000E+14	.74413E+01	.54751E+00	.86913E+00
.20000E+14	.18690E+01	.54751E+00	.70536E+00
.40000E+14	.46781E+00	.54751E+00	.54501E+00
.80000E+14	.11699E+00	.54751E+00	.87191E+00

DOPING LEVEL .100E+24

F	ALPHA	REFLECT	TABS
.10000E+10	.11982E+06	.10000E+01	0.
.20000E+10	.11982E+06	.10000E+01	0.
.40000E+10	.11982E+06	.10000E+01	0.
.80000E+10	.11981E+06	.99999E+00	0.
.10000E+11	.11980E+06	.99998E+00	0.
.20000E+11	.11975E+06	.99992E+00	0.
.40000E+11	.11952E+06	.99966E+00	0.
.80000E+11	.11861E+06	.99864E+00	0.
.10000E+12	.11794E+06	.99785E+00	0.
.20000E+12	.11261E+06	.99074E+00	0.
.40000E+12	.95397E+05	.95306E+00	0.
.80000E+12	.59197E+05	.75680E+00	0.
.10000E+13	.46082E+05	.66244E+00	0.
.20000E+13	.16190E+05	.55234E+00	0.
.40000E+13	.45040E+04	.54761E+00	.91978E-03
.80000E+13	.11587E+04	.54751E+00	.12673E+00
.10000E+14	.74413E+03	.54751E+00	.24007E+00
.20000E+14	.18690E+03	.54751E+00	.54072E+00
.40000E+14	.46781E+02	.54751E+00	.52401E+00
.80000E+14	.11699E+02	.54751E+00	.85124E+00

THICKNESS= .127000 INCHES

GERMANIUM

DOPING LEVEL .250E+20

FREQUENCY (Hz) ALPHA	ABSORPTION COEFF. cm^{-1}	REFLECTION COEFF.	TRANSMISSION COEFF.
.10000E+10	.71563E+02	.75082E+00	.98528E+00
.20000E+10	.71562E+02	.65338E+00	.75033E+00
.40000E+10	.71560E+02	.61494E+00	.49053E+00
.80000E+10	.71551E+02	.60385E+00	.45580E+00
.10000E+11	.71544E+02	.60247E+00	.57242E+00
.20000E+11	.71487E+02	.60062E+00	.47319E+00
.40000E+11	.71260E+02	.60015E+00	.41957E+00
.80000E+11	.70365E+02	.60004E+00	.60134E+00
.10000E+12	.69708E+02	.60002E+00	.42846E+00
.20000E+12	.64678E+02	.60001E+00	.54176E+00
.40000E+12	.50192E+02	.60000E+00	.44379E+00
.80000E+12	.26473E+02	.60000E+00	.63958E+00
.10000E+13	.19546E+02	.60000E+00	.87493E+00
.20000E+13	.61454E+01	.60000E+00	.93283E+00
.40000E+13	.16421E+01	.60000E+00	.88759E+00
.80000E+13	.41772E+00	.60000E+00	.72109E+00
.10000E+14	.26790E+00	.60000E+00	.65093E+00
.20000E+14	.67164E-01	.60000E+00	.48039E+00
.40000E+14	.16803E-01	.60000E+00	.76803E+00
.80000E+14	.42014E-02	.60000E+00	.55636E+00

DOPING LEVEL .100E+22

F	ALPHA	REFLECT	TABS
.10000E+10	.28625E+04	.99957E+00	.28632E-05
.20000E+10	.28625E+04	.99829E+00	.57556E-05
.40000E+10	.28624E+04	.99327E+00	.11748E-04
.80000E+10	.28620E+04	.97442E+00	.25523E-04
.10000E+11	.28618E+04	.96147E+00	.34000E-04
.20000E+11	.28595E+04	.88122E+00	.12215E-03
.40000E+11	.28504E+04	.75004E+00	.14176E-03
.80000E+11	.28140E+04	.65185E+00	.88137E-04
.10000E+12	.27883E+04	.63433E+00	.89497E-04
.20000E+12	.25871E+04	.60796E+00	.15596E-03
.40000E+12	.20077E+04	.60122E+00	.98912E-03
.80000E+12	.10589E+04	.60009E+00	.21030E-01
.10000E+13	.78184E+03	.60003E+00	.51511E-01
.20000E+13	.24582E+03	.60000E+00	.31171E+00
.40000E+13	.65684E+02	.60000E+00	.64209E+00
.80000E+13	.16709E+02	.60000E+00	.67995E+00
.10000E+14	.10716E+02	.60000E+00	.63119E+00
.20000E+14	.26866E+01	.60000E+00	.47839E+00
.40000E+14	.67211E+00	.60000E+00	.76600E+00
.80000E+14	.16806E+00	.60000E+00	.55617E+00

DOPING LEVEL .100E+24			
FREQUENCY (Hz)	ALPHA	ABSORPTION COEFF. cm^{-1}	REFLECTION COEFF. TRANSMISSION COEFF.
.10000E+10		.28625E+06	.10000E+01 J.
.20000E+10		.28625E+06	.10000E+01 0.
.40000E+10		.28624E+06	.10000E+01 0.
.80000E+10		.28620E+06	.10000E+01 0.
.10000E+11		.28618E+06	.10000E+01 0.
.20000E+11		.28595E+06	.99998E+00 0.
.40000E+11		.28504E+06	.99993E+00 0.
.80000E+11		.28146E+06	.99972E+00 0.
.10000E+12		.27883E+06	.99955E+00 0.
.20000E+12		.25871E+06	.99791E+00 0.
.40000E+12		.20077E+06	.98656E+00 J.
.80000E+12		.10589E+06	.86812E+00 0.
.10000E+13		.78184E+05	.76750E+00 0.
.20000E+13		.24582E+05	.60720E+00 0.
.40000E+13		.65084E+04	.60013E+00 .40211E-09
.80000E+13		.16709E+04	.60000E+00 .29201E-02
.10000E+14		.10716E+04	.60000E+00 .20182E-01
.20000E+14		.26860E+03	.60000E+00 .25444E+00
.40000E+14		.67211E+02	.60000E+00 .58631E+00
.80000E+14		.16800E+02	.60000E+00 .53624E+00

SILICON

DOPING LEVEL .250E+20			
F	ALPHA	REFLECT	TABS
.10000E+10	.29950E+02	.60510E+00	.95556E+00
.20000E+10	.29955E+02	.56359E+00	.81907E+00
.40000E+10	.29955E+02	.55165E+00	.60835E+00
.80000E+10	.29953E+02	.54855E+00	.52069E+00
.10000E+11	.29951E+02	.54818E+00	.59730E+00
.20000E+11	.29936E+02	.54768E+00	.51192E+00
.40000E+11	.29879E+02	.54755E+00	.81958E+00
.80000E+11	.29652E+02	.54752E+00	.76343E+00
.10000E+12	.29484E+02	.54752E+00	.54551E+00
.20000E+12	.28154E+02	.54751E+00	.58634E+00
.40000E+12	.23849E+02	.54751E+00	.52676E+00
.80000E+12	.14799E+02	.54751E+00	.75276E+00
.10000E+13	.11520E+02	.54751E+00	.53194E+00
.20000E+13	.40476E+01	.54751E+00	.88838E+00
.40000E+13	.11260E+01	.54751E+00	.74383E+00
.80000E+13	.28967E+00	.54751E+00	.56361E+00
.10000E+14	.18003E+00	.54751E+00	.53915E+00
.20000E+14	.46726E-01	.54751E+00	.98517E+00
.40000E+14	.11695E-01	.54751E+00	.94583E+00
.80000E+14	.29247E-02	.54751E+00	.83099E+00

DOPING LEVEL .100E+22			
FREQUENCY (Hz)	ALPHA	ABSORPTION COEFF. cm^{-1}	REFLECTION COEFF. TRANSMISSION COEFF.
.10000E+10		.11982E+04	.99792E+00 .14764E-02
.20000E+10		.11982E+04	.99180E+00 .30167E-02
.40000E+10		.11982E+04	.96900E+00 .65837E-02
.80000E+10		.11981E+04	.89801E+00 .19164E-01
.10000E+11		.11980E+04	.85920E+00 .32047E-01
.20000E+11		.11975E+04	.71154E+00 .29452E-01
.40000E+11		.11952E+04	.60484E+00 .17694E-01
.80000E+11		.11861E+04	.56328E+00 .15953E-01
.10000E+12		.11794E+04	.55763E+00 .16039E-01
.20000E+12		.11261E+04	.54986E+00 .18635E-01
.40000E+12		.95397E+03	.54794E+00 .32288E-01
.80000E+12		.59197E+03	.54755E+00 .10410E+00
.10000E+13		.46082E+03	.54753E+00 .15698E+00
.20000E+13		.16190E+03	.54751E+00 .45386E+00
.40000E+13		.45040E+02	.54751E+00 .64083E+00
.80000E+13		.11587E+02	.54751E+00 .55135E+00
.10000E+14		.74413E+01	.54751E+00 .53227E+00
.20000E+14		.18090E+01	.54751E+00 .97482E+00
.40000E+14		.46781E+00	.54751E+00 .94352E+00
.80000E+14		.11699E+00	.54751E+00 .83060E+00

DOPING LEVEL .100E+24			
F	ALPHA	REFLECT	TA3S
.10000E+10	.11982E+06	.10000E+01	0.
.20000E+10	.11982E+06	.10000E+01	0.
.40000E+10	.11982E+06	.10000E+01	0.
.80000E+10	.11981E+06	.99999E+00	0.
.10000E+11	.11980E+06	.99998E+00	0.
.20000E+11	.11975E+06	.99992E+00	0.
.40000E+11	.11952E+06	.99966E+00	0.
.80000E+11	.11861E+06	.99864E+00	0.
.10000E+12	.11794E+06	.99785E+00	0.
.20000E+12	.11261E+06	.99074E+00	0.
.40000E+12	.95397E+05	.95306E+00	0.
.80000E+12	.59197E+05	.75680E+00	0.
.10000E+13	.46082E+05	.66244E+00	0.
.20000E+13	.16190E+05	.55234E+00	0.
.40000E+13	.45040E+04	.54761E+00	.34316E-06
.80000E+13	.11587E+04	.54751E+00	.16671E-01
.10000E+14	.74413E+03	.54751E+00	.63341E-01
.20000E+14	.18090E+03	.54751E+00	.41985E+00
.40000E+14	.46781E+02	.54751E+00	.74776E+00
.80000E+14	.11699E+02	.54751E+00	.79190E+00

PROGRAM TWO

FREE CARRIER CONCENTRATION FROM 200°K TO 800°K

GERMANIUM

THICKNESS=	.12700 INCHES		
	FREQUENCY	.20000E+14	
TEMPERATURE°K		DOPING LEVEL cm^{-3}	TRANSMISSION COEFF.
200.00000		.10000E+22	.47033E+00
250.00000		.10000E+22	.47033E+00
300.00000 - Room Temp.		.10237E+22	.47033E+00
350.00000		.12600E+22	.47700E+00
400.00000		.26162E+22	.47033E+00
450.00000		.70200E+22	.46390E+00
500.00000		.22973E+23	.42944E+00
550.00000		.30477E+23	.34353E+00
600.00000		.13263E+24	.14033E+00
650.00000		.20090E+24	.63101E-01
700.00000		.49106E+24	.40770E-02
750.00000		.3927E+24	.44402E-03
800.00000		.13003E+25	.52900E-05
	FREQUENCY	.50000E+14	
TEMPERATURE		DOPING LEVEL	TAJS
200.00000		.10000E+22	.50071E+00
250.00000		.10000E+22	.50071E+00
300.00000		.10237E+22	.50000E+00
350.00000		.12600E+22	.50000E+00
400.00000		.26162E+22	.50000E+00
450.00000		.70200E+22	.49020E+00
500.00000		.22973E+23	.48220E+00
550.00000		.30477E+23	.43990E+00
600.00000		.13263E+24	.30312E+00
650.00000		.20090E+24	.22211E+00
700.00000		.49106E+24	.90900E-01
750.00000		.3927E+24	.20199E-01
800.00000		.13003E+25	.35102E-02
	FREQUENCY	.40000E+14 (Hz)	
TEMPERATURE		DOPING LEVEL	TAJS
200.00000		.10000E+22	.70000E+00
250.00000		.10000E+22	.70000E+00
300.00000		.10237E+22	.70000E+00
350.00000		.12600E+22	.70000E+00
400.00000		.26162E+22	.70000E+00
450.00000		.70200E+22	.70000E+00
500.00000		.22973E+23	.72100E+00
550.00000		.30477E+23	.60000E+00
600.00000		.13263E+24	.30000E+00
650.00000		.20090E+24	.30331E+00
700.00000		.49106E+24	.22000E+00
750.00000		.3927E+24	.10000E+00
800.00000		.13003E+25	.34201E-01

TEMPERATURE °K	FREQUENCY	DOPING LEVEL $\times 10^{-3}$	TRANSMISSION COEFF.
200.00000		.10000E+22	.92433E+00
250.00000		.10009E+22	.92932E+00
300.00000		.10237E+22	.92927E+00
350.00000		.12605E+22	.92871E+00
400.00000		.26162E+22	.92550E+00
450.00000		.70255E+22	.91334E+00
500.00000		.22973E+23	.87938E+00
550.00000		.58977E+23	.80025E+00
600.00000		.13263E+24	.60545E+00
650.00000		.20090E+24	.52225E+00
700.00000		.49106E+24	.35523E+00
750.00000		.33927E+24	.20025E+00
800.00000		.13503E+25	.94030E-01
TEMPERATURE	FREQUENCY	DOPING LEVEL	TAJS
200.00000		.10000E+22	.95075E+00
250.00000		.10009E+22	.95576E+00
300.00000		.10237E+22	.95075E+00
350.00000		.12605E+22	.90005E+00
400.00000		.26162E+22	.55815E+00
450.00000		.70255E+22	.76018E+00
500.00000		.22973E+23	.56042E+00
550.00000		.58977E+23	.34055E+00
600.00000		.13263E+24	.51799E+00
650.00000		.20090E+24	.40012E+00
700.00000		.49106E+24	.38511E+00
750.00000		.33927E+24	.28001E+00
800.00000		.13503E+25	.17527E+00
TEMPERATURE	FREQUENCY	DOPING LEVEL	TAJS
200.00000		.10000E+22	.47051E+00
250.00000		.10009E+22	.47051E+00
300.00000		.10237E+22	.47051E+00
350.00000		.12605E+22	.47047E+00
400.00000		.26162E+22	.47020E+00
450.00000		.70255E+22	.40944E+00
500.00000		.22973E+23	.40703E+00
550.00000		.58977E+23	.46120E+00
600.00000		.13263E+24	.44882E+00
650.00000		.20090E+24	.42501E+00
700.00000		.49106E+24	.38326E+00
750.00000		.33927E+24	.31057E+00
800.00000		.13503E+25 - 3.7 microns	.23300E+00

TEMPERATURE°K	FREQUENCY	DOPING LEVEL ^{cm⁻³}	TRANSMISSION COEFF
200.00000		.30000E+14	
250.00000		.10000E+22	.55017E+00
300.00000		.10009E+22	.55017E+00
350.00000		.10237E+22	.55017E+00
400.00000		.12005E+22	.55012E+00
450.00000		.25102E+22	.55055E+00
500.00000		.75255E+22	.55052E+00
550.00000		.22973E+23	.55173E+00
600.00000		.55977E+23	.55455E+00
650.00000		.13263E+24	.55957E+00
700.00000		.20090E+24	.56185E+00
750.00000		.49100E+24	.56555E+00
800.00000		.55927E+24	.38734E+00
		.15503E+25	.30014E+00

TEMPERATURE	FREQUENCY	DOPING LEVEL	TAB5
200.00000		.10000E+22	.90504E+00
250.00000		.10009E+22	.90505E+00
300.00000		.10237E+22	.90502E+00
350.00000		.12005E+22	.90540E+00
400.00000		.25102E+22	.90554E+00
450.00000		.75255E+22	.90103E+00
500.00000		.22973E+23	.89995E+00
550.00000		.55977E+23	.85704E+00
600.00000		.13263E+24	.82277E+00
650.00000		.20090E+24	.74951E+00
700.00000		.49100E+24	.64744E+00
750.00000		.55927E+24	.52520E+00
800.00000		.15503E+25	.39772E+00

TEMPERATURE	FREQUENCY	DOPING LEVEL	TAB5
200.00000		.10000E+22	.79475E+00
250.00000		.10009E+22	.79470E+00
300.00000		.10237E+22	.79477E+00
350.00000		.12005E+22	.79489E+00
400.00000		.25102E+22	.79413E+00
450.00000		.75255E+22	.79220E+00
500.00000		.22973E+23	.78009E+00
550.00000		.55977E+23	.77361E+00
600.00000		.13263E+24	.74702E+00
650.00000		.20090E+24	.70273E+00
700.00000		.49100E+24	.60401E+00
750.00000		.55927E+24	.54402E+00
800.00000		.15503E+25	.43942E+00

TEMPERATURE°K	FREQUENCY	DOPING LEVEL ^{cm⁻³}	TRANSMISSION COEFF.
200.00000	.11000E+15 Hz	.13000E+22	.51555E+00
250.00000		.10009E+22	.51550E+00
300.00000		.10237E+22	.51550E+00
350.00000		.12005E+22	.51554E+00
400.00000		.20102E+22	.51552E+00
450.00000		.70255E+22	.51499E+00
500.00000		.22973E+23	.51372E+00
550.00000		.50917E+23	.51005E+00
600.00000		.13203E+24	.50430E+00
650.00000		.20090E+24	.49200E+00
700.00000		.49100E+24	.47259E+00
750.00000		.53927E+24	.44000E+00
800.00000		.15503E+25	.39390E+00

SILICON

THICKNESS=	.127000 INCHES	FREQUENCY	DOPING LEVEL	TA00
TEMPERATURE				
200.00000		.20000E+14	.10000E+22	.97432E+00
250.00000			.10000E+22	.97402E+00
300.00000			.10000E+22	.97402E+00
350.00000			.10005E+22	.97401E+00
400.00000			.10070E+22	.97474E+00
450.00000			.10550E+22	.97414E+00
500.00000			.13007E+22	.97104E+00
550.00000			.24059E+22	.95940E+00
600.00000			.50090E+22	.92550E+00
650.00000			.14523E+23	.80195E+00
700.00000			.55024E+23	.70917E+00
750.00000			.71471E+23	.51097E+00
800.00000			.14012E+24	.31794E+00

TEMPERATURE	FREQUENCY	DOPING LEVEL	TA00
200.00000	.50000E+14	.10000E+22	.94322E+00
250.00000		.10000E+22	.94322E+00
300.00000		.10000E+22	.94322E+00
350.00000		.10005E+22	.94322E+00
400.00000		.10070E+22	.94322E+00
450.00000		.10550E+22	.94317E+00
500.00000		.13007E+22	.94293E+00
550.00000		.24059E+22	.94203E+00
600.00000		.50090E+22	.93920E+00
650.00000		.14520E+23	.93222E+00
700.00000		.55024E+23	.91029E+00
750.00000		.71471E+23	.40375E+00
800.00000		.14012E+24 -7.5 microns	.42305E+00

TEMPERATURE°K	FREQUENCY	DOPING LEVEL ^{cm⁻³}	TRANSMISSION COEFF.
200.00000		.00000E+14	
250.00000		.10000E+22	.09020E+00
300.00000		.10000E+22	.09020E+00
350.00000		.10000E+22	.09020E+00
400.00000		.10000E+22	.09020E+00
450.00000		.10000E+22	.09019E+00
500.00000		.10000E+22	.09019E+00
550.00000		.13007E+22	.08980E+00
600.00000		.24059E+22	.08980E+00
650.00000		.08093E+22	.08981E+00
700.00000		.14520E+23	.07040E+00
750.00000		.33024E+23	.08212E+00
800.00000		.71471E+23	.03107E+00
		.14612E+24	.07024E+00
		.40000E+14	

TEMPERATURE	FREQUENCY	DOPING LEVEL	TRANSMISSION
200.00000		.10000E+22	.94392E+00
250.00000		.10000E+22	.94392E+00
300.00000		.10000E+22	.94392E+00
350.00000		.10000E+22	.94392E+00
400.00000		.10000E+22	.94391E+00
450.00000		.10000E+22	.94391E+00
500.00000		.13007E+22	.94201E+00
550.00000		.24059E+22	.94000E+00
600.00000		.08093E+22	.93209E+00
650.00000		.14520E+23	.91240E+00
700.00000		.33024E+23	.87110E+00
750.00000		.71471E+23	.79750E+00
800.00000		.14612E+24	.60000E+00
		.50000E+14 -6 microns	

TEMPERATURE	FREQUENCY	DOPING LEVEL	TRANSMISSION
200.00000		.10000E+22	.99327E+00
250.00000		.10000E+22	.99327E+00
300.00000		.10000E+22	.99327E+00
350.00000		.10000E+22	.99327E+00
400.00000		.10000E+22	.99320E+00
450.00000		.10000E+22	.99320E+00
500.00000		.13007E+22	.99310E+00
550.00000		.24059E+22	.99201E+00
600.00000		.08093E+22	.99170E+00
650.00000		.14520E+23	.94910E+00
700.00000		.33024E+23	.94324E+00
750.00000		.71471E+23	.93107E+00
800.00000		.14612E+24	.90999E+00

TEMPERATURE°K FREQUENCY

200.00000
250.00000
300.00000
350.00000
400.00000
450.00000
500.00000
550.00000
600.00000
650.00000
700.00000
750.00000
800.00000

.70000E+1+

DOPING LEVEL cm⁻³
.10000E+22
.10000E+22
.10000E+22
.10000E+22
.10000E+22
.10078E+22
.10650E+22
.13007E+22
.24859E+22
.30893E+22
.14520E+23
.33024E+23
.71471E+23
.14012E+24

TRANSMISSION COEFF.

.30800E+00
.30800E+00
.30800E+00
.30800E+00
.30800E+00
.30800E+00
.30800E+00
.30800E+00
.30781E+00
.30724E+00
.30579E+00
.30230E+00
.30012E+00
.29429E+00

FREQUENCY

TEMPERATURE

200.00000
250.00000
300.00000
350.00000
400.00000
450.00000
500.00000
550.00000
600.00000
650.00000
700.00000
750.00000
800.00000

.00000E+1+
DOPING LEVEL

.10000E+22
.10000E+22
.10000E+22
.10000E+22
.10078E+22
.10650E+22
.13007E+22
.24859E+22
.30893E+22
.14520E+23
.33024E+23
.71471E+23
.14012E+24

TAOS

.33000E+00
.83000E+00
.83000E+00
.83000E+00
.83000E+00
.83000E+00
.83000E+00
.83000E+00
.82000E+00
.82519E+00
.81701E+00
.80263E+00
.77001E+00

FREQUENCY

TEMPERATURE

200.00000
250.00000
300.00000
350.00000
400.00000
450.00000
500.00000
550.00000
600.00000
650.00000
700.00000
750.00000
800.00000

.90000E+1+
DOPING LEVEL

.10000E+22
.10000E+22
.10000E+22
.10000E+22
.10078E+22
.10650E+22
.13007E+22
.24859E+22
.30893E+22
.14520E+23
.33024E+23
.71471E+23
.14012E+24

TAOS

.30830E+00
.50830E+00
.30830E+00
.30830E+00
.30830E+00
.30829E+00
.30820E+00
.30813E+00
.30779E+00
.30677E+00
.30401E+00
.30032E+00
.27240E+00

TEMPERATURE°K	FREQUENCY	DOPING LEVEL cm^{-3}	TRANSMISSION COEFF.
200.00000		.10000E+15	
250.00000		.10000E+22	.77250E+00
300.00000		.10000E+22	.77250E+00
350.00000		.10000E+22	.77250E+00
400.00000		.10000E+22	.77250E+00
450.00000		.10078E+22	.77257E+00
500.00000		.10650E+22	.77251E+00
550.00000		.13607E+22	.77227E+00
600.00000		.24859E+22	.77157E+00
650.00000		.70090E+22	.76979E+00
700.00000		.14520E+23	.76585E+00
750.00000		.33624E+23	.75812E+00
800.00000		.71471E+23	.74420E+00
		.14012E+24	
TEMPERATURE	FREQUENCY	DOPING LEVEL	TABS
200.00000		.11000E+15	
250.00000		.10000E+22	.61455E+00
300.00000		.10000E+22	.61455E+00
350.00000		.10000E+22	.61455E+00
400.00000		.10000E+22	.61455E+00
450.00000		.10078E+22	.61455E+00
500.00000		.10650E+22	.61452E+00
550.00000		.13607E+22	.61443E+00
600.00000		.24859E+22	.61413E+00
650.00000		.70090E+22	.61339E+00
700.00000		.14520E+23	.61174E+00
750.00000		.33624E+23	.60848E+00
800.00000		.71471E+23	.60254E+00
		.14012E+24	

PROGRAM THREE

IMPEDANCE (Z) AT DIFFERENT FREQUENCIES AND DIFFERENT RESISTIVITIES FOR Ge AND Si

Ge

INDEX OF REFRACTION
KCOFF

4.300J

FREQ Hz

RESISTIVITY

.70000E-01 ohm-cm

ohms

Z

X ohm

IMPEDANCE

Z0 R ohm

FREQ Hz	ohms	Z	X ohm	IMPEDANCE Z0 R ohm
.50000E+09	3.5400		3.5439	7.4162
.10000E+10	3.130J		3.3796	10.092
.15000E+10	3.730J		7.4117	12.249
.20000E+10	11.120		8.0227	14.077
.25000E+10	12.437		9.2494	15.000
.30000E+10	13.059		10.311	17.114
.35000E+10	14.010		10.943	18.414
.40000E+10	15.090		11.400	19.003
.45000E+10	15.331		11.904	20.097
.50000E+10	17.515		12.263	21.709
.55000E+10	18.049		12.550	22.040
.60000E+10	19.74J		12.796	23.522
.65000E+10	20.590		12.975	24.356
.70000E+10	21.399		13.110	25.090
.75000E+10	22.170		13.206	25.800
.80000E+10	22.904		13.270	26.471
.85000E+10	23.003		13.302	27.093
.90000E+10	24.200		13.300	27.070
.95000E+10	24.900		13.206	28.223
.10000E+11	25.501		13.246	28.737
.10500E+11	26.071		13.137	29.217
.11000E+11	26.014		13.112	29.068
.11500E+11	27.120		13.024	30.093
.12000E+11	27.017		12.924	30.492
.12500E+11	28.001		12.814	30.307

INDEX OF REFRACTION RCOFF

4.00000
FREQUENCY (Hz)

RESISTIVITY

0.00000-0.2 ohm-cm

IMPEDANCE

	ohms	Z	X ohms	Z0 R ohms
.50000-+0.0	1.1002		1.1347	1.0271
.10000-+0.1	1.0002		1.0136	2.3000
.15000-+0.1	2.0003		1.0707	2.0170
.20000-+0.1	2.0010		2.0201	3.2030
.25000-+0.1	2.0033		2.0042	3.6370
.30000-+0.1	2.0060		2.7906	3.9840
.35000-+0.1	3.0070		3.0109	4.3042
.40000-+0.1	3.0019		3.2251	4.0010
.45000-+0.1	3.0033		3.0102	4.0003
.50000-+0.1	3.0070		3.0003	3.1040
.55000-+0.1	3.0000		3.7730	3.3302
.60000-+0.1	4.0031		3.3375	3.0330
.65000-+0.1	4.1000		4.0040	3.0000
.70000-+0.1	4.3000		4.2057	0.0000
.75000-+0.1	4.0017		4.3000	0.2000
.80000-+0.1	4.0000		4.0000	0.0000
.85000-+0.1	4.0100		4.0001	0.7000
.90000-+0.1	4.0000		4.7971	0.9000
.95000-+0.1	3.0000		4.0000	1.0000
.10000-+0.1	3.0000		5.0000	7.2733
.10500-+0.1	3.0000		3.0000	7.0000
.11000-+0.1	3.0000		3.0000	7.0000
.11500-+0.1	3.0000		3.0000	7.0000
.12000-+0.1	3.0000		3.0000	7.0000
.12500-+0.1	3.0000		3.0000	8.1300

INDEX OF REFRACTION RLUFF

4.0000

FREQUENCY (Hz)

.50000c+09
.10.00c+10
.15000c+10
.20000c+10
.25000c+10
.30000c+10
.35000c+10
.40000c+10
.45000c+10
.50000c+10
.55000c+10
.60000c+10
.65000c+10
.70000c+10
.75000c+10
.80000c+10
.85000c+10
.90000c+10
.95000c+10
.10000c+11
.10500c+11
.11000c+11
.11500c+11
.12000c+11
.12500c+11

RESISTIVITY

.10000c-02 ohm-cm

ohms

Z

X ohm

.57710
.81511
.99799
1.1523
1.2084
1.2411
1.2649
1.2804
1.2990
1.3233
1.3429
1.3583
1.3704
1.3833
1.3933
1.4050
1.4149
1.4221
1.4294
1.4369
1.4431
1.4492

.57322
.81178
.99453
1.1484
1.2039
1.2403
1.2687
1.2833
1.2921
1.3024
1.3100
1.3167
1.3229
1.3289
1.3349
1.3401
1.3451
1.3491
1.3531
1.3571
1.3611
1.3651

IMPEDANCE

Z0 R ohm

.81349
1.1504
1.4089
1.6269
1.8169
1.9929
2.1222
2.3000
2.4463
2.5723
2.6979
2.8170
2.9329
3.0430
3.1504
3.2537
3.3539
3.4511
3.5450
3.6377
3.7270
3.8153
3.9010
3.9849
4.0671

Si

INDEX OF REFRACTION
KCUFF

3.4200

FREQUENCY (Hz)

.50000-+10
.100000-+10
.150000-+10
.200000-+10
.250000-+10
.300000-+10
.350000-+10
.400000-+10
.450000-+10
.500000-+10
.550000-+10
.600000-+10
.650000-+10
.700000-+10
.750000-+10
.800000-+10
.850000-+10
.900000-+10
.950000-+10
.100000-+11
.105000-+11
.110000-+11
.115000-+11
.120000-+11
.125000-+11

RESISTIVITY

.750000-01ohm-cm

ohms

Z

X ohm

5.5201
5.3005
4.5101
10.590
12.205
13.440
14.501
15.020
16.031
17.555
18.525
19.424
20.285
21.110
21.917
22.090
23.430
24.150
24.851
25.522
26.160
26.792
27.554
27.974
28.533

5.0720
0.0552
7.0090
0.0306
9.0517
10.713
11.454
12.090
12.061
13.151
13.580
13.954
14.279
14.559
14.800
15.605
15.176
15.318
15.432
15.521
15.586
15.631
15.657
15.686
15.655

IMPEDANCE

Z0 R ohm

7.4192
10.397
12.265
14.100
15.730
17.192
18.527
19.750
20.901
21.970
22.972
23.910
24.807
25.645
26.440
27.203
27.921
28.603
29.253
29.870
30.455
31.019
31.553
32.062
32.540

Si

INDEX OF REFRACTION
RUFF

3.4200

FREQUENCY (Hz)

RESISTIVITY

.40000E-02 ohm-cm

ohms

L

X ohm

IMPEDANCE

Z R ohm

.50000E+04

1.1000

1.1300

1.0271

.10000E+10

1.0394

1.0144

2.3000

.10000E+10

2.0049

1.9001

2.0179

.20000E+10

2.3141

2.2674

3.2530

.25000E+10

2.0072

2.0073

3.0370

.30000E+10

2.0340

2.0007

3.9000

.35000E+10

3.0029

3.0241

4.3042

.40000E+10

3.2750

3.2315

4.0014

.45000E+10

3.4701

3.4200

4.0000

.50000E+10

3.0000

3.0000

5.1444

.55000E+10

3.3400

3.7033

5.3955

.60000E+10

4.0200

3.3433

5.0353

.65000E+10

4.1000

4.1001

5.0000

.70000E+10

4.3400

4.2000

0.0000

.75000E+10

4.0020

4.4074

0.3000

.80000E+10

4.0523

4.0492

6.5000

.85000E+10

4.7402

4.0002

0.7070

.90000E+10

4.3402

4.0190

0.9013

.95000E+10

5.0700

4.3470

7.0000

.10000E+11

5.2130

5.0731

7.2744

.10500E+11

5.3400

5.1900

7.4000

.11000E+11

5.4744

5.3137

7.0292

.11500E+11

5.0007

5.4200

7.0000

.12000E+11

5.7240

5.5420

7.9001

.12500E+11

5.0400

5.5531

0.1320

INDEX OF REFRACTION
RLUFF

3.420J

FREQUENCY (Hz)

.50000E+03
.10000E+10
.15000E+10
.20000E+10
.25000E+10
.30000E+10
.35000E+10
.40000E+10
.45000E+10
.50000E+10
.55000E+10
.60000E+10
.65000E+10
.70000E+10
.75000E+10
.80000E+10
.85000E+10
.90000E+10
.95000E+10
.10000E+11
.10500E+11
.11000E+11
.11500E+11
.12000E+11
.12500E+11

21

RESISTIVITY

.10000E-02 ohm-cm

ohms

Z

X ohm

.57713
.01501
.93101
1.1520
1.2800
1.4110
1.5242
1.6290
1.7287
1.8224
1.9110
1.9969
2.0780
2.1575
2.2330
2.3072
2.3785
2.4479
2.5153
2.5811
2.6457
2.7079
2.7692
2.8292
2.8879

.57326
.81187
.99471
1.1487
1.2843
1.4088
1.5194
1.6241
1.7224
1.8154
1.9037
1.9881
2.0690
2.1487
2.2216
2.2943
2.3645
2.4327
2.4990
2.5635
2.6264
2.6878
2.7477
2.8064
2.8638

IMPEDANCE

Z0 R ohm

.81345
1.1504
1.4363
1.6263
1.8163
1.9925
2.1522
2.3000
2.4403
2.5723
2.6979
2.8178
2.9329
3.0435
3.1504
3.2537
3.3539
3.4511
3.5457
3.6370
3.7270
3.8153
3.9011
3.9850
4.0671

PROGRAM FOUR

TRANSMITTANCE AT FREQUENCIES FROM 0.5 GHz TO 12.5 GHz
FOR DIFFERENT RESISTIVITIES AND DIFFERENT THICKNESSES

INDEX OF REFRACTION

RCOFF

4.0000

FREQUENCY (Hz)

RESIS

LENGTH

.75000E-01 ohm, 32258E-02 meters

TRANSMISSION

R

Z

X

TRANS (JB)

.50000E+09	6.3446 ohm cm	3.8439 ohms	-0.3757
.10000E+10	8.1300	5.9796	-8.7450
.15000E+10	9.7057	7.4717	-10.641
.20000E+10	11.128	8.6227	-12.258
.25000E+10	12.437	9.5494	-13.547
.30000E+10	13.659	10.311	-14.713
.35000E+10	14.810	10.943	-15.740
.40000E+10	15.898	11.468	-16.652
.45000E+10	16.931	11.904	-17.467
.50000E+10	17.913	12.263	-18.199
.55000E+10	18.849	12.556	-18.860
.60000E+10	19.740	12.790	-19.459
.65000E+10	20.590	12.973	-20.004
.70000E+10	21.399	13.110	-20.501
.75000E+10	22.170	13.208	-20.955
.80000E+10	22.904	13.270	-21.370
.85000E+10	23.603	13.302	-21.752
.90000E+10	24.268	13.306	-22.102
.95000E+10	24.900	13.286	-22.425
.10000E+11	25.501	13.246	-22.723
.10500E+11	26.071	13.187	-22.998
.11000E+11	26.614	13.112	-23.252
.11500E+11	27.128	13.024	-23.487
.12000E+11	27.617	12.924	-23.705
.12500E+11	28.081	12.814	-23.908

INDEX OF REFRACTION

RCOFF

RESIS LENGTH

4.0000

.7501E-01 ohm, 14732E-02 meters TRANSMISSION

FREQUENCY (Hz)

R

Z

X

TRANS (DB)

.50000E+09	6.3446 ohm cm	3.8439 ohms	-1.7138
.10000E+10	8.1361	5.9796	-2.5487
.15000E+10	9.7057	7.4717	-3.4632
.20000E+10	11.128	8.6227	-4.3003
.25000E+10	12.437	9.5494	-5.0297
.30000E+10	13.659	10.311	-5.6594
.35000E+10	14.810	10.943	-6.2047
.40000E+10	15.898	11.468	-6.6803
.45000E+10	16.931	11.904	-7.0982
.50000E+10	17.913	12.263	-7.4685
.55000E+10	18.849	12.556	-7.7992
.60000E+10	19.740	12.790	-8.0967
.65000E+10	20.590	12.973	-8.3662
.70000E+10	21.399	13.110	-8.6120
.75000E+10	22.170	13.208	-8.8376
.80000E+10	22.904	13.270	-9.0457
.85000E+10	23.603	13.302	-9.2386
.90000E+10	24.266	13.306	-9.4178
.95000E+10	24.900	13.286	-9.5847
.10000E+11	25.501	13.246	-9.7403
.10500E+11	26.071	13.187	-9.8853
.11000E+11	26.614	13.112	-10.020
.11500E+11	27.128	13.024	-10.146
.12000E+11	27.617	12.924	-10.262
.12500E+11	28.081	12.814	-10.370

INDEX OF REFRACTION
RCOFF

4.0000

FREQUENCY (Hz)

RESIS LENGTH

.40000E-02 ohm .32258E-02 meters TRANSMISSION

	R	Z	X	TRANS(UB)
.50000E+09	1.1662 ohm cm		1.1347 ohms	-28.380
.10000E+10	1.5402		1.6136	-41.060
.15000E+10	2.0063		1.9787	-50.802
.20000E+10	2.3163		2.2851	-59.005
.25000E+10	2.5903		2.5542	-66.219
.30000E+10	2.8388		2.7966	-72.728
.35000E+10	3.0679		3.0189	-78.699
.40000E+10	3.2819		3.2251	-84.243
.45000E+10	3.4833		3.4182	-89.437
.50000E+10	3.6744		3.6003	-94.338
.55000E+10	3.8566		3.7730	-98.987
.60000E+10	4.0311		3.9375	-103.42
.65000E+10	4.1989		4.0948	-107.66
.70000E+10	4.3608		4.2457	-111.72
.75000E+10	4.5174		4.3909	-115.64
.80000E+10	4.6692		4.5309	-119.41
.85000E+10	4.8168		4.6661	-123.07
.90000E+10	4.9603		4.7971	-126.60
.95000E+10	5.1003		4.9241	-130.03
.10000E+11	5.2370		5.0473	-133.36
.10500E+11	5.3705		5.1672	-136.60
.11000E+11	5.5013		5.2839	-139.75
.11500E+11	5.6294		5.3976	-142.83
.12000E+11	5.7550		5.5085	-145.83
.12500E+11	5.8783		5.6168	-148.76

INDEX OF REFRACTION
RCOFF

4.0000

FREQUENCY (Hz)

.50000E+09
.10000E+10
.15000E+10
.20000E+10
.25000E+10
.30000E+10
.35000E+10
.40000E+10
.45000E+10
.50000E+10
.55000E+10
.60000E+10
.65000E+10
.70000E+10
.75000E+10
.80000E+10
.85000E+10
.90000E+10
.95000E+10
.10000E+11
.10500E+11
.11000E+11
.11500E+11
.12000E+11
.12500E+11

RESIS LENGTH

.40000E-02 ohm, 14732E-02 meters TRANSMISSION

R	Z	X	TRANS (JB)
1.1662 ohm cm		1.1347 ohms	-11.386
1.6402		1.6136	-17.193
2.0063		1.9787	-21.660
2.3163		2.2851	-25.421
2.5903		2.5542	-28.728
2.8388		2.7966	-31.712
3.0679		3.0189	-34.450
3.2819		3.2251	-36.992
3.4833		3.4182	-39.374
3.6744		3.6003	-41.620
3.8566		3.7730	-43.752
4.0311		3.9375	-45.784
4.1989		4.0948	-47.727
4.3608		4.2457	-49.593
4.5174		4.3909	-51.388
4.6692		4.5309	-53.119
4.8168		4.6661	-54.793
4.9603		4.7971	-56.414
5.1003		4.9241	-57.986
5.2370		5.0473	-59.514
5.3705		5.1672	-60.999
5.5013		5.2839	-62.446
5.6294		5.3976	-63.857
5.7550		5.5085	-65.233
5.8783		5.6168	-66.577

INDEX OF REFRACTION

RCOFF

4.0000

FREQUENCY (Hz)

.50000E+09
.10000E+10
.15000E+10
.20000E+10
.25000E+10
.30000E+10
.35000E+10
.40000E+10
.45000E+10
.50000E+10
.55000E+10
.60000E+10
.65000E+10
.70000E+10
.75000E+10
.80000E+10
.85000E+10
.90000E+10
.95000E+10
.10000E+11
.10500E+11
.11000E+11
.11500E+11
.12000E+11
.12500E+11

RESIS

LENGTH

.10000E-02ohm.32258E-02 meters

R Z
.57716 ohm cm

X
.57322 ohms

TRANSMISSION
TRANS(DB)

.81511
.99799
1.1523
1.2884
1.4115
1.5249
1.6304
1.7296
1.8235
1.9129
1.9983
2.0804
2.1593
2.2356
2.3094
2.3809
2.4505
2.5181
2.5841
2.6485
2.7114
2.7729
2.8331
2.8922

.81178
.99453
1.1484
1.2839
1.4063
1.5187
1.6233
1.7215
1.8143
1.9024
1.9866
2.0673
2.1449
2.2197
2.2921
2.3621
2.4301
2.4961
2.5604
2.6230
2.6842
2.7439
2.8023
2.8594

-59.060
-84.610
-104.22
-120.75
-135.30
-148.46
-160.54
-171.79
-182.34
-192.32
-201.80
-210.85
-219.53
-227.88
-235.92
-243.70
-251.24
-258.55
-265.65
-272.57
-279.31
-285.88
-292.31
-298.59
-304.74

INDEX OF REFRACTION

RCOFF

4.0000

FREQUENCY (Hz)

.50000E+09
.10000E+10
.15000E+10
.20000E+10
.25000E+10
.30000E+10
.35000E+10
.40000E+10
.45000E+10
.50000E+10
.55000E+10
.60000E+10
.65000E+10
.70000E+10
.75000E+10
.80000E+10
.85000E+10
.90000E+10
.95000E+10
.10000E+11
.10500E+11
.11000E+11
.11500E+11
.12000E+11
.12500E+11

RESIS

LENGTH

.10000E-02ohm .14732E-02 meters

TRANSMISSION

R

Z

X

TRANS (dB)

.57716 ohm cm	.57322 ohms	-25.364
.81511	.81178	-37.044
.99799	.99453	-46.009
1.1523	1.1484	-53.564
1.2884	1.2839	-60.218
1.4115	1.4063	-66.230
1.5249	1.5187	-71.755
1.6304	1.6233	-76.895
1.7296	1.7215	-81.720
1.8235	1.8143	-86.280
1.9129	1.9024	-90.615
1.9983	1.9866	-94.754
2.0804	2.0673	-98.721
2.1593	2.1449	-102.54
2.2356	2.2197	-106.21
2.3094	2.2921	-109.77
2.3809	2.3621	-113.21
2.4505	2.4301	-116.56
2.5181	2.4961	-119.80
2.5841	2.5604	-122.97
2.6485	2.6230	-126.05
2.7114	2.6842	-129.05
2.7729	2.7439	-131.99
2.8331	2.8023	-134.86
2.8922	2.8594	-137.67

Si

INDEX OF REFRACTION
RCOFF

3.4200

FREQUENCY (Hz)

.50000E+09
.10000E+10
.15000E+10
.20000E+10
.25000E+10
.30000E+10
.35000E+10
.40000E+10
.45000E+10
.50000E+10
.55000E+10
.60000E+10
.65000E+10
.70000E+10
.75000E+10
.80000E+10
.85000E+10
.90000E+10
.95000E+10
.10000E+11
.10500E+11
.11000E+11
.11500E+11
.12000E+11
.12500E+11

RESIS LENGTH

.75J00E-01ohm.32258E-02meters

R Z

X

TRANSMISSION
TRANS(DB)

6.3281 ohm cm
8.0803
9.6161
10.996
12.263
13.446
14.561
15.620
16.631
17.599
18.529
19.424
20.285
21.116
21.917
22.690
23.436
24.156
24.851
25.522
26.168
26.792
27.394
27.974
28.533

3.8728 ohms
6.0552
7.6096
8.8366
9.8517
10.713
11.454
12.098
12.660
13.151
13.580
13.954
14.279
14.559
14.800
15.005
15.176
15.318
15.432
15.521
15.586
15.631
15.657
15.666
15.659

-6.4003
-8.8187
-10.781
-12.426
-13.851
-15.109
-16.234
-17.248
-18.168
-19.007
-19.777
-20.486
-21.141
-21.747
-22.309
-22.832
-23.319
-23.774
-24.199
-24.596
-24.968
-25.317
-25.645
-25.953
-26.243

INDEX OF REFRACTION
RCOFF

3.4200

FREQUENCY (Hz)

.50000E+09
.10000E+10
.15000E+10
.20000E+10
.25000E+10
.30000E+10
.35000E+10
.40000E+10
.45000E+10
.50000E+10
.55000E+10
.60000E+10
.65000E+10
.70000E+10
.75000E+10
.80000E+10
.85000E+10
.90000E+10
.95000E+10
.10000E+11
.10500E+11
.11000E+11
.11500E+11
.12000E+11
.12500E+11

RESIS LENGTH

.75000E-01 ohm .14732E-02 meters TRANSMISSION

R	Z	X	TRANS (DB)
6.3281 ohm cm		3.8728 ohms	-1.7269
8.0803		6.0552	-2.5884
9.6161		7.6096	-3.5319
10.996		8.8366	-4.3997
12.263		9.8517	-5.1630
13.446		10.713	-5.8305
14.561		11.454	-6.4175
15.620		12.098	-6.9385
16.631		12.660	-7.4050
17.599		13.151	-7.8263
18.529		13.580	-8.2097
19.424		13.954	-8.5610
20.285		14.279	-8.8847
21.116		14.559	-9.1844
21.917		14.800	-9.4632
22.690		15.005	-9.7234
23.436		15.176	-9.9669
24.156		15.318	-10.195
24.851		15.432	-10.410
25.522		15.521	-10.612
26.168		15.586	-10.802
26.792		15.631	-10.982
27.394		15.657	-11.150
27.974		15.666	-11.310
28.533		15.659	-11.460

INDEX OF REFRACTION
RCOFF

3.4200

FREQUENCY (Hz)

.50000E+09
.10000E+10
.15000E+10
.20000E+10
.25000E+10
.30000E+10
.35000E+10
.40000E+10
.45000E+10
.50000E+10
.55000E+10
.60000E+10
.65000E+10
.70000E+10
.75000E+10
.80000E+10
.85000E+10
.90000E+10
.95000E+10
.10000E+11
.10500E+11
.11000E+11
.11500E+11
.12000E+11
.12500E+11

RESIS LENGTH

.40000E-02 ohm, 32258E-02 meters TRANSMISSION

R	Z	X	TRANS(DB)
1.1660 ohm cm		1.1350 ohms	-28.387
1.6394		1.6144	-41.081
2.0049		1.9801	-50.840
2.3141		2.2874	-59.064
2.5872		2.5573	-66.301
2.8348		2.8007	-72.835
3.0629		3.0241	-78.834
3.2758		3.2315	-84.409
3.4761		3.4258	-89.635
3.6659		3.6092	-94.569
3.8468		3.7833	-99.254
4.0200		3.9493	-103.72
4.1864		4.1081	-108.00
4.3469		4.2606	-112.11
4.5020		4.4074	-116.06
4.6523		4.5492	-119.88
4.7982		4.6862	-123.58
4.9402		4.8190	-127.16
5.0785		4.9478	-130.63
5.2135		5.0731	-134.01
5.3454		5.1950	-137.30
5.4744		5.3137	-140.50
5.6007		5.4295	-143.63
5.7245		5.5426	-146.68
5.8460		5.6531	-149.67

INDEX OF REFRACTION

RCOFF

3.4200

RESIS

LENGTH

.40000E-02 ohms 14732E-02 meters TRANSMISSION

FREQUENCY (Hz)

R

Z

X

TRANS (JB)

.50000E+09	1.1660 ohm cm	1.1350 ohms	-11.389
.10000E+10	1.6394	1.6144	-17.203
.15000E+10	2.0049	1.9801	-21.677
.20000E+10	2.3141	2.2874	-25.448
.25000E+10	2.5872	2.5573	-28.766
.30000E+10	2.8348	2.8007	-31.761
.35000E+10	3.0629	3.0241	-34.512
.40000E+10	3.2758	3.2315	-37.067
.45000E+10	3.4761	3.4258	-39.463
.50000E+10	3.6659	3.6092	-41.726
.55000E+10	3.8468	3.7833	-43.874
.60000E+10	4.0200	3.9493	-45.922
.65000E+10	4.1864	4.1081	-47.883
.70000E+10	4.3469	4.2606	-49.767
.75000E+10	4.5020	4.4074	-51.580
.80000E+10	4.6523	4.5492	-53.331
.85000E+10	4.7982	4.6862	-55.025
.90000E+10	4.9402	4.8190	-56.667
.95000E+10	5.0785	4.9478	-58.260
.10000E+11	5.2135	5.0731	-59.809
.10500E+11	5.3454	5.1950	-61.317
.11000E+11	5.4744	5.3137	-62.787
.11500E+11	5.6007	5.4295	-64.221
.12000E+11	5.7245	5.5426	-65.621
.12500E+11	5.8460	5.6531	-66.989

INDEX OF REFRACTION
RCOFF

3.4200

RESIS LENGTH

.10000E-02ohm.32258E-02meters TRANSMISSION

FREQUENCY (Hz)	R	Z	X	TRANS (dB)
.50000E+09	.57713	ohm cm	.57326	ohms -59.864
.10000E+10	.81501		.81187	-84.621
.15000E+10	.99781		.99471	-104.24
.20000E+10	1.1520		1.1487	-120.78
.25000E+10	1.2886		1.2843	-135.35
.30000E+10	1.4110		1.4068	-148.51
.35000E+10	1.5242		1.5194	-160.61
.40000E+10	1.6296		1.6241	-171.87
.45000E+10	1.7287		1.7224	-182.44
.50000E+10	1.8224		1.8154	-192.43
.55000E+10	1.9116		1.9037	-201.93
.60000E+10	1.9969		1.9881	-211.01
.65000E+10	2.0786		2.0690	-219.70
.70000E+10	2.1570		2.1467	-228.07
.75000E+10	2.2336		2.2218	-236.14
.80000E+10	2.3072		2.2943	-243.94
.85000E+10	2.3785		2.3645	-251.49
.90000E+10	2.4479		2.4327	-258.83
.95000E+10	2.5153		2.4990	-265.96
1.0000E+11	2.5811		2.5635	-272.90
1.0500E+11	2.6452		2.6264	-279.66
1.1000E+11	2.7079		2.6878	-286.26
1.1500E+11	2.7692		2.7477	-292.72
1.2000E+11	2.8292		2.8064	-299.02
1.2500E+11	2.8879		2.8638	-305.20

INDEX OF REFRACTION
RCOFF

RESIS LENGTH

3.4200	.10000E-02 ohms	14732E-02 meters	TRANSMISSION
FREQUENCY (Hz)	R	Z	TRANS(DB)
.50000E+09	.57713 ohms cm	.57326 ohms	-25.366
.10000E+10	.81501	.81187	-37.049
.15000E+10	.99781	.99471	-46.017
.20000E+10	1.1520	1.1487	-53.578
.25000E+10	1.2880	1.2843	-60.237
.30000E+10	1.4110	1.4068	-66.255
.35000E+10	1.5242	1.5194	-71.787
.40000E+10	1.6296	1.6241	-76.933
.45000E+10	1.7287	1.7224	-81.765
.50000E+10	1.8224	1.8154	-86.333
.55000E+10	1.9116	1.9037	-90.676
.60000E+10	1.9969	1.9881	-94.824
.65000E+10	2.0788	2.0690	-98.800
.70000E+10	2.1575	2.1467	-102.62
.75000E+10	2.2336	2.2218	-106.31
.80000E+10	2.3072	2.2943	-109.88
.85000E+10	2.3785	2.3645	-113.33
.90000E+10	2.4479	2.4327	-116.68
.95000E+10	2.5153	2.4990	-119.94
.10000E+11	2.5811	2.5635	-123.12
.10500E+11	2.6452	2.6264	-126.21
.11000E+11	2.7079	2.6878	-129.23
.11500E+11	2.7692	2.7477	-132.18
.12000E+11	2.8292	2.8064	-135.06
.12500E+11	2.8879	2.8638	-137.88

APPENDIX B

Graphs

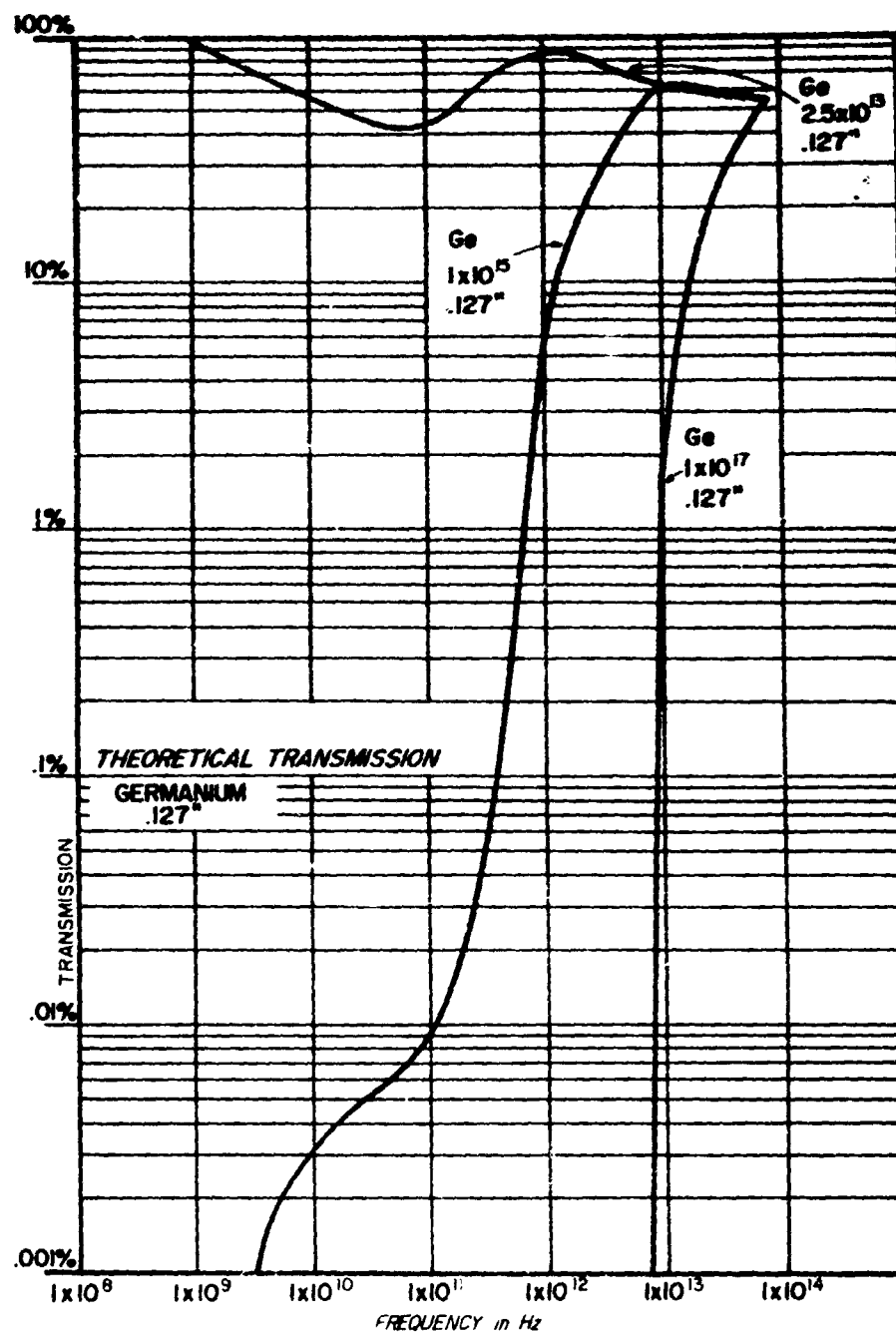


FIGURE B-1

Theoretical Transmission of Germanium
(0.127-in.) at 3 Doping Levels

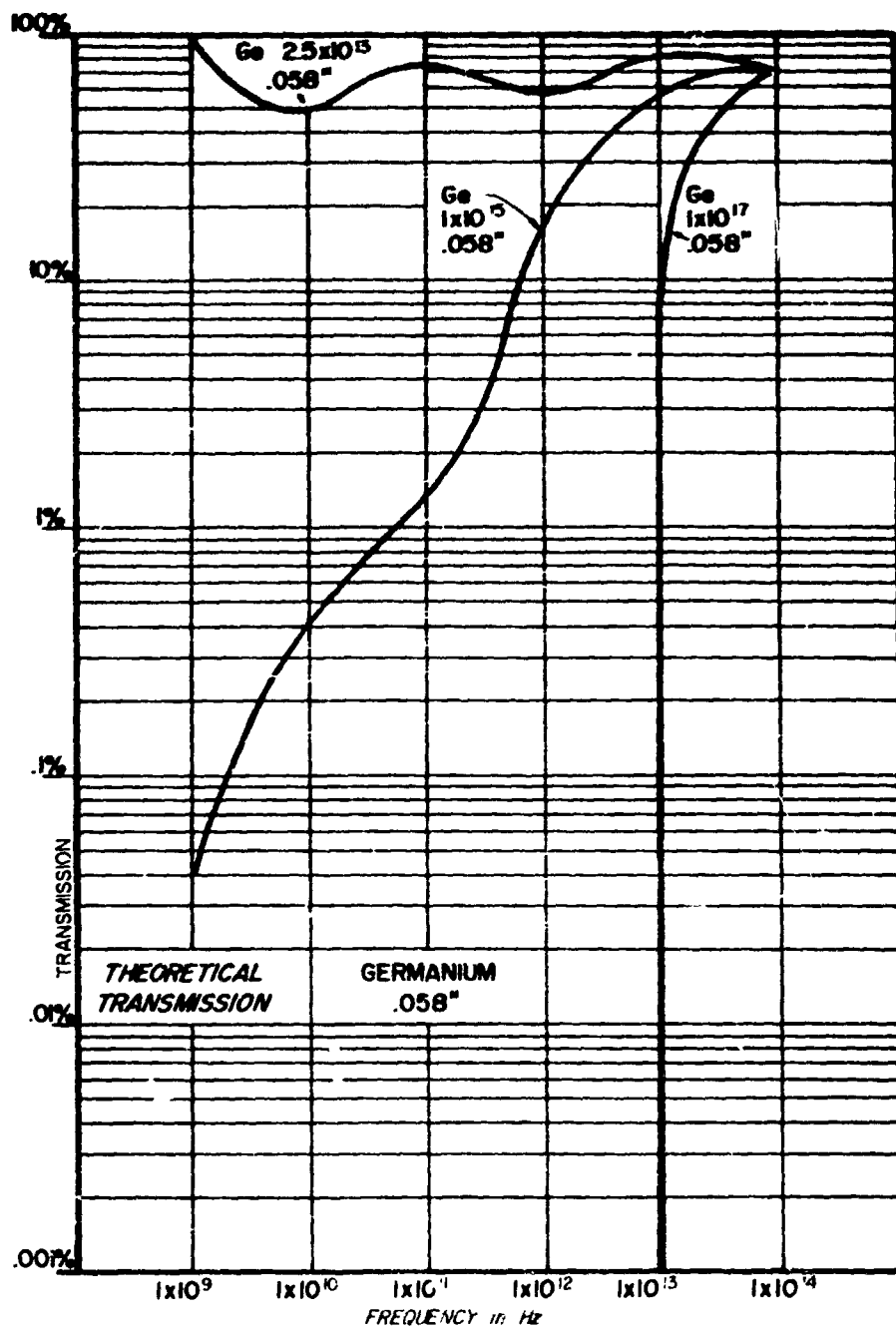


FIGURE B-2

Theoretical Transmission of Germanium
(0.058-in.) at 3 Doping Levels

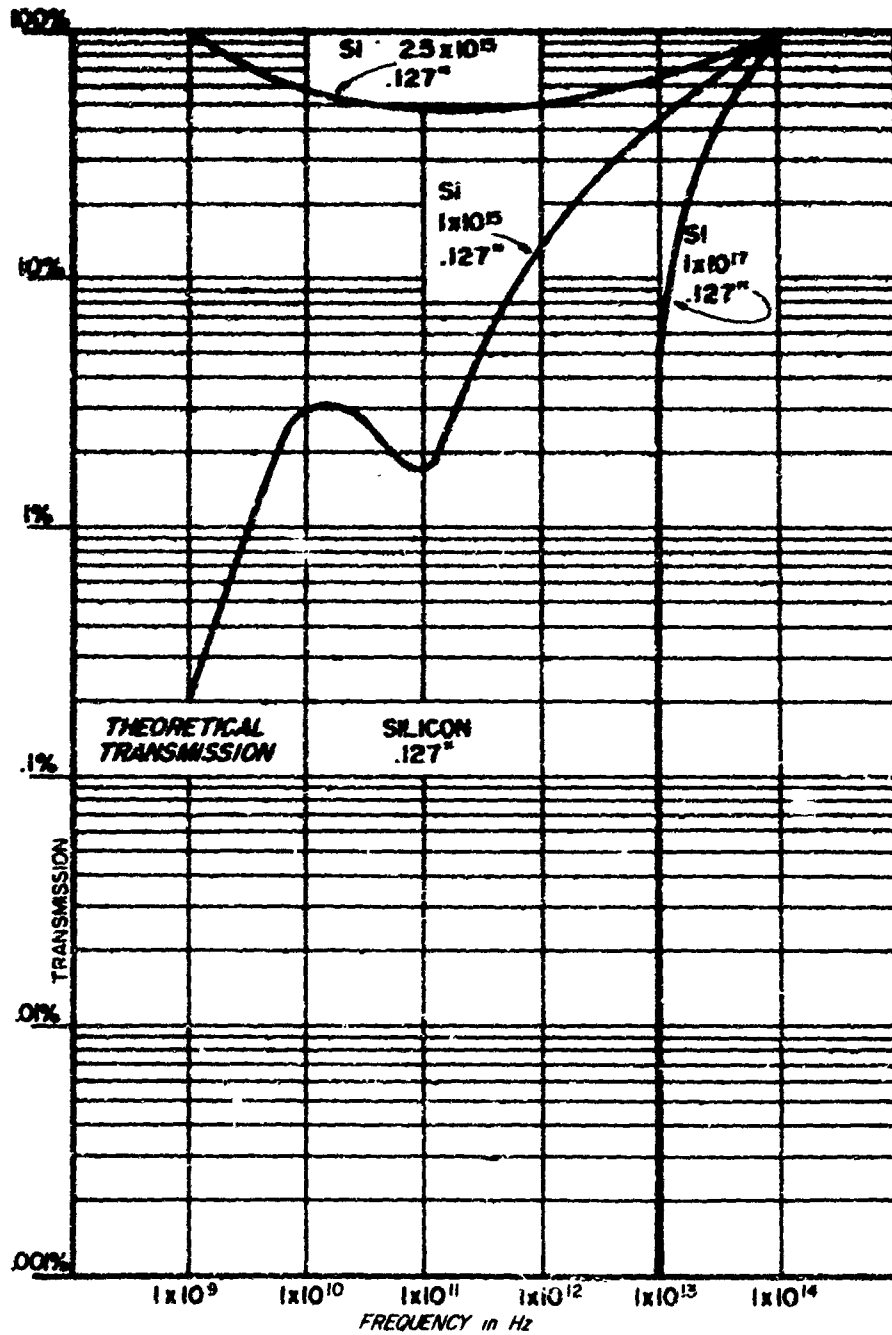


FIGURE B-3

Theoretical Transmission of Silicon
(0.127-in.) at 3 Doping Levels

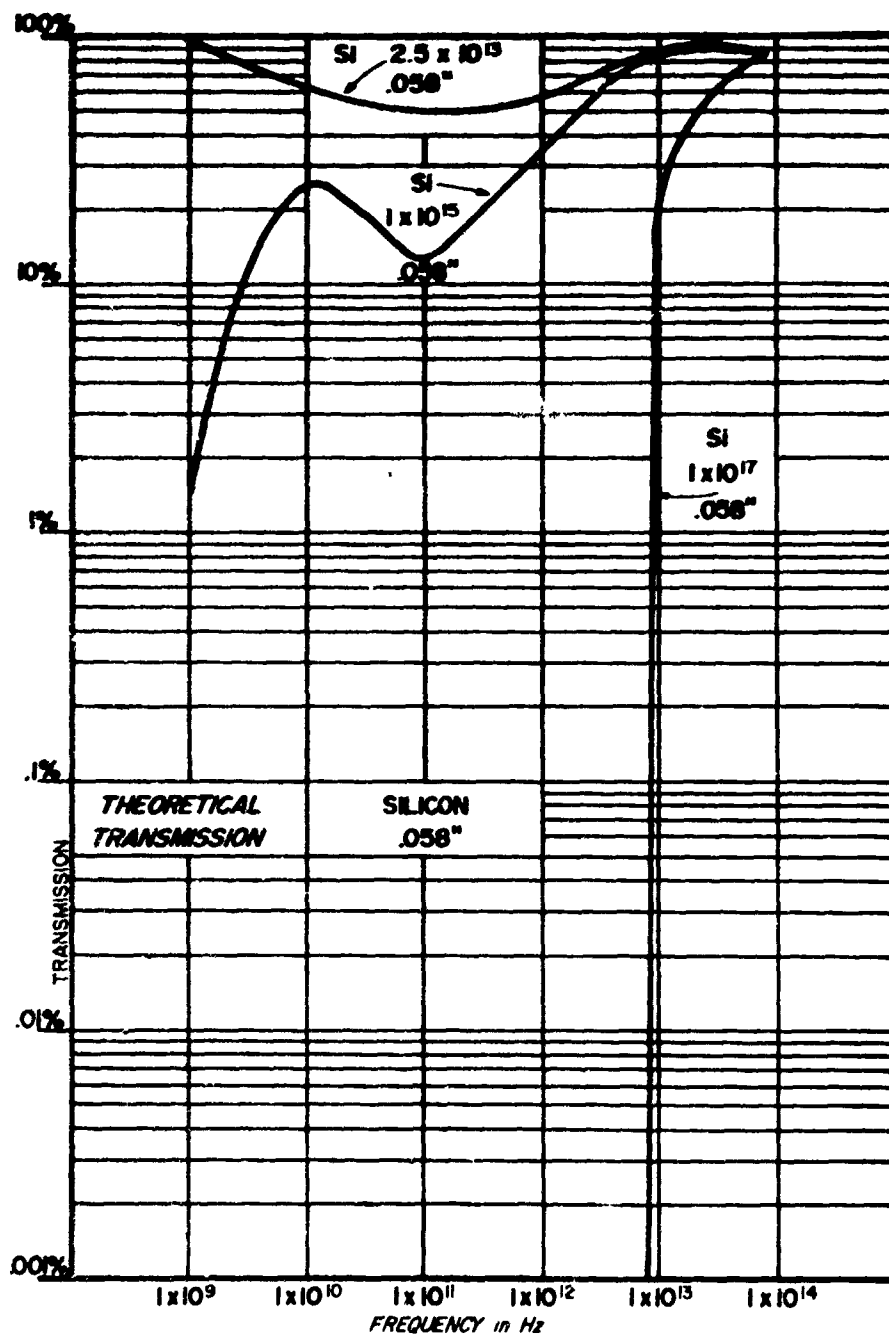


FIGURE B-4

Theoretical Transmission of Silicon
(0.058-in.) at 3 Doping Levels

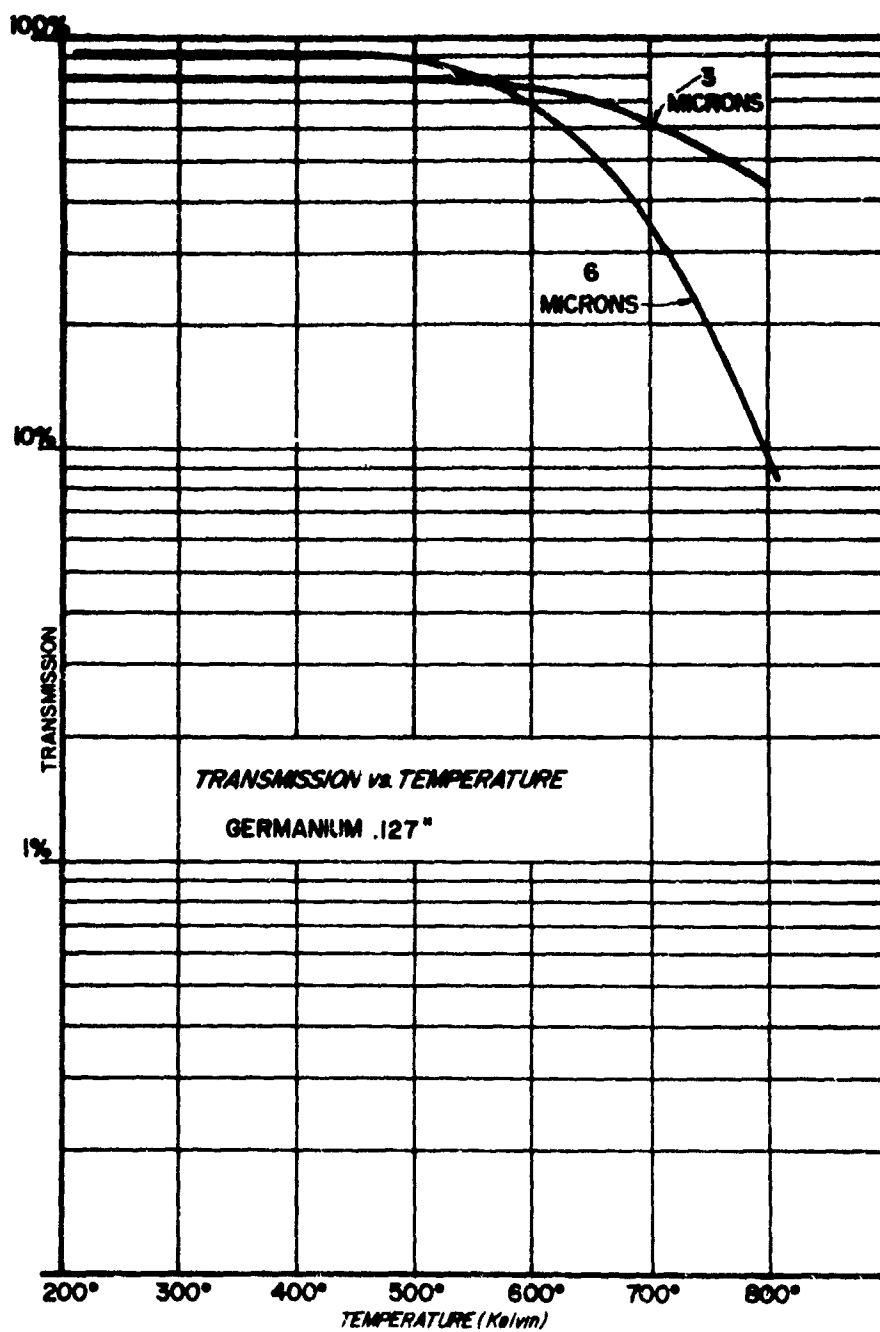


FIGURE B-5

Transmission vs Temperature Measurements for Germanium
(0.127-in.) at 2 Wavelengths

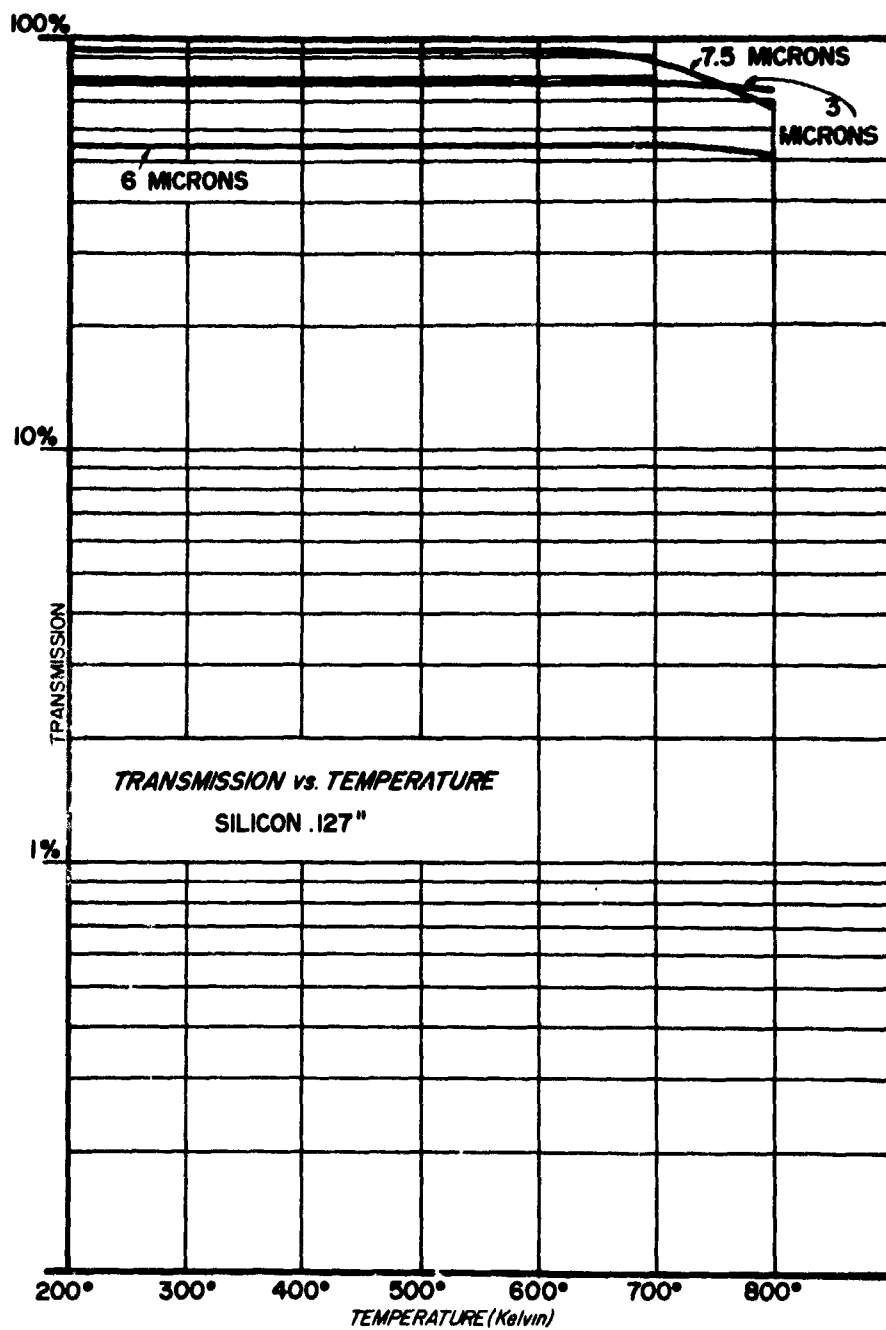


FIGURE B-6

**Transmission vs Temperature Measurements for Silicon
(0.127-in.) at 3 Wavelengths**

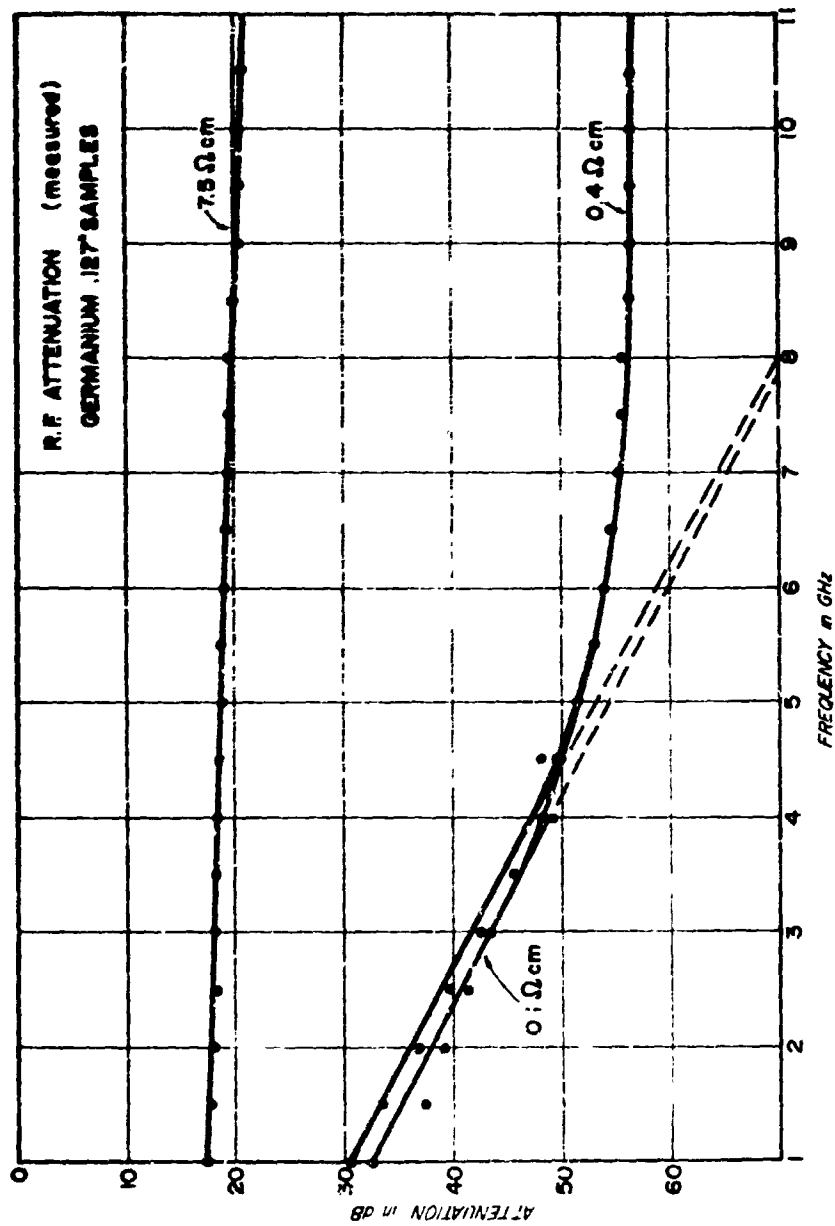


FIGURE B-7
Measured RF Attenuation of Germanium Samples
(0.127-in.) of Varied Resistivity

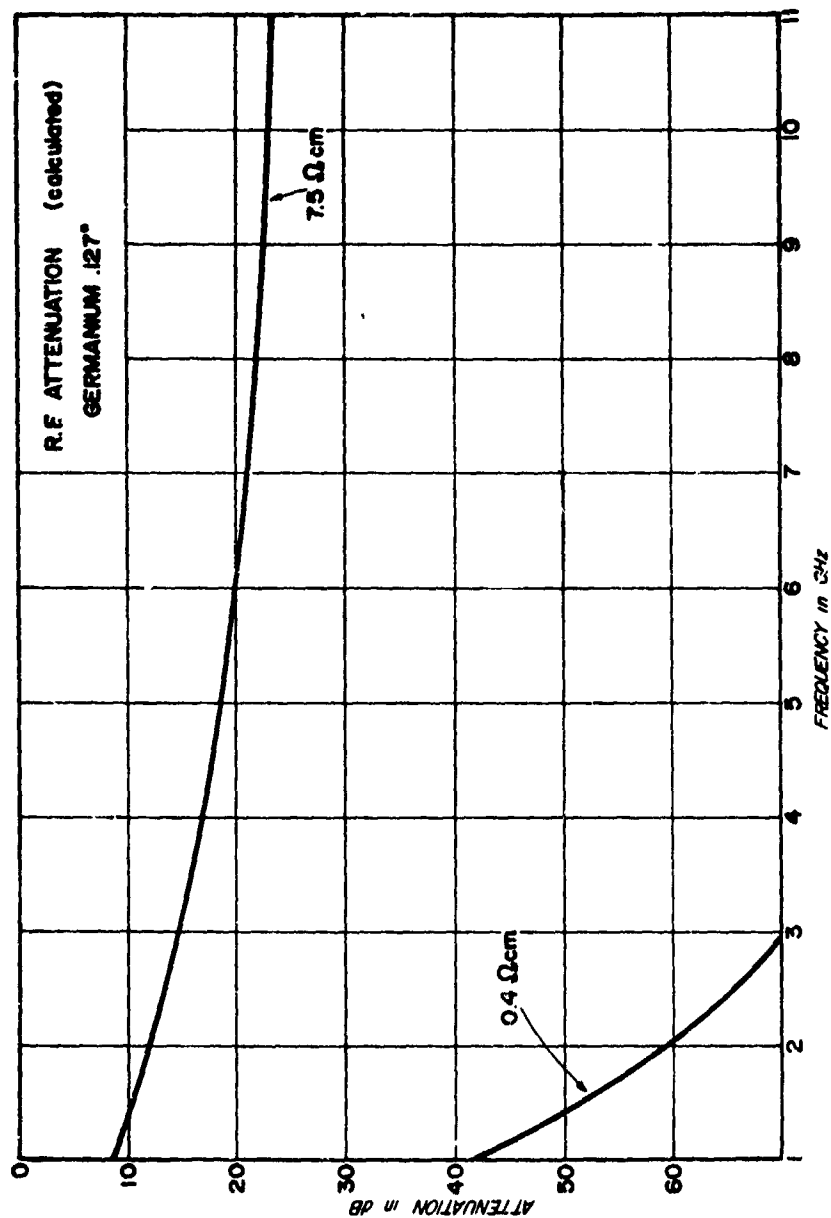


FIGURE B-8
Calculated RF Attenuation of Germanium Samples
(0.127-in.) of Varied Resistivity

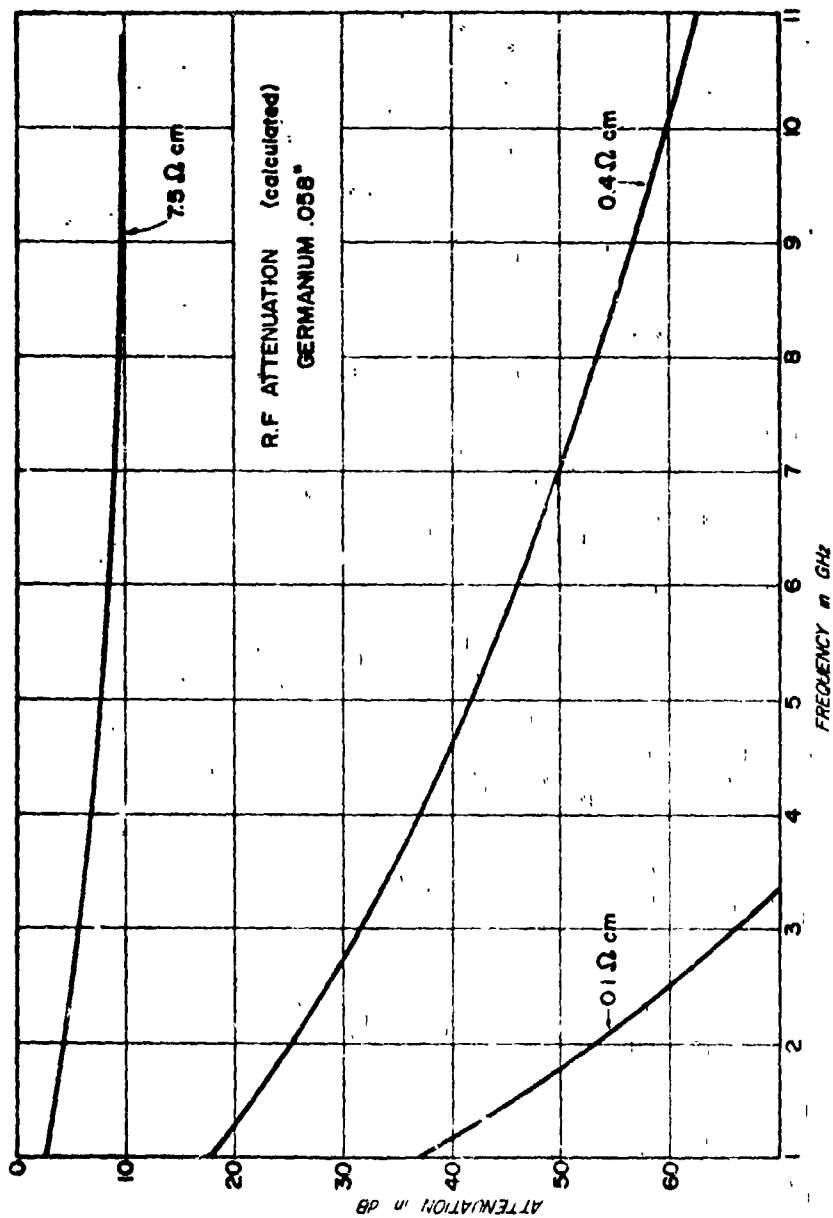
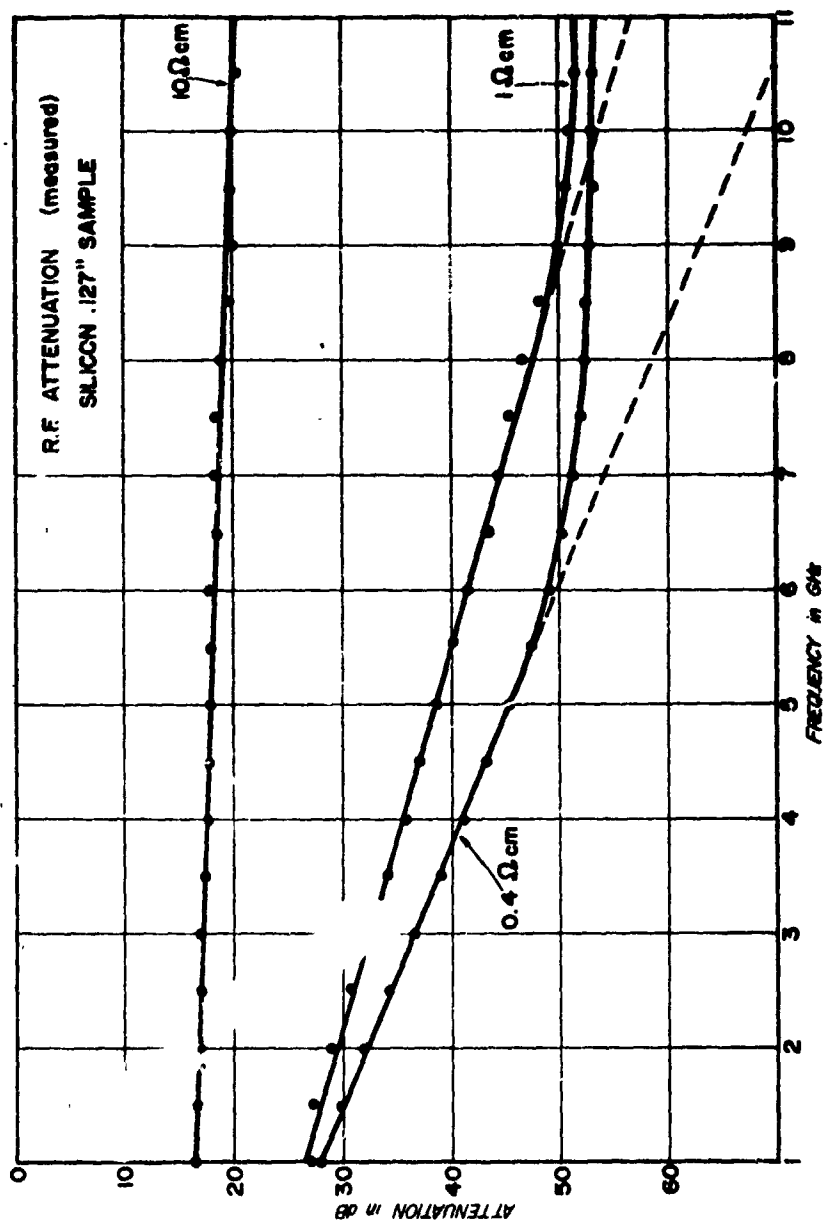


FIGURE B-9
Calculated RF Attenuation of Germanium Samples
(0.058-in.) of Varied Resistivity



Measured RF Attenuation of Silicon Samples
(0.127-in.) of Varied Resistivity

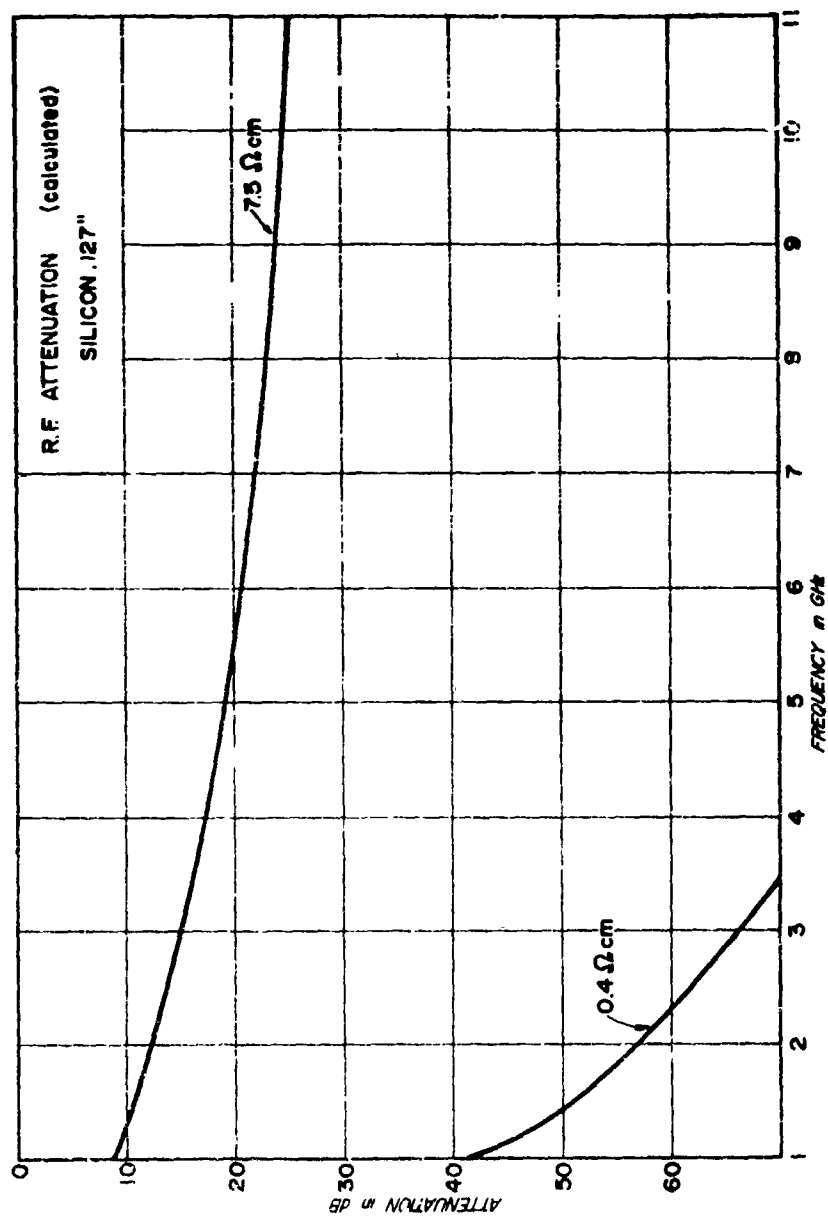


FIGURE B-11
Calculated RF Attenuation of Silicon Samples
(0.127-in.) of Varied Resistivity

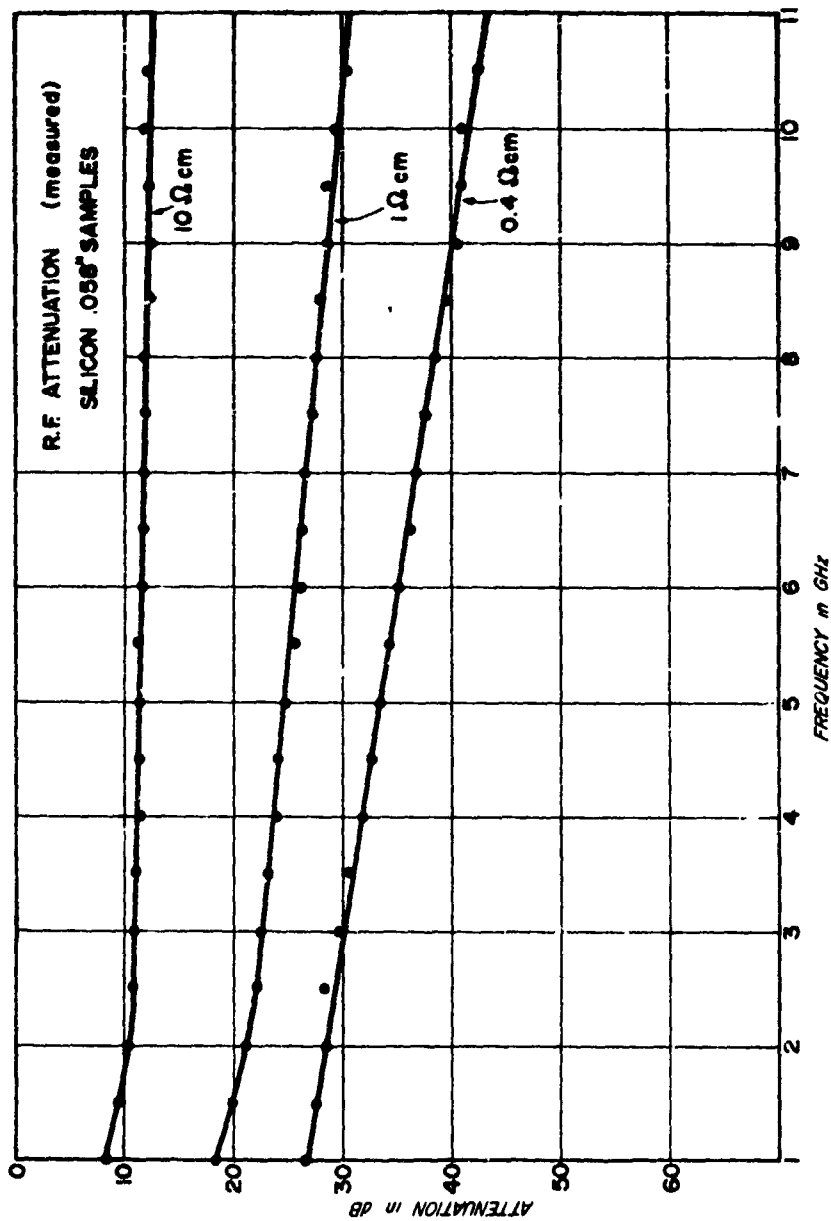


FIGURE B-12
Measured RF Attenuation of Silicon Samples
(0.058-in.) of Varied Resistivity

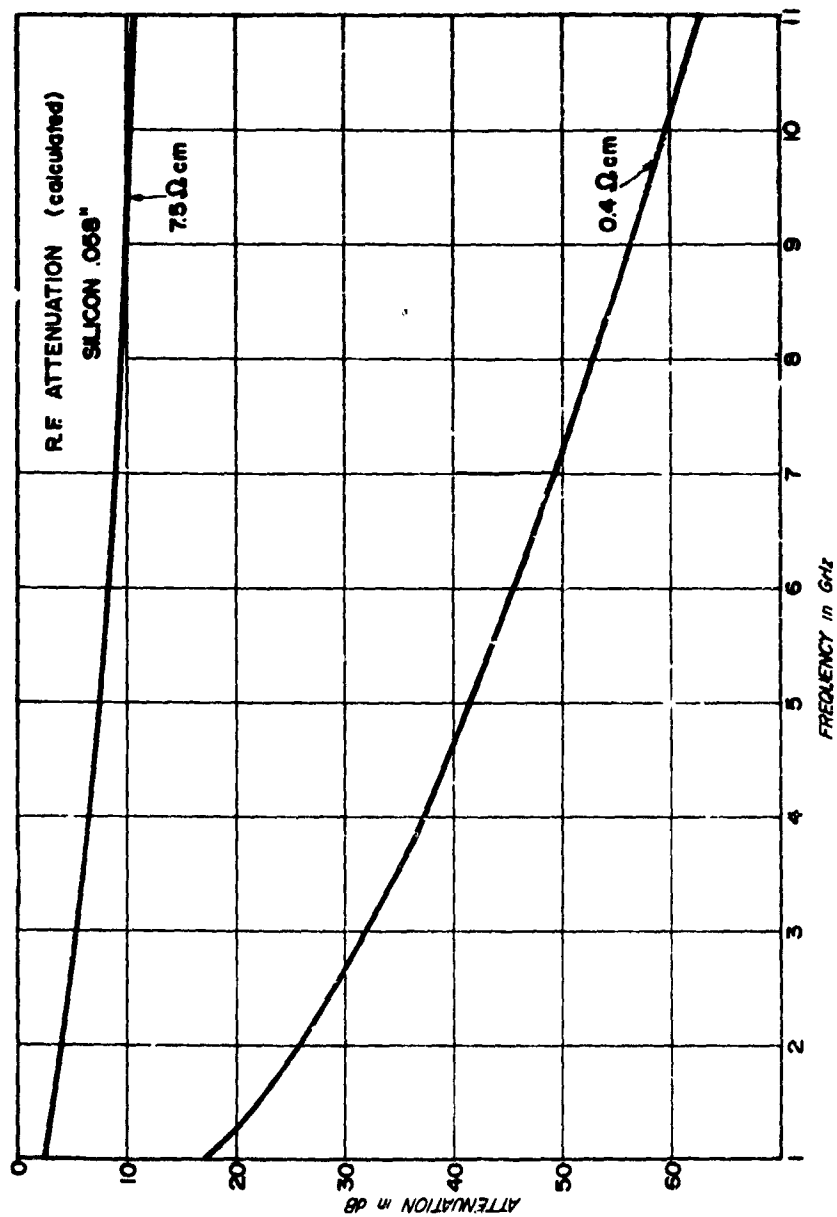


FIGURE B-13
Measured RF Attenuation of Silicon Samples
(0.058-in.) of Varied Resistivity