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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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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 wre 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.

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MICROWAVE PROPERTIES OF GERMANIUM AND SILICON WINDOWS

by

Robert W. Lothrop

Advanced Systems Department

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FOREWORD

Microwave attenuation measurments 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:

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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 photo $h\nu \geqslant E_g$ (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:

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

where

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

$$\gamma = \frac{1}{\tau} = \frac{e}{\mu m} \tag{2}$$

and where

m = free carrier mass
e = electronic charge (1.6×10^{-19} C)
m = free carrier mobility

Solving for X,

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

As t gets very large, $C_2 \epsilon^{-t}$ 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

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

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

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

where

N is the total number of electrons per unit volume.

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

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

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,

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

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,

$$\nabla^2 \vec{E} + k^2 \vec{E} = 0 \ . \tag{8}$$

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

$$k = k' - jk'' \tag{9}$$

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

$$\vec{E} = \vec{E}_0 \epsilon^{-k''z} \epsilon^{-jk'z} \ . \tag{10}$$

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

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

Substituting in for γ,

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

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: $2.5 \times 10^{13}/cm^3$, $1 \times 10^{15}/cm^3$, and $1 \times 10^{17}/cm^3$. 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.

$$\text{incident wave} \rightarrow \begin{array}{c} e^{jk_0X} \rightarrow \\ Re^{-jk_0X} \leftarrow \end{array} \Bigg| \begin{array}{c} Ae^{jkX} \rightarrow \\ Be^{-jkX} \leftarrow \end{array} \Bigg| \; Te^{jk_0X}$$

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

$$1 + R = A + B \tag{13}$$

$$jk_0(1 - R) = jk(A - B) \tag{14}$$

$$Te^{jk_0a} = Ae^{jka} + Be^{-jka} \tag{15}$$

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

therefore

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

where

a = thickness

$k = \beta + j\alpha$

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

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

therefore

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

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

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

where

m is an integer and
t is the thickness.

Destructive interference will occur at wavelengths when

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

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

The reflection coefficient for different samples can be calculated from

$$R = \frac{1 - n^*}{1 + n^*} \tag{21}$$

where

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

Therefore,

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

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,

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

and for silicon as

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

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 0.1Ωcm for germanium, and 10, 1, and 0.4Ωcm for silicon. When a sample is placed in a line, the impedance of the line at the point may be calculated.

$$Z \text{ Sample} = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \tag{25}$$

where

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

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

$$G = \frac{2\pi\sigma}{\ln b/a} \tag{28}$$

and

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

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,

$$T = \frac{\text{V TRANSMITTED}}{\text{V INCIDENT}} = \frac{Z_T}{Z_0 \sin h\, \gamma L + Z_T \cos h\, \gamma L} \tag{30}$$

where

$$Z_T = 50\,\Omega$$
$$\gamma = \gamma + j\beta \ .$$

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.

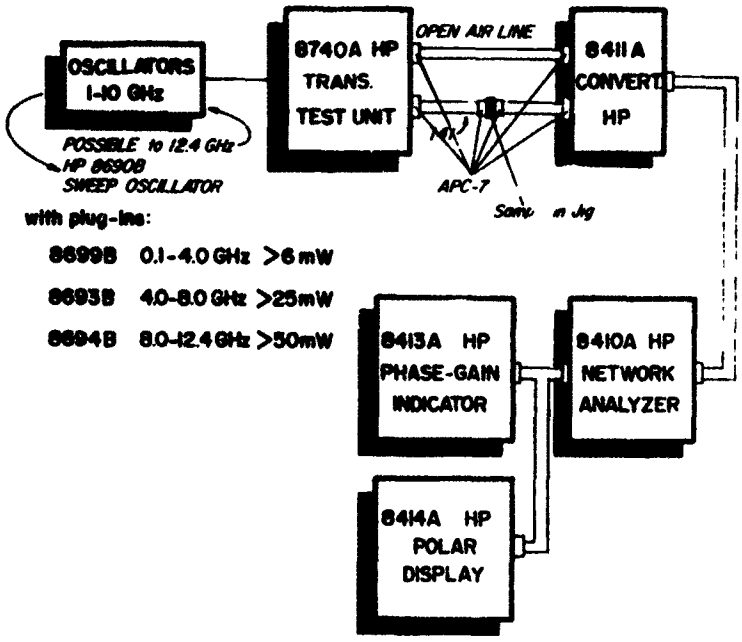
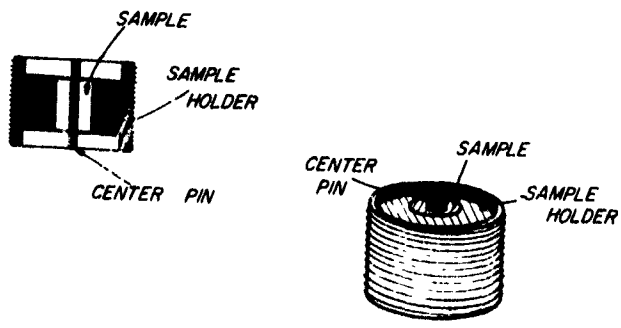


FIGURE 1

Test Setup for RF Measurements



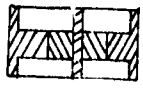


FIGURE 2

Positioning of Sample within Jig

TABLE 1

MEASURED ATTENTUATION (dB) OF SILICON

Freq. (GHz)	Resistivity (Ω cm) 10	1	0.4	10	1	0.4
		0.127-in			0.058-in	
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 $2 \pm .5\ \Omega$ 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 Ω cm where the absorption drops to almost zero. A 2 Ω 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 Ω 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)Ω cm resistivity polished with 1/4 μm 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

PROGRAM ONE

```
      PROGRAM  LOTH(INPUT,OUTPUT, OPL,TAPE6=OPL)
      COMPLEX T,T1,T2,T3,T4,TP,TN
      COMPLEX T11,T41,RHON,SIN,R1,R2,R3,R4
      REAL KO,MUO
      DIMENSION AMU(2),AM(2),D(2),C(3),LABEL(2)
      DIMENSION Z(4), WIDTH(3)
      DATA Z/1.,2.,4.,8./
      DATA WIDTH/.127,.058,.7/
      PI=3.14159265358932
      E=1.6E-19
      AMU(1)=.38
      AMU(2)=.136
      EO=8.85E-12
      CO=3.E+8
      AMASS=9.11E-31
      AM(1)=.12
      AM(2)=.26
      DO 230 M=1,3
      WRITE(6, 125 )WIDTH(4-M)
125   FORMAT(1H1,*THICKNESS= *F10.6,* INCHES*)
      A=WIDTH(4-M)*.02E4
      D(1)=4.0
      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)/9HGERMANIUM/
      DATA LABEL(2)/7HSILICON/
      DO 230 LP=1,2
      MUO=AMU(LP)*AM(LP)
      TAU=(MUO*AMASS)/E
      DN = D(LP)
      ALPHA1=E*AMU(LP)/(2.*EO*CO*DN)
      BETA1= DN*COO
391   WRITE(6, 110)LABEL(LP)
395   DELF=10.
      DO 230 LM=1,3
      WRITE(6, 115)C(LM)
115   FORMAT(10X,*DOPING LEVEL*,F10.3)
```

```
      F0=.3E+9
      WRITE(6,1219)
1219  FORMAT(5X,*F*,12X,*ALPHA*,12X,*REFLECT*,15X,*TABS*)
      CN=C(LM)
119    FORMAT(30X,A10)
      DO 230 II=1,5
      DO 230 JJ=1,4
      F=F(JJ)*10.**(II+8)
      W=2.*PI*F
      ALPHA=(ALPHA1*CN)/(1.+(W*TAU)**2)
      BETA =BETA1*W
      RAT=CO/W
      RAT=CMPLX(RAT,0.)
      SIM=CMPLX(BETA,ALPHA)
      RHON=RAT*SIM
      IF (RHON.GT.1.E0) 2,4
2     RABS=1.
      GO TO6
4     R1=1.-RHON
      R2=CMPLX(1.,0.)
      R3=R2 + RHON
      R4=R1/R3
      RABS=CABS(R4)
6     IF(ALPHA.GT..1E0)117,118
117   TOT=0.
      GO TO 119
118   KO=W*COO
      AA=ALPHA*A
      AB=A* BETA
      A1=(KO**2+BETA**2-ALPHA**2)/KO
      B1=(2.*AA)/KO
      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)
      TD = T1*T2 + T3*T4
      TN=CMPLX(TN2,TN11)
      T=TN/TD
      TOT=CABS(T)
119   WRITE(6, 120 )F,ALPHA,RABS,TOT
120   FORMAT(4(5X,F11.5))
230   CONTINUE
      END
```

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

THICKNESS= .700000 INCHES

GERMANIUM

DOPING LEVEL .250E+20

FREQUENCY (Hz) ALPHA	ABSORBTION COEFF. cm^{-3}	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	.69708E+02	.60002E+00	.18067E+00
.20000E+12	.64678E+02	.60001E+00	.20596E+00
.40000E+12	.50192E+02	.60000E+00	.25314E+00
.80000E+12	.28473E+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	TAJS
.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	.28146E+04	.65185E+00	.14289E-21
.10000E+12	.27883E+04	.63433E+00	.21251E-21
.20000E+12	.25871E+04	.60796E+00	.69229E-20
.40000E+12	.20077E+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-0[illegible]
.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	ABSORBTION 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	.10000E+01	0.
.40000E+11	.28504E+06	.99998E+00	0.
.80000E+11	.28146E+06	.99993E+00	0.
.10000E+12	.27883E+06	.99972E+00	0.
.20000E+12	.25871E+06	.99955E+00	0.
.40000E+12	.20677E+06	.99791E+00	0.
.80000E+12	.10589E+06	.98656E+00	0.
.10000E+13	.78184E+05	.86812E+00	0.
.20000E+13	.24582E+05	.76750E+00	0.
.40000E+13	.65684E+04	.60720E+00	0.
.80000E+13	.16709E+04	.60013E+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
		.60000E+00	.42675E+00

SILICON

DOPING LEVEL .250E+20

F	ALPHA	REFLECT	TABS
.10000E+10	.29950E+02	.60510E+00	.48160E+00
.20000E+10	.29955E+02	.56359E+00	.42986E+00
.40000E+10	.29955E+02	.55165E+00	.38237E+00
.80000E+10	.29953E+02	.54855E+00	.41533E+00
.10000E+11	.29951E+02	.54818E+00	.45706E+00
.20000E+11	.29930E+02	.54768E+00	.44743E+00
.40000E+11	.29879E+02	.54755E+00	.41957E+00
.80000E+11	.29652E+02	.54752E+00	.37737E+00
.10000E+12	.29484E+02	.54752E+00	.37603E+00
.20000E+12	.28154E+02	.54751E+00	.46970E+00
.40000E+12	.23849E+02	.54751E+00	.49126E+00
.80000E+12	.14799E+02	.54751E+00	.50064E+00
.10000E+13	.11520E+02	.54751E+00	.49353E+00
.20000E+13	.40476E+01	.54751E+00	.64876E+00
.40000E+13	.11260E+01	.54751E+00	.53525E+00
.80000E+13	.28967E+00	.54751E+00	.93567E+00
.10000E+14	.18603E+00	.54751E+00	.79558E+00
.20000E+14	.46726E-01	.54751E+00	.60341E+00
.40000E+14	.11095E-01	.54751E+00	.57707E+00
.80000E+14	.29247E-02	.54751E+00	.63861E+00

DOPING LEVEL .10JE+22

FREQUENCY (Hz) ALPHA	ABSORBTION COEFF. cm^{-3}	REFLECTION COEFF.	TRANSMISSION COEFF.
.10000E+10	.11982E+04	.99792E+00	.39383E-10
.20000E+10	.11982E+04	.99180E+00	.80439E-10
.40000E+10	.11982E+04	.96900E+00	.17580E-09
.80000E+10	.11981E+04	.89861E+00	.51237E-09
.10000E+11	.11980E+04	.85920E+00	.85697E-09
.20000E+11	.11975E+04	.71154E+00	.79456E-09
.40000E+11	.11952E+04	.60484E+00	.49362E-09
.80000E+11	.11861E+04	.56328E+00	.50797E-09
.10000E+12	.11794E+04	.55763E+00	.56330E-09
.20000E+12	.11261E+04	.54986E+00	.14198E-08
.40000E+12	.95397E+03	.54794E+00	.30157E-07
.80000E+12	.59197E+03	.54755E+00	.18805E-04
.10000E+13	.46082E+03	.54753E+00	.19362E-03
.20000E+13	.16190E+03	.54751E+00	.39365E-01
.40000E+13	.45040E+02	.54751E+00	.29687E+00
.80000E+13	.11587E+02	.54751E+00	.68991E+00
.10000E+14	.74413E+01	.54751E+00	.68314E+00
.20000E+14	.18690E+01	.54751E+00	.59010E+00
.40000E+14	.46781E+00	.54751E+00	.57417E+00
.80000E+14	.11699E+00	.54751E+00	.63763E+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	.11653E-34
.80000E+13	.11587E+04	.54751E+00	.79128E-09
.10000E+14	.74413E+03	.54751E+00	.12566E-05
.20000E+14	.18690E+03	.54751E+00	.25231E-01
.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	ABSORBTION COEFF. cm^{-3}	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	.70365E+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	.20473E+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

JOPING LEVEL .100E+22

F	ALPHA	REFLECT	TABS
.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	.28146E+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	.65084E+02	.60000E+00	.68777E+00
.80000E+13	.16709E+02	.60000E+00	.55693E+00
.10000E+14	.10716E+02	.60000E+00	.75302E+00
.20000E+14	.26860E+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	ABSORBTION 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	.65084E+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	TABS
.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 ABSORBTION COEFF. cm^{-3}	REFLECTION COEFF.	TRANSMISSION COEFF.
.10000E+10	.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	.14295E+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	ABSORBTION COEFF. cm^{-3}	REFLECTION COEFF.	TRANSMISSION COEFF.
.10000E+10	.71563E+02	.75082E+00	.98528E+00
.20000E+10	.71562E+02	.65338E+00	.75030E+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	.47318E+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	.54170E+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	.27683E+04	.63433E+00	.89497E-04
.20000E+12	.25871E+04	.60796E+00	.15596E-03
.40000E+12	.20677E+04	.60122E+00	.98912E-03
.80000E+12	.10589E+04	.60009E+00	.21030E-01
.10000E+13	.78184E+03	.60003E+00	.51511E-01
.20000E+13	.24982E+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	ABSORBTION 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	.65084E+04	.60013E+00	.40211E-09
.80000E+13	.16709E+04	.60000E+00	.29201E-02
.10000E+14	.10716E+04	.60000E+00	.20182E-01
.20000E+14	.26866E+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	.29956E+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	.41476E+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	ABSORBTION COEFF. cm^{-3}	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	.64183E+00
.80000E+13	.11587E+02	.54751E+00	.55135E+00
.10000E+14	.74413E+01	.54751E+00	.53227E+00
.20000E+14	.18590E+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	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	.34316E-06
.80000E+13	.11587E+04	.54751E+00	.16671E-01
.10000E+14	.74413E+03	.54751E+00	.63341E-01
.20000E+14	.18590E+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= .12700J INCHES

FREQUENCY .20000E+14

TEMPERATURE°K	DOPING LEVEL cm^{-3}	TRANSMISSION COEFF.
200.00000	.10000E+22	.47039E+00
250.00000	.10009E+22	.47039E+00
300.00000 —Room Temp.	.10237E+22	.47034E+00
350.00000	.12605E+22	.47705E+00
400.00000	.26162E+22	.47563E+00
450.00000	.78255E+22	.46390E+00
500.00000	.22973E+23	.42944E+00
550.00000	.56977E+23	.34353E+00
600.00000	.13263E+24	.19639E+00
650.00000	.20090E+24	.63101E-01
700.00000	.49186E+24	.90775E-02
750.00000	.53927E+24	.44402E-03
800.00000	.13503E+25	.52985E-05

FREQUENCY .30000E+14

TEMPERATURE	DOPING LEVEL	TAUS
200.00000	.10000E+22	.50071E+00
250.00000	.10009E+22	.50071E+00
300.00000	.10237E+22	.50069E+00
350.00000	.12605E+22	.50045E+00
400.00000	.26162E+22	.50497E+00
450.00000	.78255E+22	.49925E+00
500.00000	.22973E+23	.48225E+00
550.00000	.56977E+23	.43996E+00
600.00000	.13263E+24	.35612E+00
650.00000	.20090E+24	.22211E+00
700.00000	.49186E+24	.95954E-01
750.00000	.53927E+24	.25199E-01
800.00000	.13503E+25	.35182E-02

FREQUENCY .40000E+14 (Hz)

TEMPERATURE	DOPING LEVEL	TAUS
200.00000	.10000E+22	.70000E+00
250.00000	.10009E+22	.70000E+00
300.00000	.10237E+22	.70059E+00
350.00000	.12605E+22	.70045E+00
400.00000	.26162E+22	.70204E+00
450.00000	.78255E+22	.70191E+00
500.00000	.22973E+23	.72154E+00
550.00000	.56977E+23	.65445E+00
600.00000	.13263E+24	.53045E+00
650.00000	.20090E+24	.36331E+00
700.00000	.49186E+24	.22043E+00
750.00000	.53927E+24	.10450E+00
800.00000	.13503E+25	.34281E-01

FREQUENCY .50000E+14

TEMPERATURE °K	DOPING LEVEL cm^{-3}	TRANSMISSION COEFF.
200.00000	.10000E+22	.92933E+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	.68345E+00
650.00000	.20690E+24	.52225E+00
700.00000	.49106E+24	.35523E+00
750.00000	.53927E+24	.20625E+00
800.00000	.13503E+25	.99036E-01

FREQUENCY .60000E+14

TEMPERATURE	DOPING LEVEL	TRANS
200.00000	.10000E+22	.56675E+00
250.00000	.10009E+22	.56576E+00
300.00000	.10237E+22	.56075E+00
350.00000	.12605E+22	.56005E+00
400.00000	.20162E+22	.55815E+00
450.00000	.70255E+22	.56018E+00
500.00000	.22973E+23	.56042E+00
550.00000	.58977E+23	.54059E+00
600.00000	.13263E+24	.51799E+00
650.00000	.20090E+24	.46012E+00
700.00000	.49100E+24	.38511E+00
750.00000	.53927E+24	.28001E+00
800.00000	.13503E+25	.17327E+00

FREQUENCY .70000E+14

TEMPERATURE	DOPING LEVEL	TRANS
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	.20162E+22	.47025E+00
450.00000	.70255E+22	.40944E+00
500.00000	.22973E+23	.40703E+00
550.00000	.58977E+23	.46120E+00
600.00000	.13263E+24	.44682E+00
650.00000	.20090E+24	.42501E+00
700.00000	.49100E+24	.35326E+00
750.00000	.53927E+24	.31037E+00
800.00000	.13503E+25	.23300E+00

– 3.7 microns

FREQUENCY .30000E+14

TEMPERATURE°K	DOPING LEVEL cm^{-3}	TRANSMISSION COEFF
200.00000	.10000E+22	.55017E+00
250.00000	.10009E+22	.55016E+00
300.00000	.10237E+22	.55017E+00
350.00000	.12605E+22	.55012E+00
400.00000	.20162E+22	.55005E+00
450.00000	.70255E+22	.55402E+00
500.00000	.22973E+23	.55173E+00
550.00000	.50977E+23	.54455E+00
600.00000	.13263E+24	.52957E+00
650.00000	.20090E+24	.50185E+00
700.00000	.49100E+24	.45505E+00
750.00000	.53927E+24	.38734E+00
800.00000	.13503E+25	.30014E+00

FREQUENCY .90000E+14

TEMPERATURE	DOPING LEVEL	TABS
200.00000	.10000E+22	.90504E+00
250.00000	.10009E+22	.90503E+00
300.00000	.10237E+22	.90502E+00
350.00000	.12605E+22	.90540E+00
400.00000	.20162E+22	.90454E+00
450.00000	.70255E+22	.90103E+00
500.00000	.22973E+23	.89095E+00
550.00000	.50977E+23	.85704E+00
600.00000	.13263E+24	.82277E+00
650.00000	.20090E+24	.74951E+00
700.00000	.49100E+24	.64744E+00
750.00000	.53927E+24	.52520E+00
800.00000	.13503E+25	.39772E+00

FREQUENCY .10000E+15 −3 microns

TEMPERATURE	DOPING LEVEL	TABS
200.00000	.10000E+22	.79473E+00
250.00000	.10009E+22	.79470E+00
300.00000	.10237E+22	.79477E+00
350.00000	.12605E+22	.79409E+00
400.00000	.20162E+22	.79415E+00
450.00000	.70255E+22	.79220E+00
500.00000	.22973E+23	.76009E+00
550.00000	.50977E+23	.77361E+00
600.00000	.13263E+24	.74702E+00
650.00000	.20090E+24	.70273E+00
700.00000	.49100E+24	.60401E+00
750.00000	.53927E+24	.54402E+00
800.00000	.13503E+25	.43942E+00

FREQUENCY .11000E+13 Hz

TEMPERATURE°K	DOPING LEVEL cm^{-3}	TRANSMISSION COEFF.
200.00000	.10000E+22	.91555E+00
250.00000	.10009E+22	.91550E+00
300.00000	.10237E+22	.91550E+00
350.00000	.12605E+22	.91594E+00
400.00000	.20162E+22	.91542E+00
450.00000	.70255E+22	.91499E+00
500.00000	.22973E+23	.91372E+00
550.00000	.50977E+23	.91005E+00
600.00000	.13263E+24	.90430E+00
650.00000	.20090E+24	.49206E+00
700.00000	.49100E+24	.47259E+00
750.00000	.53927E+24	.44065E+00
800.00000	.13503E+25	.39390E+00

SILICON

THICKNESS= .12700 INCHES

FREQUENCY .20000E+14

TEMPERATURE	DOPING LEVEL	TABS
200.00000	.10000E+22	.97432E+00
250.00000	.10600E+22	.97402E+00
300.00000	.10000E+22	.97482E+00
350.00000	.10005E+22	.97401E+00
400.00000	.10078E+22	.97474E+00
450.00000	.10550E+22	.97414E+00
500.00000	.13607E+22	.97104E+00
550.00000	.24659E+22	.95940E+00
600.00000	.50098E+22	.92550E+00
650.00000	.14525E+23	.84795E+00
700.00000	.33624E+23	.70917E+00
750.00000	.71471E+23	.51097E+00
800.00000	.14012E+24	.31794E+00

FREQUENCY .30000E+14

TEMPERATURE	DOPING LEVEL	TABS
200.00000	.10000E+22	.94322E+00
250.00000	.10000E+22	.94322E+00
300.00000	.10000E+22	.94322E+00
350.00000	.10005E+22	.94322E+00
400.00000	.10078E+22	.94322E+00
450.00000	.10550E+22	.94317E+00
500.00000	.13607E+22	.94293E+00
550.00000	.24659E+22	.94203E+00
600.00000	.50598E+22	.93920E+00
650.00000	.14525E+23	.93222E+00
700.00000	.33624E+23	.91029E+00
750.00000	.71471E+23	.84375E+00
800.00000	.14012E+24	.42305E+00

–7.5 microns

FREQUENCY .0000E+14

1 TEMPERATURE°K	DOPING LEVEL cm^{-3}	TRANSMISSION COEFF.
200.0000	.1000E+22	.0902E+00
250.0000	.1000E+22	.0902E+00
300.0000	.1000E+22	.0902E+00
350.0000	.1000E+22	.0902E+00
400.0000	.1007E+22	.0901E+00
450.0000	.1005E+22	.0901E+00
500.0000	.1307E+22	.0896E+00
550.0000	.2405E+22	.0886E+00
600.0000	.5889E+22	.0859E+00
650.0000	.1452E+23	.0704E+00
700.0000	.3302E+23	.0621E+00
750.0000	.7147E+23	.0310E+00
800.0000	.1461E+24	.7705E+00

FREQUENCY .4000E+14

TEMPERATURE	DOPING LEVEL	TRANS
200.0000	.1000E+22	.9432E+00
250.0000	.1000E+22	.9432E+00
300.0000	.1000E+22	.9432E+00
350.0000	.1000E+22	.9432E+00
400.0000	.1007E+22	.9431E+00
450.0000	.1005E+22	.9431E+00
500.0000	.1307E+22	.9429E+00
550.0000	.2405E+22	.9400E+00
600.0000	.5889E+22	.9329E+00
650.0000	.1452E+23	.9124E+00
700.0000	.3302E+23	.8711E+00
750.0000	.7147E+23	.7930E+00
800.0000	.1461E+24	.6891E+00

FREQUENCY .5000E+14 ~6 microns

TEMPERATURE	DOPING LEVEL	TRANS
200.0000	.1000E+22	.5527E+00
250.0000	.1000E+22	.5527E+00
300.0000	.1000E+22	.5527E+00
350.0000	.1000E+22	.5527E+00
400.0000	.1007E+22	.5526E+00
450.0000	.1005E+22	.5525E+00
500.0000	.1307E+22	.5515E+00
550.0000	.2405E+22	.5521E+00
600.0000	.5889E+22	.5517E+00
650.0000	.1452E+23	.5491E+00
700.0000	.3302E+23	.5432E+00
750.0000	.7147E+23	.5157E+00
800.0000	.1461E+24	.4953E+00

FREQUENCY .70000E+14

TEMPERATURE°K	DOPING LEVEL cm^{-3}	TRANSMISSION COEFF.
200.00000	.10000E+22	.50000E+00
250.00000	.10000E+22	.50000E+00
300.00000	.10000E+22	.50000E+00
350.00000	.10005E+22	.50000E+00
400.00000	.10078E+22	.50000E+00
450.00000	.10650E+22	.50000E+00
500.00000	.13007E+22	.50000E+00
550.00000	.24859E+22	.50000E+00
600.00000	.50898E+22	.50781E+00
650.00000	.14526E+23	.50724E+00
700.00000	.33624E+23	.50579E+00
750.00000	.71471E+23	.50290E+00
800.00000	.14012E+24	.50012E+00
		.54429E+00

FREQUENCY .80000E+14

TEMPERATURE	DOPING LEVEL	TABS
200.00000	.10000E+22	.83000E+00
250.00000	.10000E+22	.83000E+00
300.00000	.10000E+22	.83000E+00
350.00000	.10005E+22	.83000E+00
400.00000	.10078E+22	.83000E+00
450.00000	.10650E+22	.83000E+00
500.00000	.13007E+22	.83050E+00
550.00000	.24859E+22	.83040E+00
600.00000	.50898E+22	.83001E+00
650.00000	.14526E+23	.82804E+00
700.00000	.33624E+23	.82519E+00
750.00000	.71471E+23	.81761E+00
800.00000	.14012E+24	.80263E+00
		.77661E+00

FREQUENCY .90000E+14

TEMPERATURE	DOPING LEVEL	TABS
200.00000	.10000E+22	.58630E+00
250.00000	.10000E+22	.58630E+00
300.00000	.10000E+22	.58630E+00
350.00000	.10005E+22	.58630E+00
400.00000	.10078E+22	.58630E+00
450.00000	.10650E+22	.58629E+00
500.00000	.13007E+22	.58626E+00
550.00000	.24859E+22	.58613E+00
600.00000	.50898E+22	.58779E+00
650.00000	.14526E+23	.58677E+00
700.00000	.33624E+23	.58401E+00
750.00000	.71471E+23	.58032E+00
800.00000	.14012E+24	.57240E+00

FREQUENCY .10000E+15

TEMPERATURE°K	DOPING LEVEL cm^{-3}	TRANSMISSION COEFF.
200.00000	.10000E+22	.77250E+00
250.00000	.10000E+22	.77250E+00
300.00000	.10000E+22	.77250E+00
350.00000	.10005E+22	.77250E+00
400.00000	.10078E+22	.77250E+00
450.00000	.10650E+22	.77257E+00
500.00000	.13607E+22	.77251E+00
550.00000	.24859E+22	.77227E+00
600.00000	.50696E+22	.77157E+00
650.00000	.14520E+23	.76979E+00
700.00000	.33624E+23	.76585E+00
750.00000	.71471E+23	.75812E+00
800.00000	.14012E+24	.74420E+00

FREQUENCY .11000E+15

TEMPERATURE	DOPING LEVEL	TAUS
200.00000	.10000E+22	.61455E+00
250.00000	.10000E+22	.61455E+00
300.00000	.10000E+22	.61455E+00
350.00000	.10005E+22	.61455E+00
400.00000	.10078E+22	.61455E+00
450.00000	.10650E+22	.61455E+00
500.00000	.13607E+22	.61452E+00
550.00000	.24859E+22	.61443E+00
600.00000	.50696E+22	.61413E+00
650.00000	.14526E+23	.61339E+00
700.00000	.33624E+23	.61174E+00
750.00000	.71471E+23	.60848E+00
800.00000	.14012E+24	.60254E+00

PROGRAM THREE

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

Ge

INDEX OF REFRACTION
KCOFF
4.3000

RESISTIVITY
.7500E-01 ohm-cm

FREQ Hz	Z ohms	X ohm	IMPEDANCE ZO R ohm
.50000E+09	5.3465	5.6439	7.4162
.10000E+10	5.1305	5.9796	10.092
.15000E+10	9.7357	7.4117	12.245
.20000E+10	11.125	8.0227	14.077
.25000E+10	12.437	9.5494	15.000
.30000E+10	13.059	10.311	17.114
.35000E+10	14.510	10.943	18.414
.40000E+10	15.396	11.408	19.003
.45000E+10	16.931	11.904	20.057
.50000E+10	17.915	12.263	21.709
.55000E+10	18.549	12.556	22.048
.60000E+10	19.743	12.796	23.522
.65000E+10	20.590	12.975	24.356
.70000E+10	21.399	13.110	25.090
.75000E+10	22.170	13.208	25.800
.80000E+10	22.904	13.270	26.471
.85000E+10	23.603	13.302	27.093
.90000E+10	24.268	13.306	27.676
.95000E+10	24.900	13.286	28.223
.10000E+11	25.501	13.246	28.735
.10500E+11	26.071	13.187	29.217
.11000E+11	26.614	13.112	29.668
.11500E+11	27.126	13.024	30.093
.12000E+11	27.617	12.924	30.492
.12500E+11	28.081	12.814	30.867

INDEX OF REFRACTION

RCOFF

4.000

RESISTIVITY

.4600E-02 ohm-cm

FREQUENCY (Hz)	ohms Z	X ohm	IMPEDANCE ZO R ohm
.50000E+09	1.1002	1.1347	1.0271
.10000E+10	1.5452	1.0136	2.3006
.15000E+10	2.3003	1.9707	2.8179
.20000E+10	2.5103	2.2851	3.2538
.25000E+10	2.5933	2.5542	3.6376
.30000E+10	2.5365	2.7906	3.9849
.35000E+10	3.3079	3.0169	4.3042
.40000E+10	3.2019	3.2251	4.6013
.45000E+10	3.4033	3.4162	4.8803
.50000E+10	3.5744	3.6003	5.1443
.55000E+10	3.5505	3.7730	5.3952
.60000E+10	4.0311	3.9375	5.6350
.65000E+10	4.1909	4.0948	5.8650
.70000E+10	4.3608	4.2457	6.0863
.75000E+10	4.5174	4.3909	6.2990
.80000E+10	4.6692	4.5309	6.5062
.85000E+10	4.8106	4.6601	6.7063
.90000E+10	4.9605	4.7971	6.9005
.95000E+10	5.1005	4.9241	7.0894
.10000E+11	5.2370	5.0473	7.2733
.10500E+11	5.3705	5.1672	7.4521
.11000E+11	5.5013	5.2839	7.6270
.11500E+11	5.6294	5.3976	7.7993
.12000E+11	5.7550	5.5085	7.9684
.12500E+11	5.8783	5.6168	8.1304

INDEX OF REFRACTION

RCUFF

4.0000

RESISTIVITY

.10000E-02 ohm-cm

IMPEDANCE

FREQUENCY (Hz)	ohms	∠	X ohm	Z0 R ohm
.50000E+09	.57710		.57322	.81345
.10000E+10	.81511		.81178	1.1504
.15000E+10	.99799		.99453	1.4089
.20000E+10	1.1525		1.1484	1.6269
.25000E+10	1.2084		1.2839	1.8169
.30000E+10	1.4115		1.4003	1.9925
.35000E+10	1.5249		1.5187	2.1522
.40000E+10	1.5304		1.6233	2.3006
.45000E+10	1.7290		1.7215	2.4405
.50000E+10	1.8235		1.8143	2.5725
.55000E+10	1.9129		1.9024	2.6979
.60000E+10	1.9963		1.9800	2.8170
.65000E+10	2.0804		2.0673	2.9329
.70000E+10	2.1593		2.1449	3.0436
.75000E+10	2.2350		2.2137	3.1504
.80000E+10	2.3094		2.2921	3.2537
.85000E+10	2.3009		2.3621	3.3539
.90000E+10	2.4505		2.4301	3.4511
.95000E+10	2.5181		2.4901	3.5456
.10000E+11	2.5841		2.5604	3.6377
.10500E+11	2.5465		2.6230	3.7276
.11000E+11	2.7114		2.6842	3.8153
.11500E+11	2.7729		2.7439	3.9010
.12000E+11	2.8331		2.8023	3.9849
.12500E+11	2.8922		2.8594	4.0671

Si

INDEX OF REFRACTION
KCUFF
3.4200

RESISTIVITY
.75000E-01ohm-cm

FREQUENCY (Hz)	ohms	X ohm	IMPEDANCE ∠θ R ohm
.50000E+09	5.3281	5.0728	7.4192
.10000E+10	8.3005	6.0552	10.397
.15000E+10	9.5101	7.0090	12.265
.20000E+10	10.990	8.0306	14.100
.25000E+10	12.265	9.0517	15.730
.30000E+10	13.440	10.713	17.192
.35000E+10	14.501	11.454	18.527
.40000E+10	15.620	12.098	19.758
.45000E+10	16.631	12.661	20.901
.50000E+10	17.599	13.151	21.970
.55000E+10	18.529	13.580	22.972
.60000E+10	19.424	13.954	23.910
.65000E+10	20.285	14.279	24.807
.70000E+10	21.116	14.559	25.649
.75000E+10	21.917	14.800	26.440
.80000E+10	22.690	15.005	27.203
.85000E+10	23.436	15.176	27.921
.90000E+10	24.156	15.318	28.603
.95000E+10	24.851	15.432	29.253
.10000E+11	25.522	15.521	29.870
.10500E+11	26.166	15.586	30.459
.11000E+11	26.792	15.631	31.019
.11500E+11	27.394	15.657	31.553
.12000E+11	27.974	15.666	32.062
.12500E+11	28.533	15.659	32.546

Si

INDEX OF REFRACTION
RCOFF
3.4200

RESISTIVITY
.40000E-02 ohm-cm

FREQUENCY (Hz)	IMPEDANCE ohms	∠	X ohm	∠θ R ohm
.50000E+09	1.1550		1.1350	1.6271
.10000E+10	1.5394		1.5144	2.3005
.15000E+10	2.0049		1.9601	2.6179
.20000E+10	2.3141		2.2674	3.2556
.25000E+10	2.5072		2.5573	3.6378
.30000E+10	2.6346		2.6007	3.9850
.35000E+10	3.0029		3.0241	4.3042
.40000E+10	3.2756		3.2315	4.6014
.45000E+10	3.4761		3.4256	4.8805
.50000E+10	3.5059		3.5092	5.1444
.55000E+10	3.5406		3.7633	5.3955
.60000E+10	4.0200		3.9433	5.6353
.65000E+10	4.1064		4.1081	5.8654
.70000E+10	4.3404		4.2005	6.0357
.75000E+10	4.5020		4.4674	6.3003
.80000E+10	4.6523		4.5492	6.5066
.85000E+10	4.7982		4.6802	6.7070
.90000E+10	4.9402		4.8196	6.9013
.95000E+10	5.0765		4.9478	7.0903
.10000E+11	5.2135		5.0731	7.2744
.10500E+11	5.3454		5.1950	7.4533
.11000E+11	5.4744		5.3137	7.6292
.11500E+11	5.6007		5.4295	7.8005
.12000E+11	5.7245		5.5426	7.9681
.12500E+11	5.8460		5.6531	8.1325

INDEX OF REFRACTION

RLUFF

3.4200

RESISTIVITY

.1000E-02 ohm-cm

FREQUENCY (Hz)	ohms	X ohm	IMPEDANCE Z0 R ohm
.50000E+09	.57713	.57326	.81345
.10000E+10	.81501	.81187	1.1504
.15000E+10	.99781	.99471	1.4069
.20000E+10	1.1520	1.1487	1.6269
.25000E+10	1.2860	1.2843	1.8169
.30000E+10	1.4110	1.4088	1.9925
.35000E+10	1.5242	1.5194	2.1522
.40000E+10	1.6296	1.6241	2.3006
.45000E+10	1.7287	1.7224	2.4405
.50000E+10	1.8224	1.8154	2.5723
.55000E+10	1.9110	1.9037	2.6979
.60000E+10	1.9969	1.9881	2.8178
.65000E+10	2.0786	2.0690	2.9329
.70000E+10	2.1575	2.1467	3.0435
.75000E+10	2.2336	2.2216	3.1504
.80000E+10	2.3072	2.2943	3.2537
.85000E+10	2.3785	2.3645	3.3539
.90000E+10	2.4479	2.4327	3.4511
.95000E+10	2.5153	2.4990	3.5457
.10000E+11	2.5811	2.5635	3.6376
.10500E+11	2.6452	2.6264	3.7276
.11000E+11	2.7079	2.6878	3.8153
.11500E+11	2.7692	2.7477	3.9011
.12000E+11	2.8292	2.8064	3.9850
.12500E+11	2.8879	2.8638	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 RESIS LENGTH

4.0000 .75000E-01 ohm. .32258E-02 meters TRANSMISSION

FREQUENCY (Hz)	R	Z	X	TRANS(DB)
.50000E+09	6.3446 ohm cm		3.8439 ohms	-6.3757
.10000E+10	8.1300		5.9796	-8.7450
.15000E+10	9.7057		7.4717	-10.641
.20000E+10	11.128		8.6227	-12.238
.25000E+10	12.437		9.5494	-13.547
.30000E+10	13.659		10.311	-14.713
.35000E+10	14.816		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	.75010E-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	8.1300		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	24.268		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

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

FREQUENCY (Hz)	R	Z	X	TRANS(DB)
.50000E+09	1.1662 ohm cm		1.1347 ohms	-28.380
.10000E+10	1.6402		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

RESIS .40000E-02 ohm, LENGTH .14732E-02 meters

FREQUENCY (Hz)	R	Z	X	TRANSMISSION TRANS(DB)
.50000E+09	1.1662 ohm cm		1.1347 ohms	-11.386
.10000E+10	1.6402		1.6136	-17.193
.15000E+10	2.0063		1.9787	-21.660
.20000E+10	2.3163		2.2851	-25.421
.25000E+10	2.5903		2.5542	-28.728
.30000E+10	2.8388		2.7966	-31.712
.35000E+10	3.0679		3.0189	-34.450
.40000E+10	3.2819		3.2251	-36.992
.45000E+10	3.4833		3.4182	-39.374
.50000E+10	3.6744		3.6003	-41.620
.55000E+10	3.8566		3.7730	-43.752
.60000E+10	4.0311		3.9375	-45.784
.65000E+10	4.1989		4.0948	-47.727
.70000E+10	4.3608		4.2457	-49.593
.75000E+10	4.5174		4.3909	-51.388
.80000E+10	4.6692		4.5309	-53.119
.85000E+10	4.8168		4.6661	-54.793
.90000E+10	4.9603		4.7971	-56.414
.95000E+10	5.1003		4.9241	-57.986
.10000E+11	5.2370		5.0473	-59.514
.10500E+11	5.3705		5.1672	-60.999
.11000E+11	5.5013		5.2839	-62.446
.11500E+11	5.6294		5.3976	-63.857
.12000E+11	5.7550		5.5085	-65.233
.12500E+11	5.8783		5.6168	-66.577

INDEX OF REFRACTION

RCOFF 4.0000

RESIS .10000E-02 ohm

LENGTH .32258E-02 meters

FREQUENCY (Hz)	R	Z	X	TRANSMISSION TRANS(DB)
.50000E+09	.57716 ohm cm		.57322 ohms	-59.060
.10000E+10	.81511		.81178	-84.610
.15000E+10	.99799		.99453	-104.22
.20000E+10	1.1523		1.1484	-120.75
.25000E+10	1.2884		1.2839	-135.30
.30000E+10	1.4115		1.4063	-148.46
.35000E+10	1.5249		1.5187	-160.54
.40000E+10	1.6304		1.6233	-171.79
.45000E+10	1.7296		1.7215	-182.34
.50000E+10	1.8235		1.8143	-192.32
.55000E+10	1.9129		1.9024	-201.80
.60000E+10	1.9983		1.9866	-210.85
.65000E+10	2.0804		2.0673	-219.53
.70000E+10	2.1593		2.1449	-227.88
.75000E+10	2.2356		2.2197	-235.92
.80000E+10	2.3094		2.2921	-243.70
.85000E+10	2.3809		2.3621	-251.24
.90000E+10	2.4505		2.4301	-258.55
.95000E+10	2.5181		2.4961	-265.65
.10000E+11	2.5841		2.5604	-272.57
.10500E+11	2.6485		2.6230	-279.31
.11000E+11	2.7114		2.6842	-285.88
.11500E+11	2.7729		2.7439	-292.31
.12000E+11	2.8331		2.8023	-298.59
.12500E+11	2.8922		2.8594	-304.74

INDEX OF REFRACTION

RCOFF

4.0000

RESIS .10000E-02 ohm LENGTH .14732E-02 meters TRANSMISSION

FREQUENCY (Hz)	R	Z	X	TRANS (DB)
.50000E+09	.57716 ohm cm		.57322 ohms	-25.364
.10000E+10	.81511		.81178	-37.044
.15000E+10	.99799		.99453	-46.009
.20000E+10	1.1523		1.1484	-53.564
.25000E+10	1.2884		1.2839	-60.218
.30000E+10	1.4115		1.4063	-66.230
.35000E+10	1.5249		1.5187	-71.755
.40000E+10	1.6304		1.6233	-76.895
.45000E+10	1.7296		1.7215	-81.720
.50000E+10	1.8235		1.8143	-86.280
.55000E+10	1.9129		1.9024	-90.615
.60000E+10	1.9983		1.9866	-94.754
.65000E+10	2.0804		2.0673	-98.721
.70000E+10	2.1593		2.1449	-102.54
.75000E+10	2.2356		2.2197	-106.21
.80000E+10	2.3094		2.2921	-109.77
.85000E+10	2.3809		2.3621	-113.21
.90000E+10	2.4505		2.4301	-116.56
.95000E+10	2.5181		2.4961	-119.80
.10000E+11	2.5841		2.5604	-122.97
.10500E+11	2.6485		2.6230	-126.05
.11000E+11	2.7114		2.6842	-129.05
.11500E+11	2.7729		2.7439	-131.99
.12000E+11	2.8331		2.8023	-134.86
.12500E+11	2.8922		2.8594	-137.67

Si

INDEX OF REFRACTION

RCOFF	RESIS	LENGTH		
3.4200	.75000E-01 ohm	.32258E-02 meters		TRANMISSION
FREQUENCY (Hz)	R	Z	X	TRANS(DB)
.50000E+09	6.3281 ohm cm		3.8728 ohms	-6.4003
.10000E+10	8.0803		6.0552	-8.8187
.15000E+10	9.6161		7.6096	-10.781
.20000E+10	10.996		8.8366	-12.426
.25000E+10	12.263		9.8517	-13.851
.30000E+10	13.446		10.713	-15.109
.35000E+10	14.561		11.454	-16.234
.40000E+10	15.620		12.098	-17.248
.45000E+10	16.631		12.660	-18.168
.50000E+10	17.599		13.151	-19.007
.55000E+10	18.529		13.580	-19.777
.60000E+10	19.424		13.954	-20.486
.65000E+10	20.285		14.279	-21.141
.70000E+10	21.116		14.559	-21.747
.75000E+10	21.917		14.800	-22.309
.80000E+10	22.690		15.005	-22.832
.85000E+10	23.436		15.176	-23.319
.90000E+10	24.156		15.318	-23.774
.95000E+10	24.851		15.432	-24.199
.10000E+11	25.522		15.521	-24.596
.10500E+11	26.168		15.586	-24.968
.11000E+11	26.792		15.631	-25.317
.11500E+11	27.394		15.657	-25.645
.12000E+11	27.974		15.666	-25.953
.12500E+11	28.533		15.659	-26.243

INDEX OF REFRACTION

RCOFF

3.4200

RESIS .75000E-01 ohm

LENGTH .14732E-02 meters

FREQUENCY (Hz)	R	Z	X	TRANSMISSION TRANS(DB)
.50000E+09	6.3281 ohm cm		3.8728 ohms	-1.7269
.10000E+10	8.0803		6.0552	-2.5884
.15000E+10	9.6161		7.6096	-3.5319
.20000E+10	10.996		8.8366	-4.3997
.25000E+10	12.263		9.8517	-5.1630
.30000E+10	13.446		10.713	-5.8305
.35000E+10	14.561		11.454	-6.4175
.40000E+10	15.620		12.098	-6.9385
.45000E+10	16.631		12.660	-7.4050
.50000E+10	17.599		13.151	-7.8263
.55000E+10	18.529		13.580	-8.2097
.60000E+10	19.424		13.954	-8.5610
.65000E+10	20.285		14.279	-8.8847
.70000E+10	21.116		14.559	-9.1844
.75000E+10	21.917		14.800	-9.4632
.80000E+10	22.690		15.005	-9.7234
.85000E+10	23.436		15.176	-9.9669
.90000E+10	24.156		15.318	-10.195
.95000E+10	24.851		15.432	-10.410
.10000E+11	25.522		15.521	-10.612
.10500E+11	26.168		15.586	-10.802
.11000E+11	26.792		15.631	-10.982
.11500E+11	27.394		15.657	-11.150
.12000E+11	27.974		15.666	-11.310
.12500E+11	28.533		15.659	-11.460

INDEX OF REFRACTION

RCOFF	RESIS	LENGTH		
3.4200	.40000E-02 ohm	.32258E-02 meters		TRANSMISSION
FREQUENCY (Hz)	R	Z	X	TRANS(DB)
.50000E+09	1.1660 ohm cm		1.1350 ohms	-28.387
.10000E+10	1.6394		1.6144	-41.081
.15000E+10	2.0049		1.9801	-50.840
.20000E+10	2.3141		2.2874	-59.064
.25000E+10	2.5872		2.5573	-66.301
.30000E+10	2.8348		2.8007	-72.835
.35000E+10	3.0629		3.0241	-78.834
.40000E+10	3.2758		3.2315	-84.409
.45000E+10	3.4761		3.4258	-89.635
.50000E+10	3.6659		3.6092	-94.569
.55000E+10	3.8468		3.7833	-99.254
.60000E+10	4.0200		3.9493	-103.72
.65000E+10	4.1864		4.1081	-108.00
.70000E+10	4.3469		4.2606	-112.11
.75000E+10	4.5020		4.4074	-116.06
.80000E+10	4.6523		4.5492	-119.88
.85000E+10	4.7982		4.6862	-123.58
.90000E+10	4.9402		4.8190	-127.16
.95000E+10	5.0785		4.9478	-130.63
.10000E+11	5.2135		5.0731	-134.01
.10500E+11	5.3454		5.1950	-137.30
.11000E+11	5.4744		5.3137	-140.50
.11500E+11	5.6007		5.4295	-143.63
.12000E+11	5.7245		5.5426	-146.68
.12500E+11	5.8460		5.6531	-149.67

INDEX OF REFRACTION

RCOFF

3.4200

RESIS .40000E-02 ohm. LENGTH .14732E-02 meters TRANSMISSION

FREQUENCY (Hz)	R	Z	X	TRANS(DB)
.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 .10000E-02 ohm LENGTH .32258E-02 meters

FREQUENCY (Hz)	R	Z	X	TRANSMISSION TRANS(DB)
.50000E+09	.57713 ohm cm		.57326 ohms	-59.064
.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	2.1575		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
.10000E+11	2.5811		2.5635	-272.90
.10500E+11	2.6452		2.6264	-279.66
.11000E+11	2.7079		2.6878	-286.26
.11500E+11	2.7692		2.7477	-292.72
.12000E+11	2.8292		2.8064	-299.02
.12500E+11	2.8879		2.8638	-305.20

INDEX OF REFRACTION
RCOFF
3.4200

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

FREQUENCY (Hz)	R	Z	X	TRANSMISSION TRANS(DB)
.50000E+09	.57713 ohm cm		.57326 ohms	-25.366
.10000E+10	.81501		.81187	-37.049
.15000E+10	.99781		.99471	-46.017
.20000E+10	1.1526		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

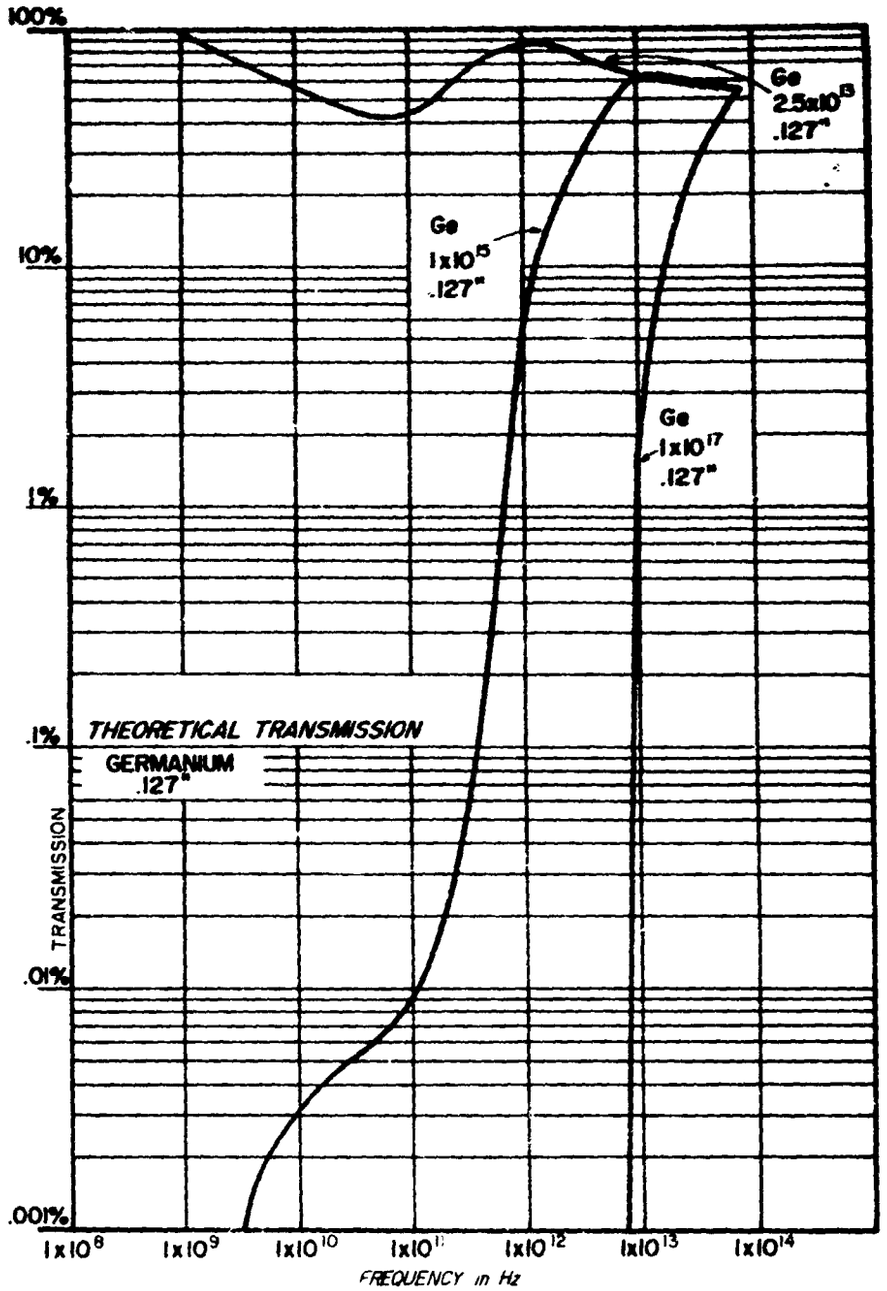


FIGURE B-1

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

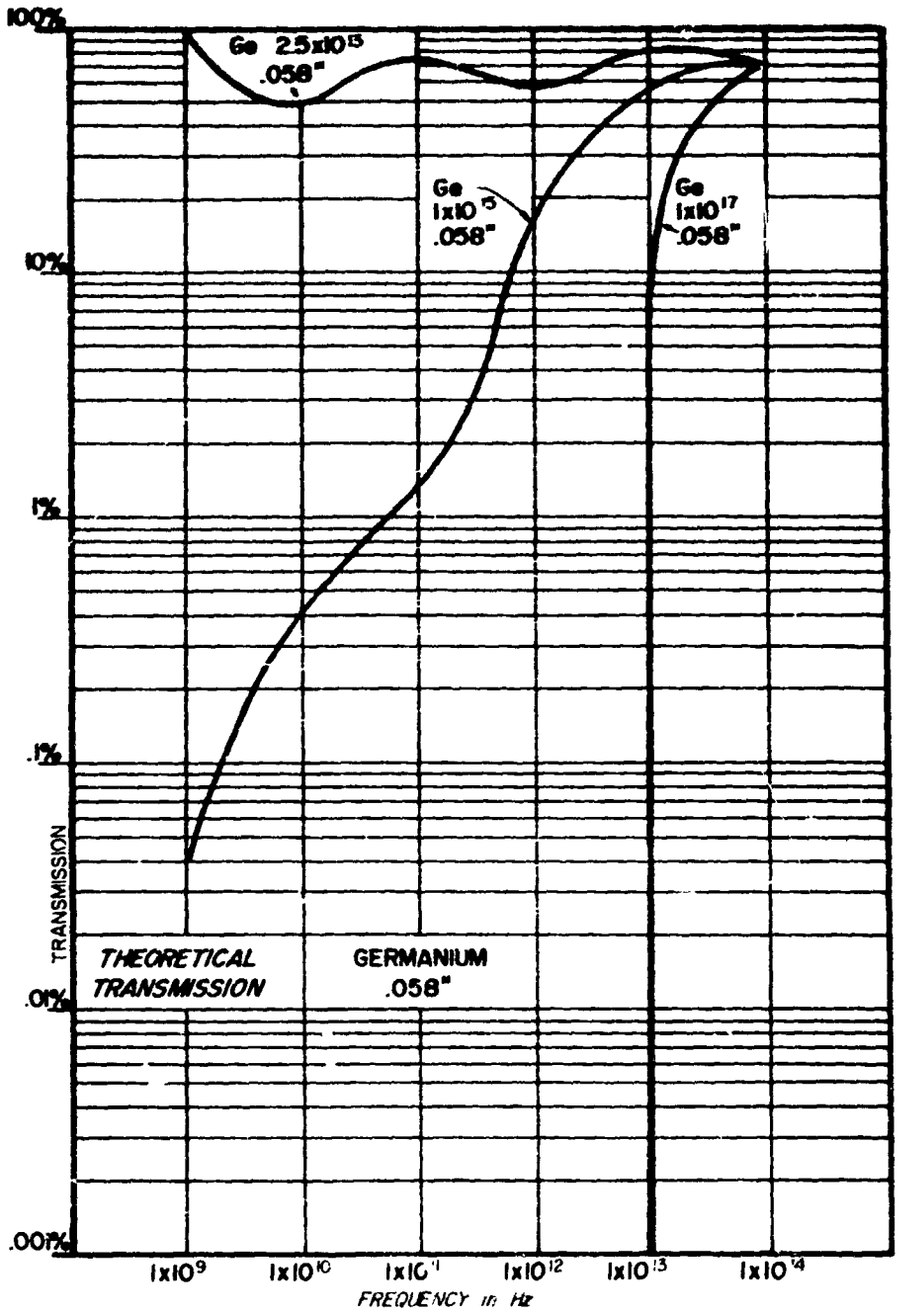


FIGURE B-2

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

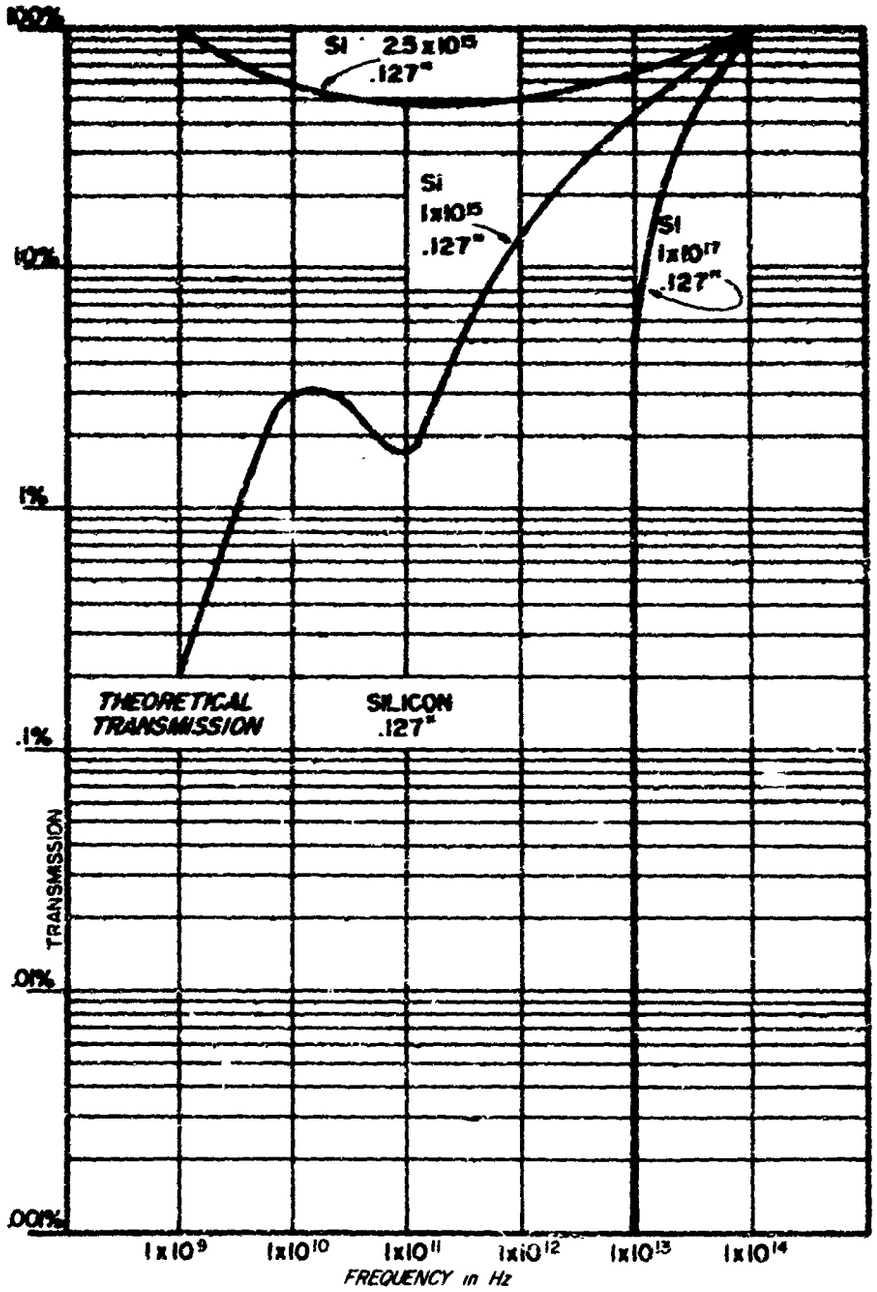


FIGURE B-3

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

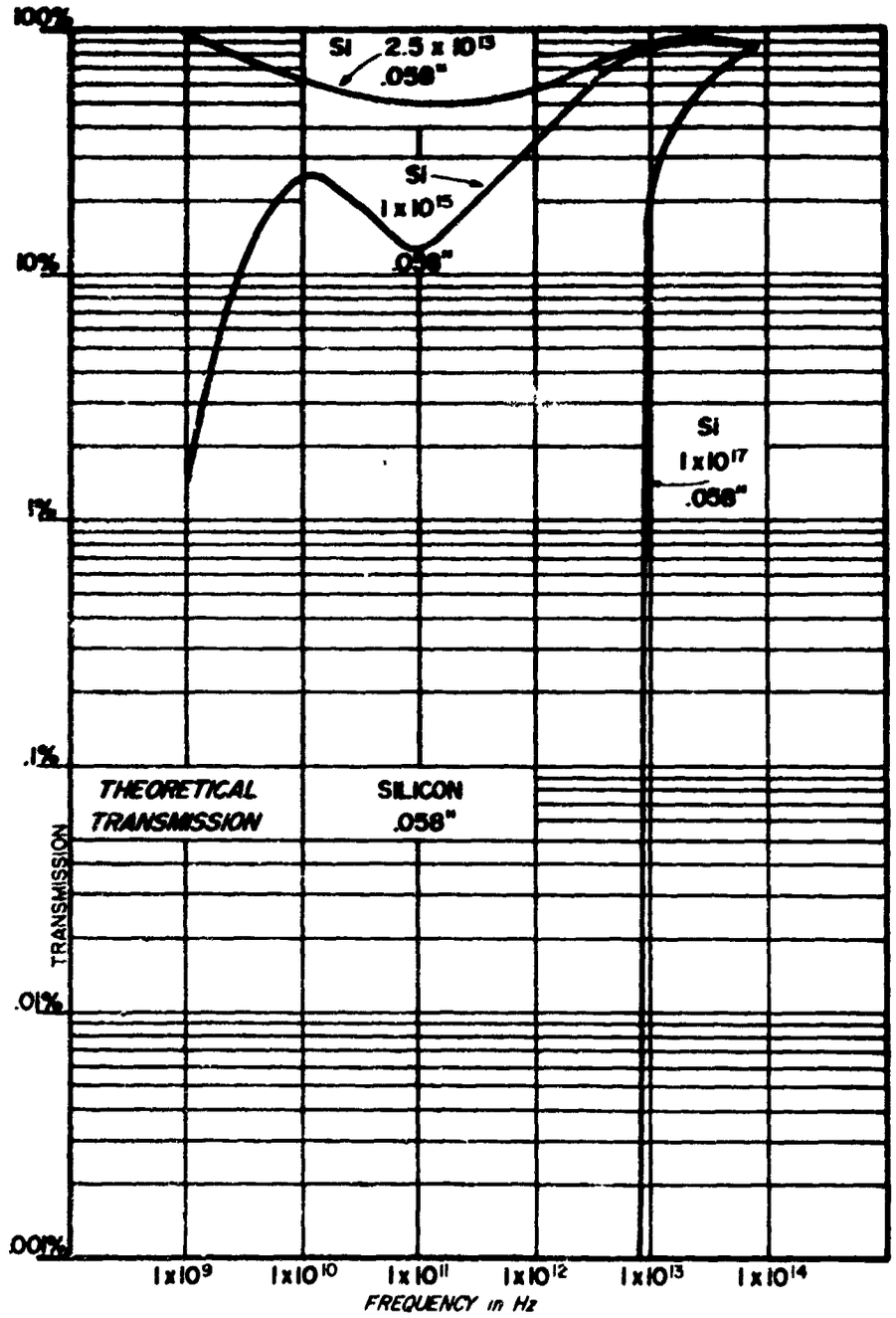


FIGURE B-4

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

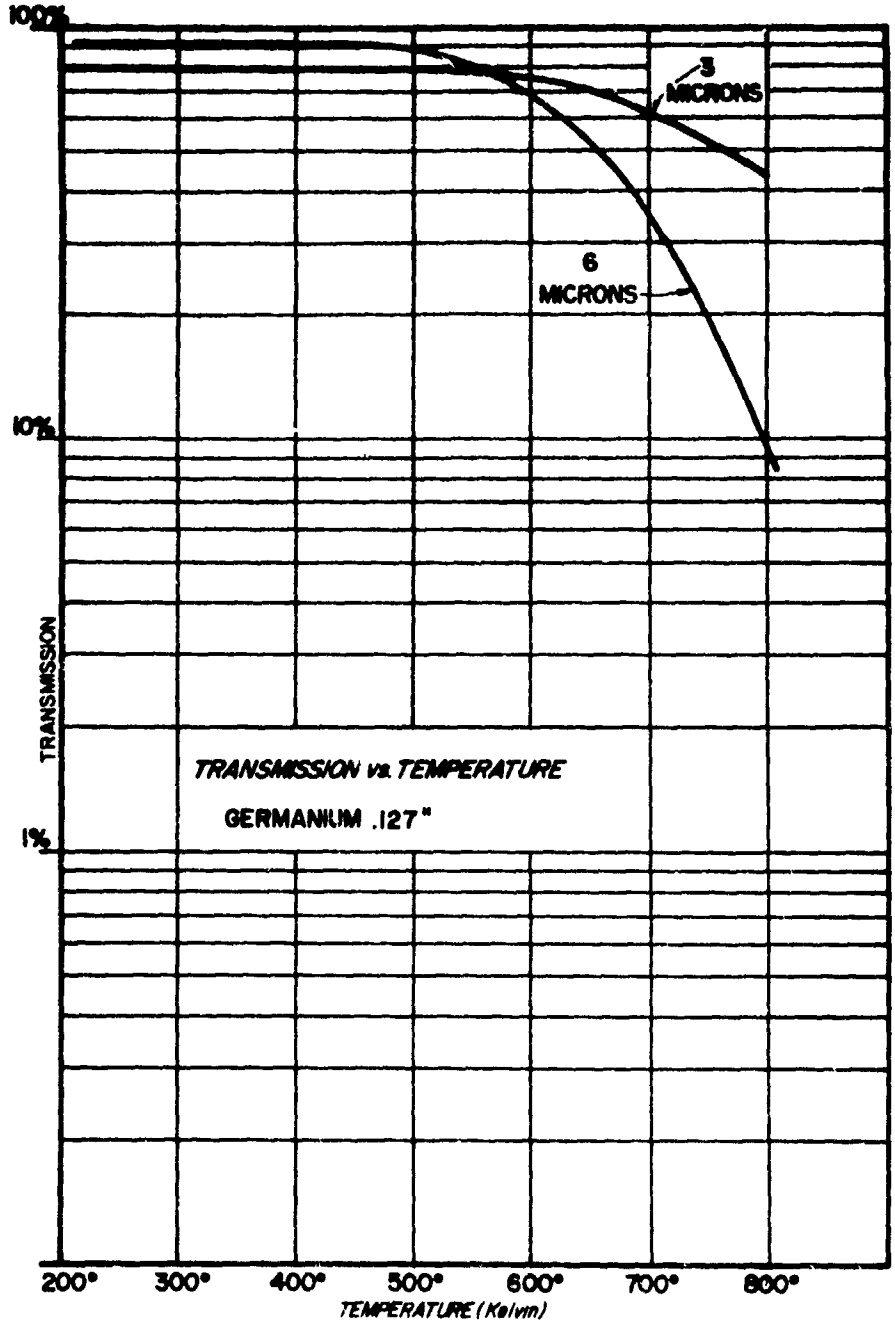


FIGURE B-5

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

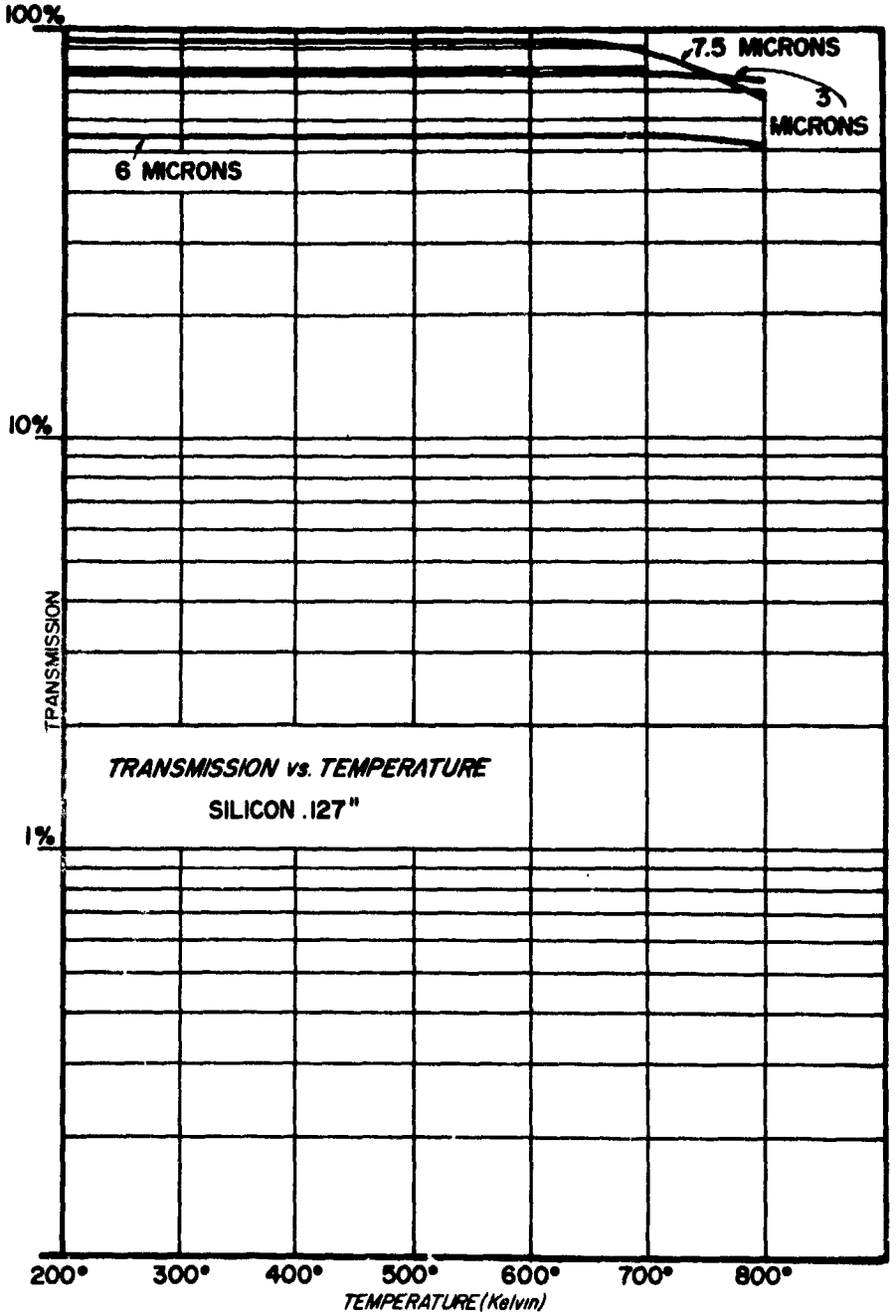


FIGURE B-6

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

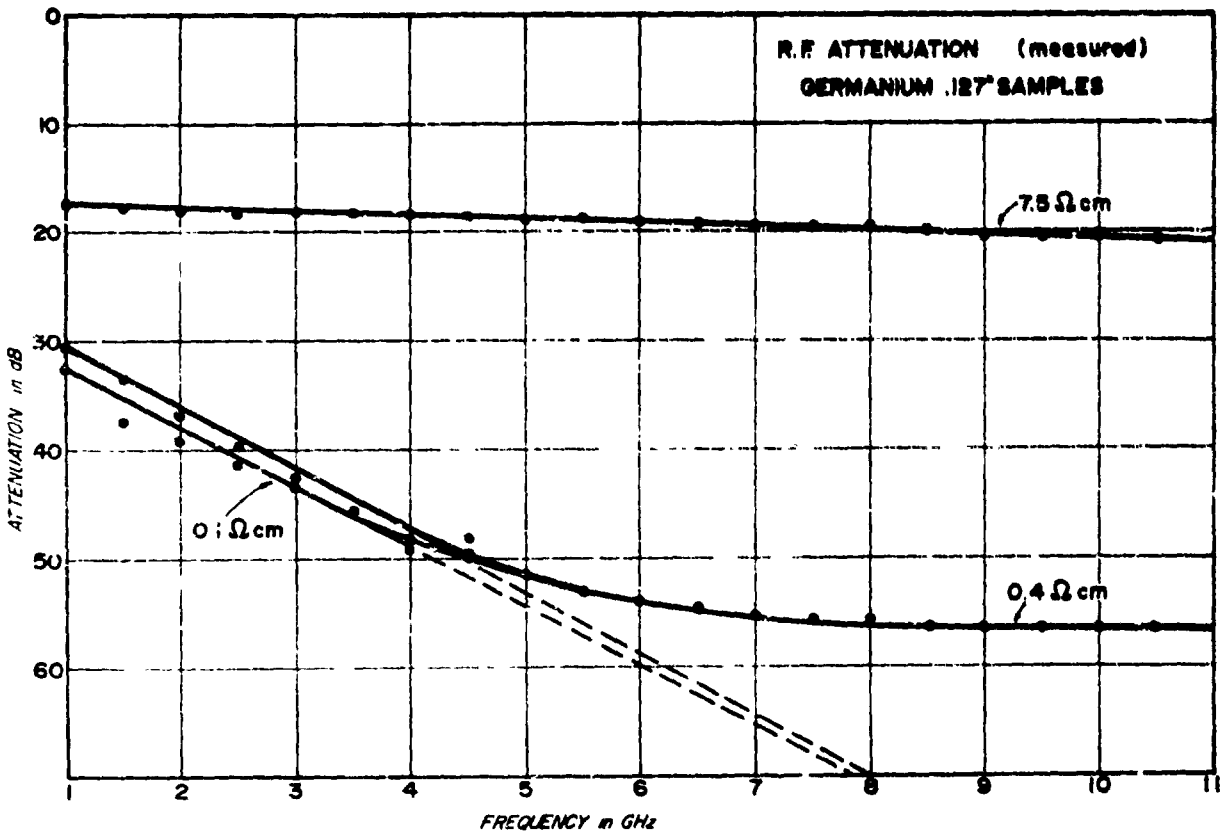


FIGURE B-7

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

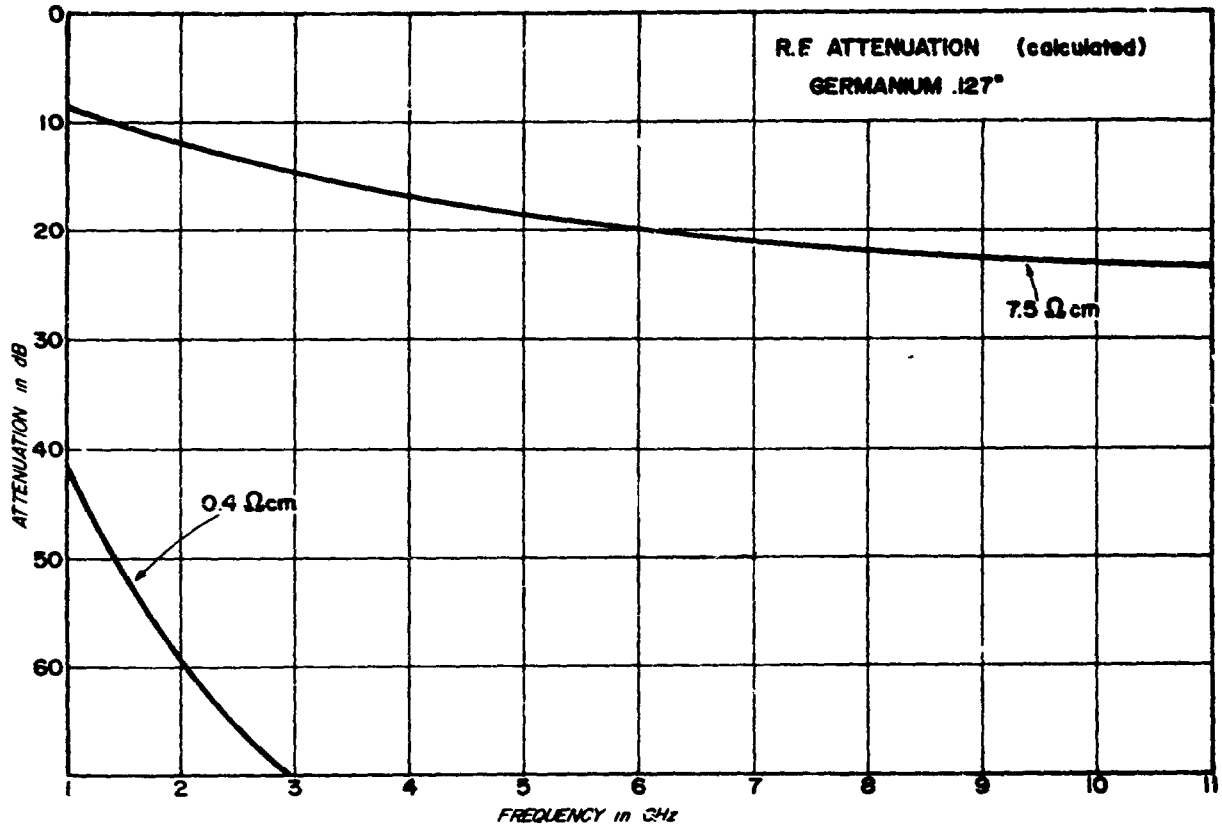


FIGURE B-8

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

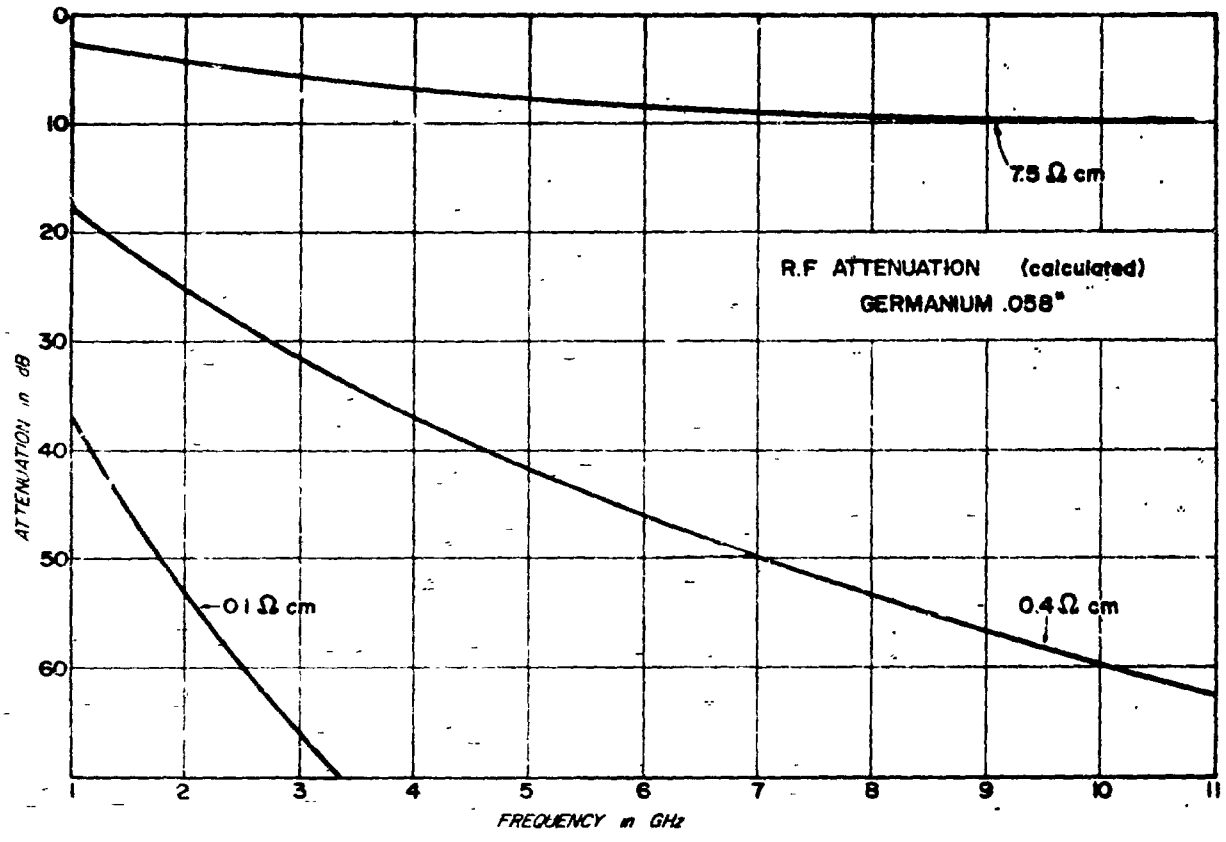
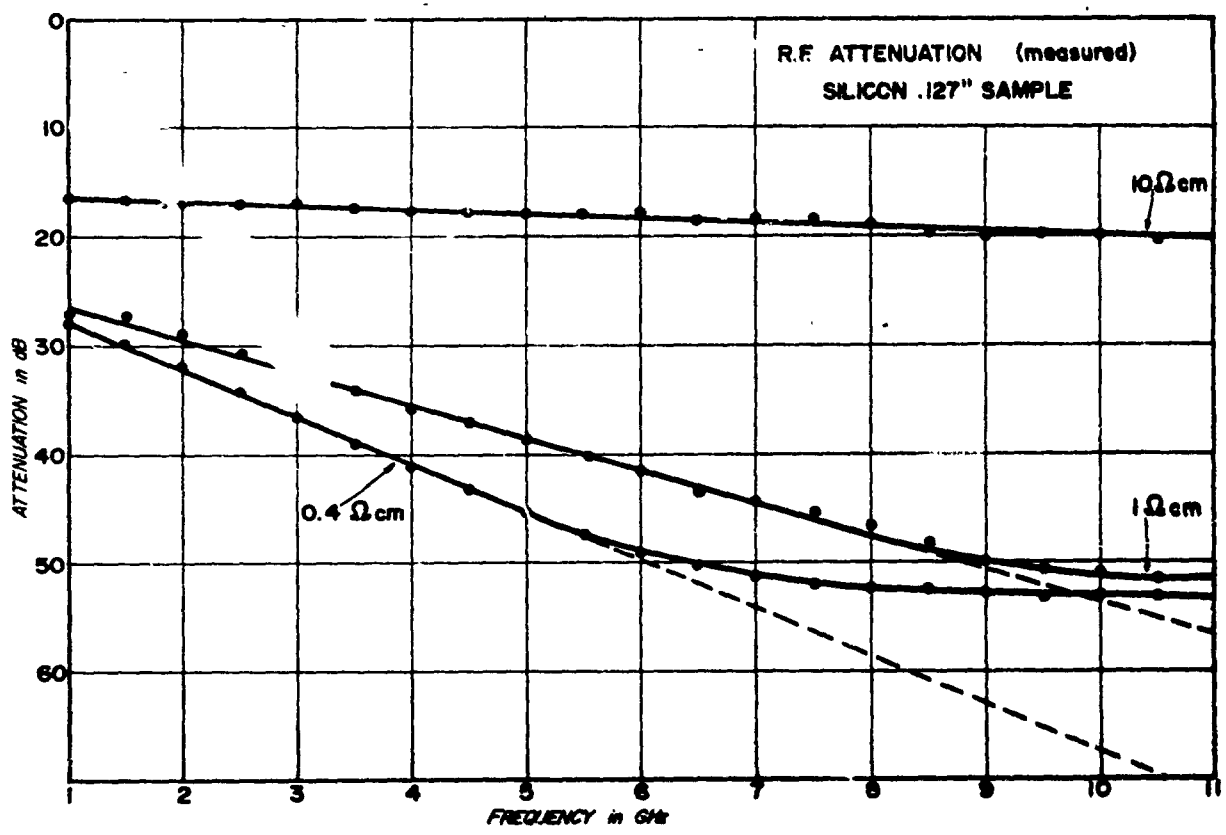


FIGURE B-9

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



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

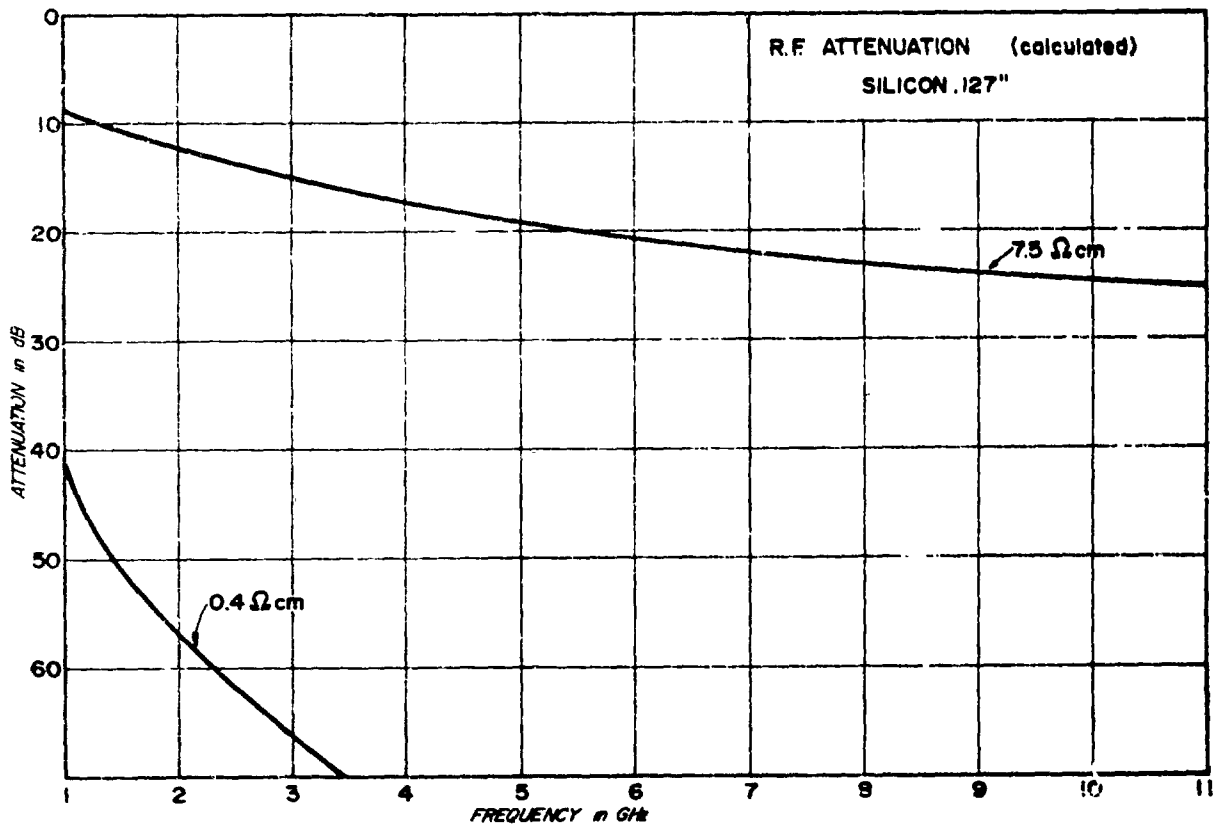


FIGURE B-11

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

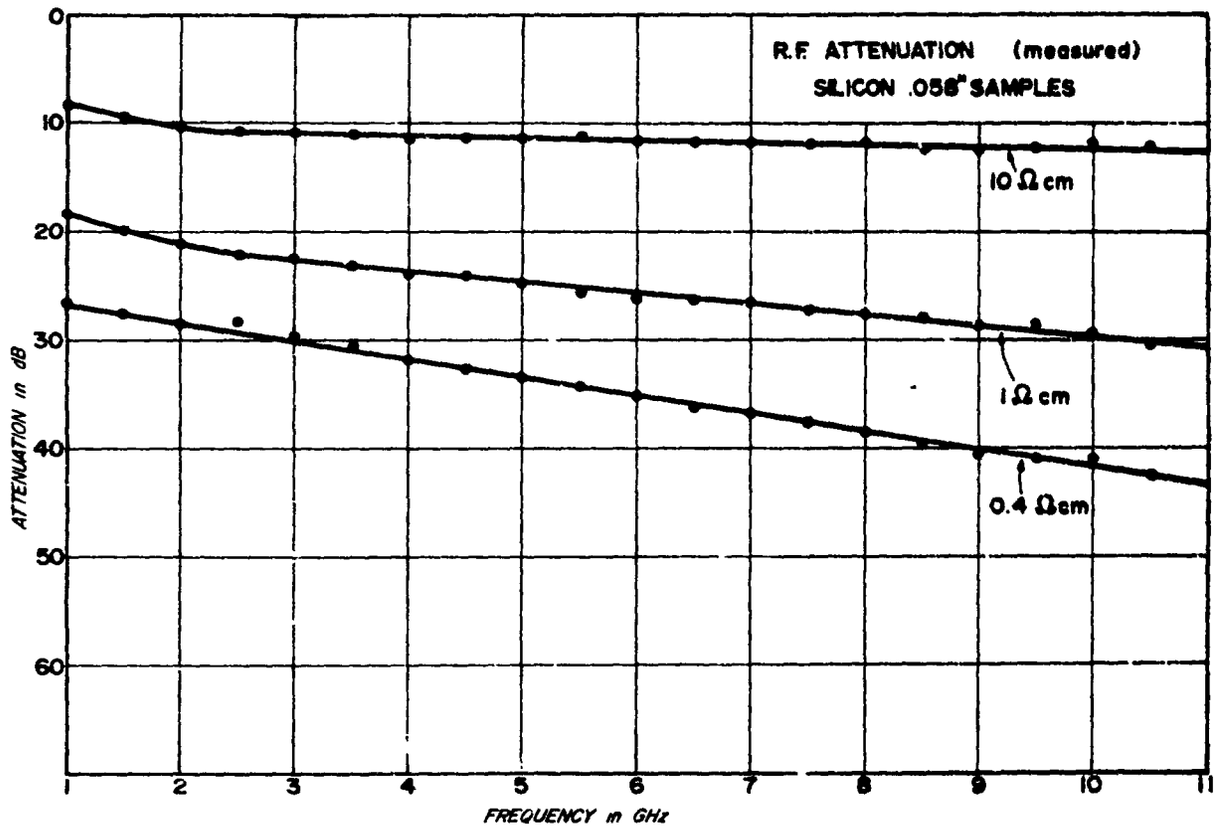


FIGURE B-12

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

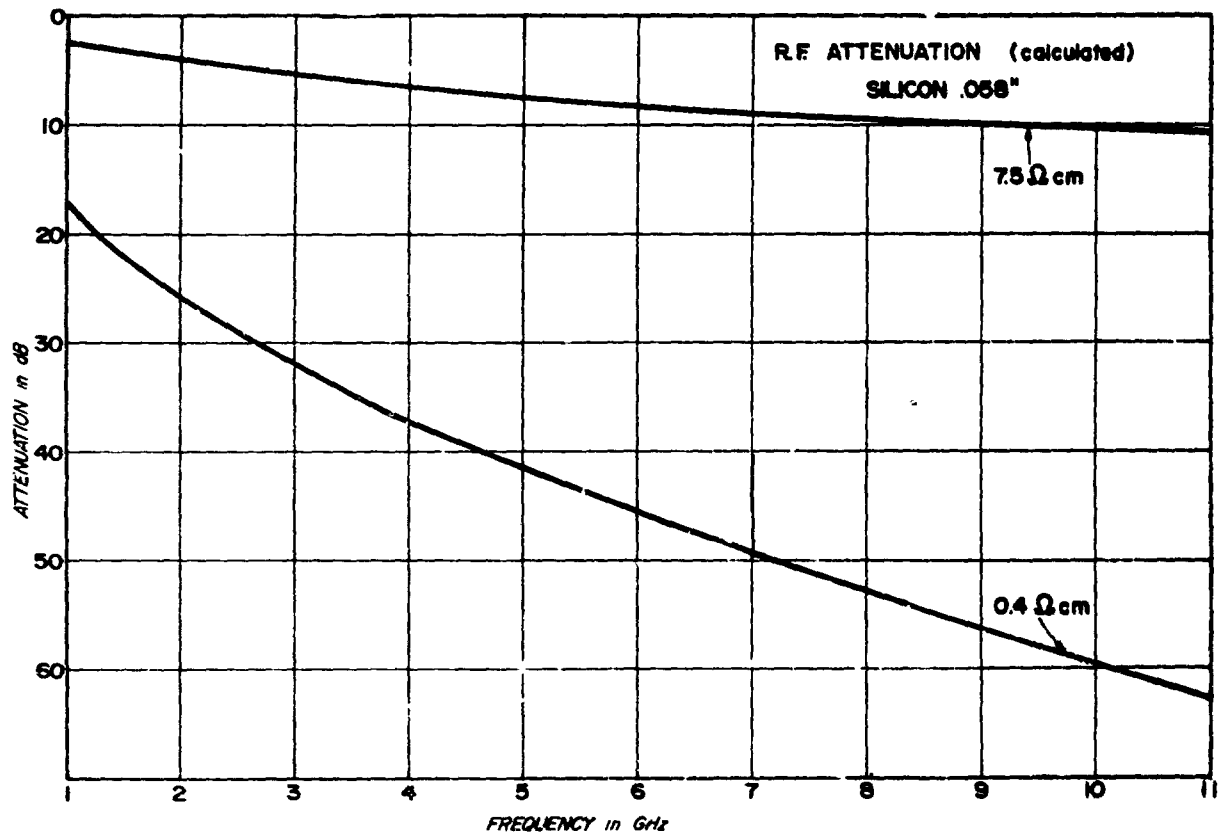


FIGURE B-13

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