DESIGN AND MODELING OF SCHOTTKY BARRIER PHOTODIODES

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BY

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ABSTRACT

The computer program developed by T.B. Remple for the analysis of PiN photodiodes has been modified to handle Schottky barrier cases. The fundamental physics involved in the original model is summarized and the theories for a metal-semiconductor interface are presented. The boundary values for n, p, and ψ are then defined in such a way that $\psi(x)$ would be in agreement with the thermionic-diffusion theory. An equivalent circuit approach is used to determine the RC response of the photodetector. While the modified version of the computer model provides very detailed analysis of the device, it is also very expensive to run. A simplified model is therefore employed for the design process. The objective is to design an Au-nGe photodiode with a risetime less than 50 psecs. The set of optimum design parameters obtained with the simplified model is then taken as the input to the modified version of Remple's program for further analysis. The theoretical risetime of the optimum design is found to be about 45 psecs.

ACKNOWLEDGEMENTS

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GLOSSARY OF SYMBOLS

n	N	electron concentration
p	P	hole concentration
ψ	PSI	electric potential
J_n	JN	electron current
J_p	JP	hole current
J_{disp}	JDISP	displacement current
J	JTOT	total current
μ_n	MN	electron mobility
μ_p	MP	hole mobility
G	G	photo-generation term
U	U	recombination term
N_D		donor concentration
N_A		acceptor concentration
D		diffusion constant
τ_n	TRN	electron lifetime
τ_p	TRP	hole lifetime
$q\phi_T$	ETRAP	energy level of trapping centres
n_A	NA	atomic density of metal
E_F		Fermi energy
ϕ_n		quasi-Fermi level for electrons
ϕ_p		quasi-Fermi level for holes

V_e, V_c	VE,VC	voltages applied at the two end points of the diode
E_c		conduction band energy level
E_i		intrinsic energy level
E_v		valence band energy level
ϕ_m	PM	work function of metal
ϕ_{b0}	PB0	asymtotic value of ϕ_{bn} at zero applied field
ϕ_{bn}	PBN	barrier height with applied field
Δ	PIT	potential across interfacial layer
χ	PEA	electron affinity
$\Delta\phi$	PBL	image force lowering
V_{bi}	PBI	built-in potential
V_g	EGAP	energy gap of semiconductor
V_n	PVN	potential difference between Fermi-level and the conduction band
Q_S		surface state density on semiconductor
Q_M		surface charge density on metal
ε_s		permittivity of semiconductor
ε_i		permittivity of interfacial layer
x_m	XM	location of barrier maximum
x_d	XDPLE	depletion layer thickness

CHAPTER 1

INTRODUCTION

Computer modeling has been widely used in different applications for the past decade. This is due to the fact that it is usually much cheaper and easier to predict the behaviour of a certain device with a computer model than to achieve the same goal by actually building and testing the device. The computer approach is also more efficient in terms of the amount of time involved. In addition, sometimes the solution to the set of equations defining the model cannot be obtained analytically. Computer analysis is therefore necessary for obtaining a solution numerically or graphically. These features make designing with a computer model highly desirable. In this paper, a computer model which describes the performance characteristics of semiconductor photodiodes is presented. The original program was written by T. Remple[1] for the analysis of PiN photodiodes. The present work involves the modification of the program to model Schottky barrier diodes and the design of an Au-nGe Schottky diode with risetime less than 50 psecs. The physics of metal-semiconductor interface which leads to the establishment of boundary conditions for the model is described in Chapter 2. An equivalent circuit of the photodiode is used to determine the electronic response time and to overcome the instability in convergence as discovered by Remple. A simplified model for the photodiode is presented in Chapter 3. The model is used to obtain a set of optimum design values which can give a minimum current risetime of 45 psecs. In this chapter, the fundamental physics of semiconductor devices is summarized and a brief description of PHODIM, the original computer program, is given .

1.1 Review of Physics

The photodiode model is set up to predict the output current as a function of time when the doping profile of the semiconductor diode, the applied voltage and the input light intensity as a function of time are all given. Six basic mathematical equations are involved in the model and they are described as follows:

Maxwell's equation: The current density is expressed as the sum of electron current, hole current and the displacement current.

$$J(t) = J_n(x,t) + J_p(x,t) + J_{disp}(x,t)$$

$$= J_n(x,t) + J_p(x,t) + \frac{\partial}{\partial t}\frac{\partial \psi}{\partial x}(x,t) \qquad (1.1.1)$$

Carrier-Transport equations: Each of the particle currents consists of a drift component and a diffusion component.

$$J_n(x,t) = \mu_n(x,t)\left[n(x,t)\frac{\partial \psi}{\partial x}(x,t) - \frac{\partial n}{\partial x}(x,t)\right] \qquad (1.1.2)$$

$$J_p(x,t) = \mu_p(x,t)\left[p(x,t)\frac{\partial \psi}{\partial x}(x,t) + \frac{\partial p}{\partial x}(x,t)\right] \qquad (1.1.3)$$

Continuity equations: The net influx of carriers into a region is determined by the generation and recombination of carriers in that region, and the particle currents flowing in and out of the region.

$$\frac{\partial n}{\partial t}(x,t) = G(x,t) - U(x,t) - \frac{\partial J_n}{\partial x}(x,t) \qquad (1.1.4)$$

$$\frac{\partial p}{\partial t}(x,t) = G(x,t) - U(x,t) - \frac{\partial J_p}{\partial x}(x,t) \qquad (1.1.5)$$

Poisson's equation : The electrostatic potential is defined in terms of the net space charge density.

$$\frac{\partial^2 \psi}{\partial x^2}(x,t) = n(x,t) - p(x,t) - N_D(x) + N_A(x) \qquad (1.1.6)$$

It is noted that the above equations are given in their dimensionless form. The normalization factors employed are listed in Appendix A. In addition, the Einstein's relation has also been used to simplifly the equations into the above forms. It is given by

$$D = \frac{kT}{q}\mu \qquad (1.1.7)$$

where k = Boltzmann constant

T = temperature in °K

q = electronic charge

Both of the carrier mobilities and the recombination function can be defined in terms of carrier densities and semiconductor material properties. Mobility is given by

$$\mu' = \frac{v_{sat}}{E} \tanh\left(\frac{\mu E}{v_{sat}}\right) \qquad (1.1.8)$$

where $E = -\frac{\partial\psi}{\partial x}$ and v_{sat} is the saturation velocity.

μ is defined as

$$\mu = F_s(w) \frac{\mu_I \ \mu_L}{\mu_I + \mu_L} \qquad (1.1.9)$$

where

$$\mu_I = \frac{K_1}{(N_A + N_D + \Theta p)} \left\{ \ln\left[1 + \left(\frac{K_2}{n + \Theta p}\right)\right]\right\} \qquad (1.1.10)$$

The quantities μ_L, K_1, K_2 and Θ are material properties and are given in Appendix B for Germanium. $F_s(w)$ is a transcendental function which is defined in Appendix C.

The standard Shockley-Read model is used for the recombination function $U(x,t)$.

$$U(x,t) = \frac{n(x,t)\ p(x,t)}{\tau_p\left[n(x,t) + \exp(\Phi_T)\right] + \tau_n\left[p(x,t) + \exp(\Phi_T)\right]}$$

(1.1.11)

It is assumed that the energy level of the trapping centres is coincide with the Fermi level in this model. Hence ϕ_T is equal to zero in the present case.

The photo-generation term and the doping profile are determined by the operating condition and the type of diode respectively. Both quantities are pre-defined functions. The generation term G(x,t) can be one of the three different forms which are given in Appendix D. Now the six fundamental equations can be expressed in terms of the variables J, J_n, J_p, n, p, and ψ. Only three of these variables are independent and they are arbitrarily chosen to be n, p and ψ.

1.2 Description of PHODIM

A computer program PHODIM written by T. Remple solves the above set of differential equations and obtains the output current as a function of time. A detailed description of the numerical methods employed in the program can be found in Stark's or Remple's paper.[1][2] The basic steps of operation of the program can be summarized by a flow diagram shown in Figure 1.

The approximations and assumptions made in the derivation of the model are listed as follows:

(i) One dimension: Current crowding and spreading effects are ignored.

(ii) No avalanching or breakdown: The model does not include an avalanche mechanism and does not predict when breakdown is going to occur.

(iii) No degeneracy: Effects of heavily doped region on the operation of the main part of the photodiode are assumed to be small.

(iv) No thermoelectric effects or thermal transport: The carrier temperature gradient is assumed to be zero. Otherwise, two additional components would have to be included in the current-transport equations.

PHODIM was originally written for the analysis of PiN photodiodes. Attempts were made by Remple to model for the Schottky barrier case by assuming a P^+N

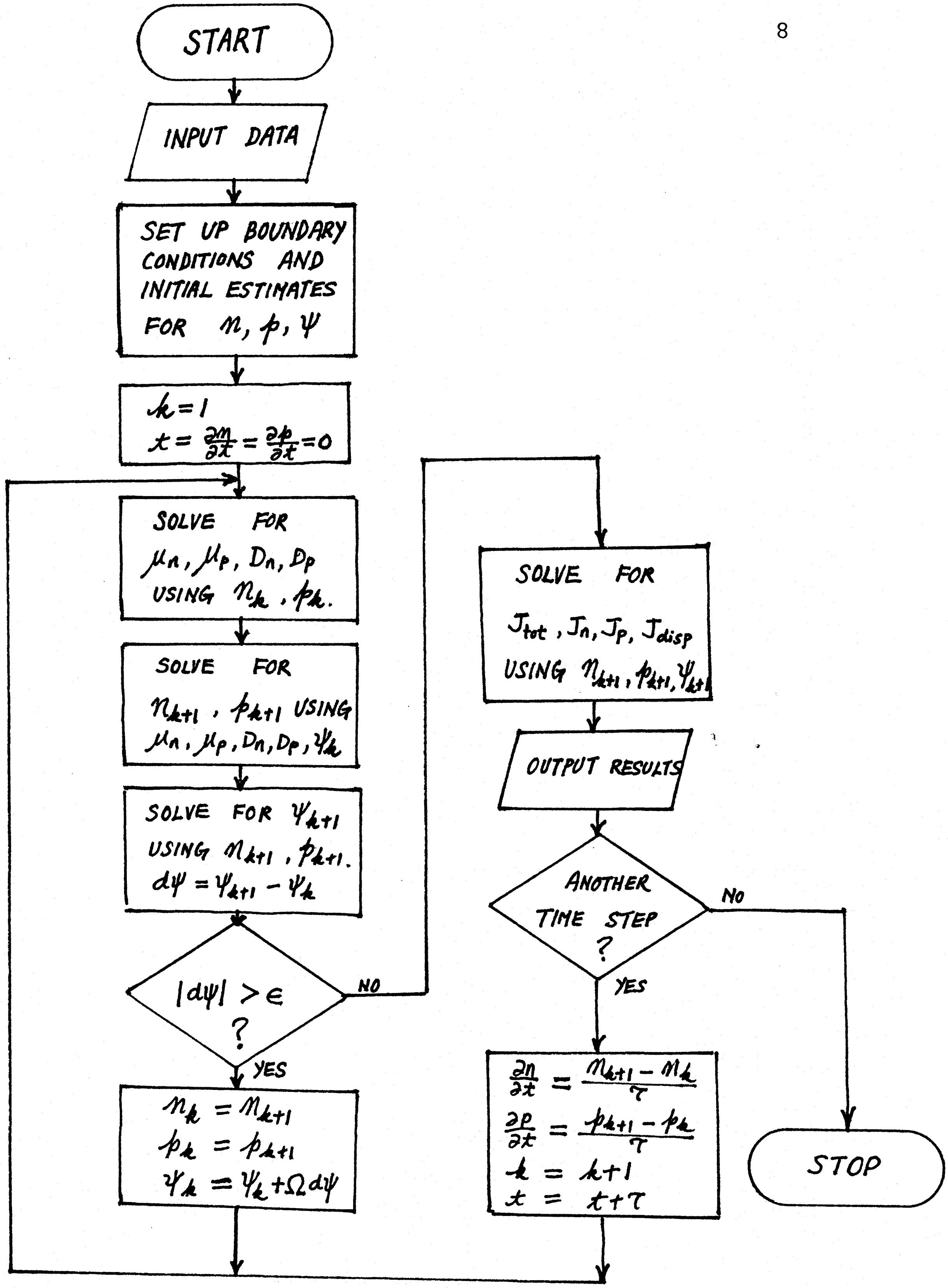


FIGURE 1

Flow Diagram for PHODIM

structure. This approach, however, did not work due to several problems. First, a heavily doped P region does not exist in practice. Second, the approach predicted that the total current consists of electron and hole currents instead of electron current only (for n-type semiconductor). Third, instability in convergence was observed for the Schottky case. The present work is therefore carried out to solve these problems.

CHAPTER 2

MODELING OF SCHOTTKY BARRIER PHOTODIODES

The fundamental equations given in the previous chapter are derived from the semiconductor physics and therefore hold true for both the PiN and the Schottky barrier photodiodes. The major difference is the boundary conditions used for solving the set of equations. In this chapter, the physics of a metal-semiconductor interface which leads to the setting up of appropriate boundary conditions is discussed. The electric potential ψ is assumed to be a specific profile which is predicted by the thermionic-diffusion theory. The original program PHODIM used to have problems in stability and convergence. The problems can be removed if the electronic response of the photodiode is accounted for as described in Section 2.3. Finally, SCHOT, the modified version of PHODIM, is evaluated in terms of the physical meaning of the solution.

2.1 Schottky Barrier Formation

The barrier height of a metal-semiconductor junction is, in general, determined by the metal work function and the semiconductor surface states. The effects of these two quantities can be illustrated theoretically by considering two limiting cases. Figure 2(a) shows the case in the absence of surface states. At the beginning, the metal and the semiconductor are kept far away from each other and the system is not in thermal equilibrium. As the semiconductor is brought closer to the metal, an electric field builds up between the surfaces as electrons flow from the semiconductor to the metal to lower the Fermi level in the semiconductor. Equilibrium is reached when the Fermi levels on both sides are lined up. Since there are no surface states in this case, the electrons that flow to the metal must come from the ionization of impurity atoms. Because of the relatively low doping concentration, the flowing of electrons into the metal causes the energy levels in the semiconductor to bend upwards and a depletion region region is resulted. In the limit, δ is decreased

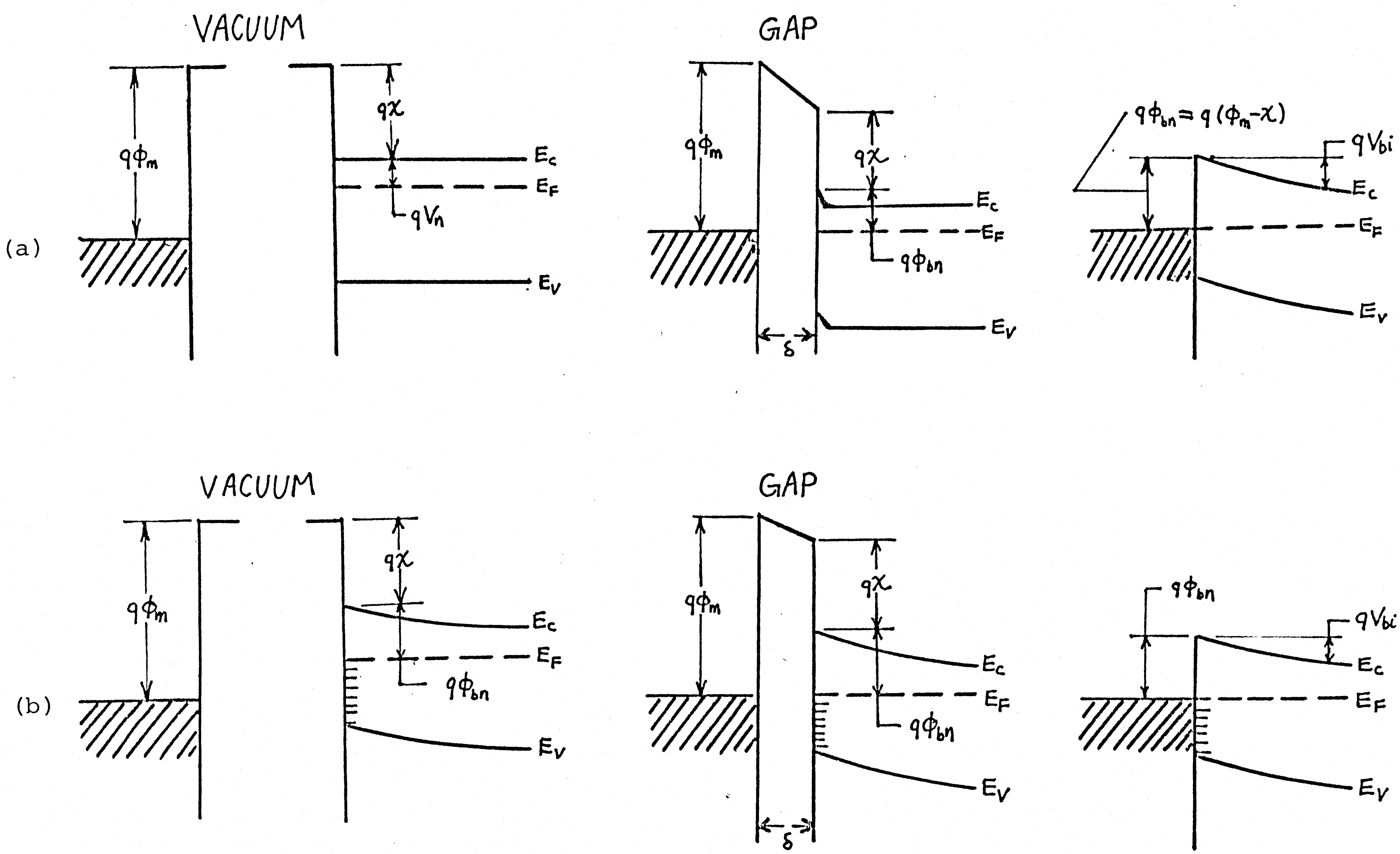


FIGURE 2

Schottky Barrier Formation

to atomic distance and the gap becomes transparent to electrons. The barrier height ϕ_{bn} is then given by the difference between the metal work function and the electron affinity of the semiconductor.

Figure 2(b) shows the case where a large density of surface states is present on the semiconductor surface. When the metal and the semiconductor are separated, the surface states are assumed to be occupied to the Fermi level E_F. Once again, when the surfaces are brought close to each other and the system is in equilibrium, an electric field is produced in the gap. However, now the density of the surface states is sufficiently large to supply the electrons flowing into the metal without altering the Fermi level significantly. The Fermi level is said to be 'pinned' and the barrier height in the limiting case ($\delta \to 0$) is determined by the properties of the semiconductor alone.

An interfacial layer of permittivity ε_i is usually introduced in the derivation of an expression for the barrier height. It is assumed that the layer is of atomic dimensions and that it is transparent to electrons and can with stand electric potential across it. Figure 3 illustrates the situation for n-type semiconductor. As mentioned before, electrons will flow form the semiconductor to occupy the surface states in the interfacial layer adjacent to the metal surface. At equilibrium, the density of the negative charge accumulated on the metal surface must be equal to the atomic density of the metal, n_A. The boundary condition at x = 0 can be defined as follows:

$$n(0) = n_A \qquad (2.1.1)$$

Also, the quasi-Fermi potentials for electrons and holes are assumed to be equal to that of the metal at x = 0.

$$E_F(0,t) = \phi_n(0,t) = \phi_p(0,t) = V_e(t) \qquad (2.1.2)$$

The quasi-Fermi potential relationships are:

$$n = \exp(\psi - \phi_n) \qquad (2.1.3)$$

$$p = \exp(\phi_p - \psi) \qquad (2.1.4)$$

Combining the above three equations gives

$$p(0) = 1/n(0) \qquad (2.1.5)$$

The electric potential at x = 0 is then written as

$$\psi(0,t) = \ln(n_A) + V_e(t) \qquad (2.1.6)$$

Since the interfacial layer has a permittivity that is different from that of the semiconductor, the quantities in the above equations should be normalized by a different factor. This means that the energy levels would be, in general, discontinuous at the interface (i.e. similar to the case of a heterojunction). For the purpose of numerical analysis, the photodiode is divided into a number of mesh points along its length. In the case of a homojunction (e.g. PiN), the same set of normalization factors is used for the entire mesh region. For a heterojunction, two mesh regions of different normalization factors would be required. In the present study, another approach

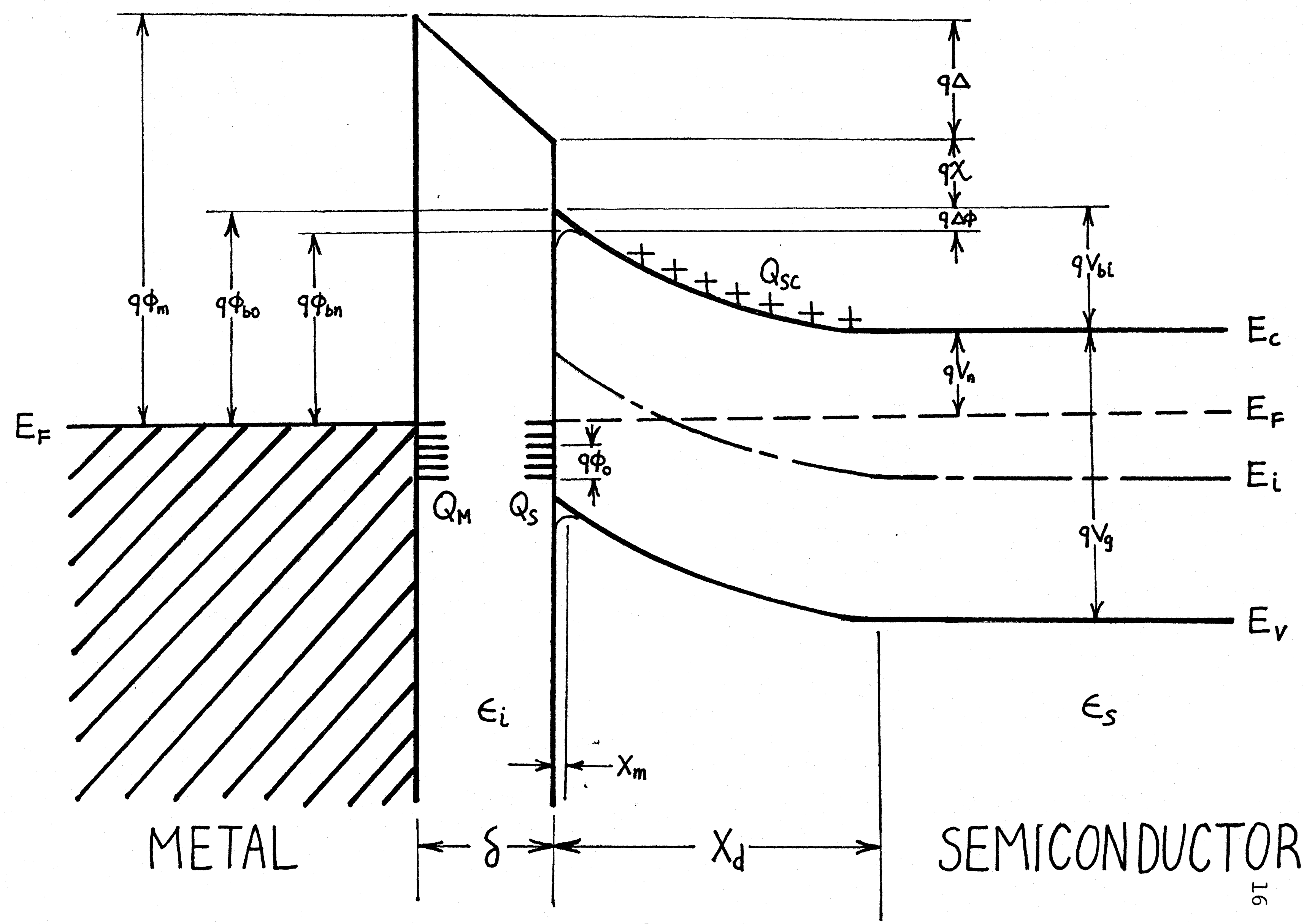


FIGURE 3

Notations used for Schottky Barrier Theories is employed. Since the interfacial layer is a theoretical one and the value of ε_i is an unknown anyway, it was assumed that $\varepsilon_i = \varepsilon_s$ in the calculations and a correction factor $\Delta\psi$ is introduced.

$$\psi(0,t) = \ln(n_A) + \Delta\psi + V_e(t) \qquad (2.1.7)$$

It should be noted that the quantities in eq.(2.1.7) are normalized with the same factors as for the semiconductor region (and are different from those for eq.(2.1.6)). This approach simplifies the case by defining a continuous energy band at the interface. The high concentration of negative charge accumulated on the surface causes an electric potential barrier for the holes to form near the interface. $\Delta\psi$ is adjusted in such a way that $\psi(x)$ is in accordance with that predicted by the thermionic-diffusion theory. Further discussion on the theory will be given in the next section.

Boundary conditions at $x = x_L$ are set up by assuming an ohmic contact as

$$n(L) \cdot p(L) = 1 \qquad (2.1.8)$$

and

$$E_F(L,t) = \phi_n(L,t) = \phi_p(L,t) = V_c(t) \quad . \tag{2.1.9}$$

In addition, charge neutrality requires that

$$n - p - N_D = 0 \quad . \tag{2.1.10}$$

Substituting eq.(2.1.3) and eq.(2.1.4) into the above equation and solving, we get

$$\psi(L,t) = V_c(t) + \ln\left\{\left[\left(\frac{N_D}{2}\right)^2 + 1\right]^{\frac{1}{2}} + \frac{N_D}{2}\right\} . \tag{2.1.11}$$

The boundary values for n, p and ψ are now completely defined and a particular solution to the set of fundamental equations can be obtained.

2.2 Thermionic-Diffusion Theory

In the present model, it is assumed that the thermionic-diffusion theory will apply so that the electric potential can be expressed as

$$\frac{E_c(x)}{q} = \phi_{bn} + \Delta\phi - V(x) - \frac{q}{16\pi\varepsilon_s x} \tag{2.2.1}$$

where
$$\begin{cases} \phi_{bn} = \text{barrier height} \\ \Delta\phi = \text{barrier lowering due to image force} \\ V(x) = \text{barrier lowering due to applied field} \\ \dfrac{q}{16\pi\varepsilon_s x} = \text{image force potential .} \end{cases}$$

Assuming that the voltage drops across the depletion layer only and the electric field varies linearly within this region, we get

$$E(x) = \begin{cases} \dfrac{qN_D}{\varepsilon_s}(x_d - x) = E_m - \dfrac{qN_D}{\varepsilon_s}x & ; \quad 0 \leqslant x \leqslant x_d \\ 0 & ; \quad x_d \leqslant x \leqslant x_L \end{cases} \qquad (2.2.2)$$

where $E_m = \dfrac{qN_D x_d}{\varepsilon_s}$.

The potential variation due to the applied field can then be derived as

$$V(x) = \int_0^x E(x)\,\partial x$$

$$= \begin{cases} E_m x - \dfrac{qN_D}{2\varepsilon_s}x^2 & ; \quad 0 \leqslant x \leqslant x_d \\ \dfrac{E_m x_d}{2} & ; \quad x_d \leqslant x \leqslant x_L . \end{cases} \qquad (2.2.3)$$

The width of the depletion region can be obtained by employing the one-sided abrupt junction approximation as

$$x_d = \left[\frac{2\varepsilon_s}{qN_D}\left(V_{bi} - V - \frac{kT}{q}\right)\right]^{\frac{1}{2}} \tag{2.2.4}$$

where $V_{bi} = \phi_{bn} - V_n$

and $$V_n = \frac{E_g}{2} - \ln\left\{\left[\left(\frac{N_D}{2}\right)^2 + 1\right]^{\frac{1}{2}} + \frac{N_D}{2}\right\}.$$

x_m, which is defined as the location of the maximum potential, is given by setting $\frac{\partial E_c}{\partial x} = 0$ and using the fact that $E \cong E_m$.

$$x_m = \left[\frac{q}{16\pi\varepsilon_s E_m}\right]^{\frac{1}{2}} \tag{2.2.5}$$

The barrier lowering is then given by

$$\Delta\phi = \left[\frac{q\, E_m}{4\pi\varepsilon_s}\right]^{\frac{1}{2}} = 2E_m x_m\ . \tag{2.2.6}$$

Since ϕ_n is an unknown and is required for the evaluation of x_d, x_m and $\Delta\phi$, an iterative scheme has to be set up to solve for the parameters. This can be achieved (refer to Figure 3) with two additional relations.

$$\phi_{bn} = \phi_{b0} - \Delta\phi \tag{2.2.7}$$

$$\phi_{b0} = \phi_m - \chi - \Delta \tag{2.2.8}$$

The iterating routine starts with an initial guess of $\phi_{bn} = \phi_{bo}$ and stops when the change in ϕ_{bn} between successive iterations is small (smaller than, say, one percent). A flow diagram of the procedure is given in Figure 4.

Once $\frac{E_c(x)}{q}$ is determined, $\psi(x)$ can be evaluated according to

$$\psi(x) = \frac{E_g}{2q} - \frac{E_c(x)}{q} . \qquad (2.2.9)$$

The initial estimates for n and p are given by

$$n(x) = N_D \qquad (2.2.10)$$

$$p(x) = \frac{1}{n(x)} . \qquad (2.2.11)$$

Since $\psi(x)$ is a pre-defined function, an initial estimate to the variable is not required. Instead, one has to provide a suitable value for $\Delta\psi$ which is a part of the boundary conditions. This has already been discussed in detail in the previous section.

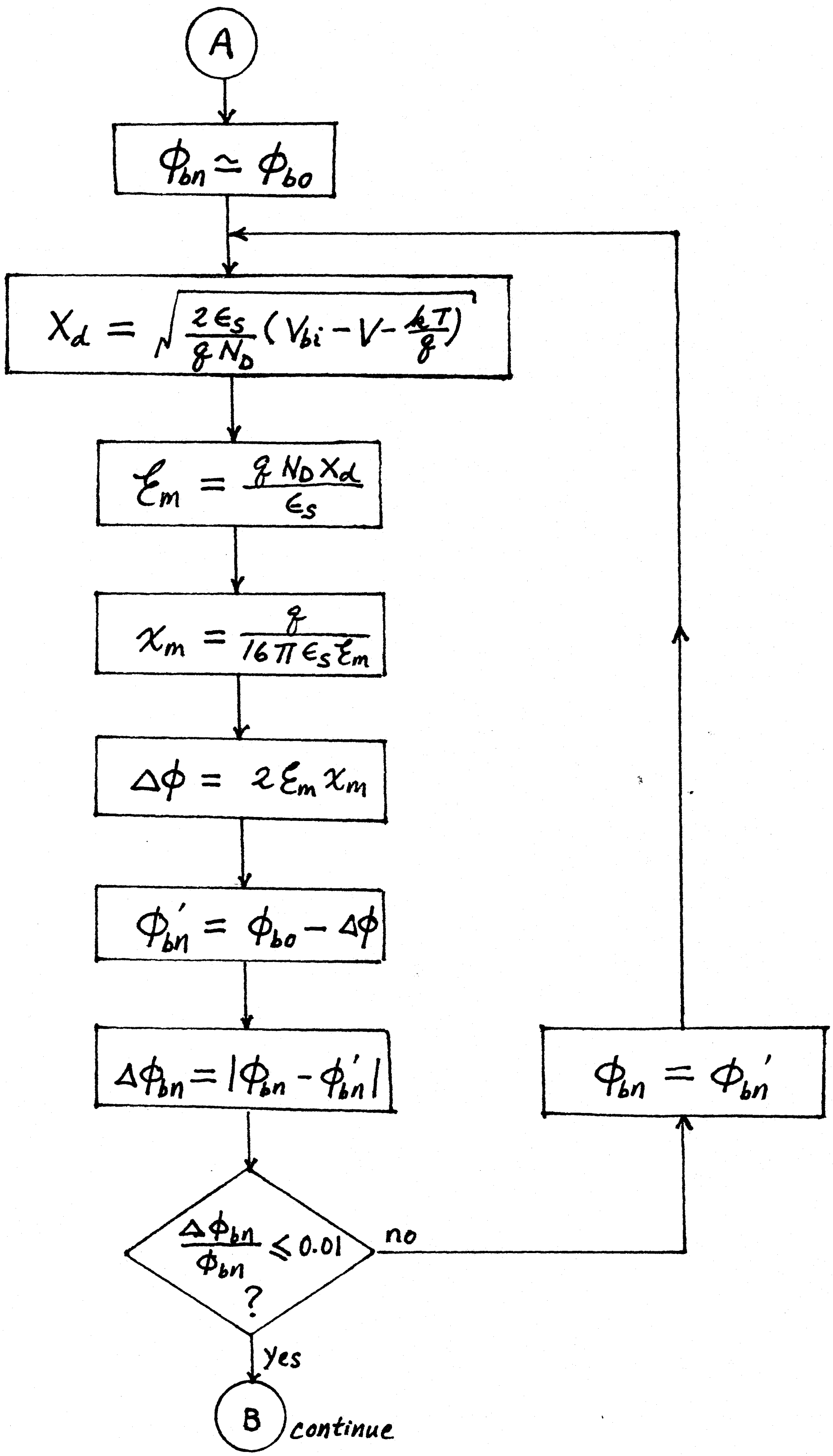


FIGURE 4

Flow Diagram for Evaluation of ϕ_{bn}

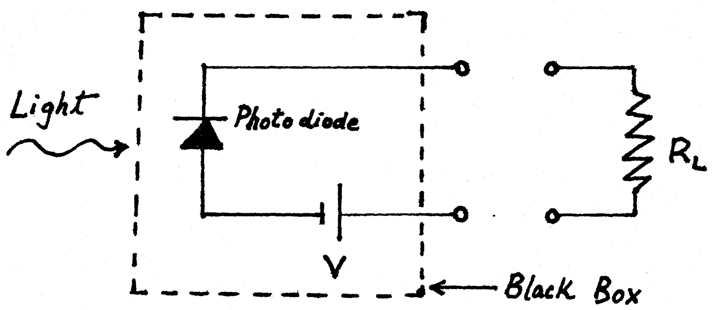
2.3 Electronic Response Time

In PHODIM, the boundary values for ψ are time dependent. The bias voltage for each time step is calculated by taking into account the voltage drop across the load resistor in the previous time step. The approach has been shown to cause both convergence and stability problems near the end points of the diode and at the barrier for the Schottky barrier case. A different method is therefore employed here to determine the electronic response of the circuit.

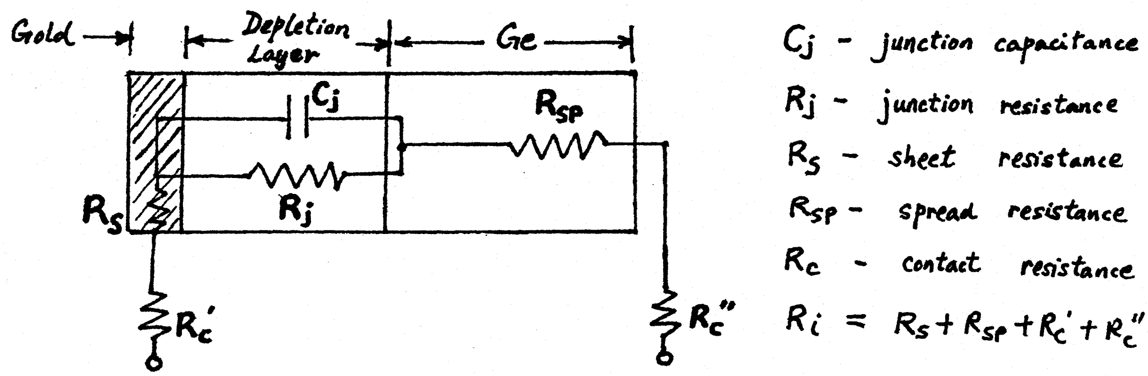
An equivalent circuit of the photodiode is set up. This is shown in Figure 5(c). For $R_j >> (R_L + R_i)$ and $R_L >> R_i$, which are uaually the cases, the circuit can be further simplified to that in Figure 5(d). The simplified circuit is easily identified to be a RC circuit and Kirchhoff's law gives

$$\frac{\partial i}{\partial t} = \frac{1}{RC}(I_{gen} - i) \qquad (2.3.1)$$

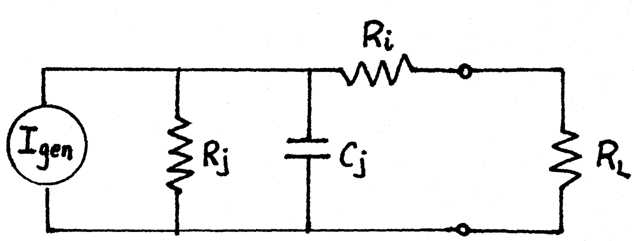
The short-circuited current output of the diode (I_{gen}) can be calculated with SCHOT (or PHODIM) by setting



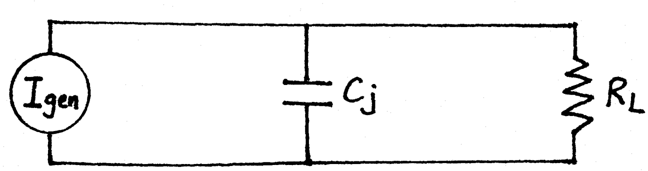
(a) Basic photodetector system



(b) Equivalent circuit for photodiode



(c) Equivalent circuit for photodetector system



(d) Simplified equivalent circuit

FIGURE 5

Equivalent Circuit for the Photodetector

$R_L = 0$. Once $I_{gen}(t)$ is obtained, the actual current output can be determined by solving eq.(2.3.1). A computer program JPLOT employing the Runge-Kutta method of order two is used to obtain numerical solutions to the first order differential equation. The modified version of PHODIM, SCHOT, provides a punched deck of the results of the transient analysis which can then be used as the input to JPLOT for determining the RC response of the circuit.

2.4 Computer Model SCHOT

SCHOT was written according to the theories outlined in the previous sections. An user's guide to the operation of the computer preogam is given in Appendix E and a full listing of the program is given in Appendix G.

Convergence is usually not a problem for the case of PiN diodes but this is no longer true for the Schottky barrier diodes. Since both n and p change significantly and $\frac{\partial \psi}{\partial x}$ reverses in sign within 0.01 μm near the metal-semiconductor interface, it is important that a very fine mesh $((x_{i+1} - x_i) \sim x_m)$

is chosen for this region. In addition, the user should minimize the number of points in the charge neutrality region (by defining $x_L \gtrsim x_d$). The reason is that the change in ψ between successive iterations is much smaller than that in the depletion region and hence the acceleration parameter for convergence would impose too large a correction for ψ in the neutral region. A slow convergence rate therefore results. When the mesh points are properly chosen, solution to each time step should be obtainable for less 100 iterations.

The steady state solution for n, p and ψ is shown in Figure 6. It can be seen that by choosing appropriate boundary conditions, a potential barrier and a depletion region are created in the semiconductor. In addition, the existence of an inversion layer (i.e. a p-region) near the metal-semiconductor interface is also predicted. A sudden jump in the potential function is usually found near $x = x_m$. This is believed to be caused by a numerical instability in that region.

The steady state solution also indicates

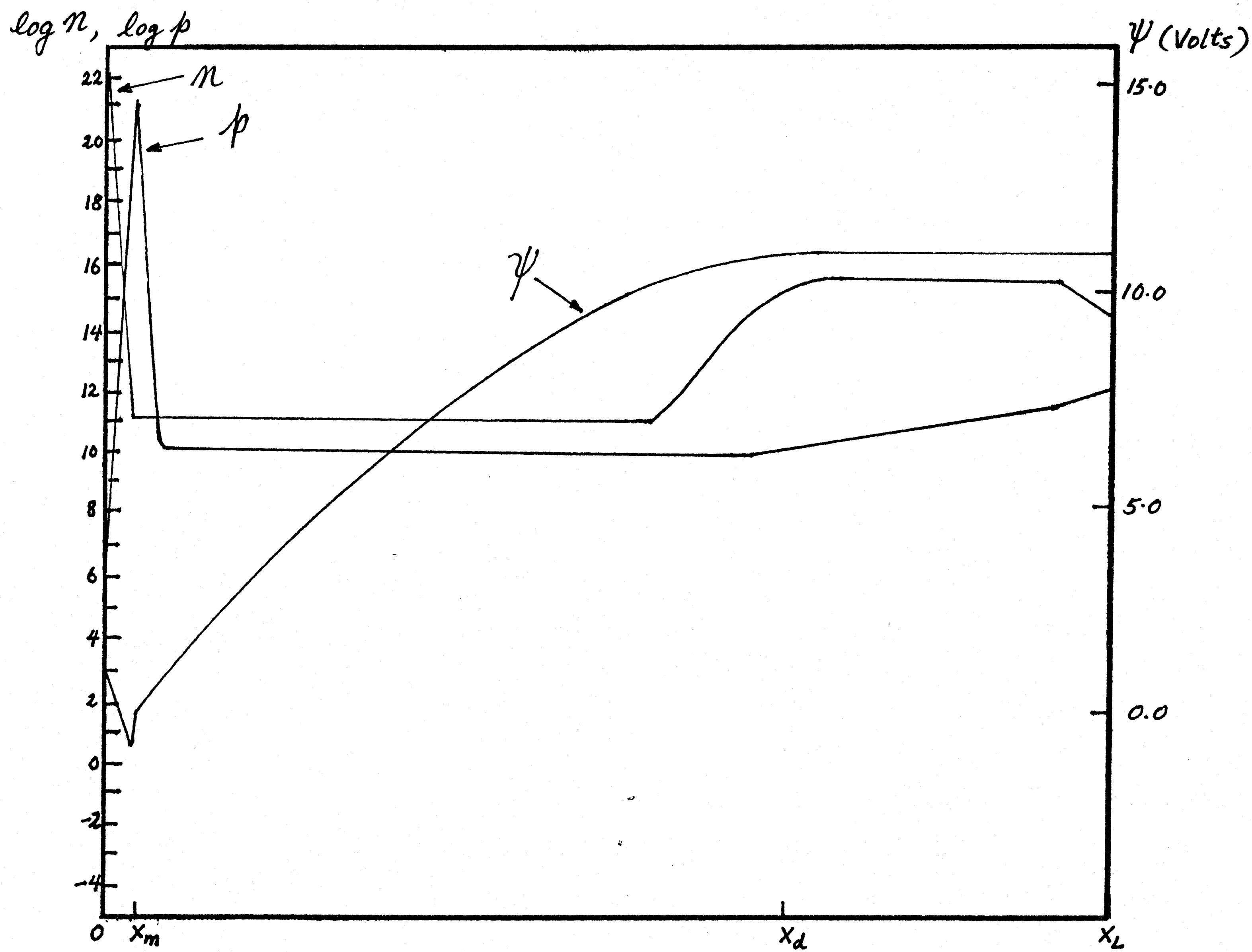


FIGURE 6 Steady State Solution for n, p and ψ

that the majority carriers (electrons in this case) are responsible for the current flow ($J_n >> J_p$). This is in agreement with accepted theories. However, the magnitude of the total current predicted by the model is smaller than that by the thermionic-diffusion theory. This is so because electrons are injected from the metal with a different velocity than that used in the present Shockley-Read model. Hence a thermionic recombination velocity should be defined at the interface for exact modeling of the steady case. However, since it is the photo-response of the diode that is of major interest, the fact that $\psi(x)$ agrees with the thermionic-diffusion theory insures that the transient analysis would not be affected.

Figure 7 shows the general profile of the photo-generated carrier currents. It can be seen that the hole current (J_p) is blocked by the barrier at $x = x_m$ and drops rapidly to close to zero at $x = 0$. It is also noticed that the electron current (J_n) reverses in direction (changes in sign) near the interface. The reversal is caused by the emission

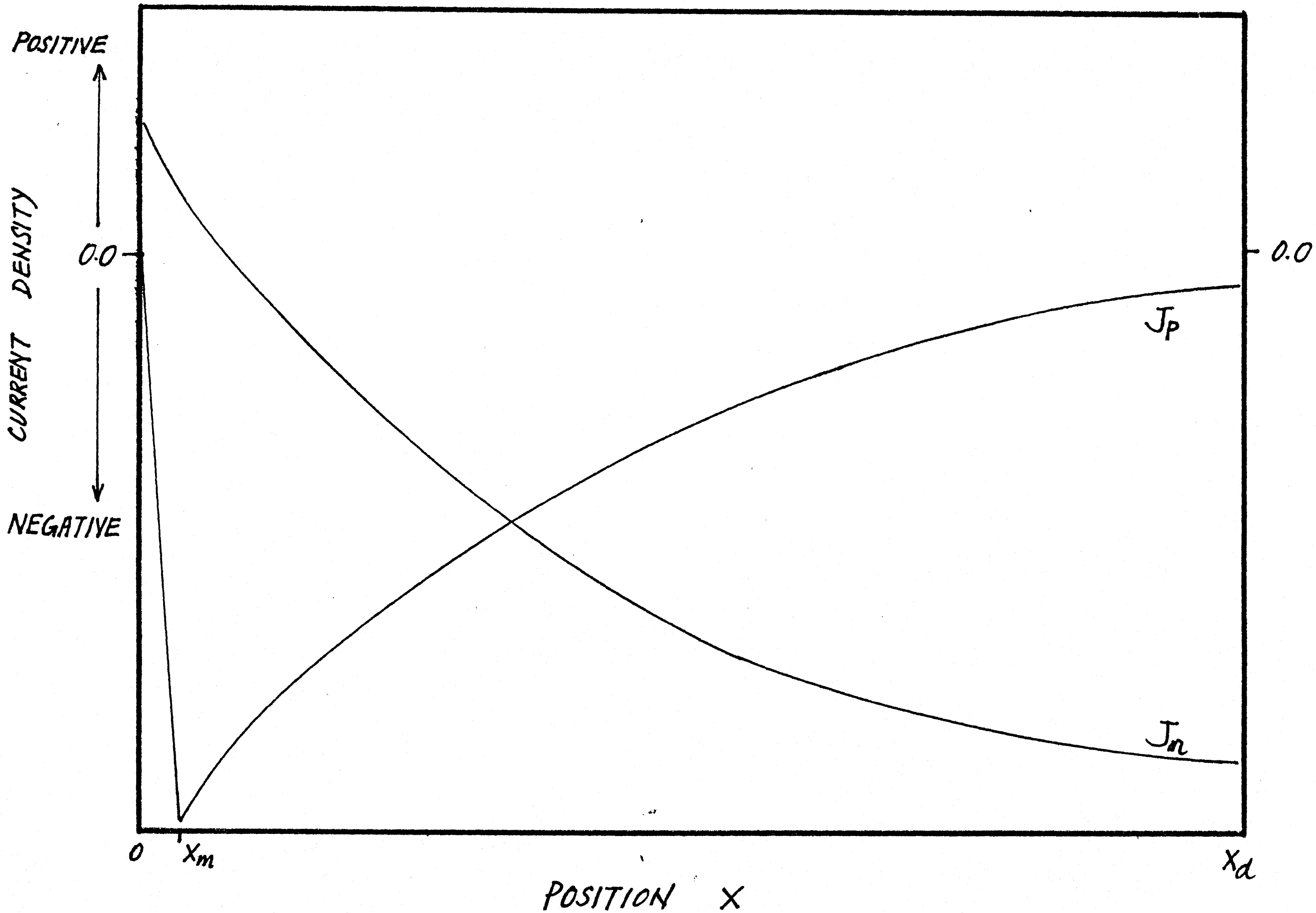


FIGURE 7 Photo-generated Carrier Currents in the Depletion Region

current towards the metal. The same effect has also been predicted by a theoretical analysis based on a different approach carried out by M. Lavagna et al.[4] Lavagna also suggested that quantum efficiency of the diode would decrease for an increasing absorption coefficient because of this effect. However, no attempt has been made to study this aspect with the present model.

CHAPTER 3

DESIGN OF SCHOTTKY BARRIER PHOTODIODES

The computer model SCHOT described earlier provides a very detailed analysis of the photodiode device. However, the program is very expensive to run. For this reason, a much simpler model is employed here for the design process. Once the region of interest is defined, the program SCHOT can be used to carry out further analysis. The theory of the simplified model and the method of analysis are presented in this chapter. The optimum design parameters are given in Section 3.3 and detailed analysis of the design is discussed in the last section.

3.1 Theory

A simple model based on the abrupt junction approximation is used to determine the step response of Schottky barrier photodiodes. The derivation of the model is summarized as follows:

The depletion layer width of the photodiode is given by

$$x_d = \left[\frac{2\varepsilon_s}{qN_D}(V_{bi} - V)\right]^{1/2} \tag{3.1.1}$$

where

$$V_{bi} = \phi_{bn} - V_n \cong \phi_{b0} - V_n \tag{3.1.2}$$

$$V_n = \frac{1}{q}(E_c - E_F) \tag{3.1.3}$$

The maximum electric field occurs near the metal-semiconductor junction and is given by

$$E_m = \frac{qN_D}{\varepsilon_s} x_d \tag{3.1.4}$$

Now, assuming that the electrons generated by the input light traverse the depletion region with saturation velocity, one can calculate the transit time required as follows.

$$\tau_t = 0.79 \frac{x_d}{v_{sat}} \tag{3.1.5}$$

Another factor that affects the response of the photodiode is the electrical characteristics of the circuit. In general, the device can be represented by a simple RC circuit (refer to Figure 5). The RC response time of the circuit can then be given by

$$\tau_{RC} = 2.2\ R_L C_j \qquad (3.1.6)$$

The constants 0.79 and 2.2 in equations (3.1.5) and (3.1.6) come from the fact that the 10-90% risetime is being considered. The junction capacitance is defined as

$$C_j = \frac{\varepsilon_s A}{x_d} \qquad (3.1.7)$$

where A is the cross-sectional area of the diode.

The risetime of the diode can then be calculated by adding τ_t and τ_{RC} orthogonally:

$$\tau = (\tau_t^{\,2} + \tau_{RC}^{\,2})^{1/2} \qquad (3.1.8)$$

Finally, the quantum efficiency of the diode can be obtained from the following equation.

$$\eta = 1 - \exp(\frac{x_d}{\alpha}) \qquad (3.1.9)$$

where α is the absorption length of the semiconductor material for a particular wavelength.

The approximations and assumptions used in the model are described as below:

(i) In order for the above theory to apply, the following condition must hold true:

$$V_{valid} < V < V_{br}$$

where V_{valid} is the voltage at which $E_m = 10\ E_{sat}$

E_{sat} is the saturation field

and V_{br} is the breakdown voltage and is given by

$$V_{br} \cong 60\ (\frac{E_g}{1.1})^{3/2}\ (\frac{N_D}{10^{16}\ cm^{-3}})^{-3/4}\ \text{volts} \qquad (3.1.10)$$

(ii) Semiconductor is non-degenerate.

(iii) By taking the approximation made in eq. (3.1.2), the effect of image force is being neglected. If this effect were to be included, an iterative scheme would have to be set up to calculate for the barrier lowering (refer to Section 2.2). However, since the lowering is only a very small value, the inclusion of the image force seems to be unnecessary.

3.2 Analysis and Results

From the above equations, one can see that the risetime of the photodiode depends on four parameters, namely, doping density(N_D), applied voltage(V), load resistance(R_L), and area of the diode(A). A computer program based on the above theory was written and was used to compute the risetimes of the photodiode for different values of the parameters. The range of analysis is defined as follows:

$A = 0.5\text{x}10^{-3}$, $0.5\text{x}10^{-4}$, $0.5\text{x}10^{-5}$ cm^2

R_L= 10, 30, 50 ohms

N_D= $0.1\text{x}10^{16}$ to $1.0\text{x}10^{16}$ cm^{-3} at $0.1\text{x}10^{16}$ cm^{-3} intervals

V = 0 to 80 volts with 1 volt intervals

A set of graphs is then obtained by carrying out the above analysis. Each plot gives τ vs. V for the whole range of doping densities and for a fixed value of cross-sectional area and load resistance. In addition, four more curves are present in each plot and they are

(A) Breakdown limit: $V = V_{br}$.

(B) Saturation limit: $E_m = 10\ E_{sat}$

(C) 1/4 Breakdown voltage: $V = 1/4\ V_{br}$

(D) 2x Absorption length: $x_d = 2\alpha$.

Finally, another plot of τ vs. η is given to provide information about the amount of quantum efficiency that one must give up in order to gain better response. This single plot contains all of the data points within the range of analysis as defined before.

3.3 Optimum Design

The objective is to design a photodetector with a minimum risetime less than 50 psecs. The materials to be used are gold and germanium. All values used for calculations are therefore based on

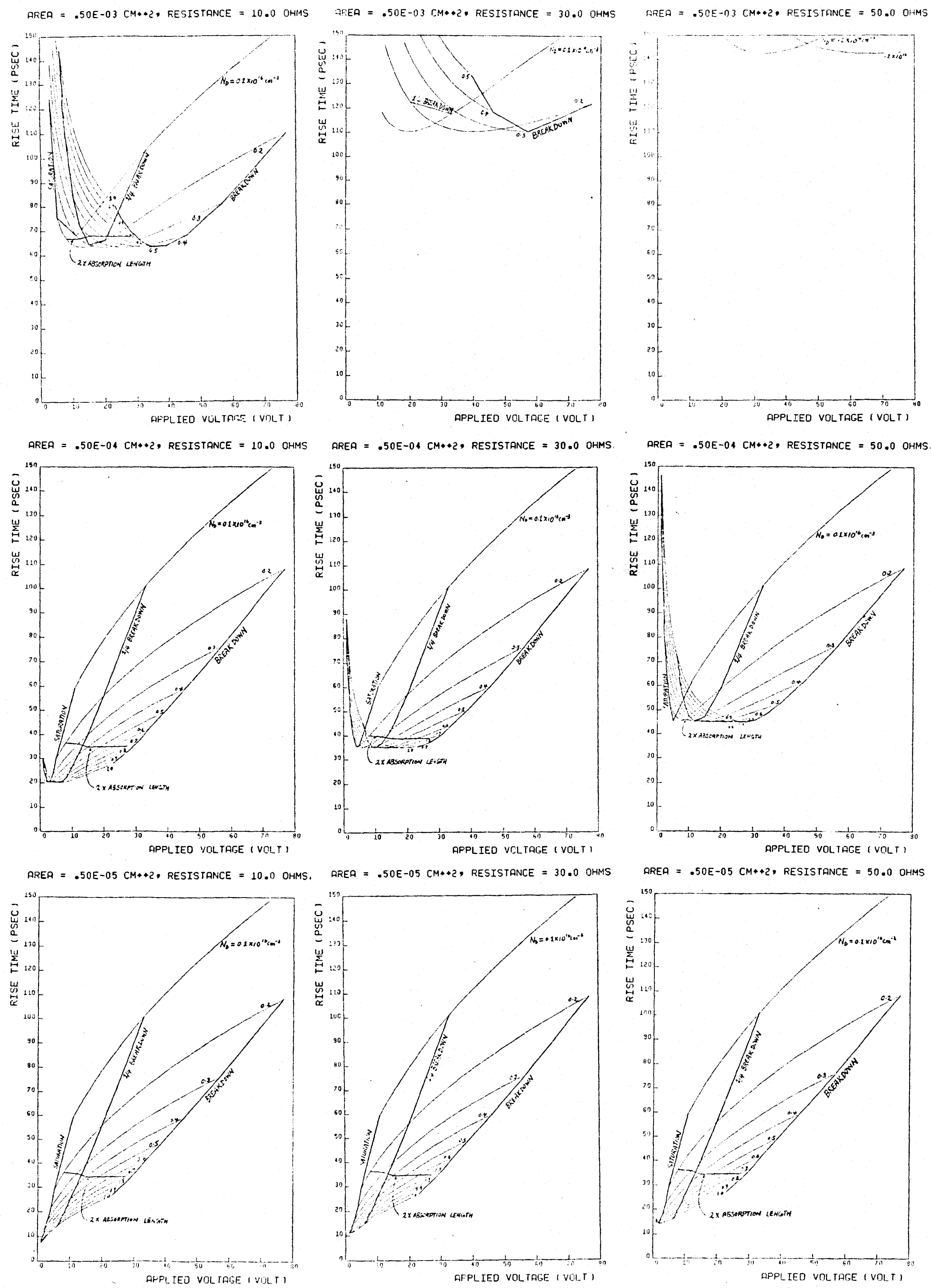


FIGURE 8

Photodetector Risetime as a Function of V, N_D, R_L and Area

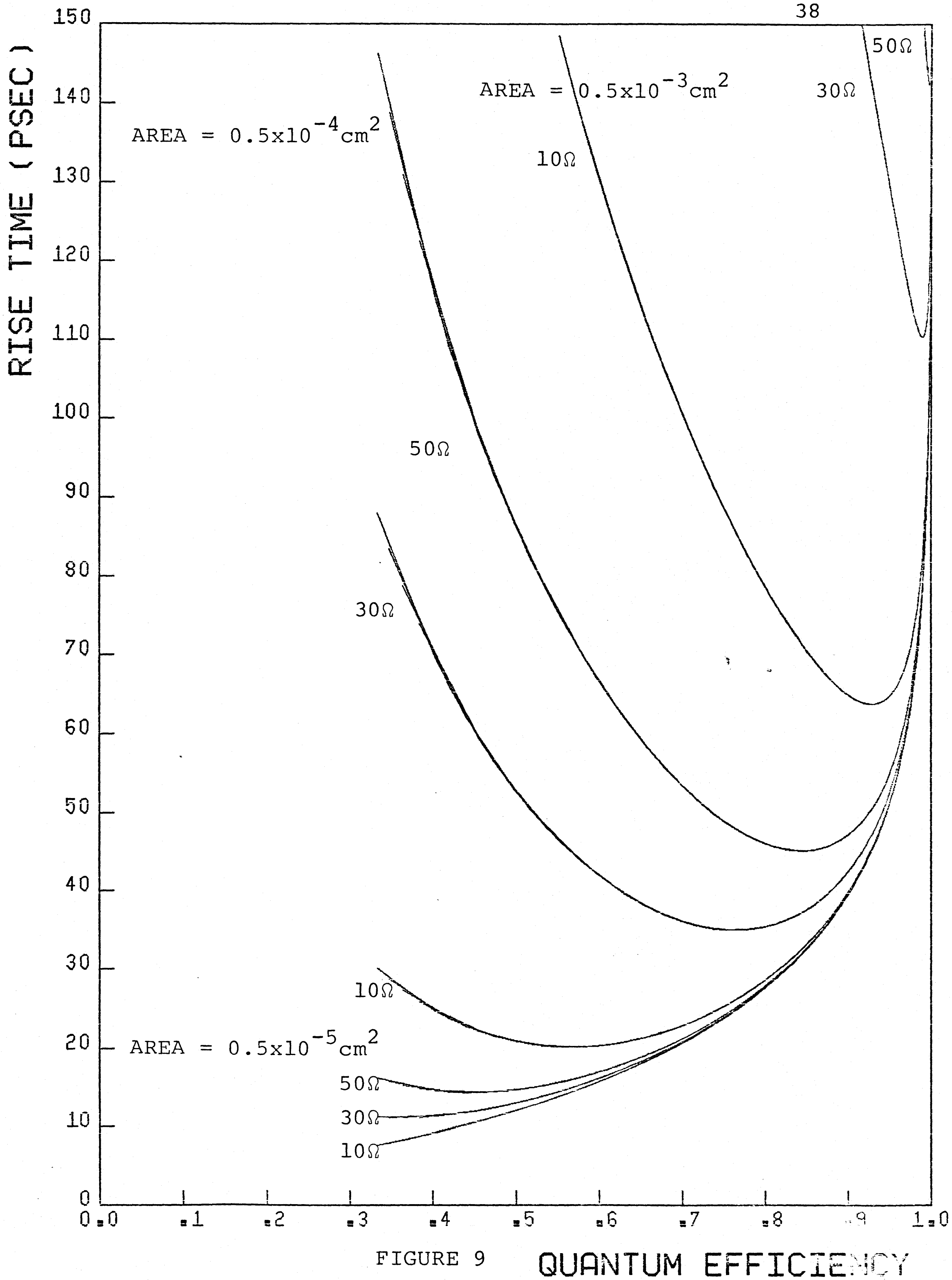


FIGURE 9

Quantum Efficiency of Photodetector versus risetime material properties of these two elements.

From equation (3.1.5), it can be seen that the transit time can be reduced by choosing a smaller depletion width. However, the capacitance is inversely proportional to x_d and hence a certain optimum value for x_d must exist. In addition,the RC response of the device depends also on the area of the diode and the value of the load resistance. Decreasing A and/or R_L would therefore produce better response characteristics. It can be seen from Figure 8 that a risetime of 7 pecs can be achieved for a photodiode with $A = 0.5x10^{-5}$ cm^2, R_L = 10 ohms and N_D = $1.0x10^{16}$ cm^{-3}. However, these numbers are not very practical ones since several other factors must be taken into consideration in the design of photodiodes. These factors are to be described as follows.

(1) Breakdown and saturation limits:

It is important that the operating voltage of the diode is far enough away from both V_{valid} and V_{br} so that small variation of applying field will not cause maximum electric field to fall below saturation value nor to drive the device into breakdown. Hence one would like to choose a doping density for which (V_{br} - V_{valid}) is large enough and that the operating point (minimum risetime) is far away from both limits.

(2) Power matching:

In order to deliver maximum power to the external circuitry, the value of the load resistor must not be too small. A value of about 50 ohms is most typical.

(3) Intensity problem:

In order for the device to operate under low light intensity condition, the cross-sectional area of the diode must be large enough. Otherwise, a lens must be used to focus the beam down to a spot of size comparable to that of the diode. If the area of the diode were made too small, then the focusing of light may become a problem. Furthermore, direct compatibility with optical fibres requires an area of approximately 0.8×10^{-4} cm^2 (i.e. a circular spot of 100 μm in diameter).

(4) Quantum efficiency:

Quantum efficiency can be improved significantly by increasing x_d until up to a certain point (about twice the absorption length). The price that one must pay for this improvement in sensitivity is, of course, the increase of the risetime. Figure 9 is provided especially for the observation of this effect. Notice that each 'single' curve that appears in the plot is actually an overlap of curves with different values of N_D ranging from 0.1×10^{16} to 1.0×10^{16} cm^{-3}.

By making use of Figures 8 and 9, and by taking all of the above factors into account, it is concluded that the following set of values seems to be able to provide an optimum operating condition (see also Figure 10):

$A = 0.5 \times 10^{-4}$ cm^2

$R_L = 50$ ohms

$N_D = 0.3 \times 10^{16}$ cm^{-3}

$V = 10$ volts

Finally, if one demands a risetime better

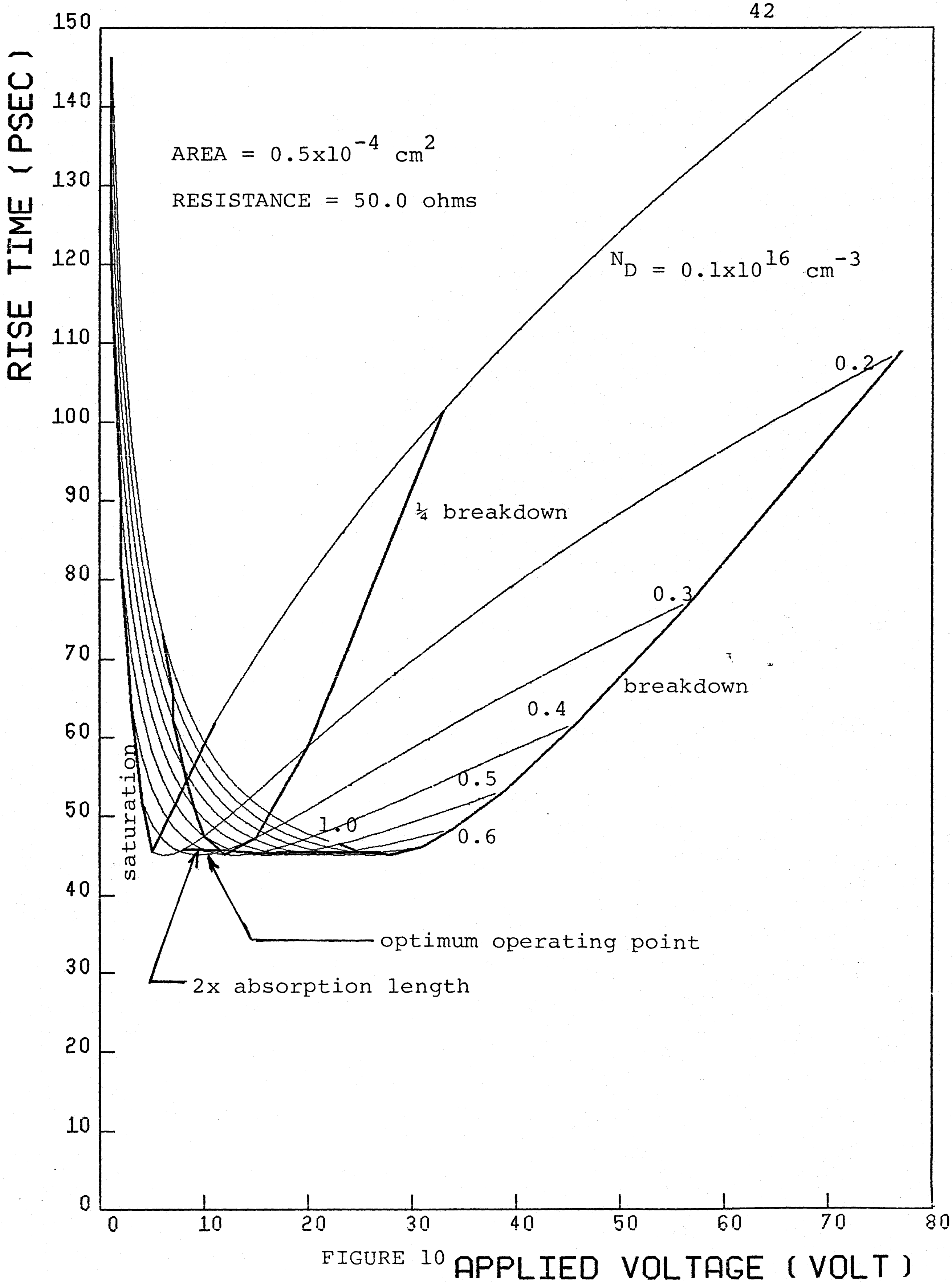


FIGURE 10

Optimum Design Parameters

than 45 psecs, one can achieve this goal only by giving up some of the other desirable features as discussed before. For applications where light intensity is high, further reduction of the risetime may be possible. A compromise must then be made with all factors being specified according to the needs of a particular application.

3.4 Detailed Analysis of Optimum Design

The set of parameters obtained with the simplified model for the optimum design is used as the input to SCHOT for a more detailed analysis. The theoretical light input is assumed to be a step function (increases from zero to peak power in less than 0.5 psec). The wavelength of the light input is chosen to be 1.3 μm because both signal attenuation and chromatic dispersion through a high quality fiber made of silica are minimum in this wavelength region. Smaller bandgap materials are required for operation at this wavelength and hence germanium is selected for this purpose. The constants listed in Appendix B for germanium are used for analysis. Finally, variable time steps are employed because of the rapid change in light power within the first 0.5 psec of the transient analysis.

With the above input values, SCHOT was run to iterate ψ down to a tolerance of 2.0×10^{-8} volt. JPLOT was then used to determine the RC response and to obtain a plot of the current output. Figure 11 shows the current as a function of time together with the theoretical light input profile (both are in normalized units). It can be seen that the 10-90% risetime of the output current is about 44 psec. The depletion width of the diode is 2.45 μm. Both of these values are very close to those obtained with the simplified model. Hence one can conclude that the simple model is indeed a fairly accurate one and that the results of the design analysis are therefore quite dependable.

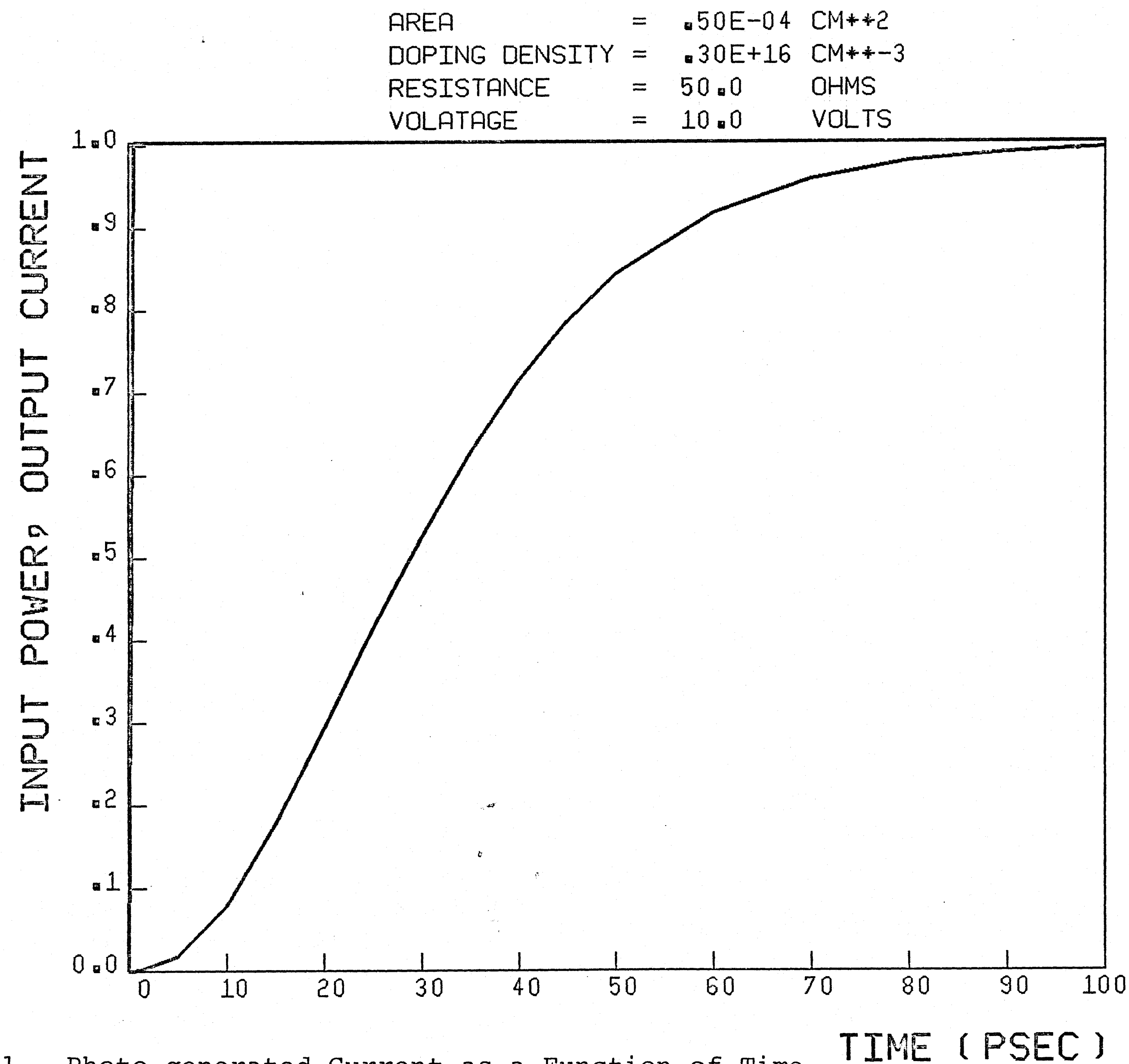


FIGURE 11 Photo-generated Current as a Function of Time

CHAPTER 4

CONCLUSIONS

The computer model PHODIM for the analysis of PiN photodiodes and the physics behind it are described at the beginning of this paper. In order to modify the program to handle Schottky barrier diodes, a different set of boundary conditions is required. In the present model, it is assumed that an interfacial layer exists between the metal and the semiconductor. The Fermi-level difference across the layer causes electrons to flow from the semiconductor into the metal resulting in the formation of a depletion layer. The boundary value for n is assumed to be equal to the atomic density of the metal. p(0) is then defined as the reciprocal of n(0). It is also assumed that $\psi(x)$ is given by the thermionic-diffusion theory. $\psi(0)$ is defined in such a way that the above condition will be satisfied. In order to overcome the instability and convergence problem of PHODIM, another computer program JPLOT was written to determine the RC response of the device. By solving the first order differential equation of the equivalent circuit numerically, a plot of the output current as a function of time can be obtained. Since the modified program is expensive to run, a much simpler model is used to calculate for the design parameters. SCHOT is then employed for a detailed analysis of the set of optimum design parameters chosen.

No new experimental data is available at this moment for the testing of the model. However, the results obtained for the optimum design parameters appear to be quite reasonable as compared to previous experimental results given in Remple's paper. Both the detailed and the simplified model predict a 45 psec risetime for a diode with a depletion width of about 2.5 μm. Despite the problems with the steady state solution, the present model should be very useful in ultra-high speed photodiode design.

APPENDIX A
NORMALIZATION FACTORS FOR GERMANIUM

quantity	variable	normalized by	germanium	units
position coordinate	x	$L_D = \left(\frac{\varepsilon_0 V_t}{e\, n_t}\right)^{\frac{1}{2}}$	$9.70290\text{x}10^{-5}$	cm
time coordinate	t	$L_D{}^2/D_0$	$9.41463\text{x}10^{-9}$	s
electrostatic potential		$V_t = \frac{kT}{e}$	0.025875	V
quasi-Fermi levels	ϕ_n, ϕ_p	V_t	0.025875	V
applied voltages	V_e, V_c	V_t	0.025875	V
electric field	E	V_t/L_D	$2.66673\text{x}10^{2}$	V/cm
carrier densities	n, p	n_t	$2.4\text{x}10^{13}$	cm^{-3}
impurity densities	N, N_D, N_A	n_t	$2.4\text{x}10^{13}$	cm^{-3}
current densities	J, J_n, J_p	$-eD_0 n_t/L_D$	$-3.96253\text{x}10^{-2}$	A/cm^2
generation-recombination rate	U	$D_0 n_t/L_D 2$	$2.55070\text{x}10^{21}$	cm^{-3}/s
carrier-diffusion constants	D_n, D_p	$1/D_0$	1	s/cm^2
carrier mobilities ($\mu = 1/\gamma$)	$\gamma_n{}^{-1}, \gamma_p{}^{-1}$	D_0/V_t	38.6473	$cm^2/V.s$

APPENDIX B

MATERIAL PROPERTIES OF GERMANIUM

quantity	variable	value at 300 K
atomic density	n_A	$4.4\text{x}10^{23}$ cm^{-3}
relative permittivity	ε_r	15.8
electron affinity	χ	4.0 V
energy gap	E_g	0.66 eV
intrinsic concentration	n_i	$2.4\text{x}10^{23}$ cm^{-3}
lattice mobility	μ	μ_n-3900 cm^2/Vs
		μ_p-1900 cm^2/Vs
recombination lifetime	τ	τ_n-10^{-3} s
		τ_p-10^{-3} s
saturation velocity	v_{sat}	n-$0.6\text{x}10^7$ cm/s
		p-$0.1\text{x}10^8$ cm/s
saturation field	E_{sat}	$5.0\text{x}10^3$ V/cm
absorption length	α	1.3 µm for λ=1.3 µm
quantum efficiency	η	0.45 for λ=1.3 µm
	Θ	n - 0.5
		p - 0.0
	K_1	$4.38922\text{x}10^{21}$
	K_2	$2.52246\text{x}10^{21}$

APPENDIX C

TRANSCENDENTAL FUNCTION

$F_s(w)$ is a transcendental function that can be approximated as follows.

$w \leqslant 0.08$, $$F_s = 1 - 3.44w + 13.99w^2$$

$0.08 \leqslant w \leqslant 3.8$, $$F_s = \frac{14.16 + 45.22w + 31.06w^2}{15.72 + 76.34w + 36.00w^2}$$

$3.8 \leqslant w$, $$F_s = 1 - \frac{1.442}{w} + \frac{2.137}{w^2}$$

APPENDIX D

GENERATION TERM

The function that is used to model the photo-generation process is given by

$$G(x,t) = \frac{P\xi}{E_{ph}\alpha A} \exp(-\frac{x}{\alpha})\ t_{fact}$$

where P = maximum power of light input

ξ = efficiency of diode

E_{ph} = energy per photon

α = absorption length

A = area of diode

t_{fact} = time factor which is determined by the shape of the light pulse.

Three time functions for the light input are permitted by the program.

(1) Pulse:

$$t_{fact} = (\frac{t}{\tau})^2 \exp\left\{\frac{1}{2}(1 - \frac{t}{\tau})^2\right\}$$

(2) Step function:

$$t < 0, \qquad t_{fact} = 0$$

$$0 \leqslant t \leqslant \tau, \qquad t_{fact} = \frac{t}{\tau}$$

$$\tau < t, \qquad t_{fact} = 1$$

(3) Sinusoidal:

$$t_{fact} = \sin(\frac{\pi}{2\tau} t)$$

APPENDIX E

USER'S GUIDE TO SCHOT

The procedures for running the present program are quite similar to those for PHODIM. The variable directory at the beginning of the program has been updated to include variables used in the Schottky barrier case. Some of the variables are also defined along with their mathematical symbols in the Glossary of Symbols. The array TEST is consisted of switches which control program flow and provide different options. Several new switches have been introduced and they are described below.

TEST(19): Selects iteration limit-
The switch allows the user to define a limit to the number of iterations per time step.

TEST(20): Selects type of diodes-
Three choices are available, namely, PiN, P^+N and Schottky barrier diodes. The

switch determines the necessary parameters to be read into the computer, and provides appropriate initial estimates and boundary conditions.

TEST(22): Selects semiconductor material- Either germanium or silicon can be selected. The switch will decide the correct normalization factors to be used and define suitable values for the mobilities of the carriers.

TEST(23): Gives transient output on punched cards- When this switch is on, the output will include a deck of punched cards. Each card provides information (JTOT and POWER) of a mesh point for a certain time step. The point for which results are desired is specified by the input variable IXT.

TEST(24): Selects light intensity functions- Three different functions are possible They are pulse,step function and sinusoidal. Further details are given in Appendix D.

Other TEST options have already been described in Remple's paper. The input procedure is also very similar to that of PHODIM's. The only thing that needs to be noted is that the boundary value for $\psi(0,t)$ is set by defining PIMGS as

$$\text{PIMGS} = \psi(0,t) + \phi_{bn} \quad .$$

APPENDIX F

USER'S GUIDE TO JPLOT

The input deck for JPLOT is mainly comprised of the punched outputs from SCHOT. Several sets of data can be processed at the same time. The number of sets of data is indicated by the first card. For each set of data, two additional cards are required for providing information on the design parameters of the photodiode. Finally, the number of time steps (the number of cards obtained from SCHOT) is given by another card. The punched deck from SCHOT is then put behind the above cards. The input deck arrangement is summarized as follows.

Card #1 NSET - number of sets of data

Card #2 R, AREA, XDPLE - load resistance, area of diode and depletion width

Card #3 N_D, V, XL - doping density, applied voltage and length of diode

Card #4	N - number of time steps	
Card #5	IXT, TIME, JTOT, POWER	punched deck from SCHOT
Card #6	"	
.	"	
.	"	
.	"	
Card #5+N	"	

APPENDIX G

PROGRAM LISTING OF SCHOT

```
      PROGRAM SCHOT (INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,
     +   TAPE7=PUNCH)
C     MAIN PROGRAM
C
      COMMON DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST(30),IXT,
C
     +   ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +   VSATP,XL,XO,ACOLL,BCOLL,CCOLL,XCMAX,XCMIN,XEFLAT,XEGAUS,
     +    XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,EFMAX,XM,PBI,
     +    PVN,XIMG,VIFAC,NA,
C
     +   CVOLTS(20),DFSPL(4),DFSPH(4),DX(201),EVOLTS(20),HN(201),
     +   HP(201),HPSI(201),INPROF(201),INPROFG(201),INX(201),
     +   JN(201),JNK(201),JP(201),JPK(201),MI1(201),MI2(201),
     +   MI3(201),MN(201),MP(201),PROF(201),PROFG(201),SP(4),
     +   SSTIME(20),TATIME(100),TVTIME(20),U(201),UK(201),X(201),
     +    PAV(201),PIMG(201),
C
     +   N(201),NK(201),P(201),PK(201),PSI(201),PSIK(201),PSIOLD(201)
C
C
      INTEGER DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST,IXT
C
C     ****************************************************************
C     ****************************************************************
C     *************** INDEX FOR INTEGER VARIABLES *********************
C     ****************************************************************
C     ****************************************************************
C
C     DIVSUM - IN REMESH, SUM OF (ANY STEP .GT. MAX ALLOWED/ORIGINAL STEP SIZE).
C     INDEX - USED IN REMESH.
C     INPLUS - POINT AT WHICH WE CONSIDER REGION TO BE N+.
C     INXJCN - JUNCTION POINT FOR INPUT PROFILE.
C     IPPLUS - POINT AT WHICH WE CONSIDER REGION TO BE P+.
C     JCN - POINT WHERE THE DOPING CHANGES SIGN (IE. THE JUNCTION).
C     IWS1 - COUNTS THE NUMBER OF ITERATIONS NEEDED FOR SOLUTION TO CONVERGE.
C     IWS2 - USED IN SYSTEMS. THE POINT WHICH HAD LARGEST CORRECTION TO PSI.
C     IWS3,IWS4 - INTEGER WORKING STORAGE.
C     IXT - PUNCHED TRASIENT OUTPUT FOR THIS POINT NO..
C     LOC - INDEX OF MESH POINT NOW BEING ASSIGNED A POSITION X IN REMESH.
C     MESHIN - NUMBER OF MESH POINTS USED TO INPUT PROFILE.
C     NMESH - NUMBER OF SPATIAL MESH POINTS MINUS ONE.
C     NMESHP1 - NMESH PLUS ONE.
C     NSS - NUMBER OF TIMES AT WHICH A STEADY STATE ANALYSIS IS DESIRED.
C     NTA - NUMBER OF TRANSIENT ANALYSIS TIMES.
C     NTV - NUMBER OF TRANSIENT VOLTAGES.
C     SSINDEX - STEADY STATE INDEX, INDICATING WHICH MONITOR POINT IS NEXT.
C     TAINDEX - INDEX SPECIFYING WHICH TATIME IS BEING ANALYZED.
C     TVINDEX - INDEX SPECIFYING WHICH TVTIME WILL OCCUR NEXT.
C     TEST(30) - USED AS SWITCHES.  0=OFF, 1=ON.
C                  1 - USES TATIME INSTEAD OF FIXED TAU.
C                  2 - STEADY STATE ANALYSIS ONLY.
C                  3 - GIVES REMESH AFTER INITIAL STEADY STATE.
C                  4 - GIVES FULL PRINTOUT.
C                  5 - GIVES VERSATEC PLOT.
C                  6 - USES STEADY STATE BOUNDARY VOLTAGES DURING TRANSIENCE.
C                  9 - GIVES LINEPRINTER PLOT OF PROFN.
C                 10 - READS INITIAL GUESS FROM DATA CARDS.
C                 11 - GIVES REMESH PRINTOUT.
C                 13 - REMESH ON INITIAL ESTIMATE INSTEAD OF FIXED MESH STEADY S
C                 14 - GIVES PRINTOUT OF INITIAL ESTIMATE.
C                 15 - GIVES PUNCHED DECK OF STEADY STATE.
```

```
C                    16 - USES OMEGA OPTIMIZATION ROUTINE IN SYSTEMS.
C                    17 - USES ALGORITHM TO DETERMINE PROFILE.
C                    18 - ZERO=FIXED MESH.
C                         ONE=FOUR REGIONS OF DIFFERENT FIXED MESH.
C                         TWO=MESH FROM PROFILE USED.
C                    19 - SETS UP ITERATION LIMIT.
C                         ZERO  = UNLIMITED.
C                         ONE   = MAXIMUM NO. OF ITERATIONS IS 100.
C                         TWO   = MAXIMUM NO. OF ITERATIONS IS 200.
C                         THREE = MAXIMUM NO. OF ITERATIONS IS 300.
C                         FOUR  = MAXIMUM NO. OF ITERATIONS IS 400.
C                         FIVE  = MAXIMUM NO. OF ITERATIONS IS 500.
C                    20 - GIVES BETTER INITIAL ESTIMATES AND BOUNDARY CONDITIONS.
C                         ZERO  = PIN DIODES.
C                         ONE   = P+ N DIODES.
C                         TWO   = SCHOTTKY DIODES.
C                    22 - SELECTS MATERIAL.
C                         ZERO  = SILICON.
C                         ONE   = GERMANIUM.
C                    23 - GIVES PUNCHED DECK OF TRANSIENT STATES.
C                    24 - CHOOSES INPUT PULSE SHAPE.
C                         0     = EXPONENTIAL.
C                         1     = RECTANGULAR.
C                         2     = SINUSOIDAL.
C
C      ***************************************************************************
C
       REAL ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +    EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +    HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +    NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +    QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +    TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +     VSATP,XL,X0,XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,
     +     EFMAX,XM,PBI,PVN,XIMG,VIFAC,HT1,NA
C
C      ***************************************************************************
C      ***************************************************************************
C      *************** INDEX FOR REAL VARIABLES **********************************
C      ***************************************************************************
C      ***************************************************************************
C
C
C      ABSCOEF - ABSORBTION COEFFICIENT OF PHOTODIODE TO INCIDENT RADIATION.
C      AREA - AREA OF PHOTODIODE.
C      BETA - IMPLICITNESS FACTOR, DEFINED ON PAGE 44.
C      DPSIMAX - MAXIMUM CHANGE IN PSI BETWEEN ITERATIONS.
C      DPSIAVE - AVERAGE CHANGE IN PSI BETWEEN ITERATIONS.
C      DPSISD - STANDARD DEVIATION OF THE CHANGE IN PSI BETWEEN ITERATIONS.
C      DQTTY - FRACTION OF QTTYSUM USED TO STEP OFF NEQ MESH SIZE.
C      EFMAX - MAX. ELECTRIC FIELD ACROSS DEPLETION LAYER.
C      EGAP - ENERGY GAP OF SEMICONDUTOR.
C      EPHOTON - ENERGY OF INCIDENT PHOTONS.
C      EPI - LOWER LIMIT OF GRAPH FOR DOPING PROFILE PLOT.
C      EPSDAVE - MAXIMUM DPSIAVE ACCEPTABLE FOR FINAL SOLUTION.
C      EPSDMAX - MAXIMUM DPSIMAX ACCEPTABLE FOR FINAL SOLUTION.
C      EPSDSD - MAXIMUM DPSISD ACCEPTABLE FOR FINAL SOLUTION.
C      ESAT - ELECTRIC FIELD NEEDED FOR SATURATION VELOCITY (VOLTS/CM).
C      ETRAP - ENERGY OF TRAP LEVEL (ELECTRON VOLTS).
C      FRAC - USED TO INTERPOLATE BETWEEN POINTS.
C      G - TERM TO GIVE THE NUMBER OF ELECTRON-HOLE PAIRS BEING GENERATED.
C      H - LENGTH OF TRANSISTOR (INX(MESHIN+1)) DIVIDED BY NMESH.
C      HT - HOLDS T WHILE MONITOR CALCULATES STEADY STATE.
C      HTAU - HOLDS TAU WHILE MONITOR CALCULATES STEADY STATE.
C      HVC - HOLDS VC WHILE MONITOR CALCULATES STEADY STATE.
C      HVE - HOLDS VE WHILE MONITOR CALCULATES STEADY STATE.
C      INBETA - INPUT VALUE OF BETA.  USED IN TRANSIENT ANALYSIS.
C      JDISP - DISPLACEMENT CURRENT DENSITY.
C      JEST - ESTIMATED DIODE CURRENT, TO CALCULATE VOLTAGE DROP ACROSS RLOAD.
C      JFAC - CURRENT DENSITY NORMALIZATION FACTOR = -5.919547 E-7 A/CM**2.
C      JRESIS - CURRENT GOING THROUGH LOAD RESISTOR.
C      JTOT - TOTAL CURRENT DENSITY.
C      LAMBDA - WAVELENGTH OF INCIDENT PHOTONS.
C      LFAC - LENGTH NORMALIZATION FACTOR 3.59454 E-3 CM.
C      MFAC - MOBILITY NORMALIZATION FACTOR = 38.6473 CM**2/V-S.
C      NA - ATOMIC DENSITY OF METAL.
C      NFAC - DOPING NORMALIZATION FACTOR = 1.328168 E10 CM**-3.
C      OMEGA - ACCELERATION PARAMETER USED IN SYSTEMS.
C      PBI - PN MINUS PVN.
C      PBL - IMAGE FORCE BARRIER LOWERING.
C      PBN - BARRIER HEIGHT WITH BIAS VOLTAGE APPLIED.
C      PBO - BARRIER HEIGHT IF NEGLECTING IMAGE FORCE EFFECT.
C      PEA - ELECTRON AFFINITY OF SEMICONDUCTOR.
C      PF - SCALAR FACTOR TO TAKE WEIGHTED MEAN OF EQUATION 3.2 AND 3.3 (POISSON)
C      PIMGS - MAX. VALUE OF PIMG.
C      PIT - POTENTIAL DUE TO INTERFACIAL STATES.
C      PM - WORK FUNCTION FOR METAL.
C      POWER - POWER OF INCIDENT BEAM IN WATTS.
C      PROFCOL - VALUE OF DOPING PROFILE AT COLLECTOR.
C      PROFEM - VALUE OF DOPING PROFILE AT EMITTER.
C      PROFINT - VALUE OF DOPING PROFILE AT INTRINSIC REGION.
C      PROFMAX - MAXIMUM DOPING CONCENTRATION (CM**-3).
C      PSINT - PSI AT THERMAL EQUILIBRIUM.
C      PVN - POTENTIAL DIFFERENCE BETWEEN CONDUCTION BAND AND
C          QAUSI-FEMI LEVEL IN N TYPE SEMICONDUCTOR.
C      QNTMEFF - QUANTUM EFFICIENCY OF PHOTODIODE.
C      QTTYSUM - SUM OF THE QUANTITY CHOSEN UPON WHICH TO BASE REMESH.
C      RLOAD - LOAD RESISTOR IN SERIES WITH DIODE.
C      T - TIME.
C      TAU - TIME STEP, OR INCREMENT.
C      TFAC - TIME NORMALIZATION FACTOR = 1.2920718 E-5 S.
```

```
C       TIMEFAC - SPECIFIES AMPLITUTE OF INPUT PULSE WITH RESPECT TO TIME.
C       TPEAK - TIME AT WHICH INPUT PULSE REACHES ITS PEAK.
C       TRISE - GAUSSIAN RISE TIME OF INPUT PULSE.
C       TRN - TIME FOR RECOMBINATION OF ELECTRONS.
C       TRP - TIME FOR RECOMBINATION OF HOLES.
C       TSTOP - TIME AT WHICH TRANSIENT ANALYSIS IS TO BE STOPPED.
C       UFAC - RECOMBINATION NORMALIZATION FACTOR = 1.02794 E+15 1/(CM**3 - SEC)
C       VC- COLLECTOR VOLTAGE.
C       VCK - PREVIOUS VALUE IN TIME OF VC.
C       VCSS - STEADY STATE APPLIED COLLECTOR VOLTAGE.
C       VE - EMITTER VOLTAGE.
C       VEK - PREVIOUS VALUE IN TIME OF VE.
C       VESS - STEADY STATE  APPLIED EMITTER VOLTAGE.
C       VFAC - VOLTAGE NORMALIZATION FACTOR = 0.025875 V.
C       VIFAC - 1./(16*3.14159*NFAC*LFAC**3.)
C       VOLUME - VOLUME THROUGH WHICH ONE SECOND OF LIGHT IS SPREAD.
C       VSATN - SATURATION VELOCITY OF ELECTRONS (CM/SEC).
C       VSATP - SATURATION VELOCITY OF HOLES (CM/SEC).
C       WS1,WS2,... - WORKING STORAGE.
C       XDPLE - DEPLETION REGION THICKNESS.
C       XIMG - IMAGE FORCE EFFECT IS DOMINANT FROM X=0 TO X=XIMG.
C       XL - LENGTH OF DIODE.
C       XM - MAX. BARRIER LOCATION.
C       X0 - USED IN REMESH.
C
C       ************************************************************************
C
        REAL CVOLTS,DFSPL,DFSPH,DX,EVOLTS,HN,HP,HPSI,INPROF,INPROFG,
     +     INX,JN,JNK,JP,JPK,MI1,MI2,MI3,MN,MP,PROF,PROFG,SP,SSTIME,
     +      TATIME,TVTIME,U,UK,X,PAV,PIMG
C
C       ************************************************************************
C       ************************************************************************
C       *************** INDEX FOR ARRAYS ***************************************
C       ************************************************************************
C       ************************************************************************
C
C       CVOLTS - COLLECTOR VOLTAGE AT SUCCESSIVE POINTS IN TIME.
C       DFSPL - LOWEST BOUNDARY OF MESH REGION TO HAVE DIFFERENT SPACING.
C       DFSPH - HIGHEST BOUNDARY OF MESH REGION TO HAVE DIFFERENT SPACING.
C       DX - DISTANCE BETWEEN ADJACENT MESH POINTS.
C       EVOLTS - EMITTER VOLTAGE AT SUCCESSIVE POINTS IN TIME.
C       HN - HOLDS N WHILE MONITOR CALCULATES STEADY STATE.
C       HP - HOLDS P WHILE MONITOR CALCULATES STEADY STATE.
C       HPSI - HOLDS PSI WHILE MONITOR CALCULATES STEADY STATE.
C       INPROF - INPUT (DONOR - ACCEPTOR) DOPING PROFILE.
C       INPROFG - INPUT (DONOR + ACCEPTOR) DOPING PROFILE.
C       INX - SPATIAL POSITIONS AT WHICH DOPING WAS READ.
C       JN - ELECTRON CURRENT DENSITY.
C       JNK - HOLDS ELECTRON CURRENT DENSITY OF PRECEDING TIME STEP.
C       JP - HOLE CURRENT DENSITY.
C       JPK - HOLDS HOLE CURRENT DENSITY OF PRECEDING TIME STEP.
C       MI1,MI2,MI3 - PARABOLIC INTEGRATION COEFFICIENTS.
C       MN - ELECTRON MOBILITY.
C       MP - HOLE MOBILITY.
C       PAV - POTENTIAL FUNCTION DUE TO APPLIED BIAS.
C       PROF - INTERPOLATED DOPING PROFILE FROM INPROFN TO ACTUAL MESH USED.
C       PROFG - INTERPOLATED DOPING PROFILE FROM INPROFG TO ACTUAL MESH USED.
C       SP - SPACING TO BE USED IN REGION OF DIFFERENT SPACING.
C       SSTIME - TIMES AT WHICH STEADY STATE ANALYSIS IS DESIRED.
C       TATIME - VARIABLE TIME STEP SIZES.
C       TVTIME - TIMES AT WHICH TRANSIENT VOLTAGES ARE GIVEN.
C       U - RECOMBINATION TERM.
C       UK - HOLDS RECOMBINATION TERM OF PRECEDING TIME STEP.
C       X - POSITION COORDINATE.  NUMBER OF POINTS IS FIXED.  MESH SIZES CHANGE.
C
C       ************************************************************************
C
        DOUBLE N,NK,P,PK,PSI,PSIK,PSIOLD
C
C       ************************************************************************
C       ************************************************************************
C       *************** INDEX FOR DOUBLE PRECISION VARIABLES *******************
C       ************************************************************************
C       ************************************************************************
C
C       N - ELECTRON CARRIER DENSITY FOR EACH SPACIAL POINT.
C       NK - HOLDS ELECTRON CARRIER DENSITY OF PREDEDING TIME STEP.
C       P - HOLE CARRIER DENSITY FOR EACH SPACIAL POINT.
C       PK - HOLDS HOLE CARRIER DENSITY OF PRECEDING TIME STEP.
C       PSI - POTENTIAL FOR EACH SPACIAL POINT.
C       PSIK - HOLDS POTENTIAL OF PRECEDING TIME STEP.
C       PSIOLD - HOLDS POTENTIAL OF PRECEDING ITERATION STEP.
C
C       ************************************************************************
C
```

```
C
C
C     READ IN PROGRAM TEST OPTIONS.
C
      DO 10 I=1,26,5
         READ 5,TEST(I),TEST(I+1),TEST(I+2),TEST(I+3),TEST(I+4)
5        FORMAT (5(9X,I1))
10       PRINT 12,I,TEST(I),I+1,TEST(I+1),I+2,TEST(I+2),I+3,TEST(I+3),
     +      I+4,TEST(I+4)
12       FORMAT ("0TEST(",I2,")=",I5/
     +   " TEST(",I2,")=",I5/
     +   " TEST(",I2,")=",I5/
     +   " TEST(",I2,")=",I5/
     +   " TEST(",I2,")=",I5)
C
C     ******************************************************************
C
C     NORMALIZATION FACTORS FOR SILICON.
C
      IF ( TEST(22) .NE. 0 )  GOTO 1
      JFAC=-5.919547 E-7
      LFAC=35.945 E-4
      MFAC=38.6473
      NFAC=1.328168 E+10
      TFAC=1.2920718 E-5
      UFAC=1.02794 E+15
      VFAC=.025875
C
C     ******************************************************************
C
C     NORMALIZATION FACTORS FOR GERMANIUM.
C
1     IF ( TEST(22) .NE. 1 )  GOTO 2
      JFAC=-3.96253 E-2
      LFAC=9.70290 E-5
      MFAC=38.6473
      NFAC=2.4 E+13
      TFAC=9.41463 E-9
      UFAC=2.55070 E+21
      VFAC=.025875
2     CONTINUE
C
C
C     ******************************************************************
C
C     READ IN LOCATION FOR TRANSIENT PUNCHED OUTPUT.
C
      IF ( TEST(23) .NE. 1 )  GOTO 14
      READ 13,IXT
13    FORMAT(I10)
      IXT=IXT+1
14    CONTINUE
C
C     ******************************************************************
C
C     READ IN DIODE PARAMETERS.
C
      READ 15,ABSCOEF,AREA,LAMBDA,POWER,RLOAD
      READ 15,QNTMEFF,HTAU,TPEAK,TRISE
15    FORMAT (5F10.0)
      PRINT 18,ABSCOEF,AREA,LAMBDA,POWER,RLOAD,QNTMEFF,HTAU*1.E12,
     +   TPEAK*1.E12,TRISE*1.E12
18    FORMAT ("0ABSCOEF = ",F10.4," MICROMETERS."/
     +   " AREA    = ",E10.4," CM**2."/
     +   " LAMBDA  = ",F10.4," MICROMETERS."/
     +   " POWER   = ",E10.4," WATTS."/
     +   " RLOAD   = ",E10.4," OHMS."/
     +   " QNTMEFF = ",F10.4/
     +   " TAU     = ",F10.4," PSEC."/
     +   " TPEAK   = ",F10.4," PSEC."/
     +   " TRISE   = ",F10.4," PSEC.")
      ABSCOEF=ABSCOEF/LFAC/1.E4
      EPHOTON=1.98647E-19/LAMBDA
      HTAU=HTAU/TFAC
      JFAC=JFAC*AREA
      TPEAK=TPEAK/TFAC
      TRISE=TRISE/TFAC
      VOLUME=AREA*ABSCOEF*LFAC
      G=POWER/VOLUME/EPHOTON*QNTMEFF/UFAC
C
C     ******************************************************************
C
C     READ IN TOLERANCES.
C
      READ 15,OMEGA,EPSDMAX,EPSDAVE,EPSDSD
20    FORMAT (I10,4F10.0)
      PRINT 30,OMEGA,EPSDMAX,EPSDAVE,EPSDSD
30    FORMAT ("0OMEGA   = ",F10.4/
     +   " EPSDMAX = ",E10.4," VOLTS."/
     +   " EPSDAVE = ",E10.4," VOLTS."/
     +   " EPSDSD  = ",E10.4," VOLTS.")
      EPSDMAX=EPSDMAX/VFAC
      EPSDAVE=EPSDAVE/VFAC
      EPSDSD=EPSDSD/VFAC
```

```
C
C     ******************************************************************
C
C     READ IN MOBILITY DATA.
C
      READ 15,ESAT,VSATN,VSATP
      PRINT 100,ESAT,VSATN,VSATP
100   FORMAT ("0ESAT     = ",E10.4," VOLTS/CM."/
     +   " VSATN    = ",E10.4," CM/SEC."/
     +   " VSATP    = ",E10.4," CM/SEC.")
C
C     ******************************************************************
C
C     READ IN RECOMBINATION DATA.
C
      READ 15,ETRAP,TRN,TRP
      PRINT 120,ETRAP,TRN,TRP
120   FORMAT ("0ETRAP    = ",F10.4," VOLTS."/
     +   " TRN      = ",E10.4," SEC."/
     +   " TRP      = ",E10.4," SEC.")
      ETRAP=EXP(ETRAP/VFAC)
      TRN=TRN/TFAC
      TRP=TRP/TFAC
C
C     ******************************************************************
C
C     READ IN TRANSIENT DRIVING VOLTAGES.
C
130   READ 20,NTV,VCSS,VESS,JEST
      PRINT 140,VCSS,VESS
140   FORMAT ("0VCSS     = ",F10.4," VOLTS."/
     +   " VESS     = ",F10.4," VOLTS.")
      VCSS=VCSS/VFAC
      VESS=VESS/VFAC
      WS1=.5*JEST*RLOAD/VFAC
      VC=VCSS+WS1
      VE=VESS-WS1
      IF ( NTV .EQ. 0 )  TEST(6)=1
      IF ( NTV .EQ. 0 )  GOTO 250
      IF ( TEST(6) .EQ. 0 )  PRINT 150,NTV
150   FORMAT ("0",I4," TRANSIENT APPLIED VOLTAGES."/
     +   " NUMBER",6X,"TIME (PSEC)",6X,"VC (VOLTS)",6X,"VE (VOLTS)")
      DO 170 I=1,NTV
         READ 15,TVTIME(I),CVOLTS(I),EVOLTS(I)
         IF ( TEST(6) .EQ. 0 )  PRINT 160,I,TVTIME(I)*1.E12,
     +      CVOLTS(I),EVOLTS(I)
160      FORMAT (I5,3F15.4)
         TVTIME(I)=TVTIME(I)/TFAC
         CVOLTS(I)=CVOLTS(I)/VFAC
170      EVOLTS(I)=EVOLTS(I)/VFAC
250   TVINDEX=0
C
C     ******************************************************************
C
C     READ TIMES AT WHICH STEADY-STATE CALCULATIONS ARE TO BE MADE.
C
      READ 20,NSS
      IF ( NSS .EQ. 0 )  GOTO 270
      DO 260 I=1,NSS
         READ 15,SSTIME(I)
260      SSTIME(I)=SSTIME(I)/TFAC
270   SSINDEX=1
      SSTIME(NSS+1)=0.
C
C     ******************************************************************
C
C     READ IN TRANSIENT ANALYSIS TIMES.
C
      READ 20,NTA,INBETA,TSTOP
      PRINT 275,NTA,INBETA,TSTOP*1.E12
275   FORMAT ("0NTA      = ",I5/
     +   " INBETA   = ",F10.4/
     +   " TSTOP    = ",F10.4," PSEC."/)
      TSTOP=TSTOP/TFAC
      IF ( NTA .EQ. 0 )  GOTO 290
      DO 280 I=1,NTA
         READ 15,TATIME(I)
280      TATIME(I)=TATIME(I)/TFAC
290   TAINDEX=0
C
C     ******************************************************************
C
C     READ IN SCHOTTKY DIODE PARAMETERS.
C
      IF ( TEST(20) .NE. 2 )  GOTO 299
      READ 295, NA
295   FORMAT (E10.5)
      READ 15, PM,PEA,PIT,EGAP,PIMGS
      PBO=PM-PEA-PIT
      PRINT 297, PBO,PM,PEA,PIT,EGAP,PIMGS,NA
```

```
299   CONTINUE
C
C     ******************************************************************
C
C     READ IN MESH SPACING
C
      H=0.
C     IF TEST(18)=0, USE UNIFORMLY SPACED MESH.
C
      IF ( TEST(18) .NE. 0 )  GOTO 310
      READ 20,NMESH,XL
      XL=XL/LFAC/1.E4
      H=XL/NMESH
      NMESHP1=NMESH+1
      DO 300 I=1,NMESHP1
         X(I)=(I-1)*H
         DX(I)=H
300      JN(I)=JNK(I)=JP(I)=JPK(I)=NK(I)=PK(I)=PSIK(I)=J(I)=UK(I)=1.E-35
      GOTO 360
C
C     IF TEST(18)=1, USER SPECIFIES REGIONS OF DIFFERENT MESH SPACING.
C
310   IF ( TEST(18) .NE. 1 )  GOTO 347
      READ 15,XL,H
      XL=XL/LFAC/1.E4
      H=H/LFAC/1.E4
      CHAR=10H0
      DO 320 I=1,4
         READ 15,DFSPL(I),DFSPH(I),SP(I)
         PRINT 315,CHAR,I,DFSPL(I),I,DFSPH(I),I,SP(I)
315      FORMAT (A1,"DFSPL(",I1,")= ",F10.4,10X,"DFSPH(",I1,")= ",F10.4,
     +      10X,"SP(",I1,")= ",F10.4,10X,"MICROMETERS.")
         DFSPL(I)=DFSPL(I)/LFAC/1.E4
         DFSPH(I)=DFSPH(I)/LFAC/1.E4
         SP(I)=SP(I)/LFAC/1.E4
320      CHAR=10H
      I=1
      X(I)=0.
      JN(I)=JNK(I)=JP(I)=JPK(I)=NK(I)=PK(I)=PSIK(I)=U(I)=UK(I)=1.E-35
330      I=I+1
         DO 340 J=1,4
            IF ( X(I-1) .LT. DFSPL(J)  .OR.  X(I-1) .GT. DFSPH(J) )
     +         GOTO 340
            X(I)=X(I-1)+SP(J)
            GOTO 345
340         CONTINUE
         X(I)=X(I-1)+H
345      DX(I)=X(I)-X(I-1)
         JN(I)=JNK(I)=JP(I)=JPK(I)=NK(I)=PK(I)=PSIK(I)=U(I)=UK(I)=1.E-35
         IF ( X(I) .LT. XL )  GOTO 330
      NMESH=I-1
C
C     ******************************************************************
C
C     IF TEST(17)=0, READ IN DOPING PROFILE.
C     IF TEST(18)=2, MESH USED WILL BE THAT USED TO INPUT PROFILE.
C
347   IF ( TEST(17) .NE. 0 )  GOTO 360
      READ 20,MESHIN,EPI
      EPI=EPI/NFAC
      MESHIP1=MESHIN+1
      DO 350 I=1,MESHIP1
         READ 15,WS1,INPROF(I)
         IF ( INPROF(I) .LT. 0. )  INXJCN=I
         INPROF(I)=INPROFG(I)=ALOG(ABS(INPROF(I)/NFAC))
         INX(I)=WS1/LFAC/1.E4
350      IF ( TEST(18) .EQ. 2 )  X(I)=INX(I)
      IF ( TEST(18) .EQ. 2 )  NMESH=MESHIN
360   NMESHP1=NMESH+1
      XL=X(NMESHP1)
      PRINT 370,NMESH,XL*LFAC*1.E4,H*LFAC*1.E4
370   FORMAT ("0NMESH    = ",I5/
     +   " XL        = ",F10.4," MICROMETERS."/
     +   " H         = ",F10.4," MICROMETERS.")
C
C     IF TEST(17)=1, USE ALGORITHM TO DETERMINE DOPING PROFILE.
C
      IF ( TEST(17) .NE. 1 )  GOTO 390
380   READ 15,EPI,PROFEM,PROFINT,PROFCOL
      READ 15,XEFLAT,XEGAUS
      READ 15,XCMIN,XCMAX,ACOLL,BCOLL,CCOLL
      PRINT 385,EPI,PROFEM,PROFINT,PROFCOL,XEFLAT,XEGAUS,
     +   XCMIN,XCMAX,ACOLL,BCOLL,CCOLL
385   FORMAT ("0EPI      = ",E10.4," CM**-3."/
     +   " PROFEM   = ",E10.4," CM**-3."/
     +   " PROFINT  = ",E10.4," CM**-3."/
     +   " PROFCOL  = ",E10.4," CM**-3."//
     +   " XEFLAT   = ",F10.4," MICROMETERS."/
     +   " XEGAUS   = ",F10.4," MICROMETERS."//
     +   " XCMIN    = ",F10.4," MICROMETERS."/
     +   " XCMAX    = ",F10.4," MICROMETERS."/
     +   " ACOLL    = ",F10.4/
     +   " BCOLL    = ",F10.4," MICROMETERS."/
     +   " CCOLL    = ",F10.4," MICROMETERS."/)
```

```
      EPI=EPI/NFAC
      PROFEM=PROFEM/NFAC
      PROFINT=PROFINT/NFAC
      PROFCOL=PROFCOL/NFAC
      XEFLAT=XEFLAT/LFAC/1.E4
      XEGAUS=XEGAUS/LFAC/1.E4
      XCMIN=XCMIN/LFAC/1.E4
      XCMAX=XCMAX/LFAC/1.E4
      BCOLL=XCMIN+BCOLL/LFAC/1.E4
      CCOLL=CCOLL/LFAC/1.E4
C
C     CALCULATE PARABOLIC INTEGRATION COEFFICIENTS.
390   DO 400 I=2,NMESH
C
         WS11=DX(I)
         WS12=DX(I+1)
         WS13=WS11*WS11
         WS14=WS11*WS12
         WS15=WS12*WS12
         MI1(I)=(WS13+2.*(WS14-WS15))/24./WS11
         MI3(I)=(WS15+2.*(WS14-WS13))/24./WS12
400      MI2(I)=(WS11+WS12)/2.-MI1(I)-MI3(I)
C
C     CALCULATES PARAMETERS FOR SCHOTTKY DIODE.
C
      IF ( TEST(20) .NE. 2 )  GOTO 650
      WS1=PROFEM
      WS2=SQRT(WS1*WS1/4.+1.)+ABS(WS1/2.)
      PVN=SIGN(ALOG(WS2),WS1)
      PVN=EGAP/2.-PVN
C
C     APPROXIMATION - PBN=PBO
C
      PBI=PBO-PVN
      WS70=0.
      I=1
600   XDPLE=SQRT(2.*(PBI-VE+VC-1)/PROFEM)
      EFMAX=PROFEM*XDPLE
      VIFAC=1./(16*3.14159*NFAC*LFAC**3.)
      XM=SQRT(VIFAC/EFMAX)
      PBL=2.*EFMAX*XM
      PBN=PBO-PBL
      WS50=PBN-PVN
      WS60=(PBI-WS50)/WS50
      IF ( ABS(WS60) .LE. .01 )  GOTO 610
      IF ( ABS(WS60) .LE. ABS(WS70) )  PBI=WS50
      IF ( ABS(WS60) .GT. ABS(WS70) .OR. WS60*WS70 .LT. 0. )
     + PBI=(PBI+WS50)/2.
      WS70=WS60
      IF ( I .GE. 100 )   GOTO 605
      I=I+1
      GOTO 600
605   PRINT 606
606   FORMAT (" ********** ERROR IN PBI IS .GT. 1 PER CENT.")
610   PRINT 620, PBN*VFAC,PBL*VFAC,XDPLE*LFAC*1.E4,XM*LFAC*1.E4
620   FORMAT (" PBN       = ",F10.4," VOLTS."/
     + " PBL       = ",F10.4," VOLTS."/
     + " XDPLE     = ",F10.4," MICROMETERS."/
     + " XM        = ",F10.4," MICROMETERS.")
650   CONTINUE
C
C     DETERMINE PROFILE FOR MESH BEING USED.
C
      CALL PROFILE
C
C     IF TEST(9)=1, OUTPUT LINEPRINTER PLOT OF PROFILE.
C
      IF ( TEST(9) .NE. 1 )  GOTO 800
      WS1=ALOG(ABS(EPI/1.E4))
      RANGE=(ALOG(ABS(PROFMAX))-WS1)/100.
      DO 530 I=1,NMESHP1
         IWS1=(ALOG(ABS(PROF(I)))-WS1)/RANGE
         IF ( IWS1 .LT. 0 ) IWS1=0
         CHAR=10H-
         IF ( PROF(I) .GT. 0. )  CHAR=10H+
530      PRINT 540,(I-1),X(I)*LFAC*1.E4,PROF(I)*NFAC,IWS1+3,CHAR
540      FORMAT (I4,F9.4,E13.5,=X,A1)
C
C     ******************************************************************
C
C     SET UP INITIAL ESTIMATES.
C
800   T=-3
C
C     ******************************************************************
C
      CALL INITIAL
C
```

```
C       SOLVE FOR STEADY STATE SOLUTION.
C
        BETA=1.
        TAU=1.E100
C          FORCES STEADY STATE.
C
C       IF TEST(14)=1, OUTPUT INITIAL ESTIMATE.
C
        IF ( TEST(14) .NE. 1 )  GOTO 860
        PRINT 850
850     FORMAT ("0INITIAL ESTIMATE")
        CALL OUTVALU
C
C       IF TEST(13)=0, CALCULATE FIXED MESH STEADY STATE VALUES.
C
860     IF ( TEST(13) .NE. 0 )  GOTO 990
870     PRINT 880,EPSDMAX*VFAC,EPSDAVE*VFAC,EPSDSD*VFAC,OMEGA
880     FORMAT ("0EPSDMAX = ",E11.5,10X," EPSDAVE = ",E11.5,10X,
       +   " EPSDSD = ",E11.5,10X," OMEGA = ",F6.4)
        PRINT 940
940     FORMAT ("0MAX. PNT.",7X,"DPSIMAX",9X,"DPSIAVE",8X,"DPSISD",8X,
       +   "OMEGA",8X,"NO. OF POS. PNTS.")
C
        CALL SYSTEMS
C
        PRINT 970,IWS1
970     FORMAT ("0FIXED MESH STEADY STATE CONVERGED AFTER",I6,
       +   " ITERATIONS"/" FIXED MESH STEADY STATE VALUES.")
        T=-2.
        CALL CURRENT
        DO 980 I=1,NMESHP1
           JNK(I)=JN(I)
           JPK(I)=JP(I)
           NK(I)=N(I)
           PK(I)=P(I)
           PSIK(I)=PSI(I)
980        UK(I)=U(I)
        CALL OUTVALU
        T=-1.
        IF ( TEST(2) .EQ. 1  .AND.  TEST(3) .NE. 1 )  GOTO 2410
C          ONLY FIXED MESH STEADY STATE REQUIRED IF CONTROL GOES TO 2410.
C
C       IF TEST(3)=1, CALCULATE REMESHED STEADY STATE VALUES.
C
        IF ( TEST(3) .NE. 1 )  GOTO 1340
990     T=-1.
        CALL REMESH
        CALL INITIAL
        PRINT 880,EPSDMAX*VFAC,EPSDAVE*VFAC,EPSDSD*VFAC,OMEGA
        PRINT 940
C
        CALL SYSTEMS
C
        PRINT 1280,IWS1
1280    FORMAT ("0VARIABLE MESH STEADY STATE CONVERGED AFTER",
       +   I5," ITERATIONS.")
        CALL CURRENT
        DO 1290 I=1,NMESHP1
           JNK(I)=JN(I)
           JPK(I)=JP(I)
           NK(I)=N(I)
           PK(I)=P(I)
           PSIK(I)=PSI(I)
1290       UK(I)=U(I)
        CALL OUTVALU
        IF ( TEST(2) .EQ. 1 )  GOTO 2410
C          ONLY VARIABLE MESH STEADY STATE REQUIRED.
C
C
C       ************************************************************************
C
C       BEGIN TRANSIENT ANALYSIS.
C
1340    PRINT 1350
1350    FORMAT ("0####")
        BETA=INBETA
        T=0.
        TAU=HTAU
C
C       REST OF PROGRAM IS CALCULATED FOR EACH STEP.
C
1700    TAINDEX=TAINDEX+1
C
C       IF TEST(1)=1, USER HAS INPUT TRANSIENT ANALYSIS TIMES.
C
        IF ( TEST(1) .NE. 1 )  GOTO 1800
        IF ( TAINDEX .GT. NTA )  GOTO 2350
        TAU=TATIME(TAINDEX)
C
C       IF TEST(1)=0, A CONSTANT TAU DETERMINES TRANSIENT ANALYSIS TIMES.
C
```

```
1800  T=T+TAU
1810  VCK=VC
      VEK=VE
      CALL VOLTAGE
C
      PRINT 2100,TAINDEX,T*TFAC
2100  FORMAT ("0"////" STEP =",I3,4X,"TIME = ",E11.5)
C
      DO 2110 I=1,NMESHP1
         JNK(I)=JN(I)
         JPK(I)=JP(I)
         NK(I)=N(I)
         PK(I)=P(I)
         PSIK(I)=PSI(I)
2110     UK(I)=U(I)
      IPPP1=IPPLUS+1
      INPP1=INPLUS+1
      DO 2120 I=1,IPPLUS
2120     PSI(I)=PSI(I)+(VE-VEK)
      DO 2160 I=IPPP1,INPLUS
2160     PSI(I)=PSI(I)+((VE-VEK)*(INPLUS-I)+(I-IPPP1)*(VC-VCK))/
     +      (INPLUS-IPPP1)
      DO 2180 I=INPP1,NMESHP1
2180     PSI(I)=PSI(I)+(VC-VCK)
      PRINT 940
C
      CALL SYSTEMS
C
      PRINT 2270,IWS1
2270  FORMAT ("0TRANSIENT STEP CONVERGED AFTER",I5," ITERATIONS.")
2300  PRINT 2310,TAINDEX,T*TFAC,VC*VFAC,VE*VFAC,TIMEFAC*POWER,TAU*TFAC
2310  FORMAT ("0STEP NUMBER = ",I6,6X,"TIME = ",E11.5,4X,"VC = ",
     +   E11.5,4X,"VE = ",E11.5,4X,"POWER = ",E11.5,4X,"TAU = ",E11.5)
C
      CALL CURRENT
      CALL OUTVALU
C
C     CALCULATE STEADY STATE MONITOR POINTS.
C
      GOTO 2330
2320  CALL MONITOR
2330  IF ( T .GE. SSTIME(SSINDEX) .AND. SSINDEX .LE. NSS )  GOTO 2320
C
C     CHECK TO SEE IF PROGRAM IS DONE.
C
      IF ( T .LE. TSTOP )  GOTO 1700
C
2350  PRINT 2400
2400  FORMAT ("0TRANSIENT ANALYSIS IS OVER.")
C
2410  PRINT 2420
2420  FORMAT ("0STEP NUMBER -1.")
C
      END

C
C
      SUBROUTINE CARRIER
C     PROCEEDURE TO SOLVE CARRIER EQUATIONS.
C
      COMMON DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST(30),IXT,
     +   ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +   VSATP,XL,X0,ACOLL,BCOLL,CCOLL,XCMAX,XCMIN,XEFLAT,XEGAUS,
     +    XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,EFMAX,XM,PBI,
     +    PVN,XIMG,VIFAC,NA,
     +   CVOLTS(20),DFSPL(4),DFSPH(4),DX(201),EVOLTS(20),HN(201),
     +   HP(201),HPSI(201),INPROF(201),INPROFG(201),INX(201),
     +   JN(201),JNK(201),JP(201),JPK(201),MI1(201),MI2(201),
     +   MI3(201),MN(201),MP(201),PROF(201),PROFG(201),SP(4),
     +   SSTIME(20),TATIME(100),TVTIME(20),U(201),UK(201),X(201),
     +    PAV(201),PIMG(201),
     +   N(201),NK(201),P(201),PK(201),PSI(201),PSIK(201),PSIOLD(201)
      INTEGER DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST,IXT
      REAL ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +    VSATP,XL,X0,XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,
     +    EFMAX,XM,PBI,PVN,XIMG,VIFAC,HT1,NA
```

```
      REAL CVOLTS,DFSPL,DFSPH,DX,EVOLTS,HN,HP,HPSI,INPROF,INPROFG,
     +   INX,JN,JNK,JP,JPK,MI1,MI2,MI3,MN,MP,PROF,PROFG,SP,SSTIME,
     +   TATIME,TVTIME,U,UK,X,PAV,PIMG
      DOUBLE N,NK,P,PK,PSI,PSIK,PSIOLD
C
      DOUBLE PRECISION AN(201),BN(201),CN(201),DN(201),AP(201),BP(201),
     +   CP(201),DP(201),M1,M2,M3,WS1,WS2,WS3,WS4,WS5,WS6,WS7,WS8,WS9,
     +   WS10,WS11
      DO 100 I=2,NMESH
         M1=MI1(I)
         M2=MI2(I)
         M3=MI3(I)
         WS1=DX(I)
         WS2=DX(I+1)
         WS3=PSI(I)-PSI(I-1)
         WS4=PSI(I+1)-PSI(I)
         WS5=DEXP(WS3)
         WS6=DEXP(WS4)
         IF ( DABS(WS3) .GT. 1.E-7 )  GOTO 10
         WS7=-2./(2.+WS3*(1.+WS3*(1./3.D0+WS3/12.)))/2./WS1
         GOTO 20
10       WS7=WS3/(1.-WS5)/2./WS1
20       IF ( DABS(WS4) .GT. 1.E-7 )  GOTO 30
         WS8=-2./(2.+WS4*(1.+WS4*(1./3.D0+WS4/12.)))/2./WS2
         GOTO 40
30       WS8=WS4/(1.-WS6)/2./WS2
C
C        SET UP THE N TRIDIAGONAL MATRIX.
C
40       WS9=(MN(I)+MN(I-1))*WS7
         WS10=(MN(I+1)+MN(I))*WS8
         WS11=1./BETA/TAU
         AN(I)=WS9*WS5+M1*WS11
         BN(I)=-WS9-WS10*WS6+M2*WS11
         CN(I)=WS10+M3*WS11
         DN(I)=M1*(-U(I-1)+NK(I-1)*WS11)+M2*(-U(I)+NK(I)*WS11)+
     +      M3*(-U(I+1)+NK(I+1)*WS11)
         IF ( BETA .EQ. 1. )  GOTO 50
         DN(I)=DN(I)+(1.-BETA)/BETA*(-JN(I+1)+JN(I)-M1*UK(I-1)-
     +      M2*UK(I)-M3*UK(I+1))
C
C        SET UP THE P TRIDIAGONAL MATRIX.
C
50       WS9=(MP(I)+MP(I-1))*WS7
         WS10=(MP(I+1)+MP(I))*WS8
         AP(I)=-WS9-M1*WS11
         BP(I)=WS9*WS5+WS10-M2*WS11
         CP(I)=-WS10*WS6-M3*WS11
         DP(I)=M1*(U(I-1)-PK(I-1)*WS11) + M2*(U(I)-PK(I)*WS11) +
     +      M3*(U(I+1)-PK(I+1)*WS11)
         IF ( BETA .EQ. 1. )  GOTO 100
         DP(I)=DP(I)+(1.-BETA)/BETA*(-(JP(I+1)-JP(I))+M1*UK(I-1)+
     +      M2*UK(I)+M3*UK(I+1))
100      CONTINUE
C
C     SOLVE THE N TRIDIAGONAL MATRIX.
C
      CN(2)=CN(2)/BN(2)
      DN(2)=(DN(2)-AN(2)*N(1))/BN(2)
      DO 120 I=3,NMESH
         WS1=BN(I)-AN(I)*CN(I-1)
         CN(I)=CN(I)/WS1
120      DN(I)=(DN(I)-AN(I)*DN(I-1))/WS1
      I=NMESH
130      N(I)=DN(I)-CN(I)*N(I+1)
         I=I-1
         IF ( I .GE. 2 )  GOTO 130
C
C     SOLVE THE P TRIDIAGONAL MATRIX.
C
      AP(NMESH)=AP(NMESH)/BP(NMESH)
      DP(NMESH)=(DP(NMESH)-CP(NMESH)*P(NMESH+1))/BP(NMESH)
      I=NMESH-1
150      WS1=BP(I)-CP(I)*AP(I+1)
         AP(I)=AP(I)/WS1
         DP(I)=(DP(I)-CP(I)*DP(I+1))/WS1
         I=I-1
         IF ( I .GE. 2 )  GOTO 150
      DO 170 I=2,NMESH
```

```
C
C
      SUBROUTINE  CURRENT
C     CALCULATES PARTICLE CURRENTS JN AND JP ACCORDING TO EQUATION 5.11.
C
      COMMON DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +    IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +     TVINDEX,TEST(30),IXT,
     +    ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +    EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +    HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +    NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +    QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +    TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +    VSATP,XL,X0,ACOLL,BCOLL,CCOLL,XCMAX,XCMIN,XEFLAT,XEGAUS,
     +     XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,EFMAX,XM,PBI,
     +     PVN,XIMG,VIFAC,NA,
     +    CVOLTS(20),DFSPL(4),DFSPH(4),DX(201),EVOLTS(20),HN(201),
     +    HP(201),HPSI(201),INPROF(201),INPROFG(201),INX(201),
     +    JN(201),JNK(201),JP(201),JPK(201),MI1(201),MI2(201),
     +    MI3(201),MN(201),MP(201),PROF(201),PROFG(201),SP(4),
     +    SSTIME(20),TATIME(100),TVTIME(20),U(201),UK(201),X(201),
     +     PAV(201),PIMG(201),
     +    N(201),NK(201),P(201),PK(201),PSI(201),PSIK(201),PSIOLD(201)
      INTEGER DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +    IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +     TVINDEX,TEST,IXT
      REAL ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +    EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +    HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +    NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +    QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +    TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +     VSATP,XL,X0,XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,
     +     EFMAX,XM,PBI,PVN,XIMG,VIFAC,HT1,NA
      REAL CVOLTS,DFSPL,DFSPH,DX,EVOLTS,HN,HP,HPSI,INPROF,INPROFG,
     +    INX,JN,JNK,JP,JPK,MI1,MI2,MI3,MN,MP,PROF,PROFG,SP,SSTIME,
     +     TATIME,TVTIME,U,UK,X,PAV,PIMG
      DOUBLE N,NK,P,PK,PSI,PSIK,PSIOLD
C
      DOUBLE PRECISION WS1,WS2,WS3,WS4
      NMESHP1=NMESH+1
      DO 40 I=2,NMESHP1
         WS1=PSI(I)-PSI(I-1)
         WS3=DEXP(WS1)
         IF ( DABS(WS1) .GE. 1.E-3 )  GOTO 20
   10    WS2=-2./(2.+WS1)/DX(I)
         GO TO 30
   20    WS2=WS1/(1.-WS3)/DX(I)
   30    JN(I)=(MN(I)+MN(I-1))/2.*WS2*(N(I)-N(I-1)*WS3)
   40    JP(I)=(MP(I)+MP(I-1))/2.*WS2*(P(I-1)-P(I)*WS3)
      JN(1)=JN(2)
      JP(1)=JP(2)
      RETURN
      END
```

```
C
C
      SUBROUTINE INITIAL
C     SET UP INITIAL GUESS FOR PSI AND CARRIERS.
C
      COMMON DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +    IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +     TVINDEX,TEST(30),IXT,
     +    ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +    EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +    HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +    NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +    QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +    TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +    VSATP,XL,X0,ACOLL,BCOLL,CCOLL,XCMAX,XCMIN,XEFLAT,XEGAUS,
     +     XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,EFMAX,XM,PBI,
     +     PVN,XIMG,VIFAC,NA,
     +    CVOLTS(20),DFSPL(4),DFSPH(4),DX(201),EVOLTS(20),HN(201),
     +    HP(201),HPSI(201),INPROF(201),INPROFG(201),INX(201),
     +    JN(201),JNK(201),JP(201),JPK(201),MI1(201),MI2(201),
     +    MI3(201),MN(201),MP(201),PROF(201),PROFG(201),SP(4),
     +    SSTIME(20),TATIME(100),TVTIME(20),U(201),UK(201),X(201),
     +     PAV(201),PIMG(201),
     +    N(201),NK(201),P(201),PK(201),PSI(201),PSIK(201),PSIOLD(201)
```

```
      INTEGER DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST,IXT
      REAL ABSCOFF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +    VSATP,XL,X0,XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,
     +    EFMAX,XM,PBI,PVN,XIMG,VIFAC,HT1,NA
      REAL CVOLTS,DFSPL,DFSPH,DX,EVOLTS,HN,HP,HPSI,INPROF,INPROFG,
     +   INX,JN,JNK,JP,JPK,MI1,MI2,MI3,MN,MP,PROF,PROFG,SP,SSTIME,
     +    TATIME,TVTIME,U,UK,X,PAV,PIMG
      DOUBLE N,NK,P,PK,PSI,PSIK,PSIOLD
      DOUBLE PVN1
      DOUBLE PRECISION WS10
C
      REAL A(201),B(201),C(201),D(201)
C
      IF ( TEST(20) .EQ. 2 )  GOTO 570
C
C     IF TEST(10)=1, INITIAL GUESS IS READ FROM CARDS.
C
      IF ( TEST(10) .EQ. 0 )  GOTO 30
      READ 10,IWS1
10    FORMAT (I8,4(E18.10))
      IWS1P1=IWS1+1
      DO 12 I=1,IWS1P1
         READ 10,IWS2,D(I),A(I),B(I),C(I)
         D(I)=D(I)/LFAC/1.E4
         A(I)=ALOG(A(I)/NFAC)
         B(I)=ALOG(B(I)/NFAC)
12       C(I)=C(I)/VFAC
C
C     IMPOSE BOUNDARY CONDITIONS.
C
      PSI(1)=SIGN(ALOG(ABS(PROF(1)/2.)+SQRT(PROF(1)*PROF(1)/4.-1.)),
     +   PROF(1))
      N(1)=DEXP(PSI(1))
      P(1)=1./N(1)
      PSI(1)=VE+PSI(1)
      NMESHP1=NMESH+1
      PSI(NMESHP1)=SIGN(ALOG(ABS(PROF(NMESHP1)/2.)+
     +   SQRT(PROF(NMESHP1)*PROF(NMESHP1)/4.-1.)),PROF(NMESHP1))
      N(NMESHP1)=DEXP(PSI(NMESHP1))
      P(NMESHP1)=1./N(NMESHP1)
      PSI(NMESHP1)=VC+PSI(NMESHP1)
C
      I=J=1
21    I=I+1
         GOTO 23
22       J=J+1
23       IF ( D(J) .LT. X(I) )  GOTO 22
         FRAC=(X(I)-D(J-1))/(D(J)-D(J-1))
         N(I)=EXP(A(J-1)+FRAC*(A(J)-A(J-1)))
         P(I)=EXP(B(J-1)+FRAC*(B(J)-B(J-1)))
         PSI(I)=C(J-1)+FRAC*(C(J)-C(J-1))
         IF ( I .LE. NMESH )  GOTO 21
      GOTO 600
C
C     IF TEST(10)=0, AN ALGORITHM DETERMINES INITIAL GUESS.
C
30    IPPP1=IPPLUS+1
      INPP1=INPLUS+1
      NMESHP1=NMESH+1
      DO 70 I=1,NMESHP1
         WS1=PROF(I)
         IF ( ABS(WS1) .LE. 20 )  GOTO 40
         WS2=ABS(WS1) + ABS(1./WS1)
         GOTO 50
40       WS2=SQRT(WS1*WS1/4.+1.)+ABS(WS1/2.)
50       PSI(I)=SIGN(ALOG(WS2),WS1)
70       CONTINUE
C
      N(1)=DEXP(PSI(1))
      P(1)=1./N(1)
      N(NMESH+1)=DEXP(PSI(NMESH+1))
      P(NMESH+1)=1./N(NMESH+1)
      JCNP1=JCN+1
      DO 160 I=2,JCNP1
         P(I)=-PROF(I)
160      N(I)=1./P(I)
      JCNP2=JCN+2
      DO 170 I=JCNP2,NMESH
         N(I)=PROF(I)
170      P(I)=1./N(I)
      DO 190 I=1,IPPP1
190      PSI(I)=PSI(I)+VE
      DO 200 I=INPP1,NMESHP1
```

```
200       PSI(I)=PSI(I)+VC
C
      WS1=(PSI(INPP1)-PSI(IPPP1))/(X(INPP1)-X(IPPP1))
      WS2=PSI(IPPP1)
      DO 560 I=IPPP1,INPP1
560      PSI(I)=WS2+WS1*(X(I)-X(IPPP1))
C
C
C     SET UP INITIAL ESTIMATES AND BOUNDARY CONDITIONS FOR SCHOTTKY.
C
570   IF ( TEST(20) .NE. 2 )  GOTO 600
      XIMG=VIFAC/PIMGS
      NMESHP1=NMESH+1
      DO 580 I=1,NMESHP1
      IF ( X(I) .LT. XIMG )   PIMG(I) =PIMGS+PBL
      IF ( X(I) .GE. XIMG )   PIMG(I)=VIFAC/X(I)
      IF ( X(I) .LT. XDPLE )   PAV(I)=EFMAX*X(I)-PROFEM*X(I)*X(I)/2.
      IF ( X(I) .GE. XDPLE )   PAV(I)=PROFEM*XDPLE*XDPLE/2.
      PSI(I)=EGAP/2.+PAV(I)+PIMG(I)-PBN-PBL
      N(I)=PROFEM
      P(I)=1./N(I)
580   CONTINUE
C
      N(1)=NA
      P(1)=1./N(1)
      N(NMESHP1)=DEXP(PSI(NMESHP1)-VC+VE)
      P(NMESHP1)=1./N(NMESHP1)
C
C
600   CALL MOBREC
C
C     INITIAL GUESS NOW ESTABLISHED.
C
      RETURN
      END
C
C
      SUBROUTINE MOBREC
C     CALCULATES CARRIER MOBILITIES AND RECOMBINATION COEFFICIENTS.
C
      COMMON DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST(30),IXT,
     +   ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +   VSATP,XL,X0,ACOLL,BCOLL,CCOLL,XCMAX,XCMIN,XFFLAT,XEGAUS,
     +    XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,EFMAX,XM,PBI,
     +    PVN,XIMG,VIFAC,NA,
     +   CVOLTS(20),DFSPL(4),DFSPH(4),DX(201),EVOLTS(20),HN(201),
     +   HP(201),HPSI(201),INPROF(201),INPROFG(201),INX(201),
     +   JN(201),JNK(201),JP(201),JPK(201),MI1(201),MI2(201),
     +   MI3(201),MN(201),MP(201),PROF(201),PROFG(201),SP(4),
     +   SSTIME(20),TATIME(100),TVTIME(20),U(201),UK(201),X(201),
     +    PAV(201),PIMG(201),
     +   N(201),NK(201),P(201),PK(201),PSI(201),PSIK(201),PSIOLD(201)
      INTEGER DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST,IXT
      REAL ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DOTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +    VSATP,XL,X0,XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,
     +    EFMAX,XM,PBI,PVN,XIMG,VIFAC,HT1,NA
      REAL CVOLTS,DFSPL,DFSPH,DX,EVOLTS,HN,HP,HPSI,INPROF,INPROFG,
     +   INX,JN,JNK,JP,JPK,MI1,MI2,MI3,MN,MP,PROF,PROFG,SP,SSTIME,
     +    TATIME,TVTIME,U,UK,X,PAV,PIMG
      DOUBLE N,NK,P,PK,PSI,PSIK,PSIOLD
C
C     CALCULATE MOBILITIES.
C
      IF ( TEST(22) .NE. 0 )  GOTO 1
      WS3=480./MFAC
      WS4=1350./MFAC
C
1     IF ( TEST(22) .NE. 1 )  GOTO 2
      WS3=1900./MFAC
      WS4=3900./MFAC
2     CONTINUE
C
      DO 170 I=1,NMESHP1
      IF ( TEST(22) .NE. 0 )  GOTO 3
         WS1=2.4482E21/DLOG(1.+1.40694E20/((N(I)+P(I))*NFAC))/MFAC
3     IF ( TEST(22) .NE. 1 )  GOTO 4
         WS1=4.3893E21/DLOG(1.+2.52246E20/((N(I)+P(I))*NFAC))/MFAC
4     CONTINUE
```

```
      WS2=WS1/((PROFG(I)+P(I)*0.5)*NFAC)
      WS1=WS1/(PROFG(I)*NFAC)
      WS5=WS3/WS1
      WS6=WS4/WS2
      IF ( WS5 .GT. .08 )  GO TO 10
      WS5=(13.99*WS5-3.432)*WS5+1.
      GO TO 30
10    IF ( WS5 .GE. 3.8 )  GOTO 20
      WS5=((31.06*WS5+45.22)*WS5+14.16)/((36.*WS5+76.34)*WS5+15.72)
      GO TO 30
20    WS5=(2.137/WS5-1.442)/WS5+1.
30    IF( WS6 .GT. .08 )  GO TO 110
      WS6=(13.99*WS6-3.432)*WS6+1.
      GO TO 130
110   IF( WS6 .GE. 3.8 )  GO TO 120
      WS6=((31.06*WS6+45.22)*WS6+14.16)/((36.*WS6+76.34)*WS6+15.72)
      GO TO 130
120   WS6=(2.137/WS6-1.442)/WS6+1.
130   MP(I)=WS5*(WS1*WS3)/(WS1+WS3)
      MN(I)=WS6*(WS2*WS4)/(WS2+WS4)
      IF ( I .NE. 1 )  GOTO 140
      WS1=WS2=DABS((PSI(2)-PSI(1))/( X(2)-X(1))*VFAC/LFAC)
      GOTO 150
140   WS1=WS2=DABS((PSI(I)-PSI(I-1))/(X(I)-X(I-1))*VFAC/LFAC)
150   IF ( WS1 .LT. 1. )  GOTO 170
      MN(I)=VSATN/MFAC/WS1*TANH(MN(I)*MFAC*WS1/VSATN)
      MP(I)=VSATP/MFAC/WS1*TANH(MP(I)*MFAC*WS1/VSATP)
170   CONTINUE
C
C     CALCULATE RECOMBINATION COEFFICIENTS.
C
      WS2=T
      IF ( T .LT. 0. )  T=0.
C
C     EXPONENTIAL INPUT PULSE.
C
      IF ( TEST(24) .NE. 0 )  GOTO 180
      TIMEFAC=(T/TRISE)**2.*EXP((1.-T*T/TRISE/TRISE)/2.)
C
C     RECTANGULAR INPUT PULSE.
C
180   IF ( TEST(24) .NE. 1)  GOTO 190
      IF ( T .LT. TPEAK )  TIMEFAC=T/TPEAK
      IF ( T .GE. TPEAK )  TIMEFAC=1.0
C
C     SINUSOIDAL INPUT.
C
190   IF ( TEST(24) .NE. 2 )  GOTO 195
      TIMEFAC=SIN(3.14159/2.0/TPEAK*T)
195   CONTINUE
      WS1=G*TIMEFAC
      DO 200 I=2,NMESH
200     U(I)=(N(I)*P(I)-1.)/(TRP*(N(I)+ETRAP)+TRN*(P(I)+1./ETRAP))-
     +     WS1*EXP(-X(I)/ABSCOEF)
      T=WS2
      RETURN
      END


C
C
      SUBROUTINE MONITOR
C     COMPUTE STEADY-STATE SOLUTION AT TIME MONITOR POUNTS.
C
      COMMON DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST(30),IXT,
     +   ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +   VSATP,XL,X0,ACOLL,BCOLL,CCOLL,XCMAX,XCMIN,XEFLAT,XEGAUS,
     +    XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,EFMAX,XM,PBI,
     +    PVN,XIMG,VIFAC,NA,
     +   CVOLTS(20),DFSPL(4),DFSPH(4),DX(201),EVOLTS(20),HN(201),
     +   HP(201),HPSI(201),INPROF(201),INPROFG(201),INX(201),
     +   JN(201),JNK(201),JP(201),JPK(201),MI1(201),MI2(201),
     +   MI3(201),MN(201),MP(201),PROF(201),PROFG(201),SP(4),
     +   SSTIME(20),TATIME(100),TVTIME(20),U(201),UK(201),X(201),
     +    PAV(201),PIMG(201),
     +   N(201),NK(201),P(201),PK(201),PSI(201),PSIK(201),PSIOLD(201)
      INTEGER DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST,IXT
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      REAL ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +    VSATP,XL,X0,XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,
     +    EFMAX,XM,PBI,PVN,XIMG,VIFAC,HT1,NA
      REAL CVOLTS,DFSPL,DFSPH,DX,EVOLTS,HN,HP,HPSI,INPROF,INPROFG,
     +   INX,JN,JNK,JP,JPK,MI1,MI2,MI3,MN,MP,PROF,PROFG,SP,SSTIME,
     +    TATIME,TVTIME,U,UK,X,PAV,PIMG
      DOUBLE N,NK,P,PK,PSI,PSIK,PSIOLD
C
      BETA=1.
      HT=T
      HVC=VC
      HVE=VE
      TAU=1.E100
      NMESHP1=NMESH+1
      DO 100 I=1,NMESHP1
        HP(I)=P(I)
        HN(I)=N(I)
100     HPSI(I)=PSI(I)
      T=SSTIME(SSINDEX)
      PRINT 140,SSINDEX,T*TFAC
140   FORMAT ("0MONITOR POINT",I3,5X,"TIME = ",E11.5)
      CALL VOLTAGE
      SSINDEX=SSINDEX+1.
      IPPP1=IPPLUS+1
      DO 180 I=1,IPPP1
180     PSI(I)=PSI(I)+(VE-HVE)
      IPPP2=IPPLUS+2
      JCNP1=JCN+1
      DO 200 I=IPPP2,JCNP1
200     PSI(I)=PSI(I)+(VE-HVE)*(JCN-I+1)/(JCN-IPPLUS)
      JCNP2=JCN+2
      DO 220 I=JCNP2,INPLUS
220     PSI(I)=PSI(I)+(VC-HVC)*(I-1-JCN)/(NMESH-JCN)
      INPP1=INPLUS+1
      DO 240 I=INPP1,NMESHP1
240     PSI(I)=PSI(I)+(VC-HVC)
      PRINT 260
260   FORMAT ("0M.PT",7X,"DPSIMAX",9X,"DPSIAVE",8X,"DPSISD")
C
      CALL SYSTEMS
C
      PRINT 270,IWS1
270   FORMAT (*0MONITOR POINT CONVERGED AFTER*,I5,* ITERATIONS*)
      CALL CURRENT
      WS1=0.
C
C     INTEGRATE FOR COLLECTOR P-CHARGE.
C
      JCNP2=JCN+2
      DO 310 I=JCNP2,NMESHP1
310     WS1=WS1+(P(I-1)+P(I))*(X(I)-X(I-1))
      PRINT 390,T*TFAC,WS1*NFAC*LFAC*1.6022E-19
390   FORMAT ("0MONITOR STEADY-STATE AT TIME = ",E11.5,5X,
     +    "N-REGION P-CHARGE = ",E11.5)
      CALL OUTVALU
      BETA=INBETA
      T=HT
      TAU=HTAU
      VC=HVC
      VE=HVE
      DO 490 I=1,NMESHP1
        P(I)=HP(I)
        N(I)=HN(I)
490     PSI(I)=HPSI(I)
      PRINT 590,T*TFAC,VE*VFAC,VC*VFAC,JN(JCN)*JFAC
590   FORMAT ("0MONITOR      TIME = ",E10.4,4X,"VE = ",E10.4,4X,"VC = ",
     + E10.4,4X,"JN(JCN) = ",E10.4)
      RETURN
      END
C
C
      SUBROUTINE OUTVALU
C     OUTPUT VALUES OF ALL VARIABLES. DIFFERENT OUTPUT FOR STEADY-STATE
C     CALCULATIONS AND TRANSIENT CALCULATIONS.
C
      COMMON DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST(30),IXT,
     +   ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +   VSATP,XL,X0,ACOLL,BCOLL,CCOLL,XCMAX,XCMIN,XEFLAT,XEGAUS,
     +    XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,EFMAX,XM,PBI,
     +    PVN,XIMG,VIFAC,NA,
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     +    CVOLTS(20),DFSPL(4),DFSPH(4),DX(201),EVOLTS(20),HN(201),
     +    HP(201),HPSI(201),INPROF(201),INPROFG(201),INX(201),
     +    JN(201),JNK(201),JP(201),JPK(201),MI1(201),MI2(201),
     +    MI3(201),MN(201),MP(201),PROF(201),PROFG(201),SP(4),
     +    SSTIME(20),TATIME(100),TVTIME(20),U(201),UK(201),X(201),
     +     PAV(201),PIMG(201),
     +    N(201),NK(201),P(201),PK(201),PSI(201),PSIK(201),PSIOLD(201)
      INTEGER DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +    IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +     TVINDEX,TEST,IXT
      REAL ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +    EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +    HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +    NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +    QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +    TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +     VSATP,XL,X0,XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,
     +     EFMAX,XM,PBI,PVN,XIMG,VIFAC,HT1,NA
      REAL CVOLTS,DFSPL,DFSPH,DX,EVOLTS,HN,HP,HPSI,INPROF,INPROFG,
     +    INX,JN,JNK,JP,JPK,MI1,MI2,MI3,MN,MP,PROF,PROFG,SP,SSTIME,
     +     TATIME,TVTIME,U,UK,X,PAV,PIMG
      DOUBLE N,NK,P,PK,PSI,PSIK,PSIOLD
C
      REAL IXMN,IXMX,INMN,INMX,IPSIMN,IPSIMX,OXMN,OXMX,OYMN,OYMX,
     +    XMR,YMR,XSC,NSC,PSISC,XRNG,YRNG,SCS,HGT,NPLTP,
     +    NXD,NND,NPSID
      INTEGER NXL,NNL,NPSIL,FLAG
      DIMENSION TITLE(10),XLABEL(10),NLABEL(10),PSILABE(10)
C
      PRINT 10
10    FORMAT ("0 I",7X,"PROF",7X,"X",7X,"N",10X,"P",7X,"PSI",8X,
     +    "MN",10X,"MP",10X,"JN",10X,"JP",8X,"JDISP",7X,"JTOT",7X,"U"/)
      IWS3=NMESH/50+1
      IF ( TEST(4) .EQ. 1 )  IWS3=1
C
C     UNLESS SYSTEM SWITCH(4) IS SET, ONLY ENOUGH MESH POINTS ARE OUTPUT
C     TO FILL ONE LINEPRINTER PAGE.
C
      NMESHP1=NMESH+1
15    DO 20 I=1,NMESHP1,IWS3
        JDISP=0.
        IF ( T .GT. 0.  .AND.  I .NE. 1 )
     +      JDISP=(PSI(I)-PSI(I-1)-PSIK(I)+PSIK(I-1))/TAU/(X(I)-X(I-1))
        JTOT=(JN(I)+JP(I)+JNK(I)+JPK(I))/2.+JDISP
        IF ( I .EQ. 2 )  JRESIS=JTOT
        IF ( I .EQ. IXT )  WS80=JTOT*JFAC
20      PRINT 25,I-1,PROF(I)*NFAC,X(I)*LFAC*1.E4,N(I)*NFAC,P(I)*NFAC,
     +      PSI(I)*VFAC,MN(I)*MFAC,MP(I)*MFAC,JN(I)*JFAC,JP(I)*JFAC,
     +      JDISP*JFAC,JTOT*JFAC,U(I)*UFAC
25    FORMAT (I4,2E24.16,2E35.27/E39.27,13X,2E24.16/4X,5E24.16/)
      IF ( TEST(5) .EQ. 0 )  GOTO 900
C
C
C     VERSATEC PLOTTING ROUTINE.
C     ***************************
C
      IXMN=0.
      IXMX=XL
      INMN=-5.-ALOG10(NFAC)
      INMX=23.-ALOG10(NFAC)
      IPSIMN=VESS-5.0/VFAC
      IPSIMX=VCSS+5.0/VFAC
      OXMN=0.0
      OXMX=8.
      OYMN=0.02
      OYMX=7.1
      XMR=.084*(OXMX-OXMN)
      YMR=.095*(OYMX-OYMN)
      XRNG=OXMX-OXMN-2.*XMR
      YRNG=OYMX-OYMN-2.*YMR
      XSC=(IXMX-IXMN)/XRNG
      NSC=(INMX-INMN)/YRNG
      PSISC=(IPSIMX-IPSIMN)/YRNG
      SCS=0.1*XMR
      FLAG=0
      HGT=.1*XMR
      NT=40
      NTTT=NT*2
      GOTO 100
30    FLAG=1
C
C     PLOT OUTSIDE BORDER OF GRAPH WITH PEN 9.
C
      CALL PLOT(OXMX+2.*XMR,0.,-3)
      CALL NEWPEN(9)
      CALL PLOT(OXMN,OYMN,3)
      CALL PLOT(OXMN,OYMX,2)
      CALL PLOT(OXMX,OYMX,2)
      CALL PLOT(OXMX,OYMN,2)
      CALL PLOT(OXMN,OYMN,2)
C
C     PLOT INSIDE BORDER OF GRAPH WITH PEN 3.
C
      CALL NEWPEN(2)
      CALL PLOT(OXMN+XMR,OYMN+YMR,3)
      CALL PLOT(OXMN+XMR,OYMX-YMR,2)
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      CALL PLOT(OXMX-XMR,OYMX-YMR,2)
      CALL PLOT(OXMX-XMR,OYMN+YMR,2)
      CALL PLOT(OXMN+XMR,OYMN+YMR,2)
C
C     PLOT HEADING.
C
      IF ( T .NE. -3. )  GOTO 35
      ENCODE (NT,31,TITLE(1))
31    FORMAT (40HN,P,PSI VS. X   (INITIAL EST,STEADY STAT))
      CALL LETTER(NT,2.*HGT,0.0,OXMN+.5*(OXMX-OXMN)-NT*HGT,
     +   OYMX-.5*YMR-HGT,TITLE)
      GOTO 45
35    IF ( T .NE. -2. )  GOTO 40
      ENCODE (NT,36,TITLE(1))
36    FORMAT (40HN,P,PSI VS. X   (STEADY STAT,T=            ))
      CALL LETTER(NT,2.*HGT,0.0,OXMN+.5*(OXMX-OXMN)-NT*HGT,
     +   OYMX-.5*YMR-HGT,TITLE)
      ENCODE (NTTT,37,TITLE(1))
37    FORMAT (74X,4HPSEC,2X)
      CALL LETTER(2*NT,HGT,0.0,OXMN+.5*(OXMX-OXMN)-NT*HGT,
     +   OYMX-.5*YMR-HGT,TITLE)
      GOTO 45
40    IF ( T .LT. 0. )  GOTO 45
      ENCODE (NT,41,TITLE(1)) IFIX(T*1.E12*TFAC+.5)
41    FORMAT (18HN,P,PSI VS. X   (T=,I6,16H    ,T=            ))
      CALL LETTER(NT,2.*HGT,0.0,OXMN+.5*(OXMX-OXMN)-NT*HGT,
     +   OYMX-.5*YMR-HGT,TITLE)
      ENCODE (NTTT,42,TITLE(1))
42    FORMAT (50X,4HPSEC,20X,4HPSEC,2X)
      CALL LETTER(2*NT,HGT,0.0,OXMN+.5*(OXMX-OXMN)-NT*HGT,
     +   OYMX-.5*YMR-HGT,TITLE)
      IF ( TAU .LT. 1.E19 )  GOTO 45
      ENCODE (NTTT,43,TITLE(1))
43    FORMAT (36X,13HMONITOR POINT,31X)
      CALL LETTER(2*NT,HGT,0.0,OXMN+.5*(OXMX-OXMN)-NT*HGT,
     +   OYMX-.80*YMR-.5*HGT,TITLE)
C
C     PLOT X AXIS LABEL.
C
45    NXL=15
      ENCODE (NXL,46,XLABEL(1))
46    FORMAT (15HX (MICROMETERS))
      CALL LETTER(NXL,HGT,0.0,OXMN+.5*(OXMX-OXMN)-.5*NXL*HGT,
     +   OYMN+.35*YMR-.5*HGT,XLABEL)
C
C     PLOT N AXIS LABEL.
C
      NNL=17
      ENCODE (NNL,47,NLABEL(1))
47    FORMAT (17HLOG(N,P) (CM**-3))
      CALL LETTER(NNL,HGT,90.,OXMN+.25*XMR+.5*HGT,
     +   OYMN+.5*(OYMX-OYMN)-.5*NNL*HGT,NLABEL)
C
C     PLOT PSI AXIS LABEL.
C
      NPSIL=11
      ENCODE (NPSIL,48,PSILABE(1))
48    FORMAT (11HPSI (VOLTS))
      CALL LETTER(NPSIL,HGT,90.,OXMX-.25*XMR+.5*HGT,
     +   OYMN+.5*(OYMX-OYMN)-.5*NPSIL*HGT,PSILABE)
C
C     PLOT X AXIS SCALE.
C
      NXD=(IXMX-IXMN)*LFAC*1.E4
      I=-1
50       I=I+1
         ENCODE (3,52,XLABEL) I
52       FORMAT (I3)
         CALL LETTER(3,HGT,0.0,OXMN+XMR+I*XRNG/NXD-2*HGT,
     +      OYMN+.80*YMR-.5*HGT,XLABEL)
         CALL PLOT(OXMN+XMR+I*XRNG/NXD,OYMN+YMR,3)
         CALL PLOT(OXMN+XMR+I*XRNG/NXD,OYMN+YMR+SCS,2)
         IF ( I .LE. NXD-.99 )  GOTO 50
C
C     PLOT N AXIS SCALE.
C
      NND=INMX-INMN+.1
      IWS3=INMN+ALOG10(NFAC)
      I=-1
60       I=I+1
         ENCODE (3,62,NLABEL) IWS3+I
62       FORMAT (I3)
         CALL LETTER(3,HGT,0.0,OXMN+.70*XMR-1.5*HGT,
     +      OYMN+YMR+I*YRNG/NND-.5*HGT,NLABEL)
         CALL PLOT(OXMN+XMR,OYMN+YMR+I*YRNG/NND,3)
         CALL PLOT(OXMN+XMR+SCS,OYMN+YMR+I*YRNG/NND,2)
         IF ( I .LE. NND-.99 )  GOTO 60
```

```
C
C       PLOT PSI AXIS SCALE.
C
        NPSID=VFAC*(IPSIMX-IPSIMN)/10.+.1
        I=-1
70          I=I+1
            ENCODE (5,72,PSILABE) IPSIMN*VFAC+I*10.
72          FORMAT (F5.1)
            CALL LETTER(5,HGT,0.0,OXMX-.70*XMR-2.5*HGT,
     +         OYMN+YMR+I*YRNG/NPSID-.5*HGT,PSILABE)
            CALL PLOT(OXMX-XMR,OYMN+YMR+I*YRNG/NPSID,3)
            CALL PLOT(OXMX-XMR-SCS,OYMN+YMR+I*YRNG/NPSID,2)
            IF ( I .LE. NPSID-.99 )  GOTO 70
C
        GOTO 150
100     CALL NEWPEN(1)
        IF ( T .LT. 0. )  GOTO 150
C
C       PLOT TIME IN PREVIOUS PLOT HEADING.
C
        ENCODE (40,105,TITLE(1)) IFIX(T*1.E12*TFAC+.5)
105     FORMAT (30X,I6,4X)
        CALL LETTER(40,2.*HGT,0.0,.5*OXMX-NT*HGT,OYMX-.5*YMR-HGT,TITLE)
110     IF ( TAU .LT. 1.E19 )  GOTO 150
C
C       PLOT "MONITOR POINT" UNDERNEATH PREVIOUS PLOT HEADING.
C
        ENCODE (NTTT,120,TITLE(1))
120     FORMAT (60X,13HMONITOR POINT,7X)
        CALL LETTER(2*NT,HGT,0.0,OXMN+.5*(OXMX-OXMN)-NT*HGT,
     +     OYMX-.80*YMR-.5*HGT,TITLE)
C
C       PLOT N VS. X.
C
150     NPLTP=NMESH
        INPLTP=NPLTP
        CALL PLOT((X(1)-IXMN)/XSC+OXMN+XMR,
     +     (DLOG10(N(1))-INMN)/NSC+OYMN+YMR,3)
        DO 160 I=1,INPLTP
            J=I/NPLTP*NMESH+1.1
            CALL PLOT((X(J)-IXMN)/XSC+OXMN+XMR,
     +         (DLOG10(N(J))-INMN)/NSC+OYMN+YMR,2)
160         CONTINUE
C
C       PLOT P VS. X.
C
        CALL PLOT((X(1)-IXMN)/XSC+OXMN+XMR,
     +     (DLOG10(P(1))-INMN)/NSC+OYMN+YMR,3)
        DO 170 I=1,INPLTP
            J=I/NPLTP*NMESH+1.1
            CALL PLOT((X(J)-IXMN)/XSC+OXMN+XMR,
     +         (DLOG10(P(J))-INMN)/NSC+OYMN+YMR,2)
170         CONTINUE
C
C       PLOT PSI VS. X.
C
        CALL PLOT((X(1)-IXMN)/XSC+OXMN+XMR,
     +     (PSI(1)-IPSIMN)/PSISC+OYMN+YMR,3)
        DO 180 I=1,INPLTP
            J=I/NPLTP*NMESH+1.1
            CALL PLOT((X(J)-IXMN)/XSC+OXMN+XMR,
     +         (PSI(J)-IPSIMN)/PSISC+OYMN+YMR,2)
180         CONTINUE
        IF ( FLAG .EQ. 0 )  GOTO 30
C
C
C       OUTPUT A PUNCHED DECK OF THE STEADY STATE SOLUTION IF TEST(15)=1.
C
900     IF (.NOT.( (TEST(15).EQ.1) .AND. ( ((T.EQ.-2).AND.(TEST(3).EQ.0))
     +     .OR. (T.EQ.-1) ) ))  GOTO 1330
        WRITE (7,1310) NMESH
1310    FORMAT (I8,4(E18.10))
        DO 1320 I=1,NMESHP1
1320        WRITE (7,1310) I,X(I)*LFAC*1.E4,N(I)*NFAC,P(I)*NFAC,PSI(I)*VFAC
1330    IF ( (TEST(23) .NE. 1) .OR. (T.EQ.-3) )  GOTO 1500
        HT1=T
        IF ( HT1 .LT. 0. )  HT1=0.
        I=IXT
        WRITE (7,1310) IXT,HT1*TFAC,POWER*TIMEFAC,WS80,X(I)*LFAC*1.E4
1500    RETURN
        END
```

```
C
C
      SUBROUTINE POISSON
      SOLVES THE POISSON EQUATION. ONLY ONE CORRECTION USED HERE.
C
C
      COMMON DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST(30),IXT,
     +   ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +   VSATP,XL,XO,ACOLL,BCOLL,CCOLL,XCMAX,XCMIN,XEFLAT,XEGAUS,
     +    XOPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,EFMAX,XM,PBI,
     +    PVN,XIMG,VIFAC,NA,
     +   CVOLTS(20),DFSPL(4),DFSPH(4),DX(201),EVOLTS(20),HN(201),
     +   HP(201),HPSI(201),INPROF(201),INPROFG(201),INX(201),
     +   JN(201),JNK(201),JP(201),JPK(201),MI1(201),MI2(201),
     +   MI3(201),MN(201),MP(201),PROF(201),PROFG(201),SP(4),
     +   SSTIME(20),TATIME(100),TVTIME(20),U(201),UK(201),X(201),
     +    PAV(201),PIMG(201),
     +   N(201),NK(201),P(201),PK(201),PSI(201),PSIK(201),PSIOLD(201)
      INTEGER DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST,IXT
      REAL ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +    VSATP,XL,XO,XOPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,
     +    EFMAX,XM,PBI,PVN,XIMG,VIFAC,HT1,NA
      REAL CVOLTS,DFSPL,DFSPH,DX,EVOLTS,HN,HP,HPSI,INPROF,INPROFG,
     +   INX,JN,JNK,JP,JPK,MI1,MI2,MI3,MN,MP,PROF,PROFG,SP,SSTIME,
     +    TATIME,TVTIME,U,UK,X,PAV,PIMG
      DOUBLE N,NK,P,PK,PSI,PSIK,PSIOLD
C
      DOUBLE PRECISION A(201),B(201),C(201),D(201),M1,M2,M3,WS1,WS2,
     +   WS3,WS4,WS5
      PF=1.
C        FULLY PRESENT CYCLE CHARGE USED.
      DO 100 I=2,NMESH
         M1=MI1(I)
         M2=MI2(I)
         M3=MI3(I)
      WS1=DX(I)
      WS2=DX(I+1)
         A(I)=1./WS1-M1*PF*(N(I-1)+P(I-1))
         B(I)=-1./WS1-1./WS2-M2*PF*(N(I)+P(I))
         C(I)=1./WS2-M3*PF*(N(I+1)+P(I+1))
100      D(I)=M1*(N(I-1)-P(I-1)-PROF(I-1))+M2*(N(I)-P(I)-PROF(I))+
     +        M3*(N(I+1)-P(I+1)-PROF(I+1))+(PSI(I)-PSI(I-1))/WS1-
     +        (PSI(I+1)-PSI(I))/WS2
      C(2)=C(2)/B(2)
      D(2)=D(2)/B(2)
      DO 200 I=3,NMESH
         WS1=B(I)-A(I)*C(I-1)
         C(I)=C(I)/WS1
200      D(I)=(D(I)-A(I)*D(I-1))/WS1
      WS1=0.
      I=NMESH
300      WS1=D(I)-C(I)*WS1
         PSI(I)=PSI(I)+WS1
         I=I-1
         IF ( I .GE. 2 )  GOTO 300
280   RETURN
      END
C
C
      SUBROUTINE PROFILE
      THIS PROCEDURE DETERMINES PROFILE FOR MESH BEING USED, EITHER BY QUADRATIC
      INTERPOLATION FROM INPUT PROFILE, OR FROM AN ALGORITHM.
C
C
C
      COMMON DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST(30),IXT,
     +   ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +   VSATP,XL,XO,ACOLL,BCOLL,CCOLL,XCMAX,XCMIN,XEFLAT,XEGAUS,
     +    XOPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,EFMAX,XM,PBI,
     +    PVN.XIMG.VIFAC.NA.
```

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     +   CVOLTS(20),DFSPL(4),DFSPH(4),DX(201),EVOLTS(20),HN(201),
     +   HP(201),HPSI(201),INPROF(201),INPROFG(201),INX(201),
     +   JN(201),JNK(201),JP(201),JPK(201),MI1(201),MI2(201),
     +   MI3(201),MN(201),MP(201),PROF(201),PROFG(201),SP(4),
     +   SSTIME(20),TATIME(100),TVTIME(20),U(201),UK(201),X(201),
     +     PAV(201),PIMG(201),
     +   N(201),NK(201),P(201),PK(201),PSI(201),PSIK(201),PSIOLD(201)
      INTEGER DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +     TVINDEX,TEST,IXT
      REAL ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +     VSATP,XL,X0,XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,
     +     EFMAX,XM,PBI,PVN,XIMG,VIFAC,HT1,NA
      REAL CVOLTS,DFSPL,DFSPH,DX,EVOLTS,HN,HP,HPSI,INPROF,INPROFG,
     +   INX,JN,JNK,JP,JPK,MI1,MI2,MI3,MN,MP,PROF,PROFG,SP,SSTIME,
     +     TATIME,TVTIME,U,UK,X,PAV,PIMG
      DOUBLE N,NK,P,PK,PSI,PSIK,PSIOLD
      REAL LNPRFIN,LNPRFCO
C
      PROFMAX=0.
C
C     IF TEST(17)=0, INTERPOLATE PROFILE FROM INPUT VALUES.
C
      IF ( TEST(17) .EQ. 1 )  GOTO 800
      PROF(1)=-EXP(INPROF(1))
      PROF(NMESH+1)=EXP(INPROF(MESHIN+1))
      PROFG(1)=EXP(INPROFG(1))
      PROFG(NMESH+1)=EXP(INPROFG(MESHIN+1))
      DO 50 I=2,NMESH
         WS3=XL
         XX=X(I)
         K=2
         DO 10 J=2,MESHIN
            IF ( ABS(XX-INX(J)) .GE. WS3 )  GOTO 20
            WS3=ABS(XX-INX(J))
10          K=J
20       X0=INX(K-1)
         X1=INX(K)
         X2=INX(K+1)
         WS1=((X1-XX)*(X2-XX))/((X1-X0)*(X2-X0))
         WS2=((X2-XX)*(X0-XX))/((X2-X1)*(X0-X1))
         WS3=((X0-XX)*(X1-XX))/((X0-X2)*(X1-X2))
         IF ( K .GE. TEST(30) )  GOTO 30
         PROF(I)=-EXP(WS1*INPROF(K-1)+WS2*INPROF(K)+WS3*INPROF(K+1))
         GOTO 45
30       IF ( K .LE. TEST(30)+1)  GOTO 40
         PROF(I)=EXP(WS1*INPROF(K-1)+WS2*INPROF(K)+WS3*INPROF(K+1))
         GOTO 45
40       PROF(I)=-WS1*EXP(INPROF(K-1))+
     +      (K-TEST(30)-.5)*2.*WS2*EXP(INPROF(K))+WS3*EXP(INPROF(K+1))
45       PPOFMAX=AMAX1(PROFMAX,ABS(PROF(I)))
50       PROFG(I)=EXP(WS1*INPROFG(K-1)+WS2*INPROFG(K)+WS3*INPROFG(K+1))
      GOTO 850
C
C     IF TEST(17)=1, DETERMINE PROFILE FROM ALGORITHM.
C
800   LNPRFIN=ALOG(PROFINT)
      LNPRFCO=ALOG(PROFCOL)
      WS1=(EXP((XCMIN-BCOLL)/CCOLL)+1.)**ACOLL
      WS2=(EXP((XCMAX-BCOLL)/CCOLL)+1.)**ACOLL
      DO 830 I=1,NMESHP1
         IF ( X(I) .GE. XCMIN )  GOTO 810
         PROF(I)=EXP(-((X(I)-XEFLAT)/XEGAUS)**2.)*
     +      (PROFEM-PROFINT)+PROFINT
         IF ( X(I) .LT. XEFLAT )  PROF(I)=PROFEM
         GOTO 830
810      IF ( X(I) .GE. XCMAX )  GOTO 820
         WS3=(EXP((X(I)-BCOLL)/CCOLL)+1.)**ACOLL
         PROF(I)=EXP((WS1-WS3)/(WS1-WS2)*(LNPRFCO-LNPRFIN)+LNPRFIN)
         GOTO 830
820      PROF(I)=PROFCOL
830      PROFG(I)=ABS(PROF(I))
850   PROFMAX=AMAX1(PROFMAX,ABS(PROF(1)),ABS(PROF(NMESH+1)))
      IPPLUS=JCN=0
      INPLUS=NMESH
C
C     DETERMINES XM AND XDPLE LOCATION FOR SCHOTTKY.
C
      IF ( TEST (20) .NE. 2 )  GOTO 856
      WS11=0
      IWS1=1
      IF (X(2)-XM .GE. 0. )  GOTO 857
      DO 855 I=2,NMESHP1
      WS11=X(I)-XM
      IF ( IWS1 .NE. 1 )  GOTO 855
      IF ( WS11 .GE. 0 )  IWS1=I-1
855   CONTINUE
857   CONTINUE
      IPPLUS=IWS1
      GOTO 885
856   CONTINUE
```

```
C
      DO 880 I=2,NMESH
         IF ( IPPLUS .NE. 0 )  GOTO 860
      IF ( PROF(I) .GT. -EPI )  IPPLUS=I-2
860      IF ( JCN .NE. 0 )  GOTO 870
         IF ( PROF(I)*PROF(I-1) .LT. 0. .OR. PROF(I) .EQ. 0. ) JCN=I-2
870      IF ( INPLUS .NE. NMESH )  GOTO 880
         IF ( PROF(I) .GT. EPI )  INPLUS=I-1
880      CONTINUE
C
C     IPPLUS IS THE POINT AT WHICH WE CONSIDER REGION TO BE P+.
C     JCN IS THE POINT WHERE THE DOPING CHANGES SIGN I.E. THE JUNCTION.
C     INPLUS IS THE POINT AT WHICH WE CONSIDER REGION TO BE N+.
C
C
C     CALCULATES THE DEPLETION LAYER WIDTH USING ONE-SIDED ABRUPT JUNCTION.
C
       IF ( TEST(20) .NE. 1 )  GOTO 895
      PSINT=ALOG(-PROFEM*PROFINT)
      XDPLE=SQRT(2.0*(PSINT-VE+VC)/PROFINT)
C
885   WS11=0
      WS12=X(IPPLUS)+XDPLE
      IF ( WS12 .GE. XL )  GOTO 895
      IWS1=IPPLUS
      DO 890 I=IPPLUS,NMESHP1
         WS11=X(I)-WS12
         IF ( IWS1 .NE. IPPLUS )  GOTO 890
         IF (WS11 .GE. 0. )  IWS1=I-1
890      CONTINUE
      INPLUS=IWS1
C
C     INPLUS REDEFINED AS LOCATION OF DEPLETION REGION.
C
895   CONTINUE
      PRINT 900,IPPLUS,JCN,INPLUS
900   FORMAT ("0IPPLUS   = ",I5/
     +   " JCN      = ",I5/
     +   " INPLUS   = ",I5)
      RETURN
      END



C
C
      SUBROUTINE REMESH
C     THIS PROCEDURE CALCULATES A NEW SPATIAL MESH DISTRIBUTION FOR THE
C     PROBLEM SUCH THAT A GIVEN QUANTITY HAS EVENLY DISTRIBUTED STEPS
C     OVER THE MESH.  HERE POTENTIAL IS USED.
C
      COMMON DIVSUM, INDEX, INPLUS, INXJCN, IPPLUS, JCN, IWS1, IWS2, IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +     TVINDEX,TEST(30),IXT,
     +   ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +   VSATP,XL,X0,ACOLL,BCOLL,CCOLL,XCMAX,XCMIN,XEFLAT,XEGAUS,
     +     XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,EFMAX,XM,PBI,
     +     PVN,XIMG,VIFAC,NA,
     +   CVOLTS(20),DFSPL(4),DFSPH(4),DX(201),EVOLTS(20),HN(201),
     +   HP(201),HPSI(201),INPROF(201),INPROFG(201),INX(201),
     +   JN(201),JNK(201),JP(201),JPK(201),MI1(201),MI2(201),
     +   MI3(201),MN(201),MP(201),PROF(201),PROFG(201),SP(4),
     +   SSTIME(20),TATIME(100),TVTIME(20),U(201),UK(201),X(201),
     +     PAV(201),PIMG(201),
     +   N(201),NK(201),P(201),PK(201),PSI(201),PSIK(201),PSIOLD(201)
      INTEGER DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +     TVINDEX,TEST,IXT
      REAL ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +     VSATP,XL,X0,XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,
     +     EFMAX,XM,PBI,PVN,XIMG,VIFAC,HT1,NA
      REAL CVOLTS,DFSPL,DFSPH,DX,EVOLTS,HN,HP,HPSI,INPROF,INPROFG,
     +   INX,JN,JNK,JP,JPK,MI1,MI2,MI3,MN,MP,PROF,PROFG,SP,SSTIME,
     +     TATIME,TVTIME,U,UK,X,PAV,PIMG
      DOUBLE N,NK,P,PK,PSI,PSIK,PSIOLD
C
      REAL A(201),B(201),C(201),D(201),E(201),F(201),K(201)
C
```

```
      QTTYSUM=X0=0.
      K(1)=0.
      WS1=DLOG(N(1))
      WS2=DLOG(P(1))
      WS6=ALOG(1.E20/NFAC)-ALOG(1.E-2/NFAC)
      WS7=VCSS-VESS
      NMESHP1=NMESH+1
      DO 40  I=2,NMESHP1
         WS3=DLOG(N(I))
         WS4=DLOG(P(I))
         WS5=PSI(I)-PSI(I-1)
         K(I)=K(I-1)+ABS(WS3-WS1)/WS6+ABS(WS4-WS2)/WS6+ABS(WS5)/WS7
         WS1=WS3
40       WS2=WS4
C           ANOTHER QUANTITY MAY BE CHOSEN BY CHANGING THESE LINES.
      QTTYSUM=K(NMESHP1)
      DQTTY=QTTYSUM/NMESH
      DIVSUM=0
      INDEX=NMESH
60    DQTTY=DQTTY*(INDEX+DIVSUM)/NMESH
      J=1
      INDEX=0
      DO 240  I=2,NMESH
         IF ( (I-1)*DQTTY .GE. QTTYSUM )  GOTO 250
         GOTO 90
80          J=J+1
90          IF ( (I-1)*DQTTY .GT. K(J+1) )  GOTO 80
            INDEX=INDEX+1
            F(INDEX+1)=X(J)+((I-1)*DQTTY-K(J))/(K(J+1)-K(J))*
     +         (X(J+1)-X(J))
240      CONTINUE
250   INDEX=INDEX+1
      DIVSUM=0
      F(1)=0.
      F(INDEX+1)=XL
      INDEXP1=INDEX+1
      DO 300  I=2,INDEXP1
         B(I)=IFIX((F(I)-F(I-1))/(3.0*H))
C        MAX STEP OF 1.5*ORIGINAL ALLOWED.
300      DIVSUM=DIVSUM+B(I)
      IF ( DIVSUM+INDEX .NE. NMESH )  GOTO 60
C
      K(NMESH+1)=X0=XL
      LOC=NMESH
      I=INDEX+1
340      J=B(I)
         K(LOC+1)=F(I)
         X0=K(LOC+1)
         LOC=LOC-1
         IF ( J .LE. 0 )  GOTO 450
            FRAC=(F(I)-F(I-1))/(J+1)
            JP1=J+1
            DO 440  JK=2,JP1
               K(LOC+1)=X0-FRAC
               X0=K(LOC+1)
440            LOC=LOC-1
450      I=I-1
         IF ( I .GE. 2 )  GOTO 340
C
      INDEXP2=INDEX+2
      NMESHP1=NMESH+1
      DO 490  I=INDEXP2,NMESHP1
         F(I)=-H
490      B(I)=-1.
      B(1)=-1.
C
C     IF TEST(11)=1, PRINT REMESH OUTPUT.
C
      IF ( TEST(11) .EQ. 0 )  GOTO 555
      PRINT 520
520   FORMAT("0REDISTRIBUTED X VALUES"/3X,"I",8X,"F(I)/H",5X,
     +  "DIVISOR(I)",4X,"K(I)/H",4X,"(K(I)-K(I-1))/H")
      DO 540  I=2,NMESHP1
540      PRINT 550,I-1,F(I)/H,IFIX(B(I)),K(I)/H,(K(I)-K(I-1))/H
550      FORMAT (I5,6X,F7.2,8X,I3,7X,F7.2,7X,F7.5)
555   PRINT 580,INDEX,DIVSUM
580   FORMAT ("0REMESH COMPLETED.  INDEX=",I4,"    DIVSUM=",I4)
C
C     INTERPOLATE AT NEW X VALUES.
C
      DO 800 I=2,NMESH
         XX=K(I)
         IWS4=0
         X0=XL
         IMIN=1
         IMIN1=IMIN+1
650      DO 700  J=IMIN1,NMESHP1
            WS2=ABS(XX-X(J))
            IF ( WS2 .LE. X0 )  GOTO 700
            IMIN=J-2
            IWS4=1
            GO TO 710
```

```
700         X0=WS2
710      IF ( IWS4 .EQ. 0 )  IMIN=NMESH-1
C           NO POINT FOUND THEREFORE NEAREST TO ENDPOINT.
         X0=X(IMIN)
         X1=X(IMIN+1)
         X2=X(IMIN+2)
         WS1=((X1-XX)*(X2-XX))/((X1-X0)*(X2-X0))
         WS2=((X2-XX)*(X0-XX))/((X2-X1)*(X0-X1))
         WS3=((X0-XX)*(X1-XX))/((X0-X2)*(X1-X2))
         A(I)=DEXP(WS1*DLOG(N(IMIN))+WS2*DLOG(N(IMIN+1))+
     +      WS3*DLOG(N(IMIN+2)))
         B(I)=DEXP(WS1*DLOG(P(IMIN))+WS2*DLOG(P(IMIN+1))+
     +      WS3*DLOG(P(IMIN+2)))
         C(I)=WS1*PSI(IMIN)+WS2*PSI(IMIN+1)+WS3*PSI(IMIN+2)
         D(I)=DEXP(WS1*DLOG(NK(IMIN))+WS2*DLOG(NK(IMIN+1))+
     +      WS3*DLOG(NK(IMIN+2)))
         E(I)=DEXP(WS1*DLOG(PK(IMIN))+WS2*DLOG(PK(IMIN+1))+
     +      WS3*DLOG(PK(IMIN+2)))
         F(I)=WS1*PSIK(IMIN)+WS2*PSIK(IMIN+1)+WS3*PSIK(IMIN+2)
         HN(I)=WS1*JNK(IMIN)+WS2*JNK(IMIN+1)+WS3*JNK(IMIN+2)
800      HP(I)=WS1*JPK(IMIN)+WS2*JPK(IMIN+1)+WS3*JPK(IMIN+2)
      DO 880 I=2,NMESH
         N(I)=A(I)
         P(I)=B(I)
         PSI(I)=C(I)
         NK(I)=D(I)
         PK(I)=E(I)
         PSIK(I)=F(I)
         JNK(I)=HN(I)
         JPK(I)=HP(I)
         X(I)=K(I)
880      DX(I)=X(I)-X(I-1)
C
      CALL PROFILE
C
      DO 900 I=2,NMESH
         WS11=DX(I)
         WS12=DX(I+1)
         WS13=WS11*WS11
         WS14=WS11*WS12
         WS15=WS12*WS12
         MI1(I)=(WS13+2.*(WS14-WS15))/24./WS11
         MI3(I)=(WS15+2.*(WS14-WS13))/24./WS12
900      MI2(I)=(WS11+WS12)/2.-MI1(I)-MI3(I)
      RETURN
      END


C
C
      SUBROUTINE SYSTEMS
C     ITERATES PSI,N,P TO SOLUTION DICTATED BY TOLERANCES.
C
      COMMON DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST(30),IXT,
     +   ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +   VSATP,XL,X0,ACOLL,BCOLL,CCOLL,XCMAX,XCMIN,XEFLAT,XEGAUS,
     +    XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,EFMAX,XM,PBI,
     +    PVN,XIMG,VIFAC,NA,
     +   CVOLTS(20),DFSPL(4),DFSPH(4),DX(201),EVOLTS(20),HN(201),
     +   HP(201),HPSI(201),INPROF(201),INPROFG(201),INX(201),
     +   JN(201),JNK(201),JP(201),JPK(201),MI1(201),MI2(201),
     +   MI3(201),MN(201),MP(201),PROF(201),PROFG(201),SP(4),
     +   SSTIME(20),TATIME(100),TVTIME(20),U(201),UK(201),X(201),
     +    PAV(201),PIMG(201),
     +   N(201),NK(201),P(201),PK(201),PSI(201),PSIK(201),PSIOLD(201)
      INTEGER DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +    TVINDEX,TEST,IXT
      REAL ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +    VSATP,XL,X0,XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,
     +    EFMAX,XM,PBI,PVN,XIMG,VIFAC,HT1,NA
      REAL CVOLTS,DFSPL,DFSPH,DX,EVOLTS,HN,HP,HPSI,INPROF,INPROFG,
     +   INX,JN,JNK,JP,JPK,MI1,MI2,MI3,MN,MP,PROF,PROFG,SP,SSTIME,
     +    TATIME,TVTIME,U,UK,X,PAV,PIMG
      DOUBLE N,NK,P,PK,PSI,PSIK,PSIOLD
C
```

```
C       IWS1=NO. OF ITERATION.
C       IWS2=PRESENT MAX. POINT.
C       IWS6=NO. OF POSITIVE POINTS.
C
        DPSIMAX=DPSIAVE=DPSISD=0.
        IWS1=0
        WS20=.2E-8
C
C       SET UP ITERATION LIMIT.
        IF ( TEST(19) .EQ. 0 )  GOTO 150
        IF ( TEST(19) .EQ. 1 )  ILIMIT=100
        IF ( TEST(19) .EQ. 2 )  ILIMIT=200
        IF ( TEST(19) .EQ. 3 )  ILIMIT=300
        IF ( TEST(19) .EQ. 4 )  ILIMIT=400
        IF ( TEST(19) .EQ. 5 )  ILIMIT=500
C
90      IWS1=IWS1+1
        IF ( IWS1 .LE. ILIMIT )  GOTO 150
         PRINT 100
100     FORMAT (" ITERATION LIMIT EXCEEDED. ")
        PRINT 110, ILIMIT
110     FORMAT ("ILIMIT= ",I5)
        CALL CURRENT
        CALL OUTVALU
        STOP
150     CONTINUE
C
        DO 140 I=1,NMESHP1
140        PSIOLD(I)=PSI(I)
C
        CALL MOBREC
        CALL CARRIER
        CALL POISSON
        CALL POISSON
C
        OLDPSIM=DPSIMAX
        DPSIMAX=DPSIAVE=DPSISD=0.
        IWS6=0
        DO 280 I=1,NMESHP1
           WS1=(PSI(I)-PSIOLD(I))
           IF ( WS1 .GE. 0 )  IWS6=IWS6+1
           IF ( ABS(WS1) .LE. ABS(DPSIMAX) )  GOTO 270
              DPSIMAX=WS1
              IWS2=I-1
270        DPSIAVE=DPSIAVE+WS1
280        DPSISD=DPSISD+WS1*WS1
        DPSIAVE=DPSIAVE/NMESH
        DPSISD=SQRT(DPSISD/NMESH)
C
C       USES OMEGA OPTIMIZATION ROUTINE.
C
        IWS7=0
        IF ( TEST(16) .EQ. 1 .AND. IWS1 .EQ. 1 )  OMEGA=.9
        IF ( TEST(16) .EQ. 0  .OR.  IWS1 .EQ. 1 )  GOTO 290
        IF( OMEGA .GT. 10. )  OMEGA =.9
        IF ( (OLDPSIM-DPSIMAX)/OLDPSIM .LT. 1.  .AND.  OMEGA .LT. 4. )
     +     OMEGA=OMEGA/.7
        IF ( (OLDPSIM-DPSIMAX)/OLDPSIM .GT. 1.  .AND.  OMEGA .GT. .55 )
     +     OMEGA=OMEGA*.7
        IF ( ABS(OLDPSIM) .LT. ABS(DPSIMAX)  .AND.  OMEGA .GT. .9 )
     +     OMEGA=.9
290     IF (ABS(DPSIMAX*VFAC) .GT. 2. ) OMEGA=1./ABS(DPSIMAX)/VFAC
        DO 295 I=1,NMESHP1
           PSI(I)=PSIOLD(I)+OMEGA*(PSI(I)-PSIOLD(I))
295     CONTINUE
C
300     PRINT 310,IWS2,DPSIMAX*VFAC,DPSIAVE*VFAC,DPSISD*VFAC,OMEGA,IWS6
310     FORMAT (I4,6X,3(E11.5,4X),F9.5,I9)
        IF ( T .LE. 0. )  GOTO 330
        IF ( ABS(DPSIMAX*VFAC) .GE. WS20 )  GOTO 330
        WS20=WS20/1.5
        CALL CURRENT
        CALL OUTVALU
        IF ( ABS(DPSIMAX*VFAC) .LE. .264E-9 )  STOP
330     IF ( ABS(DPSIMAX) .GT. EPSDMAX  .OR. ABS(DPSIAVE) .GT. EPSDAVE
     +   .OR.  DPSISD .GT. EPSDSD  .OR. IWS1 .LT. 5 )  GOTO 90
C          FIVE CYCLES MINIMUM.
        CALL MOBREC
        CALL CARRIER
        RETURN
        END
```

```
C
C
      SUBROUTINE VOLTAGE
C     CALCULATES BOUNDARY VOLTAGES AT ANY POINT IN TIME BY LINEAR
C     INTERPOLATION FROM GIVEN DATA VALUES.
C
      COMMON DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +     TVINDEX,TEST(30),IXT,
     +   ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +   VSATP,XL,X0,ACOLL,BCOLL,CCOLL,XCMAX,XCMIN,XEFLAT,XEGAUS,
     +     XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,EFMAX,XM,PBI,
     +     PVN,XIMG,VIFAC,NA,
     +   CVOLTS(20),DFSPL(4),DFSPH(4),DX(201),EVOLTS(20),HN(201),
     +   HP(201),HPSI(201),INPROF(201),INPROFG(201),INX(201),
     +   JN(201),JNK(201),JP(201),JPK(201),MI1(201),MI2(201),
     +   MI3(201),MN(201),MP(201),PROF(201),PROFG(201),SP(4),
     +   SSTIME(20),TATIME(100),TVTIME(20),U(201),UK(201),X(201),
     +     PAV(201),PIMG(201),
     +   N(201),NK(201),P(201),PK(201),PSI(201),PSIK(201),PSIOLD(201)
      INTEGER DIVSUM,INDEX,INPLUS,INXJCN,IPPLUS,JCN,IWS1,IWS2,IWS3,
     +   IWS4,LOC,MESHIN,NMESH,NMESHP1,NSS,NTA,NTV,SSINDEX,TAINDEX,
     +     TVINDEX,TEST,IXT
      REAL ABSCOEF,AREA,BETA,DPSIAVE,DPSIMAX,DPSISD,DQTTY,EPHOTON,
     +   EPI,EPSDAVE,EPSDMAX,EPSDSD,ESAT,ETRAP,G,H,HT,HTAU,HVC,
     +   HVE,INBETA,JDISP,JEST,JFAC,JRESIS,JTOT,LAMBDA,LFAC,MFAC,
     +   NFAC,OMEGA,PF,POWER,PROFCOL,PROFEM,PROFINT,PROFMAX,QNTMEFF,
     +   QTTYSUM,RLOAD,T,TAU,TFAC,TIMEFAC,TPEAK,TRISE,TRN,TRP,
     +   TSTOP,UFAC,VC,VCK,VCSS,VE,VEK,VESS,VFAC,VOLUME,VSATN,
     +     VSATP,XL,X0,XDPLE,PSINT,PBO,PBN,PIT,PM,PEA,PBL,EGAP,PIMGS,
     +     EFMAX,XM,PBI,PVN,XIMG,VIFAC,HT1,NA
      REAL CVOLTS,DFSPL,DFSPH,DX,EVOLTS,HN,HP,HPSI,INPROF,INPROFG,
     +   INX,JN,JNK,JP,JPK,MI1,MI2,MI3,MN,MP,PROF,PROFG,SP,SSTIME,
     +     TATIME,TVTIME,U,UK,X,PAV,PIMG
      DOUBLE N,NK,P,PK,PSI,PSIK,PSIOLD
C
      WS1=.5*JRESIS*RLOAD*JFAC/VFAC
      IF ( NTV .NE. 0 )  GOTO 50
      VC=VCSS+WS1
      VE=VESS-WS1
      RETURN
C
50    IF ( TVTIME(NTV) .GT. T )  GOTO 110
      VC=CVOLTS(NTV)+WS1
      VE=EVOLTS(NTV)-WS1
      RETURN
C
100   TVINDEX=TVINDEX+1
110   IF ( TVTIME(TVINDEX) .LE. T )  GOTO 100
      FRAC=(T-TVTIME(TVINDEX-1))/(TVTIME(TVINDEX)-TVTIME(TVINDEX-1))
      VC=CVOLTS(TVINDEX-1)+FRAC*(CVOLTS(TVINDEX)-CVOLTS(TVINDEX-1))
      VE=EVOLTS(TVINDEX-1)+FRAC*(EVOLTS(TVINDEX)-EVOLTS(TVINDEX-1))
      RETURN
      END
```

APPENDIX H

PROGRAM LISTING OF JPLOT

```
      PROGRAM JPLOT (INPUT,OUTPUT)
C
C     MAIN PROGRAM
C
      COMMON N,TMAX,PMAX,JMAX,RC,R,C,ND,V,XL,AREA
      COMMON/RCT1/POWER(50),JTOT(50),JRC(50),TIME(50)
C
      REAL TIME,POWER,JTOT,JRC,PMAX,JMAX,J,JGEN,RC,K1,K2
     +     ,ND,V,XL
      INTEGER N,IWS1
C
C
C     READ NO. OF SETS OF DATA.
C
      READ 10, NSET
10    FORMAT (I10)
      DO 1000 K=1,NSET
      PRINT 30,K
30    FORMAT (1H1,  " ANALYSIS FOR DATA SET NO. ",I2//)
      PRINT 40
40    FORMAT (" POWER = INPUT LIGHT POWER"/
     +        " JTOT  = SHORT CIRCUIT CURRENT"/
     +        " JRC   = OUTPUT CURRENT"//)
C
      READ 50, R,AREA,XDPLE
      READ 50, ND,V,XL
50    FORMAT (3E10.4)
      ESL=8.854E-14
      ESLS=15.8*ESL
      C=ESLS*AREA/XDPLE/1.E-4
      RC=R*C*1.E+12
C
C     READ IN NO. OF DATA POINTS.
C
      READ 100, N
100   FORMAT (I10)
C
C     READ IN DATA POINTS.
C     DETERMINE MAX VALUES OF INPUTS.
C
      READ 120,IWS1,TIME(1),POWER(1),JTOT(1),X
120   FORMAT(I8,4(E18.10))
      JTOT(1)=ABS(JTOT(1))
      POWER(1)=ABS(POWER(1))
      PRINT 130, IWS1,X
130   FORMAT(" JTOT VS. TIME FOR POINT NO. ",I3//
     +   " POSITION X = ",F10.5," MICROMETERS."//)
      PRINT 135, AREA,XL,ND,V,XDPLE,R,C,RC
135   FORMAT(" AREA        = ",E10.5," CM**2."/
     +       " XL          = ",F10.2," MICROMETERS."/
     +       " ND          = ",E10.5," CM**-3"/
     +       " V           = ",F10.2," VOLTS."/
     +       " XDPLE       = ",F10.2," MICROMETERS."//
     +       " R           = ",F10.2," OHMS."/
     +       " C           = ",E10.2," FARADS."/
     +       " RC          = ",F10.2," PSECS."//)
C
```

```
      PMAX=-9999.
      JMAX=-9999.
      TMAX=-9999.
C
      DO 200 I=2,N
      READ 140,TIME(I),POWER(I),JTOT(I)
140   FORMAT(8X,3(E18.10))
      JTOT(I)=ABS(JTOT(I))
      POWER(I)=ABS(POWER(I))
      IF ( PMAX .LT. POWER(I) )  PMAX=POWER(I)
      IF ( JMAX .LT. JTOT(I) )  JMAX=JTOT(I)
      IF ( TMAX .LT. TIME(I)*1.E12 )  TMAX=TIME(I)*1.E12
200   CONTINUE
      PRINT 220
220   FORMAT (1H1,10X,"TIME(PSEC)",8X,"POWER",10X,"JTOT"//)
C
      DO 300 I=1,N
      IF ( TIME(I) .LT. 0. )  TIME(I)=0.
C
C     NORMALISE BOTH POWER AND CURRENT.
C
      POWER(I)=POWER(I)/PMAX
      JTOT(I)=JTOT(I)/JMAX
C
      TIME(I)=TIME(I)*1.E12
      CALL PLOTPT (TIME(I),POWER(I),10)
      CALL PLOTPT (TIME(I),JTOT(I),4)
300   CONTINUE
C
C     GIVES A LISTING OF THE NORMALIZED DATA.
C
      CALL TABLE (POWER,JTOT,TIME)
C
C     OUTPUT LINEPRINTER PLOT.
C
      CALL OUTPLT
      PRINT 500
500   FORMAT("                    0 DENOTES INPUT POWER "/
     +       "                    * DENOTES SHORT CIRCUIT CURRENT "/)
C
C     CALCULATES FOR RC RESPONSE.
C
      CALL RCTIME
      PRINT 600
600   FORMAT(1H1,10X,"TIME(PSEC)",9X,"JTOT",11X,"JRC"//)
      CALL TABLE (JTOT,JRC,TIME)
      DO 650 I=1,N
      CALL PLOTPT (TIME(I),JRC(I),4)
650   CONTINUE
C
C     OUTPUT LINEPRINTER PLOT.
C
      CALL OUTPLT
      PRINT 660
660   FORMAT("                    * DENOTES OUTPUT CURRENT "/)
      PRINT 670
670   FORMAT(1H1)
C
C
C     GIVES VERSATEC PLOTS.
C
      CALL VPLOT (POWER,JTOT,TIME,1)
      CALL VPLOT (JTOT,JRC,TIME,2)
      CALL VPLOT (POWER,JRC,TIME,3)
      CALL VPLOT (POWER,JRC,TIME,0)
C
1000  CONTINUE
C
C     END THE PLOT FILE.
C
1010  CALL PLOT (0.,0.,999)
C
      STOP
      END
```

```
      SUBROUTINE RCTIME
C
C     CALCULATE FOR RC RESPONSE.
C
      COMMON/RCT1/POWER(50),JTOT(50),JRC(50),TIME(50)
      COMMON N,TMAX,PMAX,JMAX,RC,R,C,ND,V,XL,AREA
      REAL TIME,POWER,JTOT,JRC,PMAX,JMAX,J,JGEN,RC,K1,K2
     +   ,ND,V,XL
C
C     DIFFERENTIAL EQUATION FOR RC CIRCUIT.
C
      FDJ(J,JGEN,RC)=(JGEN-J)/RC
C
C
      JRC(1)=0.0
      J=0.0
      JGEN=0.0
C
      N1=N-1
      DO 1600 K=1,N1
      NSTEP=10
      DT=(TIME(K+1)-TIME(K))/NSTEP
      DJGEN=(JTOT(K+1)-JTOT(K))/NSTEP
      IF ( DT .GT. .1)  GOTO 1300
      DT=(TIME(K+1)-TIME(K))/2.
      DJGEN=(JTOT(K+1)-JTOT(K))/2.
      NSTEP=2
 1300 CONTINUE
      DO 1500 I=1,NSTEP
      K1=DT*FDJ(J,JGEN,RC)
      K2=DT*FDJ(J+K1,JGEN+DJGEN,RC)
      J=J+.5*(K1+K2)
      JGEN=JGEN+DJGEN
 1500 CONTINUE
      JRC(K+1)=J
 1600 CONTINUE
C
      RETURN
      END


      SUBROUTINE TABLE (POWER,JTOT,TIME)
C
C     LIST DATA POINTS, CALCULATE FOR 10-90 PERCENT RISETIMES AND FWHM.
C
      COMMON N,TMAX,PMAX,JMAX,RC,R,C,ND,V,XL,AREA
      DIMENSION POWER(50),JTOT(50),JRC(50),TIME(50)
      REAL TIME,POWER,JTOT,JRC,PMAX,JMAX,J,JGEN,RC,K1,K2
     +   ,ND,V,XL
C
      IWS1=0
      IWS2=0
C
      DO 300 I=1,N
      X=TIME(I)
      Y1=POWER(I)
      Y2=JTOT(I)
C
C     DETERMINES WHEN INPUT AND OUTPUT EXCEED 10 AND 90 PERCENT.
C
      IF ( I .EQ. 1 )  GOTO 248
      IF ( Y1 .EQ. POWER(I-1) )  GOTO 232
      IF ( IWS1 .NE. 0 )  GOTO 225
      IF ( Y1 .GT. 0.1 )  IWS1=1
      TS1=(X-TIME(I-1))*(.1-POWER(I-1))/(Y1-POWER(I-1))+TIME(I-1)
  225 CONTINUE
      IF ( IWS1 .NE. 1 )  GOTO 230
      IF ( Y1 .GT. .5)  IWS1=2
      TM1=(X-TIME(I-1))*(.5-POWER(I-1))/(Y1-POWER(I-1))+TIME(I-1)
  230 CONTINUE
      IF ( IWS1 .NE. 2 )  GOTO 231
      IF ( Y1 .GT. .9 )  IWS1=3
      TF1=(X-TIME(I-1))*(.9-POWER(I-1))/(Y1-POWER(I-1))+TIME(I-1)
  231 CONTINUE
      IF ( IWS1 .NE. 3 )  GOTO 232
      IF ( Y1 .GT. .5 )  GOTO 232
      IWS1=4
      TN1=(X-TIME(I-1))*(.5-POWER(I-1))/(Y1-POWER(I-1))+TIME(I-1)
  232 CONTINUE
      IF ( Y2 .EQ. JTOT(I-1) )  GOTO 242
      IF ( IWS2 .NE. 0 )  GOTO 235
      IF ( Y2 .GT. 0.1 )  IWS2=1
      TS2=(X-TIME(I-1))*(.1-JTOT(I-1))/(Y2-JTOT(I-1))+TIME(I-1)
  235 CONTINUE
      IF ( IWS2 .NE. 1 )  GOTO 240
      IF ( Y2 .GT. .5)  IWS2=2
      TM2=(X-TIME(I-1))*(.5-JTOT(I-1))/(Y2-JTOT(I-1))+TIME(I-1)
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```
240   CONTINUE
      IF ( IWS2 .NE. 2 )  GOTO 241
      IF ( Y2 .GT. .9 )  IWS2=3
      TF2=(X-TIME(I-1))*(.9-JTOT(I-1))/(Y2-JTOT(I-1))+TIME(I-1)
241   CONTINUE
      IF ( IWS2 .NE. 3 )  GOTO 242
      IF ( Y2 .GT. .5 )  GOTO 242
      IWS2=4
      TN2=(X-TIME(I-1))*(.5-JTOT(I-1))/(Y2-JTOT(I-1))+TIME(I-1)
242   CONTINUE
248   CONTINUE
C
      PRINT 250, X,Y1,Y2
250   FORMAT(10X,3(F10.5,5X)/)
300   CONTINUE
C
      JMAX=JMAX*AREA
      POUT=R*JMAX**2
      PRINT 400, PMAX,JMAX,POUT
400   FORMAT(" MAX. INPUT POWER   = ",E10.5," WATTS."/
     +       " MAX. OUTPUT CURRENT= ",E10.5," AMP"/
     +       " MAX. OUTPUT POWER  = ",E10.5," WATTS."//)
C
C     CALCULATES FOR 10-90 PERCENT RISETIMES.
C
      TRISE1=TF1-TS1
      TRISE2=TF2-TS2
      PRINT 450, TRISE1
450   FORMAT(" 10-90 PERCENT INPUT RISETIME = ",F6.2," PSEC.")
      PRINT 460, TRISE2
460   FORMAT(" 10-90 PERCENT OUTPUT RISETIME= ",F6.2," PSEC."//)
C
C     CALCULATES FOR FWHM OF PULSE WHENEVER APPLICABLE.
C
      IF ( IWS1 .NE. 4 )  GOTO 470
      FWHM1=TN1-TM1
      PRINT 465, FWHM1
465   FORMAT (" FWHM OF INPUT PULSE          = ",F6.2," PSEC.")
470   CONTINUE
      IF ( IWS2 .NE. 4 )  GOTO 480
      FWHM2=TN2-TM2
      PRINT 475, FWHM2
475   FORMAT (" FWHM OF OUPUT PULSE          = ",F6.2," PSEC."//)
480   CONTINUE
C
      RETURN
      END


      SUBROUTINE VPLOT (POWER,JTOT,TIME,IOPT)
C
C     VERSATEC PLOTTING ROUTINE.
C
      COMMON N,TMAX,PMAX,JMAX,PC,R,C,ND,V,XL,AREA
      DIMENSION POWER(50),JTOT(50),JPC(50),TIME(50)
      REAL TIME,POWER,JTOT,JRC,PMAX,JMAX,J,JGEN,RC,K1,K2
     +    ,ND,V,XL
C
      IF ( IOPT .EQ. 0 )  GOTO 1020
C
C     DRAW OUTER LIMIT OF PLOTTING AREA WITH PEN 9.
C
      CALL NEWPEN(9)
      CALL PLOT (0.,.02,3)
      CALL PLOT (0.,7.,2)
      CALL PLOT (8.,7.,2)
      CALL PLOT (8.,.02,2)
      CALL PLOT (0.,.02,2)
C
C     SCALE DATA TO ALLOW ONE INCH MARGIN ALL AROUND.
C
      CALL FACTOR (N,TIME,POWER,7.,6.02,1.,1.)
C
C     DETERMINE MIN AND MAX VALUES OF DATA AND DRAW BORDER USING PEN 2.
C
      CALL NEWPEN(2)
      CALL INCHTO (1.0,1.0,XMN,YMN)
      CALL INCHTO (7.,6.02,XMX,YMX)
      CALL PLTLN (XMN,YMN,XMN,YMX)
      CALL PLTLN (XMN,YMX,XMX,YMX)
      CALL PLTLN (XMX,YMX,XMX,YMN)
      CALL PLTLN (XMX,YMN,XMN,YMN)
C
C     PLOT CURVES WITH PEN 4.
C
      CALL NEWPEN(4)
      N1=N-1
      DO 800 I=1,N1
      CALL PLTLN (TIME(I),POWER(I),TIME(I+1),POWER(I+1))
800   CALL PLTLN (TIME(I),JTOT(I),TIME(I+1),JTOT(I+1))
```

```
C
C       PLOT X AXIS LABEL.
C
        CALL LETTER (12,.15,0.0,5.2,.45," TIME (PSEC)")
C
C       PLOT Y AXIS LABEL.
C
        IF ( IOPT .NE. 1 )  GOTO 810
        CALL LETTER (35,.15,90.,0.5,.75," INPUT POWER, SHORT CIRCUIT CURRE
       +NT")
810     CONTINUE
        IF ( IOPT .NE. 2 )  GOTO 820
        CALL LETTER (38,.13,90.,0.5,1.0," SHORT CIRCUIT CURRENT, OUTPUT CU
       +RRENT")
820     CONTINUE
        IF ( IOPT .NE. 3 )  GOTO 830
        CALL LETTER (28,.15,90.,0.5,1.8," INPUT POWER, OUTPUT CURRENT")
830     CONTINUE
C
C       PLOT DIVISIONS ON X AXIS.
C
        CALL NEWPEN(2)
        NX=INT(TMAX/10.)+1
        X1=.85
        DO 900 I=1,NX
        CALL PLOT (X1+.15,1.0,3)
        CALL PLOT (X1+.15,1.1,2)
        IWS0=(I-1)*10
        ENCODE (3,850,XSCALE) IWS0
850     FORMAT(I3)
        IF ( TMAX .GT. 150.)  GOTO 860
        CALL LETTER (3,0.1,0.0,X1,.85,XSCALE)
        GOTO 870
860     CALL LETTER (3,.05,0.0,X1,.85,XSCALE)
870     CONTINUE
        X1=X1+60./TMAX
900     CONTINUE
C
C       PLOT DIVISIONS ON Y AXIS.
C
        Y1=1.0
        DO 1000 I=1,11
        CALL PLOT (1.0,Y1,3)
        CALL PLOT (1.1,Y1,2)
        WS0=(I-1)*0.1
        ENCODE (3,950,YSCALE) WS0
950     FORMAT(F3.1)
        CALL LETTER (3,0.1,0.0,.65,Y1,YSCALE)
        Y1=Y1+0.5
1000    CONTINUE
C
C       PRINT HEADING OF GRAPHS.
C
        ENCODE (8,1002,C1) AREA
        ENCODE (8,1002,C2) ND
        ENCODE (5,1004,C3) R
        ENCODE (5,1004,C4) V
1002    FORMAT (E8.2)
1004    FORMAT (F5.1)
C
        CALL LETTER (33,.10,0.0,2.50,6.70,
       +  " AREA                 =               CM**2  ")
        CALL LETTER (33,.10,0.0,2.50,6.50,
       +  " DOPING DENSITY =               CM**-3")
        CALL LETTER (33,.10,0.0,2.50,6.30,
       +  " RESISTANCE           =               OHMS   ")
        CALL LETTER (33,.10,0.0,2.50,6.10,
       +  " VOLATAGE             =               VOLTS  ")
C
        CALL LETTER (8,0.10,0.0,4.3,6.70,C1)
        CALL LETTER (8,0.10,0.0,4.3,6.50,C2)
        CALL LETTER (5,0.10,0.0,4.3,6.30,C3)
        CALL LETTER (5,0.10,0.0,4.3,6.10,C4)
C
C       END THIS PLOT.
C
        CALL PLOT (.1,.1,-3)
C
1020    RETURN
        END
```

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