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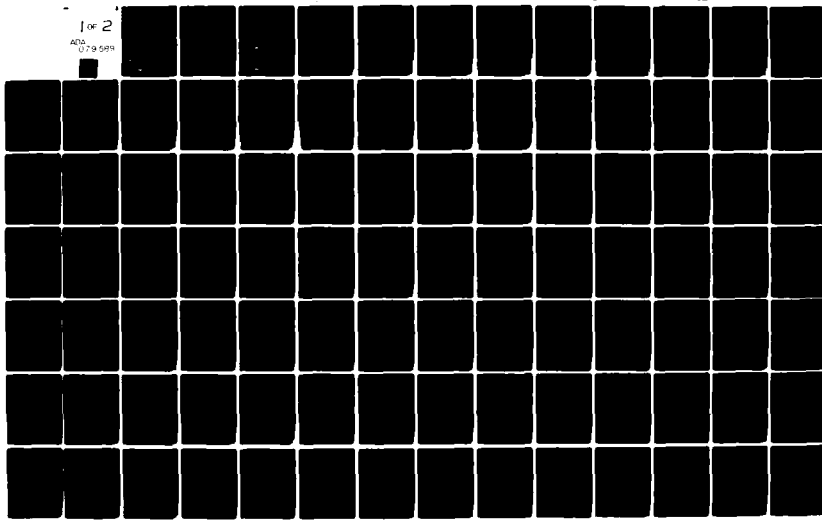
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GAAS ANALOG INTEGRATED CIRCUITS (GAAS RF-LSI). PHASE I. PROGRES--ETC(U)
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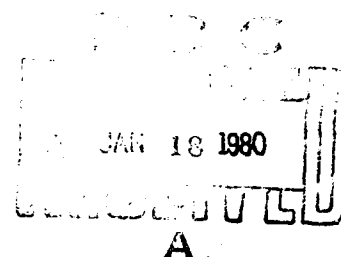
GaAs ANALOG INTEGRATED CIRCUITS (GaAs RF-LSI)

PHASE I PROGRESS REPORT

VOLUME II. APPENDICES

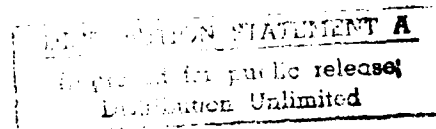
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NAVAL ELECTRONIC SYSTEMS COMMAND
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PHASE I, PROGRESS REPORT,

VOLUME II APPENDICES.

⑪ Aug 79

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APPENDIX A DERIVATION OF FET MODELING CODE

2.1 INTRODUCTION

The TRW FET model is biased on a two region approximation to the conditions under the gate. The following sections derive the noise figure from this assumption. Section 5 indicates how a variable vertical doping profile is included in the model and Section 6 describes how the parasitic resistances and capacitances are calculated.

2. THE INTRINSIC FET

2.1 THE FET MODEL

One of the many FET models that have been developed in the last decade, with the fewest restrictions and assumptions, is the Grebene-Ghandi model. Its fundamental principle is a two-piece linear approximation of the velocity-field characteristic of a semiconductor exhibiting velocity saturation as shown in Figure 2-1.

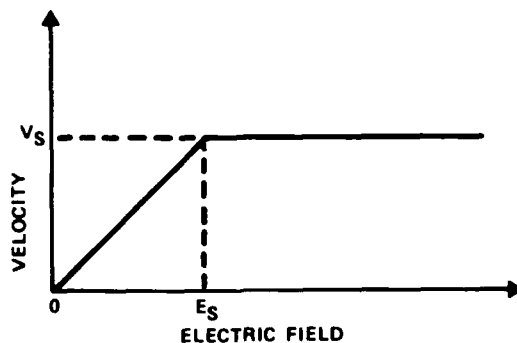
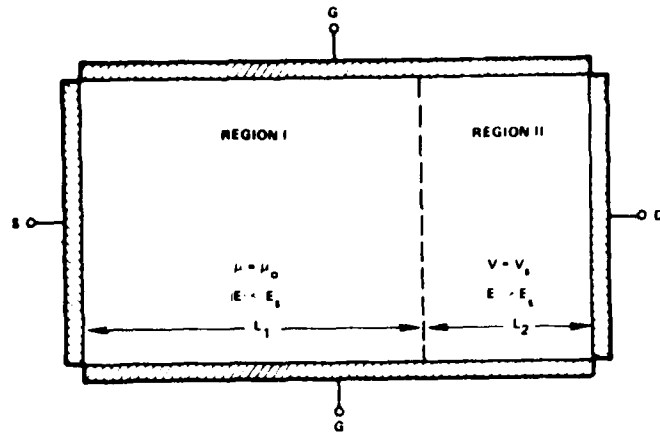


Figure 2-1. Two-Piece Linear Approximation of the Velocity-Field Characteristic of a Semiconductor Exhibiting Velocity Saturation

This velocity-field characteristic divides the intrinsic FET model into two regions: region I of length L_1 the constant mobility region where the velocity is field-dependent; and region II of length L_2 the constant velocity region where the electric field has exceeded the critical field E_s and the carriers travel at the saturation velocity V_s independent of field strength. This two-region model for the intrinsic FET is shown in Figure 2-2. The piecewise linear approximation of the velocity-field characteristic necessarily involves compromise in the choice of values used of E_s , μ_0 , and V_s . The mobility (μ_0) is evaluated from the doping density (N_0) by the use of a Taylor Series expansion as

$$\mu_0 = 10[-2.751 \times 10^{-3} \times \log^3(N_0) + 1.0249 \times 10^{-1} \times \log^2(N_0) - 1.251 \times \log(N_0) + 8.8249] \quad (2-1)$$



REGION I: CONSTANT MOBILITY REGION, FIELD DEPENDENT VELOCITY
 REGION II: CONSTANT VELOCITY REGION, FIELD INDEPENDENT VELOCITY

Figure 2-2. Two Section Model of the FET

Equation (2-1) is in essence the result of curve fitting techniques applied to the velocity - doping characteristic for type GaAs as given by Sze¹ in the range $10^{14} < N_0 < 10^{18}$

For a typical mobility value of $\mu_0 = 4500 \text{ cm}^2/\text{V-sec}$ E_s needs to be chosen as 2.9 kV/cm in order to obtain the typical saturation velocity of

$$V_s = \mu_0 E_s = (4500 \text{ cm}^2/\text{V-sec}) (2.9 \text{ kV/cm}) = 1.3 \times 10^7 \text{ cm/sec.}$$

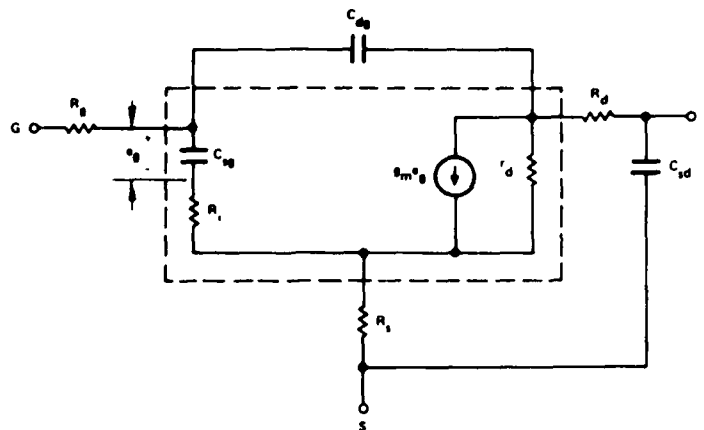
This choice for E_s is somewhat lower than the measured saturation field

$$3 \text{ kV/cm} < E_s < 4 \text{ kV/cm};$$

however, it is the only compromise made throughout the model, and the choice is certainly justifiable on the basis of good correlation between theoretical and experimental data of noise, dc conditions, and small signal parameters.

2.2 SMALL SIGNAL PARAMETERS

The FET model outlined in Section 2-1 has an equivalent circuit as shown in Figure 2-3.



CIRCUIT ELEMENTS ENCLOSED BY THE DASHED LINES PERTAIN TO THE INTRINSIC DEVICE
CIRCUIT ELEMENTS NOT ENCLOSED BY THE DASHED LINES INDICATE THE PARASITICS CONTRIBUTED BY THE ANCILLARY REGIONS

Figure 2-3. Small Signal Equivalent Circuit of the FET

The circuit elements enclosed by the dashed line constitute the intrinsic FET (region under the gate) and elements outside the dashed line are the parameters contributed by the ancillary regions. A prospective sketch of the FET indicating the geometric regions responsible for each circuit element is shown in Figure 2-4. Each of these circuit elements can be expressed as a function of the characteristic dimensions of the device, corresponding doping concentration of the region under consideration, and the dc biasing conditions.

Figure 2-5 is a cross-sectional diagram of the intrinsic FET showing various geometrical dimensions and potentials used in the equations to follow. From Figure 2-5 by adding potential drops inside the FET (i.e., in the channel and depletion region) and equating this sum to the externally applied voltages the following equations result:

$$V_{sg} = W(x) - \phi + V(x)$$

or

$$W(x) = V_{sg} + \phi - V(x) \quad (2-2)$$

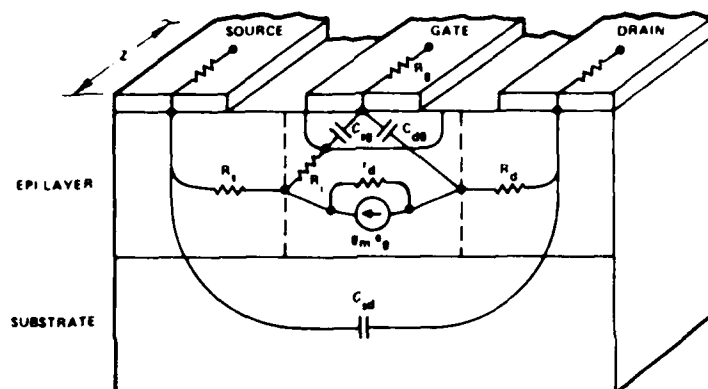


Figure 2-4. Perspective Sketch of the FET Indicating Geometric Regions Responsible for each Equivalent Circuit Element

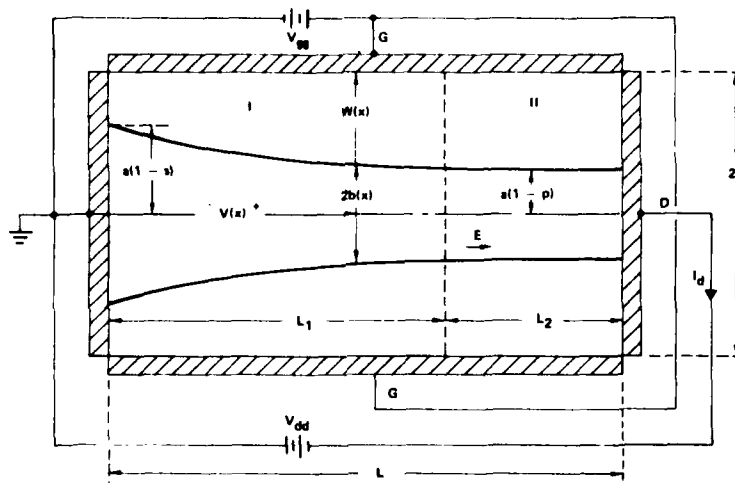


Figure 2-5. Cross-Sectional Diagram of the Idealized FET showing Geometrical Dimensions and Potentials

Here $V(x)$ is the potential at position x in the channel with respect to the source while $W(x)$ is the potential in the channel with respect to the gate. In particular, $W(x)$ is the potential drop across the depletion region. It does not include the built-in potential of the gate, ϕ . Therefore, ϕ adds to the gate bias, V_{sg} and is typically

$$0.6 \text{ volt} \leq \phi \leq 0.7 \text{ volt}$$

for GaAs Schottky barrier junction using aluminum metallization. At the source ($x = 0$), $V(0) = 0$, and equation 2-2 becomes

$$W(0) \equiv W_s = V_{sg} + \phi$$

At the interface of regions I and II, ($x = L_1$), $V(L_1) = V_p$, and equation (2-2) becomes

$$W(L_1) = W_p = V_{sg} + \phi - V_p \quad (2-4)$$

at the drain ($x=L$), $V(L) = V_{sd}$, and equation (2-2) becomes

$$W(L) \equiv W_d = V_{sg} + \phi - V_{sd} \quad (2-5)$$

The gate-to-channel potential required to totally deplete the channel of carriers is given by the expression ²

$$W_{oo} = \left(\frac{qN_o}{2\epsilon_r\epsilon_o} \right) a^2 \quad (2-6)$$

where $q = 1.6 \times 10^{-19}$ coulombs, N_o = doping concentration in the channel, $\epsilon_r = 12.5$ is the relative dielectric constant of GaAs, $\epsilon_o = 8.854 \times 10^{-14}$ farads/cm is the permittivity of free space, and 'a' is the half-thickness of the semiconductor between the gate electrodes (see Figure 2-5). Since equations (2-3), (2-4), and (2-5) are simply the potential of the depleted region at three different points along the channel, they can be written in the form of equation (2-6) as

$$W_s = \left(\frac{qN_o}{2\epsilon_r\epsilon_o} \right) (sa)^2 = W_{oo}s^2 \quad (2-7)$$

$$W_p = \left(\frac{qN_o}{2\epsilon_r\epsilon_o} \right) (pa)^2 = W_{oo}p^2 \quad (2-8)$$

$$W_d = \left(\frac{qN_o}{2\epsilon_r\epsilon_o} \right) (da)^2 = W_{oo}d^2 \quad (2-9)$$

From equations (2-6), (2-7), and (2-8) "s" and "p" can be expressed as

$$s = (W_s/W_{00})^{1/2} \quad (2-10)$$

$$p = (W_p/W_{00})^{1/2} \quad (2-11)$$

The quantities s, p, and d are reduced or normalized potentials. The following analysis will derive the characteristics of the FET in terms of s and p.

The potential across the depletion region can be found by assuming that the potential changes in the y direction much more rapidly than in the x direction. That is

$$\frac{\partial W(x)}{\partial y} \gg \frac{\partial V(x)}{\partial x}$$

This condition is satisfied when the channel thickness, a, is much smaller than the channel length, L. Making this assumption allows one to calculate the y component of the electric field using Gauss' law. Integrating a second time gives the potential W(x). Since there are no surface charges along the edges of the depletion region, the potential is

$$\begin{aligned} W(x) &= \left(\frac{qN_0}{2\epsilon_r\epsilon_0} \right) [a - b(x)]^2 \\ &= \left(\frac{qN_0}{2\epsilon_r\epsilon_0} \right) a^2 [1 - b(x)/a]^2 \\ &= W_{00} [1 - b(x)/a]^2 \end{aligned} \quad (2-12)$$

where b(x) is half the channel opening at point x (see Figure 2-5), and (1 - b(x)/a) is the fractional depth of the depletion region at the same point. It is convenient to define this fractional depth as

$$w(x) = 1 - b(x)/a \quad (2-13)$$

Then equation (2-12) can be written as

$$W(x) = W_{00} [w(x)]^2 \quad (2-14)$$

Comparing equation (2-14) to (2-7) and (2-8) indicates that s and p correspond to w(x). Therefore, s and p not only represent reduced potentials but are also related to the depth of the depletion region. In Figure 2-5, (1-s) and (1-p) are accordingly

indicated as the fractional channel openings at the source end and in region II, respectively. The drain current at point x is given by Ohm's law as

$$I_d = 2b(x) Z \sigma [\partial W(x)/\partial x] \quad (2-15)$$

where Z is the gate width,

$$\sigma = q\mu_0 N_0$$

the conductivity of the undepleted region of the channel and $\partial W(x)/\partial x = E_x(x)$ the longitudinal field in the channel at point x . From equation (2-14) the expression for the longitudinal field can be written in terms of the fractional channel opening as

$$\frac{\partial W(x)}{\partial x} = 2W_{00} w(x) \frac{dw(x)}{dx} \quad (2-16)$$

From equation (2-13) the expression for the half-channel opening can be obtained as

$$b(x) = a[1-w(x)] \quad (2-17)$$

By the use of equation (2-16) and (2-17) equation (2-15) can be written as

$$I_d dx = 4a\sigma Z W_{00} [1 - w(x)] w(x) dw(x) \quad (2-18)$$

Both sides of equation (2-18) can be integrated for region I in which the limits of integration for x are 0 and L_1 , and the limits for $w(x)$ are s and p (see Figure 2-5). The result of this integration yields

$$I_d = \frac{2a\sigma Z W_{00}}{L_1} f_1(s,p) \quad (2-19)$$

where

$$f_1(s,p) = p^2 - s^2 - \frac{2}{3}(p^3 - s^3) \quad (2-20)$$

In region II the carriers travel at their saturation velocity given by

$$V_s = \mu_0 E_s \quad (2-21)$$

where E_s is the critical longitudinal electric field at which the carriers reach their saturation velocity. Also in region II (or the constant velocity region) half the channel opening is given by

$$b = a(1-p) \quad (2-22)$$

and remains constant for $L_1 < x < L$, thus the expression for the drain current in this region is

$$I_d = 2b\sigma ZE_s \quad (2-23)$$

or by equation (2-22), equation (2-23) can be rewritten as

$$I_d = 2a\sigma ZE_s(1 - p) \quad (2-24)$$

Since there is current continuity across the interface of regions I and II, an expression for L_1 can be obtained from equations (2-19) and (2-24)

$$L_1 = \frac{W_{00}}{E_s} \left[\frac{f_1(s, p)}{(1 - p)} \right] \quad (2-25)$$

Both the drain current and the length of region I are now expressed in terms of s and p . To determine the values of these parameters it also is necessary to express V_{sd} in terms of the reduced potentials.

The source-to-drain potential drop in the channel can be calculated by integrating the longitudinal electric field from $x = 0$ to $x = L$; this integration is done in two parts: from $x = 0$ to L_1 (region I) and from $x = L_1$ to $x = L$ (region II). For region I the longitudinal electric field is given by equation (2-16)

$$\text{Thus} \quad \int_0^{L_1} \frac{\partial W(x) dx}{\partial x} = 2W_{00} \int_0^{L_1} w(x) \left[\frac{dw(x)}{dx} \right] dx \quad (2-26)$$

which yields

$$W(L_1) - W(0) = W_{00} [w^2(L_1) - w^2(0)] \quad (2-27)$$

From equation (2-13) the fractional depth of the depletion layer can be obtained as

$$w(L_1) = 1 - b(L_1)/a = p \quad (2-28)$$

$$w(0) = 1 - b(0)/a = s \quad (2-29)$$

Substitution of equation (2-28) and (2-29) on the right-hand side of equation (2-27) and substitution of equation (2-3) and (2-4) on the left-hand side of (2-27) gives

$$-V_p = W_{00} (p^2 - s^2) \quad (2-30)$$

For region II the longitudinal electric field is determined entirely by free charges on the drain electrode (neglecting carrier accumulation). In this region the potential satisfies the two-dimensional Laplace's equation

$$\nabla^2 \phi = 0 \quad (2-31)$$

For the asymmetrical transistor the boundary conditions for equation (2-31) are:

$$\begin{aligned} \frac{\partial \phi}{\partial y}(x, 0) &= 0 & L_1 < x < L \\ \phi(x, a) &= 0 & L_1 < x < L \\ \phi(L_1, y) &= 0 & -0 < y < a \\ \frac{\partial \phi}{\partial y}(L_1, y) &= E_s & -0 < y < a \end{aligned} \quad (2-32)$$

Equations (2-31) and (2-32) form a well-formulated boundary-value problem; the solution to this problem is

$$\phi(x, y) = \sum_{n=0}^{\infty} A_n \cos \left[\frac{(2n+1)\pi y}{2a} \right] \sinh \left[\frac{(2n+1)\pi (x - L_1)}{2a} \right] \quad (2-33)$$

which can be truncated to

$$\phi(x, y) \simeq -\frac{2a}{\pi} E_s \cos \left(\frac{\pi y}{2a} \right) \sinh \left[\frac{\pi (x - L_1)}{2a} \right] \quad (2-34)$$

in which only the first term is considered. This approximation removes the terms with large arguments in the exponentials of the hyperbolic sine term which vary rapidly with y . The voltage across region II is therefore

$$\phi(L, 0) - \phi(L_1, 0) = -\frac{2a}{\pi} E_s \sinh \left[\frac{\pi (L - L_1)}{2a} \right] \quad (2-35)$$

where $\phi(L_1, 0) = 0$ due to the boundary conditions given by equation (2-32). The overall source-to-drain potential drop in the channel is finally obtained from equations (2-30) and (2-35) as

$$\begin{aligned} V_{sd} &= W_{oo} \left\{ (p^2 - s^2) + \frac{2a}{\pi} \left(\frac{E_s}{W_{oo}} \right) \sinh \left[\frac{\pi (L - L_1)}{2a} \right] \right\} \\ &= W_{oo} \left\{ (p^2 - s^2) + \frac{2}{\pi} \left(\frac{a}{L} \right) \xi \sinh \left[\frac{\pi (L - L_1)}{2a} \right] \right\} \end{aligned} \quad (2-36)$$

where

$$\xi = \frac{E_s L}{W_{00}} \quad (2-37)$$

Equations (2-3) and (2-7) relate s to the gate voltage. After substituting for L_1 , equation (2-36) relates s and p to V_{sd} . Therefore, given the bias conditions and the physical properties of the FET, the reduced potentials s and p may be found. Although these equations have been derived for the intrinsic FET, they are still useful when parasitic resistances in the source and drain region of a practical device are included. These parasitics introduce additional voltage drops which are expressed as a parasitic resistance times the drain current. However, using (2-24) for the drain current, one can still reduce the problem to two equations in the unknowns s and p . The following sections will derive additional device parameters and ultimately the minimum noise figure in terms of s and p .

2.2.1 Transconductance

The transconductance of a FET device is defined as

$$g_m = \left. \frac{dI_d}{dV_{sg}} \right|_{V_{sd} = \text{constant}} \quad (2-38)$$

From equations (2-27) and (2-38) the transconductance can be expressed alternately as

$$\begin{aligned} g_m &= - \frac{\partial I_d}{\partial p} \frac{\partial p}{\partial V_{sg}} = 2a\sigma ZE_s \left(\frac{\partial s}{\partial V_{sg}} \right) \\ &= 2a\sigma ZE_s \left(\frac{\partial p}{\partial s} \right) \left(\frac{\partial s}{\partial V_{sg}} \right) \end{aligned} \quad (2-39)$$

From equations (2-3) and (2-7) $\partial s / \partial V_{sg}$ can be obtained as

$$\frac{\partial s}{\partial V_{sg}} = \frac{1}{2sW_{00}} \quad (2-40)$$

Also from equation (2-36) since $dV_{sd} = 0$

$$2pdp - 2sds - \frac{\xi}{L} \cosh \left[\frac{\pi(1 - L_1)}{2a} \right] dL_1 = 0 \quad (2-41)$$

Also from equation (2-25)

$$dL_1 = \frac{W_{00}}{E_s} \left\{ \left[2p + \frac{E_s}{W_{00}} \left(\frac{L_1}{1-p} \right) \right] dp - 2s \frac{1-s}{1-p} ds \right\} \quad (2-42)$$

Substituting (2-42) into (2-41) and collecting terms, the ratio dp/ds can be obtained as

$$\frac{dp}{ds} = \frac{2s(1-s) \cosh [\pi(L - L_1)/2a] - 2s(1-p)}{[2p(1-p) + E_s L_1/W_{00}] \cosh [\pi(L - L_1)/2a] - 2p(1-p)} \quad (2-43)$$

Substitution of equations (2-40) and (2-43) into equation (2-39) yields for the transconductance

$$g_m = \frac{I_s}{W_{00}} \left\{ \frac{(1-s) \cosh [L - L_1]/2a - (1-p)}{[2p(1-p) + \xi L_1/L] \cosh [\pi(L - L_1)/2a] - 2p(1-p)} \right\} \quad (2-44)$$

$$= \frac{I_s}{W_{00}} f_g(s,p)$$

where

$$I_s = 2a\sigma Z E_s$$

$$f_g(s,p) = \frac{(1-s) \cosh [\pi L_2/2a] - (1-p)}{[2p(1-p) + \xi L_1/L] \cosh [\pi L_2/2a] - 2p(1-p)} \quad (2-45)$$

The quantity I_s is the saturation current and represents the maximum current that could flow through the channel assuming no depleted region. Notice that the transconductance function, f_g , is only a function of s and p since $L_2 = L - L_1$, and equation 2-25 defines L_1 in terms of s and p .

2.2.2 Output Resistance

The output resistance is defined as

$$r_d = - \left. \frac{dV_{sd}}{dI_d} \right|_{V_{sg} = \text{constant}} \quad (2-46)$$

Following a process similar to that outlined for the transconductance, the output resistance can also be written in terms of I_s , W_{00} and a function of s and p .

$$r_d = \left(\frac{W_{00}}{I_s} \right) \left\{ \frac{2p(1-p) + \xi(L_1/L) \cosh [\pi L_2/2a] - 2p(1-p)}{1-p} \right\} \quad (2-47)$$

$$= \left(\frac{W_{00}}{I_s} \right) f_r(s,p)$$

where

$$f_r(s,p) = \left\{ \frac{[2p(1-p) + \xi(L_1/L)] \cosh [\pi L_2/2a] - 2p(1-p)}{1-p} \right\} \quad (2-48)$$

2.2.3 Gate-Source Capacitance

The gate-source capacitance is defined as the rate of change of the free charge on the gate electrode with respect to the gate bias voltage when the drain potential is held fixed.

$$C_{sg} = \left. \frac{dQ_g}{dV_{sg}} \right|_{V_{sd} = \text{constant}} \quad (2-49)$$

The gate charge can be obtained by a simple application of Gauss' Law as

$$Q_g = \int \vec{D} \cdot d\vec{s} = \epsilon_r \epsilon_0 \int \vec{E} \cdot d\vec{s} \quad (2-50)$$

In equation (2-50) the differential surface element of the gate is

$$d\vec{s} = \hat{y} \, z \, dx \quad (2-51)$$

where $\hat{y}$ is a unit vector normal to the gate surface. Also in equation (2-50) the electric field under consideration is

$$\vec{E} = \hat{y} \, E_y \quad (2-52)$$

or the y component of the field. This electric field has two different expressions:

$$E_{y1}(x,a) \text{ in region I and } E_{y2}(x,a) \text{ in region II.}$$

From equation (2-12) the field in region I can be calculated as

$$E_{y1}(x,a) = \frac{dW(x)}{db(x)} = \frac{2W_{00}}{a} [1 - b(x)/a] \quad (2-53)$$

In region II there is an additional component due to the Laplacian potential of equation (2-34); consequently

$$\begin{aligned} E_{y2}(x,a) &= \left. \frac{dW(x)}{db(x)} \right|_{x=L_1} + \left. \frac{d\phi(x,y)}{dy} \right|_{y=a} \\ &= \left(\frac{2W_{00}}{a} \right) p + E_s \sinh \frac{\pi(x-L_1)}{2a} \end{aligned} \quad (2-54)$$

Substitution of equations (2-52) through (2-54) into equation (2-50) yields

$$\begin{aligned}
 Q_g &= \left(\frac{2W_{00}\epsilon_r\epsilon_0}{a} \right) \left[\int_0^{L_1} E_{y1}(x,a)dx + \int_{L_1}^L E_{y2}(x,a)dx \right] \\
 &= \left(\frac{2W_{00}\epsilon_r\epsilon_0}{a} \right) \left\{ \frac{\frac{2}{3}(p^3 - s^3) - \frac{1}{2}(p^4 - s^4)}{(p^2 - s^2) - \frac{2}{3}(p^3 - s^3)} L_1 + p(1 - L_1) \right. \\
 &\quad \left. + \left(\frac{aE_s}{2W_{00}} \right) \left(\frac{2a}{\pi} \right) \left[\cosh \frac{\pi(L - L_1)}{2a} - 1 \right] \right\} \\
 &= 2qN_0 aZ \left\{ \frac{f_2(s,p)}{f_1(s,p)} L_1 + pL_2 + \left(\frac{\epsilon_s a^2}{\pi L} \right) \left[\cosh \frac{\pi(L - L_1)}{2a} - 1 \right] \right\}
 \end{aligned} \tag{2-55}$$

where

$$f_2(s,p) = \frac{2}{3}(p^3 - s^3) - \frac{1}{2}(p^4 - s^4) \tag{2-56}$$

and the gate-source capacitance expression (2-49) can be obtained from (2-55) by performing the following differentiations³

$$\begin{aligned}
 C_{sg} &= \left. \frac{dQ_g}{dV_{sg}} \right|_{V_{sd} = \text{constant}} = \left(\frac{dQ_g}{dp} \right) \left(\frac{dp}{dV_{sg}} \right) \bigg|_{V_{sd} = \text{constant}} \\
 &= \epsilon_r \epsilon_0 Z f_c
 \end{aligned} \tag{2-57}$$

where $f_c = f_{c1} + f_{c2} + 1.56$

$$f_{c1} = \left(\frac{2}{f_1} \right) \left(\frac{L_1}{a} \right) \left\{ f_g \left[\frac{2p^2(1 - p^2) + f_2}{1 - p} \right] - s(1 - s) \right\} \tag{2-58}$$

$$f_{c2}(s,p) = 2 \left(\frac{L_2}{a} \right) f_g + (1 - 2pf_g) \left[2 \left(\frac{L}{a} \right) \frac{p}{\epsilon \cosh(\pi L_2/2a)} + \tanh \frac{\pi L_2}{2a} \right] \tag{2-59}$$

The first two terms of the capacitance function, f_c , are the contributions due to region I and region II. The numerical term accounts for the fringing capacitance and is taken from the work of Wasserstrom and McKenna⁴.

2.2.4 Gate Charging Resistance

At the present, there is no formal analytic expression for R_i in the two section model of the FET. It is simply assumed that the time constant $\tau = R_i C_{sg}$ is proportional to the transit time through the channel. From the experimental data of Brehm and Vendelin⁵ this transit time is set to

$$\tau = R_i C_{sg} = 4 \times 10^{-12} \text{ sec} \quad (2-60)$$

From experimental data this product scales with gate length and consequently equation (2-60) can be written as

$$\tau = K L R_i C_{sg} \quad (2-61)$$

where K is a proportionality constant ($K = 0.5/\mu\text{m}$) then from equations (2-60) and (2-61)

$$R_i = \frac{4 \times 10^{-12}}{K L C_{sg}} = \frac{8 \times 10^{-12}}{L C_{sg}} \quad (2-62)$$

where L is in μm .

2.2.5 Summary of the Small Signal Analysis of the Intrinsic FET

It is useful to review the results of this section before proceeding with the noise analysis. The model is based on the assumption that the channel under the gate can be divided into two regions. In the first region, the carrier behavior is ohmic. In the second region the carriers move at a saturated drift velocity that does not increase with increased electric field.

A pair of reduced potentials, s and p , are then defined. A second assumption gives a physical significance to these parameters. One assumes that the electric field component along the channel is much smaller than the component perpendicular to the channel. Then one can determine the electric field and potential in terms of the charge distribution in the channel. From the form of the potential, s can be related to the fractional opening of the channel at the source end of the gate and p can be related to the opening at the interface between regions I and II. This assumption sets limits on the applicability of the model. In practice, it is satisfied for gate lengths somewhat larger than the channel depth. Fortunately, such conditions also correspond to most devices of practical interest.

After defining s and p , the bias conditions, V_{sg} and V_{sd} , are expressed in terms of these parameters. The resulting equations must be solved numerically for practical situations which include parasitic source and drain resistances, but they provide a means of obtaining values for s and p . It is then possible to express all of the small signal parameters in terms of s , p and the physical properties of the FET. The following sections will develop the form of the noise figure, again in terms of the reduced potentials s and p .

3. NOISE ANALYSIS FOR THE INTRINSIC FET

Noise in a microwave GaAs FET is produced by sources intrinsic to the device and thermal sources associated with the parasitic resistances. The intrinsic noise arises from two mechanisms: the first mechanism is the thermal or Johnson noise produced in region I; the second mechanism is the diffusion noise in the velocity saturated section (region II).

It is convenient for noise figure calculations to represent the internal noise sources of the intrinsic FET by noise generators suitably connected to the external terminals as shown in Figure 3-1.



Figure 3-1. The Intrinsic FET with Two Noise Sources
 I_G Represents the Induced Gate Noise,
 I_D Represents the Drain Circuit Noise

This representation in terms of external current generators is useful because the output generator can be identified with the short-circuit channel noise generated in the source-drain path, while the input generator can be related to the noise current induced in the gate circuit by the charge fluctuations in the drain current.

3.1 DRAIN CIRCUIT NOISE

The open-circuit drain voltage fluctuation produced by sources in region I is⁶

$$\overline{|v_{d1}|^2} = \left(\frac{4kT_0 \Delta f}{2a\sigma Z/L_1} \right) \left(\frac{P_0 + P_\delta}{(1-p)^2} \right) \cosh^2 \left(\frac{\pi L_2}{2a} \right) \quad (3-1)$$

where

$$P_0 = (f_1)^{-1} \left[(p^2 - s^2) - 4/3 (p^3 - s^3) + 1/2 (p^4 - s^4) \right] \quad (3-2)$$

and

$$P_{\delta} = 2\delta(f_1^{-1})(1-p)^3 \left[(s-p) + \ln \left(\frac{1-s}{1-p} \right) \right] \quad (3-3)$$

The voltage fluctuations are due to Johnson noise generated in region I. Therefore, a kT_0 term occurs in which k is Boltzman's constant and T_0 is the reference temperature (300K) of the channel. Noise is produced over a frequency spectrum and equation (3-1) gives the resulting voltage fluctuations at the drain for a frequency bandwidth Δf . There are two terms in this equation. The first (proportional to P_0) represents the normal Johnson noise contribution as calculated for electrons in region I. The second term (containing P_{δ}) provides for the fact that the effective noise temperature of the carriers is higher than that of the crystal when an electric field is present to move them through the crystal. This "hot" electron term contains an emperical constant, δ , which relates the effective temperature to the reference temperature, T_0 . The value of δ is modified from its published value⁷ of 6 to a value of 1.19 to provide for the reduced saturation field of 2.9 kV/cm used here.

The open circuit drain voltage fluctuation produced by sources in region II is⁶

$$\overline{v_{d2}^2} = I_d \frac{64a^2}{\pi^5 V_s^3} \left[\frac{q D \Delta f}{(\epsilon_r \epsilon_0)^2 Z^2} \right] \left[\frac{\sin^2 \pi(1-p)/2a}{(1-p)^2} \right] \left[\exp \frac{\pi L_2}{a} - 4 \exp \frac{\pi L_2}{2a} + 3 + \frac{\pi L_2}{a} \right] \quad (3-4)$$

This fluctuation in voltage at the drain occurs when dipole layers form in region II of the channel. The layers drift toward the drain with a velocity determined by the diffusion constant, D , of the carriers. When the dipoles form they induce a voltage at the drain and at the region I-region II interface. The voltage appears as a pulse with the pulses described by a frequency spectrum. Equation (3-4) gives the drain voltage fluctuation due to pulses in a frequency bandwidth Δf .

The noise voltage contributions from each region are due to different mechanisms and are uncorrelated. Therefore, their mean squares add. Both contributions are developed across the output resistance, r_d , so the resulting noise fluctuation may be written in terms of a current at the drain, i_d . Specifically:

$$i_{d1} = v_{d1}/r_d \quad (3-5)$$

$$i_{d2} = v_{d2}/r_d$$

$$\overline{i_{d1}^2} + \overline{i_{d2}^2} = \overline{i_d^2} \quad (3-6)$$

3.2 GATE CIRCUIT NOISE

Noise voltages produced in the channel are coupled capacitively to the gate. These charge fluctuations on the gate in turn modulate the current through the channel and thus appear as noise at the drain. The short-circuit gate current fluctuation produced by sources in region I is given by⁶

$$\overline{i_{g1}^2} = \omega^2 \left(\frac{16kT_0 \Delta f}{a\sigma/L_1 Z} \right) \left(\frac{\epsilon_r \epsilon_0 L_1}{\gamma a} \right)^2 (R_0 + R_\delta) \quad (3-7)$$

where

$$\gamma = \frac{(1-p)^2 f_r}{f_1 \cosh(\pi L_2/2a)} \quad (3-8)$$

and

$$R_0 = (f_1^{-3}) \left\{ (\kappa')^2 (p^2 - s^2) - 4/3 \kappa' (\kappa' + \gamma) (p^3 - s^3) + 1/2 [(\kappa')^2 + 4\kappa'\gamma + \gamma^2] \cdot (p^4 - s^4) - 4/5 (\kappa'\gamma + \gamma^2) (p^5 - s^5) + \gamma^2/3 (p^6 - s^6) \right\} \quad (3-9)$$

$$R_\delta = \delta (1-p)^3 (f_1)^{-3} \left\{ -2(\kappa' - \gamma)^2 \left[p - s + \ln \left(\frac{1-p}{1-s} \right) \right] + (2\kappa'\gamma - \gamma^2) (p^2 - s^2) - 2/3 \gamma^2 (p^3 - s^3) \right\} \quad (3-10)$$

$$\kappa' = (f_1)^{-1} \left[-1/3 (p^3 - s^3) + 1/6 (p^4 - s^4) + (s^2 - 2/3 s^3) (p - s) \right] + \gamma p \quad (3-11)$$

$$\kappa' = \kappa + (L_2/L_1) (1 - p) \quad (3-12)$$

Notice that this noise term is similar to the region I channel contribution (3-1). The observation is not surprising because both contributions are due to the same Johnson noise generated in region I. Because the boundary of region I is not a short circuit, but the conditions of region II, γ is included to represent the modified boundary condition. If region II were not present, ($L_2 = 0$) the hyperbolic cosine term in (3-8) would be one and $\gamma = 1$. That is, one would have the short-circuit condition again.

The short-circuit gate current fluctuations produced by sources in region II are given by⁶

$$\overline{i_{g2}^2} = \omega^2 I_d \left(\frac{64a^3 q D \Delta f}{\pi^5 V_s^5} \right) \left[\frac{L_1 \kappa' (\gamma = 0)}{\epsilon_r \epsilon_0 a Z (1-p)^2 r_d} \right]^2 \sin^2[\pi(1-p)/2] \cdot \left(\exp \pi L_2/a - 4 \exp \pi L_2/2a + 3 + \pi L_2/a \right) \quad (3-13)$$

This contribution is quite similar to the drain circuit noise (3-4) which is also produced by the formation of dipole layers in region II.

3.3 THE CORRELATION COEFFICIENT

The Johnson noise produced in region I and the noise due to dipole layer generation in region II are independent of each other. However, the noise contributions from gate and drain for a given region are correlated. There is full correlation between i_{g2} and i_{d2} with a capacitive 90 degree phase shift between the currents. Thus,

$$\overline{i_{g2} * i_{d2}} = j \left(\left[\overline{i_{g2}^2} \right] \cdot \left[\overline{i_{d2}^2} \right] \right)^{1/2} \quad (3-14)$$

The correlation between i_{g1} and i_{d1} is not complete and the combined noise current is given by⁸

$$\overline{i_{g1} * i_{d1}} = j \left[\frac{S_0 + S_\delta}{(R_0 + R_\delta)^{1/2} (P_0 + P_\delta)^{1/2}} \right] \left(\left[\overline{i_{g1}^2} \right] \cdot \left[\overline{i_{d1}^2} \right] \right)^{1/2} \quad (3-15)$$

where

$$S_0 = (f_1)^{-2} \left\{ \kappa \cdot [(p^2 - s^2) - 4/3 (p^3 - s^2) + 1/2 (p^4 - s^4)] + \gamma [-2/3 (p^3 - s^3) + (p^4 - s^4) - 2/5 (p^5 - s^5)] \right\} \quad (3-16)$$

$$S_\delta = 2\delta(f_1)^{-2} (1 - p)^3 \left\{ (\kappa - \gamma) [s - p + \ln(\frac{1-s}{1-p})] + 1/2 \gamma (p^2 - s^2) \right\} \quad (3-17)$$

The overall correlation coefficient is defined by the expression

$$jC = \overline{i_g * i_d} / \left(\left[\overline{i_g^2} \right] \left[\overline{i_d^2} \right] \right)^{1/2} \quad (3-18)$$

$$= \left[\frac{S_0 + S_\delta}{(R_0 + R_\delta)^{1/2} (P_0 + P_\delta)^{1/2}} \right] \cdot \left(\frac{\overline{i_{g1}^2}}{\overline{i_g^2}} \right)^{1/2} \left(\frac{\overline{i_{d1}^2}}{\overline{i_d^2}} \right)^{1/2} + \left(\frac{\overline{i_{g2}^2}}{\overline{i_g^2}} \right)^{1/2} \left(\frac{\overline{i_{d2}^2}}{\overline{i_d^2}} \right)^{1/2}$$

Substitution of equations (3-1) through (3-7), and equation (3-13) in equation (3-18) yields

$$C = \frac{S_0 + S_\delta}{(R_0 + R_\delta)^{1/2} (P_0 + P_\delta)^{1/2}} \sqrt{\frac{P_1 R_1}{PR}} + \sqrt{\frac{P_2 R_2}{PR}} \quad (3-19)$$

where

$$P_1 = \frac{(1-p)}{f_1 f_g} (P_0 + P_\delta) \quad (3-20)$$

$$P_2 = \frac{1-p}{\epsilon f_r^2 f_g} \left(\frac{L}{a}\right) f_3 \quad (3-21)$$

$$P = P_1 + P_2 \quad (3-22)$$

$$R_1 = 4 \left(\frac{L}{a}\right)^2 \left(\frac{f_1}{1-p}\right)^3 \left(\frac{1}{\epsilon f_g}\right)^2 \left(\frac{f_g}{f_c^2}\right) (R_0 + R_\delta) \quad (3-23)$$

$$R_2 = 4 \left(\frac{L}{a}\right)^3 \left[\frac{1}{\epsilon(1-p)}\right]^3 \left(\frac{f_1^2 f_g}{f_r^2 f_c^2}\right) [\kappa'(\gamma = 0)]^2 f_3 \quad (3-24)$$

$$R = R_1 + R_2 \quad (3-25)$$

$$f_3 = \frac{16}{\pi^3} \left(\frac{D}{D_0}\right) \left[\frac{\sin(\pi/2)(1-p)}{(\pi/2)(1-p)}\right]^2 \left(\exp \frac{\pi L_2}{a} - 4 \exp \frac{\pi L_2}{2a} + \frac{\pi L_2}{a}\right) \quad (3-26)$$

The final form of the correlated noise, given by (3-19), reflects the partial correlation between region I contributions (the first term) and the total correlation between region II contributions (the second term). The noise figure developed in the following sections will be expressed in terms of the quantities R, P and C listed here.

4. NOISE FIGURE ANALYSIS FOR THE FET

4.1 INTRODUCTION

The noise figure analysis to follow will be based on the equivalent circuit for the FET shown in Figure 2-3. The assumed configuration will be common source, with the gate considered as the input port and the drain considered as the output port. This configuration was chosen because it represents the typical front-end stage of a microwave receiver. Due to the amplification mechanism of the FET; the greater contribution to the overall noise figure of the device is provided by those elements connected to the input port; while the contribution to the noise by the elements connected to the output port is small; under this line of reasoning the noise contribution of the drain resistance and, the drain-gate capacitance C_{dg} , the source drain capacitance C_{sd} , and the parasitic resistance R_d (see Figure 2-3) can be neglected without incurring significant error and greatly simplifying the equivalent circuit to be used in the noise analysis (see Figure 4-1).

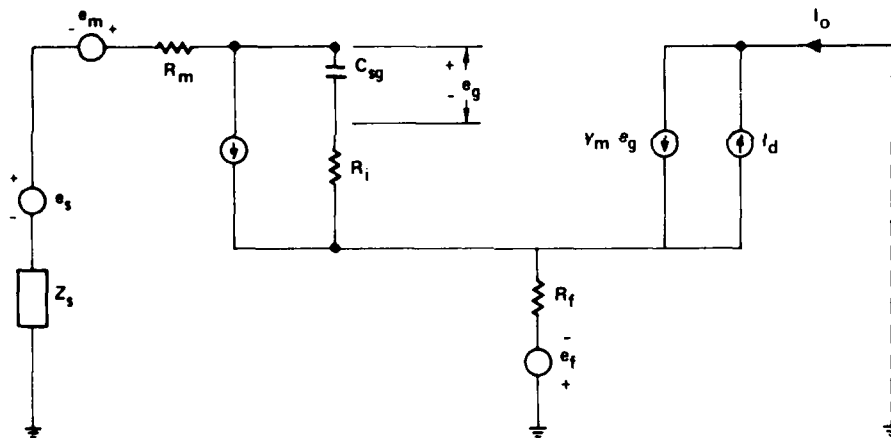


Figure 4-1. Simplified Equivalent Circuit Model

4.2 NOISE FIGURE DERIVATION

The intrinsic FET shown in the simplified schematic of Figure 4-1 can be represented by two short-circuit Y parameters.

$$Y_{11} = \frac{j\omega C_{sg}}{1 + j\omega C_{sg} R_i} \quad (4-1)$$

$$Y_{21} = \frac{g_m}{1 + j\omega C_{sg} R_i} \quad (4-2)$$

Also, the noise Figure F for this simplified circuit can be expressed as

$$F = 1 + \frac{|i_g + i_s + i_{go} + i_{do}|^2}{|i_z|^2} \quad (4-3)$$

where i_g , i_s , i_{go} , i_{do} , and i_z are the noise components in the short-circuited drain-source path produced by the noise generators e_{gn} , e_{sn} , i_g , i_d , and e_{zn} , respectively. The noise generators representing the extrinsic thermal sources R_g , R_s , and the real part of Z_s are given by their mean square values as

$$\overline{|e_{gn}|^2} = 4kT_0 R_g \Delta f \quad (4.4)$$

$$\overline{|e_{sn}|^2} = 4kT_0 R_s \Delta f \quad (T_0 = 300^\circ K) \quad (4.5)$$

$$\overline{|e_{zn}|^2} = 4kT_0 (\text{Re} Z_s) \Delta f \quad (4.6)$$

where "Re" denotes "real part of"

Analyzing the circuit of Figure 4-1, equation (4.3) can alternatively be expressed as

$$F = 1 + \frac{1}{\text{Re} Z_s} \left\{ R_g + R_s + |R_g + R_s + Z_s|^2 \frac{\overline{|i_g|^2}}{4kT_0 \Delta f} \right. \\ \left. + \left| \frac{1 + Y_{11} (R_g + R_s + Z_s)}{Y_{21}} \right|^2 \frac{\overline{|i_d|^2}}{4kT_0 \Delta f} \right. \\ \left. - 2\text{Re} \left[(R_g + R_s + Z_s) \left(\frac{1 + Y_{11} (R_g + R_s + Z_s)}{Y_{21}} \right)^* \frac{i_g^* i_d}{4kT_0 \Delta f} \right] \right\} \quad (4.7)$$

The terms of equation (4-7) that contain the intrinsic noise current sources i_g and i_d can be written alternatively as

$$\overline{\left| \frac{i_g}{4kT_0 \Delta f} \right|^2} = \frac{\omega^2 C_{sg}^2}{g_m} R \quad (4-8)$$

$$\overline{\left| \frac{i_d}{4kT_0 \Delta f} \right|^2} = g_m P \quad (4-9)$$

$$\frac{\overline{i_g i_d}}{4kT_0 \Delta f} = \frac{jC \left(\overline{i_g^2} \overline{i_d^2} \right)^{1/2}}{4kT_0 \Delta f} = jC \omega C_{sg} (RP)^{1/2} \quad (4-10)$$

where R , P , and C are defined by equations (3-25), (3-22) and (3-19), respectively.

4.3 MINIMUM NOISE FIGURE

From equation (4-7) and using equations (4-8), (4-9), and (4-10) the minimum noise figure can be evaluated by setting the partial derivative of the noise figure with respect to the source impedance Z_s equal to 0. This yields

$$Z_s \text{ opt} = R_s \text{ opt} + j X_s \text{ opt} \quad (4-11)$$

where

$$R_s \text{ opt} = \left\{ R_g + R_s + \text{Re} \left[\frac{1 - C(R/P)^{1/2}}{Y_{11} [1 - C(R/P)^{1/2}]^2 - (1 - C^2) R/P} \right] \right\}^2 \quad (4-12)$$

$$+ \left[\frac{g_m (R_g + R_s) + K_r (1 + \omega^2 C_{sg}^2 R_i^2)}{\omega^2 C_{sg}^2 K_g} \right]^2 \}^{1/2}$$

$$X_s \text{ opt} = -\text{Im} \left[\frac{1 - C(R/P)^{1/2}}{Y_{11} [1 - C(R/P)^{1/2}]^2 - (1 - C^2) R/P} \right] \quad (4-13)$$

where

$$K_r = \frac{R(1 - C^2)}{[1 - C(R/P)^{1/2}]^2 + (1 - C^2) R/P} \quad (4-14)$$

and "Im" denotes "imaginary part of." Also

$$K_g = P \{ [1 - C(R/P)^{1/2}]^2 + (1 - C^2) R/P \} \quad (4-15)$$

With this optimum source impedance given by equation (4-11) the minimum noise figure can be found by substitution of equation (4-11) into equation (4-7). Also since the noise figure is a frequency dependent function, equation (4-7) can be expanded as a power series in ω ; this yields

$$\begin{aligned} F_{\min} = & 1 + 2 \left(\frac{f}{f_T} \right) \left\{ PR (1 - C^2) + g_m \left(\frac{T}{T_0} \right) (R_g + R_s) \left[P(1 - C(R/P)^{1/2})^2 + R(1 - C^2) \right] \right\}^{1/2} \\ & + 2 \left(\frac{f}{f_T} \right)^2 \left\{ g_m \left(\frac{T}{T_0} \right) (R_g + R_s) P \left[(1 - C(R/P)^{1/2})^2 + ((1 - C^2) R/P) \right] \right. \\ & \left. + g_m R_i P \left[1 - C(R/P)^{1/2} \right] \right\} \end{aligned} \quad (4-16)$$

where the term $\omega C_{sg}/g_m$ in the expansion has been expressed as f/f_T ($f_T = g_m/2\pi C_{sg}$). f_T is the gain-bandwidth product of the FET or the frequency at which the current gain of the device drops to unity.

4.4 TEMPERATURE EFFECTS ON NOISE FIGURE

From Equation (4-16) the straight-forward dependence of noise figure on the device temperature can be observed in the terms that contain the ratio T/T_0 . There is, however, a very strong dependence of gain on the ratio T/T_0 given by the expression

$$g_m = \frac{f_g(s,p)}{W_{00}} (2aZE_s) (\mu_0 N_0) \left(\frac{T}{T_0} \right)^{1.5} \quad (4-17)$$

From equations (4-16) and (4-17), it can clearly be observed that the dependence of noise figure on temperature can best be evaluated by a numerical process. After describing the contributions of the ancillary regions to FET noise figure, the results of the numerical analysis will be presented.

5. FET WITH VARIABLE DOPING PROFILE

5.1 SMALL SIGNAL PARAMETERS

Consider the FET as shown in Figure 2-5 with a doping concentration $N(y)$ which is a function of the depth below the gate. It is convenient for the analysis to follow, to change the coordinate system in Figure 2-5 such that $y = 0$ at the upper left-hand corner of the region under the gate and consider only the upper half of the device. By Poisson's equation

$$\frac{dE_y}{dy} = \frac{q}{\epsilon_r \epsilon_0} N(y) \quad (5-1)$$

and

$$E_y(y) = \frac{q}{\epsilon_r \epsilon_0} [\overline{N(y)} + C_1] \quad (5-2)$$

where the notation $\overline{N(y)}$ represents

$$\int_0^y N(y) dy$$

Similarly,

(5-3)

$$\overline{\overline{N(y)}} = \int_0^y \overline{N(y)} dy$$

At the depletion depth $y = y_d$, it is required that $E_y = 0$; thus from equation (5-2)

$$E_y(y_d) = \frac{q}{\epsilon_r \epsilon_0} [\overline{N(y_d)} + C_1] = 0 \quad (5-4)$$

and

$$E_y(y) = \frac{q}{\epsilon_r \epsilon_0} [\overline{N(y)} - \overline{N(y_d)}] \quad (5-5)$$

The potential across the depletion layer can be obtained by direct integration of equation (5-5). Thus,

$$W(y) = \int E_y^- \cdot dy = \int E_y dy = \frac{q}{\epsilon_r \epsilon_0} \left[\overline{N}(y) - y \overline{N}(y_d) + C_2 \right] \quad (5-6)$$

since $W(y) = 0$ at $z = 0$ the constant C_2 in equation (5-6) can be evaluated as $C_2 = -\overline{N}(0)$

and

$$W(y) = \frac{q}{\epsilon_r \epsilon_0} \left[\overline{N}(y) - y \overline{N}(y_d) - \overline{N}(0) \right] \quad (5-7)$$

Equation (5-7) is analogous to equation (2-12) of the constant doping profile case. It is convenient for the following analysis to introduce the dimensionless variable $\omega = y/a^\dagger$ where ω runs from 0 to 1 across the epilayer; using this dimensionless variable equation (5-7) can be rewritten as

$$W(\omega) = \frac{qa^2}{\epsilon_r \epsilon_0} \left[\overline{N}(\omega) - \omega \overline{N}(\omega_d) \right] \quad (5-8)$$

where the term $\overline{N}(0) = 0$ has been dropped.

In equation (5-8)

$$\overline{N}(\omega) = \int_0^\omega N(\omega) d\omega \text{ and } \overline{N}(\omega_d) = \int_0^{\omega_d} N(\omega) d\omega$$

The potential across the depletion region is $W(\omega_d)$ where

$$W(\omega_d) = \frac{qa^2}{\epsilon_r \epsilon_0} \left[\overline{N}(\omega_d) - \omega_d \overline{N}(\omega_d) \right] \quad (5-9)$$

By considering the integral

$$\int_0^{\omega_d} \omega N(\omega) d\omega$$

[†] ω when used as normalized channel depth is not to be confused with angular frequency.

and integrating by parts; it can be shown that:

$$\int_0^{\omega_d} \omega N(\omega) d\omega = \omega_d \overline{N(\omega_d)} - \int_0^{\omega_d} N(\omega) d\omega \quad (5-10)$$

thus equation (5-9) can be alternately written as

$$W(\omega_d) = \frac{-qa^2}{\epsilon_r \epsilon_0} \int_0^{\omega_d} \omega N(\omega) d\omega \quad (5-11)$$

Using equation (5-11), the potential required to deplete the entire epilayer of carriers is

$$W_{00} = \frac{qa^2}{\epsilon_r \epsilon_0} [\overline{N(1)} - \overline{N(1)}] = \frac{qa^2}{\epsilon_r \epsilon_0} \int_0^1 \omega N(\omega) d\omega \quad (5-12)$$

The potential expressed by equation (5-12) is analogous to W_{00} of equation (2-6) for the constant doping profile case.

To calculate the total drain current flowing in the channel, one can follow a procedure very similar to that of Section 2.2, equations (2-16) through (2-20), and by Ohm's law at a distance x from the source

$$I_d = q\mu_0 Z \left[\int_{y_d}^a N(y_d) dy \right] E_x(x) \quad (5-13)$$

Using the dimensionless variable ω , equation (5-13) can also be written as

$$\begin{aligned} I_d &= q\mu_0 Z a E_x(x) \int_{\omega_d}^1 N(\omega) d\omega \\ &= q\mu_0 Z a E_x(x) [\overline{N(1)} - \overline{N(\omega_d)}] \end{aligned} \quad (5-14)$$

To evaluate $E_x(x)$ one can start from equation (2-2) properly modified for the variable profile case, thus:

$$E_x(x) = - \frac{dV(x)}{dx} \quad (5-15)$$

$$E_x(x) = - \frac{d}{dx} [V_{sg} + \phi - W(\omega_d)]$$

$$E_x(x) = \frac{d\omega_d}{dx} \cdot \frac{dW(\omega_d)}{d\omega_d}$$

and from equation (5-11)

$$\frac{dW(\omega_d)}{d\omega_d} = \frac{qa^2}{\epsilon_r \epsilon_0} \omega_d N(\omega_d) \quad (5-16)$$

Using equations (5-15) and (5-16), equation (5-14) becomes:

$$I_d = \frac{\mu_0 Z q^2 a^3}{\epsilon_r \epsilon_0} \frac{[\overline{N(1)} - \overline{N(\omega_d)}] \omega_d N(\omega_d) \frac{d\omega_d}{dx}}{\quad} \quad (5-17)$$

Integration of equation (5-17) over the length of region I i.e., from $x = 0$ to $x = L_1$ yields (dropping subscripts)

$$I_d = \frac{\mu_0 Z q^2 a^3}{\epsilon_r \epsilon_0 L_1} f_1(s, p) \quad (5-18)$$

where

$$f_1(s, p) = \overline{N(1)} \int_s^p \omega N(\omega) d\omega - \int_s^p \omega N(\omega) \overline{N(\omega)} d\omega \quad (5-19)$$

In equation (5-19) the quantities s and p represent the values of $\omega = y/a$ at $x = 0$ and $x = L_1$, respectively. Also the function $f_1(s, p)$ described by equation (5-19) is analogous to the one described by equation (2-20) in the constant doping profile case.

From the general equations (2-3) and (2-4) it can be concluded that the potential drop from $x = 0$ to $x = L_1$ (across region I) is

$$V(L_1) - V(0) = W_p - W_s \quad (5-20)$$

Also since at $x = L_1$ the carriers reach their saturation velocity and $E_x(x) = E_s$, then the expression for the drain current in region II is

$$I_d = q\mu_0 Z a E_s [\overline{N(1)} - \overline{N(p)}] \quad (5-21)$$

Thus equations (2-3), (2-4), (5-18), (5-19), (5-20), and (5-21) establish relations between the quantities s , p , L_1 and I_d to the potentials V_{sg} , $V(L_1)$ and the corresponding doping density integrals.

In region II the potential function $\phi(x,y)$ is assumed to be determined by the charges in the depleted region and free charges on the drain electrode, consequently,

$$\phi(x,y) = \phi_1(x,y) + \phi_2(x,y) \quad (5-22)$$

where $\phi_1(x,y)$ is the potential due to the depletion charges and $\phi_2(x,y)$ is the potential due to free charges on the drain. To solve for $\phi_2(x,y)$ the process to follow is that of Section 2.2, equations (2-31) and (2-32); this yields the result.

$$\phi_2(x,y) = \frac{2a}{\pi} E_s \sin\left(\frac{\pi y}{2a}\right) \sinh\left[\frac{\pi(x - L_1)}{2a}\right] \quad (5-23)$$

From equation (5-7) the potential $\phi_1(x,y)$ is obtained as

$$\phi_1(x,y) = \frac{q}{\epsilon_r \epsilon_0} \left[\overline{N(y)} - y \overline{N(pa)} \right] \quad (5-24)$$

However, this potential given by equation (5-24) gives no E_x contribution in region II, gives zero electric field at the channel and zero potential at $y = 0$; consequently, the potential due to $\phi_1(x,y) + \phi_2(x,y)$ measured along the channel from $x = L_1$ to $x = L_2$ is due entirely to ϕ_2 . Adding the potential drop from $x = 0$ to $x = L$ one can obtain from equations (5-20) and (5-23) the source to drain voltage given by

$$V_{sd} = W(p) - W(s) + \frac{2a}{\pi} E_s \sinh\left[\frac{\pi(L - L_1)}{2a}\right] \quad (5-25)$$

Equation (5-25) with equations (5-18) and (5-20) enables one to solve for the current-voltage relationship of the FET. From equations (5-18) and (5-21) I_d can be eliminated; this yields

$$L_1 = \frac{qa^2}{\epsilon_r \epsilon_0 E_s} \left[\frac{f_1(s,p)}{N(T) - N(p)} \right] \quad (5-26)$$

Equation (5-26) is analogous to equation (2-25) for the constant profile case but $f_1(s,p)$ is given in this case by equation (5-19).

Just as in the constant doping profile case, equations (5-25) and (5-26) form a pair must be solved simultaneously in order to determine p , s , then L_1 and I_d .

5.1.1 Transconductance

Following the same procedure as the one outlined in Section 2.2.1 and from equations (2-38), (5-11), (5-20), (5-21), (5-25), and (5-26), the expression for the

transconductance for the variable doping profile case can be shown to be

$$g_m = \frac{\epsilon_r \epsilon_0 \mu_0 Z E_s}{a} f_g(s, p) \quad (5-27)$$

where

$$f_g(s, p) = \frac{[\overline{N(T)} - \overline{N(s)}] \cosh(\pi L_2/2a) - [\overline{N(T)} - \overline{N(p)}]}{\{p[\overline{N(T)} - \overline{N(p)}] + \epsilon_r \epsilon_0 E_s L_1 / qa^2\} \cosh(\pi L_2/2a) - p[\overline{N(T)} - \overline{N(p)}]} \quad (5-28)$$

This expression given by equation (5-28) reduces to that of equation (2-45) when $N(\omega) = N_0 = \text{constant}$.

5.1.2 Output Resistance

Following the same procedure as the one outlined in Section 2.2.2 and using equations (2-46), (5-25), and (5-26) the expression for the output resistance can be obtained as

$$r_d = \frac{a}{\epsilon_r \epsilon_0 \mu_0 Z E_s} f_r(s, p) \quad (5-29)$$

where

$$f_r(s, p) = \frac{[\cosh(\pi L_2/2a) - 1] \{p[\overline{N(1)} - \overline{N(p)}]\} + (\epsilon_r \epsilon_0 E_s L_1 / qa^2) \cosh(\pi L_2/2a)}{\overline{N(1)} - \overline{N(p)}} \quad (5-30)$$

5.1.3 Gate Source Capacitance

From Section 2.2.3 and using equations (2-49), (5-23) through (5-26) the gate-source capacitance can be expressed as

$$C_{sg} = C_1 + C_2 + 1.56 \epsilon_r \epsilon_0 Z \quad (5-31)$$

where C_1 and C_2 are the capacitance contributions due to regions I and II, respectively. The numerical term accounts for the fringing capacitance as in the constant profile case. The capacitance contribution due to region I is given by

$$C_1 = \frac{qaZ}{E_s} \left\{ f_g(s, p) \left[p\overline{N(p)} + \frac{f_2(s, p)}{[\overline{N(1)} - \overline{N(p)}]^2} \right] - \left[\frac{\overline{N(i)} - \overline{N(s)}}{\overline{N(1)} - \overline{N(p)}} \right] \overline{N(s)} \right\} \quad (5-32)$$

where

$$f_2(s, p) = \overline{N(1)} \int_s^p \omega_d N(\omega_d) \overline{N(\omega_d)} d\omega_d - \int_s^p \omega_d N(\omega_d) [\overline{N(\omega_d)}]^2 d\omega_d \quad (5-33)$$

and the capacitance contribution due to region II is

$$C_2 = \frac{\epsilon_r \epsilon_0 Z L_2}{a} f_g(s, p) + \left[\frac{qaZ \overline{N(p)} + \epsilon_r \epsilon_0 Z E_s \sinh(\pi L_2/2a)}{E_s \cosh(\pi L_2/2a)} \right] \cdot [1 - f_g(s, p)] \quad (5-34)$$

5.1.4 Gate Charging Resistance

On the basis of the assumption of Section 2.2.4 that the time constant $\tau = R_i C_{sg}$ is proportional to the transit time through the channel one can write

$$\tau = \int_0^{L_1} \frac{dx}{\mu_0 E_x(x)} + \int_{L_1}^L \frac{dx}{v_s} \quad (5-35)$$

The first integral on the right-hand side of equation (5-35) can be evaluated using equations (5-14) and (5-17) thus:

$$\frac{1}{\mu_0} \int_0^{L_1} \frac{dx}{E_x(x)} = \frac{q^3 \mu_0 Z^2 a^4}{\epsilon_r \epsilon_0 I_d^2} \int_0^{L_1} [\overline{N(1)} - \overline{N(\omega_d)}] \omega_d N(\omega_d) d\omega_d \quad (5-36)$$

The second integral on the right-hand side of equation (5-35) is simply L_2/v_s , consequently, from equations (5-35) and (5-36)

$$R_i = \frac{1}{C_{sg}} \left[\frac{q^3 \mu_0 Z^2 a^4}{\epsilon_r \epsilon_0 I_d^2} \int_0^{L_1} [\overline{N(1)} - \overline{N(\omega_d)}] \omega_d N(\omega_d) d\omega_d + \frac{L_2}{\mu_0 E_s} \right] \quad (5-37)$$

5.2 NOISE ANALYSIS FOR THE INTRINSIC FET WITH VARIABLE DOPING PROFILE

5.2.1 Drain Circuit Noise

The open-circuit voltage fluctuation produced by sources in region I for the variable doping profile case is

$$\overline{|v_{dl}|^2} = \frac{4kT \Delta f}{I_d} \left(\frac{P_o + P_\delta}{[N(1) - N(p)]^2} \right) \cosh^2 \left(\frac{\pi L_2}{2a} \right) \quad (5-38)$$

where

$$P_o = \int_s^p [N(1) - N(\omega)]^2 \omega N(\omega) d\omega \quad (5-39)$$

and

$$P_\delta = \delta [N(1) - N(p)]^3 \int_s^p \frac{\omega N(\omega) d\omega}{[N(1) - N(\omega)]} \quad (5-40)$$

whereas the open circuit drain voltage fluctuation produced by sources in region II is given by the same expression as for the constant doping profile case or equation (3-4), equations (5-38) through (5-40) are analogous to equations (3-1) through (3-3), respectively. As in the constant doping profile case, the noise voltage contributions of the two regions are uncorrelated and their mean squares added.

5.2.2 Gate Circuit Noise

The short-circuit gate current fluctuation produced by sources in region I for the variable doping profile is

$$\overline{|i_{gl}|^2} = \omega^2 \left(\frac{qaZL_1}{r_d I_d} \right)^2 \left(\frac{qa^2}{\epsilon_r \epsilon_0 I_d} \right) \frac{\cosh^2 (\pi L_2 / 2a)}{[N(1) - N(p)]^2} (R_o + R_\delta) \quad (5-41)$$

where

$$\gamma = 1 + \left(\frac{qa^2}{\epsilon_r \epsilon_0} \right) p \frac{[N(1) - N(p)]}{E_s L_1} \left[1 - \frac{1}{\cosh (\pi L_2 / 2a)} \right] \quad (5-42)$$

and

$$R_o = \int_s^p [-\kappa' + \gamma \overline{N(\omega_d)}]^2 [\overline{N(1)} - \overline{N(\omega_d)}]^2 \omega_d N(\omega_d) d\omega_d \quad (5-43)$$

$$R_\delta = \delta [\overline{N(1)} - \overline{N(p)}]^3 \int_s^p \frac{[-\kappa' + \gamma \overline{N(\omega_d)}]^2}{[\overline{N(1)} - \overline{N(\omega_d)}]} \omega_d N(\omega_d) d\omega_d \quad (5-44)$$

$$\kappa' = \frac{\mu_o q^2 a^3 z}{\epsilon_r \epsilon_o I_d L_1} \int_s^p f_1(\omega_d, s) N(\omega_d) d\omega_d + \int_0^p \gamma N(\omega_d) d\omega_d + \frac{L_2}{L_1} [\overline{N(1)} - \overline{N(p)}] \quad (5-45)$$

Equations (5-41) through (5-45) are analogous to equations (3-7) through (3-10) and equation (3-12) respectively for the constant doping profile case.

The short circuit gate current fluctuation produced by sources in region II is given by the same expression as for the constant doping profile case or equation (3-13).

5.2.3 Correlation Coefficient

Following the same argument given in Section 3.3, the correlation coefficient C is given by equation (3-19) in which the expressions for P_o , P_δ , R_o , R_δ are given by equations (5-39), (5-40), (5-43) and (5-44), respectively. For S_o and S_δ the expressions are

$$S_o = - \int_s^p [-\kappa' + \gamma \overline{N(\omega_d)}] [\overline{N(1)} - \overline{N(\omega_d)}]^2 \omega_d N(\omega_d) d\omega_d \quad (5-46)$$

$$S_\delta = -\delta [\overline{N(1)} - \overline{N(p)}]^3 \int_s^p \left[\frac{-\kappa' + \gamma \overline{N(\omega_d)}}{[\overline{N(1)} - \overline{N(\omega_d)}]} \right] \omega_d N(\omega_d) d\omega_d \quad (5-47)$$

and for P_1 , P_2 , P , R_1 , R_2 and R the expressions are

$$P_1 = \left(\frac{qa^2}{\epsilon_r \epsilon_o r_d^2 g_m I_d} \right) \frac{\cosh^2(\pi L_2/2a)}{[\overline{N(1)} - \overline{N(p)}]^2} (P_o + P_\delta) \quad (5-48)$$

$$P_2 = \left(\frac{a I_d}{4 g_m r_d^2 \mu_0^2 E_s^3 \epsilon_r^2 \epsilon_0^2 Z^2} \right) f_3 \quad (5-49)$$

$$P = P_1 + P_2 \quad (5-50)$$

$$R_1 = \left(\frac{q^3 a^4 Z^2 L_1^2 g_m}{r_d^2 \epsilon_r \epsilon_0 I_d^3 C_{sg}^2} \right) \frac{\cosh^2 (\pi L_2 / 2a)}{[N(1) - N(p)]^2} (R_o + R_\delta) \quad (5-51)$$

$$R_2 = \left(\frac{q^2 a^3 L_1^2 g_m}{4 r_d^2 \epsilon_r^2 \epsilon_0^2 I_d C_{sg}^2 \mu_0^2 E_s^3} \right) (\kappa')^2 f_3 \quad (5-52)$$

$$R = R_1 + R_2 \quad (5-53)$$

The function f_3 of equations (5-49) and (5-52) is the same as for the constant doping profile case and is given by equation (3-26).

5.3 NOISE FIGURE ANALYSIS FOR THE INTRINSIC FET

The process to follow in order to obtain the noise figure for the FET with variable doping profile is the same as the one outlined in Section 4.2; this leads to identical expressions as those given in that section; consequently, they will not be rewritten here. It must be understood, however, that the expressions for P_1 , P_2 , P , R_1 and R_2 are given by equations (5-48) through (5-52), respectively. The same line of argument is followed for the minimum noise figure derivation of Section 4.3 and the temperature effects on noise figure expression of Section 4.4.

6. ANCILLARY REGIONS

For the purpose of developing analytical expressions for the parasitic resistance R_g , R_s , and R_d it is convenient to set up a coordinate system and establish dimensions (see Figure 2-4) as shown in Figure 6-1.

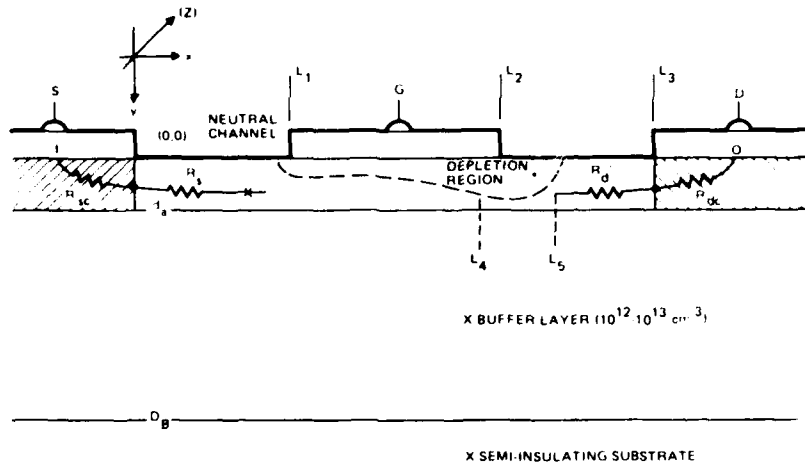


Figure 6-1. FET Cross-section

6.1 PARASITIC SOURCE RESISTANCE

The parasitic source series resistance consists of a metal sheet resistance term similar to the gate series resistance, but also includes contact resistance from metal to GaAs (R_{sc}) and channel resistance between the gate and source contact metalizations (R'_s). If ρ_{sch} is the sheet resistance of the channel, R'_s (Figure 6-1) may be estimated as

$$R'_s = \frac{\rho_{sch} L_1}{2} \quad (6-1)$$

The contact resistance may be described as a distributed resistor network as indicated in Figure 6-2. The equations which describe this system are

$$I(x) = \int_0^x V(x) G dx ; \text{ or, } \frac{\partial I}{\partial x} = V(x) G \quad (6-2)$$

$$V(x) = V(0) + \int_0^x I(x) R dx ; \text{ or, } \frac{\partial V}{\partial x} = I(x) R \quad (6-3)$$

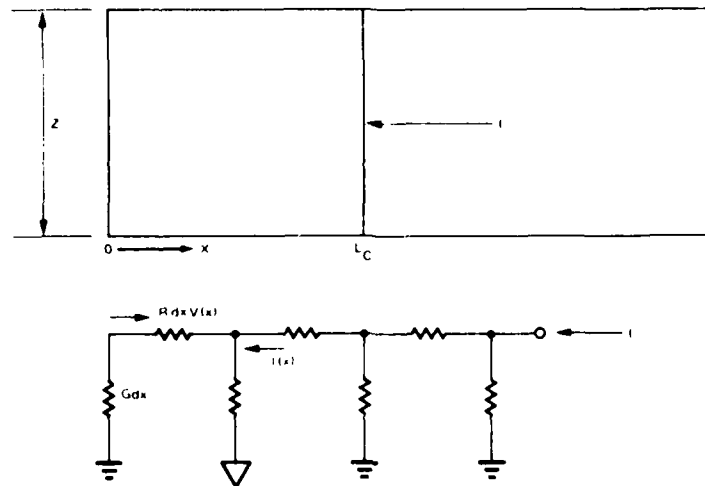


Figure 6-2. Contact Resistance and Equivalent Circuit

These can be combined to a single equation

$$\frac{\partial^2 I}{\partial x^2} = RG I(x) \quad (6-4)$$

G is determined by the specific contact resistance, ρ_c , which is typically $10^{-4} \Omega \cdot \text{cm}^2$

$$G = \frac{Z}{\rho_c}$$

R is determined by the sheet resistance of the GaAs under the contact metal. For an active implant of $10^{14}/\text{cm}^2$, this sheet should be $\rho_{sc0} \approx 15 \Omega/\square$

$$R = \frac{\rho_{sc0}}{Z}$$

thus

$$\gamma^2 = RG = \left(\frac{\rho_{sc0}}{\rho_c} \right) \approx 1.5 \times 10^5$$

solutions to 6.3 have the form

$$I = Ae^{\gamma x} + Be^{-\gamma x} \quad (6-5)$$

The boundary conditions are that

$$I = 0 \text{ @ } x = 0$$

$$I = I_c \text{ @ } x = L_c$$

thus

$$I = I_c (e^{\gamma x} - e^{-\gamma x}) / (e^{\gamma L_c} - e^{-\gamma L_c}) \quad (6-6)$$

$$V(x) = \frac{1}{G} \frac{\partial I}{\partial x}$$

or

$$V(x) = \frac{I_c \gamma}{G} \left[\frac{(e^{\gamma x} + e^{-\gamma x})}{(e^{\gamma L_c} - e^{-\gamma L_c})} \right] \quad (6-7)$$

Contact resistance is $V(L_c)/I(L_c)$, so

$$R_{sc} = \frac{(\gamma/G) (e^{\gamma L_c} + e^{-\gamma L_c})}{(e^{\gamma L_c} - e^{-\gamma L_c})}$$

but

$$\gamma = \sqrt{RG}$$

so

$$R_{sc} = \frac{(\rho_{sco} \rho_c)^{1/2}}{Z} \left(\frac{1 + e^{-2\gamma L_c}}{1 - e^{-2\gamma L_c}} \right) \quad (6-8)$$

Clearly, the most effective way to minimize R_{sc} is to minimize both ρ_{sco} and ρ_c and make $2\gamma L_c \gg 1$. For the values quoted, $2\gamma L_c \approx 1$ at $L_c = 13 \mu m$, indicating that contact resistance cannot be improved by making contacts longer than about $40 \mu m$. Total resistance R_s is therefore

$$R_s = \frac{(\rho_{sco} \rho_c)^{1/2}}{Z} \left(\frac{1 + e^{-2 \frac{(\rho_{sco})^{1/2}}{(\rho_c)^{1/2}} L_c}}{1 - e^{-2 \frac{(\rho_{sco})^{1/2}}{(\rho_c)^{1/2}} L_c}} \right) + \frac{\rho_{sch} L_1}{Z} + \frac{\rho_{shs} L_c}{2Z} \quad (6-9)$$

here

ρ_{sco} = sheet resistance of GaAs under contact metal

ρ_c = specific contact resistivity - metal to GaAs

ρ_{sch} = sheet resistance of channel between contact and gate

L_c = contact length

L_1 = space contact to gate

ρ_{shs} = sheet resistance of source contact metal

Z = device width

6.2 PARASITIC DRAIN RESISTANCE

The parasitic drain resistance R_d is calculated the same way as R_s , with L_1 replaced by $L_3 - L_2$ and L_c replaced by the drain contact length. In fact, most device designs have symmetrical source and drain geometries, leading to $R_d = R_s$.

6.3 PARASITIC GATE RESISTANCE

The parasitic gate series resistance R_g is due to the series resistance of the gate metallization; for the single lump equivalent circuit it is the resistance from the gate terminal to the center of the device

$$R_g \approx \frac{\rho_{shg} Z}{2 L_g} \quad (6-10)$$

where ρ_{shg} is the sheet resistance of the gate metallization, Z is the gate width, and L_g is the gate length ($L_g = L_2 - L_1$ in Figure 6-1). R_g can be minimized by keeping ρ_{shg} low (thick aluminum) or by keeping the effective Z small by paralleling several devices with small gate widths rather than using a single device with large gate width.

6.4 SOURCE-DRAIN AND GATE-DRAIN CAPACITANCES

The expression for inter-electrode capacitances between parallel strips immersed in an infinite dielectric medium was developed by Smythe⁹; modifying his expression to account for the air dielectric above the electrodes the expression for both capacitances C_{dg} and C_{sd} becomes

$$C_{dg}, C_{sd} = (\epsilon_r + 1) \epsilon_0 Z \frac{K[(1-k^2)^{1/2}]}{K(k)} \quad (6-11)$$

where $K(k)$ is the complete elliptical integral of the first kind given by¹⁰

$$K(k) = \int_0^{\pi/2} (1 - k \sin^2 \theta)^{-1/2} d\theta \quad (6-12)$$

the argument k of equations (6-11) and (6-12) is given by

$$k_{dg} = \left[\frac{L_3 - L_2}{(L_3 - L_2) + (L_2 - L_1)} \right]^{1/2}$$

$$k_{sd} = \left[\frac{(2L_s + L_3)L_3}{(L_s + L_3)^2} \right]^{1/2}$$

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B-1


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70 CALL GDTION2(100)
85 IF (100.00.0) GO TO 90
95 GO TO 90
STOP
END

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*OP 1 SUBROUTINE INTERPOL (IIP)
C THIS SUBROUTINE OUTPUTS DETAILED LISTING FOR GATE SET IF INPUT
C PARAMETERS
C
COMMON/CONSTS/ECCHARG,AMOD3,SAT,DIELC,BCLTZK,DIFCON,PI
COMMON/EXTPAR/CL,7,A,DOPEC,T,VGC,VDD,RFF,RPOR,RPM,ATITLE(7),OMI,F,
1 IPREFL,OMIN(101),DOF(101),DUPR(101),DUE28(101)
COMMON/CALC/C,S,CO,ALISAT,AID,WCL,SATDEX,APGU
COMMON/OUTPUT/FMTN,GM,CSG,CGD,CSD,RPI,CL1,CL2,RD,KSOPT,XSOPT
COMMON/ANCOAR/SSG,SL,DOPES,DUPESG,RSCS,RSHS,RSHG,SGD,DL,
1 GCPED,DOP,GO,RSCD,RSHD,IREF,I3YM
C
C DISPLAY+ENTER A DESCRIPTIVE HEADING FOR THIS RUN.*
READ(4,210) ATITLE
FORMAT (7A10)
IF (IOP.GT.0) CALL VALUES(IOP)
IF (IOP.LT.0) IOP = -1*IOP
IW00 = 0
IF (VDD.GT.-50.) GO TO 214
IW00 = 1
VDD = (-1.)*W00
210 DISPLAY+CALCULATE PARASITICS? (0=NO 1=TRW 2=FUKUI)*
ACCEPT IPARAS
IF (IPARAS.CO.1) CALL ANCIL(IOP)
IF (IPARAS.CO.2) CALL ANCIL2(IOP)
IF (IPARAS.CO.3) GO TO 220
C
C IF ANCIL IS NOT CALLED..CGD AND CSD CALCULATED. STUGRAT IS THE
C RATIO OF SOURCE CONTACT LENGTH TO GATE LENGTH. INTERELECTRODE
C DISTANCES EQUAL GATE LENGTH.
C
STUGRAT = 0.
CGD = 13.5/12.5*DIELC+Z
AMOD3 = SORT((2.+6.*STUGRAT)/(3.+STUGRAT)**2)
APF04 = SORT(1.-24.*AMOD3)
CSD = CGD*ELLIP(AMOD4)/:ELLIP(AMOD3)
220 CALL VALUES(IOP)
CALL PCALC(IOP)
IF (IERR.NE.0) GO TO 230
CALL NFVAL

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C
C B=GIN D-TAILED OUTPUT
C
      GMD = GM*F8.2
      GMTERM = GM/(1.+GM*PPF)
      GAMPO = GM/7./CT/CS6/10.9
      WRITE(5,234) EWIN,GMD,GMTERM,GAMBW
      WRITE(7,234) EWIN,GMD,GMTERM,GAMRWC
      FORMAT(14,10X,'UTLIS-FIGURE **F8.4,* DR**/,7X,*TRANSCDUCT*',
     1 *ANC**F8.2,** MHD**/,12X,*TERMINAL GM **F8.2,
     2 * AMP**/,10X,*CUT-OFF FREQUENCY **F8.2,** GHZ**/)
      IF (IERP.F8.-1) WRITE(5,235)
      IF (IERP.F8.-1) WRITE(7,235)
      FORMAT(24)*,* ELECTRON VELOCITY SATURATED OVER ENTIRE GATE*,
     1 * REGION. IHL**/,14,* ACCURACY OF THESE PRODUCTIONS*,
     2 * IS IMPLIED.*)
      WRITE(5,236)
      WRITE(7,236)
      FORMAT(14,*CAPACITANCE (PF)*,20X,*RESISTANCE (OHM)*/,22X,
     1 *INTRINSIC*)
      CSGC = CSG*1.E12
      CGDC = CND*1.E12
      WRITE(5,238) CSG,KPI,CGDJ,RD
      WRITE(7,238) CSG,KPI,CGDU,RD
      FORMAT(14,*CGG**F6.4,25X,*RI (GATE CHARGE)**F8.2,/* CGD **
     1 ,F6.4,37X,*RD (OUTPUT) **F8.2,/*PARASITIC*)
      CSDD = CSD*1.E12
      WRITE(5,240) CSDD,KPM,PPF,XDR
      WRITE(7,240) CSDD,KPM,PPF,XDR
      FORMAT(14,*CSD**F6.4,26X,*RM (GATE METAL)**F8.2,/*42X,
     1 *PE (SOURCE) **F8.2,/*42X,*RDR (DRAIN) **F8.2)
      WRITE(5,242)
      WRITE(7,242)
      FORMAT(14,/,5X,*REGION I*,2*X,*REGION II*)
      GL1D = GL1*1.E4
      GL2D = GL2*1.E4
      GLIPT = GLI*100./GL

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VDD = (-1.)+UDD
INCC = 1
DISPLAY=NEW DESCRIPTIVE HEADINGS=
P.10 (4.222) ATTL:
GC TH 210
RETURN
ICP = 0
P-TUPA
END

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266

270

280

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*OP 2 SUBROUTINE PATIONS (IOP)
C
C THIS SUBROUTINE CALCULATES AND DISPLAYS VARIOUS PARAMETERS
C
COMMON/CONST/ICCHARG,ANLC,ISAT,DI,LC,BOLIZK,DIFCIN,PI
COMMON/XTDAP/GL,7,A,DOPEC,T,VGG,VDD,RPF,PPOR,PPM,ATITLE(7),PHI,F,
1 TPOCFIL,DOCSIN(IOL),DOPI(IOL),DOPI(IOL),DIP2B(IOL)
COMMON/CAL/70,5,CC,AISAT,AID,M,CSATD,X,AFGU
COMMON/PAP/UT/FMTN,GM,CSG,SGD,CSO,PL,GLI,GL2,RD,RSOPT,XSOPT
COMMON/TO/TL,FY(50),FY(50,10),FG(50),NPT,PLN
COMMON/ANCPAR/SSG,SL,DUPES,DOPESG,RSCS,RSHS,SGD,DL,
1 GPF,DOPLGD,RSCD,RSHO,IPEG,ISYM
C
DISPLAY=2 AND A DESCRIPTIVE HEADING FOR THIS RUN.*
READ(4,310) ATITLE
FORMAT (7A10)
310 DISPLAY*CALCULATE S-PARAMETERS TOO (1=YES)2*
ACCEPT TSPAS
IF (IOP.GT.0) CALL VALUES(IOP)
IF (IOP.LT.0) IOP = -1*IOP
IMCO = 0
IF (VDD.GT.-99.) GO TO 311
IMCO = 1
VDD = (-1.)*WDD
C
311 DISPLAY*CALCULATE PARASITICS2(C=NG 1=TRW 2=FUKUI)*
ACCEPT TPAPAS
IF (IPAPAS.EQ.1) CALL ANCIL(IOP)
IF (IPAPAS.EQ.2) CALL ANCIL2(IOP)
312 DISPLAY*NUMBER OF PARAMETER TO BE VARIED2 (U=LIST)*
ACCEPT IWANT
IF (IWANT.EQ.0) GO TO 310
DISPLAY*GATE LENGTH 1*
DISPLAY*GATE WIDTH 2*
DISPLAY*CHANNEL DEPTH 3*
DISPLAY*DOING DENSITY 4*
DISPLAY*DEVICE TEMP 5*
DISPLAY*GATE BIAS 6*
DISPLAY*DATA BIAS 7*
DISPLAY*RSR 8*
DISPLAY*PCD 9*

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DISPLAY* SIGNAL FREQ      10*
DISPLAY* INITIAL-TN POTENTIAL 11*
DISPLAY* CAP* RESISTANCE 13*
DISPLAY* DIFFUSION CONSTANT 12*
DISPLAY* TURN ON OR OFF THE OPTION TO SET VGG AUTOMATICALLY*
DISPLAY* TO A FRACTION OF PINCH-OFF 16*
DISPLAY* ENTER THE NUMBER OF THE PARAMETER YOU WANT TO VARY.*
315 ACCEPT WANT
316 IF (IWANT.NE.14) GO TO 312
C
C SET OPTION TO ADJUST VGG TO A FRACTION OF PINCH-OFF
C
DISPLAY* THE GATE VOLTAGE CAN BE SET TO A FRACTION OF PINCH-OFF*
DISPLAY* OPTION ON = OPTION (OFF)*
ACCEPT IRTAS
IF (IBIAS.EQ.0) GO TO 312
DISPLAY* WILL SET VGG = X(WDO-PHI). ENTER X*
ACCEPT FRIAS
GO TO 312
C
318 IREV17 = 90
IF (IPARAS.EQ.1) CALL ANCIL(IREV17)
IF (IPARAS.EQ.2) CALL ANCIL2(IREV17)
320 IF (IOP.EQ.7.AND.IWANT.EQ.4) GO TO 400
DISPLAY* INITIAL AND FINAL VALUES AND INTERVAL SIZE FOR*
DISPLAY* VAP1 TO CAPAMETER2*
ACCEPT VAP1,VAR2,VINT
IF (VAP1.GT.VAR2.AND.VINT.GT.0) VINT = -1.*VINT
CALL VALUES2(IOP)
GO TO (451,452,453,454,455,456,457,458,459,460,461,462,463,
1 464,465) IWANT
325 N = INT((VAR2-VAP1)/VINT)+1
NPT = N
IUSC2 = 0
IPC2 = 0
C
C LOOP THROUGH CALCULATIONS FOR EACH VALUE OF PARAMETER
C
DO 350 I=1,N
VAR = VAP1+(I-1)*VINT
FX(I) = VAR
GO TO (371,372,373,374,375,376,377,378,379,380,381,382,383,

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330 1 994,225) TUNT
      IF (IPAPAC,50,1) CGO = STUGPAT*(40.-5.-2)
      IF (IPAPAC,50,7) GO TO 332
      ICAP = 1
      CALL DCALC (IPAPAC)
      IF (IPAPAC,50,1) TMS,CG = 1
      IF (IPAPAC,50,66) GO TO 350
      ISMGR = 1
      IF (IPAPAC,50,1) CALL CHUNCH(15,M,1)
      IF (IPAPAC,50,1) CALL CHUNCH2(15,M,1)
      AISATC = AISAT*1.73
      AICO = AYO*1.52
      GAO = CMT*1.52
      CMT,PAO = CMT/(1.+GMA*1.5)
      IF (ICAP,50,1) GO TO 334
      GAMPAC = CMT/2./ST/CGO/1.024

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C GAIN CALCULATED IS MAX AVAILABLE POWER GAIN FOR THE PROPERLY
C MATCHED DEVICE (MATCHED FOR OPTIMUM NOISE FIGURE). THEREFORE
C IT IS THE ASSOCIATED GAIN IF THE DEVICE IS STABLE. OTHERWISE
C IT IS THE MAXIMUM STABLE GAIN.
C
C IF (IPAPAC,50,1) GO TO 332
C
C IF ANCIL IS NOT CALLED...CGO AND CSC CALCULATED. STUGPAT IS THE
C RATIO OF STUB CONTACT LENGTH TO GATE LENGTH. INTERELECTRODE
C DISTANCE IS TOTAL GATE LENGTH.
C
C STUGPAT = 20.
C CGO = 13.5/12.5*PI*LC*Z
C AMS03 = SCOT*(10.+6.*STUGPAT)/(3.+STUGPAT)**2)
C AMS04 = SCOT*(10.-AMS03*AMS03)
C CSC = CMT*PI*2*W*AMS04/4*LC*Z*(AMS03)

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```

C TO SET CSC AND CGO TO ARBITRARY VALUES SET ICAP TO 1
C
C ICAP = 1
C IF (ICAP,50,1) GO TO 332
C CGO = CMT*1.52
C CSC = CMT*1.52
C WRITE(6,231) CSC,CGO
C WRITE(7,231) CSC,CGO

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331  FORMAT(1H, 'C000 =', F7.4, ' AND C01 =', F7.4, ' ENTER NEW VALUES*)
      ACCEPT C000, C001
      C00 = C000 + 1.0E-12
      C01 = C000 + 1.0E-12
332  CALL SPAP(1700, CAIN)
      FG(I) = GAIN
333  FY(I, 1) = FMIN
      IF (IWANT.NE.4) GO TO 330
      VAR = VAP * .5E-17
336  IF (IEPP.NE.-1) GO TO 338
C
C   NORMAL OUTPUT
C
      4PIT: (5, 240) VAP, AIDC, (MT, RM), CMC, FMIN, GANB, C, H, GAIN
      WRITE (7, 240) VAP, AIDC, (MT, RM), CMC, FMIN, GANB, C, H, GAIN
      GO TO 344
C
C   NORMAL OUTPUT WITH * TO DENOTE CRUNCH2 USED
C
336  WRITE (5, 240) VAP, AIDC, (MT, RM), CMC, FMIN, GANB, C, H, GAIN
      WRITE (7, 240) VAP, AIDC, (MT, RM), CMC, FMIN, GANB, C, H, GAIN
340  FORMAT(1H, 'F11.2, F9.1, F8.2, *, *, F5.2, F1.4, F9.2, F10.2, F7.2)
342  FORMAT(1H, '1H, F10.2, F9.1, F8.2, *, *, F5.2, F11.4, F9.2, F10.2, F7.2)
344  IF (ISPAD.NE.1) GO TO 350
      GFLAG = -99.
      CALL SPAP(1700, GELAG)
350  CONTINUE
      IF (IUC002.EQ.0) GO TO 354
      WRITE(5, 352)
      WRITE(7, 352)
352  FORMAT(1H, '1, 24 *, * ELECTRON DRIFT VELOCITY SATURATED FOR *,
      1 * ENTIRE GATE REGION. 1H, *, 1H, * ACCURACY OF THESE*,
      2 * OPERATIONS IS UNVERIFIED.*)
354  DISPLAY = *
      DISPLAY = *
      DISPLAY = *
      DISPLAY = * YOU WANT A NOISE FIGURE PLOT? (1=YES) *
      ACCEPT IPLNT
      IF (IFLNT.NE.1) GO TO 354
      NLN = 1
      CALL FSTPLNT (JDD, IWANT, ATAIL)
358  WRITE(5, 340)
360  FORMAT(1H, 'EMPTY, MAKE A REVISED RUN (-1), CHANGE OPTION (0)*,

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1      /END CONCLUDE SESSION (112*)
      ACCEPT WANT
      IF (IWANT) 362,366,368
      DISPLAY=FIRST D-S-51 ANY VALU.S.*
362    VDOFLO = VDO
      CALL NEWVAL
      CALL CHECK(TOP)
      IF (VDO.NF.VDORLO) IWDO = ,
      IF (VDO.EQ.1) VDO = (-1.)*WDO
      IF (VDO.GT.WDO) GO TO 364
      IWDO = 1
      VDO = (-1.)*WDO
364    DISPLAY=ENTERED ANOTHER DESCRIPTIVE TITLE*
      READ (4,211) ATTITL
      GO TO 315
366    RETURN
368    ICP = 0
      RETURN
C      REVISE VALUE OF PARAMETER AND CALL CHECK
C
371    GL = VAP*1.E-4
      GO TO 380
372    Z = VAP*1.E-4
      GO TO 380
373    A = VAP*1.E-4
      GO TO 380
374    DCPFC = VAP
      GO TO 380
375    T = VAP
      GO TO 380
376    VGG = VAP
      GO TO 380
377    VED = VAP
      GO TO 380
378    RFF = VAP
      GO TO 380
379    RFUP = VAP
      GO TO 380
380    F = VAP*1.E0
      GO TO 380
381    PHI = VAP

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362 GO TO 374
363 DISPLAY*DOPODAM*ENDR*
364 K*TURN
365 RFM = VAP
366 GO TO 330
367 DISPLAY*YOU CAN NOT REACH THIS PART OF THE PROGRAM*
368 RETURN
369 DIFCON = VAR
370 GO TO 330
371 IK-VIZ = 00
372 IF (IPAPAS.EC.1) CALL ANCIL(IOP)
373 IF (IPAPAS.EC.2) CALL ANCIL2(ICF)
374 IFLAG = -1
375 CALL CHECK (TELAC)
376 IF (IMV.EC.1) VON = (-1.)*WUG
377 IF (IFLAG.NE.-1) GO TO 330
378 WRITE (5,302) VAR
379 FORMAT (F15.2,1X,*WUG > PHI*)
380 GO TO 350
381 IPHI = INT(PI*1000.)
382 CALL CHECK (IPHI)
383 GO TO 301

```

C THIS SECTION CONTROLS THIS SUBROUTINE WHEN OP 7 IS CHOSEN.
 C DISPLAY*OPTION 7 AUTOMATICALLY VARIES THE DOPING CONCEN*
 C DISPLAY*TRATION TO OBTAIN THE MINIMUM NOISE FIGURE. YOU*
 C DISPLAY*MUST CHOOSE A DIFFERENT PARAMETER TO VARY.*
 C GO TO 312

C THE NOISE FIGURE IS OPTIMIZED BY VARYING DOPING. THE ROUTINE
 C OPERATES ON THE ASSUMPTION THAT THE OPTIMUM IS NEAR
 C 10*17 ATOMS/CC. IN ADDITION, IT MUST BE POSSIBLE TO
 C COMPUTE THE NOISE FIGURE AT THIS INITIAL CONCENTRATION.
 C DOPIC = 1.717
 C IF (IPAPAS.EC.1) IOP = 17
 C CALL NOTSE(IOP,IUSEC2)
 C IF (FMTN.EC.0) GO TO 408
 C FY(I,1) = 0.
 C WRITE(5,405) VAR
 C FORMAT(F11.2,4X,*NOISE FIGURE CANNOT BE CALCULATED.*)
 C IOP = 7
 C FY(I,1) = 0.

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400  GO TO 350
    FAT17 = FMIN
    FSAVE = FMIN
    DOPLC = 0.14
    ST = 1.16
410  CALL NMISE(INP,YUSEC2)
    IF (FMIN.GT.FSAVE) GO TO 422
    IF (FMIN.LT.0.) GO TO 416
    FSAVE = FMIN
    DOPEC = DOPEC-ST
    GO TO 410
416  FSAVE = 1000.
    DOPEC = DOPEC+.5*ST
    ST = ST/10.
    GO TO 410
422  IF (FSAVE.NE.FAT17) GO TO 430
    DOPEC = 1.01517
    CALL NMISE(INP,YUSEC2)
    IF (FMIN.GT.FAT17) GO TO 426
    ST = -1.014
    GO TO 414
426  ST = 1.015
    FAT17 = -99.
    GO TO 414
430  IF (ST.EQ.1.014) GO TO 418
    DOPEC = DOPEC+ST
    FMIN = FSAVE
    FY(I,1) = FMIN
    AISATD = AISAT*1.E3
    AIDG = AID*1.E3
    GMD = GM*1.E2
    GMTEMPN = GM/(1.+GM*PPF)
    GAMPLF = GM/2./DT/CSG/1.09
    IF (IFADAC.LT.1) GO TO 432
    STGRAT = 20.
    CED = 12.5/12.5*DI*LC*Z
    AMOD3 = SCRT((2.+6.*STGRAT)/(3.+STJGRAT)**2)
    AMOD4 = SCRT(1.-AMJOD3*AMOD3)
    CSD = CSD+1110*(AMJOD4)/ELLIP(AMOD3)
432  CALL SPAR(INP,GAIN)
    FG(1) = GAIN
    IF (IUSEC2.EQ.1) GO TO 438

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```

C
C NORMAL OUTPUT
C
      WRITE (5,240) VAR,AIDC,GMTERMQ,GMF,FMIN,GANB*U,WUO,GAIN
      WRITE (7,240) VAR,AIDC,GMTERMQ,GMF,FMIN,GANB*U,WUO,GAIN
      GO TO 444
438  WRITE (5,342) VAR,AIDC,GMTERMQ,GMF,FMIN,GANB*U,WUO,GAIN
      WRITE (7,342) VAR,AIDC,GMTERMQ,GMF,FMIN,GANB*U,WUO,GAIN
      IFC2 = TUSC2
444  WRITE (5,446) QDFFC
      WRITE (7,446) QDFFC
446  FORMAT(14,*,4BX,*,AT*,E10.2,*,ATOMS/CC*)
      IF (ISPAR.NF.1) GO TO 450
      CAIN = -QD.
      CALL SOAP(TMD,GAIN)
450  ICP = 7
      IUSEC2 = ICP2
      GO TO 350

C
C END OF NOISE COMPUTATION ROUTINE.
C
451  WRITE (5,471)
      WRITE (7,471)
471  FORMAT(14,*,
           1 QY,*,N,F,*,7X,*,FI*,7X,*,WUO GAIN*,/)
      GO TO 325
452  WRITE (5,472)
      WRITE (7,472)
472  FORMAT(14,*,
           1 QY,*,N,F,*,7X,*,FI*,7X,*,WUO GAIN*,/)
      GO TO 325
453  WRITE (5,473)
      WRITE (7,473)
473  FORMAT(14,*,
           1 QY,*,N,F,*,7X,*,FI*,7X,*,WUO GAIN*,/)
      GO TO 325
454  WRITE (5,474)
      WRITE (7,474)
474  FORMAT(14,*,QDFFC,CON XL-17,*,3X,*,ID*,5X,*,GMT/GM*,
           1 QY,*,N,F,*,7X,*,FI*,7X,*,WUO GAIN*,/)
      GO TO 325
455  WRITE (5,475)

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475 WRITE (7,475)
   FORMAT(1H,*,
1    QY,*,N,F,*,7X,*,FI*,7X,*,WCO GAIN*,/)
   GO TO 325

456 WRITE (5,476)
   WRITE (7,476)
476 FORMAT(1H,*,
1    QY,*,N,F,*,7X,*,FI*,7X,*,WCO GAIN*,/)
   GO TO 325

457 WRITE (5,477)
   WRITE (7,477)
477 FORMAT(1H,*,
1    QY,*,N,F,*,7X,*,FI*,7X,*,WCO GAIN*,/)
   GO TO 325

458 WRITE (5,478)
   WRITE (7,478)
478 FORMAT(1H,*,
1    QY,*,N,F,*,7X,*,FI*,7X,*,WCO GAIN*,/)
   GO TO 325

459 WRITE (5,479)
   WRITE (7,479)
479 FORMAT(1H,*,
1    QY,*,N,F,*,7X,*,FI*,7X,*,WCO GAIN*,/)
   GO TO 325

460 WRITE (5,480)
   WRITE (7,480)
480 FORMAT(1H,*,
1    QY,*,N,F,*,7X,*,FI*,7X,*,WCO GAIN*,/)
   GO TO 325

461 WRITE (5,481)
   WRITE (7,481)
481 FORMAT(1H,*,
1    QY,*,N,F,*,7X,*,FI*,7X,*,WCO GAIN*,/)
   GO TO 325

462 GO TO 382
463 WRITE (5,483)
   WRITE (7,483)
483 FORMAT(1H,*,
1    QY,*,N,F,*,7X,*,FI*,7X,*,WCO GAIN*,/)
   GO TO 325

464 DISPLAY*14 IS NOT AN AVAILABLE PARAMETER. TRY AGAIN.*
   GO TO 312

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465  WRITE(5,405)
      WRITE(7,405)
465  FORMAT(1H,*, DYES CONST,*,3X,*,ID*,6X,*,GFI/GM*,
1      QV,*,F.E.,*,7X,*,FI*,7X,*,WCC GAIN*,/)
      GO TO 325
      END

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```

*RAPIDIN
  SUBROUTINE RAPIDIN (IGF)
C
C THIS SUBROUTINE CAN BE USED INSTEAD OF EVALUATE WHEN THE USER
C IS FAMILIAR WITH THE PROGRAM
C
COMMON/CONSTS/ECCHARG,AMUO,ESAT,DIELC,BOLTZK,DIFCON,PI
COMMON/VTAP/CL7,A,DOPEC,T,VGG,VDD,RPF,RPD,RP1,ATITL(7),PHI,F,
1  TPROFIL,DOPIN(101),DUP(101),DOPR(101),DUP2R(101)
COMMON/CALC/F,S,G,AISAT,AID,WCO,SATCX,APGU
COMMON/CAPUT/FM1N,GM,CSG,CGD,CSD,RPI,GL1,GL2,RD,RSOPT,XSEPT
COMMON/ANCPAR/SSG,SL,DOPES,DOPEG,RSCS,RSHS,RSHG,SGD,OL,
1  NPDF,DCPLGD,RSCD,RSMD,IREG,ISYM
504 DISPLAY+ENTER L7,A,T,VGG,VDD,RSG,RGD,FGATE,F+
ACCEPT GL7,A,T,VGG,VDD,RPF,RPDR,RFM,F
GL = GL1,F=4
Z = Z1,F=4
A = A1,F=4
F = F1,F9
DISPLAY+DOPES PROFILE OPTION (D=LIST)2*
ACCEPT IORFIL
IF (IOPFIL.NE.0) GO TO 509
DISPLAY#1- CONSTANT*
DISPLAY#2- ARBITRARY*
DISPLAY+PROFILE OPTION DESIRED2*
ACCEPT IORFIL
509 GO TO (510,520) IORFIL
510 DISPLAY+DOPES2*
ACCEPT DOPFC
GO TO 576
520 DISPLAY+NUMBER OF VALUES2*
ACCEPT NPDF
DISPLAY+ENTER VALUES IN E15/CC. START AT GATE METAL.*
ACCEPT (DOPIN,I=1,NPDF)
DO 522 I=1,NPDF
522 DOPIN(I) = DOPIN(I)*1.E16
GO TO 576
576 CALL CHECK (TOD)
IF (ICP.NE.-2) GO TO 578
DISPLAY+AN INPUT ERROR PROBABLY OCCURED. REENTER.*
IOP = 4
GO TO 504

```

```

576 DISPLAY+OPTION NUMBER2+
  ACCEPT YOF
  MICH = IOD
  IOP = -1+IOP
  GO TO (591,592,593,584,585,586,587) MICH
581 RETURN
582 CALL OPTION1 (IOD)
  RETURN
583 CALL OPTION3 (IOD)
  RETURN
584 GO TO 576
585 IOP = -1+IOD
  CALL ANCIL(IOP)
  RETURN
586 CALL INCHAP(IOD)
  RETURN
587 CALL OPTION2(IOD)
  RETURN
  END

```

```

*ANCIL
SUBROUTINE ANCIL (IOP)
C THIS SUBROUTINE EVALUATES THE PARASITIC RESISTANCES AND CAPACITANCES
C
COMMON/CONSTS/ECCHARG,AMUO,ESAT,DIELC,BOLTZK,DIFCJN,PI
COMMON/EXTRAP/CL,7,A,DOPEC,T,VGG,VDD,RPF,RPDR,RPM,ATITL(7),PHI,F,
1 IPRRFL,DOPIN(101),DOP(101),DOPB(101),DOP2B(101)
COMMON/PAROUT/FMTN,GM,CSG,CGD,CSD,RPI,GL1,GL2,RD,RSDPT,XSDPT
COMMON/ANCCOR/SSG,SL,DOPES,DOPESG,RSCS,RSHS,RSHG,SGD,DL,
1 JOPCU,DOP_GD,RSCD,PSHD,IREG,ISYM
C
COTH(X) = (EXP(2.*X)+1.)/(EXP(2.*X)-1.)
RES(X) = -1./(ECCHARG*DOBLTY(X,T)*X*A)
C
C ALL ANCILLARY REGION PARAMETERS HAVE DEFAULT VALUES TO REDUCE
C THE AMOUNT OF INPUT TIME.
C
C SOURCE REGION
IF (IOP.EQ.00) GO TO 650
DISPLAY*ANCILLARY REGION PARAMETER OPTIONS* (U=LIST)*
ACCEPT IANCR
IF (IANCR.NE.0) GO TO 604
DISPLAY* ANCILLARY REGION OPTIONS*
DISPLAY* *
DISPLAY*1- USE INTERNAL DEFAULT VALUES.*
DISPLAY*2- USE DEFAULT VALUES WITH POSSIBLE CHANGES.*
DISPLAY*3- USE PRESENT VALUES.*
DISPLAY*4- USE PRESENT VALUES WITH SOME CHANGES.*
DISPLAY* *
DISPLAY*NOTE: ONCE A PARAMETER SET IS GENERATED, IT IS*
DISPLAY* RETAINED AND MAY BE MODIFIED AND USED*
DISPLAY* THROUGHOUT THE SESSION.*
DISPLAY* *
DISPLAY* ENTER THE DESIRED OPTION*
ACCEPT IANCR
GO TO (406,606,650,609) IANCR
604 SL = 20.0-4
606 ISSG = 1
SLO = SL*1.74
DOPES = 1.0F17
DOPESG = 1.0F17
RSCS = 1.0E-4

```

```

RSHS = 0.14
C GATE REGION
  RSHG = 0.05
  IF (GL*CT,0.0) GO TO 608
  GL = 0.5F-4
  Z = 2.0F-2
  A = 0.2F-4
  DOPED = 5.0E14
  T = 200.
608 GLD = GL*1.74
  SSGD = GL*7
  SGDO = GL*0
  YD = 7*1.74
C DRAIN REGION
  DL = SL
  ISGD = 1
  OLD = DL*1.74
  DOPED = 0.0005
  DOPEDD = DOPED*0.5
  RSCD = 0.5C
  RSHD = RSHS
C MC IVER EQUATIONS INCLUSION PARAMETER
  IREC = 2
C DOPING PARAMETER ALONG CHANNEL LENGTH
  ISYM = 2
  IF (IANGP,0.1) GO TO 650
  DISPLAY*DISPLAY DEFAULT VALUES2 (1=YES)*
  ACCEPT TOPVIEW
  IF (IPREV,0.1) GO TO 670
  DISPLAY*TO CHANNEL * MAXIMUM:
  DISPLAY*ENTER NUMBER (0=LIST, 16=NO CHANGE)*
  ACCEPT TPAP
  IFREVUE = 0
  IF (IPAP,0.14) GO TO 650
  IF (IPAR,0.1) GO TO 620
  DISPLAY*
  DISPLAY*ANCILLARY REGION PARAMETER LIST*
  DISPLAY*

```

DISPLAY*	SOURCE REGION*	1*
DISPLAY*SOURCE-GATE SEPARATION (MICRONS)		
DISPLAY*NOTE: UNLESS CONTACT SEPARATION IS SET, DEFAULT*		
DISPLAY*VALUE OF GATE LENGTH IS USED. AFTER SETTING VALUE,**		
DISPLAY*DEFAULT CAN BE RESTORED BY ENTERING NEGATIVE VALUE.**		
DISPLAY*SOURCE CONTACT LENGTH (MICRONS)		2*
DISPLAY*DOPTING CONC. OF SOURCE REGION (ATOMS/CC)		3*
DISPLAY*DOPTING CONC. OF INTERMEDIATE SOURCE**		
DISPLAY* GATE REGION (ATOMS/CC)		4*
DISPLAY*SPECIFIC CONTACT RESISTIVITY (OHM-CM-CM)		5*
DISPLAY*SHEET RESISTANCE OF SOURCE CONTACT*		
DISPLAY* METAL (OHM/SQUARE)		6*
DISPLAY* *		
DISPLAY* GATE REGION*		
DISPLAY*GATE WIDTH (MICRONS)		7*
DISPLAY*GATE LENGTH (MICRONS)		8*
DISPLAY*SHEET RESISTANCE OF GATE CONTACT*		
DISPLAY* METAL (OHM/SQUARE)		9*
DISPLAY* *		
DISPLAY* DRAIN REGION*		
DISPLAY*GATE-DRAIN SEPARATION (MICRONS)		10*
DISPLAY*DEFAULT IS CHANGED OR SET AS FOR S-G*		
DISPLAY*SEPARATION.*		
DISPLAY*DRAIN CONTACT LENGTH (MICRONS)		11*
DISPLAY*DOPTING CONC. OF DRAIN REGION (ATOMS/CC)		12*
DISPLAY*DOPTING CONC. OF INTERMEDIATE GATE**		
DISPLAY* DRAIN REGION (ATOMS/CC)		13*
DISPLAY*SPECIFIC CONTACT RESISTIVITY (OHM-CM-CM)		14*
DISPLAY*SHEET RESISTANCE OF DRAIN CONTACT*		
DISPLAY* METAL (OHM/SQUARE)		15*
DISPLAY* *		
DISPLAY*TO STOP MAKING CHANGES TYPE		16*
DISPLAY* *		
DISPLAY*THAT RESISTANCE UNDER THE SOURCE AND*		
DISPLAY*DRAIN CONTACTS:**		
DISPLAY* VALUE = 1 TO IGNORE CONTRIBUTION*		
DISPLAY* VALUE = 2 TO APPROXIMATE CONTRIBUTION*		
DISPLAY* USING MC IVERS EQUATIONS		17*
DISPLAY* *		
DISPLAY*DOPTING CONCENTRATION IN ALL ANCILLARY*		
DISPLAY*REGIONS:**		
DISPLAY* VALUE = 1 PROVIDES INDIVIDUAL VALUES*		

FOR EACH REGION*

DISPLAY* VALU* = 2 MAX'S CONCENTRATION OF ANCILLARY*
 DISPLAY* TH. SAM. AS UNDER THE GATE*
 DISPLAY* VALU* = 3 MAX'S INTER LECTURE DOPING*
 DISPLAY* SAM. AS FOR GATE REGION*
 DISPLAY* CONTACT DOPING MAY BE DIFFERENT 14*

620 GO TO 610
 DISPLAY*NEW VALU*→*
 ACCEPT Y
 GO TO (631,632,633,634,635,636,637,638,639,640,641,642,
 643,644,645,650,647,649) IPAR

631 SSGO = Y
 SSG = Y+1.F-4
 ISSG = 0
 IF (X+1.F-4) ISSG = 1
 GO TO 610

632 SLO = X
 SL = X+1.F-4
 GO TO 610

633 DOPES = X
 GO TO 610

634 DOPESG = Y
 GO TO 610

635 RSCS = Y
 GO TO 610

636 RSHS = Y
 GO TO 610

637 ZO = X
 Z = X+1.F-4
 GO TO 610

638 GLO = Y
 GL = X+1.F-4
 GO TO 610

639 RSHG = X
 GO TO 610

640 SGDO = Y
 SGD = Y+1.F-4
 ISGD = 0
 IF (X+1.F-4) ISGD = 1
 GO TO 610

641 OLO = X

```

DL = X+1,F-4
GO TO 610
DOPEO = Y
GO TO 610
DOPEO = Y
GO TO 610
RSCD = X
GO TO 610
RSHD = Y
GO TO 610
IF (INT(X).EQ.1) IREG = 1
IF (INT(X).EQ.2) IREG = 2
GO TO 610
ISYM = INT(Y)
GO TO 610

C PARASITIC RESISTANCE CALCULATIONS
650 IF (ISSG.EQ.1) SSG = GL
IF (ISGD.EQ.1) SGD = GL
IF (ISYM.EQ.1) G7 TJ 652
IF (ISYM.EQ.2) G8 TJ 651
DOPEO = DOPEC
DOPEO = DOPEC
DOPEO = DOPEC
DOPEO = DOPEC
RPF = RES(DOPEO)*SSG/Z
GO TO 656
ACOTH = SQRT(RES(DOPEO)/RSCD)*SL
IF (ACOTH.GT.370.) GO TO 634
RPF = COTH(ACOTH)*SQRT(RES(DOPEO)*RSCD)/Z
1 +RES(DOPEO)*SSG/Z+RSHD*Z/2./SL
656 IF (IRFG.EQ.2) G9 TO 650
DOPEO = DOPEC
RPF = RES(DOPEO)*SGD/Z
GO TO 660
ACOTH = SQRT(RES(DOPEO)/RSCD)*DL
IF (ACOTH.GT.370.) GO TO 634
RPF = COTH(ACOTH)*SQRT(RES(DOPEO)*RSCD)/Z
1 +RES(DOPEO)*SGD/Z+RSHD*Z/2./DL

```

```

C CAPACITANCE CALCULATIONS
660 AMOD1 = SQRT(CGD/(SGD+GL))
    AMOD2 = SQRT(1.-AMOD1*AMOD1)
    CGD = 13.5*DTPLC/12.5*Z*ELLIP(AMOD2)/ELLIP(AMOD1)
    SSD = SGD+GL+SGD
    AMOD3 = SQRT((2.*SL+SSD)*SSD/(SL+SSD)**2)
    AMOD4 = SQRT(1.-AMOD3*AMOD3)
    CSD = 13.5*DTPLC/12.5*Z*ELLIP(AMOD4)/ELLIP(AMOD3)
    IF (IDP.EQ.OC) RETURN
    DISPLAY*DTOLAY INPUT AND PARASITIC VALUES (1), PARASITICS*
    DISPLAY*ONLY (2) OR NO LISTS (3)*
    ACCEPT IWANT
    IUSE = 0
    GC TO (570,6F4,600) IWANT
670 WRITE (5,670)
    WRITE(7,672)
672 FORMAT (14I,/,14,*,INPUT VALUES FOR ANCILLARY REGION ANALYSIS*,
           /,30X,*,SOURCE*,6X,*,GATE*,5X,*,DRAIN*,/)
674 WRITE (5,674) SL0,GL0,DLC,2J,2J,2J,7C
    WRITE(7,674) SL0,GL0,DLC,2J,2J,2J,7C
676 FORMAT(14,*,10X,*,CONTACT LENGTH (MICRONS):*,3F10.2,/,
           14,*,10X,*,CONTACT WIDTH (MICRONS):*,3F10.2)
    WRITE(5,678) SSG0,SGDD
    WRITE(7,678) SSG0,SGDD
678 FORMAT(14,*,2X,*,SEPARATION FROM GATE (MICRONS):*,F10.2,
           1 F20.2)
    WRITE(5,680) DTPEC,DOP=C,DOPED,DOPESG,DOP4GD
    WRITE(7,680) DTPEC,DOPEC,DOPED,DOPESG,DOP4GD
680 FORMAT(14,*,7X,*,DOPING UNDER CONTACT (/CC):*,3E10.2,/,
           14,*,4X,*,DOPING BETWEEN CONTACTS (/CC):*,E10.2,
           2 F20.2)
    WRITE(5,682) RSCS,RSCD,RSHS,RSHG,RSHD
    WRITE(7,682) RSCS,RSCD,RSHS,RSHG,RSHD
682 FORMAT(14,*,2X,*,SPECIFIC CONTACT RES. (OHM-CM2):*,E10.2,
           1 F20.2,/,14,*,2X,*,SHEET RES. OF CONTACT (OHM/SQ.):*,
           2 F10.2,/)
    IF (IPREVUS.NE.1) GO TO 604
    IPREVUS = 0
    GC TO 570
684 WRITE (5,684)
    WRITE(7,686)

```

```

686  FORMAT(1H,*,PARASITIC RESISTANCE (OHM) AND CAPACITANCE (PF) *,
      1  *RE-VICE*,/)
      CSDD = CSO*1.E12
      CGDD = CGO*1.E12
      WRITE(5,600) DOF,CSDD,RFM,CGDD,FPCR
      WRITE(7,600) DOF,CSDD,RPM,CGDD,RFDR
688  FORMAT(14,5X,*S P-S (RF)*, F10.2,10X,*S-D CAP*,
      1  F10.4,/,14,5X,*G RES (RM)*,F10.2,10X,
      2  *G-D CAP*,F10.4,/,14,4X,*D RES (RDR)*,
      3  F10.2,/)
      IF (IOP.NE.5) GO TO 690
      DISPLAY*NEXT, MAKE A REVISED RUN (-1), CHANGE OPTION (0)*
      DISPLAY*OR CONCLUDE SESSION (1)2*
      ACCEPT TWANT
      IF (IWANT) A10,600,692
690  RETURN
692  IOP = 0
      RETURN
694  DISPLAY*SOURCE RESISTANCE CANNOT BE CALCULATED. THE CONT.*
      DISPLAY*RESISTANCE, DEFPING CLING, UP CHANNEL DEPTH MUST BE*
      DISPLAY*INCREASED.*
      GO TO A10
      END

```

```

*ELLIP FUNCTION ELLIP(AMOD)
C FUNCTION TO EVALUATE THE COMPLETE ELLIPTICAL INTEGRAL OF THE
C FIRST KIND
      ELLIP = 0.
      DX = 3.14159/2./30.
      DO 695 I=1,30
        AI = FLOAT(I)
        X = (AI-.5)*DX
        ELLIP = ELLIP+DY/SQRT(1.-AMOD*SIN(X)**2)
      695 RETURN
      END

```

```

*IVCHAR
SUBROUTINE TVCHAP (IDP)
C
C THIS SUBROUTINE CALCULATES DRAIN CURRENT VS. DRAIN VOLTAGE
C
COMMON/CONST/ECARG,AMLO,=SAT,DIELC,BOLTZK,DIFCJN,PI
COMMON/EXTPAR/GL,Z,A,DOPEG,T,VGG,VDD,PPF,RPDR,RPM,ATITLE(7),PHI,F,
1 TORRETL,DOPEIN(10),DUP(10),DPR(10),DTP2R(10)
COMMON/CALC/P,S,C,AISAT,AID,WDS,SATDEX,ARGJ
COMMON/PARTUT/FVIN,GM,CEG,CGD,CED,PP1,GL1,GL2,RD,RSOPT,XSOPT
COMMON/TOTLT/FY(50),FY(50,10),FG(50),NFT,NLN
COMMON/ANCPAP/SSG,SL,DGPES,DGPESG,RSCS,RSHS,RSHG,SGD,DL,
1 JPD,DOPEGD,RSCD,RSHD,IREG,ISYM
DIMENSION VAPUT(10),VPIJ(10)
704 DISPLAY*CHOUT: INFO. (0), REGULAR (1), HIGH SPEED (2)*
ACCEPT TSPEN
IF (ISPEF,NF,0) GO TO 706
DISPLAY*TVCHAP MAY BE USED IN TWO MODES.*
DISPLAY* *
DISPLAY*1- REGULAR. CALCULATES 29 DATA POINTS OVER A*
DISPLAY* RANGE OF 3, 6 OR SOME OTHER VALUE OF VDD.*
DISPLAY* YOU CHOOSE WHETHER THE CURVES ARE OUTPUT AS*
DISPLAY* TABLES, PLOTS OR BOTH.*
DISPLAY*2- HIGH SPEED. CALCULATES 6 DATA POINTS (1-6V)*
DISPLAY* WITH OUTPUT AS TABLES. THIS MODE IS USEFUL*
DISPLAY* WHEN ADJUSTING PARAMETERS TO FIT EMPIRICAL*
DISPLAY* DATA.*
DISPLAY* *
GO TO 704
706 DISPLAY*ENTER A DESCRIPTIVE HEADING FOR THIS RUN.*
READ(4,708) ATITLE
708 FORMAT (7A10)
IF (IDP.GT.0) CALL VALUES(IDP)
IF (IDP.LT.0) IDP = -1*100
IF (VDD.GT.-90.) GO TO 711
VDD = -900
IDP = 1
710 IDP = 1
711 DISPLAY*CALCULATE PARASITICS? (0=NO 1=TRW 2=FUKUI)*
ACCEPT TPAPAS
IF (IPAPAS.EQ.1) CALL ANCIL(IDP)
IF (IPAPAS.EQ.2) CALL ANCIL2(IDP)
712 DISPLAY*THIS PORTION COMPUTES DRAIN CURRENT VS. DRAIN BIAS.*

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714 DISPLAY*CHOOSE A MAXIMUM VDD OF 3V, 6V OR ANOTHER VALUE.*
    ACCEPT VDDMAX
    DISPLAY*YOU MAY ALSO VARY ANOTHER PARAMETER.*
    DISPLAY*NUMBER OF PARAMETERS (0 = LIST, 1 = VGG)*
    ACCEPT IWANT
    IF (IWANT.NE.0) GO TO 718
    DISPLAY*GATE LENGTH
    DISPLAY*GATE WIDTH
    DISPLAY*CHANNEL DEPTH
    DISPLAY*DOING DENSITY
    DISPLAY*DEVICE TEMP
    DISPLAY*GATE BIAS
    DISPLAY*DRAIN BIAS
    DISPLAY*RES
    DISPLAY*DCG
    DISPLAY*SIGAL FREQ
    DISPLAY*MULTI-IN POTENTIAL
    DISPLAY*NO 3RD VARIABLE
    DISPLAY*GATE RESISTANCE
    DISPLAY* *
715 DISPLAY*ENTER THE NUMBER OF THE PARAMETER YOU WANT TO VARY.*
    ACCEPT IWANT
716 IF (IWANT.NE.12) GO TO 720
    J = 1
    GO TO 724
720 DISPLAY*INITIAL AND FINAL VALUES OF PARAMETER*
    DISPLAY*AND INTERVAL BETWEEN CALCULATIONS*
    ACCEPT VAP1,VAP2,VINT
    IF (VAP1.GT.VAP2) VINT = (-1.)*ABS(VINT)
    NLN = INT((VAP2-VAP1)/VINT)+1
    J = 0
    DISPLAY*ENTER Y AND Y WHERE RGD = X + Y VGG*
    ACCEPT RGDN,PGNC
C LOOP THROUGH VALUES OF CHOSEN PARAMETER
C
    DO 728 I=1,NLN
    IPR = J1
    VAR = VAP1+(ELIAT(J1)-1.)*VINT
    J = J+1
    VARGUT(J) = VAR
    GO TO (771,772,773,774,775,776,777,778,779,780,781,792,7F3)IWANT

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```

724 IERR = 0
    IF (IWANT.NE.0) RPDR = RGD.-VGS+GDC
    CALL VDCALC(ITOP,VF)
    IF (I-00.NE.00) GO TO 728
    J = J-1
    GO TO 738
726 VPIM(J) = VC-AID*(RPF+RPDR)
    IF (ISDEFD.NE.0) GO TO 870
    NFI = 20
C
C LOOP THROUGH VALUES OF VDD
C
    DO 736 I=1,NPT
    IF (I.LT.20) VDD = 0.1*FLDGT(I-1)*VDDMAX/0.
    IF (I.GT.20) VDD = 0.2*FLDGT(I-17)*VDDMAX/0.
728 IF (VDD.LT.VDINT(J)) GO TO 732
    IERR = 0
    CALL PCALC (IERR)
    IF (IERR.NE.00) GO TO 734
    DISPLAY*0 NOT CALCULATED AT VDD =*,VDD,*,THE SATURATED REGION.*
730 DISPLAY*VDC =*,VGS,*WHICH MAY BE TOO NEGATIVE.*
    J = J-1
    GO TO 738
732 IERR = 0
    CALL DCALC(IERR)
    IF (IERR.NE.00) GO TO 734
    DISPLAY*IN NOT CALCULATED AT VDD =*,VDD,*,THE UNSATURATED REGION.*
    GO TO 730
734 FX(I) = VDD
736 FY(I,J) = -1.*AID*1.e3
738 CONTINUE
    IF (ISDEFD.NE.0) GO TO 760
C
C BEGIN OUTPUT SELECTION AND OUTPUT
C
    NLN = J
    WRITE(5,740) J
    FORMAT(110,*,CURVES HAVE BEEN GENERATED.*)
    IF (J.NE.0) GO TO 760
742 DISPLAY*DISPLAY I-V DATA* (I=Y,S)*
    ACCEPT TTABE
    CALL VALUE52(I70)

```

```

743 IF (ITABLE,EO,0) GO TO 758
    WRITE (5,744)
    WRITE (7,744)
744 FORMAT(14,/,/,1X,*,FLI DC CHARACTERISTICS*,/)
    OF 756 J=1,MIN
    DISPLAY* *
746 GO TO (851,852,853,854,855,856,857,858,859,360,861,862,863)IWANT
    WRITE (5,749)
    WRITE (7,749)
748 FORMAT(14,*,OX,*VDD (V)*,6X,*DRAIN CURRENT (MA X -1)*,/)
    IF (ISPEED,EO,2) GO TO 872
    DO 750 I=1,MET
750 WRITE (5,752) FX(I),FY(I,J)
    WRITE (7,753) FX(I),FY(I,J)
752 FORMAT(14,*,EX,ELC,3,5X,FLJ,3)
756 CONTINUE
    DISPLAY* *
758 DISPLAY* *
    DISPLAY*DC YOU WANT A PLOT OF THE I-V CURVES? (1,0)*
    ACCEPT IPLT
    IF (IPLT,EO,0) GO TO 760
    CALL FETPLT (I70,IWANT,ATITLE)

C
C END OF OUTPUT SECTION
C
760 WRITE (5,742)
762 FORMAT (//,*NEXT, MAKE A REVISED RUN (-1), CHANGE OPTION (0)*,
1 /,*OP CONCLUDE SESSION (1)2*)
    ACCEPT IWANT
764 IF (IWANT) 744,766,768
    DISPLAY*FIRST RESET ANY VALUES.*
    CALL NEWVAL
    CALL CHECK(IOP)
    DISPLAY*ENTER ANOTHER DESCRIPTIVE TITLE*
    READ (4,70P) ATITLE
    GO TO 715
766 RETURN
768 IOP = 0
    RETURN
771 GL = VAR*1.5-4
772 Z = VAR*1.5-4

```

```

773 GO TO 709
    A = VAP*1.E-4
774 GO TO 709
    DPLC = VAP
775 GO TO 799
    T = VAP
776 GO TO 709
    VGG = VAP
777 GO TO 724
    VDD = VAP
778 GO TO 724
    RPF = VAP
779 GO TO 724
    QCDP = VAP
780 GO TO 724
    F = VAP*1.E0
781 GO TO 724
    PHI = VAP
782 GO TO 709
783 GO TO 712
    RPM = VAP
784 GO TO 724
789 IFLAG = -1
    CALL CHECK (IFLAG)
791 IF (IFLAG.EQ.-2) WRITE(5,792) VAR
792 FORMAT (1F5.2,1Y,*,XLL > PHI*)
    IREVIZ = 99
    IF (IPARAS.EQ.1) CALL ANCIL1(IREVIZ)
    IF (IPARAS.EQ.2) CALL ANCIL2(IREVIZ)
796 GO TO 724
    IPHI = INT(PHI*1000.)
    CALL CHECK (IPHI)
797 GO TO 701
    *FITE(F,RR1) VAPOUT(J)
    WRITE(7,RR1) VAPOUT(J)
798 GO TO 744
    WRITE(5,RR2) VAPOUT(J)
    WRITE(7,RR2) VAPOUT(J)
799 GO TO 744
    WRITE(5,RR3) VAPOUT(J)
    WRITE(7,RR3) VAPOUT(J)
800 GO TO 744

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```

054 WRITE (5,884) VARGOUT(J)
    WRITE (7,884) VARGOUT(J)
    GO TO 744
055 WRITE (5,885) VARGOUT(J)
    WRITE (7,885) VARGOUT(J)
    GO TO 746
056 WRITE (5,886) VARGOUT(J),VPING(J)
    WRITE (7,886) VARGOUT(J),VPING(J)
    GO TO 745
057 WRITE (5,887) VARGOUT(J)
    WRITE (7,887) VARGOUT(J)
    GO TO 746
058 WRITE (5,888) VARGOUT(J)
    WRITE (7,888) VARGOUT(J)
    GO TO 745
059 WRITE (5,889) VARGOUT(J)
    WRITE (7,889) VARGOUT(J)
    GO TO 746
060 WRITE (5,890) VARGOUT(J)
    WRITE (7,890) VARGOUT(J)
    GO TO 746
061 WRITE (5,891) VARGOUT(J)
    WRITE (7,891) VARGOUT(J)
    GO TO 746
062 WRITE (5,892) VARGOUT(J)
    WRITE (7,892) VARGOUT(J)
    GO TO 745

```

C THIS SECTION IS USED FOR THE HIGH SPEED CALCULATIONS

```

C
070 IF (IP0,50,1) CALL VALUES2(IOP)
    WRITE (5,871) RPS,PPDR,RPM
    WRITE (7,871) RPS,PPDR,RPM
071 FORMAT(14,*,P50,*,F6.1,5X,*,RGD,*,F6.1,5X,*,RGATE,*,F5.1)
    GO TO (851,852,853,854,855,856,857,858,859,360,861,862,863)IWANT
072 DO 876 I=1,5
    VCD = SIGNAT(I)*VCDMAX/C.
    IERR = 0
    IF (VCD,LE,VPING(J)) CALL DCALC(IERR)
    IF (VCD,GT,VPING(J)) CALL PCALC(IERR)
    IF (IERR,50,0) GO TO 874

```

DISPLAY*IF NOT FOUND AT VDD =*,VDD
GO TO 876

874

AIDC = -AID*1.52
WRITE(5.752) VDD,AIDC
*R11(7.752) VDD,AIDC

C

C AFTER LAST DC POINT, N.F. CALCULATED AT THAT BIAS

C

IF (I.LT.4) GO TO 876

IERR = 0

CALL PCALC (IERR)

IF (IERR.EQ.-1) IUSEC2 = 1

IF (IERR.EQ.09) GO TO 876

ISMOKE = 0

IF (IERR.EQ.-1) CALL CRUNCH(IISMOKE)

IF (IERR.EQ.-1) CALL CRUNCH2(IISMOKE)

AISATQ = AYSAT*1.53

AIDC = AID*1.53

GMD = GM*1.53

GMTERMP = GMD/(1.+GM*RPF)

IF (IISMOKE.EQ.09) GO TO 334

GANBW = GM/2./PI/CSG/1.59

C

C GAIN CALCULATED IS MAX AVAILABLE POWER GAIN FOR THE PROPERLY

C MATCHED DEVICE (MATCHED FOR OPTIMUM NOISE FIGURE). THEREFORE

C IT IS THE ASSOCIATED GAIN IF THE DEVICE IS STABLE. OTHERWISE

C IT IS THE MAXIMUM STABLE GAIN.

C

IF (IPARAS.EQ.1) GO TO 332

C

C IF ANCIL IS NOT CALLED...CGD AND CSD CALCULATED. STUGRAT IS THE

C RATIO OF SOURCE CONTACT LENGTH TO GATE LENGTH. INTERELECTRODE

C DISTANCES EQUAL GATE LENGTH.

C

STUGRAT = 20.

CGD = 13.5/12.5*DI*LC#2

AMOD3 = SQRT(C.+4.*STUGRAT)/(3.+STUGRAT)**2)

AMOD4 = SQRT(1.-AMOD3*AMOD3)

CSD = CGD+LIP(AMOD4)/ELLIP(AMOD3)

CALL SCAP(IERR,GAIN)

FG(1) = GAIN

FY(1,1) = FMIN

334

B-35

```

IF (IWANT.NE.4) GO TO 336
VAR = VAR+1.-17
336 IF (IERR.FO.-1) GO TO 330

```

```

C
C NORMAL OUTPUT
C

```

```

WRITE (5,340) GINTERMO,GMO,FMIN,GANBWO,WCO,GAIN
WRITE (7,340) GINTERMO,GMO,FMIN,GANBWO,WCO,GAIN
GO TO 376

```

```

C
C NORMAL OUTPUT WITH * TO DENOTE CRUNCH2 USED
C

```

```

338 WRITE (5,342) GINTERMO,GMO,FMIN,GANBWO,WCO,GAIN
WRITE (7,342) GINTERMO,GMO,FMIN,GANBWO,WCO,GAIN
340 FORMAT (14,20X,F0.2,*,F5.2,F11.4,F9.2,F10.2,F7.2)
342 FORMAT(14,14X,10X,F8.2,*,F5.2,F11.4,F9.2,F10.2,F7.2)
C

```

```

C C END OF N.O. CALCULATION
C

```

```

276 CONTINUE
DISPLAY*CONTINUE> (1=YES)*
ACCEPT ICONTN
IF (IGTN.FO.1) GO TO 736
GO TO 760

```

```

C C END OF HIGH SPEED CALCULATION SECTION
C

```

```

881 FORMAT(14,2X,GATE LENGTH =*,F6.2,*,MICRONS*)
882 FORMAT(14,2X,GATE WIDTH =*,F6.2,*,MICRONS*)
883 FORMAT(14,2X,CHANNEL DPTH =*,F6.3,*,MICRONS*)
884 FORMAT(14,2X,CHANNEL DENSITY =*,F10.2,*,ATJMS/CC*)
885 FORMAT(14,2X,DEVICE TEMPERATURE =*,F6.2,*,K*)
886 FORMAT(14,2X,VCC =*,F6.2,*,V. VPINCH = VSD AT VDD =*,F7.3,*,V*)
887 FORMAT(14,2X,DATA BIAS =*,F6.3,*,V*)
888 FORMAT(14,2X,S-G RESISTANCE =*,F6.2,*,OHM*)
889 FORMAT(14,2X,D RESISTANCE =*,F6.2,*,OHM*)
890 FORMAT(14,2X,FREQUENCY =*,F6.2,*,GHZ*)
891 FORMAT(14,2X,BUILT-IN POTENTIAL =*,F6.2,*,V*)
893 FORMAT(14,2X,CAT METALIZATION RESISTANCE =*,F7.3,*,OHM*)
END

```

```

*NEWVAL
SUBROUTINE NEWVAL
C
C THIS SUBROUTINE IS USED TO CHANGE THE VALUE OF A PARAMETER
C AFTER THE PROGRAM IS BEGUN
C
COMMON/CONSTS/RECHARG,AMUO,ESAT,DIELC,BULTZK,DIFCON,PI
COMMON/EXTCAP/CL,TA,COPEC,T,VGS,VDD,RPF,FPD,RPA,ATTILC(7),PHI,P,
1 TPRFIL,COFIN(10),DUP(10),DTPB(10),DTPB(10),DTPB(10),DTPB(10)
COMMON/CAPOUT/FMIN,GM,CSG,CGD,CSO,RPI,GL1,GL2,RD,RCPT,XSOP
DISPLAY*NUMBER OF PARAMETER TO BE CHANGED(0=LIST, 12=NO CHANGES)*
906 ACCEPT TWANT
IF (IWANT.LE.15) GO TO 907
DISPLAY*VALUE*,IWANT,*,IS NOT POSSIBLE. TRY AGAIN*
GO TO 906
907 IF (IWANT.EQ.0) GO TO 910
IF (IWANT.EQ.12) RETURN
IF (IWANT.EQ.14) GO TO 934
DISPLAY*NEW VALUE*,
ACCEPT Y
908 GO TO (921,922,923,924,925,926,927,928,929,930,931,932,933,
1 934,935) IWANT
910 WRITE (5,912)
912 FORMAT (//)
DISPLAY*GATE LENGTH 1*
DISPLAY*GATE WIDTH 2*
DISPLAY*CHANNEL DEPTH 3*
DISPLAY*DOPING DENSITY 4*
DISPLAY*DEVICE TEMP 5*
DISPLAY*GATE BIAS 6*
DISPLAY*DRAIN BIAS 7*
DISPLAY*RESG 8*
DISPLAY*RCO 9*
DISPLAY*STATIC LOGS 10*
DISPLAY*BUILT-IN POTENTIAL 11*
DISPLAY*PHI IS NORMALLY CALCULATED INTERNALLY. IT*
DISPLAY*IS POSSIBLE TO VARY PHI USING OPTION 3.*
DISPLAY*STOP CHANGES 12*
DISPLAY*GATE RESISTANCE 13*
DISPLAY*CHANGE AN ANCILLARY* 14*
DISPLAY*REGION PARAMETER 14*
916 WRITE (5,912)

```

```

15*
DISPLAY*HIGH FIELD DIFFUSION CONSTANT
DISPLAY*ENTER THE NUMBER OF THE PARAMETER YOU WISH TO*
DISPLAY*CHANGE.*
GO TO 015
921 GL = X*1.E-4
GO TO 050
922 Z = X*1.E-4
GO TO 050
923 A = X*1.E-4
GO TO 050
924 DOPEC = Y
GO TO 050
925 Y = X
GO TO 050
926 VGG = Y
IF (VGG,1.E-2,0) GO TO 950
DISPLAY*NOTE*...VGG IS NORMALLY NEGATIVE. YOU MAY WISH*
DISPLAY*TO CHANGE THE VALUE YOU JUST ENTERED.*
GO TO 050
927 VDD = Y
GO TO 050
928 RFE = X
GO TO 050
929 RPDR = X
GO TO 050
930 F = X*1.E0
GO TO 050
931 PHI = Y
GO TO 050
932 RETURN
933 RPM = X
GO TO 050
934 CALL ANCIL(TMP)
GO TO 050
935 DIFCON = X
GO TO 050
950 DISPLAY*NEXT PARAMETER2 (12=NO MORE CHANGES)*
ACCEPT TMANT
GO TO 007
END

```



```

1110 DISPLAY* *
    DISPLAY*ENTERED NUMBER OF VERTICAL PROFILE DESIRED*
    ACCEPT*ENTER*
    GO TO (1110,1120) IF PROFIL
    DISPLAY*ENTERED CONSTANT DOPAC IS ATOMS/CC*
    ACCEPT*ENTER*
    GO TO 1145
1120 DISPLAY*ENTERED N. THE NUMBER OF DOPAC VALUES TO BE ENTERED*
    ACCEPT* *
    DISPLAY*ENTERED THE VALUES OF DOPAC BEGINNING AT THE GATE-CHANNEL*
    DISPLAY*INTERFAC IN UNITS OF 215 ATOMS/CC*
    ACCEPT (DOPAC,I=1,N)
    DO 1124 I=1,N
1124 DOPAC(I) = DOPAC(I)*1.216
    GO TO 1145
1145 DISPLAY*ENTERED DEVICE OPERATING TEMPERATURE IN DEGREES KELVIN*
    ACCEPT* *
    DISPLAY*ENTERED THE GATE AND DRAIN DC BIAS VOLTAGES. FOR AN*
    DISPLAY*ENTERED GATE-AS FET, THE GATE IS UNBIASED OR NEGATIVE.*
    DISPLAY*IF YOU WANT THE DRAIN VOLTAGE TO EQUAL THE PINCH-OFF*
    DISPLAY*VOLTAGE, LET VDD BE -999.0.*
    ACCEPT VGG, VDD
    DISPLAY*ENTER THE SOURCE TO GATE RESISTANCE, THE GATE TO DRAIN*
    DISPLAY*RESISTANCE AND THE GATE METALIZATION RESISTANCE*
    DISPLAY*(GMS). IF AN ANALYSIS OF INTRINSIC FET PROPERTIES IS*
    DISPLAY*REQUIRED, THESE VALUES CAN BE SET TO 0.0.*
    ACCEPT DSE, DGR, RPM
    DISPLAY*ENTERED THE SIGNAL FREQUENCY (GHZ)*
    ACCEPT F
    F = F*1.09
    CALL CHECK (100)
    IF (ICD,EO,2,00,100,EG,3) RETURN
C
C OUTPUT SECTION
C
    ENTRY VALUOS?
1150 WRITE(5,1152) ATTITLE
    WRITE(7,1153) ATTITLE
1152 FORMAT(11,7A10,/)
1153 FORMAT(141,7A10,/)
    GLO = GL*1.04
    ZO = Z*1.04

```

```

AC = A*1.54
FCUT = F*1.5-C
WRITE(5,1154) CL7, VGG
WRITE(7,1154) CL7, VGG
1154 FORMAT(14,*,GATE LENGTH
1      F7.2,*,V*)
IF (VDD.LT.-50.) GO TO 1153
WRITE(5,1154) 70, VDD
WRITE(7,1154) 70, VDD
1155 FORMAT(14,*,GATE WIDTH
1      F7.2,*,V*)
GO TO 1162
1158 WRITE(5,1160) 20
WRITE(7,1160) 20
1160 FORMAT(14,*,GATE WIDTH
1162 WRITE(5,1164) 10, RPF
WRITE(7,1164) 10, RPF
1164 FORMAT(14,*,CHANNEL DEPTH
1      F7.2,*,CHMS*)
WRITE(5,1164) 0.0000, RPDF
WRITE(7,1164) 0.0000, RPDF
1166 FORMAT(14,*,DOOPING DENSITY
1      F7.2,*,CHMS*)
WRITE(5,1168) T, RPM
WRITE(7,1168) T, RPM
1168 FORMAT(14,*,SERVICE TEMP
1      F7.2,*,CHMS*)
WRITE(5,1170) FCUT
WRITE(7,1170) FCUT
1170 FORMAT(14,*,FREQ.
1      F7.2,*,GHZ*,//)
RETURN
END

```

*PCALC

```

SUBROUTINE PCALC(I,RR)
COMMON/VTDPAR/CL,7,A,DEBEC,I,VCC,VDD,REF,RDPF,RBY,ATITL(7),FHI,F,
1  TDPCEI,CONIN(10),DOP(10),DOPP(10),DJP2(10)
COMMON/CALC/S,C,ALS,AID,XL,SATDEX,AFGU
FNS(X) = (VCC+AISAT*(1.-X)*RDPF+FHI)/WOL

```

```

C  FNS(X) = S+S WHEN V = P
C  IF (IERP.NE.7) TPR = C
APL = (VCC+PFI)/WOL
IF (APL.GE.0.) GO TO 1220
IF (IERP.EQ.7) GO TO 1212
DISPLAY+VGG+PFI > U. VGG IS TOO POSITIVE. THE CHANNEL*
DISFLAY+IS RING PIAS.0 POSITIV- BY TH. GATE.*

```

```

1212 IERR = 99

```

```

RETURN

```

```

1220 IF (APL.LT.1.) GO TO 1224
IF (IERP.EQ.7) GO TO 1212
DISPLAY+(VCC+PFI)/WOL > 1. THE CHANNEL BELOW THE GATE IS*
DISFLAY+NEW BASED BEYOND THE VOLTAGE NECESSARY TO DEPLETE*
DISFLAY+THE ORIGIN OF CARRIERS. VGG IS TOO NEGATIVE.*
GO TO 1212

```

```

1224 PL = SQRT(APL)

```

```

PH = 1.-1.E-5

```

```

1230 STEP = (PH-PL)/10.

```

```

IF (STEP.GT.1.E-9) GO TO 1240

```

```

IF (IERP.EQ.7) GO TO 1212

```

```

DISPLAY+STEP IS TOO SMALL. PROGRAM STOPPED BEFORE CONVERGENCE.*

```

```

DISPLAY+TO OCCURED. P=,P,CK =,CK

```

```

IERR = 90

```

```

RETURN

```

```

1240 DO 1250 I = 1,11

```

```

P = PL+(I-1)*STEP

```

```

SXS = FNS(P)

```

```

F1 = P-D-SXS-2./3.*(P**3-SXS**1.5)

```

```

ASINH = ARGH*(1.+F1/SATDEX/(1.-F1))

```

```

IF (ASTNH.LT.-740.) GO TO 1270

```

```

CH = VCC+AISAT*(1.-P)*(RPF+RDPF)+WOL*(F*P-SXS-SATDEX*(1.-XF(ASINH)

```

```
1  -XP(-ASTNH))/2./ARGU)

```

```

IF (ABS(CH).LT.1.E-4) GO TO 1260

```

```

IF (CK.GT.0.) GO TO 1270

```

```

1250 CONTINUE

```

```

1260 IF (IERP.EQ.7) GO TO 1212
    DISPLAY=TRUE PART OF THE PROGRAM IS NOT REACHED UNLESS THE EQUATION
    DISPLAYATIONS HAVE NOT CONVERGED TO A VALUE FOR P IN SUBROUTINE*
    DISPLAY=FALSE - **F**CK **GCK
    IERR = 0
    RETURN
1270 PL = P-STEP
    PH = F
    GO TO 1230
1280 S = SCRT(CVC)
    AID = ATCAT*(1.-P)
    IF (S.GE.0) IERP = -1
    RETURN
    END

```

```

*CRUNCH
SUBROUTINE CRUNCH(IUF)
COMMON/CONSTS/TECHARG,AMUC,SAT,DIFLC,BOLIZK,(IFCON,PI
COMMON/EXTDAP/CL7,A,D,LC,T,VEC,VLC,RVF,RFOR,RFM,ATILE(7),PHI,F,
1 TOPREV,ORPIN(14),ORF(101),ORPB(101),DOP2B(101)
COMMON/CALC/PS,GO,AISAT,AIO,WUG,SATDEX,ARGU
COMMON/PAPOUT/EMIN,GM,CSG,CGD,CSD,RPI,GL1,GL2,RD,RSOPT,XSOPT
NAMLIST/CAPS/CSG,CGD,CSD,CL,CAD,ICAPS
COMPLAV VII,Y21,7C,ARG
FN(N) = P+H-S+H
CSO(ARG) = DEAL(ARG)**2+AIMAG(ARG)**2

C
C CALCULATE
C ROOM TEMPERATURE DIFFUSION CONSTANT, EMPIRICAL CONSTANT
C LINKING THE ELECTRON TEMPERATURE TO THE ELECTRIC FIELD
DIFCNC = AMIO*BOLIZK*300./ECHARG
DEL = -5.56*T/223.+8.67
F1 = FN(2)-2./3.*FN(3)

C
C EVALUATE THE FUNCTIONS OF PUCEL, HAUS, AND STATZ. THE LABELS
C USED IN THIS PROGRAM CORRESPOND TO THOSE USED IN THIP 94P.3.
C
C FROM F1, THE LENGTHS OF REGIONS I AND II CAN BE FOUND.
PF = 1.-0
1318 GL1 = -GL*F1/SATDEX/PP
GL2 = GL-GL1
ARGU2 = PI*GL2/2./A
CDSHA2 = (EXP(ARGU2)+EXP(-ARGU2))/2.
PPP = 2.*0+00

C
F2 = 2./3.*FN(3)-.5*FN(4)
F31 = 16./PI**3*PI*FCN/DIFCNC*(SIN(PI/2.*PPP)/(PI/2.)/PPP)**2
F32 = (EXP(2.*ARGU2)-4.*EXP(ARGU2)+3.+2.*ARGU2)
F3 = F32*F31

C
FC = ((1.-S)*CDSHA2-PP)/((PPP-SATDEX*GL1/GL)*CDSHA2-PPP)
FR = ((PPP-SATDEX*GL1/GL)*CDSHA2-PPP)/PP
FJ = WUG*FR/AISAT
FC1 = GL1/F1/A*(FC*(PPP+PPP+2.*F2)/PD-2.*S*(1.-S))
FC2 = 2.*GL2/A*FG+(1.-2.*F*FC)*(2.*GL2/A/SATDEX/CDSHA2+
1 (EXP(2.*ARGU2)-1.)/(EXP(2.*ARGU2)+1.))
FC = FC1+FC2+1.5A

```

```

C
1327  GAMA = RO+RO*F1/COJHA2
      CAY = (-FN(2)/3.+FN(4)/6.+5*(1.-2.*S/3.)*FN(1))/F1+GAMA*F
      CAYPR = CAY+CL7/CL1*F
      CAYPRO = CAYPR-GAMA*F

      RC = (CAYPR*(CAYPR*FN(2)-4.*(CAYPR+GAMA)*FN(3)/3.)
1        + (CAYPR*(CAYPR+4.*GAMA)+GAMA*GAMA)/2.*FN(4)
2        -4.*GAMA*(CAYPR+GAMA)/5.*FN(5)+GAMA*GAMA/3.*FN(6))/F1*+3
      RDEL = F1*(OF/F1)*+3*(-2.*(CAYPR-GAMA)*+2*(FN(1)+ALJG(FP/(1.-S))))
1        +GAMA*(2.*CAYPR-GAMA)*FN(2)-2.*GAMA*GAMA/3.*FN(3))
      SU = (CAYPR*(FN(2)-4.*FN(3)/3.+5*FN(4))
1        +GAMA*(-2.*FN(3)/3.+F1(4)-2.*FN(5)/5.))/F1/F1
      SDCL = 2.*DEL*(PP/F1)*+2*PP
1        + ((CAYPR-GAMA)*(-FN(1)+ALOG((1.-S)/PP))+GAMA*FN(2)/2.)
      PC = (FN(2)-4.*FN(3)/3.+5*FN(4))/F1
      PDEL = 2.*DEL/F1*PP*+3*(-FN(1)+ALOG((1.-S)/PP))

C
      P1 = PP*(PO+PDEL)/F1/FG/GAMA/GAMA
      P2 = PP*GL*F3/SATDEX/FK/FR/FG/A
      R1 = (2.*GL/A/SATDEX/GAMA/FC)*+2*(F1/PP)*+3*FG*(RO+RDEL)
      R2 = (2.*F1*CAYPR/FR/FC)*+2*(GL/A/SATDEX/PP)*+3*FG*F3
      IF (P1.LE.0.OR.R1.LE.0) GO TO 1330
      IF (P2.LE.0.OR.R2.LE.0) GO TO 1330
      IF (R1.LE.0.OR.PDEL.LE.0) GO TO 1330
      IF (P2.LE.0.OR.PDEL.LE.0) GO TO 1330
      IF (S1.LE.0.OR.SDEL.LE.0) GO TO 1350
      GO TO 1340
1330  IF (IGP.FO.7) GO TO 1346
      DISPLAY*CPUNCH SMOKING+ MODEL BREAK DOWN.*
      GO TO 1344

C
1340  C = ((SO+RDEL)*SQRT(P1*R1/(RO+RDEL))/(PO+PDEL))
1        +SQRT((P2+R2))/SQRT((P1+P2)*(K1+R2))
      IF (C.LE.1.) GO TO 1350
      IF (IGP.FO.7) GO TO 1346
      DISPLAY*CORRELATION COEFFICIENT GREATER THAN ONE+ C =*,C
1344  WRITE (5,1344) P,S
1346  FORMAT(*NOT+ NOT CALCULATED. P =*,F10.3,* S =*,F10.6)
      FMIN = 0.
      GM = 0.
      IGP = 00

1348

```

```

C
1350  RAT = SQRT((PI**2)/(PI**2))
      CAT = (1.-C*CAT)**2+(1.-C*C)*RAT*RAT
      CAYG = (71+22)*CAT
      CAYC = (1.-C*CAT)/CAT
      CAYR = (R1+22)*(1.-C*C)/CAT

C      EXACTLY, CALCULAT
C      SOURCE TO DRAIN CAPACITANCE, TRANSDUCTANCE, GAIN-
C      BANDWIDTH PRODUCT, AND MINIMUM NOISE FIGURE AT
C      FREQUENCY F
      CSG = NYELC**7*FC
      IF (ICASE.EQ.1) GO TO 1362

C      CHANGE TO SET CAPACITOR VALUES
C
      CSGD = CSG*1.E12
      CGD0 = CGD*1.E12
      CSCD = CSC*1.E12
      C10 = C1*1.E12
      CPAD0 = CPAD*1.E12
      WRITE(5,1350) CSGD,CGD0,CSD0,C10
      WRITE(7,1360) CSCD,CGD0,CSD0,C10
1360  FORMAT(14,*,CSG=*,F7.4,X,CGD=*,F7.4,X,CSD=*,F7.4,X,
      *C1=*,F7.4,X,CPAD=*,F7.4)
      1  DISPLAY*CHANGE ANY VALUE USING ENAME == VALUE IN FARADS*
      READ(4,CAPS)

C
1362  GM = AFSAT/WND*FG
      GANBW = GM/CSG/2./PI
      RPI = 2.*C-2*CL/CSG
      FMIN = 1.+2.*F/GANBW*SQRT((CAYG*(CAYR+GM*(RPM+RPF))*T/300.))
      1  2.*(F/GANBW)**2*CAYG*GM*((RPM+RPF)*T/300.+CAYC*RPI)
      FMIN = 10*ALOG10(FMIN)

C      THE FOLLOWING COMPUTES NOISE WITH CGD AND C1 INCLUDED
C
1364  W = 2.*DT*F
      Y11 = CMPLX(0.,W*CSG)/CMPLX(1.,W*CSG*RPI)+CMPLX(0.,W*(CGD+C1))
      Y21 = CMPLX(GM,0.)/CMPLX(1.,W*CSG*RPI)-CMPLX(0.,W*CGD)
      GGN = (W*CSG)**2/GM*(R1+R2)

```

```

GDN = GM*(PI*F2)
AFG = Y11*SORT(GDN)/Y21-CMPLX(0.,C*SORT(GDN))
GN = GDN*(AGN)+(1.-C*C)*GGN
RN = RDN+PDE+GDN*(1.-C*C)*GGN/CLN(Y21)/CN
AFG = GDN*GDNJG(Y11)/CSC(Y21)+CMPLX(0.,C*SORT(GDN*GDN))/Y21
ZC = RDN+PDE+ARG/CN
RC = RFAL(TC)
RSDPT = SORT(PDC*RC+RN/GN)
FMINC = 1.+2.*GN*(RC+RSDPT)
FMINC = 10.*ALOG10(FMINC)
WRITE(5,1366) FMINC
WRITE(7,1366) FMINC
FORMAT(14,7Y,4NF(WITH CAPS))=*,F6.3,* DB*
1366
C
C CALCULATE THE OPTIMUM SOURCE IMPEDANCE FOR LOW NOISE.
C
SGF = 2.*PI*F*CSG
Y11 = CMPLX(0.,SGF)/CMPLX(1.,SGF*RP1)
ZC = RDN+PDE+PAGC/Y11
GN = GAYG+CGC*SGF/GN
RN = PDN+PDE+GAYR*(1.+GN/GAYG*RP1*RP1)
RSDPT = SORT(PDAL(ZC)**2+RN/GN)
XSDPT = -AIMAG(ZC)
1370 AKFUG = .033
TGL = GL*1.F4
TF = F*1.F-2
TODPEC = DDPC*1.F-16
TA = A*1.F4
TZ = Z*J0.
T1 = AKFUG*TE*TGL**(.5./6.)*(TODPEC/TA)**(1./6.)
T2 = T1*SORT(TZ)
T3 = SORT(PDE+CGN)
T4 = 1.+T2*T3
FMINF = 10.*ALOG10(T4)
WRITE(5,1374) FMINF
WRITE(7,1374) FMINF
1374 FORMAT(14,11Y,4NF(FUKUI))=*,F6.3,* DB*
1380 CONTINUE
C PRINT OUT OF INTERMEDIATE VALUES CONTROLLED BY IPRINT
C
IPRINT = 0
IF (IPRINT.EQ.0) RETURN

```

```

1  WRITE(7,1) F3,FC,FG,FR
   FORMAT(14,1,14,1,F3=12.3,4X,FC=12.3,4X,FG=12.3,4X,FR=12.3,4X,
   1  4Y,EP=1,F3.3)
   2  WRITE(7,4) F3,F32,F
   FORMAT(14,1,F3=12.3,4X,F32=12.3,4X,F=12.3,4X,
   2  WRITE(7,2) DAT,CAT,C
   FORMAT(14,1,PAT=12.3,4X,CAT=12.3,4X,C=12.3,4X,
   3  WRITE(7,3) CAYG,CAYK,CAYC
   FORMAT(14,1,CAYG=12.3,4X,CAYK=12.3,4X,CAYC=12.3,4X,
   4  WRITE(7,4) C1,C2,C12
   FORMAT(14,1,C1=12.3,4X,C2=12.3,4X,C12=12.3,4X,
   1  4Y,EP=1,F3.3)
   PAD = 01+P2
   RAD = 01+P3
   5  WRITE(7,5) PAD,PAN
   FORMAT(14,1,PAD=12.3,4X,PAN=12.3,4X,
   6  RC = REAL(7C)
   WRITE(5,7) GN,RC,PSOPT
   7  WRITE(7,7) GN,RC,PSOPT
   FORMAT(14,1,GN=12.3,4X,RC=12.3,4X,PSOPT=12.3,4X,
   RETURN
   END

```

```

*CHECK
SUBROUTINE CHECK (IDP)
C
C THIS SUBROUTINE CHECKS TO MAKE SURE THAT THE GATE RIAS HAS NOT
C PINCHED OFF THE CHANNEL.
C
COMMON/CONSTS/ECCHARG,AMLO,ESAT,DIELC,BOLTZK,DIFCON,PI
COMMON/EXTPAR/CL,7,A,DOPEC,I,VGG,VDD,PPF,PPDF,RPV,ATITL(7),PHI,F,
1 IDPROFIL,DOPIN(101),DDP(101),DDFE(101),DT22R(101)
COMMON/CALC/7,S,G,ALISAT,AID,VOL,SATDIX,ARGU
C
C SET UP ARRAY WITH VALUES OF DOPING
C
GO TO (1420,1430) IPROFIL
C
C FOR ARBITRARY DOPELINES, STRAIGHT LINE APPROXIMATIONS ARE USED TO
C INTERPOLATE BETWEEN POINTS
C
1410 DOPSUM = 0.
DO 1414 J=1,101
XJ = (FLNAT(J)-1.)/100.
1412 XI = FLNAT(I-1)/(NDOP-1)
I2 = I+1
X12 = FLNAT(I2-1)/(NDOP-1)
IF (XJ.LE.X12) GO TO 1414
I = I+1
GO TO 1412
1414 DDP(J) = DDPIN(I)+(XI-XJ)*(DDPIN(I2)-DDPIN(I))/(X1-X12)
DOPSUM = DOPSUM+DDP(J)
DOPEC = DOPSUM/101.
1420 WORKF = 0.
9ANGAP = 1.522-5.8E-4*I+1/(I+300)
DDPINTP = 1.177
IF (IDP.GT.-10) GO TO 1430
PHI = FLNAT(IDP)/1000.
GO TO 1440
C
C THE FOLLOWING ERROR MAY OCCUR WHEN OPTIMIZING DOPEC
C
1430 IF (DOPEC.GT.DDPINTP) GO TO 1436
DISPLAY*DOPE CONCENTRATION HAS BECOME UNREALISTICALLY*
DISPLAY*LOW.*

```

```

GO TO 1407
1436 ARING = DDPB(ARRAY,NTR)
IF (IPPERFL*(N-1)) ANLES = DDP(I)/DPERINR
PHI = -WOO*F+PANGA-/2.+RELIZK*I/(CHRG*ALIG(A*RLUC))
1440 A-LV = VOLTIV(DPERCOT)
GC = A*ECHARGC*AMPD+DDREC
AISAT = CG*Z*ECAT
C CALCULATION OF WOO. THE VOLTAGE REQUIRED TO DIRECTLY OFF THE
C CHANNEL IS WORKOUT.
C
GO TO (1450,1460) IPRFIL
1450 WCO = A*GQ/P./DIELC/AMUO
GO TO 1480
C
C FOR A NON-UNIFORM VERTICAL PROFILE TWO ARRAYS MUST BE GENERATED.
C THE N-BAR ARRAY..
C
1460 DCPB(I) = O.
DO 1462 I=1,7
I2 = I+1
1462 DCPB(I) = DCPB(I)+(DEFF(I)+.5)*(DCPB(I2)-DCPB(I))*DJ
OC 1464 I=9,101
CALL DINT(NTR,I,.OL,ANS)
1464 DCPB(I) = ANS
C
C THE P-DUAL RAC ARRAY
C
DCP2B(I) = O.
DO 1466 I=1,7
I2 = I+1
1466 DCP2B(I) = DCP2B(I)+(DCPB(I)+.5*(DCPB(I2)-DCPB(I)))*DJ
DO 1468 I=9,101
CALL DINT(NTR,I,.OL,ANS)
1468 DCP2B(I) = ANS
WCO = CHARGC*A*/DIELC*(DCPB(101)-DCP2B(101))
ARGU = PI*GL/2./A
SATDEX = ECAT*GL/WCO
IF (WCO<LT.CHIT) RETURN.
IF (ICP<LT.O) GO TO 1490
DISPLAY=THE BUILT-IN POTENTIAL, PHI, IS NOW NEGATIVE.*
DISPLAY>THAN THE GATE-TO-CHANNEL DEPLETION POTENTIAL,*
DISPLAY=WOO. EITHER THE CHANNEL DEPTH MUST BE INCREASED,*

```

DISPLAY*THE RPTING CONCENTRATION INCREASED, ER PHI MADE*
DISPLAY*LESS NEGATIVE*
CALL ATUVAL
C/ TO 1435
1490 IOP = -2
RETURN
END

```

*MOBLTY
C      FUNCTION MOBLTY(DJFLC,T)
C
C      FUNCTION DETERMINES THE LOW FIELD MOBILITY OF THE SEMICONDUCTOR
C      USING AN EMPIRICAL RELATION
      MOBLTY = (4.2E+2 - 2.5762E-14*DJFLC + 5.61197E-32*DJFLC*DJFLC
1        - 6.005E-50*DJFLC**3 + 3.0693E-63*DJFLC**4
2        - 4.47E-77*DJFLC**5)*(300./T)**1.5
      RETURN
      END

```

AD-A079 589

TRW DEFENSE AND SPACE SYSTEMS GROUP REDONDO BEACH CA F/G 9/5
GAAS ANALOG INTEGRATED CIRCUITS (GAAS RF-LSI). PHASE I. PROGRES--ETC(U)
AUG 79 N00039-78-C-0305

UNCLASSIFIED

2 OF 2

AD-A079 589



END
DATE
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2-80

DOC

*FETPL01

SUBROUTINE FETPL01(IOP,IPAR,ATITLE)
COMMON/ATOP/IV(EV(EO)),FY(EO,1),FC(EO),OUT,NLN
DIMENSION ATITLE(4)

WRITE(3) IOP,IPAR,NPT,NLN

WRITE(3) ATITLE

WRITE(3) (EV(I),I=1,NPT)

DO 1510 J=1,NLN

1510 WRITE(3) (FY(I,J),I=1,NPT)

IF (IOP.NE.3) RETURN

DO 1520 J=1,NLN

1520 WRITE(3) (FC(I),I=1,NPT)

RETURN

END

```

**VPCALC
SUBROUTINE VPCALC(I,LP,V,P)
COMMON/EXTNAC/PL,PH,A,C,D,E,G,I,VGG,VGC,BPF,RPF,ATIL,(7),D-I,S,
J      VGRF,Y,CONAN(101),OJE(101),DBR(101),CLPDP(101)
COMMON/CALCAL/VG,CG,ICAT,AD,X,CAID,X,AFGL
FNS(X) = (VGC+ATCAL*(1.-X)*RPF+PHI)/WOL
C
C FNS(X) = COS WHEN Y = P
IERP = 0
APL = (VGC+BPF)/WOL
IF (APL.CE.O.) GO TO 1620
DISPLAY*VGG+PHI > 0. THE CHANNEL IS BEING BIASED POSITIVE.*
DISPLAY*THAT IS, VGG IS TOO POSITIVE.*
IERP = 99
RETURN
1620 IF (APL.LT.1.) GO TO 1624
DISPLAY*(VGG+PHI)/WOL > 1. THE CHANNEL BELOW THE GATE IS*
DISPLAY*NOW BIASED BEYOND THAT VOLTAGE WHICH DEPLETES THE*
DISPLAY*CHANNEL OF CARRIERS. THAT IS, VGG IS TOO*
DISPLAY*NEGATIVE.*
IERP = 99
RETURN
1624 PL = 1.E-6
PH = 1.E-4
1630 STEP = (PH-PL)/10.
IF (STEP.GT.1.E-8) GO TO 1640
DISPLAY*STEP TOO SMALL. PROGRAM STOPPED BEFORE CONVERGENCE*
DISPLAY*TO OCCURRED. P=*,P,*CK **,CK
IERP = 99
RETURN
1640 DO 1650 I = 1,11
P = PL+(I-1)*STEP
SXS = FNS(P)
FI = O.O-CVS-.7/O.*(F**3-SXS**1.O)
CK = SATOFY*(1.-O)+FI
IF (ABS(CK).LT.1.E-4) GO TO 1660
IF (CK.GT.O.) GO TO 1670
CONTINUE
1650 DISPLAY*THIS PART OF THE PROGRAM IS NOT REACHED UNLESS THE EQUA=*
1660 DISPLAY*CTIONS HAVE NOT CONVERGED TO A VALUE FOR P IN SUBROUTINE*
DISPLAY*VPCALC. P =*,P,*CK **,CK
IERP = 99

```

```

RETURN
OL = P-STEP
PH = P
CT = 1430
S = SGT(SVC)
AIC = AISCAT*(1.-P)
VP = -1.*V00*(P+D-SXS)
RETURN
END

```

1670

1680

```

*NOISE
SUBROUTINE NOISE(TOP,IUSEC2)
COMMON/COMMON1/CPHAG,ANCO,ESAT,CILLC,BULTX,LIQCTM,PA
COMMON/COMMON2/CI,7,A,DUPFC,T,VCC,VED,RFC,EPOR,RPM,ATITL(7),B41,F,
1  IPONETL,ONPIN(101),DIP(101),DUPR(101),DUP2B(101)
COMMON/CALC/CS,CC,AISAT,AID,MU,SATDEX,APGU
COMMON/COMMON3/EMTN,GM,CSG,CGO,CSD,RPI,GL1,GL2,RD,RSQPT,XSOPT
COMMON/COMMON4/SC,SL,DUPES,DIP,SG,RSCS,PSHS,FSHG,SGD,DL,
1  ONFJ,DOF,GO,RSCD,PSHD,IRIG,ISYM
ICK = -1
CALL CHECK(TOP)
IF (ICK.EQ.-2) GO TO 1060
IERR = 7
IANC = 00
1040 IF (IDP.EQ.17) CALL APCIL(IANC)
IUSEC2 = 1
CALL PCALC(IERR)
IF (IERR.EQ.-1) IUSEC2 = 1
IF (IERR.EQ.00) GO TO 1060
ISMKE = 7
IF (IERR.NE.-1) CALL CRUNCH(ISMKE)
IF (IERR.EQ.-1) CALL CRUNCH2(ISMKE)
IF (ISMKE.EQ.00) GO TO 1060
RETURN
1060 FMIN = 1
RETURN
END

```

```

*DCALC      SUBROUTINE DCALC(IERR)
COMMON/VTAP/CT,TA,DDP,CT,VCC,VDD,REF,PPH,ATI(1:7),P-I,P,
1  TORPTI,POBIN(1:10),JPR(1:10),JPER(1:10),BT,2N(1:10)
COMMON/CALC/C,S,C,MSAT,AID,MOD,SATDIX,ARGJ
FNS(X) = (VCC+V*PPH+PHI)/WUO
FND(X) = (VCC-X*PPH+PHI-VDD)/WUO
C
C  FNS(X) = S*S WHEN X = ID
C  FND(X) = 0.0 WHEN X = ID
C  IERR = 0
APL = (VCC+PHI)/WUO
IF (APL.GE.0.) GO TO 1720
DISPLAY+VCC+PHI > 0. ID CANNOT BE CALCULATED.*
DISPLAY+VCC IS TOO POSITIVE.*
IERR = 99
RETURN
1720 IF (APL.LT.1.) GO TO 1724
DISPLAY+VCC+PHI < WUO. THE GATE VOLTAGE IS*
DISPLAY+PHI GREATER THAN THAT REQUIRED TO DEPLET.*
DISPLAY+PHI CHANNEL OF CARRIERS.*
IERR = 99
RETURN
1724 AIDL = 0.
AIDH = ATSAT
1730 STEP = (AIDH-AIDL)/10.
IF (ABS(STEP).GT.1.E-8) GO TO 1740
DISPLAY+STEP IS TOO SMALL. PROGRAM STOPPED BEFORE CONVERGENCE*
DISPLAY+TOO ID OCCURRED. ID=*,AID,*CK =*,CK
IERR = 99
RETURN
1740 DC 1750 I = 1,11
AID = AIDL+(FLD*AT(1)-1.)*STEP
SXS = FNS(AID)
DXD = FND(AID)
CK = AID+CG+*WUO/GL*(DXD-SXS-2./3.*(DXD**1.5-SXS**1.5))
IF (ABS(CK).LT.1.E-4) GO TO 1750
IF (CK.LT.0.) GO TO 1770
CONTINUE
1750 DISPLAY+THIS PART OF THE PROGRAM IS NOT REACHED UNLESS THE EQUA=*
1760 DISPLAY+TIONS HAVE NOT CONVERGED TO A VALUE FOR P IN SUBROUTINE*
DISPLAY+DCALC. ID =*,AID,*CK =*,CK

```

1770 IERR = 99
RETURN
AIDL = AYD-57-5
AIOH = AIO
GD TC 1730
1780 S = SCPT(SYCS)
RETURN
FAD


```

1838 FORMAT(CON OF T2 1 2*)
      CGDC = CGC*1.712
1840 WRITE(4,1040) CGDC
      FORMAT(CAP OF S*,20.3)
      WRITE(4,1041)
1842 FORMAT(CON ON T2 2 3*)
      WRITE(4,1044) RFI
1844 FORMAT(ROFF -- S*,210.3)
      WRITE(4,1045)
1846 FORMAT(CON OF T2 1 4*)
      WRITE(4,1040) RPF
1848 FORMAT(RPS FE S*,210.3)
      WRITE(4,1050)
1850 FORMAT(CON OF T2 4 5*)
      WRITE(4,1051)
1852 FORMAT(DEC RR T2 2 5*)
      WRITE(4,1054) RPK
1854 FORMAT(RRS AA S*,210.3)
      WRITE(4,1056) RPR
1856 FORMAT(ROFF OF S*,210.3)
      CGDC = CGC*1.712
      WRITE(4,1059) CGDC
1858 FORMAT(CAP ON CA*,210.3)
      WRITE(6,1060)
1860 FORMAT(CAX AA DD*)
      WRITE(4,1062) TCMPOF
1862 FORMAT(ORT AA S*,11,*, 50*)
      WRITE(6,1064)
1864 FORMAT(ENCL*)
      DISPLAY=ENTER FREQ. RANGE (GHZ)*
      DISPLAY*(FMIN, FMAX, INTERVAL)*
      ACCEPT FMIN,FMAX,FINT
      FMIN = FMIN*1.73
      FMAX = FMAX*1.73
      FINT = FINT*1.73
      WRITE(6,1070) FMIN,FMAX,FINT
1870 FORMAT(CQ.3,210.3)
      WRITE(4,1064)
      DISPLAY=COMPACT FILE CREATED WITH NAME STAGE3. MAKE IT*
      DISPLAY=COMMENT BY USING*
      DISPLAY* *
      DISPLAY=REQ,TAPE5= NEW FILE NAME*

```

```

DISPLAY* *
DISPLAY*REFRONT CALLING COMPACT. DO YOU WANT MORE INFO.*
DISPLAY*WHEN USING COMPACT? (1 = YES)*
ACCEPT*YES
IF (CINTEL,NO) RETURN
DISPLAY*WHEN BACK IN MACC,REPLACE TAPE6 AS SHOWN ABOVE.*
DISPLAY*TURN PUM COMPACT USING THESE TWO COMMANDS:*
DISPLAY* *
DISPLAY*TT,COMPACT/AC=CCM4LAB*
DISPLAY*COMPACT*
DISPLAY* *
DISPLAY*THE PROGRAM WILL ASK FOR THE FILE NAME YOU HAVE*
DISPLAY*CHOSEN AND FOR THE MODE OF OPERATION. SELECT*
DISPLAY*OPTION 1 (ANALYSIS). *
DISPLAY*NOTE: IF YOU CALL FOR PARAMETERS MORE THAN ONCE*
DISPLAY*IN A RUN OF THIS SET PROGRAM THE SETS OF COMPACT*
DISPLAY*DATA WILL BE WRITTEN CONSECUTIVELY ON TAPE6. IT*
DISPLAY*WILL THEN BE NECESSARY TO SEPARATE EACH SET AND FORM*
DISPLAY*A DISTINCT PERMANENT FILE WITH EACH SET BEFORE RUNNING*
DISPLAY*COMPACT.*
R. TURN
END

```

```
C
C CRUNCH2
SUBPR(TIME,CRUNCH2(IGM)
COMPIA/CONSTS/ICHARG,APL,ICAT,DIFCN/DIFCN0,PI
COMPLX/VTCAS/CL7/APL/ICAT,VOC/VOC0,EXP(FR)/EXP(RATILU(7)),-I95,
1 YOC/YOC0,IR(1,2),EXP(1,1)*COS(1,1)*DIFCN(DIFCN)
COMPN/CALC/P,CO,CO,AISAT,AID,RDS,SATOEX,AFGJ
COMPN/PAPOT/EMTN,GMCSGCGD,CLE,KPI,GL1,GL2,RD,R3,JPI,XSOPT
COMPLX VII,7C
C
C CALCULATE
C ROOM TEMPERATURE DIFFUSION CONSTANT, EMPIRICAL CONSTANT
C LINKING THE ELECTRON TEMPERATURE TO THE ELECTRIC FIELD
DIFCN0 = AMIN+RLTZK*300./ECHARF
DEL = -P.EAT/222.+B.(7
C
C EVALUATE THE FUNCTIONS OF FUEL, HAUS, AND STATZ FOR THE
C CASE OF L2 = L. (P = S).
PP = 1e-n
GL1 = O.
GL2 = CL
COSHA = (EXP(APCU)+EXP(-ARGU))/2.
PPP = 2.*ppn
C
F31 = 14./PI**3*DIFCN/DIFCN0*(SIN(PI/2.*PP)/(PI/2.)/PP)**2
F32 = (EXP(2.*ARGU)-4.*EXP(ARGU)+3.+2.*ARGU)
F3 = F31+F32
C
FC = .5/O
FR = 2.*P*(COSHA-1.)
RD = WQ*FP/AISAT
FC = GL/A/P+1.56
P2 = GL*PP*F3/A/SATD.LX/FG/FR/FR
R2 = (2.*GL*FC/A/FC)**2*P2
C
C = 1.
1940 RAT = EXPRT(P2/R2)
1950 CAT = (1.-CAT)*RAT**2+(1.-C*C)*RAT*RAT
CAYC = P2*CAT
CAYC = (1.-C*PAT)/CAT
CAYR = P2*(1.-C*C)/CAT
C
C FINALLY, CALCULATE
```



```

*SPAR SUBROUTINE C022(C02,GAIN)
C
C THIS SUBROUTINE CALCULATES THE S-PLANE LOSS AND MAX GAIN
C
COMMON/CONNECTS/CONHANG,AMU,ESAT,DI,LC,BULTZK,[(IFC3)*PI
COMMON/EXTRAP/CL,7,A,GO,PC,T,VGC,VOD,RPF,FPF,RP,ATLTL(7),FHL,F,
1 FDECTI,PPFIN(101),PP(101),DJ,*(101),C02P23(101)
COMMON/PAROUT/EMT,GM,CSG,SGD,FSU,FDL,CLL,CLL2,RPD,NS,PI,XS,DT
COMPLEX Y(3,3),C0V1,YC,1,YI,YR,YF,YCS,S(2,2),DINRM,7,SGDT,64MS
1 ,SGDN,CAPL,A1,A2,BP(2,2)
C
C CHECK THAT CAPACITIVE RESISTANCES HAVE NONZERO VALUES.
C
C IF (R0M,NC,0,AND,RPF,NE,0,AND,RPDR,NE,0.) GO TO 1520
DISFLAY=CAPACITV CANNOT BE CALCULATED WITHOUT PARASITIC RESISTANCE
GAIN = -99.95
RETURN
C
1920 Y(1,2) = CMPLX(C0,2)*PI*F*UGO)
Y(1,3) = -1./CMPLX(RP1,-1./2./PI/F/CSG)-CMPLX(0,2)*PI*F*CL)
Y(1,1) = -Y(1,2)-Y(1,3)+1./RPM
CPX1 = GM/CMPLX(1,2)*PI*F*CSG*FPF)
Y(2,1) = -Y(1,2)-CPX1
Y(2,2) = Y(1,2)-1./RPDR-1./RO
Y(2,3) = C0V1+1./PC
Y(3,1) = C0V1-Y(1,3)
Y(3,2) = CMPLX(1,0/RO,0,0)
Y(3,3) = -Y(2,3)+Y(1,3)-1./RPF
C
YDET = Y(1,1)*Y(2,2)*Y(3,3)-Y(2,3)*Y(3,2))
1 -Y(1,2)*Y(2,1)*Y(3,3)-Y(2,3)*Y(3,1))
2 +Y(1,3)*Y(2,1)*Y(3,2)-Y(2,2)*Y(3,1))
C
C THE Y-PARAMETERS CAN NOW BE CALCULATED
C
1930 YI = 1./RPM*(1,+(Y(2,3)*Y(3,2)-Y(2,2)*Y(3,3))/RPM/YDET)+
1 CMPLX(0,2)*PI*F*CSG)
YF = (Y(1,3)*Y(2,2)-Y(1,2)*Y(3,2))/RPM/PPDR/YDET
YF = (Y(3,3)*Y(2,1)-Y(2,3)*Y(3,1))/RPM/FPDP/YDET
YB = 1./RPM*(1,+(Y(1,1)*Y(3,3)-Y(1,3)*Y(3,1))/RPM/YDET)
1 +CMPLX(0,2)*PI*F*CSG)

```

```

C C APAGI = 2.*REAL(YI)*REAL(YD)-REAL(YF*YF)
C C AMAC2 = AMAGI+AVAGI-CABS(YF*YR)**2
C C NEXT THE CAPACITORS ARE CALCULATED FOR A 50 OHM LINE
C C ZCR = 1./50.
C C OS = (ZCR+YI)*(ZCR+YD)-YR*YF
C C S(1,1) = ((ZCR-YI)*(ZCR+YD)+YR*YF)/DS
C C S(1,2) = -(2.*YD+7CR)/DS
C C S(2,1) = -(2.*YF+7CR)/DS
C C S(2,2) = ((ZCR+YI)*(ZCR-YD)+YR*YF)/DS
C C THE MAGNITUDES ARE
C C 1940 S11 = CABS(S(1,1))
C C S12 = CABS(S(1,2))
C C S21 = CABS(S(2,1))
C C S22 = CABS(S(2,2))
C C THE ANGLES IN DEGREES
C C 1950 S1A = ATAN2(ATMAG(S(1,1)),REAL(S(1,1)))*180./PI
C C S12A = ATAN2(ATMAG(S(1,2)),REAL(S(1,2)))*180./PI
C C S21A = ATAN2(ATMAG(S(2,1)),REAL(S(2,1)))*180./PI
C C S22A = ATAN2(ATMAG(S(2,2)),REAL(S(2,2)))*180./PI
C C TO DETERMINE THE GAIN: 1- S22 IS FOUND WITH THE OPTI
C C MATCH. 2- THE MATCHING LOAD IS DETERMINED. 3- S FR
C C ARE CALCULATED FOR THE FET WITH ITS MATCHING SECTIONS.
C C STABILITY FACTOR AND GAIN ARE CALCULATED.
C C ZO = 50.
C C OPTIMUM SOURCE IMPEDANCE AND REFLECTION COEFFICIENT
C C ZSOPT = CMPLX(CSOPT,XSOPT)
C C GMS = (ZSOPT-ZO)/(ZSOPT+ZO)
C C S22 OF FET WITH SOURCE MATCHING AND REFLECTION COEFFIC
C C S22P = S(2,2)+GAMS*S(1,2)*S(2,1)/(1.-GAMS*S(1,1))
C C GAML = CONJG(S22P)
C C S-PARAMETERS OF FET AND MATCHING SECTIONS
C C DENOM = (1.-GAMS*C(1,1))*(1.-GAML*S(2,2))-GAMS*GAML
C C A1 = (1.-CONJG(GAMS))*SORT((1.-CABS(GAMS))*#2)/CABS(A1)

```

```

A2 = (1.-CONJG(GAML))*SQRT(1.-CABS(GAML)**2)/CABS(1.-GAML)
SF(1,1) = CONJG(A1)/A1*((1.-GVL**2,2))*((S(1,1)-C)RUG(CAMS)))+
      CAVLAS(1,2)*S(2,1))/DENM
SF(1,2) = CONJG(A2)/A1*(S(1,2)*(1.-CABS(CAMS)**2)/DENM
SF(2,1) = CONJG(A1)/A1*(S(1,1)+(1.-CABS(CAVL)**2)/DENM
SF(2,2) = CONJG(A2)/A2*((1.-GAMS**S(1,1))*(S(2,2)-CONJG(GAML))+
      GAVCAS(1,2)*S(2,1))/DENM
1

```

C THE STABILITY FACTOR

```

STABLE = (1.+CABS(SF(1,1)*SP(2,2)-SP(1,2)*SP(2,1))**2
      -CABS(SF(1,1))**2-CABS(SF(2,2))**2)/2.
1
2

```

C THE ASSOCIATED GAIN IS THE MAXIMUM AVAILABLE POWER GAIN IF THE
 C MATCHED DEVICE IS STABLE (STABLE>1). IF DEVICE IS UNSTABLE, THE
 C GAIN CALCULATED WILL BE THE MAXIMUM STABLE GAIN. GAIN=(STABLE>1)

```

STA = STABLE
IF (STABLE.LT.1.) STA = 1.
GAMAX = CABS(SF(2,1)/SP(1,2))*(STA-SQRT(STA*STA-1.))
IF (GAIN.LT.00.) GO TO 1960
GAIN = 10.*ALOG10(GAMAX)
RETURN

```

C THIS SECTION PRINTS OUT THE S-PARAMETERS

```

1960 WRITE(5,1062) S11,S11A,S12,S12A
      WRITE(7,1062) S11,S11A,S12,S12A
1962 FORMAT(1H,*,S11:*,F8.3,4X,*,F6.1,5X
      *,S12:*,F8.3,4X,*,F6.1)
1
      WRITE(5,1064) S21,S21A,S22,S22A
      WRITE(7,1064) S21,S21A,S22,S22A
1964 FORMAT(1H,*,S21:*,F8.3,4X,*,F6.1,5X
      *,S22:*,F8.3,4X,*,F6.1)
1

```

C OUTPUT OPTIMUM SOURCE AND LOAD IMPEDANCE

```

GINV = CABS(GAMS)
GINA = ATAN2(AIMAG(GAMS),REAL(GAMS))*180./PI
GOUTM = CABS(GAML)
GOUTA = ATAN2(AIMAG(GAML),REAL(GAML))*180./PI
WRITE(5,1066) GINM,GINA,GOUTM,GOUTA

```

```

1966 WRITE(7,1066) GAIN,GAINA,GOUT,GOUTA
      FORMAT(1H,30PTIMIN,30L4C,2F7.2,2X,*,F6.1,6X,
1      30PTIMIN,17AD,2F7.2,2X,*,F6.1)
      IF (STABLE,0.1) GO TO 1974
      STOP
      WRITE(5,1072) STABLE
      WRITE(7,1073) STABLE
1972 FORMAT(1X,*,F6.3,*, 2X, DUTY NOT INHERENTLY STABLE,/,1H )
      RETURN

C      CALCULATE THE MAXIMUM POWER GAIN
C
1976 GAIN = 10.*ALOG10(S21/S12*(STABLE-SQRT(STABLE*STABLE-1.)))
C
C      CALCULATE THE ASSOCIATED GAIN
C
      ZSOPT = CMPLY(PDSOPT,XSOPT)
      ZO = 50.
      GAMS = (ZSOPT-70)/(ZSOPT+ZO)
      S22P = S(2,2)+C(1,2)*S(2,1)*CABS/(1.-S(1,1)*GAMS)
      ASSGAIN = (1.-CABS(GAMS)**2)/CABS(1.-S(1,1)*GAMS)**2*S21*S21
      / (1.-CABS(S22P)**2)
1      IF (ASSGAIN.LE.0.) GO TO 1980
      ASSGAIN = 10.*ALOG10(ASSGAIN)
      WRITE(5,1078) STABLE,GAIN,ASSGAIN
      WRITE(7,1079) STABLE,GAIN,ASSGAIN
1978 FORMAT(1X,*,F6.2,*, 2X, DUTY INHERENTLY STABLE WITH MAX POWER,
1      * GAIN OF,*,F6.2,*, 2X,/,1H,*,THE ASSOCIATED GAIN IS,
2      F5.2,*, DB,/,1H )
      RETURN
1980 DISPLAY*ASSOCIATED GAIN CALCULATED IS NEGATIVE. WILL RETURN.*
      RETURN
      END

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*ANCIL2
SUBROUTINE ANCIL2 (JDP)
C THIS SUBROUTINE EVALUATES THE PARABOLIC P DISTANCES USING THE
C EQUATIONS OF THE COMPI MODEL
C
COMMON/CONSTS/EC4ARG,AMLO,LSAT,DIFLC,BCLTZK,DIFCON,PI
COMMON/EXTCAP/CL7,A,DUFIC,T,VGG,VDD,RPF,RPDR,RPM,ATITLL(7),P4I,F,
1 TPRTEL,OTFELN(101),DUF(101),D3PR(101),D3P2B(101)
COMMON/PARFOUT/PMYN,GM,CSG,CGD,CSD,P2I,GL1,GL2,WD,RSQRT,XSQRT
COMMON/ANCCAP/SCG,SL,DUPES,D3P2G,RSCS,RGHS,KSHG,SGD,UL,
1 JNDED,DUPEGD,RSCD,KSHD,IKCG,ISYM
C
RHO = 3.
H = GL*1.54/2.
2010 RC = 2.
SSG = 1.5-4
A1 = .35-4
A2 = A1
TZ = 2*10.
TGL = GL*1.54
TF = F*1.5-0
ISSG = SSC*1.54
TDOP = NOPEC*1.5-10
TA1 = A1*1.54
TA2 = A2*1.54
C
C GATE RESISTANCE. FEED COMPENSATES FOR DIFFERENT FEED CONFIGURATIONS
C
2030 FEED = 16.
RGM = 3.3*RHN*TZ/H/TGL/FEED
RGSE = .6*T7*SQRT(RHD*TF/H/TGL)
RPM = RGM*OGC
RSCHA = 1.5*TSRG/TDOP/TA1/TZ
RSCGN = COT(.15*PC/TDOP/TA2)/T7
RPF = RSCHA+RSCGN
2040 RPDR = DBF
RETURN
END

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100 REM PROGRAM CALCULATES FET CHARACTERISTICS USING PUCCEL MODEL AS
110 REM MODIFIED BY J. M. ANDRES TO INCORPORATE ARBITRARY VERTICAL DOPING PROFILE.
120 REM PROFILE ENTERED AT N1 POINTS AND SEVERAL FUNCTIONS ARE COMPUTED AND
130 REM STORED AT EACH POINT. SOLUTION INVOLVES INTERPOLATION BETWEEN
140 REM STORED POINTS TO DETERMINE SP, IC AND OTHER QUANTITIES.
150 REM USER SUPPLIES W1, MOBILITY, EL, SATURATION FIELD, A, CHANNEL DEPTH,
160 REM Z, GATE WIDTH, L, GATE LENGTH, R1 AND R3 GATE-SOURCE AND GATE-DRAIN
170 REM RESISTANCES, T, THE UCLTA IN ELECTRON TEMPERATURE, D, THE DIFFUSION CONSTANT DIVIDED BY D, AND R4, THE GATE
    RESISTANCE.
180 READ U1, EL, A, Z, L, R1, R3, D, T, R4
190 W1=1.6E-19*A+2/P.854E-14/L2.5
200 G1=1.6E-10*7*U1*EL*A
210 AS=PI*L/2/A
220 PRINT INPUT NUMBER OF SEGMENTS
230 INPUT N1
240 DIM N(G:N1)+ N(I) IS DOPING DENSITY FUNCTION
250 DIM A(G:N1)+ A(I) IS INTEGRAL OF N(I)
260 DIM B(G:N1)+ B(I) IS INTEGRAL OF N(I) TIMES I
270 DIM C(G:N1)+ C(I) IS INTEGRAL OF N(I) TIMES I
300 A(0)=0, B(0)=0, C(0)=0, H=1/N1
310 N(0)=1.76*62*3F16 + GAUSSIAN PROFILE HERE • CAN PUT IN ANY N(I)
320 FOR I=1 TO N1
330 N(I)=N(0)+10*EXP(-(I-N1)+2/N1+2/.43429)
333 NEXT I
335 FOR I=1 TO N1-1
340 A(I)=A(I-1)+H*(2/3*N(I)-1/12*N(I+1)+5/12*N(I-1))
341 NEXT I
342 A(N1)=A(N1-1)+H*(5/12*N(N1)+2/3*N(N1-1)-1/12*N(N1-2))
345 FOR I=1 TO N1-1
350 B(I)=B(I-1)+H*2*(2/3*I*N(I)-1/12*(I+1)*N(I+1)+5/12*(I-1)*N(I-1))
360 C(I)=C(I-1)+H*2*(2/3*I*N(I)+A(I)-1/12*(I+1)*N(I+1)+5/12*(I-1)*N(I-1))
361 NEXT I
362 B(N1)=B(N1-1)+H*2*(5/12*N(N1)+2/3*(N1-1)*N(N1-1)-1/12*(N1-2)*N(N1-2))
363 C(N1)=C(N1-1)+H*2*(5/12*N(N1)+A(N1)+2/3*(N1-1)*N(N1-1)-1/12*(N1-2)*N(N1-2))
390 PRINT INPUT VGG (USUALLY NEGATIVE)
400 PRINT INPUT V1
410 INPUT V1
420 R2=R3+4*V1 + EMPIRICAL INCREASE OF DRAIN RESISTANCE WITH VGG
430 V1=V1+Q + INCLUSION OF BUILT-IN POTENTIAL (CHOSEN TO FIT)
440 S=U1*P=0
450 DEF FNS(I,J)=V1-W1*B(I)+R1*G1*(A(N1)-A(J))
460 DEF FNY(I,J)=1-(A(N1)+B(J)-3(I)-C(J)+C(I))/EL/L*W1/(A(N1)-A(J))

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470 FOR I=0 TO N1
480 IF FNS(I,I)>0 THEN S=0
490 S1=I-1
500 GO TO 520
510 NEXT I
520 FOR J=0 TO N1
530 IF FNY(S1,J)>0 THEN 560
540 P1=J-1
550 GO TO 570
560 NEXT J
570 D1=(FNS(S1+1,P1)-FNS(S1-1,P1))/2
580 D2=(FNY(S1+1,P1)-FNY(S1-1,P1))/2
590 F1=(FNS(S1,P1+1)-FNS(S1,P1-1))/2
600 F2=(FNY(S1,P1+1)-FNY(S1,P1-1))/2
610 H1=-FNS(S1,P1)
620 H2=-FNY(S1,P1)
630 S2=(H1+F2-H2+F1)/(D1+F2-D2+F1)
640 P2=(D1+H2-D2+H1)/(D1+F2-D2+F1)
650 S=(S1+S2)/N1,P=(P1+P2)/N1
660 IF S=50 AND P=50 THEN 700
670 S0=S,P0=P
671 IF S2<0 THEN S1=S1+INT(S2+.5)
672 IF P2<0 THEN P1=P1+INT(P2+.5)
673 IF S2>0 THEN S1=S1+INT(S2+.5)
674 IF P2>0 THEN P1=P1+INT(P2+.5)
690 GO TO 570
700 PRINT S=S0,P=P0
710 A1=A(S1)+S2*(A(S1+1)-A(S1-1))/2+S2+2/2*(A(S1+1)-2*A(S1)+A(S1-1))
720 A2=A(P1)+P2*(A(P1+1)-A(P1-1))/2+P2+2/2*(A(P1+1)-2*A(P1)+A(P1-1))
730 B1=B(S1)+S2*(B(S1+1)-B(S1-1))/2+S2+2/2*(B(S1+1)-2*B(S1)+B(S1-1))
740 B2=B(P1)+P2*(B(P1+1)-B(P1-1))/2+P2+2/2*(B(P1+1)-2*B(P1)+B(P1-1))
750 PRINT ID=I,G1*(A(N1)-A2)
760 V2=W1*(B2-R1)
770 V3=V2+G1*(R1+R2)*(A(N1)-A2)
780 PRINT VSD=V2,V3,VDD=V3+V2
790 PRINT TYPE VDD
800 INPUT V4
810 IF V4<0 THEN GO TO 400
820 IF V4<V3 THEN GO TO 200
830 P1=S1
840 DEF FNV(I,J)=W1*(P(J)-B(I))+E1*L/A/2*(EXP(A*S*FNY(I,J))-EXP(-A*S*FNY(I,J)))
850 DEF FNV(I,J)=V4-FNV(I,J)-G1*(R1+R2)*(A(N1)-A(J))

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THIS VDD IS THAT JUST SATURATING AT END OF FET

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860 D4=(FNS(S1+1,P1))-FNC(S1-1,P1))/2
870 F4=(FNS(S1,P1+1))-FNC(S1,P1-1))/2
880 H4=-FNS(S1,P1)
890 D3=(FNV(S1+1,P1))-FNV(S1-1,P1))/2
900 F3=(FNV(S1,P1+1))-FNV(S1,P1-1))/2
910 H3=-FNV(S1,P1)
920 S2=(H4+F3-H3+F4)/(D4+F3-D3+F4)
930 P2=(D4+H3-D3+H4)/(D4+F3-D3+F4)
940 S=(S1+S2)/N1,P=(P1+P2)/N1
950 IF S=SQ AND P=PO THEN 990
960 SU=S,PC=P
962 IF S2<0 THEN C1=S1+INT(S2+.5)
964 IF P2<0 THEN C1=P1+INT(P2+.5)
966 IF S2>0 THEN C1=S1+INT(S2+.5)
970 IF P2>0 THEN C1=P1+INT(P2+.5)
980 GO TO 860
990 A1=A(S1)+S2*(A(S1+1)-A(S1-1))/2+S2+2*(A(S1+1)-2*A(S1)+A(S1-1))/2
1000 A2=A(P1)+P2*(A(P1+1)-A(P1-1))/2+P2+2*(A(P1+1)-2*A(P1)+A(P1-1))/2
1010 B1=B(S1)+S2*(B(S1+1)-B(S1-1))/2+S2+2*(B(S1+1)-2*B(S1)+B(S1-1))/2
1020 B2=B(P1)+P2*(B(P1+1)-B(P1-1))/2+P2+2*(B(P1+1)-2*B(P1)+B(P1-1))/2
1030 C1=C(S1)+S2*(C(S1+1)-C(S1-1))/2+S2+2*(C(S1+1)-2*C(S1)+C(S1-1))/2
1040 C2=C(P1)+P2*(C(P1+1)-C(P1-1))/2+P2+2*(C(P1+1)-2*C(P1)+C(P1-1))/2
1041 DEF FNC(I)=H*Y*Y*(I)*(A(I))+2
1042 F=0
1043 FOR I=S1 TO P1-1
1044 F=F+H*(2/3+FNC(I)+F/12+FNC(I+1)-1/12+FNC(I-1))
1045 NEXT I
1046 F=F-H*S2*FNC(S1)-H/4*S2+2*(FNC(S1+1)-FNC(S1-1))
1047 D2=F+H*P2*FNC(P1)+H/4*P2+2*(FNC(P1+1)-FNC(P1-1))
1048 D1=0
1070 L1=(A(N1)*(R2-P1)-C2+C1)/E1/L*W1/(A(N1)-A2)
1080 L2=L-L1
1090 C3=(EXP(A3*L2)+EXP(-A3*L2))/2
1100 S3=(EXP(A3*L2)-EXP(-A3*L2))/2
1110 G5=G1/W1*(A(N1)-A1)*CS-A(N1)+A2/(F*(A(N1)-A2)*(CS-1)+E1*L*W1/W1*CS)
1120 R5=W1/G1*(P*(A(N1)-A2)*(CS-1)+E1*L*W1/W1*CS)/(A(N1)-A2)
1130 PRINT "S=S,P=P,ID=ID=GI*(A(N1)-A2)
1130 PRINT "EQUIVALENT CIRCUIT PARAMETERSE
1140 PRINT "C=C,G=G,P=P,D=D,R=R,G=GM=GS/(1+GS*F1)
1150 C4=G5*W1/G1*(P+A2+(A(N1)*(C2-C1)-D2+D1)/(A(N1)-A2)+2)
1160 C4=Z+1.6E-19*A/E1*(C4-(A(N1)-A1)*A1/(A(N1)-A2))
1170 C5=(1-P*G5*W1/C1)*(Z+1.6E-19*A*A2/E1/CS+Z*12.5+8.854E-14*SS/CS)

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1180 C5=C5+2*1.5F-10*A*L2*L*G5/G1
1190 C6=C4+C5+7*12.F+9.85E-14*1.56
1191 T=(A(N1))+2*(P1-P1)-2*A(N1)*(C2-C1)+D2-D1
1192 T=L/L1/L1*(T*W1/L1/(A(N1)-A2)+L2)+T IS TRANSIT TIME
1193 R5=T/C6/4 P5 IS GATE CHARGING RESISTANCE (FACTOR OF 4 GIVES FIT)
1194 PRINT T=T,P5
1200 PRINT ECG=1/C6
1210 G2=W1/L1/L1/L1*(A(N1)-A2)*(1-L/C5)+1 G2 IS GAMMA
1220 DEF FNF(I)=N(T)*(A(N1)*B(I)-C(I))
1230 F=C
1240 FOR I=S1 TO P1-1
1250 F=F+H*(2/3*FNF(I)+5/12*FNF(I+1)-1/12*FNF(I-1))
1260 NEXT I
1270 F=F-H*S2*FNF(S1)-H/4*S2+2*(FNF(S1+1)-FNF(S1-1))
1275 F=F+H*P2*FNF(P1)+H/4*P2+2*(FNF(P1+1)-FNF(P1-1))
1280 F=F-(A(N1)*P1-C1)*(A2-A1)
1290 K5=F*W1/L1/L1/L1/(A(N1)-A2)-G2+A2-L2/L1*(A(N1)-A2)+ K5 IS -K#
1300 K1=K5+G2*A2
1320 DEF FNP(I)=H*T*N(T)*(A(N1)-A(I))+2
1330 F=0
1340 FOR I=S1 TO P1-1
1350 F=F+H*(2/3*FNP(I)+5/12*FNP(I+1)-1/12*FNP(I-1))
1360 NEXT I
1370 F=F-H*S2*FNP(S1)-H/4*S2+2*(FNP(S1+1)-FNP(S1-1))
1375 P4=F+H*P2*FNP(P1)+H/4*P2+2*(FNP(P1+1)-FNP(P1-1))+ P4 IS P0
1380 DEF FNG(I)=H*I*N(I)/(A(N1)-A(I))
1390 F=0
1400 FOR I=S1 TO P1-1
1410 F=F+H*(2/3*FNG(I)+5/12*FNG(I+1)-1/12*FNG(I-1))
1420 NEXT I
1430 F=F-H*S2*FNG(S1)-H/4*S2+2*(FNG(S1+1)-FNG(S1-1))
1435 F=F+H*P2*FNG(P1)+H/4*P2+2*(FNG(P1+1)-FNG(P1-1))
1440 P5=F*D5*(A(N1)-A2)+3 P5 IS P DELTA
1460 DEF FNR(I)=H*(I*N(I)*(K1+G2*A(I))+2*(A(N1)-A(I))+2)
1470 F=0
1480 FOR I=S1 TO P1-1
1490 F=F+H*(2/3*FNR(I)+5/12*FNR(I+1)-1/12*FNR(I-1))
1500 NEXT I
1510 F=F-H*S2*FNR(S1)-H/4*S2+2*(FNR(S1+1)-FNR(S1-1))
1515 T0=F+H*P2*FNR(P1)+H/4*P2+2*(FNR(P1+1)-FNR(P1-1))+ T0 IS R0
1520 DEF FNT(I)=H*(I*N(I)*(K5+G2*A(I))+2*(A(N1)-A(I)))
1530 F=C

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1540 FOR I=S1 TO P1-1
1550 F=F+H*(2/3*FNT(I)+5/12*FNT(I+1)-1/12*FNT(I-1))
1560 NEXT I
1570 F=F-H*S2*FNT(S1)-H/4*S2*2*(FNT(S1+1)-FNT(S1-1))
1575 F=F+H*P2*FNT(P1)+H/4*P2*2*(FNT(P1+1)-FNT(P1-1))
1580 T3=F*O3*(A(N1)-A2)+3 T3 IS 9 DELTA
1600 DEF FNU(T)=H*(T*N(T))*(K3+G2*A(I))*(A(N1)-A(I))+2
1610 F=C
1620 FOR I=S1 TO P1-1
1630 F=F+H*(2/3*FNU(I)+5/12*FNU(I+1)-1/12*FNU(I-1))
1640 NEXT I
1650 F=F-H*S2*FNU(S1)-H/4*S2*2*(FNU(S1+1)-FNU(S1-1))
1655 F=F+H*P2*FNU(P1)+H/4*P2*2*(FNU(P1+1)-FNU(P1-1))
1660 S4=F T4 IS 5
1670 DEF FN(X)=H*(I*N(T))*(K3+G2*A(I))/(A(N1)-A(I))
1680 F=0
1690 FOR I=S1 TO P1-1
1700 F=F+H*(2/3*FN(X(I)+5/12*FN(X(I+1)-1/12*FN(X(I-1))
1710 NEXT I
1720 F=F-H*S2*FN(X(S1)-H/4*S2*2*(FN(X(S1+1)-FN(X(S1-1))
1725 F=F+H*P2*FN(X(P1)+H/4*P2*2*(FN(X(P1+1)-FN(X(P1-1))
1730 S5=F*O5*(A(N1)-A2)+3 S5 IS 5 DELTA
1750 P5=H*O5*2/P5+2/G5/G1/(A(N1)-A2)+3*(P4+P5)+ P5 IS P1
1770 T1=G5*O5+2/P5+2/G5/G1/(A(N1)-A2)+3*(Z+12.5*8.85E-14*L1/L/A)+2
1780 T1=T1*(T)+T3/(A(N1)-A2)+3 T1 IS R1
1800 C7=(S4+S5)/(O4+P5)*(TC+T3)+.5+ C7 IS C11
1820 F7=16/PI*O5*(O5+T1/77/T3)+.5+(P6+T2/P7/T3)+.5+ C6 IS C CORRELATION
1830 F7=F7*(FVPI*O5*L2)-4*EXF(A5*L2)+3+2*AS*L2)+ F7 IS LITTLE F3
1840 P6=F7*G1*(A(N1)-A2)*A/4/G5/=1+3/(O1*RS*Z+12.5*8.85E-14)+2+ P6 IS P2
1850 T2=P6*(Z+1.5E-12)*A/G1*L1/(A(N1)-A2)*L/C6*G5*K1)+2+ T2 IS R2
1870 P7=P5+P6 O7 IS O=PI+P2
1880 T3=T1+T2 T3 IS R=K1+R2
1890 C9=C7*(O5+T1/77/T3)+.5+(P6+T2/P7/T3)+.5+ C6 IS C CORRELATION
1900 K2=P7-2*O5*(O5+T1/77/T3)+.5+T3 T2 IS K SUB 3
1910 K3=(P7-C9*(P7*O5)+.5)/K2 T3 IS K SUB C
1920 K4=P7*O5*(1-C9*2)/K2 T4 IS K SUB R
1925 PRINTENOTIF PARAMETERS VS FREQ FOR BIAS VOLTAGES SELECTED=
1930 PRINT TYPE FOR CHZ
1940 INPUT F
1945 IF F<0 THEN 700
1950 F=F*1E9
1960 G3=(2*PI*F*C6)+2*K2/G5 T4 IS LITTLE G SUB N

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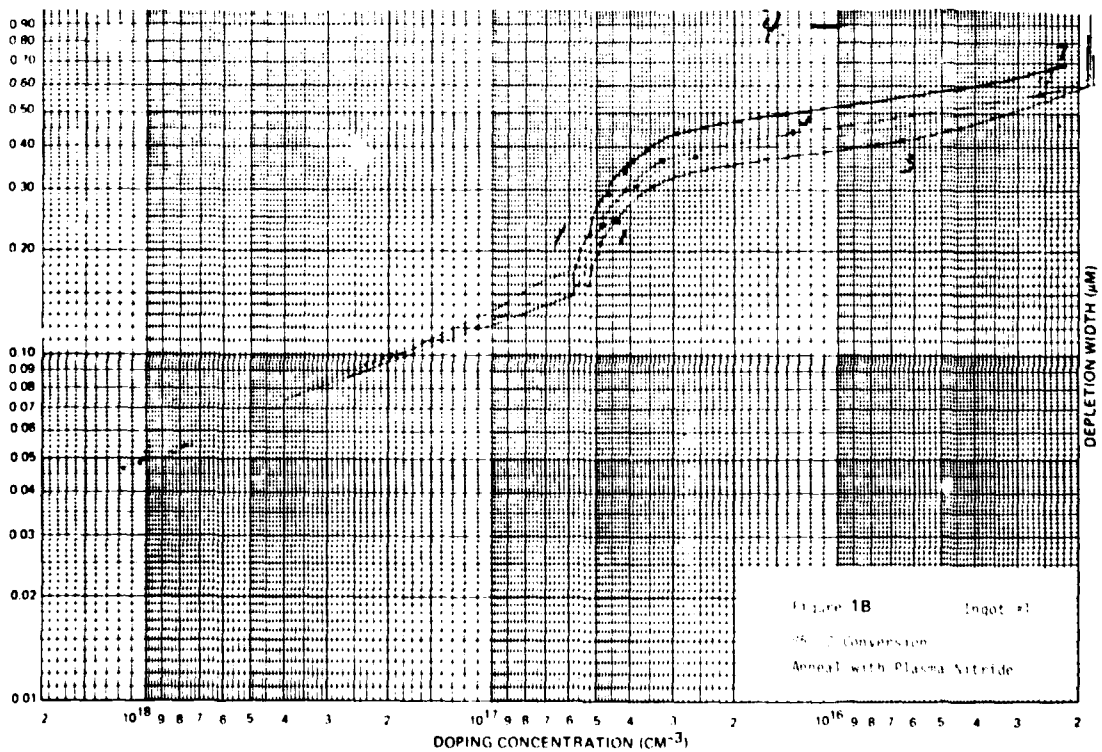
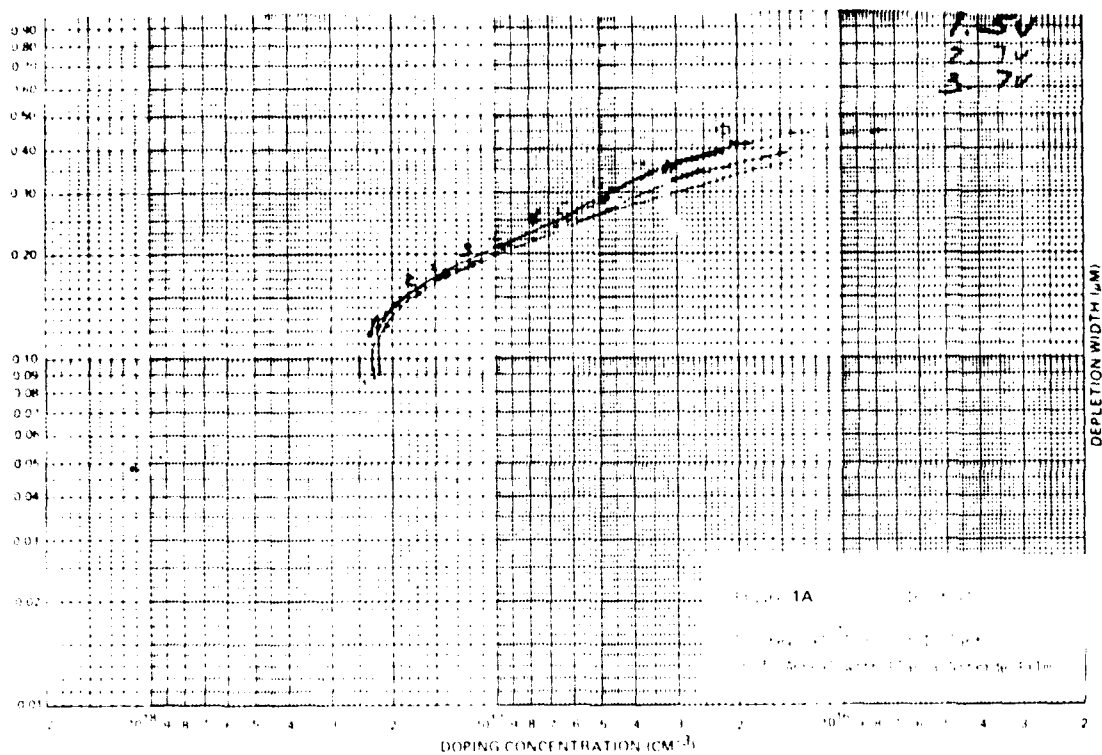
1970 R6=R1+R4+(1+(2*PI*F*G6*R5)*2)*K4/G3+ R5 IS LITTLE R SUR N
1980 R7=R1+R4+K1*DE + R7 IS R SUR C
1990 X7=-K3/(2*PI*F*G6)+ X7 IS X SLB C
2000 PRINT "CN=:",CN,"DN=:",DN,"ER=:",ER,"J=:",(P7*2+R2/G3)*.5,"EX=:",X7
2010 F5=1+2*G3*(R7+(P7*2+R6/G3)*.5)
2020 PRINT "FOPT=:",F5,"FOPT(D8)=:",10*L*LOG10(F5)
2030 GO TO 1930
2040 DEF FNG(T,J)=W1*(J)+R2/K1*(1+3(I))-V4-V1/R1*(P1+R2)
2050 DEF FND(T,J)=P1+W1*G1/E1/L*(A(N1)*(R(J)-B(I))-C(J)+C(I))+V1-W1*(P(I)
2060 D5=FNG(S1+1,P1)-FND(S1,P1)
2070 D6=FNG(S1+1,P1)-FNG(S1,P1)
2080 F5=FND(S1,P1+1)-FND(S1,P1)
2090 F6=FNG(S1,P1+1)-FNG(S1,P1)
2100 H5=-FNG(S1,P1)
2110 H6=-FNG(S1,P1)
2120 S2=(H5*F5-H6*F5)/(D5*F6-D6*F5)
2130 P2=(D5*H6-D6*H5)/(D5*F6-D6*F5)
2140 S=(S1+S2)/N1,P=(P1+P2)/N1
2150 IF S=S0 AND P=P0 THEN 2190
2160 S0=S,P0=P
2170 S1=S1+INT(S2),P1=P1+INT(P2)
2180 GO TO 2040
2190 B1=B(S1)+S2*(R(S1+1)-B(S1))
2200 B2=B(P1)+P2*(R(P1+1)-B(P1))
2210 C1=C(S1)+S2*(C(S1+1)-C(S1))
2220 C2=C(P1)+P2*(C(P1+1)-C(P1))
2230 PRINT "ID=:",W1*G1/F1/L*(A(N1))*(B2-B1)-C2+C1)
2240 GO TO 79
2250 DATA 4500,2900,2.0E-5,265E-4,2E-4,15,25,1.2,0.316,0.8
2260 END

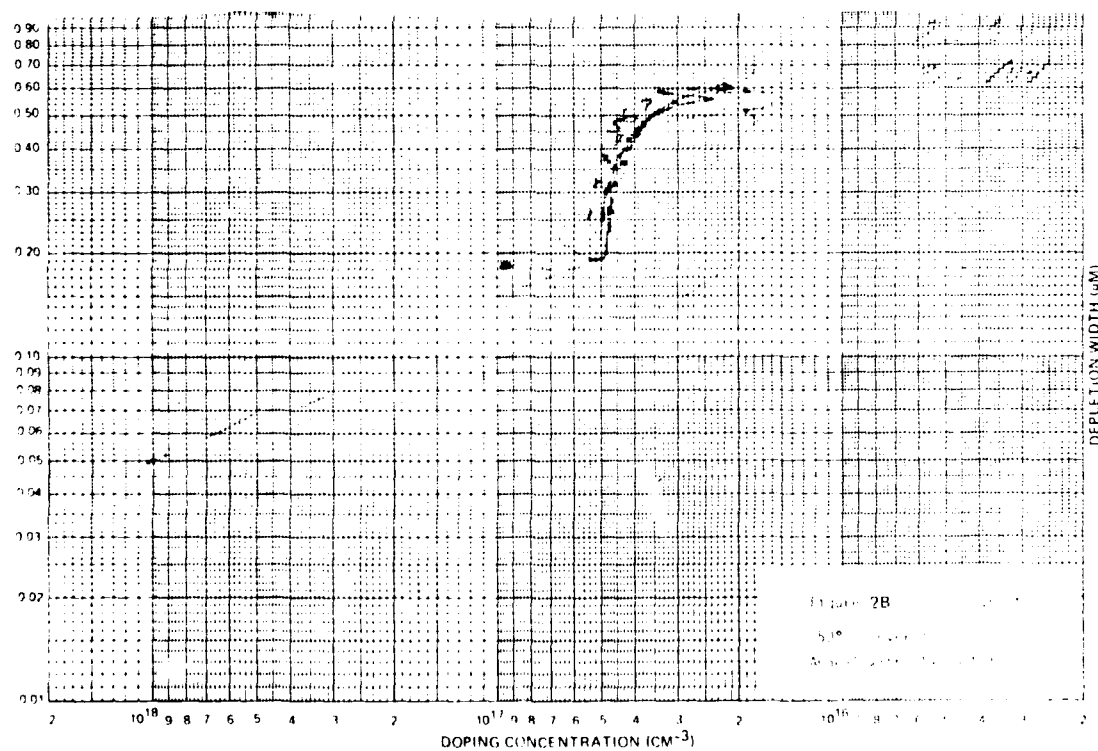
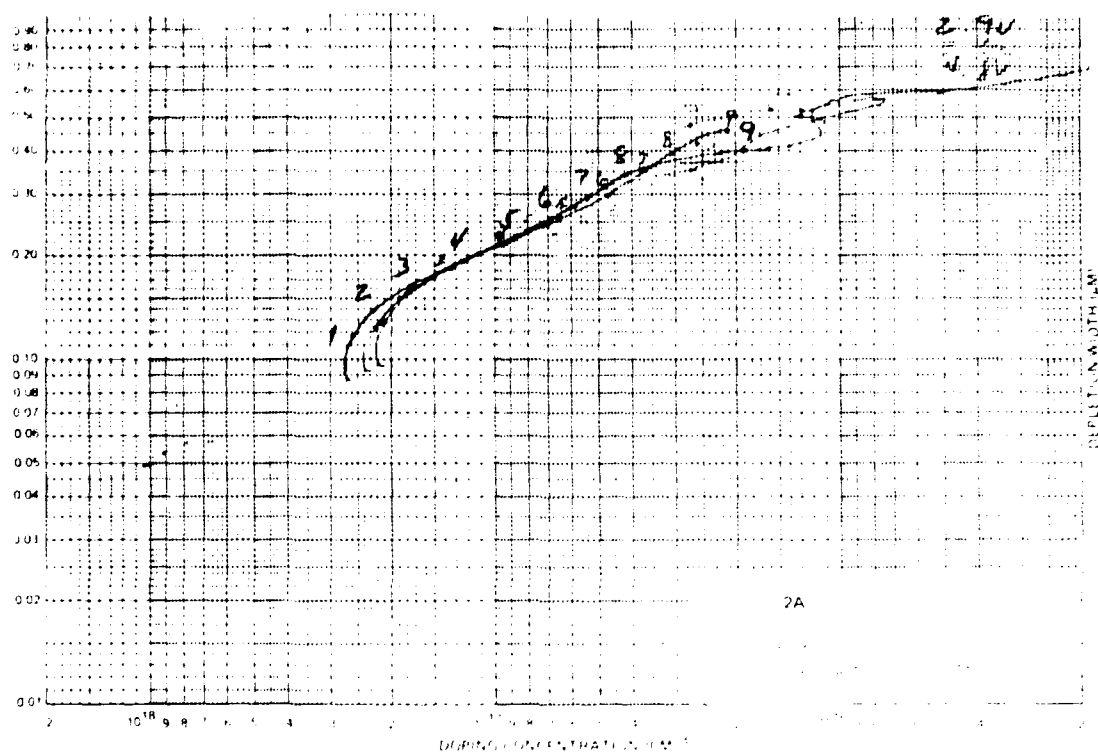
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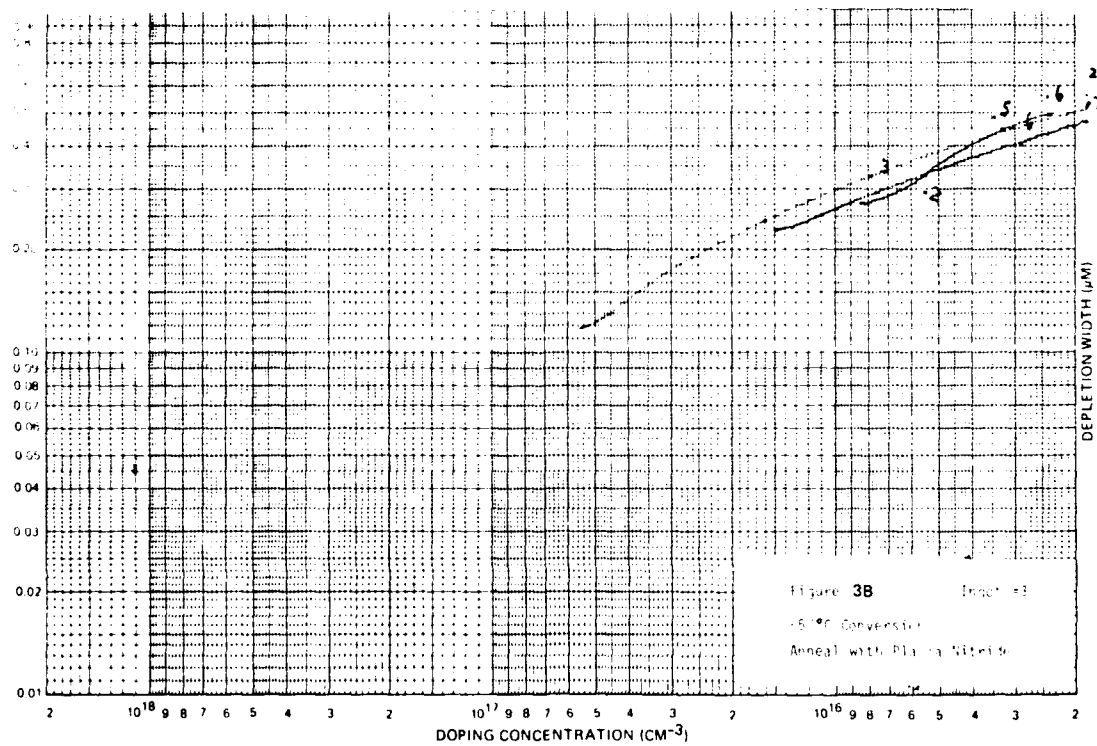
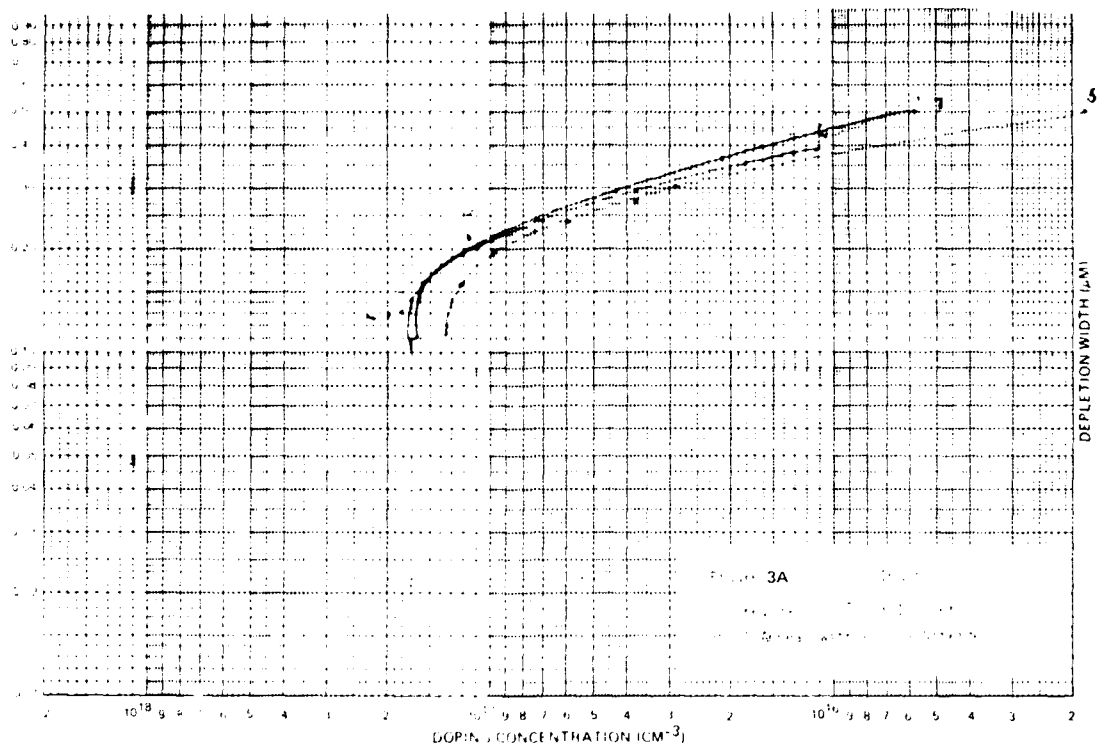
APPENDIX C
SUPPLEMENTARY PROCESSING DATA

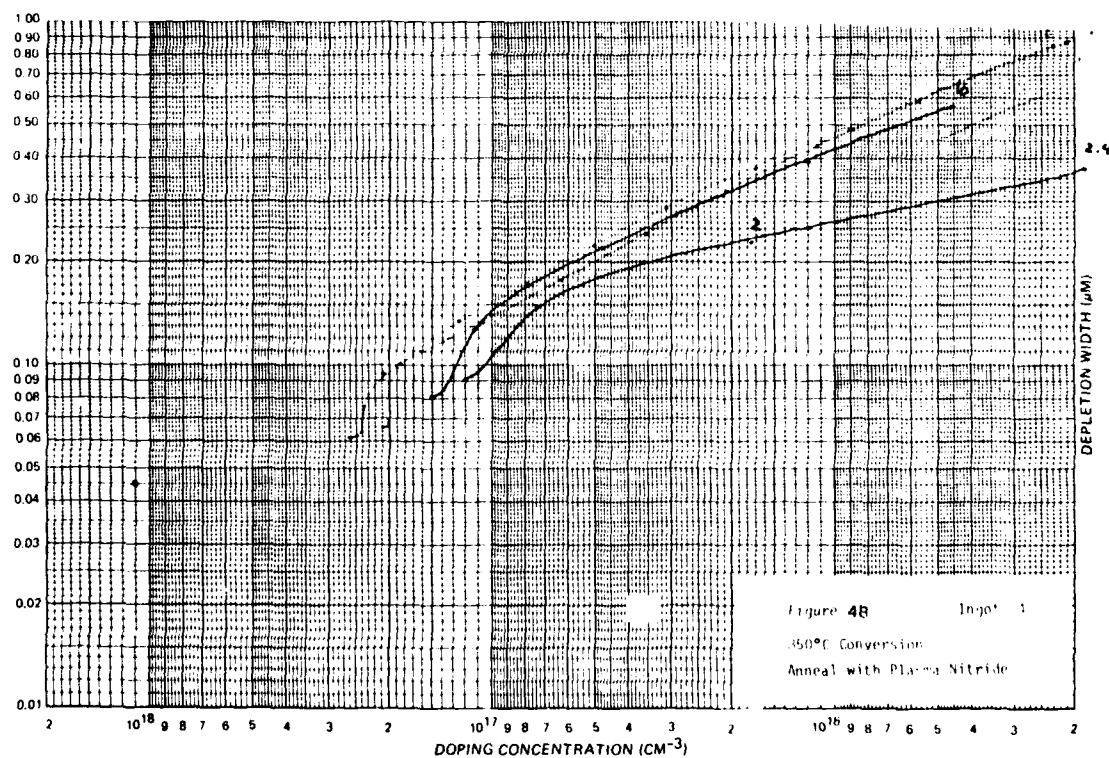
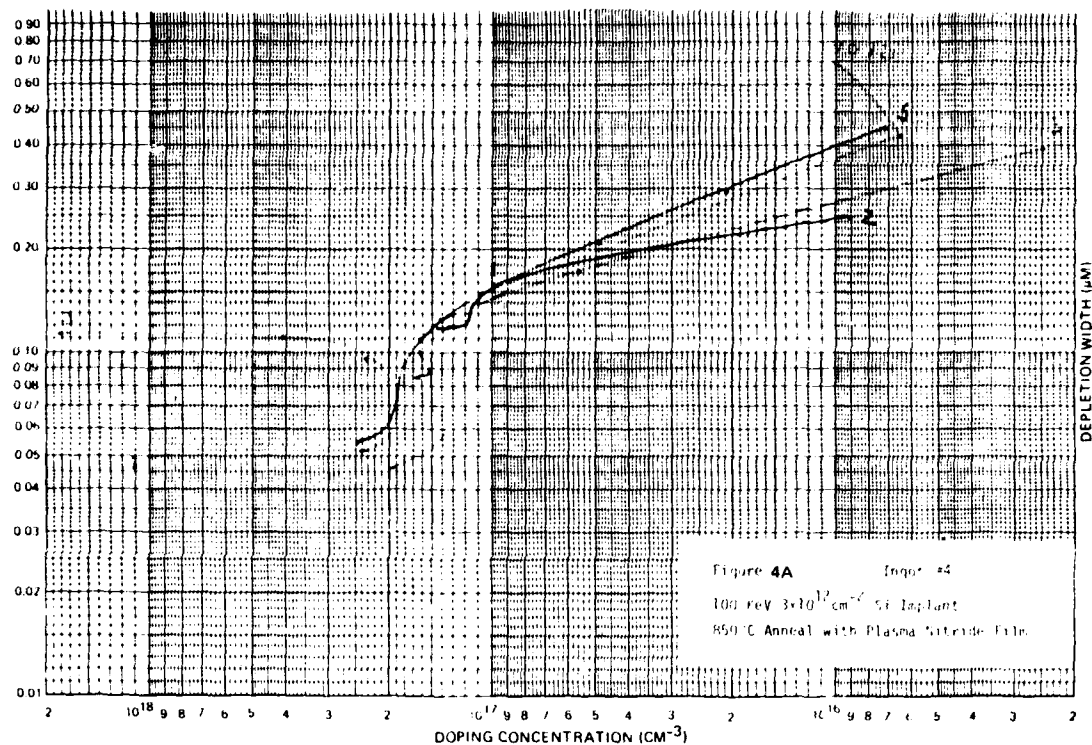
Several GaAs samples from different vendors were evaluated for thermal conversion and implant damage enhanced conversion. Data shown in Figures 1 through 5 is typical of ingots which did not pass the qualification tests. The A figures show thermal conversion without implant. The B figures show ion implant profiles characteristic of these wafers which convert.

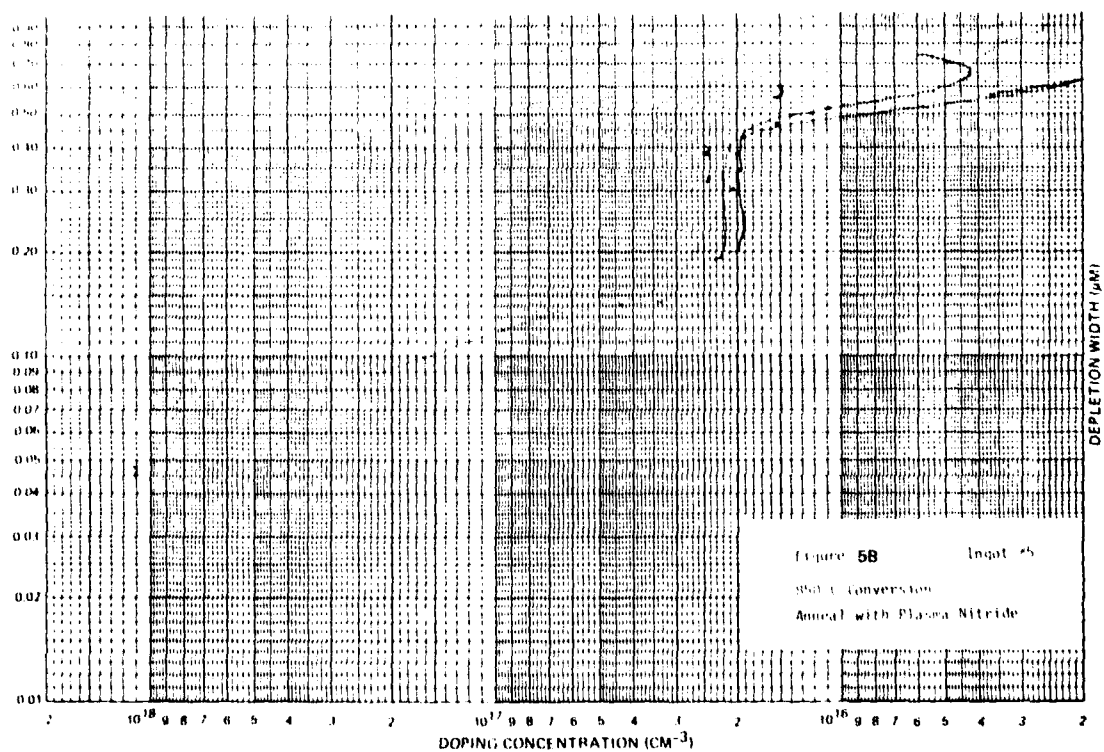
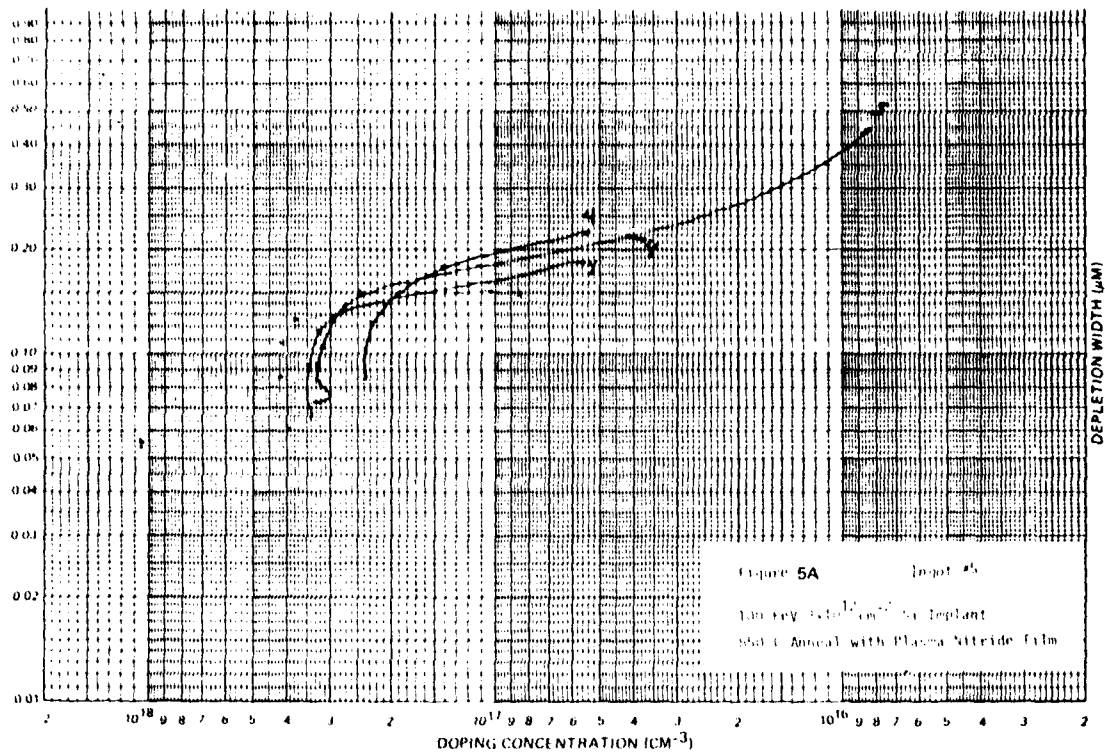
The implant data of a series of qualified wafers which have been implanted for device and circuit application are presented in Figures 6 through 36 in two groups: 100 keV implants for a pinchoff of 1 to 2 volts are shown in Figures 6 through 28 and 200 keV implants for a 3 to 4 volt pinchoff are shown in Figures 29 through 36. This data indicates a high degree of repeatability.

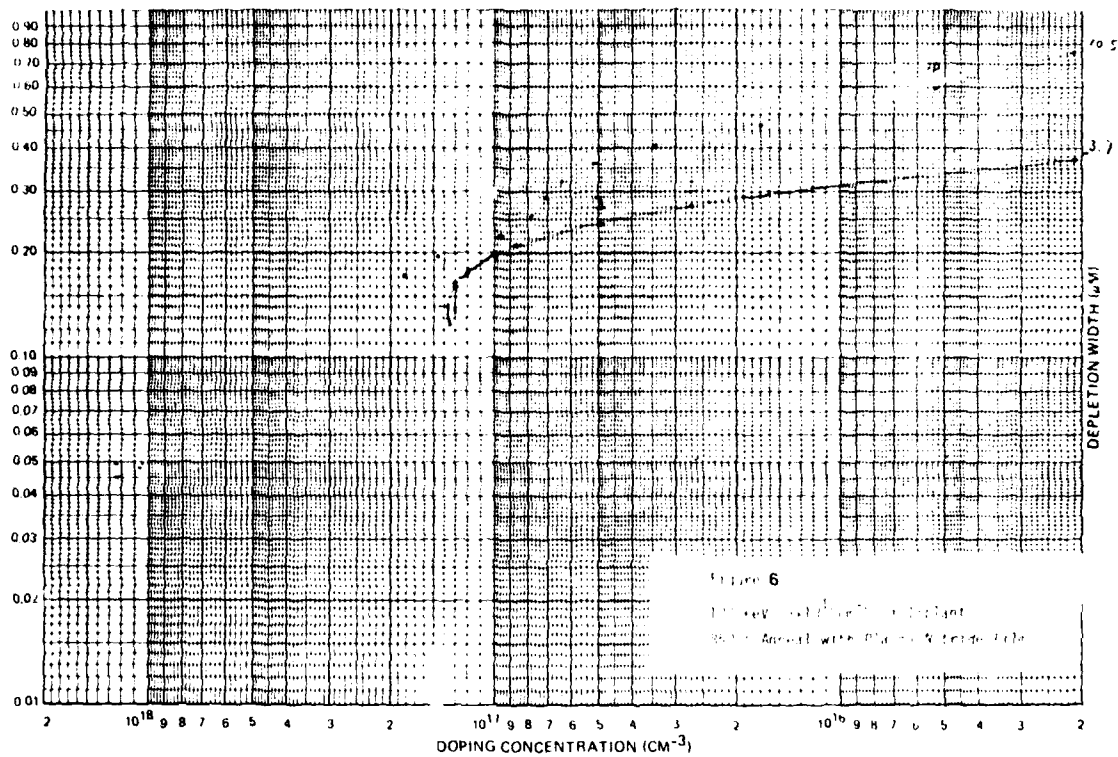


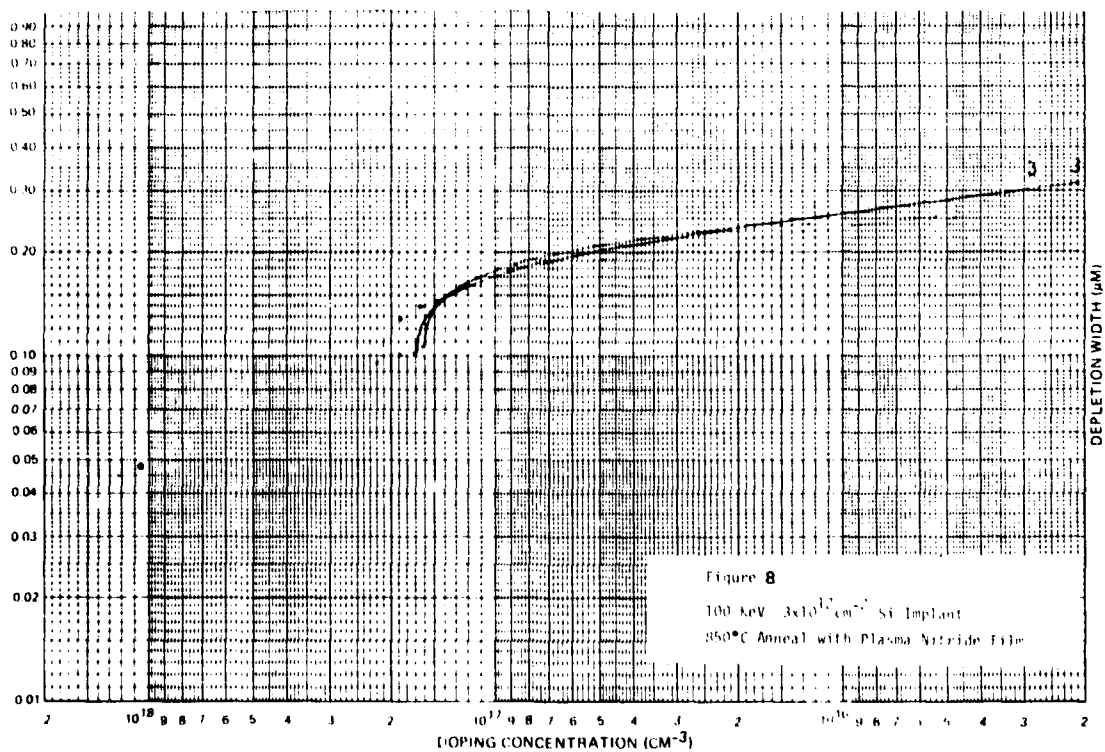
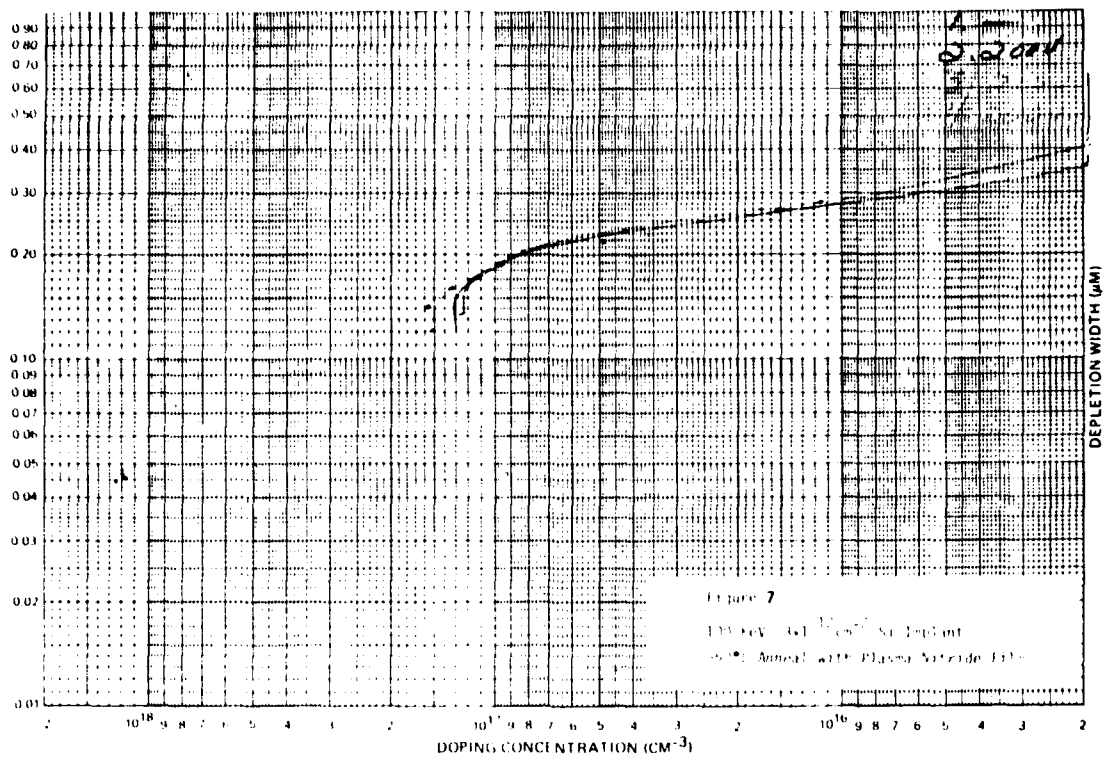


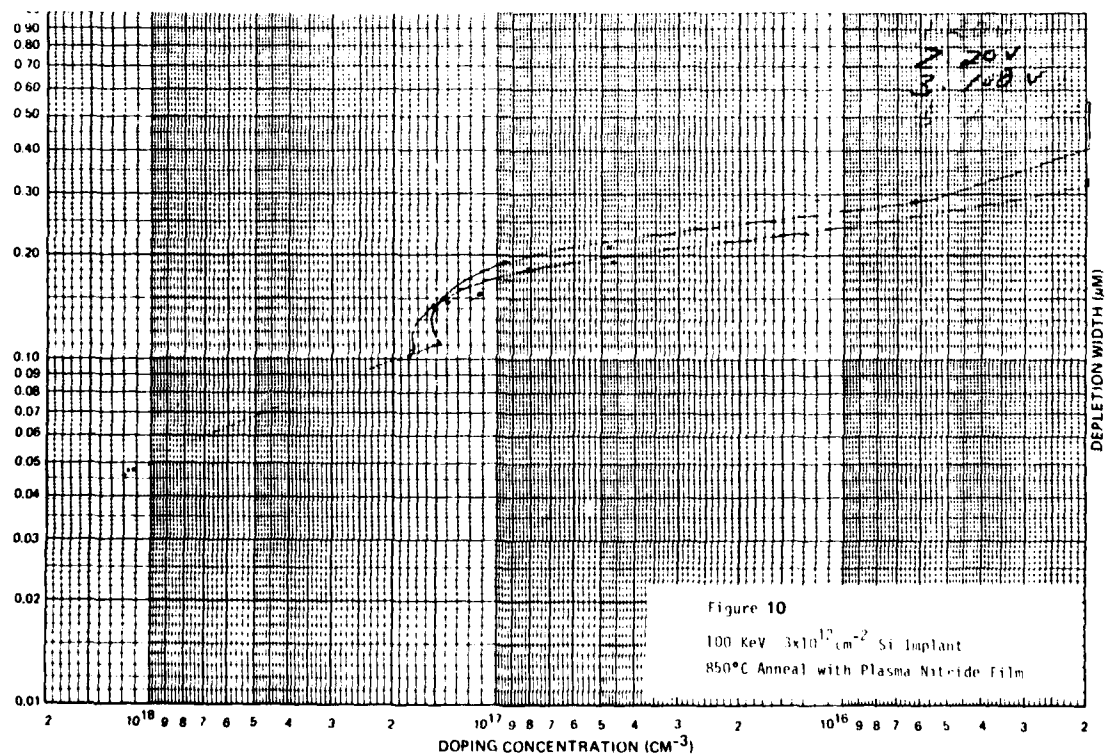
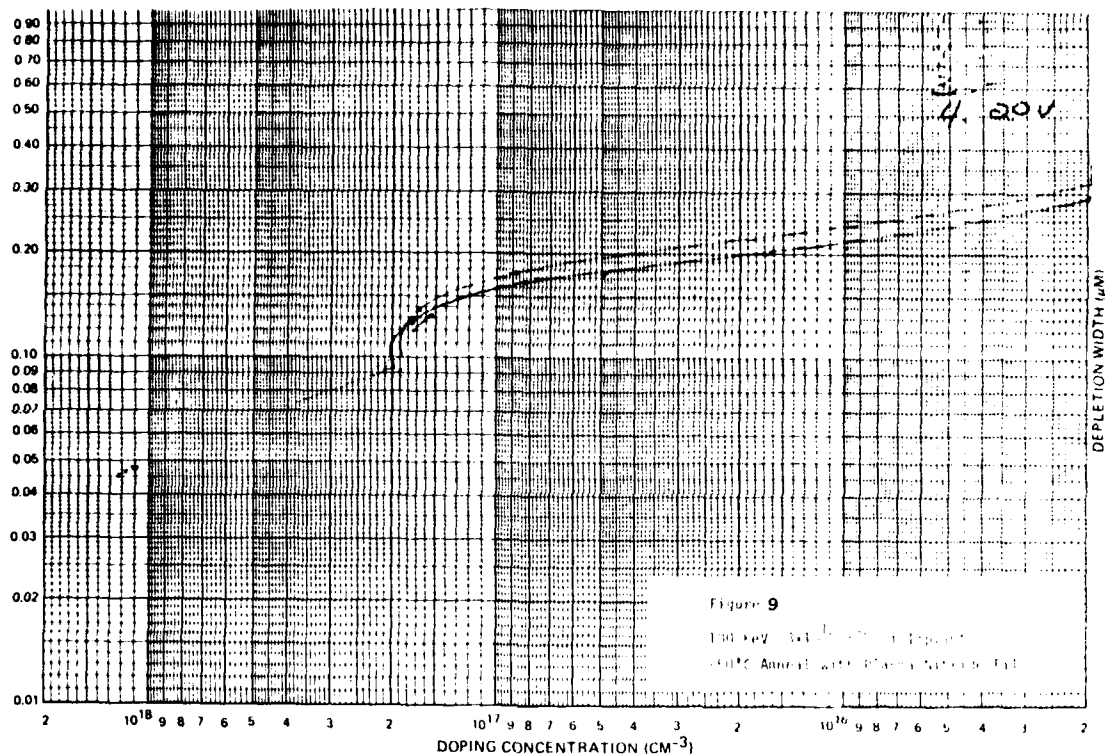


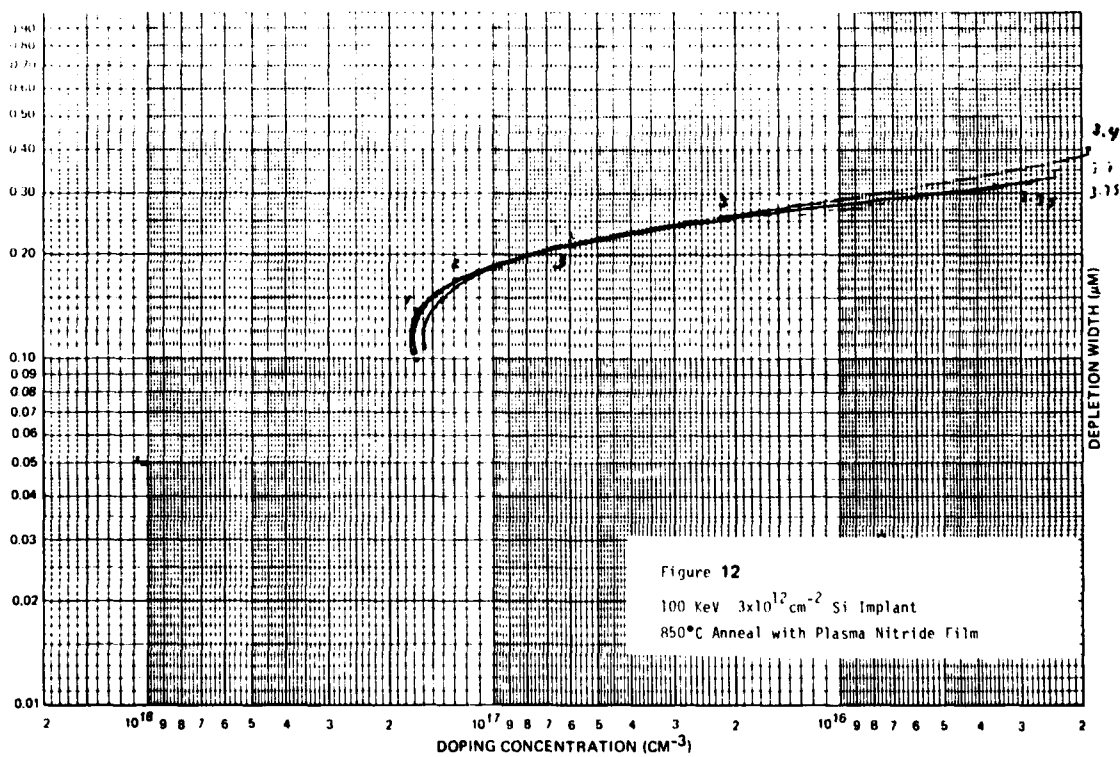
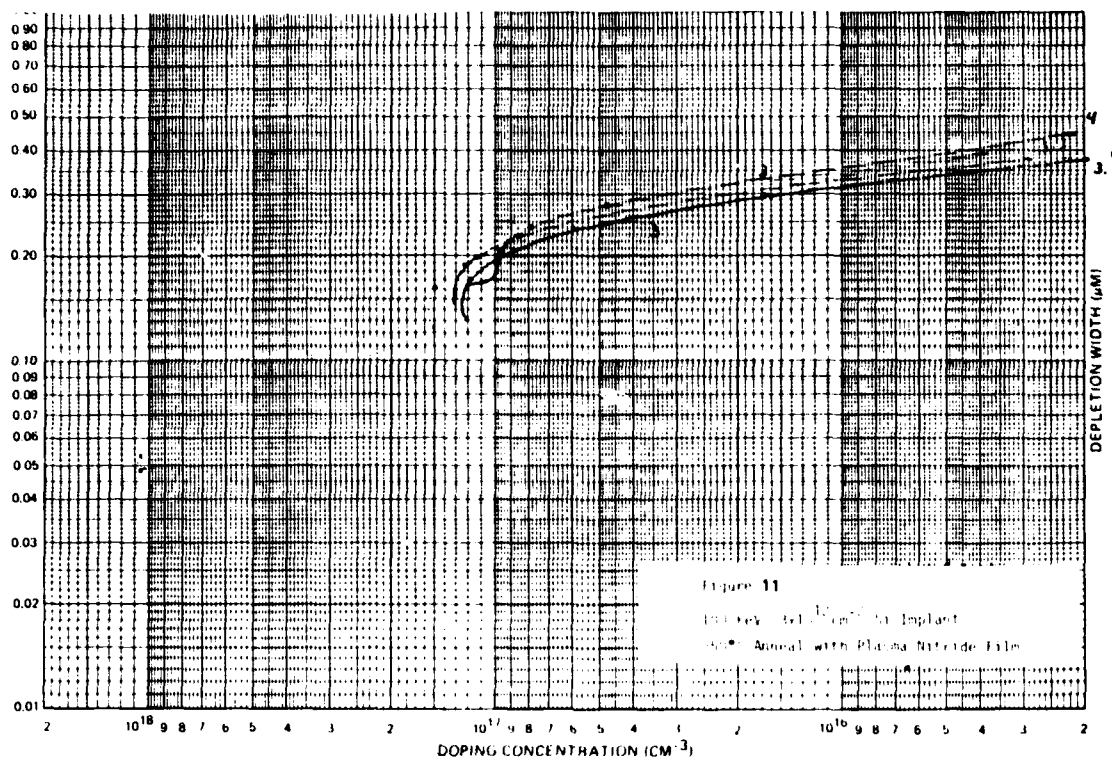


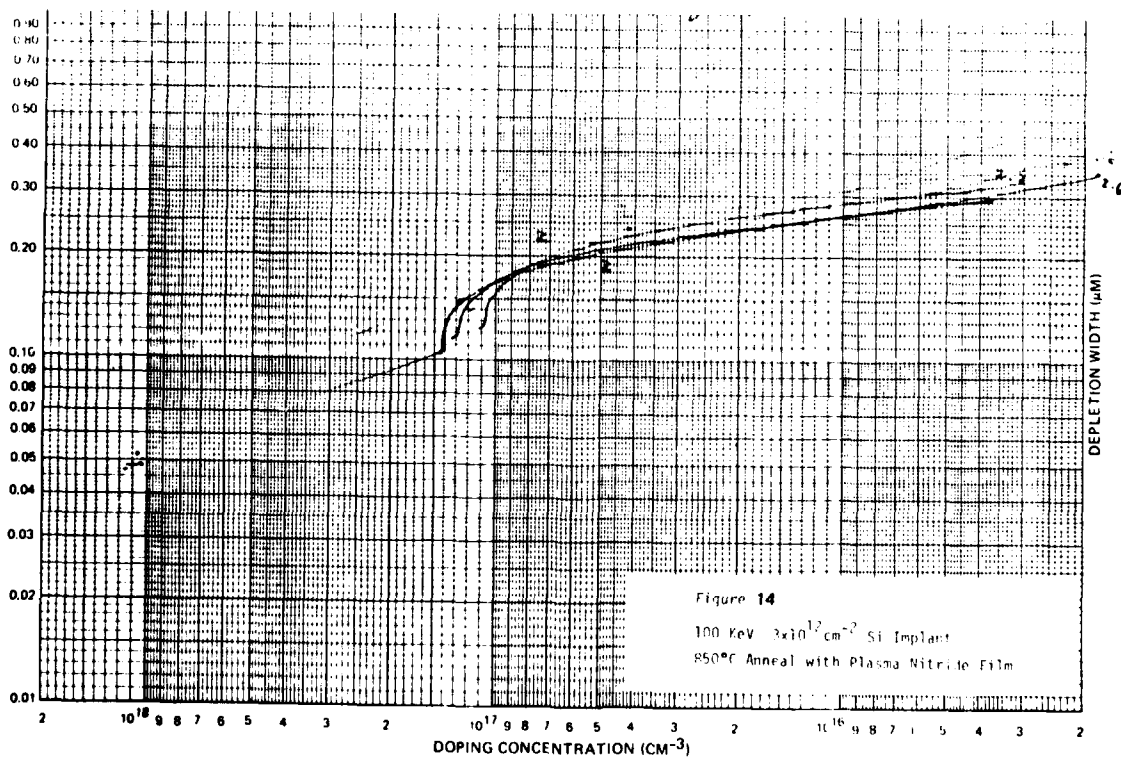
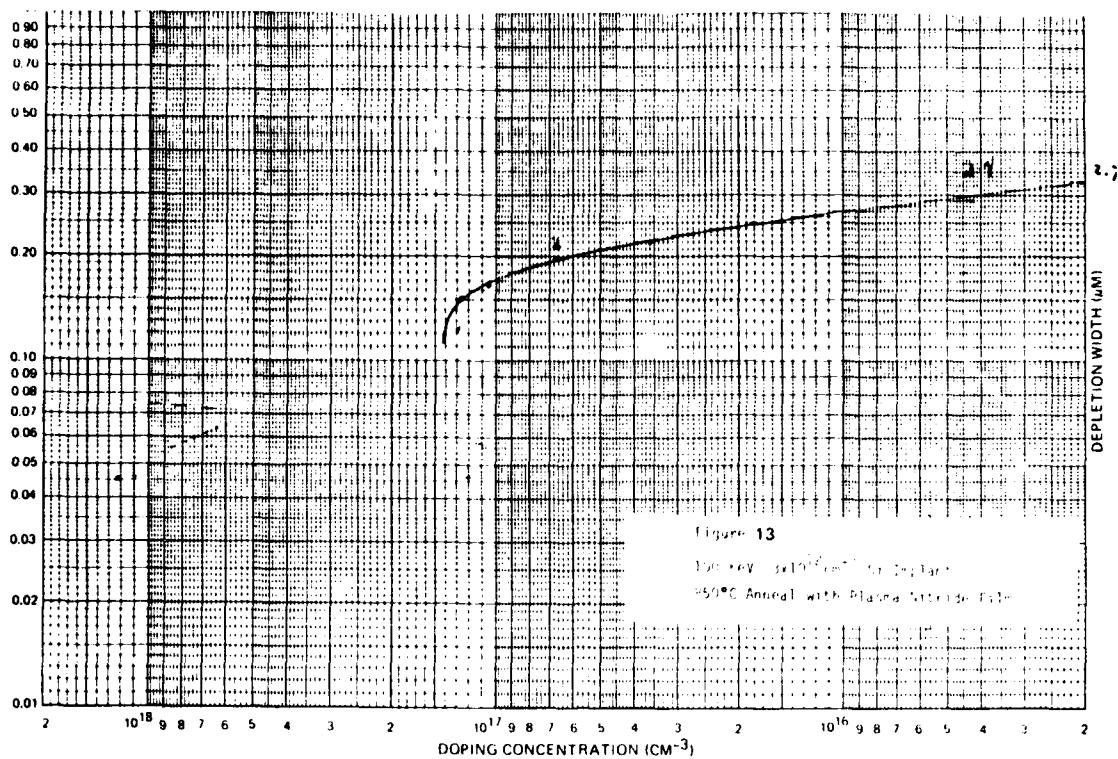


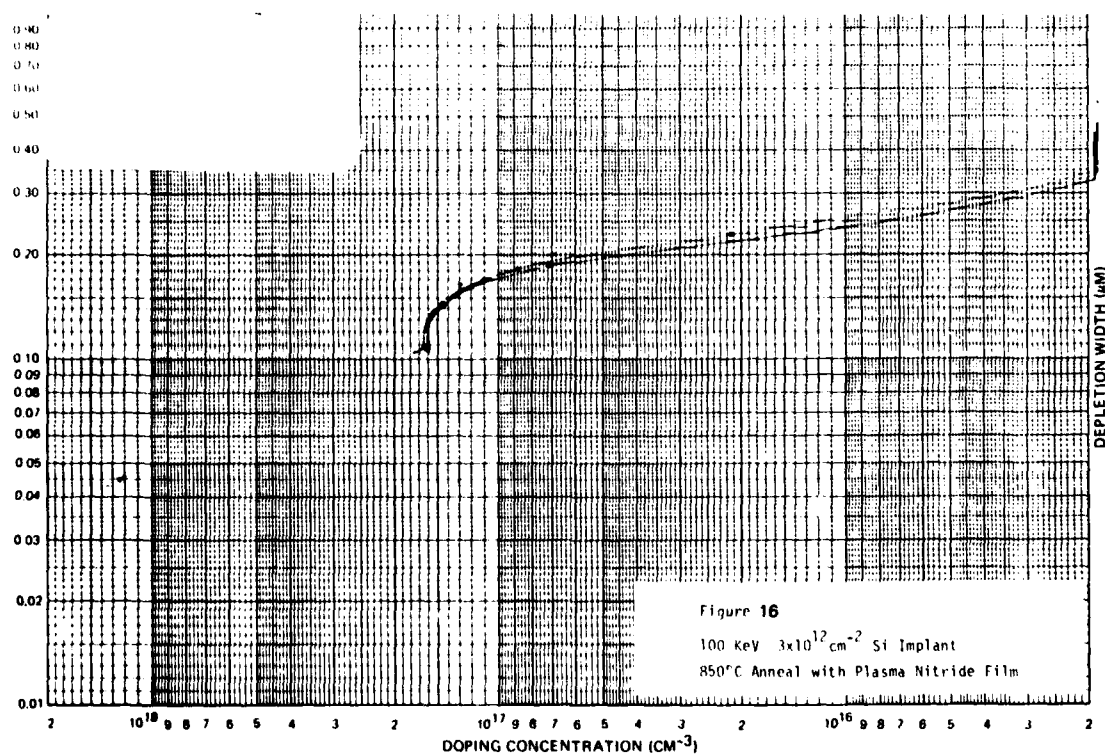
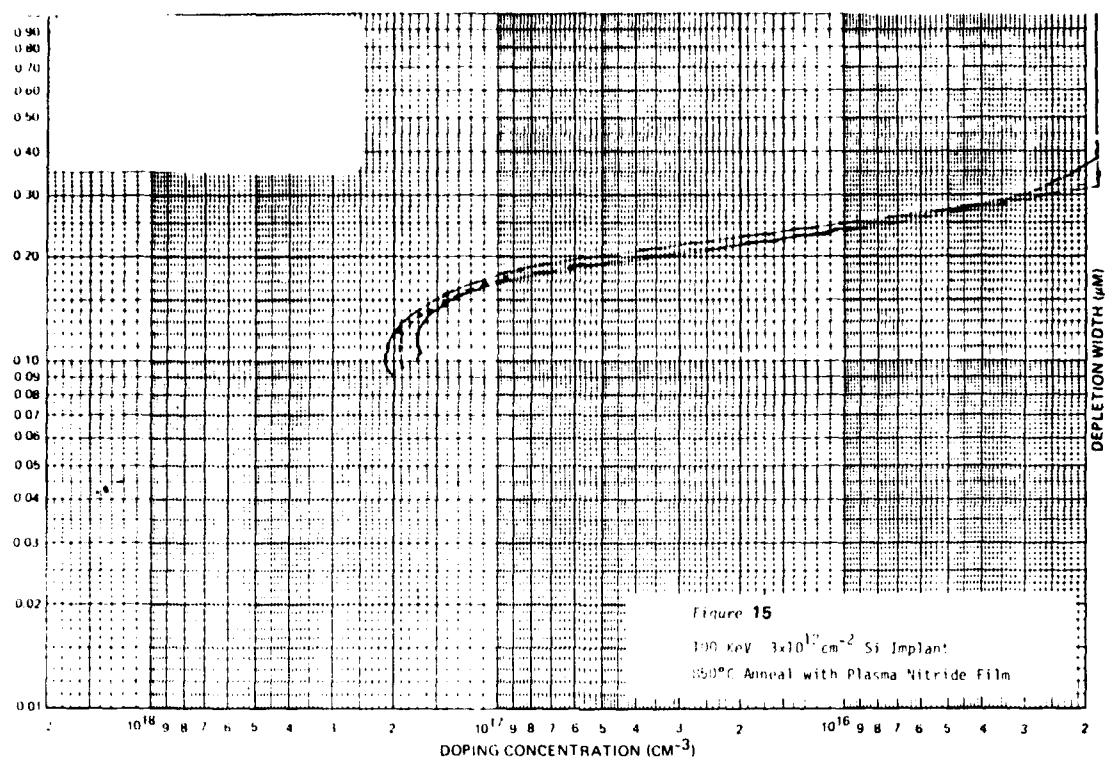


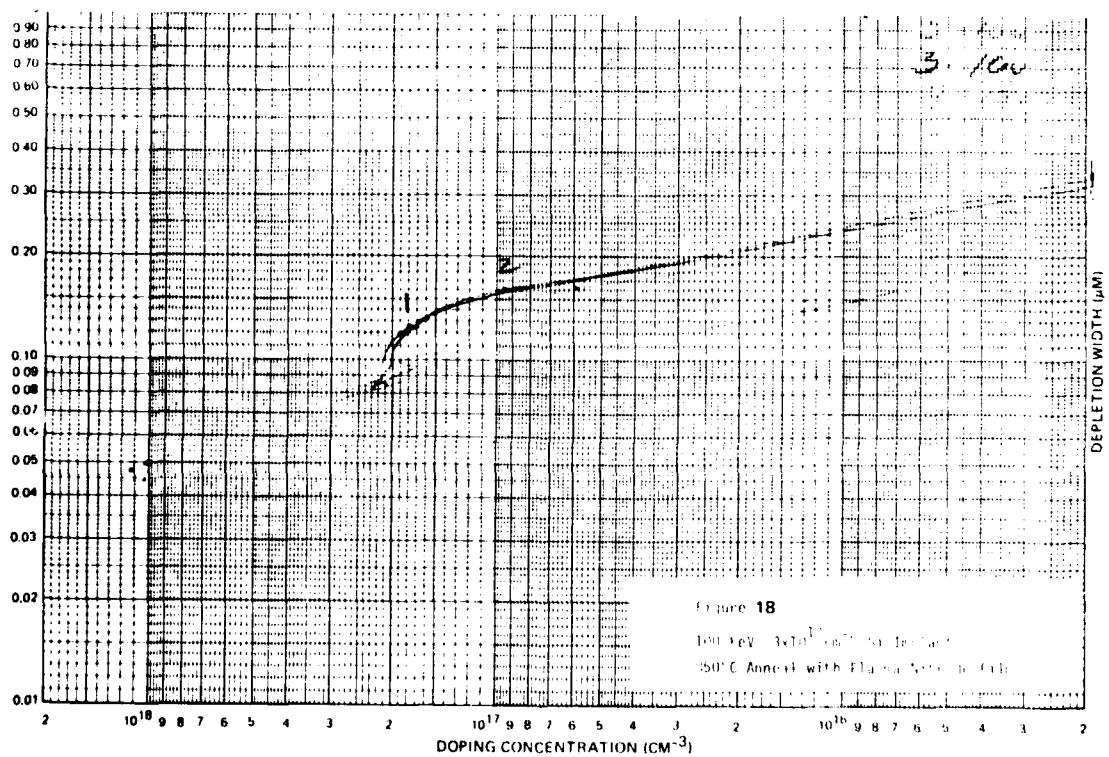
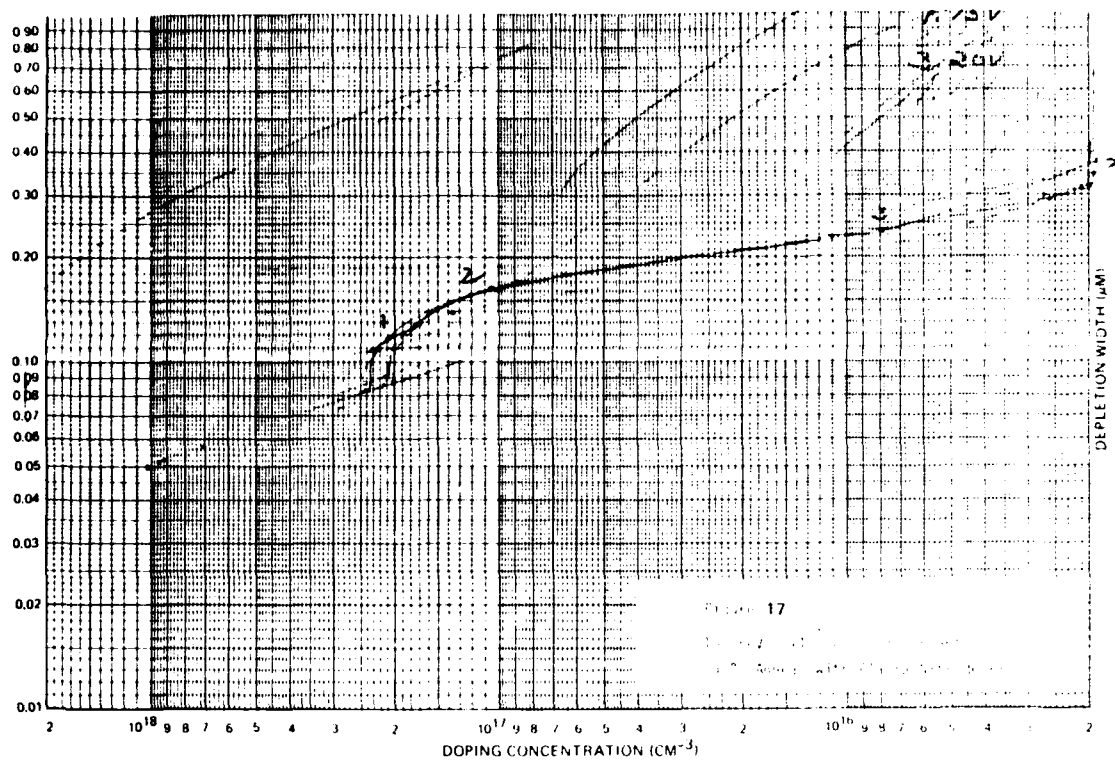


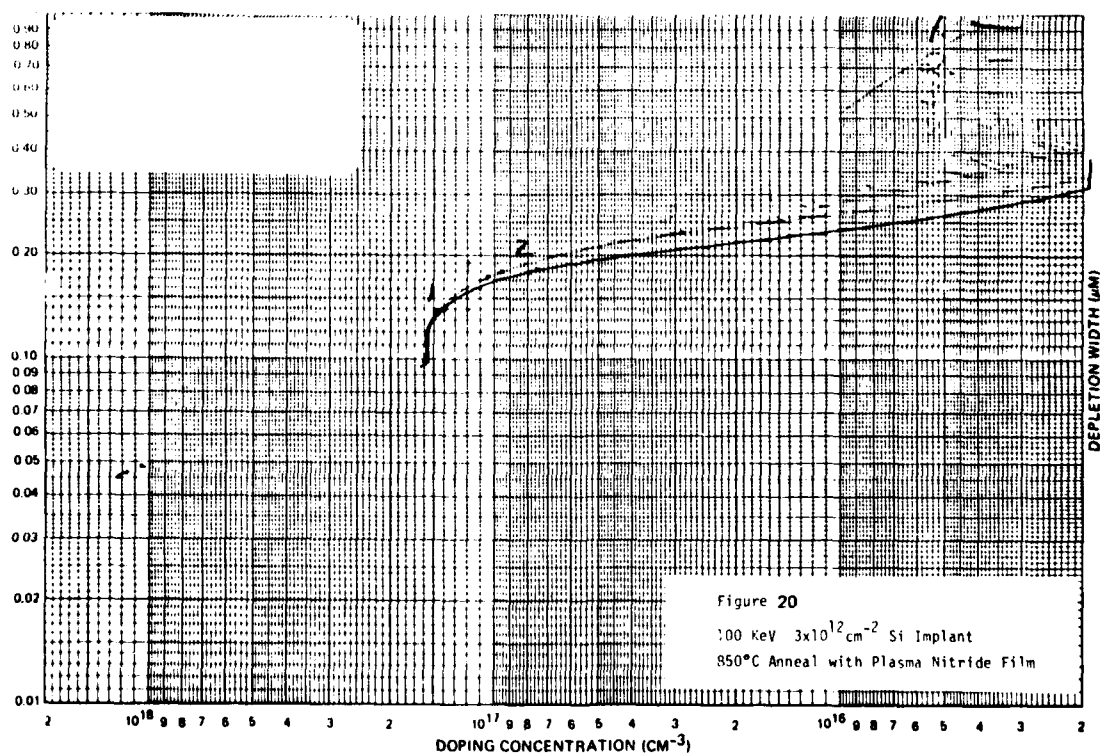
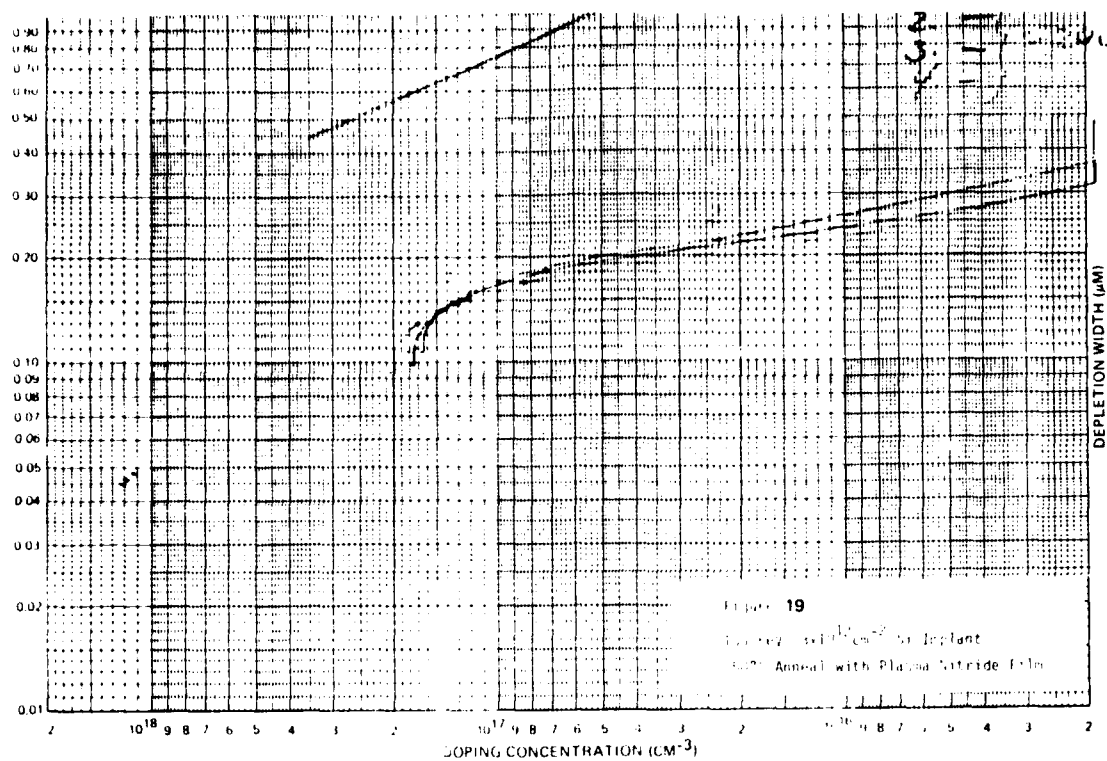


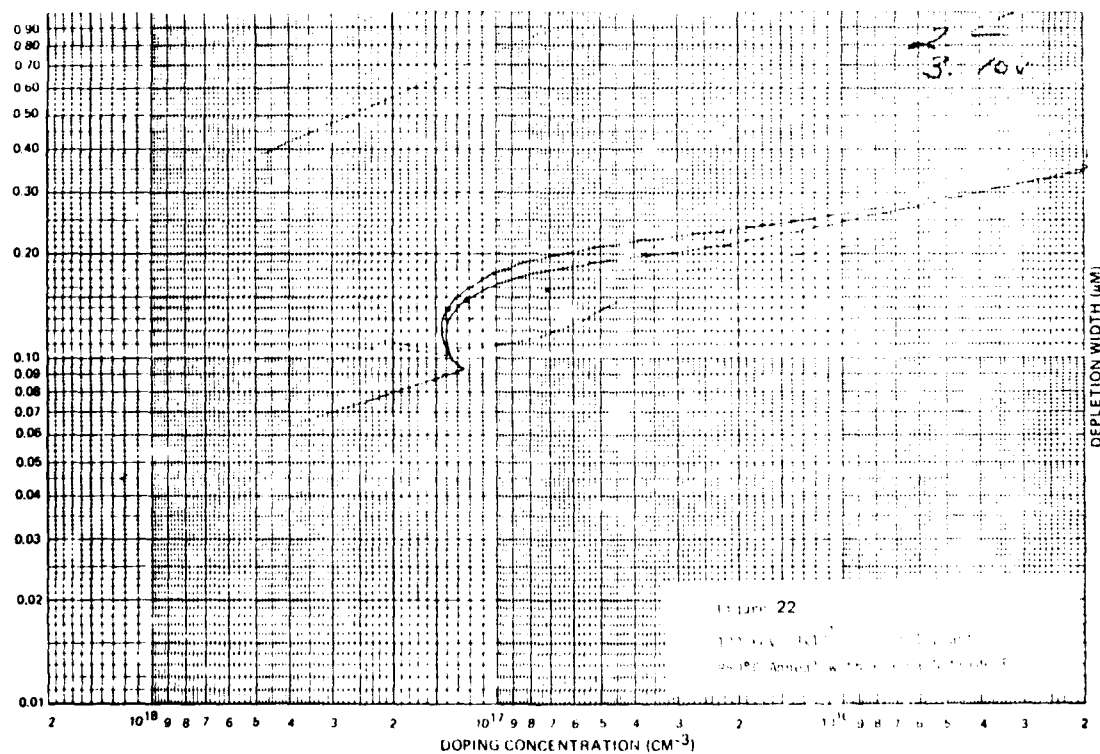
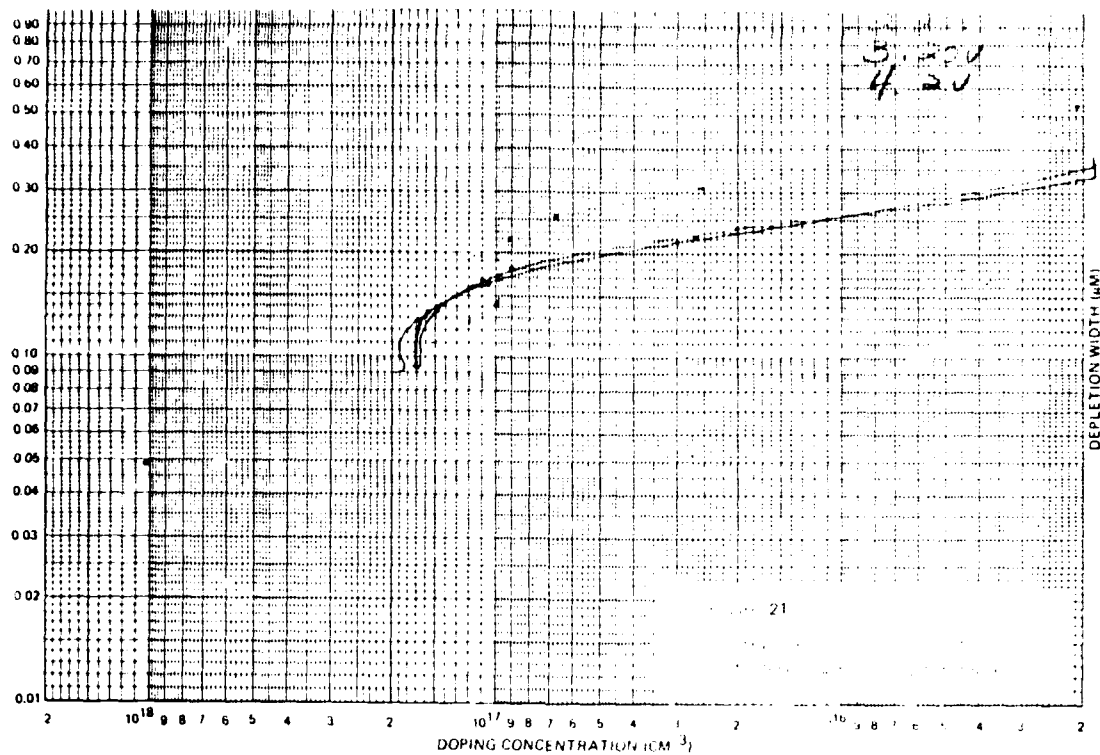


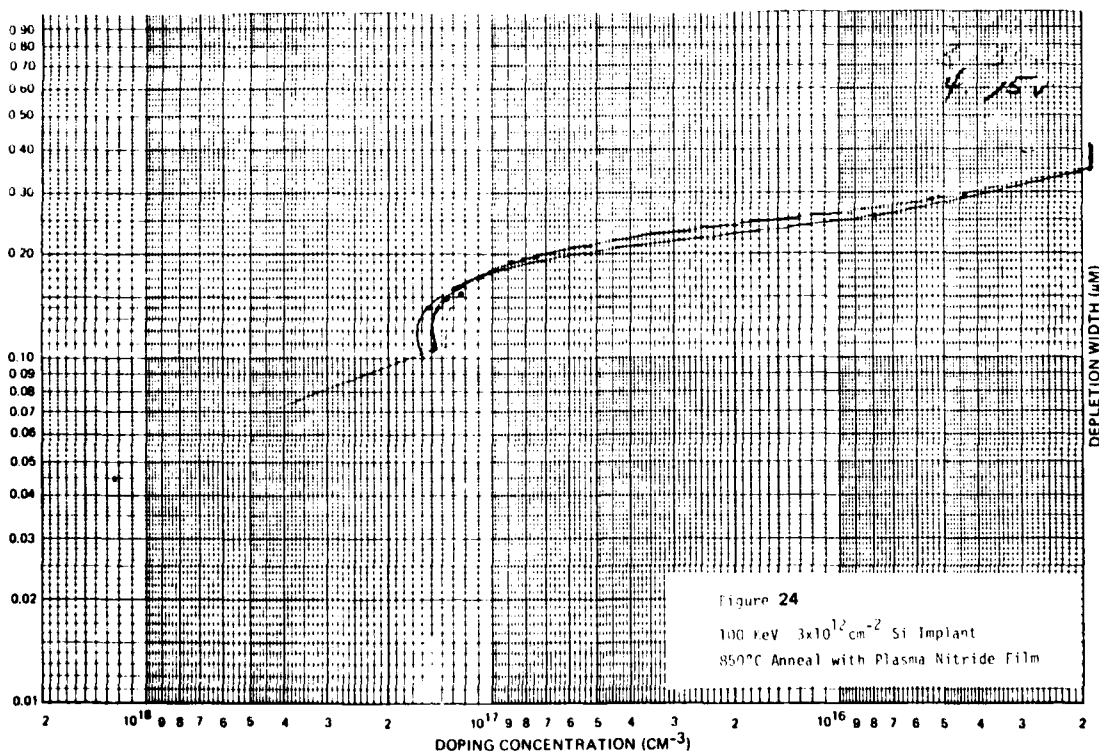
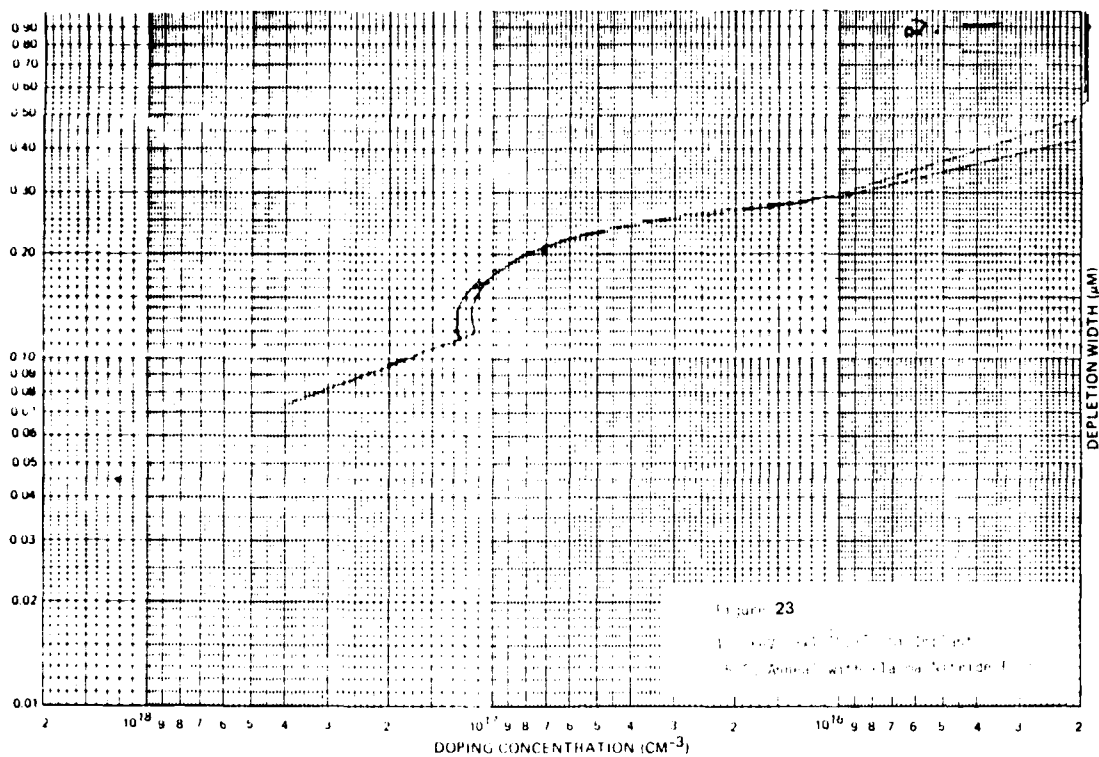


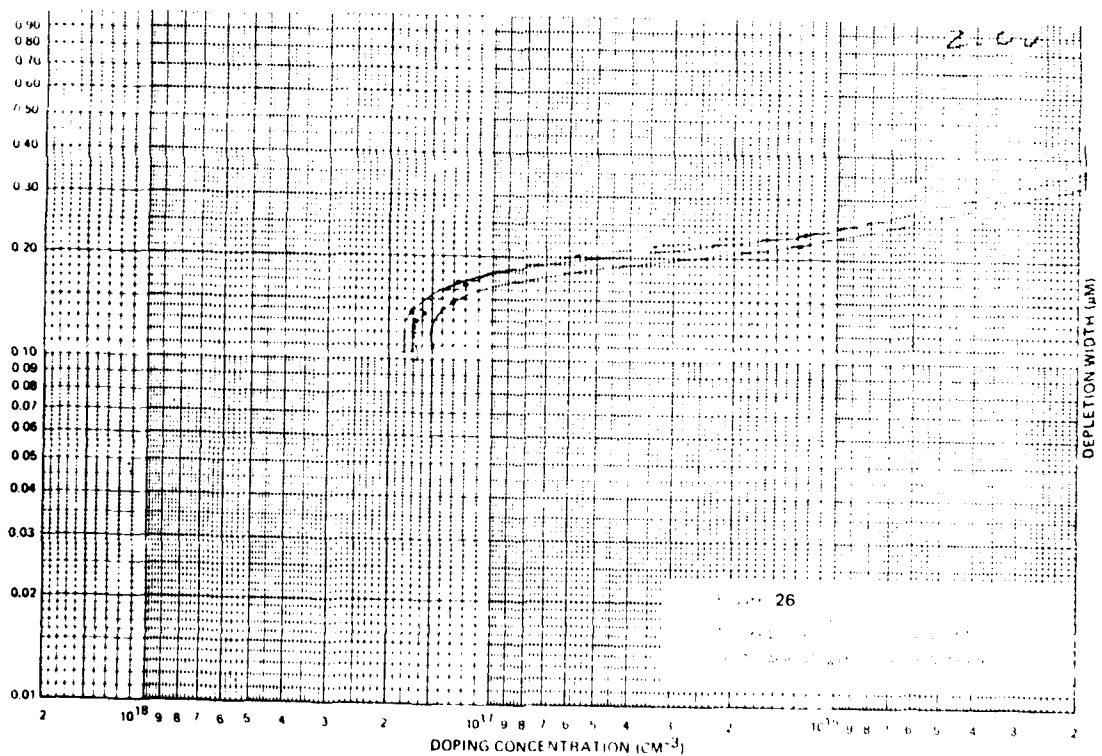
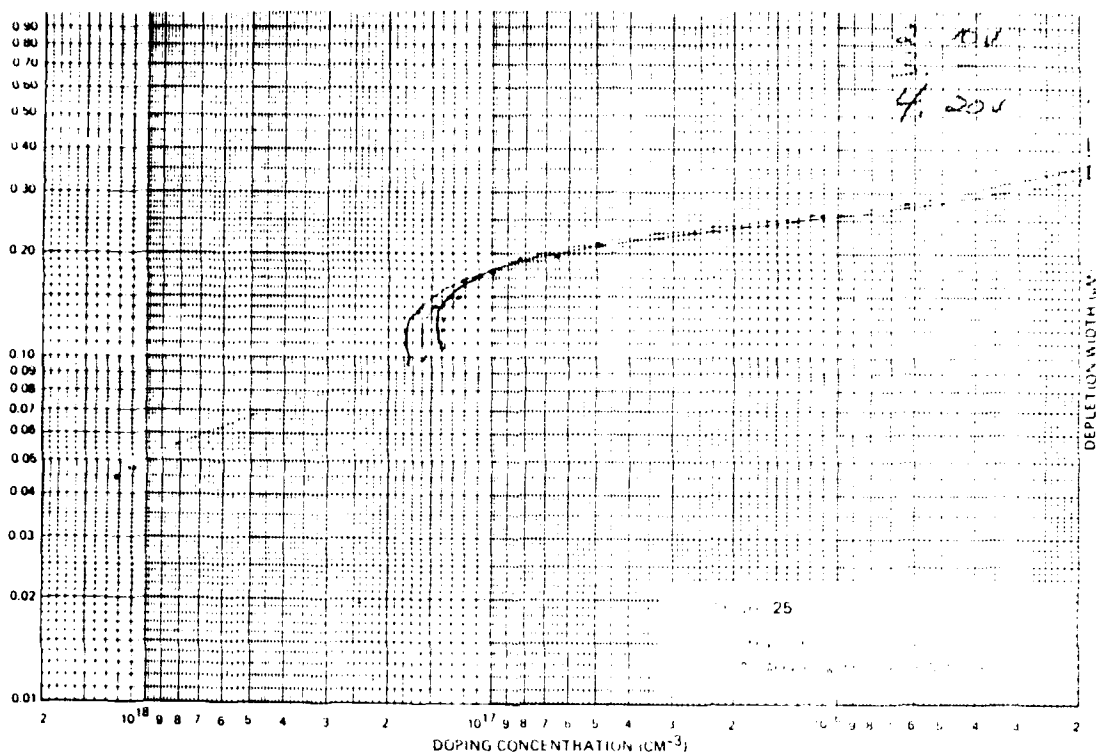


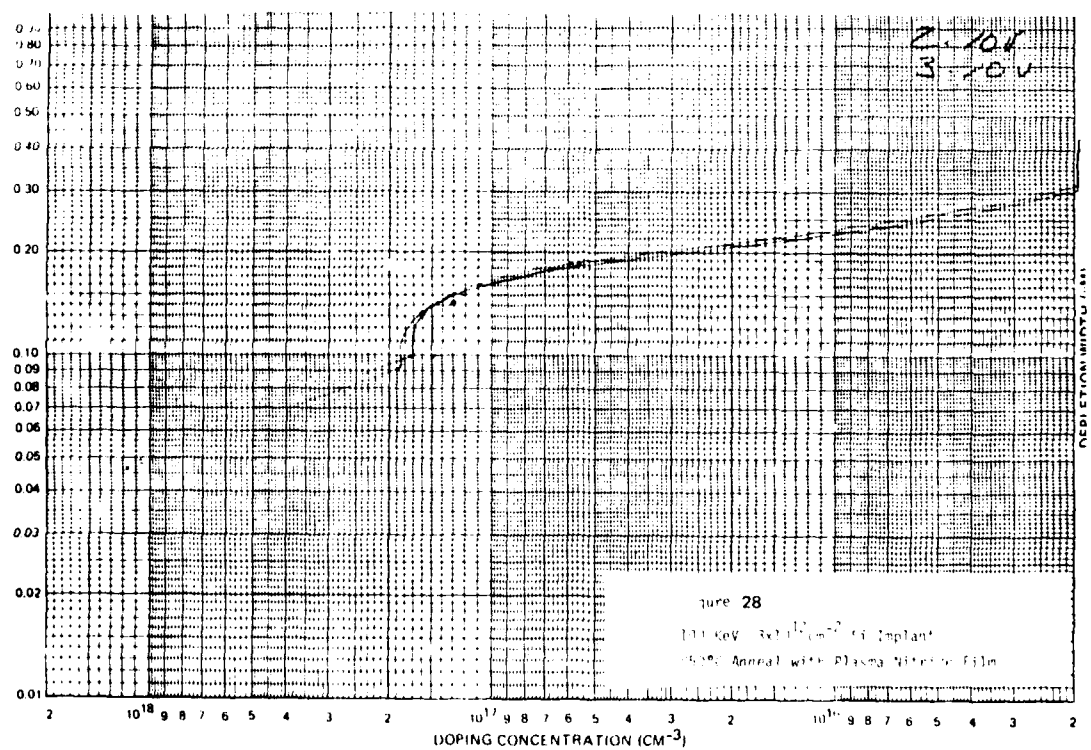
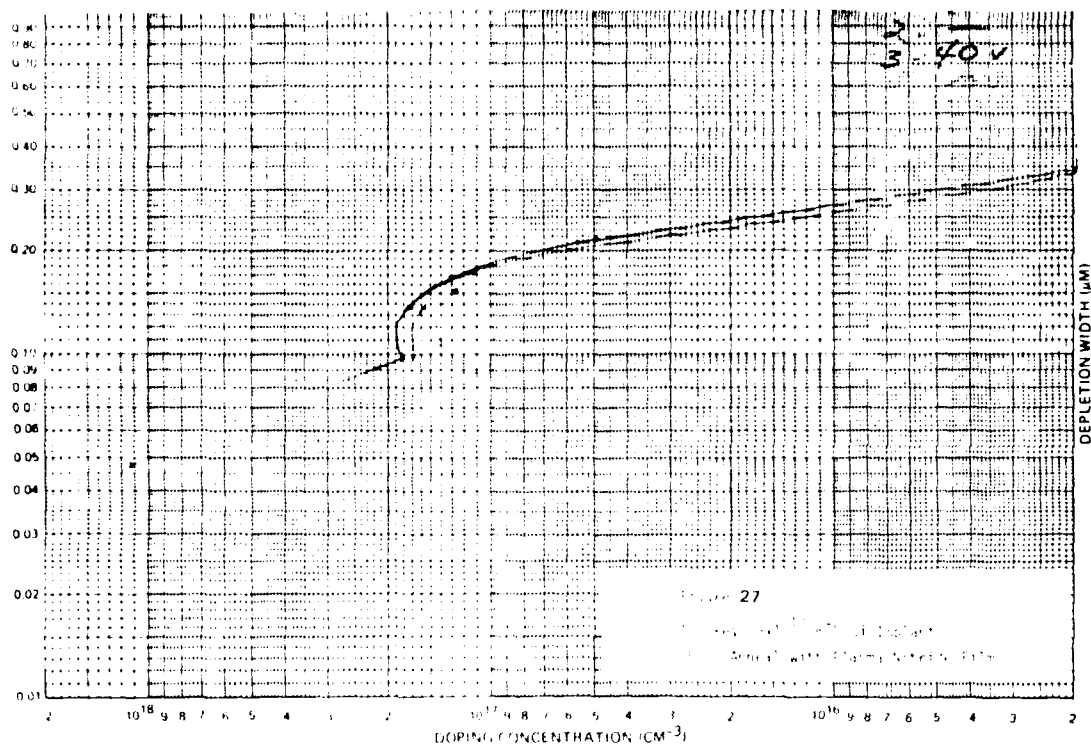


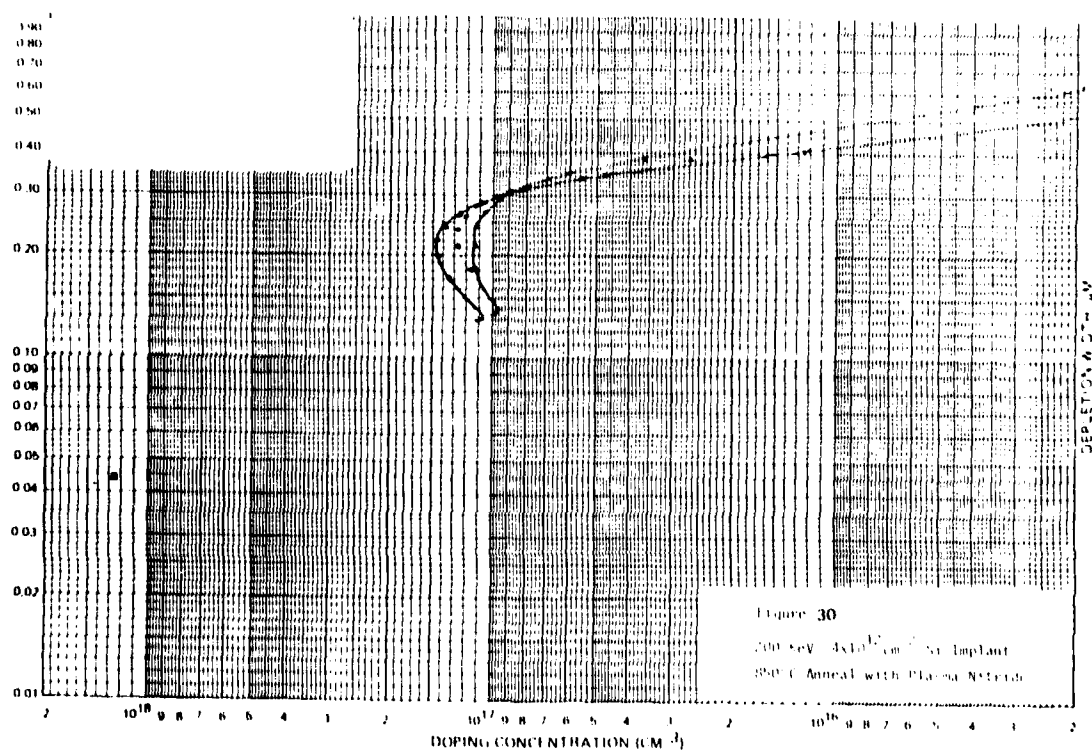
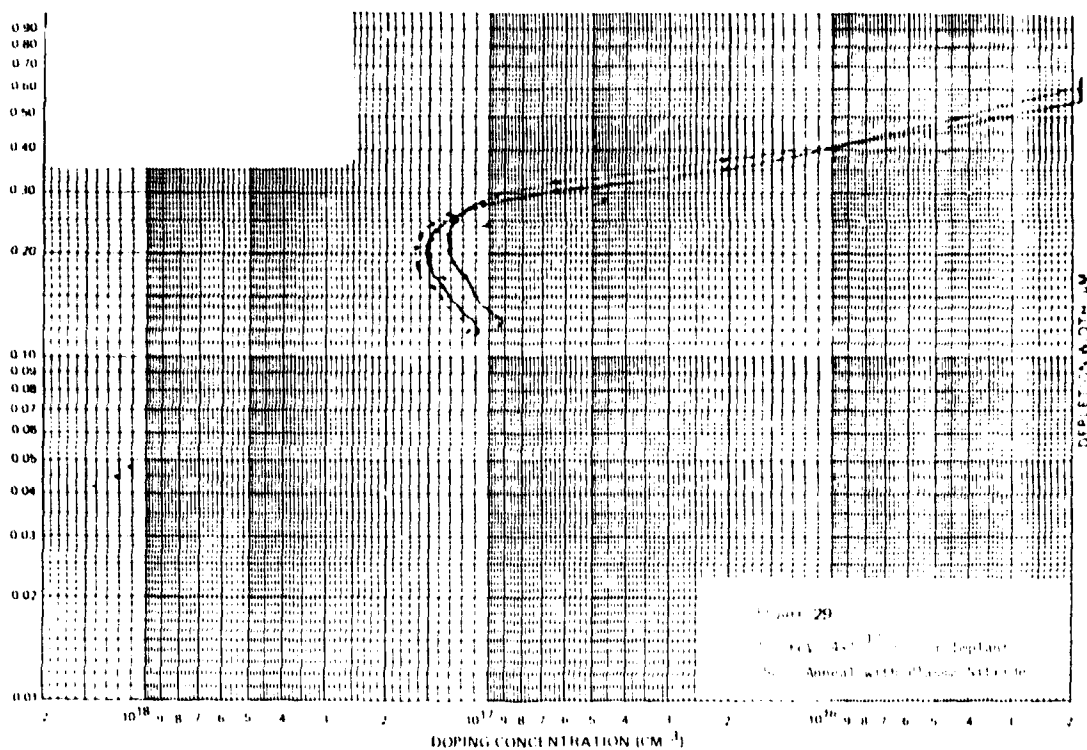


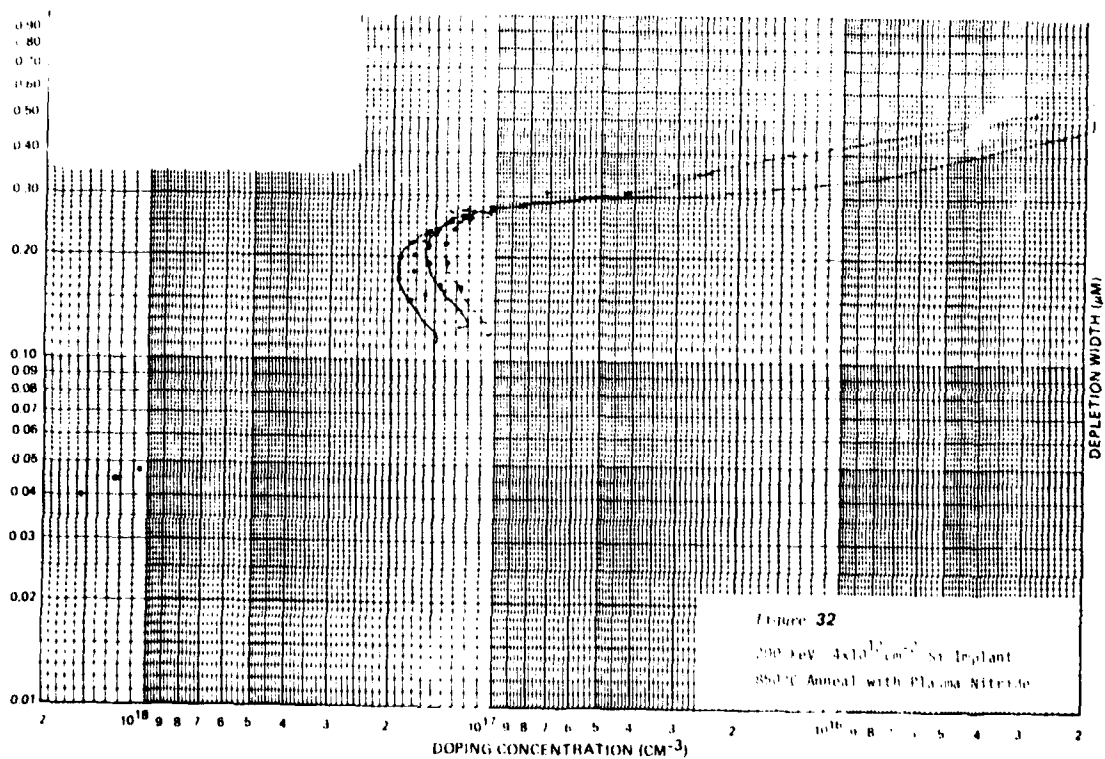
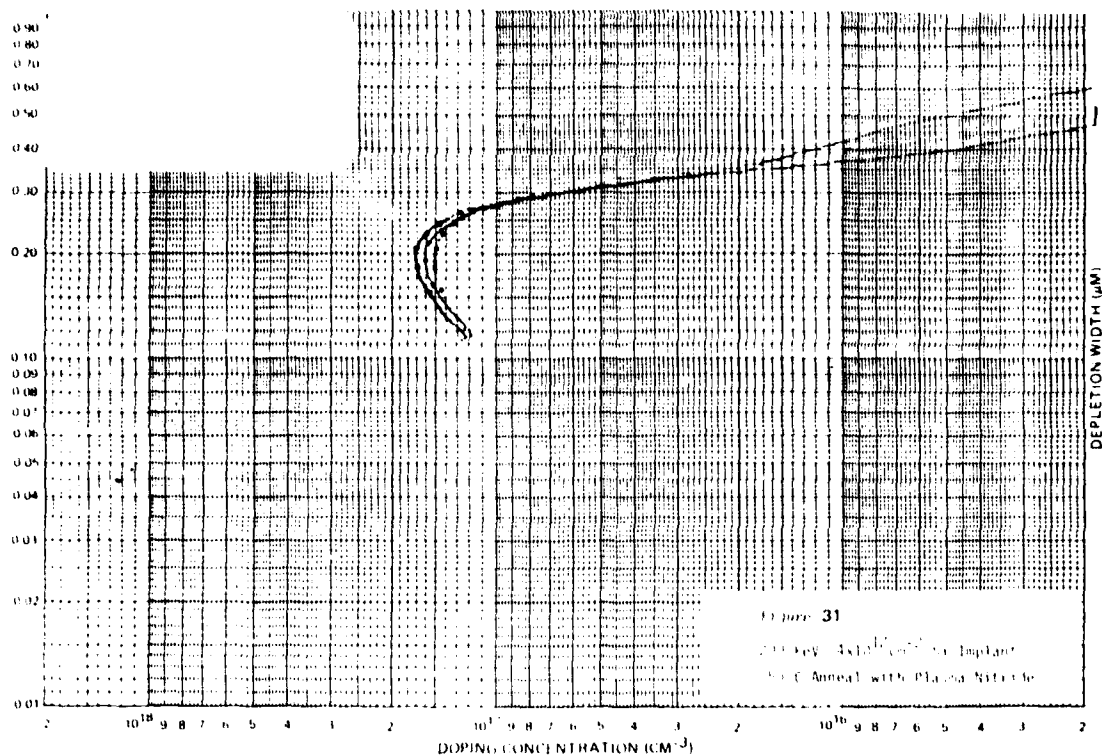


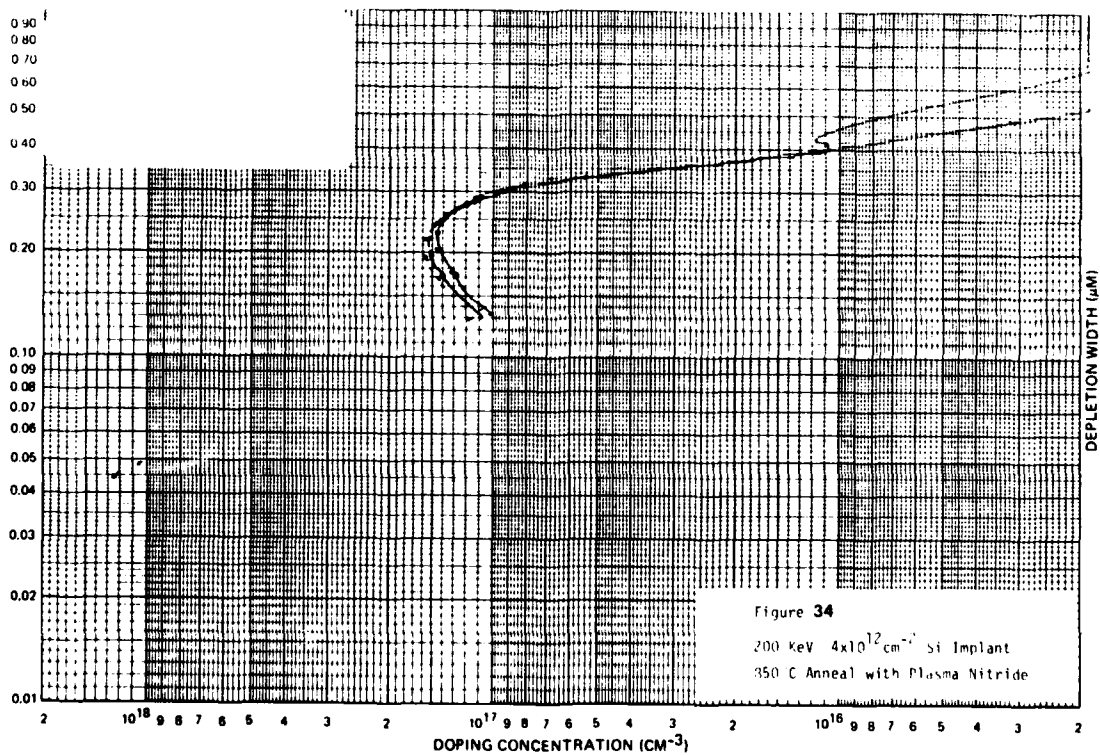
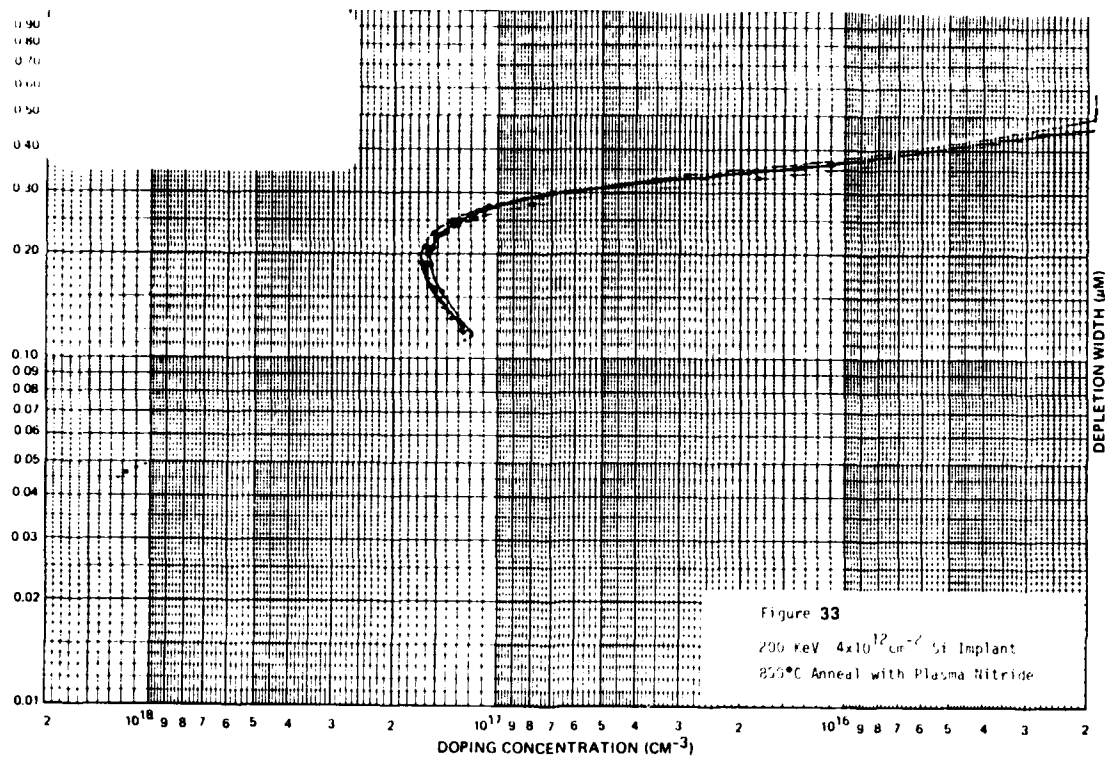


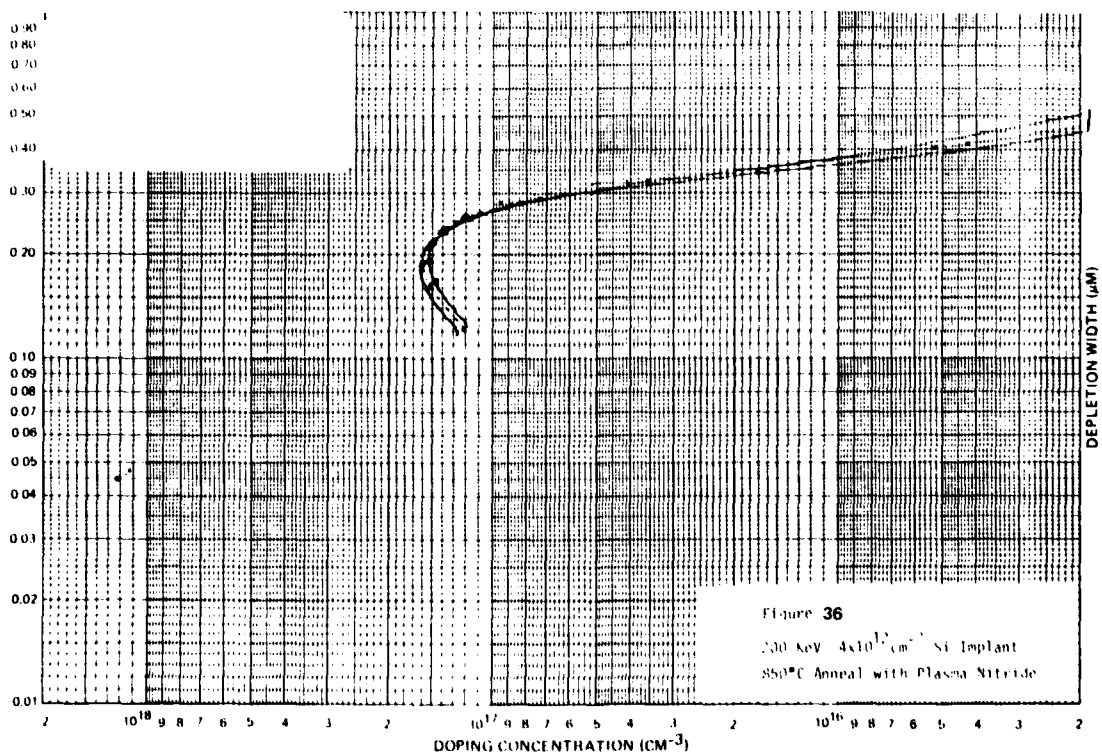
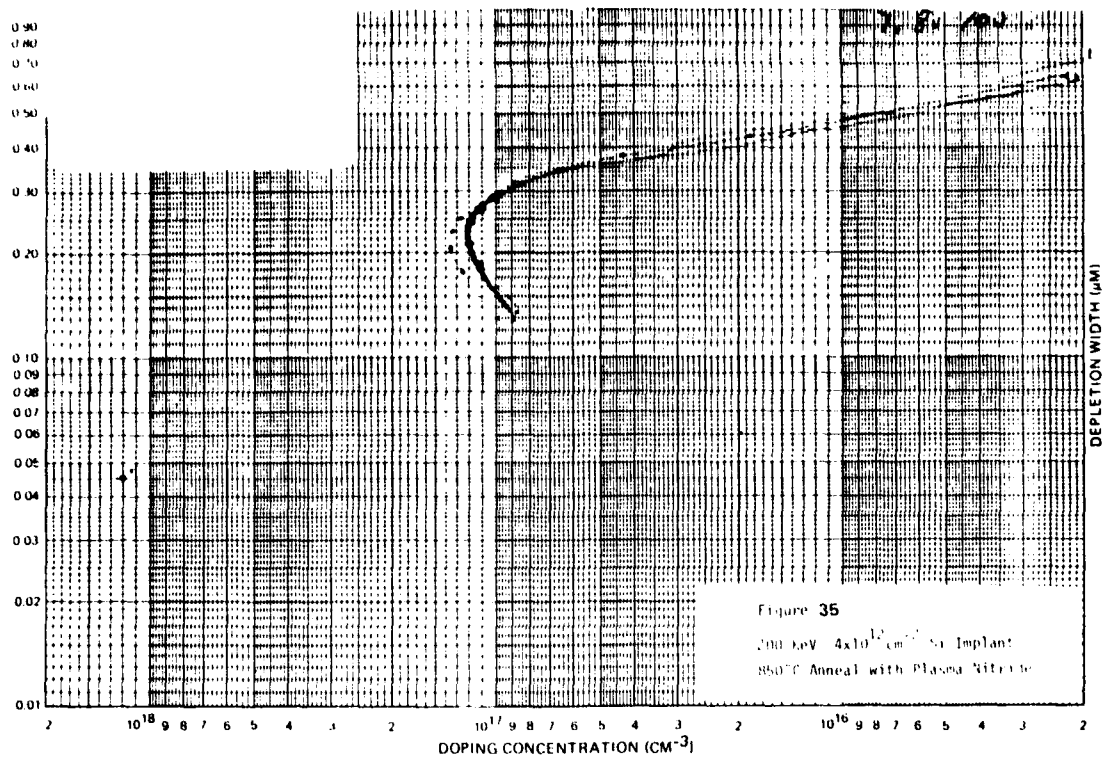












APPENDIX D
SUPPORTING ANALYSIS AND DATA FOR THE
ANALOG MULTIPLIER DESIGNS

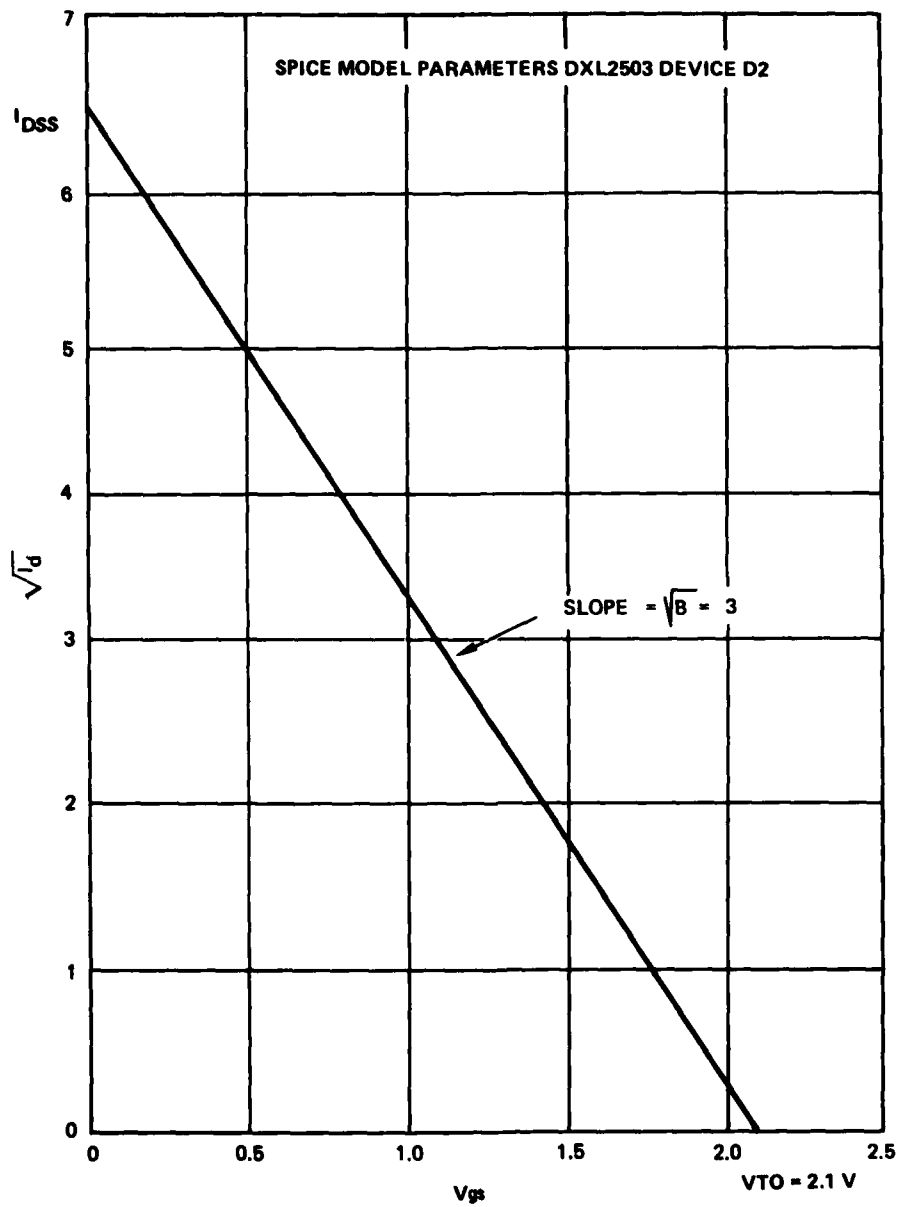


Figure 1. Spice Parameters for Device D2

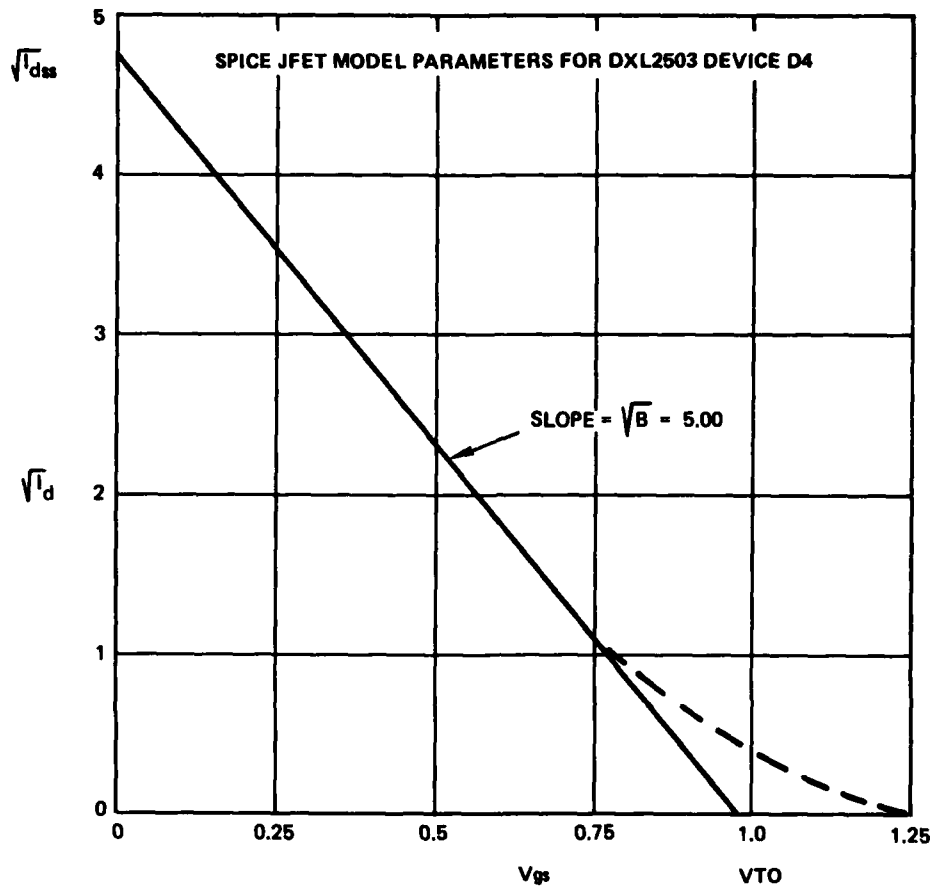


Figure 2. Spice Parameters for Device D4

The purpose of the appendix is to show that the drain to source voltage of transistor Q_5 (and Q_6) is $1/3$ the differential voltage $\frac{A}{2} - \frac{\bar{A}}{2}$.

Figure 3 is a redrawing of the basic differential amplifier stage shown in Figure 5-15. Figure 4 is the equivalent differential mode half circuit about the x-x' axis of symmetry.

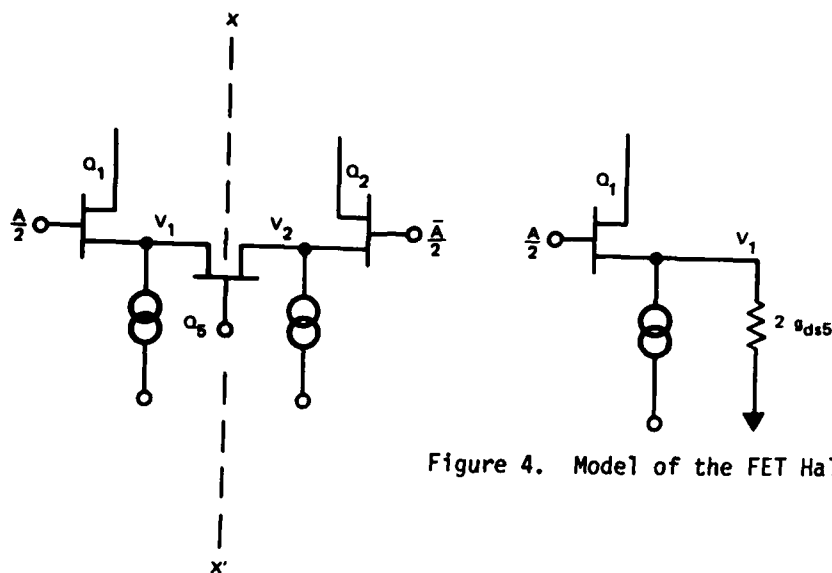


Figure 3. FET Differential Pair

Figure 4. Model of the FET Half-Pair

Solving for V_{ds5}

$$V_{ds5} = V_1 - V_2 \quad (1)$$

$$V_1 = \left[\frac{g_{m1}}{g_{m1} + 2g_{ds5}} \right] A/2 \quad (2)$$

$$V_2 = \left[\frac{g_{m2}}{g_{m2} + 2g_{ds5}} \right] A/2 \quad (3)$$

If it can be shown that

$$g_{m1} = g_{m2} = \text{average value of } g_{ds5} \quad (4)$$

then substituting (4) into (2) and (3)

$$V_1 = 1/3 A/2 \quad (5)$$

$$V_2 = 1/3 \bar{A}/2 \quad (6)$$

$$V_{ds5} = V_1 - V_2 = 1/3 \frac{A}{2} - 1/3 \frac{\bar{A}}{2} = 1/3 A \quad (7)$$

It is only left to show that (4) is correct under certain conditions. These conditions are that Q_1 , Q_2 , and Q_5 must have identical geometries and doping levels, and that Q_5 be driven by a perfectly symmetrical sinewave.

Using the data taken from DXL2503 device, the following table shows that for a given gate voltage, g_m and g_{ds} are approximately equal.

V_g	g_m	g_{ds}
0	35	40
0.5	30	34
1.0	15	17
1.5	2.6	6

If all gates are dc grounded and the current sources are adjusted such that the source of Q_1 and Q_2 is at 1 volt, then notice that the source of Q_5 is at 1 volt. Therefore, $V_{GS1} = V_{GS2} = V_{GS5}$ and $g_{m1} = g_{m2} \approx g_{ds5}$. When signals are applied, V_{gs1} and V_{gs2} change very little because the RF voltage is small; therefore, g_{m1} and g_{m2} remain constant. g_{ds5} varies sinusoidally at the LO rate from its dc value of 15 mmho up to its maximum value of ≈ 30 mmho down to a minimum of 0 mmho. It can clearly be seen that g_{ds5} average = 15 mmho, the dc value of g_{ds5} . Hence, $g_{m1} = g_{m2} =$ average value of g_{ds5} .

TRW SPICE (01/15/70) 03/29/79. 14.55.02.

VARIABLE TRANSCONDUCTANCE MULTIPLIER

INPUT LISTING TEMPERATURE = 27.000 DEG C

```
V00 11 0 DC 9.0
VG1 1 0 DC 3
VG2 0 10 DC .50
VLD 9 8 SIN(0 .50 50HZ)
VRF 2 3 SIN(0 .01 100HZ)
R1 2 1 51
R2 3 1 51
R3 9 10 51
R4 8 10 51
RD1 11 4 250
RD2 11 6 250
J1 4 2 5 JDX2503
J2 6 3 5 JDX2503
J3 4 3 7 JDX2503
J4 6 2 7 JDX2503
J5 5 9 0 JDXL2502
J6 7 8 0 JDXL2503
.MODEL JDX2503 NJF(VTN=-1 BETA=11M CGS=.015P CGD=.04P RD=3.4 RS=2)
.MODEL JDXL2503 NJF(VTN=-1 BETA=22M CGS=.02P CGD=.06P RD=3.4 RS=2)
.FOUR 20HZ V(4,4)
.TRAN .025NS 1.025NS
.PLOT TPAN V(4,4)
.END
```

TRW SPICE (01/15/79)

03/29/79. 14.55.03.

VARIABLE TRANSCONDUCTANCE MULTIPLIER

JFET MODEL PARAMETERS TEMPERATURE = 27.000 DEG C

TYPE	JNY2503	JNXL2503
	NJF	NJF
VTO	-1.000	-1.000
BETA	1.10E-02	2.20E-02
RD	3.400	3.400
RS	2.000	2.000
C6S	1.50E-14	2.00E-14
C6D	4.00E-14	6.00E-14

TRW SPICE (01/15/79)

03/29/79. 14.55.22.

VARIABLE TRANSCONDUCTANCE MULTIPLIER

INITIAL TRANSIENT SOLUTION TEMPERATURE = 27.000 DEG C

NODE	VOLTAGE	NODE	VOLTAGE	NODE	VOLTAGE	NODE	VOLTAGE
(1)	3.0000 (2)	3.0000 (3)	3.0000 (4)	7.6824			
(5)	3.5053 (6)	7.6824 (7)	3.5053 (8)	-0.5000			
(9)	-0.5000 (10)	-0.5000 (11)	9.0000				

VOLTAGE SOURCE CURRENTS
NAME CURRENT

VDD -1.054E-02

VG1 8.018E-12

VG2 -3.479E-12

VLO 1.110E-16

VRF 6.661E-16

TOTAL POWER DISSIPATION 9.49E-02 WATTS

```

TRW SPICE (01/15/79)      03/29/79. 14.55.22.
VARIABLE TRANSCONDUCTANCE MULTIPLIER
OPERATING POINT INFORMATION      TEMPERATURE = 27.000 DEG C
*****

```

```

**** JFETS
MODEL      J1      J2      J3      J4      J5      J6
ID         JDX2503 JDX2503 JDX2503 JDX2503 JDX2503 JDX2503
VGS        2.64E-03 2.64E-03 2.64E-03 2.64E-03 5.27E-03 5.27E-03
VDS        -.505   -.505   -.505   -.505   -.505   -.505
           4.177   4.177   4.177   4.177   3.505   3.505

```

TRW SPICE (01/15/79)

03/29/79. 14.56.17.

VARIABLE TRANSCONDUCTANCE MULTIPLIER

TRANSIENT ANALYSIS

TEMPERATURE = 27.000 DEG C

TIME V(4,5)

	-2.000E-02	-1.000E-02	0.000	1.000E-02	2.000E-02
0.000	5.694E-14	.	+	.	.
2.500E-11	-1.073E-02	.	+	.	.
5.000E-11	-9.465E-03	.	+	.	.
7.500E-11	1.193E-02	.	.	+	.
1.000E-10	2.130E-04	.	+	.	.
1.250E-10	1.810E-02	.	.	.	+
1.500E-10	9.850E-03	.	.	+	.
1.750E-10	-3.830E-04	.	+	.	.
2.000E-10	5.659E-03	.	.	.	.
2.250E-10	-1.863E-02	.	.	.	.
2.500E-10	-6.273E-03	.	+	.	.
2.750E-10	-1.104E-02	.	+	.	.
3.000E-10	-9.455E-03	.	+	.	.
3.250E-10	1.193E-02	.	.	+	.
3.500E-10	2.259E-04	.	+	.	.
3.750E-10	1.809E-02	.	.	.	+
4.000E-10	9.816E-03	.	.	+	.
4.250E-10	-3.769E-04	.	+	.	.
4.500E-10	5.680E-03	.	.	.	.
4.750E-10	-1.862E-02	.	.	.	.
5.000E-10	-6.241E-03	.	+	.	.
5.250E-10	-1.104E-02	.	+	.	.
5.500E-10	-9.481E-03	.	+	.	.
5.750E-10	1.193E-02	.	.	+	.
6.000E-10	2.130E-04	.	+	.	.
6.250E-10	1.810E-02	.	.	.	+

TRW SPICE (01/15/79)

03/29/79. 14.56.21.

VARIABLE TRANSCONDUCTANCE MULTIPLIER

FOURIER ANALYSIS

TEMPERATURE = 27.000 DEG C

FOURIER COMPONENTS OF TRANSIENT RESPONSE V(4,6)

HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	2.000E+00	5.764E-07	1.000000	-27.465	0.000
2	4.000E+00	1.227E-02	21294.137118	-93.638	-66.173
3	6.000E+00	8.930E-07	1.549187	125.099	152.564
4	8.000E+00	1.096E-04	190.127504	-56.226	-38.761
5	1.000E+01	2.331E-07	.404380	-130.984	-103.519
6	1.200E+01	4.579E-07	.794341	-138.554	-111.089
7	1.400E+01	5.836E-07	1.185952	114.520	141.985
8	1.600E+01	9.420E-03	16342.157404	39.714	67.179
9	1.800E+01	5.178E-07	.898224	73.242	100.707

TOTAL HARMONIC DISTORTION = ***** PERCENT

JOB CONCLUDED