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A User Oriented Computer Program for the Analysis of Microwave Mixers, and A Study of the Effects of the Series Inductance and Diode Capacitance on the Performance of Some Simple Mixers

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ABSTRACT

This report describes a user oriented computer program for analyzing microwave and millimeter-wave mixers. The program can be used for mixers with a single Schottky-barrier diode whose I-V and C-V characteristics are known. The diode mount is assumed lossless but may have external loads at any number of sideband and LO harmonic frequencies.

The program first performs a nonlinear analysis to determine the diode conductance and capacitance waveforms produced by the local oscillator. A small-signal linear analysis is then used to find the conversion loss, port impedances, and input noise temperature of the mixer. In the noise analysis thermal noise from the series resistance of the diode and shot noise from the periodically pumped current in the diode conductance are considered.

Examples are given, including a study of the effects of the series inductance and diode capacitance on the performance of some simple mixer circuits using (i) a conventional Schottky diode, (ii) a Schottky diode in which there is no capacitance variation, and (iii) a Mott diode. It is shown that the parametric effects of the voltage dependent capacitance of a conventional Schottky diode may be either detrimental or beneficial depending on the diode and circuit parameters.

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1. Introduction

As a result of recent work on the theory of microwave and millimeter-wave mixers [1,2], it is now possible to predict their performance with reasonable accuracy. The purpose of this report is to make available a user oriented computer program for determining the performance of single-diode mixers. The relevant mixer theory is reviewed and the implementation of the Fortran code described. To illustrate the operation of the program a study of the performance of three simple mixers is presented. These are: an ideal Schottky-diode mixer in which the junction capacitance has the usual voltage dependence, a Schottky-diode mixer in which the junction capacitance is assumed independent of voltage, and a Mott-diode mixer for which the junction capacitance is an experimentally determined function of applied voltage.

The mixer analysis is carried out in three parts. First, the diode conductance and capacitance waveforms produced by the local oscillator are determined using a nonlinear circuit analysis. Next, a linear small-signal analysis is used to find the input and output impedances and the conversion loss between the mixer ports. Finally, the shot and thermal noise contributions from the diode are determined.

The most difficult step in analyzing a mixer is finding the diode waveforms produced by the local oscillator. In earlier work by Torrey and Whitmer [3] and others, a sinusoidal driving voltage across the diode junction was assumed, with the implication that the harmonics of the local oscillator were short circuited. Fleri and Cohen [4] used a numerical integration algorithm to obtain the voltage waveforms for a diode with nonlinear conductance and capacitance in a simple lumped element embedding network. However this method can not be used if the embedding circuit contains distributed elements, which is usually the case for microwave mixers. Egami [5], using a harmonic balance technique, was able to consider arbitrary embedding impedances, but convergence was difficult to achieve when more than three local oscillator harmonics were considered. In another approach, developed by Gwarek [6], the embedding network is represented as a simple lumped element circuit in series with a string of voltage sources one at each harmonic of the local oscillator. The amplitudes and phases of these generators are adjusted to keep the apparent terminal impedance of the circuit equal to that of the actual embedding network. Although the scheme works well for many mixers, it is strongly dependent on the guessed values of the lumped circuit elements and does not converge for all embedding impedances. A final technique,based on an earlier one developed in our laboratory [7], solves the nonlinear problem as a series of reflections between the diode and embedding network. The algorithm operates in the time domain when considering the diode and in the frequency domain when dealing with the embedding network. Although this multiple reflection technique often requires more time than Gwarek's method, solutions have been obtained for all the mixer circuits we have tried and no initial guesses are required. As a result this method is used in the large-signal section of the mixer analysis program described in this report.

The small-signal analysis follows that of Held and Kerr [1] which is an extension of the original theory of frequency conversion put forward by Torrey and Whitmer [3]. The small-signal properties of the mixer are derived from a knowledge of the large-signal waveforms at the diode terminals and the impedance of the embedding network.

In analyzing the noise properties of a mixer it is important to take into account the partial correlation of the periodically varying shot noise at the various sideband frequencies. Following earlier work by Strutt [8], van der Ziel [9], Kim [10], Dragone [11], and Uhlir* [12], the theory of noise in Schottky diode mixers was investigated by Held and Kerr [1] and put into a form suitable for computer analysis. This noise theory is used in the computer program presented in this report.

The mixer analysis program allows arbitrary embedding impedances at the harmonics of the local oscillator and the sideband frequencies, and any Schottky diode can be used. The diode series resistance includes a frequency dependent component due to skin effect. The program cannot handle diodes with voltage dependent series resistance or in which charge storage effects are significant, i. e. it is assumed that the carrier recombination time is small compared with the period of the local oscillator. In all cases the diode mount is assumed lossless and reciprocal. The run time for the program as listed in Appendix I is 32 seconds on an IBM 360/95 computer.

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[*] The authors thank Dr. Uhlir for bringing his excellent paper to their attention.

2. Outline of the Necessary Theory

The parameters most often used to characterize the small signal performance of a mixer are: the conversion loss between the signal and intermediate frequencies, the input and output impedances, and the equivalent input noise temperature. These quantities can all be determined if the Fourier coefficients of the diode conductance and capacitance waveforms and the embedding impedance at each sideband frequency are known. The first step in the analysis is therefore to determine the conductance and capacitance waveforms produced at the diode by the local oscillator.

2.1 Solution of the Large-Signal Problem

The equivalent circuit of the mixer is shown in Fig. 1. Expressions for the

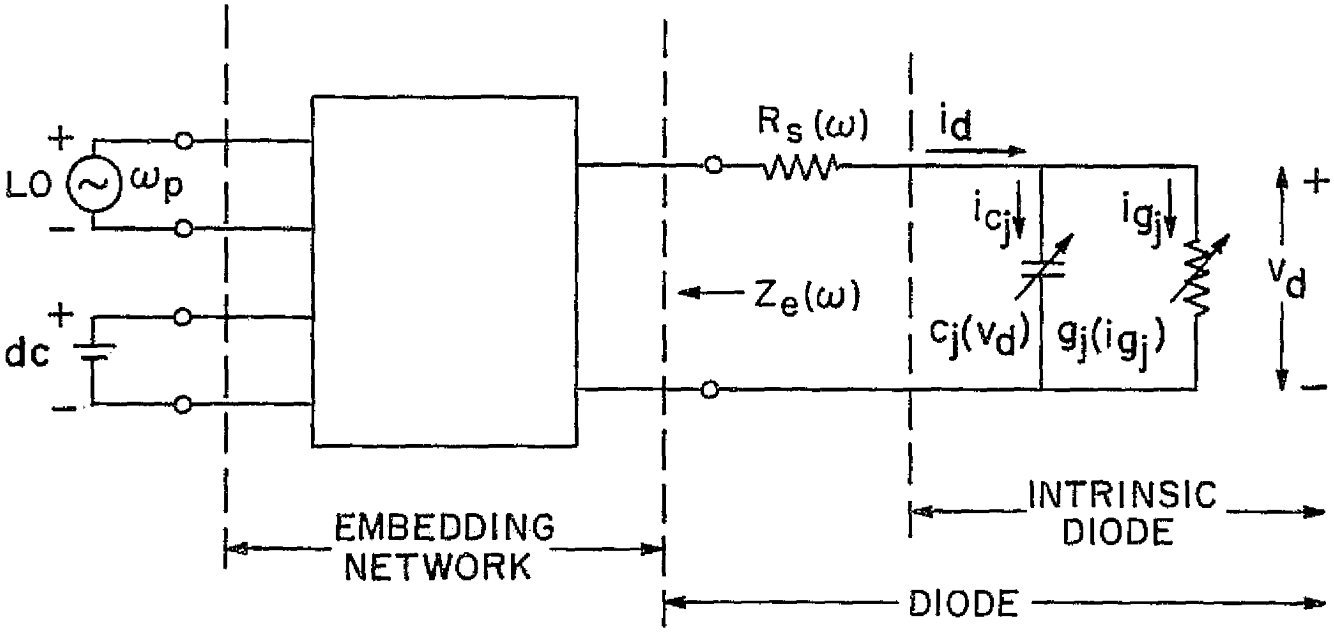

Fig. 1: The equivalent circuit of the mixer.

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diode conductance current and capacitance current are well known:

$$i_{g_j} = i_s [\exp(\alpha v_d) - 1] \quad , \tag{1}$$

$$i_{c_j} = c_j \frac{dv_d}{dt} \quad , \tag{2}$$

where

$$\alpha = q/\eta kT \quad , \tag{3}$$

and

$$c_j = c_0(1 - v_d/\phi)^{-\gamma} \tag{4}$$

The differential conductance is obtained from (1):

$$g_j = \frac{di_d}{dt} = \alpha i_s \exp(\alpha v_d) = \alpha(i_{g_j} + i_s) \cong \alpha i_{g_j} \quad . \tag{5}$$

The voltage and current at the diode can be written in terms of their Fourier coefficients as follows:

$$v_d(t) = \sum_{n=-\infty}^{+\infty} V_{d_n} \exp(jn\omega_p t) \ , \ V_{d_{-n}} = V^*_{d_n} \quad , \tag{6}$$

$$i_d(t) = i_{g_j}(t) + i_{c_j}(t) = \sum_{n=-\infty}^{+\infty} I_{d_n} \exp(jn\omega_p t) \ , \ I_{d_{-n}} = I_{d_n}^* \tag{7}$$

where ω_p is the local oscillator frequency.

The conditions imposed on the steady state response of the mixer circuit by the embedding network can more conveniently be expressed in the frequency domain. Referring to Fig. 1:

$$\frac{V_{d_n}}{I_{d_n}} = -\left[Z_e(n\omega_p) + R_s(n\omega_p) \right] \ , \quad n = 2, 3, \ldots \infty \tag{8a}$$

$$\frac{V_{d_1} - V_1}{I_{d_1}} = -\left[Z_e(\omega_p) + R_s(\omega_p) \right] \ , \tag{8b}$$

$$\frac{V_{d_0} - V_0}{I_{d_0}} = -\left[Z_e(0) + R_s(0) \right] \ , \tag{8c}$$

where V_1 and V_0 are the Thevenin equivalent LO and dc voltages seen by the diode. The frequency dependence of R_s is due to the skin effect which we will assume to be represented by

$$R_s(f) = R_s(dc) + R_{skin}\sqrt{f} \quad , \qquad (9)$$

where R_{skin} (Ohms/$\sqrt{Hz}$) is a constant for a particular diode. The effects of diode heating on the series resistance* will not be included in this report.

If (6) and (7) can be solved for $v_d(t)$ and $i_d(t)$ then (1)-(5) can be used to find $i_{g_j}(t)$, $g_j(t)$ and $c_j(t)$ which along with $Z_e(\omega)$ determine the small signal behavior of the mixer. As mentioned in the introduction, a method of solution which works well for a broad range of embedding impedances is the multiple reflection technique [7] which is described below.

The circuit of Fig. 1 is modified by inserting a transmission line of arbitrary characteristic impedance Z_0 between the diode and the embedding network as shown in Fig. 2. By making the transmission line an integral number of wavelengths long at the LO frequency, and hence at the harmonics of the LO, the steady-state waveforms in the modified network will be the same as those in the original circuit. The desired voltages and currents can then be obtained by alternately solving the two circuits shown in Fig. 3 in an iterative procedure.

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[*] Decker and Weinreb (see ref. [1]) have shown that the dc series resistance of the diode determined from a dc log I-V plot includes a negative component due to heating of the diode by the test signal. When the resistance is determined at microwave frequencies this effect is no longer present and thus the deduced value of dc resistance will be larger than the apparent value obtained from the dc log I-V plot.

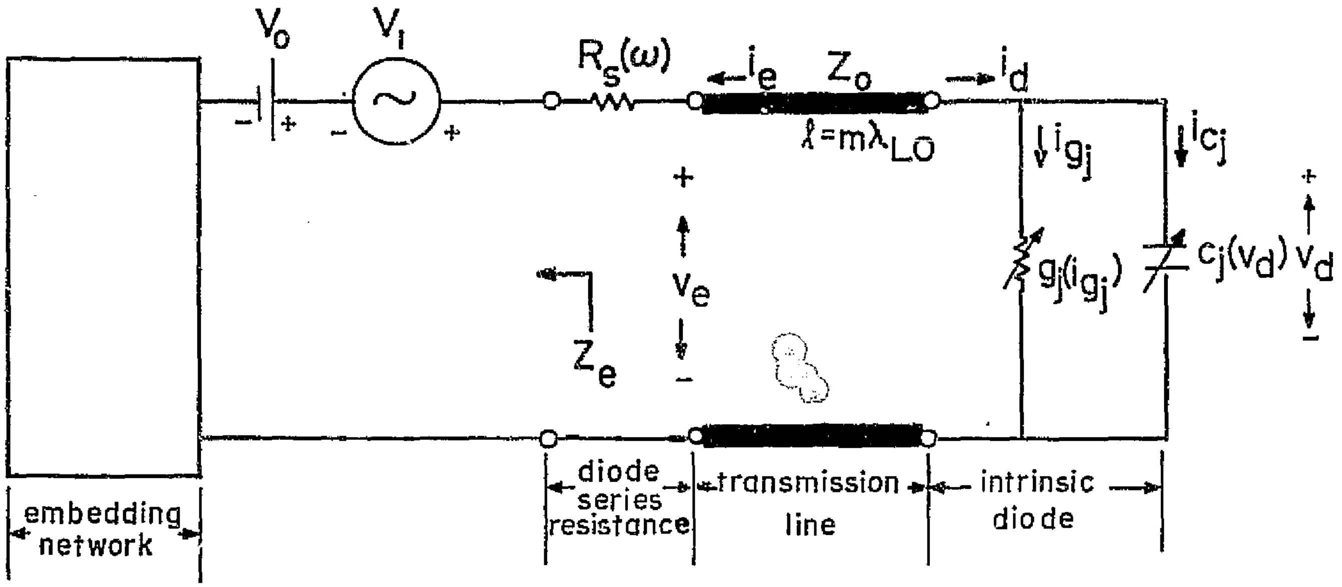

Fig. 2: The equivalent circuit of the mixer modified by the insertion of a long transmission line of length $m\lambda_{LO}$ ($m \to \infty$) and characteristic impedance Z_0. The steady state $v_d(t)$ and $i_d(t)$ of this circuit will be the same as in the circuit of Fig. 1. V_0 and V_1 are the Thevenin equivalent dc and LO source voltages.

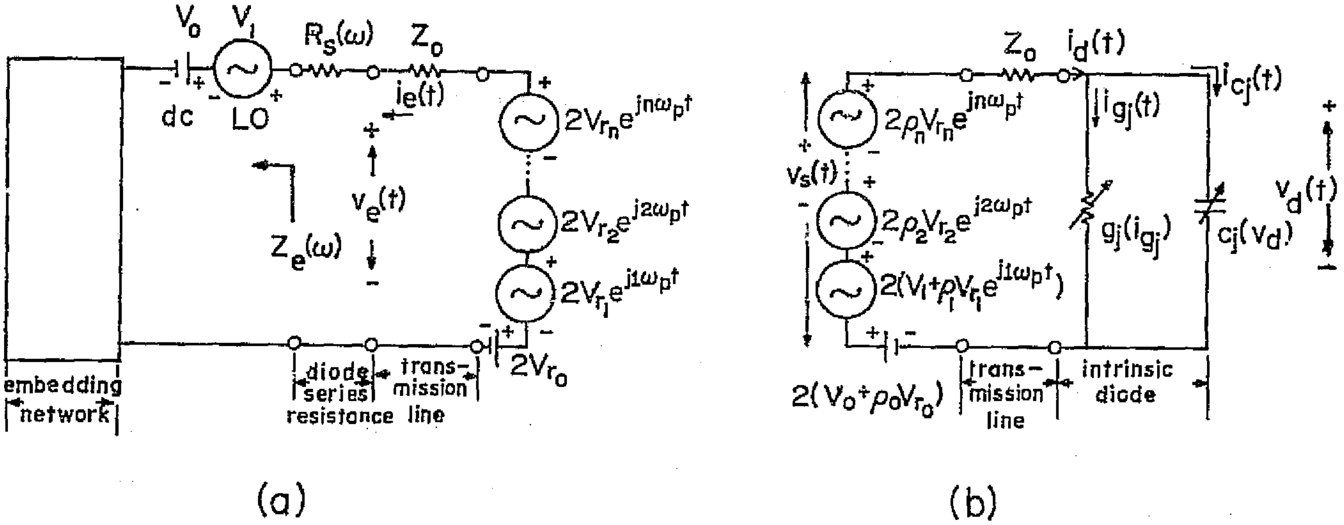

Fig. 3: The two circuits which must be solved iteratively to obtain the steady state solution to the network of Fig. 2. The linear network (a) is analyzed in the frequency domain while the nonlinear circuit (b) is solved in the time domain. V_0 and V_1 are the Thevenin equivalent dc and LO source voltages.

Initially a wave propagates along the transmission line towards the diode in Fig. 2. This wave contains voltage components only at the local oscillator frequency and dc. The initial dc wave incident on the diode is

$$V_{i_0} = V_0 Z_0/(Z_0 + Z_e(0) + R_s(0)) , \qquad (10)$$

and the initial incident wave at frequency ω_p is

$$V_{i_1} = V_1 Z_0/(Z_0 + Z_e(1) + R_s(1)) , \qquad (11)$$

where V_0 and V_1 are the Thevenin equivalent dc and LO source voltages seen by the diode and $Z_e(n)$ represents the embedding network impedance at harmonic n (frequency $n\omega_p$) of the local oscillator.

After the steady state has been reached between the transmission line and the diode, the wave reflected from the diode contains components at all harmonics of the local oscillator. Denoting the incident and reflected voltages at frequency $n\omega_p$ by V_{i_n} and V_{r_n} we have at the diode:

$$V_{d_n} = V_{i_n} + V_{r_n} , \qquad (12)$$

$$I_{d_n} = (V_{i_n} - V_{r_n})/Z_0 . \qquad (13)$$

V_{d_n} and I_{d_n} are the Fourier coefficients of the diode voltage and current as given in (6) and (7). They can be determined by solving the state equation of the network in Fig. 3b in the time domain and then performing a Fourier analysis. Inspection of Fig. 3b yields the state equation:

$$\frac{dv_d(t)}{dt} = \left(\frac{v_s(t) - v_d(t)}{Z_0} - i_{g_j}(t) \right) / c_j(t) \; , \tag{14}$$

Note that $v_s(t) = V_0 + V_1$ on the first cycle.

Equation (14) can be solved for $v_d(t)$, and then $i_d(t)$, V_{d_n}, and I_{d_n} can be found using (6) and (7). Now (12) and (13) can be used to determine V_{r_n} :

$$V_{r_n} = V_{d_n} - V_{i_n} \tag{15}$$

or

$$V_{r_n} = (V_{d_n} - I_{d_n} Z_0) / 2 \; . \tag{16}$$

The wave represented by V_{r_n} travels back towards the embedding network where it is reflected and a new wave is launched towards the diode. The amplitude of this newly reflected wave is determined by the embedding network reflection coefficient at each LO harmonic:

$$\rho_n = \frac{Z_e(n) + R_s(n) - Z_0}{Z_e(n) + R_s(n) + Z_0} , \qquad (17)$$

and is

$$V'_{i_n} = \rho_n V_{r_n} . \qquad (18)$$

The wave now incident on the diode is the sum of the reflected wave given in (18) and that of the previous reflection cycle, i.e. $V_{i_n} \rightarrow V_{i_n} + \rho_n V_{r_n}$. At the diode a new state equation can be written and solved to obtain the voltage and current in the time domain. The Fourier coefficients can be calculated and the wave reflected from the diode found from (15) and (16). The new incident wave is again determined using (18) and the cycle is repeated until the voltages and currents at the two ends of the transmission line are equal, that is (referring to Fig. 2):

$$|V_{d_n}| = |V_{e_n}| \quad \text{for} \quad n > 1 \qquad (19)$$

and

$$|I_{d_n}| = |I_{e_n}| \quad \text{for} \quad n > 1 . \qquad (20)$$

At this point the solution has completely converged and

$$\frac{|V_{d_n}|}{|I_{d_n}|} = \frac{|V_{e_n}|}{|I_{e_n}|} = |Z_e(n) + R_s(n)|, \text{ for } n > 1 . \tag{21}$$

In practice perfect convergence will not be achieved in a finite time. However, a convergence parameter can be formed to indicate when the waveforms at the two ends of the transmission line are sufficiently close to one another to merit halting the iteration procedure:

$$\delta(n) = \{ |(V_{d_n} / I_{d_n})| / |Z_e(n) + R_s(n)| \} - 1 , \text{ for } n > 1 . \tag{22}$$

The solution is considered to have converged when $\delta(n) \le \epsilon$ for all $n > 1$, where ϵ is an arbitrarily set limit.

2.2 Small-Signal Analysis

2.2.1 Frequency and Subscript Notation

If a mixer is pumped at frequency ω_p and has an intermediate frequency ω_0, the only small-signals which can produce an IF response are at the sideband frequencies $(\omega_0 + n\omega_p,\ n = 0, \pm 1, \pm 2 \ldots)$. Following Saleh [13] it is useful to define the sideband frequencies by:

$$\omega_n = \omega_0 + n\omega_p \qquad n = 0, \pm 1, \pm 2, \pm 3, \ldots \tag{23}$$

For $n < 1$ the sideband frequencies are seen to be negative. A brief comment on the meaning of these negative frequency terms is given in the footnote.*

Saleh's frequency notation leads to a considerable simplification of the mixer theory. Using this notation all upper sideband frequencies $(\omega_0 + |n|\,\omega_p)$ are considered positive, while all lower sideband frequencies $(\omega_0 - |n|\,\omega_p)$ are negative. The sideband frequency index n is used as a subscript with the various electrical quantities and hence the upper sideband, intermediate, and lower sideband frequencies are: $\omega_{+1} = \omega_0 + \omega_p$, ω_0, and $\omega_{-1} = \omega_0 - \omega_p$; and V_{+1}, V_0 and V_{-1} represent voltages at these frequencies.

2.2.2 Small-Signal Conversion Matrix

Using the sideband notation described in the previous section let $\widetilde{\delta I}$ and $\widetilde{\delta V}$ denote the vectors of the small-signal sideband currents (δI_n) and voltages (δV_n) at the terminals of the intrinsic diode (the diode excluding its series resistance). Then

$$\widetilde{\delta I} = [\ldots, \delta I_1, \delta I_0, \delta I_{-1}, \ldots]^t$$

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* Electrical quantities are frequently described by a single complex quantity associated with some frequency, assumed positive. For example, a voltage of frequency ω may be described simply by its complex half-amplitude V, implying an instantaneous voltage $v(t) = V e^{j\omega t} + V^* e^{-j\omega t}$. It is just as meaningful to work with a negative frequency $(-\omega)$ and the conjugate of the complex half-amplitude (V^*), provided the convention is clearly understood. Impedances and admittances are then simply the conjugates of their conventional positive frequency values, i.e. $Z(-\omega) = V^*/I^* = Z^*(\omega)$.

and

$$\widetilde{\delta V} = [\ldots, \delta V_1, \delta V_0, \delta V_{-1}, \ldots]^t \qquad (25)$$

Torrey and Whitmer [3] have shown that $\widetilde{\delta I}$ and $\widetilde{\delta V}$ are related via a conversion admittance matrix $\widetilde{Y}$ defined by

$$\widetilde{\delta I} = \widetilde{Y}\ \widetilde{\delta V} \quad . \qquad (26)$$

If the row and column numbering of the square matrix $\widetilde{Y}$ correspond with the sideband numbering, $\widetilde{Y}$ can be written out as

$$\widetilde{Y} = \begin{bmatrix} & \vdots & \vdots & \vdots & \\ \cdots & Y_{11} & Y_{10} & Y_{1-1} & \cdots \\ \cdots & Y_{01} & Y_{00} & Y_{0-1} & \cdots \\ \cdots & Y_{-11} & Y_{-10} & Y_{-1-1} & \cdots \\ & \vdots & \vdots & \vdots & \end{bmatrix} , \qquad (27)$$

with element values given by [3] :

$$Y_{mn} = G_{m-n} + j(\omega_0 + m\,\omega_p)\ C_{m-n} \quad . \qquad (28)$$

G_{m-n} and C_{m-n} are the (m-n) th Fourier coefficients of the diode conductance and capacitance waveforms, $g_j(t)$ and $c_j(t)$, and are defined by:

$$g_j(t) = \sum_{n=-\infty}^{\infty} G_n \exp[jn\omega_p t] , \quad G_{-n} = G_n^* , \tag{29}$$

$$c_j(t) = \sum_{n=-\infty}^{\infty} C_n \exp[jn\omega_p t] , \quad C_{-n} = C_n^* . \tag{30}$$

G_{m-n} and C_{m-n} are given by:

$$G_{m-n} = \frac{1}{T} \int_{-\frac{T}{2}}^{T/2} g_j(t) \exp[-j(m-n)\omega_p t]\, dt , \tag{31}$$

$$C_{m-n} = \frac{1}{T} \int_{-\frac{T}{2}}^{T/2} c_j(t) \exp[-j(m-n)\omega_p t]\, dt , \tag{32}$$

where the integration is taken over one period T of the local oscillator.

The matrix $\tilde{Y}$ can be regarded as the admittance matrix of a multifrequency multiport network, as shown in Fig. 4, in which there is one port for every sideband frequency ω_n. If the embedding impedances Z_{e_n} and diode series resistance R_{s_n} corresponding to the sideband frequencies ω_n are now connected in parallel with the intrinsic diode an augmented network is formed as shown by the broken line in Fig. 4.

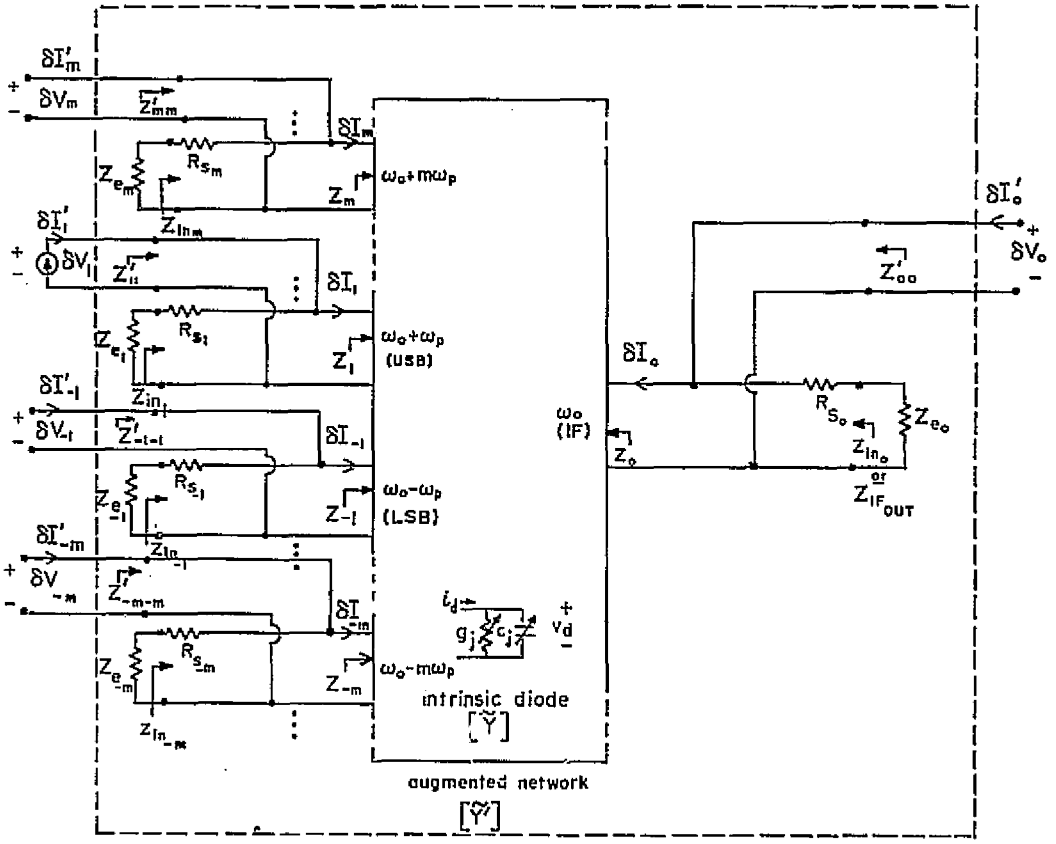

Fig. 4: The small signal representation of the mixer as a multifrequency linear multiport network. The voltage and current δV_m and δI_m are the small-signal components at frequency $(\omega_0 + m\,\omega_p)$ at the intrinsic diode. Each port represents one sideband frequency. The conversion matrix $\tilde{Y}$ is the admittance matrix of the intrinsic diode. The augmented network includes all the sideband embedding impedances Z_{e_m} and is characterized by the augmented admittance matrix $\tilde{Y}'$. $\delta I_1'$ is the equivalent signal current generator which is connected at port 1 during normal mixer operation, the other ports being open circuited. During the noise analysis equivalent shot and thermal noise current sources $\delta I'_{S_m}$ and $\delta I'_{T_m}$ are connected to all ports.

The ports of the augmented network correspond to the terminals of the intrinsic diode at the various sideband frequencies and do not represent physically accessible ports in the real mixer. The augmented network can be described by the admittance matrix $\tilde{Y}'$, defined by

$$\widetilde{\delta I'} = \tilde{Y}' \, \widetilde{\delta V} \tag{33}$$

where

$$\widetilde{\delta I'} = [\ldots, \delta I'_1, \delta I'_0, \delta I'_{-1}, \ldots]^t$$

and

$$\widetilde{\delta V} = [\ldots, \delta V_1, \delta V_0, \delta V_{-1}, \ldots]^t \quad , \tag{34}$$

δV_m and $\delta I'_m$ are the small signal voltage and current, at sideband $\omega_m = \omega_0 + m\,\omega_p$ (port m), of the augmented network. The elements of the augmented admittance matrix $\tilde{Y}'$ are given by

$$Y'_{mn} = Y_{mn} \qquad m \neq n \tag{35a}$$

and

$$Y'_{mm} = Y_{mm} + [Z_{e_m} + R_{s_m}]^{-1} \quad , \; m = n \quad . \tag{35b}$$

Inverting (33) gives

$$\widetilde{\delta V} = \widetilde{Z'}\ \widetilde{\delta I'}\ , \tag{36}$$

where

$$\widetilde{Z'} = (\widetilde{Y'})^{-1}\ . \tag{37}$$

The impedance matrix $\widetilde{Z'}$ enables us to calculate the conversion loss and the input and output impedances of the mixer and is also needed in computing the noise temperature.

2.2.3 Mixer Port Impedances

The impedance Z_m of any port of the intrinsic diode (see Fig. 4) can be found by open circuiting the corresponding embedding impedance Z_{e_m} and then forming the $\widetilde{Z'}$ matrix defined by (36). The desired port impedance is given by the mm-th element of the newly formed $\widetilde{Z'}$ matrix:

$$Z_m = Z'_{mm,\,\infty}\ , \tag{38}$$

where the subscript ∞ indicates that $\widetilde{Z'}$ has been formed with Z_{e_m} open circuited. The corresponding mixer input impedance seen by the embedding circuit includes the diode series resistance and is

$$Z_{in_m} = Z_m + R_{s_m} = Z'_{mm,\,\infty} + R_{s_m}\ . \tag{39}$$

In particular the IF output impedance is given by

$$Z_{IF_{out}} = Z_{in_0} = Z_0 + R_{s_0} = Z'_{00,\infty} + R_{s_0} \quad . \tag{40}$$

Throughout the remainder of this report it will be assumed that the IF load impedance Z_{e_0} is conjugate-matched to the IF output impedance of the mixer, thereby minimizing the conversion loss. Once the mixer performance with matched IF is known it is a simple matter to calculate the performance with any other IF termination. The value of the conjugate-matched IF load impedance is, using (40),

$$Z_{e_0} = Z^*_{IF_{out}} = (Z'_{00,\infty} + R_{s_0})^* = Z'^*_{00,\infty} + R_{s_0} \quad , \tag{41}$$

where $Z'_{00,\infty}$ is the center element of the $\widetilde{Z}'$ matrix with $Z_{e_0} = \infty$. Rather than reforming the $\widetilde{Z}'$ matrix each time an input impedance is calculated, the intrinsic diode port impedance Z_m can be found from (referring to Fig. 4):

$$Z'_{mm} = (Z_{e_m} + R_{s_m}) \,\|\, Z_m \quad , \tag{42}$$

where Z'_{mm} is the mm-th element of the mixer impedance matrix formed with the IF load impedance conjugate-matched to the IF output impedance. The corresponding mixer input impedance is then

$$Z_{in_m} = R_{s_m} + \frac{(Z_{e_m} + R_{s_m})\, Z'_{mm}}{(Z_{e_m} + R_{s_m}) - Z'_{mm}} \quad . \tag{43}$$

2.2.4 Conversion Loss

The conversion loss from sideband j to sideband i in a mixer is

$$L_{ij} \triangleq \left(\frac{\text{power available from the signal source at sideband } \omega_j}{\text{converted power from the signal source, delivered to the load at sideband } \omega_i} \right) \quad .$$

Consider for the moment only the intrinsic diode shown in Fig. 4. The power available from impedance $(Z_{e_j} + R_{s_j})$ at the j-th sideband is

$$P_{\text{available}} = \tfrac{1}{4} \left| \delta I'_j \right|^2 \operatorname{Re}[Z_{e_j} + R_{s_j}] \quad . \tag{44}$$

The power delivered to a load impedance $(Z_{e_i} + R_{s_i})$ at sideband i is, using (36)

$$P_{\text{delivered}} = \operatorname{Re}[\delta V_i \; \delta I'^{*}_i] = \frac{\left| Z'_{ij} \right|^2 \left| \delta I'_j \right|^2 \operatorname{Re}[Z_{e_i} + R_{s_i}]}{\left| Z_{e_i} + R_{s_i} \right|^2} \quad . \tag{45}$$

Dividing (44) by (45) gives the conversion loss L'_{ij} of the intrinsic diode:

$$\frac{P_{\text{available}}}{P_{\text{delivered}}} = L'_{ij} = \frac{|Z_{e_i} + R_{s_i}|^2 \; |Z_{e_j} + R_{s_j}|^2}{4\,|Z'_{ij}|^2 \;\mathrm{Re}[Z_{e_j} + R_{s_j}]\;\mathrm{Re}[Z_{e_i} + R_{s_i}]} \,. \tag{46}$$

To find the conversion loss of the actual mixer, the additional loss in the series resistance at the input and output frequencies must be included. This is accounted for by two terms:

$$K_j \overset{\Delta}{=} \frac{\text{Power Available from } Z_{e_j}}{\text{Power available from } Z_{e_j} + R_{s_j}} = \mathrm{Re}[Z_{e_j} + R_{s_j}] / \mathrm{Re}[Z_{e_j}] \tag{47}$$

$$K_i \overset{\Delta}{=} \frac{\text{Power delivered to } Z_{e_i} + R_{s_i}}{\text{Power delivered to } Z_{e_i}} = \mathrm{Re}[Z_{e_i} + R_{s_i}] / \mathrm{Re}[Z_{e_i}] \,. \tag{48}$$

Multiplying K_i and K_j by L'_{ij} gives the expression for the loss of the mixer in converting from sideband j to sideband i:

$$L_{ij} = K_i\, K_j\, L'_{ij} = \frac{|Z_{e_i} + R_{s_i}|^2 \; |Z_{e_j} + R_{s_j}|^2}{4\,|Z'_{ij}|^2 \;\mathrm{Re}[Z_{e_i}]\;\mathrm{Re}[Z_{e_j}]} \,, \tag{49}$$

where Z'_{ij} is the ij$^{\text{th}}$ element of the impedance matrix $\widetilde{Z}'$ of the augmented network as defined in (36).

2.3 Mixer Noise Theory

The noise observed in a Schottky diode comes mainly from three sources, (i) shot noise due to the statistical nature of the current flow across the depletion layer, (ii) thermal noise due to the random motion of the charge carriers in the undepleted semiconductor material and (iii) noise due to lattice scattering, which occurs in regions of high current density. At room temperature the noise contribution due to lattice scattering is usually small enough to be approximated by a slight increase in the temperature of the diode series resistance to T_{eq} [1, 2]. In cryogenic mixers however, scattering noise may account for a more substantial part of the overall noise and a more complex analysis than is performed here is required to take account of its partially correlated components.

The equivalent circuit of the Schottky diode, including noise sources, is shown in Fig. 5(a). T_{eq} is the equivalent temperature of the series resistance and includes the effects of lattice scattering and pump heating. k is Boltzmann's constant and q the electronic charge. In Fig. 5(b) the thermal and shot noise are both represented as equivalent current sources in parallel with the intrinsic diode. $\overline{\delta i_T^2}$ and $\overline{\delta i_S^2}$ are the mean-square values of the thermal and shot noise currents in the frequency range f to $f+\Delta f$. These current sources can be regarded as generating a multitude of quasi-sinusoidal frequency components, each with its own amplitude and phase. In the multifrequency multiport equivalent circuit of the mixer, Fig. 4, the noise sources can be included by connecting a noise current source at each sideband frequency to the appropriate port of the augmented network.

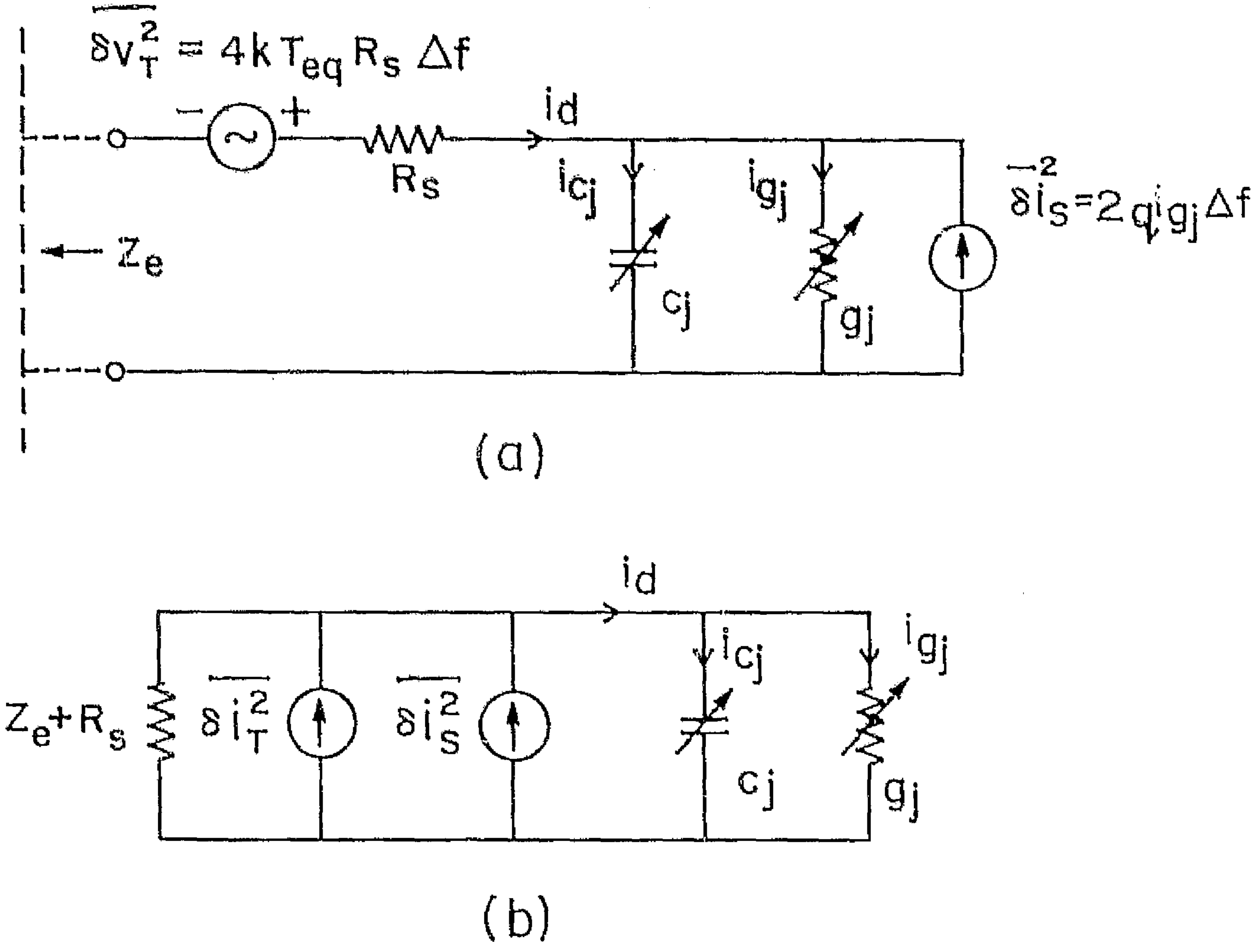

Fig. 5: (a) The equivalent circuit of the diode including noise sources. T_{eq} is the equivalent temperature of the series resistance and takes into account pump heating and lattice scattering noise. (b) The equivalent circuit with the thermal noise source $\overline{\delta v_T^2}$ transformed into a current source $\overline{\delta i_T^2}$. The sideband components of the noise sources are treated in the same way as the equivalent small-signal current sources $\delta I'_m$ applied at the ports of the augmented network of Fig. 4.

As seen by the intrinsic diode, the thermal noise current source in Fig. 5(b) is

$$\overline{\delta i_T^2} = \frac{4\,k\,T_{eq}\,R_{s_m}\,\Delta f}{|Z_{e_m} + R_{s_m}|^2} \quad . \tag{50}$$

At the intermediate frequency $(m = 0)$ the mixer is conjugate matched with $Z_{e_0} = (Z_0 + R_{s_0})^*$. As seen by the IF load Z_{e_0} the equivalent thermal noise current source connected to the IF port of the augmented network is

$$\overline{\delta i_T^2} = \frac{4\,k\,T_{eq}\,R_{s_0}\,\Delta f}{|Z_0|^2} = \frac{4\,k\,T_{eq}\,R_{s_0}\,\Delta f}{|Z_{e_0} - R_{s_0}|^2} \quad . \tag{51}$$

Since the noise performance of the mixer is determined from the total noise power delivered to the IF load Z_{e_0}, (51) rather than (50) must be used to account for IF noise in the series resistance that is delivered to the IF load.

The mean square value of the shot noise current source in Fig. 5(b) is given by the usual expression:

$$\overline{\delta i_S^2} = 2\,q\,i_{g_j}\,\Delta f \quad . \tag{52}$$

2.3.1 Shot Noise

The shot noise in a mixer arises from the current produced in the diode conductance by the local oscillator and dc bias. It can be considered as white (Gaussian) noise, amplitude modulated by the LO waveform. Dragone [11] and Uhlir [12] have investigated the properties of this modulated noise and shown that there is partial correlation between the quasi-sinusoidal components at the various sideband frequencies. The correlated components at these sidebands are down converted in the diode to the intermediate frequency where they add vectorially.

Let $\delta I'_{S_n}$ represent the quasi-sinusoidal component, at frequency ω_n, of the periodically pumped shot noise current source in Fig. 5(b). Each of the sideband components $\delta I'_{S_n}$ is connected to the complete equivalent circuit of the mixer, Fig. 4, at the appropriate sideband port. We define $\widetilde{\delta I'_S}$ and $\widetilde{\delta V_S}$ as the vectors of the input shot noise currents and voltages at the ports:

$$\widetilde{\delta I'_S} = [\ldots\ \delta I'_{S_1}\ \ \delta I'_{S_0}\ \ \delta I'_{S_{-1}}\ \ \ldots]^t$$

and

$$\widetilde{\delta V_S} = [\ldots\ \delta V_{S_1}\ \ \delta V_{S_0}\ \ \delta V_{S_{-1}}\ \ \ldots]^t \tag{53}$$

Using (36) the output noise voltage at the IF is

$$\delta V_{S_0} = \widetilde{Z}'_0\ \widetilde{\delta I'_S} \quad , \tag{54}$$

where $\tilde{Z}'_0$ is the zeroth or center row of the augmented impedance matrix $\tilde{Z}'$ defined in equation (36). It follows that

$$\delta V_{S_0} \cdot \delta V_{S_0}^{*} = \tilde{Z}'_0 \; \widetilde{\delta I}'_S \cdot (\tilde{Z}'_0 \; \widetilde{\delta I}'_S)^{*} = \tilde{Z}'_0 \; \widetilde{\delta I}'_S \; \widetilde{\delta I}'^{\dagger}_S \; \tilde{Z}'^{\dagger}_0 \quad , \tag{55}$$

where $\dagger$ indicates the conjugate transpose of a matrix.

Taking the ensemble average* of (55) yields

$$\langle | \delta V_{S_0} |^2 \rangle = \tilde{Z}'_0 \; \langle \widetilde{\delta I}'_S \; \widetilde{\delta I}'^{\dagger}_S \rangle \; \tilde{Z}'^{\dagger}_0 \quad . \tag{56}$$

$\langle \widetilde{\delta I}'_S \; \widetilde{\delta I}'^{\dagger}_S \rangle$ is the shot noise current correlation matrix and has the general element $\langle \delta I'_{S_m} \; \delta I'^{*}_{S_n} \rangle$. It can be shown that [11], [12] :

$$\langle \delta I'_{S_m} \; \delta I'^{*}_{S_n} \rangle = 2 \, q \, I_{m-n} \, \Delta f \quad , \tag{57}$$

where I_{m-n} is the (m-n)th Fourier coefficient of the diode conductance current is defined by

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* Taking the ensemble average is equivalent to considering a small but finite bandwidth as must be used in any physical measurement. The finite bandwidth contains a multitude of quasi-sinusoidal noise components with random amplitudes and phases.

$$i_{g_j}(t) = \sum_{n=-\infty}^{\infty} I_n \exp[jn\omega_p t] \quad , \quad I_{-n} = I_n^* \quad . \tag{58}$$

I_{m-n} is then given by:

$$I_{m-n} = \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} i_{g_j}(t) \quad \exp[-j(m-n)\omega_p t]\, dt \quad , \tag{59}$$

where the integration is taken over one LO cycle.

2.3.2 Thermal Noise

Thermal noise generated in the diode series resistance has components which are uncorrelated at the various sideband frequencies. Let $\delta I'_{T_n}$ represent the quasi-sinusoidal component at sideband frequency ω_n of the thermal noise current source in Fig. 5(b), and let δV_{T_n} be the sideband noise voltage produced by $\delta I'_{T_n}$. The noise voltage produced at the IF port of the augmented network (Fig. 4) by the thermal noise at all the sidebands can be found using equation (36):

$$\delta V_{T_0} = \tilde{Z}'_0 \ \widetilde{\delta I'_T} \quad , \tag{60}$$

where $\widetilde{\delta I'_T} = [\ldots, \delta I'_{T_1}, \delta I'_{T_0}, \delta I'_{T_{-1}}, \ldots]$ is the vector of input thermal noise currents at the sideband ports of Fig. 4 and $\widetilde{Z'_0}$ is the center row of the augmented impedance matrix $\widetilde{Z}'$. From (60)

$$\delta V_{T_0} \cdot \delta V^*_{T_0} = \widetilde{Z'_0} \; \widetilde{\delta I'_T} \cdot (\widetilde{Z'_0} \; \widetilde{\delta I'_T})^* = \widetilde{Z'_0} \; \widetilde{\delta I'_T} \; \widetilde{\delta I'^{\dagger}_T} \; Z'^{\dagger}_0 \quad . \tag{61}$$

Taking the ensemble average gives

$$\langle | \delta V_{T_0} |^2 \rangle = \widetilde{Z'_0} \; \langle \widetilde{\delta I'_T} \; \widetilde{\delta I'^{\dagger}_T} \rangle \; Z'^{\dagger}_0 \quad . \tag{62}$$

The square matrix $\langle \widetilde{\delta I'_T} \; \widetilde{\delta I'^{\dagger}_T} \rangle$ is the thermal noise current correlation matrix. Since the thermal noise components at the various sideband frequencies are uncorrelated the elements $\langle \delta I'_{T_m} \; \delta I'^*_{T_n} \rangle = 0$ unless m = n, i. e. the matrix is diagonal. From equations (50) and (51):

$$\langle \delta I'_{T_m} \; \delta I'^*_{T_m} \rangle = \frac{4kT_{eq} \; R_{s_m} \; \Delta f}{|Z_{e_m} + R_{s_m}|^2} \quad , \quad m \neq 0 \tag{63a}$$

$$\langle \delta I'_{T_0} \; \delta I'^*_{T_0} \rangle = \frac{4kT_{eq} \; R_{s_0} \; \Delta f}{|Z_{e_0} - R_{s_0}|^2} \quad , \quad m = 0 \tag{63b}$$

$$\langle \delta I'_{T_m} \ \delta I'^{*}_{T_n} \rangle = 0 \ , \quad m \neq n \ . \tag{63c}$$

2.3.3 Total Mixer Noise

The total output noise voltage of the mixer is obtained by combining the thermal and shot noise components. From (56) and (62):

$$\langle |V_{N_0}|^2 \rangle = \widetilde{Z}'_0 \ [\langle \widetilde{\delta I}'_S \ \widetilde{\delta I}'^{\dagger}_S \rangle + \langle \widetilde{\delta I}'_T \ \widetilde{\delta I}'^{\dagger}_T \rangle] \ \widetilde{Z}'^{\dagger}_0 \ . \tag{64}$$

It follows that the noise power delivered to the matched IF load Z_{e_0} from the mixer itself is

$$P_0 = \langle |V_{N_0}|^2 \rangle \ \mathrm{Re}[Z_{e_0}] / |Z_{e_0} + R_{s_0}|^2 \ . \tag{65}$$

The equivalent input noise temperature T_M of the mixer is the temperature to which the signal source conductance must be heated to give the same output noise from a noiseless but otherwise identical mixer as the actual mixer would produce when its signal source conductance was maintained at absolute zero temperature. Thus,

$$T_M \triangleq P_0 \ L_{01} / k \, \Delta f \ . \tag{66}$$

Using (65) and equation (49) for L_{01} (the conversion loss from the signal frequency to the IF)

$$T_M = \frac{\langle |V_{N_0}|^2 \rangle \, |Z_{e_1} + R_{s_1}|^2}{4k \, \Delta f |Z'_{01}|^2 \, \mathrm{Re}[Z_{e_1}]} , \tag{67}$$

where Z'_{01} is an element of the augmented impedance matrix $\tilde{Z}'$ defined in (36).

T_M is the single-sideband input noise temperature of the mixer, meaning that all the noise of the mixer is attributed to a hypothetical source at the signal frequency. It is related to the single sideband noise figure by:

$$F_{SSB} = 1 + \frac{T_M}{290^\circ K} . \tag{68}$$

When describing the performance of a mixer whose physical input port is coupled to both the signal and image frequencies, it is more convenient to talk in terms of a double-sideband noise temperature T_{DSB} . T_{DSB} is the temperature to which the signal and image source conductances must be heated to give the same output noise from a noiseless but otherwise identical mixer as the actual mixer would produce when its signal and image source conductances were maintained at absolute zero temperature. For mixers in which the conversion loss from the signal and image frequencies L_{01} and L_{0-1} are equal

$$T_{DSB} = T_{SSB}/2 \tag{69}$$

and when $L_{01} \neq L_{0-1}$

$$T_{DSB} = \frac{T_{SSB}}{1 + \dfrac{L_{01}}{L_{0-1}}} \tag{70}$$

2.4 Summary of Mixer Theory

The performance of a mixer can be characterized by its conversion loss and equivalent input noise temperature. These quantities depend on the large-signal waveforms at the diode and on the embedding impedances of the mixer at the small-signal sideband frequencies. The diode waveforms can be found using the multiple reflection technique described in section 2.1. Once a steady state solution has been obtained, the Fourier coefficients of the conductance and capacitance waveforms can be extracted and used to find the conversion admittance matrix which relates the small-signal sideband currents and voltages of the intrinsic diode. An augmented admittance matrix can then be formed, which describes the multiport network consisting of the intrinsic diode, the diode series resistance, and the sideband embedding impedances. The inverse of this matrix is the augmented impedance matrix $\tilde{Z}'$, whose elements are used to calculate the conversion loss at the various sideband frequencies and the input impedances of the mixer ports. It is assumed throughout that the IF load impedance is conjugate-matched to the IF output impedance.

In the noise analysis, two components are considered: shot noise in the junction, and thermal noise in the series resistance. These are represented by equivalent noise current sources in parallel with the intrinsic diode. The periodically varying shot noise has correlated components, while the thermal noise does not. Correlation matrices are formed and evaluated for both shot and thermal noise sources. The shot noise correlation matrix has elements related to the Fourier coefficients of the large-signal diode conductance current, while the thermal noise correlation matrix depends upon the embedding impedances at the sideband frequencies. The two matrices together yield the total output noise voltage from which the equivalent input noise temperature of the mixer can be calculated. The analysis is complete at this point.

2.4.1 Comment on the Effect of the Number of Frequencies Considered

In transforming these procedures into a workable computer program there is a practical limit on the number of harmonics of the local oscillator which can be used. This means that the small-signal admittance matrix $\underset{\sim}{Y}$ will be truncated above some finite harmonic number, which is equivalent to short circuiting the intrinsic diode at all higher sideband frequencies. In the nonlinear analysis the restriction on the number of harmonics is equivalent to terminating the intrinsic diode in an impedance Z_0, the characteristic impedance of the hypothetical transmission line, at all higher frequencies. As long as the number of harmonics considered is not too small this approximation is a reasonable one.

In the next section the computer program based on this analysis is described.

3. Description of the Mixer Analysis Program

Using the theory given in the previous sections, a user oriented computer program was written which can readily accommodate a variety of mixer problems.

The program requires as inputs (i) the embedding impedances seen by the diode at each harmonic of the local oscillator and at the harmonic sidebands, (ii) the diode characteristics, including an arbitrary capacitance-voltage dependence, and (iii) the operating conditions for the mixer, i. e. the bias voltage applied to the diode, rectified current, pump and intermediate frequencies, and the equivalent diode temperature. Other variables which can be input to change specific program operations will be discussed later in this section.

The output includes (i) the large signal current and voltage waveforms at the diode, (ii) the Fourier coefficients of the diode conductance and capacitance, (iii) the conversion loss between every pair of sideband frequencies, (iv) the IF output impedance, (v) the input impedance at each sideband, and (vi) the equivalent single-sideband input noise temperature.

The remainder of this section explains the program in detail and illustrates the steps used for running it. A complete annotated listing of the program appears in Appendix I and a general flowchart is given in Fig. 6. A list of the main program variables and their counterparts in the theory developed in parts one and two of this report can be found in Fig. 7.

3.1 Program Implementation

The program begins with a call to subroutine LGSIG to do the nonlinear analysis using the multiple reflection method described in section 2.1. The embedding network

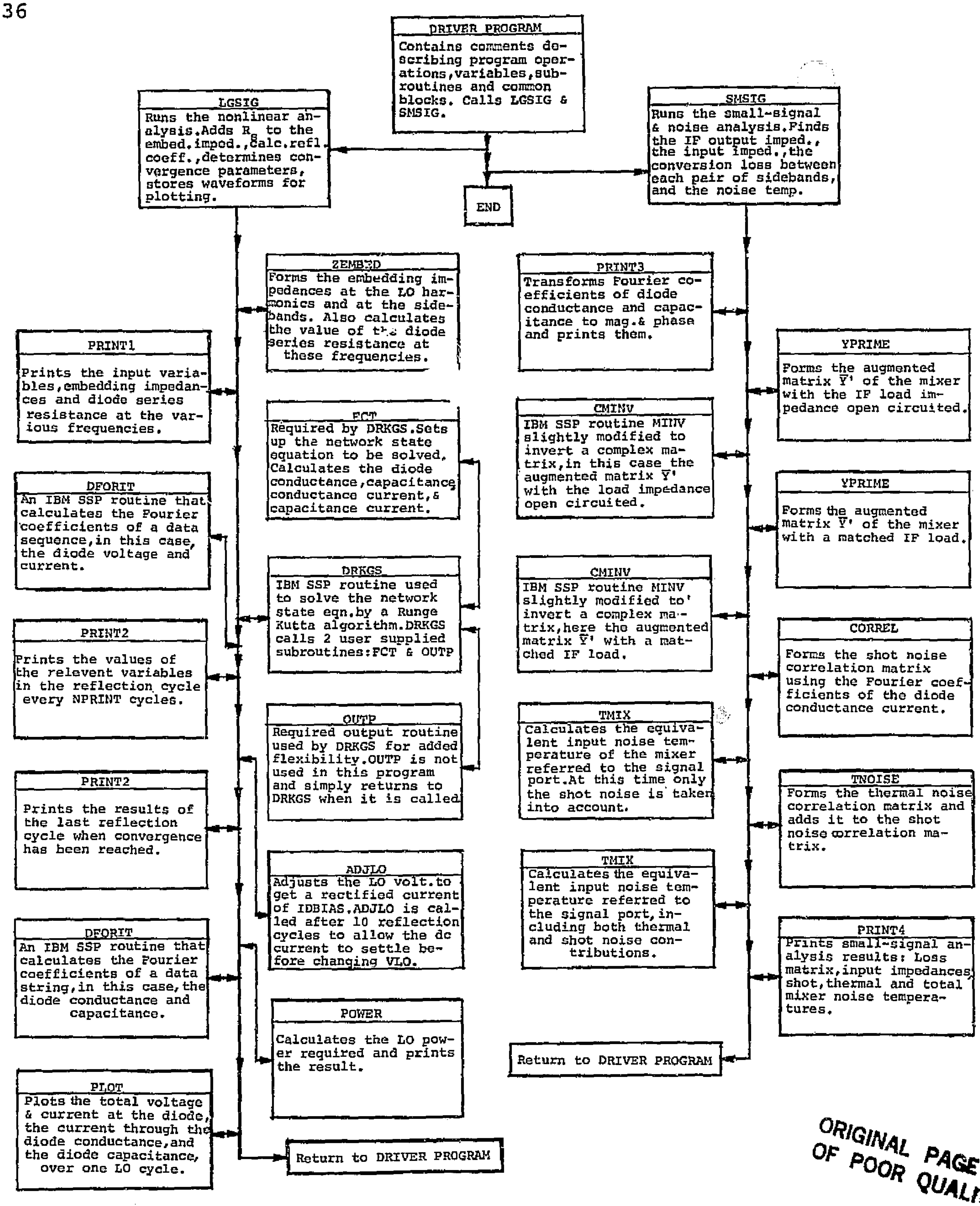

Fig. 6: Chart illustrating the general flow of the mixer analysis program and the operations of the subroutines.

VARIABLE	PROGRAM NAME
c_0	C0
c_j	CJ
C_{m-n}	FC(m-n+1)
g_j	GJ
G_{m-n}	FG(m-n+1)
i_{c_j}	ICJ
I_{d_n}	IDCOS(n+1)-JIDSIN(n+1)
i_d	IGJ + ICJ
i_{g_j}	IGJ
I_{m-n}	FG(m-n+1)/ALP
i_s	IS
k	BOLTZ
L_{ij}	LIJ
q	QEL
R_s	RS
$R_s(dc)$	RS
$R_s(n\omega_p)$	RSLO
R_{s_m}	RSSB
R_{skin}	RSKIN
T_{eq}	TEQ
T_M	TM
V_0	VDC
V_1	VLO
V_{d_n}	VDCOS (n+1) - JVDSIN (n+1)
v_d	Y (1)
V_{i_0}	VIDC
V_{i_n}	VI (n) = AV (n) - JBV (n)
V_{r_0}	VRDC or DVRDC
V_{r_n}	VR or DVR
Y	A
Y'	A

VARIABLE	PROGRAM NAME
Z'(o/c. IF)	A
Z' (matched IF)	A
Z_0 (T. line imp.)	Z0
$Z_e(0) + R_s(dc)$	ZEMBDC
$Z_e(n\omega_p) + R_s(n\omega_p)$	ZEMB
$Z_e(n\omega_p)$	ZER + jZEI
Z_{e_m}	ZEMBSB
$Z_{IF_{out}}$	ZIFOUT
Z'_{ij}	A(NHD2P1-i, NHD2P1-j)
Z_{in}	ZIN
Z'_{mm}	A(NHD2P1-m, NHD2P1-m)
$Z'_{mm,\infty}$	A(NHD2P1-m, NHD2P1-m)
α	ALP
γ	GAM
δ	ZQ-1
ϵ	ZQACC
π	PI
ρ	RHO
ρ_0	RHODC
ϕ	PHI
ω_0	WIF
ω_p	WP
$\langle \widetilde{\delta I'_S}\, \widetilde{\delta I'^{\dagger}_S} \rangle$	COR
$\langle \widetilde{\delta I'_T}\, \widetilde{\delta I'^{\dagger}_T} \rangle$	COR
$\langle \lvert \delta V_{N_0} \rvert^2 \rangle$	VSQ
$\langle \lvert \delta V_{S_0} \rvert^2 \rangle$	VSQ
$\langle \lvert \delta V_{T_0} \rvert^2 \rangle$	VSQ
dv_d/dt	DERY (1)

Fig. 7: Alphabetical list of the main variables used in the theory in this report, and their counterparts in the mixer analysis program.

impedances $Z_e(n)$ (ZER + jZEI) and the sideband impedances Z_{e_m} (ZEMBSB) are input in the BLOCK DATA program or formed, up to the highest harmonic of the LO (NH), assumed even, in subprogram ZEMBED. The real and imaginary parts of the embedding impedance $Z_e(n)$ at harmonic n become elements n of the arrays ZER and ZEI. The dc term is considered separately. The embedding impedance Z_{e_m} at sideband m becomes, in the notation of section 2.2.1, array element $\left(\frac{NH}{2} + 1 - m\right), m = 0, \pm 1, \pm 2, \ldots \pm \frac{NH}{2}$ of ZEMBSB. The diode series resistance at each LO harmonic (RSLO) and at the sideband frequencies (RSSB) is also formed in subprogram ZEMBED using equation (9). The array element notation for RSLO is the same as that used for ZER and ZEI, that is R_s at harmonic n becomes array element n of RSLO. Similarly, the notation used for RSSB is the same as that of ZEMBSB, R_s at sideband m becomes array element $\left(\frac{NH}{2} + 1 - m\right)$ of RSSB.

The reflection coefficients, (RHO) of the embedding network at the various LO harmonics are found using (17) for a given value of the transmission line characteristic impedance Z_0(Z0). After initializing the incident voltage at the diode from (10) and (11), the input data are printed through subroutine PRINT1.

The next step in the nonlinear analysis is to find the local oscillator voltage V_1(VLO) at which the desired rectified diode current (IDBIAS) is obtained. An outer loop (JLO) is established which zeros in on the required LO voltage. To do this, ten reflection cycles of the large signal analysis are run after which the dc current (IDCOS(1), the first Fourier coefficient of the total current in the diode) is compared with the desired value IDBIAS, and VLO is appropriately changed. The loop continues until the desired and calculated currents agree within a preset accuracy (IDCACC).

The time domain calculation of the current and voltage at the diode is accomplished by using the IBM SSP routine DRKGS which solves the network state equation

(14) for the circuit of Fig. 3b using a Runge-Kutta algorithm. The problem is time scaled so that the LO period is 2π seconds. Each LO cycle contains a fixed number of points (NPTS) and DRKGS is called separately to integrate the circuit equations over each of the (NPTS-1) intervals per LO cycle. Subroutine FCT, called by DRKGS, supplies the state equation (14). The resulting values of the total diode current i_d (IGJ + ICJ), voltage v_d (Y(1)), conductance g_j (GJ), and capacitance c_j (CJ) for each point are stored in arrays. The integration loop is repeated NLO times to allow a steady state to be reached and then the IBM SSP routine FORIT is used to find the Fourier coefficients of the final voltage and current waveforms. At this point the voltages reflected from the diode at each LO harmonic can be found from (15) or (16) and the new incident voltages determined from (17) and (18). The convergence of the solution is checked using (22) and if more iterations are required (ZQFLAG $\neq$ 0) the procedure is repeated from the beginning of the DRKGS integration. However, if the impedances at both ends of the transmission line are equal within some fixed accuracy ϵ (ZQACC) at all harmonics of the LO above the first, then the large signal analysis is complete. The results of the last iteration are printed via subroutine PRINT2 and subroutine POWER is called to calculate and print the required LO power.* The Fourier

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* We have found that convergence of the nonlinear analysis can generally be made more rapid if the embedding impedances at dc and the LO frequency, $Z_e(0)$ and $Z_e(1)$, are artifically set equal to the characteristic impedance Z_0 of the hypothetical transmission line. Provided the LO and dc bias sources are appropriately adjusted this has no effect on the steady-state waveforms. In computing the LO power required to drive the mixer (i. e. available power from the LO source), the correct value of $Z_e(1)$ must be replaced and the LO source voltage adjusted accordingly. It follows that, in terms of the LO source voltage V_{LO}, when $Z_e(0) = Z_0$, the LO power required to drive the actual mixer (with $Z_e(1)$ at its original value) is:

$$P_{LO} = \frac{|V_{LO}|^2}{8\,\mathrm{Re}[Z_e(1)]} \; \frac{|R_s(1) + Z_e(1) + Z_0 * ZQ(1)|^2}{|Z_0 * (1 + ZQ(1))|^2} , \qquad (71)$$

where ZQ(1) is the convergence parameter given in (22) when n = 1.

coefficients of the diode conductance and capacitance are now found using FORIT, after having un-time-scaled the frequency dependent terms. Finally, the diode conductance and capacitance, total diode current, and voltage across the diode are plotted over one LO cycle using subroutine PLOT.

After the large-signal analysis is finished subroutine SMSIG is called to perform the small-signal analysis described in section 2.2. The Fourier coefficients of the diode conductance and capacitance (GJCOS, GJSIN, CJCOS, CJSIN) obtained in the large-signal section are converted to complex form (FG, FC) and printed in subroutine PRINT3. Calculation of the conversion loss matrix (XLMAT) and input and output impedances then begins by forming the small-signal admittance matrix $\widetilde{Y}$ (A in the program) of equation (26) using (28). The IF load impedance is open circuited at this stage and the augmented admittance matrix of (33) $\widetilde{Y}'$ is formed in subroutine YPRIME by adding $(Z_{e_m} + R_{s_m})^{-1}$ to the diagonal terms of $\widetilde{Y}$ (A). $\widetilde{Y}'$ (A) is inverted to obtain $\widetilde{Z}'$ (A) using the IBM SSP routine MINV (matrix inversion), slightly modified to handle a complex matrix (CMINV). The IF output impedance (ZIFOUT) is the center element Z'_{00} (A(NHD2P1, NHD2P1)) of this matrix plus the diode series resistance R_{s_0} (see eq. (40)). If IF load impedance is set equal to the complex conjugate of ZIFOUT and the augmented admittance matrix is again formed and inverted to give $\widetilde{Z}'$ (A) for the mixer with a matched IF load. The elements of the conversion loss matrix (LIJ) and the input impedances at the sideband ports (ZIN) are then found using (43) and (49).

The noise analysis proceeds according to section 2.3 and begins with the formation of the shot noise correlation matrix $\langle \delta\widetilde{I}'_S \; \delta\widetilde{I}'^{\dagger}_S \rangle$ in subroutine CORREL, using (57). The equivalent input shot noise temperature (SHOT) referred to the signal port is calculated in subroutine TMIX using equation (67) with $\langle |\delta V_{N_0}|^2 \rangle$ replaced by

$\langle |\delta V_{S_0}|^2 \rangle$ as given by (56) and (57). The total mixer output noise voltage is found, using subroutine TNOISE, by adding the shot noise correlation matrix to the thermal noise correlation matrix given by (63) - see equation (64). Subroutine TMIX is then used to find the total equivalent input noise temperature (TM) at the signal port. The thermal component (THERM) is found by subtracting the shot noise contribution (SHOT) from the total noise temperature (TM). The results of the conversion loss and noise analyses are printed using subroutine PRINT4. This completes the program.

For a more detailed description of the operation of the program the reader is referred to the comments in the program listing and the general flow chart of Fig. 6.

3.2 Running the Mixer Analysis Program

A listing of the mixer analysis program in its simplest form appears in Appendix I along with the output of a run. Using the IBM Fortran IV-H compiler, the execution time for this particular listing is 32 seconds on an IBM 360-95 computer. The comments in the listing provide a step by step description of the Fortran coding and explain the meanings of the variables. To run the program the following information must be supplied by the user via the BLOCK DATA subprogram:

(1) The embedding network impedances at the LO frequency and the higher harmonics as real and imaginary parts (ZER, ZEI) in Ohms.

(2) The sideband impedances in complex form(ZEMBSB)in Ohms, where sideband m corresponds to array element (NH/2 + 1 - m) and there are NH+1 array elements in all. Note that for all lower sidebands ($m<0$) the sideband frequency is negative and the ZEMBSB(NH/2 + 1 - m) is therefore the conjugate of the positive frequency impedance.

(3) The LO frequency (FP) and the intermediate frequency (IF) in Hertz.

(4) The dc bias voltage across the diode (VDBIAS) in Volts.

(5) The desired rectified current (IDBIAS) in Amperes.

(6) The equivalent temperature of the diode series resistance (TEQ) in degrees Kelvin.

(7) The diode series resistance at dc (RS) in Ohms.

(8) The diode skin resistance constant (RSKIN) in Ohms/$\sqrt{\text{Hertz}}$.

(9) The reverse saturation current of the diode (IS) in Amperes.

(10) The diode contact potential ϕ(PHI) in Volts.

(11) The diode capacitance at zero volts (C0) in Farads.

(12) The diode capacitance law exponent γ (GAM).

(13) The diode I-V law exponent $\alpha \triangleq q/\eta kT$ (ALP) in (Volts)$^{-1}$.

The values of the remaining variables are somewhat arbitrary and have been optimized for the example given in Appendix I. The following information may prove useful in choosing values for these variables when running other examples.

The characteristic impedance (Z0) of the hypothetical transmission line inserted between the diode and the embedding network for the nonlinear analysis has a significant effect on the number of reflection cycles required for convergence. Values near 200 Ohms result in a fairly rapid rate of convergence for the example in Appendix I and also for the examples in section 4.1 in which the embedding impedances above the first harmonic are open circuited. However a lower value (50 Ohms) gave somewhat faster convergence when the embedding impedances above the first harmonic were short circuited.

The initial value of the local oscillator voltage (VLO) and the initial increment (VLOINC) used to zero in on the desired dc rectified current can be chosen so as to avoid many time consuming loops in the large signal analysis. If, as in the examples in the next section, many runs are desired with only slight variations in the circuit parameters VLO will change very little between each run and VLOINC should be made fairly small.

The number of LO cycles needed to reach a steady state (NLO) for the circuit of Fig. 3b in the nonlinear analysis, need not be greater than one for the examples given in this report (bear in mind that the solution will continue settling in successive reflection cycles) but some circuits may require additional settling time. NLO can be increased by changing the appropriate statement in the BLOCK DATA routine.

If the dc current reached after ten reflection cycles in the nonlinear analysis is not sufficiently close to its ultimate value it may be necessary to increase the reflection cycle number at which the LO voltage is adjusted. This is accomplished by changing the program step which follows statement label 10 in subroutine LGSIG.

The results of any of the reflection cycles in the nonlinear analysis can be printed by adjusting the parameter NPRINT in the BLOCK DATA subprogram which causes results to be written out every NPRINT cycles. Upper limits on other program loops such as the total number of allowed nonlinear analysis cycles (NITER) or VLO adjustments (NVLO) can be increased or decreased as desired by changing the variables appearing in the common block labelled LOOPS.

The local oscillator cycle was divided into 50 parts (51 points) in these examples to yield a reasonable number of data points for plotting the diode current, voltage, capacitance and conductance waveforms and to avoid aliasing.* If the number of points (NPTS, assumed odd) is altered some of the array dimensions must also be changed. In subroutine LGSIG the variables VDDATA, IDDATA, IGJDAT, ICJDAT, CJDATA and GJDATA all have dimension NPTS.

If other than eight harmonics of the local oscillator are to be considered the variable NH (assumed even) must be set to that number in the BLOCK DATA subprogram. Also the following array dimensions must be changed in subroutines LGSIG, SMSIG, FCT, and BLOCK DATA to the value NH, if they represent LO harmonics, or to NH + 1, if they refer to the sidebands:

ZER, ZEI, RSLO, AV, BV, ZEMB, RHO, VI, VR, DVR, ZQMAG and ZQPHA must be dimensioned NH and ZEMBSB, RSSB, CJCOS, CJSIN, GJCOS, GJSIN, VDCOS, VDSIN, IDCOS, IDSIN, A, COR, FG, FC, T, ZIN, XLMAT, GJMAG, GJPHA, CJMAG, CJPHA, WK1 and WK2 must be dimensioned NH + 1. In addition certain print formats will also have to be altered.

The relationship chosen to represent the variation of diode series resistance with frequency due to the skin effect involves the determination of a constant (RSKIN) which will be different for every diode. An increase in the resistance at 100 GHz. of 30% of

---

* The sampling theorem indicates that if NH harmonics are considered, it should only be necessary to consider 2 * NH + 1 points in the diode waveforms. This would be true if the waveforms produced by the Runge-Kutta integration contained <u>only</u> NH harmonics. However the integration solves the circuit of Fig. 3(b) quite faithfully and, because of the exponential nonlinearity of the diode, harmonics above NH are present in the waveform. These are ignored in successive reflection cycles of the nonlinear analysis. If only 2* NH + 1 points are considered in the waveforms, the phenomenon of aliasing will occur, by which higher frequency components are "mixed" with harmonics of the sampling frequency thereby causing errors in the computed Fourier coefficients.

the dc value has been assumed in the example in Appendix I of this report. RSKIN can be changed via the BLOCK DATA subprogram. A frequency dependent reactive term may also be added to the diode series resistance by making RSKIN, RSSB, and RSLO complex.

It is also possible to use a different capacitance-voltage law for the diode than that given in equation (4). This is illustrated by the Mott diode examples discussed in the next section.

4. Examples Using the Mixer Analysis Program: A Study of the Effects of the Series Inductance and Diode Capacitance on Some Simple Mixer Circuits

In this section the mixer analysis program is used to study the effects of the series inductance and diode capacitance on the performance of the simple mixer circuits shown in Figs. 8 and 9. The embedding networks were chosen to simulate mixers in which there is inductance due to the diode package or contact whisker. Higher harmonics are either short circuited outside the series inductance, or open circuited as shown. The mixer performance is investigated for three different diodes: (i) a Schottky diode with $\gamma = 1/2$, (ii) the same Schottky diode but without a voltage-dependent capacitance ($\gamma = 0$), and (iii) a Mott diode with an experimentally determined capacitance-voltage relationship (see Figs. 10 and 11). The program in Appendix I was modified to allow multiple runs with varying values of series inductance (LS) or diode capacitance (C0). As these changes are typical of the alterations which might be made by other users of the program they are detailed in the next section.

4.1 Program Alterations for Running the Examples in this Section

The main driver program was altered to allow repeated runs with different values of diode capacitance C0 or series inductance LS and to enable the results to be stored on a disk file. The impedances at the LO harmonics and the sideband frequencies are formed at the start of each new run in subroutine ZEMBED rather than inputting them through the BLOCK DATA program, and the diode series resistance is taken to be independent of frequency. (RSKIN=0). The capacitance-voltage relationship of the Mott diode (Fig. 11) was determined from the doping profile* (Fig. 10) using a piece-wise linear

---

* The data on the doping profile of the Mott diode was supplied by M. V. Schneider of Bell Telephone Laboratories, Holmdel, N. J.

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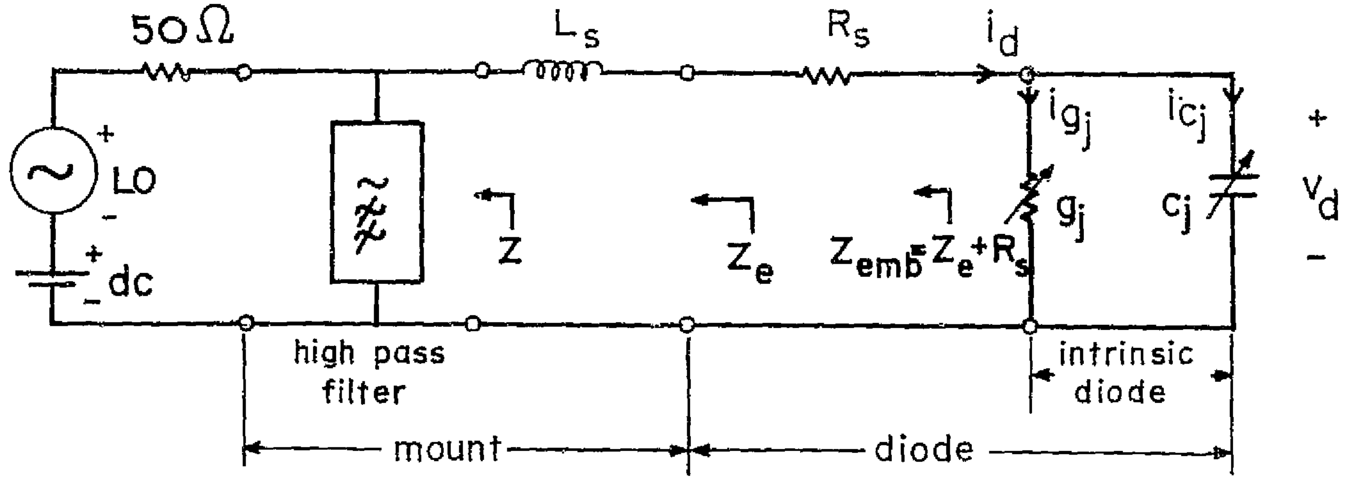

Fig. 8: The equivalent circuit of a simple mixer. The filter passes all frequencies above the signal and image, thus shorting out the higher LO harmonics and sideband frequencies.

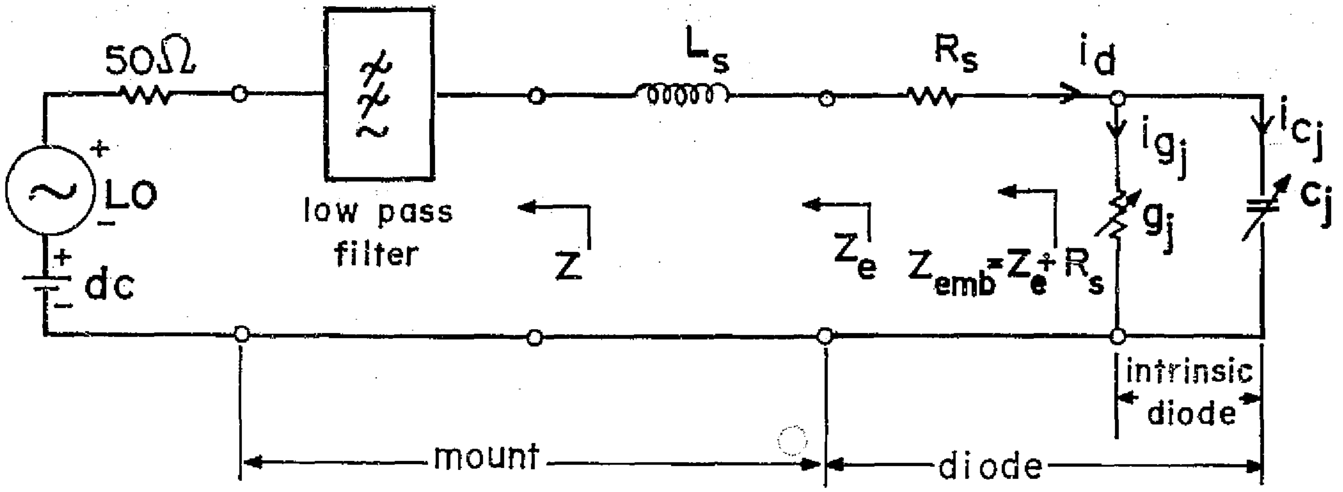

Fig. 9: The equivalent circuit of a simple mixer. The filter stops all frequencies above the signal and image, thus open circuiting the higher LO harmonics and sideband frequencies.

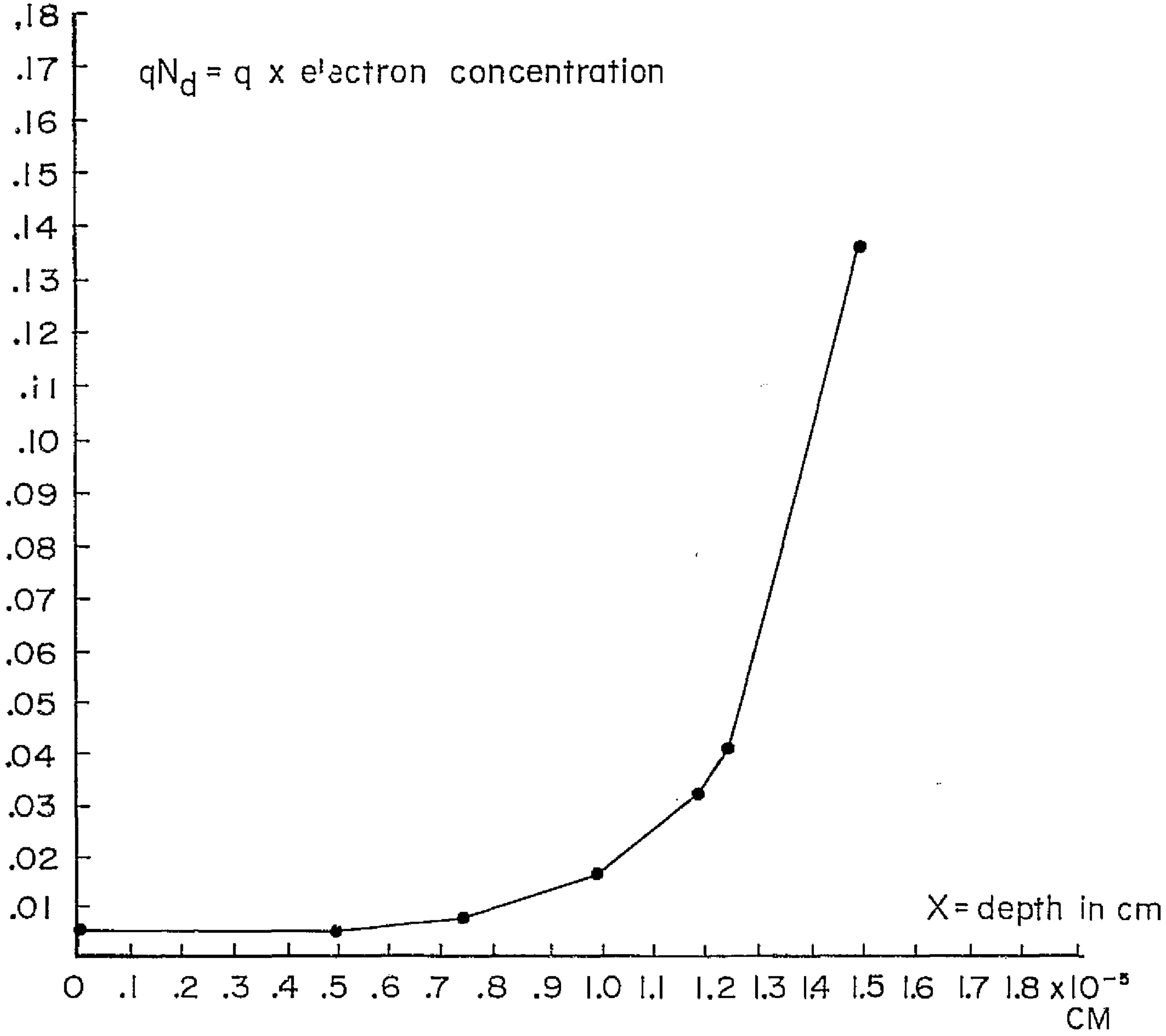

Fig. 10: Piecewise-linear approximation to the doping profile (donor concentration vs. depth) for the Mott diode used in the examples. The data (dots) were kindly supplied by M. V. Schneider, Bell Laboratories, Holmdel, N. J.

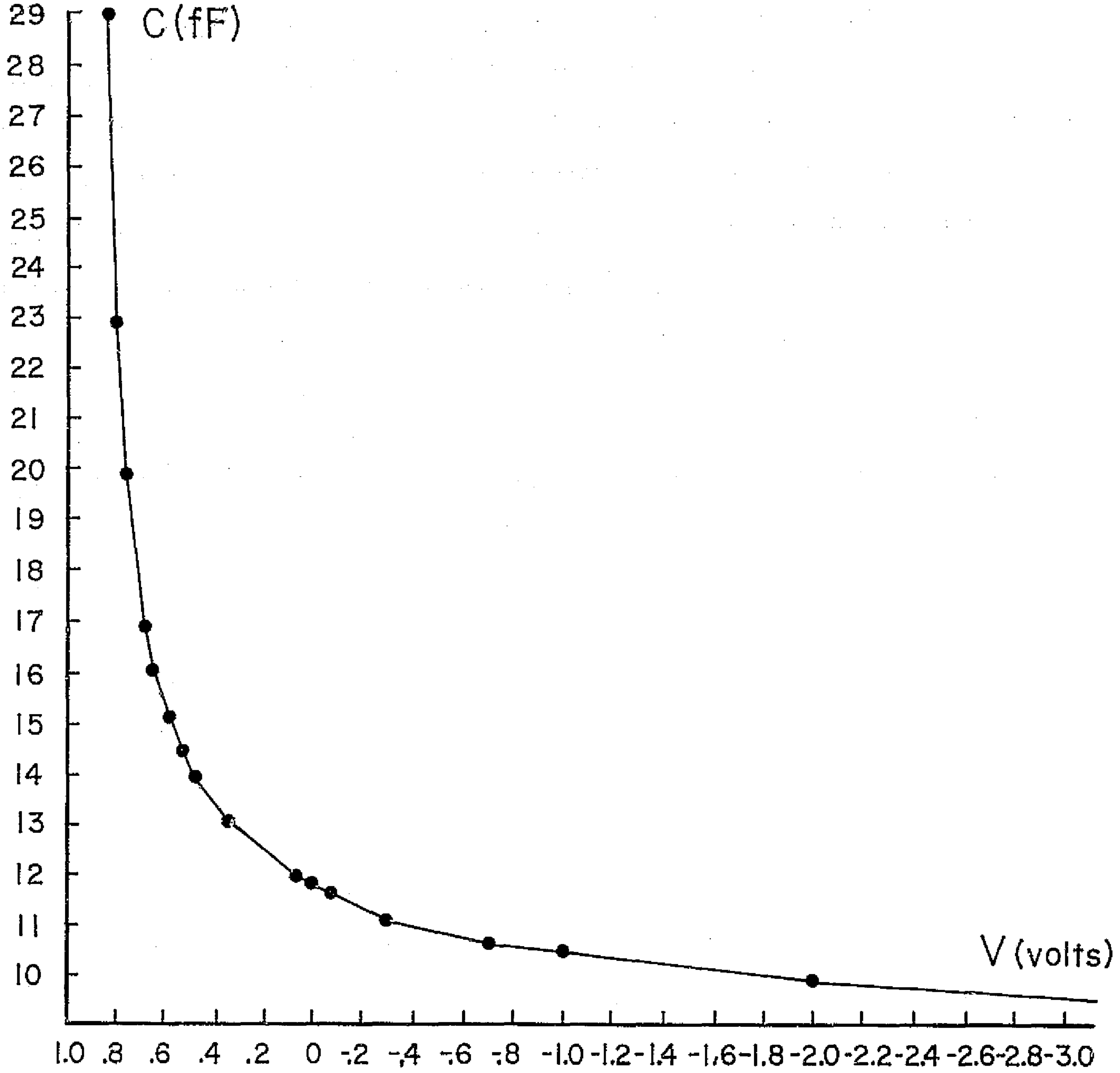

Fig. 11: Piecewise-linear approximation to the capacitance-voltage relationship of the Mott diode whose doping profile appears in Fig. 10. The slope and C axis intercept for each of the linear regions is supplied to the mixer analysis program for the calculation of the diode capacitance at any given voltage.

approximation. The C-V dependence was incorporated into the program by defining an internal function C(VD) whose value is the capacitance at a given diode voltage Y(1). The function routine is handed the value of the diode voltage by subroutine FCT and a search is conducted through a series of predefined voltage regions until the one in which Y(1) lies, is found. Then, data for the slope and intercept of the C-V straight line approximation in that region is used to calculate the value of C(VD). Appendix II contains

Appendix II contains a list of the modifications which must be made to the program in Appendix I to run each of the examples.

4.2 Computed Results and Discussion

The simple mixer circuits of Figs. 8 and 9 were analyzed with three different diodes: a Ga As Schottky diode (including nonlinear capacitance), a Ga As Schottky diode with constant capacitance, and a practical Ga As Mott diode. In each case the diode was forward biased at 0.4 V and the LO level was adjusted to give a rectified dc current of 2.0 mA. The signal frequency (taken as the upper sideband) was 119 GHz while the LO and intermediate frequencies were 115 GHz and 4 GHz respectively. The conversion loss (upper sideband to IF), equivalent input noise temperature, and real part of the IF output impedance were plotted as functions of the series inductance, which was allowed to vary from 0.01 nH to 0.25 nH. These results are given in Appendix III, section A III. 1. Note that skin effect was not taken into account in these examples.

The effect of the junction capacitance on the mixer perfromance was then investigated for the Schottky diode (with and without nonlinear capacitance) in the same two circuits-Figs. 8 and 9. To isolate the effects of the diode capacitance and series inductance, the series resistance was assumed constant at 4.4 Ohms. It should be noted that this leads to some unrealistically high (and low) diode cutoff frequencies. C0 was varied from 1 to 20 fF for each of nine values of LS between 0.04 and 0.2 nH.

Again the noise temperature, conversion loss and output impedance were plotted, this time as functions of the junction capacitance for each value of LS (Appendix III, Section A III.2).

In Appendix III, section A III.1, the performance of the Schottky, Mott, and $\gamma = 0$ diode mixers operating with an LO frequency of 115 GHz and an IF of 4 GHz are compared. It is assumed that each diode has a zero-bias capacitance (C0) of 11.8 fF. Notice that the minimum noise temperature is achieved with the constant capacitance diode; however this should not be assumed to be a general result, as will be demonstrated below. Except for the Schottky diode with constant capacitance, the minima in the noise temperature and conversion loss for each mixer circuit do not occur at the same value of LS.

A broader view of the performance of these mixers is obtained from the graphs in Section A III.2, in which LS is held constant while C0 is varied. In all cases the effect of increasing series inductance is to sharpen the noise temperature and conversion loss minima and shift them towards smaller values of C0. Better performance is obtained for larger values of LS, with a corresponding increase in the IF output impedance.

Amongst the results there are some points, particularly for low values of series inductance, which appear to be randomly scattered. This is due to the fact that for low values of the series inductance each increment in LS causes a large change in the resonant frequency of the diode with the external circuit. If these resonances fall near harmonics of the LO the diode waveforms can be strongly affected, and so can the embedding impedance seen by the small-signal sidebands near these harmonics.

The LO power required was between 1 and 7 mW in every case.

An interesting result of this analysis is that the parametric effects of the junction capacitance do not necessarily degrade the mixer performance.

5. Summary and Concluding Remarks

In this report a user oriented computer program for the analysis of microwave and millimeter-wave mixers has been presented. The necessary mixer theory was briefly described and used as the basis of the mixer analysis program. The operation of the program was discussed as well as some useful modifications.

As an example of the program's use, a study of the effects of the series inductance and diode capacitance on the performance of two simple mixer circuits was undertaken. Three different diodes were used: a Schottky diode, a Schottky diode with no capacitance variation, and a Mott diode.

The results show clear minima in the conversion loss and noise temperature as the inductance and capacitance are varied. The parametric effects of the voltage dependent diode capacitance are found to have either beneficial or detrimental effects on the mixer performance, depending on the circuit and diode parameters.

APPENDIX I

Listing and Sample Run of the Mixer Analysis Program

This program calculates the performance of a mixer, given the embedding network impedances at the harmonics of the LO and the sideband frequencies. The theory is described in section 2 of this report and section 3 outlines the program operation. The flow chart (Fig. 6) and table of variables (Fig. 7) may be found helpful in understanding the workings of the program and are repeated in this appendix for convenience.

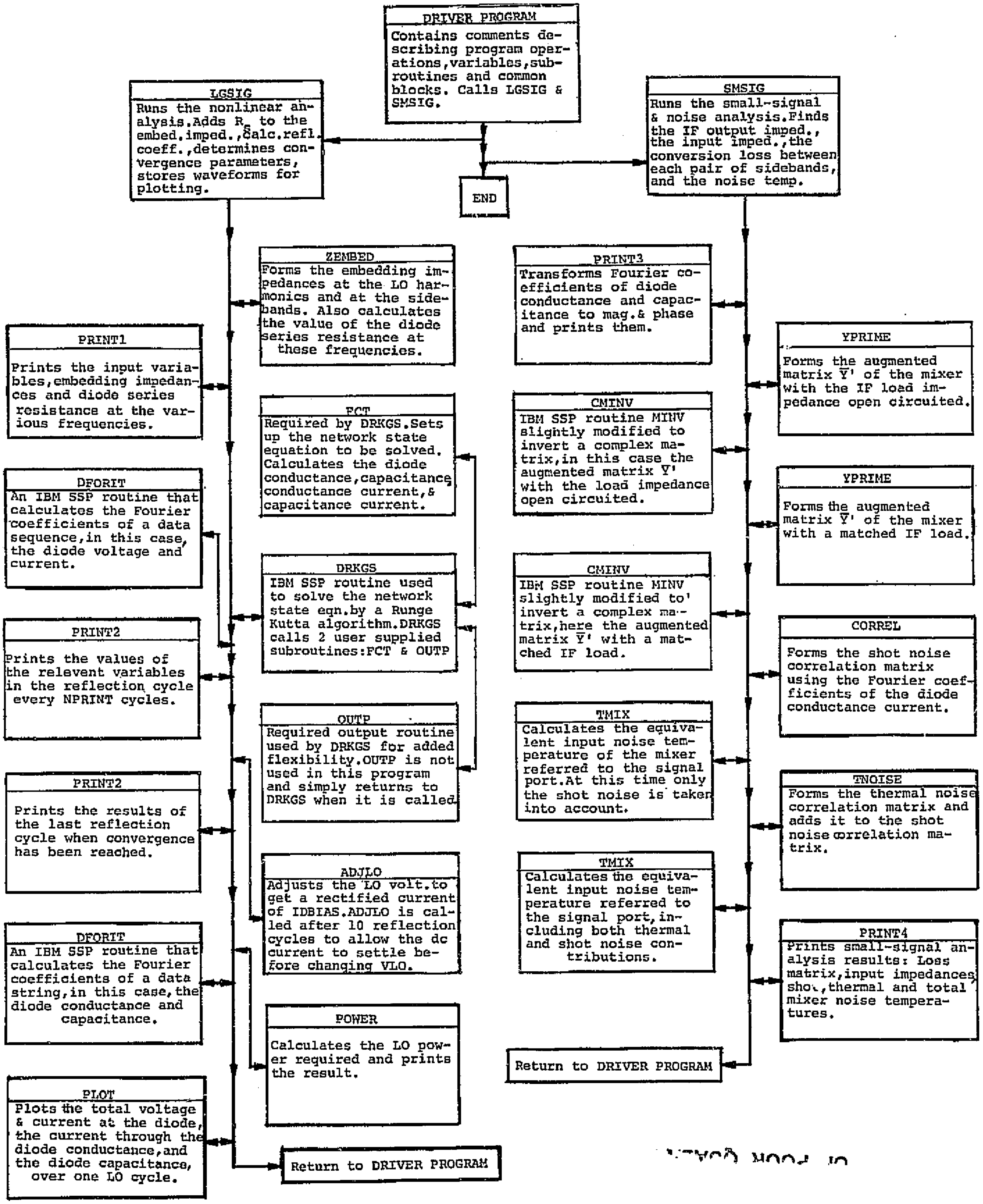

Chart illustrating the general flow of the mixer analysis program and the operations of the subroutines.

VARIABLE	PROGRAM NAME
c_0	C0
c_j	CJ
C_{m-n}	FC(m-n+1)
g_j	GJ
G_{m-n}	FG(m-n+1)
i_{c_j}	ICJ
I_{d_n}	IDCOS(n+1)-JIDSIN(n+1)
i_d	IGJ + ICJ
i_{g_j}	IGJ
I_{m-n}	FG(m-n+1)/ALP
i_s	IS
k	BOLTZ
L_{ij}	LIJ
q	QEL
R_s	RS
$R_s(dc)$	RS
$R_s(n\omega_p)$	RSLO
R_{s_m}	RSSB
R_{skin}	RSKIN
T_{eq}	TEQ
T_M	TM
V_0	VDC
V_1	VLO
V_{d_n}	VDCOS (n+1) - JVDSIN (n+1)
v_d	Y (1)
V_{i_0}	VIDC
V_{i_n}	VI (n) = AV (n) - JBV (n)
V_{r_0}	VRDC or DVRDC
V_{r_n}	VR or DVR
Y	A
Y'	A
$Z'(o/c.\ IF)$	A
Z' (matched IF)	A
Z_0 (T. line imp.)	Z0
$Z_e(0) + R_s(dc)$	ZEMBDC
$Z_e(n\omega_p) + R_s(n\omega_p)$	ZEMB
$Z_e(n\omega_p)$	ZER + jZEI
Z_{e_m}	ZEMBSB
$Z_{IF_{out}}$	ZIFOUT
Z'_{ij}	A(NHD2P1-i, NHD2P1-j)
Z_{in}	ZIN
Z'_{mm}	A(NHD2P1-m, NHD2P1-m)
$Z'_{mm,\infty}$	A(NHD2P1-m, NHD2P1-m)
α	ALP
γ	GAM
δ	ZQ-1
ϵ	ZQACC
π	PI
ρ	RHO
ρ_0	RHODC
ϕ	PHI
ω_0	WIF
ω_p	WP
$\langle \widetilde{\delta I'_S}\, \widetilde{\delta I'^{\dagger}_S} \rangle$	COR
$\langle \widetilde{\delta I'_T}\, \widetilde{\delta I'^{\dagger}_T} \rangle$	COR
$\langle \lvert \delta V_{N_0} \rvert^2 \rangle$	VSQ
$\langle \lvert \delta V_{S_0} \rvert^2 \rangle$	VSQ
$\langle \lvert \delta V_{T_0} \rvert^2 \rangle$	VSQ
dv_d / dt	DERY (1)

Alphabetical list of the main variables used in the theory in this report, and their counterparts in the mixer analysis program.

```
C
C
C
C                            MIXER ANALYSIS PROGRAM
C
C
C
C                         P.H.SIEGEL  AND  A.R.KERR
C                     GODDARD INSTITUTE FOR SPACE STUDIES
C                      NASA-GODDARD SPACE FLIGHT CENTER
C                              2880 BROADWAY
C                           NEW YORK,N.Y. 10025
C
C
C
C    GENERAL INFORMATION
C
C    THIS PROGRAM ANALYZES MIXERS WITH A SINGLE SCHOTTKY-BARRIER DIODE
C  WHOSE I-V AND C-V CHARACTERISTICS ARE KNOWN. ARBITRARY EMBEDDING
C  IMPEDANCES AT THE SIDEBAND AND LO HARMONIC FREQUENCIES ARE ALLOWED.
C  THE DIODE MOUNT IS ASSUMED LOSSLESS AND RECIPROCAL.
C
C    THE PROGRAM IS ORGANIZED INTO TWO MAIN SECTIONS. THE FIRST PER-
C  FORMS A NONLINEAR ANALYSIS TO DETERMINE THE DIODE WAVEFORMS PRO-
C  DUCED BY THE LOCAL OSCILLATOR. THE SECOND PERFORMS A SMALL-SIGNAL
C  AND NOISE ANALYSIS TO COMPUTE THE CONVERSION LOSS, PORT IMPEDANCES,
C  AND NOISE TEMPERATURE OF THE MIXER.
C
C    THE NONLINEAR ANALYSIS IS BASED ON THE MULTIPLE RELECTION METHOD
C  (A.R.KERR,IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES,
C  VOL.MTT-23,NO.10,PP.828-831,OCT.1975) DEVELOPED EARLIER IN OUR
C  LABORATORY, MODIFIED TO TAKE INTO ACCOUNT THE NONLINEAR CAPACITANCE
C  OF THE DIODE.
C
C    THE SMALL-SIGNAL ANALYSIS IS BASED ON THAT OF D.N.HELD AND
C  A.R.KERR,IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES,
C  VOL.MTT-26,NO.2,PP.49-61,FEB.1978.
C
C
C    PROGRAM NOTES
C
C    TWO MAIN SUBROUTINES CONTROL THE ANALYSIS: LGSIG WHICH PERFORMS
C  THE NONLINEAR ANALYSIS AND SMSIG WHICH COMPUTES THE SMALL-SIG-
C  NAL AND NOISE PROPERTIES OF THE MIXER. EACH OF THESE CALLS A NUM-
C  BER OF SECONDARY SUBROUTINES WHICH PERFORM SPECIFIC CALCULATIONS
C  OR CONTROL THE OUTPUTTING OF RESULTS.
C    DATA IS INPUT VIA THE BLOCK DATA SUBPROGRAM. THE FOLLOWING
C  INFORMATION MUST BE SUPPLIED BY THE USER:
C
C  1) THE EMBEDDING IMPEDANCES AT THE LO FREQUENCY AND THE HIGHER
C     HARMONICS AS REAL AND IMAGINARY PARTS (ZER,ZEI) IN OHMS.
C  2) THE SIDEBAND IMPEDANCES IN COMPLEX FORM (ZEMBSB) IN OHMS,WHERE
C     SIDEBAND M IS ARRAY ELEMENT (NH/2+1-M) AND THERE ARE NH+1 ARRAY
C     ELEMENTS IN ALL.NOTE THAT,BECAUSE ALL LOWER SIDEBANDS ARE TREATED
C     AS NEGATIVE FREQUENCIES,VALUES OF ZEMBSB FOR LOWER SIDEBANDS MUST
C     BE THE CONJUGATES OF THEIR USUAL POSITIVE FREQUENCY VALUES.
C  3) THE LO FREQUENCY (FP) AND THE INTERMEDIATE FREQUENCY (IF) IN HZ.
C  4) THE DESIRED RECTIFIED CURRENT (IDBIAS) IN AMPERES.
```

```
C  5) THE DC BIAS VOLTAGE ACROSS THE DIODE (VDBIAS) IN VOLTS.
C  6) THE DIODE SERIES RESISTANCE AT DC (RS) IN OHMS.
C  7) THE DIODE SKIN RESISTANCE CONSTANT (RSKIN) IN OHMS/SQRT(HZ).
C  8) THE DIODE EQUIVALENT TEMPERATURE (TEQ) IN DEGREES K.
C  9) THE DIODE REVERSE SATURATION CURRENT (IS) IN AMPERES.
C  10) THE DIODE CAPACITANCE AT ZERO VOLTS (C0) IN FARADS.
C  11) THE DIODE CONTACT POTENTIAL (PHI) IN VOLTS.
C  12) THE DIODE CAPACITANCE LAW EXPONENT (GAM).
C  13) THE DIODE I-V LAW EXPONENT (ALP=Q/NKT) IN 1/VOLTS.
C
C    THERE ARE SEVERAL OTHER VARIABLES WHICH MAY BE ADJUSTED TO
C  CONTROL THE OPERATION OF THE PROGRAM. THEIR VALUES HAVE BEEN
C  OPTIMIZED FOR THE LISTING WHICH FOLLOWS AND MAY BE ALTERED
C  WHEN THE PROGRAM IS USED FOR OTHER PROBLEMS. THESE VARAIBLES ARE:
C
C  ACC:THE ACCURACY OF THE RUNGE KUTTA INTEGRATION USED TO SOLVE THE
C      STATE EQUATION OF THE DIODE NETWORK.
C  IDCACC:THE ACCURACY WITH WHICH THE DC CURRENT MUST APPROACH THE
C         DESIRED VALUE (IDBIAS).
C  NLO:THE NUMBER OF LO CYCLES NEEDED TO REACH A STEADY STATE IN THE
C      NONLINEAR ANALYSIS ROUTINE. SINCE SETTLING OCCURS IN SUCCESSIVE
C      REFLECTION CYCLES NLO CAN USUALLY BE SET TO ONE.
C  NPRINT:THE NUMBER OF CYCLES BETWEEN PRINTOUTS OF THE INTERMEDIATE
C         RESULTS IN THE NONLINEAR ANALYSIS.
C  NPTS:THE NUMBER OF INTERVALS+1 INTO WHICH THE LO CYCLE IS DIVIDED
C       FOR THE INTEGRATION AND STORAGE OF DATA POINTS. TO AVOID
C       ALIASING NPTS SHOULD BE CHOSEN CONSIDERABLY LARGER THAN
C       (2*NH+1) THE VALUE REQUIRED BY THE SAMPLING THEOREM.
C  VLO:THE INITIAL VALUE OF THE LOCAL OSCILLATOR VOLTAGE.
C  VLOINC:THE INITIAL INCREMENT SIZE USED TO ZERO IN ON THE DESIRED
C         DC RECTIFIED CURRENT (IDBIAS).
C  ZQACC: THE DEGREE OF CONVERGENCE OF THE FINAL SOLUTION IN THE NON-
C         LINEAR ANALYSIS.
C  Z0:THE CHARACTERISTIC IMPEDANCE OF THE HYPOTHETICAL TRANSMISSION
C     LINE INSERTED BETWEEN THE DIODE AND EMBEDDING NETWORK. Z0 HAS A
C     SIGNIFIGANT EFFECT ON THE RATE OF CONVERGENCE OF THE NONLINEAR
C     ANALYSIS.
C
C    IF THE DC CURRENT REACHED AFTER TEN REFLECTION CYCLES IN THE
C  NONLINEAR ANALYSIS IS NOT SUFFICIENTLY CLOSE TO IDBIAS,THE CYCLE
C  NUMBER AT WHICH THE LO VOLTAGE IS ADJUSTED MUST BE INCREASED. THIS
C  IS ACCOMPLISHED BY CHANGING THE STEP AFTER STATEMENT LABEL 10 IN
C  THE LGSIG ROUTINE.
C
C    THE USER MAY FIND IT NECESSARY TO ALTER OTHER PROGRAM VARIABLES
C  FOR SPECIFIC PROBLEMS. FOR THIS REASON A LIST OF ALL THE VARIABLES
C  (EXCEPT THOSE INTERNAL TO THE IBM SSP ROUTINES USED IN THE PROGRAM),
C  SUBROUTINES AND COMMON BLOCKS USED IN THE PROGRAM FOLLOWS.
C
C
C    LIST OF VARIABLES
C
C  A: THE SMALL-SIGNAL AUGMENTED ADMITTANCE (Y') OR IMPEDANCE (Z')
C     MATRIX OF THE MIXER.
C  ACC: THE INTEGRATION ACCURACY USED IN DRKGS.
C  ALP: THE DIODE I-V LAW EXPONENT (Q/NKT).
C  AUX: DRKGS STORAGE ARRAY OF DIMENSION (8,NDIM).
C  AV: REAL PART OF THE VOLTAGE WAVE INCIDENT ON THE DIODE AT EACH
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```
C        HARMONIC.
C    BLANK: A NUMERIC USED FOR PLOTTING A BLANK.
C    BOLTZ: BOLTZMANN'S CONSTANT (1.38 E-23).
C    BV: IMAGINARY PART OF THE VOLTAGE WAVE INCIDENT ON THE DIODE AT
C        EACH LO HARMONIC.
C    CJ: FREQUENCY SCALED DIODE JUNCTION CAPACITANCE USED IN LGSIG.
C    CJCOS: FOURIER COSINE COEFFICIENTS OF THE DIODE CAPACITANCE.
C    CJDATA: STORAGE ARRAY CONTAINING THE DIODE CAPACITANCE FOR EACH
C            OF THE NPTS POINTS IN THE LOCAL OSCILLATOR CYCLE.
C    CJMAG: THE MAGNITUDES OF THE FOURIER CAPACITANCE COEFFICIENTS.
C    CJPHA: PHASES OF THE FOURIER CAPACITANCE COEFFICIENTS (IN DEGREES).
C    CJPOS: POSITION OF CJ IN THE PLOT OF DIODE CAPACITANCE.
C    CJSIN: FOURIER SINE COEFFICIENTS OF THE DIODE CAPACITANCE.
C    COR: THE NOISE CURRENT CORRELATION MATRIX USED IN THE NOISE ANALYSIS.
C    C0: THE DIODE CAPACITANCE AT ZERO VOLTS (IN FARADS).
C    C0POS: POSITION OF C0 IN THE GRAPH OF THE DIODE CAPACITANCE.
C    DERY: INITIALLY THE RKGS ERROR PARAMETER AND LATER THE DERIVATIVE
C          IN THE NETWORK STATE EQUATION (DY(I)/DT).
C    DET: DETERMINANT OF THE A MATRIX AS RETURNED BY THE CMINV ROUTINE.
C    DOT: A NUMERIC USED FOR PLOTTING A DOT.
C    DVR: DIFFERENCE IN THE REFLECTED VOLTAGE BETWEEN TWO CYCLES.
C    DVRDC: DIFFERENCE IN THE DC REFLECTED VOLTAGE BETWEEN TWO CYCLES.
C    FC: COMPLEX FOURIER COEFFICIENTS OF THE DIODE CAPACITANCE (HALF
C        AMPLITUDE).
C    FG: COMPLEX FOURIER COEFFICIENTS OF THE DIODE CONDUCTANCE (HALF
C        AMPLITUDE).
C    FP: THE LOCAL OSCILLATOR OR PUMP FREQUENCY IN HERTZ.
C    GAM: THE DIODE CAPACITANCE EXPONENT.
C    GJ: THE DIODE CONDUCTANCE.
C    GJCOS: FOURIER COSINE COEFFICIENTS OF THE DIODE CONDUCTANCE.
C    GJDATA: STORAGE ARRAY CONTAINING THE VALUES OF THE DIODE
C            CONDUCTANCE FOR EACH OF THE NPTS POINTS IN THE LO CYCLE.
C    GJMAG: MAGNITUDES OF THE FOURIER CONDUCTANCE COEFFICIENTS.
C    GJPHA: PHASES OF THE FOURIER CONDUCTANCE COEFFICIENTS (IN DEGREES).
C    GJSIN: FOURIER SINE COEFFICIENTS OF THE DIODE CONDUCTANCE.
C    I: ARRAY ELEMENT OR COUNTING VARIABLE.
C    ICJ: THE CURRENT THROUGH THE DIODE CAPACITANCE.
C    ICJDAT: STORAGE ARRAY FOR ICJ AT EACH POINT IN THE LO CYCLE.
C    IDBIAS: DESIRED RECTIFIED CURRENT AT WHICH THE MIXER IS TO BE
C            OPERATED (IN AMPS).
C    IDCACC: DESIRED ACCURACY OF THE CALCULATED DC CURRENT,MEASURED AS
C            THE MAXIMUM TOLERABLE DEVIATION FROM THE DESIRED DC CURRENT
C            ,IDBIAS.
C    IDCOS: FOURIER COSINE COEFFICIENT OF THE TOTAL DIODE CURRENT.
C    IDDATA: STORAGE ARRAY CONTAINING THE VALUES OF THE TOTAL DIODE
C            CURRENT FOR EACH OF THE NPTS POINTS IN THE LO CYCLE.
C    IDPOS: POSITION OF ID ON THE GRAPH OF TOTAL CURRENT IN THE DIODE.
C    IDSIN: FOURIER SINE COEFFICIENT OF THE TOTAL DIODE CURRENT.
C    IER: THE ERROR MESSAGE CODE OF SUBROUTINE DFORIT.
C    IF: THE INTERMEDIATE FREQUENCY IN HERTZ.
C    IGJ: THE CURRENT THROUGH THE DIODE CONDUCTANCE.
C    IGJDAT: STORAGE ARRAY CONTAINING VALUES OF THE DIODE CONDUCTANCE
C            CURRENT FOR EACH OF THE NPTS POINTS IN THE LO CYCLE.
C    IGJPOS: POSITION OF IGJ ON THE GRAPH OF DIODE CONDUCTANCE CURRENT.
C    IHLF: DRKGS PARAMETER GIVING THE NUMBER OF TIMES THE INTEGRATION
C          INTERVAL HAS BEEN HALVED OR DOUBLED.
C    IMZIN: IMAGINARY PART OF THE INPUT IMPEDANCE AT EACH SIDEBAND.
C    IS: DIODE SATURATION CURRENT (IN AMPS).
```

```
C  ITER: LOOP REPRESENTING THE REFLECTION CYCLES IN THE NONLINEAR
C        ANALYSIS
C  IVLO: COUNTING VARIABLE USED TO SIGNAL THE END OF THE JLO LOOP.
C  J: ARRAY ELEMENT OR COUNTING VARIABLE.
C  JH: LOOP OVER THE LO HARMONICS.
C  JLO: LOOP OVER THE LO CYCLES OF INTEGRATION TO OBTAIN STEADY STATE.
C  JPRINT: KEEPS TRACK OF THE CYCLES WHOSE RESULTS ARE TO BE PRINTED.
C  JPT: LOOP OVER THE INTERVALS FOR WHICH DRKGS WILL INTEGRATE.
C  JVLO: LOOP FOR ZEROING IN ON THE DESIRED RECTIFIED CURRENT (IDBIAS).
C  K: ARRAY ELEMENT OR COUNTING VARIABLE.
C  LIJ: CONVERSION LOSS FROM SIDEBAND J TO SIDEBAND I.
C  LOFLAG: A FLAG TO KEEP COUNT OF THE NUMBER OF TIMES VLO HAS BEEN
C            LOWERED TO TRY AND OBTAIN THE DESIRED RECTIFIED CURRENT.
C  LOPWR: THE REQUIRED LO POWER FOR A RECTIFIED CURRENT OF IDBIAS.
C  LOVLO: THE LOWER BOUND OF THE VLO ADJUSTMENT DONE IN SUBROUTINE
C         ADJLO.
C  MAXID: MAXIMUM VALUE OF ID IN AN LO CYCLE (USED FOR PLOTTING).
C  MAXIGJ: MAXIMUM VALUE OF IGJ IN AN LO CYCLE (USED FOR PLOTTING).
C  MAXCJ: MAXIMUM VALUE OF CJ IN AN LO CYCLE (USED FOR PLOTTING).
C  MAXVD: MAXIMUM VALUE OF VD IN AN LO CYCLE (USED FOR PLOTTING).
C  MINCJ: MINIMUM VALUE OF CJ IN AN LO CYCLE (USED FOR PLOTTING).
C  NDIM: THE NUMBER OF DIFFERENTIAL EQUATIONS TO BE SOLVED BY DRKGS.
C  NH: TOTAL NUMBER OF LO HARMONICS CONSIDERED IN THE ANALYSIS.
C  NHARM: USED IN PRINT1 AS THE TOTAL NUMBER OF LO HARMONICS.
C  NHD2: THE TOTAL NUMBER OF LO HARMONICS DIVIDED BY TWO.
C  NHD2P1: THE TOTAL NUMBER OF LO HARMONICS DIVIDED BY TWO, PLUS ONE.
C  NHP1: THE TOTAL NUMBER OF LO HARMONICS PLUS ONE (# OF SIDEBANDS).
C  NHP2: THE NUMBER OF LO HARMONICS PLUS 2.
C  NITER: TOTAL NUMBER OF ITERATIONS ALLOWED FOR ACHIEVING FULL CONVER-
C         GENCE AFTER THE DESIRED RECTIFIED CURRENT HAS BEEN OBTAINED.
C  NLO: THE TOTAL NUMBER OF LOCAL OSCILLATOR CYCLES TO BE INTEGRATED
C       THROUGH IN ORDER TO REACH A STEADY STATE.
C  NPRINT: CONTROLS THE REFLECTION CYCLE NUMBER AT WHICH THE PRINTING
C          OF THE INTERMEDIATE RESULTS OCCURS.
C  NPTS: THE NUMBER OF INTERVALS + 1 OVER WHICH DRKGS INTEGRATES.
C  NSB: SIDEBAND TO WHICH THE EQUIVALENT NOISE TEMPERATURE OF THE
C       MIXER IS REFERRED TO IN SUBROUTINE TMIX.
C  NVLO: THE NUMBER OF TIMES THE LO VOLTAGE IS ALLOWED TO BE ADJUSTED.
C  PHI: DIODE CONTACT POTENTIAL (IN VOLTS).
C  PI: THE CONSTANT PI.
C  PRMT: ARRAY USED BY RKGS CONTAINING THE FOLLOWING VARIABLES:
C         PRMT(1): THE LOWER BOUND OF THE INTEGRATION INTERVAL.
C         PRMT(2): THE UPPER BOUND OF THE INTEGRATION INTERVAL.
C         PRMT(3): THE INITIAL INTEGRATION INTERVAL STEP SIZE.
C         PRMT(4): THE INTEGRATION ACCURACY.
C         PRMT(5): ALLOWS HALTING OF THE RKGS ROUTINE IF SET TO 0.
C  QEL: THE CHARGE OF THE ELECTRON (1.6 E-19 COULOMBS).
C  REZIN: REAL PART OF THE INPUT IMPEDANCE AT EACH SIDEBAND.
C  RHO: THE COMPLEX VOLTAGE REFLECTION COEFFICIENT OF THE EMBEDDING
C       NETWORK (INCLUDING RS) AT EACH LO HARMONIC.
C  RHODC: THE DC REFLECTION COEFFICIENT OF THE EMBEDDING NETWORK (IN-
C         CLUDING RS).
C  RS: LOW FREQUENCY DIODE SERIES RESISTANCE MEASURED AT A HIGH ENOUGH
C      FREQUENCY THAT THERMAL EFFECTS ARE NEGLIGIBLE BUT SKIN EFFECTS
C      HAVE NOT YET BECOME SIGNIFIGANT.
C  RSKIN: CONSTANT WHICH DETERMINES THE SKIN RESISTANCE FOR A
C          PARTICULAR DIODE,WHERE RS=RS+RSKIN*SQRT(F) AT FREQUENCY F.
C  RSLO: VALUES OF RS AT THE LO HARMONICS.
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C  RSSB: VALUES OF RS AT THE SIDEBAND FREQUENCIES.
C  SHOT: THE SHOT NOISE CONTRIBUTION TO THE TOTAL MIXER TEMPERATURE.
C  STAR: A NUMERIC USED FOR PLOTTING AN ASTERISK.
C  T: INTERMEDIATE VARIABLE IN THE MIXER TEMPERATURE CALCULATION.
C  TEQ: THE EQUIVALENT TEMPERATURE OF THE DIODE SERIES RESISTANCE
C       INCLUDING THE EFFECTS OF LATTICE SCATTERING AND LO HEATING.
C  THERM: THE THERMAL NOISE CONTRIBUTION TO THE TOTAL MIXER TEMPERATURE.
C  TM: THE TOTAL EQUIVALENT INPUT NOISE TEMPERATURE OF THE MIXER.
C  UPFLAG: A FLAG TO KEEP COUNT OF THE NUMBER OF TIMES VLO HAS BEEN
C          RAISED TO TRY AND GET THE DESIRED RECTIFIED CURRENT IDBIAS.
C  UPVLO: THE UPPER BOUND OF VLO DURING ADJUSTMENTS DONE IN ADJLO.
C  V: THE SUM OF THE INSTANTANEOUS SOURCE VOLTAGES AT ALL LO HARMONICS.
C  VDBIAS: THE DC BIAS VOLTAGE ACROSS THE DIODE AND SERIES RESISTANCE.
C  VDC: THE DC VOLTAGE SEEN BY THE DIODE.
C  VDCOS: FOURIER COSINE COEFFICIENTS OF THE VOLTAGE ACROSS THE DIODE.
C  VDDATA: STORAGE ARRAY CONTAINING Y(1),THE VOLTAGE ACROSS THE DIODE
C          AT EACH OF THE NPTS POINTS IN THE LO CYCLE.
C  VDINIT: INITIAL GUESS FOR THE VOLTAGE ACROSS THE DIODE.
C  VDPOS: POSITION OF VD ON THE GRAPH OF THE VOLTAGE ACROSS THE DIODE.
C  VDSIN: FOURIER SINE COEFFICIENTS OF THE VOLTAGE ACROSS THE DIODE.
C  VI: COMPLEX VOLTAGE WAVE INCIDENT ON THE DIODE AT EACH HARMONIC.
C  VIDC: DC VOLTAGE INCIDENT ON THE DIODE.
C  VLO: AMPLITUDE OF THE LOCAL OSCILLATOR VOLTAGE.
C  VLOINC: AMOUNT BY WHICH THE LO VOLTAGE IS INCREMENTED WHEN TRYING
C          TO OBTAIN THE DESIRED DC CURRENT IDBIAS.
C  VR: COMPLEX VOLTAGE WAVE REFLECTED FROM THE DIODE AT EACH HARMONIC.
C  VRDC: DC VOLTAGE WAVE REFLECTED FROM THE DIODE AT EACH HARMONIC.
C  VSQ: MEAN SQUARE OUTPUT NOISE VOLTAGE.
C  VX: INTERMEDIATE VARIABLE FOR THE COMPLEX VOLTAGE WAVEFORM.
C  VXDC: INTERMEDIATE VARIABLE FOR THE DC VOLTAGE WAVEFORM.
C  WIF: 2*PI*INTERMEDIATE FREQUENCY.
C  WK1: WORK SPACE USED IN THE MATRIX INVERSION ROUTINE CMINV.
C  WK2: WORK SPACE USED IN THE MATRIX INVERSION ROUTINE CMINV.
C  WP: 2*PI*PUMP FREQUENCY.
C  X: THE DEPENDENT VARIABLE IN DRKGS (X=2*PI*FP*TIME).
C  XLMAT: THE CONVERSION LOSS MATRIX WHICH GIVES THE CONVERSION
C         LOSSES BETWEEN PAIRS OF SIDEBANDS.
C  Y: DRKGS VARIABLE TO BE FOUND (Y=VOLTAGE ACROSS THE DIODE WITHOUT
C     THE SERIES RESISTANCE).
C  YCPOS: USED FOR PLOTTING THE DIODE CAPACITANCE.
C  YGPOS: USED FOR PLOTTING THE CURRENT THROUGH THE DIODE CONDUCTANCE.
C  YIDPOS: USED FOR PLOTTING THE TOTAL DIODE CURRENT.
C  YPT: A DO LOOP VARIABLE USED FOR PLOTTING POINTS ACROSS A PAGE.
C  YVDPOS: USED FOR PLOTTING THE VOLTAGE ACROSS THE DIODE.
C  ZD: THE EFFECTIVE DIODE IMPEDANCE AT EACH HARMONIC (VD/ID).
C  ZEI: IMAGINARY PART OF THE EMBEDDING IMPEDANCE AT EACH LO HARMONIC.
C  ZEMB: COMPLEX EMBEDDING IMPEDANCE AT EACH LO HARMONIC INCLUDING
C        THE DIODE SERIES RESISTANCE.
C  ZEMBSB: THE EMBEDDING IMPEDANCES AT THE SIDEBAND FREQUENCIES.
C  ZER: REAL PART OF THE EMBEDDING IMPEDANCE AT EACH LO HARMONIC.
C  ZERO: A NUMERIC USED FOR PLOTTING AN O.
C  ZIFOUT: IF PORT IMPEDANCE INCLUDING THE DIODE SERIES RESISTANCE.
C  ZIN: INPUT IMPEDANCES AT THE SIDEBANDS INCLUDING THE DIODE
C       SERIES RESISTANCE.
C  ZQ: IMPEDANCE QUOTIENT (ZD/ZE) AT EACH HARMONIC (USED AS THE LARGE
C      SIGNAL CONVERGENCE PARAMETER).
C  ZQACC: DESIRED DEGREE OF CONVERGENCE MEASURED AS THE DEVIATION FROM
C         UNTIY OF (THE IMPEDANCE AT THE DIODE/EMBEDDING IMPEDANCE).
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C  ZQFLAG: THE NUMBER OF HARMONICS WHICH HAVE NOT YET CONVERGED IN A
C          PARTICULAR CYCLE OF THE NONLINEAR ANALYSIS.
C  ZQMAG: MAGNITUDE OF THE IMPEDANCE QUOTIENT (ZQ).
C  ZQPHA: PHASE OF THE IMPEDANCE QUOTIENT (ZQ) IN DEGREES.
C  Z0: CHARACTERISTIC IMPEDANCE OF THE HYPOTHETICAL TRANSMISSION LINE
C      INSERTED BETWEEN THE DIODE AND THE EMBEDDING NETWORK.
C
C
C    LIST OF SUBROUTINES
C
C  ADJLO: SUBROUTINE FOR ADJUSTING THE LOCAL OSCILLATOR VOLTAGE UNTIL
C         THE DC CURRENT IS CLOSE ENOUGH TO THE DESIRED VALUE,IDBIAS.
C  CMINV: IBM SSP PROGRAM SLIGHTLY MODIFIED TO INVERT A COMPLEX MATRIX.
C  CORREL: SUBROUTINE FOR FORMING THE NOISE CORRELATION MATRIX.
C  DFORIT: DOUBLE PRECISION VERSION OF AN IBM SSP PROGRAM WHICH
C          PERFORMS A FOURIER ANALYSIS ON A PERIODIC WAVEFORM.
C  DRKGS: AN IBM SSP PROGRAM WHICH SOLVES A SYSTEM OF DIFFERENTIAL
C         EQUATIONS USING A RUNGE-KUTTA ALGORITHM.
C  FCT: SUBROUTINE,FOR USE WITH DRKGS,CONTAINING THE NETWORK STATE
C       EQUATION.
C  LGSIG: CONTROL PROGRAM FOR THE LARGE-SIGNAL,NONLINEAR ANALYSIS.
C  OUTP: OUTPUT ROUTINE REQUIRED BY DRKGS BUT NOT USED IN THIS PROGRAM.
C  PLOT: SUBROUTINE FOR PLOTTING THE LARGE-SIGNAL DIODE WAVEFORMS.
C  POWER: CALCULATES THE LO POWER REQUIRED FOR THE ACTUAL MIXER.
C  PRINT1: CONTROLS THE PRINTING OF INITIAL VALUES.
C  PRINT2: CONTROLS THE PRINTING OF VARIABLES FOR A PARTICULAR CYCLE
C          OF THE NONLINEAR ANALYSIS.
C  PRINT3: WRITES THE FOURIER COEFFICIENTS OF THE DIODE CONDUCTANCE
C          AND CAPACITANCE.
C  PRINT4: PRINTS THE RESULTS OF THE SMALL-SIGNAL AND NOISE ANALYSIS.
C  SMSIG: CONTROL PROGRAM FOR THE SMALL-SIGNAL AND NOISE ANALYSIS.
C  TMIX: SUBROUTINE FOR CALCULATING THE EQUIVALENT NOISE TEMPERATURE
C        OF THE MIXER.
C  TNOISE: ADDS THE THERMAL NOISE COMPONENT TO THE CORRELATION MATRIX.
C  YPRIME: SUBROUTINE FOR FORMING THE AUGMENTED MATRIX Y'.
C  ZEMBED: FORMS THE EMBEDDING IMPEDANCES AT THE HARMONICS OF THE LO
C          AND AT THE HARMONIC SIDEBANDS AND THE SERIES RESISTANCE
C          AT THESE FREQUENCIES.
C
C
C     LIST OF COMMON BLOCKS
C
C  COMMON/ADJVLO/:CONTAINS VARIABLES USED IN THE ADJUSTMENT OF THE LO
C                 VOLTAGE TO GIVE A DC CURRENT OF IDBIAS.
C  COMMON/CONST/:CONTAINS CONSTANTS USED IN THE PROGRAM.
C  COMMON/DIODE/:CONTAINS DIODE PARAMETERS.
C  COMMON/FORITS/:CONTAINS VARIABLES RETURNED BY DFORIT.
C  COMMON/IMPED/:CONTAINS INPUT EMBEDDING IMPEDANCES AND THE DIODE
C                SERIES RESISTANCE AT THE VARIOUS FREQUENCIES.
C  COMMON/IVMAG/:CONTAINS THE FOURIER COEFFICIENTS OF THE DIODE CON-
C                DUCTANCE AND CAPACITANCE IN MAGNITUDE AND PHASE.
C  COMMON/LOOPS/:CONTAINS THE LIMITS OF THE VARIOUS PROGRAM LOOPS.
C  COMMON/RKG/:CONTAINS THE INITIAL VALUES FOR THE DRKGS INTEGRATION.
C  COMMON/TLINE/:CONTAINS PARAMETERS EFFECTING THE CONVERGENCE OF THE
C                NONLINER ANALYSIS.
C  COMMON/VOLTS/:CONTAINS VALUES OF THE CIRCUIT VOLTAGES AND CURRENTS.
C
C
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C    BEGIN THE MIXER ANALYSIS.
C
C
C---CALL LGSIG TO DO THE LARGE SIGNAL ANALYSIS
      CALL LGSIG
C---CALL SMSIG TO DO THE SMALL-SIGNAL AND NOISE ANALYSIS
      CALL SMSIG
      STOP
      END



      SUBROUTINE LGSIG
C
C    LGSIG PERFORMS THE NONLINEAR ANALYSIS OF THE MIXER TO DETERMINE
C  THE DIODE CONDUCTANCE AND CAPACITANCE WAVEFORMS PRODUCED BY THE
C  LOCAL OSCILLATOR. THE MULTIPLE REFLECTION METHOD IS USED,(A.R.KERR,
C  IEEE TRANS.ON MICROWAVE THEORY AND TECH.,VOL.MTT-23,NO.10,PP.828-831,
C  OCT.1975) MODIFIED TO INCLUDE THE NONLINEAR CAPACITANCE OF THE DIODE.
C  ALL INITIALIZED VARIABLES ARE INPUT THROUGH THE BLOCK DATA PROGRAM
C  AND ARE TRANSFERRED THROUGH COMMON STATEMENTS.
C    THE OUTPUT INCLUDES:
C  1) VALUES OF THE INITIALIZED VARIABLES AND INPUT DATA.
C  2) THE EMBEDDING IMPEDANCES AND DIODE SERIES RESISTANCE AT THE
C     LO HARMONICS AND SIDEBAND FREQUENCIES.
C  3) THE RESULTS OF SOME OR ALL OF THE REFLECTION CYCLES.
C  4) THE RESULTS OF THE FINAL REFLECTION CYCLE.
C  5) THE REQUIRED LO POWER OF THE MIXER.
C  6) THE FOURIER COEFFICIENTS OF THE DIODE CONDUCTANCE AND CAPACITANCE.
C  7) PLOTS OF THE DIODE VOLTAGE, TOTAL CURRENT, CONDUCTANCE CURRENT,
C     AND CAPACITANCE OVER A SINGLE LO CYCLE.
C    TO CHANGE THE DIMENSIONS OF ANY ARRAY SIMPLY CHANGE THE APPROPRIATE
C  VARIABLE IN THE TYPE STATEMENT IN THIS ROUTINE,SUBROUTINE SMSIG, AND
C  SUBPROGRAM BLOCK DATA. (AV AND BV MUST ALSO HAVE THEIR DIMENSIONS
C  ADJUSTED IN SUBROUTINE FCT).
C    THE SUBROUTINES DRKGS,DFORIT AND CMINV ARE IBM SSP PROGRAMS AND
C  ALL EXCEPT DRKGS HAVE BEEN SLIGHTLY ALTERED FOR USE IN THIS ANALYSIS.
C
C---THE VARIABLES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
C---FOR COMMON/ADJVLO/:
      REAL*8 LOVLO,UPVLO,VLOINC,IDCACC
      INTEGER UPFLAG,LOFLAG
C---FOR COMMON/CONST/:
      REAL*8 QEL,BOLTZ,PI,TEQ
C---FOR COMMON/DIODE/:
      REAL*8 ALP,PHI,GAM,C0,IS,RS,RSKIN,FP,IF,IGJ,ICJ,GJ,CJ
C---FOR COMMON/FORITS/:
      REAL*8 GJCOS(9),GJSIN(9),CJCOS(9),CJSIN(9),VDCOS(9),VDSIN(9)
      REAL*8 IDCOS(9),IDSIN(9)
      INTEGER IER
C---FOR COMMON/IMPED/:
      COMPLEX*16 ZEMBSB(9)
      REAL*8 ZER(8),ZEI(8),ZEMBDC,RSLO(8),RSSB(9)
C---FOR COMMON/LOOPS/:
      INTEGER NH,NLO,NVLO,NPTS,NPRINT,NITER
C---FOR COMMON/RKG/:
      REAL*8 ACC,VDINIT
      INTEGER NDIM
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C---FOR COMMON/TLINE/:
      REAL*8 Z0,ZQACC
      INTEGER ZQFLAG
C---FOR COMMON/VOLTS/:
      REAL*8 AV(8),BV(8),VIDC,VLO,VDBIAS,IDBIAS
C---FOR VARIABLES NOT IN ANY COMMON BLOCKS:
      COMPLEX*16 RHO(8),ZEMB(8),VI(8),VR(8),DVR(8),VX,ZD,ZQ
      REAL*8 Y(1),DERY(1),PRMT(5),AUX(8,1)
      REAL*8 VRDC,DVRDC,VXDC,VDC,RHODC,LOPWR
      REAL*8 ICJDAT(51),IGJDAT(51),CJDATA(51),GJDATA(51)
      REAL*8  VDDATA(51),IDDATA(51),ZQMAG(8),ZQPHA(8)
      INTEGER IHLF,ITER,IVLO,JVLO,JLO,JPT,JH,NHP1,NHD2,NHD2P1
C---THE COMMON BLOCKS USED ARE:
      COMMON/ADJVLO/LOVLO,UPVLO,LOFLAG,UPFLAG,VLOINC,IDCACC
      COMMON/CONST/QEL,BOLTZ,PI,TEQ
      COMMON/DIODE/ALP,PHI,GAM,C0,IS,RS,RSKIN,FP,IF,IGJ,ICJ,GJ,CJ
      COMMON/FORITS/GJCOS,GJSIN,CJCOS,CJSIN,VDCOS,VDSIN,IDCOS,IDSIN,IER
      COMMON/IMPED/ZER,ZEI,ZEMBDC,ZEMBSB,RSLO,RSSB
      COMMON/LOOPS/NH,NLO,NVLO,NPTS,NPRINT,NITER
      COMMON/RKG/ACC,VDINIT,NDIM
      COMMON/TLINE/Z0,ZQACC,ZQFLAG
      COMMON/VOLTS/AV,BV,VIDC,VLO,VDBIAS,IDBIAS
C---SINCE THE FCT AND OUTP SUBPROGRAMS ARE CALLED BY DRKGS THEY MUST BE
C---DEFINED EXTERNALLY
      EXTERNAL FCT,OUTP
C---DEFINE SOME USEFUL CONSTANTS
      NHP1=NH+1
      NHD2=NH/2
      NHD2P1=NH/2+1
C---CALL ZEMBED TO FORM THE EMBEDDING IMPEDANCES
      CALL ZEMBED(ZER,ZEI,ZEMBDC,ZEMBSB,RS,RSLO,RSSB,RSKIN,FP,IF
     1,PI,NH,NHP1,NHD2P1)
C---SET THE IMPEDANCE AT DC AND THE FIRST HARMONIC TO Z0 TO SPEED THE
C---ANALYSIS. THIS DOES NOT EFFECT THE DIODE WAVEFORMS PROVIDED THE
C---BIAS VOLTAGE IS ADJUSTED TO GIVE THE DESIRED DC VOLTAGE AT THE
C---DIODE TERMINALS. THIS IS DONE 5 LINES BEFORE STATEMENT LABEL 2.
      ZEMB(1)=DCMPLX(Z0,0.0D0)
      ZEMBDC=Z0
C---FORM THE SET OF COMPLEX IMPEDANCES WITH THE SERIES RESISTANCE ADDED
      DO 1 JH=2,NH
    1 ZEMB(JH)=DCMPLX(ZER(JH)+RSLO(JH),ZEI(JH))
C---CALCULATE THE REFLECTION COEFFICIENT OF THE EMBEDDING NETWORK AT
C---EACH LO HARMONIC
      RHODC=(ZEMBDC-Z0)/(ZEMBDC+Z0)
      DO 13 JH=1,NH
   13 RHO(JH)=(ZEMB(JH)-Z0)/(ZEMB(JH)+Z0)
C---INITIALIZE THE VARIABLES FOR THE VLO ADJUSTMENT LOOP
      JVLO=1
      IVLO=NVLO
      UPFLAG=0
      LOFLAG=0
C---INITIALIZE VARIABLES FOR THE INTEGRATION BY DRKGS
      PRMT(4)=ACC
      PRMT(3)=2.0D0*PI/DFLOAT(NPTS)
      PRMT(2)=PRMT(3)
      PRMT(1)=0.0D0
      Y(1)=VDINIT
      DERY(1)=1.0D0
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C---CALCULATE THE DC SOURCE VOLTAGE FROM THE GIVEN BIAS VOLTAGE,VDBIAS,
C---ACROSS THE DIODE PLUS SERIES RESISTANCE
      VDC=VDBIAS+IDBIAS*(ZEMBDC-RS)
C---SET THE INITIAL INCIDENT AND REFLECTED VOLTAGES
      DO 2 JH=1,NH
      VI(JH)=DCMPLX(0.0D0,0.0D0)
      VR(JH)=DCMPLX(0.0D0,0.0D0)
      AV(JH)=0.0D0
    2 BV(JH)=0.0D0
C---THE DC TERMS
      VRDC=0.0D0
      VIDC=VDC*Z0/(Z0+ZEMBDC)
C---RETURN HERE IF THE LO VOLTAGE HAS BEEN ADJUSTED
   15 ITER=0
C---SET THE INCIDENT VOLTAGE AT THE LO FREQUENCY AND STORE THE RESULTS
      VX=VLO*Z0/(ZEMB(1)+Z0)
      AV(1)=DREAL(VX)
      BV(1)=-DIMAG(VX)
      VI(1)=VX
C---CALL PRINT1 TO WRITE THE INITIAL CONDITIONS
      IF(JVLO.NE.1) GOTO 3
      CALL PRINT1(ZEMB,ZEMBDC,ZER,ZEI,ZEMBSB,PRMT,Y,DERY,VLO,VDBIAS
     1,IDBIAS,RSSB,RSLO,NH,NHP1,NHD2)
C---START THE REFLECTION CYCLE
    3 ITER=ITER+1
C---PRINT ONLY AFTER MULTIPLES OF NPRINT CYCLES HAVE BEEN COMPLETED
      JPRINT=MOD(ITER,NPRINT)
C---BEGIN THE LO CYCLE LOOP FOR REACHING STEADY STATE BETWEEN THE
C---DIODE AND TRANSMISSION LINE AND SET THE INTEGRATION INTERVAL
      DO 6 JLO=1,NLO
      PRMT(1)=0.0D0
      PRMT(2)=PRMT(3)
      DO 5 JPT=1,NPTS
      CALL DRKGS(PRMT,Y,DERY,NDIM,IHLF,FCT,OUTP,AUX)
C---RESET THE DRKGS ERROR WEIGHT FOR THE NEXT INTERVAL
      DERY(1)=1.0D0
      IF(JLO.NE.NLO) GOTO 14
      IF(JPT.EQ.NPTS)  GOTO 4
C---STORE THE RESULTS FOR EACH POINT STARTING AT TIME T=0
      VDDATA(JPT+1)=Y(1)
      IDDATA(JPT+1)=IGJ+ICJ
      IGJDAT(JPT+1)=IGJ
      ICJDAT(JPT+1)=ICJ
      GJDATA(JPT+1)=GJ
      CJDATA(JPT+1)=CJ
      GOTO 14
    4 VDDATA(1)=Y(1)
      IDDATA(1)=IGJ+ICJ
      GJDATA(1)=GJ
      CJDATA(1)=CJ
      IGJDAT(1)=IGJ
      ICJDAT(1)=ICJ
C---GO ON TO THE NEXT TIME INTERVAL
   14 PRMT(1)=PRMT(2)
      PRMT(2)=PRMT(2)+PRMT(3)
    5 CONTINUE
    6 CONTINUE
C---CALL DFORIT TO FORM THE FOURIER COEFFICIENTS OF THE DIODE CURRENT
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C---AND VOLTAGE
      CALL DFORIT(VDDATA,NPTS/2,NH,VDCOS,VDSIN,IER)
      CALL DFORIT(IDDATA,NPTS/2,NH,IDCOS,IDSIN,IER)
C---SET THE FLAG FOR THE CONVERGENCE TESTS
      ZQFLAG=0
C---FIND THE DIODE IMPEDANCES AND CALCULATE THE REFLECTED VOLTAGE
C---WAVEFORMS
      DO 7 JH=1,NH
      ZD=DCMPLX(VDCOS(JH+1),-VDSIN(JH+1))/DCMPLX(IDCOS(JH+1),
     1-IDSIN(JH+1))
      VX=DCMPLX(VDCOS(JH+1),-VDSIN(JH+1))-DCMPLX(AV(JH),-BV(JH))
C---FIND THE CHANGE IN THE REFLECTED VOLTAGE SINCE THE LAST CYCLE
      DVR(JH)=VX-VR(JH)
      VR(JH)=VX
C---CALCULATE THE IMPEDANCE RATIOS AT EACH LO HARMONIC TO DETERMINE
C---THE DEGREE OF CONVERGENCE
      ZQ=ZD/ZEMB(JH)
      ZQMAG(JH)=CDABS(ZQ)
      ZQPHA(JH)=DATAN2(DIMAG(ZQ),DREAL(ZQ))*57.29577951D0
      IF(JH.EQ.1) GOTO 7
      IF(ZQMAG(JH).GT.1.0D0+ZQACC) ZQFLAG=ZQFLAG+1
      IF(ZQMAG(JH).LT.1.0D0-ZQACC) ZQFLAG=ZQFLAG+1
    7 CONTINUE
C---THE DC REFLECTED VOLTAGE AND ITS CHANGE SINCE THE LAST CYCLE
      VXDC=0.5D0*(VDCOS(1)-Z0*IDCOS(1))
      DVRDC=VXDC-VRDC
      VRDC=VXDC
      IF(JPRINT.NE.0) GOTO 9
C---CALL PRINT2 TO WRITE THE RESULTS OF THIS REFLECTION CYCLE
      IF(JVLO.NE.IVLO) GOTO 9
      CALL PRINT2(RHO,VI,VR,DVR,VDCOS,VDSIN,IDCOS,IDSIN,ZQMAG,ZQPHA,
     1VRDC,DVRDC,VIDC,RHODC,AV,BV,ITER,ZQFLAG,JVLO,NH,NHP1)
    9 CONTINUE
C---FIND THE NEW VOLTAGE INCIDENT ON THE DIODE AT THE LO AND HARMONICS
      DO 10 JH=1,NH
      VX=VI(JH)+RHO(JH)*DVR(JH)
      VI(JH)=VX
      AV(JH)=DREAL(VX)
   10 BV(JH)=-DIMAG(VX)
C---FIND THE NEW DC VOLTAGE WAVE INCIDENT ON THE DIODE
      VIDC=VIDC+RHODC*DVRDC
C---DON'T ADJUST THE DC CURRENT UNTIL WE HAVE RUN FOR ENOUGH CYCLES TO
C---REACH A STEADY STATE
      IF(ITER.NE.10) GOTO 11
C---ADJUST THE DC CURRENT TO THE DESIRED VALUE BY CHANGING VLO
      CALL ADJLO(JVLO,IVLO,VLO,IDCOS,IDBIAS,NHP1)
C---WAS THIS THE LAST VLO ADJUSTMENT LOOP?
      IF(JVLO.EQ.IVLO) GOTO 11
C---REPEAT THE ANALYSIS WITH A NEW VALUE OF VLO
      JVLO=JVLO+1
      GOTO 15
C---WAS THIS THE LAST REFECTION CYCLE ALLOWED?
   11 IF(ITER.EQ.NITER) GOTO 12
C---HAS THE SOLUTION CONVERGED?
      IF(ZQFLAG.EQ.0) GOTO 12
C---GO ON TO THE NEXT REFLECTION CYCLE
      GOTO 3
C---CALL PRINT2 TO WRITE THE RESULTS OF THE FINAL REFLECTION CYCLE
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   12 CALL PRINT2(RHO,VI,VR,DVR,VDCOS,VDSIN,IDCOS,IDSIN,ZQMAG,ZQPHA,
     1VRDC,DVRDC,VIDC,RHODC,AV,BV,ITER,ZQFLAG,JVLO,NH,NHP1)
C---CALL POWER TO FIND THE REQUIRED LO POWER
      CALL POWER(ZQMAG(1),ZQPHA(1),ZER(1),ZEI(1),RSLO(1),VLO,Z0,LOPWR)
C---UNSCALE THE CAPACITANCE VALUES (THEY WERE SCALED IN SUBROUTINE FCT
C---WHICH IS CALLED BY THE DRKGS INTEGRATION ROUTINE).
      DO 19 JPT=1,NPTS
   19 CJDATA(JPT)=CJDATA(JPT)/(2.0D0*PI*FP)
C---FINISH THE ANALYSIS BY OBTAINING THE FOURIER COEFFICIENTS OF THE
C---DIODE CONDUCTANCE AND CAPACITANCE.
      CALL DFORIT(GJDATA,NPTS/2,NH,GJCOS,GJSIN,IER)
      CALL DFORIT(CJDATA,NPTS/2,NH,CJCOS,CJSIN,IER)
C---CALL PLOT TO PRINT THE DIODE WAVEFORMS IN THE TIME DOMAIN
      CALL PLOT (IGJDAT,CJDATA,VDDATA,IDDATA,NPTS,ITER,C0)
      RETURN
      END



      SUBROUTINE ZEMBED(ZER,ZEI,ZEMBDC,ZEMBSB,RS,RSLO,RSSB,RSKIN,
     1FP,IF,PI,NH,NHP1,NHD2P1)
C
C       ZEMBED FORMS THE EMBEDDING IMPEDANCES AT THE HARMONICS OF THE
C     LO AND AT THE SIDEBAND FREQUENCIES (ASSUMING THEY HAVE NOT BEEN
C     INPUT VIA THE BLOCK DATA PROGRAM). IT ALSO FORMS THE SERIES
C     RESISTANCE,INCLUDING SKIN EFFECT,AT THESE FREQUENCIES.
C       NOTE THAT IF YOU WISH TO INPUT THE SIDEBAND EMBEDDING IMPEDAN-
C     CES THROUGH THE BLOCK DATA SUBPROGRAM THE SIDEBAND FREQUENCY NO-
C     TATION MUST BE TAKEN INTO ACCOUNT. ALL LOWER SIDEBAND EMBEDDING
C     IMPEDANCES (ZEMBSB(I) , I.GT.(NH/2)+1 ) SHOULD BE FORMED AS THE
C     COMPLEX CONJUGATES OF THEIR POSITIVE FREQUENCY VALUES. THIS IS
C     CONSISTANT WITH THE USE OF NEGATIVE FREQUENCIES FOR ALL LOWER
C     SIDEBANDS. NOTE THAT SIDEBAND I IS ARRAY ELEMENT (NH/2 + 1 -I)
C     IN THIS FREQUENCY NOTATION.
C
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
      COMPLEX*16 ZEMBSB(NHP1)
      REAL*8 ZER(NH),ZEI(NH),ZEMBDC,RS,RSKIN,FP,IF,PI
      REAL*8 RSSB(NHP1),RSLO(NH)
      INTEGER NH,NHP1,NHD2P1,K,I
C---IN THIS EXAMPLE THE EMBEDDING IMPEDANCES AT THE LO HARMONICS
C---AND AT THE SIDEBAND FREQUENCIES HAVE BEEN INPUT VIA THE BLOCK DATA
C---SUBPROGRAM AND THUS THEY WILL NOT BE FORMED IN THIS SUBROUTINE
C
C---FORM THE SERIES RESISTANCE OF THE DIODE AT THE LO HARMONICS AND
C---THE SIDEBAND FREQUENCIES. THE FREQUENCY DEPENDENCE DUE TO THE
C---SKIN EFFECT IS ASSUMED TO HAVE THE FORM RS(F)=RS+RSKIN*SQRT(F)
      DO 40 I=1,NHP1
      K=NHD2P1-I
      RSSB(I)=RS+RSKIN*DSQRT(DABS(FP*K+IF))
      IF(I.EQ.NHP1) GOTO 40
      RSLO(I)=RS+RSKIN*DSQRT(I*FP)
   40 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE POWER(ZQMAG,ZQPHA,ZER,ZEI,RSLO,VLO,Z0,LOPWR)
C---
C---POWER CALCULATES AND PRINTS THE REQUIRED LO POWER USED BY THE
C---MIXER WITH THE ORIGINAL VALUE OF ZE(1) (BEFORE IT WAS SET TO Z0).
C---
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
      COMPLEX*16 ZQ,ZE
      REAL*8 ZER,ZEI,ZQMAG,ZQPHA,RSLO,VLO,Z0,LOPWR,D
C---TRANSFORM ZQMAG AND ZQPHA INTO THE REAL AND IMAGINARY PARTS
C---OF A COMPLEX NUMBER
      D=DSQRT(1+(DTAN(ZQPHA/57.29577951D0))**2)
      ZQ=DCMPLX(ZQMAG/D,ZQMAG*DTAN(ZQPHA/57.29577951D0)/D)
      ZE=DCMPLX(ZER,ZEI)
C---CALCULATE THE LO POWER
      LOPWR=(CDABS(VLO*(RSLO+ZE+ZQ*Z0)/(Z0+Z0*ZQ))**2)/(8.0D0*ZER)
C---PRINT THE RESULTS
      WRITE(6,100) LOPWR
  100 FORMAT(//2X,'REQUIRED LO POWER:',1PE10.3//)
      RETURN
      END



      SUBROUTINE ADJLO(JVLO,IVLO,VLO,IDCOS,IDBIAS,NHP1)
C---
C---SUBROUTINE ADJLO ADJUSTS THE LOCAL OSCILLATOR VOLTAGE UNTIL
C---THE RECTIFIED CURRENT IS WITHIN IDCACC OF THE DESIRED VALUE,IDBIAS.
C---
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
C---FOR COMMON/ADJVLO/:
      REAL*8 LOVLO,UPVLO,VLOINC,IDCACC
      INTEGER UPFLAG,LOFLAG
C---FOR VARIABLES NOT IN ANY COMMON BLOCKS:
      REAL*8 IDCOS(NHP1),VLO,IDBIAS
      INTEGER JVLO,IVLO,NHP1
C---THE COMMON BLOCKS USED ARE:
      COMMON/ADJVLO/LOVLO,UPVLO,LOFLAG,UPFLAG,VLOINC,IDCACC
C---IF THIS IS ALREADY THE LAST VLO LOOP THEN DON'T OUTPUT
      IF(JVLO.EQ.IVLO) GOTO 25
      WRITE(6,100) JVLO,IDBIAS
  100 FORMAT(/'  VALUES OF THE DC CURRENT AND LO VOLTAGE FOR CYCLE ',
     1I2,' OF THE LOOP FOR ADJUSTING VLO TO GIVE ',F8.6,' AMPS ARE:')
      WRITE(6,110) IDCOS(1),VLO
  110 FORMAT(10X,'  IDCOS(1)=',F8.6,T35,' VLO BEFORE ADJUSTMENT:',F8.5)
      IF(IDCOS(1).GT.IDBIAS+(IDBIAS*IDCACC)) GOTO 10
      IF(IDCOS(1).LT.IDBIAS-(IDBIAS*IDCACC)) GOTO 15
      IVLO=JVLO
      GOTO 20
   10 UPVLO=VLO
C---KEEP TRACK OF THE NUMBER OF TIMES VLO IS GREATER THAN ITS DESIRED
C---VALUE
      UPFLAG=UPFLAG+1
C---IF WE HAVE NOT YET PASSED THE DESIRED VLO CHANGE VLO
      IF(LOFLAG.EQ.0) GOTO 11
      VLO=VLO-(UPVLO-LOVLO)/2.0D0
      GOTO 20
   11 VLO=VLO-VLOINC
```

```
      IF(VLO.LT.0.0) VLO=0.0D0
      GOTO 20
   15 LOVLO=VLO
C---KEEPING TRACK OF THE NUMBER OF TIMES VLO IS LESS THAN ITS DESIRED
C---VALUE
      LOFLAG=LOFLAG+1
C---IF WE HAVE NOT YET PASSED THE DESIRED VLO,CHANGE VLO
      IF(UPFLAG.EQ.0) GOTO 16
      VLO=VLO+(UPVLO-LOVLO)/2.0D0
      GOTO 20
   16 VLO=VLO+VLOINC
   20 WRITE(6,120) VLO
  120 FORMAT( T35,' VLO AFTER ADJUSTMENT: ',F8.5)
   25 RETURN
      END



      SUBROUTINE DRKGS(PRMT,Y,DERY,NDIM,IHLF,FCT,OUTP,AUX)
C---
C---DRKGS IS AN IBM SSP PROGRAM WHICH SOLVES A SYSTEM OF DIFFERENTIAL
C---EQUATIONS BY THE RUNGE-KUTTA ALGORITHM. IT HAS NOT BEEN ALTERED
C---FOR THIS ANALYSIS.
C---
      DIMENSION Y(1),DERY(1),AUX(8,1),A(4),B(4),C(4),PRMT(1)
      DOUBLE PRECISION PRMT,Y,DERY,AUX,A,B,C,X,XEND,H,AJ,BJ,CJ,R1,R2,
     1DELT
      DO 1 I=1,NDIM
    1 AUX(8,I)=.06666666666666666667D0*DERY(I)
      X=PRMT(1)
      XEND=PRMT(2)
      H=PRMT(3)
      PRMT(5)=0.D0
      CALL FCT(X,Y,DERY)
      IF(H*(XEND-X))38,37,2
    2 A(1)=.5D0
      A(2)=.29289321881345248D0
      A(3)=1.7071067811865475D0
      A(4)=.16666666666666667D0
      B(1)=2.D0
      B(2)=1.D0
      B(3)=1.D0
      B(4)=2.D0
      C(1)=.5D0
      C(2)=.29289321881345248D0
      C(3)=1.7071067811865475D0
      C(4)=.5D0
      DO 3 I=1,NDIM
      AUX(1,I)=Y(I)
      AUX(2,I)=DERY(I)
      AUX(3,I)=0.D0
    3 AUX(6,I)=0.D0
      IREC=0
      H=H+H
      IHLF=-1
      ISTEP=0
      IEND=0
    4 IF((X+H-XEND)*H)7,6,5
```

```
    5 H=XEND-X
    6 IEND=1
    7 CALL OUTP(X,Y,DERY,IREC,NDIM,PRMT)
      IF(PRMT(5))40,8,40
    8 ITEST=0
    9 ISTEP=ISTEP+1
      J=1
   10 AJ=A(J)
      BJ=B(J)
      CJ=C(J)
      DO 11 I=1,NDIM
      R1=H*DERY(I)
      R2=AJ*(R1-BJ*AUX(6,I))
      Y(I)=Y(I)+R2
      R2=R2+R2+R2
   11 AUX(6,I)=AUX(6,I)+R2-CJ*R1
      IF(J-4)12,15,15
   12 J=J+1
      IF(J-3)13,14,13
   13 X=X+.5D0*H
   14 CALL FCT(X,Y,DERY)
      GOTO 10
   15 IF(ITEST)16,16,20
   16 DO 17 I=1,NDIM
   17 AUX(4,I)=Y(I)
      ITEST=1
      ISTEP=ISTEP+ISTEP-2
   18 IHLF=IHLF+1
      X=X-H
      H=.5D0*H
      DO 19 I=1,NDIM
      Y(I)=AUX(1,I)
      DERY(I)=AUX(2,I)
   19 AUX(6,I)=AUX(3,I)
      GOTO 9
   20 IMOD=ISTEP/2
      IF(ISTEP-IMOD-IMOD)21,23,21
   21 CALL FCT(X,Y,DERY)
      DO 22 I=1,NDIM
      AUX(5,I)=Y(I)
   22 AUX(7,I)=DERY(I)
      GOTO 9
   23 DELT=0.D0
      DO 24 I=1,NDIM
   24 DELT=DELT+AUX(8,I)*DABS(AUX(4,I)-Y(I))
      IF(DELT-PRMT(4))28,28,25
   25 IF (IHLF-10)26,36,36
   26 DO 27 I=1,NDIM
   27 AUX(4,I)=AUX(5,I)
      ISTEP=ISTEP+ISTEP-4
      X=X-H
      IEND=0
      GOTO 18
   28 CALL FCT(X,Y,DERY)
      DO 29 I=1,NDIM
      AUX(1,I)=Y(I)
      AUX(2,I)=DERY(I)
      AUX(3,I)=AUX(6,I)
```

```
      Y(I)=AUX(5,I)
   29 DERY(I)=AUX(7,I)
      CALL OUTP(X-H,Y,DERY,IHLF,NDIM,PRMT)
      IF(PRMT(5))40,30,40
   30 DO 31 I=1,NDIM
      Y(I)=AUX(1,I)
   31 DERY(I)=AUX(2,I)
      IREC=IHLF
      IF(IEND)32,32,39
   32 IHLF=IHLF-1
      ISTEP=ISTEP/2
      H=H+H
      IF(IHLF)4,33,33
   33 IMOD=ISTEP/2
      IF(ISTEP-IMOD-IMOD)4,34,4
   34 IF(DELT-.02D0*PRMT(4))35,35,4
   35 IHLF=IHLF-1
      ISTEP=ISTEP/2
      H=H+H
      GOTO 4
   36 IHLF=11
      CALL FCT(X,Y,DERY)
      GOTO 39
   37 IHLF=12
      GOTO 39
   38 IHLF=13
   39 CALL OUTP(X,Y,DERY,IHLF,NDIM,PRMT)
   40 RETURN
      END



      SUBROUTINE FCT(X,Y,DERY)
C---
C---FCT IS REQUIRED BY DRKGS AND SUPPLIES THE NETWORK STATE EQUATION TO
C---BE SOLVED. NOTE THAT THE JUNCTION CAPACITANCE HAS BEEN FREQUENCY
C---SCALED BY 2*PI*FP SO THAT ONE LO CYCLE OCCURS IN 2*PI SECONDS
C---
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
C---FOR COMMON/CONST/:
      REAL*8 QEL,BOLTZ,PI,TEQ
C---FOR COMMON/DIODE/:
      REAL*8 ALP,PHI,GAM,C0,IS,RS,RSKIN,FP,IF,IGJ,ICJ,GJ,CJ
C---FOR COMMON/LOOPS/:
      INTEGER NH,NLO,NVLO,NPTS,NPRINT,NITER
C---FOR COMMON/TLINE/:
      REAL*8 Z0,ZQACC
      INTEGER ZQFLAG
C---FOR COMMON/VOLTS/:
      REAL*8 AV(8),BV(8),VIDC,VLO,VDBIAS,IDBIAS
C---FOR VARIABLES NOT IN ANY COMMON BLOCKS:
      REAL*8 X,Y(1),DERY(1),V
      INTEGER JH
C---THE COMMON BLOCKS USED ARE:
      COMMON/CONST/QEL,BOLTZ,PI,TEQ
      COMMON/DIODE/ALP,PHI,GAM,C0,IS,RS,RSKIN,FP,IF,IGJ,ICJ,GJ,CJ
      COMMON/LOOPS/NH,NLO,NVLO,NPTS,NPRINT,NITER
      COMMON/TLINE/Z0,ZQACC,ZQFLAG
```

```
      COMMON/VOLTS/AV,BV,VIDC,VLO,VDBIAS,IDBIAS
C---CALCULATE THE TOTAL VOLTAGE ON THE TRANSMISSION LINE INCIDENT ON
C---THE DIODE.
      V=VIDC
      DO 1 JH=1,NH
    1 V=V+AV(JH)*DCOS(JH*X)+BV(JH)*DSIN(JH*X)
C---MULTIPLY BY 2 TO FIND THE EQUIVALENT SOURCE VOLTAGE ASSOCIATED
C---WITH THE TRANSMISSION LINE IMPEDANCE Z0
      V=V*2.0D0
C---FIND THE FREQUENCY SCALED JUNCTION CAPACITANCE.
C---NOTE THAT THE DIODE VOLTAGE Y(1) IS ARTIFICIALLY CLAMPED IF IT
C---EXCEEDS .999*PHI. THIS AVOIDS ERROR MESSAGES DURING THE INITIAL
C---TRANSIENT IN THE NUMERICAL SOLUTION.
      CJ=2.0D0*PI*FP*C0/(1.0D0-DMIN1(Y(1),0.999*PHI)/PHI)**GAM
C---FIND THE CURRENT THROUGH THE DIODE CONDUCTANCE
      IGJ=IS*(DEXP(ALP*DMAX1(-174.0D0/ALP,DMIN1(Y(1),174.0D0/ALP)))
     1-1.0D0)
C---DVD/DT
      DERY(1)=((V-Y(1))/Z0-IGJ)/CJ
C---FIND THE CURRENT THROUGH THE DIODE CAPACITANCE AND THE DIODE
C---CONDUCTANCE
      ICJ=DERY(1)*CJ
      GJ=IGJ*ALP+IS*ALP
      RETURN
      END



      SUBROUTINE OUTP(X,Y,DERY,IHLF,NDIM,PRMT)
C---
C---OUTP IS REQUIRED BY DRKGS BUT IS NOT USED IN THIS PROGRAM
C---
      REAL*8 X,Y(1),DERY(1),PRMT(5)
      INTEGER IHLF,NDIM
      RETURN
      END



      SUBROUTINE DFORIT(FNT,N,M,A,B,IER)
C---
C---DFORIT IS A DOUBLE PRECISION VERSION OF FORIT,AN IBM SSP ROUTINE
C---THAT PERFORMS A FOURIER ANALYSIS ON A PERIODICALLY VARYING FUNCTION.
C---IT COMPUTES THE COEFFICIENTS OF THE TERMS IN THE SERIES WHICH
C---IS GIVEN BY:A(1)+SUM(A(N)COS((N-1)X)+B(N)SIN((N-1)X)) N=2,3,4...
C---
C---THE PARAMETERS USED ARE:
C---FNT/: TABULATED VALUES OF THE FUNCTION TO BE ANALYSED
C---      NOTE THAT FNT(1) CORRESPONDS TO TIME T=0
C---M/: THE MAXIMUM ORDER OF THE HARMONICS TO BE FITTED
C---N/: DEFINES THE INTERVAL OVER WHICH THE POINTS ARE TAKEN. THE
C---   INTERVAL GOES FROM 0 TO 2*PI AND 2N+1 POINTS ARE TAKEN AS DATA.
C---A/: THE FOURIER COSINE COEFFICIENTS
C---B/: THE FOURIER SINE COEFFICIENTS
C---IER/: THE RESULTANT ERROR  MESSAGE CODE WHERE IER=0 MEANS NO ERROR,
C---      IER=1 MEANS N IS LESS THAN M, AND IER=2 MEANS M IS LESS THAN 0
C---
      REAL*8 A(1),B(1),FNT(1),CONST
```

```
      REAL*8 COEF,C,S,C1,S1,AN,FNTZ,U0,U1,U2,Q
      INTEGER N,M
      IER=0
   20 IF(M) 30,40,40
   30 IER=2
      RETURN
   40 IF(M-N) 60,60,50
   50 IER=1
      RETURN
   60 AN=N
      COEF=2.0D0/(2.0D0*AN+1.0D0)
      CONST=3.14159265358979D0*COEF
      S1=DSIN(CONST)
      C1=DCOS(CONST)
      C=1.0D0
      S=0.0D0
      J=1
      FNTZ=FNT(1)
   70 U2=0.0D0
      U1=0.0D0
      I=2*N+1
   75 U0=FNT(I)+2.0D0*C*U1-U2
      U2=U1
      U1=U0
      I=I-1
      IF(I-1) 80,80,75
   80 A(J)=COEF*(FNTZ+C*U1-U2)
      B(J)=COEF*S*U1
      IF(J-(M+1)) 90,100,100
   90 Q=C1*C-S1*S
      S=C1*S+S1*C
      C=Q
      J=J+1
      GO TO 70
  100 A(1)=A(1)*0.5D0
      RETURN
      END



      SUBROUTINE SMSIG
C
C      SMSIG PERFORMS THE SMALL-SIGNAL AND NOISE ANALYSIS OF THE MIXER
C    TO DETERMINE THE CONVERSION LOSS BETWEEN ALL PAIRS OF SIDEBANDS,
C    THE INPUT AND OUTPUT IMPEDANCES, AND THE EQUIVALENT INPUT NOISE
C    TEMPERATURE. THE THEORY IS BASED ON THAT OF D.N.HELD AND A.R.KERR,
C    IEEE TRANS.ON MICROWAVE THEORY AND TECH.,VOL.MTT-26,NO.2,PP.49-61,
C    FEB.1978.
C      ALL INITIALIZED VARIABLES ARE INPUT THROUGH THE BLOCK DATA SUB-
C    PROGRAM AND ARE TRANSFERRED THROUGH COMMON BLOCKS.
C      THE OUTPUT INCLUDES:
C    1) THE CONVERSION LOSS BETWEEN ALL PAIRS OF SIDEBANDS (PRINTED
C       AS A CONVERSION LOSS MATRIX).
C    2) THE INPUT IMPEDANCES OF THE MIXER AT EACH SIDEBAND.
C    3) THE OUTPUT IMPEDANCE AT THE IF.
C    4) THE EQUIVALENT INPUT NOISE TEMPERATURE AND ITS SHOT AND THERMAL
C       COMPONENTS.
C      THE SUBSCRIPT NOTATION USED IN THE PROGRAM TO IDENTIFY THE NH+1
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C  SMALL-SIGNAL SIDEBANDS IS THAT OF A.A,M. SALEH,'THEORY OF RESISTIVE
C  MIXERS',M.I.T. PRESS,CAMBRIDGE,MASS.,1971. SIDEBAND FREQUENCY
C  (IF+N*LO) IS DENOTED BY THE ARRAY SUBSCRIPT (NH/2 + 1 - N). THE
C  LOWER SIDEBANDS ARE TREATED AS NEGATIVE FREQUENCIES CONSIDERABLY
C  SIMPLIFYING THE EQUATIONS IN THE ANALYSIS.
C    IF ARRAY DIMENSIONS ARE ALTERED THEY MUST BE CHANGED HERE, IN
C  SUBROUTINE LGSIG AND IN THE BLOCK DATA PROGRAM, IN ADDITION THE
C  PRINT FORMAT OF THE CONVERSION LOSS MATRIX MUST BE ALTERED IF
C  OTHER THAN EIGHT LO HARMONICS ARE CONSIDERED.
C
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
C---FOR COMMON/CONST/:
      REAL*8 QEL,BOLTZ,PI,TEQ
C---FOR COMMON/DIODE/:
      REAL*8 ALP,PHI,GAM,C0,IS,RS,RSKIN,FP,IF,IGJ,ICJ,GJ,CJ
C---FOR COMMON/FORITS/:
      REAL*8 GJCOS(9),GJSIN(9),CJCOS(9),CJSIN(9),VDCOS(9),VDSIN(9)
      REAL*8 IDCOS(9),IDSIN(9)
      INTEGER IER
C---FOR COMMON/IMPED/:
      COMPLEX*16 ZEMBSB(9)
      REAL*8 ZER(8),ZEI(8),ZEMBDC,RSLO(8),RSSB(9)
C---FOR COMMON/LOOPS/:
      INTEGER NH,NLO,NVLO,NPTS,NPRINT,NITER
C---FOR VARIABLES NOT IN ANY COMMON BLOCKS:
      COMPLEX*16 A(9,9),COR(9,9),FG(9),FC(9)
      COMPLEX*16 T(9),ZIN(9),ZIFOUT,DET
      REAL*8 XLMAT(9,9),TM,THERM,SHOT,LIJ
      REAL*8 GJMAG(9),GJPHA(9),CJMAG(9),CJPHA(9)
      INTEGER JH,NHP1,NHD2P1,NHD2,WK1(9),WK2(9),I,J
C---THE COMMON BLOCKS USED ARE:
      COMMON/CONST/QEL,BOLTZ,PI,TEQ
      COMMON/DIODE/ALP,PHI,GAM,C0,IS,RS,RSKIN,FP,IF,IGJ,ICJ,GJ,CJ
      COMMON/FORITS/GJCOS,GJSIN,CJCOS,CJSIN,VDCOS,VDSIN,IDCOS,IDSIN,IER
      COMMON/IMPED/ZER,ZEI,ZEMBDC,ZEMBSB,RSLO,RSSB
      COMMON/IVMAG/GJMAG,GJPHA,CJMAG,CJPHA
      COMMON/LOOPS/NH,NLO,NVLO,NPTS,NPRINT,NITER
C---DEFINE SOME USEFUL CONSTANTS
      NHP1=NH+1
      NHD2=NH/2
      NHD2P1=NHD2+1
C---FORM THE COMPLEX FOURIER COEFFICIENTS OF THE DIODE CONDUCTANCE
C---AND CAPACITANCE
      DO 10 JH=2,NHP1
      FG(JH)=DCMPLX(GJCOS(JH),-GJSIN(JH))*0.5D0
   10 FC(JH)=DCMPLX(CJCOS(JH),-CJSIN(JH))*0.5D0
      FG(1)=DCMPLX(GJCOS(1),0.0D0)
      FC(1)=DCMPLX(CJCOS(1),0.0D0)
C---CALL PRINT3 TO WRITE THE FOURIER COEFFICIENTS
      CALL PRINT3(FG,FC,GJMAG,GJPHA,CJMAG,CJPHA,NH,NHP1)
C---OPEN CIRCUIT THE IF LOAD TO FIND THE IF PORT IMPEDANCE
      ZEMBSB(NHD2P1)=DCMPLX(1.0D10,0.0D0)
C---FORM THE Y' MATRIX WITH THE OPEN CIRCUITED IF BY CALLING YPRIME
      CALL YPRIME(FG,FC,NHD2,NHD2P1,NHP1,FP,IF,A,ZEMBSB,RSSB)
C---TAKE THE INVERSE OF THE Y' MATRIX TO FIND THE OUTPUT IMPEDANCE
      CALL CMINV(A,NHP1,DET,WK1,WK2,NHP1*NHP1)
C---THE IF OUTPUT IMPEDANCE IS THE CENTER ELEMENT OF THE Z' MATRIX+RS
      ZIFOUT=A(NHD2P1,NHD2P1)+RSSB(NHD2P1)
```

```
C---CONJUGATE MATCH THE IF LOAD IMPEDANCE TO THE IF PORT IMPEDANCE
      ZEMBSB(NHD2P1)=DCONJG(ZIFOUT)
C---FORM THE Y' MATRIX WITH A MATCHED IF LOAD
      CALL YPRIME(FG,FC,NHD2,NHD2P1,NHP1,FP,IF,A,ZEMBSB,RSSB)
C---INVERT THE Y' MATRIX TO OBTAIN THE Z' MATRIX
      CALL CMINV(A,NHP1,DET,WK1,WK2,NHP1*NHP1)
C---FORM THE CONVERSION LOSS MATRIX AND INPUT IMPEDANCE AT EACH SIDEBAND
      DO 50 I=1,NHP1
      ZIN(I)=RSSB(I)+A(I,I)*(RSSB(I)+ZEMBSB(I))/(RSSB(I)+ZEMBSB(I)
     1-A(I,I))
      DO 40 J=1,NHP1
      IF(I-J) 20,30,20
   20 LIJ=((CDABS(RSSB(I)+ZEMBSB(I))*CDABS(RSSB(J)+ZEMBSB(J))/
     1(2.0D0*CDABS(A(I,J))))**2)/(DREAL(ZEMBSB(I))*DREAL(ZEMBSB(J)))
C---CONVERT TO DB WHEN FORMING THE LOSS MATRIX
      XLMAT(I,J)=10.0D0*DLOG10(LIJ)
      GOTO 40
C---THE DIAGONAL ELEMENTS HAVE NO OBVIOUS MEANING AND ARE ZEROED FOR
C---CONVENIENCE
   30 XLMAT(I,J)=0.0D0
   40 CONTINUE
   50 CONTINUE
C---BEGIN THE NOISE ANALYSIS BY FORMING THE SHOT NOISE CORRELATION
C---MATRIX
      CALL CORREL(ALP,FG,COR,NHP1)
C---CALCULATE THE EQUIVALENT INPUT NOISE TEMPERATURE CONSIDERING THE
C---SHOT NOISE ONLY
      CALL TMIX(NHD2,SHOT,T,COR,A,RSSB,ZEMBSB,NHP1,NHD2P1)
C---ADD THE THERMAL NOISE COMPONENT TO THE SHOT NOISE CORRELATION MATRIX
      CALL TNOISE(COR,RSSB,ZEMBSB,NHP1,NHD2P1)
C---RECALCULATE THE EQUIVALENT NOISE TEMPERATURE NOW INCLUDING BOTH
C---SHOT AND THERMAL NOISE CONTRIBUTIONS
      CALL TMIX(NHD2,TM,T,COR,A,RSSB,ZEMBSB,NHP1,NHD2P1)
C---FIND THE THERMAL NOISE COMPONENT OF THE EQUIVALENT INPUT NOISE
C---TEMPERATURE OF THE MIXER
      THERM=TM-SHOT
C---CALL PRINT4 TO PRINT THE RESULTS OF THE SMALL-SIGNAL AND NOISE
C---ANALYSIS
      CALL PRINT4(XLMAT,ZIN,ZIFOUT,TM,THERM,SHOT,NHD2,NHP1,NHD2P1)
      RETURN
      END



      SUBROUTINE YPRIME(FG,FC,NHD2,NHD2P1,NHP1,FP,IF,A,ZEMBSB,RSSB)
C---
C---YPRIME FORMS THE AUGMENTED ADMITTANCE MATRIX Y' (A) OF THE MIXER
C---
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
C---FOR COMMON/CONST/:
      REAL*8 QEL,BOLTZ,PI,TEQ
C---FOR VARIABLES NOT IN ANY COMMON BLOCKS:
      COMPLEX*16 ZEMBSB(NHP1),A(NHP1,NHP1),FG(NHP1),FC(NHP1)
      REAL*8 FP,IF,WP,WIF,RSSB(NHP1)
      INTEGER NHD2,NHD2P1,NHP1,I,J
C---THE COMMON BLOCKS USED ARE:
      COMMON/CONST/QEL,BOLTZ,PI,TEQ
      WIF=2.0D0*PI*IF
```

```
      WP=2.0D0*PI*FP
C---FORM THE ADMITTANCE MATRIX Y OF THE INTRINSIC DIODE
      DO 60 I=1,NHP1
      DO 50 J=1,NHP1
   20 IF(J-I) 30,40,40
C---FIND THE LOWER HALF OF THE Y MATRIX
   30 A(I,J)=DCONJG(FG(I-J+1))+DCMPLX(0.0D0,WIF+WP*(NHD2P1-I))
     1*DCONJG(FC(I-J+1))
      GOTO 50
C---FIND THE UPPER HALF OF THE Y MATRIX
   40 A(I,J)=FG(J-I+1)+DCMPLX(0.0D0,WIF+WP*(NHD2P1-I))*FC(J-I+1)
   50 CONTINUE
   60 CONTINUE
C---ADD 1/(RS+ZEMBSB) TO THE DIAGONAL ELEMENTS OF Y TO FORM THE
C---AUGMENTED ADMITTANCE MATRIX Y' OF THE MIXER
      DO 70 I=1,NHP1
   70 A(I,I)=A(I,I)+1.0D0/(ZEMBSB(I)+RSSB(I))
      RETURN
      END



      SUBROUTINE CORREL(ALP,FG,COR,NHP1)
C---
C---CORREL FORMS THE NOISE CURRENT CORRELATION MATRIX FOR THE SHOT
C---NOISE. THE THERMAL NOISE COMPONENTS ARE ADDED IN SUBROUTINE
C---TNOISE.
C---
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
      COMPLEX*16 FG(NHP1),COR(NHP1,NHP1)
      REAL*8 QEL,BOLTZ,PI,TEQ,ALP
      INTEGER NHP1,I,J
C---THE COMMON BLOCKS USED ARE:
      COMMON/CONST/QEL,BOLTZ,PI,TEQ
C---FORM THE SHOT NOISE CORRELATION MATRIX USING I=FG/ALP
      DO 10 I=1,NHP1
      DO 20 J=1,I
      COR(J,I)=2.0D0*QEL*FG(I-J+1)/ALP
   20 COR(I,J)=DCONJG(COR(J,I))
   10 CONTINUE
      RETURN
      END



      SUBROUTINE TNOISE(COR,RSSB,ZEMBSB,NHP1,NHD2P1)
C---
C---TNOISE FORMS THE THERMAL NOISE CURRENT CORRELATION MATRIX AND
C---ADDS IT TO THE SHOT NOISE CORRELATION MATRIX.
C---
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
      COMPLEX*16 COR(NHP1,NHP1),ZEMBSB(NHP1)
      REAL*8 QEL,BOLTZ,PI,TEQ,RSSB(NHP1)
C---THE COMMON BLOCKS USED ARE:
      COMMON/CONST/QEL,BOLTZ,PI,TEQ
C---SINCE THE THERMAL NOISE MATRIX IS DIAGONAL ADD THESE ELEMENTS TO
C---THE DIAGONAL TERMS OF THE SHOT NOISE CORRELATION MATRIX
      DO 35 I=1,NHP1
```

```
      IF(I.EQ.NHD2P1) GOTO 30
      COR(I,I)=COR(I,I)+4.0D0*BOLTZ*TEQ*RSSB(I)/
     1(CDABS(ZEMBSB(I)+RSSB(I)))**2
      GOTO 35
C---AT THE IF THE THERMAL NOISE TERM IS GIVEN BY:
   30 COR(I,I)=COR(I,I)+4.0D0*BOLTZ*TEQ*RSSB(I)/
     1(CDABS(ZEMBSB(I)-RSSB(I)))**2
   35 CONTINUE
      RETURN
      END



      SUBROUTINE TMIX(NSB,TM,T,COR,A,RSSB,ZEMBSB,NHP1,NHD2P1)
C---
C---TMIX COMPUTES THE EQUIVALENT SINGLE SIDEBAND INPUT NOISE
C---TEMPERATURE OF THE MIXER REFERRED TO SIDEBAND NSB.
C---NOTE THAT SIDEBAND NSB IS ARRAY SUBSCRIPT NH/2 + 1 - NSB.
C---
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
      COMPLEX*16 COR(NHP1,NHP1),A(NHP1,NHP1),ZEMBSB(NHP1),VSQ,T(NHP1)
      REAL*8 QEL,BOLTZ,PI,TEQ,TM,RSSB(NHP1)
      INTEGER I,J,NSB,NHP1,NHD2P1
C---THE COMMON BLOCKS USED ARE:
      COMMON/CONST/QEL,BOLTZ,PI,TEQ
C---POST MULTIPLY COR BY THE CONJUGATE TRANSPOSE OF THE CENTER ROW
C---OF THE Z' MATRIX (ROW 0)
      DO 10 I=1,NHP1
      T(I)=0.0D0
      DO 20 J=1,NHP1
   20 T(I)=T(I)+COR(I,J)*DCONJG(A(NHD2P1,J))
   10 CONTINUE
C---PREMULTIPLY COR BY THE CENTER ROW OF THE MIXER Z' MATRIX
      VSQ=0.0D0
      DO 30 I=1,NHP1
   30 VSQ=VSQ+A(NHD2P1,I)*T(I)
C---COMPUTE THE EQUIVALENT INPUT NOISE TEMPERATURE OF THE MIXER
      TM=(DREAL(VSQ)*(CDABS(ZEMBSB(NSB)+RSSB(NSB)))**2)/
     1(BOLTZ*4.0D0*DREAL(ZEMBSB(NSB))*(CDABS(A(NHD2P1,NSB))**2))
      RETURN
      END



      SUBROUTINE CMINV(A,N,D,L,M,NSQ)
C---
C---CMINV IS A SLIGHTLY MODIFIED VERSION OF THE IBM SSP ROUTINE MINV
C---FOR INVERTING A COMPLEX MATRIX. ONLY THE FIRST TWO STATEMENTS AND
C---THOSE NUMBERED 10 AND 45 HAVE BEEN ALTERED.
C---
      COMPLEX*16 A,D,BIGA,HOLD
      DIMENSION A(NSQ),L(N),M(N)
      D=1.0D0
      NK=-N
      DO 80 K=1,N
      NK=NK+N
      L(K)=K
      M(K)=K
```

```
      KK=NK+K
      BIGA=A(KK)
      DO 20 J=K,N
      IZ=N*(J-1)
      DO 20 I=K,N
      IJ=IZ+I
   10 IF(CDABS(BIGA)-CDABS(A(IJ))) 15,20,20
   15 BIGA=A(IJ)
      L(K)=I
      M(K)=J
   20 CONTINUE
      J=L(K)
      IF(J-K) 35,35,25
   25 KI=K-N
      DO 30 I=1,N
      KI=KI+N
      HOLD=-A(KI)
      JI=KI-K+J
      A(KI)=A(JI)
   30 A(JI) =HOLD
   35 I=M(K)
      IF(I-K) 45,45,38
   38 JP=N*(I-1)
      DO 40 J=1,N
      JK=NK+J
      JI=JP+J
      HOLD=-A(JK)
      A(JK)=A(JI)
   40 A(JI) =HOLD
   45 IF(CDABS(BIGA)) 48,46,48
   46 D=0.0D0
      RETURN
   48 DO 55 I=1,N
      IF(I-K) 50,55,50
   50 IK=NK+I
      A(IK)=A(IK)/(-BIGA)
   55 CONTINUE
      DO 65 I=1,N
      IK=NK+I
      HOLD=A(IK)
      IJ=I-N
      DO 65 J=1,N
      IJ=IJ+N
      IF(I-K) 60,65,60
   60 IF(J-K) 62,65,62
   62 KJ=IJ-I+K
      A(IJ)=HOLD*A(KJ)+A(IJ)
   65 CONTINUE
      KJ=K-N
      DO 75 J=1,N
      KJ=KJ+N
      IF(J-K) 70,75,70
   70 A(KJ)=A(KJ)/BIGA
   75 CONTINUE
      D=D*BIGA
      A(KK)=1.0D0/BIGA
   80 CONTINUE
      K=N
```

```
  100 K=(K-1)
      IF(K) 150,150,105
  105 I=L(K)
      IF(I-K) 120,120,108
  108 JQ=N*(K-1)
      JR=N*(I-1)
      DO 110 J=1,N
      JK=JQ+J
      HOLD=A(JK)
      JI=JR+J
      A(JK)=-A(JI)
  110 A(JI) =HOLD
  120 J=M(K)
      IF(J-K) 100,100,125
  125 KI=K-N
      DO 130 I=1,N
      KI=KI+N
      HOLD=A(KI)
      JI=KI-K+J
      A(KI)=-A(JI)
  130 A(JI) =HOLD
      GO TO 100
  150 RETURN
      END



      SUBROUTINE PRINT1(ZEMB,ZEMBDC,ZER,ZEI,ZEMBSB,PRMT,Y,DERY,VLO,
     1VDBIAS,IDBIAS,RSSB,RSLO,NHARM,NHP1,NHD2)
C---
C---PRINT1 WRITES THE VALUES OF THE INPUT VARIABLES AND THE INITIAL
C---CONDITIONS FOR THE NONLINEAR ANALYSIS SECTION OF THE PROGRAM.
C---
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
C---FOR COMMON/ADJLO/:
      REAL*8 LOVLO,UPVLO,VLOINC,IDCACC
      INTEGER LOFLAG,UPFLAG
C---FOR COMMON/CONST/:
      REAL*8 QEL,BOLTZ,PI,TEQ
C---FOR COMMON/DIODE/:
      REAL*8 ALP,PHI,GAM,C0,IS,RS,RSKIN,FP,IF,IGJ,ICJ,GJ,CJ
C---FOR COMMON/LOOPS/:
      INTEGER NH,NLO,NVLO,NPTS,NPRINT,NITER
C---FOR COMMON/RKG/:
      REAL*8 ACC,VDINIT
      INTEGER NDIM
C---FOR COMMON/TLINE/:
      REAL*8 Z0,ZQACC
      INTEGER ZQFLAG
C---FOR VARIABLES NOT IN ANY COMMON BLOCKS:
      COMPLEX*16 ZEMB(NHARM),ZEMBSB(NHP1)
      REAL*8 VDBIAS,IDBIAS,VLO,ZQACC,Z0,ZEMBDC,PRMT(5),Y(1),DERY(1)
      REAL*8 ZER(NHARM),ZEI(NHARM),RSSB(NHP1),RSLO(NHARM)
      INTEGER NHARM,NHP1,NHD2,I,K,J
C---THE COMMON BLOCKS USED ARE:
      COMMON/ADJVLO/LOVLO,UPVLO,LOFLAG,UPFLAG,VLOINC,IDCACC
      COMMON/CONST/QEL,BOLTZ,PI,TEQ
      COMMON/DIODE/ALP,PHI,GAM,C0,IS,RS,RSKIN,FP,IF,IGJ,ICJ,GJ,CJ
```

```
      COMMON/LOOPS/NH,NLO,NVLO,NPTS,NPRINT,NITER
      COMMON/RKG/ACC,VDINIT,NDIM
      COMMON/TLINE/Z0,ZQACC,ZQFLAG
C---PRINT THE TITLE
      WRITE(6,50) FP
   50 FORMAT(1H1,1X,' ANALYSIS OF A ',-9PF6.2,' GHZ MICROWAVE MIXER'/
     *1X,50('-'))
C---WRITE THE VALUES OF THE RELEVENT VARIABLES.
      WRITE (6,75)
   75 FORMAT(/1X,'INPUT DATA')
      WRITE(6,100)
  100 FORMAT(//1X,' DIODE PARAMETERS:',T25,'ALP',T41,'PHI',T56,'GAM',
     1T71,'RS',T85,'C0',T100,'IS',T113,'RSKIN')
      WRITE(6,110) ALP,PHI,GAM,RS,C0,IS,RSKIN
  110 FORMAT(19X,4(F10.3,5X),2(1PE10.3,5X),1PE10.3)
      WRITE(6,120) FP,IF,TEQ
  120 FORMAT(/1X,' OPERATING FREQUENCIES AND TEMPERATURE:'.T50,'FP',
     1T65,'IF',T79,'TEQ'/T45,2(1PE10.3,5X),0PF10.3)
      WRITE(6,130) VDBIAS,IDBIAS
  130 FORMAT(/1X,' BIAS SETTINGS:',T24,'VDBIAS',T38,'IDBIAS'/T20,
     1F10.3,5X,F10.6)
      WRITE(6,140) VLO,VLOINC,IDCACC
  140 FORMAT(/1X,' ADJVLO VARIABLES:',T25,'VLO',T39,'VLOINC',T54,
     1'IDCACC'/T21,3(F10.6,5X))
      WRITE(6,150) PRMT(1),PRMT(2),PRMT(3),PRMT(4),Y(1),DERY(1),NDIM
  150 FORMAT(/1X,' DRKGS VARIABLES:',T21,'PRMT(1)',T35,'PRMT(2)',T50,
     1'PRMT(3)',T65,'PRMT(4)',T80,'Y(1)',T95,'DERY(1)',T110,'NDIM'/
     2T20,'(LOW LIM)',T35,'(UP LIM)',T50,'(INCR)',T66,'(ACC)',T80,
     3'(VD)',T95,'(DV/DT)',T109,'(NEQS)'/
     4T22,F10.8,1X,2( F10.8,5X),1PE10.3,2X,2(0PF10.3,6X),4X,I2)
      WRITE(6,160) NITER,NLO,NVLO,NPTS,NHARM,NPRINT
  160 FORMAT(/1X,' LOOP LIMITS:',T21,'NITER',T31,'NLO',T40,'NVLO'
     1T51,'NPTS',T62,'NHARM',T72,'NPRINT'/T21.I4,6X,2(I2,8X),1X,
     2I2,09X,I2,8X,I3)
      WRITE(6,170) Z0,ZQACC
  170 FORMAT(/1X,' CONVERGENCE PARAMETERS:',T40,'Z0',T57,'ZQACC'/
     1T34,F10.2,10X,1PE10.3)
      WRITE(6,180) ZEMBDC,ZEMBDC,NHD2,ZEMBSB(1)
  180 FORMAT(///1X,' EMBEDDING IMPEDANCES:',T48,'HARMONICS OF THE LO'
     1T105,'HARMONIC SIDEBANDS'/T25,'HARM#',T37,'ZER',T50,
     *'ZEI',T71,'ZEMB',T92,'SIDEBAND#',T112,'ZEMBSB'/T26,'DC',T33,
     *1PE10.3,T61,1PE10.3,T95,I2,T103,1PE10.3,T116,1PE10.3)
      DO 10 I=1,NHARM
      K=NHD2-I
      J=I+1
   10 WRITE(6,190) I,ZER(I),ZEI(I),ZEMB(I),K,ZEMBSB(J)
  190 FORMAT(1X,T26,I2,T33,2(1PE10.3,3X),T61,2(1PE10.3,3X),T95,I2,
     *T103,1PE10.3,T116,1PE10.3)
      WRITE(6,200) RS,NHD2,RSSB(1)
  200 FORMAT(///1X,' DIODE SERIES RESISTANCES:',T32,'HARMONICS OF THE
     1,' LO',T64,'HARMONIC SIDEBANDS'/T34,'HARM#',T44,'RS(F)',T62,
     2'SIDEBAND#',T77,'RS(F)'/T35,'DC',T41,F8.4,T65,I2,T74,F8.4)
      DO 20 I=1,NHARM
      K=NHD2-I
      J=I+1
   20 WRITE(6,210) I,RSLO(I),K,RSSB(J)
  210 FORMAT(1X,T35,I2,T41,F8.4,T65,I2,T74,F8.4)
C---WRITE THE HEADING FOR THE NEXT SECTION OF PRINTOUT
```

```
      WRITE(6,220)
  220 FORMAT(1H1,'RESULTS OF THE VLO ADJUSTMENTS'//)
      RETURN
      END



      SUBROUTINE PRINT2(RHO,VI,VR,DVR,VDCOS,VDSIN,IDCOS,IDSIN,ZQMAG,
     1ZQPHA,VRDC,DVRDC,VIDC,RHODC,AV,BV,ITER,ZQFLAG,JVLO,NH,NHP1)
C---
C---PRINT2 WRITES THE RESULTS OF EACH REFLECTION CYCLE OF THE LOOP
C---ITER IN SUBROUTINE LGSIG.
C---
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
      COMPLEX*16 RHO(NH),VR(NH),VI(NH),DVR(NH)
      REAL*8 VDCOS(NHP1),VDSIN(NHP1),IDCOS(NHP1),IDSIN(NHP1),ZQMAG(NH)
      REAL*8 ZQPHA(NH),VIDC,VRDC,DVRDC,RHODC,AV(NH),BV(NH)
      INTEGER ITER,JVLO,NH,NHP1
C---WRITE THE RESULTS OF THE REFLECTION CYCLE
      WRITE(6,100) ITER,JVLO
  100 FORMAT(////1X,'NONLINEAR ANALYSIS RESULTS:  REFLECTION CYCLE #'
     1,I4,' IN VLO ADJUSTMENT LOOP NUMBER',I3/)
      WRITE(6,110)
  110 FORMAT(/2X,'AV(I),BV(I)')
      WRITE(6,120) (I,AV(I),BV(I),I=1,NH)
  120 FORMAT(1H+,6(8X,4(I7,1PE12.3,1PE12.3)/1X))
      WRITE(6,130)
  130 FORMAT(/2X,'VR')
      WRITE(6,120) (I,VR(I),I=1,NH)
      WRITE(6,140)
  140 FORMAT(/2X,'DVR')
      WRITE(6,120) (I,DVR(I),I=1,NH)
      WRITE(6,150)
  150 FORMAT(/2X,'VDCOS,VDSIN')
      WRITE(6,120) (I,VDCOS(I+1),VDSIN(I+1),I=1,NH)
      WRITE(6,160)
  160 FORMAT(/2X,'IDCOS,IDSIN')
      WRITE(6,120) (I,IDCOS(I+1),IDSIN(I+1),I=1,NH)
      WRITE(6,170)
  170 FORMAT(/2X,'ZQMAG,ZQPHA')
      WRITE(6,180) (I,ZQMAG(I),ZQPHA(I),I=1,NH)
  180 FORMAT(1H+,6(8X,4(I7,1PE12.3,0PF7.0,5X)/1X))
      WRITE(5,190) VDCOS(1),IDCOS(1),VRDC,DVRDC,ZQFLAG
  190 FORMAT(//2X,'DC TERMS:  VDCOS=',1PE10.3,T35,'IDCOS=',1PE10.3,
     1T54,'VRDC=',1PE10.3,T76,'DVRDC=',1PE10.3///2X,'ZQFLAG=',I2)
      RETURN
      END



      SUBROUTINE PRINT3(FG,FC,GJMAG,GJPHA,CJMAG,CJPHA,NH,NHP1)
C---
C---PRINT3 WRITES THE FOURIER COEFFICIENTS OF THE DIODE CONDUCTANCE
C---AND CAPACITANCE WHICH ARE USED IN THE SMALL-SIGNAL ANALYSIS.
C---
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
      COMPLEX*16 FG(NHP1),FC(NHP1)
      REAL*8 GJMAG(NHP1),GJPHA(NHP1),CJMAG(NHP1),CJPHA(NHP1)
```

```
      INTEGER NHP1,NH
C---TRANSFORM THE FOURIER COEFFICIENTS TO MAGNITUDES (HALF AMPLITUDES)
C---AND PHASES (IN DEGREES)
      DO 10 I=1,NHP1
      GJMAG(I)=CDABS(FG(I))
      CJMAG(I)=CDABS(FC(I))
      GJPHA(I)=DATAN2(DIMAG(FG(I)),DREAL(FG(I)))*57.29577951D0
   10 CJPHA(I)=DATAN2(DIMAG(FC(I)),DREAL(FC(I)))*57.29577951D0
      WRITE(6,50)
   50 FORMAT(1H1,'RESULTS OF THE SMALL-SIGNAL ANALYSIS'/)
      WRITE(6,100)
  100 FORMAT(/1X,' FOURIER COEFFICIENTS OF THE DIODE',
     1' CONDUCTANCE AND CAPACITANCE WAVEFORMS'/)
      WRITE(6,110)
  110 FORMAT(/2X,'GJMAG,GJPHA')
      WRITE(6,120) (I,GJMAG(I+1),GJPHA(I+1),I=1,NH)
  120 FORMAT(1H+,6(8X,4(I7,1PE12.3,0PF7.0,5X)/1X))
      WRITE(6,130)
  130 FORMAT(/2X,'CJMAG,CJPHA')
      WRITE(6,120) (I,CJMAG(I+1),CJPHA(I+1),I=1,NH)
      WRITE(6,140) GJMAG(1),CJMAG(1)
  140 FORMAT(//2X,'DC TERMS:  GJMAG = ',1PE10.3,4X,'CJMAG = '
     1,1PE10.3/)
      RETURN
      END



      SUBROUTINE PRINT4(XLMAT,ZIN,ZIFOUT,TM,THERM,SHOT,NHD2,NHP1,NHD2P1)
C---
C---SUBROUTINE PRINT4 WRITES THE RESULTS OF THE SMALL-SIGNAL
C---AND NOISE ANALYSIS. THESE INCLUDE THE CONVERSION LOSS MATRIX,
C---THE INPUT IMPEDANCE AT EACH SIDEBAND, THE IF OUTPUT IMPEDANCE,
C---AND THE EQUIVALENT INPUT NOISE TEMPERATURE OF THE MIXER WITH ITS
C---THERMAL AND SHOT NOISE COMPONENTS.
C---
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
      COMPLEX*16 ZIN(NHP1),ZIFOUT
      REAL*8 XLMAT(NHP1,NHP1),TM,THERM,SHOT,REZIN(9),IMZIN(9)
      INTEGER NHP1,I,J,K,NHD2P1,NHD2P2,NHD2
C---DEFINE THE ARRAY ELEMENT WHICH CORRESPONDS TO THE LOWER SIDEBAND
      NHD2P2=NHD2P1+1
      WRITE(6,100)
  100 FORMAT(//44X,'CONVERSION  LOSS  MATRIX (DB)'/)
      WRITE(6,200)
  200 FORMAT(1X,T25,'4',T35,'3',T45,'2',T55,'1',T65,'0',T74,'-1',T84,
     1'-2',T94,'-3',T104,'-4'//)
      DO 10 I=1,NHP1
      K=NHD2P1-I
   10 WRITE(6,300) K,(XLMAT(I,J),J=1,NHP1)
  300 FORMAT(9X,I4,4X,9F10.2 )
      WRITE(6,350) XLMAT(NHD2P1,NHD2),XLMAT(NHD2P1,NHD2P2)
  350 FORMAT(//2X,'UPPER SIDEBAND CONVERSION LOSS:  L(0,1)  =',F7.2,
     *' DB'//2X,'LOWER SIDEBAND CONVERSION LOSS:  L(0,-1) =',F7.2,
     *' DB'/)
      WRITE (6,390)
  390 FORMAT(2X,'INPUT IMPEDANCES',T25,'4',T35,'3',T45,'2',T55,'1',
     *T65,'0',T74,'-1',T84,'-2',T94,'-3',T104,'-4')
```

```
      DO 20 I=1,NHP1
      REZIN(I)=DREAL(ZIN(I))
   20 IMZIN(I)=DIMAG(ZIN(I))
      WRITE(6,400) (REZIN(I),I=1,NHP1)
  400 FORMAT (/3X,' REAL(ZIN):',3X,9F10.2)
      WRITE(6,500) (IMZIN(I),I=1,NHP1)
  500 FORMAT (/3X,' IMAG(ZIN):',3X,9F10.2)
      WRITE (6,550) ZIFOUT
  550 FORMAT(//2X,'IF OUTPUT IMPEDANCE:   ZIFOUT = ',F8.2,' + J'
     *F8.2)
      WRITE(6,600) TM,THERM,SHOT
  600 FORMAT(//2X,'EQUIVALENT INPUT NOISE TEMPERATURES:',T52,'TM'
     1T67,'THERM',T82,'SHOT',T98/T46,F10.1,T62,F10.1,T77,F10.1)
      RETURN
      END



      SUBROUTINE PLOT(IGJDAT,CJDATA,VDDATA,IDDATA,NPTS,ITER,C0)
C---
C---SUBROUTINE PLOT GRAPHS THE CURRENT THROUGH THE DIODE CONDUCTANCE
C---(IGJ),THE DIODE CAPACITANCE (CJ),THE TOTAL CURRENT THROUGH THE
C---DIODE (IGJ+ICJ), AND THE VOLTAGE ACROSS THE INTRINSIC DIODE TER -
C---MINALS (V(1)) (WHICH DOES NOT INCLUDE THE DIODE SERIES RESISTANCE)
C---AS FUNCTIONS OF TIME,OVER ONE LOCAL OSCILLATOR CYCLE.
C---
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:
      REAL*8 IGJDAT(NPTS),CJDATA(NPTS),VDDATA(NPTS),IDDATA(NPTS)
      REAL*8 MAXIGJ,MAXCJ,MAXVD,MAXID,MINCJ,C0
      INTEGER ITER,JPT,YPT,NPTS,IGJPOS,CJPOS,C0POS,VDPOS,IDPOS,C,ZERO
      INTEGER BLANK,DOT,STAR,YGPOS(50),YCPOS(50),YIDPOS(50),YVDPOS(50)
C---DEFINE THE NUMERICS USED IN THE GRAPHS
      DATA BLANK,DOT,STAR,C,ZERO/' ','.','*','C','0'/
C---DETERMINE THE GRAPH SCALES
      MAXIGJ=DABS(IGJDAT(1))
      MAXCJ=DABS(CJDATA(1))
      MINCJ=CJDATA(1)
      MAXVD=DABS(VDDATA(1))
      MAXID=DABS(IDDATA(1))
      DO 10 JPT=2,NPTS
      IF(MAXIGJ.LT.DABS(IGJDAT(JPT))) MAXIGJ=DABS(IGJDAT(JPT))
      IF(MAXCJ.LT.DABS(CJDATA(JPT))) MAXCJ=DABS(CJDATA(JPT))
      IF(MINCJ.GT.CJDATA(JPT)) MINCJ=CJDATA(JPT)
      IF(MAXVD.LT.DABS(VDDATA(JPT))) MAXVD=DABS(VDDATA(JPT))
      IF(MAXID.LT.DABS(IDDATA(JPT))) MAXID=DABS(IDDATA(JPT))
   10 CONTINUE
C---THE GRAPH HEADINGS
      WRITE(6,100) ITER
  100 FORMAT(1H1,1X,'GRAPHS FOR REFLECTION CYCLE NUMBER ',I4/)
      WRITE(6,110)
  110 FORMAT(/3X,'IGJ(MA)',5X,'DIODE CONDUCTANCE CURRENT VS TIME FOR',
     1' ONE LO CYCLE',T67,'  CJ(PF)',5X,'DIODE CAPACITANCE VS',
     2' TIME FOR ONE LO CYCLE'/)
C---THE LOOP FOR THE POINTS TO PLOTTED VERTICALLY DOWN THE PAGE
C---PREVENT A DIVISION BY 0 IF THE CAPACITANCE DOES NOT VARY
      IF(MAXCJ.EQ.MINCJ) MAXCJ=MAXCJ+1.0D0
C---LET C0 BE THE Y AXIS IF IT IS NOT IN THE RANGE MINCJ TO MAXCJ
      IF(C0.LT.MINCJ) MINCJ=C0
```

```
      IF(C0.GT.MAXCJ) MAXCJ=C0
      C0POS=01+DINT(50.0D0/(MAXCJ-MINCJ)*(C0-MINCJ)+DSIGN(0.5D0,C0))
      DO 2 JPT=1,NPTS
      IGJPOS=01+DINT(50.0D0/MAXIGJ*IGJDAT(JPT)+DSIGN(0.5D0,IGJDAT(JPT)))
      CJPOS=01+DINT(50.0D0/(MAXCJ-MINCJ)*(CJDATA(JPT)-MINCJ)+DSIGN(
     10.5D0,CJDATA(JPT)))
C---SET THE GRAPH LIMITS
      IF(IGJPOS.LT.1) IGJPOS=1
      IF(IGJPOS.GT.50) IGJPOS=50
      IF(CJPOS.LT.1) CJPOS=1
      IF(CJPOS.GT.49) CJPOS=49
C---CLEAR THE HORIZONTAL LINE
      DO 1 YPT=1,50
      YCPOS(YPT)=BLANK
    1 YGPOS(YPT)=BLANK
C---SET THE GRAPH'S Y AXIS
      YGPOS(1)=DOT
      YCPOS(C0POS)=DOT
C---THE PLOTTED POINTS ARE REPRESENTED AS ASTERIKS
      YGPOS(IGJPOS)=STAR
      YCPOS(CJPOS)=STAR
C---WRITE 'C0' ON THE Y AXIS OF THE CAPACITANCE GRAPH
      IF(C0POS.EQ.50) GOTO 6
      IF(JPT.EQ.1) YCPOS(C0POS)=C
      IF(JPT.EQ.1) YCPOS(C0POS+1)=ZERO
      GOTO 7
    6 IF(JPT.EQ.1) YCPOS(C0POS-1)=C
      IF(JPT.EQ.1) YCPOS(C0POS)=ZERO
    7 CONTINUE
C---PRINT THIS LINE OF THE GRAPHS
      WRITE(6,120) IGJDAT(JPT),(YGPOS(YPT),YPT=1,50),CJDATA(JPT),
     1(YCPOS(YPT),YPT=1,50)
  120 FORMAT(3PF9.3,2X,50A1,3X,12PF9.4,2X,50A1)
    2 CONTINUE
      WRITE(6,100) ITER
      WRITE(6,130)
  130 FORMAT(//3X,'ID(MA)',5X,'TOTAL DIODE CURRENT VS TIME FOR ONE LO',
     1' CYCLE',T67,' VD(VOLTS)',8X,' DIODE VOLTAGE VS TIME FOR',
     2' ONE LO CYCLE'/)
C---THE DO LOOP FOR THE POINTS TO BE PLOTTED VERTICALLY DOWN THE PAGE
      DO 4 JPT=1,NPTS
      IDPOS=25+DINT(25.0D0/MAXID*IDDATA(JPT)+DSIGN(0.5D0,IDDATA(JPT)))
      VDPOS=25+DINT(25.0D0/MAXVD*VDDATA(JPT)+DSIGN(0.5D0,VDDATA(JPT)))
C---SET THE GRAPH LIMITS
      IF(IDPOS.LT.1) IDPOS=1
      IF(IDPOS.GT.50) IDPOS=50
      IF(VDPOS.LT.1) VDPOS=1
      IF(VDPOS.GT.50) VDPOS=50
C---CLEAR THE HORIZONTAL LINE
      DO 5 YPT=1,50
      YIDPOS(YPT)=BLANK
      YVDPOS(YPT)=BLANK
    5 CONTINUE
C---SET THE Y AXIS
      YIDPOS(25)=DOT
      YVDPOS(25)=DOT
C---THE PLOTTED POINTS ARE REPRESENTED AS ASTERIKS
      YIDPOS(IDPOS)=STAR
```

```
      YVDPOS(VDPOS)=STAR
C---PRINT THIS LINE OF THE GRAPHS
      WRITE(6,140) IDDATA(JPT),(YIDPOS(YPT),YPT=1,50),VDDATA(JPT),
     1(YVDPOS(YPT),YPT=1,50)
  140 FORMAT(3PF9.3,2X,50A1,3X,0PF9.3,2X,50A1)
    4 CONTINUE
    3 RETURN
      END



      BLOCK DATA
C---
C---FOR COMMON/ADJLO/:
      REAL*8 LOVLO,UPVLO,VLOINC,IDCACC
      INTEGER LOFLAG,UPFLAG
C---FOR COMMON/CONST/:
      REAL*8 QEL,BOLTZ,PI,TEQ
C---FOR COMMON/DIODE/:
      REAL*8 ALP,PHI,GAM,C0,IS,RS,RSKIN,FP,IF,IGJ,ICJ,GJ,CJ
C---FOR COMMON/IMPED/:
      COMPLEX*16 ZEMBSB(9)
      REAL*8 ZER(8),ZEI(8),ZEMBDC,RSLO(8),RSSB(9)
C---FOR COMMON/LOOPS/:
      INTEGER NH,NLO,NVLO,NPTS,NPRINT,NITER
C---FOR COMMON/RKG/:
      REAL*8 ACC,VDINIT
      INTEGER NDIM
C---FOR COMMON/TLINE/:
      REAL*8 Z0,ZQACC
      INTEGER ZQFLAG
C---FOR COMMON/VOLTS/:
      REAL*8 AV(8),BV(8),VIDC,VLO,VDBIAS,IDBIAS
C---THE COMMON BLOCKS USED ARE:
      COMMON/ADJVLO/LOVLO,UPVLO,LOFLAG,UPFLAG,VLOINC,IDCACC
      COMMON/CONST/QEL,BOLTZ,PI,TEQ
      COMMON/DIODE/ALP,PHI,GAM,C0,IS,RS,RSKIN,FP,IF,IGJ,ICJ,GJ,CJ
      COMMON/IMPED/ZER,ZEI,ZEMBDC,ZEMBSB,RSLO,RSSB
      COMMON/LOOPS/NH,NLO,NVLO,NPTS,NPRINT,NITER
      COMMON/RKG/ACC,VDINIT,NDIM
      COMMON/TLINE/Z0,ZQACC,ZQFLAG
      COMMON/VOLTS/AV,BV,VIDC,VLO,VDBIAS,IDBIAS
C---VARIABLES ARE INITIALIZED AS FOLLOWS:
C---COMMON/ADJVLO/ VARIABLES:
      DATA VLOINC,IDCACC/0.5D0,0.02D0/
C---COMMON/CONST/VARIABLES:
      DATA QEL,BOLTZ,PI/1.602192D-19,1.38062D-23,3.14159265358979D0/
      DATA TEQ/296.0D0/
C---COMMON/DIODE/VARIABLES:
      DATA ALP,PHI,GAM/40.0D0,1.1D0,0.5D0/
      DATA C0,IS,RS/2.0D-13,5.0D-9,5.0D0/
      DATA FP,IF/15.0D9,15.0D8/
      DATA RSKIN/4.7434D-6/
C---COMMON/IMPED/VARIABLES:
      DATA ZER(1),ZER(2),ZER(3)/48.0D0,64.48D0,29.02D0/
      DATA ZER(4),ZER(5),ZER(6)/59.18D0,43.5D0,68.31D0/
      DATA ZER(7),ZER(8)/61.45D0,81.49D0/
      DATA ZEI(1),ZEI(2),ZEI(3)/18.74D0,99.15D0,166.6D0/
```

```
      DATA ZEI(4),ZEI(5),ZEI(6)/232.4D0,299.2D0,367.8D0/
      DATA ZEI(7),ZEI(8)/438.5D0,511.4D0/
      DATA ZEMBSB(1),ZEMBSB(2)/(59.18D0,232.4D0),(29.02D0,166.6D0)/
      DATA ZEMBSB(3),ZEMBSB(4)/(64.48D0,99.15D0),(48.0D0,18.74D0)/
      DATA ZEMBSB(5),ZEMBSB(6)/(50.0D0,0.0D0),(48.0D0,-18.774D0)/
      DATA ZEMBSB(7),ZEMBSB(8)/(64.48D0,-99.15D0),(29.02D0,-166.6D0)/
      DATA ZEMBSB(9)/(59.18D0,-232.4D0)/
      DATA ZEMBDC/50.0D0/
C---COMMON/LOOPS/VARIABLES:
      DATA  NH,NLO,NPTS,NVLO,NITER,NPRINT/8,1,51,50,500,100/
C---COMMON/RKG/VARIABLES:
      DATA VDINIT,ACC,NDIM/0.0D0,1.0D-6,1/
C---COMMON/TLINE/VARIABLES:
      DATA Z0,ZQACC/200.0D0,0.01D0/
C---COMMON/VOLTS/VARIABLES:
      DATA VDBIAS,IDBIAS/0.0D0,0.002D0/
      DATA VLO/2.50D0/
      END
```

```
  ANALYSIS OF A  15.00 GHZ MICROWAVE MIXER
---------------------------------------------------------

INPUT DATA

 DIODE PARAMETERS:      ALP            PHI            GAM            RS          CO             IS            RSKIN
                       40.000         1.100          0.500          5.000      2.000D-13      5.000D-09      4.743D-06

 OPERATING FREQUENCIES AND TEMPERATURE:          FP             IF             TEQ
                                             1.500D+10      1.500D+09      296.000

 BIAS SETTINGS:         VDBIAS        IDBIAS
                         0.0         0.002000

 ADJVLO VARIABLES:      VLO            VLOINC          IDCACC
                       2.500000       0.500000        0.020000

 DRKGS VARIABLES:   PRMT(1)        PRMT(2)        PRMT(3)        PRMT(4)        Y(1)          DERY(1)       NDIM
                   (LOW LIM)      (UP LIM)       (INCR)          (ACC)         (VD)          (DV/DT)       (NEQS)
                     0.0        0.12319971     0.12319971     1.000D-06       0.0           1.000           1

 LOOP LIMITS:        NITER      NLO       NVLO        NPTS        NHARM      NPRINT
                      500       1         50          51          8         100

 CONVERGENCE PARAMETERS:                 Z0                ZOACC
                                       200.00            1.000D-02


 EMBEDDING IMPEDANCES:                         HARMONICS OF THE LO                                              HARMONIC SIDEBANDS
                        HARM#        ZER           ZEI                  ZEMB                  SIDEBAND#            ZEMBSB
                         DC      2.000D+02                    2.000D+02                           4          5.918D+01    2.324D+02
                          1      4.800D+01    1.874D+01       2.000D+02    0.0                    3          2.902D+01    1.666D+02
                          2      6.448D+01    9.915D+01       7.030D+01    9.915D+01              2          6.448D+01    9.915D+01
                          3      2.902D+01    1.666D+02       3.503D+01    1.666D+02              1          4.800D+01    1.874D+01
                          4      5.918D+01    2.324D+02       6.534D+01    2.324D+02              0          5.000D+01    0.0
                          5      4.350D+01    2.992D+02       4.980D+01    2.992D+02             -1          4.800D+01   -1.877D+01
                          6      6.931D+01    3.678D+02       7.473D+01    3.678D+02             -2          6.448D+01   -9.915D+01
                          7      6.145D+01    4.385D+02       6.799D+01    4.385D+02             -3          2.902D+01   -1.666D+02
                          8      8.149D+01    5.114D+02       8.813D+01    5.114D+02             -4          5.918D+01   -2.324D+02


 DIODE SERIES RESISTANCES:    HARMONICS OF THE  LO             HARMONIC SIDEBANDS
                                HARM#      RS(F)             SIDEBAND#       RS(F)
                                 DC       5.0000                 4          6.1763
                                  1       5.5809                 3          6.0229
                                  2       5.8216                 2          5.8419
                                  3       6.0062                 1          5.6093
                                  4       6.1619                 0          5.1837
                                  5       6.2990                -1          5.5511
                                  6       6.4230                -2          5.8008
                                  7       6.5370                -3          5.9893
                                  8       6.6422                -4          6.1473
```

```
RESULTS OF THE VLO ADJUSTMENTS


  VALUES OF THE DC CURRENT AND LO VOLTAGE FOR CYCLE  1 OF THE LOOP FOR ADJUSTING VLO TO GIVE 0.002000 AMPS ARE:
              IDCOS(1)=0.002145       VLO BEFORE ADJUSTMENT: 2.50000
                                      VLO AFTER ADJUSTMENT:  2.00000

  VALUES OF THE DC CURRENT AND LO VOLTAGE FOR CYCLE  2 OF THE LOOP FOR ADJUSTING VLO TO GIVE 0.002000 AMPS ARE:
              IDCOS(1)=0.001749       VLO BEFORE ADJUSTMENT: 2.00000
                                      VLO AFTER ADJUSTMENT:  2.25000

  VALUES OF THE DC CURRENT AND LO VOLTAGE FOR CYCLE  3 OF THE LOOP FOR ADJUSTING VLO TO GIVE 0.002000 AMPS ARE:
              IDCOS(1)=0.001945       VLO BEFORE ADJUSTMENT: 2.25000
                                      VLO AFTER ADJUSTMENT:  2.37500

  VALUES OF THE DC CURRENT AND LO VOLTAGE FOR CYCLE  4 OF THE LOOP FOR ADJUSTING VLO TO GIVE 0.002000 AMPS ARE:
              IDCOS(1)=0.002044       VLO BEFORE ADJUSTMENT: 2.37500
                                      VLO AFTER ADJUSTMENT:  2.31250

  VALUES OF THE DC CURRENT AND LO VOLTAGE FOR CYCLE  5 OF THE LOOP FOR ADJUSTING VLO TO GIVE 0.002000 AMPS ARE:
              IDCOS(1)=0.001994       VLO BEFORE ADJUSTMENT: 2.31250
                                      VLO AFTER ADJUSTMENT:  2.31250


NONLINEAR ANALYSIS RESULTS:  REFLECTION CYCLE #  19 IN VLO ADJUSTMENT LOOP NUMBER  5

 AV(I),BV(I)  1    1.156D+00   0.0            2  -3.787D-02  -5.629D-02       3   5.908D-03  -1.142D-02       4   3.095D-03  -3.953D-03
              5    2.377D-03  -2.350D-03      6   1.804D-03  -1.155D-03       7   1.267D-03  -6.206D-04       8   9.298D-04  -3.916D-04

 VR           1   -9.323D-01  -4.106D-01      2   1.196D-01   3.070D-03       3   1.266D-02  -9.451D-03       4   5.878D-03  -2.987D-03
              5    3.612D-03  -1.448D-03      6   2.331D-03  -9.868D-04       7   1.467D-03  -5.955D-04       8   1.070D-03  -3.664D-04

 DVR          1    1.608D-07  -2.797D-07      2   3.946D-07  -8.784D-07       3   5.568D-06  -7.002D-06       4  -4.904D-07  -1.416D-06
              5    1.093D-06  -4.677D-07      6  -1.095D-05  -4.292D-07       7  -1.405D-05   1.031D-05       8  -2.184D-05   7.265D-06

 VDCOS,VDSIN  1    2.240D-01   4.106D-01      2   8.173D-02  -5.936D-02       3   1.656D-02  -1.965D-03       4   8.973D-03  -9.668D-04
              5    5.988D-03  -9.017D-04      6   4.140D-03  -1.759D-04       7   2.749D-03  -2.836D-05       8   2.019D-03  -3.329D-05

 IDCOS,IDSIN  1    1.044D-02  -2.053D-03      2  -7.873D-04  -2.661D-04       3  -3.379D-05  -1.043D-04       4  -1.392D-05  -3.470D-05
              5   -6.180D-06  -1.898D-05      6  -2.608D-06  -1.075D-05       7  -9.241D-07  -6.096D-06       8  -6.082D-07  -3.831D-06

 ZGMAG,ZGPHA  1    2.197D-01   -73.           2   1.000D+00   180.            3   9.999D-01   180.            4   9.998D-01   180.
              5    1.000D+00   180.           6   9.984D-01  -180.            7   1.005D+00  -179.            8   1.003D+00  -178.

 DC TERMS:  VDCOS=-8.844D-03     IDCOS= 1.994D-03   VRDC=-2.038D-01        DVRDC=-1.499D-07

 ZGFLAG= 0

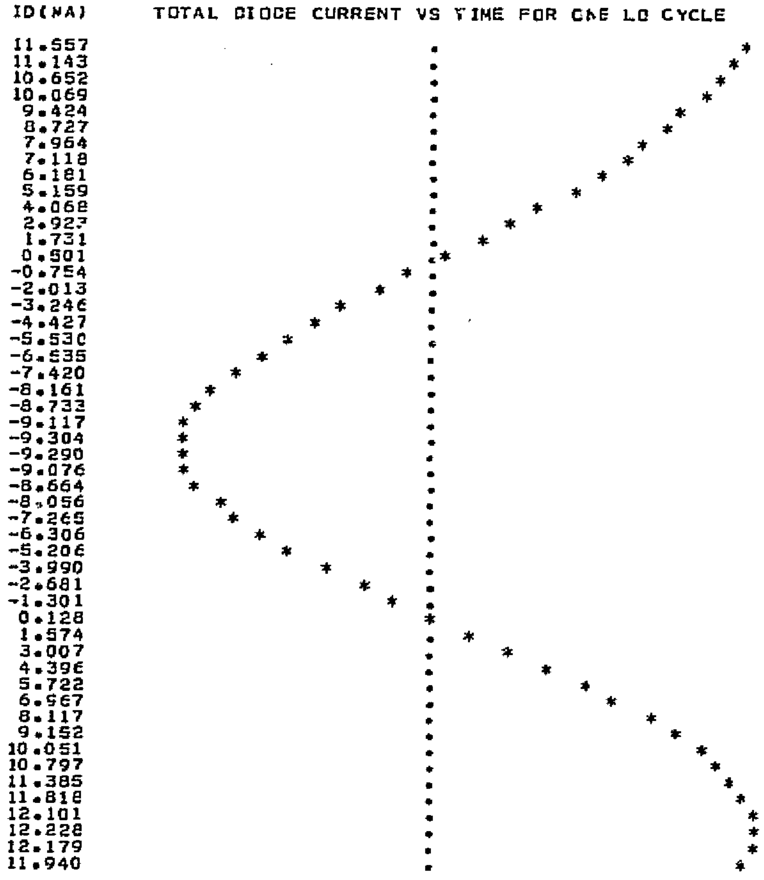
 REQUIRED LO POWER: 1.474D-03
```

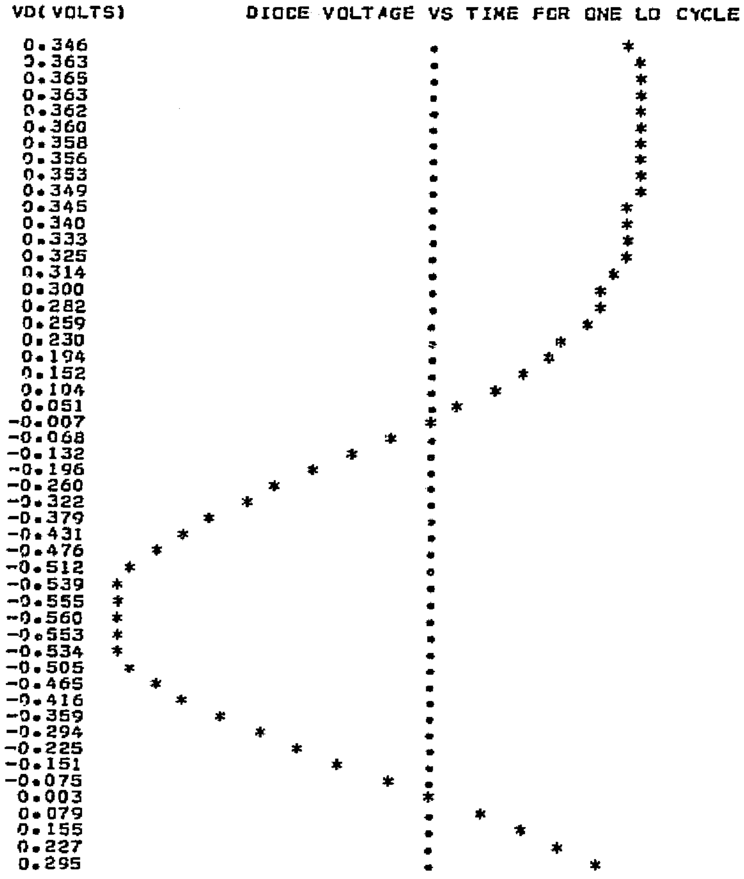
```
GRAPHS FOR REFLECTION CYCLE NUMBER   19

 IGJ(MA)     DIODE CONDUCTANCE CURRENT VS TIME FOR ONE LO CYCLE   CJ(PF)     DIODE CAPACITANCE VS TIME FOR ONE LO CYCLE

  5.147  .                       *                               0.2416                         CO                       *
 10.216  .                                              *        0.2444                         .                        *
 10.756  .                                                *      0.2446                         .                        *
 10.318  .                                               *       0.2444                         .                        *
  9.725  .                                            *          0.2442                         .                        *
  9.074  .                                         *             0.2439                         .                        *
  8.371  .                                      *                0.2436                         .                        *
  7.606  .                                  *                    0.2432                         .                        *
  6.773  .                              *                        0.2427                         .                        *
  5.881  .                          *                            0.2421                         .                        *
  4.948  .                      *                                0.2414                         .                        *
  4.004  .                  *                                    0.2406                         .                        *
  3.076  .             *                                         0.2396                         .                       *
  2.208  .         *                                             0.2383                         .                      *
  1.441  .      *                                                0.2366                         .                     *
  0.827  .   *                                                   0.2346                         .                    *
  0.401  . *                                                     0.2320                         .                  *
  0.158  .*                                                      0.2287                         .                *
  0.049  *                                                       0.2248                         .              *
  0.012  *                                                       0.2204                         .           *
  0.002  *                                                       0.2154                         .        *
  0.000  *                                                       0.2102                         .     *
  0.000  *                                                       0.2048                         .  *
 -0.000  *                                                       0.1994                        *.
 -0.000  *                                                       0.1941                     *   .
 -0.000  *                                                       0.1890                  *      .
 -0.000  *                                                       0.1842               *         .
 -0.000  *                                                       0.1799            *            .
 -0.000  *                                                       0.1759          *              .
 -0.000  *                                                       0.1725        *                .
 -0.000  *                                                       0.1695      *                  .
 -0.000  *                                                       0.1671     *                   .
 -0.000  *                                                       0.1652   *                     .
 -0.000  *                                                       0.1639   *                     .
 -0.000  *                                                       0.1631  *                      .
 -0.000  *                                                       0.1628  *                      .
 -0.000  *                                                       0.1632  *                      .
 -0.000  *                                                       0.1641   *                     .
 -0.000  *                                                       0.1656    *                    .
 -0.000  *                                                       0.1677     *                   .
 -0.000  *                                                       0.1704       *                 .
 -0.000  *                                                       0.1737         *               .
 -0.000  *                                                       0.1776           *             .
 -0.000  *                                                       0.1823              *          .
 -0.000  *                                                       0.1876                 *       .
 -0.000  *                                                       0.1935                     *   .
  0.000  *                                                       0.2002                         *
  0.000  *                                                       0.2076                         .   *
  0.002  *                                                       0.2157                         .        *
  0.044  *                                                       0.2245                         .              *
  0.656  .  *                                                    0.2337                         .                   *
```

GRAPHS FOR REFLECTION CYCLE NUMBER 19


TOTAL DIODE CURRENT VS TIME FOR ONE LO CYCLE


DIODE VOLTAGE VS TIME FOR ONE LO CYCLE

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RESULTS OF THE SMALL-SIGNAL ANALYSIS

 FOURIER COEFFICIENTS OF THE DIODE CONDUCTANCE AND CAPACITANCE WAVEFORMS

 GJMAG,GJPHA  1   7.138D-02   -38.          2   5.070D-02   -72.          3   2.853D-02   -95.          4   1.610D-02   -93.
              5   1.357D-02   -86.          6   1.135D-02   -92.          7   8.810D-03   -93.          8   7.359D-03   -92.

 CJMAG,CJPHA  1   2.146D-14   -60.          2   2.448D-15     5.          3   1.920D-15   -12.          4   7.772D-16   -17.
              5   4.888D-16    -5.          6   3.504D-16    -8.          7   2.330D-16   -10.          8   1.683D-16    -8.

 DC TERMS:  GJMAG =  7.476D-02    CJMAG =  2.062D-13

                                        CONVERSION  LOSS  MATRIX (DB)
                         4         3         2         1         0        -1        -2        -3        -4

            4           0.0      38.24     36.71     32.35     32.05     36.30     44.04     59.41     67.43
            3          39.37      0.0      28.59     32.77     34.12     37.00     47.17     61.69     66.77
            2          36.72     30.33      0.0      14.07     27.47     28.41     36.23     63.34     53.21
            1          35.10     30.77     15.81      0.0       9.87     27.91     27.28     37.84     42.76
            0          34.56     37.54     22.24      6.51      0.0       5.95     22.42     36.88     34.21
           -1          42.58     37.44     27.59     28.72      5.47      0.0      14.60     30.25     34.26
           -2          52.42     59.71     36.17     28.03     27.37     13.01      0.0      29.34     35.68
           -3          66.72     62.22     48.13     37.20     33.84     32.43     27.55      0.0      38.75
           -4          67.34     59.91     44.72     36.34     31.90     31.70     35.65     37.55      0.0

 UPPER SIDEBAND CONVERSION LOSS:  L(0,1)  =   6.51 DB
 LOWER SIDEBAND CONVERSION LOSS:  L(0,-1) =   5.95 DB
 INPUT IMPEDANCES        4         3         2         1         0        -1        -2        -3        -4
   REAL(ZIN):           9.14      8.01     10.16     19.35     94.14     23.38     10.97      8.10      9.26
   IMAG(ZIN):          -5.57    -13.52    -20.55    -38.64    -18.36     44.21     22.60     14.43      9.99

 IF OUTPUT IMPEDANCE:   ZIFOUT =    94.14 + J  -18.36

 EQUIVALENT INPUT NOISE TEMPERATURES:                 TM              THERM           SHOT
                                                     458.3            148.2           310.1
```

APPENDIX II

Modifications to the Mixer Analysis Program for Running the Examples in Section 4

The mixer analysis program appearing in Appendix I of this report must be altered slightly in order to use it for the examples described in section 4. The appropriate statement modifications for running each example are listed on the following pages. Line numbers indicate whether the statements are to be inserted between or used as replacements for those in the program of Appendix I.

A II.1: Alterations to the program in Appendix I for studying the effects of series inductance on the performance of the simple mixer circuit of Fig. 9 using a conventional Schottky-barrier diode. To represent the circuit of Fig. 8 replace line 622 with DATA ZR/50.0D0, 7*0.01D0 , and substitute DATA Z0,ZQACC/ 50.0D0,0.01D0/ for line 1696. For the Schottky diode whose junction capacitance is independent of voltage set GAM to zero in line 1674.

```
C  LS: THE DIODE SERIES INDUCTANCE WHICH WHEN COMBINED WITH ZR AND        190.1
C      ZI PRODUCES THE EMBEDDING IMPEDANCES ZER AND ZEI.                  190.2
C  LSDAT: ARRAY HOLDING THE VALUES OF LS FOR A COMPLETE RUN OF THE        190.3
C         PROGRAM.                                                        190.4
C  NRUN: COUNTS THE NUMBER OF COMPLETE RUNS OF THE PROGRAM.               209.1
C  RESULT: ARRAY FOR STORING RESULTS OF COMPLETE RUNS OF THE PROGRAM.     221.1
C  ZI: IMAGINARY PART OF THE IMPEDANCE OF THE DIODE MOUNT WHICH WHEN      283.1
C      COMBINED WITH LS PRODUCES THE EMBEDDING IMPEDANCE ZEI.             283.2
C  ZR: REAL PART OF THE IMPEDANCE OF THE DIODE MOUNT WHICH WHEN           294.1
C      COMBINED WITH LS PRODUCES THE EMBEDDING IMPEDANCE ZER.             294.2
C---THE MAIN DRIVER PROGRAM                                               351.01
C---                                                                     351.02
C---THE VARIABLE TYPES USED IN THIS ROUTINE ARE AS FOLLOWS:               351.03
C---FOR COMMON/CONST/:                                                    351.04
      REAL*8 QEL,BOLTZ,PI,TEQ                                             351.05
C---FOR COMMON/DIODE/:                                                    351.06
      REAL*8 ALP,PHI,GAM,C0,IS,RS,RSKIN,FP,IF,IGJ,ICJ,GJ,CJ               351.07
C---FOR COMMON/TLINE/:                                                    351.08
      REAL*8 Z0,ZQACC                                                     351.09
      INTEGER ZQFLAG                                                      351.1
C---FOR COMMON/VOLTS/:                                                    351.11
      REAL*8 VLO,VDBIAS,IDBIAS,AV(8),BV(8),VIDC                           351.12
C---FOR VARIABLES NOT IN ANY COMMON BLOCKS:                               351.13
      COMPLEX*16 ZIFOUT                                                   351.14
      REAL*8 LSDAT(35),LS,RESULT(20,20),LOPWR,SHOT,THERM,TM,XLMAT(9,9)    351.15
      INTEGER NRUN                                                        351.16
C---THE COMMON BLOCKS USED ARE:                                           351.17
      COMMON/CONST/QEL,BOLTZ,PI,TEQ                                       351.18
      COMMON/DIODE/ALP,PHI,GAM,C0,IS,RS,RSKIN,FP,IF,IGJ,ICJ,GJ,CJ         351.19
      COMMON/TLINE/Z0,ZQACC,ZQFLAG                                        351.2
      COMMON/VOLTS/AV,BV,VIDC,VLO,VDBIAS,IDBIAS                           351.21
C---THE VALUES OF LS FOR THE VARIOUS PROGRAM RUNS                         351.22
      DATA LSDAT/1.0D-11,1.5D-11,2.0D-11,2.5D-11,3.0D-11,3.5D-11,         351.23
     *4.0D-11,4.5D-11,5.0D-11,5.5D-11,6.0D-11,6.5D-11,7.0D-11,7.5D-11     351.24
     *,8.0D-11,8.5D-11,9.0D-11,9.5D-11,10.0D-11,10.5D-11,11.0D-11,        351.25
     *12.0D-11,13.0D-11,14.0D-11,15.0D-11,16.0D-11,17.0D-11,18.0D-11,     351.26
     *19.0D-11,20.0D-11,21.0D-11,22.0D-11,23.0D-11,24.0D-11,25.0D-11/     351.27
      NRUN=0                                                              351.28
C---RUN THE PROGRAM AS MANY TIMES AS THERE IS DATA                        351.29
      DO 10 I=1,35                                                        351.3
C---SET LS TO ITS VALUE FOR THIS RUN                                      351.31
      LS=LSDAT(I)                                                         351.32
      CALL LGSIG(LS,LOPWR)                                                353.
      CALL SMSIG(TM,SHOT,XLMAT,ZIFOUT)                                    355.
C---INCREMENT THE VARIABLE WHICH COUNTS THE NUMBER OF RUNS                355.01
      NRUN=NRUN+1                                                         355.02
C---STORE THE RESULTS OF EACH RUN IN AN ARRAY                             355.03
      RESULT(NRUN,1)=C0                                                   355.04
      RESULT(NRUN,2)=RS                                                   355.05
      RESULT(NRUN,3)=IS                                                   355.06
      RESULT(NRUN,4)=FP                                                   355.07
      RESULT(NRUN,5)=IF                                                   355.08
      RESULT(NRUN,6)=ALP                                                  355.09
      RESULT(NRUN,7)=PHI                                                  355.1
      RESULT(NRUN,8)=GAM                                                  355.11
      RESULT(NRUN,9)=IDBIAS                                               355.12
      RESULT(NRUN,10)=VDBIAS                                              355.13
      RESULT(NRUN,11)=TEQ                                                 355.14
```

C-2

```
      RESULT(NRUN,12)=Z0                                                355.15
      RESULT(NRUN,13)=VLO                                               355.16
      RESULT(NRUN,14)=LOPWR                                             355.17
      RESULT(NRUN,15)=LS                                                355.18
      RESULT(NRUN,16)=DREAL(ZIFOUT)                                     355.19
      RESULT(NRUN,17)=DIMAG(ZIFOUT)                                     355.2
      RESULT(NRUN,18)=XLMAT(5,4)                                        355.21
      RESULT(NRUN,19)=TM                                                355.22
      RESULT(NRUN,20)=SHOT                                              355.23
   10 CONTINUE                                                          355.24
C---WRITE THE RESULTS OF ALL THE RUNS                                   355.25
      WRITE(6,150)                                                      355.26
  150 FORMAT(1H1,1X,'RESULTS OF THE RUNS ON THIS PRINTOUT'//59X,'DATA'/ 355.27
     1/T5,'C0',T16,'RS',T27,'IS',T38,'FP',T49,'IF',T59,'ALP',T70,'PHI', 355.28
     2T81,'GAM',T91,'IDBIAS',T102,'VDBIAS',T114,'TEQ',T126,'Z0')        355.29
      WRITE(6,180)(RESULT(1,J),J=1,12)                                  355.3
  180 FORMAT (/12(1PE10.3,1X))                                          355.31
      WRITE(6,190)                                                      355.32
  190 FORMAT(///58X,'RESULTS'//T6,'VLO',T19,'LOPWR',T32,'LS',T41,       355.33
     1'RE(ZIFOUT)',T54,'IM(ZIFOUT)',T69,'XL(0,1)',T84,'TM',T96,         355.34
     2'SHOT',T109,'THERM')                                              355.35
      DO 20 I=1,NRUN                                                    355.36
      THERM=RESULT(I,19)-RESULT(I,20)                                   355.37
C---WRITE THE RESULTS OF ALL THE RUNS ON A DISK FILE                    355.38
      WRITE(12) (RESULT(I,J),J=1,20)                                    355.39
      WRITE(6,200) (RESULT(I,J),J=13,20),THERM                          355.4
  200 FORMAT(/1X,9(1PE10.3,3X))                                         355.41
   20 CONTINUE                                                          355.42
      SUBROUTINE LGSIG(LS,LOPWR)                                        361.
      REAL*8 LS                                                         418.1
      CALL ZEMBED(ZER,ZEI,ZEMBDC,ZEMBSB,LS,RS,RSLO,RSSB,RSKIN,FP,IF     437.
     1,IDBIAS,RSSB,RSLO,LS,NH,NHP1,NHD2)                                487.
      SUBROUTINE ZEMBED(ZER,ZEI,ZEMBDC,ZEMBSB,LS,RS,RSLO,RSSB,RSKIN,    600.
      REAL*8 ZER(NH),ZEI(NH),ZEMBDC,LS,RS,RSKIN,FP,IF,PI,ZR(8),ZI(8)    618.
C---THE IMPEDANCES OF THE DIODE MOUNT ARE GIVEN:                        621.
      DATA ZR/50.0D0,7*1000.0D0/                                        622.
      DATA ZI/8*0.0D0/                                                  623.
C---FORM THE EMBEDDING IMPEDANCES AT EACH HARMONIC OF THE LO            623.1
      DO 10 I=1,NH                                                      623.2
      ZER(I)=ZR(I)                                                      623.3
   10 ZEI(I)=ZI(I)+2.0D0*PI*FP*DFLOAT(I)*LS                             623.4
C---FORM THE SIDEBAND IMPEDANCES (SIDEBAND I = ELEMENT NH/2 + 1 - I)    623.5
      DO 30 I=1,NHP1                                                    623.6
      K=NHD2P1-I                                                        623.7
      IF(K.EQ.0) GOTO 20                                                623.8
      ZEMBSB(I)=DCMPLX(ZR(IABS(K)),DSIGN(ZI(IABS(K)),DFLOAT(K))+        623.9
     1LS*2.0D0*PI*(DFLOAT(K)*FP+IF))                                    624.
      GOTO 30                                                           624.1
   20 ZEMBSB(I)=DCMPLX(ZEMBDC,0.0D0)                                    624.2
   30 CONTINUE                                                          624.3
      SUBROUTINE SMSIG(TM,SHOT,XLMAT,ZIFOUT)                            969.
     1VDBIAS,IDBIAS,RSSB,RSLO,LS,NHARM,NHP1,NHD2)                      1305.
      REAL*8 ZER(NHARM),ZEI(NHARM),RSSB(NHP1),RSLO(NHARM),LS           1329.
      WRITE(6,175) LS                                                  1371.1
  175 FORMAT(/1X,' ADDITIONAL INPUT DATA:',T50,'LS'/T46,1PE10.3)       1371.2
      DATA VLOINC,IDCACC/0.1D0,0.02D0/                                 1669.
      DATA TEQ/295.0D0/                                                1672.
      DATA ALP,PHI,GAM/34.78D0,0.90D0,0.5D0/                           1674.
      DATA C0,IS,RS/1.18D-14,1.4D-15,4.4D0/                            1675.
      DATA FP,IF/115.0D9,4.0D9/                                        1676.
      DATA RSKIN/0.0D0/                                                1677.
C*** DELETE LINES 1683 TO 1693 SINCE THE EMBEDDING IMPEDANCES ARE       1683.
C*** FORMED IN SUBROUTINE ZEMBED.                                      1684.
      DATA NH,NLO,NPTS,NVLO,NITER,NPRINT/8,1,51,50,500,100/            1692.
      DATA VDINIT,ACC,NDIM/0.0D0,1.0D-6,1/                             1694.
      DATA Z0,ZQACC/200.0D0,0.01D0/                                    1696.
      DATA VDBIAS,IDBIAS/0.4D0,0.002D0/                                1698.
      DATA VLO/1.30D0/                                                 1699.
```

A II. 2: Alterations to the program in Appendix I for studying the effects of the series inductance on the performance of the simple mixer circuits of Figs. 8 and 9, using a Mott diode with the C-V relation given in Fig. 11. Only changes which are additional to those in AII. 1 are listed.

```
C  B: THE Y INTERCEPTS OF THE C-V PIECEWISE LINEAR APPROXIMATION         117.1
C     USED FOR THE MOTT DIODE EXAMPLES.                                  117.2
C  C: THE CAPACITANCE AT VOLTAGE Y(1) FOR THE MOTT DIODE.                121.1
C  C(VD): FUNCTION WHICH RETURNS A VALUE OF CAPACITANCE FOR A GIVEN      302.1
C         VOLTAGE AT THE TERMINALS OF THE MOTT DIODE.                    302.2
      REAL*8 X,Y(1),DERY(1),V,C                                          864.
      CJ=2.0D0*PI*FP*C(DMIN1(Y(1),0.999D0*PHI))                          884.
      REAL FUNCTION C*8(VD)                                              898.01
C---                                                                     898.02
C---C(VD) IS USED FOR THE MOTT DIODE EXAMPLES ONLY.                      898.03
C---THIS FUNCTION ROUTINE RETURNS THE PROPER VALUE OF CAPACITANCE FOR    898.04
C---A GIVEN VALUE OF THE DIODE VOLTAGE AS CALCULATED IN DRKGS.           898.05
C---IT USES DATA FOR THE SLOPE AND C INTERCEPT OF THE PIECEWISE          898.06
C---LINEAR APPROXIMATION TO THE C-V CURVE OF THE MOTT DIODE. THE DOPING  898.07
C---PROFILE OF THE MOTT DIODE WAS KINDLY SUPPLIED BY M.V.SCHNEIDER,      898.08
C---BELL LABORATORY,HOLMDEL,N.J.                                         898.09
C---                                                                     898.1
C---THE VARIABLE TYPES USED IN THIS SUBROUTINE ARE AS FOLLOWS:           898.11
      REAL*8 M(17),B(17),VLIM(18),VD                                     898.12
C---THE SLOPE AND INTERCEPT DATA                                         898.13
      DATA M/1.2D-16,6.D-16,9.D-16,1.103D-15,1.783D-15,2.375D-15,3.D-15  898.14
     1,3.964D-15,6.615D-15,9.2D-15,10.455D-15,15.833D-15,21.75D-15       898.15
     2,37.5D-15,74.D-15,154.5D-15,4132.657D-15/                          898.16
      DATA B/9.78D-15,11.1D-15,11.4D-15,11.542D-15,11.753D-15,11.8D-15   898.17
     1,11.8D-15,11.742D-15,10.841D-15,9.626D-15,9.036D-15,5.917D-15      898.18
     2,2.13D-15,-8.58D-15,-36.32D-15,-100.72D-15,-3442.372D-15/          898.19
C---THE VOLTAGE LIMITS ON THE REGIONS OF CAPACITANCE VARIATION           898.2
      DATA VLIM/-4.D0,-2.D0,-1.D0,-7.D-1,-.31D0,-8.D-2,0.D0,6.D-2,.34D0  898.21
     1,.47D0,.52D0,.58D0,.64D0,.68D0,.76D0,.8D0,.84D0,.8991D0/           898.22
      I=1                                                                898.23
      IF(VD.LT.VLIM(1)) GOTO 15                                          898.24
      IF(VD.EQ.VLIM(I)) GOTO 10                                          898.25
      IF(VD.GT.VLIM(18)) GOTO 20                                         898.26
C---FIND THE REGION IN WHICH THE VOLTAGE FROM DRKGS FALLS AND CALC. C    898.27
    5 IF(VD.GT.VLIM(I)) GOTO 10                                          898.28
      C=M(I-I)*VD+B(I-1)                                                 898.29
      GOTO 25                                                            898.3
   10 I=I+1                                                              898.31
      GOTO 5                                                             898.32
   15 WRITE(6,100) VD,VLIM(I)                                            898.33
  100 FORMAT(////1X,'UNDERFLOW: VD =',F8.4,' IS LESS THAN ',F7.4//)      898.34
      GOTO 25                                                            898.35
   20 WRITE(6,200) VD,VLIM(18)                                           898.36
  200 FORMAT(////1X,'OVERFLOW: VD =',F8.5,' IS GREATER THAN ',F8.5//)    898.37
   25 RETURN                                                             898.38
      END                                                                898.39
                                                                         898.4
                                                                         898.41
                                                                         898.42
```

A II. 3: Alterations to the program in Appendix I for studying the performance of the Schottky diode mixers when the zero voltage junction capacitance C0 is varied. One value of series inductance is used for each run. Only changes which are additional to those listed in A II. 1 are shown here.

```
C  C0DAT: ARRAV HOLDING THE VALUES OF C0 FOR EACH RUN OF THE ENTIRE      131.1
C          ANALYSIS.                                                      131.2
      REAL*8 C0DAT(20),LS,RESULT(20,20),LOPWR,SHOT,THERM,TM,XLMAT(9,9)   351.15
C---THE VALUES OF C0 FOR THE VARIOUS PROGRAM RUNS                         351.22
      DATA C0DAT/1.0D-15,,2.0D-15,,3.0D-15,4.0D-15,5.0D-15,6.0D-15,       351.23
     *7.0D-15,8.0D-15,9.0D-15,10.0D-15,11.0D-15,12.0D-15,13.0D-15,        351.24
     *14.0D-15,15.0D-15,16.0D-15,17.0D-15,18.0D-15,19.0D-15,              351.25
     *20.0D-15/                                                           351.26
      DATA LS/.04D-9/                                                     351.27
      DO 10 I=1,20                                                        351.3
C---SET C0 TO ITS VALUE FOR THIS RUN                                      351.31
      C0=C0DAT(I)                                                         351.32
      RESULT(NRUN,1)=LS                                                   355.04
      RESULT(NRUN,15)=C0                                                  355.18
     1/T5,'LS',T16,'RS',T27,'IS',T38,'FP',T49,'IF',T59,'ALP',T70,'PHI',   355.28
  190 FORMAT(///58X,'RESULTS'//T6,'VLO',T19,'LOPWR',T32,'C0',T41,         355.33
```

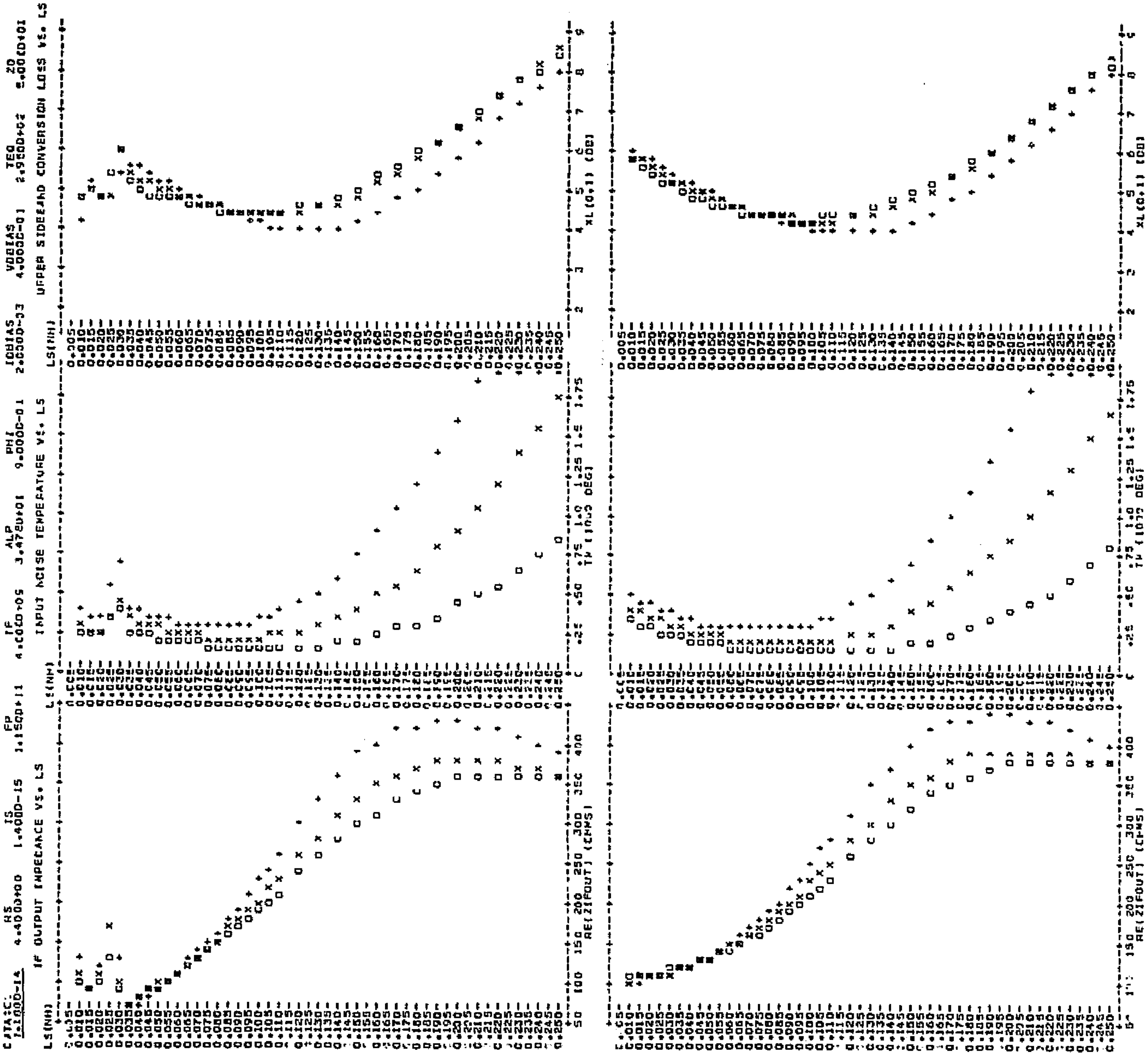
APPENDIX III

Results of Program Runs to Study the Effects of Series Inductance and Junction Capacitance on the Performance of Some Simple Mixer Circuits Described in Section 4

This appendix contains graphs of the equivalent input noise temperature, upper sideband conversion loss and IF output impedance as a function of series inductance LS and junction capacitance C0.

The mixer analysis program, with the modifications in Appendix II, was used for each of three diodes in the mixer circuits of Figs. 8 (short circuited harmonics) and 9 (open circuited harmonics). The diodes were forward biased at 0.4 V in all cases, and the LO power adjusted to give a rectified dc current of 2.0 mA. The signal, LO, and intermediate frequencies were 119 GHz, 115 GHz, and 4 GHz respectively.

A III. 1: Mixer performance data plotted as a function of series inductance for three different diodes in the simple mixer circuits of (a) Fig. 8 and (b) Fig. 9. In all cases the diodes were forward biased at 0.4, and the LO level adjusted to give a rectified current of 2.0 mA. The signal, LO and intermediate frequencies were 119 GHz, 115 GHz and 4 GHz respectively.



(a)

s/c harmonics

(b)

o/c harmonics

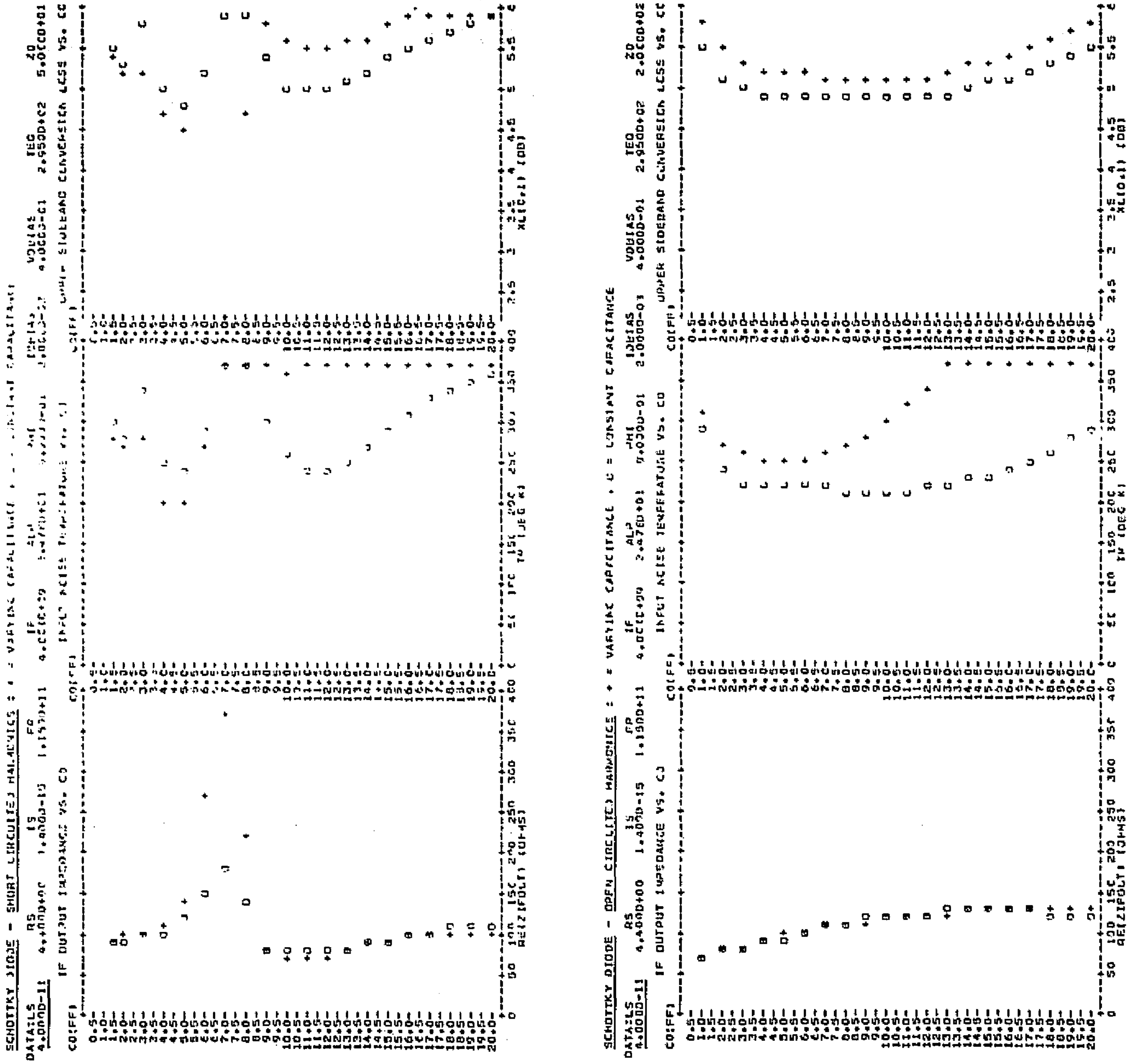
C0 = 11.8 fFd.

+ = Schottky diode with varying capacitance (GAM=0.5)

O = Schottky diode with constant capacitance (GAM=0)

x = Mott diode with a realistic C-V variation

A III. 2 Mixer performance data plotted as a function of zero voltage junction capacitance for a conventional Ga As Schottky diode (GAM = .5) and a Ga As Schottky diode with no capacitance variation (GAM=0) in the mixer circuits of (a) Fig. 8 and (b) Fig. 9. The diodes were forward biased to 0.4 V and the LO level adjusted to give a rectified current of 2.0 mA. The signal, LO and intermediate frequencies were 119 GHz, 115 GHz and 4 GHz respectively. Graphs appear for nine different values of series inductance LS.



(a)

s/c harmonics

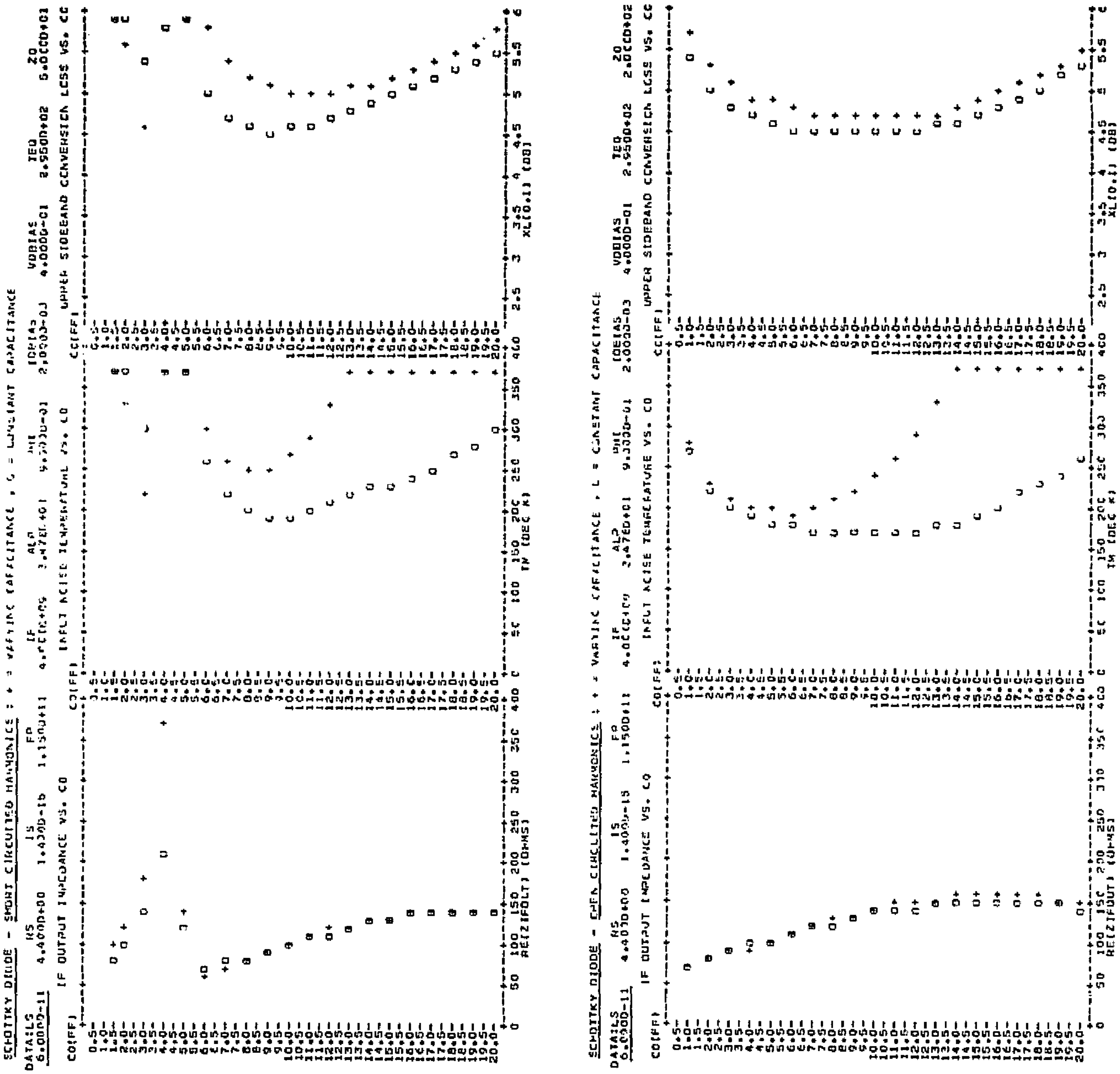
(b)

o/c harmonics

LS = 0.04 nH.

+ = varying capacitance (GAM=0.5)

O = constant capacitance (GAM=0)



(a)

s/c harmonics

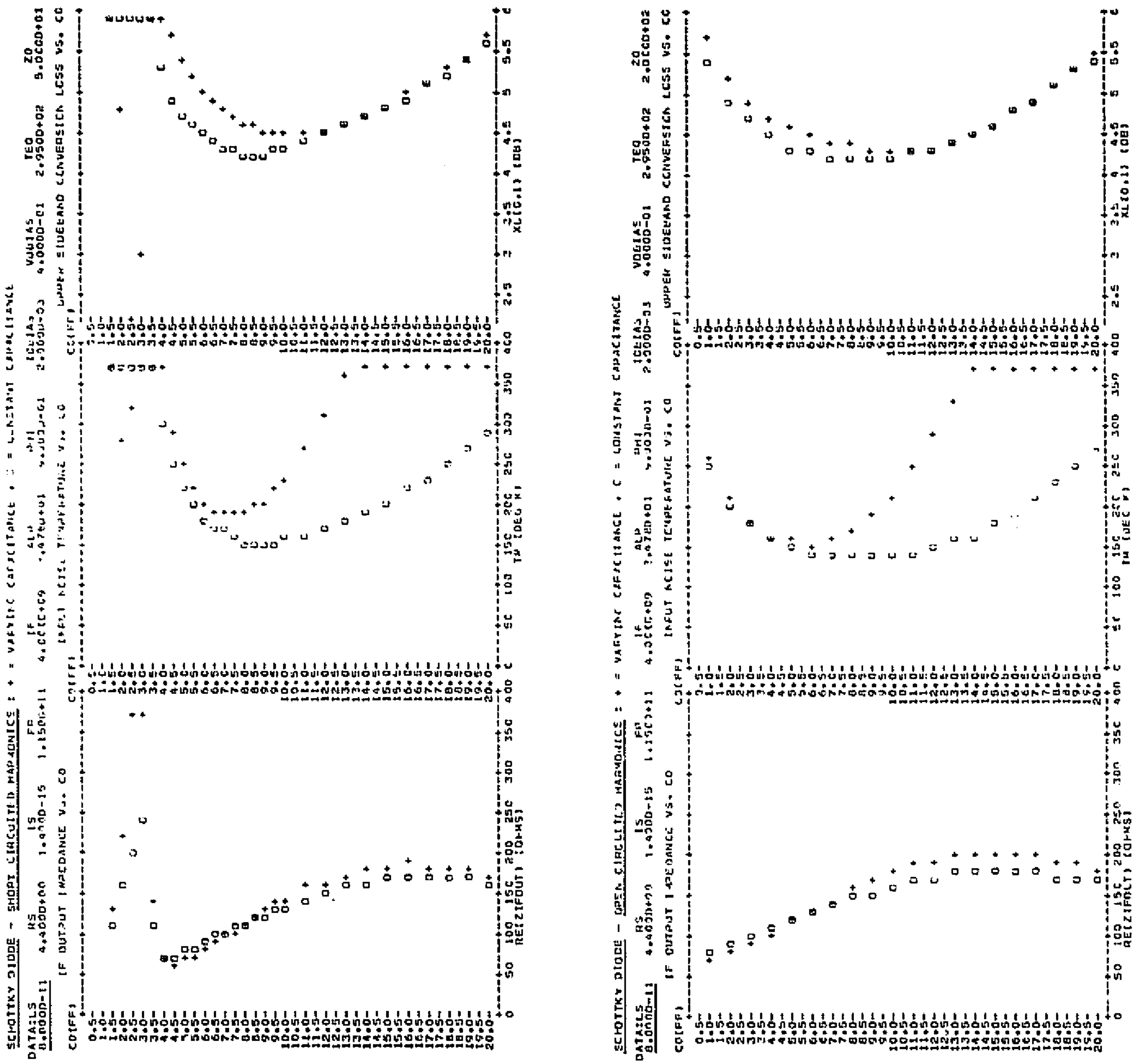
(b)

o/c harmonics

LS = 0.06 nH.

+ = varying capacitance (GAM=0.5)

O = constant capacitance (GAM=0)



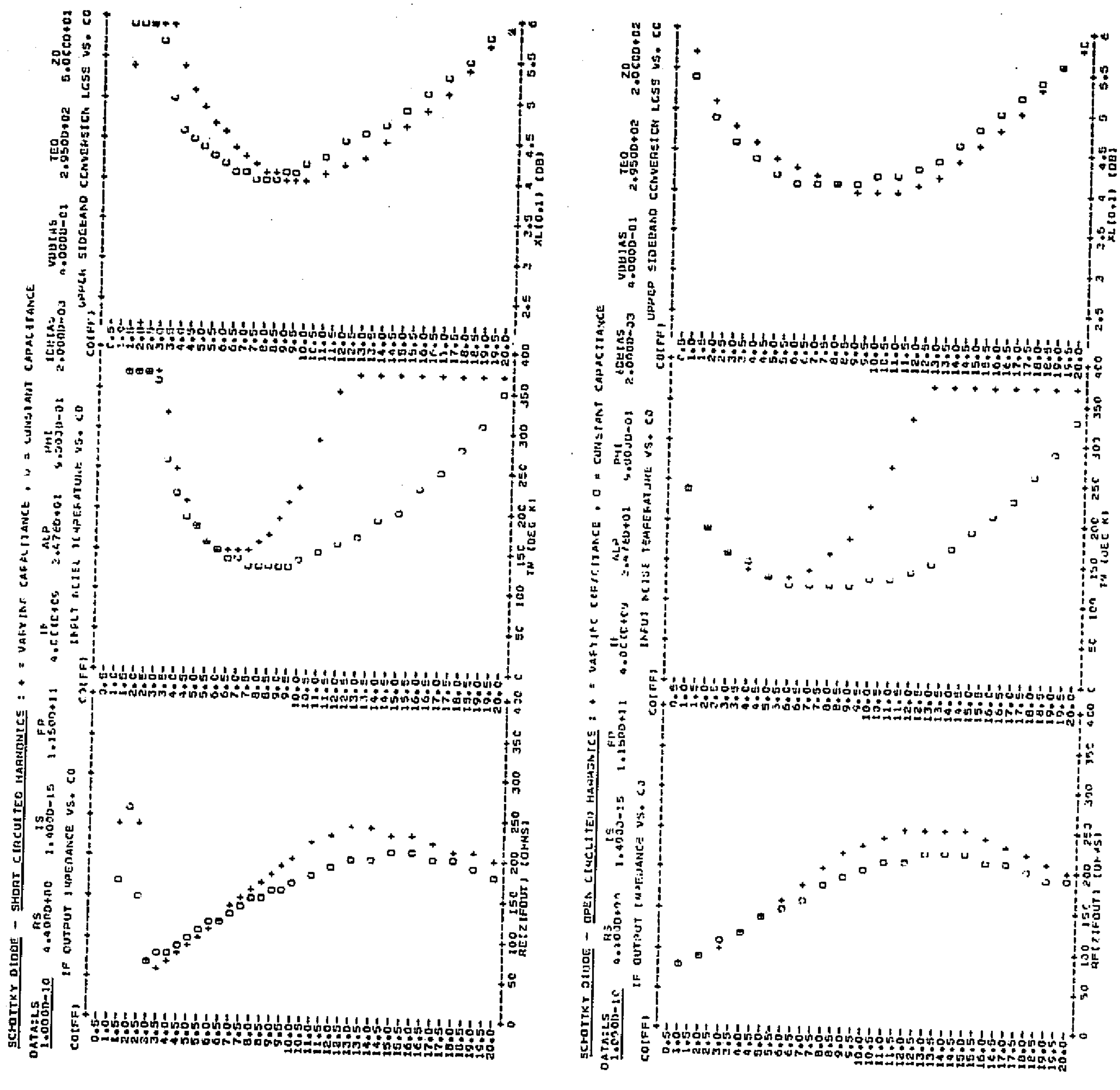
(a) s/c harmonics

(b) o/c harmonics

LS = 0.08 nH.

+ = varying capacitance (GAM=0.5)

O = constant capacitance (GAM=0)



(a)

s/c harmonics

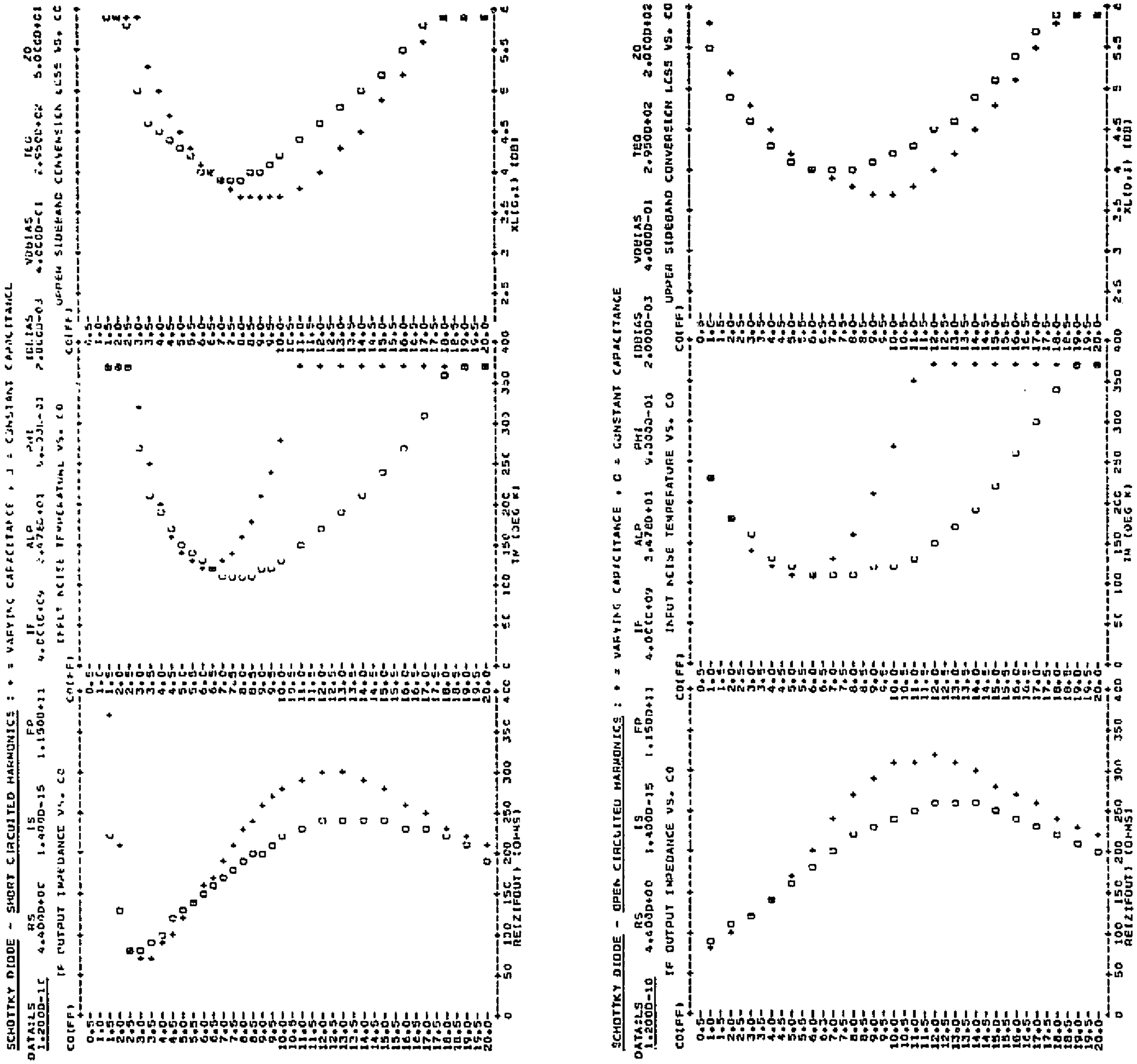
(b)

o/c harmonics

LS = 0.10 nH.

+ = varying capacitance (GAM=0.5)

O = constant capacitance (GAM=0)



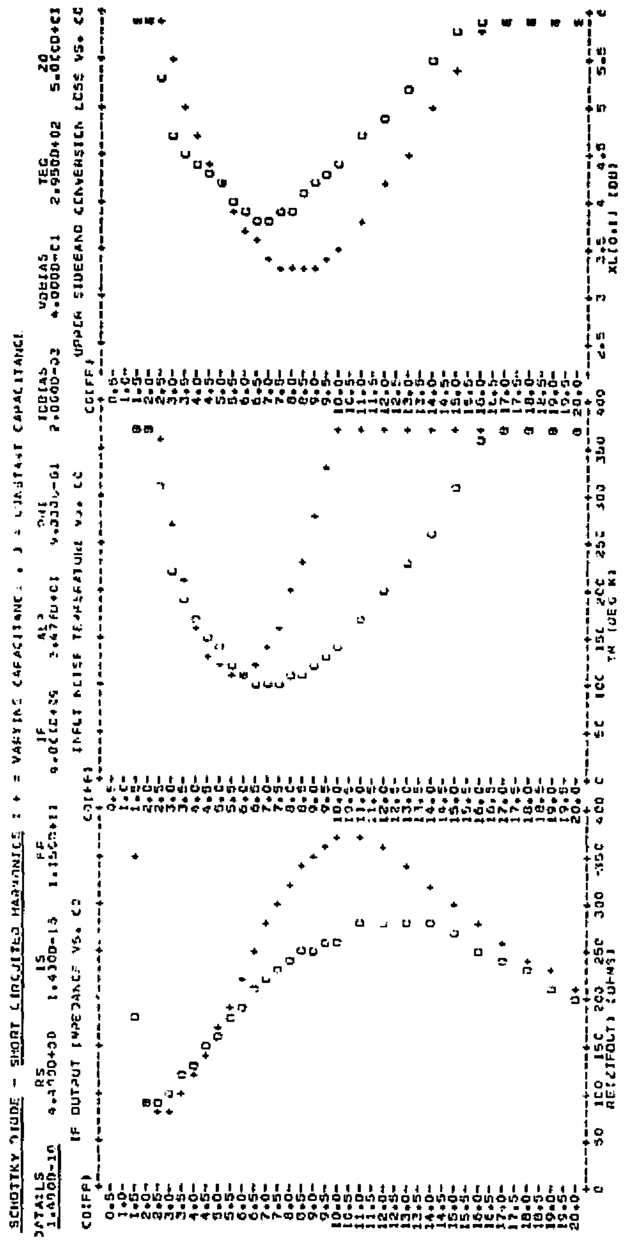
(a)
s/c harmonics

(b)
o/c harmonics

LS = 0.12 nH.

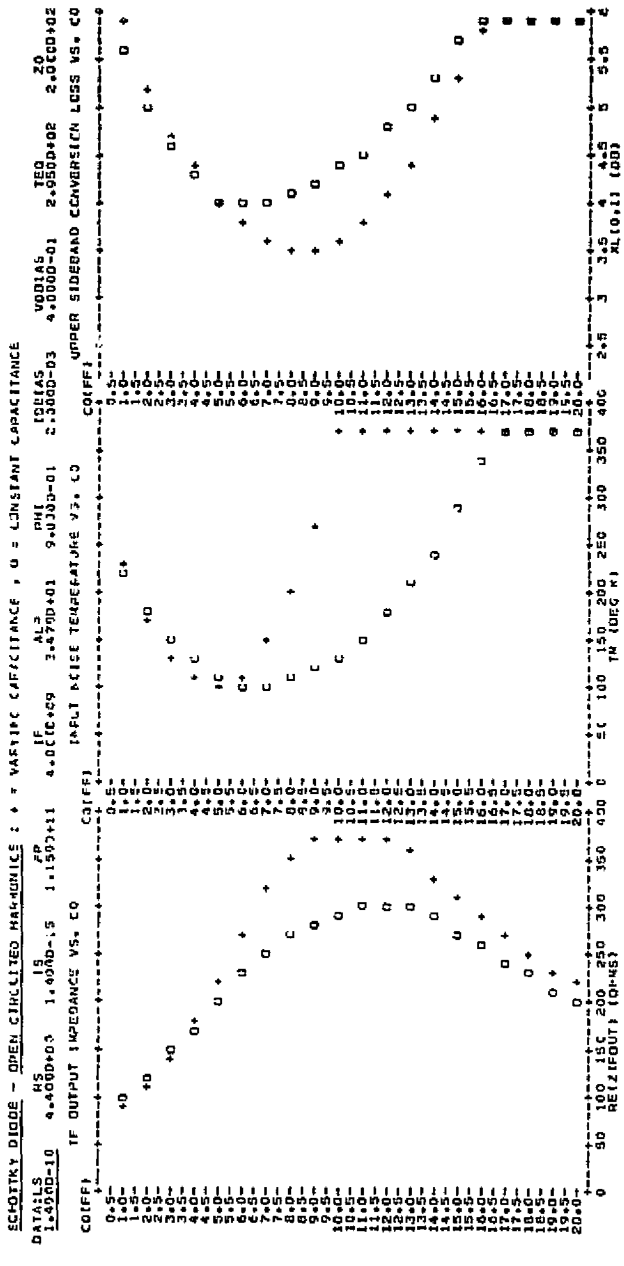
+ = varying capacitance (GAM=0.5)

O = constant capacitance (GAM=0)



(a)

s/c harmonics



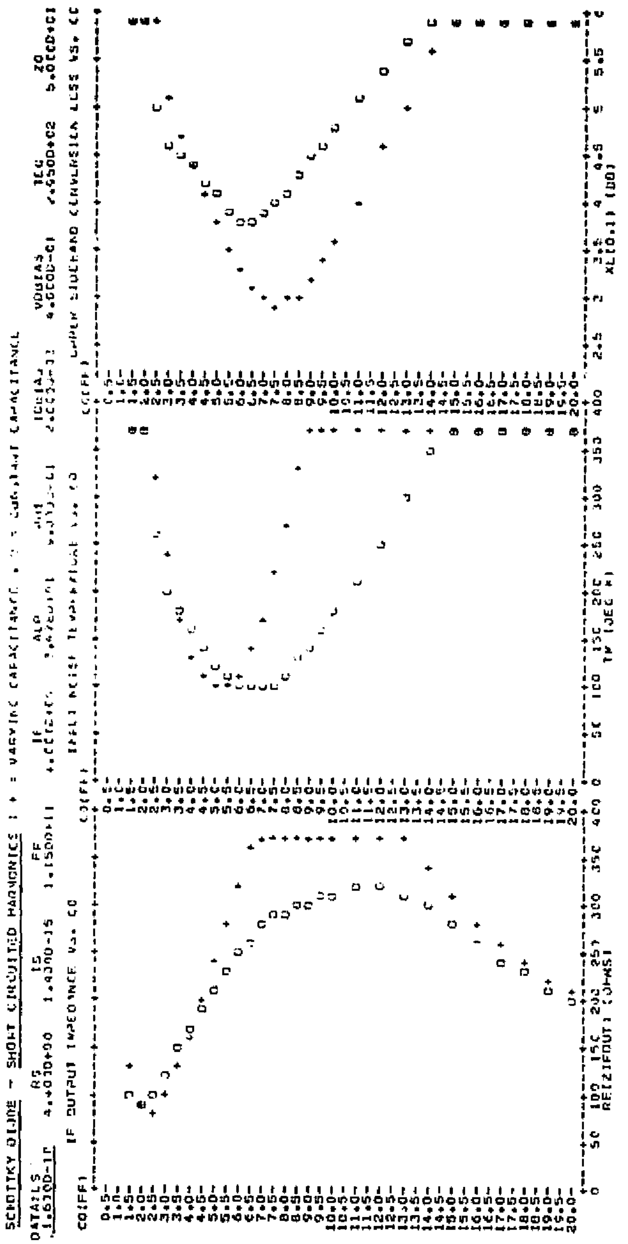
(b)

o/c harmonics

LS = 0.14 nH.

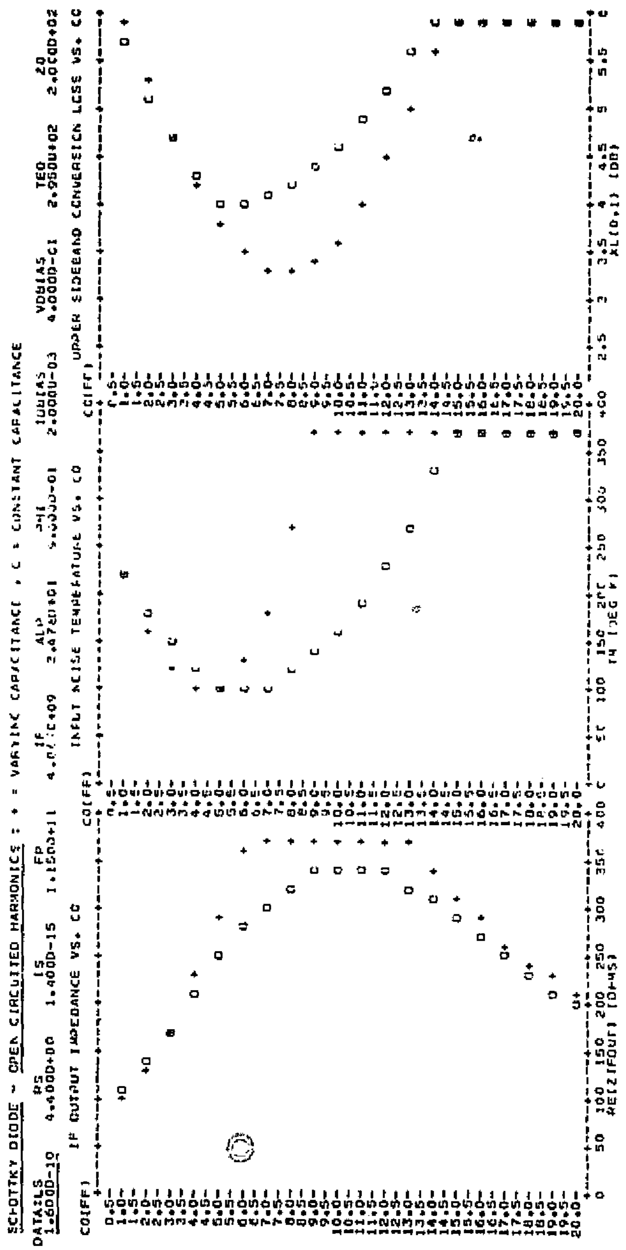
+ = varying capacitance (GAM=0.5)

O = constant capacitance (GAM=0)



(a)

s/c harmonics



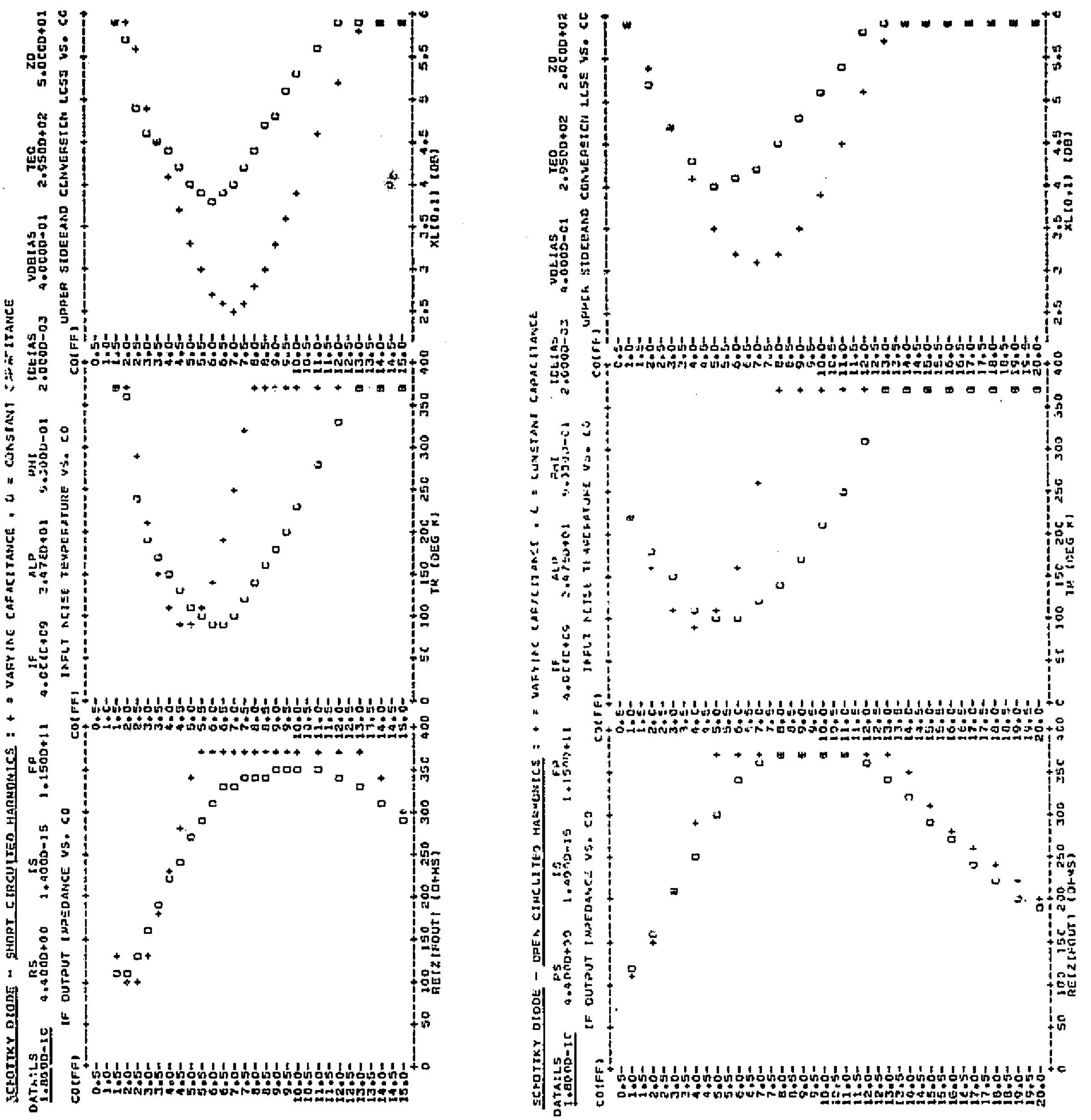
(b)

o/c harmonics

LS = 0.16 nH.

+ = varying capacitance (GAM=0.5)

O = constant capacitance (GAM=0)



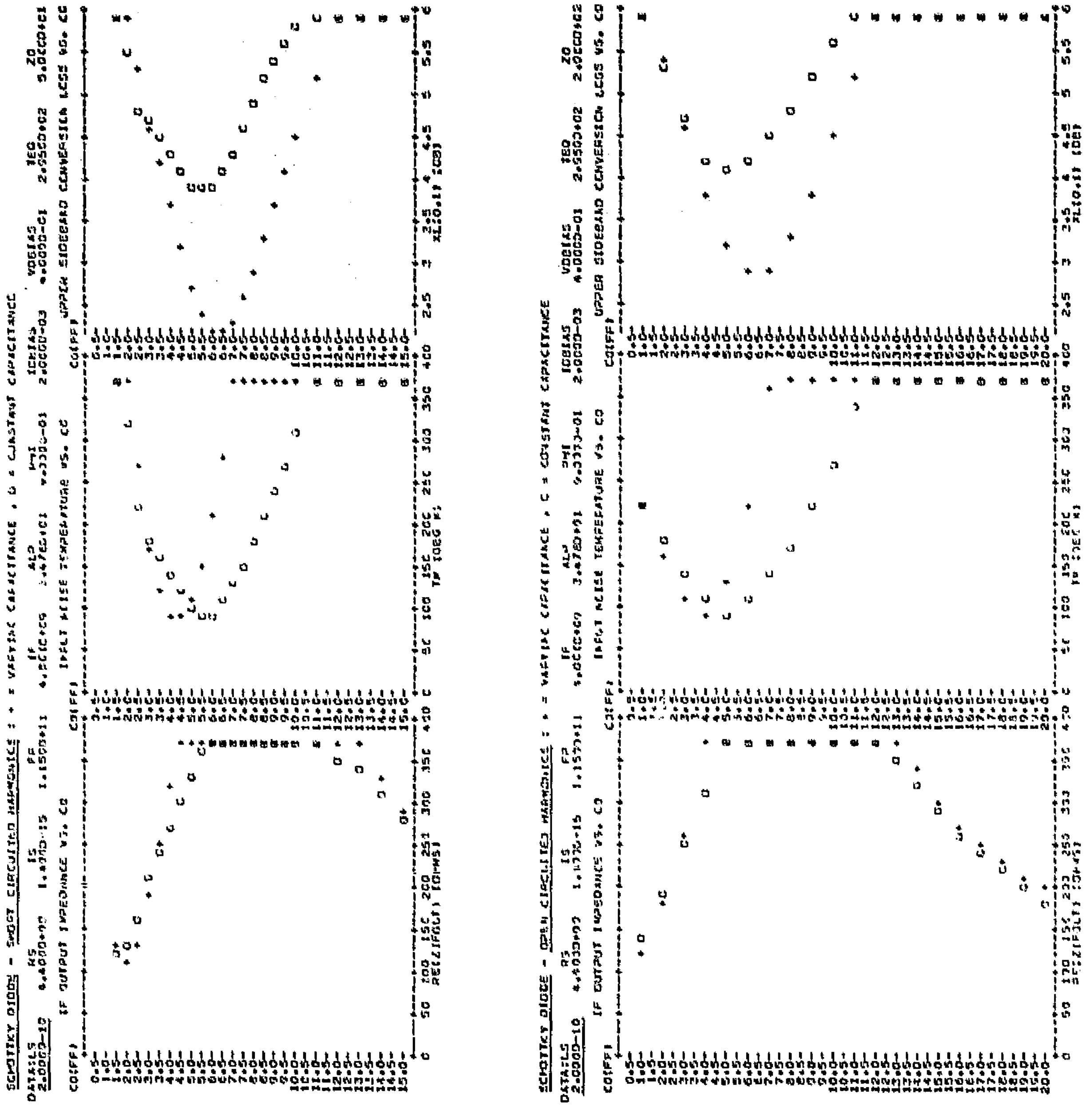
(a)
s/c harmonics

(b)
o/c harmonics

LS = 0.18 nH.

+ = varying capacitance (GAM=0.5)

O = constant capacitance (GAM=0)



(a)

s/c harmonics

(b)

o/c harmonics

LS = 0.2 nH.

+ = varying capacitance (GAM=0.5)

O = constant capacitance (GAM=0)

ACKNOWLEDGEMENT

The authors wish to thank M. V. Schneider of Bell Telephone Laboratories, Holmdel, N. J. for supplying the data on the doping profile of his Mott diodes.

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