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Frequency Domain Analysis of a Class of Nonlinear Networks

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LINCOLN LABORATORY

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ABSTRACT

A method for analyzing in the frequency domain the performance of linear networks containing nonlinear resistors. This method is applied to the evaluation of the frequency performance of a reactively terminated mixer.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

CONTENTS

FREQUENCY DOMAIN ANALYSIS
OF A CLASS OF NONLINEAR NETWORKS

The evaluation of the frequency performance of networks containing nonlinear devices is normally very involved. This report describes a procedure by which the frequency domain performance of networks containing devices that may be represented as nonlinear resistors can be evaluated with any desired accuracy. Since only general statements can be made about the application of this method to the whole class of networks considered, the detailed analysis of a balanced mixer, together with its frequency selective terminations, is presented as an example.

The Problem

The general problem considered is a network containing nonlinear resistors controlled by one or more independent voltages and/or currents embedded in a linear frequency invariant network (Fig. 1). Also, ports 1 and 2 are assumed to be the input and output ports of a 2-port N (dashed lines, Fig. 1). Later, the problem of embedding N in a general linear network including reactive elements is considered.

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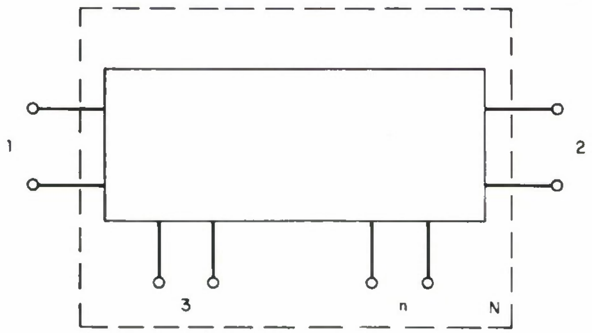

Fig. 1. Frequency invariant network containing nonlinear resistors.

Some Theoretical Considerations

The nonlinear resistors are assumed to be monotonic and representable, over the frequency band of interest, by some curve or family of curves (Fig. 2). The single curve type [i.e., Fig. 2(a)] will be a two-terminal device (e.g., a diode). If the device possesses three terminals, with one used in the fashion of a grid on a triode or gate on an FET, the multiple curve type description [Fig. 2(b)] is necessary. By analogy this scheme can be extended to cover more control parameters. The currents flowing through the nonlinear resistors will be referred to as $f_i(v)$, $f_i(v_1, v_2)$, etc., respectively (Fig. 2) to distinguish them from currents in the linear portion of the network.

Assume for the time being that only m two-terminal nonlinear resistors are present in the network. If these resistors are extracted to form m ports and if the n input ports are supplied with voltage sources V_{si} fed through resistors R_{si}, Fig. 3 results. It will be assumed for the time being that the V_{si} are DC voltages. The reason for this will become apparent later. NR_i stands for nonlinear resistance i. The current at the i^{th} output port is then $f_i(v_i)$ where v_i is the voltage across the port. Defining a $2n \times 2m$ transmission matrix between the n input and m nonlinear resistor ports with elements A, B, C, and D (each of which is an $n \times m$ matrix containing constants only),

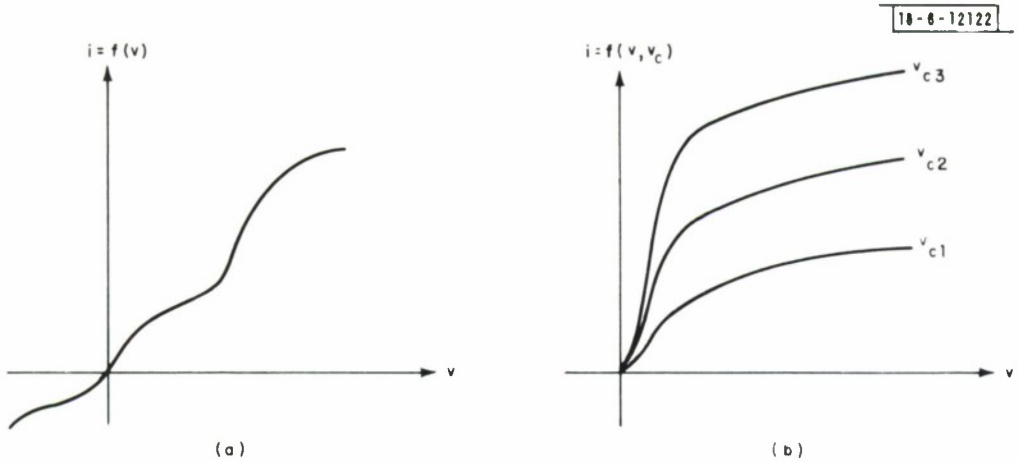

Fig. 2. Typical nonlinear resistance curves.

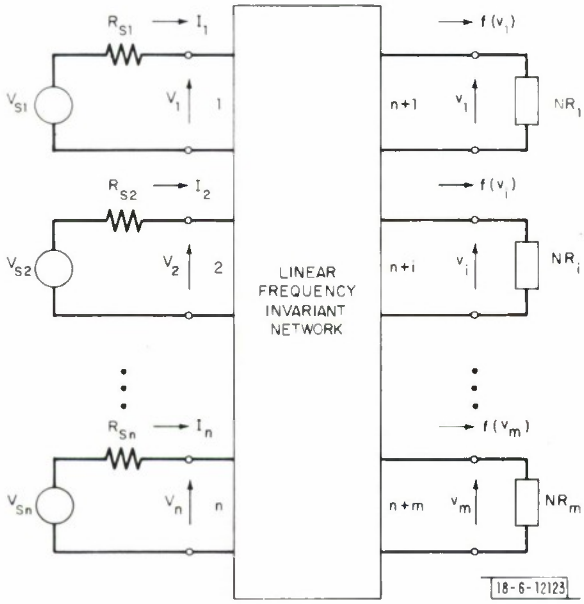

Fig. 3. (n + m)-port linear network terminated in nonlinear resistors at the m-ports.

$$\underset{\sim}{V}_s = (R_s C + A)\,\underset{\sim}{v} + (R_s D + B)\,\underset{\sim}{f}(v) \tag{1}$$

where V_s is an $n \times 1$ column vector, $\underset{\sim}{v}$ and $\underset{\sim}{f}(v)$ are $m \times 1$ column vectors and R_s is an $n \times n$ diagonal matrix with resistor R_{si} in the $i \times i$ position (for $i = 1, 2 \ldots n$).

If three-terminal nonlinear devices are now considered as well, then for each such device wherever there was one output port in Fig. 3 there will now be two. This scheme is illustrated in Fig. 4. It is assumed that no current flows into the control port. This can obviously be done with no loss in generality by merely assuming the resistance (if any) across this port as being

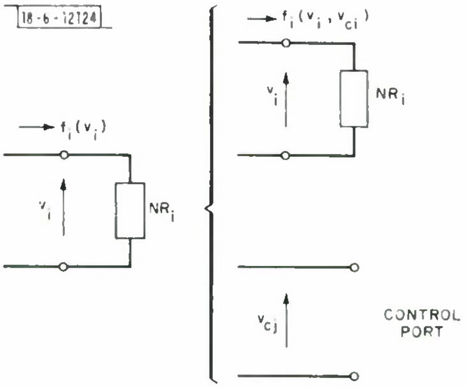

Fig. 4. Transformation of a single to a double controlled nonlinear resistor.

absorbed into the main network. So if there are k of these three-terminal devices present, the number of output ports will be increased to $(m + k)$. An equation essentially in the same form as that given in Eq. (1) will still hold; however, the transmission matrix elements will be $n \times (m + k)$ matrices and $\underset{\sim}{f}(v)$ will be a function of two voltage variables, v_i and v_{cj}, for each of the three-terminal devices. If devices with more than two control parameters are used, the foregoing principles still hold merely increasing the order of the transmission matrices and appropriately changing $\underset{\sim}{f}(v)$. Also, the controlling parameters need not be voltages, they may be any mixture of currents and voltages. No matter what the complexity of the devices, however, an equation of the form shown in Eq. (1) will always be obtainable by standard linear analysis techniques.

V-I curves for each of the nonlinear devices are assumed to be available, so for any one vector $\underset{\sim}{v}$ the vector $\underset{\sim}{f}(v)$ may be evaluated. This may require some interpolation if three or more terminal nonlinear devices are present. From a knowledge of $\underset{\sim}{v}$ and $\underset{\sim}{f}(v)$, by use of Eq. (1) the corresponding vector $\underset{\sim}{V}_s$ can be found. Also for any one vector $\underset{\sim}{v}$ a unique vector $\underset{\sim}{V}_s$ exists. The reverse is also true. Thus given sufficient space a large enough table can be constructed that will permit reverse interpolations, i.e., given a vector $\underset{\sim}{V}_s$ the corresponding vector $\underset{\sim}{v}$ can be found to within some specified accuracy.

Now consider Fig. 2(a). For any value of v, v_i a corresponding unique value $f(v_i)$ exists. Since $f(v_i)$ is a current, a resistance $R_i = v_i/f(v_i)$ may be defined. Again for a given v_i, R_i is unique. So from a given V-I curve, R_i can be easily found for each v. The same is quite obviously true of a family of curves [Fig. 2(b)]; however, here two variables v_i and v_{ci} are required to define R_i.

So for any given vector, $\underset{\sim}{V}_s$, each nonlinear element can be replaced by its corresponding value, R_i. In effect, for each value of V_s the entire network can be replaced by a purely positive linear network. If we consider the 2-port N (Fig. 1) and assume that all its V_{si} are on ports other than 1 and 2, then for each value of V_s one can write down any of the 2-port matrices by straightforward linear network analysis methods. Consider the h-matrix; then

$$v_1 = h_{11}(\underset{\sim}{V}_s)\, i_1 + h_{12}(\underset{\sim}{V}_s)\, v_2$$

$$i_2 = h_{21}(\underset{\sim}{V}_s)\, i_1 + h_{22}(\underset{\sim}{V}_s)\, v_2 \tag{2}$$

as $\underset{\sim}{V}_s$ is changed to some new value, the h-parameters will also change. This dependence is implied by the notation used in Eq. (2).

So far it has been assumed that the elements of V_s are DC voltages. But the main aim of this paper is to investigate the frequency performance of the networks considered. The foregoing discussion can be applied to this aim in the following manner. Assume that each of the voltages in $\underset{\sim}{V}_s$ is some sinusoidally varying signal. The frequency of each of these voltages used need not be the same. It will, however, be assumed that the magnitude of one V_{si} is far larger than that of all the others. The reason for this assumption will become apparent later. Let this dominant voltage be denoted by V_{so} and its frequency by f_o. Now let V_{so} and all the other V_{si} be sampled over one complete cycle of V_{so}. Each set of samples will determine one complete vector V_s and hence one value for each of the h-parameters. If n samples are taken, this will determine the n different values each of the h-parameters assumes over one cycle of V_{so}. Since V_{so} was assumed to be dominant, this pattern will be repeated to a high degree of accuracy over each cycle of V_{so}. This scheme is illustrated in Fig. 5, taking $h_{12}(\underset{\sim}{V}_s)$ as an example. Of course, all the other V_{si} present are also sampled at the same rate as V_{so}. The envelope of the resultant magnitudes of $h_{ij}(\underset{\sim}{V}_s)$, $(i, j = 1, 2)$ represents the variation of these parameters in time over

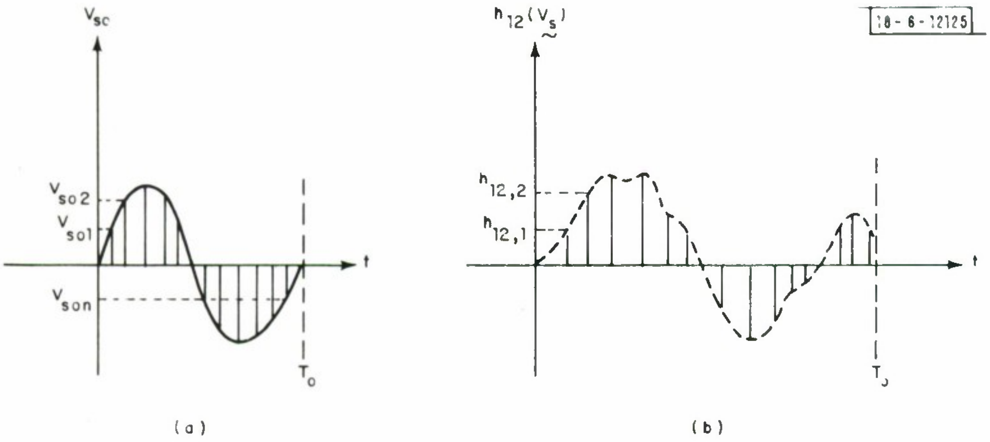

Fig. 5. (a) V_{so} input waveform, (b) possible resultant $h_{12}(\underset{\sim}{V}_s)$ waveform.

a period T_o. The reason for choosing one dominant V_{si} is now apparent. If more than one V_{si} were dominant the periodicity of the h-parameters could well become indeterminate, at least in a general case. In many practical networks the assumption that one drive is dominant as far as the nonlinearities are concerned is founded. The example to be considered will illustrate this. At this stage, cases have to be considered on an individual basis, especially if the dominance of only one V_{si} can no longer be assumed. In this case, each of the four h_{ij} parameters can be expanded in a Fourier series with a fundamental period ω_o. Thus

$$h_{11}(t) = \sum_{i=0}^{\infty} H_{11,i} \exp[ji\omega_o t] \tag{3a}$$

$$h_{12}(t) = \sum_{i=0}^{\infty} H_{12,i} \exp[ji\omega_o t] \tag{3b}$$

$$h_{21}(t) = \sum_{i=0}^{\infty} H_{21,i} \exp[ji\omega_o t] \tag{3c}$$

$$h_{22}(t) = \sum_{i=0}^{\infty} H_{22,i} \exp[ji\omega_o t] \quad . \tag{3d}$$

So the problem posed at the beginning has now been reduced to a 2-port problem with a set of h-parameters given in Eq. (3). The amplitudes and fundamental frequency of these parameters is determined by V_{so}. A number of other V_{si} may also be present. It has to be noted that any DC voltage supplies can also be represented by a V_{si}. These DC voltages may be any required magnitude, comparable or even greater than V_{so}, since they will not introduce a periodic variation.

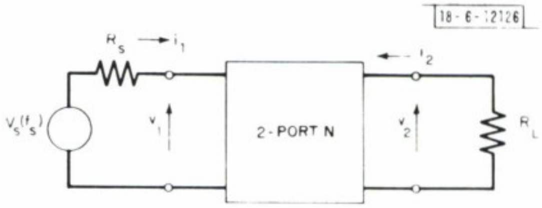

Fig. 6. The 2-port N shown in Fig. 1 with source and load terminations.

In the most general case, the 2-port considered will be supplied by some voltage V_s at frequency f_s (Fig. 6) on port 1 and work into some load R_L. The voltages and currents on the two sides of the network will have frequency components at $(f_s \pm kf_o)$ for $-\infty < k < \infty$, so denoting $|v_{2\ell}| \exp[j \arg(v_{2\ell})]$ by $V_{2\ell}$ and $|i_{1m}| \exp[j \arg(i_{1m})]$ by I_{1m},

$$v_2(t) = \sum_{\ell=-\infty}^{\infty} V_{2\ell} \exp[j(\omega_s + \ell\omega_o) t] \tag{4a}$$

$$i_1(t) = \sum_{m=-\infty}^{\infty} I_{1m} \exp[j(\omega_s + m\omega_o) t] \quad . \tag{4b}$$

Similar expressions hold for the other parameters. Thus from Eqs. (2), (3) and (4):

$$v_1(t) = \sum_{i=0}^{\infty} H_{11,i} \exp[ji\omega_o t] \times \sum_{m=-\infty}^{\infty} I_{1m} \exp[j(\omega_s + m\omega_o) t]$$

$$+ \sum_{i=0}^{\infty} H_{12,i} \exp[ji\omega_o t] \times \sum_{\ell=-\infty}^{\infty} V_{2c} \exp[j\omega_s + \ell\omega_o) t]$$

$$= \sum_{m=-\infty}^{\infty} \left(\sum_{i=0}^{\infty} H_{11,i} I_{1m} \quad \exp j\,[\omega_s + (m+i)\,\omega_o]\,t + \exp j\,[\omega_s + (m-i)\,\omega_o]\,t \right)$$

$$+ \sum_{\ell=-\infty}^{\infty} \left(\sum_{i=0}^{\infty} H_{12,i} V_{2\ell} \quad \exp j\,[\omega_s + (\ell+i)\,\omega_o]\,t + \exp j\,[\omega_s + (\ell-i)\,\omega_o]\,t \right) \quad , \tag{5}$$

but since $v_1(t)$ will also be of the same form as the expressions in Eq. (4), i.e.,

$$v_1(t) = \sum_{n=-\infty}^{\infty} V_{1n} \exp[j(\omega_s + n\omega_o) t] \tag{6}$$

it follows from Eqs. (5) and (6) that

$$V_{1n} = \sum_{i=0}^{\infty} [H_{11,i}(I_{1,n-i} + I_{1,n+i}) + H_{12,i}(V_{2,n-i} + V_{2,n+i})] \tag{7}$$

and by the same argument

$$I_{2k} = \sum_{i=0}^{\infty} [H_{21,i}(I_{1,n-i} + I_{1,n+i}) + H_{22,i}(V_{2,n-i} + V_{2,n+i})] \quad . \tag{8}$$

Since $-\infty \leqslant n \leqslant \infty$ and $-\infty \leqslant k \leqslant \infty$, Eqs. (7) and (8) define a $2n \times 2k$ matrix with both dimensions stretching from $-\infty$ to $+\infty$. In every practical case the coefficients $H_{ab,i}$ will decrease as i increases, also [Eq. (4)] the coefficient V_{2k} and I_{1m} will decrease with an increase in $\cdot$k, so only a finite portion of the matrix has to be considered for any required accuracy. For example, assume that only the first three H-parameter coefficients need be considered, then Eq. (7) reduces to

$$\begin{aligned} V_{1,n} = {} & H_{11,o} I_{1,n} + H_{11,1}(I_{1,n-1} + I_{1,n+1}) + H_{11,2}(I_{1,n-2} + I_{1,n+2}) \\ & + H_{11,3}(I_{1,n-3} + I_{1,n+3}) + H_{12,o} V_{2,n} + H_{12,1}(V_{2,n-1} + V_{2,n+1}) \\ & + H_{12,2}(V_{2,n-2} + V_{2,n+2}) + H_{12,3}(V_{2,n-3} + V_{2,n+2}) \quad . \end{aligned} \tag{9}$$

Equation (8) will reduce to an analogous expression. If it is further assumed that only $V_{1,-2}$, $V_{1,-1} \ldots V_{1,2}$ are of interest, then Eq. (9) may be rewritten in matrix form as

$$
\begin{bmatrix} V_{1,-2} \\ V_{1,-1} \\ V_{1,0} \\ V_{1,1} \\ V_{1,2} \end{bmatrix}
=
\left[\begin{array}{ccc|ccccc|ccc}
H_{11,3} & H_{11,2} & H_{11,1} & H_{11,0} & H_{11,1} & H_{11,2} & H_{11,3} & 0 & 0 & 0 & 0 \\
0 & H_{11,3} & H_{11,2} & H_{11,1} & H_{11,0} & H_{11,1} & H_{11,2} & H_{11,3} & 0 & 0 & 0 \\
0 & 0 & H_{11,3} & H_{11,2} & H_{11,1} & H_{11,0} & H_{11,1} & H_{11,2} & H_{11,3} & 0 & 0 \\
0 & 0 & 0 & H_{11,3} & H_{11,2} & H_{11,1} & H_{11,0} & H_{11,1} & H_{11,2} & H_{11,3} & 0 \\
0 & 0 & 0 & 0 & H_{11,3} & H_{11,2} & H_{11,1} & H_{11,0} & H_{11,1} & H_{11,2} & H_{11,3}
\end{array}\right]
\left[\begin{array}{c} I_{1,-5} \\ I_{1,-4} \\ I_{1,-3} \\ \hline I_{1,-2} \\ I_{1,-1} \\ I_{1,0} \\ I_{1,1} \\ I_{1,2} \\ \hline I_{1,3} \\ I_{1,4} \\ I_{1,5} \end{array}\right]
\tag{10}
$$

$$
+
\left[\begin{array}{ccc|ccccc|ccc}
H_{12,3} & H_{12,2} & H_{12,1} & H_{12,0} & H_{12,1} & H_{12,2} & H_{12,3} & 0 & 0 & 0 & 0 \\
0 & H_{12,3} & H_{12,2} & H_{12,1} & H_{12,0} & H_{12,1} & H_{12,2} & H_{12,3} & 0 & 0 & 0 \\
0 & 0 & H_{12,3} & H_{12,2} & H_{12,1} & H_{12,0} & H_{12,1} & H_{12,2} & H_{12,3} & 0 & 0 \\
0 & 0 & 0 & H_{12,3} & H_{12,2} & H_{12,1} & H_{12,0} & H_{12,1} & H_{12,2} & H_{12,3} & 0 \\
0 & 0 & 0 & 0 & H_{12,3} & H_{12,2} & H_{12,1} & H_{12,0} & H_{12,1} & H_{12,2} & H_{12,3}
\end{array}\right]
\begin{bmatrix} V_{2,-5} \\ V_{2,-4} \\ V_{2,-3} \\ V_{2,-2} \\ V_{2,-1} \\ V_{2,0} \\ V_{2,1} \\ V_{2,2} \\ V_{2,3} \\ V_{2,4} \\ V_{2,5} \end{bmatrix}
$$

Since the number of voltages and currents must be the same, only the portions of the matrices and column vectors inside the dashed lines need be considered. Equation (8) may, of course, also be written in a matrix form analogous to Eq. (10). Denoting the left-hand side of Eq. (10) by $\underset{\sim}{V}_{1,n}$, the two truncated column vectors on the right side by $\underset{\sim}{I}_{1,n}$ and $\underset{\sim}{V}_{2,n}$, and using a similar notation for the other relevant entities, Eqs. (7) and (8) may be rewritten as

$$
\left[\begin{array}{c} \underset{\sim}{V}_{1,n} \\ \hline \underset{\sim}{I}_{2,n} \end{array}\right]
=
\left[\begin{array}{c|c} \underset{\sim}{H}_{11} & \underset{\sim}{H}_{12} \\ \hline \underset{\sim}{H}_{21} & \underset{\sim}{H}_{22} \end{array}\right]
\left[\begin{array}{c} \underset{\sim}{I}_{1,n} \\ \hline \underset{\sim}{V}_{2,n} \end{array}\right] .
\tag{11}
$$

Each of the $\underset{\sim}{H}$-parameters is an $n \times n$ matrix of constants, thus Eq. (11) describes the h-matrix of a linear 2 port with n input and n output ports, however, since each $\underset{\sim}{V}_{1,n}$, etc., is associated with one specific frequency, this 2 port differs fundamentally from a conventional linear network in that each port is associated with a distinct frequency different from all the others. Figure 7 is the pictorial representation of Eq. (11). Despite the fact that each port is associated with a different frequency, the network itself is linear and hence any transfer parameter can be

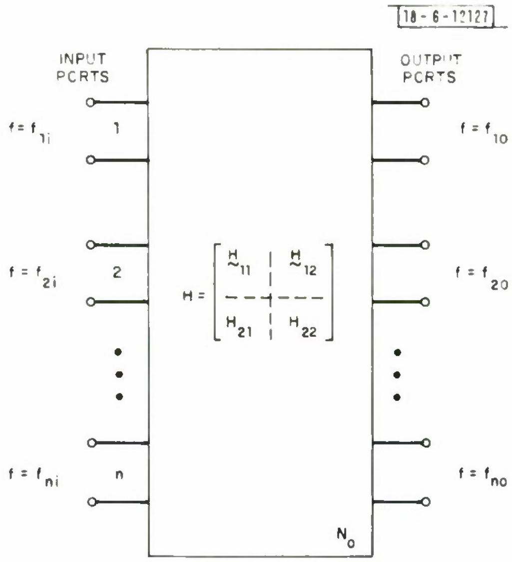

Fig. 7. Resultant linearization of the nonlinear 2-port N.

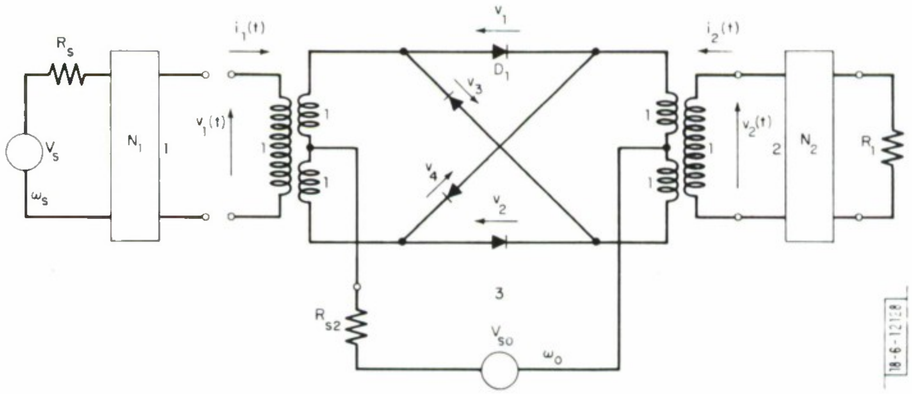

Fig. 8. Balanced mixer terminated in matching networks N_1 and N_2.

computed using simply linear methods. Thus, for example, if the power transfer between input port 1 and output port i is required, this will be given by the $|S_{1,i}|^2$ where $S_{1,i}$ is the 1, i entry in the scattering matrix of network N_o. As far as the original 2-port N is concerned, $|S_{1,i}|^2$ defines the power transfer from port 1 at frequency $f_{1,i}$ to port 2 at frequency $f_{2,i}$. Any other parameters may be evaluated in a similar manner.

To recap, given a 2-port N containing nonlinear resistors, find the time performance of its h-parameters (or any other set for that matter), expand these in a Fourier series, collect the dominant coefficients to form Eq. (11) and the nonlinear 2-port problem is reduced to an equivalent linear 2n-port problem. For example;

The Balanced Ring Mixer

Problem: Investigate the frequency performance of the balanced mixer (Fig. 8) and determine the characteristics of matching networks placed on the input and output ports (networks N_1 and N_2), which will give the smallest insertion loss between the signals at source frequency and the required output frequency.

Let the RF signal at angular frequency ω_s be applied to port 1, the LO signal to port 3, and let port 2 be the output port at which the IF signal at angular frequency $(\omega_s - \omega_o)$ is extracted. The 3-coil transformers are assumed to be frequency invariant over the band of interest. Assuming the LO drive is dominant (this is a very fair assumption in the case) it will be found on inspection that

$$v_1 = v_2 = V_{so}$$

$$v_3 = v_4 = -V_{so} \quad . \tag{12}$$

This simplifies matters very much since none of the interpolation procedures described at the beginning need be used. It is also assumed that the diodes are matched, and hence, have essentially the same V-I characteristics. These will be taken to be of the form shown in Fig. 9(a). With this assumption and the V_{so} drive as shown in Fig. 9(b), the resultant diode resistance performance against time will very nearly be that shown in Fig. 9(c). An additional degree of sophistication is added in Fig. 9(c) by assuming the rise and fall times are unequal. From Eq. (12) it follows that diodes D_1 and D_2 will have a resistance waveform of the type shown in Fig. 9(c). Let this resistance be denoted by R(t). The resistances of diodes D_3 and D_4 will have the same shape as R(t), however, they will be shifted by 180° with respect to R(t). For this reason these impedances will be referred to as $R_-(t)$. By a straightforward Fourier analysis of Fig. 9(c), it follows that

$$R_+(t) = \frac{1}{2}(R_b + R_f) + \frac{1}{2}(R_b - R_f)\,\epsilon(t) \tag{13a}$$

$$R_-(t) = \frac{1}{2}(R_b + R_f) - \frac{1}{2}(R_b - R_f)\,\epsilon(t) \tag{13b}$$

where

$$\epsilon(t) = \sum_{n=1}^{\infty} \frac{1}{2}\left[\frac{\sin n\pi(\frac{\delta a}{T})}{n\pi(\frac{\delta a}{T})} + \frac{\sin n\pi(\frac{\delta b}{T})}{n\pi(\frac{\delta b}{T})}\right] \times \frac{\sin\frac{n\pi}{2}}{\frac{n\pi}{2}} \times \cos n\omega_o t \tag{14}$$

$$= \sum_{n=1}^{\infty} k(n)\,\frac{\sin\frac{n\pi}{2}}{n\pi/2}\cos n\omega_o t \quad . \tag{14a}$$

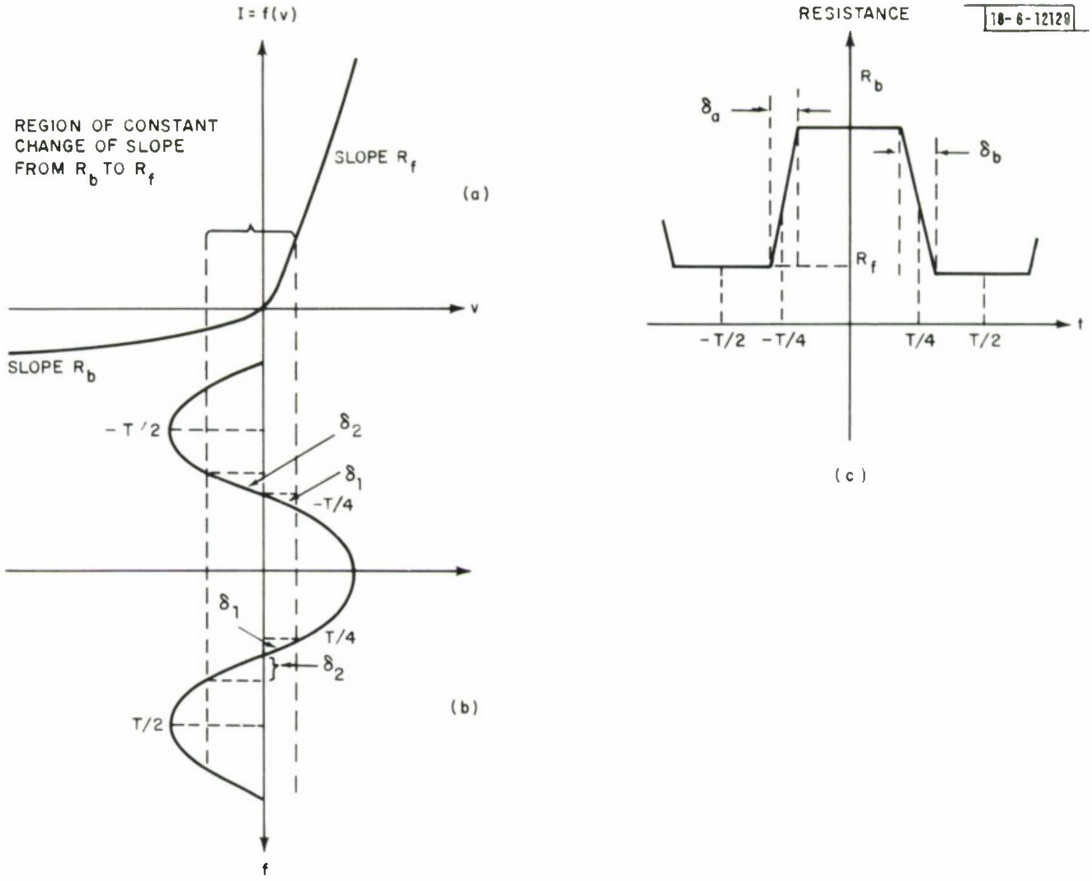

Fig. 9. (a) Diode characteristic, (b) V_{SO} cosine wave versus time, (c) resultant resistance/time performance of a diode driven by the V_{SO} shown in (b).

This is a trapezoidal wave of ±1 magnitude. It should be noted that if $\delta a = \delta b = 0$, $k(n) = 1$, then for all n and $\epsilon(t)$ reduces to

$$u(t) = \sum_{n=1}^{\infty} \frac{\sin \frac{n\pi}{2}}{\frac{n\pi}{2}} \cos n\omega_o t \quad , \tag{15}$$

which is the Fourier expansion of a square wave varying between +1 and −1.

An equivalent derivation on a conductance basis, assuming the two diode slopes to be G_b and G_f gives

$$G_+(t) = \frac{1}{2}(G_f + G_b) - \frac{1}{2}(G_f - G_b)\,\epsilon(t) \tag{16a}$$

$$G_-(t) = \frac{1}{2}(G_f + G_b) + \frac{1}{2}(G_f - G_b)\,\epsilon(t) \quad . \tag{16b}$$

$G_+(t)$ and $G_-(t)$ are defined in the same fashion as $R_+(t)$ and $R_-(t)$.

Assuming the instantaneous resistances (conductances) of the four diodes in Fig. 8 to be, respectively, R_1, R_2, R_3, R_4 (G_1, G_2, G_3, G_4) then the instanteous h-matrix between ports 1 and 2 is given by

$$(h) = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} = \begin{bmatrix} \left(\frac{1}{G_1 + G_3} + \frac{1}{G_2 + G_4}\right) & \frac{R_1R_2 - R_3R_4}{(R_1 + R_3)(R_2 + R_4)} \\ -\frac{R_1R_2 - R_3R_4}{(R_1 + R_3)(R_2 + R_4)} & \left(\frac{1}{R_1 + R_3} + \frac{1}{R_2 + R_4}\right) \end{bmatrix} \tag{17}$$

but $R_1 = R_2 = R_+(t)$ and $R_3 = R_4 = R_-(t)$, or vice versa.

A similar set of relations holds for the Y parameters. Using Eqs. (13), (16) and (17):

$$h_{11} = \frac{2}{G_b + G_f} \tag{18a}$$

$$h_{12} = -h_{21} = \left(\frac{R_b - R_f}{R_b + R_f}\right) \epsilon(t) \tag{18b}$$

$$h_{22} = \frac{2}{R_b + R_f} \quad . \tag{18c}$$

It is interesting to note, that h_{11} and h_{22} reduce to time invariant immittances. Using $\epsilon(t)$ in the form given in Eq. (14a)

$$h_{12} = -h_{21} = \frac{2}{\pi}\left(\frac{R_b - R_f}{R_b + R_f}\right)\Big[k(1)\cos\omega_o t - \frac{1}{3}k(3)\cos 3\omega_o t + \ldots$$

$$+ \frac{(-1)^n}{(2n+1)} k(2n+1)\cos(2n+1)\,\omega_o t \ldots\Big]$$

it follows that

$$H_{11,o} = \frac{2}{G_b + G_f} \quad ; \quad H_{11,i}\Big|_{i \neq o} = 0 \tag{19a}$$

$$H_{22,o} = \frac{2}{R_b + R_f} \quad ; \quad H_{22,i}\Big|_{i \neq o} = 0 \tag{19b}$$

$$H_{12,o} = H_{21,o} = 0 \tag{19c}$$

$$H_{12,i}\Big|_{i \neq o} = H_{21,i}\Big|_{i \neq o} = \frac{2}{\pi}\left(\frac{R_b - R_f}{R_b + R_f}\right) \sum_{i=1}^{\infty} \frac{\sin\frac{i\pi}{2}}{i} k(i) \quad . \tag{19d}$$

Equation (19) completely defines all parameters in the 2n-port H-matrix. Table I gives a number of ratios for k(n). In each instance the rise and fall times have been assumed equal (i.e., $\delta_a = \delta_b$). It should be noted that the fundamental component (i.e., n = 1) in each of the cases considered is very close to unity, and as n increases k(n) departs from unity. So the higher order harmonics are attenuated to a larger degree than the fundamental. This fact will actually aid the mixer design. More will be said about this when the numerical results of this example are discussed.

TABLE I RATIOS FOR k(n)			
n	$\delta_a = \delta_b = 0.01$	$\delta_a = \delta_b = 0.05$	$\delta_a = \delta_b = 0.1$
1	0.999812	0.995865	0.983641
3	0.998433	0.963397	0.858397
5	0.995865	0.900316	0.636620
7	0.991945	0.810335	0.367884
9	0.986725	0.698648	0.109294

Assuming $\delta_a = \delta_b = 0$, the H-matrix of the same order as that in Eq. (10) becomes

$$
\begin{bmatrix} V_{1,-2} \\ V_{1,-1} \\ V_{1,o} \\ V_{1,1} \\ V_{1,2} \\ \hline I_{1,-2} \\ I_{2,-1} \\ I_{2,o} \\ I_{2,1} \\ I_{2,2} \end{bmatrix}
=
\left[\begin{array}{ccccc:ccccc}
H_{11,o,-2} & 0 & 0 & 0 & 0 & 0 & 1 & 0 & -\frac{1}{3} & 0 \\
0 & H_{11,o,-1} & 0 & 0 & 0 & 1 & 0 & 1 & 0 & -\frac{1}{3} \\
0 & 0 & H_{11,o,o} & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\
0 & 0 & 0 & H_{11,o,1} & 0 & -\frac{1}{3} & 0 & 1 & 0 & 1 \\
0 & 0 & 0 & 0 & H_{11,o,2} & 0 & -\frac{1}{3} & 0 & 1 & 0 \\
\hdashline
0 & 1 & 0 & -\frac{1}{3} & 0 & H_{22,o,-2} & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 0 & -\frac{1}{3} & 0 & H_{22,o,-1} & 0 & 0 & 0 \\
0 & 1 & 0 & 1 & 0 & 0 & 0 & H_{22,o,o} & 0 & 0 \\
-\frac{1}{3} & 0 & 1 & 0 & 1 & 0 & 0 & 0 & H_{22,o,1} & 0 \\
0 & -\frac{1}{3} & 0 & 1 & 0 & 0 & 0 & 0 & 0 & H_{22,o,2}
\end{array}\right]
\begin{bmatrix} I_{1,-2} \\ I_{1,-1} \\ I_{1,o} \\ I_{1,1} \\ I_{1,2} \\ \hline V_{2,-2} \\ V_{2,-1} \\ V_{2,o} \\ V_{2,1} \\ V_{2,2} \end{bmatrix}
\tag{20}
$$

where $H_{11,o,k} = 1/(R_b + R_f)$ evaluated at $\omega = \omega_s + k\omega_o$ and $H_{22,o,k} = 1/(R_b + R_f)$ evaluated at $\omega = \omega_s + k\omega_o$. Equation (20) represents a 10-port passive reciprocal network with 5 input and 5 output ports. A number of important conclusions about the character of this 10-port can be drawn from Eq. (20). This can best be done by writing out some of the equations, thus:

$$V_{1,-2} = H_{11,o,-2} I_{1,-2} + V_{2,-1} - \frac{1}{3} V_{2,1} \tag{21a}$$

$$V_{1,-1} = H_{11,o,-1} I_{1,-1} + V_{2,-2} + V_{2,o} - \frac{1}{3} V_{2,2} \tag{21b}$$

$$V_{1,o} = H_{11,o,o} I_{1,o} + V_{2,-1} + V_{2,1} \tag{21c}$$

$$V_{1,1} = H_{11,o,1} I_{1,1} - \frac{1}{3} V_{2,-2} + V_{2,o} + V_{2,2} \tag{21d}$$

$$V_{1,2} = H_{11,o,2} I_{1,2} - \frac{1}{3} V_{2,-1} + V_{2,1} \tag{21e}$$

The frequency associated with any one port is determined by the voltage (or current suffix), thus $V_{1,i}$ is at a frequency $\omega_s + i\omega_o$, etc. So from Eq. (21) it follows that components at even multiples of the angular frequency ω_o on the output ports will produce components at odd multiples of ω_o at the input ports and vice versa. From Fig. 8 it can be seen on inspection that the input voltage components will contain the voltage $V_{1,o}$ (i.e., at ω_s), so there will be a current component $I_{1,o}$. This will result in only odd suffix voltages and currents on the output ports, which in turn will produce only even suffix voltages and currents on the input ports. As a result, only even harmonics of ω_o will be present on the input ports and only odd harmonics on the output ports. This has an important consequence because it implies that all $V_{1,i}$, $I_{1,i}$ for i odd, and $V_{2,i}$, $I_{2,i}$ for i even, will have zero amplitude. So two of the input ports and three of the output ports of the 10 ports are, for practical purposes, nonexistent. So they may be ignored. Since the mixer will be used (in this example) as a down converter, the component $V_{2,-1}$ is the required output. So from equations of the type given in Eq. (21) the input and output voltages, in decreasing order of magnitude, can be written as follows:

Input Magnitudes	Output Magnitudes
$V_{1,o}$	$V_{2,-1}$
$V_{1,-2}$	$V_{2,1}$
$V_{1,2}$	$V_{2,-3}$
$V_{1,-4}$	$V_{2,3}$
$V_{1,4}$	$V_{2,-5}$
.	.
.	.
.	.

and similarly for currents. Using these magnitudes as the new column vectors, a new 10-port matrix may be constructed by inspection of Eq. (10), thus

$$\begin{bmatrix} V_{1,o} \\ V_{1,-2} \\ V_{1,2} \\ V_{1,-4} \\ V_{1,4} \\ \hline I_{2,-1} \\ I_{2,1} \\ I_{2,-3} \\ I_{2,3} \\ I_{2,-5} \end{bmatrix} = \left[\begin{array}{ccccc:ccccc} H_{11,o,o} & 0 & 0 & 0 & 0 & 1 & 1 & -\frac{1}{3} & -\frac{1}{3} & \frac{1}{5} \\ 0 & H_{11,o,-2} & 0 & 0 & 0 & 1 & -\frac{1}{3} & 1 & \frac{1}{5} & -\frac{1}{3} \\ 0 & 0 & H_{11,o,2} & 0 & 0 & -\frac{1}{3} & 1 & \frac{1}{5} & 1 & -\frac{1}{7} \\ 0 & 0 & 0 & H_{11,o,-4} & 0 & -\frac{1}{3} & \frac{1}{5} & 1 & -\frac{1}{7} & 1 \\ 0 & 0 & 0 & 0 & H_{11,o,4} & \frac{1}{5} & -\frac{1}{3} & -\frac{1}{7} & 1 & \frac{1}{9} \\ \hdashline 1 & 1 & -\frac{1}{3} & -\frac{1}{3} & \frac{1}{5} & H_{22,o,-1} & 0 & 0 & 0 & 0 \\ 1 & -\frac{1}{3} & 1 & \frac{1}{5} & -\frac{1}{3} & 0 & H_{22,o,1} & 0 & 0 & 0 \\ -\frac{1}{3} & 1 & \frac{1}{5} & 1 & -\frac{1}{7} & 0 & 0 & H_{22,o,-3} & 0 & 0 \\ -\frac{1}{3} & \frac{1}{5} & 1 & -\frac{1}{7} & 1 & 0 & 0 & 0 & H_{22,o,3} & 0 \\ \frac{1}{5} & -\frac{1}{3} & -\frac{1}{7} & 1 & \frac{1}{9} & 0 & 0 & 0 & 0 & H_{22,o,-5} \end{array}\right] \begin{bmatrix} I_{1,o} \\ I_{1,-2} \\ I_{1,2} \\ I_{1,-4} \\ I_{1,4} \\ \hline V_{2,-1} \\ V_{2,1} \\ V_{2,-3} \\ V_{2,3} \\ V_{2,-5} \end{bmatrix} \tag{22}$$

By inspection of Fig. 8 it follows that Eq. (12), which governs the voltage distribution across the diodes, will be unaffected by connecting general 2-ports (N_1 and N_2) in series with ports 1 and 2. If this is done, the 10-port can be represented as shown in Fig. 10.

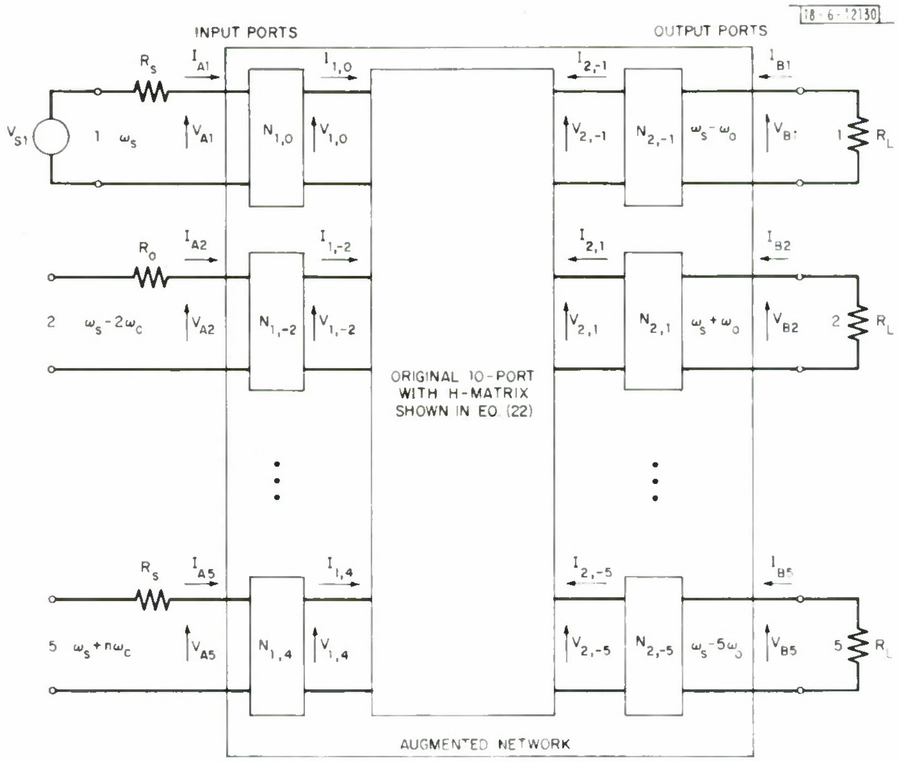

Fig. 10. Augumented 10-port network.

The networks N_1 and N_2 appear on each port evaluated at the port frequency. Let the augmented 10-port input magnitudes be denoted by $\underset{\sim}{V}_A$ and $\underset{\sim}{I}_A$ and those on the output ports by $\underset{\sim}{V}_B$ and $\underset{\sim}{I}_B$ (Fig. 10), then since the transmission matrix of $N_{1,o}$ is

$$\begin{pmatrix} V_{A1} \\ I_{A1} \end{pmatrix} = \begin{bmatrix} A_{1,o} & B_{1,o} \\ C_{1,o} & D_{1,o} \end{bmatrix} \begin{bmatrix} V_{1,o} \\ I_{1,o} \end{bmatrix}$$

the overall transmission matrix of networks $N_{1,i}(\underset{\sim}{T}_1)$ becomes

$$\begin{bmatrix} \underset{\sim}{V}_A \\ \hline \underset{\sim}{I}_A \end{bmatrix} = \left[\begin{array}{c|c} \underset{\sim}{A}_1 & \underset{\sim}{B}_1 \\ \hline \underset{\sim}{C}_1 & \underset{\sim}{D}_1 \end{array}\right] \begin{bmatrix} \underset{\sim}{V}_{1,i} \\ \hline \underset{\sim}{I}_{1,i} \end{bmatrix} \tag{23}$$

where each of matrices A_1, B_1, etc., is a diagonal matrix with entries $A_{1,o}$, $A_{1,-2}$, etc., for (A_1) in the leading diagonal. A similar matrix (T_2) may be defined for the output ports, thus

$$\begin{bmatrix} \underset{\sim}{V}_{2,i} \\ \hline \underset{\sim}{I}_{2,i} \end{bmatrix} = \left[\begin{array}{c|c} \underset{\sim}{A}_2 & \underset{\sim}{B}_2 \\ \hline \underset{\sim}{C}_2 & \underset{\sim}{D}_2 \end{array}\right] \begin{bmatrix} \underset{\sim}{V}_B \\ \hline \underset{\sim}{I}_B \end{bmatrix} \quad . \tag{24}$$

Converting the H-matrix of the unaugmented 10-port into an equivalent transmission matrix (T_o), then the overall transmission matrix of the augmented 10-port (T) is given by

$$[T] = [T_1] \; [T_o] \; [T_2] = \left[\begin{array}{c|c} \underset{\sim}{A} & \underset{\sim}{B} \\ \hline \underset{\sim}{C} & \underset{\sim}{D} \end{array}\right] \quad . \tag{25}$$

If it is now assumed that the load and source resistors R_s and R_L are equal, and that R_s $R_L = 1$, then the scattering matrix parameters of the augmented network is given by

$$\underset{\sim}{S}_{11} = \underset{\sim}{U} - 2 \times (\underset{\sim}{C} + \underset{\sim}{D}) \times \Delta^{-1} \tag{26a}$$

$$\underset{\sim}{S}_{12} = \underset{\sim}{S}_{21} = -2 \times \Delta^{-1} \tag{26b}$$

$$\underset{\sim}{S}_{22} = \underset{\sim}{U} - 2 \times \Delta^{-1} \times (\underset{\sim}{B} + \underset{\sim}{D}) \tag{26c}$$

where U is the unit matrix and $\Delta = \underset{\sim}{A} + \underset{\sim}{B} + \underset{\sim}{C} + \underset{\sim}{D}$. The scattering matrix

$$[\underset{\sim}{S}] = \left[\begin{array}{ccccc|ccccc} s_{11} & s_{12} & \cdots & & s_{15} & s_{16} & \cdots & & & s_{1,10} \\ s_{21} & & & & \cdot & \cdot & & & & \\ \cdot & & & & \cdot & \cdot & & & & \cdot \\ \cdot & & \underset{\sim}{S}_{11} & & \cdot & \cdot & & \underset{\sim}{S}_{12} & & \cdot \\ \cdot & & & & & & & & & \cdot \\ s_{51} & & \cdots & & s_{55} & s_{56} & \cdots & & & \\ \hline s_{61} & & \cdots & & s_{65} & s_{66} & \cdots & & & s_{6,10} \\ \cdot & & & & \cdot & \cdot & & & & \\ \cdot & & \underset{\sim}{S}_{21} & & \cdot & \cdot & & \underset{\sim}{S}_{22} & & \\ \cdot & & & & \cdot & \cdot & & & & \\ s_{10,1} & & \cdots & & s_{10,5} & s_{10,6} & \cdots & & & \end{array}\right] \tag{27}$$

has the property that

$$|s_{16}|^2 = \frac{\text{Power delivered to output port 1}}{\text{Max. available power at input port 1}}$$

$$= \frac{\text{Power delivered to frequency } (\omega_s - \omega_c)}{\text{Max. available power at source frequency } \omega_s} \quad . \tag{28}$$

In similar fashion all the other $|s_{1j}|^2$ are ratios of the powers delivered to the frequency at port j to the maximum available power from the source. So an evaluation of the s_{1j} permits a computation of how much power goes into each of the frequencies present on both sides of the mixer. Also, the input impedance Z_j at the j^{th} port:

$$Z_j = \frac{1 - s_{jj}}{1 + s_{jj}} \quad . \tag{29}$$

So from a knowledge of the s_{jj}, the input impedances on both sides of the mixer at all the frequencies are available.

Using the above mathematical background, a computer program has been written to evaluate these power and impedance distributions.

MODCAP

Based on the mathematical background described, a Fortran program was written to analyze the performance of a modulator connected between two general filters, hence the name MODCAP for MODulator Circuit Analysis Program. The MODCAP program appears at the back of this report.

The purpose of the program is to evaluate the power transfer ratio from the input port at input angular frequency ω_s to the power at all the other frequencies assumed present at both ports. For example, if the strongest five harmonics at the input and output ports are considered, the situation depicted in Fig. 10 ensues. The program will evaluate the power transfer (as a ratio in dB) between input port 1 and any of the remaining nine ports. It will also evaluate the input impedances at the input and output ports at all the frequencies considered. Further, the program will evaluate the amount of change induced in the power transfer ratios and impedances if some element or elements constituting the network change by a specified amount. All of these calculations can be carried out in three different modes:

1. A single frequency is specified in the data for the input and local oscillator drive.
2. A band of input frequencies around some nominal value is specified together with a single local oscillator frequency. In this case, the output frequencies are also grouped in bands.
3. The input frequency extends over a band and a single local oscillator frequency is chosen to be a single frequency. The program will automatically change the nominal local oscillator frequency for each frequency in the input band such that a specified single output frequency results.

In each case the program evaluates the harmonics automatically at single frequencies or in frequency bands depending on the mode used. In its present form, due to storage limitations, the program has these maximum values:

1. The filters terminating the mixer on each side must have no more than 10 nodes and contain only two or three terminal elements. For ten nodes there can only be three terminal elements.
2. The maximum number of harmonics on each side of the mixer cannot exceed 10.
3. The same number of harmonics always have to be considered on each of the two ports.
4. If frequency bands around each harmonic are used, they can contain no more than 21 frequencies.
5. If effects of one or more element changes are investigated, only 42 sets of variations can be accommodated.

All of these constraints can be overridden by appropriate dimensioning.

Data is entered via a subroutine. Data for a typical case are shown in the MODCAP input data (program) at the end of this report where:

M specifies the number of frequencies in each harmonic band.

N is the number of harmonics including the fundamental considered on each side.

HINOD (a) is where a = 1 and 2 for the highest node numbers in network 1 and 2, respectively.

RISE is the fractional rise time of switching wave shape (δ_a/T) (Fig. 9c).

FALL is the fractional fall time of switching wave shape (δ_b/T) (Fig. 9e).

RT is the magnitude of source and load resistor. If unequal terminations are required transformers have to be included in networks 1 or 2.

X(a, i, j) is element X(L, R or C) of network a(1 or 2) appearing between nodes i and j. The units are Henries, Ohms and Farads and the values are entered in floating point form, e.g., L(1, 3, 5) = 5.86E-6 in network 1. The inductor appearing between nodes 3 and 5 has a value of 5.86 μH.

If 3-terminal devices (e.g., transformers) appear in either of the terminating networks, their presence and location is described as follows:

Each device is assigned a consecutive number. Their input node is labelled E1, the output node E2 and the common node E3. The network number and device are in brackets:

E1(2, 1) = 1

E2(2, 1) = 2

E3(2, 1) = 3 .

This notation tells the computer that in network 2 the input node of 3-terminal device 1 is connected to the node labelled 1. The output node of device 1 in network 2 is connected to node 2 and the common node of device 1 in network 2 is connected to node 4. This describes the location of device 1 in network 2. The electrical parameters of 3-terminal devices are specified by their H-matrix. All four H-parameters must be frequency independent. H11 and H22 are in units of Ohms and Mhos, respectively; the remaining two are dimensionless. All magnitudes are again specified in floating point form. For example, H11(2, 1) = 0.5EO means that H11 of device 1 in network 2 is 0.5 Ohms.

If frequency bands are used these are entered as FR(i) = value where i = 1, 2, . . . M. If the frequencies are equally spaced they can be entered by specifying the first frequency FR(1) = 'value', the increment DR(2) = 'value' and the last frequency FR(7) = 'value'. Frequencies can be entered sequentially or with increments or a combination of both. There may be as many increments as necessary, but the total number of frequencies cannot exceed 21.

FLON is the nominal local oscillator frequency.

FIFN is the nominal output frequency. This is 0.0 for modes 1 and 2 and assumes some non-zero value only for mode 3.

This completes the nominal data input. If no variations are required, a RETURN card follows FIFN and then 'i CONTINUE' cards where i = 1, 2. . . 42. After 42 CONTINUE, a STOP and an END card completes the data input.

If variations are required, the 2 CONTINUE card follows the RETURN card. A 'VAR = 1' card is inserted next. Following is the first set of variations. Thus NEWR(1, 1, 5) = 0.607EO means that the old value of the resistor in network 1 between nodes 1 and 5 assumes the new value of 0.607 Ohms. At the end of the first set of variations a RETURN card has to be inserted. If there is more than one variation, the procedure is repeated with VAR = 2, etc.

NOTE:

The nodes in the two terminating networks have to be labelled as follows: the input node has to be node 1, the output node is labelled 2, internal nodes are labelled arbitrarily, and the highest node number is assigned to the common ground node.

MODCAP INPUT DATA

```
//              'GORSKI-POPIEL KCC7',MSGLEVEL=1      MODCAP
//FORG EXEC     FORTRANG
//SYSIN  DD     *
C THIS IS THE MAIN CALLING PROGRAM MODCAP                              MOD00010
      INTEGER HINOD(2),VAR,LA(10),MA(10),E1(2,3),E2(2,3),E3(2,3)       MOD00020
      REAL   NEWR(2,10,10), NEWL(2,10,10), NEWC(2,10,10),              MOD00030
     1L(2,10,10), R(2,10,10), C(2,10,10), BTA(100),                    MOD00040
     2YR(2,10,10), YT(2,10,10), F(2,10,11), FR(22),                    MOD00050
     3DR(22), ALPHA(10,10), BETHA(10,10), QN(11,20), Q(11,20),         MOD00060
     4PN(11,20),P(11,20),H11(2,3),H11L(2,3),H12(2,3),H12F(2,3),        MOD00070
     5H21(2,3),H21F(2,3),H22(2,3),H22C(2,3)                            MOD00080
      COMPLEX*16 AR1(100),AR2(100),BR1(100),BR2(100),AR3(100)          MOD00090
      COMPLEX*16   Y(2,10,10),A1(10,11),B1(10,11),C1(10,11),D1(10,11), MOD00100
     1A2(10,11),B2(10,11),C2(10,11),D2(10,11),DELTA(100),              MOD00110
     2S11(10,10),S22(10,10),ZN(11,20),Z(11,20),DZ,SUM(20),             MOD00120
     3AT(10,10),BT(10,10),CT(10,10),DT(10,10),                         MOD00130
     4TAT(100),TBT(100),TCT(100),TDT(100),U(10,10),TU(100),            MOD00140
     5T1(100),T2(100),TT1(100),TT2(100),S21(10,10),YT(2,10,10)         MOD00150
      COMMON N,M,HINOD,RISE,FALL,VAR,FLON,FIFN,FR,DR,NEWR,NEWL,        MOD00160
     1NEWC,R,L,C,(Q,PT/BL1/E1,E2,E3,H11,H11L,H12,H12F,H21,H21F,H22,H22C MOD00170
     2/BL2/I,J,K,JT,MT,F,W/BL3/ZN,PN,Z,P,QN,Q                         MOD00180
      DO 200 I=1,20                                                    MOD00190
200   SUM(I)=(0.0,0.0)                                                 MOD00200
      DO 160 IMI=1,100                                                 MOD00210
      AR1(IMI)=(0.0,0.0)                                               MOD00220
      AR2(IMI)=(0.0,0.0)                                               MOD00230
      AR3(IMI)=(0.0,0.0)                                               MOD00240
      BR1(IMI)=(0.0,0.0)                                               MOD00250
      BR2(IMI)=(0.0,0.0)                                               MOD00260
      BTA(IMI)=0.0                                                     MOD00270
      T1(IMI)=(0.0,0.0)                                                MOD00280
      T2(IMI)=(0.0,0.0)                                                MOD00290
      TT1(IMI)=(0.0,0.0)                                               MOD00300
      TT2(IMI)=(0.0,0.0)                                               MOD00310
      TAT(IMI)=(0.0,0.0)                                               MOD00320
      TBT(IMI)=(0.0,0.0)                                               MOD00330
      TCT(IMI)=(0.0,0.0)                                               MOD00340
      TDT(IMI)=(0.0,0.0)                                               MOD00350
```

```
160   DELTA(MI)=(0.0,0.0)                                   MOD00360
      DO 170 I=1,10                                         MOD00370
      DO 170 J=1,10                                         MOD00380
      AT(I,J)=(0.0,0.0)                                     MOD00390
      BT(I,J)=(0.0,0.0)                                     MOD00400
      CT(I,J)=(0.0,0.0)                                     MOD00410
      DT(I,J)=(0.0,0.0)                                     MOD00420
      S11(I,J)=(0.0,0.0)                                    MOD00430
      S22(I,J)=(0.0,0.0)                                    MOD00440
      S21(I,J)=(0.0,0.0)                                    MOD00450
      ALPHA(I,J)=0.0                                        MOD00460
170   BETHA(I,J)=0.0                                        MOD00470
      DO 150 I = 1,2                                        MOD00480
      DO 150 J=1,10                                         MOD00490
      DO 150 K=1,10                                         MOD00500
      YT(I,J,K)=(0.0,0.0)                                   MOD00510
      R(I,J,K) = 0.0                                        MOD00520
      L(I,J,K) = 0.0                                        MOD00530
      C(I,J,K) = 0.0                                        MOD00540
      YR(I,J,K)=0.0                                         MOD00550
      YI(I,J,K)=0.0                                         MOD00560
      NEWR(I,J,K)=0.0                                       MOD00570
      NEWL(I,J,K)=0.0                                       MOD00580
      NEWC(I,J,K)=0.0                                       MOD00590
150   Y(I,J,K)=(0.0,0.0)                                    MOD00600
      DO 151 I=1,22                                         MOD00610
      DR(I) = 0.0                                           MOD00620
151   FR(I) = 0.0                                           MOD00630
      DO 180 I=1,11                                         MOD00640
      DO 180 J=1,20                                         MOD00650
      ZN(I,J)=(0.0,0.0)                                     MOD00660
      Z(I,J)=(0.0,0.0)                                      MOD00670
      QN(I,J)=0.0                                           MOD00680
      Q(I,J)=0.0                                            MOD00690
      PN(I,J)=0.0                                           MOD00700
```

```
180   P(I,J)=0.0                                                   MOD00710
      DO 190 I=1,10                                                MOD00720
      DO 190 J=1,11                                                MOD00730
      A1(I,J)=(0.0,0.0)                                            MOD00740
      B1(I,J)=(0.0,0.0)                                            MOD00750
      C1(I,J)=(0.0,0.0)                                            MOD00760
      D1(I,J)=(0.0,0.0)                                            MOD00770
      A2(I,J)=(0.0,0.0)                                            MOD00780
      B2(I,J)=(0.0,0.0)                                            MOD00790
      C2(I,J)=(0.0,0.0)                                            MOD00800
190   D2(I,J)=(0.0,0.0)                                            MOD00810
      DO 310 I=1,2                                                 MOD00820
      DO 310 J=1,3                                                 MOD00830
      H11(I,J)=0.0                                                 MOD00840
      H11L(I,J)=0.0                                                MOD00850
      H12(I,J)=0.0                                                 MOD00860
      H12F(I,J)=0.0                                                MOD00870
      H21(I,J)=0.0                                                 MOD00880
      H21F(I,J)=0.0                                                MOD00890
      H22(I,J)=0.0                                                 MOD00900
      H22C(I,J)=0.0                                                MOD00910
      E1(I,J)=0.0                                                  MOD00920
      E2(I,J)=0.0                                                  MOD00930
310   E3(I,J)=0.0                                                  MOD00940
      VAR = 0                                                      MOD01000
      ISQ=0
      IQ = 1                                                       MOD01010
      CALL DATA                                                    MOD01020
      DO 1 I=1,2                                                   MOD01030
      J = HINUD(I)                                                 MOD01040
      DO 1 IX=1,J                                                  MOD01050
      DO 1 IY=1,J                                                  MOD01060
      NEWR(I,IX,IY) = R(I,IX,IY)                                   MOD01070
      NEWL(I,IX,IY) = L(I,IX,IY)                                   MOD01080
      NEWC(I,IX,IY) = C(I,IX,IY)                                   MOD01090
1     CONTINUE                                                     MOD01100
270   CONTINUE                                                     MOD01110
      IF (IQ-1) 3,2,3                                              MOD01120
C BEGINNING OF SUBROUTINE ALPHA                                     MOD01130
2     G1 = RISE                                                    MOD01140
      G2 = FALL                                                    MOD01150
```

```
      PI = 3.141593                                                     MOD01160
      IE = 1                                                            MOD01170
      JF = 1                                                            MOD01180
120   M1 = (-1)**JF                                                     MOD01190
121   M2 = (-1)**IE                                                     MOD01200
      QI = IE                                                           MOD01210
      QJ = JF                                                           MOD01220
      IF(M1-M2) 122,123,124                                             MOD01230
122   ALPHA(IE,JF) = (-1.)**((JF-IE+1)/2)/(0.5*PI*(QI-QJ))              MOD01240
      GO TO 134                                                         MOD01250
123   ALPHA(IE,JF) = (-1.)**((IE+JF-2)/2)/(0.5*PI*(QI+QJ-1))            MOD01260
      GO TO 134                                                         MOD01270
124   ALPHA(IE,JF) = (-1.)**((IE-JF+1)/2)/(0.5*PI*(QJ-QI))              MOD01280
134   IF(G1+G2) 125,126,125                                             MOD01290
125   ZI= 1/ABS(ALPHA(IE,JF))                                           MOD01300
      IF(G1) 128,127,128                                                MOD01310
127   XI = 0.5                                                          MOD01320
      GO TO 130                                                         MOD01330
128   XI = (SIN(ZI*PI*G1))/(2.*ZI*PI*G1)                                MOD01340
      IF(G2) 130,129,130                                                MOD01350
129   YJ = 0.5                                                          MOD01360
      GO TO 131                                                         MOD01370
130   YJ = (SIN(ZI*PI*G2))/(2.*ZI*PI*G2)                                MOD01380
131   ALPHA(IE,JF) = (XI+YJ)*ALPHA(IE,JF)                               MOD01390
126   IE = IE+1                                                         MOD01400
      IF(IE-N) 121,121,132                                              MOD01410
132   JF = JF+1                                                         MOD01420
      IE = 1                                                            MOD01430
      IF(JF-N) 120,120,133                                              MOD01440
C END OF SUBROUTINE ALPHA                                                MOD01450
133   CALL ARRAY(2,N,N,10,10,BTA,ALPHA)                                 MOD01460
      CALL MINV(BTA,N,DET,LA,MA)                                        MOD01470
      CALL ARRAY(1,N,N,10,10,BTA,BETHA)                                 MOD01480
C THE FREQUENCY EVALUATION CARDS BEGIN HERE. IF USED AS A SUBROUTINE    MOD01490
C THIS PART IS CALLED 'SUBROUTINE FREQ'                                 MOD01500
```

```
      I = 0                                                             MO001510
      J = 0                                                             MO001520
51    J = J+1                                                           MO001530
      IF(FR(J)) 51,52,51                                                MO001540
52    IF(J-M) 53,53,57                                                  MO001550
53    I1 =J-1                                                           MO001560
54    J = J+1                                                           MO001570
      IF(FR(J)) 55,54,55                                                MO001580
55    I  = I1                                                           MO001590
56    I = I+1                                                           MO001600
      FR(I) =FR(I-1)+DR(I1)                                             MO001610
      IF(I-J+1) 56,51,56                                                MO001620
57    J = 1                                                             MO001630
58    K = 1                                                             MO001640
      MAA = (-1)**J                                                     MO001650
      IF(MAA) 64,64,59                                                  MO001660
59    IF(K-M) 60,60,69                                                  MO001670
60    IF(FIFN) 62,61,62                                                 MO001680
61    F(1,J,K) = ABS(FR(K)-J*FLON)                                      MO001690
      F(2,J,K) = FR(K)+(J-1)*FLON                                       MO001700
      GO TO 63                                                          MO001710
62    F(1,J,K) = ABS(FR(K)-J*(FR(K)-FIFN))                              MO001720
      F(2,J,K) = FIFN+J*FLON                                            MO001730
63    K = K+1                                                           MO001740
      GO TO 59                                                          MO001750
64    IF(K-M) 65,65,69                                                  MO001760
65    IF(FIFN) 67,66,67                                                 MO001770
66    F(1,J,K) = FR(K)+(J-1)*FLON                                       MO001780
      F(2,J,K) = ABS(FR(K)-J*FLON)                                      MO001790
      GO TO 68                                                          MO001800
67    F(1,J,K) =FR(K)+(J-1)*(FR(K)-FIFN)                                MO001810
      F(2,J,K) = ABS(FIFN-(J-1)*FLON)                                   MO001820
68    K = K+1                                                           MO001830
      GO TO 64                                                          MO001840
69    J = J+1                                                           MO001850
      IF(J-N) 58,58,4                                                   MO001860
C THE FREQUENCY EVALUATION CARDS END HERE                                MO001870
4     GO TO 70                                                          MO001880
3     CONTINUE
```

```
C THE FILTER EVALUATION CARDS BEGIN HERE. IF USED AS A SUBROUTINE      MOD01930
C THIS PART IS CALLED 'SUBROUTINE DMATE' (FOR  DIAGONAL MATRIX          MOD01940
C EVALUATION)                                                           MOD01950
70    I = 1                                                             MOD01960
71    J = 1                                                             MOD01970
      K = 1                                                             MOD01980
      IX = 1                                                            MOD01990
      IY = 1                                                            MOD02000
99    IF(NEWR(I,IX,IY)) 72,73,72                                        MOD02010
72    YR(I,IX,IY) = -RT/NEWR(I,IX,IY)                                   MOD02020
      GO TO 74                                                          MOD02030
73    YR(I,IX,IY) = 0.0                                                 MOD02040
74    W = 2*3.1415926*F(I,J,K)                                          MOD02050
      IF(K-1) 75,77,75                                                  MOD02060
75    IF(F(I,J,1)-F(I,J,K)) 77,76,77                                    MOD02070
76    A2(J,K) = A2(J,1)                                                 MOD02080
      B2(J,K) = B2(J,1)                                                 MOD02090
      C2(J,K) = C2(J,1)                                                 MOD02100
      D2(J,K) = D2(J,1)                                                 MOD02110
      GO TO 87                                                          MOD02120
77    IF(NEWL(I,IX,IY)) 79,78,79                                        MOD02130
78    YI(I,IX,IY) = -W*NEWC(I,IX,IY)*RT                                 MOD02140
      GO TO 80                                                          MOD02150
79    YI(I,IX,IY) = (RT/(W*NEWL(I,IX,IY)))-(W*NEWC(I,IX,IY)*RT)         MOD02160
80    A = YR(I,IX,IY)                                                   MOD02170
      B = YI(I,IX,IY)                                                   MOD02180
      Y(I,IX,IY) = CMPLX(A,B)                                           MOD02190
      IX = IX+1                                                         MOD02200
      IF(IX-HINOD(I)) 99,99,81                                          MOD02210
81    IX = 1                                                            MOD02220
      IY = IY+1                                                         MOD02230
      IF (IY-HINOD(I)) 99,99,82                                         MOD02240
82    IG = HINOD(I)                                                     MOD02250
      DO 152 IX = 2,IG                                                  MOD02260
      KI = IX-1                                                         MOD02270
      DO 152 IY=1,KI                                                    MOD02280
      Y(I,IX,IY) = Y(I,IX,IY)+Y(I,IY,IX)                                MOD02290
152   Y(I,IY,IX) = Y(I,IX,IY)                                           MOD02300
      IA = HINOD(I)                                                     MOD02310
      DO 92 JA=1,IA                                                     MOD02320
```

```
      SUM(JA) = (0.0,0.0)                                                 MDD02330
      DO 91 JB=1,IA                                                       MDD02340
91    SUM(JA) = SUM(JA)+Y(I,JA,JB)                                        MDD02350
92    Y(I,JA,JA) = -SUM(JA)                                               MDD02360
      DO 313 JT=1,3                                                       MDD02370
      IF(E1(I,JT)) 313,313,311                                            MDD02380
311   CALL TWOPRT                                                         MDD02390
      DO 312 JA=1,IA                                                      MDD02400
      DO 312 JB=1,IA                                                      MDD02410
312   Y(I,JA,JB)=Y(I,JA,JB)+YT(I,JA,JB)                                   MDD02420
313   CONTINUE                                                            MDD02430
      IF(HINOD(I)-3) 184,184,83                                           MDD02440
83    IA = HINOD(I)-3                                                     MDD02450
      DO 84 IZ=1,IA                                                       MDD02460
      IS = HINOD(I)-IZ                                                    MDD02470
      IB = IS-1                                                           MDD02480
      DO 84 IY=1,IB                                                       MDD02490
      DO 84 IX=1,IB                                                       MDD02500
      Y(I,IX,IY) = Y(I,IX,IY)-(Y(I,IX,IS)*Y(I,IS,IY)/Y(I,IS,IS))          MDD02510
84    CONTINUE                                                            MDD02520
184   IF(I-1) 85,85,86                                                    MDD02530
85    A1(J,K) = -Y(1,2,2)/Y(1,2,1)                                        MDD02540
      B1(J,K) = -1.0/Y(1,2,1)                                             MDD02550
      C1(J,K) = -(Y(1,1,1)*Y(1,2,2)-Y(1,1,2)*Y(1,2,1))/Y(1,2,1)           MDD02560
      D1(J,K) = -Y(1,1,1)/Y(1,2,1)                                        MDD02570
      GO TO 87                                                            MDD02580
86    A2(J,K) = -Y(2,2,2)/Y(2,2,1)                                        MDD02590
      B2(J,K) = -1.0/Y(2,2,1)                                             MDD02600
      C2(J,K) = -(Y(2,1,1)*Y(2,2,2)-Y(2,1,2)*Y(2,2,1))/Y(2,2,1)           MDD02610
      D2(J,K) = -Y(2,1,1)/Y(2,2,1)                                        MDD02620
87    K = K+1                                                             MDD02630
      IF(K-M) 88,88,89                                                    MDD02640
88    IX= 1                                                               MDD02650
      IY = 1                                                              MDD02660
      GO TO 99                                                            MDD02670
89    K = 1                                                               MDD02680
      J = J+1                                                             MDD02690
      IF(J-N) 88,88,90                                                    MDD02700
90    I = I+1                                                             MDD02710
      IF(I-2) 71,71,95                                                    MDD02720
```

```
C END OF FILTER EVALUATION CARDS                                          MOD02730
95    DO 18 K=1,M                                                         MOD02740
      DO 5 IX=1,N                                                         MOD02750
      DO 5 IY=1,N                                                         MOD02760
      AT(IX,IY)=A1(IY,K)*ALPHA(IX,IY)*A2(IY,K)+B1(IX,K)*BETHA(IX,IY)      MOD02770
     1*C2(IY,K)                                                           MOD02780
      BT(IX,IY)=A1(IY,K)*ALPHA(IX,IY)*B2(IY,K)+B1(IX,K)*BETHA(IX,IY)      MOD02790
     1*D2(IY,K)                                                           MOD02800
      CT(IX,IY)=C1(IY,K)*ALPHA(IX,IY)*A2(IY,K)+D1(IX,K)*BETHA(IX,IY)      MOD02810
     1*C2(IY,K)                                                           MOD02820
5     DT(IX,IY)=C1(IY,K)*ALPHA(IX,IY)*B2(IY,K)+D1(IX,K)*BETHA(IX,IY)      MOD02830
     1*D2(IY,K)                                                           MOD02840
C BEGINNING OF MATRIX CALCULATIONS                                        MOD02850
      DO 250 IO=1,N                                                       MOD02860
      DO 250 JO=1,N                                                       MOD02870
      IF(IO-JO) 202,201,202                                               MOD02880
201   J(IO,IO)=(1.0,0.0)                                                  MOD02890
      GO TO 250                                                           MOD02900
202   J(IO,JO)=(0.0,0.0)                                                  MOD02910
250   CONTINUE                                                            MOD02920
      CALL CARRAY (2,N,N,10,10,TAT,AT)                                    MOD02930
      CALL CARRAY (2,N,N,10,10,TBT,BT)                                    MOD02940
      CALL CARRAY (2,N,N,10,10,TCT,CT)                                    MOD02950
      CALL CARRAY (2,N,N,10,10,TDT,DT)                                    MOD02960
      CALL CARRAY (2,N,N,10,10,TU,U)                                      MOD02970
      CALL CGMADD (TAT,TBT,AR1,N,N)                                       MOD02980
      CALL CGMADD (TCT,TDT,AR2,N,N)                                       MOD02990
      CALL CGMADD (TBT,TDT,AR3,N,N)                                       MOD03000
      CALL CGMADD (AR1,AR2,DELTA,N,N)                                     MOD03010
      CALL CMINV (DELTA,N,DET,LA,MA)                                      MOD03020
      KD=N*N                                                              MOD03030
      DO 203 IP=1,KD                                                      MOD03040
203   DELTA(IP)=2.0*DELTA(IP)                                             MOD03050
      DO 161 IN=1,N                                                       MOD03060
      CALL LOC (IN,1,IJ,N,N,0)                                            MOD03070
161   S21(IN,1)=-1.0*DELTA(IJ)                                            MOD03080
      CALL CGMPRD(AR3,DELTA,T1,N,N,N)                                     MOD03090
      CALL CGMSUB (TU,T1,TT1,N,N)                                         MOD03100
      DO 96 IM=1,N                                                        MOD03110
      CALL LOC (IM,1,IJ,N,N,0)                                            MOD03120
      S11(IM,1)=TT1(IJ)                                                   MOD03130
      CALL LOC (IM,IM,IJ,N,N,0)                                           MOD03140
```

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96     S11(IM,IM)=TT1(IJ)                                          M0003150
       CALL CGMPRD(DELTA,AR3,T2,N,N,N)                             MOD03160
       CALL CGMSUB (TT1,T2,TT2,N,N)                                M0003170
       DO 97 IN=1,N                                                MOD03180
       CALL LOC(IN,IN,IJ,N,N,0)                                    M0003190
97     S22(IN,IN) = TT2(IJ)                                        M0003200
C END OF MATRIX CALCULATIONS                                        MOD03210
       DO 18 IX=1,N                                                M0003220
       IF(IQ-1) 12,6,12                                            MOD03230
6      PN(K,IX) = REAL(S11(IX,1)*DCONJG(S11(IX,1)))                M0003240
       PN(K,IX) = 10.*ALOG10(PN(K,IX))                             M0003250
       PN(K,(IX+N)) = REAL(S21(IX,1)*DCONJG(S21(IX,1)))            MOD03260
       PN(K,(IX+N)) = 10.*ALOG10(PN(K,(IX+N)))                     M0003270
       Y1 = AIMAG(S11(IX,IX))                                      M0003280
       IF(Y1) 8,46,8                                               M0003290
46     X1 = REAL(S11(IX,IX))                                       M0003300
       IF(X1+1) 8,7,8                                              M0003310
7      QN(K,IX) = 0.0                                              M0003320
       GO TO 9                                                     MOD03330
8      QN(K,IX) =1.0                                               M0003340
       ZN(K,IX) = -((S11(IX,IX)-1.0)/(S11(IX,IX)+1.0))*RT          M0003350
9      Y2 = AIMAG(S22(IX,IX))                                      M0003360
       IF(Y2) 11,47,11                                             MOD03370
47     X2 = REAL(S22(IX,IX))                                       M0003380
       IF(X2+1) 11,10,11                                           M0003390
10     QN(K,(IX+N)) = 0.0                                          M0003400
       GO TO 18                                                    M0003410
11     QN(K,(IX+N)) = 1.0                                          M0003420
       ZN(K,(IX+N)) = -((S22(IX,IX)-1.0)/(S22(IX,IX)+1.0))*RT      MOD03430
       GO TO18                                                     MOD03440
12     P(K,IX) = REAL(S11(IX,1)*DCONJG(S11(IX,I)))                 MOD03450
       P(K,IX) = 10.*ALOG10(P(K,IX))                               M0003460
       P(K,(IX+N)) = REAL(S21(IX,1)*DCONJG(S21(IX,I)))             M0003470
       P(K,(IX+N)) = 10.*ALOG10(P(K,(IX+N)))                       M0003480
       Y1 = AIMAG(S11(IX,IX))                                      MOD03490
       IF(Y1) 14,48,14                                             M0003500
48     X1 = REAL(S11(IX,IX))                                       M0003510
       IF(X1+1) 14,13,14                                           M0003520
13     Q(K,IX) = 0.0                                               M0003530
       GO TO 15                                                    M0003540
```

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14    Q(K,IX) = 1.0                                                    MOD03550
      Z(K,IX) = -((S11(IX,IX)-1.0)/(S11(IX,IX)+1.0))*RT                MOD03560
15    Y2 = AIMAG(S22(IX,IX))                                           MOD03570
      IF(Y2) 17,49,17                                                  MOD03580
49    X2 = REAL(S22(IX,IX))                                            MOD03590
      IF(X2+1) 17,16,17                                                MOD03600
16    Q(K,(IX+N)) = 0.0                                                MOD03610
      GO TO 18                                                         MOD03620
17    Q(K,(IX+N)) = 1.0                                                MOD03630
      Z(K,(IX+N)) = -((S22(IX,IX)-1.0)/(S22(IX,IX)+1.0))*RT            MOD03640
18    CONTINUE                                                         MOD03650
      WRITE (6,504) IQ
504   FORMAT (T5,'IQ=',I2)
      CALL PRINT
      IF(ISQ) 311,314,311
314   CONTINUE
      IQ =IQ+1                                                         MOD04110
      IF(IQ-2) 262,262,260                                             MOD04120
260   DO 261 I=1,2                                                     MOD04130
      J = HINOD(I)                                                     MOD04140
      DO 261 IX = 1,J                                                  MOD04150
      DO 261 IY = 1,J                                                  MOD04160
      NEWR(I,IX,IY) = R(I,IX,IY)                                       MOD04170
      NEWL(I,IX,IY) = L(I,IX,IY)                                       MOD04180
      NEWC(I,IX,IY) = C(I,IX,IY)                                       MOD04190
261   CONTINUE                                                         MOD04200
262   CALL DATA                                                        MOD04210
      IF(ISQ) 311,315,311
315   CONTINUE
      GO TO 270                                                        MOD04370
      END                                                              MOD04380
      SUBROUTINE DATA                                                  MOD04390
      INTEGER   HINOD(2),VAR,E1(2,3),E2(2,3),E3(2,3)                   MOD04400
      REAL       R(2,10,10),L(2,10,10),C(2,10,10),FR(22),DR(22),       MOD04410
     1NEWR(2,10,10),NEWL(2,10,10),NEWC(2,10,10),H11(2,3),H11L(2,3),    MOD04420
     2H12(2,3),H12F(2,3),H21(2,3),H21F(2,3),H22(2,3),H22C(2,3)         MOD04430
      COMMON     N,M,HINOD,RISE,FALL,VAR,FLON,FIFN,FR,DR,              MOD04440
     1NEWR,NEWL,NEWC,R,L,C,IQ,RT/BL1/E1,E2,E3,                         MOD04450
     2H11,H11L,H12,H12F,H21,H21F,H22,H22C                              MOD04460
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22, MOD04470
     123,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42),IQ  MOD04480
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```
1     CONTINUE                                                          MOD04490
      M=7
      N=5                                                               MOD04510
      HINOD(1) = 6                                                      MOD04520
      HINOD(2)=4                                                        MOD04530
      RISE = 0.1                                                        MOD04540
      FALL = 0.1                                                        MOD04550
      RT = 50.0                                                         MOD04560
      L(1,3,5)=5.68E-6                                                  MOD04570
      C(1,3,4)=90.94E-12                                                MOD04580
      C(1,2,4)=2.0E-12                                                  MOD04590
      R(1,2,4)=5.0E0                                                    MOD04600
      R(1,1,5)=2.5E0                                                    MOD04610
      R(2,1,3)=1.2E0                                                    MOD04620
      R(2,1,4)=2.46E3                                                   MOD04630
      R(2,3,4)=1.2E6                                                    MOD04640
      L(2,1,4)=1.96E-6                                                  MOD04650
      C(2,1,4)=3.225E-9                                                 MOD04660
      C(2,3,4)=8.0E-12                                                  MOD04670
      E1(2,1)=1                                                         MOD04680
      E2(2,1)=2                                                         MOD04690
      E3(2,1)=4                                                         MOD04700
      H11(2,1)=0.5E0
      H12(2,1)=1.570796E0                                               MOD04720
      H21(2,1)=-1.570796E0                                              MOD04730
      H22(2,1)=1.25E-3                                                  MOD04740
      FR(1)=6.7E6
      OR(1)=0.1E6                                                       MOD04760
      FR(7)=7.3E6
      FLON = 5.0E6                                                      MOD04780
      FIFN = 0.0                                                        MOD04790
      RETURN                                                            MOD04800
2     CONTINUE                                                          MOD04820
      VAR=1                                                             MOD04830
      NEWR(1,1,5)=0.4070E0                                              MOD04840
      NEWC(1,3,4)=3.732E-10                                             MOD04850
      NEWL(1,3,5)=1.384E-6                                              MOD04860
      NEWL(2,1,4)=9.92E-6                                               MOD04870
      NEWC(2,1,4)=6.45E-10                                              MOD04880
      NEWR(2,1,4)=12.3E3                                                MOD04890
      RETURN                                                            MOD04900
```

```
 3    CONTINUE                                                      MOD04910
      VAR=2                                                         MOD04920
      NEWR(1,1,5)=0.607E0                                           MOD04930
      NEWC(1,3,4)=3.732E-10                                         MOD04940
      NEWL(1,3,5)=1.384E-6                                          MOD04950
      NEWL(2,1,4)=3.27E-6                                           MOD04960
      NEWC(2,1,4)=1.935E-9                                          MOD04970
      NEWR(2,1,4)=4.1E3                                             MOD04980
      RETURN                                                        MOD04990
 4    CONTINUE                                                      MOD05000
 5    CONTINUE
 6    CONTINUE
 7    CONTINUE
 8    CONTINUE
 9    CONTINUE
 10   CONTINUE
 11   CONTINUE
 12   CONTINUE
 13   CONTINUE
 14   CONTINUE
 15   CONTINUE
 16   CONTINUE
 17   CONTINUE
 18   CONTINUE
 19   CONTINUE
 20   CONTINUE
 21   CONTINUE
 22   CONTINUE
 23   CONTINUE
 24   CONTINUE
 25   CONTINUE
 26   CONTINUE
 27   CONTINUE
 28   CONTINUE
 29   CONTINUE
 30   CONTINUE
 31   CONTINUE
 32   CONTINUE
 33   CONTINUE
```

```
34    CONTINUE
35    CONTINUE
36    CONTINUE
37    CONTINUE
38    CONTINUE
39    CONTINUE
40    CONTINUE
41    CONTINUE
42    CONTINUE
      STOP                                                              MOD04930
      END                                                               MOD08430
C                                                                       MOD05240
C     ..................................................................MOD05250
C                                                                       MOD05260
C        SUBROUTINE  CMINV                                              MOD05270
C                                                                       MOD05280
C        PURPOSE                                                        MOD05290
C                                                                       MOD05300
C        INVERT A GENERAL MATRIX                                        MOD05310
C        CONTAINING COMPLEX ELEMENTS                                    MOD05320
C                                                                       MOD05330
C        USAGE AND CALLING CONVENTION                                   MOD05340
C        SAME AS FOR MINV.                                              MOD05350
C                                                                       MOD05360
      SUBROUTINE CMINV(A,N,D,L,M)                                       MOD05370
      DIMENSION L(1),M(1)                                               MOD05380
      COMPLEX*16 A(1),D,BIGA,HOLD                                       MOD05390
      D=(1.0,0.0)                                                       MOD05400
      NK=-N                                                             MOD05410
      DO 80 K=1,N                                                       MOD05420
      NK=NK+N                                                           MOD05430
      L(K)=K                                                            MOD05440
      M(K)=K                                                            MOD05450
      KK=NK+K                                                           MOD05460
      BIGA=A(KK)                                                        MOD05470
      DO 20 J=K,N                                                       MOD05480
      IZ = N*(J-1)                                                      MOD05490
      DO 20 I=K,N                                                       MOD05500
      IJ=IZ+I                                                           MOD05510
10    IF(CDABS(BIGA)-CDABS(A(IJ))) 15,20,20                             MOD05520
15    BIGA=A(IJ)                                                        MOD05530
      L(K)=I                                                            MOD05540
```

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      M(K)=J                                                            MDDD555D
   20 CONTINUE                                                          MODD556D
      J=L(K)                                                            MDDD557D
      IF(J-K) 35,35,25                                                  MODD558D
   25 KI=K-N                                                            MODD559D
      DO 30 I=1,N                                                       MODD5600
      KI=KI+N                                                           MODD561D
      HOLD=-A(KI)                                                       MODD562D
      JI=KI-K+J                                                         MODD563D
      A(KI)=A(JI)                                                       MODD564D
   30 A(JI)=HOLD                                                        MDDD565D
   35 I=M(K)                                                            MODD566D
      IF(I-K) 45,45,38                                                  MODD567D
   38 JP=N*(I-1)                                                        MODD568D
      DO 40 J=1,N                                                       MDDO569D
      JK=NK+J                                                           MDDD57DD
      JI=JP+J                                                           MDDO571D
      HDLD=-A(JK)                                                       MDDD572D
      A(JK)=A(JI)                                                       MODD573D
   40 A(JI)=HOLD                                                        MODD574D
   45 IF(CDABS(BIGA)) 48,46,48                                          MODD5750
   46 D=(0.0,0.0)                                                       MUDD576D
      RETURN                                                            MUDO577D
   48 DO 55 I=1,N                                                       MODD578D
      IF(I-K) 50,55,50                                                  MDDD579D
   50 IK=NK+I                                                           MDDD58DD
      A(IK)=A(IK)/(-BIGA)                                               MDDD581D
   55 CONTINUE                                                          MDDD582D
      DO 65 I=1,N                                                       MODD583D
      IK=NK+I                                                           MODD584D
      HDLD=A(IK)                                                        MDDD585D
      IJ=I-N                                                            MODD586D
      DO 65 J=1,N                                                       MODD587D
      IJ=IJ+N                                                           MUDO588D
      IF(I-K) 60,65,60                                                  MDDD589D
   60 IF(J-K) 62,65,62                                                  MODD59DD
   62 KJ=IJ-I+K                                                         MODD591D
      A(IJ)=HOLD*A(KJ)+A(IJ)                                            MUDD592D
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```
65    CONTINUE                                                          MODD593D
      KJ=K-N                                                            MODD594D
      DO 75 J=I,N                                                       MODD595D
      KJ=KJ+N                                                           MODD596D
      IF(J-K) 70,75,70                                                  MODD597D
70    A(KJ)=A(KJ)/BIGA                                                  MODD598D
75    CONTINUE                                                          MODD599D
      D=D*BIGA                                                          MODD6000
      A(KK)=1.0/BIGA                                                    MODD601D
80    CONTINUE                                                          MODD6D2D
      K=N                                                               MODD603D
100   K=(K-1)                                                           MODD604D
      IF(K) 150,150,105                                                 MODD605D
105   I=L(K)                                                            MODD606D
      IF(I-K) 120,120,108                                               MODD6070
108   JQ=N*(K-1)                                                        MODD608D
      JR=N*(I-1)                                                        MODD6090
      DO 110 J=1,N                                                      MODD610D
      JK=JQ+J                                                           MODD6110
      HOLD=A(JK)                                                        MODD6120
      JI=JR+J                                                           MODD6130
      A(JK)=-A(JI)                                                      MODD614D
110   A(JI)=HOLD                                                        MODD615D
120   J=M(K)                                                            MODD616D
      IF(J-K) 100,100,125                                               MODD617D
125   KI=K-N                                                            MODD618D
      DO 130 I=1,N                                                      MODD619D
      KI=KI+N                                                           MODD620D
      HOLD=A(KI)                                                        MODD621D
      JI=KI-K+J                                                         MODD622D
      A(KI)=-A(JI)                                                      MODD623D
130   A(JI)=HOLD                                                        MODD624D
      GO TO 100                                                         MODD625D
150   RETURN                                                            MODD626D
      END                                                               MODD6270
```

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C                                                                       MOD06280
C     ..................................................................MOD06290
C                                                                       MOD06300
C        SUBROUTINE  CGMPRD                                             MOD06310
C                                                                       MOD06320
C        PURPOSE                                                        MOD06330
C                                                                       MOD06340
C        MULTIPLICATION OF TWO GENERAL MATRICES                         MOD06350
C        CONTAINING COMPLEX ELEMENTS                                    MOD06360
C                                                                       MOD06370
C        USAGE AND CALLING CONVENTION                                   MOD06380
C        SAME AS FOR GMPRD                                              MOD06390
C                                                                       MOD06400
      SUBROUTINE CGMPRD (A,B,R,N,M,L)                                   MOD06410
      COMPLEX*16 A(1),B(1),R(1)                                         MOD06420
      IR=0                                                              MOD06430
      IK=-M                                                             MOD06440
      DO 10 K=1,L                                                       MOD06450
      IK=IK+M                                                           MOD06460
      DO 10 J=1,N                                                       MOD06470
      IR=IR+1                                                           MOD06480
      JI=J-N                                                            MOD06490
      IB=IK                                                             MOD06500
      R(IR)=(0.0,0.0)                                                   MOD06510
      DO 10 I=1,M                                                       MOD06520
      JI=JI+N                                                           MOD06530
      IB=IB+1                                                           MOD06540
   10 R(IR)=R(IR)+A(JI)*B(IB)                                           MOD06550
      RETURN                                                            MOD06560
      END                                                               MOD06570
C                                                                       MOD06580
C     ..................................................................MOD06590
C                                                                       MOD06600
C        SUBROUTINE  CGMSUB                                             MOD06610
C                                                                       MOD06620
C        PURPOSE                                                        MOD06630
C        SUBTRACTION OF TWO GENERAL MATRICES                            MOD06640
C        CONTAINING COMPLEX ELEMENTS                                    MOD06650
C                                                                       MOD06660
C        USAGE AND CALLING CONVENTION                                   MOD06670
C        SAME AS FOR GMSUB                                              MOD06680
```

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C                                                                       MOD06690
      SUBROUTINE CGMSUB (A,B,R,N,M)                                     MOD06700
      COMPLEX*16 A(1),B(1),R(1)                                         MOD06710
      NM=N*M                                                            MOD06720
      DO 10 I=1,NM                                                      MOD06730
   10 R(I)=A(I)-B(I)                                                    MOD06740
      RETURN                                                            MOD06750
      END                                                               MOD06760
C                                                                       MOD06770
C     ..................................................................MOD06780
C                                                                       MOD06790
C        SUBROUTINE  CGMADD                                             MOD06800
C                                                                       MOD06810
C        PURPOSE                                                        MOD06820
C                                                                       MOD06830
C        ADDITION OF TWO GENERAL MATRICES                               MOD06840
C        CONTAINING COMPLEX*16 ELEMENTS                                 MOD06850
C                                                                       MOD06860
C        USAGE AND CALLING CONVENTION                                   MOD06870
C        SAME AS FOR GMADD                                              MOD06880
C                                                                       MOD06890
      SUBROUTINE CGMADD (A,B,R,N,M)                                     MOD06900
      COMPLEX*16 A(1),B(1),R(1)                                         MOD06910
      NM=N*M                                                            MOD06920
      DO 10 I=1,NM                                                      MOD06930
   10 R(I)=A(I)+B(I)                                                    MOD06940
      RETURN                                                            MOD06950
      END                                                               MOD06960
C                                                                       MOD06970
C     ..................................................................MOD06980
C                                                                       MOD06990
C        SUBROUTINE  CARRAY                                             MOD07000
C                                                                       MOD07010
C        PURPOSE                                                        MOD07020
C                                                                       MOD07030
C        CONVERT DATA FROM SINGLE                                       MOD07040
C        TO DOUBLE DIMENSION OR VICE VERSA                              MOD07050
C        FOR ARRAYS CONTAINING COMPLEX*16 ELEMENTS                      MOD07060
C                                                                       MOD07070
C        USAGE AND CALLING CONVENTION                                   MOD07080
C        SAME AS FOR ARRAY                                              MOD07090
C                                                                       MOD07100
```

```
      SUBROUTINE CARRAY (MODE,I,J,N,M,S,D)                              MOD07110
      COMPLEX*16 S(1),D(1)                                              MOD07120
      NI = N-I                                                          MOD07130
      IF(MODE-1) 100, 100, 120                                          MOD07140
100   IJ=I*J+1                                                          MOD07150
      NM=N*J+1                                                          MOD07160
      DO 110 K=1,J                                                      MOD07170
      NM=NM-NI                                                          MOD07180
      DO 110 L=1,I                                                      MOD07190
      IJ=IJ-1                                                           MOD07200
      NM=NM-1                                                           MOD07210
110   D(NM)=S(IJ)                                                       MOD07220
      GO TO 140                                                         MOD07230
120   IJ=0                                                              MOD07240
      NM=0                                                              MOD07250
      DO 130 K=1,J                                                      MOD07260
      DO 125 L=1,I                                                      MOD07270
      IJ=IJ+1                                                           MOD07280
      NM=NM+1                                                           MOD07290
125   S(IJ)=D(NM)                                                       MOD07300
130   NM=NM+NI                                                          MOD07310
140   RETURN                                                            MOD07320
      END                                                               MOD07330
      SUBROUTINE ARRAY (MODE,I,J,N,M,S,D)                               MOD07340
      DIMENSION S(1),D(1)                                               MOD07350
      NI = N-I                                                          MOD07360
      IF(MODE-1) 100, 100, 120                                          MOD07370
100   IJ=I*J+1                                                          MOD07380
      NM=N*J+1                                                          MOD07390
      DO 110 K=1,J                                                      MOD07400
      NM=NM-NI                                                          MOD07410
      DO 110 L=1,I                                                      MOD07420
      IJ=IJ-I                                                           MOD07430
      NM=NM-1                                                           MOD07440
110   D(NM)=S(IJ)                                                       MOD07450
      GO TO 140                                                         MOD07460
120   IJ=0                                                              MOD07470
      NM=0                                                              MOD07480
      DO 130 K=1,J                                                      MOD07490
      DO 125 L=1,I                                                      MOD07500
      IJ=IJ+1                                                           MOD07510
      NM=NM+1                                                           MOD07520
```

```
125   S(IJ)=D(NM)                                        MOD07530
130   NM=NM+NI                                           MOD07540
140   RETURN                                             MOD07550
      END                                                MOD07560
      SUBROUTINE LOC(I,J,IR,N,M,MS)                      MOD07570
      IX = I                                             MOD07580
      JX = J                                             MOD07590
      IF (MS-1) 10,20,30                                 MOD07600
10    IRX = N*(JX-1)+IX                                  MOD07610
      GO TO 36                                           MOD07620
20    IF (IX-JX) 22,24,24                                MOD07630
22    IRX = IX+(JX*JX-JX)/2                              MOD07640
      GO TO 36                                           MOD07650
24    IRX = JX+(IX*IX-IX)/2                              MOD07660
      GO TO 36                                           MOD07670
30    IRX = 0                                            MOD07680
      IF (IX-JX) 36,32,36                                MOD07690
32    IRX = IX                                           MOD07700
36    IR = IRX                                           MOD07710
      RETURN                                             MOD07720
      END                                                MOD07730
      SUBROUTINE MINV(A,N,D,L,M)                         MOD07740
      DIMENSION A(1),L(1),M(1)                           MOD07750
      D = 1.0                                            MOD07760
      NK=-N                                              MOD07770
      DO 80 K=1,N                                        MOD07780
      NK=NK+N                                            MOD07790
      L(K)=K                                             MOD07800
      M(K)=K                                             MOD07810
      KK=NK+K                                            MOD07820
      BIGA=A(KK)                                         MOD07830
      DO 20 J=K,N                                        MOD07840
      IZ = N*(J-1)                                       MOD07850
      DO 20 I=K,N                                        MOD07860
      IJ=IZ+I                                            MOD07870
10    IF(ABS(BIGA)-ABS(A(IJ))) 15,20,20                  MOD07880
15    BIGA=A(IJ)                                         MOD07890
      L(K)=I                                             MOD07900
      M(K)=J                                             MOD07910
```

```
20    CONTINUE                                    MO007920
      J=L(K)                                      MO007930
      IF(J-K) 35,35,25                            MO007940
25    KI=K-N                                      MO007950
      DO 30 I=1,N                                 MO007960
      KI=KI+N                                     MO007970
      HOLD=-A(KI)                                 MO007980
      JI=KI-K+J                                   MO007990
      A(KI)=A(JI)                                 MO008000
30    A(JI)=HOLD                                  MO008010
35    I=M(K)                                      MO008020
      IF(I-K) 45,45,38                            MO008030
38    JP=N*(I-1)                                  MO008040
      DO 40 J=1,N                                 MO008050
      JK=NK+J                                     MO008060
      JI=JP+J                                     MO008070
      HOLD=-A(JK)                                 MO008080
      A(JK)=A(JI)                                 MO008090
40    A(JI)=HOLD                                  MO008100
45    IF(BIGA) 48,46,48                           MO008110
46    D = 0.0                                     MO008120
      RETURN                                      MO008130
48    DO 55 I=1,N                                 MO008140
      IF(I-K) 50,55,50                            MO008150
50    IK=NK+I                                     MO008160
      A(IK)=A(IK)/(-BIGA)                         MO008170
55    CONTINUE                                    MO008180
      DO 65 I=1,N                                 MO008190
      IK=NK+I                                     MO008200
      HOLD=A(IK)                                  MO008210
      IJ=I-N                                      MO008220
      DO 65 J=1,N                                 MO008230
      IJ=IJ+N                                     MO008240
      IF(I-K) 60,65,60                            MO008250
60    IF(J-K) 62,65,62                            MO008260
62    KJ=IJ-I+K                                   MO008270
      A(IJ)=HOLD*A(KJ)+A(IJ)                      MO008280
65    CONTINUE                                    MO008290
      KJ=K-N                                      MO008300
      DO 75 J=1,N                                 MO008310
      KJ=KJ+N                                     MO008320
      IF(J-K) 70,75,70                            MO008330
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70    A(KJ)=A(KJ)/BIGA                                                   MOD08340
75    CONTINUE                                                           MOD08350
      D=D*BIGA                                                           MOD08360
      A(KK)=1.0/BIGA                                                     MOD08370
80    CONTINUE                                                           MOD08380
      K=N                                                                MOD08390
100   K=(K-1)                                                            MOD08400
      IF(K) 150,150,105                                                  MOD08410
105   I=L(K)                                                             MOD08420
      IF(I-K) 120,120,108                                                MOD08430
108   JQ=N*(K-1)                                                         MOD08440
      JR=N*(I-1)                                                         MOD08450
      DO 110 J=1,N                                                       MOD08460
      JK=JQ+J                                                            MOD08470
      HOLD=A(JK)                                                         MOD08480
      JI=JR+J                                                            MOD08490
      A(JK)=-A(JI)                                                       MOD08500
110   A(JI)=HOLD                                                         MOD08510
120   J=M(K)                                                             MOD08520
      IF(J-K) 100,100,125                                                MOD08530
125   KI=K-N                                                             MOD08540
      DO 130 I=1,N                                                       MOD08550
      KI=KI+N                                                            MOD08560
      HOLD=A(KI)                                                         MOD08570
      JI=KI-K+J                                                          MOD08580
      A(KI)=-A(JI)                                                       MOD08590
130   A(JI)=HOLD                                                         MOD08600
      GO TO 100                                                          MOD08610
150   RETURN                                                             MOD08620
      END                                                                MOD08630
C     ...............................................................MOD08640
C        SUBROUTINE  TWOPRT                                              MOD08650
C     ...............................................................MOD08660
C        PURPOSE                                                         MOD08670
C                                                                        MOD08680
C        TO CONVERT THE TWO-PORT H MATRIX PARAMETERS SPECIFIED IN THE    MOD08690
C        DATA SUBROUTINE , INTO Y MATRIX PARAMETERS AND TO ASSIGN TO     MOD08700
C        THEM THEIR PROPER LOCATIONS IN THE OVERALL INDEFINITE           MOD08710
C        ADMITTANCE MATRIX                                               MOD08720
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C     ..................................................................MOD08730
      SUBROUTINE TWOPRT                                                 MOD08740
      INTEGER E1(2,3),E2(2,3),E3(2,3)                                   MOD08750
      REAL H11(2,3),H11L(2,3),H12(2,3),H12F(2,3),H21(2,3),              MOD08760
     1H21F(2,3),H22(2,3),H22C(2,3),F(2,10,11),A(4),B(4)                 MOD08770
      COMPLEX*16 YT(2,10,10),DEL,X1,X2,X3,X4                            MOD08780
      COMMON /BL1/ E1,E2,E3,H11,H11L,H12,H12F,H21,H21F,H22,H22C         MOD08790
     1/BL2/ I,J,K,JT,YT,F,W                                             MOD08800
      DO 10 J1=1,2                                                      MOD08810
      DO 10 J2=1,10                                                     MOD08820
      DO 10 J3=1,10                                                     MOD08830
   10 YT(J1,J2,J3)=(0.0,0.0)                                            MOD08840
      DO 11 I1=1,4                                                      MOD08850
      A(I1)=0.0                                                         MOD08860
   11 B(I1)=0.0                                                         MOD08870
      A(1)=H11(I,JT)                                                    MOD08880
      B(1)=W*H11L(I,JT)                                                 MOD08890
      X1=CMPLX(A(1),B(1))                                               MOD08900
      A(2)=H22(I,JT)                                                    MOD08910
      B(2)=W*H22C(I,JT)                                                 MOD08920
      X2=CMPLX(A(2),B(2))                                               MOD08930
      IF(H12F(I,JT)) 1,2,1                                              MOD08940
    1 B(3)=F(I,J,K)/H12F(I,JT)                                          MOD08950
      X3=CMPLX(1.,B(3))                                                 MOD08960
      X3=H12(I,JT)/X3                                                   MOD08970
      GO TO 3                                                           MOD08980
    2 A(3)=H12(I,JT)                                                    MOD08990
      X3=CMPLX(A(3),0.0)                                                MOD09000
    3 IF(H21F(I,JT)) 4,5,4                                              MOD09010
    4 B(4)=F(I,J,K)/H21F(I,JT)                                          MOD09020
      X4=CMPLX(1.,B(4))                                                 MOD09030
      X4=H21(I,JT)/X4                                                   MOD09040
      GO TO 6                                                           MOD09050
    5 A(4)=H21(I,JT)                                                    MOD09060
      X4=CMPLX(A(4),0.0)                                                MOD09070
    6 DEL=X1*X2-X3*X4                                                   MOD09080
      L=E1(I,JT)                                                        MOD09090
      M=E2(I,JT)                                                        MOD09100
      N=E3(I,JT)                                                        MOD09110
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```
      YT(I,L,L)=1./X1                                                   MOD09120
      YT(I,L,M)=-1.*X3/X1                                               MOD09130
      YT(I,M,L)=X4/X1                                                   MOD09140
      YT(I,M,M)=DEL/Y1                                                  MOD09150
      YT(I,L,N)=-1*(YT(I,L,L)+YT(I,L,M))                                MOD09160
      YT(I,M,N)=-1*(YT(I,M,L)+YT(I,M,M))                                MOD09170
      YT(I,N,L)=YT(I,L,N)                                               MOD09180
      YT(I,N,M)=YT(I,M,N)                                               MOD09190
      YT(I,N,N)=-1*(YT(I,L,N)+YT(I,M,N))                                MOD09200
      RETURN                                                            MOD09210
      END                                                               MOD09220
      SUBROUTINE PRINT
      INTEGER   HINOD(2),VAR
      REAL    NEWR(2,10,10),NEWL(2,10,10),NEWC(2,10,10),PN(11,20),
     1         P(11,20),F(2,10,11),QN(11,20),Q(11,20),
     2         FR(22),DR(22),R(2,10,10),L(2,10,10),C(2,10,10)
      COMPLEX*16    ZN(11,20),Z(11,20),DZ,YT(2,10,10)
      COMMON    N,M,HINOD,RISE,FALL,VAR,FLON,FIFN,FR,DR,NEWR,NEWL,
     1NEWC,R,L,C,IQ,DT/BL1/E1,E2,E3,H11,H11L,H12,H12F,H21,H21F,H22,H22C
     2/BL2/I,J,K,JT,YT,F,W/BL3/ZN,PN,Z,P,QN,Q
      WRITE (6,500) IQ
500   FORMAT(T5,'IQ=',I2)
      WRITE(6,501) HINOD(1),HINOD(2)
501   FORMAT(T5,'HINOD(1)=',I2,'HINOD(2)=',I2)
      WRITE(6,502) N
502   FORMAT(T5,'N=',I2)
      WRITE(6,503) M
503   FORMAT(T5,'M=',I2)
      IF(IQ-2) 1,2,2
1     WRITE(6,101)                                                      MOD00950
101   FORMAT(T33,'NOMINAL VALUES' ///)                                  MOD00970
      GO TO 3
2     WRITE(6,109) VAR                                                  MOD04240
109   FORMAT(///,T33,'VARIATION',I3,///)                                MOD04250
      IF(VAR-1) 303,303,304                                             MOD04260
303   MV=0                                                              MOD04270
      NV=1                                                              MOD04280
304   MV=MV+1                                                           MOD04290
      IF(MV-6) 306,305,305                                              MOD04300
305   MV=MV-5                                                           MOD04310
      NV=NV+1                                                           MOD04320
306   RFQ=1.2+(NV-1)*0.4                                                MOD04330
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      IFQ=2*VAR-IO*(NV-1)-1                                            MOD04340
      WRITE(6,110) RFQ,IFQ                                             MU004350
110   FORMAT(T30,'RFQ=',F4.1,T42,'IFQ=',I2,///)                        MU004360
3     DO 320 I=1,2
      J=HINOD(I)
      DO 320 IX=1,J
      DO 320 IY=1,J
      IF(NEWR(I,IX,IY)) 321,322,321
321   WRITE(6,401) I,IX,IY,NEWR(I,IX,IY)
401   FORMAT(T5,'NEWR(',I1,',',I1,',',I1,')=',1PE13.6)
322   IF(NEWL(I,IX,IY)) 323,324,323
323   WRITE(6,402) I,IX,IY,NEWL(I,IX,IY)
402   FORMAT(T5,'NEWL(',I1,',',I1,',',I1,')=',1PE13.6)
324   IF(NEWC(I,IX,IY)) 325,320,325
325   WRITE(6,403) I,IX,IY,NEWC(I,IX,IY)
403   FORMAT(T5,'NEWC(',I1,',',I1,',',I1,')=',1PE13.6)
320   CONTINUE
      IF(IQ-2) 4,5,5
4     WRITE(6,102)                                                     M0000960
102   FORMAT (T1,'OFREQUENCY',T36,'IMPEDANCE',                         MOD00980
     1T70,'GT FROM PORT 1 (DB)',//)                                    MOD00990
      GO TO 6
5     WRITE(6,103)                                                     M0001900
103   FORMAT (///,T1,'OFREQUENCY',T19,'IMPEDANCE',T37,'NOM.IMP.-IMP.', MOD01910
     1T60,'GT FROM PORT 1 (DB)',T81,'NOM.GT-GT(FROM PORT 1)',//)       M0001920
6     NN = 2*N                                                         M0403660
      DO 30 J=1,NN                                                     M0003670
      IF(J-1) 300,171,300                                              MOD03680
300   IF(J-N) 30,30,172                                                M0003690
171   WRITE(6,119) J                                                   M0003700
119   FORMAT(T2,'INPUT PORT',I3)                                       M0003710
      GO TO 173                                                        M0003720
172   JJ=J-N                                                           M0003730
      IF(JJ-1) 30,182,30                                               M0003740
182   WRITE(6,185) JJ                                                  M0003750
185   FORMAT(/,T2,'OUTPUT PORT',I3)                                    MOD03760
      GO TO 173                                                        MU003770
183   WRITE(6,181) JJ                                                  MOD03780
181   FORMAT(T2,'OUTPUT PORT',I3)                                      M0003790
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173   CONTINUE                                                    MOD03800
      DO 30 K=1,M                                                 MOD03810
      IF(J-N) 19,19,20                                            MOD03820
19    FI = F(1,J,K)                                               MOD03830
      GO TO 21                                                    MOD03840
20    JNX=J-N                                                     MOD03850
      FI = F(2,JNX,K)                                             MOD03860
21    IF(IQ-1) 25,22,25                                           MOD03870
22    IF(QN(K,J)) 23,24,23                                        MOD03880
23    WRITE(6,104) FI,ZN(K,J),PN(K,J)                             MOD03890
104   FORMAT(1PE12.4,22X,1PE9.2,1PE9.2,19X,1PE12.2,/)             MOD03900
      GO TO 30                                                    MOD03910
24    WRITE(6,105) FI,PN(K,J)                                     MOD03920
105   FORMAT(1PE12.4,22X,'INFINITE',28X,1PE12.2,/)                MOD03930
      GO TO 30                                                    MOD03940
25    DP = PN(K,J)-P(K,J)                                         MOD03950
      IF(QN(K,J)-Q(K,J)) 28,26,29                                 MOD03960
26    IF(QN(K,J)) 29,29,27                                        MOD03970
27    DZ = ZN(K,J)-Z(K,J)                                         MOD03980
      WRITE(6,106) FI,Z(K,J),DZ,P(K,J),DP                         MOD03990
106   FORMAT(1PE12.4,5X,1PE9.2,1PE9.2,1PE9.2,1PE9.2,5X,1PE9.2,    MOD04000
     111X,1PE9.2,/)                                               MOD04010
      GO TO 30                                                    MOD04020
28    WRITE(6,107) FI,Z(K,J),P(K,J),DP                            MOD04030
107   FORMAT(1PE12.4,5X,1PE9.2,1PE9.2,1X,'INFINITE',14X,          MOD04040
     11PE9.2,11X,1PE9.2,/)                                        MOD04050
      GO TO 30                                                    MOD04060
29    WRITE(6,108) FI,P(K,J),DP                                   MOD04070
108   FORMAT(1PE12.4,6X,'INFINITE',10X,'INFINITE',14X,            MOD04080
     11PE9.2,11X,1PE9.2,/)                                        MOD04090
30    CONTINUE                                                    MOD04100
      RETURN
      END
```

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13. ABSTRACT

A method for analyzing in the frequency domain the performance of linear networks containing nonlinear resistors. This method is applied to the evaluation of the frequency performance of a reactively terminated mixer.

14. KEY WORDS

frequency domain analysis	nonlinear resistors
linear network	reactively terminated mixer