THESIS

MICHIGAN STATE UNIVERSITY LIBRARIES
3 1293 00805 4482

L

This is to ~~certify~~ that the

thesis entitled

Microwave Oscillator Simulation

presented by

Michael J. Schnars

has been accepted towards fulfillment
of the requirements for

M.S. degree in Elec. Engr.

Jon C. Freeman
Major professor

Date Feb. 25, 1983

O-7639

MSU is an Affirmative Action/Equal Opportunity Institution

PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.

DATE DUE	DATE DUE	DATE DUE
[illegible]		

MSU Is An Affirmative Action/Equal Opportunity Institution
c:\circ\datedue.pm3-p.

MICROWAVE OSCILLATOR

SIMULATION

By

Michael John Schnars

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Electrical Engineering and System Science

1983

ABSTRACT

MICROWAVE OSCILLATOR

SIMULATION

By

Michael John Schnars

A new technique of analysis of the waveguide-coaxial IMPATT diode oscillator is presented. The circuit is modeled as sections of transmission line with shunt admittance elements representing the circuit tuning screws and coupling apertures.

The circuit models are used as elements of ABCD matrices and the circuit analysis is performed by computer. The computer program provides data lists of the circuit variable values, plots, or a complete statistical analysis of the circuit data. The program was written to allow easy modification of the models used, the circuit structure, or variation of a single circuit parameter.

The program also allows circuit losses to be varied, and mismatches at the load or stabilizing resistor can be varied to determine their effect on circuit performance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

INTRODUCTION

The use of an IMPATT diode as a microwave power source requires considerable design ingenuity to ensure that the oscillator is stable and that spurious oscillations cannot occur as a result of reflections from either the D.C. bias filter or output mismatches. To aid in the design analysis, a new computer simulation of the oscillator has been developed. Rather than modeling the circuit as lumped elements as was previously done, (Ref. 10, 11, 12, 13), the circuit is modeled using ABCD parameters, with each element of the circuit modeled as one ABCD matrix. This allows great flexibility in the choice of models for each element of the circuit, from sections of transmission line, to data values obtained from experimental measurement of the circuit element. The circuit used for the oscillator is a general single-tuned, waveguide-coaxial circuit sometimes called a Kurokawa-type resonator (Ref. 14). The IMPATT diode is biased into reverse avalanche breakdown, and because of the transit time of the charge carriers through the diode, it acts as a negative resistance, which, in an appropriate circuit, will cause oscillation to occur. The configuration of the circuit is easily changeable to allow comparison of different designs. The circuit parameters (radius, etc.) can be changed over a wide range of values, or lossy materials can be introduced into the circuit to see the effect on the overall circuit performance. The simulation is performed at

20 frequencies over the range of 17.7-19.7 GHZ. The program calculates the circuit efficiency, the cavity Q's, relative load power, input admittance, reflection coefficient, and the frequency derivative of the susceptive part of the input admittance (susceptance slope). The program can provide plots of these variables, or lists of their data points over the frequency range, or analyze the data points and provide mean value, standard deviation, and several other measures of the central tendency and variability of the distributions of the circuit variables.

Work of this type is urgently needed to aid in efforts to develop power combiners using 4 or 6 IMPATT diodes. An accurate model of each individual oscillator is required to allow predictions of the response of each oscillator as its load admittance is changed as they are combined, and from variations in the IMPATT diodes from different production runs.

Benefits and Limitations of Modeling

The major benefits of computer modeling of the diode and resonant structure come from the speed of execution of the program. Analyzing the circuit by hand calculations can take several hours at each frequency. The program provides a convenient method to analyze a new design, or to compare several different designs by simply changing the appropriate ABCD matrix. The program can also be used to analyze and improve existing design. If, for example, lower noise is required, the information on the movement of the device line (Appendix 6) can be used to improve the device angle for lower noise. In this complex circuit, varying a single parameter may affect several different aspects of the circuit. For example, increasing the coupling aperture (d_1) increases the input admittance and magnitude of the reflection coefficient but decreases the cavity Q, Q_o. LT1 (the tuning screw waveguide length), however, can be used to increase Q_o so as to compensate for the actions of d_1. These type of trade-offs are easily viewed, using the results of the computer simulation.

The graphs generated by the program can also be used to find when 'loops' will form in the reflection coefficient locus (indicating possible instabilities in the operating point) while tuning the device. The effect of losses on circuit performance can be predicted and compared to experimental results. This could be used to determine if plating the inside of the resonant cavity to increase the 'Q' is worth the extra expense.

Also, since the program can be used to determine what the optimum value and variation of the device impedance should be, it would be possible to change the package of the IMPATT diode to match the impedance the circuit can present when the stabilizing loss is small.

The model of the oscillator has several inherent assumptions and limitations. In order for the analysis to be meaningful, the assumption that the evanescent fields of obstacles do not interact must be made, and over moding in the cavity due to the quartz rod is not included.

The circuit is assumed to be reciprocal, and all restrictions on variable range indicated in the section on the ABCD models must be met.

Computer Program Format

The program is written in Fortran 4 and is 2000 lines long. Fortran was chosen because this provides compatibility with other computer installations, and allowed usage of the CalCom plot routines. Also, the large number of external and intrinsic functions, and the array manipulation commands of Fortran make this language a natural choice.

This program was written to help in the design and analysis process of microwave oscillators. Shown in Appendix 1, Figures 1 and 2 are side and top views of the specific oscillator circuit chosen for simulation and the names of the circuit parameters. Figure 3 shows an equivalent circuit of the oscillator and indicates the circuit sections the models represent. The planes shown in Figure 3 and listed in Table 1 partition the equivalent circuit into cells, each of which is represented by one ABCD matrix. The circuit is analyzed by starting at the load and finding the admittance looking toward the load at each successive plane until the admittance the IMPATT diode would see at plane 1 is found. Then, by assuming the diode acts as a 1-volt source at plane 1, the voltage and current is found at each plane out to the load.

The analysis is then repeated at each frequency desired. Except for the model used for the quartz rod, the program can be run at any frequency desired, using any increment size between frequencies (up to 20 frequencies per run total). The currently used model for the quartz rod, however, restricts the program to 17.7-19.7 GHZ and 0.1 GHZ step sizes. This is because the model for the quartz rod was determined from experimental data, and the data was taken at these points. The program is set up so that by changing the value of a flag variable from '0' to '1' at the start of the program, any desired combination and number of parameters can be used each run, and any combination of the possible types of outputs can be selected. Appendix 1, Table 2 lists the variables used in controlling the program actions, and Appendix 2 lists the arrays used in the program and typical values of the circuit parameters.

To use the program, the parameters to be varied are first selected (for example, the length of the 1/4 wave transformer, and the cavity height). The program will analyze the effect of the variation of each parameter separately. Next, the range of the variables are chosen. The variables can have any value, with up to 10 increments of any size in each run. The type of output desired is selected next. For initial runs, outputting only the data indicates the variation of the distribution of the circuit variables values, gives good indications of trends, is very cheap, and avoids the large amount of data that would be generated if the actual value of the load power, etc., were output at each frequency for each value of each variable.

After initial runs, the points of maximum effectiveness of each variable can be determined, and the range narrowed to the region of interest. For final runs, data lists and graphs with multiple curves can be output for complete analysis. The program description is contained in Appendix 8, and Appendix 11 has the program listing which indicates in the symbolic reference map what the program variables names mean.

ABCD Matrix Models

The ABCD or 'cascade' parameters were chosen because in the analysis of the circuit, the input voltages and currents are transferred through each circuit model to find the output voltages and currents, and the input admittance to each model is also easily found with these parameters. In addition, the ABCD parameters provide ease of the modification of the model of each element, and (under the reciprocity assumption) the inverse of the 2 x 2 matrix is easily calculated - providing great computational advantage in this case. Also, the ABCD parameters allow easy incorporation of the frequency variation of the models used for the admittance elements.

The ABCD models used for the computer simulation are shown in Appendix 3, Table 3. These were developed from Reference 17. Table 4 shows the ABCD elements used for each section of the model. Figure 4 shows the voltages and currents defined for the ABCD model.

For the circuit model, a total of 18 ABCD matrices were required. Of these, 7 are admittance models and 11 are sections of transmission line.

For the development of the model, the load was set to the value of the characteristic admittance of the output waveguide - i.e., we consider no mis-match at the load for simplicity. One may include these reflections if desired.

The model used for the metallic tuning screws is a T-pad of impedences Ref. (1) (Fig. 5). The corresponding ABCD elements are $A = 1 + \frac{Z_1}{Z_3}$ $B = \frac{Z_1 Z_2 + Z_2 Z_3 + Z_1 Z_3}{Z_3}$ $C = \frac{Z_1}{Z_3}$ $D = 1 + \frac{Z_2}{Z_3}$. In our case, $Z_1 = -jX_a$ and $Z_2 = Z_1$ and $Z_3 = -jX_b$. Then the elements B and D become $B = \frac{Z_1^2}{Z_3} + 2Z_1$ and $D = 1 + Z_1/Z_3$. The reactances X_a and X_b are defined as $X_a = Z_o'(1.55 \times 10^{-3}t)$ and $X_b = Z_o'(3.9525/t)$ where t is the depth of the tuning screw, and can vary from 0 to 0.12 inch. The values of the constants were determined from the graphs of experimental data in Ref.(1).

With this model, the tuning screws are used to tune for maximum power. Two metallic capacitive tuning screws are used so the one closest to the iris (at a distance of $\lambda g/8$) will act as a capacitor in parallel with the iris. The second screw (at a distance of $\lambda g/4$) will act as an inductor in parallel with the iris. Since the iris is modeled as an inductance (Ref. 2), the first tuning screw effectively increases the iris diameter, and the second effectively decreases the iris diameter. The elements of the iris ABCD matrix are: $A = D = 1$, $B = 0$ and $C = -jB_i$ where $B_i = \frac{3ab}{2}\frac{\lambda_g}{\pi}\frac{Y_o'}{d_3}$ (d_3 is the iris diameter and a and b are the waveguide dimensions). This model is valid in the wavelength range $2a > \lambda > a$ and for the diameter of the iris $<< \lambda/\pi$.

The model of the quartz rod was determined directly from (unpublished) experimental data measured at Bell labs. It can be shown (Appendix 4) that the data can be used to directly generate the ABCD model. The elements are $A = D = 1$, $B = 0$, $C = Yq$ where $Yq = \frac{-2\rho in}{1 + \rho in}$ where ρin is the reflection coefficient measured experimentally. We assume only TE_{10} (H_{10} mode and guide cutoff is 14.1 GHZ.

The coupling between the air dielectic coaxial line and the resonant cavity (through the oblong aperture) is modeled by a π-pad (Ref. 3). The elements of the pad (Fig. 6, Appendix 3) are defined as $B_a = Yo\ P/(2\lambda_o r_2^2 \ln(r2/r_1))$ and $B_b = (Yo\ \lambda_o r_2^2 \ln(r_2/r_1))/M$ where $P = \frac{d_1 d_2}{24E(\varepsilon)}$ and $M = \frac{d_1{}^3\ \pi\ \varepsilon^2}{24\ (F(\varepsilon) - E(\varepsilon))}$ and $\varepsilon = (1 - (d_2/d_1)^2)^{1/2}$.

$F(\varepsilon)$ and $E(\varepsilon)$ are complete elliptic integrals of the first and second kind, respectively. From an analysis of M and P (Ref. 4), these functions can be represented over the range of interest by a straight-line approximation, which is used by our model. This model is valid for $d_1 \ll \lambda$, and for the wavelength range for which only the principal mode can be propagated in the coaxial guide and only the H_{10} mode in the rectangular guide. It is also assumed the curvature of the coax containing the aperture has negligible effect, and the coax outer wall is assumed to have zero thickness.

The step discontinuity (Fig. 7, Appendix 3) in the coaxial radius is modeled as a capacitance (Ref. 5). The defining equation is $Y_{step} = \frac{jf}{9.95 \times 10^{12}}$ where f is the frequency in H_z. This is valid over the entire range of radii of interest.

The remainder of the sections of the oscillator are modeled as sections of transmission line. The ABCD elements are $A = \cosh(\gamma L)$, $B = \sinh(\gamma L)/Y_{OL}$, $C = Y_{OL} \sinh(\gamma L)$ and $D = \cosh(\gamma L)$ where $\gamma = \alpha + j\beta$ and L and Y_{OL} are the length and characteristic admittance of the line in question. The values of α and β are different in the air dielectric coax, the teflon dielectric coax, and the waveguide. The specific equations used in each case are recorded in Appendix 5. The method used in determining the admittance in the waveguide is covered in Appendix 5.

Circuit Analysis

The analysis of the circuit is easily effected using the ABCD parameters as previously described. Starting at the load, the input admittance to each section is found by using $Y_{in} = \frac{C + (D)(Y_L)}{A + (B)(Y_L)}$. This is then combined with the load admittance of the next section (if any). This is the new load admittance of the next section, and the next input admittance is then found as described above. The circuit is reduced in this fashion from plane 18 to 9, and from 19 to 7 so the circuit is reduced into the coupling pad (Fig. 8, Appendix 3). The input admittance of the coupling pad is then found as $Y_{in} = \frac{(Y_{in}^{6-19} - jB_a)(Y_{in}^{9-18} - jB_a)}{(Y_{in}^{6-19} - jB_a + Y_{in}^{9-18} - jB_b)} - jB_a$.

Then the reduction down to the diode is performed by finding the input admittance to each section using the ABCD parameters. As the circuit is reduced, the input admittance at each plane is stored in an array, and the reflection coefficient at each plane is calculated using $\rho_{in} = \frac{Y_{in} - Y_{oL}}{Y_{in} + Y_{oL}}$ and the value is saved. After the above reduction is performed at each desired frequency, an array of 20 values (one for each frequency) is obtained for the input admittance and reflection coefficient as seen by the diode and can be an output (the values of the admittance and reflection coefficient at each plane can also be an output). At the diode plane, once the input admittance is known, we use a 1-volt generator to represent the diode. The current is then calculated using $I_1 = Y_{in}V_1$ (V_1 = 1 volt) and the input power is $P_{in} = \frac{1}{2}\,RE\,(V_1 I^*_1)$. The next step in the analysis is to find the voltage and current at each plane using $\begin{bmatrix} V_2 \\ I_2 \end{bmatrix} = \begin{bmatrix} D & -B \\ C & A \end{bmatrix} \begin{bmatrix} V_1 \\ I_1 \end{bmatrix}$ (as defined in Fig. 4, Appendix 3). The voltage and currents are found from plane 1 to 5 (the coupling pad). At this point a new ABCD matrix is defined. Since we are not interested in the voltages and currents in the stabilizing load, we define a matrix to transfer the voltages and currents from plane 5 to plane 9 (Fig. 9, Appendix 3). $A = 1 + \frac{-jB_b}{Y_{stab} - jB_a}$, $B = \frac{1}{Y_{stab} - jB_a}$

$C = -jB_a - jB_b + \frac{(-jB_a)(-jB_b)}{(Y_{stab} - jB_a)}$ and $D = 1 + \frac{-jB_a}{(Y_{stab} - jB_a)}$.

The remaining voltages and currents out to the load can now be found using the remaining ABCD matrices. At the load, the power is found as $P_L = \frac{1}{2}\,RE\,(V_{18} I^*_{18})$ and the circuit efficiency is found as $\eta_{ckt} = \frac{P_L}{P_{in}}$. The voltage and current at each plane is saved, and can be an output.

Since all circuit variables are now known, we can calculate a 'secondary' set of variables. First, by defining the values of admittance the diode needs to work into (the device window) as $0.93 \leq |\rho^I| \leq 0.985$ and $-35° \leq \rho^I \leq -45°$ (based on experimental work), we can find the angle of intersection between the device line (assumed radial) and the locus of the input admittance. This angle is the device angle, and the points of the input admittance contained in the device window is the "effective bandwidth" of the circuit. The program also determines the frequency which is nearest the device window, if none are in it. (A complete analysis of the device angle is contained in Appendix 6.) Since the circuit input admittance is known, we can find the input susceptance slope using $Y_{in} = G_{in} + j B_{in}$ so that the susceptance slope = $\partial B_{in}/\partial\omega$. Also, the cavity Q's are $Q_L = \dfrac{\lambda_o}{2RE\ (Y_{in})}$ and also

$Q_{ex} = \dfrac{Q_L}{\eta\, ckt}$ and $Q_o = \left(\dfrac{1}{Q_L} - \dfrac{1}{Q_{ex}} \right)^{-1}$.

At this point, the circuit has been completely characterized. All values of all variables at each point in the circuit are known. However, since 33 circuit parameters can be varied in 10 increments each run, and analyzed at 20 frequencies for each value of each increment of each variable, it is easy to generate massive amounts of data. To facilitate the analysis of the data, the program provides one final aid to analysis. For each of the variables of major interest (efficiency, load power, input admittance, magnitude of reflection coefficient, angle of reflection coefficient, susceptance slope, Q_L, Q_o, and Q_{ex}), the program analysis distribution variability. The program considers each parameter being varied separately, and uses the first value of the parameter as a reference point. Then, for each increment of the parameter, the program calculates the mean values, standard deviation, number of points larger than the reference, the average value of increase of the points larger than the reference, the number of points less than the reference, the average value standard deviation, and mean value of decrease of the points less than the reference. The program also determines which increment of the parameter has the largest value, and which has the smallest value over the frequency range, and the frequency at which they occur. (The information on the smallest values can be used, for example, to decrease the complex part of the load power if the load is mismatched.) For each of these statistical values, the program can either print them directly or compare them and print which increment has the best value, the percent increase over the reference, the value of the circuit parameter at that increment and the best value itself. If, for example, the depth of a tuning screw is being varied, then the program can analyze the circuit and tell what value of the tuning screw (if any) gave the largest increase in the mean value of the efficiency (for example), the percent increase, and what the largest value of the mean was, and which increment of the tuning screw gave it (Table 12, Appendix 9). Since only four numbers are output (for each statistical variable -- mean, standard deviation, etc., and each circuit variable -- efficiency, load power, etc.), two pages of data provides all information of interest from ten increments of a variable. Thus, every parameter in the circuit can be varied and only 70 pages of data are generated, and it is not necessary to know every value of the circuit variables at every frequency to analyze the circuit. This is of great aid when trying to increase the mean value of the load power, for example, since four numbers indicate which value of the variable gave the best results. Also, the design trade-offs are immediately obvious since the statistical information indicates whether the efficiency (for example) was affected or not.

Data Analysis

Since the program was designed to allow optimization of the circuit for a particular application (i.e., maximum bandwidth, or efficiency, etc.) or to compare several different circuit designs, no 'best' values for the circuit parameters can be given. However, by analyzing the data generated by the program over typical ranges of the parameters, it is possible to determine the effect each of the parameters has on the circuit.

In order to see general trends, Appendix 7 contains (for the lossless case) tables that indicate the effect of each circuit parameter on the circuit performance. The mean and standard deviation were chosen as examples, although similar tables could be made for each statistical variable. Appendix 7, Table 5 shows the range over which the parameters were varied, and the corresponding circuit variable over which they had the largest effect on its mean value. Table 8 shows the standard deviation of the circuit variable each parameter has the largest effect upon. Here the parameter range is constant. It should be noted, for different ranges of the parameters, the variable of maximum effect, and the magnitude of the effect, may change. Table 6 shows which variables each circuit parameter can effect a change in the mean value of at least 0.1% or greater. Table 7 shows which variables each circuit parameter effects the standard deviation by 0.1% or greater. Again, the specific variables affected may vary with range; these tables are provided only as an example.

From Tables 6 and 7, several interesting effects can be noted. The only circuit parameter that affects the mean value of every variable is the quartz rod. The only circuit parameters that affect the standard deviation of every variable are the quartz rod, and the cavity width (b). From Table 8 we note the effects of TS1 and TS2 are complementary - they invidually tune different aspects of the circuit, as expected. In this circuit, a major source of the loss of power (inefficiency) is loss in the stabilizing load. From Tables 6 and 7, the effect of adding a band stop filter can be seen in the variance of power and efficiency with the changes in the length of the filter (LF) and impedance of the filter (Z_C). The reason for the many different types of statistical data made available from this program is more obvious upon examination of Tables 5-8. A particular parameter may increase only the mean, or the standard deviation, or the largest maximum value, etc., and depending on the type of 'curve shaping' that is required for the specific application, the effect of any single parameter could be lost if only one type of statistical analysis was used.

A feel for the general response of the oscillator can be obtained from the graphs in Appendix 10, Figures 12-27. Figure 12 shows the reflection coefficient as the 1/4 wave transformer varies 4 thousandths of an inch. The reflection coefficient locus pivots about one point (18.35 GHZ) and expands outward. Figure 13 shows a similar response from varying r_1 by 4 thousandths, except the point of rotation has moved up in frequency causing the area of maximum change of reflection coefficient to move up in frequency also. Figure 14 shows the effect of varying the iris (d_1) from eliptical to circular. This has a large effect on the low frequency values of the reflection coefficient. The effects of reflections from the stabilizing load can be seen in Figure 15 where Y_{stab} (Y_S) varies from 0.6 to 0.0 mmhos. The value of Y_{stab} in the other plots is matched to Y_O, which is normally 20 mmhos. The variation of load power (with load matched to output waveguide at all frequencies), caused by varying r_1 4 thousandths is shown in Figure 16. The point of maximum power moves down in frequency and the curve becomes more peaked. Figure 17 shows (as the cavity height (a) varies 4 thousands) how the point of maximum power moves up in frequency and the curve becomes more peaked. Figures 18 and 19 show the variation of the imaginary part of the input admittance as the air dielectric tip length (L_x) and the quartz rod depth (Q rod) are changed. L_x has its largest effect at the ends of the frequency range, and the quartz rod changes the maximum value of the curve. The curves tend to remain constant over the upper part of the frequency range. Figures 20 and 21 show the effect of L_x and the quartz rod on the real part of the input admittance. L_X affects the ends and upper portion of the curve, and the quartz rod shifts the point of maximum value and spreads the curve out. The curve tends to its highest values at the upper frequencies, and has less variation in this region. The variation in the efficiency with changes in the cavity height and iris is shown in Figures 22 and 23. The movement and increase of the maximum value occur as the coupling of the output load changes with the iris diameter, and a changes the resonant frequency of the cavity. At higher frequencies, where the real part of the input admittance is largest, the efficiency drops off rapidly and approaches a constant value. Coupling to the output is decreasing, and more power is being lost in Y_{stab}. In Figures 24 and 25, Q_L is seen to drop to a constant value at the higher frequencies, and responds to the quartz rod more than the air dielectric tip. Increasing Q_L at the higher frequencies will increase the efficiency and the bandwidth also. Figures 26 and 27 show the input susceptance slope vs. efficiency with the largest changes at the lowest and highest efficiencies, as expected.

Validity of Modeling

The verification of the results of this program come from several sources. The actual values calculated by the program were compared to values calculated by hand using the defining equations to determine if there were any errors in implementing the equations in the computer model. More importantly, the response of the circuit as predicted by the computer model is identical to the response of actual circuits that were constructed and their performance measured at Bell Labs by Dr. J. Freeman. Also, the computer model behaves 'logically' -- if the stabilizing load is open-circuited and there is no loss in the ciruit, the efficiency becomes 100% because all power input to the circuit goes to the load.

Future Enhancements

There are several enhancements that may be added to the program to aid in analysis. To prevent an unstable configuration, it would be desirable to have the program perform sensitivity calculations, perhaps by varying each parameter a small amount and checking the change in the outputs. Also, a small noise generator could be added to the diode generator to see its effect. Another area for further work would be to consider this program as a subprogram to a master control program. Then it would be possible to sequence the variables one at a time, then two at a time, etc., and try all orders of all combinations, and try combining several oscillator models. Due to the amount of computer time this would require and the costs involved, this would almost have to be done under a grant. The use of the Textronix graphics terminals to view the plots would be a great aid in this. It would also be possible to have the program analyze its own data, and return a set of circuit parameters that would optimize (for example) the mean value of the circuit efficiency. Another area for further investigation would be further refinements in the ABCD parameter models. It may be possible to use a rectangular aperture for the coupling between the coaxial line and resonant cavity to improve the bandwidth, for example. To incorporate nonlinear effects, piece-wise linear models could be used. Another possibility is to incorporate more experimental data into the ABCD models. This would be particularly useful in the ranges where models are not available.

Summary

A new computer model for analyzing microwave oscillator circuits has been presented. This model provides an extremely accurate simulation of the frequency response of the actual circuits. Since it is extremely easy to analyze the circuit using computer simulation, this model should be invaluable in the design and optimization of microwave circuits. The capabilities of the circuit have been covered and some of the results from the program have been presented. Since the program is written in Fortran, it can be easily used at any computer installation.

References

(1) Microwave Engineer's Handbook, Vol 1, Artech 1971, p. 75.

(2) MIT Radiation Laboratory Series Waveguide Handbook, Vol. 10, Editor: Marcuitz, p. 239.

(3) MIT Radiation Laboratory Series Waveguide Handbook, Vol 10, p. 368.

(4) MIT Radiation Laboratory Series Waveguide Handbook, Vol 10, p. 242.

(5) Step Cap Microwave Engineer's Handbook, Vol. 1, p. 111.

(6) M.I.T. Radiation Laboratory Series, p. 73.

(7) Field Theory of Guided Waves, Collin, McGraw-Hill, 1960, p. 183.

(8) Microwave Techniques, Mooijweer, MacMillan, 1971, p. 250.

(9) Microwave Devices, John Wiley, 1976, Editors: Howes, Morgan, p. 216.

(10) Circuit Design for MM-Wave IMPATT Oscillators, N. Kenyon, M.T.T. Microwave Theory and Techniques, Microwave Symp., June 1970.

(11) Equivalent Circuit and Tuning Characteristics of Resonant-CAP Type IMPATT Diode Oscillators, N. Kenyon, Euro. Microwave Conference, 1973.

(12) A Study of a Single-Tuned, Waveguide-Coaxial Circuit for IMPATT Oscillators and IMPATT Diodes Characterization, R. Wroblewski, Euro. Microwave Conf., June 1974.

(13) Short Communications Single-Tuned Solid-State Microwave Oscillators, N. D. Kenyon, Circuit Theory and Applications, Vol 1, 1973, pp 387-393.

(14) 140 GHZ Silicon IMPATT Power Combiner Development, Kai Chang, G. M. Hayashibara and F. Thrower, Microwave Journal, June 1981.

(15) Principles of Microwave Circuits, Montgomery, et al, Dover, 1965, p. 168.

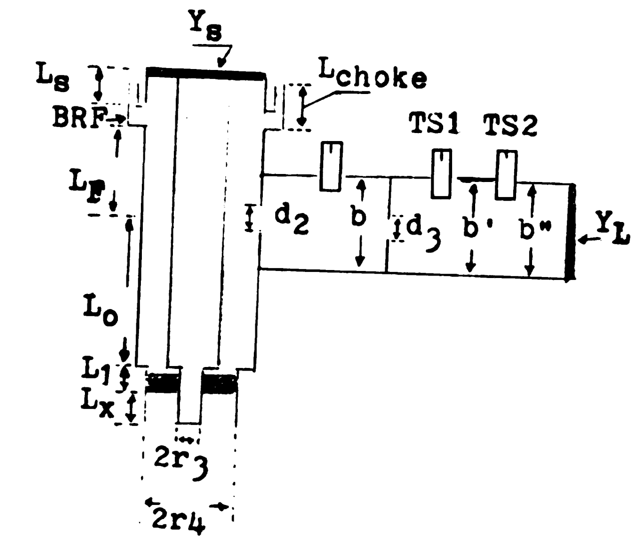
(16) MIT Radiation Laboratory Series, Vol 10, p. 364.

(17) CAD of Microwave Circuits, GUPTA, GARG, CHADHA, ARTECH, 1981.

APPENDICES

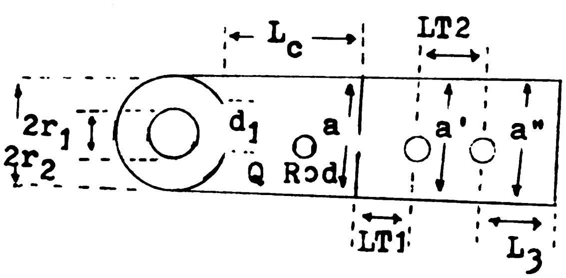
APPENDIX 1

CIRCUIT AND CONTROL VARIABLES



$2r_3$ coax tip inner diameter
$2r_4$ coax tip outer diameter
b cavity height
b' tuning screw height
b'' output height
BRF band reject filter
d_2 coupling pad height
d_3 cavity iris diameter
L_1 dielectric length
L_{choke} BRF length
L_F cavity to BRF length
L_0 step cap. to cavity
L_s BRF to Y_s length
L_x air tip length
Y_L output load
Y_s stabilizing load
TS1 tuning screw 1
TS2 tuning screw 2

Figure 1: Side View of Oscillator



$2r_1$ coax inner diameter
$2r_2$ coax outer diameter
a cavity width
a' tuning screw width
a'' output width
d_1 coupling pad width
L_3 TS2 to Y_L length
L_c cavity length
LT1 iris to TS1 length
LT2 TS1 to TS2 length
Q Rod quartz rod

Figure 2: Top View of Oscillator

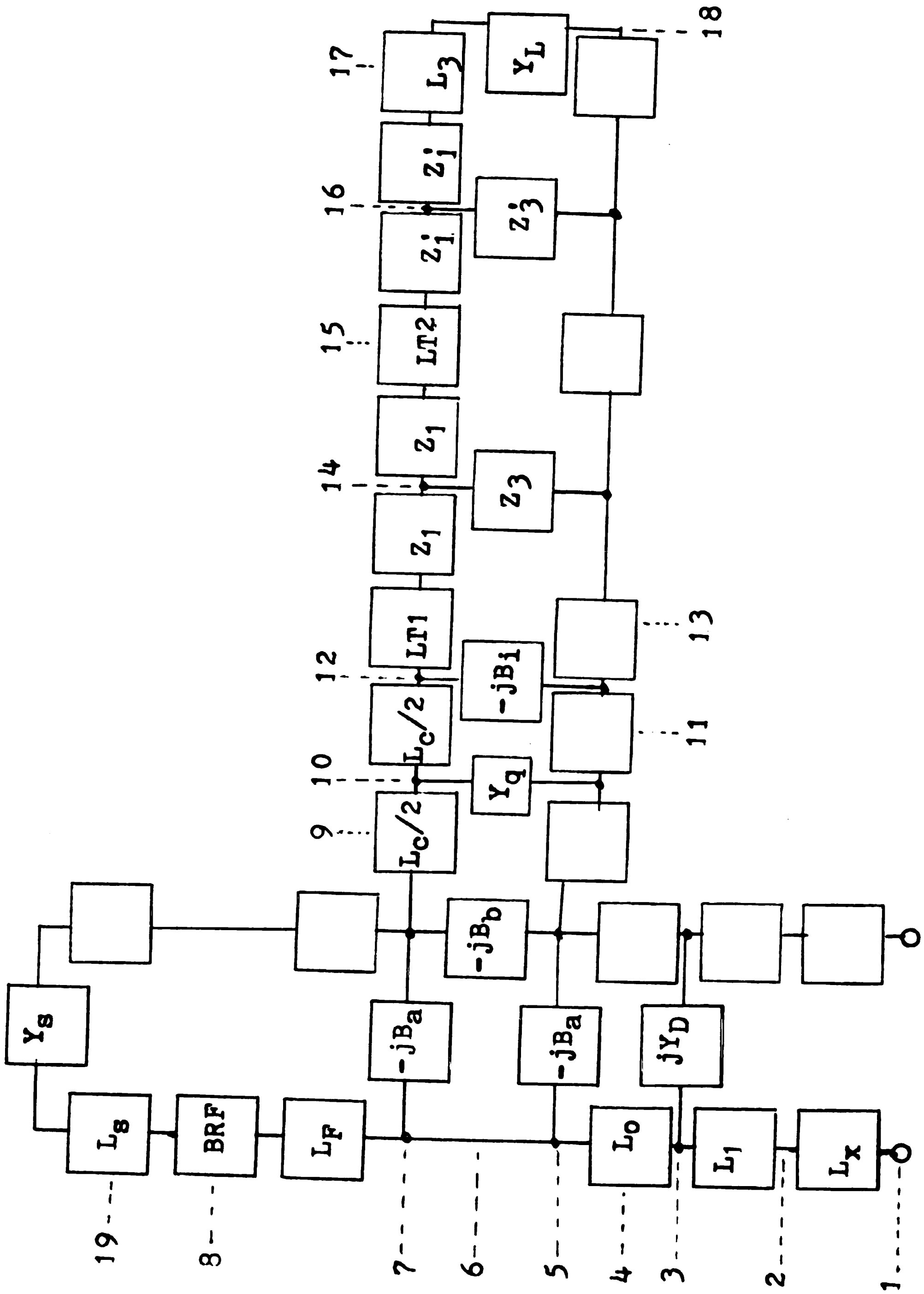


Figure 3: Equivalent Circuit

TABLE 1

PLANES USED FOR CIRCUIT DIVISION

Plane	Physical Location
1	Plane of diode
2	Edge of transformer (in air)
3	At capacitive step (in teflon)
4	Above step (in air)
5	At physical bottom of cavity
6	Physically at center line of cavity, electrically at plane of coupling pad
7	Top of cavity to bottom of band reject filter
8	Band reject filter
9	Outside of coax to quartz rod waveguide end
10	Quartz rod
11	Quartz rod to iris waveguide end
12	Iris
13	Iris to TS1 waveguide end
14	Tuning screw #1
15	TS1 to TS2 waveguide end
16	Tuning screw #2
17	TS2 to Y_L waveguide end
18	Y_L plane
19	Y_S plane

TABLE 2

PROGRAM CONTROL VARIABLES

Print Control Variables

IW(1)=0	No losses in circuit, Print no losses
IW(2)=0	No band reject filter, Print no BRF
IW(3)=0	No tuning screw 1, Print no TS1
IW(4)=0	No tuning screw 2, Print no TS2
IW(5)=1	Print values of frequency, variable value, quartz rod reactance, B array, YE array, BE array, and all ABCD parameters at each frequency, for each value of variable. See Table 9, Appendix 9.
IW(6)=1	Print plane number, current value of variable, Y array, YN array, V array, C array, at each plane, for each variable value. See Table 10, Appendix 9.
IW(7)=1	Print RCM and RCA arrays at each plane, for each variable value. See Table 10, Appendix 9.
IW(8)=1	Print plane number, EA, CMAG, CANG, and PL arrays at each plane, for each variable value. See Table 10, Appendix 9.
IW(9)=1	Print plane number, YC and PC array at each plane, for each variable value. See Table 10, Appendix 9.
IW(10)=1	Print plane number, SSA, QL arrays at each plane, for each variable value. See Table 10, Appendix 9.
IW(11)=0	Plot input reflection coefficient on polar axis. See Figure 12, Appendix 10.
IW(12)=0	Plot real part of input admittance vs. frequency. See Figure 16, Appendix 10.
IW(13)=0	Plot imaginary part of input admittance vs. frequency. See Figure 18, Appendix 10.
IW(14)=0	Plot real part of load power vs. frequency. See Figure 20, Appendix 10.
IW(15)=0	Plot efficiency vs. frequency. See Figure 22, Appendix 10.

TABLE 2 (cont'd)

IW(16)=0	Plot QL vs. frequency. See Figure 24, Appendix 10.
IW(17)=0	Plot susceptance slope vs. frequency. See Figure 26, Appendix 10.
IW(18)=1	Print all statistical values for all variables at each frequency, for each variable value. See Table 11, Appendix 9.
IW(19)=1	Print array IEXT with statistical outputs or plots (for each identification). See Table 11, Appendix 9.
IW(20)=1	Print best values of statistical data. See Table 12, Appendix 9.

Run Control Variables

Values of NA array elements to vary that parameter (order is determined by location in NA array).

NA Value	Variable	NA Value	Variable	NA Value	Variable
1	L_x	13	a	25	λ_c
2	LTR	14	b	26	λ_W
3	L_O	15	r_1	27	a'
4	L_F	16	r_2	28	b'
5	Z_C	17	r_3	29	a"
6	LT_1	18	r_4	30	b"
7	LT_2	19	d_1	31	QRL depth
8	LT_3	20	d2	32	Y_{stab}
9	L_S	21	d_3	33	Y_L
10	L_C	22	$(\varepsilon r)^{1/2}$		
11	TS1	23	α A		
12	TS2	24	α D		

APPENDIX 2

PROGRAM ARRAYS

Length Arrays and Typical Values

Array Element	Variable	Typical Value (inches)	Array Element	Variable	Typical Value
S(1)	L_X	.015	D(1)	a	.42
S(2)	LTR	.115	D(2)	b	.17
S(3)	L_O	.010	D(3)	r_1	.032
S(4)	HC/2	.085	D(4)	r_2	.0735
S(5)	L_F	.073	D(5)	r_3	.0315
S(6)	LC/2	.225	D(6)	r_4	.05
S(7)	LT1	λ g'/8(0.119)	D(7)	d_1	.26
S(8)	LT2	λ g'/4(0.239)	D(8)	d_2	.16
S(9)	LT3	.1	D(9)	d_3	.145
S(10)	L_S	.1	D(10)	P	1
S(11)	L_{Choke}	λ o/4(0.158)	D(11)	M	1
S(12)	TS1	.05	D(12)	a'	.42
S(13)	TS2	.05	D(13)	b'	.17
S(14)	QRL	1 TURN	D(14)	a"	.42
			D(15)	b"	.17
			D(16)	λ	1
			D(17)	λ cav	1
			D(18)	λ 'G	1
			D(19)	$(\varepsilon_r)^{1/2}$	1.435
			D(20)	λ "G	1

Note: Variables set to "one" (except QRL) are evaluated elsewhere in the program.

<u>Variable Arrays</u>

Array	Variable	Array	Variable	Array	Variable
G(1)	$(\gamma a)Lx$	YE(1)	Yod	B(1)	Ystep
G(2)	(γ_{TR}) LTR	YE(2)	Yot	B(2)	Z_c
G(3)	(γ_{TR}) LTR	YE(3)	Yot	B(3)	Y_2
G(4)	(γ_a) L_O	YE(4)	Yo	B(4)	$-jB_2$
G(5)	(γ_a) HC/2	YE(5)	Yo	B(5)	Z_1
G(6)	(γ_a) HC/2	YE(6)	Yo	B(6)	Z_3
G(7)	(γ_a) L_F	YE(7)	Yo	B(7)	Z_1'
G(8)	(γ_a) L_F	YE(8)	Yo	B(8)	Z_3'
G(9)	(γ_c) LC/2	YE(9)	Yo'	B(9)	Y_L
G(10)	(γ_c) LC/2	YE(10)	Yo'	B(10)	Y_{stab}
G(11)	(γ_c) LC/2	YE(11)	Yo'	B(11)	$-jB_a$
G(12)	(γ_c) LC/2	YE(12)	Yo'	B(12)	$-jB^b$
G(13)	(γ_{wg}') LT1	YE(13)	Yo"		
G(14)	(γ_{wg}') LT1	YE(14)	Yo"		
G(15)	(γ_{wg}') LT2	YE(15)	Yo"		
G(16)	(γ_{wg}') LT2	YE(16)	Yo"		
G(17)	(γ_{wg}'') LT3	YE(17)	Yo"		
G(18)	(γ_a) LS	YE(18)	Yo		
AT(1)	α_{air}	BE(1)	B_{air}		
AT(2)	α_{die}	BE(2)	B_{die}		
AT(3)	α_{choke}	BE(3)	B_{choke}		
AT(4)	α_{cavity}	BE(4)	B_{cav}		
AT(5)	α_{wg}	BE(5)	B_{wg}		
AT(6)	α''_{wg}	BE(6)	B''_{wg}		

SV Array Utilization

Elements Variables	1 Eff	2 R.PWR	3 Y_{in}	4 MRFL	5 ARFL	6 Y_{in} (slope)	7 Q_L	8 Q_o	9 Q_{ex}
Mean	x	x	x	x	x				
S.D.	x	x	x	x	x				
Xp	x	x	x	x	x				
Xsum/Xp	x	x	x	x	x				
Xm	x	x	x	x	x				
Largest	x	x	x	x	x				
Freq. largest	x	x	x	x	x				
Smallest	x	x	x	x	x				
Freq. smallest	x	x	x	x	x				
-AV	x	x	x	x	x				
Device angle	x	x	x	x	x				
Freq. close .95	x	x	x	x	x				
Freq. close 40	x	x	x	x	x				
# |BW|	x	x	x	x	x				
18.7	x	x	x	x	x				
# BW	x	x	x	x	x				
Mean						x	x	x	x
S.D.						x	x	x	x
Xp						x	x	x	x
Xsum/Xp						x	x	x	x
Xm						x	x	x	x
Largest						x	x	x	x
Freq. largest						x	x	x	x
Smallest						x	x	x	x
Freq. smallest						x	x	x	x
-AV						x	x	x	x

APPENDIX 3

TABLE 3

ABCD MATRIX MODELS

T-Pad	$A = 1 + Z_1/Z_3$
	$B = (Z_1, Z_2 + Z_2Z_3 + Z_1Z_3)/Z_3$
	$C = 1/Z_3$
	$D = 1 + Z_2/Z_3$
Pi-Pad	$A = Y_2/Y_3$
	$B = 1/Y_3$
	$C = (Y_1Y_2 + Y_2Y_3 + Y_1Y_3)/Y_3$
	$D = 1 + Y_2Y_3$
Series Element	$A = 1$
	$B = Z$
	$C = 0$
	$D = 1$
Shunt Element	$A = 1$
	$B = 0$
	$C = Y$
	$D = 1$
Thru Connection	$A = 1$
	$B = 0$
	$C = 0$
	$D = 1$

TABLE 3 (cont'd.)

Transmission Line	$A = \cosh \gamma L$
	$B = (\sinh \gamma L)/Y_o$
	$C = Y_o \sinh \gamma L$
	$D = \cosh \gamma L$
Input Admittance	$Y_{in} = \dfrac{C + (D)(Y_L)}{A + (B)(Y_L)}$
Input Current Reflection Coefficient	$\rho_{in}^{I} = \dfrac{Y_{in} - Y_L}{Y_{in} + Y_L}$
Zero Length Attenutator	$A = (10^X + 10^{-X})\ ½$
	$B = Z_o/(10^X - 10^{-X})½$
	$C = (10^X - 10^{-X})/2Z_o$
	$D = (10^x + 10^{-x})½$
	$X = \alpha/20$

TABLE 4

ABCD Matrix Equations

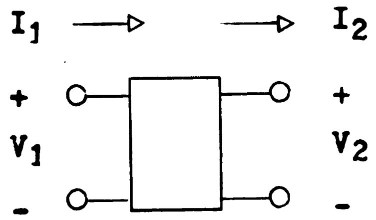
Array Element Section Name	ABCD Elements	Defining Equations
A(1, X)	$A_1 = \cosh \gamma_{air} L_x$	$\gamma_{air} = \alpha_{air} + \beta_{air}$
Air dielectric coax tip	$B_1 = (\sinh \gamma_{air} L_x)/Y_{OD}$	
	$C_1 = Y_{OD} \sinh Y_{air} L_x$	$Y_{OD} = (60 \ln(r_2/r_3))^{-1/2}$
	$D_1 = \cosh \gamma_{air} L_x$	
A(2,X)	$A_2 = \cosh \gamma_{TR} L_1$	$\gamma_{TR} = \alpha_{TR} + \beta_{TR}$
Teflon dielectric coax line	$B_2 = (\sinh \gamma_{TR} L_1)/Y_{OT}$	$\gamma_{OT} = \gamma_o/(\varepsilon r)^{1/2}$
	$C_2 = Y_{OT} \sinh \gamma_{TR} L_1$	
	$D_2 = \cosh \quad _{TR} L_1$	$Y_{OT} = \varepsilon r/(60 \ln(r_2/r_3))$
A(3,X)	$A_3 = 1$	$Y_{step} = f/9.95 \times 10^{12}$
step	$B_3 = 0$	
discontinuity	$C_3 = Y_{step}$	
	$D_3 = 1$	
A(4,X)	$A_4 = \cosh \gamma_{air} L_o$	
air coax	$B_4 = (\sinh \gamma_{air} L_o)/y_o$	
	$C_4 = Y_o \sinh \gamma_{air} L_o$	
	$D_4 = \cosh \gamma_{air} Lo$	
A(5,X)	$A_5 = 1 - jbb/(Y_{stab} - jB_a)$	
coupling pad	$B_5 = (Y_{stab} - jB_a)^{-1/2}$	
	$C_5 = -jB_a = jB_b - B_a B_b/(Y_{stab} - jB_a)$	
	$D_5 = jB_a/(Y_{stab} - jB_a)$	
A(6,X)	$A_6 = \cosh \gamma_{airHC/2}$	
Top of	$B_6 = (\sinh \gamma_{airHC/2})/Y_o$	
cavity	$C_6 = Y_o \sinh \gamma_{air}{}^{HC}/2$	
	$D_6 = \cosh \gamma_{air}{}^{HC}/2$	

TABLE 4, continued

Array Element Section Name	ABCD Elements	Defining Equations
A(7,X)	$A_7 = \cosh \gamma_{air} L_F$	$L_F = (\lambda_{o/4} - H_{c/2})$
Cavity	$B_7 = (\sinh \gamma_{air} L_F)/Y_o$	
to BRF	$C_7 = Y_o \sinh \gamma air\ L_F$	
	$D_7 = \cosh \gamma_{air} L_F$	
A(8,X)	$A_8 = 1$	$Z_c = Z_{choke} \tanh \gamma 1_{choke}$
BRF	$B_8 = Z$	$1_{choke} = \lambda_o/4$
	$C_8 = 0$	$\alpha choke = 2 \times 10^{-6}$neper/mil
	$D_8 = 1$	$\beta choke = 2\pi/\lambda_o$ $Z_{choke} = 6$
A(9,X)	$A_9 = \cosh \gamma_{cav} L_c/2$	cav = cav + cav
Coupling Pad	$B_9 = (\sinh \gamma_{cav} L_c/2)\ Y_o'$	$Y_o' = \dfrac{Y_o \gamma_o 4 \pi r_2 2 \ln(r_2/r_1)}{(ab\ \lambda wg)}$
to Quartz Rod	$C_9 = Y_o' \sinh \gamma_{cav} L_c/2$	
	$D_9 = \cosh \gamma_{cav} L_c/2$	
A(10,X)	$A_{10} = 1$	
	$B_{10} = 0$	$Yq = Y_o' \dfrac{-2\,\Gamma_{in}}{1 + \Gamma_{in}}$
	$C_{10} = y_q$	
	$D_{10} = 1$	
A(11,X)	$A_{11} = \cosh \gamma_{cav} L_c/2$	
Quartz Rod	$B_{11} = (\cosh \gamma\ cav\ L_c/2)/Y_o'$	
to Iris	$C_{11} = Y_o' \cosh \gamma_{cav}\ L_c/2$	
	$D_{11} = \cosh \gamma_{cav} L_c/2$	
A(12,X)	$A_{12} = 1$	
Iris	$B_{12} = 0$	
	$C_{12} = jB_2$	
	$D_{12} = 1$	

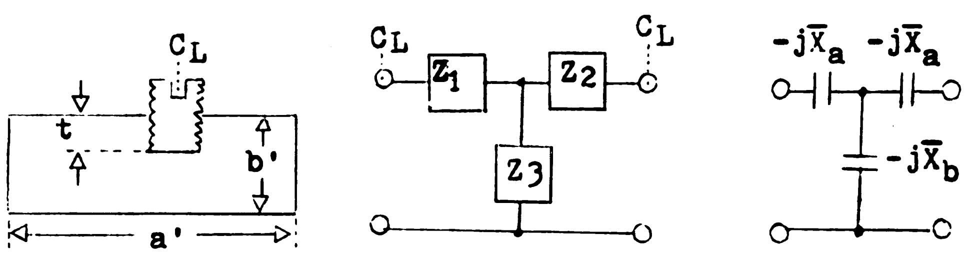
TABLE 4, continued

Array Element Section Name	ABCD Elements	Defining Equations
A(13,X)	$A_{13} = \cosh \gamma_{wg} LT_1$	
Iris	$B_{13} = (\sinh \gamma_{wg} LT_1)/Y_o''$	
to TS2	$C_{13} = Y_o'' \sinh \gamma_{wg} LT_1$	
	$D_{13} = \cosh \gamma_{wg} LT_1$	
A(14,X)	$A_{14} = 1 + Z_1/Z_3$	$Z_1 = Z_2 = -jX_a$
TS1	$B_{14} = (Z_1Z_2 + Z_2Z_3 + Z_1Z_3)/Z_3$	$Z_3 = -jX_b$
	$C_{14} = 1/Z_3$	$X_a = Z_o''\ (1.55\text{x}10^{-3} t_1'')$
	$D_{14} = 1 + Z_2/Z_3$	$X_b = Z_o''\ (3.9525/t_1'')$
A(15,X)	$A_{15} = \cosh \gamma_{wg} LT_2$	
TS1 to	$B_{15} = (\sinh \gamma_{wg} LT_2)/Y_o''$	
TS2	$C_{15} = Y_o'' \sinh \gamma_{wg} LT_2$	
	$D_{15} = \cosh \gamma_{wg} LT_2$	
A(16,X)	$A_{16} = 1 + Z_1/Z_3$	
TS2	$B_{16} = (Z_1Z_2 + Z_2Z_3 + Z_1Z_3)/Z_3$	
	$C_{16} = 1/Z_3$	
	$D_{16} = 1 + Z_2/Z_3$	
A(17,X)	$A_{17} = \cosh \gamma_{wg} LT_3$	
TS2 to	$B_{17} = (\sinh \gamma_{wg} LT_3)/Y_o''$	
Y_L	$C_{17} = Y_o'' \sinh \gamma_{wg} LT_3$	
	$D_{17} = \cosh \gamma_{wg} LT_3$	
A(18,X)	$A_{18} = \cosh \gamma_{air} L_S$	
BRF to	$B_{18} = \sinh \gamma_{air} L_S$	
Y_{stab}	$C_{18} = Y_o \sinh \gamma_{air} L_S$	
	$D_{18} = \cosh \gamma_{air} L_S$	



$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$$

Figure 4: ABCD Voltages and Currents

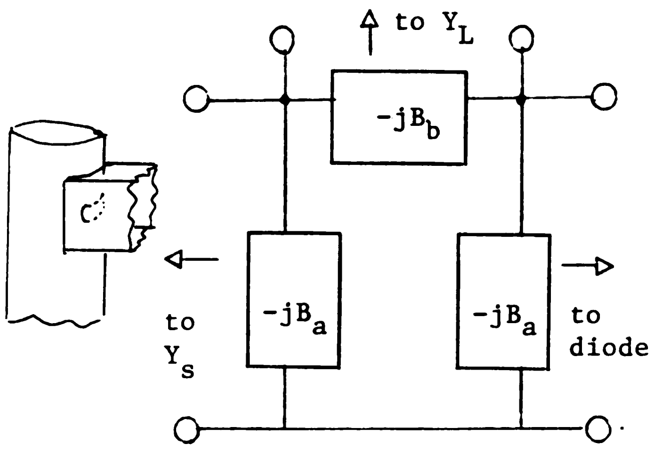


$A=1+Z_1/Z_2$ $B=(Z_1Z_2+Z_2Z_3+Z_1Z_3)/Z_3$ $C=1/Z_3$ $D=1+Z_2/Z_3$

$Z_1=-jX_a$ $Z_2=Z_1$ $Z_3=-jX_b$ $\overline{X}_a=Z_o'(1.55\times10^{-3}t)$

$\overline{X}_b=Z_o'(3.9525/t)$

Figure 5: Tuning Screw Model



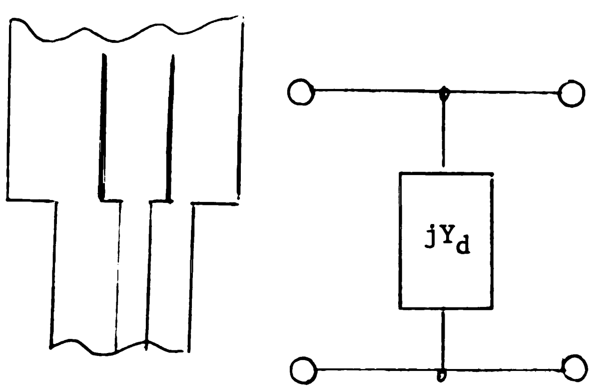
$$B_a = \frac{Y_o P}{2\lambda_o r_2^{\,2} \ln(r_2/r_1)}$$

$$B_b = \frac{Y_o \lambda_o r_2^{\,2} \ln(r_2/r_1)}{M}$$

$$P = d_1 d_2^{\,2} \pi/24$$

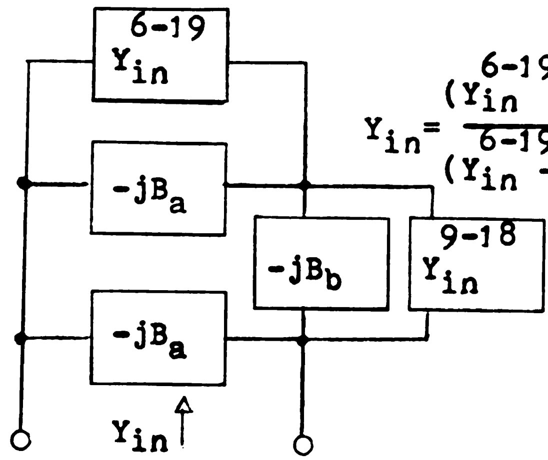
$$M = \left(\left(\frac{7.1}{9}\right)\left(\frac{d_2}{d_1}\right) \quad 0.2\right) d_1^{\,3}/6$$

Figure 6: Coupling Pad Model



$$Y_d = 10.05 f \times 10^{-14}$$

Figure 7: Step Capacitor Model



$$Y_{in} = \frac{(Y_{in}^{6-19} - jB_a)(Y_{in}^{9-18} - jB_a)}{(Y_{in}^{6-19} - jB_a + Y_{in}^{9-18} - jB_b)} - jB_a$$

Figure 8: Coupling Pad Inward Reduction Model

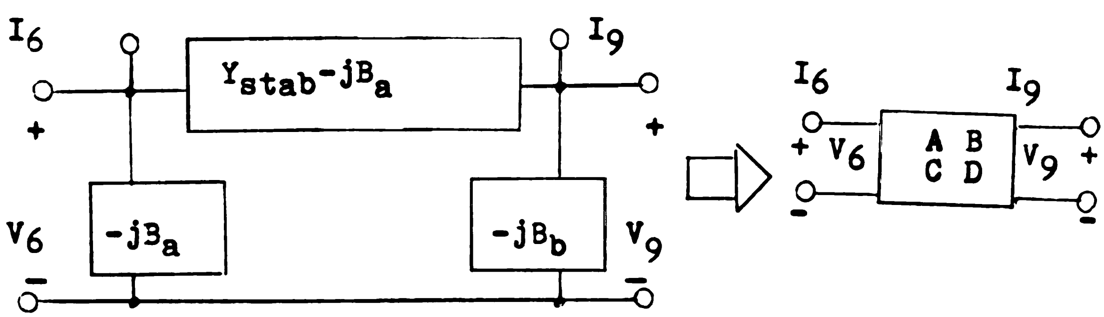


Figure 9: Coupling Pad Outward Reduction Model

APPENDIX 4

Quartz Rod Analysis

In order to obtain a model for a quartz rod in a rectangular waveguide (Fig. 10A), we will consider the quartz rod as a variable admittance. We need then to determine (Fig. 10B) Yq, where $Yq = Gq + jBq$ and Gq is greater than zero, but Bq could have either sign. From Fig. 10C we note that if we know Γ_{in}, and Y_o is the characteristic admittance of the waveguide, then

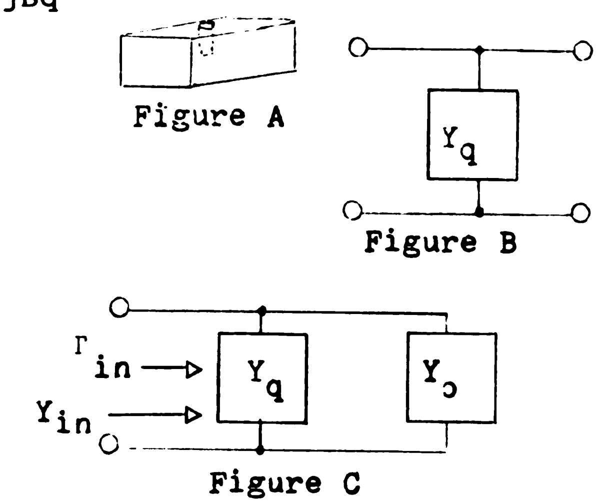


Figure 10: Quartz Rod Model

$$\overline{Y}_{in} = \frac{1 - \Gamma in}{1 + \Gamma in} \quad \text{and} \quad \overline{Y}_{in} = \overline{Y}q + 1 \quad \text{so} \quad \overline{Y}q + 1 = \frac{1 - \Gamma in}{1 + \Gamma in}$$

or $\overline{Y}q = \dfrac{1 - \Gamma in}{1 + \Gamma in} - 1 = \dfrac{-2\ \Gamma in}{1 + \Gamma in}$. By using $\Gamma\ in = \rho\angle\phi$

and $\Gamma\ in = \Gamma\ real + \Gamma\ imag.$ where $\Gamma real = \rho \cos \phi$

and $\Gamma\ imag. = \rho \sin \phi$ so $Yq = \dfrac{-2\ Yo\ (\rho \cos \phi + j \rho \sin \phi)}{1 + (\rho \cos \phi + j \rho \sin \phi)}$

This is the expression used in the program for Yq. The values for ρ and ϕ of the input reflection coefficient were obtained from experimental data taken at Bell labs by Dr. J. Freeman. The waveguide was terminated in its characteristic admittance and the input reflection coefficient was measured at 20 frequencies from 17.7 to 19.7 GHZ in 0.1 GHZ steps; this was done for 16 turns of the quartz rod, from zero to full penetration. These data values are stored in an array and the proper set of reflection coefficient values are chosen depending on the depth of quartz rod chosen by the user.

APPENDIX 5

Attenuation, Phase Factor and Impedence Equations

For the attentuation in the air dielectric co-axial line we use (Ref. 6) $\alpha_{air} = 2.7 \times 10^{-8} (f)^{1/2}(1+r_2/r_1)/(r_2 \ln(r_2/r_1)$ neper/mil. For $r_1 = 32$ mil. and $r_2 = 73.5$ mil., at 18.7 GHZ

$\alpha_{air} = 1.99 \times 10^{-4} \frac{\text{neper}}{\text{mil.}}$. For losses in the teflon transformer we must add the dielectric loss to the conductor loss. The dielectric loss is $\alpha_{die} = 3.145 \frac{(\varepsilon_r)^{1/2}}{(\text{mil.})} \tan\delta$ $\frac{\text{neper}}{\text{mil.}}$ where $\tan\delta$ is the loss tangent (Ref. 7). Experimentally $\tan\delta = 0.0028$ at 3 GHZ, and $\tan\delta = 0.0053$ at 25 GHZ, for our program we use $\tan\delta = 0.005$. Then

$\alpha_{die} = 1.57 \times 10^{-2} (\varepsilon_r)^{1/2}/\lambda \quad \frac{\text{neper}}{\text{mil.}}$. At 18.7 GHZ,

$\alpha_{die} = 3.57 \times 10^{-5}$ neper/mil., and the losses in the transformer are:

$\alpha_{tot} = \alpha_{air} + \alpha_{die} = 23.486 \times 10^{-5}$neper/mil. For losses in the cavity the unloaded quality factor is given by (Ref. 8) $Q_o = \frac{\omega_o L}{R} \simeq \frac{\pi \lambda_g^2}{2 \alpha L \lambda^2}$, and using 4550 as the value for Q_o and L = 450 mil. gives

$\alpha_{cav} = 1.76 \times 10^{-6}$ neper/mil.

The phase factor in the air-dielectric coax is given by $\beta_{air} = 2\pi/\lambda_o$. The phase factor in the waveguide is given by $\beta_c = 2\pi/\lambda_g$ where λ_g is the guide wavelength

$\lambda_g = \lambda_o / (1 - (\frac{\lambda_o}{2a})^2)^{1/2}$ and a is the guide width.

The phase factor in the teflon transformer is give by

$\beta_T = \frac{2\pi}{\lambda_T}$ where $\lambda_T = \lambda_o/(\varepsilon_r)^{1/2}$.

Method of Impedence Determination

In the coaxial line the absolute value of the admittance is known as $Y_o = (60\ln(r_2/r_1))^{-1}$. To find the admittance in the waveguide, we relate it to the admittance of the coax by (Ref. 3) $Y_o' = \frac{Y_o \lambda 4 \pi r_2^2 \ln(r_2/r_1)}{\lambda gab}$. This is consistent with the model used for the coupling pad. This can be written in the form $Y_o' = \frac{2 Y_o \lambda}{ab \lambda_g} (2 \pi r_2^2 \ln(\frac{r_2}{r_1}))$.

The classical expression (Ref. 8, Ref. 13) for the admittance of a waveguide is $Y_o'' = \frac{Y_o a \lambda}{2b \lambda_g}$. This is done by choosing the voltage equal to the line integral of the electric field. If two waveguides of different sizes are joined, the admittance will transfer as

$$\frac{Y_o''}{Y_o'} = \frac{Y_o a \lambda}{2b \lambda_g} \bigg/ \frac{Y_o a' \lambda}{2b' \lambda'_g} = \frac{ab' \lambda'_g}{a'b \lambda_g}.$$

However, by choosing the constant of proportionality equal to a/2 between the voltage and line integral of the electric field the admittance becomes $Y_o'' = \frac{2Y_o \lambda}{ab \lambda g}$ which is the form we use. The admittance between two waveguides then transfers as $\frac{Y_o''}{Y_o'} = \frac{2Y_o \lambda}{ab \lambda_g} \bigg/ \frac{2Y_o}{a'b' \lambda'_g} = \frac{a'b' \lambda'_g}{ab \lambda g}$ as in Ref. 16 and the program.

APPENDIX 6

Device-Circuit Angle

Under steady state oscillation, the IMPATT diode will have a current flowing through it that is a periodic function of time at the frequency of oscillation. Because of the high Q of the cavity, we assume its filtering action will keep the harmonic components of the current small. The current is then given by $i(t) = A \cos(\omega t + \phi) +$ (small harmonic components $\simeq 0$) where A is the amplitude and ϕ is the phase of the fundamental component. The corresponding device voltage $V_d(t)$ may have in-phase components given by $-R(A)A \cos(\omega t + \phi)$ and out-phase components give by $\overline{X}(A)A \sin(\omega t + \phi)$. In addition to the fundamental components, the device voltage may contain harmonic components which may not be small. The device voltage is

$V_d(t) = RE(-\overline{Z}(A)A\exp[j(\omega t + \phi)]),$ + (harmonic components)

where $\overline{Z}(A) = \overline{R}(A) - J\overline{X}(A)$ and $-\overline{Z}(A)$ is called the device impedence. Because we are tuning to the fundamental components of the current and assume small harmonics, the device impedence is a function of A only. The circuit impedence as seen by the diode is $Z(\omega) = R(\omega) + jX(\omega)$. The voltage developed across this impedence due to i(t) is

$V_c(t) = RE(Z(\omega)A\exp[j(\omega t + \phi)])$ + (harmonic components).

Depending on the magnitude of $R(n\omega)$ and $X(n\omega)$, the harmonic components of $V_c(t)$ may not be small. For free-running oscillators, the sum of $V_c(t)$ and $V_d(t)$ must equal to zero since no external voltage is applied: $V_c(t) + V_d(t) = 0$. Substituting for $V_c(t)$ and $V_d(t)$, multiplying by $\cos(\omega t + \phi)$ and $\sin(\omega t + \phi)$, and integrating over one r.f. cycle, we have $[R(\omega) - \overline{R}(A)]A = 0$ and $[X(\omega) + \overline{X}(A)]A = 0$ or, equivalently, $[Z(\omega) = \overline{Z}(A)]I = 0$ where $I = A\exp[j(\omega t + \phi)]$. This indicates the condition for steady state free oscillation: $Z(\omega) = \overline{Z}(A)$. By plotting $Z(\omega)$ and $\overline{Z}(A)$ on the same graph, a plot similar to Fig. 11A is obtained. The intersection of the $\overline{Z}(A)$ and $Z(\omega)$ locus give the amplitude and frequency of oscillation. The $\overline{Z}(A)$ locus is called the device line and the $Z(\omega)$ locus is called the impedence locus. If, for a given frequency, the value on the device line is known, then the required value of the impedence locus for oscillation at that frequency can be determined. This is basically how the program determines the bandwidth of the oscillator. By knowing (from measurements) the device line for a specific packaged IMPATT is at $0.95\angle -40°$ for oscillation at 18.7 GHZ, the program finds the points on the impedence locus which will allow oscillation. By allowing both A and ϕ to be slowing varying functions of time, it can be shown (Ref. 9) the condition for the intersection between the device line and impedence locus to represent a stable operating

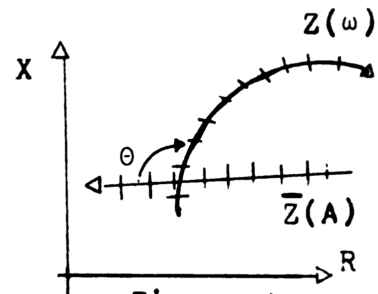


Figure A

Figure 11: Device Angle

point is $A_o \left|\frac{\partial Z(A_o)}{\partial A}\right| \left|\frac{\partial Z(\omega_o)}{\partial \omega}\right| \sin\theta > 0$ where θ is defined in Fig. A. In other words, the intersecting angle measured clockwise from the device line to the impedence locus must be less than 180° for stable operation. The program determines this angle as follows: A straight line is defined through the two points on the impedence locus closest to the desired point on the device line as shown in Fig. 11B. Using the angles in Fig. B, $\tan\psi = \frac{b(\omega_2) - b(\omega_1)}{g(\omega_2) - g(\omega_1)}$

since $\theta = \pi - \psi$ then $\psi = \pi - \theta$ and $\tan\psi = \tan(\pi-\theta)$

or $\tan\psi = -\tan\theta$ so $\theta = \tan^{-1}\left(\frac{b(\omega_2) - b(\omega_1)}{g(\omega_2) - g(\omega_1)}\right)$

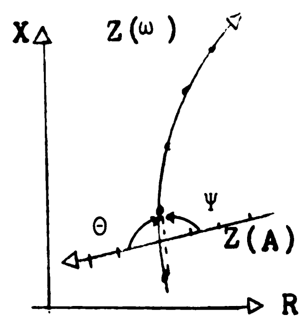


Figure B

Figure 11: Device Angle

It can also be shown (Ref. 10) that the power spectrum of the amplitude fluctuation is given by

$$|\delta A(t)|^2 = \frac{2\left|\frac{\partial Z(\omega_o)}{\partial \omega}\right|^2 |e(f)|^2}{\omega^2\left|\frac{\partial Z(\omega_o)}{\partial \omega}\right|^4 + \left(s\bar{R}(A_o)\frac{\partial X(\omega_o)}{\partial \omega} - r\bar{R}(A_o)\frac{\partial X(\omega_o)}{\partial \omega}\right)^2}$$

where s is the saturation factor of the negative resistance and is given by $s = \frac{-A}{\bar{R}(A_o)} \frac{\partial \bar{R}(A_o)}{\partial A}$ and r is the saturation factor of the device reactance and is given by

$$r = \frac{A_o}{\bar{R}(A_o)} \frac{\partial \bar{X}(A_o)}{\partial A}.$$

The power spectrum of the frequency fluctuation of the oscillator is

When the intersecting angle between the device line and the impedence locus becomes sharp, $s\bar{R}(A_0)\frac{\partial X(\omega_0)}{\partial \omega}-r\bar{R}(A_0)\frac{\partial R(\omega_0)}{\partial \omega}$ in the denominators of the power spectrum of the amplitude and frequency flucutations becomes small since it is proportional to the sine of the intersecting angle. Then, the low frequency components of both the amplitudue and frequency fluctuations become large. The oscillator becomes noisy as the intersecting angle approaches 0° or 180°. The desired angle then is 90°. The program finds the frequency where the device angle is closest to 90° to aid in attempts at noise reduction.

APPENDIX 7

VARIABLE EFFECTS

TABLE 5

Variables That Parameter has Dominant Effect On (Mean Value)

Affected Circuit Variable (in percent)

Parameter	Eff	P	Y_{inr}	Y_{ini}	MR	AR	RS	Q_L	Q_o	Q_{ex}	Range (in inches)
Lx		1.6									.17-.1716
LTR										5	
LO	3										.01-0.116
LF										6	.1-.14
Z_c		3									.01-4.01
LT1									.8		.11-.126
LT2										6.0	.15-.19
QRod									359		0-4
L_s											.204-.2808
L_c											.18-.212
TS1	52										.05-.25
TS2										12	.001-.04
a		3									.41-.418
b									7		.174-.178
r_1		14.4									.036-.0392
r_2							2.5				.0695-0731
r_3							15.39				.0335-.0351
r_4	18										.054-.078
d_1			12								.2-.28
d_2							.7				.155-.159
iris	11.43										.149-.158
εr			2.3								1.44-1.456

TABLE 6

Variable That Parameter Effects by at Least 0.1% (Mean Value)

Parameter	Eff	P	Y_{inr}	Y_{ini}	MR	AR	RS	Q_L	Q_o	Q_{ex}
Lx		x	x	x			x	x		x
LTR					x			x	x	x
LO		x	x	x						x
LF	x	x			x	x	x	x	x	x
Z_c	x	x	x			x				
LT1	x	x								x
LT2								x	x	x
QRod	x	x	x	x	x	x	x	x	x	x
L_s										
L_c										
TS1	x	x								
TS2								x	x	x
a			x			x	x			
b	x	x	x	x			x	x	x	x
r_1	x	x	x	x				x	x	
r_2			x			x	x			x
r_3				x	x	x	x	x	x	x
r_4		x	x							
d_1			x	x	x					
d_2					x			x		
iris(d_3)	x	x				x				
εr				x	x		x	x	x	x

TABLE 7

Variable That Parameter Effects by at Least 0.1% (Standard Deviation)

Parameter	Eff	P	Y_{inr}	Y_{ini}	MR	AR	RS	Q_L	Q_o	Q_{ex}
Lx		x	x				x	x	x	x
LTR								x	x	x
LO		x	x	x	x	x	x			
LF	x	x	x	x		x	x	x	x	
Z_c		x	x	x	x	x	x	x	x	
LT_1	x	x	x	x	x	x	x		x	
LT_2			x	x	x	x	x	x	x	x
QRod	x	x	x	x	x	x	x	x	x	x
L_S										
L_c										
TS1	x	x								
TS2			x	x	x	x	x	x	x	
a				x			x			
b	x	x	x	x	x	x	x	x	x	x
r_1	x	x	x	x	x	x	x	x	x	
r_2										
r_3								x	x	x
r_4		x	x	x	x	x	x			
d_1			x		x					
d_2										
iris(d_3)	x	x								
εr		x					x	x	x	x

TABLE 8

Variable That Parameter Has Dominant Effect On (Standard Deviation)

Parameter	Eff P	Y_{inr}	Y_{ini}	MR	AR	RS	Q_L	Q_o	Q_{ex}
Lx	2.02								
LTR							.4		
LO	5								
LF	6								
Z_c		3.1							
LT1								.99	
LT2									6
QRod								565	
L_s									
L_c									
TS1	32								
TS2									10
a						9			
b						11			
r_1			14.6						
r_2									
r_3									4.7
r_4					97				
d_1							357		
d_2									
iris	6.9								
εr		.638							.77

Appendix 8

PROGRAM DESCRIPTION

Line #	
1	Specify input and output devices
2-12	Dimension arrays
12-14	Specify complex variables
15-17	Define functions used in Program - cosh, sinh and U (reduction function)
18-165	Fill RHOL and PHIL with all quartz rod magnitude and angle values
166-167	Fill D array with default values
168-169	Fill S array with default values
170-171	Fill ISTAT with character variables to print with statistical values
172-173	Fill MEXT with blanks - if losses, Q Rod, BRF, TS1, TS2 are removed later, array is changed
174	Fill ISTAY with values to print with best statistical values
175-183	Fill IDASH array with characters to separate statistical values
189	Fill IEXT with run identification number
191-195	Initiatlize NA, IW, W arrays (W is no longer used elsewhere in program)
196-230	Choose variables to run and order by setting values of NA ARRAY; 999 terminals run
231-242	Choose waits, plots, writes, and losses, Q Rod, BRF, TS1, TS2
243	Initialize loop counter (one loop per variable)
244	Top of loop for each new parameter; kv = current parameter #
245	Set default value of choke impedence
246-250	Remove losses, BRF, TS1, TS2, add in Q Rod
251-252	Check if done
253-255	Find desired parameter and go initialize it
256-728	These lines contain the identification and range variables for each parameter. The ones used for every parameter are: CV = current value of parameter; VI = variable increment; IBCE = name of variable to print; IC = length of variable name (up to 16); IBCD = variable name with equal sign for plotting with dashed lines IL = length of IBCD (up to 16) LN = number of times to increment CV (can have any value up to 10 since is decremented and checked to zero) CVS = starting value of parameter (for printing) CVF = default stop value (for printing) IN = number of decimal places to print on plots

Line #

FV = value to reset parameter to after all done
LK, NR = copies of loop number (LN)

In addition, LC, LF, ZC Set IBPF to 1 (to flag band stop filler in use)
TS1, LT1 sets ITSA to 1 flag tuning screw 1 being used
TS2, LT2 sets ITSB to 1 flag tuning screw 2 being used
AA, AD, AC, AW sets ITEN to 1

Q Rod turn 19 - turn 0 (no zero array index)

729-732	Set losses, tuning screws and band stop filter flags if required for all parameters (i.e., IW = 1) or flag set during initialization (i.e., ITEN = 1)
733	Save copy of CVF
734	Set values of attenuation for air, dielectric, cavity, waveguide
737-738	Set constant Pi
739	Top of frequency loop for each increment of a parameter
740-714	Reset loop frequency counter (LF) and starting frequency (F)
742	Top of loop for each frequency increment
743-745	Jump to set value of parameter being varied
746-814	Depending on which parameter is being varied, one variable is set equal to CV each increment of CV. Lines 807 and 808 are example of how the Q Rod (for example) can have non-sequential (random) steps and be removed on last increment.
815	Store frequencies run in printing array
816-819	Calculate circuit values that have size or frequency dependence
820-827	Find Q Rod turn desired (= JJ). Fill RHO and PHI with magnitude and angle values for that turn from RHOL and PHIL; convert PHI to radians
828-830	Calculate waveguide wavelengths
831-836	Calculate attentuation used with each of the 6 different phase factors
837-845	If no losses desired, reset attenuation array to zero
846-851	Calculate the 6 different phase factors
852-869	Calculate characteristic admittance for each of the 18 ABCD matrices
870-899	Calculate the 7 admittances that shunt transmission line sections. Lines 890-893 checks that we don't set Y_L, Y_{stab}, Y_o" or Y_o if they are being varied.
900-922	Calculate gamma (+j) for each of the 18 ABCD matrices
923-928	Pretend all ABCD's are transmission lines and initialize them

Line #	
929-977	Properly initialize ABCD matrices of shunt elements and tuning screws, etc., and remove BPF, Q Rod, and TS1, TS2 if not desired
978-993	Calculations of input admittance, done in three sections: Y_L to coupling pad, Y_{stab} to coupling pad, coupling pad to diode. Y_L (Y(18)) must be initialized (line 978). Indexes J and K are reversed because we are counting down. Lines 987 and 988 are coupling pad reduction.
994-995	Find input current from diode
996-1016	Find volatage and current at each plane. Lines 1005-1010 are coupling pad outward reduction.
1017-1020	Normalize input admittance.
1021-1029	Find reflection coefficient at each plane and convert to polar. Check real part of rectangular reflection coefficient to avoid dividing by zero. If zero, set angle = 999.99.
1030-1038	All calculations for this frequency interval are done. Writes are now performed of variables that will change with frequency. As with all writes in this program, a check of the flag array IW is performed to determine if the write is desired or not.
1039-1042	Increment loop count and frequency value and check if done.
1043-1055	All calculations for this increment of this parameter are done. Writes (if desired) are now performed for the variables over the entire frequency range.
1056-1075	Now calculate load power and efficiency and input reflection coefficient for each value of frequency (these all have 20 values - one for each frequency)
1076-1086	Calculate Q_L, RSA, Q_E, Q_o - these have 19 values since they depend on frequency differences.
1087-1090	Increment variables and loop if more increments desired.
1091-1105	Take 1st values of arrays for plotting.
1106-1132	Write rest of data for parameter.
1133-1163	Initialize arrays and variables for statistical analysis. Values set to 1000 are beyond possible values (so find smallest).
1064-1245	20 point variables statistical analysis.
1165	Set up for mean.
1166	Set up for standard deviation (temporary storage).
1167-1174	Find # pts. larger and smaller than reference and their average value.
1175-1180	Value closest to .95 (mag. rfl. coeff.)
1181-1186	Value closest to -40 (angle rfl. coeff.)
1187-1191	Device window magnitude.

Line #	
1192-1196	Device window angle.
1197-1207	Largest and smallest value over parameter range.
1208	Find SD
1209	Find mean.
1210	# greater.
1211	# less.
1212	Check to avoid division by zero.
1312	+ average
1214	Jump to avoid resetting.
1215-1216	If zero divisor set + average to zero.
1216-1218	Locate largest and smallest.
1219-1220	Bandwidth
1221	Carry over
1222	Avoid zero divisor
1223	Average
1224-1226	Set to zero if divisor = 0
1227-1233	Device angle
1234	Largest value
1235-1240	Change zero to reference #.
1241	Frequency of largest
1242	Value of smallest
1243	Frequency of smallest
1246-1321	19 point statistical values using same format and variables as 20 point analysis described above.
1322-1329	Initialize for finding best values of statistical variables - VAKP = Varaible values; PKEP = best %; AKEP = best value; IKEP = increment # of best value.
1330	Count from 1 not 0.
1333-1336	Initialize variables beyond range.
1338-1340	Skip for reflection coefficient.
1341-1142	Find largest statistical value.
1343	Save largest as reference.
1344-1349	Largest valid data.
1350-1358	Find value furthest (less) from reference (not largest of small)
1359-1365	Find smallest S.D.
1366-1376	Smallest average value of # of points less than reference (skip if reference)
1377-1385	Translate numbers if reference is best value.
1386-1391	Get rid of non valid numbers.
1392-1452	Find best statistical values for 19 point arrays, same format and variables as described above for 20 point arrays.
1453-1465	Write circuit configuration if desired.
1466-1593	Statistical writes (if desired).
1494-2073	These are the plotting routines. All follow the same format so only one is described in detail.
1594-1595	Check of plot desired.
1596	Set buffer size
1597	Set plot limit

Line #

1598	Set new origin
1599-1602	Write titles
1603-1606	Draw lines under titles
1607-1626	Write no losses, etc., depending on circuit configuration. If one title is missing, others will automatically move up.
1627-1629	Write run # if desired.
1630-1643	Write variable name with equal sign, value of variable and draw dashed line to that curve (twice).
1644-1655	Draws circle, plots angle values and marks. Other routines draw axis after PLIMIT routine and call scale to scale plot values to fit on graph.
1656-1670	Plotting routines that plot multiple curves on same graph.
1594-1670	Reflection coefficient plot.
1671-1737	Y real vs. Freq.
1738-1804	Y mag vs. Freq.
1805-1871	Real pwr vs. freq.
1872-1938	Eff vs. freq.
1939-2006	Q_L vs. freq.
2007-2073	SS vs. freq.
2074-2076	Find variable just run.
2077-2141	Reset variable (any special run specific conditions (losses) etc. can be reset now)
2142-2144	Increment counter check if done, if not, loop.

Table 9

Parameter Values

F .1770000E+11 CV = .1500000E-01 HT = -.7383338E-02 .2515219E-02

B

0.	.1778894E-02	0.	-.5266711E-01	.1397777E-03	-.4801253E-04
0.	-.1089756E+00	0.	-.1771370E+02	0.	-.3733053E+04
0.	-.8051683E+01	0.	-.8212717E+04	.9625317E-02	0.
.2335031E-01	0.	0.	-.3801342E-02	0.	-.3273010E-01

YE

.3720833E-01	.5375447E-01	.5375447E-01
.2335031E-01	.2335031E-01	.2335031E-01
.2335031E-01	.2335031E-01	.9404045E-02
.9404045E-02	.9404045E-02	.9404045E-02
.9625317E-02	.9625317E-02	.9625317E-02
.9625317E-02	.9625317E-02	.2335031E-01

BE

.9416000E+01	.1360612E+02	.9416000E+01
.5719346E+01	.5719346E+01	.5719346E+01

ABCD MATRIX

.99004E+00	0.	0.	.37841E+01	0.	.52367E-02	.99004E+00	0.
-.21118E-01	0.	0.	.18599E+02	0.	.53742E-01	-.21118E-01	0.
.10000E+01	0.	0.	0.	0.	.17789E-02	.10000E+01	0.
.99464E+00	0.	0.	.44278E+01	0.	.24142E-02	.99464E+00	0.
.68281E+00	0.	0.	.31288E+02	0.	.17060E-01	.68281E+00	0.
.68281E+00	0.	0.	.31288E+02	0.	.17060E-01	.68281E+00	0.
.58850E+00	0.	0.	.34625E+02	0.	.18879E-01	.58850E+00	0.
.10000E+01	0.	0.	0.	0.	0.	.10000E+01	0.
.28014E+00	0.	0.	.10208E+03	0.	.90275E-02	.28014E+00	0.
.10000E+01	0.	0.	0.	.13978E-03	-.48013E-04	.10000E+01	0.
.28014E+00	0.	0.	.10208E+03	0.	.90275E-02	.28014E+00	0.
.10000E+01	0.	0.	0.	0.	-.10898E+00	.10000E+01	0.
.77358E+00	0.	0.	.65836E+02	0.	.60995E-02	.77358E+00	0.
.10000E+01	0.	0.	0.	0.	0.	.10000E+01	0.
.41408E+00	0.	0.	.94568E+02	0.	.87614E-02	.41408E+00	0.
.10000E+01	0.	0.	0.	0.	0.	.10000E+01	0.
-.14450E+00	0.	0.	.10280E+03	0.	.95243E-02	-.14450E+00	0.
-.34296E+00	0.	0.	.40229E+02	0.	.21934E-01	-.34296E+00	0.

A9
p2

TABLE 10

VARIABLE VALUES

LP 3 CV .1500000E-01

	Y		YN		V		C
51911E-02	.10482E-01	.96571E-01	.19500E+00	-.22820E+01	-.52152E+00	-.63797E-02	-.26628E-01
.47100E-02	.11493E-01	.87620E-01	.21380E+00	-.21683E+01	-.42028E+00	-.53824E-02	-.26898F-01
.41856E-02	.12776E-01	.77864E-01	.23767E+00	-.20424E+01	-.32680E+00	-.43736E-02	-.27461E-01
.35843E-02	.14497E-01	.66679E-01	.26968E+00	-.19000E+01	-.23930E+00	-.33411E-02	-.28401E-01
.29780E-02	.16914E-01	.55400E-01	.31464E+00	-.17359E+01	-.16425E+00	-.23889E-02	-.29835E-01
.25529E-02	.20613E-01	.47492E-01	.38347E+00	-.15370E+01	-.10978E+00	-.16609E-02	-.31963E-01
.32536E-02	.26607E-01	.60527E-01	.49497E+00	-.13005E+01	-.99971E-01	-.15715E-02	-.34928E-01
.89608E-02	.36516E-01	.16670E+00	.67931E+00	-.10218E+01	-.17332E+00	-.28271E-02	-.38865E-01
.29880E-01	.41399E-01	.55586E+00	.77014E+00	-.75659E+00	-.38773E+00	-.65555E-02	-.42907E-01
.43888E-01	.19049E-01	.81646E+00	.35438E+00	-.62605E+00	-.75161E+00	-.13158E-01	-.44913E-01
.34627E-01	.46110E-02	.64417E+00	.85780E-01	-.74250E+00	-.11315E+01	-.20493E-01	-.42606E-01
.26617E-01	.16440E-02	.49517E+00	.30583E-01	-.10197E+01	-.13329E+01	-.24950E-01	-.37154E-01
.21850E-01	.15995E-02	.40647E+00	.29756E-01	-.12903E+01	-.13469E+01	-.26037E-01	-.31494E-01
.18935E-01	.21805E-02	.35225E+00	.40563E-01	-.14776E+01	-.12644E+01	-.25222E-01	-.27164E-01
.17020E-01	.28245E-02	.31663E+00	.52545E-01	-.15889E+01	-.11561E+01	-.23779E-01	-.24165E-01
.15677E-01	.34452E-02	.29163E+00	.64091E-01	-.16486E+01	-.10489E+01	-.22231E-01	-.22123E-01
.14683E-01	.40091E-02	.27315E+00	.74582E-01	-.16761E+01	-.95260E+00	-.20791E-01	-.20707E-01
.13923E-01	.45148E-02	.25900E+00	.83989E-01	-.16837E+01	-.86898E+00	-.19519E-01	-.19700E-01
.13324E-01	.49657E-02	.24787E+00	.92377E-01	-.16793E+01	-.79718E+00	-.18417E-01	-.18961E-01
.12834E-01	.53846E-02	.23876E+00	.10017E+00	-.16674E+01	-.73451E+00	-.17445E-01	-.18405E-01

RCM	RCA
.8298227E+00	.1577366E+03
.8454214E+00	.1556910E+03
.8627548E+00	.1531127E+03
.8829892E+00	.1496949E+03
.9040424E+00	.1449763E+03
.9205038E+00	.1379636E+03
.9073269E+00	.1271973E+03
.7963427E+00	.1106029E+03
.5121023E+00	.9363669E+02
.2156410E+00	.1063414E+03
.2223133E+00	.1634597E+03
.3381919E+00	.1753615E+03
.4224344E+00	.1759180E+03
.4797371E+00	.1746985E+03
.5201444E+00	.1733178E+03
.5499921E+00	.1719894E+03
.5729190E+00	.1707888E+03
.5910126E+00	.1697168E+03
.6056015E+00	.1687642E+03
.6178009E+00	.1678805E+03

TABLE 10 (cont'd.)

LN 1

EA	CMAG	CANG	LOAD POWER
.3086205E-01	.8763068E+00	-.3764268E+02	.3504740E-03
.4566669E-01	.8872321E+00	-.3995275E+02	.4234267E-03
.7076493E-01	.8993325E+00	-.4266260E+02	.5176853E-03
.1189100E+00	.9134576E+00	-.4600874E+02	.6476384E-03
.2167261E+00	.9280412E+00	-.5035684E+02	.8260250E-03
.4149172E+00	.9388565E+00	-.5651988E+02	.1081934E-02
.5892012E+00	.9251050E+00	-.6581960E+02	.1439143E-02
.4436097E+00	.8193370E+00	-.8032439E+02	.1942877E-02
.2481592E+00	.5258034E+00	-.9286765E+02	.2512772E-02
.1440860E+00	.2920794E+00	-.6644713E+02	.2577612E-02
.9093712E-01	.3779237E+00	-.3668904E+02	.2701339E-02
.6262050E-01	.4856615E+00	-.3270469E+02	.2126544E-02
.4566815E-01	.5568877E+00	-.3377948E+02	.1524578E-02
.3490792E-01	.6033960E+00	-.3569456E+02	.1075234E-02
.2776845E-01	.6352879E+00	-.3762406E+02	.7754367E-03
.2273145E-01	.6582823E+00	-.3947860E+02	.5743799E-03
.1905191E-01	.6755632E+00	-.4122705E+02	.4376207E-03
.1629899E-01	.6889098E+00	-.4287717E+02	.3426103E-03
.1420858E-01	.6994353E+00	-.4443945E+02	.2752542E-03
.1253927E-01	.7080306E+00	-.4595285E+02	.2250647E-03

TABLE 10 (cont'd.)

LN 1

YC		PC	
.2271229E-01	-.1047491E+00	.7009479E-03	-.1264830E-14
.1854423E-01	-.9929000E-01	.8468535E-03	-.1743397E-15
.1463113E-01	-.9327433E-01	.1035371E-02	-.5308254E-15
.1089292E-01	-.8645950E-01	.1295277E-02	-.8656270E-15
.7622755E-02	-.7852689E-01	.1652050E-02	.7251144E-15
.5215181E-02	-.6889842E-01	.2163868E-02	-.4857226E-16
.4885064E-02	-.5718773E-01	.2878285E-02	.1387779E-16
.8759399E-02	-.4304894E-01	.3885754E-02	-.5759282E-15
.2025129E-01	-.2939712E-01	.5025544E-02	-.1491862E-14
.3994297E-01	-.2338411E-01	.5755223E-02	.3191891E-15
.5941115E-01	-.3130045E-01	.5402679E-02	-.1637579E-14
.6791845E-01	-.4664712E-01	.4253088E-02	.4579670E-15
.6676764E-01	-.5993297E-01	.3049155E-02	.1190020E-14
.6160401E-01	-.6821150E-01	.2150468E-02	-.1249001E-15
.5585021E-01	-.7263581E-01	.1550873E-02	-.3894454E-15
.5053614E-01	-.7465036E-01	.1148760E-02	.5273559E-15
.4593983E-01	-.7525047E-01	.8752414E-03	.3122502E-15
.4204067E-01	-.7501567E-01	.6852206E-03	-.9020562E-16
.3874479E-01	-.7429206E-01	.5505084E-03	.1136244E-15
.3589757E-01	-.7326605E-01	.4501295E-03	.9662410E-15

LN 2

QL	RSA
.2219315E+02	.5688957E-01
.3004112E+02	.6271586E-01
.4323256E+02	.7100694E-01
.6771947E+02	.8253381E-01
.1175954E+03	.9990019E-01
.2091703E+03	.1209804E+00
.2697825E+03	.1452816E+00
.1461029E+03	.1400413E+00
.2916607E+02	.6416972E-01
-.1734232E+02	-.7501506E-01
-.2377185E+02	-.1535861E+00
-.1840291E+02	-.1370628E+00
-.1187230E+02	-.8757346E-01
-.7011450E+01	-.4794827E-01
-.3647047E+01	-.2267255E-01
-.1352684E+01	-.7619624E-02
.2661314E+00	.1363569E-02
.1424127E+01	.6678198E-02
.2310288E+01	.9982649E-02

TABLE 11

Statistical Values

NO LOSSES   NO BRF   NO TS1   NO TS2

LC = .1000 $ IN .1400 TO .1800 $ 09/23/82 $ RUN1,SET1

DEV ANG = -20.37 $ F NEAR .95 = .1780E+11 $ F NEAR-40 = .1780E+11 $ .95BW = 0.

-40 3W = 4.000 $ VARIABLE INCR 5 $

FREQ	EFFICIENCY	LOAD POWER		INPUT ADMITANCE		MAG RFL	ANG RFL
.1770E+11	.8252E-01	.1726E-02	-.4857E-15	.2092E-01	-.1155	.3845	-33.73
.1780E+11	.1252	.2047E-02	-.5492E-15	.1634E-01	-.1035	.3867	-37.37
.1790E+11	.1672	.2415E-02	-.2984E-15	.1444E-01	-.8822E-01	.3335	-43.57
.1800E+11	.1749	.2810E-02	-.7286E-15	.1687E-01	-.7336E-01	.8448	-50.66
.1810E+11	.1431	.3178E-02	0.	.2221E-01	-.5924E-01	.7321	-57.70
.1820E+11	.1040	.3433E-02	-.1422E-14	.3302E-01	-.4886E-01	.5722	-58.81
.1830E+11	.7444E-01	.3482E-02	.5794E-15	.4670E-01	-.4233E-01	.4693	-48.74
.1840E+11	.5432E-01	.3287E-02	.3408E-15	.6051E-01	-.4335E-01	.4681	-36.40
.1850E+11	.4107E-01	.2910E-02	-.2220E-15	.7086E-01	-.4875E-01	.5096	-29.98
.1860E+11	.3187E-01	.2443E-02	-.8119E-15	.7667E-01	-.5633E-01	.5536	-27.72
.1870E+11	.2545E-01	.1993E-02	-.4441E-15	.7830E-01	-.6495E-01	.5890	-27.38
.1880E+11	.2077E-01	.1602E-02	-.3816E-15	.7713E-01	-.7166E-01	.6164	-27.95
.1890E+11	.1730E-01	.1286E-02	-.2637E-15	.7435E-01	-.7663E-01	.6373	-28.70
.1900E+11	.1474E-01	.1046E-02	-.1441E-14	.7094E-01	-.7995E-01	.6530	-29.67
.1910E+11	.1275E-01	.8586E-03	.4536E-15	.6737E-01	-.8205E-01	.6651	-30.70
.1920E+11	.1117E-01	.7136E-03	.1587E-15	.6389E-01	-.8322E-01	.6746	-31.74
.1930E+11	.9948E-02	.6034E-03	-.5846E-15	.6070E-01	-.8367E-01	.6818	-32.75
.1940E+11	.8951E-02	.5176E-03	-.6453E-15	.5783E-01	-.8364E-01	.6873	-33.73
.1950E+11	.8152E-02	.4507E-03	.2307E-15	.5529E-01	-.8326E-01	.6913	-34.66
.1960E+11	.7518E-02	.3994E-03	.2882E-15	.5313E-01	-.8266E-01	.6948	-35.52
MEAN	.5677E-01	.1860E-02	-.3156E-15	.5184E-01	-.7348E-01	.6722	-36.30
STD DEV	.5670E-01	.1088E-02	.5584E-15	.2286E-01	.1939E-01	.1333	9.792
+ PTS	0.	0.	0.	0.	0.	0.	0.
+ AV	0.	0.	0.	0.	0.	0.	0.
- PTS	20.00	20.00	20.00	20.00	20.00	20.00	20.00
LARGEST	.1749	.3482E-02	.5794E-15	.7830E-01	-.4233E-01	.9067	-27.38
F LARGE	.1800E+11	.1130E+11	.1830E+11	.1870E+11	.1830E+11	.1780E+11	.1870E+11
SMALL	.7518E-02	.3994E-03	-.1441E-14	.1444E-01	-.1155	.4681	-58.81
F SMALL	.1960E+11	.1960E+11	.1980E+11	.1790E+11	.1770E+11	.1840E+11	.1820E+11
- AV	0.	0.	0.	0.	0.	0.	0.

FREQ	YIN SLOPE	QL	QO	QE
.1770E+11	.1301	58.15	63.30	764.7
.1790E+11	.1438	61.00	93.52	653.2
.1730E+11	.1407	96.26	115.6	575.6
.1800E+11	.1411	82.11	99.51	469.6

A9
p6

TABLE 11 (cont'd.)

.1810E+11	.1118	47.06	54.92	320.9
.1820E+11	.5732E-01	16.23	18.12	156.1
.1830E+11	-.7140E-02	-1.427	-1.542	-19.17
.1840E+11	-.5704E-01	-8.814	-9.321	-162.3
.1850E+11	-.8176E-01	-10.79	-11.25	-262.7
.1860E+11	-.8020E-01	-9.781	-10.10	-306.9
.1870E+11	-.6715E-01	-8.018	-8.227	-315.0
.1880E+11	-.4969E-01	-6.023	-6.151	-290.0
.1890E+11	-.3322E-01	-4.177	-4.251	-241.5
.1900E+11	-.2099E-01	-2.766	-2.807	-187.7
.1910E+11	-.1169E-01	-1.622	-1.643	-127.3
.1920E+11	-.4473E-02	-.6546	-.6620	-58.60
.1930E+11	.2747E-03	.4232E-01	.4274E-01	4.257
.1940E+11	.3798E-02	.6141	.6196	65.60
.1950E+11	.5974E-02	1.010	1.018	123.9
MEAN	.1730E-01	17.33	20.57	58.63
STD DEV	.7981E-01	35.96	42.02	337.4
+ PTS	0.	0.	0.	0.
+ AV	0.	0.	0.	0.
- PTS	19.00	19.00	19.00	10.00
LARGEST	.1487	96.26	115.6	784.7
F LARGE	.1790E+11	.1790E+11	.1790E+11	.1770E+11
SMALL	-.8176E-01	-10.79	-11.25	-315.0
F SMALL	.1850E+11	.1850E+11	.1850E+11	.1870E+11
- AV	0.	0.	0.	0.

TABLE 12

Best Statistical Values

NO LOSSES NO BRF NO TS1 NO TS2 RUN1,SET1

LC VARYING FROM .1400 TO .1800 03/23/82 BEST VALUE ORDER-PERCENT,INCR,VAR VALUE,BEST VALUE RN= .1400

		EFFICIENCY	LOAD PWR	V IN	MRFL	ARFL	RS	QL	QO	QE
MEAN	>	0.	0.	0.	0.	0.	0.	0.	0.	0.
		IMAG	0.	0.						
	I	5	5	5	5	5	5	5	5	5
		IMAG	5	5						
	V	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000
		IMAG	.1000	.1000						
	$	.5677E-01	.1060E-02	.5184E-01	.6722	-36.90	.1730E-01	17.33	20.57	50.63
		IMAG	-.3156E-15	-.7348E-01						
STD DEV	>	0.	0.	0.	0.	0.	0.	0.	0.	0.
		IMAG	0.	0.						
	I	5	5	5	5	5	5	5	5	5
		IMAG	5	5						
	V	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000
		IMAG	.1000	.1000						
	$	.5678E-01	.1000E-02	.2286E-01	.1333	9.792	.7981E-01	35.96	42.02	337.4
		IMAG	.5584E-15	.1939E-01						
+ PTS	>	0.	0.	0.	0.	0.	0.	0.	0.	0.
		IMAG	0.	0.						
	I	5	5	5	5	5	5	5	5	5
		IMAG	5	5						
	V	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000
		IMAG	.1000	.1000						
	$	0.	0.	0.	0.	0.	0.	0.	0.	0.
		IMAG	0.	0.						
+ AV	>	0.	0.	0.	0.	0.	0.	0.	0.	0.
		IMAG	0.	0.						
	I	5	5	5	5	5	5	5	5	5
		IMAG	5	5						
	V	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000
		IMAG	.1000	.1000						
	$	0.	0.	0.	0.	0.	0.	0.	0.	0.
		IMAG	0.	0.						
- PTS	>	0.	0.	0.	0.	0.	0.	0.	0.	0.
		IMAG	0.	0.						
	I	5	5	5	5	5	5	5	5	5
		IMAG	5	5						
	V	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000
		IMAG	.1000	.1000						
	$	20.00	20.00	20.00	20.00	20.00	19.00	19.00	13.00	19.00
		IMAG	20.00	20.00						
LARGEST	P	0.	0.	0.	0.	0.	0.	0.	0.	0.
		IMAG	0.	0.						
	I	5	5	5	5	5	5	5	5	5
		IMAG	5	5						
	V	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000
		IMAG	.1000	.1000						
	$	.1749	.3452E-02	.7930E-01	.9067	-27.30	.1407	96.26	115.6	784.7
		IMAG	.5794E-15	-.4233E-01						
- SMALL	>	0.	0.	0.	0.	0.	0.	0.	0.	0.
		IMAG	0.	0.						
	I	5	5	5	5	5	5	5	5	5
		IMAG	5	5						
	V	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000
		IMAG	.1000	.1000						
	$	20.00	20.00	20.00	20.00	20.00	19.00	19.00	13.00	19.00
		IMAG	20.00	20.00						
SMALL	>	0.	0.	0.	0.	0.	0.	0.	0.	0.
		IMAG	0.	0.						
	I	5	5	5	5	5	5	5	5	5
		IMAG	5	5						
	V	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000
		IMAG	.1000	.1000						
	$	.7510E-02	.3994E-03	.1444E-01	.4601	-50.01	-.8176E-01	-10.79	-11.25	-315.0
		IMAG	-.1441E-14	-.1155						
- SD	>	0.	0.	0.	0.	0.	0.	0.	0.	0.
		IMAG	0.	0.						
	I	5	5	5	5	5	5	5	5	5
		IMAG	5	5						
	V	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000
		IMAG	.1000	.1000						
	$	.5678E-01	.1000E-02	.2286E-01	.1333	9.792	.7981E-01	35.96	42.02	337.4
		IMAG	.5584E-15	.1939E-01						
- AV	>	0.	0.	0.	0.	0.	0.	0.	0.	0.
		IMAG	0.	0.						
	I	5	5	5	5	5	5	5	5	5
		IMAG	5	5						
	V	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000
		IMAG	.1000	.1000						
	$	0.	0.	0.	0.	0.	0.	0.	0.	0.
		IMAG	0.	0.						

APPENDIX 10

PLOTS

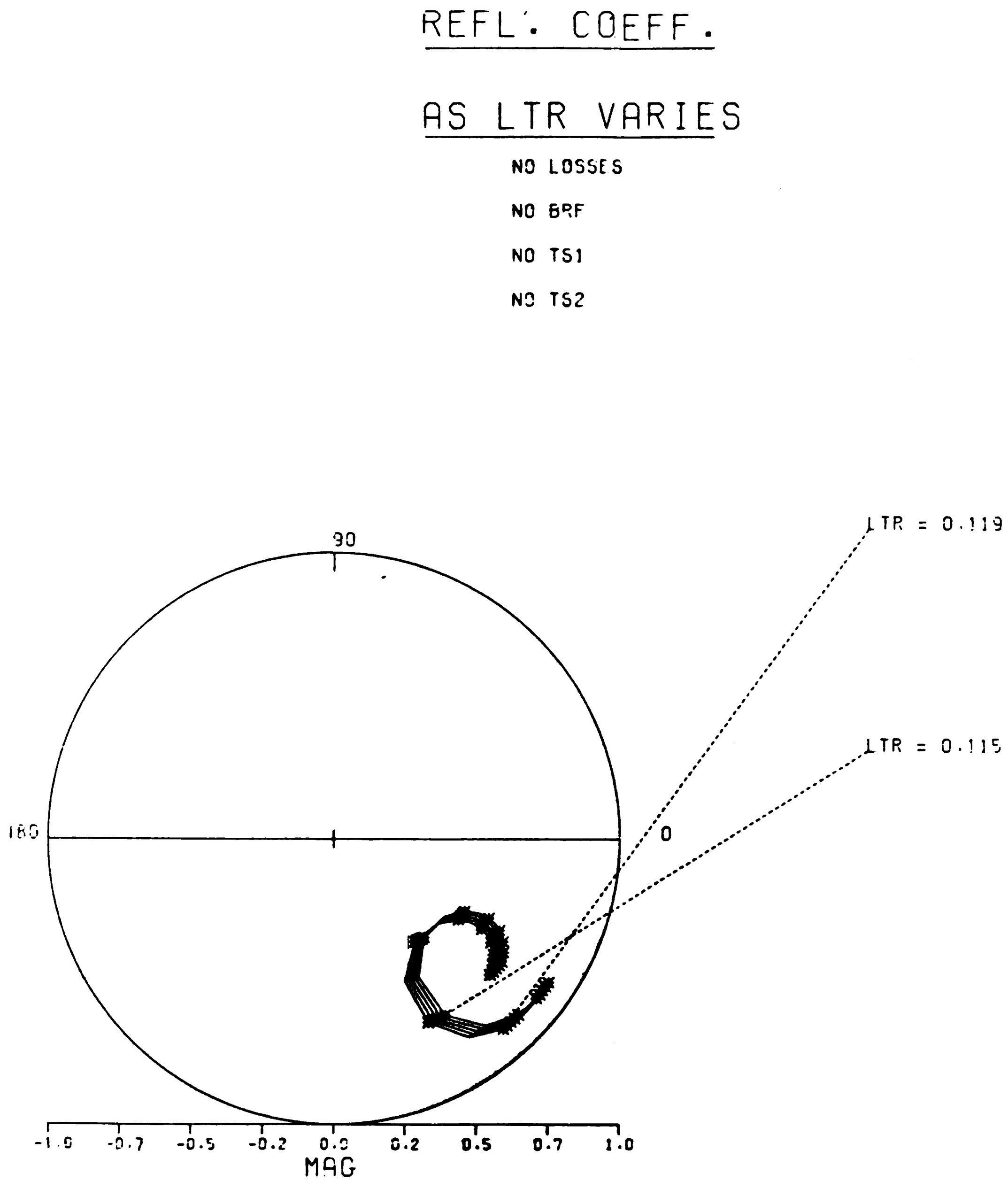


Figure 12: Reflection Coefficient as LTR Varies

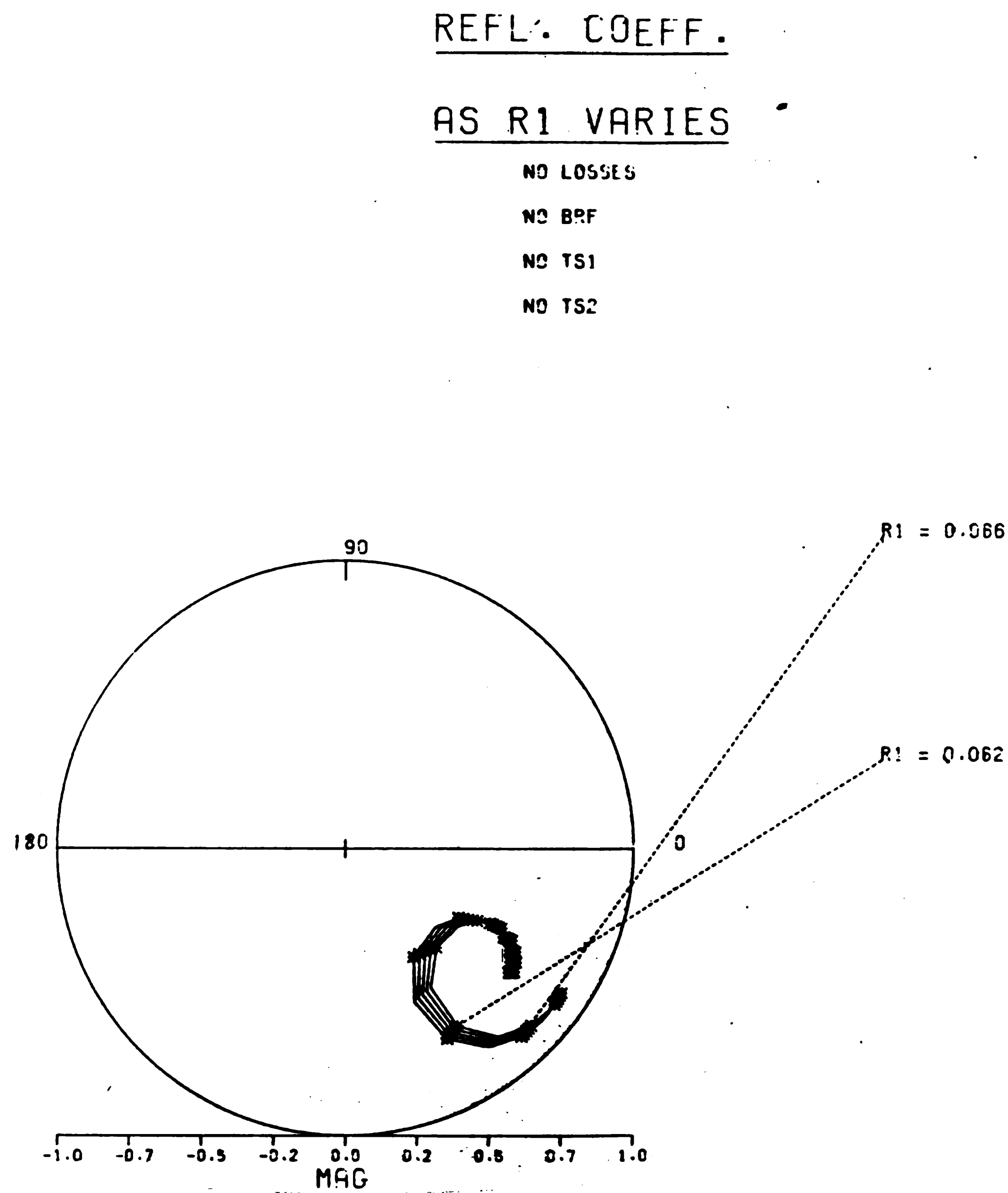


Figure 13: Reflection Coefficient as r_1 Varies

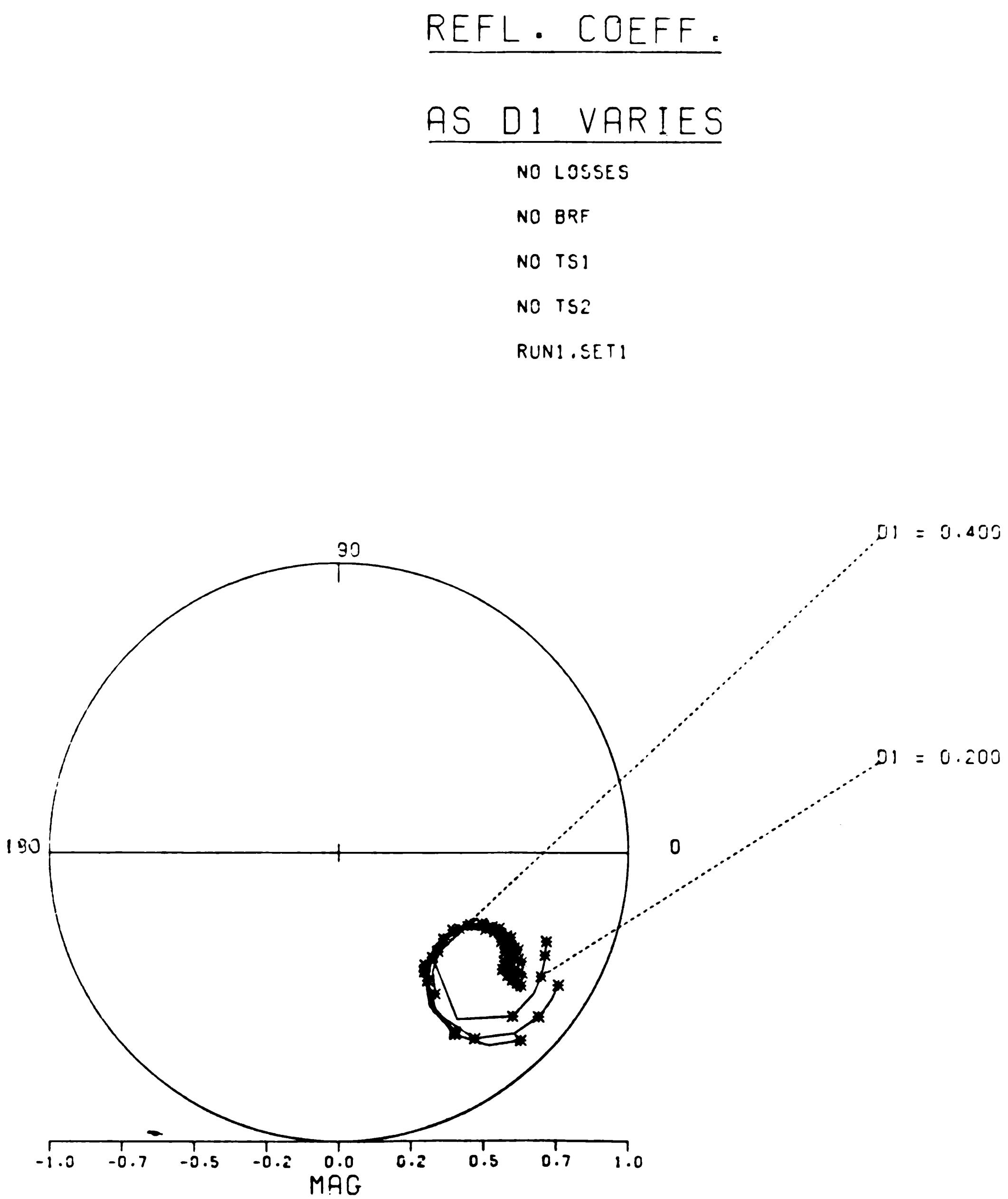


Figure 14: Reflection Coefficient as d_1 Varies

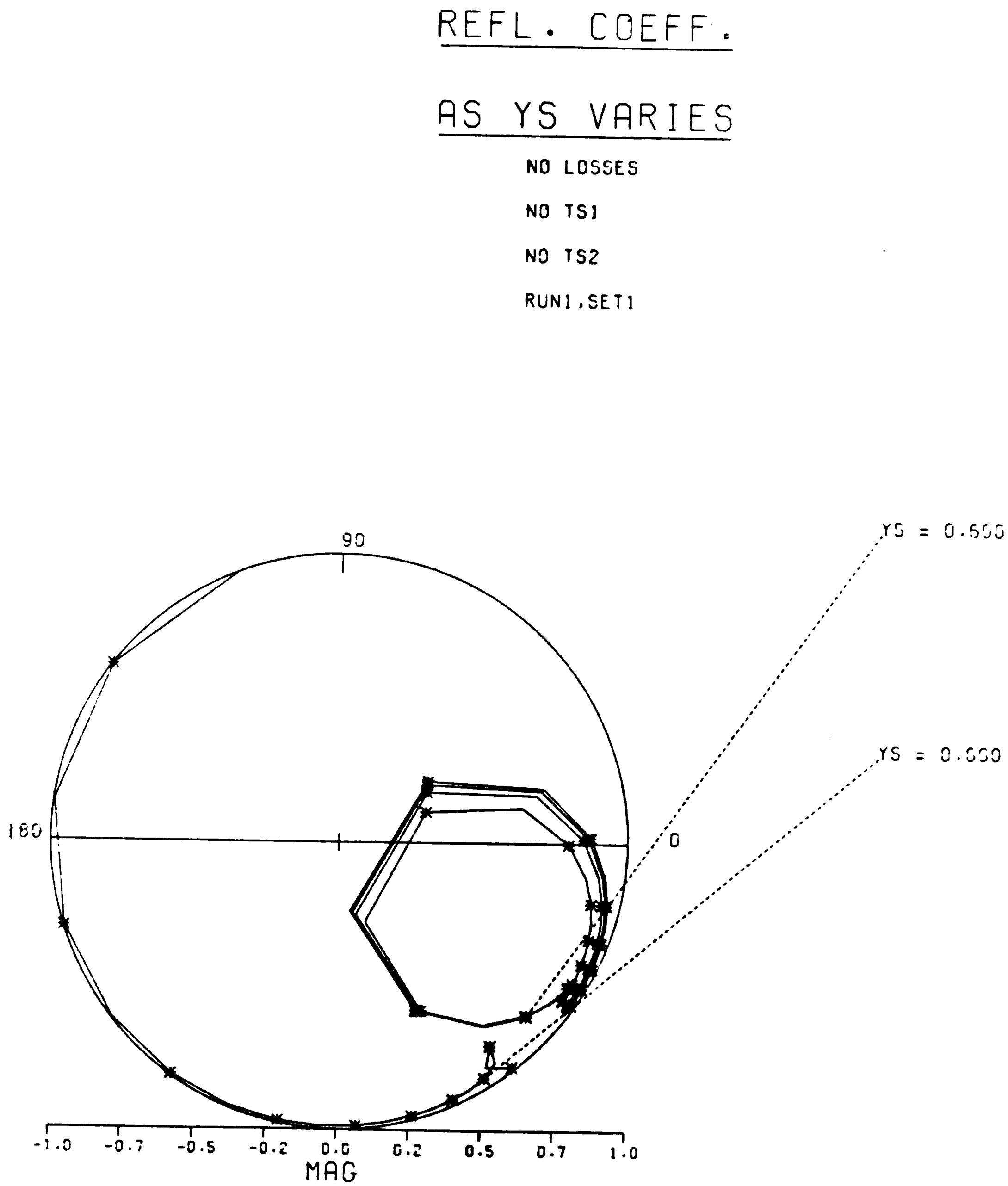


Figure 15: Reflection Coefficient as Y_s Varies

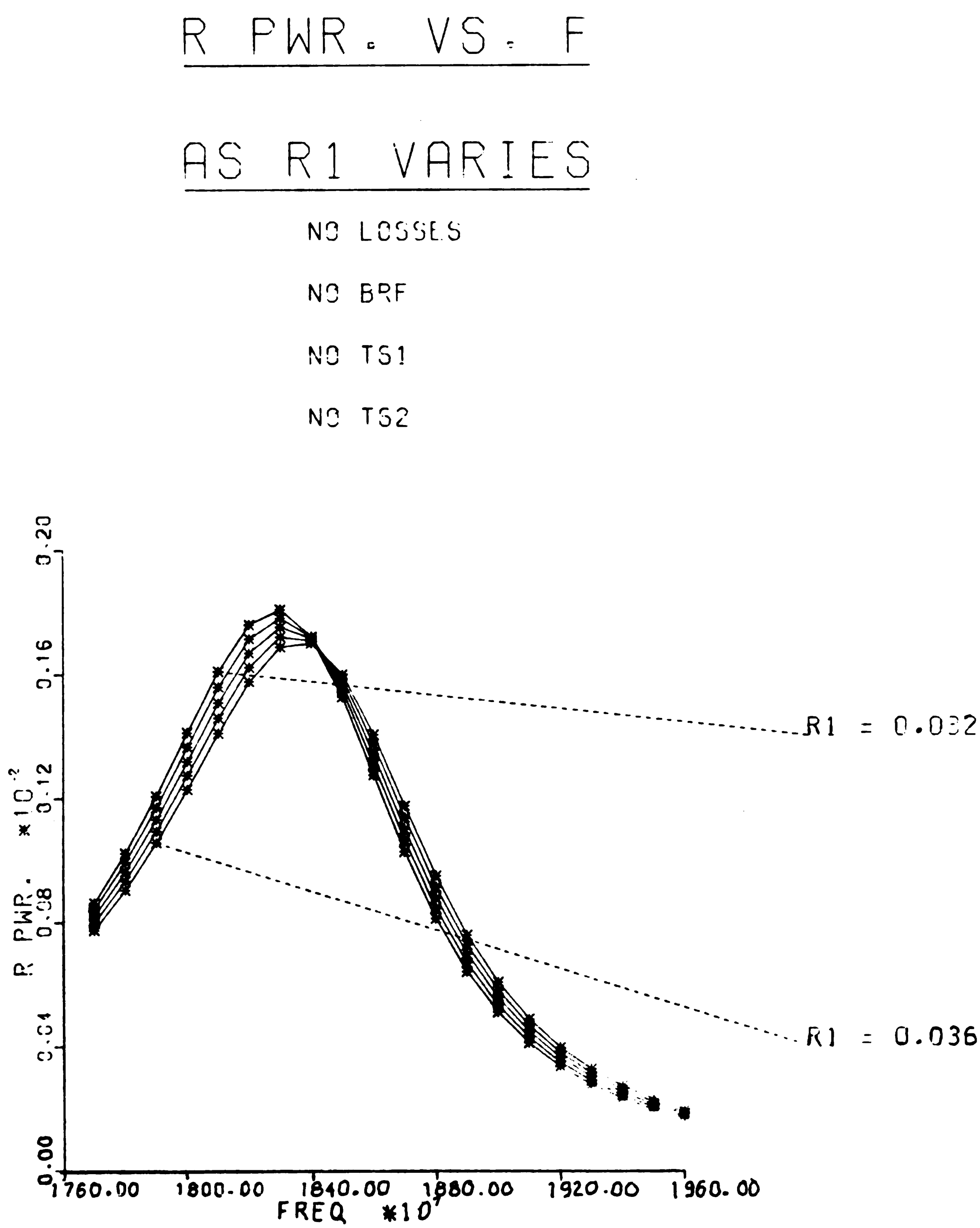


Figure 16: Real Power as r_1 Varies

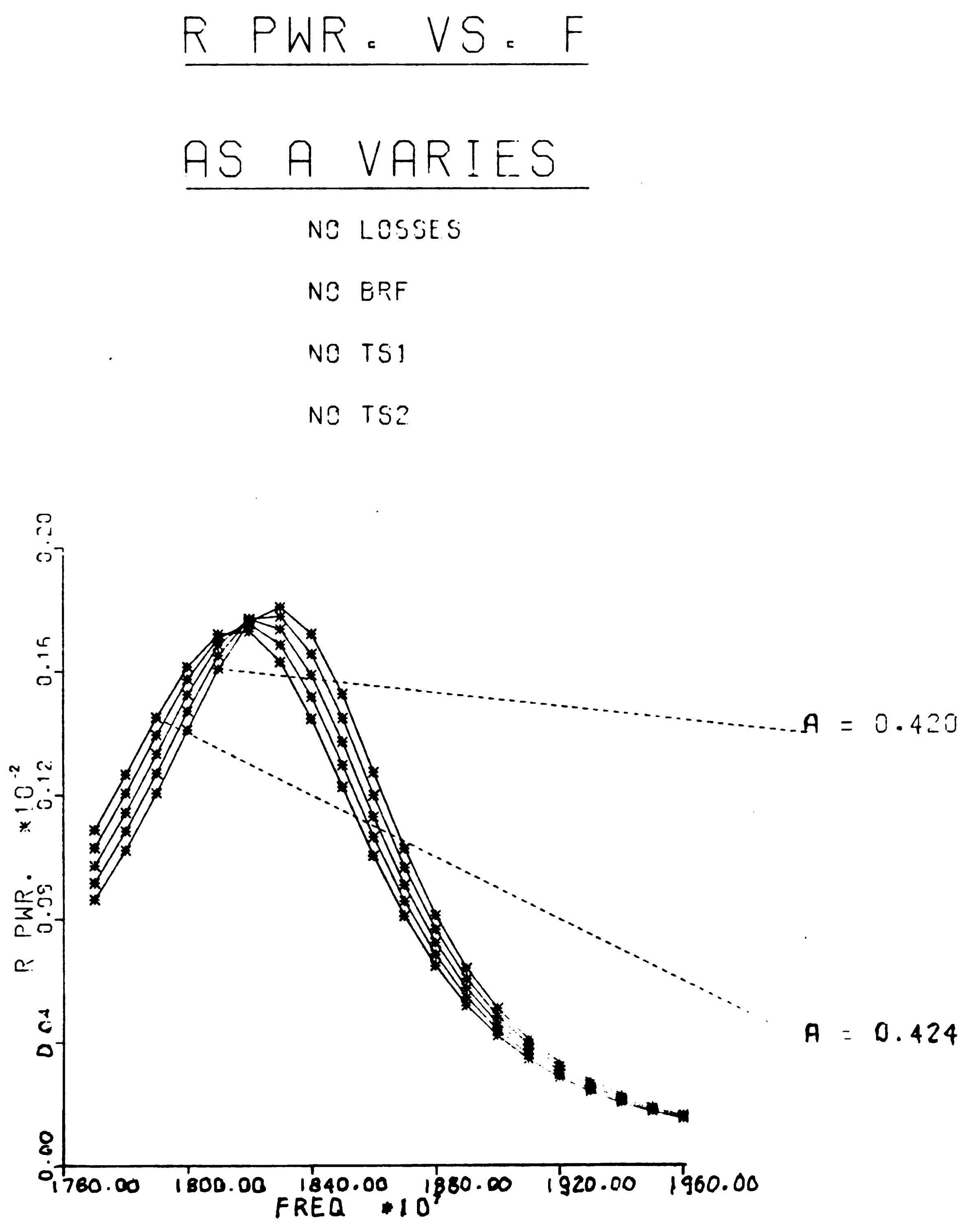


Figure 17: Real Power as a Varies

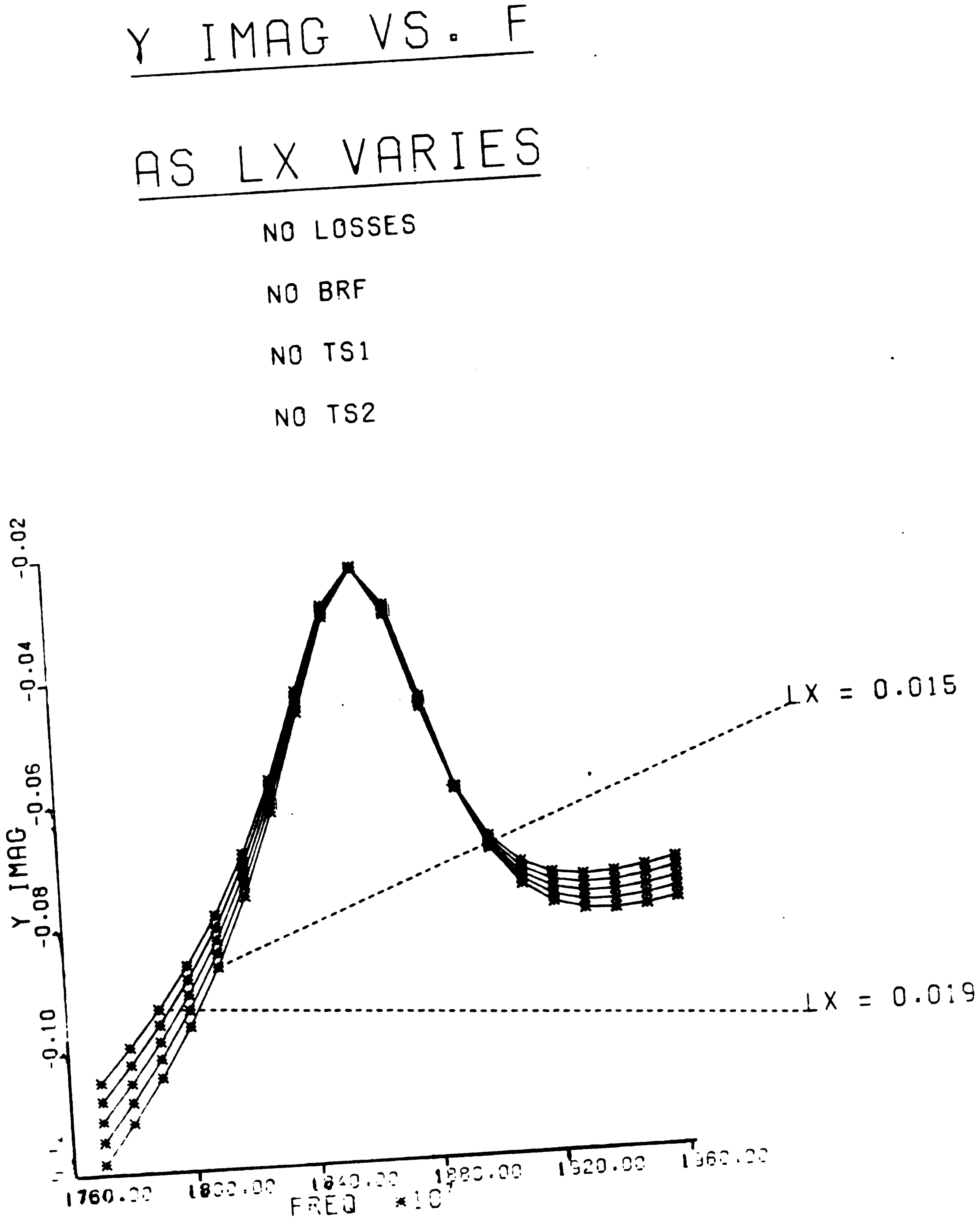


Figure 18: Y Imag. as L_X Varies

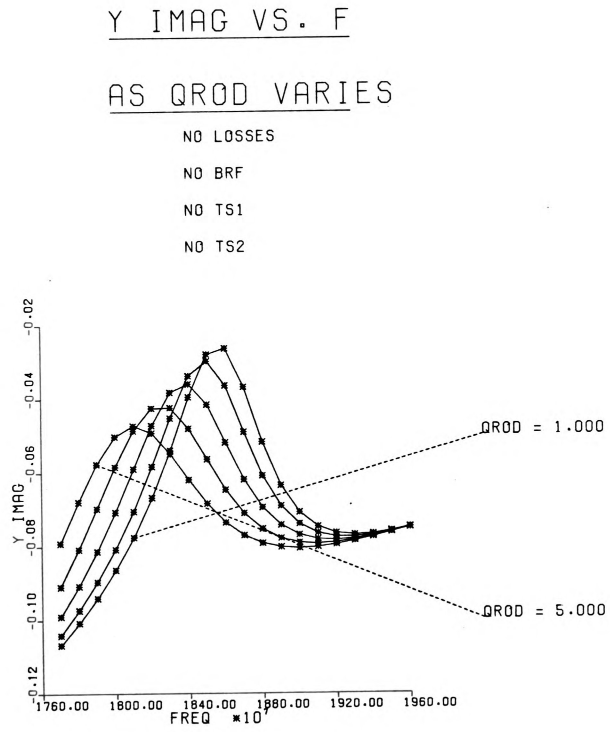


Figure 19: Y Imag. as Q Rod Varies

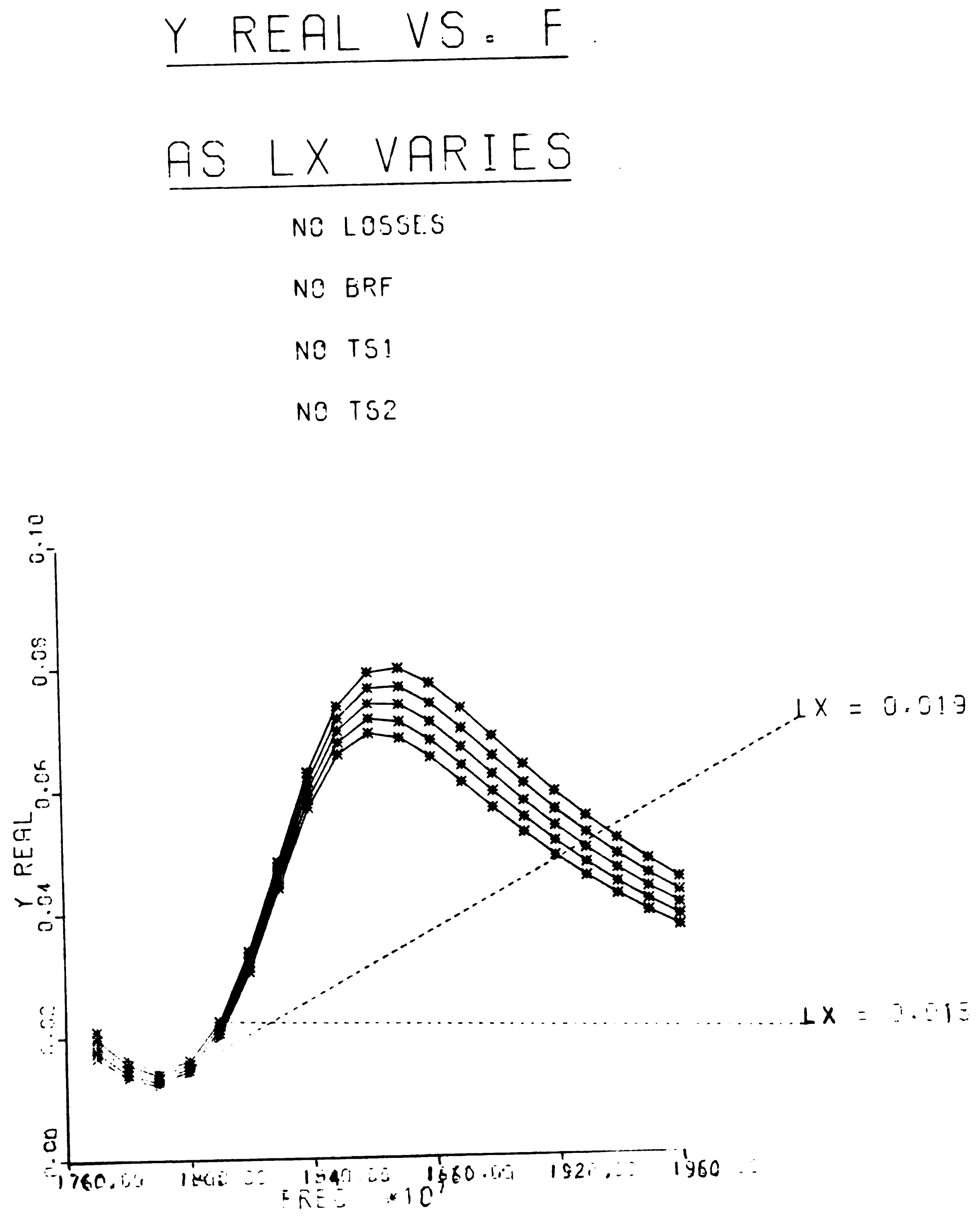


Figure 20: Y Real as L_x Varies

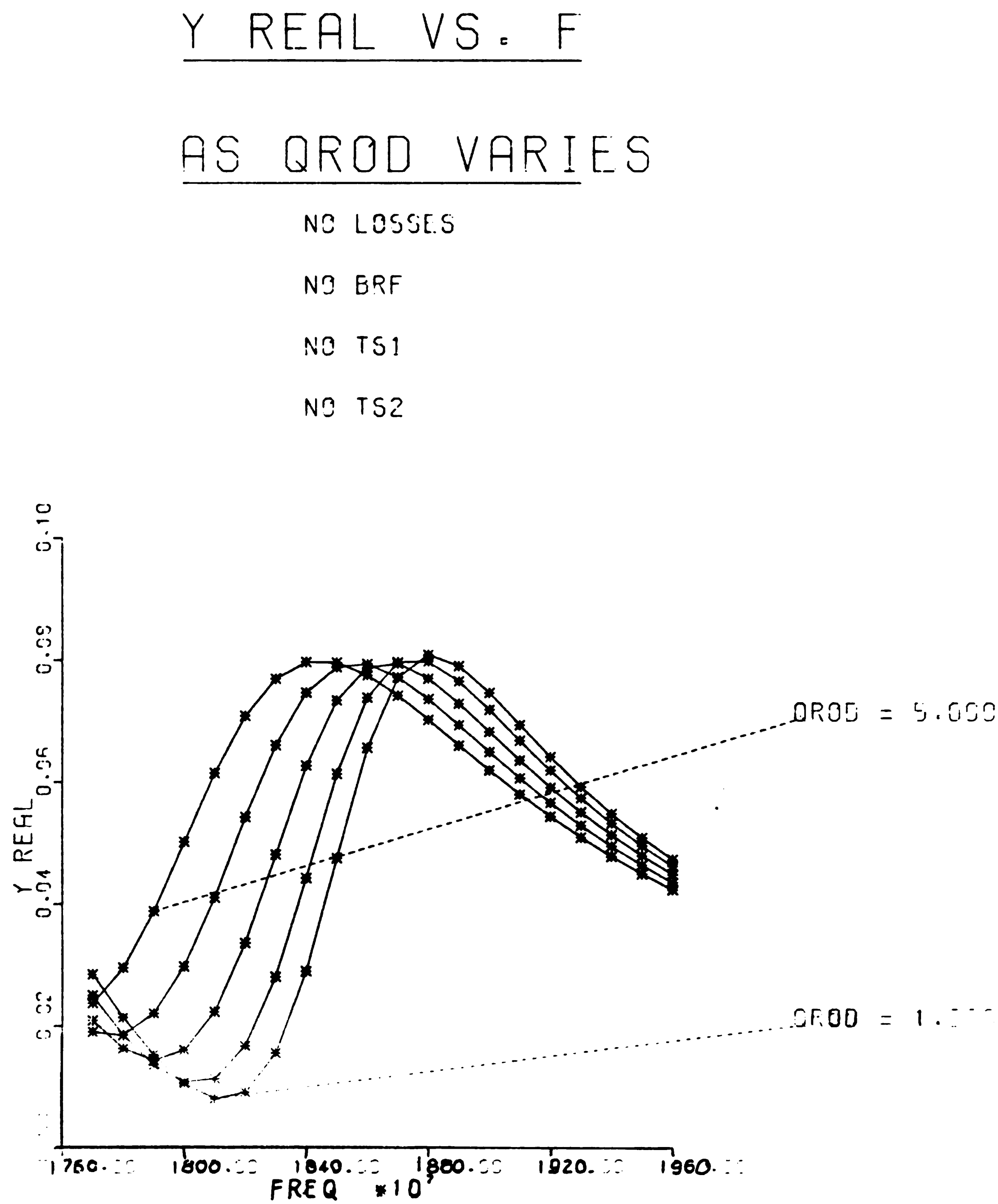


Figure 21: Y Real as Q Rod Varies

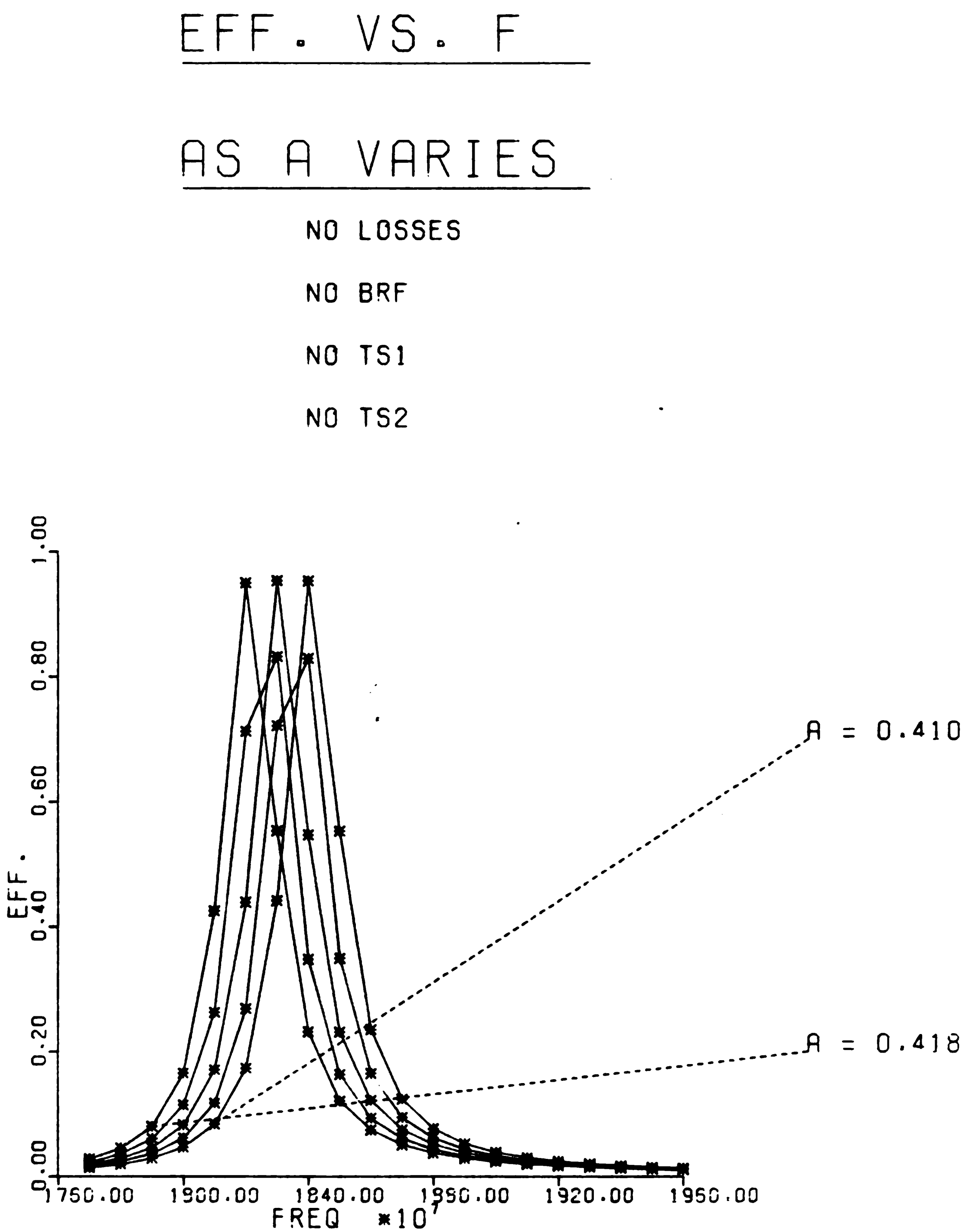


Figure 22: Eff. as a Varies

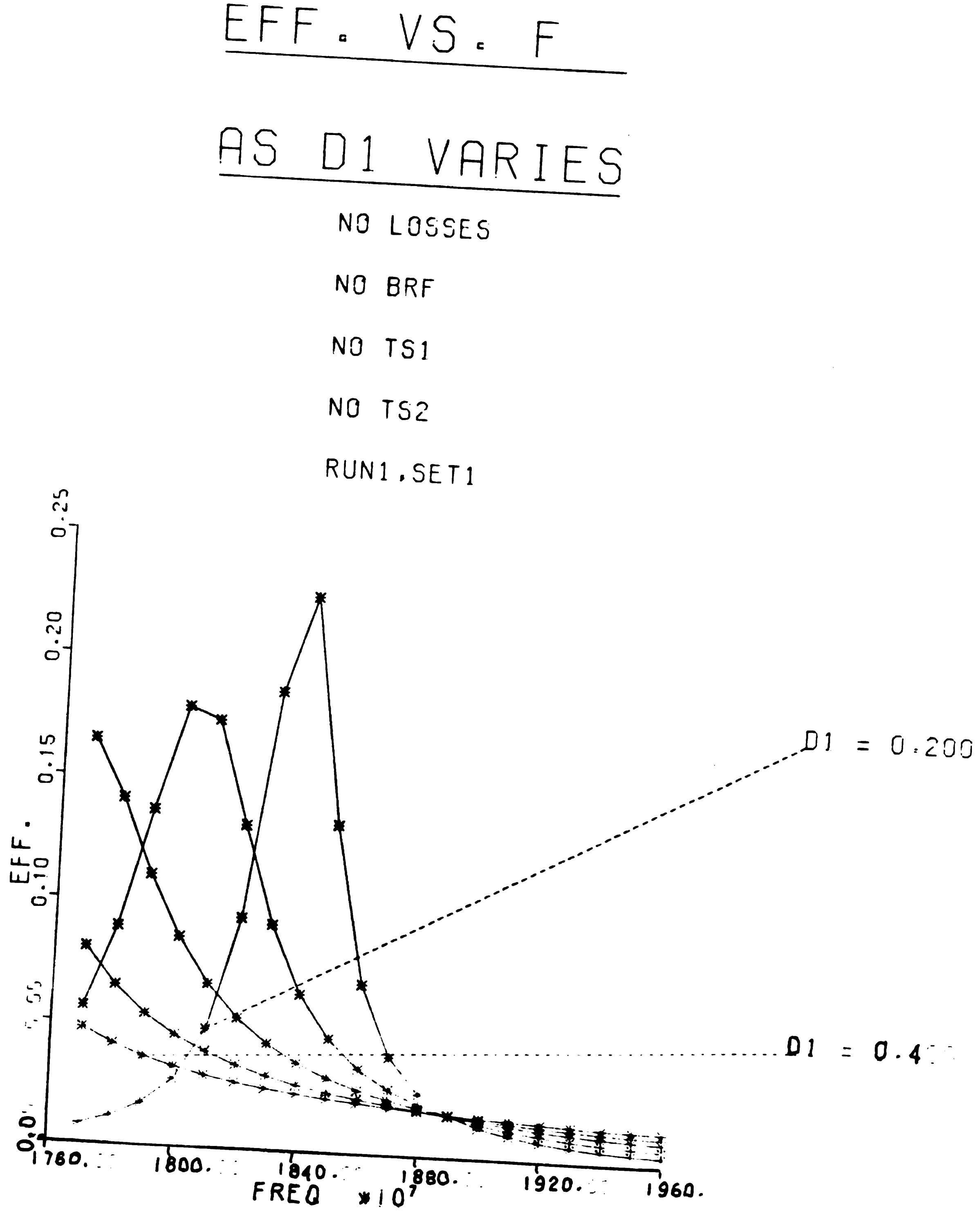


Figure 23: Eff. as d_1 Varies

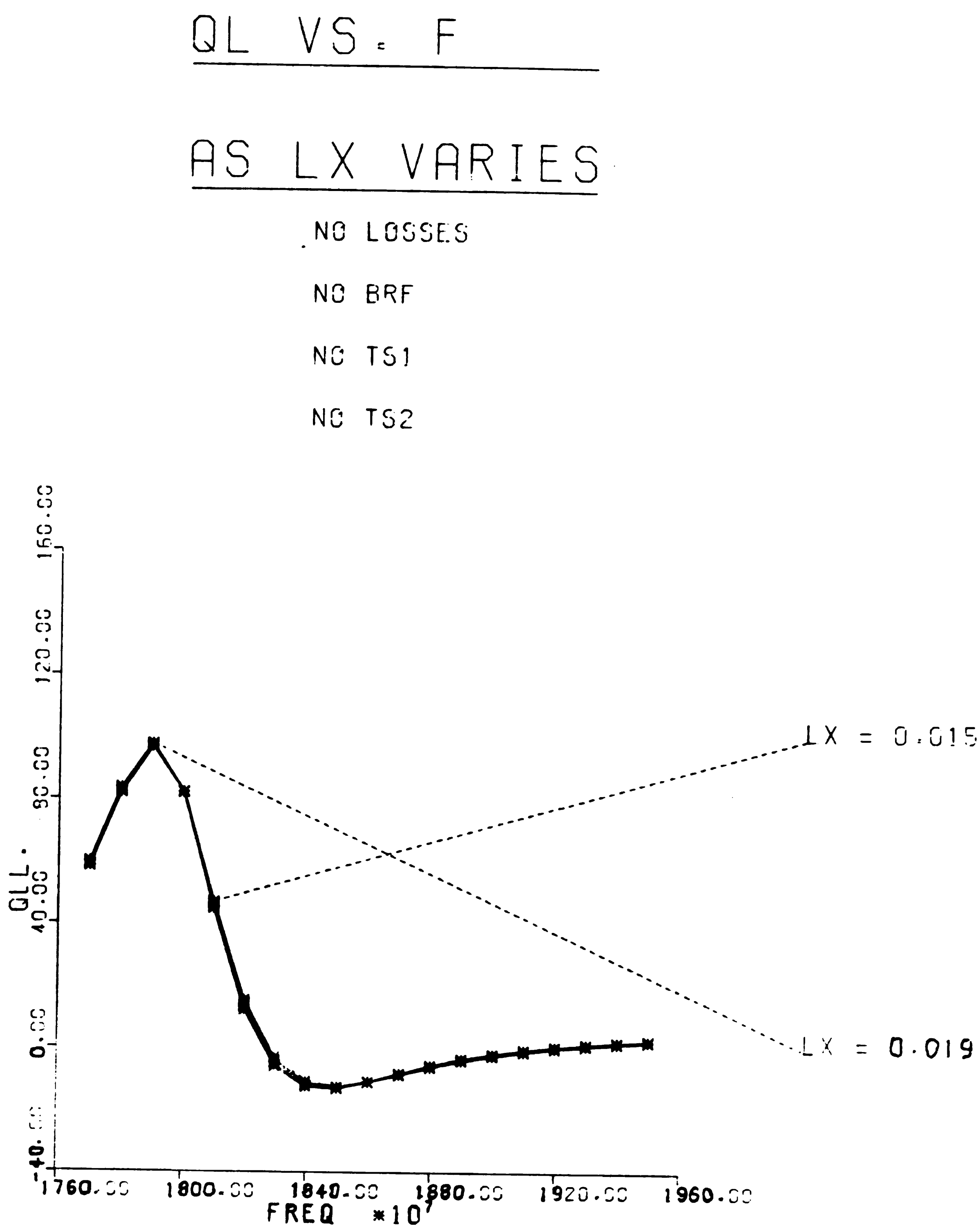


Figure 24: Q_L as L_x Varies

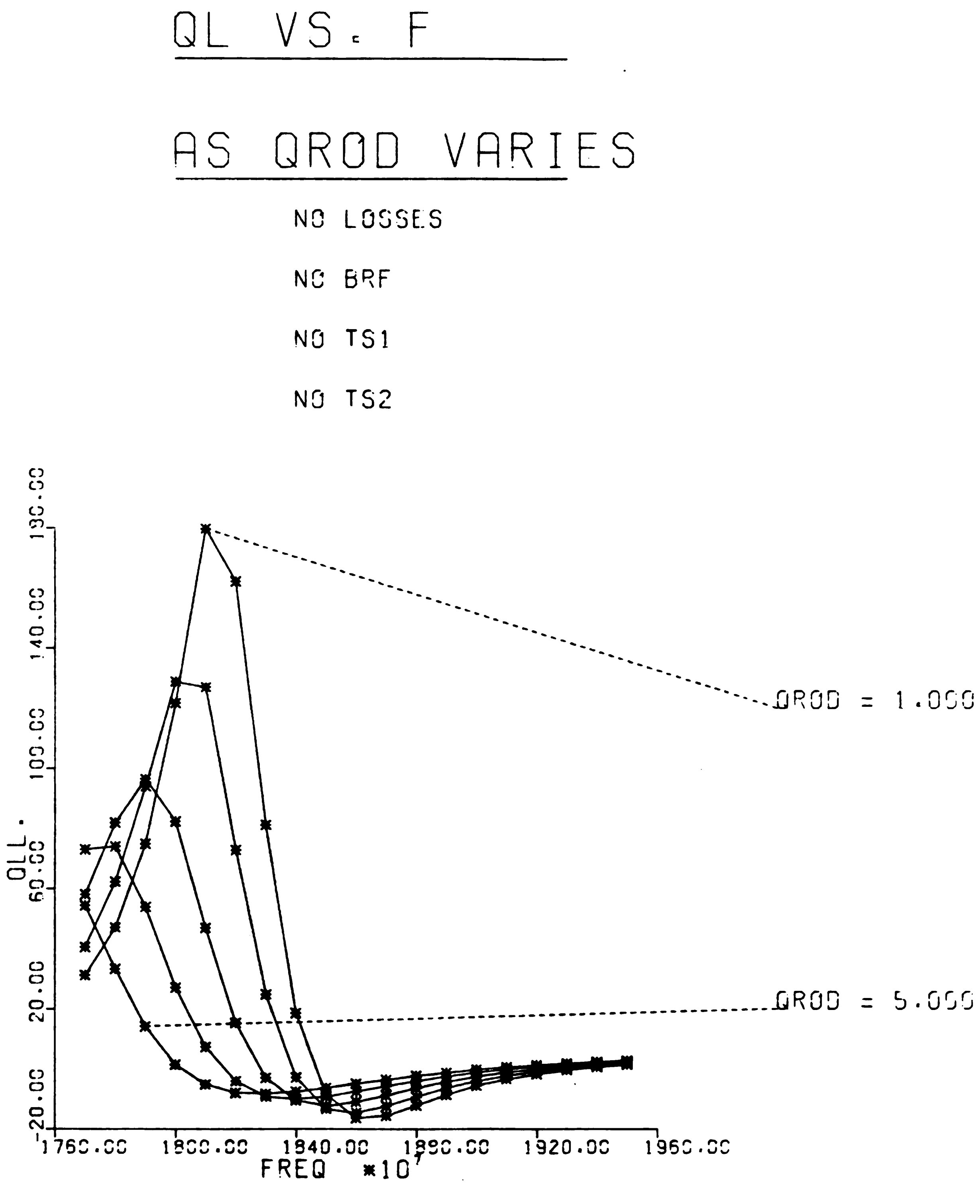


Figure 25: Q_L as Q Rod Varies

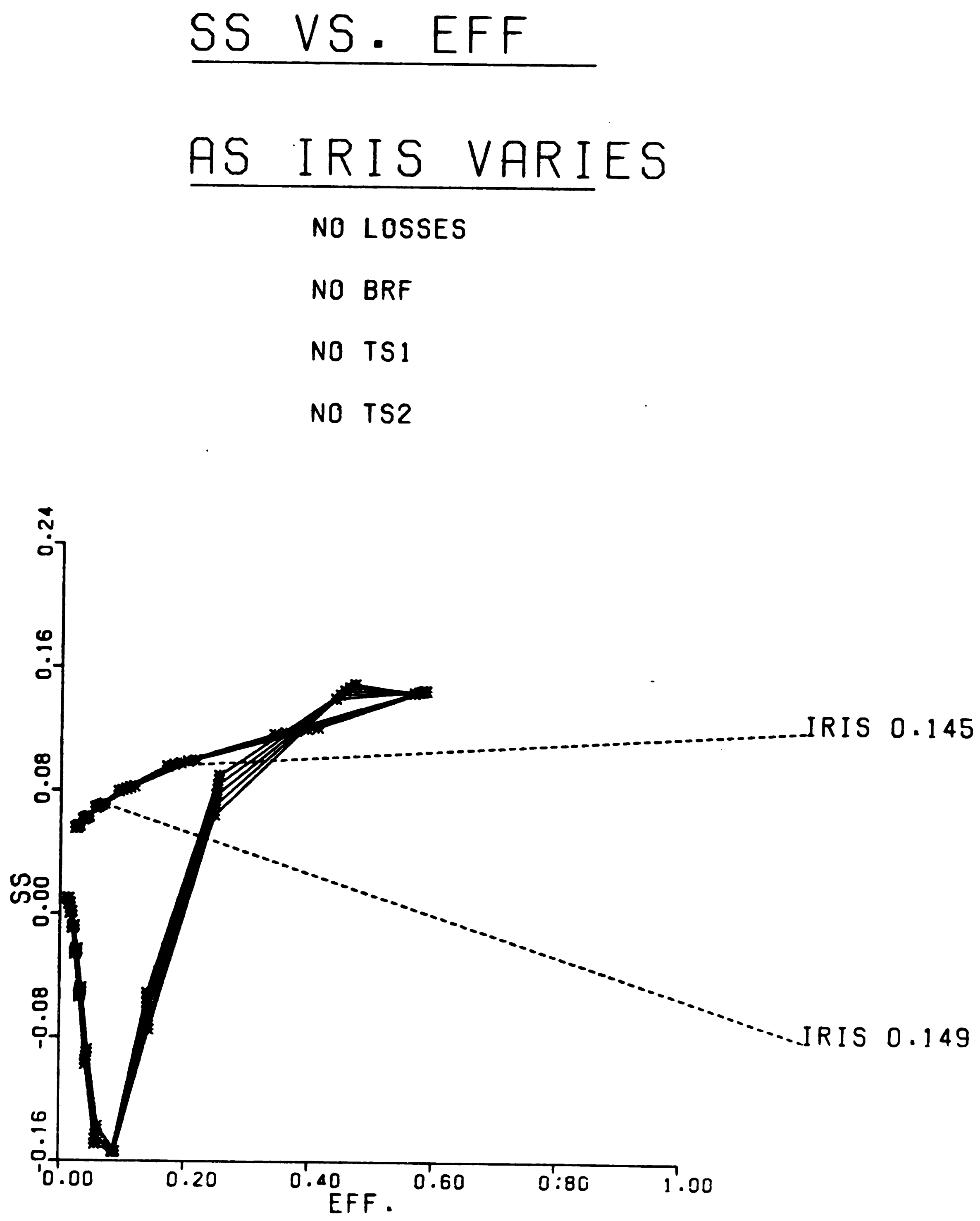


Figure 26: SS as Q Rod Varies

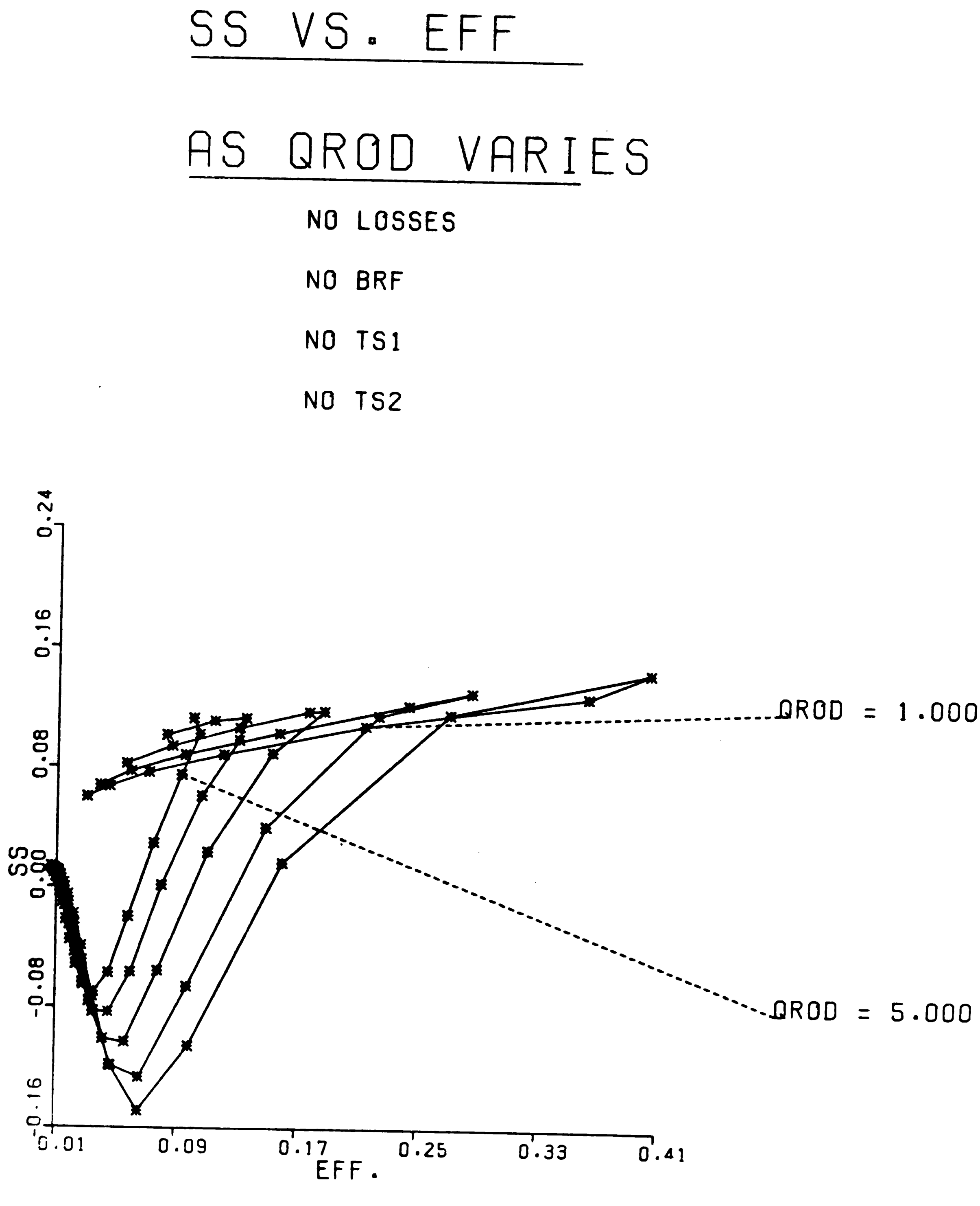


Figure 27: SS as Q Rod Varies

APPENDIX 11

PROGRAM LISTING

```
 PROGRAM IMPATT (INPUT,OUTPUT=/600,TAPE 1=INPUT,TAPE 2=OUTPUT
1,DEBUG=OUTPUT)
 DIMENSION A(4,18),AT(6),B(12),BE(6),C(18,20),CANG(20,10),
+CALIN(20),CMAG(20,10),CMLIN(20),CRFL(18,20),
+D(20),E(22),EA(20,10),FREQ(22),G(18),PC(20,10),
+QE(19,10),QL(19,10),QO(19,10),RP(22),RS(21),RSA(19,10),S(14),
+V(18,20),Y(19,20),YC(20,10),YE(18),YI(22),YR(22),IBCD(2),
+RHOL(20,19),QLL(21),QEL(19),QOL(19),BUFF(257),PHIL(20,19),
+PHI(20),RHO(20),RCM(18,20),RCA(18,20),PL(20,10),PI(20,10),
+YN(19,20),W(50),NA(50),TH(30,10,15),SV(30,10,15),FV(50),ISTAT(10),
+MEXT(5),IKEP(15,15),VAKP(15,15),AKEP(15,15),PKEP(15,15),IDASH(20),
+ISTAY(4),IW(50)
 COMPLEX A,B,CRFL,G,PC,T,V,Y,YC,HC,HS,HT,U,Z,TT,UU,VV,WW,XX,CZ,C,
+YN,XCM,YCM
 HC(Z)=0.5*(CEXP(Z)+CEXP(-Z))
 HS(Z)=0.5*(CEXP(Z)-CEXP(-Z))
 U(TT,UU,VV,WW,XX)=(TT+UU*XX)/(VV+WW*XX)
 DATA (RHOL(I,19),I=1,20)/.0078,.0094,.0122,.0152,.0186,
1.0219,.0253,.0281,.0308,
1.0331,.0346,.0359,.0366,.0368,.0367,.0361,.0350,.0335,.0318,
2.0294/
 DATA (PHIL(I,19),I=1,20)/161.188,139.5540,124.5911,114.237,
1106.8487,101.2420,
197.1011,93.2916,90.105,87.3641,84.7929,82.3989,80.3324,78.5326,
276.5970,74.8381,73.1030,71.3951,69.6742,68.0252/
 DATA (RHOL(I,1),I=1,20)/.0122,.0098,.0083,.0082,.0099,
1.0123,.0152,.0177,.0203,
1.0225,.0242,.0254,.0261,.0264,.0263,.0259,.0248,.0233,.0216,
2.0198/
 DATA (PHIL(I,1),I=1,20)/222.107,207.2782,184.7225,156.7893,
1131.8347,116.3619,
1105.7453,98.4342,92.7609,88.3594,84.5734,81.1229,78.3072,
275.4949,73.063,70.5756,67.9893,65.0994,62.3166,59.0475/
 DATA (RHOL(I,2),I=1,20)/.0257,.0221,.0186,.0148,.0112,
1.0082,.0063,.0056,.0067,
1.0083,.0098,.011,.0118,.0123,.0124,.0121,.0114,.0105,.0096,
2.0086/
 DATA (PHIL(I,2),I=1,20)/242.763,239.2133,234.1598,228.024,
1217.7869,202.9862,
1177.3372,143.4016,114.9076,98.1074,86.929,78.8102,72.5009,
266.6686,61.2353,55.3858,48.7497,40.855,30.4565,17.4437/
 DATA (RHOL(I,3),I=1,20)/.0466,.0426,.0386,.0344,.0302,.0262,
1.0223,.0188,.0155,
1.0129,.0108,.0096,.0092,.0092,.0099,.0112,.0126,.0144,.0164,
2.0185/
 DATA (PHIL(I,3),I=1,20)/249.242,248.0244,246.7458,245.635,
1244.6009,243.8962,
1243.5802,244.1092,245.7893,249.2446,254.7996,262.8421,271.1251,
2279.3492,285.1996,287.9301,288.852,288.3847,286.3466,284.6053/
 DATA (RHOL(I,4),I=1,20)/.0699,.0658,.0617,.0573,.0528,
1.0488,.0448,.0415,.0382,
1.0356,.0338,.0326,.032,.0319,.0324,.0333,.0346,.0364,.0385,
2.0406/
 DATA (PHIL(I,4),I=1,20)/251.291,250.6152,250.1132,249.9678,
2249.749,249.8943,
1250.3858,251.5381,252.9608,254.9165,257.1737,259.7487,261.981,
2264.4385,266.4471,268.0135,269.0861,269.6558,269.7372,269.5997/
 DATA (RHOL(I,5),I=1,20)/.0953,.0912,.0868,.0823,.0778,.0737,
1.0699,.0664,.0633,
1.0609,.0589,.0577,.0570,.057,.0574,.0583,.0597,.0613,.0633,
2.0656/
 DATA (PHIL(I,5),I=1,20)/251.582,251.2187,251.0497,251.0643,
1251.1210,251.5279,
1251.9692,252.9065,253.9483,255.2268,256.6169,258.0949,
2259.2127,260.7374,261.6848,262.7396,263.4029,263.7955,
3264.07,264.0829/
 DATA (RHOL(I,6),I=1,20)/.126,.122,.1175,.1129,.1083,
1.1041,.1004,.0968,.0937,
1.0914,.0894,.0884,.0876,.0875,.088,.0889,.0902,.0919,.0938,
2.096/
 DATA (PHIL(I,6),I=1,20)/250.765,250.6168,250.5887,250.7189,
1250.8367,251.2791,
1251.6775,252.3748,253.1264,254.0704,254.9123,255.9574,
2256.7038,257.6202,258.3360,258.9602,259.3833,259.7337,
3259.8978,259.8936/
 DATA (RHOL(I,7),I=1,20)/.158,.153,.1484,.1437,.139,
1.1348,.1311,.1274,
```

```
1.1245,.1221,.1203,.1191,.1184,.1184,.1189,.1198,.1211,
2.1227,.1246,.1268/
 DATA (PHIL(I,7),I=1,20)/249.808,249.6757,249.7158,249.9125,
1250.0419,250.4445,
1250.7741,251.3748,252.0111,252.7058,253.3751,254.1135,254.6701,
2255.3522,255.8512,256.3274,256.6383,256.8496,257.0214,257.0308/
 DATA (RHOL(I,8),I=1,20)/.190,.1857,.181,.1762,.1714,
1.1673,.1635,.1599,.157,
1.1548,.1528,.1517,.1511,.151,.1516,.1525,.1538,.1553,.1572,.1594/
 DATA (PHIL(I,8),I=1,20)/248.294,248.2497,248.3633,248.5573,
1248.7072,249.0906,
1249.4425,249.8873,250.3708,251.0254,251.4849,252.0581,252.5066,
2253.016,253.4197,253.7629,253.9808,254.1487,254.2884,254.2530/
 DATA (RHOL(I,9),I=1,20)/.224,.219,.2144,.2095,.2047,
1.2005,.1968,.1932,.1903,
1.188,.1861,.1852,.1844,.1844,.185,.186,.1872,.1888,.1906,.1928/
 DATA (PHIL(I,9),I=1,20)/246.689,246.6565,246.7874,247.0161,
2247.1478,247.4797,
1247.7697,248.2272,248.6109,249.1432,249.5449,249.9664,250.312,
2250.7338,250.9992,251.3217,251.5246,251.6288,251.7089,251.7275/
 DATA (RHOL(I,10),I=1,20)/.256,.2513,.2465,.2415,.2366,
1.2325,.2289,.2253,.2225,
1.22,.2182,.2174,.2165,.2165,.2172,.2181,.2194,.2206,.2225,.2246/
 DATA (PHIL(I,10),I=1,20)/244.933,244.8894,245.0584,245.2711,
1245.4076,245.7078,
1245.9513,246.3429,246.7015,247.1265,247.4734,247.8603,248.1066,
2248.4498,248.6655,248.9473,249.0809,249.1585,249.2694,249.2809/
 DATA (RHOL(I,11),I=1,20)/.292,.2866,.2817,.2766,.2717,
1.2677,.2642,.2606,.2577,
1.2553,.2535,.2527,.2517,.2517,.2526,.2534,.2546,
2.2559,.2575,.2595/
 DATA (PHIL(I,11),I=1,20)/243.04,243.0513,243.2344,243.428,
1243.5865,243.8536,
1244.1056,244.4382,244.7429,245.143,245.4088,245.6969,245.9138,
2246.2078,246.3912,246.618,246.7345,246.8043,246.8847,
3246.8852/
 DATA (RHOL(I,12),I=1,20)/.325,.3202,.3152,.3103,.3053,
1.3011,.2978,.2942,.2914,
1.289,.2872,.2863,.2852,.2851,.286,.2869,.2881,.2894,.2909,.2927/
 DATA (PHIL(I,12),I=1,20)/241.016,241.0615,241.204,241.4426,
1241.5659,241.8189,
1242.0355,242.3254,242.6001,242.9303,243.1699,243.4178,
2243.5676,243.8574,244.0168,244.1961,244.2812,244.2926,244.3943,
3244.422/
 DATA (RHOL(I,13),I=1,20)/.361,.3556,.3506,.3456,.3407,
1.3364,.3333,.3296,.3269,
1.3245,.3227,.3219,.3208,.3206,.3215,.3223,.3234,.3246,.326,
2.3277/
 DATA (PHIL(I,13),I=1,20)/238.894,238.9441,239.1112,239.336,
1239.4545,239.7172,
1239.9069,240.1533,240.4068,240.7037,240.8967,241.1034,241.2284,
2241.4624,241.5885,241.7492,241.8284,241.8312,241.9317,241.9531/
 DATA (RHOL(I,14),I=1,20)/.395,.3902,.3852,.3802,.3754,
1.3712,.3681,.3644,.3618,
1.3594,.3575,.3567,.3555,.3553,.3561,.3569,.3579,.3591,.3602,
2.3619/
 DATA (PHIL(I,14),I=1,20)/236.934,236.9701,237.1497,237.3776,
1237.4691,237.7131,
1237.8972,238.1358,238.3428,238.6161,238.7937,238.9444,239.0484,
2239.2636,239.3739,239.533,239.5803,239.5895,239.6893,239.7236/
 DATA (RHOL(I,15),I=1,20)/.434,.4284,.4235,.4186,.4137,.4097,
1.4065,.4029,.4002,
1 .3979,.3959,.3951,.3938,.3937,.3945,.3951,.3961,.397,.398,.3995/
 DATA (PHIL(I,15),I=1,20)/243.264,234.3069,234.4924,234.6991,
1234.7664,234.9699,
1235.1235,235.3296,235.5288,235.7443,235.8951,236.0158,236.1112,
2236.2706,236.36,236.4702,236.5271,236.5406,236.6523,236.6505/
 DATA (RHOL(I,16),I=1,20)/.475,.4693,.4644,.4594,.4547,
1.4507,.4479,.4443,.4416,
1.4393,.4373,.4366,.4351,.4349,.4356,.4362,.4371,.4379,.4386,.4399/
 DATA (PHIL(I,16),I=1,20)/231.703,231.7456,231.9192,232.1393,
1232.2042,232.4119,
1232.5433,232.733,232.8862,233.0733,233.1866,233.2936,233.3337,
2233.5135,233.5705,233.701,233.7308,233.7576,233.8533,233.8563/
 DATA (RHOL(I,17),I=1,20)/.531,.526,.5213,.5162,.5117,
1.5078,.5054,.5018,.4992,
1.4969,.4949,.4941,.4926,.4923,.493,.4935,.4942,.4947,.4954,.4964/
```

```
      DATA (PHIL(I,17),I=1,20)/227.698,227.7445,227.9015,228.098,
     1228.1632,228.3272,
     1228.4042,228.5585,228.6724,228.8391,228.9148,228.9696,229.0001,
     2229.137,229.1814,229.2859,229.3164,229.294,229.4266,229.4366/
      DATA (RHOL(I,18),I=1,20)/.543,.5381,.5334,.5286,
     1.5241,.5203,.5179,.5144,.512,
     1.5096,.5074,.5069,.5053,.5049,.5057,.506,.5068,.5073,.5079,.5088/
      DATA (PHIL(I,18),I=1,20)/227.347,227.3912,227.5572,227.7573,
     1227.8071,227.9813,
     1228.0792,228.2296,228.3514,228.4866,228.5800,228.6255,228.6645,
     2228.78,228.8308,228.9457,228.9579,228.9626,229.0765,229.0816/
      DATA D/0.42,0.174,0.036,0.0735,0.0345,0.054,0.25,0.16,0.149,1.0,
     +1.0,0.42,0.17,0.42,0.17,1.0,1.0,1.0,1.445,1.0/
      DATA S/0.018,0.117,0.011,0.085,0.1,0.225,0.12,0.2,0.3,
     +0.234,0.18,0.11,0.05,19.0/
      DATA ISTAT/7H   MEAN,7HSTD DEV,7H  + PTS,7H   + AV,7H  - PTS,
     +7HLARGEST,7HF LARGE,7H  SMALL,7HF SMALL,7H   - AV/
      DATA MEXT/9H         ,9H         ,9H         ,
     +9H         /
      DATA ISTAY/1HP,1HI,1HV,1HB/
      IDASH(1)=10H$$$$$$$$$$$
      IDASH(2)=10H$$$$$$$$$$$
      IDASH(3)=10H$$$$$$$$$$$
      IDASH(4)=10H$$$$$$$$$$$
      IDASH(5)=10H$$$$$$$$$$$
      IDASH(6)=10H$$$$$$$$$$$
      IDASH(7)=10H$$$$$$$$$$$
      IDASH(8)=10H$$$$$$$$$$$
      IDASH(9)=10H$$$$$$$$$$$
      IDASH(10)=10H$$$$$$$$$$$
      IDASH(11)=10H$$$$$$$$$$$
      IDASH(12)=10H$$$$$$$$$$$
      IDASH(13)=10H$$$$$$$$$$$
      IDASH(14)=5H$$$$$
      IEXT=9HRUN1,SET1
      IEXL=9
      DO 400 I=1,50
      NA(I)=0.0
      IW(I)=0
      W(I)=0.0
  400 CONTINUE
      NA(1)=1
      NA(2)=999
      NA(3)=3
      NA(4)=4
      NA(5)=5
      NA(6)=6
      NA(7)=7
      NA(8)=31
      NA(9)=9
      NA(10)=10
      NA(11)=11
      NA(12)=12
      NA(13)=13
      NA(14)=14
      NA(15)=15
      NA(16)=16
      NA(17)=17
      NA(18)=18
      NA(19)=19
      NA(20)=20
      NA(21)=21
      NA(22)=22
      NA(23)=23
      NA(23)=999
      NA(24)=24
      NA(25)=25
      NA(26)=26
      NA(27)=27
      NA(28)=28
      NA(29)=29
      NA(30)=30
      NA(31)=31
      NA(32)=32
      NA(33)=33
      NA(34)=999
      IW(5)=1
```

```
      IW(6)=1
      IW(7)=1
      IW(8)=1
      IW(9)=1
      IW(10)=1
      IW(11)=1
      IW(12)=1
      IW(13)=1
      IW(14)=1
      IW(16)=1
      IW(17)=1
      LC=1
  500 KV=NA(LC)
      ZC=6.0
      ITEN=0
      IBPF=0
      ITSA=0
      ITSB=0
      IROD=1
      IF(KV.EQ.999)501,550
  550 CONTINUE
      GO TO (502,503,504,505,506,507,508,509,510,511,512,513,514,
     +515,516,517,518,519,520,521,522,523,524,525,526,527,528,
     +529,530,531,532,533,534),KV
  502 CV=0.015
      VI=0.001
      IBCE=2HLX
      IC=2
      IBCD(1)=5HLX =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(1)=0.18
      LK=LN
      NR=LN
      GO TO 300
  503 CV=0.116
      VI=0.0004
      IBCE=3HLTR
      IC=3
      IBCD(1)=6HLTR =
      IL=6
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(2)=0.117
      LK=LN
      NR=LN
      GO TO 300
  504 CV=0.01
      VI=0.0004
      FV(3)=0.011
      IBCE=2HLO
      IC=2
      IBCD(1)=5HLO =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      LK=LN
      NR=LN
      GO TO 300
  505 CV=0.1
      FV(4)=0.1
      VI=.01
      IBCE=2HLF
      IC=2
      IBCD(1)=5HLF =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
```

```
      LK=LN
      NR=LN
      IBPF=1
      GO TO 300
  506 CV=0.01
      FV(5)=4
      VI=1.0
      IBCE=2HZC
      IC=2
      IBCD(1)=5HZC =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      LK=LN
      NR=LN
      IBPF=1
      GO TO 300
  507 CV=0.11
      VI=0.004
      FV(6)=0.12
      IBCE=3HLT1
      IC=3
      IBCD(1)=6HLT1 =
      IL=6
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      LK=LN
      NR=LN
      ITSA=1
      GO TO 300
  508 CV=0.15
      FV(7)=0.2
      VI=.01
      IBCE=3HLT2
      IC=3
      IBCD(1)=6HLT2 =
      IL=6
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      LK=LN
      NR=LN
      ITSB=1
      GO TO 300
  509 CV=.3
      VI=.001
      IBCE=3HLT3
      IC=3
      IBCD(1)=6HLT3 =
      IL=6
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(8)=CV
      LK=LN
      NR=LN
      GO TO 300
  510 CV=0.204
      VI=0.0192
      FV(9)=0.204
      IBCE=2HLS
      IC=[illegible]
      IBCD(1)=5HLS =
      IL=[illegible]
      LN=[illegible]
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=[illegible]
      LK=LN
      NR=LN
      GO TO 300
```

```
 511 CV=0.18
     VI=0.008
     FV(10)=0.18
     IBCE=2HLC
     IC=2
     IBCD(1)=5HLC =
     IL=5
     LN=5
     CVS=CV
     CVF=CV+VI*(LN-1)
     IN=3
     LK=LN
     NR=LN
     IBPF=1
     GO TO 300
 512 CV=.05
     VI=.05
     IBCE=3HTS1
     IC=3
     IBCD(1)=6HTS1 =
     IL=6
     LN=5
     CVS=CV
     CVF=CV+VI*(LN-1)
     IN=3
     FV(11)=CV
     LK=LN
     NR=LN
     ITSA=1
     GO TO 300
 513 CV=0.001
     VI=0.0098
     FV(12)=0.05
     IBCE=3HTS2
     IC=3
     IBCD(1)=6HTS2 =
     IL=6
     LN=5
     CVS=CV
     CVF=CV+VI*(LN-1)
     IN=3
     LK=LN
     NR=LN
     ITSB=1
     GO TO 300
 514 CV=0.41
     VI=0.002
     FV(13)=0.42
     IBCE=1HA
     IC=1
     IBCD(1)=4HA =
     IL=4
     LN=5
     CVS=CV
     CVF=CV+VI*(LN-1)
     IN=3
     LK=LN
     NR=LN
     GO TO 300
 515 CV=0.174
     FV(14)=0.174
     VI=.001
     IBCE=1HB
     IC=1
     IBCD(1)=4HB =
     IL=4
     LN=5
     CVS=CV
     CVF=CV+VI*(LN-1)
     IN=3
     LK=LN
     NR=LN
     GO TO 300
 516 CV=0.036
     VI=0.00[illegible]
     FV(15)=0.036
     IBCE=2H[illegible]
```

```
      IC=2
      IBCD(1)=5HR1 =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      LK=LN
      NR=LN
      GO TO 300
  517 CV=0.0695
      VI=0.0009
      FV(16)=0.0735
      IBCE=2HR2
      IC=2
      IBCD(1)=5HR2 =
      IL=5
      LN=5
      CVS=CV
      IN=3
      CVF=CV+VI*(LN-1)
      LK=LN
      NR=LN
      GO TO 300
  518 CV=0.0335
      VI=0.0004
      FV(17)=0.0345
      IBCE=2HR3
      IC=2
      IBCD(1)=5HR3 =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      LK=LN
      NR=LN
      GO TO 300
  519 CV=0.054
      VI=0.006
      IBCE=2HR4
      IC=2
      IBCD(1)=5HR4 =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(18)=CV
      LK=LN
      NR=LN
      GO TO 300
  520 CV=.2
      VI=0.02
      FV(19)=0.25
      IBCE=2HD1
      IC=2
      IBCD(1)=5HD1 =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      LK=LN
      NR=LN
      GO TO 300
  521 CV=0.155
      FV(20)=0.16
      VI=.001
      IBCE=2HD2
      IC=2
      IBCD(1)=5HD2 =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
```

```
      LK=LN
      NR=LN
      GO TO 300
  522 CV=0.145
      VI=0.001
      IBCE=4HIRIS
      IC=4
      IBCD(1)=7HIRIS =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(21)=CV
      LK=LN
      NR=LN
      GO TO 300
  523 CV=1.44
      VI=0.004
      FV(22)=1.455
      IC=2
      IBCD(1)=5HEP =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      LK=LN
      NR=LN
      GO TO 300
  524 CV=.2
      VI=.01
      IBCE=2HAA
      IC=2
      IBCD(1)=5HAA =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(23)=CV
      LK=LN
      NR=LN
      ITEN=1
      GO TO 300
  525 CV=.03
      VI=.001
      IBCE=2HAD
      IC=2
      IBCD(1)=5HAD =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(24)=CV
      LK=LN
      NR=LN
      ITEN=1
      GO TO 300
  526 CV=.002
      VI=.0001
      IBCE=2HAC
      IC=2
      IBCD(1)=5HAC =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(25)=CV
      LK=LN
      NR=LN
      ITEN=1
      GO TO 300
  527 CV=.002
      VI=.0001
```

```
      IBCE=2HAW
      IC=2
      IBCD(1)=5HAW =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(26)=CV
      LK=LN
      NR=LN
      ITEN=1
      GO TO 300
  528 CV=.42
      VI=.001
      IBCE=2HA1
      IC=2
      IBCD(1)=5HA1 =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(27)=CV
      LK=LN
      NR=LN
      GO TO 300
  529 CV=.17
      VI=.001
      IBCE=2HB1
      IC=2
      IBCD(1)=5HB1 =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(28)=CV
      LK=LN
      NR=LN
      GO TO 300
  530 CV=.42
      VI=.001
      IBCE=2HA2
      IC=2
      IBCD(1)=5HA2 =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(29)=CV
      LK=LN
      NR=LN
      GO TO 300
  531 CV=.17
      VI=.001
      IBCE=2HB2
      IC=2
      IBCD(1)=5HB2 =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(30)=CV
      LK=LN
      NR=LN
      GO TO 300
  532 CV=1.0
      IA(18)=1
      FV(31)=19.0
      VI=1.0
      IBCE=4HQRCD
      IC=4
      IBCD(1)=7HQRCD =
      IL=7
```

```
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      LK=LN
      NR=LN
      GO TO 300
  533 CV=.001E-3
      VI=150.0E-3
      IBCE=2HYS
      IC=2
      IBCD(1)=5HYS =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(32)=20E-3
      LK=LN
      NR=LN
      GO TO 300
  534 CV=.02
      VI=.0001
      IBCE=2HYL
      IC=2
      IBCD(1)=5HYL =
      IL=5
      LN=5
      CVS=CV
      CVF=CV+VI*(LN-1)
      IN=3
      FV(33)=CV
      LK=LN
      NR=LN
  300 CONTINUE
      IWTE=ITEN+IW(1)
      IWTA=ITSA+IW(3)
      IWTB=ITSB+IW(4)
      IWBR=IBPF+IW(2)
      CVX=CVF
      ATA=.2
      ATD=.03
      ATC=2E-3
      ATW=ATC
      PP=3.141592654
   11 CONTINUE
      LF=1
      F=17.7E9
    1 CONTINUE
      GO TO (602,603,604,605,606,607,608,609,610,611,612,613,614,
     +615,616,617,618,619,620,621,622,623,624,625,626,627,628,
     +629,630,631,632,633,634),KV
  602 S(1)=CV
      GO TO 301
  603 S(2)=CV
      GO TO 301
  604 S(3)=CV
      GO TO 301
  605 S(5)=CV
      GO TO 301
  606 ZC=CV
      GO TO 301
  607 S(7)=CV
      GO TO 301
  608 S(8)=CV
      GO TO 301
  609 S(9)=CV
      GO TO 301
  610 S(10)=CV
      GO TO 301
  611 S(11)=CV
      GO TO 301
  612 S(12)=CV
      GO TO 301
  613 S(13)=CV
      GO TO 301
  614 D(1)=CV
```

```
      GO TO 301
  615 D(2)=CV
      GO TO 301
  616 D(3)=CV
      GO TO 301
  617 D(4)=CV
      GO TO 301
  618 D(5)=CV
      GO TO 301
  619 D(6)=CV
      GO TO 301
  620 D(7)=CV
      GO TO 301
  621 D(8)=CV
      GO TO 301
  622 D(9)=CV
      GO TO 301
  623 D(19)=CV
      GO TO 301
  624 ATA=CV
      GO TO 301
  625 ATD=CV
      GO TO 301
  626 ATC=CV
      GO TO 301
  627 ATW=CV
      GO TO 301
  628 D(12)=CV
      GO TO 301
  629 D(13)=CV
      GO TO 301
  630 D(14)=CV
      GO TO 301
  631 D(15)=CV
      GO TO 301
  632 S(14)=CV
      IF(CV.EQ.4)S(14)=19.0
      IF(CV.EQ.5)IROD=0
      GO TO 301
  633 B(10)=CV
      GO TO 301
  634 B(9)=CV
      GO TO 301
  301 CONTINUE
      FREQ(LF)=F
      D(16)=1.1811E10/F
      D(10)=D(7)*(D(8)**2)*PP/24
      D(11)=(7.1*D(8)/(9*D(7))+0.2)*(D(7)**3)/6
      S(4)=D(2)/2
      JJ=INT(S(14))
      DO 380 I=1,20
      RHO(I)=RHOL(I,JJ)
      PHI(I)=PHIL(I,JJ)
  380 CONTINUE
  370 DO 371 I=1,20
      PHI(I)=(PHI(I)*3.141592654)/180
  371 CONTINUE
      D(17)=D(16)/((1-((D(16)/(2*D(1)))**2))**0.5)
      D(18)=D(16)/((1-((D(16)/(2*D(12)))**2))**0.5)
      D(20)=D(16)/((1-((D(16)/(2*D(14)))**2))**0.5)
      AT(1)=ATA
      AT(2)=ATA+ATD
      AT(3)=ATA
      AT(4)=ATC
      AT(5)=ATW
      AT(6)=ATW
      IF(IWTE.EQ.0)401,402
  401 CONTINUE
      AT(1)=0.0
      AT(2)=0.0
      AT(3)=0.0
      AT(4)=0.0
      AT(5)=0.0
      AT(6)=0.0
  402 CONTINUE
      BE(1)=2*PP/D(16)
      BE(2)=BE(1)*D(19)
```

```
      BE(3)=BE(1)
      BE(4)=2*PP/D(17)
      BE(5)=2*PP/D(18)
      BE(6)=2*PP/D(20)
      YE(1)=1/(60*ALOG(D(6)/D(5)))
      YE(2)=D(19)/(60*ALOG(D(6)/D(5)))
      YE(3)=YE(2)
      YE(4)=1/(60*ALOG(D(4)/D(3)))
      YE(5)=YE(4)
      YE(6)=YE(4)
      YE(7)=YE(4)
      YE(8)=YE(4)
      YE(9)=YE(4)*D(16)*4*PP*(D(4)**2)*ALOG(D(4)/D(3))/(D(17)*D(1)*D(2))
      YE(10)=YE(9)
      YE(11)=YE(9)
      YE(12)=YE(9)
      YE(13)=YE(9)*D(17)*D(1)*D(2)/(D(18)*D(14)*D(15))
      YE(14)=YE(13)
      YE(15)=YE(13)
      YE(16)=YE(13)
      YE(17)=YE(13)
      YE(18)=YE(4)
      X=F/9.95E12
      B(1)=CMPLX(0.,X)
      CZ=CMPLX(AT(3),BE(3))
      XX=CZ*S(11)
      B(2)=ZC*HS(CZ)/HC(CZ)
      RFI=RHO(LF)*SIN(PHI(LF))
      RFR=RHO(LF)*COS(PHI(LF))
      Z=CMPLX(RFR,RFI)
      HT=Z
      B(3)=-2*YE(9)*Z/(1+Z)
      X=-3.0*D(12)*D(13)*YE(13)*D(18)/(2.0*PP*(D(9)**3))
      B(4)=CMPLX(0.,X)
      X=-1.55*S(12)/YE(13)
      B(5)=CMPLX(0.,X)
      X=-3.9525/(YE(13)*S(12))
      B(6)=CMPLX(0.,X)
      X=-1.55*S(13)/YE(13)
      B(7)=CMPLX(0.,X)
      X=-3.9525/(YE(13)*S(13))
      B(8)=CMPLX(0.,X)
      IF(KV.EQ.32)650,651
  651 B(10)=CMPLX(YE(4),0.)
  650 CONTINUE
      IF(KV.EQ.33)652,653
  653 B(9)=CMPLX(YE(17),0.)
  652 CONTINUE
      X=-YE(4)*D(10)/(2*D(16)*(D(4)**2)*ALOG(D(4)/D(3)))
      B(11)=CMPLX(0.,X)
      X=-YE(4)*D(16)*(D(4)**2)*ALOG(D(4)/D(3))/D(11)
      B(12)=CMPLX(0.,X)
      T=CMPLX(AT(1),BE(1))
      G(1)=T*S(1)
      G(4)=T*S(3)
      G(5)=T*S(4)
      G(6)=G(5)
      G(7)=T*S(5)
      G(8)=G(7)
      G(18)=T*S(10)
      T=CMPLX(AT(2),BE(2))
      G(2)=T*S(2)
      G(3)=G(2)
      T=CMPLX(AT(4),BE(4))
      G(9)=T*S(6)
      G(10)=G(9)
      G(11)=G(9)
      G(12)=G(9)
      T=CMPLX(AT(5),BE(5))
      G(13)=T*S(7)
      G(14)=G(13)
      G(15)=T*S(8)
      G(16)=G(15)
      T=CMPLX(AT(6),BE(6))
      G(17)=T*S(9)
      DO 2 I=1,18
      A(1,I)=HC(G(I))
```

```
      A(2,I)=HS(G(I))/YE(I)
      A(3,I)=HS(G(I))*YE(I)
      A(4,I)=HC(G(I))
    2 CONTINUE
      A(1,3)=1.0
      A(2,3)=0.0
      A(3,3)=B(1)
      A(4,3)=1.0
      A(1,8)=1.0
      A(2,8)=B(2)
      A(3,8)=0.0
      A(4,8)=1.G
      A(1,10)=1.0
      A(2,10)=0.0
      A(3,10)=B(3)
      A(4,10)=1.0
      A(1,12)=1.0
      A(2,12)=0.0
      A(3,12)=B(4)
      A(4,12)=1.0
      XCM=(2*B(5)+(B(5)**2)/B(6))
      YCM=1.0/B(6)
      A(1,14)=1.0+(B(5)/B(6))
      A(2,14)=XCM
      A(3,14)=YCM
      A(4,14)=1.0+B(5)/B(6)
      XCM=(2*B(7)+(B(7)**2)/B(8))
      YCM=1.0/B(8)
      A(1,16)=1.0+(B(7)/B(8))
      A(2,16)=XCM
      A(3,16)=YCM
      A(4,16)=1.0+B(7)/B(8)
      IF(IWBR.EQ.0)403,404
  403 CONTINUE
      A(2,8)=0.0
  404 CONTINUE
      IF(IROD.EQ.0)256,257
  256 A(3,10)=0.0
  257 CONTINUE
      IF(IWTA.EQ.0)405,406
  405 CONTINUE
      A(1,14)=1.0
      A(2,14)=0.0
      A(3,14)=0.0
      A(4,14)=1.0
  406 CONTINUE
      IF(IWTB.EQ.0)407,408
  407 CONTINUE
      A(1,16)=1.0
      A(2,16)=0.0
      A(3,16)=0.0
      A(4,16)=1.0
  408 CONTINUE
      Y(18,LF)=B(9)
      DO 3 I=1,9
      J=18-I
      K=19-I
      Y(J,LF)=U(A(3,J),A(4,J),A(1,J),A(2,J),Y(K,LF))
    3 CONTINUE
      Y(19,LF)=U(A(3,18),A(4,18),A(1,18),A(2,18),B(10))
      Y(8,LF)=U(A(3,8),A(4,8),A(1,8),A(2,8),Y(19,LF))
      Y(7,LF)=U(A(3,7),A(4,7),A(1,7),A(2,7),Y(8,LF))
      Z=U(A(3,6),A(4,6),A(1,6),A(2,6),Y(7,LF))
      Y(6,LF)=(Z*B(11))*(Y(9,LF)*B(12))/(Z*B(11)+Y(9,LF)*B(12))*B(11)
      DO 4 I=1,5
      J=6-I
      K=7-I
      Y(J,LF)=U(A(3,J),A(4,J),A(1,J),A(2,J),Y(K,LF))
    4 CONTINUE
      V(1,LF)=CMPLX(1.0,0.0)
      C(1,LF)=Y(1,LF)*V(1,LF)
      DO 5 I=1,5
      J=I+1
      V(J,LF)=A(4,I)*V(I,LF)-A(2,I)*C(I,LF)
      C(J,LF)=A(1,I)*C(I,LF)-V(I,LF)*A(3,I)
    5 CONTINUE
      C(7,LF)=CMPLX(1.0,1.0)
```

```
      C(8,LF)=CMPLX(1.0,1.0)
      V(7,LF)=CMPLX(1.0,1.0)
      V(8,LF)=CMPLX(1.0,1.0)
      TT=1.0+(B(12)/(Z+B(11)))
      UU=1.0/(Z+B(11))
      VV=B(11)+B(12)+B(11)*B(12)/(Z+B(11))
      WW=1.0+(B(11)/(Z+B(11)))
      V(9,LF)=WW*V(6,LF)-UU*C(6,LF)
      C(9,LF)=TT*C(6,LF)-VV*V(6,LF)
      DO 6 I=1,9
      J=I+8
      K=I+9
      V(K,LF)=A(4,J)*V(J,LF)-A(2,J)*C(J,LF)
      C(K,LF)=A(1,J)*C(J,LF)-V(J,LF)*A(3,J)
    6 CONTINUE
      DO 25 I=1,18
      YN(I,LF)=Y(I,LF)/YE(I)
      YN(18,LF)=Y(18,LF)/B(9)
      YN(19,LF)=Y(19,LF)/YE(4)
      CRFL(I,LF)=(YN(I,LF)-1)/(YN(I,LF)+1)
      RCM(I,LF)=CABS(CRFL(I,LF))
      XR=REAL(CRFL(I,LF))
      XI=AIMAG(CRFL(I,LF))
      IF(XR.EQ.0.0)100,101
  100 RCA(I,LF)=999.99
      GO TO 25
  101 RCA(I,LF)=ATAN2(XI,XR)*180/PP
   25 CONTINUE
      IF(IW(5).EQ.0)409,410
  410 CONTINUE
      WRITE(2,99) F,CV,HT,(B(I),I=1,12),(YE(I),I=1,18),(BE(I),I=1,6),
     +((A(I,J),I=1,4),J=1,18)
   99 FORMAT(1X,*F*,E14.7,5X,*CV = *,E14.7,5X,*HT = *,3X,E14.7,1X,E14.7,
4    +//,1X,25X,*B*,//,4(3(10X,E14.7,2X,E14.7,2X)/,1X),1X,25X,*YE*,//,
     +6(3(10X,E14.7,2X)/,1X),1X,25X,*BE*,//,2(3(10X,E14.7,2X)/,1X),1X,
     +25X,*ABCD MATRIX*,//,18(4(2X,E12.5,1X,E12.5,2X)/,1X))
  409 CONTINUE
      LF=LF+1
      F=F+0.1E9
      IF(LF.EQ.21)9,1
    9 CONTINUE
      DO 98 LP=1,18
      IF(IW(6).EQ.0)411,412
  412 CONTINUE
      WRITE(2,96) LP,CV,(Y(LP,I),YN(LP,I),V(LP,I),C(LP,I),I=1,20)
   96 FORMAT(1X,25X,*LP*,I9,10X,*CV*,10X,E15.7,//,1X,25X,*Y*,25X,*YN*,
     +25X,*V*,25X,*C*,//,20(4(2X,E12.5,1X,E12.5,2X)/,1X))
  411 CONTINUE
      IF(IW(7).EQ.0)413,414
  414 CONTINUE
      WRITE(2,97) (RCM(LP,I),RCA(LP,I),I=1,20)
   97 FORMAT(1X,15X,*RCM*,15X,*RCA*,//,20(2(10X,E14.7)/,1X))
  413 CONTINUE
   98 CONTINUE
      DO 7 I=1,20
      YC(I,LN)=Y(1,I)
      XR=REAL(C(18,I))
      XI=AIMAG(C(18,I))
      XN=-XI
      TT=CMPLX(XR,XN)
      PC(I,LN)=V(18,I)*TT
      UU=V(18,I)*TT
      PL(I,LN)=0.5*REAL(UU)
      XR=REAL(C(1,I))
      XI=AIMAG(C(1,I))
      XN=-XI
      TT=CMPLX(XR,XN)
      UU=V(1,I)*TT
      PI(I,LN)=0.5*REAL(UU)
      EA(I,LN)=PL(I,LN)/PI(I,LN)
      CMAG(I,LN)=CABS(CRFL(1,I))
      XR=REAL(CRFL(1,I))
      XI=AIMAG(CRFL(1,I))
      CANG(I,LN)=ATAN2(XI,XR)*180/PP
    7 CONTINUE
      DO 8 I=1,19
      XR=REAL(Y(1,I))
```

```
      XI=AIMAG(Y(1,I))
      J=I+1
      XJ=AIMAG(Y(1,J))
      QL(I,LN)=(18.7E9)*(XJ-XI)/(2*XR*0.1E9)
      RSA(I,LN)=(XJ-XI)/0.1
      QE(I,LN)=QL(I,LN)/EA(I,LN)
      QO(I,LN)=QE(I,LN)*QL(I,LN)/(QE(I,LN)-QL(I,LN))
    8 CONTINUE
      LN=LN-1
      CV=CV+VI
      IF(LN.EQ.0)10,11
   10 CONTINUE
      LN=LK
      DO 12 I=1,20
      YR(I)=REAL(YC(I,LK))
      YI(I)=AIMAG(YC(I,LK))
      RP(I)=PL(I,LK)
      E(I)=EA(I,LK)
      CMLIN(I)=CMAG(I,LK)
      CALIN(I)=CANG(I,LK)
   12 CONTINUE
      DO 13 I=1,19
      QLL(I)=QL(I,LK)
      QEL(I)=QE(I,LK)
      QOL(I)=QO(I,LK)
      RS(I)=RSA(I,LK)
   13 CONTINUE
      DO 91 I=1,LN
      LA=I
      IF(IW(8).EQ.0)415,416
  416 CONTINUE
      WRITE(2,90) LA,(EA(J,I),CMAG(J,I),CANG(J,I),PL(J,I),J=1,20)
   90 FORMAT(1X,25X,*LN*,I9,//,1X,25X,*EA*,25X,*CMAG*,25X,*CANG*,25X,
     +*LOAD POWER*,//,20(4(15X,E15.7)/,1X))
  415 CONTINUE
   91 CONTINUE
      DO 92 I=1,LN
      LA=I
      IF(IW(9).EQ.0)417,418
  418 CONTINUE
      WRITE(2,93) LA,(YC(J,I),PC(J,I),J=1,20)
   93 FORMAT(1X,25X,*LN*,I9,//,1X,25X,*YC*,50X,*PC*,//,
     +20(2(15X,E15.7,2X,E15.7,5X)/,1X))
  417 CONTINUE
   92 CONTINUE
      DO 94 I=1,LN
      LA=I
      IF(IW(10).EQ.0)419,420
  420 CONTINUE
      WRITE(2,95) LA,(QL(J,I),RSA(J,I), J=1,19)
   95 FORMAT(1X,25X,*LN*,I9,//,1X,25X,*QL*,25X,*RSA*,//,
     +19(2(15X,E15.7)/,1X))
  419 CONTINUE
   94 CONTINUE
      DO 302 K=1,7
      DO 303 J=1,LN
      DO 304 I=1,20
      SV(I,J,K)=0.0
      TH(I,J,1)=EA(I,J)
      TH(I,J,2)=REAL(PC(I,J))
      TH(I,J,3)=AIMAG(PC(I,J))
      TH(I,J,4)=REAL(YC(I,J))
      TH(I,J,5)=AIMAG(YC(I,J))
      TH(I,J,6)=CMAG(I,J)
      TH(I,J,7)=CANG(I,J)
  304 CONTINUE
  303 CONTINUE
  302 CONTINUE
      DO 305 K=1,7
      DO 306 J=1,LN
      BD=TH(20,J,K)
      BB=BD
      XP=0.0
      XM=0.0
      XMUM=0.0
      XSUM=0.0
      XK=1000.0
```

```
      WK=1000.0
      BWM=0.0
      KA=0.0
      KR=0.0
      IM=0.0
      INB=0.0
      BWA=0.0
      KB=1
      DO 307 I=1,20
      SV(1,J,K)=TH(I,J,K)+SV(1,J,K)
      SV(3,J,K)=(TH(I,J,K)**2)+SV(3,J,K)
      XS=TH(I,J,K)-TH(I,NR,K)
      IF(XS.GT.0.0)308,309
  308 XP=XP+1.0
      XSUM=XSUM+XS
      GO TO 310
  309 XM=XM+1.0
      XMUM=XMUM+XS
  310 CONTINUE
      WR=.95-TH(I,J,6)
      WT=ABS(WR)
      IF(WT.LT.WK)311,312
  311 KR=I
      WK=WT
  312 CONTINUE
      WA=-40-TH(I,J,7)
      WB=ABS(WA)
      IF(WB.LT.XK)313,314
  313 KA=I
      XK=WB
  314 CONTINUE
      IF(TH(I,J,6).LT.0.985)315,316
  315 IF(TH(I,J,6).GT.0.93)317,318
  317 BWM=BWM+1.0
  316 CONTINUE
  318 CONTINUE
      IF(TH(I,J,7).GT.-45.0)319,320
  319 IF(TH(I,J,7).LT.-35.0)321,322
  321 BWA=BWA+1.0
  320 CONTINUE
  322 CONTINUE
      BC=TH(I,J,K)-BD
      IF(BC.GT.0.0)323,324
  323 BD=TH(I,J,K)
      IM=I
  324 CONTINUE
      BC=TH(I,J,K)-BB
      IF(BC.LT.0.0)325,326
  325 BB=TH(I,J,K)
      INB=I
  326 CONTINUE
  307 CONTINUE
      SV(2,J,K)=(((SV(3,J,K)-(SV(1,J,K)**2)/20)/19)**0.5)
      SV(1,J,K)=SV(1,J,K)/20
      SV(3,J,K)=XP
      SV(5,J,K)=XM
      IF(XP.EQ.0.0)327,328
  328 SV(4,J,K)=XSUM/XP
      GO TO 329
  327 SV(4,J,K)=0.0
  329 CONTINUE
      SV(12,J,K)=17.6E9+0.1E9*KR
      SV(13,J,K)=17.6E9+0.1E9*KA
      SV(14,J,K)=BWM
      SV(16,J,K)=BWA
      SV(15,J,K)=TH(10,J,6)
      IF(XM.EQ.0.0)842,843
  843 SV(10,J,K)=XMUM/XM
      GO TO 844
  842 SV(10,J,K)=0.0
  844 CONTINUE
      XDL=TH(10,J,6)*COS(TH(10,J,7))
      YDL=TH(10,J,6)*SIN(TH(10,J,7))
      XDP=TH(9,J,6)*COS(TH(9,J,7))
      YDP=TH(9,J,6)*SIN(TH(9,J,7))
      DTT=((YDP-YDL)/(XDP-XDL))
      DT=ATAN(DTT)*180/PP
```

```
      SV(11,J,K)=-TH(10,J,7)-DT
      SV(6,J,K)=BD
      IF(IM.EQ.0)560,561
  560 IM=20
  561 CONTINUE
      IF(INB.EQ.0)562,563
  562 INB=20
  563 CONTINUE
      SV(7,J,K)=17.6E9+0.1E9*IM
      SV(8,J,K)=BB
      SV(9,J,K)=17.6E9+0.1E9*INB
  306 CONTINUE
  305 CONTINUE
      DO 702 K=8,11
      DO 703 J=1,LN
      DO 704 I=1,19
      SV(I,J,K)=0.0
      TH(I,J,8)=RSA(I,J)
      TH(I,J,9)=QL(I,J)
      TH(I,J,10)=QO(I,J)
      TH(I,J,11)=QE(I,J)
  704 CONTINUE
  703 CONTINUE
  702 CONTINUE
      DO 705 K=8,11
      DO 706 J=1,LN
      BD=TH(19,J,K)
      BB=BD
      XP=0.0
      XM=0.0
      XMUM=0.0
      XSUM=0.0
      XK=0.0
      WK=0.0
      BWM=0.0
      KA=0.0
      KR=0.0
      IM=0.0
      INB=0.0
      BWA=0.0
      KB=1
      DO 707 I=1,19
      SV(17,J,K)=TH(I,J,K)+SV(17,J,K)
      SV(19,J,K)=(TH(I,J,K)**2)+SV(19,J,K)
      XS=TH(I,J,K)-TH(I,NR,K)
      IF(XS.GT.0.0)708,709
  708 XP=XP+1.0
      XSUM=XSUM+XS
      GO TO 710
  709 XM=XM+1.0
      XMUM=XMUM+XS
  710 CONTINUE
      BC=TH(I,J,K)-BD
      IF(BC.GT.0.0)723,724
  723 BD=TH(I,J,K)
      IM=I
  724 CONTINUE
      BC=TH(I,J,K)-BB
      IF(BC.LT.0.0)725,726
  725 BB=TH(I,J,K)
      INB=I
  726 CONTINUE
  707 CONTINUE
      SV(18,J,K)=(((SV(19,J,K)-(SV(17,J,K)**2)/19)/18)**0.5)
      SV(17,J,K)=SV(17,J,K)/19
      SV(19,J,K)=XP
      SV(21,J,K)=XM
      IF(XP.EQ.0.0)727,728
  728 SV(20,J,K)=XSUM/XP
      GO TO 729
  727 SV(20,J,K)=0.0
  729 CONTINUE
      IF(IM.EQ.0)555,556
  555 IM=20
  556 CONTINUE
      IF(INB.EQ.0)557,558
  557 INB=20
```

```
 558 CONTINUE
     SV(22,J,K)=BD
     SV(23,J,K)=17.6E9+0.1E9*IM
     SV(24,J,K)=BB
     SV(25,J,K)=17.6E9+0.1E9*INB
     IF(XM.EQ.0.0)845,846
 846 SV(26,J,K)=XMUM/XM
     GO TO 847
 845 SV(26,J,K)=0.0
 847 CONTINUE
 706 CONTINUE
 705 CONTINUE
     DO 840 I=1,15
     DO 841 J=1,15
     VAKP(I,J)=0.0
     PKEP(I,J)=0.0
     AKEP(I,J)=0.0
     IKEP(I,J)=0
 841 CONTINUE
 840 CONTINUE
     ILKK=LK+1
     DO 822 I=1,10
     DO 823 K=1,7
     WMAT=-1000.0
     DAY=1000.0
     CAY=1000.0
     WAY=1000.0
     DO 824 J=1,LN
     IF(I.EQ.5)251,252
 251 IF(J.EQ.NR)253,252
 252 CONTINUE
     WMAS=SV(I,J,K)-WMAT
     IF(WMAS.GT.0.0)820,821
 820 WMAT=SV(I,J,K)
     IKEP(I,K)=ILKK-J
     AKEP(I,K)=CVS+VI*(ILKK-J-1)
     VAKP(I,K)=SV(I,J,K)
     PKEP(I,K)=(SV(I,J,K)-SV(I,NR,K))*100/SV(I,NR,K)
 821 CONTINUE
 253 CONTINUE
     WMAY=SV(5,J,K)-WAY
     IF(WMAY.LT.0.0)280,281
 280 IKEP(7,K)=ILKK-J
     WAY=SV(5,J,K)
     PKEP(7,K)=(SV(5,J,K)-SV(5,NR,K))*100/SV(5,NR,K)
     VAKP(7,K)=SV(5,J,K)
     AKEP(7,K)=CVS+VI*(ILKK-J-1)
 281 CONTINUE
     WDAY=SV(2,J,K)-DAY
     IF(WDAY.LT.0.0)282,283
 282 IKEP(9,K)=ILKK-J
     PKEP(9,K)=(SV(2,J,K)-SV(2,NR,K))*100/SV(2,NR,K)
     AKEP(9,K)=CVS+VI*(ILKK-J-1)
     VAKP(9,K)=SV(2,J,K)
     DAY=SV(2,J,K)
 283 CONTINUE
     IF(J.EQ.NR)254,255
 255 CONTINUE
     WCAY=SV(10,J,K)-CAY
     IF(WCAY.LT.0.0)284,285
 284 CAY=SV(10,J,K)
     IKEP(10,K)=ILKK-J
     AKEP(10,K)=CVS+VI*(ILKK-J-1)
     VAKP(10,K)=SV(10,J,K)
 285 CONTINUE
 254 CONTINUE
 824 CONTINUE
     IF(IKEP(I,K).EQ.0)268,269
 268 IKEP(I,K)=1
 269 CONTINUE
     IF(AKEP(I,K).EQ.0.0)270,271
 270 AKEP(I,K)=CVS
 271 CONTINUE
     IF(VAKP(I,K).EQ.0.0)272,273
 272 VAKP(I,K)=SV(I,NR,K)
 273 CONTINUE
     PKEP(10,K)=0.0
```

```
      PKEP(3,K)=0.0
      PKEP(4,K)=0.0
      PKEP(5,K)=0.0
  823 CONTINUE
  822 CONTINUE
      DO 825 I=17,26
      DO 826 K=8,11
      WMAR=-1000.0
      WAY=1000.0
      DAY=1000.0
      CAY=1000.0
      DO 827 J=1,LN
      IRV=I-16
      IF(IRV.EQ.5)640,641
  640 IF(J.EQ.NR)642,641
  641 CONTINUE
      WMAS=SV(I,J,K)-WMAR
      IF(WMAS.GT.0.0)826,829
  828 WMAR=SV(I,J,K)
      IKEP(IRV,K)=ILKK-J
      AKEP(IRV,K)=CVS+VI*(ILKK-J-1)
      VAKP(IRV,K)=SV(I,J,K)
      PKEP(IRV,K)=(SV(I,J,K)-SV(I,NR,K))*100/SV(I,NR,K)
  829 CONTINUE
  642 CONTINUE
      WMAY=SV(18,J,K)-WAY
      IF(WMAY.LT.0.0)286,287
  286 IKEP(9,K)=ILKK-J
      WAY=SV(18,J,K)
      PKEP(9,K)=(SV(18,J,K)-SV(18,NR,K))*100/SV(18,NR,K)
      VAKP(9,K)=SV(18,J,K)
      AKEP(9,K)=CVS+VI*(ILKK-J-1)
  287 CONTINUE
      WDAY=SV(21,J,K)-DAY
      IF(WDAY.LT.0.0)288,289
  288 DAY=SV(21,J,K)
      IKEP(7,K)=ILKK-J
      PKEP(7,K)=(SV(21,J,K)-SV(21,NR,K))*100/SV(21,NR,K)
      VAKP(7,K)=SV(21,J,K)
      AKEP(7,K)=CVS+VI*(ILKK-J-1)
  289 CONTINUE
      IF(J.EQ.NR)643,644
  644 CONTINUE
      WCAY=SV(26,J,K)-CAY
      IF(WCAY.LT.0.0)290,291
  290 CAY=SV(26,J,K)
      IKEP(10,K)=ILKK-J
      AKEP(10,K)=CVS+VI*(ILKK-J-1)
  291 CONTINUE
  643 CONTINUE
  827 CONTINUE
      IF(IKEP(I,K).EQ.0)260,261
  260 IKEP(I,K)=1
  261 CONTINUE
      IF(AKEP(I,K).EQ.0.0)262,263
  262 AKEP(I,K)=CVS
  263 CONTINUE
      IF(VAKP(I,K).EQ.0.0)264,265
  264 VAKP(I,K)=SV(I,NR,K)
  265 CONTINUE
      PKEP(3,K)=0.0
      PKEP(4,K)=0.0
      PKEP(5,K)=0.0
      PKEP(10,K)=0.0
  826 CONTINUE
  825 CONTINUE
      IF(IWTE.EQ.0)736,735
  736 MEXT(1)=9HNO LOSSES
  735 CONTINUE
      IF(IWBR.EQ.0)740,739
  740 MEXT(2)=9H   NO ERF
  739 CONTINUE
      IF(IWTA.EQ.0)744,743
  744 MEXT(3)=9H   NO TS1
  743 CONTINUE
      IF(IWTB.EQ.0)748,747
  748 MEXT(4)=9H   NO TS2
```

```
747 CONTINUE
    IF(IW(19).EQ.0)750,751
751 MEXT(5)=IEXT
750 CONTINUE
    IF(IW(20).EQ.0)850,851
851 CONTINUE
    WRITE(2,865)(IDASH(I),I=1,14),(MEXT(M),M=1,5)
865 FORMAT(1H1,///,13A10,A5,/,1X,5(2X,A10,1X))
    WRITE(2,860)(IDASH(I),I=1,14)
    STRY=DATE(MTRY)
    RN=CVS+VI*(LK-NR)
    WRITE(2,551)IBCE,CVS,CVF,STRY,RN
551 FORMAT(1X,A10,* VARYING FROM *,G12.4,* TO *,G12.4,2X,A10,1X,
   +*BEST VALUE ORDER-PERCENT,INCR,VAR VALUE,BEST VALUE*,1X,*RN=*,
   +G12.4)
    WRITE(2,860)(IDASH(I),I=1,14)
    WRITE(2,901)
901 FORMAT(1X,*$*,12X,*$*,1X,*EFFICIENCY*,1X,*$*,2X,*LOAD PWR*,2X,*$*,
   +4X,*Y IN*,4X,*$*,4X,*MRFL*,4X,*$*,4X,*ARFL*,4X,*$*,5X,*RS*,5X,*$*,
   +5X,*QL*,5X,*$*,5X,*QO*,5X,*$*,5X,*QE*,5X,*$*)
    WRITE(2,860)(IDASH(I),I=1,14)
    WRITE(2,860)(IDASH(I),I=1,14)
    ISTAT(7)=7H- SMALL
    ISTAT(9)=7H   - SD
    DO 630 I=1,10
    WRITE(2,903)ISTAT(I),ISTAY(1),PKEP(I,1),PKEP(I,2),PKEP(I,4),
   +(PKEP(I,K),K=6,11),PKEP(I,3),PKEP(I,5)
903 FORMAT(1X,A10,1X,A1,1X,9(G12.4,1X),/,19X,*IMAG*,5X,G12.4,2X,G12.4)
    WRITE(2,904)ISTAY(2),IKEP(I,1),IKEP(I,2),IKEP(I,4),
   +(IKEP(I,K),K=6,11),IKEP(I,3),IKEP(I,5)
904 FORMAT(1X,11X,A1,1X,9(4X,I4,5X),/,19X,*IMAG*,5X,4X,I4,4X,2X,
   +4X,I4,)
    WRITE(2,905)ISTAY(3),AKEP(I,1),AKEP(I,2),AKEP(I,4),
   +(AKEP(I,K),K=6,11),AKEP(I,3),AKEP(I,5)
905 FORMAT(1X,11X,A1,1X,9(G12.4,1X),/,19X,*IMAG*,5X,G12.4,2X,G12.4)
    WRITE(2,906)ISTAY(4),VAKP(I,1),VAKP(I,2),VAKP(I,4),
   +(VAKP(I,K),K=6,11),VAKP(I,3),VAKP(I,5)
906 FORMAT(1X,11X,A1,1X,9(G12.4,1X),/,19X,*IMAG*,5X,G12.4,2X,G12.4)
    WRITE(2,860)(IDASH(M),M=1,14)
830 CONTINUE
    ISTAT(7)=7HF LARGE
    ISTAT(9)=7HF SMALL
850 CONTINUE
    IF(IW(18).EQ.0)730,731
731 CONTINUE
    ILRV=LK+1
    DO 732 L=1,LN
    LIRV=ILRV-L
    WRITE(2,867)(IDASH(I),I=1,10),IDASH(14),(MEXT(M),M=1,4)
867 FORMAT(1H1,///,10A10,A5,/,1X,4(2X,A10,1X))
    WRITE(2,861)(IDASH(I),I=1,1C),IDASH(14)
    WRITE(2,911)IBCD(1),CVX,CVS,CVF,STRY,MEXT(5)
911 FORMAT(1X,*$*,1X,A13,G12.4,1X,*$*,2X,*IN *,G10.4,* TO *,G10.4,*$*,
   +8X,A10,4X,*$*,3X,A20)
    WRITE(2,861)(IDASH(I),I=1,1C),IDASH(14)
    WRITE(2,913)SV(11,L,6),SV(12,L,6),SV(13,L,6),SV(14,L,6)
913 FORMAT(1X,*$*,3X,*DEV ANG =*,G12.4,3X,*$*,1X,*F NEAR .95 =*,G12.4,
   +2X,*$*,2X,*F NEAR-40 =*,G12.4,2X,*$*,3X,*.95BW =*,G12.4)
    WRITE(2,861)(IDASH(I),I=1,10),IDASH(14)
    WRITE(2,915)SV(16,L,6),LIRV
915 FORMAT(1X,*$*,3X,*-40 BW =*,G12.4,4X,*$*,5X,*VARIABLE INCR *,I2,
   +6X,27X,*$*)
    WRITE(2,861)(IDASH(I),I=1,10),IDASH(14)
    WRITE(2,861)(IDASH(I),I=1,10),IDASH(14)
    WRITE(2,918)
918 FORMAT(1X,*$*,5X,*FREQ*,4X,*$*,2X,*EFFICIENCY*,1X,*$*,7X,
   +*LOAD POWER*,10X,*$*,5X,*INPUT ADMITANCE*,5X,*$*,2X,*MAG RFL*,
   +2X,*$*,3X,*ANG RFL*)
    WRITE(2,861)(IDASH(I),I=1,10),IDASH(14)
    IDAS=0
    DO 5?0 J=1,5
    DO ??1 I=1,4
    IDAS=IDAS+1
    WRITE(2,92?)FREQ(IDAS),EA(IDAS,L),PC(IDAS,L),YC(IDAS,L),
   +CMAG(IDAS,L),CANG(IDAS,L)
920 FORMAT(1X,2X,G12.4,2X,G12.4,2X,G12.4,1X,G12.4,2X,G12.4,1X,G12.4,
   +2X,G12.4,2X,G12.4,)
```

```
801 CONTINUE
    WRITE(2,861)(IDASH(I),I=1,10),IDASH(14)
800 CONTINUE
    WRITE(2,861)(IDASH(I),I=1,10),IDASH(14)
    IDAS=0
    DO 802 J=1,2
    DO 803 I=1,5
    IDAS=IDAS+1
    WRITE(2,923)ISTAT(IDAS),SV(IDAS,L,1),SV(IDAS,L,2),SV(IDAS,L,3),
   +SV(IDAS,L,4),SV(IDAS,L,5),SV(IDAS,L,6),SV(IDAS,L,7)
923 FORMAT(1X,2X,A10,4X,G12.4,2X,G12.4,1X,G12.4,2X,G12.4,1X,G12.4,2X,
   +2X,G12.4,2X,G12.4)
803 CONTINUE
    WRITE(2,861)(IDASH(I),I=1,10),IDASH(14)
802 CONTINUE
    WRITE(2,861)(IDASH(I),I=1,10),IDASH(14)
    WRITE(2,862)(IDASH(I),I=1,6),IDASH(14)
    WRITE(2,927)
927 FORMAT(1X,*$*,4X,*FREQ*,5X,*$*,2X,*YIN SLOPE*,3X,*$*,3X,*QL*,
   +5X,*$*,6X,*QO*,5X,*$*,6X,*QE*)
    WRITE(2,862)(IDASH(I),I=1,6),IDASH(14)
    IDAS=0
    DO 804 J=1,5
    DO 805 I=1,4
    IDAS=IDAS+1
    IF(IDAS.EQ.20)806,807
807 CONTINUE
    WRITE(2,929)FREQ(IDAS),RSA(IDAS,L),QL(IDAS,L),QO(IDAS,L),
   +QE(IDAS,L)
929 FORMAT(1X,2X,G12.4,2X,G12.4,2X,G12.4,1X,G12.4,2X,G12.4)
806 CONTINUE
805 CONTINUE
    WRITE(2,862)(IDASH(I),I=1,6),IDASH(14)
804 CONTINUE
    WRITE(2,862)(IDASH(I),I=1,6),IDASH(14)
    IDAS=16
    IDAT=0
    DO 808 J=1,2
    DO 809 I=1,5
    IDAT=IDAT+1
    IDAS=IDAS+1
    WRITE(2,932)ISTAT(IDAT),SV(IDAS,L,8),SV(IDAS,L,9),SV(IDAS,L,10),
   +SV(IDAS,L,11)
932 FORMAT(1X,2X,A10,4X,G12.4,2X,G12.4,1X,G12.4,2X,G12.4)
809 CONTINUE
    WRITE(2,862)(IDASH(I),I=1,6),IDASH(14)
808 CONTINUE
    CVX=CVX-VI
732 CONTINUE
730 CONTINUE
860 FORMAT(1X,13A10,A5)
861 FORMAT(1X,10A10,A5)
862 FORMAT(1X,6A10,A5)
    IF(IW(11).EQ.0)421,422
421 CONTINUE
    CALL PLOTS(BUFF,257,0)
    CALL PLIMIT (25.0)
    CALL PLOT (4.21875,5.21875,23)
    CALL SYMBOL(1.0,9.0,.28,12HREFL. COEFF.,0,12)
    CALL SYMBOL(1.0,8.0,.28,3HAS ,0,3)
    CALL SYMBOL(999.0,999.0,.28,IBCE,0,IC)
    CALL SYMBOL(999.0,999.0,.28,7H VARIES,0,7)
    CALL PLOT(1.0,8.9,3)
    CALL PLOT(4.25,8.9,2)
    CALL PLOT(1.0,7.9,3)
    CALL PLOT(4.25,7.9,2)
    WX=7.5
    IF(IWTE.EQ.0)332,333
332 CALL SYMBOL(2.0,WX,.14,9HNO LOSSES,0,9)
    WX=WX-0.5
333 CONTINUE
    IF(IWBR.EQ.0)334,335
334 CONTINUE
    CALL SYMBOL(2.0,WX,.14,6HNO BRF,0,6)
    WX=WX-0.5
335 CONTINUE
    IF(IWTA.EQ.0)336,337
```

```
  336 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS1,0,6)
      WX=WX-0.5
  337 CONTINUE
      IF(IWTB.EQ.0)338,339
  338 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS2,0,6)
      WX=WX-0.5
  339 CONTINUE
      IF(IW(19).EQ.0)758,759
  759 CALL SYMBOL(2.0,WX,.14,IEXT,0,IEXL)
  758 CONTINUE
      CALL SYMBOL(6.0,3.5,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVF,0,IN)
      CALL SYMBOL(6.0,1.0,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVS,0,IN)
      TVR=3.21875*CMAG(3,1)
      TVP=CANG(3,1)*PP/180
      TVX=TVR*COS(TVP)
      TVY=TVR*SIN(TVP)
      CALL DASHLN(6.0,3.5,TVX,TVY,.042,.042)
      TVR=3.21875*CMAG(5,LN)
      TVP=CANG(5,LN)*PP/180
      TVX=TVR*COS(TVP)
      TVY=TVR*SIN(TVP)
      CALL DASHLN(6.0,1.0,TVX,TVY,.042,.042)
      CALL AXIT (-3.21875,-3.21875,3HMAG,-3,0.3106796,0,
     1-1,0.25,1,1,0.112,0.2,0.112,0)
      CALL SYMBOL (-3.7,0,.14,3H180,0,3)
      CALL SYMBOL (0,3.3,.14,2H90,0,2)
      CALL SYMBOL (3.7,0,.14,1H0,0,1)
      CALL PLOT (-3.21875,0,3)
      CALL PLOT (3.21875,0,2)
      CALL PLOT (0,3.21875,3)
      CALL PLOT (0,3.0,2)
      CALL PLOT (0,0.1,3)
      CALL PLOT (0,-0.1,2)
      CALL PLOT (0,0,3)
      CALL CIRCLE (0.,0.,0.,360.,3.21875)
   17 CONTINUE
      CALL POLAR (CMLIN,CALIN,20,1,2,11,-3.21875,3.21875)
      LN=LN-1
      IF(LN.EQ.0)16,18
   18 DO 15 I=1,20
      CMLIN(I)=CMAG(I,LN)
      CALIN(I)=CANG(I,LN)
   15 CONTINUE
      GO TO 17
   16 CONTINUE
      CALL PLOT(10.0,-5.21875,23)
      CALL PLOT (0.,0.,3)
      CALL PLOT(0.0,0.0,999)
  422 CONTINUE
      IF(IW(12).EQ.0)423,424
  423 CONTINUE
      LN=LK
      CALL PLOTS(BUFF,257,0)
      CALL PLIMIT (25.0)
      CALL PLOT(2.0,1.0,23)
      CALL SCALE(YR(1),5.0,20,1)
      CALL SCALE(FREQ(1),5.0,20,1)
      CALL AXIS(0.,0.,4HFREQ,-4,5.,0.,FREQ(21),FREQ(22))
      CALL AXIS(0.,0.,6HY REAL,6,5.,90.,YR(21),YR(22))
      CALL SYMBOL(1.0,9.0,.28,12HY REAL VS. F,0,12)
      CALL SYMBOL(1.0,8.0,.28,3HAS ,0,3)
      CALL SYMBOL(999.0,999.0,.28,IBCD,0,IC)
      CALL SYMBOL(999.0,999.0,.28,7H VARIES,0,7)
      CALL PLOT(1.0,8.9,3)
      CALL PLOT(4.25,8.9,2)
      CALL PLOT(1.0,7.9,3)
      CALL PLOT(4.25,7.9,2)
      WX=7.5
      IF(IWTS.EQ.0)342,343
  342 CONTINUE
      CALL SYMBOL(2.0,WX,.14,9HNO LOSSES,0,9)
      WX=WX-0.5
  343 CONTINUE
```

```
      IF(IWBR.EQ.0)344,345
  344 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO BRF,0,6)
      WX=WX-0.5
  345 CONTINUE
      IF(IWTA.EQ.0)346,347
  346 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS1,0,6)
      WX=WX-0.5
  347 CONTINUE
      IF(IWTB.EQ.0)348,349
  348 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS2,0,6)
      WX=WX-0.5
  349 CONTINUE
      IF(IW(19).EQ.0)760,761
  761 CALL SYMBOL(2.0,WX,.14,IEXT,0,IEXL)
  760 CONTINUE
      CALL SYMBOL(6.0,3.5,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVF,0,IN)
      CALL SYMBOL(6.0,1.0,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVS,0,IN)
      TVN=REAL(YC(3,1))
      TVY=(TVN-YR(21))/YR(22)
      TVX=(FREQ(3)-FREQ(21))/FREQ(22)
      CALL DASHLN(6.C,3.5,TVX,TVY,.042,.042)
      TVN=REAL(YC(5,LN))
      TVY=(TVN-YR(21))/YR(22)
      TVX=(FREQ(5)-FREQ(21))/FREQ(22)
      CALL DASHLN(6.0,1.0,TVX,TVY,.042,.042)
   19 CONTINUE
      CALL LINE(FREQ,YR,20,1,1,11)
      LN=LN-1
      IF(LN.EQ.0)20,21
   21 DO 22 I=1,20
      YR(I)=REAL(YC(I,LN))
   22 CONTINUE
      GO TO 19
   20 CONTINUE
      CALL PLOT(0.,0.,3)
      CALL PLOT(10.0,-1,23)
      CALL PLOT(0.0,0.0,999)
  424 CONTINUE
      IF(IW(13).EQ.0)425,426
  425 CONTINUE
      LN=LK
      CALL PLOTS(BUFF,257,0)
      CALL PLIMIT (25.0)
      CALL PLOT(2.0,1.0,23)
      CALL SCALE(YI(1),5.0,20,1)
      CALL SCALE(FREQ(1),5.0,20,1)
      CALL AXIS(0.,0.,4HFREQ,-4,5.,0.,FREQ(21),FREQ(22))
      CALL AXIS(0.,0.,6HY IMAG,6,5.,90.,YI(21),YI(22))
      CALL SYMBOL(1.0,9.0,.28,12HY IMAG VS. F,0,12)
      CALL SYMBOL(1.0,8.0,.28,3HAS ,0,3)
      CALL SYMBOL(999.0,999.0,.28,IBCE,0,IC)
      CALL SYMBOL(999.0,999.0,.28,7H VARIES,0,7)
      CALL PLOT(1.0,8.9,3)
      CALL PLOT(4.25,8.9,2)
      CALL PLOT(1.0,7.9,3)
      CALL PLOT(4.25,7.9,2)
      WX=7.5
      IF(IWTE.EQ.0)352,353
  352 CONTINUE
      CALL SYMBOL(2.0,WX,.14,9HNO LOSSES,0,9)
      WX=WX-0.5
  353 CONTINUE
      IF(IWBR.EQ.0)354,355
  354 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO BRF,0,6)
      WX=WX-0.5
  355 CONTINUE
      IF(IWTA.EQ.0)356,357
  356 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS1,0,6)
      WX=WX-0.5
  357 CONTINUE
```

```
      IF(IWTB.EQ.0)358,359
  358 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS2,0,6)
      WX=WX-0.5
  359 CONTINUE
      IF(IW(19).EQ.0)762,763
  763 CALL SYMBOL(2.0,WX,.14,IEXT,0,IEXL)
  762 CONTINUE
      CALL SYMBOL(6.0,3.5,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVS,0,IN)
      CALL SYMBOL(6.0,1.0,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVF,0,IN)
      TVN=AIMAG(YC(3,1))
      TVY=(TVN-YI(21))/YI(22)
      TVX=(FREQ(3)-FREQ(21))/FREQ(22)
      CALL DASHLN(6.0,1.0,TVX,TVY,.042,.042)
      TVN=AIMAG(YC(5,LN))
      TVY=(TVN-YI(21))/YI(22)
      TVX=(FREQ(5)-FREQ(21))/FREQ(22)
      CALL DASHLN(6.0,3.5,TVX,TVY,.042,.042)
   35 CONTINUE
      CALL LINE(FREQ,YI,20,1,1,11)
      LN=LN-1
      IF(LN.EQ.0)36,37
   37 DO 38 I=1,20
      YI(I)=AIMAG(YC(I,LN))
   38 CONTINUE
      GO TO 35
   36 CONTINUE
      CALL PLOT(0.,0.,3)
      CALL PLOT(10.0,-1,23)
      CALL PLOT(0.0,0.0,999)
  426 CONTINUE
      IF(IW(14).EQ.0)427,428
  427 CONTINUE
      LN=LK
      CALL PLOTS(BUFF,257,0)
      CALL PLIMIT (25.0)
      CALL PLOT(2.0,1.0,23)
      CALL SCALE(RP(1),5.0,20,1)
      CALL SCALE(FREQ(1),5.0,20,1)
      CALL AXIS(0.,0.,4HFREQ,-4,5.,0.,FREQ(21),FREQ(22))
      CALL AXIS(0.,0.,6HR PWR.,6,5.,90.,RP(21),RP(22))
      CALL SYMBOL(1.0,9.0,.28,12HR PWR. VS. F,0,12)
      CALL SYMBOL(1.0,8.0,.28,3HAS ,0,3)
      CALL SYMBOL(999.0,999.0,.28,IBCE,0,IC)
      CALL SYMBOL(999.0,999.0,.28,7H VARIES,0,7)
      CALL PLOT(1.0,8.9,3)
      CALL PLOT(4.25,8.9,2)
      CALL PLOT(1.0,7.9,3)
      CALL PLOT(4.25,7.9,2)
      WX=7.5
      IF(IWTE.EQ.0)362,363
  362 CONTINUE
      CALL SYMBOL(2.0,WX,.14,9HNO LOSSES,0,9)
      WX=WX-0.5
  363 CONTINUE
      IF(IWBR.EQ.0)364,365
  364 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO BRF,0,6)
      WX=WX-0.5
  365 CONTINUE
      IF(IWTA.EQ.0)366,367
  366 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS1,0,6)
      WX=WX-0.5
  367 CONTINUE
      IF(IWTB.EQ.0)368,369
  368 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS2,C,6)
      WX=WX-0.5
  369 CONTINUE
      IF(IW(19).EQ.0)764,765
  765 CALL SYMBOL(2.0,WX,.14,IEXT,0,IEXL)
  764 CONTINUE
      CALL SYMBOL(6.0,3.5,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVS,0,IN)
```

```
      CALL SYMBOL(6.0,1.0,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVF,0,IN)
      TVN=PL(3,1)
      TVY=(TVN-RP(21))/RP(22)
      TVX=(FREQ(3)-FREQ(21))/FREQ(22)
      CALL DASHLN(6.0,1.0,TVX,TVY,.042,.042)
      TVN=PL(5,LN)
      TVY=(TVN-RP(21))/RP(22)
      TVX=(FREQ(5)-FREQ(21))/FREQ(22)
      CALL DASHLN(6.0,3.5,TVX,TVY,.042,.042)
   45 CONTINUE
      CALL LINE(FREQ,RP,20,1,1,11)
      LN=LN-1
      IF(LN.EQ.0)46,47
   47 DO 48 I=1,20
      RP(I)=PL(I,LN)
   48 CONTINUE
      GO TO 45
   46 CONTINUE
      CALL PLOT(0.,0.,3)
      CALL PLOT(10.0,-1,23)
      CALL PLOT(0.0,0.0,999)
  428 CONTINUE
      IF(IW(15).EQ.0)429,430
  429 CONTINUE
      LN=LK
      CALL PLOTS(BUFF,257,0)
      CALL PLIMIT (25.0)
      CALL PLOT(2.0,1.0,23)
      CALL SCALE(E(1),5.0,20,1)
      CALL SCALE(FREQ(1),5.0,20,1)
      CALL AXIS(0.,0.,4HFREQ,-4,5.,0.,FREQ(21),FREQ(22))
      CALL AXIS(0.,0.,6HEFF.  ,6,5.,90.,E(21),E(22))
      CALL SYMBOL(1.0,9.0,.28,10HEFF. VS. F,0,10)
      CALL SYMBOL(1.0,8.0,.28,3HAS ,0,3)
      CALL SYMBOL(999.0,999.0,.28,IBCE,0,IC)
      CALL SYMBOL(999.0,999.0,.28,7H VARIES,0,7)
      CALL PLOT(1.0,8.9,3)
      CALL PLOT(4.25,8.9,2)
      CALL PLOT(1.0,7.9,3)
      CALL PLOT(4.25,7.9,2)
      WX=7.5
      IF(IWTE.EQ.0)372,373
  372 CONTINUE
      CALL SYMBOL(2.0,WX,.14,9HNO LOSSES,0,9)
      WX=WX-0.5
  373 CONTINUE
      IF(IWBR.EQ.0)374,375
  374 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO BRF,0,6)
      WX=WX-0.5
  375 CONTINUE
      IF(IWTA.EQ.0)376,377
  376 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS1,0,6)
      WX=WX-0.5
  377 CONTINUE
      IF(IWTB.EQ.0)378,379
  378 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS2,0,6)
      WX=WX-0.5
  379 CONTINUE
      IF(IW(19).EQ.0)766,767
  767 CALL SYMBOL(2.0,WX,.14,IEXT,0,IEXL)
  766 CONTINUE
      CALL SYMBOL(6.0,3.5,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVS,0,IN)
      CALL SYMBOL(6.0,1.0,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVF,0,IN)
      TVN=EA(3,1)
      TVY=(TVN-E(21))/E(22)
      TVX=(FREQ(3)-FREQ(21))/FREQ(22)
      CALL DASHLN(6.0,1.0,TVX,TVY,.042,.042)
      TVN=EA(5,LN)
      TVY=(TVN-E(21))/E(22)
      TVX=(FREQ(5)-FREQ(21))/FREQ(22)
      CALL DASHLN(6.0,3.5,TVX,TVY,.042,.042)
```

```
   55 CONTINUE
      CALL LINE(FREQ,E,20,1,1,11)
      LN=LN-1
      IF(LN.EQ.0)56,57
   57 DO 58 I=1,20
      E(I)=EA(I,LN)
   58 CONTINUE
      GO TO 55
   56 CONTINUE
      CALL PLOT(0.,0.,3)
      CALL PLOT(10.0,-1,23)
      CALL PLOT(0.0,0.0,999)
  430 CONTINUE
      IF(IW(16).EQ.0)431,432
  431 CONTINUE
      LN=LK
      CALL PLOTS(BUFF,257,0)
      CALL PLIMIT (25.0)
      CALL PLOT(2.0,1.0,23)
      CALL SCALE(QLL(1),5.0,19,1)
      CALL SCALE(FREQ(1),5.0,19,1)
      CALL AXIS(0.,0.,4HFREQ,-4,5.,0.,FREQ(20),FREQ(21))
      CALL AXIS(0.,0.,6HQLL.  ,6,5.,90.,QLL(20),QLL(21))
      CALL SYMBOL(1.0,9.0,.28,8HQL VS. F,0,8)
      CALL SYMBOL(1.0,8.0,.28,3HAS ,0,3)
      CALL SYMBOL(999.0,999.0,.28,IBCE,0,IC)
      CALL SYMBOL(999.0,999.0,.28,7H VARIES,0,7)
      CALL PLOT(1.0,8.9,3)
      CALL PLOT(4.25,8.9,2)
      CALL PLOT(1.0,7.9,3)
      CALL PLOT(4.25,7.9,2)
      WX=7.5
      IF(IWTE.EQ.0)382,383
  382 CONTINUE
      CALL SYMBOL(2.0,WX,.14,9HNO LOSSES,0,9)
      WX=WX-0.5
  383 CONTINUE
      IF(IWBR.EQ.0)384,385
  384 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO BRF,0,6)
      WX=WX-0.5
  385 CONTINUE
      IF(IWTA.EQ.0)386,387
  386 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS1,0,6)
      WX=WX-0.5
  387 CONTINUE
      IF(IWTB.EQ.0)388,389
  388 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS2,0,6)
      WX=WX-0.5
  389 CONTINUE
      IF(IW(19).EQ.0)768,769
  769 CALL SYMBOL(2.0,WX,.14,IEXT,0,IEXL)
  768 CONTINUE
      CALL SYMBOL(6.0,3.5,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVS,0,IN)
      CALL SYMBOL(6.0,1.0,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVF,0,IN)
      TVN=QL(3,1)
      TVY=(TVN-QLL(20))/QLL(21)
      TVX=(FREQ(3)-FREQ(20))/FREQ(21)
      CALL DASHLN(6.0,1.0,TVX,TVY,.042,.042)
      TVN=QL(5,LN)
      TVY=(TVN-QLL(20))/QLL(21)
      TVX=(FREQ(5)-FREQ(20))/FREQ(21)
      CALL DASHLN(6.0,3.5,TVX,TVY,.042,.042)
   65 CONTINUE
      CALL LINE(FREQ,QLL,19,1,1,11)
      LN=LN-1
      IF(LN.EQ.0)66,67
   67 DO 68 I=1,19
      E(I)=EA(I,LK)
      QLL(I)=QL(I,LN)
   68 CONTINUE
      GO TO 65
   66 CONTINUE
```

```
      CALL PLOT(0.,0.,3)
      CALL PLOT(10.0,-1,23)
      CALL PLOT(0.0,0.0,999)
  432 CONTINUE
      IF(IW(17).EQ.0)433,434
  433 CONTINUE
      LN=LK
      CALL PLOTS(BUFF,257,0)
      CALL PLIMIT (25.0)
      CALL PLOT(2.0,1.0,23)
      CALL SCALE(RS(1),5.0,19,1)
      CALL SCALE(E(1),5.0,19,1)
      CALL AXIS(0.,0.,4HEFF.,-4,5.,0.,E(20),E(21))
      CALL AXIS(0.,0.,6HSS      ,6,5.,90.,RS(20),RS(21))
      CALL SYMBOL(1.0,9.0,.28,10HSS VS. EFF,0,10)
      CALL SYMBOL(1.0,8.0,.28,3HAS ,0,3)
      CALL SYMBOL(999.0,999.0,.28,IBCE,0,IC)
      CALL SYMBOL(999.0,999.0,.28,7H VARIES,0,7)
      CALL PLOT(1.0,8.9,3)
      CALL PLOT(4.25,8.9,2)
      CALL PLOT(1.0,7.9,3)
      CALL PLOT(4.25,7.9,2)
      WX=7.5
      IF(IWTE.EQ.0)392,393
  392 CONTINUE
      CALL SYMBOL(2.0,WX,.14,9HNO LOSSES,0,9)
      WX=WX-0.5
  393 CONTINUE
      IF(IWBR.EQ.0)394,395
  394 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO BRF,0,6)
      WX=WX-0.5
  395 CONTINUE
      IF(IWTA.EQ.0)396,397
  396 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS1,0,6)
      WX=WX-0.5
  397 CONTINUE
      IF(IWTB.EQ.0)398,399
  398 CONTINUE
      CALL SYMBOL(2.0,WX,.14,6HNO TS2,0,6)
      WX=WX-0.5
  399 CONTINUE
      IF(IW(19).EQ.0)770,771
  771 CALL SYMBOL(2.0,WX,.14,IEXT,0,IEXL)
  770 CONTINUE
      CALL SYMBOL(6.0,3.5,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVS,0,IN)
      CALL SYMBOL(6.0,1.0,.14,IBCD,0,IL)
      CALL NUMBER(999.0,999.0,.14,CVF,0,IN)
      TVN=RSA(3,1)
      TVY=(TVN-RS(20))/RS(21)
      TVX=(EA(3,1)-E(20))/E(21)
      CALL DASHLN(6.0,1.0,TVX,TVY,.042,.042)
      TVY=(RSA(5,LN)-RS(20))/RS(21)
      TVX=(EA(5,LN)-E(20))/E(21)
      CALL DASHLN(6.0,3.5,TVX,TVY,.042,.042)
   75 CONTINUE
      CALL LINE(E,RS,19,1,1,11)
      LN=LN-1
      IF(LN.EQ.0)76,77
   77 DO 78 I=1,19
      RS(I)=RSA(I,LN)
      E(I)=EA(I,LN)
   78 CONTINUE
      GO TO 75
   76 CONTINUE
      CALL PLOT(0.,0.,3)
      CALL PLOT(10.0,-1,23)
      CALL PLOT (0.0,0.0,999)
  434 CONTINUE
      GO TO (201,202,203,204,205,206,207,208,209,210,211,212,213,
     +214,215,216,217,218,219,220,221,222,223,224,225,226,227,228,229,
     +230,231,232,233),KV
  201 S(1)=FV(1)
      GO TO 250
  202 S(2)=FV(2)
```

```
      GO TO 250
  203 S(3)=FV(3)
      GO TO 250
  204 S(5)=FV(4)
      GO TO 250
  205 ZC=FV(5)
      GO TO 250
  206 S(7)=FV(6)
      GO TO 250
  207 S(8)=FV(7)
      GO TO 250
  208 S(9)=FV(8)
      GO TO 250
  209 S(10)=FV(9)
      GO TO 250
  210 S(11)=FV(10)
      GO TO 250
  211 S(12)=FV(11)
      GO TO 250
  212 S(13)=FV(12)
      GO TO 250
  213 D(1)=FV(13)
      GO TO 250
  214 D(2)=FV(14)
      GO TO 250
  215 D(3)=FV(15)
      GO TO 250
  216 D(4)=FV(16)
      GO TO 250
  217 D(5)=FV(17)
      GO TO 250
  218 D(6)=FV(18)
      GO TO 250
  219 D(7)=FV(19)
      GO TO 250
  220 D(8)=FV(20)
      GO TO 250
  221 D(9)=FV(21)
      GO TO 250
  222 D(19)=FV(22)
      GO TO 250
  223 ATA=FV(23)
      GO TO 250
  224 ATD=FV(24)
      GO TO 250
  225 ATC=FV(25)
      GO TO 250
  226 ATW=FV(26)
      GO TO 250
  227 D(12)=FV(27)
      GO TO 250
  228 D(13)=FV(28)
      GO TO 250
  229 D(14)=FV(29)
      GO TO 250
  230 D(15)=FV(30)
      GO TO 250
  231 S(14)=FV(31)
      GO TO 250
  232 B(10)=FV(32)
      GO TO 250
  233 B(9)=FV(33)
  250 LC=LC+1
      KV=NA(LC)
      IF(KV.EQ.999)501,500
  501 CONTINUE
      STCP
      END
```

MICHIGAN STATE UNIV. LIBRARIES
31293008054482