Mark I
Time-Sharing Service

Program Library Users Guide

Information Systems

Time-Sharing Service

AC Linear Network Analysis

GENERAL ELECTRIC
INFORMATION SERVICE DEPARTMENT

PREFACE

This users guide explains how the a-c frequency response of a linear network can be analyzed by using the Time-Sharing Service of General Electric's Information Service Department.

This guide was published in December 1967. The April 1968 reprint incorporated minor editorial changes and additions. The August reprint incorporates information to further define the method and procedures, a program change to allow using any file name for entering input data, and includes the latest input and output examples. This printing does not render the original obsolete and previous versions may still be used.

Users need not be programmers. However, familiarity with the system is required. Time-Sharing System Manual (229116) provides such information, and the manual should be used in conjunction with this one. For ease of comprehension, this guide includes a sample problem and its solution.

AC Linear Network Analysis is one in an ever-expanding library of time-sharing programs for use by subscribers to the Time-Sharing Service. Each program is designated by its six-character name (ACNET$, in this case) to store and retrieve it on the system. Library programs are classified as follows:

On-Line

On-line library programs can be accessed from any terminal that is connected to the system. The criteria for placing a library program on-line are its general utility and frequency of use. Unless classified as run-only (see below), on-line programs can be listed, modified, copied, or run at the discretion of the user.

To retrieve a program from the on-line library, its six-character name is used, followed by three asterisks. The three-asterisk suffix is not an integral part of the program name; it is only a requirement for retrieving the program.

An index to listings of programs in the on-line library is available by listing the library program CATLOG.

Off-Line

The off-line library consists of programs not in general demand. An index to the listings of off-line programs can be obtained by listing the library program CATOFF. Off-line library programs are available for direct placement in a specific user catalog on request from your General Electric representative.

Run-Only

Run-only is a term applied to programs that cannot be listed or permanently modified by the user. It is possible to have run-only programs in either the on-line or the off-line library. Run-only programs are designated by a dollar sign ($) in the sixth character position of the program name.

The terms under which library programs are made available to subscribers may vary between programs, or they may vary with a given program from time to time. General Electric reserves the right to change these terms at its discretion. Any questions regarding use of library programs should be directed to your General Electric representative.

CONTENTS

FIGURES

1. GENERAL INFORMATION ABOUT AC LINEAR NETWORK ANALYSIS

This FORTRAN program analyzes the a-c frequency response of a linear network given data concerning branch elements, which may consist of the following:

Resistors

Capacitors

Inductors

Current controlled dependent current sources

Independent current sources

Independent voltage sources

Four types of circuit analyses can be selected and on-line circuit modifications can be performed. In addition, the circuit node to be analyzed can be specified.

The types of analyses available are:

- A frequency sweep of the circuit where, at each frequency, the gain (both magnitude and db) and phase are indicated.

  The "gain" as used in this program is the voltage at the node under consideration. Only when a one volt input source is used will the values printed under the heading "gain" be the true amplification. If a two volt input source is used, then the value printed under the heading "gain" will be twice the value obtained using a one volt source, which is to be expected since the system is linear. Thus, when using anything other than a one volt input source, the values labeled "gain" are merely node voltages.

  The calculation of the decibels assumes a one volt input source has been used, thus db is in 20-log to the base 10 relative to one volt at 0 degrees.

- A tolerance analysis (uniform and worst case distribution) of the gain at a given frequency where the printout shows the distribution of the values of the gain due to the tolerances placed on each circuit element.

  The part partials are also given for each element. This consists of indicating percentage values for the gain and phase, for a 1 percent change in the value of the element under consideration, where 100 percent signifies a 1 to 1 correspondence. Refer to Method for further explanation.

- A Monte Carlo analysis at a specified frequency where the program randomly selects a tolerance for each element within the limits indicated in the data statements. The gain and phase are then computed using the original value of each element plus the additional increment as calculated using the random tolerance for each element.

The number of trials over which this process is to be carried out is selected and the program then prints data on the normal distribution of values obtained for the gain and phase for these trials.

The printout for the Monte Carlo analysis consists of the following at the frequency under consideration:

<u>The nominal value of the gain and phase</u>, which is the value when no tolerance increment is added to the element values.

<u>Sigma</u>, the standard deviation over n trials for the gain and phase.

<u>+3 sigma</u>, which is three standard deviations above the mean value.

<u>Upper 1 percent</u>, which is the value of the gain and the value of the phase above which 1 percent of the gain and phase lie, when using random tolerances over n number of trials. For this calculation, a normal distribution is assumed.

<u>Mean value</u> of the gain and phase.

<u>Lower 1 percent</u>.

<u>-3 sigma</u>.

- A part increment, where the capability exists to increment the value of a circuit element over a desired range in order to obtain the gain and phase at each step.

The following operations can also be performed on-line:

Modify a circuit element
Change the frequency of consideration
Analyze a new circuit node

The size of the circuit which can be processed depends on the extent to which the circuit is to be analyzed. When the tolerance analysis or Monte Carlo analysis is not desired, delete the line which calls its file into the program, thereby providing more space for data describing a larger circuit. This particular feature is described in detail under Operating Instructions.

Unless otherwise specified, the gain and phase referred to in all subroutines are taken between the highest numbered node and the reference node (0).

METHOD

After the branch data has been entered into the program, the program forms the node incidence matrix, A, the circuit admittance matrix, Y, and the current and voltage source vectors, E and I, respectively.

Node voltage equations are then formed using the matrix formula:

$$(A' \; YA)V = A' \; (I - YE)$$

where A' = transposed A and
V = desired node voltage vector.

The node voltage equations are solved by Gauss Elimination with row interchange.

Using the above circuit solving subroutine, the complex value of the gain and phase for the node under consideration is provided for use by the following analysis routines:

- Tolerance analysis

  The part partials for each element are computed by first changing the value of the element under consideration by 1% and then computing the resultant change in the values of the gain and phase. For resistors, the admittance is changed to 0.99 of the original admittance whereas for capacitors and inductors, the capacitance and inductance are changed to 1.01 of their original value.

The part partial for each element is expressed as:

$$\text{part partial} = (\Delta\,\text{gain}/\text{gain}) \times 10^4$$

Thus, if the gain were to change by 1% for a 1% change in the value of the element, the part partial would be equal to 100%, indicating a one to one correspondence.

To compute the uniform distribution, the total change in gain which can be expected, if the element were to have a value as dictated by its maximum tolerance, is expressed as:

$$\text{total expected change in gain} = (\Delta\text{gain}) \times \text{tolerance}$$

The change in gain (Δ gain) is the same as determined for computing the part partial.

This total change in gain represents the halfwidth, h, of the uniform distribution of the gain change for the element. The halfwidth for the uniform distribution of gain change is computed for every element in the circuit.

If the number of distributions computed is in excess of five and the values of the halfwidths, h, are within the ratio of 2:1, the standard deviation of the sum of a number of uniform distributions can be approximated by:

$$\left[(h_a^2 + h_b^2 + h_c^2 + \ldots \text{etc.})/3\right]^{\frac{1}{2}}$$

where h_a, h_b, and h_c, etc., are the normal distribution halfwidths for elements a, b, c, etc., respectively. This approximation for the standard deviation is determined by employing the Central Limit Theorem, which proves that the sum of a large number of uniform distributions asymptotically approaches a normal distribution as the number of uniform distributions increases. Obviously this approximation may not be valid in all cases.

The program prints the nominal value of the gain and ± 3 standard deviations from the nominal using the above method of computing the standard deviations for the uniform distribution.

The worst case distribution is computed by varying the element values within their tolerance limits as specified by the user in order to obtain the maximum shift in output. It is assumed that the sign of each element's part partial does not change.

Each element is then given a value as determined by its maximum tolerance in the direction indicated by the sign of the part partial. Thus, in computing the minimum worst case, a 10 ohm resistor with a tolerance of 10% and a negative part partial would be given a value of 11 ohms since the negative part partial indicates that, by increasing the value of the resistor, the gain at the specified node decreases.

- Sweep
  Standard sweep is 1, 2, 4, 8, 10, 20, 40, etc., cycles per second.
  Db is in 20-log to the base ten, relative to 1 volt at 0 degrees.
- Monte Carlo analysis

RESTRICTIONS

The dependent source must be a current controlled current generator.

The component tolerances must have integer values.

The size of the circuit which can be analyzed with all files included in the program is 11 nodes, 15 branches, and 20 components. Larger circuits may be analyzed by deleting files from the program as described in the Operating Instructions. With the two files deleted as described, the program can analyze a circuit containing 17 nodes, 22 branches, and 30 components. It should be noted that independent sources are not counted as components.

2. OPERATING INSTRUCTIONS

PREPARATION OF DATA

Before circuit data can be entered into the program, the following steps must be performed:

1. Redraw the circuit schematic into its equivalent circuit form, where all transistors, transformers, etc. are replaced with a proper model.

2. Number the circuit nodes from one to n where the n^{th} or last node is the output of the circuit. Node zero (0) is the reference node, and the output of the circuit is taken between the n^{th} node and the node 0.

3. Number the branches from one to b where b is the last branch. Each branch may include all or part of the generalized branch shown in Figure 1. A branch may also include more than one like parallel element such as several parallel resistors. An independent voltage source must include some kind of passive element in series with it within that total branch.

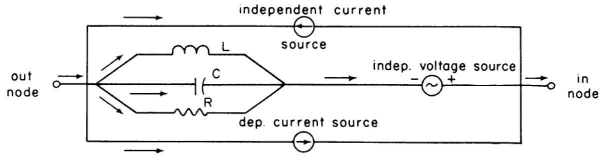

Figure 1. Generalized Circuit Branch

4. Indicate an arbitrary current flow through the entire branch:

   Currents from independent current sources must flow opposite to the general branch flow.

   Currents from dependent current sources flow with the general branch flow.

   The "out" and "in" node convention is used to indicate that the current flows "out" of some node, through the general branch, and "in" to some other node.

5. In certain subroutines the program will refer to the circuit component number. This is a number which is assigned by the program to each component to indicate the order in which it has been encountered in the data statements, though this does not include independent sources. Thus the first component in the data statement is labeled component #1, the second as component #2, and so on, disregarding independent sources.

PROCEDURE

To enter data into the program, create and save a data file using any file name up to six characters. This is done by creating the file in the following manner. Supply all underlined information.

```
SYSTEM--FØRTRAN
NEW ØR ØLD--NEW
NEW FILE NAME--DATFIL
READY
```

Now, enter line data into DATFIL as indicated below. In entering data, the controlling branch of a dependent current source must be described before the dependent current source.

1000 B, N
B = Total number of branches
N = Total number of nodes (not including reference node)

1010 Branch, out-node, in-node, type, value, tolerance, control branch:
:
through
:
9998

branch = the branch number of the element being described

out-node = the node number out of which the branch current flows into the general branch

in-node = the node number into which the branch current flows from the general branch

type = a number which indicates the kind of component being described according to the following code:

Element	Code
resistor	0
capacitor	1
inductor	2
dependent current source	3
independent voltage source	4
independent current source	5

value = the size or magnitude of the element (ohms, farads, henries, amperes, volts)

tolerance is entered in percent for all non-independent source elements. No tolerance is entered for independent sources.

control branch is the number assigned to the branch which controls the dependent current source. The control branch must be described before the dependent source in the data statements. The dependent source is controlled by the resistive part of the control branch.

9999 99, 1, 1, 1, 0.0

Line 9999 is filled with the numbers shown above.

After the data has been entered into DATFIL as described above, type SAVE followed by a carriage return. This file may be unsaved when the circuit analysis has been completed so as to minimize storage charges.

Once DATFIL has been saved, call the main program in the following manner. Supply all underlined information.

```
ØLD
ØLD FILE NAME--ACNET$***
READY
```

The name of the data file must now be supplied by typing the following line:

1 +DATFIL

If the data is entered using the file name NETFIL (as described in previous issues of this Users Guide), it is not necessary to type line 1.

Type RUN and after a certain elapsed time, the word CØMMAND? will appear at the teletypewriter. Here, type a code number followed by a carriage return to indicate the type of operation to be performed. The subroutine available for each code number is described below:

Command	Code	Description
Sweep	1	The program will ask for the frequency at which the sweep should begin and end as well as the step size to be taken. Supply this data followed by a carriage return. After the sweep, the program will ask for a new frequency. Supply this and the gain and phase will be indicated for this frequency. This should not be confused with Code 8, which asks for the frequency at which the tolerance analysis, Monte Carlo analysis, and part increment are to be executed.
Tolerance analysis	3	The uniform distribution indicates the values of the gain which are ±3 standard deviations from the mean.

Command	Code	Description
Monte Carlo	4	The program will ask for the number of trials over which the analysis is to be carried out. Enter the number followed by a carriage return.
Increment	5	The program will ask for the element number, initial value and step size to be taken. Enter the desired data followed by a carriage return. The value of the gain and phase is then printed at each step for ten steps.
Change a part	6	This routine permanently changes the component or value for the run. The program will ask for the component number, code and value. Supply this followed by a carriage return. Independent sources cannot be changed to any other element. Resistors, capacitors and inductors may be interchanged, but they may not be changed to independent or dependent sources. The values of all components, except independent sources, may be changed. When changing the value of a dependent source and its control branch, the value of the control branch must be changed first.
Change output node	7	The program will ask for the number of the node to be analyzed, then the gain and phase for the other subroutines will be computed between this node and the reference node. If this command is not given, the gain and phase are computed between the highest numbered node and the reference node.
New frequency	8	The program will ask for a new frequency to be used for executing Codes 3, 4, and 5. Remember to specify a frequency before using these analyses routines which operate at a specific frequency.
Stop	9	This command terminates the run.

PROGRAM SIZE

ACNET$ has been dimensioned to analyze circuits consisting of up to 11 nodes, 15 branches, and 20 components with all the files compiled in the program. However, these dimensions may be increased, as discussed below, to handle larger circuits.

When working with larger circuits, more space can be provided for data if exact dimensions for all program lists and matrices are used. Type the following lines into the program to specify exact circuit size:

```
3 DIMENSION G(N, N+1), B'', Y(M), P'',
        DP'', E(BR), C'''         ®

4 INTEGER IA(BR, N), IY(M, 4), IN(6)
```

where N = number of nodes
M = number of circuit components (excluding independent sources)
BR = number of branches

When the circuit to be analyzed is larger in one or two of the basic dimensions (11 nodes, 15 branches, and 20 components) and if the following relation is satisfied, enter the exact dimensions in Lines 3 and 4 of the program ACNET$ as given above.

$$4(N)(N+1) + 10M + 4BR + (BR)(N) + 6 \leq 960$$

Circuits greater in all three dimensions can be analyzed by eliminating either the tolerance analysis or Monte Carlo analysis, or both, from the program before the run. The relation which applies in each case is shown below. When the relation is satisfied, eliminate either or both of these analyses and enter the exact dimensions in Lines 3 and 4 of the program.

With tolerance analysis deleted:

$$4(N)(N+1)+10M+4BR+(BR)(N)+6 \leq 1450$$

With Monte Carlo analysis deleted:

$$4(N)(N+1)+10M+4BR+(BR)(N)+6 \leq 1450$$

With both analyses deleted:

$$4(N)(N+1)+10M+4BR+(BR)(N)+6 \leq 1992$$

When the two files are deleted from the program, a circuit of 17 nodes, 22 branches, and 30 components can be analyzed. To eliminate these files and the subroutines contained in them, type the following lines before running the program.

To eliminate the tolerance analysis, type

```
119
507 3 GØTØ A
```

To eliminate Monte Carlo, type

```
185
508 4 GØTØ A
```

If it is desired to place a file and subroutine back into the program after a run, type ØLD and recall the old program ACNET$***, which contains all the files.

3. SAMPLE PROBLEM

It is desired to determine the low frequency response of the common emitter amplifier in Figure 2.

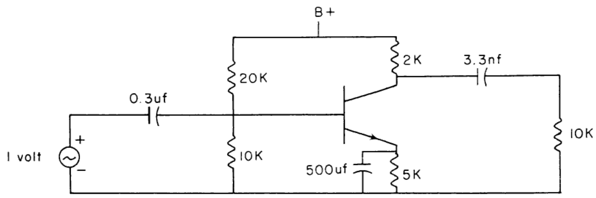

Figure 2. Emitter Amplifier Circuit

The equivalent circuit of Figure 2 must first be drawn and the transistor replaced by its appropriate model. Figure 3 shows the equivalent low frequency circuit using hybrid parameters for the transistor model.

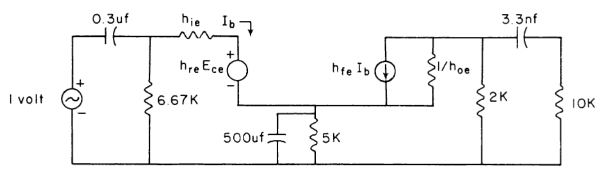

Figure 3. Equivalent Low Frequency Circuit with Voltage Controlled Dependent Voltage Source

The voltage controlled dependent voltage source in Figure 3 must be changed into a current controlled dependent current source before it can be used in the program. This is easily done using Ohm's law and Norton's theorem. The resulting equivalent circuit is shown in Figure 4.

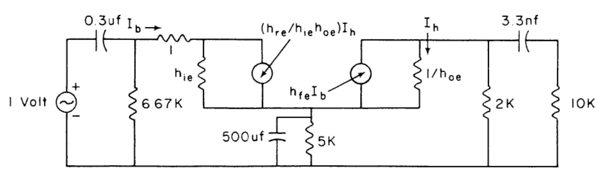

Figure 4. Equivalent Low Frequency Circuit with Current Controlled Dependent Current Source

This particular transistor has the following h-parameter values:

$h_{ie} = 2000$

$h_{re} = 6 \times 10^{-4}$ $\quad h_{fe} = 50$

$h_{oe} = 25 \times 10^{-6}$

Therefore

$h_{re}/(h_{ie}h_{oe}) = 12 \times 10^{-3}$

$1/h_{oe} = 4 \times 10^{4}$

The circuit branches and nodes are numbered as shown in Figure 5. There are 5 nodes and 11 branches. The reference node (0) is not included as a node.

Note that in Figures 4 and 5, a 1 ohm resistor has been inserted in the branch leading to the base of the transistor. Since the current controlled dependent current generator ($h_{fe}I_b$) depends on the current flowing into the base of the transistor, a passive element must be placed in this control branch as required by the program.

The solution is shown as it appears at the teletypewriter. The program is executed by supplying all underlined information.

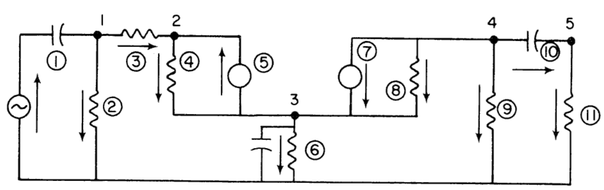

Figure 5. Equivalent Circuit with Branches and Nodes Numbered and Direction of Current Flow Indicated

INPUT FOR SAMPLE PROBLEM

```
SYSTEM--FØRTRAN
NEW ØR ØLD--NEW
NEW FILE NAME--DATFIL
READY.
```

Enter any file name up to six characters.

```
1000 11,5
1010 1,0,1,4,1
1020 1,0,1,1,0.3E-6,10
1030 2,1,0,0,6.67E3,10
1040 3,1,2,0,1,10
1050 4,2,3,0,2000,10
1060 6,3,0,0,5E3,10
1065 6,3,0,1,.5E-3,10
1070 7,4,3,3,50,10,3
1080 8,4,3,0,4E4,10
1090 5,3,2,3,12E-3,10,8
1100 9,4,0,0,2E3,10
1110 10,4,5,1,3.3E-9,10
1120 11,5,0,0,10E3,10
9999 99,1,1,1,0.0

SAVE

READY.
```

In line 1000, the number of branches (11) and number of nodes (5) are entered.

In line 1010, a 1-volt input source is used in order that the program will compute the true gain of the circuit.

In lines 1020 through 1120, the first five entries in each line indicate the branch, out-node, in-node, type of component, and the value of the component. The sixth and seventh entries, as applicable, indicate the tolerance and control branch.

Line 9999 is always filled with the numbers indicated.

OUTPUT FOR SAMPLE PROBLEM

```
ØLD
ØLD FILE NAME--ACNET$***

READY.

1 +DATFIL
RUN



ACNET$

IN ACNT1$
IN .FIRST
IN ACNT2$
IN .FIRST
```

```
COMMAND? 1

SWEEP
START, STOP, AND DELTA FREQ
(DELTA = 0 FOR STANDARD SWEEP) =? 100,10000,0

  FREQ-HZ        GAIN       GAIN-DB     PHASE-DEG
     100.        .2727      -11.29       -15.98
     200.        .9884      -.1017       -31.47
     400.        3.011       9.575       -53.52
     800.        7.276       17.24       -76.94
  .100E+04       9.284       19.35       -84.09
  .200E+04       17.92       25.07       -106.2
  .400E+04       28.74       29.17       -129.6
  .800E+04       36.54       31.26       -150.7
  .100E+05       37.97       31.59       -156.0

ANOTHER FREQ?  TYPE -1 FOR NO

F =? 5E4

  .500E+05       40.83       32.22       -175.0

F =? -1

COMMAND? 8

NEW FREQUENCY= ? 1E4

COMMAND? 3

TOLERANCE ANALYSIS AT    10000.00  HERTZ

GAIN =       37.9680
PHASE =     -155.981 DEGREES

PART PARTIALS
NUMBER  CODE   GAIN-PCT   PHASE-PCT
   1     CAP      .12        -.98
   2     RES      .03        -.22
   3     RES    103.52       -.01
   4     RES    -99.85       -.78
   5     RES     -.00         .00
   6     CAP      .00        -.02
   7     DEP    102.57       -.01
   8     RES     4.21        -.08
   9     DEP     2.53        -.03
  10     RES    84.93       -1.56
  11     CAP    13.80       -9.66
  12     RES    28.12       -8.16

   TYPE           MINIMUM    NOMINAL    MAXIMUM
UNIFORM DIST       24.9       38.0       51.0
WORST CASE         24.1       38.0       58.1

COMMAND? 4

MONTECARLO ANALYSIS AT     10000.00  HERTZ
NUMBER OF TRIALS = ? 25

                     GAIN       PHASE
NOMINAL             37.968     -155.98
SIGMA               4.7356      1.6507
+3 SIGMA            53.044     -150.89
UPPER 1-PCT         49.871     -152.00
MEAN                38.837     -155.84
LOWER 1-PCT         27.803     -159.69
-3 SIGMA            24.630     -160.79
```

```
COMMAND? 5

PART INCREMENT, 10 STEPS, AT   10000.00  HERTZ
ELEMENT NUMBER, INITIAL VALUE, STEP SIZE =? 12,1E3,1E3

          VALUE        GAIN       PHASE
          1000.        8.654      -119.5
          2000.        15.69      -127.3
          3000.        21.23      -133.8
          4000.        25.55      -139.0
          5000.        28.91      -143.2
          6000.        31.57      -146.7
          7000.        33.68      -149.7
          8000.        35.40      -152.1
          9000.        36.80      -154.2
      .1000E+05        37.97      -156.0

COMMAND? 6

PART MODIFICATION
COMPONENT NUMBER,CODE,AND VALUE =? 12,0,7E3
TOLERANCE =? 10

COMMAND? 7

NEW OUTPUT NODE NUMBER=? 4

COMMAND? 1

SWEEP
START, STOP, AND DELTA FREQ
(DELTA = 0 FOR STANDARD SWEEP) =? 100,10000,0

  FREQ-HZ           GAIN       GAIN-DB     PHASE-DEG
      100.          13.16       22.38        -104.8
      200.          23.86       27.55        -119.1
      400.          36.45       31.23        -138.8
      800.          44.53       32.97        -157.6
  .100E+04          45.83       33.22        -162.4
  .200E+04          47.08       33.46        -174.0
  .400E+04          45.30       33.12         178.7
  .800E+04          41.87       32.44         175.8
  .100E+05          40.90       32.24         175.8

ANOTHER FREQ?  TYPE -1 FOR NO

F =? -1

COMMAND? 9



AT LINE NO. 513: STOP  END
```

Computer Centers and offices of the Information Service Department are located in principal cities throughout the United States.

Check your local telephone directory for the address and telephone number of the office nearest you. Or write . . .

General Electric Company
Information Service Department
7735 Old Georgetown Road
Bethesda, Maryland 20014

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