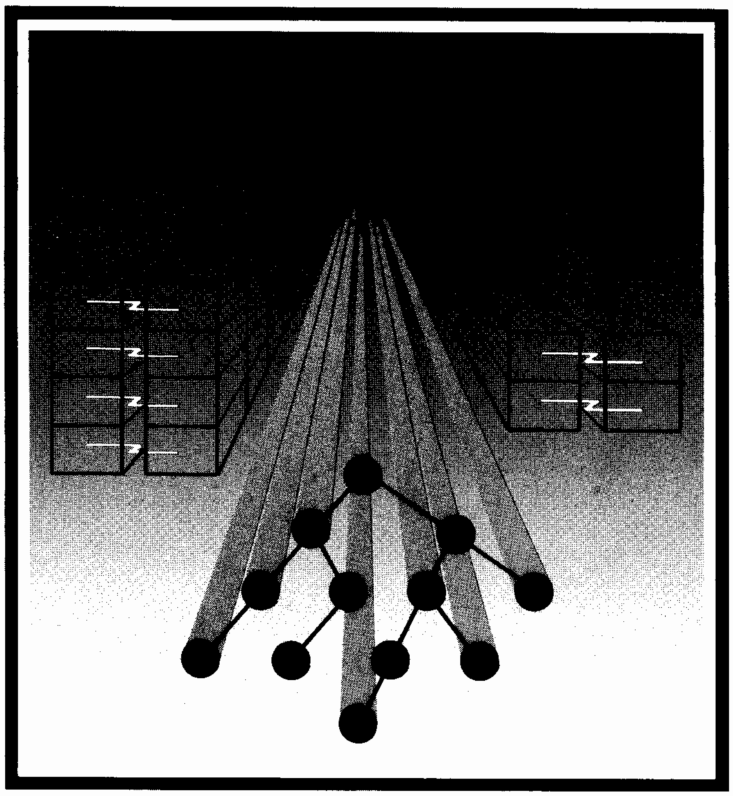
AC Circuit Analysis

For the HP 9845



HEWLETT PACKARD

AC Circuit Analysis

Part No. 09845-12621

Hewlett-Packard Desktop Computer Division
3404 East Harmony Road, Fort Collins, Colorado 80525

Important

The tape cartridge or disc containing the programs is very reliable, but being a mechanical device, is subject to wear over a period of time. To avoid having to purchase a replacement medium, we recommend that you immediately duplicate the contents of the tape onto a permanent backup tape or disc. You should also keep backup copies of your important programs and data on a separate medium to minimize the risk of permanent loss.

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Introduction

Description

This is a general purpose linear network analysis program, including effects due to component tolerances, written for the 9845 Desktop Computer.

The components allowed in the network description are resistors, capacitors, inductors, and voltage-controlled current sources. The precision and wide dynamic range of the computer make it possible to transform other active elements into the required form. For example, a voltage-controlled voltage source with zero ohms internal impedance cannot be realized, but one with 0.0001 ohms can be and the difference is negligible for almost all problems.

The network is specified by entering component values and node numbers associated with each component. As these values are entered, a table of these values and nodes is printed. This allows you to change a component value easily and rerun the program without re-entering the data for the entire network.

The network may also be stored on tape for recall in the future.

Single frequency points, log or linear frequency sweep may be specified as well as the number of frequency intervals. For each frequency, the magnitude of the output voltage (in dB), the phase, and the time delay may be printed and/or plotted. Also, the magnitude and phase of the impedance at any node may be printed and/or plotted.

The selection of the tolerance effect option allows you to determine how a random selection of component values within the tolerance ranges specified alters the magnitude, phase, time delay or impedance of the circuit. Each tolerance pass randomly selects component values prior to calculating the output parameters. The next tolerance pass repeats this procedure with a fresh random selection of component values. The program saves only the maximum and minimum values, calculated during the tolerance passes, of the selected parameter for each frequency interval. The resulting maximum and minimum envelopes approximate the range of expected variations in output parameters due to the random selection of component values in the production of the circuit.

System Configuration

This manual may be used for either of two AC Circuit Analysis program packs. One pack is for the 9845A desktop computer and the other is for the 9845B desktop computer. The packs are functionally identical with only one exception. The maximum number of nodes/components is set to 20/100 for the "A" and 25/100 for the "B". The configuration information for each system is given below:

9845A

- 9845A Desktop Computer
- option 203, 62 650 bytes of Read/Write memory
- option 500 or 501, internal thermal line printer
- option 700, graphics display subsystem
- option 370, graphics ROM
- AC Circuit Analysis software pack (part number 09845-12520). If you need to replace any of the components of the complete software pack the following part numbers should be used.

  Manual only, 09845-12621

  Program Cartridge only, 09845-12524

  Key Overlay only, 7120-7831

The following equipment can be used, optionally, to enhance the performance of your software pack.

Opt 600, second 9845 tape cartridge drive

9872A, graphics plotter

9845B, 9845C

- 9845B or 9845C (opt. 001) Desktop Computer
- option 204, 187 146 bytes of Read/Write memory
- option 560 or 561, internal thermal line printer
- option 700, graphics display subsystem (9845B Only)
- option 311, graphics ROM (9845B Only)
- AC Circuit Analysis software pack (part number 09845-12620). If you need to replace any of the components of the complete software pack the following part numbers should be used.

  Manual only, 09845-12621

  Program Cartridge only, 09845-12624

  Key Overlay only, 7120-7831

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Special Considerations

This section contains information which allows you to use the AC Circuit Analysis software more smoothly. It also contains information concerning program limitations and modifications you can make, if necessary, to make the program more specialized to your needs.

System Shutdown

The following occurrences can cause an unordered shutdown of the system:

- Power failure
- Reset (pressing control stop)
- I/O errors which cannot be trapped

You will lose data only if a power failure has occurred. You can restart the system in any case other than a power failure by pressing STOP CONTINUE and values for the variables are retained. If you want to abort the current program section and do something else, STOP CONTINUE will always result in a "Select Key" prompt. It is not recommended to use STOP CONTINUE when a plot or table of calculated values is being generated. An ABORT PLOT key is provided on the template for this purpose.

Answering Prompts

When the program needs information from you it poses a question at the bottom of the CRT. This is a prompt. All prompts in this software pack have certain features in common.

- Prompts occur at the bottom of the CRT and the program waits until you respond.
- If the response is not proper for the prompt the 9845 ignores the answer and repeats the prompt.
- Key words in the prompt are underlined.
- Certain prompts may have default values in the inverse video box. If this default value is acceptable you simply press CONTINUE and the program uses the default as the answer to the prompt.
- To the right of the prompt may be a list of suggested responses. You may answer the prompt by typing in one of the responses from the list or typing in the number indicating the position of your choice in the list. Yes/No questions may also be answered with a 1/0 response.

Modifying the Program

There are several reasons why you might wish to modify one or more sections of the program. Essentially they fall into two categories; (1) you have a different hardware configuration than the standard pack expects or (2) you want to modify the format in which data is input or output. The following sections provide guidance in some of these areas.

Changing The Maximum Number of Nodes and Components

If you want to change the maximum number of nodes or components, e.g., for various memory options, the following program lines must be modified in the manner shown.

NOTE

You would put the new numeric value of nodes or components where "nodes" or "components" are indicated.

---

290 DIM: DIM Y("Nodes","Nodes"),Z("Nodes","Nodes")

295 Nodes="Nodes"

300 DIM C(2*"Components"),C1(2*"Components"+2)

305 INTEGER Xref(0:"Nodes")

The number of bytes of memory required for a given number of nodes and components is given by the following expression:

Bytes=Nodes*(16*Nodes+2)+32*Components+49400

Changing The Source Type

If you use Op amps extensively, you may want to modify the following program line.

Change:

551 Opamp=No

To:

551 Opamp=Yes

All sources will now be called "Opamp" and the "from"node will always be 0.

Theory

Math

An electrical network with n nodes[1] can be completely specified for steady-state analysis of its n x n node admittance matrix, which in turn depends on the value of each component, the network topology (how the components are connected), and the frequency.

The node admittance matrix, [Y], is formed by starting with a null matrix (each element =0), and adding to it for each component as follows:

Let:

> y_c = the admittance of the given component,
> i and j = the numbers of the nodes the component is connected between ($i \neq 0$).

Then:

> add y_c to y_{ii} and if $j \neq 0$,
> add y_c to y_{jj},
> add $-y_c$ to y_{ij},
> add $-y_c$ to y_{ji},
> where y_{ij} = the element in the ith row and jth column of the node admittance matrix being formed.

Note that while y_{ij} is in general a complex quantity depending on frequency, each component contributes to either the real part or the imaginary part of y_{ij}:

> for resistors, $y_c = \frac{1}{R}$, where R = resistance in ohms;
>
> for inductors, $y_c = \frac{-j}{\omega L}$, where L = inductance in henries, ω = frequency in radians/second;
>
> for capacitors, $y_c = j\omega C$, where C = capacitance in farads.

1 Nodes are numbered sequentially from 0, letting node 0 be the reference node (usually ground). Then n is defined as the number of nodes, excluding node 0.

The sinusoidal steady-state performance of the network at a particular frequency is given by a set of simultaneous linear equations:

$$y_{11}v_1 + y_{12}v_2 + \dots + y_{1n}v_n = i_1$$

$$y_{21}v_1 + y_{22}v_2 + \dots + y_{2n}v_n = i_2$$

$$\dots\dots\dots\dots\dots$$

$$y_{n1}v_1 + y_{n2}v_2 + \dots + y_{nn}v_n = i_n$$

where i_n = the current entering node n from a current source (which may be either a dependent source or an independent source).

In matrix form,

$$[Y]_{nxn}\,[V]_{nx1} = [I]_{nx1},$$

where [Y] is the node admittance matrix of the network, [V] is the matrix of node voltages, and [I] is the source current matrix.

The node voltages can be found by taking the inverse of the admittance matrix and pre-multiplying both sides of the above equation:

$$[Y]^{-1}\,[Y][V] = [Y]^{-1}[I], \text{ or}$$

$$[V] = [Y]^{-1}[I].$$

The process of inverting a large matrix of complex numbers is lengthy and sometimes inaccurate. Frequently, it is necessary to find only one node voltage, and in this case, there are faster and more accurate methods available such as the following method used by this program.

Assume there are no independent current sources, and all dependent sources are voltage controlled current sources. Then, for each controlled source, subtract the transconductance, from y_{ij} where i is the number of the node the controlled current is entering and j is the node number of the controlling voltage of the source.

From this new [Y] matrix, the network transfer function, v_{out}/v_{in}, can be found as follows:

Let:

node 1 be the input node;

node 2 be the output node.

Then:

$v_{out}/v_{in} = v_2/v_1$, which is computed in this manner:

1) Partition $[Y]_{nxn}$

$$[Y]_{nxn} = \begin{bmatrix} [Y_a]_{n-1 \text{ x } n-1} & [Y_b]_{n-1 \text{ x } 1} \\ [Y_c]_{1 \text{ x } n-1} & [Y_d]_{1 \text{ x } 1} \end{bmatrix}$$

2) Form a new matrix, [Y′], of order n−1

$$[Y']_{n-1 \text{ x } n-1} = [Y_a] - \frac{[Y_b][Y_c]}{[Y_d]}$$

3) Repeat the reduction until the order of the reduced matrix [Y′] is 2. Then, $v_2/v_1 = y'_{21}/y'_{22}$

The precision and dynamic range of the 9845 makes it possible to solve the above equations fairly rapidly and with high accuracy.

Magnitude

The output magnitude is given in db by using the following expression:

$20 \log (V_{out}/V_{in})$.

Phase and Time

V_{out}/V_{in} is a complex number at a given frequency.

The Phase is given by $\phi = \text{Tan}^{-1}\left(\frac{V_{Imaginary}}{V_{Real}}\right)$

Since the Tan^{-1} function range is $-180°$ to $180°$ a phase plot which passes through $-180°$ or $180°$ may appear to have a discontinuity although it is in fact continuous.

The time delay through the circuit is given by the following:

$$\text{Time} = \frac{\phi}{360° \text{ x Frequency}}$$

Since artificial discontinuities are generated in ϕ there will be discontinuities in time at $180°$ or $-180°$

Tolerance Effect

The random values of the circuit components are selected by using the 9845 random generator in the following method:

For

V_1=nominal value of component,

$\pm T$=tolerance in percent;

R=random number, where $0 \leq R \leq 1$;

V_2=random value of the component;

Let

$$V_2 = V_1 - (T/100)\,V_1 + SGN(R-.5)SQR(SQR(R))$$

DC Analysis

A frequency of zero Hertz may not be used if inductors are in the circuit. If the impedance of a branch is zero then the corresponding entry in the admittance matrix, y_{ij}, would be infinite. For this reason 0Ω is not allowed for resistor values.

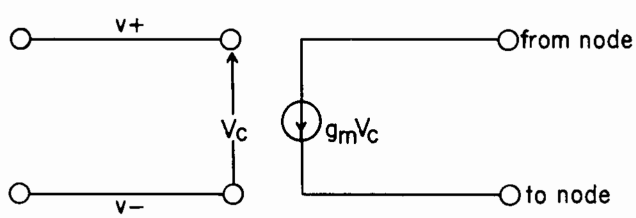
To do DC analysis when inductors are present use 10^{-18} Hz, instead of zero Hz.

Part Two Instructions

Specification of Data

1. Draw the circuit to be analyzed. Dependent sources must be transformed to voltage-controlled current sources.
2. Number the nodes. Node 0 must be the reference of ground node. The node numbers need not be sequential. However, no node number may be greater than the maximum number of nodes.
3. Note which node is to be considered the input node and which node the output node. The program assumes a one-volt source is connected between input node and node 0.
4. Enter data as specified in Special Considerations. For each passive component, enter the value of the component (in ohms, farads, or henries), and the node-numbers the component is connected between.

   Active components (voltage-controlled current sources) are specified as follows:



   The controlling voltage, v_c, is measured between the nodes (v+) and (v−), either of which may be zero. The controlled current, $g_m v_c$, leaves the "From Node" and enters the "To Node". g_m is a positive number, to reverse the direction of the current source reverse the connections to (+) and (−).

5. For logarithmic plots, the program has been set up to use "N-cycle by 70 division" semi-log paper. If you use this kind of paper, and set-up the lower-left and upper-right limits to correspond to the limits of the grid rather than the paper, the axes and tic-marks generated by the computer correspond with those on the paper.
6. For logarithmic plots, on semi-log paper, the lower and upper frequency limits should by powers-of-ten; that is, 10^5, 10^7, 10^9, etc., not 1.5×10^5, 2.3×10^6, etc.

Start Up Procedure

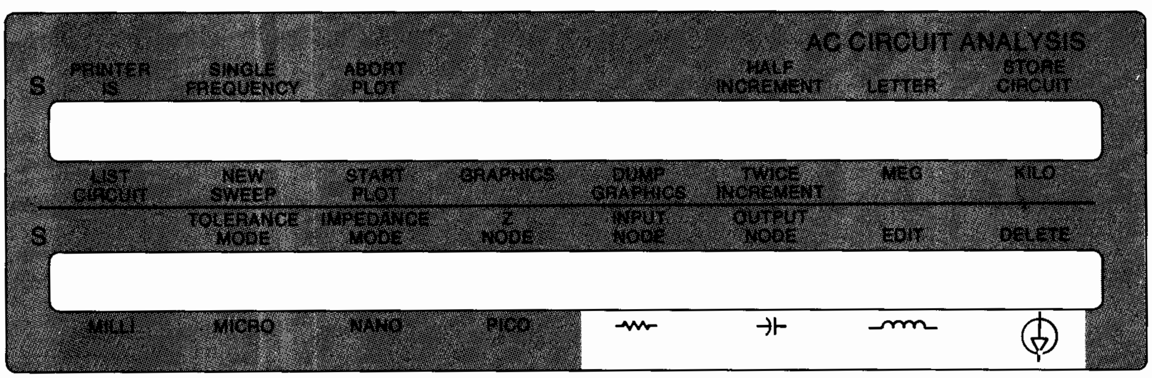
To begin operation, the program and definitions for the special function keys must be obtained from the program cartridge. Then the computer must begin running the program. To do this:

1. Turn off the computer.
2. Insert the program cartridge into the computer cartridge transport(T15).
3. Press: AUTO START so that it latches down.
4. Turn on the computer and associated peripherals.

NOTE

This loads the program and the keys from the cartridge and begins running the program.

New Circuit Definition



The circuit to be analyzed can be defined in three ways. The first case is when the circuit is being initially described. In the second case a circuit has already been described, but additional components are desired. The third case arises when a previously stored circuit is loaded from mass storage.

New Circuit

1. Press STOP and RUN to clear the memory of an existing circuit.
2. Answer the PRINTER IS prompt.
3. Answer the NEW CIRCUIT prompt with KEY-IN (alternate responses are K or simply press CONT).
4. Answer the INPUT NODE, OUTPUT NODE, and TOLERANCE MODE prompts.
5. You are now ready to key in your circuit.

Adding To An Existing Circuit

If you are adding to the circuit, you can get to this same point in the program by pressing one of the component keys (K12 through K15).

Each time you completely specify a component it is added to the circuit listing. For your convenience the program prompts you once again, for another component of the same type. You may change the component type by inputting 0 or simply pressing the COMPONENT key which indicates the component type that you desire.

If you no longer need to input circuit information you may jump out of any prompt by simply pressing another key (for example, LIST CIRCUIT).

Loading Data

A circuit may be loaded from a mass storage device. The circuit is called by its file name (maximum length 6 characters).

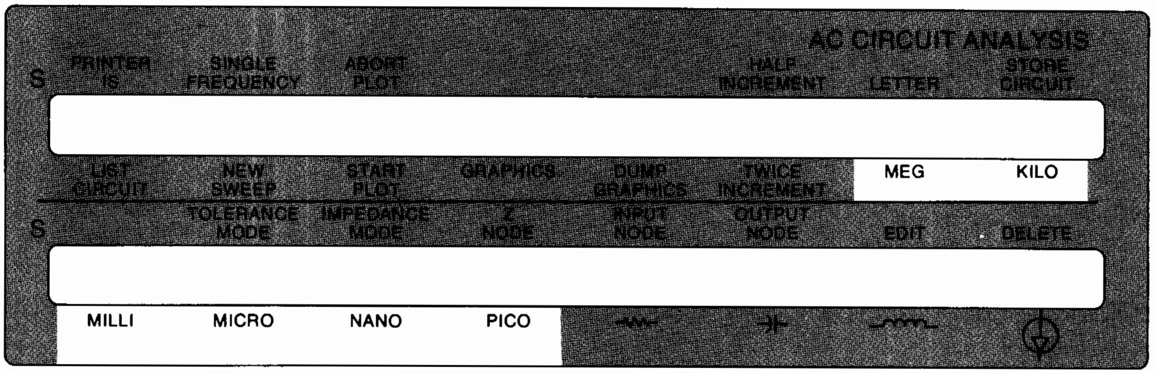
AC Circuit Analysis does not allow a circuit which is on mass storage to be merged with one that is currently loaded. For this reason, you are given the opportunity to load a new circuit only once, at the beginning of the program.

To load a circuit.

1. Press STOP and RUN to clear the program memory of any currently resident circuit.
2. Answer the PRINTER IS prompt.
3. Answer the NEW CIRCUIT? prompt with LOAD.
4. Answer the CIRCUIT NAME? prompt with the circuit name (for example, DEMO).

The circuit is then loaded and listed. A SELECT KEY prompt appears on the screen.

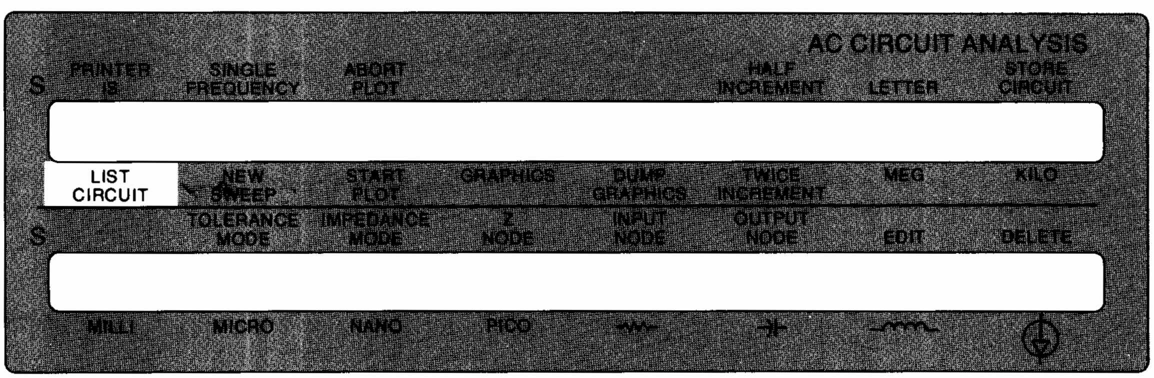
Power of Ten Suffix Keys



The suffix keys serve as an input aid when adding components, editing or scaling plots. The effect of the key is the same as multiplying a numeric input by the corresponding power of ten and then pressing CONTINUE.

For an example, suppose that the -\/\/\/- key (K12) key has been pressed and the 9845 is requesting the resistance value. If you type 1 followed by KILO (K7), the prompt is satisfied and 1 kilo ohm is registered as the resistor's value.

List Circuit

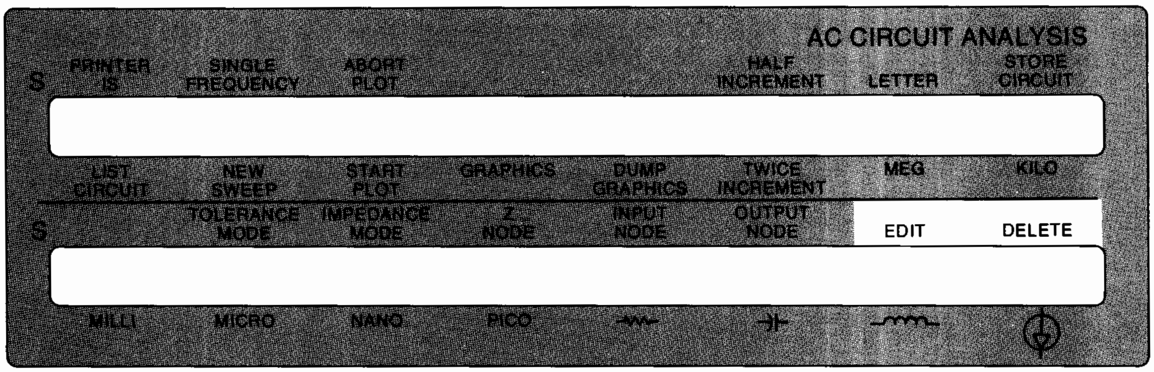


LIST CIRCUIT key (K0) provides you with an updated listing on the current system printer. If the printer is not the CRT then you have an opportunity to change the printer before the listing is executed.

All components are listed in a table and in numerical order. If components have been deleted the remaining components of the same type might be renumbered if necessary to keep consecutive component numbering.

At the top of the listing the current impedance node or input/output nodes are displayed.

Edit and Delete Prefixes



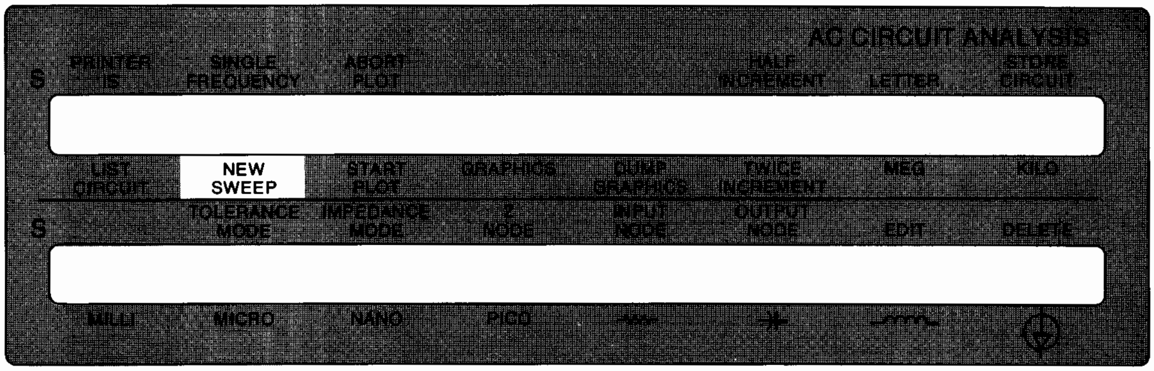
The EDIT (shift K14) and DELETE (shift K15) keys can be thought of as prefixes to the component keys (K12 through K15). The use of the component keys has been explained in the section entitled New Circuit Definition. When defining a new circuit, errors can be corrected by the use of the EDIT and DELETE keys.

When entering new components by pressing a component key, that component is not permanently stored until all information about that component has been entered. You will know that incorrect data has been permanently stored when that component line is added to the component list. To abort incorrct data which has not yet been added to the component list merely press that component key once again.

Once a component has been added to the component list it can only be changed by using the EDIT or DELETE key. Once one of these keys is depressed a blinking EDIT or DELETE appears on the screen with the current component type. You may select another component type by pressing a component key. At this point, the EDIT or DELETE may still be aborted by pressing LIST, or STOP, CONT.

Once you have edited or deleted a component, the circuit is re-listed reflecting the changes made. EDIT and DELETE prefixes are canceled after they are used. If you wish to make a second edit or deletion to the component list you must press EDIT or DELETE once again.

New Sweep



The NEW SWEEP key (K1) is used to set up the parameters for a new analysis of the circuit currently in program memory and then perform the desired analysis. The parameters are:

Sweep Type

- Logarithmic
- Linear

Sweep Limits

- Start Frequency
- End Frequency

Output Device

- CRT-Table of values on CRT
- PRINTER-Table of values on hard-copy printer
- GRAPHICS-Plot on CRT
- PLOTTER-Plot on 9872

Intervals

- Number of frequency points at which analysis is to be performed.

At this point, if you had chosen CRT or PRINTER as the output device, a table of values will now be displayed or printed. The contents of this table depends on what modes have been set.

If in Impedance Mode, the table contains:

- Frequency
- Impedance Magnitude
- Impedance Phase

If not Impedance Mode, the table contains:

- Frequency
- Transfer Function Magnitude
- Transfer Function Phase
- Transfer Function Time Delay

If in the Tolerance Mode, the table will contain the information just described but, for each frequency, there will be two values (maximum, minimum) for each of the response parameters.

If, instead of CRT or PRINTER you had chosen GRAPHICS or PLOTTER as the output device, additional prompts allow you to specify the following parameters:

Plot Type

In Impedance Mode

- Impedance Magnitude

  or

- Impedance Phase

Not in Impedance Mode

- Transfer Function Magnitude

  or

- Transfer Function Phase

  or

- Transfer Function Time Delay

Original/Multiple Graph

If you select ORIGINAL graph, the CRT graphics will be cleared and you will be prompted for the scale and grid parameters listed below. Once all of the prompts are answered the new grids and response curve will be plotted.

If you select MULTIPLE graph, you will be prompted only for the y-axis scale information and the new response curve will be plotted without erasing any existing graphics.

Scale and Grid Parameter

Minimum and maximum values for the y-axis of the plot. The x-axis scale is specified by the frequency range previously chosen.

Grid Specifications

- Log or linear grids
- Major grid spacing
- Number of minor tic marks per grid line

9845 Graphics

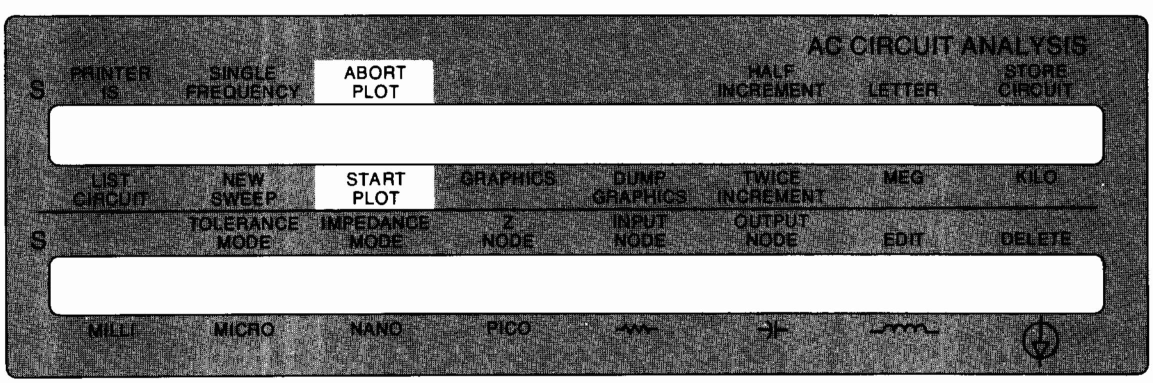
If the plot was done on the CRT, then it stays on the CRT until CONT is pressed. CONT gets you the select key prompt.

You may toggle in and out of graphics using the GRAPHICS key (K3) while a plot is being generated. This is particularly useful in tolerance mode when plots require a longer time to complete.

9872 Plotter

The 9872 plotter uses Pen 1 to make the plot. If you wish to change pens, push the appropriate pen button on the 9872 at any time. This is particularly useful for multi-color multiple plots.

Start Plot and Abort Plot



Start Plot

When you press START PLOT, a sweep of the circuit is done immediately without any prompts. The graph parameters and/or interval sizes in addition to the output device must have been previously selected by use of the NEW SWEEP key. This key is especially useful for multiple graphs. For example:

1. Create a plot using NEW SWEEP (K1)

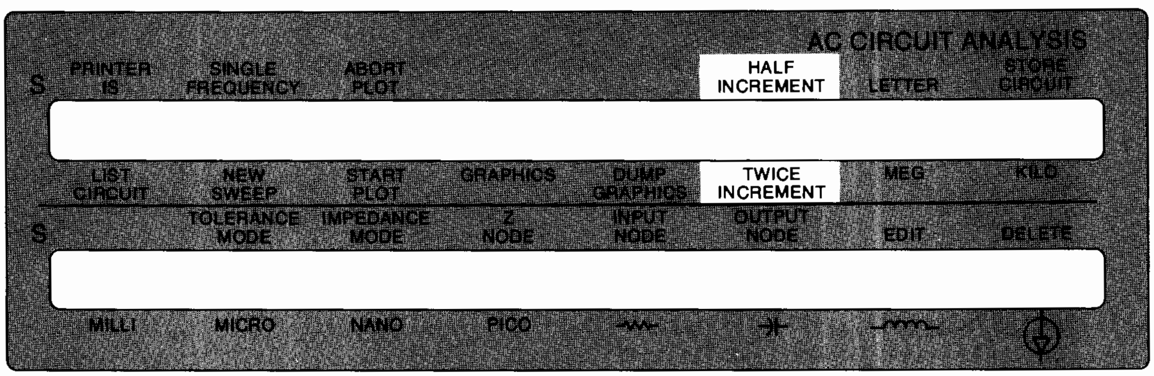
2. Edit the circuit.
3. Superimpose a new graph line on the graph already created by using START PLOT (K2)

Repeating steps 2 & 3 can create a family of curves reflecting several circuit configurations.

Abort Plot

If a plot is to be terminated before completion it is recommended to use ABORT PLOT (shift K2).

Half Increment and Twice Increment



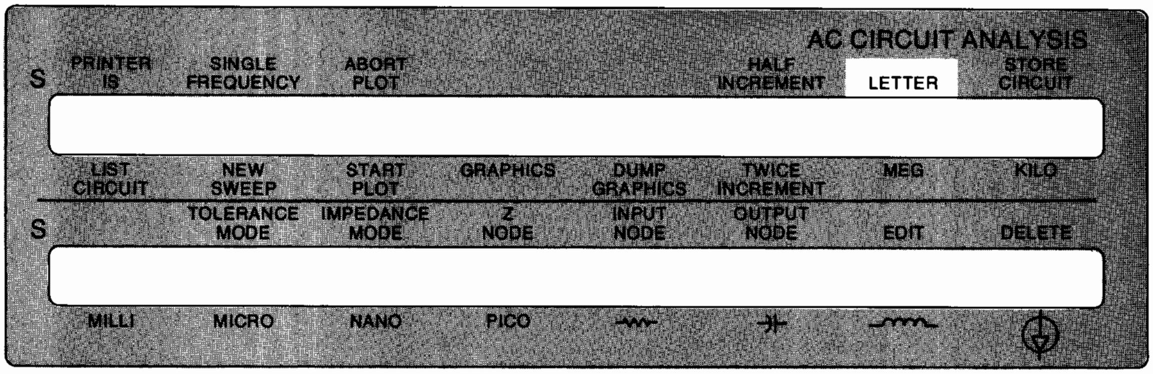
Increment modification keys are active only while an actual analysis is being plotted or printed. These keys allow you to change the frequency step size while the graph is being plotted.

This capability allows you to take smaller steps in a region of the graph where greater resolution is required and take larger steps in a region which is very linear.

Simply press the TWICE INCREMENT key (K5) to take larger steps or the HALF INCREMENT key (shift K5) to take smaller steps. Successively pressing one of these keys causes the step size to increase or decrease by a power of two each time the key is pressed.

The CRT (when not in graphics mode) displays the status of the step-size increment.

Letter



Additional labels and titles are often useful, especially when using the 9872 plotter as an output device or to label multiple curves on one graph. Pressing LETTER (shift K6) puts you into the letter mode.

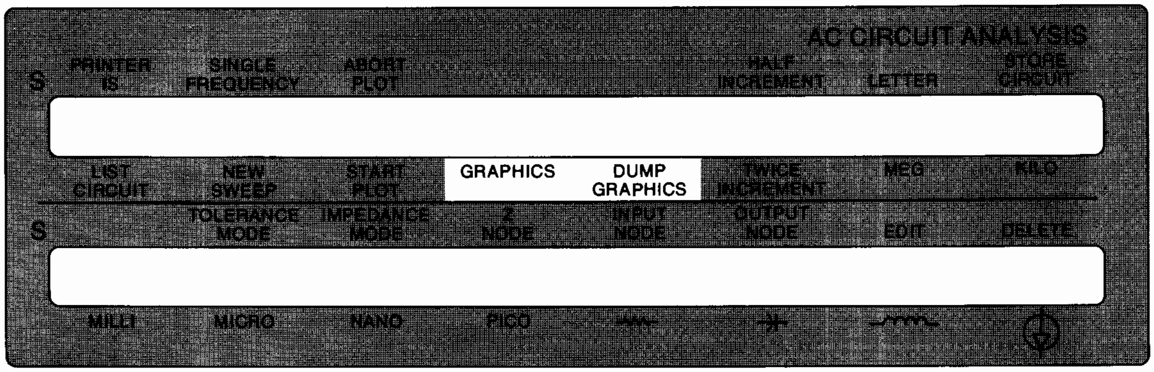
Titles on Graphs

In general titles in the graticule region on plots are not attractive and are hard to read. This is especially true when using 9845 CRT Graphics. For this reason, there is a space provided at the top of the graticule region for titles.

For example, suppose that you have just completed a graph on the CRT Graphics. Press LETTER (Shift K6). You are prompted with an opportunity to select a character height as a percentage of the graph total height. Press CONT which selects the 3% default value. You will see a cursor properly centered in the title area. Using the left-arrow key, backspace the cursor for each two characters in the title. The title can then be typed in the title area.

Extreme care must be taken because labeling errors are difficult to correct on graphics and impossible to correct on the 9872 plotter. To correct an error on graphics lettering press CONT (to exit lettering), type Pen-1 and press EXECUTE. Get back into the letter mode and type over the incorrect label (erasing it as you type). Once the label is erased you must press CONT to exit letter mode. If you want to type a new label, press the LETTER key again.

Graphics and Dump Graphics



There are two special function keys which are used in conjuntion with output device GRAPHICS. The output device is selected in the series of prompts initiated by the NEW SWEEP key (K1).

Graphics (K3)

This key simply toggles the display in and out of graphics while a plot is being generated on the 9845 CRT graphics. This allows you to review past listings which may have been printed previously on the CRT while a plot of that circuit is being generated on the CRT graphics.

This key also toggles in and out of CRT graphics if you have chosen any other form of output (printer, 9872, etc.). In this case, however, the contents of the graphics memory will be the last previous graphics display or blank if no curve has been drawn on the CRT since the computer was last turned on. In either case, it is important to note that the CRT graphics display does not necessarily reflect the current circuit analysis.

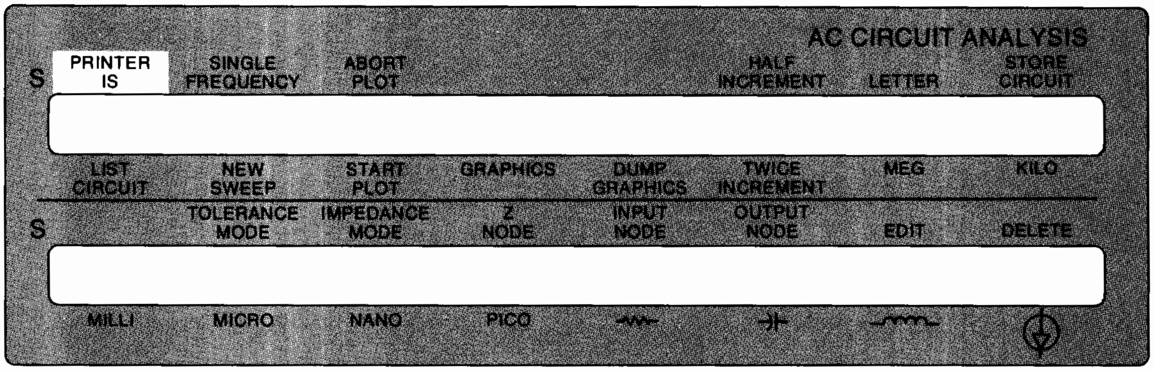
This key does not toggle the display if the program is stopped in a prompt.

This key is not used to initiate a plot. NEW SWEEP or START PLOT is used for that purpose.

Dump Graphics (K4)

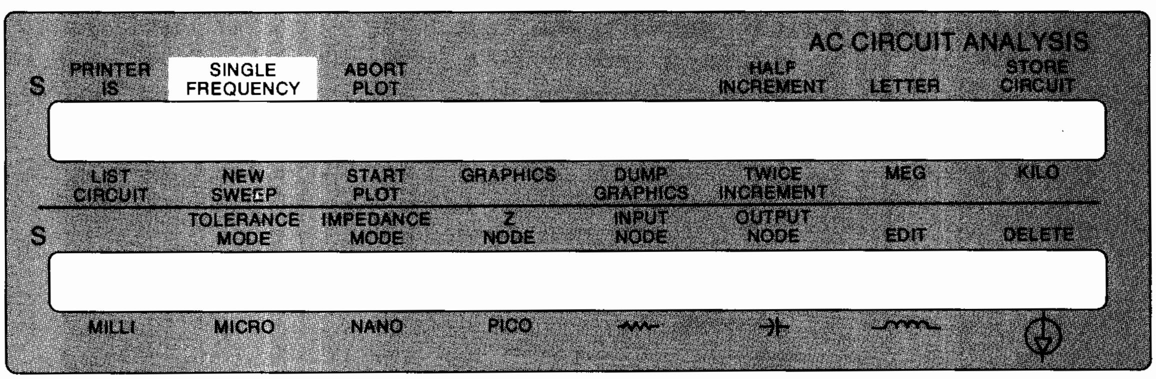
DUMP GRAPHICS (K4) is used to get a hard copy of the CRT graphics plot. Additional labels are found on the paper copy, to provide a finished permanent record of the graph.

Printer Is



The AC Circuit Analysis program keeps a running record of circuit listings, changes, plotting parameters, etc. The program can print this list on the CRT or on the Hard Copy Printer. The PRINTER IS key (shift K0) initiates a single prompt which can be answered with CRT or PRINTER. Answering CRT directs all printed matter to the CRT. PRINTER will direct all printed matter to the Hard Copy Printer.

Single Frequency Analysis

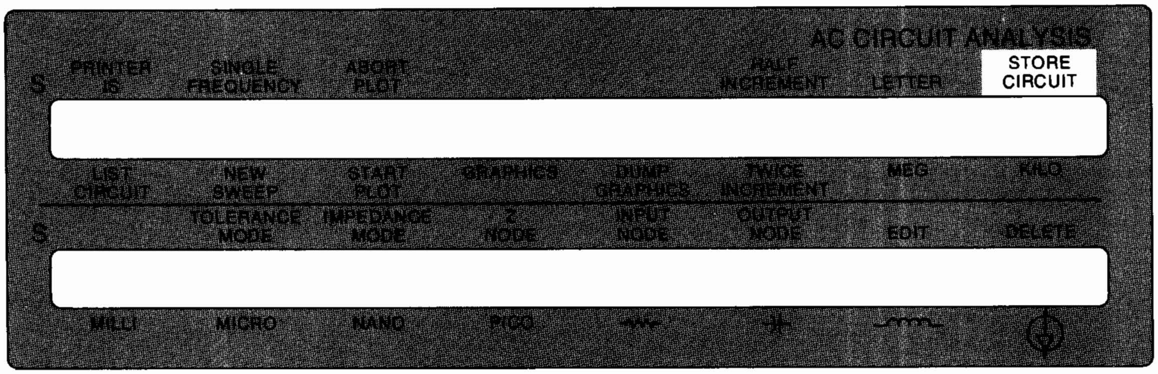


SINGLE FREQUENCY (shift K1) can be used once a circuit has been defined. It allows you to input frequencies one at a time and get the circuit response to those frequencies in a table.

This key is particularly useful when trying to find the location and value of a resonance peak.

To exit single frequency analysis, simply select another key or press CONTINUE.

Store Circuit



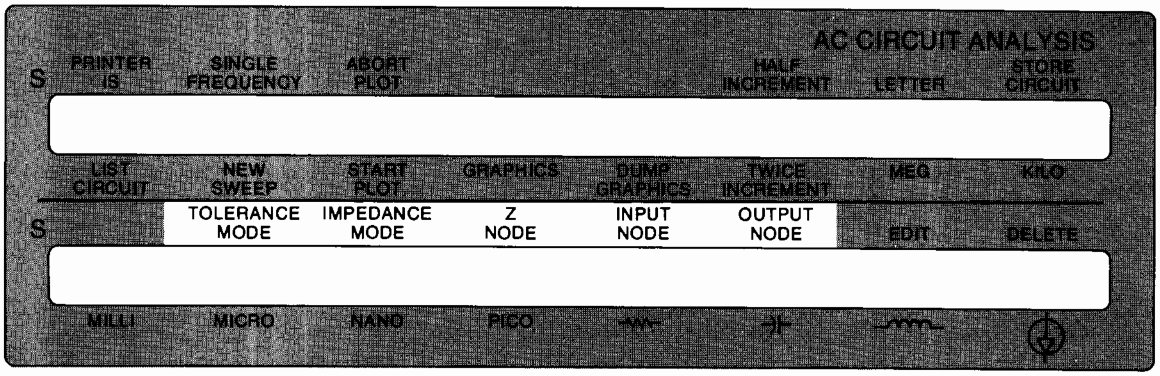
After you have entered a circuit from the keyboard you may press STORE CIRCUIT (shift K7) to store this circuit on mass storage.

In addition to the circuit topology (the types, values, and connections of all the components), the scale parameters (starting frequency, ending frequency, minimum amplitude, maximum amplitude, log/linear, etc.) and program status flags are also stored when you press STORE CIRCUIT. When the circuit is subsequently loaded into the computer, these parameters are used as the default values in the prompts for NEW SWEEP.

Protecting Your Circuit

If you have a file that you want to protect from accidental erasure then you may do so using a key word and the protect command described in the 9845 Operating and Programming Manual. Protected files may be loaded by the program but cannot be stored by the AC Circuit Analysis program.

Special Operation Modes



There are three modes of operation:

NORMAL MODE

IMPEDANCE MODE

TOLERANCE MODE

Normal Mode

When the program is loaded the mode of operation is the normal mode. This mode uses the Input Node and Output Node; and pays no attention to the Impedance Node. All plots or tables requested by NEW SWEEP assume a unit voltage source at Input Node and display results observed at Output Node. Normal mode can be thought of as a transfer function mode.

Input Node(shift K11)

Press this key to change the node defined to be the input.

Output Node(shift K12)

Press this key to change the node defined to be the output.

Impedance Mode

The impedance mode must be selected. In order to do this, press IMPEDANCE MODE (shift K10). You can tell you are in the impedance mode because there is an inverse video display saying IMPEDANCE MODE.

When in the impedance mode the program pays no attention to the Input and Output Nodes; and assumes you want impedance information at the IMPEDANCE NODE. To exit the impedance mode press IMPEDANCE MODE (shift K10) once again.

Z Node(shift K11)

Press this key to change the node defined to be the Impedance Node.

Tolerance Mode

The Normal Mode and Impedance Mode are mutually exclusive. The Tolerance Analysis may be done during either a transfer function analysis or an impedance analysis. Press TOLERANCE MODE (shift K9) to enter the Tolerance Mode. You can tell you are in the Tolerance Mode because there is an inverse video display saying TOLERANCE MODE whenever you see the "Select Key" prompt.

The Tolerance Mode generates two outputs at each frequency rather than one. The two values represent the maximum and minimum value of the output seen by taking into account the tolerances specified on each of the components when they were keyed in.

The program takes tolerances into account by stopping at each frequency long enough to calculate a number of outputs for various randomly selected circuits within the tolerance bounds of the components. The number of circuits considered at each frequency is called the number of tolerance passes. You select the number of tolerance passes through NEW SWEEP (K1) or START PLOT (K2) each time you do a new plot or table.

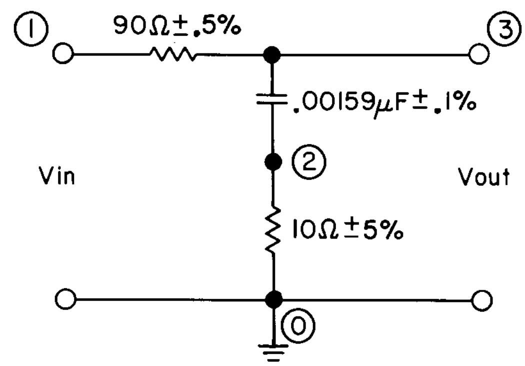
A large number of tolerance passes can significantly slow the program. However, the more circuit configurations the program is allowed to analyze at each frequency, the more likely that the maximum and minimum plotted values will be the worst case.

When inputting circuit components, Tolerance Mode must have been selected in order to be asked for tolerance values. To exit the tolerance mode simply press TOLERANCE MODE again.

Part Three Examples

Example 1-RC Filter

The schematic below shows the circuit to be analyzed. Node numbers are circled. This example will be done in detail to familiarize you with the steps necessary to input and analyze a circuit.



The analysis is to be performed over the frequency range of 100kHz to 100MHz and the desired output is:

1) tabular listing of the magnitude, phase, and time response
2) tabular listing of the input imedance response
3) semi-log plot of the magnitude response
4) semi-log plot of the phase response

Describing The Circuit

1. If the AC Circuit Analysis program has been loaded:

   a. Press: STOP RUN

   Otherwise, load the program as described in the Start-Up Procedure.

2. The following table lists the prompts that will now appear and the correct responses for this example.

PROMPT	RESPONSE
PRINTER IS CRT (CRT,PRINTER)	CRT/CONT
KEY-IN NEW CIRCUIT (KEY-IN, LOAD)	KEY/CONT
INPUT NODE IS 1 (1-25)	CONT
OUTPUT NODE IS 2 (1-25)	3
TOLERANCE MODE? NO (YES, NO)	NO/CONTINUE

3. You are now ready to enter the circuit topology (what types of components, their values, and their nodal connection) into the computer. Components must be entered in ascending order, that is, R1 is followed by R2, etc., but you can intersperse component types, that is, R1 followed by C1 followed by R2.

One valid sequence of entering the components in this example is:

1. Press: K12

   Answer: 90 CONT (for value of R1)

   Answer: 1,3 CONT (for node connections of R1)

NOTE

When prompts request two or more numbers. For example, node numbers, you must separate the numbers with a comma.

---

2. Press: K13

   Answer: .00159 MICRO (K9) (for value of C1)

> **NOTE**
> The "MICRO" refers to the title of K9 and you don't actually type the letters, M-I-C-R-O.

   Answer: 2,3 CONT (for node connections of C1)

3. Press: K12

   Answer: 10 CONT (for value of R2)

   Answer: 2,0 CONT (for node connection of R2)

Listing

You can obtain the hard-copy listing of your circuit shown in Figure 2 by:

1) Pressing: CHANGE PRINTER (shift K0)
2) Choosing the printer
3) Pressing: LIST CIRCUIT (K0)

```
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
     INPUT IS NODE 1          OUTPUT IS NODE 3          GROUND IS NODE 0
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                                   PERCENT             NODE CONNECTIONS
COMPONENT          VALUE          TOLERANCE           FROM,  TO, (+), (-)

RESISTOR 1        90   ohm           0                  1     3
RESISTOR 2        10   ohm           0                  2     0
CAPACITOR 1       1.59 nF            0                  3     2
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

Figure 2

Analyzing The Circuit

You can obtain the analysis of the circuit shown in Figure 3 by:

1) Pressing NEW SWEEP (K1)
2) Answering the appropriate prompts with the following information:

LOG plot	CRT or PRINTER as output device
100kHz start frequency	20 intervals
100MHz end frequency	

FREQUENCY	MAGNITUDE (dB)	PHASE (Deg)	TIME
100.00 kHz	-.04	-5.13	-142.57 ns
141.25 kHz	-.08	-7.22	-142.06 ns
199.53 kHz	-.17	-10.13	-141.05 ns
281.84 kHz	-.33	-14.11	-139.09 ns
398.11 kHz	-.63	-19.41	-135.44 ns
562.34 kHz	-1.18	-26.11	-128.98 ns
794.33 kHz	-2.09	-33.90	-118.54 ns
1.12 MHz	-3.48	-41.87	-103.65 ns
1.58 MHz	-5.34	-48.73	-85.40 ns
2.24 MHz	-7.57	-53.30	-66.14 ns
3.16 MHz	-9.99	-54.90	-48.23 ns
4.47 MHz	-12.42	-53.32	-33.16 ns
6.31 MHz	-14.65	-48.76	-21.47 ns
8.91 MHz	-16.51	-41.91	-13.06 ns
12.59 MHz	-17.90	-33.94	-7.49 ns
17.78 MHz	-18.82	-26.15	-4.09 ns
25.12 MHz	-19.37	-19.45	-2.15 ns
35.48 MHz	-19.67	-14.14	-1.11 ns
50.12 MHz	-19.83	-10.15	-562.57 ps
70.79 MHz	-19.91	-7.24	-283.99 ps
100.00 MHz	-19.96	-5.14	-142.85 ps

Figure 3

To obtain the tabular listing of the input impedance response shown in Figure 4, you:

1) Press: IMPEDANCE MODE (shift K10)
2) Press: START PLOT (K2)

FREQUENCY	IMPEDANCE	Z PHASE (Deg)
100.00 kHz	1.01 kohm	-84.29
141.25 kHz	715.66 ohm	-81.97
199.53 kHz	511.55 ohm	-78.73
281.84 kHz	368.97 ohm	-74.27
398.11 kHz	270.59 ohm	-68.31
562.34 kHz	204.17 ohm	-60.67
794.33 kHz	160.87 ohm	-51.57
1.12 MHz	134.01 ohm	-41.74
1.58 MHz	118.27 ohm	-32.28
2.24 MHz	109.54 ohm	-24.09
3.16 MHz	104.89 ohm	-17.56
4.47 MHz	102.48 ohm	-12.63
6.31 MHz	101.25 ohm	-9.01
8.91 MHz	100.63 ohm	-6.41
12.59 MHz	100.32 ohm	-4.55
17.78 MHz	100.16 ohm	-3.22
25.12 MHz	100.08 ohm	-2.28
35.48 MHz	100.04 ohm	-1.62
50.12 MHz	100.02 ohm	-1.14
70.79 MHz	100.01 ohm	-.81
100.00 MHz	100.01 ohm	-.57

Figure 4

To obtain the plot of the magnitude response shown in Figure 5, you:

1) Press: IMPEDANCE MODE (shift K10) again to exit the impedance mode
2) Press: NEW SWEEP (K1) and answer prompts with information shown

Log	plot
100kHz	start frequency
100MHz	end frequency
Graphics	output
20	intervals
Magnitude	plot
−25	minimum magnitude (db)
5	maximum magnitude (db)
Original	graph
Yes	semi-log grid lines
5	db per major grid line
5	minor tic marks per major grid line

3) Press: DUMP GRAPHICS (K4) to obtain a hard copy when plot is complete

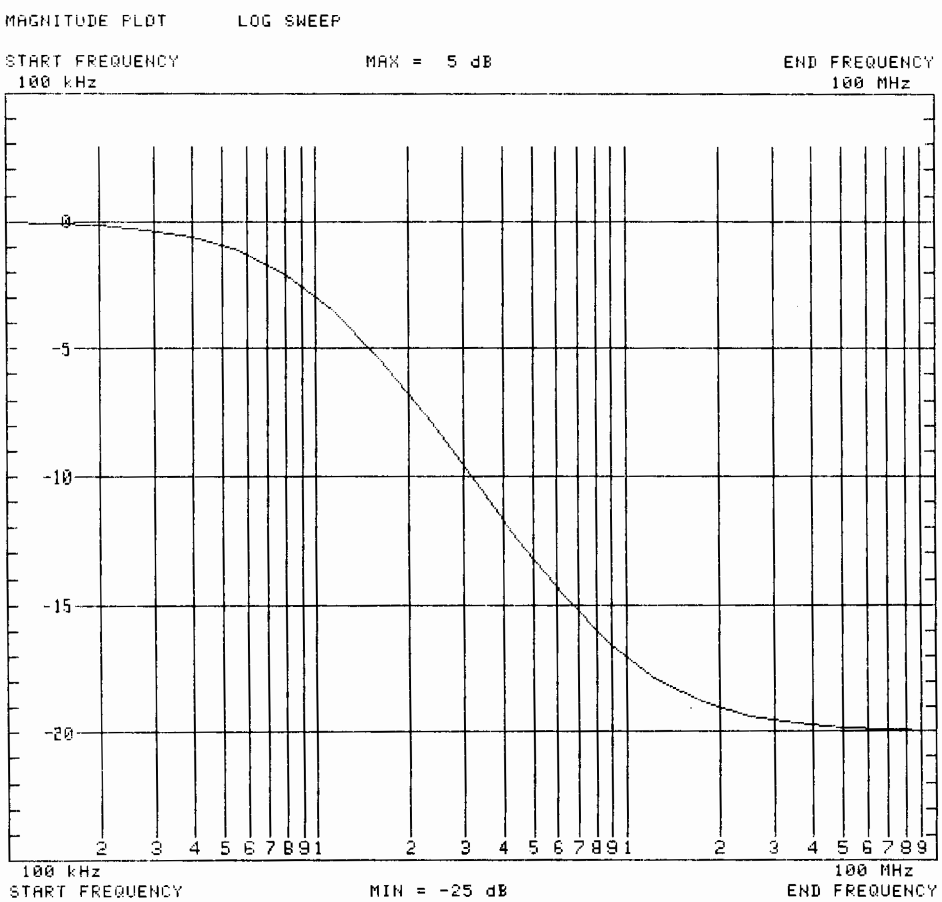


Figure 5

You can obtain the plot of the phase response shown in Figure 6 in a similar fashion.

1) Press: NEW SWEEP (K1) and answer all prompts as you did for the magnitude response except as follows.
2) Choose PHASE rather than MAGNITUDE
3) Set the plot scale for

   0 degrees maximum

   −90 degrees minimum

   10 degrees per major grid line

   10 minor tics per major grid line

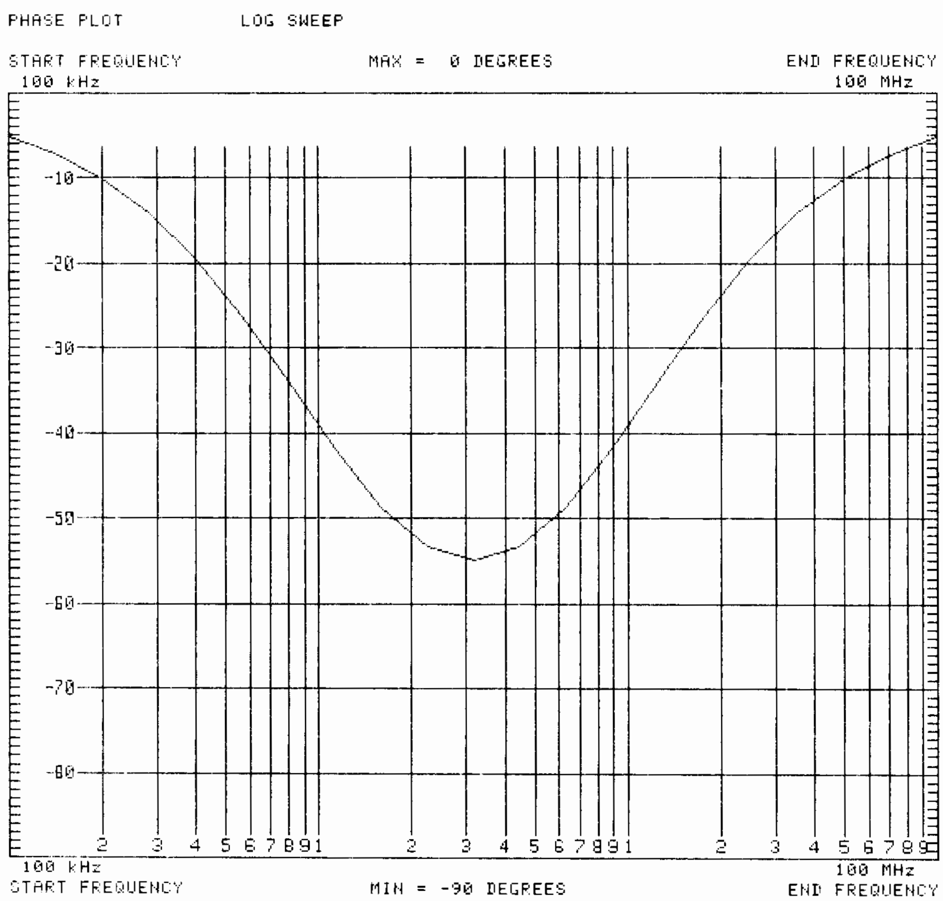
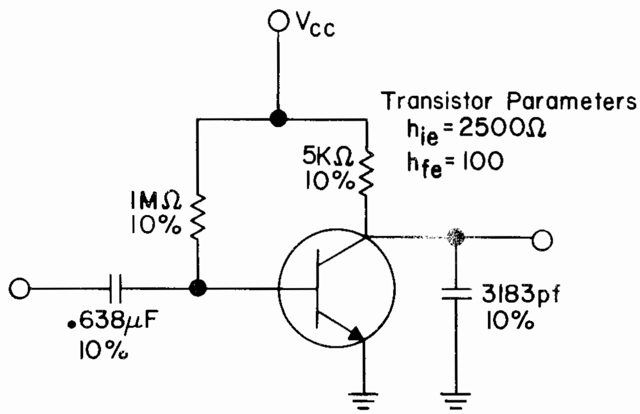


Figure 6

Example 2-Common-Emitter Amplifier

For this example, we wish to determine the magnitude response of the circuit shown below over the range of 10Hz to 100kHz. We also wish to determine the effect of component tolerances on this response.



The transistor can be modelled using a voltage controlled current source. The g_m of this source is established in the following manner:

since

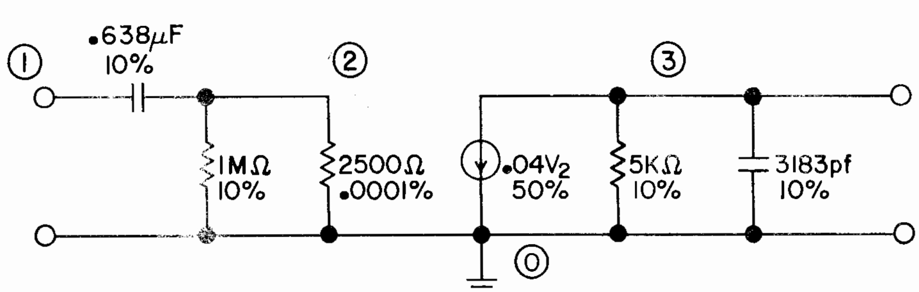
$$g_m \; v_b = h_{fe} \, i_b \text{ and}$$

$$v_b = i_b \, h_{ie},$$

solving for g_m in terms of h_{fe} and h_{ie} yields

$$g_m = \frac{h_{fe}}{h_{ie}} = \frac{100}{2500} = .04 \text{ mhos}$$

Thus, the equivalent circuit is:



Since the current source is controlled by V_2 and has the flow direction indicated, the "+" and "−" control nodes for the source are "2" and "0" respectively, and the "from" and "to" nodes for current direction are "3" and "0".

Start the program in the normal fashion and input the circuit topology. Since we are interested in both the nominal and tolerance responses, be sure to include the component tolerances in your input. Figure 7 is a listing of the circuit.

INPUT IS NODE 1   OUTPUT IS NODE 3   GROUND IS NODE 0

COMPONENT	VALUE	PERCENT TOLERANCE	NODE CONNECTIONS FROM,	TO,	(+),	(-)
RESISTOR 1	1 Mohm	10	2	0		
RESISTOR 2	2.5 kohm	.001	2	0		
RESISTOR 3	5 kohm	10	3	0		
CAPACITOR 1	638 nF	10	1	2		
CAPACITOR 2	3.183 nF	10	3	0		
SOURCE 1	40 mmho	50	3	0	2	0

Figure 7

Figure 8 is a tabular analysis of this circuit obtained by pressing NEW SWEEP (K1) while in tolerance mode (by pressing shift K9) and specifying 10 intervals with logarithmic sweep.

FREQUENCY	MAGNITUDE (dB)	PHASE (Deg)	TIME
10.00 Hz	30.06	-95.25	-26.46 ms
	18.79	-96.29	-26.75 ms
25.12 Hz	37.80	-103.01	-11.39 ms
	26.60	-105.58	-11.68 ms
63.10 Hz	44.48	-120.20	-5.29 ms
	33.56	-125.11	-5.51 ms
158.49 Hz	48.69	-146.12	-2.56 ms
	37.88	-151.05	-2.65 ms
398.11 Hz	49.99	-166.60	-1.16 ms
	39.23	-169.40	-1.18 ms
1.00 kHz	50.19	179.72	499.22 us
	39.47	-179.91	-499.76 us
2.51 kHz	50.00	170.79	188.87 us
	39.36	165.66	183.20 us
6.31 kHz	48.74	153.54	67.59 us
	38.28	143.74	63.28 us
15.85 kHz	44.61	127.97	22.43 us
	34.27	118.03	20.69 us
39.81 kHz	37.75	107.20	7.48 us
	27.46	101.93	7.11 us
100.00 kHz	30.07	97.02	2.70 us
	19.68	94.81	2.63 us

Figure 8

Figure 9 is a hard copy graphics dump of the response obtained by pressing NEW SWEEP (K1) and choosing GRAPHICS as the output mode, and 30 frequency intervals. Note that we have come out of tolerance mode (by pressing shift K9 a second time). The information for determining the vertical scale factors for the graph came from inspecting the tabular output in Figure 8.

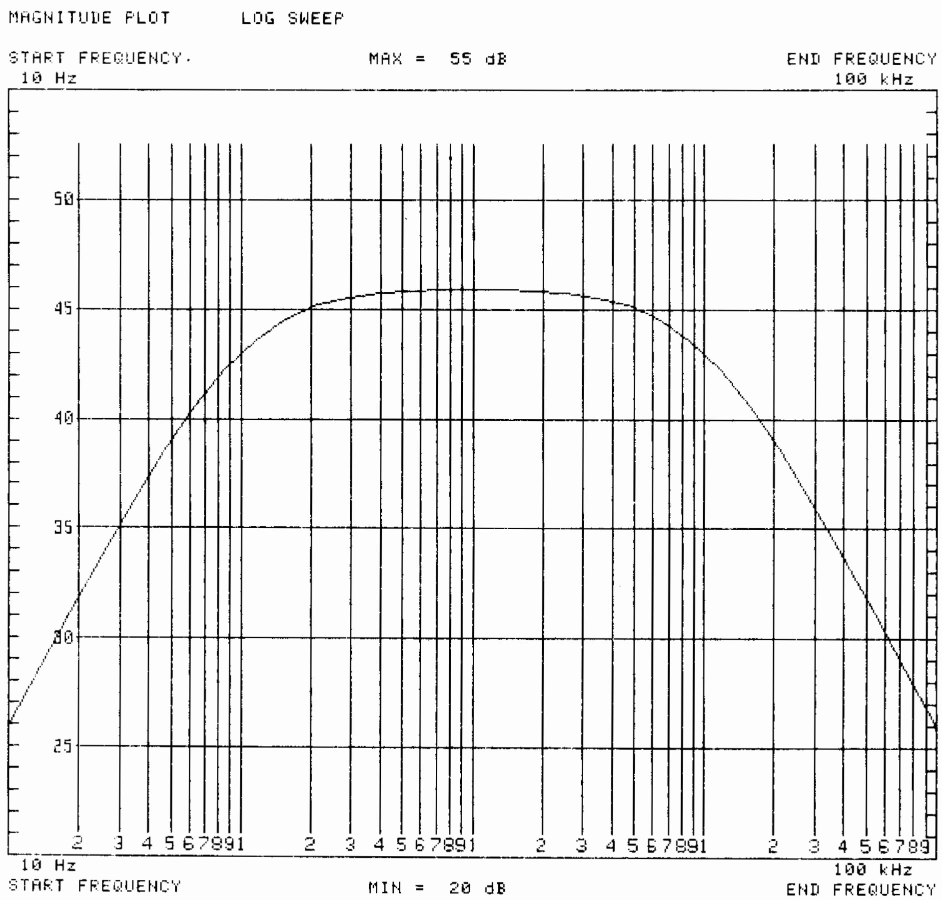


Figure 9

Finally, Figure 10 is obtained by once again going into tolerance mode and repeating NEW SWEEP (K1). This graph was created with 20 tolerance passes used for each frequency.

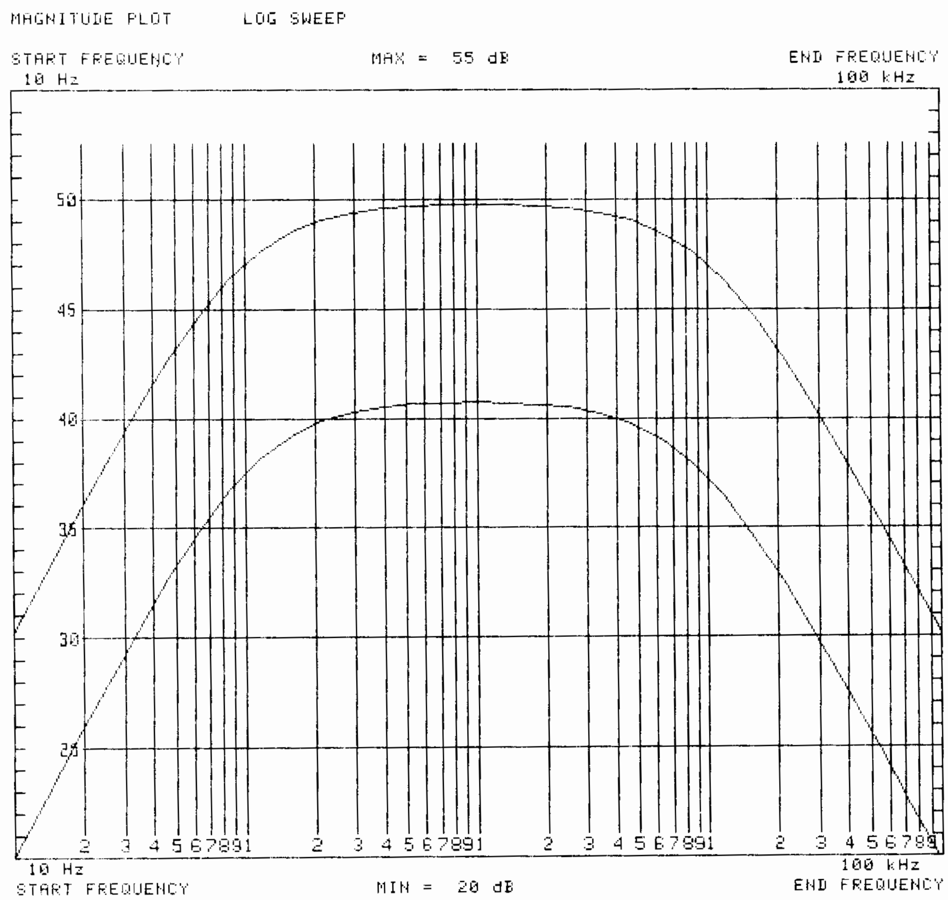
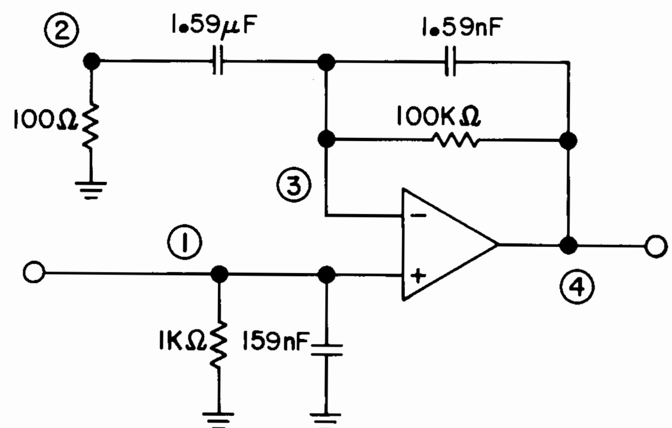


Figure 10

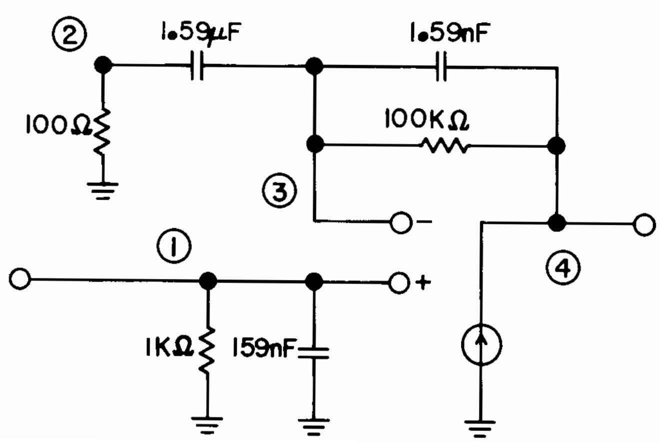
Example 3 Active Filter

In this example, we will analyze a circuit which has been previously stored on the AC Circuit Analysis tape cartridge. The purpose of this example is twofold. First, it will illustrate the usefulness of the program feature that allows storage of not only a circuit's topology but also plot scale factors, etc. Secondly, it will describe how to model an op-amp using the component types allowed in this pack.

The circuit is shown in the schematic below. We wish to analyze the magnitude response from 10Hz to 100kHz.



For this example, let's consider the op-amp to be ideal. This results in a simpler model for the circuit and is a valid assumption for many cases. Modeling the ideal op-amp using a voltage controlled current source results in the following equivalent circuit:



Start the program in the normal fashion. The circuit is stored on the same cartridge as the program in the file "DEMO". After you have answered the appropriate prompts with the information regarding the fact you want to load the circuit, the program will go to the tape cartridge, load in the circuit, and list it on the currently-specified printer. Figure 11 is the listing for the circuit.

INPUT IS NODE 1 OUTPUT IS NODE 4 GROUND IS NODE 0

COMPONENT	VALUE	PERCENT TOLERANCE	NODE CONNECTIONS FROM,	TO,	(+),	(-)
RESISTOR 1	100 ohm	20	0	2		
RESISTOR 2	100 kohm	20	3	4		
RESISTOR 3	1 kohm	20	1	0		
CAPACITOR 1	1.59 uF	20	2	3		
CAPACITOR 2	1.59 nF	20	3	4		
CAPACITOR 3	159 nF	20	1	0		
SOURCE 1	1 kmho	0	0	4	1	3

Figure 11

For this circuit, all of the scale parameters have been previously defined for all of the possible plots. Thus, to obtain the plot shown in Figure 12 press NEW SWEEP (K1) and accept all of the default values (previosly stored with the circuit) by pressing CONT whenever a choice is presented. You may choose any of the other plots available and accept the default values for them in a similar fashion.

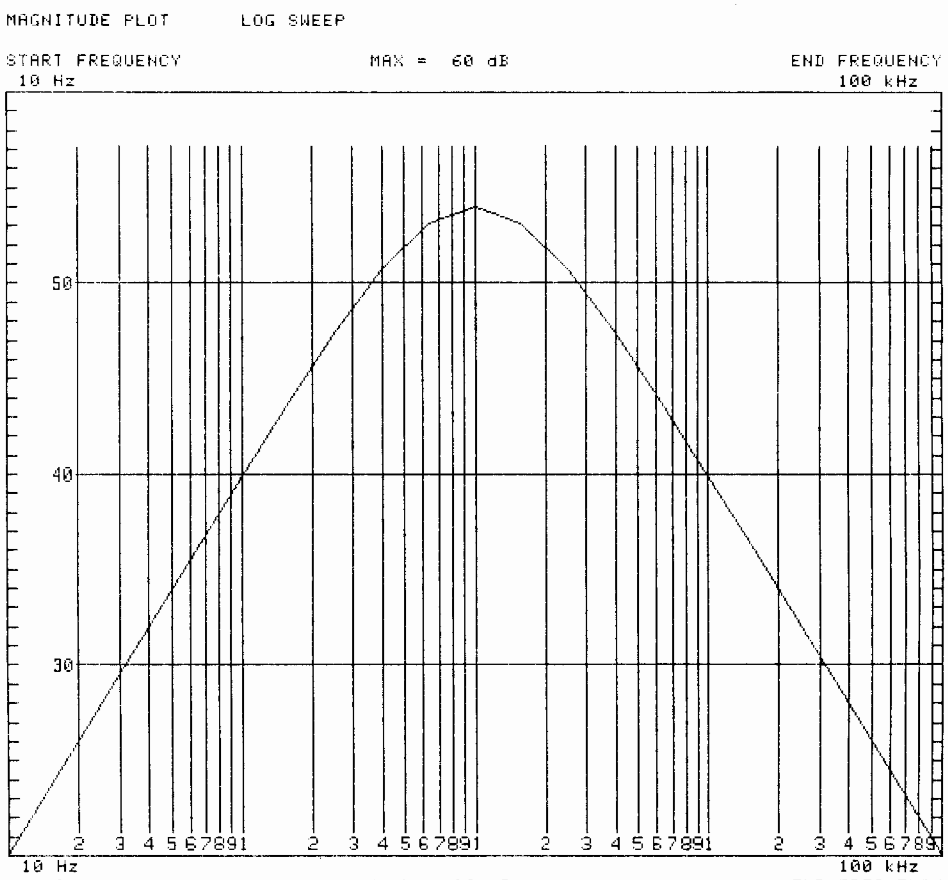
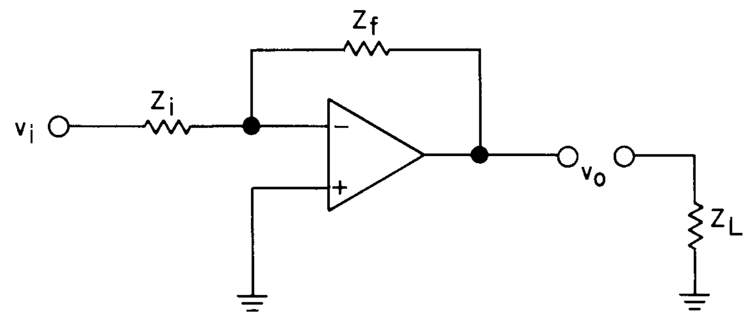


Figure 12

Derivation Of Op-Amp Model

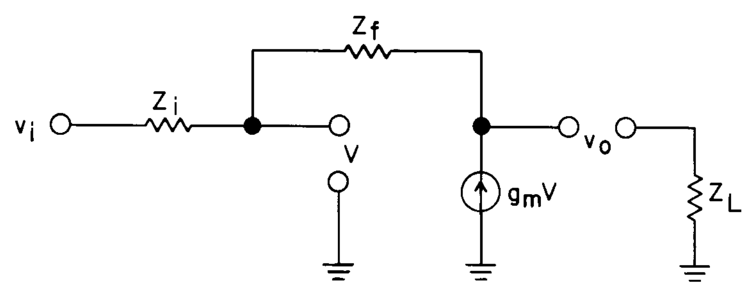
In this example, we've used a voltage-controlled-current-source to model an ideal op-amp. Let's examine the model. The circuit shown below is a simple inverting amplifier using an ideal op-amp.



The gain of this circuit is:

$$v_o / v_i = -Z_f / Z_i$$

Assume the equivalent circuit is:



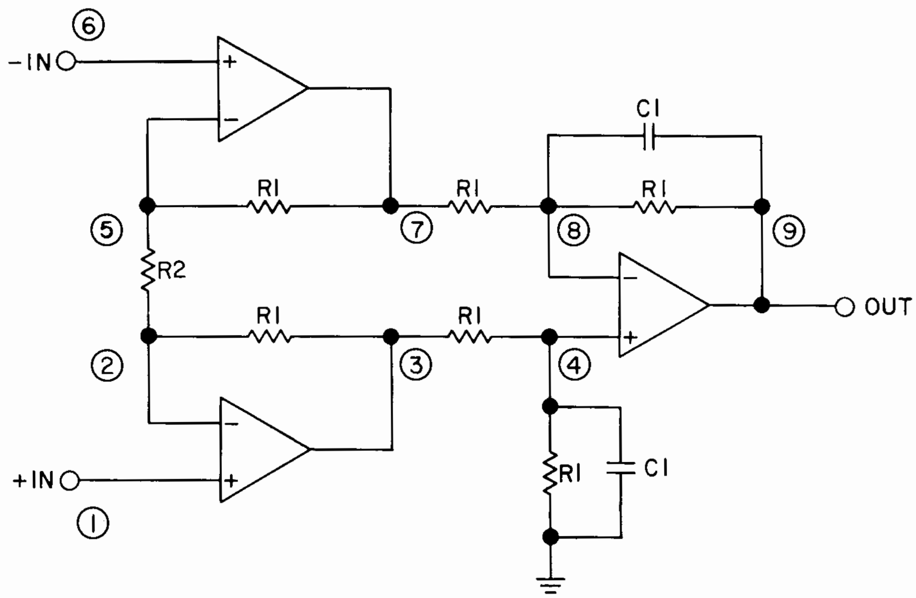
The gain for this circuit is:

$$\frac{v_o}{v_i} = \frac{-Z_f + \frac{1}{g_m}}{Z_i + \frac{1}{g_m}\left[1 + \frac{Z_f + Z_i}{Z_L}\right]}$$

For g_m arbitrarily large, that is, 1000:

$$v_o / v_i \approx -Z_f / Z_i$$

In reality, op-amps have a finite gain and a finite bandwidth. For those designs where the assumption of an ideal op-amp cannot be made, the following circuit can be used.



$A_0 = 1+2(R_1/R_2)$

$f_p = 1/(2\pi R_1C_1)$

$g_m = 1/(Z \text{ out open loop})$

$GBW = A_0 f_p$

You would now add the appropriate components to define the external networks. This circuit model for an op-amp is stored on the AC Circuit Analysis program tape in a file named OPAMP.

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