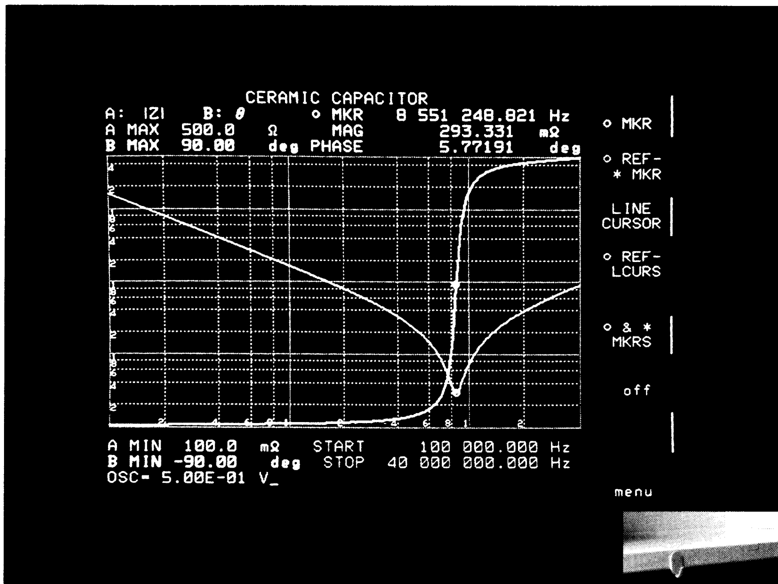
Parametric Analysis for Electronic Components and Circuit Evaluation

Application Note 339

Using the HP 4194A Impedance Gain-Phase Analyzer



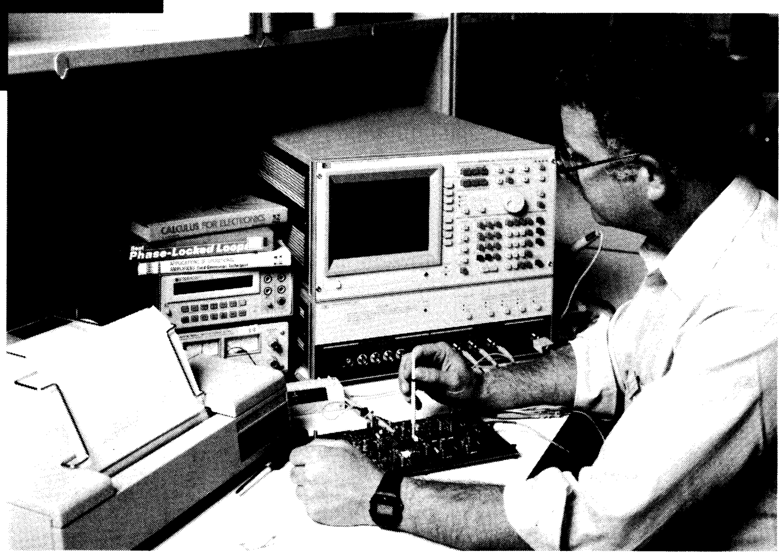


TABLE OF CONTENTS

	Impedance	Gain – Phase
Measurement		
Parameters Measured	$\lvert Z \rvert$, $\lvert Y \rvert$, θ, R, X, G, B, L, C, D, Q	Amplitude (Ratio, Absolute), Phase, Group Delay
Test Frequency	100Hz to 40MHz 1mHz Resolution	10Hz to 100MHz 1mHz Resolution
OSC Level	10mV to 1Vrms	−65dBm to +15dBm
DC Bias	0 to ±40V	
Sweep Parameters	Frequency, OSC Level and DC Bias	Frequency and OSC Level
Measurement Range	10mΩ to 100MΩ, ±180°	−107 dBm to +15dBm, ±180°
Measurement Resolution	0.1mΩ	0.001dB 0.01°
Basic Accuracy	0.17% reading	0.1dB 0.5°
Measuring Speed (Supplemental characteristics)	Approx. 3.7 ms/point (≧30kHz)	Approx. 3.5 ms/point (≧30kHz)
Sweep Points	401 points max.	401 points max.
Display		
CRT	7.5 inch Color CRT	
Display Mode	Rectangular (two kinds), Table	
Display Control	Autoscale, Superimpose, Phase Scale Expansion, Storage and etc.	
Analysis	Marker, Line Cursor, Multi Parameter Approximation and Simulation, Arithmetic Operation and Data Register Manipulation	
Program	Auto Sequence Program (ASP), HP-IB Remote Control	

Table 1. Key Specifications of 4194A

1. INTRODUCTION

The HP4194A IMPEDANCE/GAIN-PHASE ANALYZER features two measurement functions – impedance and gain/phase – for precise measurements of materials, electronic components, and circuits. This high-performance analyzer combines measurement, graphics display, and parameter analysis in one instrument that can be used for a wide range of applications, including

(1) Evaluation of basic impedance characteristics for new materials development.
(2) Extensive & sophisticated evaluation of characteristics for development of high-performance, reliable components.
(3) Programmed points measurement for high-speed parts sorting on production lines.
(4) Evaluation and analysis of component and circuit characteristics for design of reliable electronic circuits.

This application note presents typical examples of how the 4194A can be effectively used for materials and component development, circuit design, and production line applications.

2. 4194A FUNCTIONS AND APPLICATIONS

2.1 Key Features and Specifications

■ **High-speed evaluation of impedance and transmission parameters using full graphics analysis**

The 4194A's analytical capabilities include not only various data display functions using a color CRT graphic display but also a marker/line cursor (MARKER/L CURSOR) that can be used for graphic analysis, a multi-parameter approximation and simulation function that automatically calculates of 3 or 4 equivalent circuit elements based on the DUT's impedance measurement simulates frequency characteristics based on component constants, a programmed points measurement function in which only user-designated sweep points are swept, a GO/NO-GO function that performs GO/NO-GO testing based on user-designated upper and lower limit values for each measurement point, and more.

High-speed sweeps are possible for both impedance and gain/phase measurements. The maximum speed for a swept measurement (impedance) is about 4.5 msec/point. For circuit testing, the 4194A's Auto Sequence Program (ASP) and GO/NO-GO functions can be effectively used for incoming and outgoing inspection.

■ **A reliable measurement tool for electronic component characteristics evaluation with high-accuracy and high-resolution**

The 4194A performs impedance measurements across the frequency range of 100Hz – 40MHz, and has a basic measurement accuracy of 0.17%, ensuring highly accurate measurements. In addition, the 4194A's wide impedance |Z| measurement range of 10 mΩ to 100MΩ means it also excels in evaluating the resonant characteristics of high-Q devices.

Gain/phase measurements can be made at frequencies of 10Hz – 100MHz. Maximum gain measurement resolution is 0.001dB with a basic accuracy of 0.1dB, and phase measurement resolution is 0.01° with a basic accuracy of 0.5°. This is realized with the low pass-band ripple and high phase linearity needed for correct evaluation of bandpass filters.

Furthermore, frequency setting resolution for both impedance and gain/phase measurements is 1 mHz over the entire range, ensuring that no abrupt frequency characteristics changes will be overlooked.

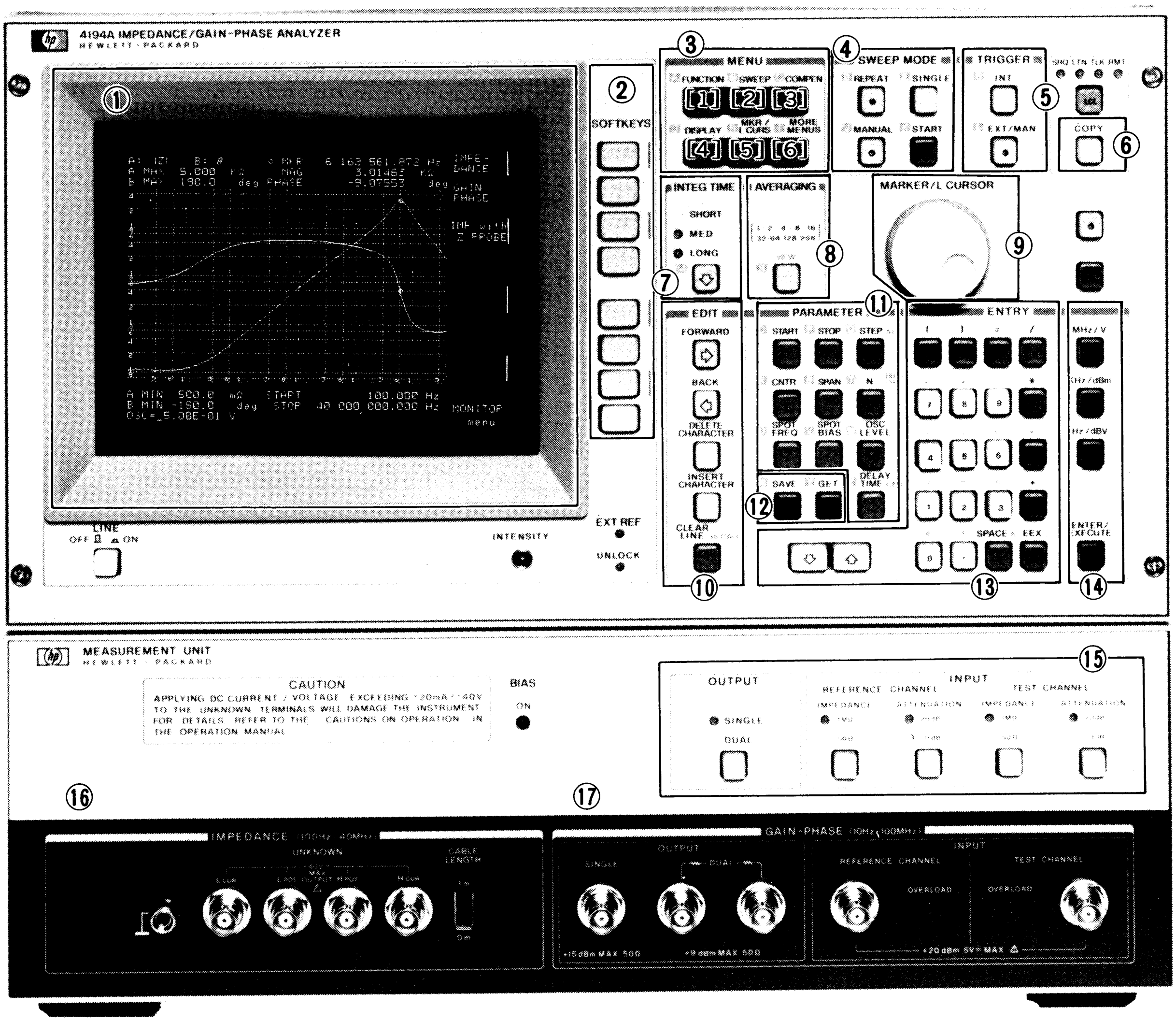
The 4194A also features automatic error compensation functions that allow you to correctly and reliably compensate measurement results for errors caused by the test fixtures residual impedance during impedance measurement or by measurement-related loss or phase differences during a gain/phase measurement. Error compensation is performed at the touch of a key. For impedance measurement, the 4194A is equipped with two compensation methods: (1) the interpolation compensation method in which the interpolation calculation enables compensation regardless of the measurement frequency range setting if the compensation data has been stored once and (2) the all-point compensation method in which all measurement points are automatically compensated.

■ **Menus and softkeys provide simple operation even for abundant functions**

4194A provides 6 menu keys for measurement, graphics display, parameter analysis, hardcopy output, and other device evaluation tasks. Combination of menu key/softkey effectively simplifies operation of device evaluation and analysis. In addition to the variable-function softkeys, 4194A provides hard keys on the front in order to realize quick and easy resetting of sweep parameters varied frequently such as start and stop values.

■ **Auto Sequence Program (ASP) lets you freely choose expanded functions and automatic control via the HP-IB**

With the 4194A's ASP function, resonant frequency detection in resonators and magnetic heads, parameter definition (e.g., insertion loss, pass-band width, group-delay distortion, etc.) in band-pass filters, graphic display of secondary constants in transmission lines, and other operations can be performed automatically. These measurement results can be output to an external device via the 4194A's 8-bit I/O interface or the HP-IB (Hewlett-Packard Interface Bus). Thus hardcopy output can be obtained on a printer or graphic plotter, enabling the 4194A to be used as a single instrument automatic measurement system. The 4194A's key specifications are listed in Table 1.



4194A Impedance/Gain-Phase Analyzer

(Circled numbers quoted to sentences in the Section 2.2 correspond to the key group numbers shown on this front panel.)

<table>
<tr><td rowspan="2"></td><td colspan="2">Impedance Measurement</td><td rowspan="2">Gain-Phase Measurement</td></tr>
<tr><td>Series Equivalent Circuit</td><td>Parallel Equivalent Circuit</td></tr>
<tr><td rowspan="2">Measurement Mode</td><td>R−X
L_S-R_S, L_S-Q
C_S-R_S, C_S-Q, C_S-D
$|Z|$-L_S, $|Z|$-C_S</td><td>G−B
L_P-G, L_P-Q
C_P-G, C_P-Q, C_P-D
$|Z|$-L_P, $|Z|$-C_P,
L_P-R_P
C_P-R_P</td><td rowspan="2">Tch/Rch(dB) − θ
Tch/Rch − θ
Tch/Rch(dB) − τ
Rch − Tch (V)
Rch − Tch (dBm)
Rch − Tch (dBV)</td></tr>
<tr><td colspan="2">$|Z| - \theta$, $|Y| - \theta$</td></tr>
<tr><td>Monitor Mode</td><td colspan="2">V (AC)

I (AC)</td><td>Rch (V)
Rch (dBm)
Rch (dBV)
Tch (V)
Tch (dBm)
Tch (dBV)</td></tr>
</table>

Table 2. Available Measurement and Monitor Modes of the 4194A

2.2 Principal Functions and Operations

The 4194A's 6 menu keys (③) provide all of the functions needed during characteristic evaluation. Each menu key causes a different set of softkey functions to be shown on the right side of the CRT screen next to the softkeys (②). In this application note [ ] indicates softkeys and ( ) indicates all other keys on the front panel.

[1] Impedance and gain/phase measurement functions

The (FUNCTION) key is used to select measurement-function softkeys. Pressing this key causes the [IMPE-DANCE], [GAIN PHASE], [IMP with Z PROBE], and [MONITOR menu] softkeys to be displayed. When the [IMPE-DANCE], [GAIN PHASE] and [IMP with Z PROBE] keys are pressed, the softkeys corresponding to each measurement function such measurement parameters mode are displayed. All together, there are 20 such measurement modes for impedance measurements and 6 for gain/phase measurement. In addition, the monitor mode selection key ([MONITOR menu]) can be used to monitor and display (1) real-time DUT voltage and current signal levels, even during measurement (impedance measurement) or (2) reference channel (Rch) and test channel (Tch) input signal levels (gain/phase measurement). (See Table 2.)
The 4194A has impedance measurement terminals (⑯) and gain/phase measurement terminals (⑰). During a gain/phase measurement the output and input selection keys (⑮) are used to set the condition for the signal output and input terminals. For signal output, the user may choose either SINGLE output or DUAL output through a built-in power splitter. In addition, both Rch and Tch channels include an impedance switch (1MΩ/50Ω with option 350 and 1MΩ/75Ω with option 375) and an attenuation switch (20dB/0dB) for matching signals and impedance, large-level signal evaluation, and other applications.

[2] Sweep measurement functions

The (SWEEP) key is used to display the softkeys for selecting sweep functions. For impedance measurement, frequency, dc bias, and signal level can be set using the [FREQ], [DC BIAS], and [OSC LVL] keys and for gain/phases measurements, frequency and signal level can be set using the [FREQ] and [OSC LVL] keys. For signal level sweep, the user can choose among three level setting units (V, dBm, and dBV) to suit each particular purpose.
Sweep modes are selected using the sweep mode selection key (④). There are also (SINGLE) and (REPEAT) keys for designating single or repeated sweeps. The (MANUAL) key is used to enable sweep measurement for the desired sweep point set with the MARKER L/CURSOR rotary knob (⑨). When either the REPEAT or SINGLE mode has been designated, sweep beginning from the first sweep point is initiated by pressing the (START) key.
As for the trigger mode selection keys (⑤), the (INT) key is for selects the internal trigger and the (EXT/MAN) key selects an external input terminal trigger or manual trigger. The integration time key (INTEG TIME, ⑦) is used to select from among SHORT, MED, or LONG integration time settings.
The averaging key (⑧) can be used to set nine levels of integrations to be averaged: 1, 2, 4, 8, 16, 32, 64, 128 and 256. When combined with the integration time selection function, this can provide more stable measurements. The parameter keys (⑪) are used to set various sweep conditions. The start value, stop value, center value, and span width keys ((START), (STOP), (CNTR), (SPAN)) are range-setting keys. For example, to set the start value at 1 MHz, press the (START) key, then the (1) key on the numeric key section (⑬), and finally, the (MHz) key (⑭). Numeric key settings can be reset via the edit keys (⑩). As for sweep resolution, up to 401 sweep measurement points can be set numerically via the (N) key, or sweep step values can be set using the (STEP) key.
The (SPOT FREQ), (SPOT BIAS), and (OSC LEVEL) keys are used to set fixed (non-sweep) parameters. The (DELAY TIME) key is useful for testing devices such as high-Q devices and semiconductors, which require a period of time before making measurement for stabilization.

[3] Automatic compensation

The compensation key ((COMPEN)) in the front panel's menu key section is used to call up the various compensation softkeys. For impedance measurement, the [ZERO OPEN] softkey is used to cancel offset on the measurement terminals with open condition and the [ZERO SHORT] softkey is used for short condition. When these keys and (EXECUTE) key have been pressed, compensation data are measured and sotred in memory. The [OPEN OFS on/off] and [SHRT OFS on/off] softkeys are used to switch execution of compensation calculation on and off. There are two error compensation modes: (1) the interpolation mode (using the [INTPOL] softkey) enables compensation across the entire frequency range by interpolation calculation, regardless of the direct compensation points, and (2) the all points compensation mode (using the [ALL POINTS] softkey) that compensation is executed at same points on which compensation data have been taken.
For gain/phase measurements, compensation data are determined by measuring through terminal conditions

and pressing the [OFST REF STORE] softkey. The [A OFFSET on/off] and [B OFFSET on/off] softkeys are used to switch execution of compensation calculation on and off. The phase angle scale expansion key ([θ SCALE exp]) enables the graphic display's default phase angle scale of −180° to +180° to be further expanded or contracted in both minus and plus directions. This permits continuous display of phase measurement data and correct frequency readings at ±180°.

[4] Display functions

The 4194A features a high-resolution, color graphics display (①) for easy-to-read displays of measurement results. This multi-color display makes even complex data quite legible and provides clear graphics displays of two or more characteristics at once. The (DISPLAY) key is used to display the softkeys used to select display functions. The display format is set via the [RECTAN X-A&B], [RECTAN A-B] and [TABLE] softkeys. Pressing the [RECTAN X-A&B] key causes sweep parameters (frequency, signal level, etc.) to be shown on the X axis and two measurement data settings on the Y axis. Pressing the [RECTAN A-B] key causes A data to be shown on the X axis and B data on the Y axis. Taking the R-X (resistance-reactance) measurement mode as an example, selecting the [RECTAN A-B] display mode enables the vector locus for impedance Z to be graphed.

Whichever graphic display mode is used, automatic optimum scaling is available via the [AUTO SCALE] softkey. The [SUPER-IMPOSE] softkey enables the operator to call up a stored display screen to be superimposed on and compared with the current screen — a function that is especially useful for checking previous measurement data before executing measurements with revised conditions. The [STORAGE on/off] softkey allows previous graphic display screens to be stored successively for later superimposition.

The [TABLE] key enables tabular reading of numerical values for measurement data, facilitating detection of minute changes when comparing two sets of measurement data.

[5] Marker/line cursor function for graphic analysis

When the [○ MKR] softkey is pressed, a marker point appears on the display along with a digital readout of the measurement data for the point indicated. Pressing the [LINE CURSOR] softkey causes a horizontal cursor line to appear (across the middle of the graph) along with numerical measurement data readings (above and below the graph) of the maximum and minimum sweep point values of sweep points that intersect the line cursor. This marker/line cursor can be moved either by turning the rotary knob (⑨) or by using numerical input to shift the cursor directly to a specific point (e.g., press [MKR=], then (1), (MHz), and (EXECUTE)). In other words, the marker is used to designate a sweep parameter (normally located on the X axis) and to obtain a measurement point reading; the line cursor is used to designate measurement data (the Y axis) and to obtain a corresponding X-axis sweep value.

The [○ REF-∗ MKR] and [○ REF-LCURS] softkeys can be used to display a sub-marker which can be moved away from the main marker to obtain dual measurement-point value readings. In addition, the [○ MKR → MAX(A)], [○ MKR → MIN(A)], [○ MKR → MAX(B)] and [○ MKR → MIN(B)] softkeys cause the main marker to be moved to the maximum or minimum measurement-point value. There is also a [LCURS AVRG] softkey which automatically moves the line cursor to indicate the measurement data's average value. The [○ & ∗ MKRS] softkey are used to define a certain range of measurement data by the main marker (○) and sub-marker (∗). Presssing the [PART SWP on/off] softkey enables a sweep within that range and pressing the [PART ANA on/off] softkey enables analytical operations (using [○ MKR → MAX(A)], [LCURS AVRG], and other softkeys) within that range.

[6] Extended functions

Pressing the (MORE MENUS) key in the front panel's menu section calls up the [PROGRAM], [HPIB DEFINE], [COPY menu], [SELF TEST], [SET PROG TABLE], [EQV CKT] and [measure page] softkeys. The softkeys provide the following functions.

[PROGRAM]	:	ASP (Auto Sequence Program)
[HPIB DEFINE]	:	HP-IB (Hewlett-Packard Interface Bus)
[COPY menu]	:	Direct copy
[SELF TEST]	:	Self-diagnostic test
[SET PROG TABLE]	:	Programmed points measurement, GO/NO-GO
[EQV CKT]	:	Multi-parameter approximation and simulation

(1) ASP function

The ASP function enables automatic measurements to be made easily with programs comprised of BASIC commands often used in measurement evaluation processes such as measurement, graphic analysis, parameter analysis, and plotting and which are input via ordinary key operation. Pressing the [PROGRAM] softkey calls up all of the ASP softkeys, including those for editing, executing, storing, and retrieving programs. (For an example of ASP programming, see section 6.)

(2) Programmed points measurement and GO/NO-GO functions

Pressing the [SET PROG TABLE] softkey calls up the program table screen for selecting sweep points. Up to 401 measurement points can be freely designated as sweep points. Furthermore, upper and lower limit values can be set for each of these measurement points. As the measurements are made, the results can be checked by the GO/NO-GO function as being under or over the limit values.

For further explanation of the GO/NO-GO function, see section 6.3.

(3) Multi-parameter approximation and simulation function

Pressing the [EQV CKT] softkey calls up the screen for selecting multi-parameter equivalent circuit modes. With $|Z| - \theta$ and $|Y| - \theta$ modes, pressing the [CALC EQV PARA] key after frequency characteristic measurement causes the DUT's equivalent circuit constant to be automatically calculated. Four modes are provided for three-component equivalent circuits using L, C and R components, and one mode for four-component devices such as resonators. When the equivalent circuit constant is input and the [SIMULATE f CHAR] softkey pressed, a frequency characteristic can be simulated based on the equivalent circuit constant.

For further explanation, see section 3.

(4) Direct copy function

A hardcopy of the display contents can be output on a connected plotter or printer by pressing the (COPY) key (⑥). The three copy modes – plot mode, print mode, and dump mode – are selected by pressing the softkeys having these names. When outputting the display contents on a plotter via the [PLOT mode] softkey, some or all of the contents can be selected for output via the [GRTCL & DATA], [DATA only] and [ALL] softkeys. [GRTCL & DATA] outputs only the graticule and measurement data, [DATA only] only the measurement data and [ALL] outputs everything except the softkey labels. If the color plotter is used, a detailed multi-color plot hardcopy can be obtained. The print mode is used to output textual information, such as ASP screen contents, to the printer. The dump mode can be used for high-speed hardcopy output of any type of screen contents on a graphics printer.

The [HPIB DEFINE] softkey, is used to designate HP-IB address numbers and the [SELF TEST] softkey selects from among more than 40 kinds of self-diagnostic test and adjustment programs provided with the 4194A. Finally, five sets of front panel settings can be stored in non-volatile memory and recalled at any time.

((SAVE) and (GET) keys (⑫))

3. EQUIVALENT CIRCUIT EVALUATION OF ELECTRONIC COMPONENTS

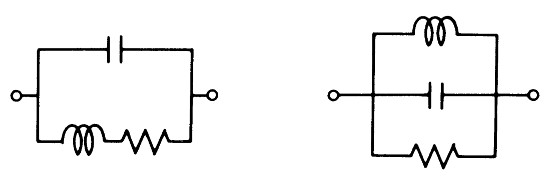
– Multi-Parameter Approximation and Simulation Function –

When dealing with realworld circuit components (resistors, capacitors, coils, etc.), impedance characteristics such as R, C and L, which are defined in terms of circuit logic and are used to describe ideal circuit components, are valid only over a limited frequency range. Beyond this range characteristics appear that are the result of parasitic elements in the component's structure. Therefore it's possible that high frequency circuits having designs that use specified values for a particular frequency fail to produce the characteristics envisioned by the designer. Circuit designers thus find it very important that equivalent circuits comprised of various combinations of components be evaluated at the frequency that the assembled circuit is intended to operate.

3.1 Equivalent Circuits of Basic Components

Coils

In coils, characteristics are influenced by loss from the coils and core materials used. These loss is expressed in inductance components as series resistance. These loss can be also expressed in inductance components as parallel resistance. Coil characteristics are also influenced by distributed capacitance between coils. This can be expressed in inductance components as series capacitance. As a result, coil equivalent circuits will have structures similar to the ones shown in Figure. 1.

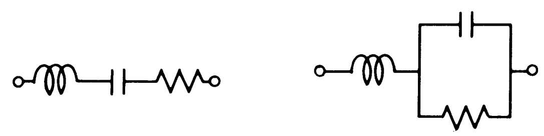


(a) General coil equivalent circuit **(b) Coil equivalent circuit expressing core loss as a parallel resistance**

Figure 1. Equivalent Circuits for Coil

Capacitors

In high-value capacitors, the resistance and inductance of the leads and electrodes act as series parasitics influencing capacitance. In low-value capacitors, dielectric loss or resistance loss caused by leakage current in the dielectric can act as parallel parasitics influencing capacitance. The equivalent circuits for such capacitors are as shown in Figure 2.



(a) High-value capacitor **(b) Low-value capacitor**

Figure 2. Equivalent circuits for Capacitor

Resistors

In resistors, pure resistance characteristics is exhibited only at low frequencies. At high frequencies, low value resistors are influenced by lead inductance, and high value resistors, by stray capacitance. (See Figure 3.)

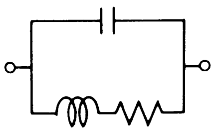
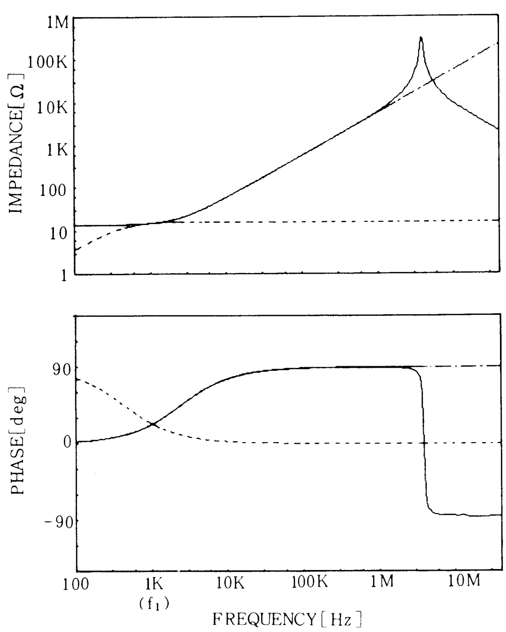


Figure 3. Equivalent Circuit for Resistor

3.2 Evaluation with Two-Component Equivalent Circuits

Within a limited frequency range, circuit component characteristics conform to two ideal parameters (equivalent resistance and either equivalent capacitance or equivalent inductance). Thus at certain frequencies within this range, impedance measurements of circuit components need only consider two-component equivalent circuits. Here we shall examine two equivalent circuits – a series equivalent circuit and a parallel equivalent circuit – for each circuit component. Figure 4 shows, their impedance characteristics. One is the actual measurement of inductor impedance characteristics and others are impedance characteristics that were calculated based on equivalent circuits and impedance measured at frequency f_1. Note that at a low frequency, the series equivalent circuit has characteristics very close to its actual value, while the parallel equivalent circuit no longer shows actual characteristics.



— - — Frequency characteristics of Series Equivalent Circuit obtained by measurement at frequency f_1.

- - - - - - Frequency characteristics of Parallel Equivalent Circuit obtained by measurement at frequency f_1.

——— Frequency characteristics of frequency sweep measurement.

Figure 4. Comparison between Actual Values and Characteristics of Two-component Equivalent Circuits

In these equivalent circuits, we can see that no impedance characteristics are exhibited at frequencies above the self-resonant point. At one measurement point, the impedance reactance could be converted into either inductance (L) or capacitance (C), but that L and C could not be divided for separate quantitative evaluation. This inability to quantify the L and C components of an impedance is evident at both high and low frequencies.

3.3 Evaluation with Three-Component Equivalent Circuits

To obtain impedance characteristics over a wide frequency range, including the component self-resonant frequency, it is necessary to use equivalent circuits having at least three components and to measure impedance frequency characteristics across a broad frequency range to determine constants. The 4194A is equipped with a Multi-parameter Approximation and Simulation function that, once given measurement values for impedance frequency characteristics, automatically calculates equivalent circuits (similar to those shown in Figure 5 (A ~ E)) and simulates frequency characteristics to obtain corresponding parameters. The procedure for obtaining multi-parameter equivalent circuit analysis is as follows.

1. Measure the DUT's impedance or admittance characteristics at any desired frequency. ($|Z| - \theta$ or $|Y| - \theta$ measurement modes and frequency sweep.)
2. Press the [MORE MENUS] key and [EQV CKT] softkey and select the desired equivalent circuit ([CKT A] , [CKT B] , [CKT C] , [CKT D] , & [CKT E] softkeys).
3. Press the [CALC EQV PARA] softkey to have the equivalent circuit calculated and the L, C and R values displayed. (See Figure 5.)

To simulate the frequency characteristics for the equivalent circuit just calculated, press the [SIMULATE f CHAR] key. Once this is done, characteristics based on indicated values are superimposed on the screen over those based on calculated values. This facilitates comparison. (See Figure 6.)

In addition, the operator can input circuit constants using the [EQV R] , [EQV L] , [EQV CA] and [EQV CB] softkeys to have the corresponding frequency characteristics displayed on the graph.

Finally, the selection guide for use of five equivalent circuits is displayed. (See Table 3.)

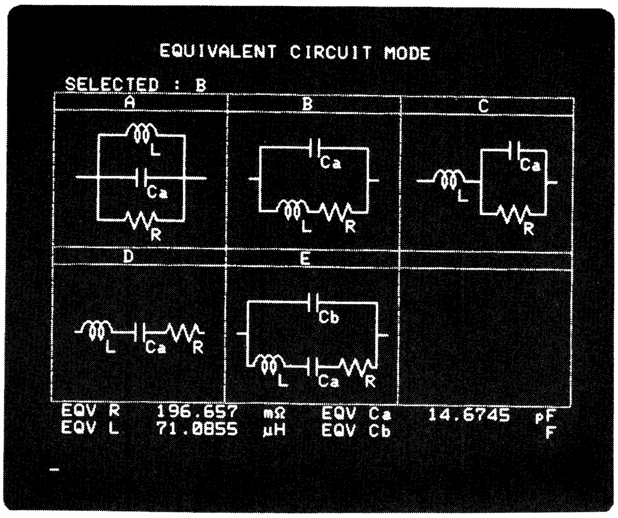


Figure 5. Calculated Equivalent Circuit Constants

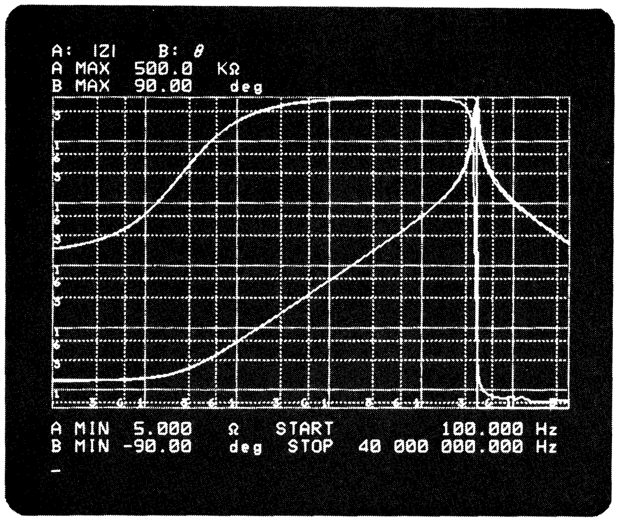


Figure 6. Comparison of Indicated Values and Approximated Values

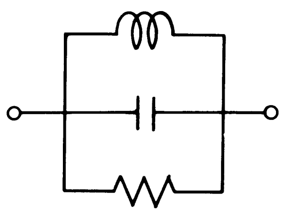
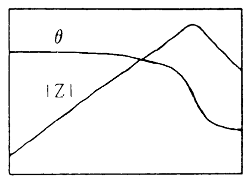
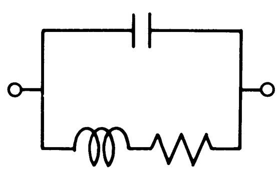
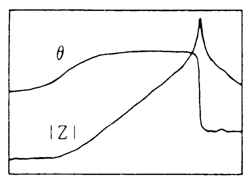
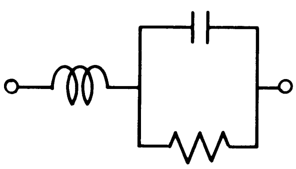
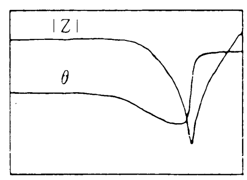
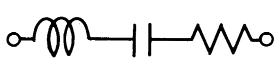
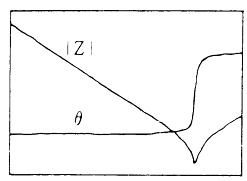
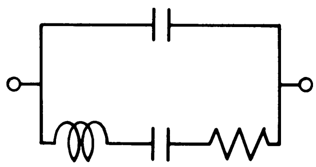
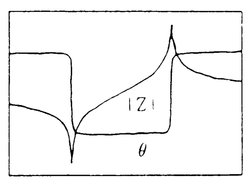
Equivalent Circuit		Examples of DUT	Trend of Characteristics in Sweep or Analysis Range
A		• Coil with high core loss	
B		• General coil • Resistor	
C		• Low-value capacitor • Capacitor with high dielectric loss or resistance loss caused by leakage current.	
D		• High-value capacitor • Capacitor with high resistance loss of the leads and electrodes.	
E		• Vibrator, Resonator (Crystal, Ceramic, Ferrite)	

Table 3. Selection Guide for Use of Five Equivalent Circuits

4. IMPEDANCE MEASUREMENT APPLICATIONS

4.1 Evaluation of Choke Coils

In this application, a choke coil used for eliminating switching noise is tested, its impedance frequency characteristics measured, its self-resonant frequency determined, and its three-component equivalent circuit constants extracted. In addition, frequency characteristics for inductance, maximum Q value based on effective Q frequency characteristics, and effective permeability (μ_e) are obtained.

The key operation is as follows.

1. Set at original settings.
   [CLEAR LINE] [Blue] (on) [R] [S] [T] [EXECUTE]
2. [SWEEP] [LOG SWEEP]
3. [COMPEN]

   Open the measurement terminals and press
   [ZERO OPEN] [EXECUTE]
   Short the measurement terminals and press
   [ZERO SHORT] [EXECUTE]
   Connect the DUT and press [OPEN OFS on/off] (on) [SHRT OFS on/off] (on) keys
   SWEEP MODE . . . . . [START]
4. [DISPLAY] [menu] [A SCALE LOG] [AUTO SCALE A]

Self-resonant frequency

At frequencies higher than the self-resonant frequency, inductors begin to exhibit capacitive reactance, which effectively reduces inductance. We must therefore regard the self-resonant frequency as an important parameter in evaluating inductors. With the 4194A, evaluation of the self-resonant frequency is easily accomplished using the marker function.

The procedure follows.

[MKR/ LCURS] [menu] [o MKR → MAX(A)]

In this example, the self-resonant frequency (SRF) = 6.789MHz, and the self-resonant point impedance = 2.314kΩ. See Figure 7.

Three-component equivalent circuit constants

The inductor's equivalent circuit is automatically calculated by the 4194A's Multi-Parameter Approximation and Simulation function.

First press the [MORE MENUS], [EQV CKT] and [CKT B] keys to select equivalent circuit model B. Then press the [CALC EQV PARA] key to have the equivalent circuit constants automatically calculated. As shown in Figure 8, LCR

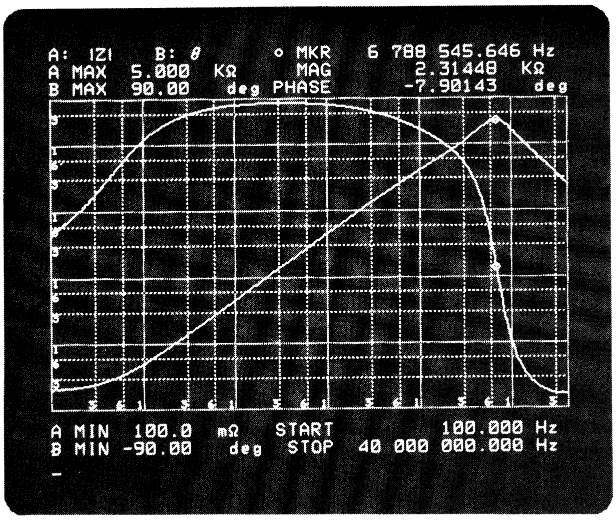


Figure 7. Frequency Characteristics for Impedance |Z|, θ

values of L = 71.09μH, Ca = 14.67pF, and R = 196.7mΩ are obtained. To see how close the circuit constants are to the actual component values, the frequency characteristics based on the calculated equivalent circuit constants are superimposed over the indicated results via the following key operations.

[more 1/2] [SIMULATE f CHAR]

The frequency characteristics have been simulated based on approximations. Frequency characteristics for other equivalent circuit models can be selected by inputting the numerical data via the [EQV R], [EQV L], [EQV CA] and [EQV CB] softkeys and can easily be compared with the indicated values.

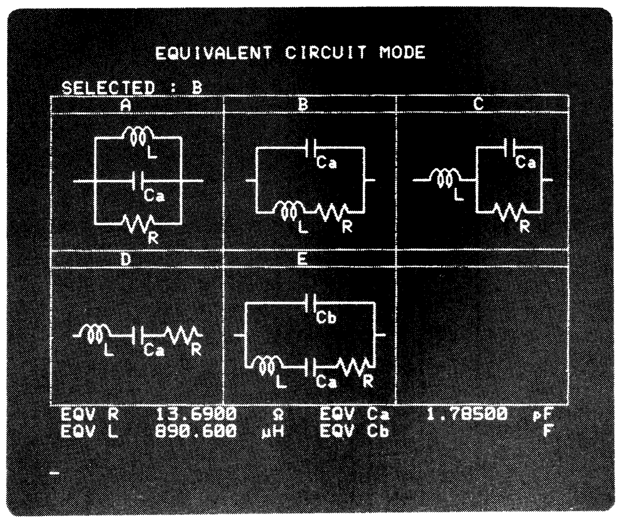


Figure 8. Automatic Approximation of Equivalent Circuit Constants

Inductance and effective Q frequency characteristics
The key operation is as follows.

1. [FUNCTION] [IMPE-DANCE] [Ls-Q]
2. [STOP] [6] [MHz] SWEEP MODE . . . [START]
3. [DISPLAY] [menu] [A SCALE LIN] [AUTO SCALE A] [more 1/3] [AUTO SCALE B]

Pressing the [MKR LCURS], [menu] and [o MKR → MAX(B)] causes the maximum Q value and the corresponding frequency to be displayed. (See Figure 9.)
As shown in Table 2 (see section 2), the 4194A comes with various impedance measurement modes that enable the operator to select the most appropriate evaluation parameter(s) for each particular application.

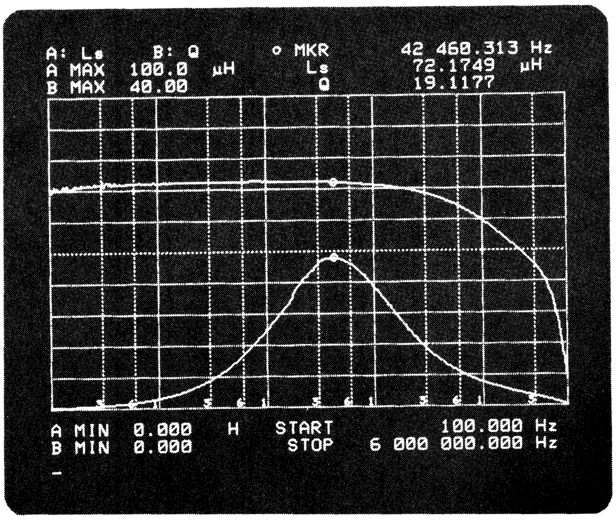


Figure 9. Inductance and Effective Q Frequency Characteristics

Effective permeability (μ_e) frequency characteristics
The frequency characteristics for effective permeability are found using the 4194A's data register calculation function.
The inductor's effective permeability is determined using the equation

$$\mu_e = \frac{L}{\mu_0 N^2} \frac{l_e}{A_e}$$

where,

- μ_0 : Absolute permeability of vacuum ($4\pi x 10^{-7}$)
- L : Self-inductance [H]
- N : No. of turns
- l_e : Core's effective magnetic path length [m]
- A_e : Core's effective cross-sectional area [m^2]

Because the self-inductance (L) values for previous measurements have been stored in the A register, the effective permeability frequency characteristics can be shown via the following key operations.

[CLEAR LINE] [Blue] (on) [A] [=] [A] [*] [1] [.] [0] [4] [EEX] [−] [1] [/] [(] [4] [.] [P] [I] [*] [1] [EEX] [−] [7] [.] [4] [0] [.] [.] [2] [*] [5] [.] [0] [4] [EEX] [−] [5] [)] [EXECUTE] [DISPLAY] [menu] [AUTO SCALE A] [more 1/3] [DISP B on/off] (off) [more 2/3] [UNIT on/off] (off)

In this example, N = 40[times], l_e = $1.04x10^{-1}$ [m], and A_e = $5.04x10^{-5}$ [m^2]. The results are shown in Figure 10.

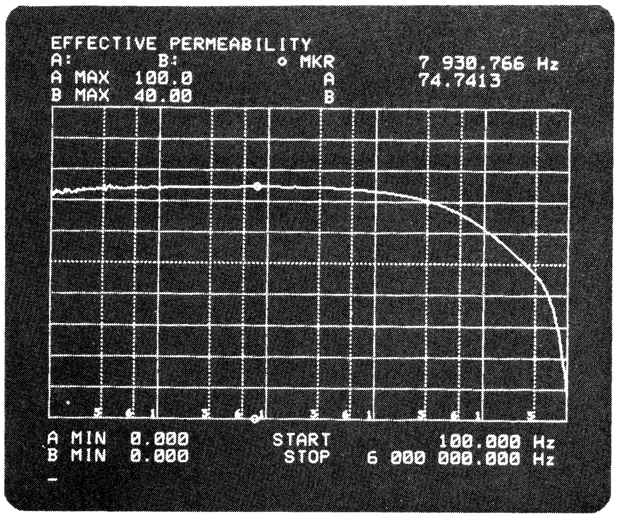


Figure 10. Effective Permeability (μ_e) Frequency Characteristics

4.2 Evaluation of Chip Capacitors

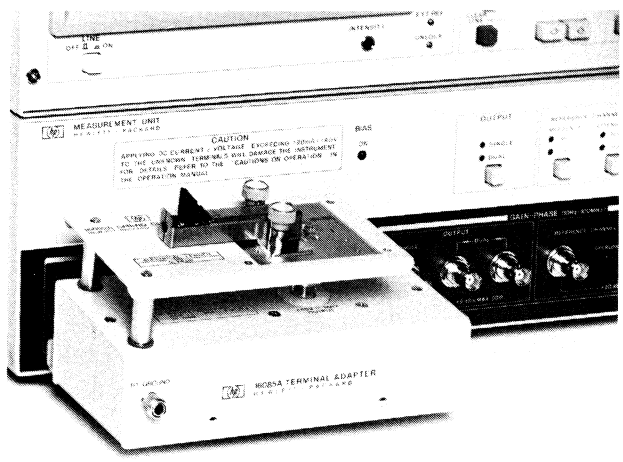


Figure 11. 4194A Using Chip Component Test Fixture (16085A, 16092A)

A special test fixture for chip component measurement is among the accessories available for the 4194A. See Figure 11. In this application, one of these test fixtures is used to measure the impedance characteristics of ceramic chip capacitors and to find the corresponding self-resonant frequency and three-component equivalent circuit constants. The key operation sequence for this is:

1. [CLEAR LINE] [Blue] (on) [R] [S] [T] [EXECUTE]

2. [SWEEP] [LOG SWEEP]

3. [COMPEN]

Open the measurement terminals and press [ZERO OPEN] [EXECUTE] .

Short the measurement terminals and press [ZERO SHORT] [EXECUTE] .

Connect the DUT and press [OPEN OFS on/off] (on) [SHRT OFS on/off] (on) .

SWEEP MODE ..... [START]

4. [DISPLAY] [menu] [A SCALE LOG] [AUTO SCALE A]

Self-resonant frequency

The key operation

[MKR/LCURS] , [menu] , [o MKR → MIN(A)] causes the self-resonant frequency and resonant impedance to be read out. In this example, the readout shows SRF = 3.449MHz and resonant impedance = 58.28mΩ. See Figure 12.

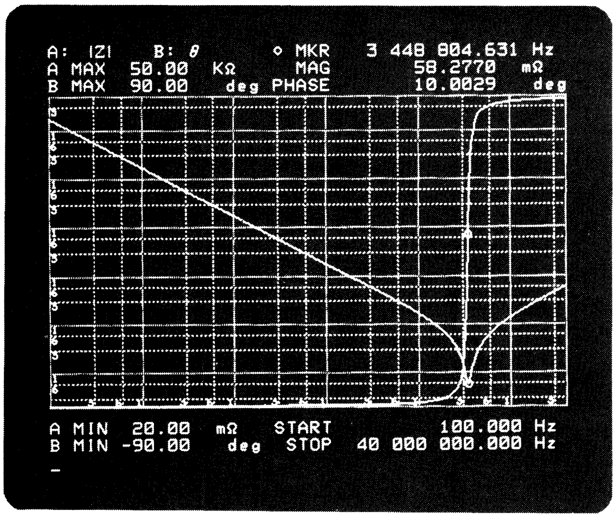


Figure 12. Impedance-Frequency Characteristics (DUT: Chip Capacitor)

Three-component equivalent circuit constants

For ceramic capacitors, equivalent circuit model C is normally used.

[MORE MENUS] [EQV CKT] [CKT D] [CALC EQV PARA]

As shown in Figure 13, R = 57.55mΩ, C_a = 100.7 nF, and L = 24.16 nH. The superimposed comparison of the measurement results and the equivalent circuit frequency characteristics based on approximated circuit constants are shown by the next key operation.

[more 1/2] [SIMULATE f CHAR]

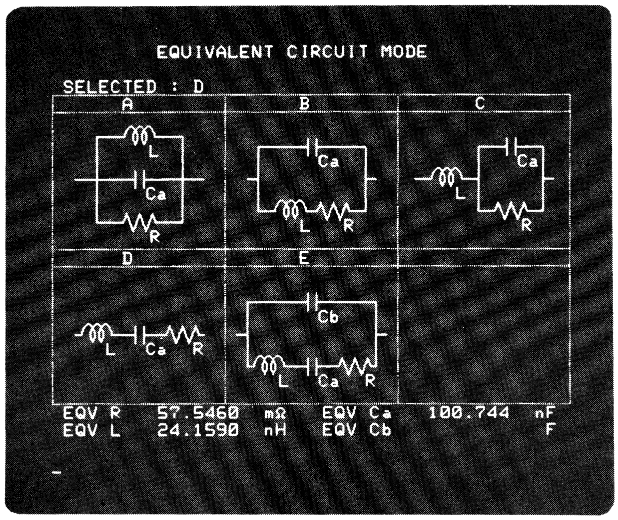


Figure 13. Automatic Calculation of Three-component Equivalent Circuit Constants

Frequency characteristics for capacitance (C) and dissipation factor (D)

Using the series-capacitance and loss-factor measurement mode:

1. [FUNCTION] [IMPEDANCE] [Cs-D]

2. [SWEEP] [LIN SWEEP] [START] [1] [kHz] [STOP] [3] [MHz]

SWEEP MODE ..... [START]

3. [DISPLAY] [menu] [A SCALE LIN] [AUTO SCALE A] [more 1/3] [AUTO SCALE B]

4. [MKR/LCURS] [o & * MKRS] [menu] [MKR=] [1] [kHz] [SMKR=] [3] [MHz] [return] [o REF - * MKR]

We obtain the results shown in Figure 14.

Although in this case the measurement is made using a frequency sweep, with the 4194A it is also possible to use a test-signal-layered (0 ~ ± 40V) dc voltage sweep and a signal level sweep (in the 10mV ~ 1 V_{rms} range).

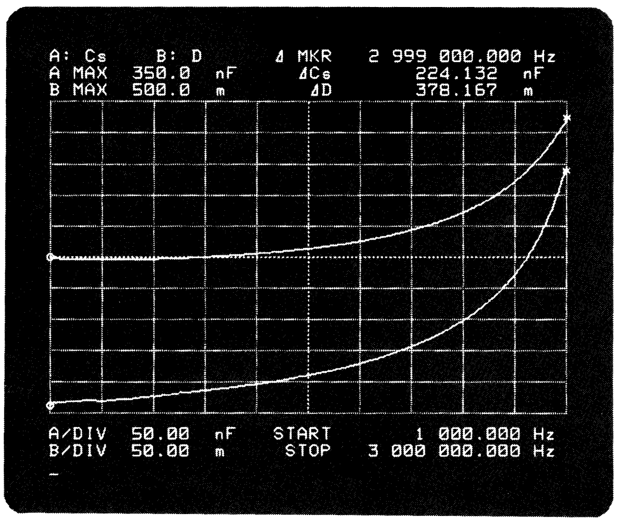


Figure 14. Frequency Characteristics for Capacitance (C) and Dissipation Factor (D)

Figure 15 shows the dc bias characteristics for a varactor diode.

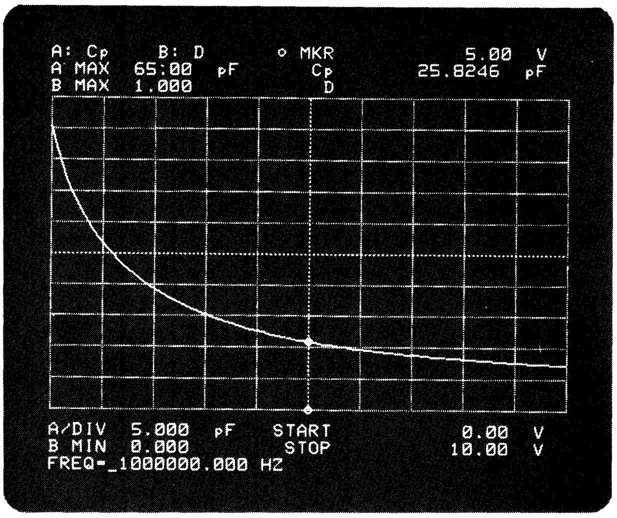


Figure 15. DC Bias Voltage Characteristics for Varactor Diode Capacitance (C)

4.3 Evaluation of Ceramic Resonators

Components based on the piezoelectric effects of dielectric have been developed and applied as electronic buzzers and sensors for OA (Office Automation) equipment, telephone equipment, and in a number of other fields. Taking the example of a ceramic resonator, a major application of these components, we shall seek to measure its impedance characteristics and define the various parameters. First, the following key operation is performed to obtain the impedance-frequency characteristics.

1. [CLEAR LINE] [Blue] (on) [R] [S] [T] [EXECUTE]
2. [CNTR] [3] [0] [MHz] [SPAN] [3] [0] [0] [kHz]
3. [COMPEN]

   Open the measurement terminals and press [ZERO OPEN] [EXECUTE] .

   Short the measurement terminals and press [ZERO SHORT] [EXECUTE] .

   Connect the DUT and press [SHRT OFS on/off] (on) [OPEN OFS on/off] (on) .

   SWEEP MODE . . . . . [START]
4. [DISPLAY] [menu] [A SCALE LOG] [AUTO SCALE A]

Measurement of resonant frequency and anti-resonant frequency

Using the 4194A's marker analysis function, the resonant frequency f_r, anti-resonant frequency f_a, resonant impedance Z_r, and anti-resonant impedance Z_a can easily be displayed on the CRT.

The key operation [MKR/LCURS] , [o MKR] , [menu] and [o MKR → MIN(A)] cause the values f_r = 29.94MHz and Z_r = 26.78Ω to be displayed. (See Figure 16.) In addition, pressing the [o MKR → MAX(A)] key causes the values f_a = 30.09 MHz and Z_a = 8.508KΩ to be displayed. The electro mechanical coupling coefficient can be found using the following equation.

$$kt = \sqrt{\frac{\pi}{2}\frac{f_r}{f_a}\tan\left(\frac{\pi}{2}\frac{\Delta f}{f_a}\right)} \qquad (\Delta f = f_a - f_r)$$

The solution kt = 0.1104 is then shown on the 4194A's CRT.

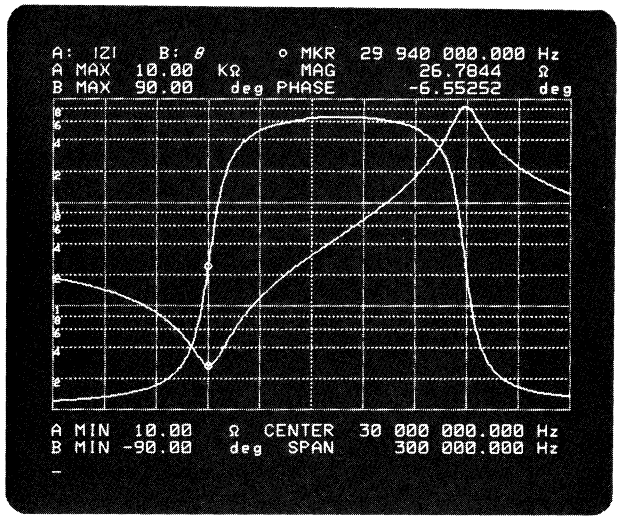


Figure 16. Impedance-Frequency Characteristics of a Ceramic Resonator

Automatic calculation of equivalent circuit constants

The resonator's electrical equivalent circuit is as shown in Figure 17(E). The 4194A can calculate effective equivalent circuit constants up to the four-component level. After impedance frequency characteristics have been measured, the key operation [MORE MENUS] , [EQV CKT] , [CKT E] , [CALC EQV PARA] causes the values R = 27.26Ω, L = 240.1μH. C_a = 117.7fF and C_b = 11.77pF to be displayed as shown in Figure 17. The mechanical Q factor, indicating the sharpness of mechanical resonance at the resonant frequency, is expressed using the following equation.

$$Qm = \frac{1}{2\pi f_r C_a R}$$

In addition, the equation for relative capacitance r is

$$r = \frac{C_b}{C_a}$$

and that for the figure of merit M is:

$$M = \frac{1}{2\pi f_r C_b R}$$

In this example, the values Qm = 1657, r = 100.1. and M = 16.56 are obtained.

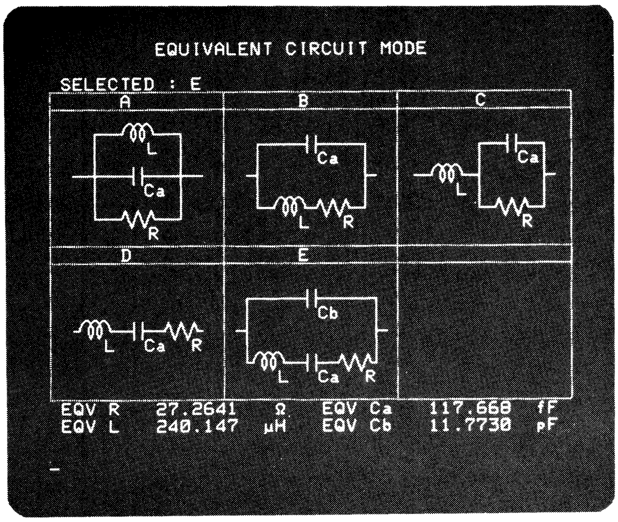


Figure 17. Automatic Calculation of Resonator Equivalent circuit constants

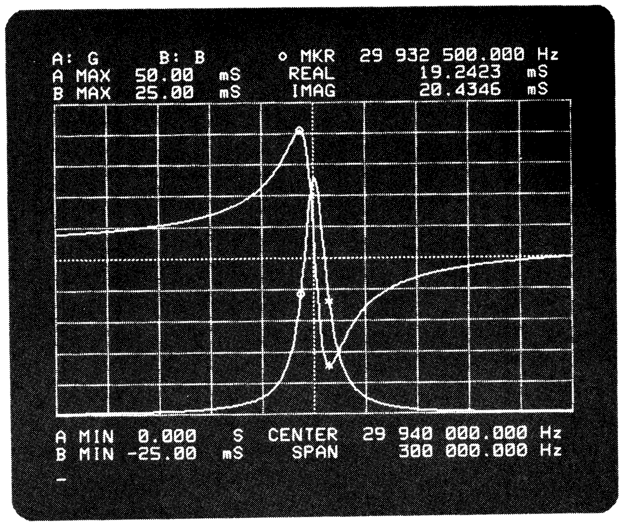


Figure 18. G and B Frequency Characteristics of a Resonator

Test Data Displays

The 4194A provides a wide selection of data display formats to suit any particular need. First, the following key sequence is performed to obtain the frequency characteristics of conductance (G) and susceptance (B).

1. (MKR/LCURS) [menu] [o MKR → MIN(A)] (CNTR) (Blue) (M) (K) (R) (EXECUTE)
2. (FUNCTION) [IMPE-DANCE] [more 1/3] [G-B]
3. SWEEP MODE . . . (START)
4. (DISPLAY) [menu] [A SCALE LIN] [AUTO SCALE A] [more 1/3] [AUTO SCALE B] (See Figure 18.)

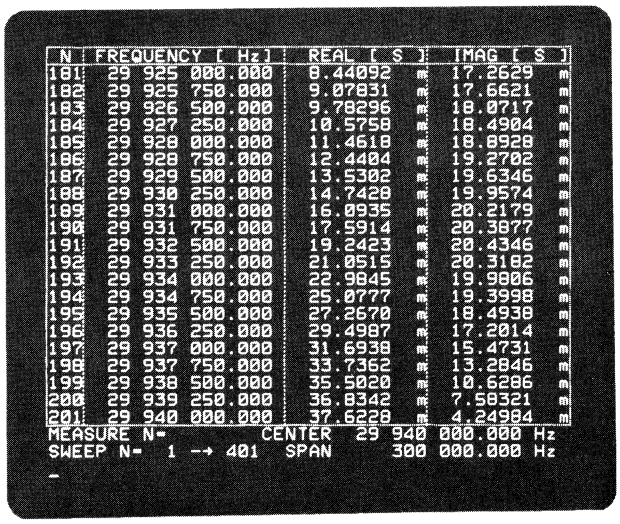
Next, to select a tabular format for numerical listing, press (DISPLAY) and [TABLE] keys.

The display data can be scrolled by pressing the [menu] key followed by the [prev page] or [next page] key to scroll one screenful at a time or else the [roll up] or [roll down] key to scroll one line at a time. The marker function is also provided for tabular displays so that, for example, the marker can be moved to certain measurement points on the graphs as needed for quick and easy confirmation of tabular data. See Figure 19.

Although the graphic displays we have seen so far have sweep parameters (frequency) on the X axis and measurement data (|Z|, θ, R, X, etc.) on the Y axis, measurement data can also be displayed on both axes to enable, for example, circle diagram displays of admittance characteristics in piezoelectric devices.

[return] [RECTAN A-B] (See Figure 20.)

This type of admittance circle diagram is useful for evaluating the Q factor of resonators. The 4194A's many measurement modes (|Z|–θ, R–X, G–B, etc.) and display modes (rectangular X–Y, rectangular A–B, tabular display) enable the DUT to be evaluated from several different perspectives. In addition to the ceramic resonator example given above, the 4194A is very effective for evaluating high-Q devices – such as crystal resonators – from 100Hz to 40MHz with 1mHz resolution and a wide impedance measurement range.



N	FREQUENCY [Hz]	REAL [S]	IMAG [S]
181	29 925 000.000	8.44092 m	17.2629 m
182	29 925 750.000	9.07831 m	17.6621 m
183	29 926 500.000	9.78296 m	18.0717 m
184	29 927 250.000	10.5758 m	18.4904 m
185	29 928 000.000	11.4618 m	18.8928 m
186	29 928 750.000	12.4404 m	19.2702 m
187	29 929 500.000	13.5302 m	19.6346 m
188	29 930 250.000	14.7428 m	19.9574 m
189	29 931 000.000	16.0935 m	20.2179 m
190	29 931 750.000	17.5914 m	20.3877 m
191	29 932 500.000	19.2423 m	20.4346 m
192	29 933 250.000	21.0515 m	20.3182 m
193	29 934 000.000	22.9845 m	19.9806 m
194	29 934 750.000	25.0777 m	19.3998 m
195	29 935 500.000	27.2670 m	18.4938 m
196	29 936 250.000	29.4987 m	17.2014 m
197	29 937 000.000	31.6938 m	15.4731 m
198	29 937 750.000	33.7362 m	13.2846 m
199	29 938 500.000	35.5020 m	10.6286 m
200	29 939 250.000	36.8342 m	7.58321 m
201	29 940 000.000	37.6228 m	4.24984 m

MEASURE N- CENTER 29 940 000.000 Hz
SWEEP N- 1 → 401 SPAN 300 000.000 Hz

Figure 19. Table Display of Resonator G and B Values

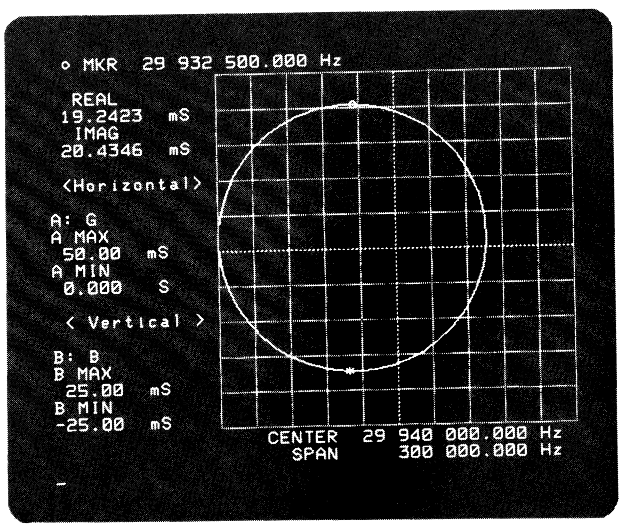


Figure 20. Circle Diagram of Resonator Admittance

5. GAIN/PHASE MEASUREMENT APPLICATIONS

5.1 Parametric Analysis of 21.4MHz Crystal Filters

An application described here is an evaluation of a 21.4 MHz crystal band-pass filter. The parameters measured are insertion loss, passband width, attenuation band width, relative attenuation of the attenuation band, pass band ripple, and group delay time deviation based on gain/phase measurement.
The gain/phase measurement configuration is set up using the following key operations.

1. (CLEAR LINE) (Blue) (R) (S) (T) (EXECUTE)
   (on)
2. [GAIN PHASE] [Tch/Rch (dB)-τ]
3. (CNTR) (2) (1) (.) (4) (MHz) (SPAN) (1) (0) (0) (kHz)
4. (COMPEN)

   With the DUT disconnected, make the through connection and press the (START) keys in the sweep section.
   When sweep is completed press the [OFST REF STORE] softkey to store the offset reference value. Connect the DUT and press the [A OFFSET on/off] (on), [B OFFSET on/off] (on), and [θ SCALE exp] softkeys and the (START) key in the sweep section, following by the key operation:
5. (DISPLAY) [menu] [AUTO SCALE A] [more 1/3] [DISP B on/off] (off)

   (The group delay display is turned off).

Insertion loss

Insertion loss (minimal loss) is defined as the minimum value of attenuation within the pass band.
Press the (MKR/LCURS), [menu], and [o MKR → MAX(A)] keys, then the marker indicates an insertion loss value of 1.360dB. (See Figure 21.)

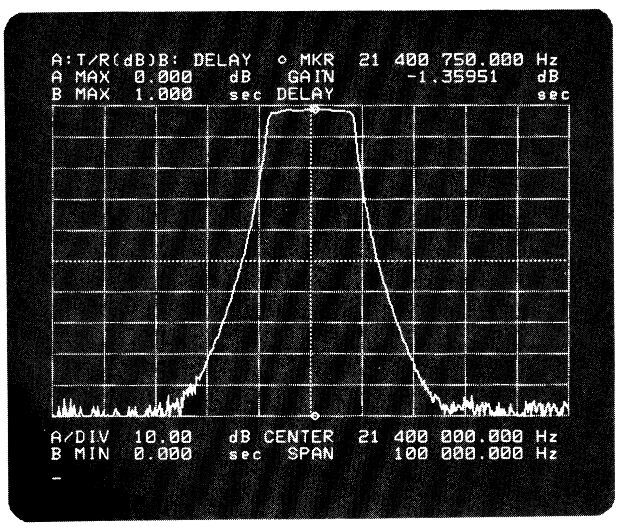


Figure 21. Insertion Loss Measurement

Pass band width and attenuation band width

The 4194A's marker/line cursor function provides a new and simple method for measuring passband width and attenuation bandwidth.

[return] [o REF-LCURS] [menu] [DLCURS=] (−) (3) (EXECUTE)

This key operation displays the two −3 dB cut-off frequencies in the upper right section of the CRT. These two cut-off frequencies are stored in the 4194A's internal registers as LCURSL and LCURSR. When the front-panel key operation [WIDTH read] is performed, the −3 dB passband width is calculated using the values stored in the internal registers. (The result is −3 dB bandwidth = 16.66 kHz in Figure 22).
Center frequency can be found by executing the SQR (LCURSR * LCURSL) calculation. SQR finds the square root and * the product of LCURSL and LCURSR. The center frequency value in this case is f_C = 21.4MHz.
The 60 dB attenuation bandwidth is found in a similar manner. First, press the [DLCURS=] (−) (6) (0) and (EXECUTE) key. Next, press [WIDTH read] to calculate and display the resultant −60 dB attenuation bandwidth (30.21 kHz).
The shape factor can be found by using the equation:

$$\text{Shape Factor SF} = \frac{-60\text{ dB bandwidth}}{-\ 3\text{ dB bandwidth}}$$

The result in this case is SF = 1.840.

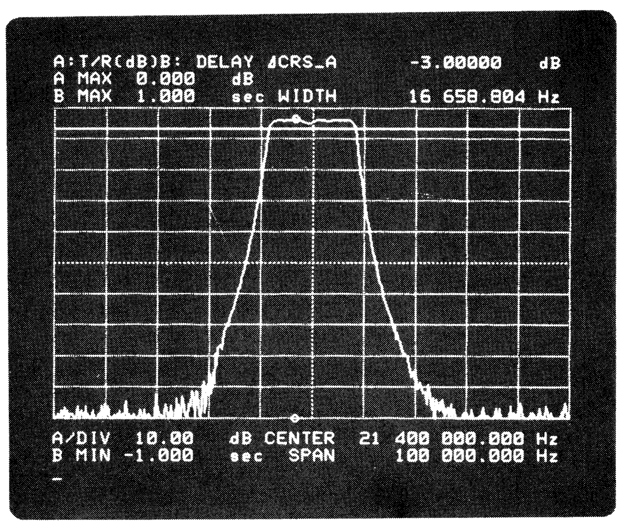


Figure 22. Pass Band Width Measurment

Relative attenuation of the attenuation band

The 4194A provides partial analysis function that the range for analysis can be freely set.

For example, pressing the [o MKR → MAX(A)] softkey move the marker to the highest value of measurement data. One such data manipulation function is used for finding the relative attenuation of the attenuation band. The key operation for this function is shown below.

1. First set the analytical scope to 21.4MHz + 30kHz ~ 21.4MHz + 50kHz as follows.
   [return], [o & * MKRS]. (move * marker to 21.43MHz via rotary knob), [menu], [o MKR control] (move ○ marker to 21.45MHz via rotary knob), [more 1/2], [STORE ANA RNG], [PART ANA on/off] (on).
2. Move the * marker to the highest value in the designated attenuation bandwidth:
   [o MKR → MAX(A)] [more 2/2] [SMKR=] (Blue) (on) (M) (K) (R) (EXECUTE)
3. Clear the analytical scope setup and move the ○ marker to the base point (i.e. the minimum loss point). [more 1/2] [PART ANA on/off] (off) [o MKR → MAX(A)]
4. The key operation [return] [o REF - * MKR] causes the relative attenuation to be displayed. (See Figure 23.)

Pass band ripple

Ripple can be found using the pass band measurement. The key operation for this is:

1. (SPAN) (1) (5) (kHz)
2. (COMPEN)

First, without connecting the DUT, make the through connection and press the (START) key in the sweep mode section.

When sweep is completed, press the [OFST REF STORE] softkey.

Connect the DUT and press the [A OFFSET on/off] (on), [B OFFSET on/off] (on) softkeys and the (START) key in the sweep mode section.

3. (DISPLAY) [menu] [AUTO SCALE A]
4. Move the * marker to the lowest gain value in the pass band:
   (MKR/ LCURS) [o & * MKRS] [menu] [more 1/2] [o MKR → MIN(A)] [more 2/2] [SMKR=] (Blue) (on) (M) (K) (R) (EXECUTE)
5. Move the ○ marker to the highest gain value in the pass band:
   [more 1/2] [o MKR → MAX(A)]
6. Press the [return] and [o REF - * MKR] softkeys to display the differential(= the ripple) between the highest and lowest gain values. (See Figure 24.)
   In this case, the ripple value is displayed as 1.163dB. With the 4194A, test frequencies can be set with 1mHz resolution over the entire frequency range. So that this enables accurate evaluation of crystal filters requiring a relative measurement resolution of 0.01dB, and other low-loss, low-ripple devices.

Group delay deviation

Perform the following key operation to turn on the group delay display (the gain display is turned off).

(DISPLAY) [menu] [DISP A on/off] (off) [more 1/3] [DISP B on/off] (on) [AUTO SCALE B]

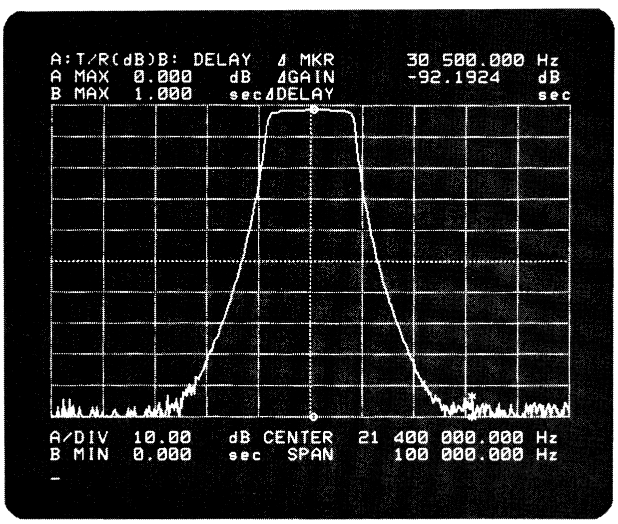


Figure 23. Measurement of Relative Attenuation

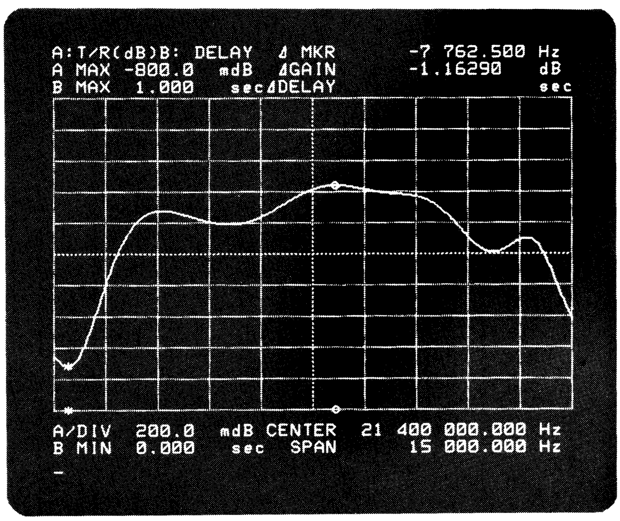


Figure 24. Pass Band Ripple Measurement

The group delay measurement aperture is set using the [ΔF] key to select the desired span width as a percentage. As shown in Figure 25, the default value for the span width setting is 0.5%. The key operation [Green], [ΔF], [5], [EXECUTE], for example, sets the aperture value to 5% of a span width (see Figure 26.) This function makes it possible for you to set the most suitable noise-free aperture for your requirements.

The key operation used to find the group delay deviation value is as follows:

1. Move the * marker to the lowest group delay value:

   [MKR/ LCURS] [o & * MKRS] [menu] [more 1/2] [o MKR → MIN(B)] [more 2/2]

   [SMKR=] [Blue (on)] [M] [K] [R] [EXECUTE]

2. Move the O marker to the highest group delay value:

   [more 1/2] [o MKR → MAX(B)]

3. Press the [return] and [o REF- * MKR] softkeys to display the group delay deviation value. (See Figure 27.)

Over the frequency range of 21.4MHz ± 7.5kHz, the group delay deviation measured is 116.0 microseconds. The 4194A provides a group delay measurement resolution of 0.1 nanoseconds. This enables you to perform high-resolution group delay evaluations of such devices as video filters whose group delay influences image quality.

Although in this case the evaluation of phase linearity is made by using group delay measurement, it becomes possible to continuously observe the phase transition over the wide range, with the 4194A's phase scale expansion function. (See Figure 28.)

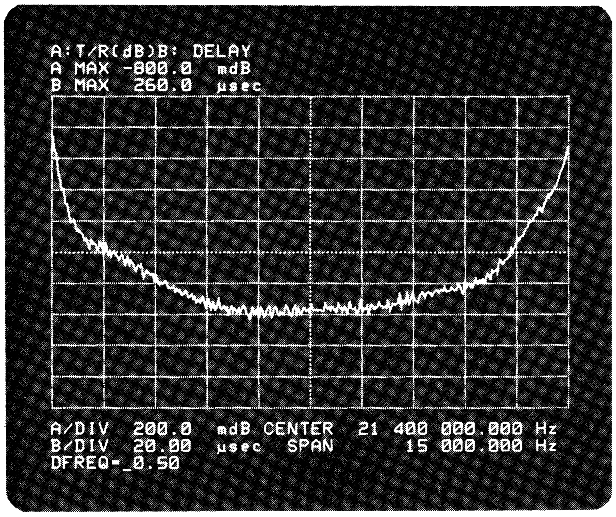


Figure 25. Group Delay Time Characteristics with a 0.5% Span-width Aperture

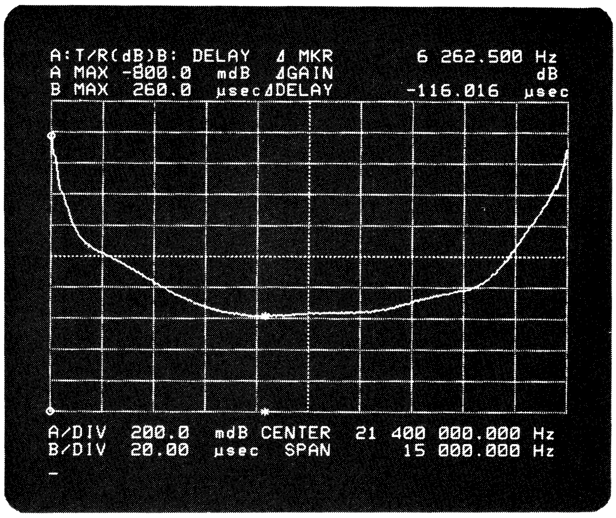


Figure 27. Group Delay Deviation Measurement

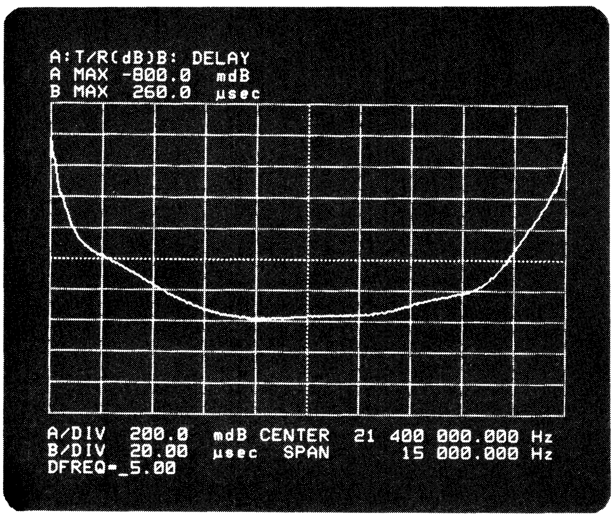


Figure 26. Group Delay Time Characteristics with a 5.0% Span-width Aperture

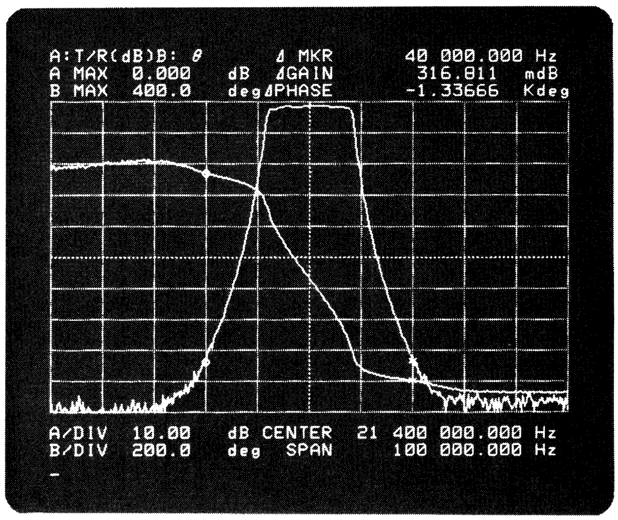


Figure 28. Gain/Phase Characteristics of a Crystal Filter using the Phase Scale Expansion Function

5.2 Evaluation of Feedback Amplifiers

In this application, the open-loop characteristics of a differential-input amplifier are measured to find the unity-gain bandwidth and gain-bandwidth (GB) product, and to evaluate the closed-loop stability based on the gain/phase margin. In addition, the frequency and gain compression characteristics are also obtained.

Closed-loop gain/phase measurement

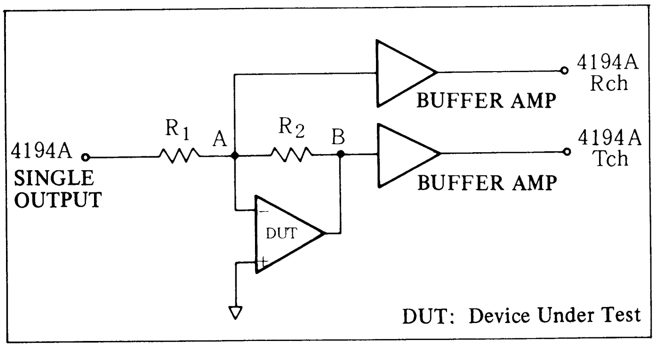


Figure 29. Open-loop Gain/Phase Measurement Circuit for Feedback Amplifier

The measurement circuit illustrated in Figure 29 is used to measure the DUT's open-loop gain. The key operation for this measurement is shown below.

1. (CLEAR LINE) (Blue (on)) (R) (S) (T) (EXECUTE)
2. [GAIN PHASE]
3. (SWEEP) [LOG SWEEP] (OSC LEVEL) (−) (2) (5) (dBm)
4. Set the signal output and input terminals:

   OUTPUT . . . (SINGLE)

   REFERENCE INPUT . . . (1MΩ)

   TEST INPUT . . . (1MΩ) (20dB)
5. (COMPEN)

   Short-circuit by connecting points A to B shown in Figure 29, and press the (START) in the sweep mode section. When sweep is completed, press the [OFST REF STORE] softkey.

   Next, connect the DUT as shown in Figure 29, and press the [A OFFSET on/off] (on), [B OFFSET on/off] (on), [θ SCALE exp] softkeys and (START) key in the sweep mode section.
6. To display your results, as shown in Figure 30, perform the following key operation.

   (DISPLAY) [menu] [AUTO SCALE A] [more 1/3] [AUTO SCALE B]

Unity-gain bandwidth and GB product are important parameters to know when evaluating an amplifier's wide-band characteristics. Unity gain bandwidth, defined as the upper frequency limit where open gain becomes 0 dB, can be found as follows.

Press the (MKR/ LCURS), [LINE CURSOR], [menu], [LCURS=], (0), and (EXECUTE) keys to move the line cursor to the 0dB gain location, from here, unity gain bandwidth f_T can be read. (See Figure 31.)

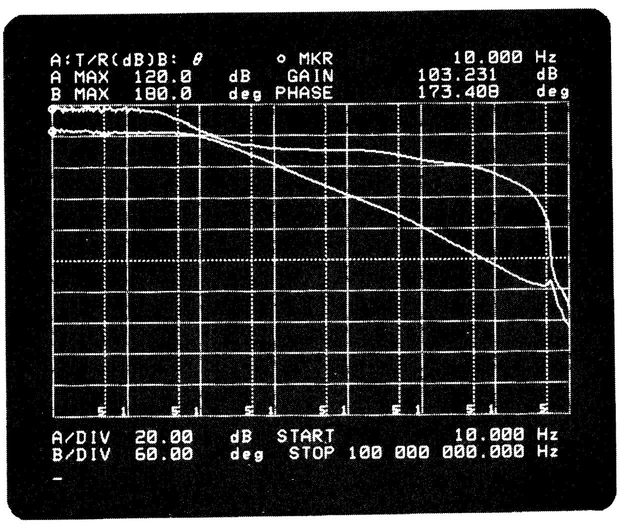


Figure 30. Results of Open-loop Gain/Phase Measurement

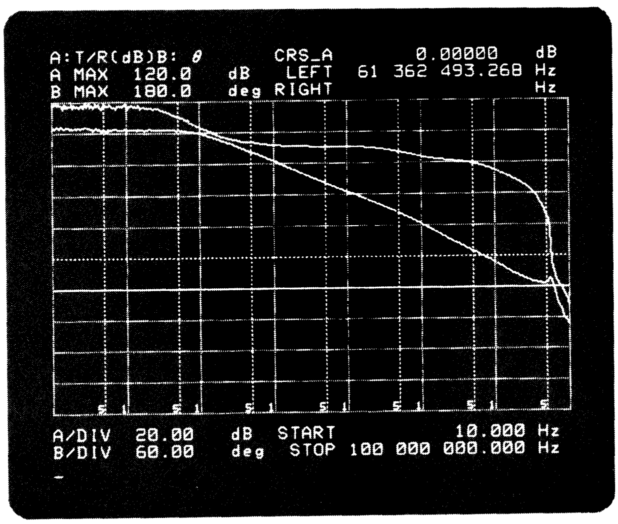


Figure 31. Unity Gain Bandwidth Measurement

To calculate GB product, move the marker to −6 dB/oct slope area of the open-circuit characteristic in order to find the frequency fm and gain G (voltage ratio) values. (Press the [return] and [○ MKR] softkeys and move the ○ MARKER via rotary knob.) These values are then used in the following equation.

GB product = G x fm

The resultant GB product value is shown in Figure 32. The key operation for this is:

([CLEAR LINE] [1] [0] [*] [-] [(] [Blue (on)] [M] [K] [R] [A] [/] [2] [0] [)] [-] [M] [K] [R] [EXECUTE])

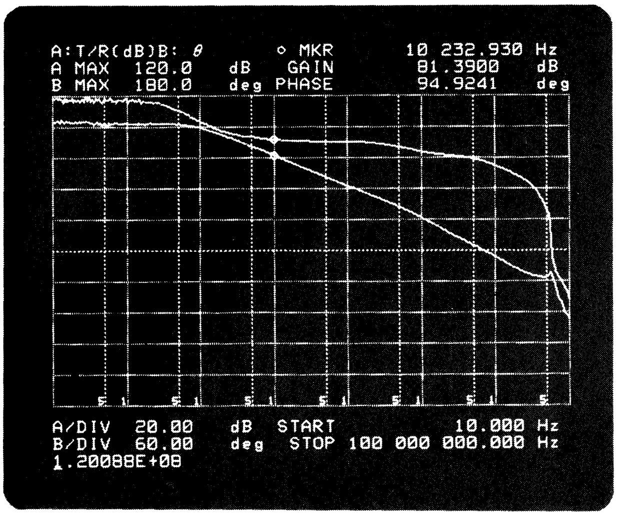


Figure 32. GB Product Measurement

Evaluation of stability

Closed-loop stability is a key factor in negative feedback circuits. This factor can be judged by making a Bode diagram of loop gain A β (A: open-loop gain, β: feedback ratio). When designing an inverting amplifier, such as the one shown in Figure 33, the feedback ratio β must be

$$\beta = \frac{R_1}{R_1 + R_2} .$$

If the value $R_1 = 511\Omega$, $R_2 = 51.1\,k\Omega$, the feedback ratio Bode diagram for loop gain $A\beta$ can be displayed on the CRT via the key operation:

[CLEAR LINE] [Blue (on)] [A] [=] [A] [+] [2] [0] [*] [L] [O] [G] [(] [5] [1] [1] [/] [(] [5] [1] [1] [+] [5] [1] [.] [1] [EEX] [3] [)] [)] [EXECUTE]

The marker is used to find the gain and phase margins, as shown in Figures 34 and 35. (gain margin: 37 dB, phase margin: 70°)

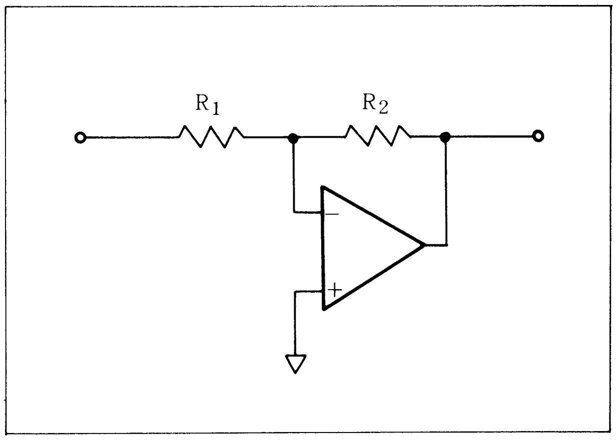


Figure 33. Negative Feedback Amplifier

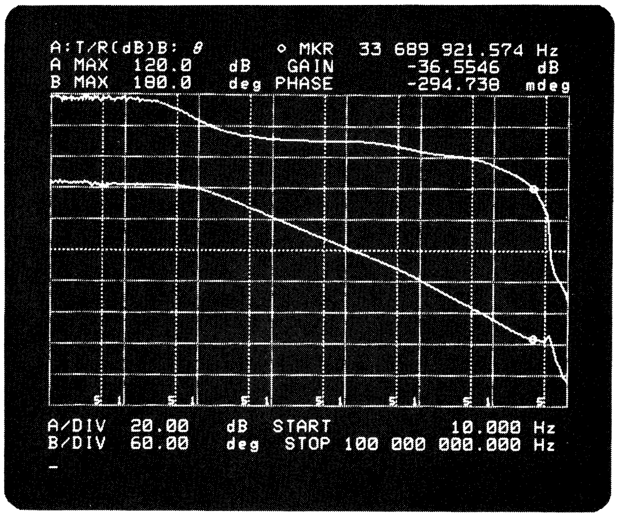


Figure 34. Gain Margin Evaluation of Amplifier with Loop Gain Aβ

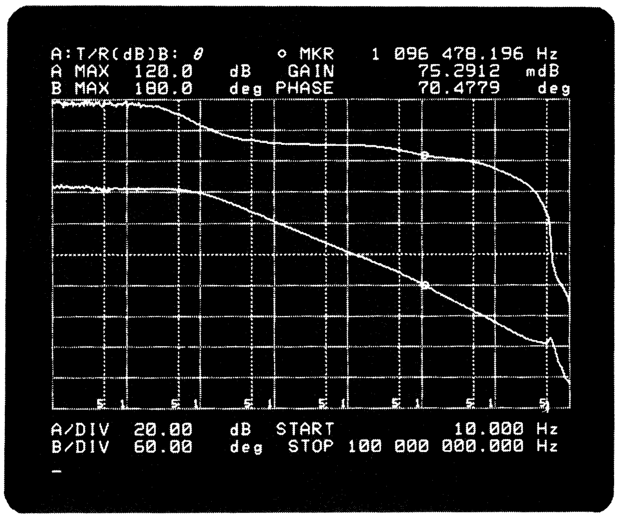


Figure 35. Phase Margin Evaluation of Amplifier with Loop Gain Aβ

Measurement of closed-loop gain/phase

The closed-loop characteistics of the circuit shown in Figure 33 are measured in this section. The marker and line cursor can be used to find the bandwidth.

The key operation for this is:

[MKR/LCURS] [menu] [o MKR → MAX(A)] [return] [o REF - LCURS] [menu]
[DLCURS=] [−] [3] [EXECUTE]

(See Figure 36.)

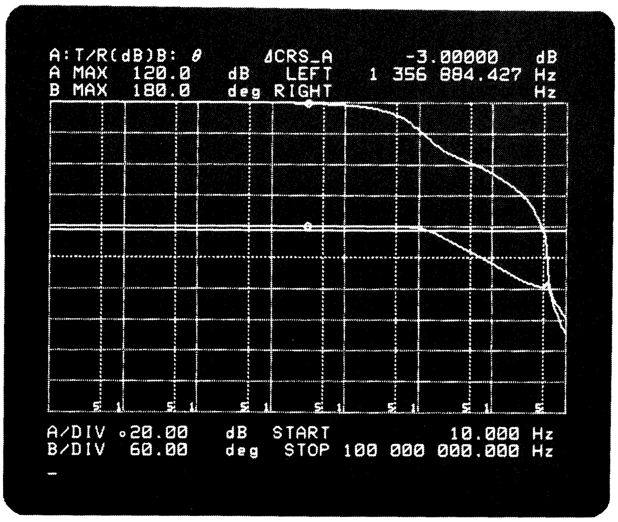


Figure 36. Bandwidth Measurement

Gain compression characteristics

The 4194A can also perform signal-level sweeps. Here, the gain compression characteristics of the negative feedback amplifier shown in Figure 33 are measured. The key operation for this is shown below.

1. [SWEEP] [more 1/2] [OSC LVL (dBm)]
2. [START] [−] [5] [0] [dBm] [STOP] [−] [2] [4] [dBm] [SPOT FREQ] [1] [0] [MHz]
3. SWEEP MODE ..... [START]
4. [DISPLAY] [menu] [AUTO SCALE A] [more 1/3] [DISP B on/off] (off)
5. [MKR/LCURS] [o MKR] [menu] [o MKR → MAX(A)] [return] [o REF- LCURS] [menu] [DLCURS=] [−] [.] [1] [EXECUTE]

Figure 37 shows the gain compression level of −100mdB found using the marker/line cursor.

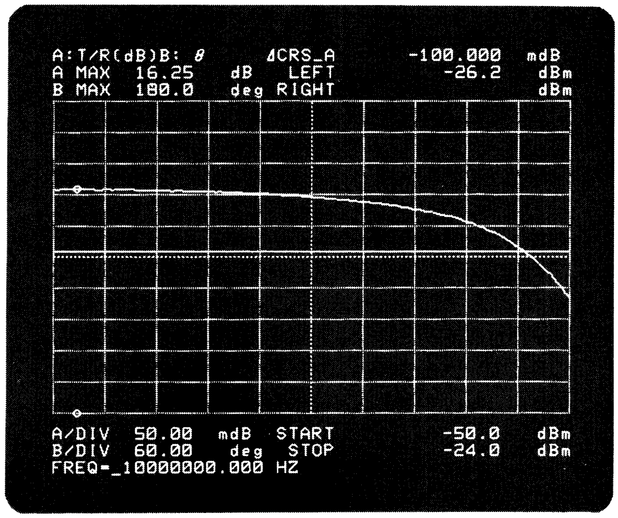


Figure 37. Gain Compression Characteristics

6. AUTOMATIC MEASUREMENT FUNCTION APPLICATIONS

This section introduces the 4194A's ASP (Auto Sequence Program) and GO/NO-GO functions. The 4194A's ASP function allows you to automatically control measurement sequences and to analyze measurement data through front panel programming without the need for an external controller. The programming commands can be selected merely by hitting front panel keys, as well as usual operation.

These commands are the same coding as for HP-IB programming commands, furthermore 13 typical BASIC commands are also used as ASP commands.

Program creation and execution

The first step in creating ASPs is to select the program editing mode via the key operation (MORE MENUS), [PROGRAM], [EDIT], and (EXECUTE). Once this is done, the program editing screen is displayed as shown in Figure 38. Most of the commands corresponding to the various selection keys need not be typed out letter by letter, but are instead automatically listed when the appropriate selection key is pressed. For example, when writing an impedance measurement program, simply pressing the (FUNCTION) and [IMPE-DANCE] keys will cause the command "FNC1" to be displayed on the editing screen. Next, press the (ENTER) key to program the command. In addition, once in program editing mode, pressing the [state-ment] softkey displays another screen which contains softkeys labeled with key BASIC words such as [IF], [THEN], [GOTO], and [BEEP]. The BASIC word keys enable the operator to directly call the corresponding commands. When programming is completed, press the [QUIT EDITOR] softkey to exit the editing mode. Program execution begins when the [RUN] softkey is pressed.

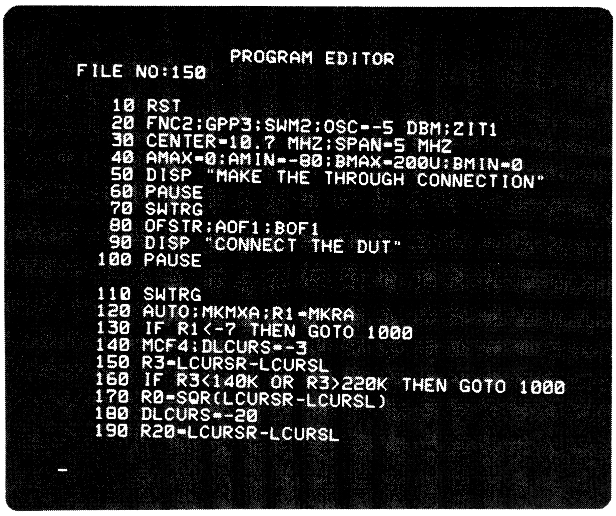


Figure 38. ASP Editing Screen (Example)

Storing and retrieving programs

The 4194A provides user memory for storage of user-created programs. An example of the key operation for storing a program is as follows:

[STORE] (1) (Green) (,) (Green) (") (Blue) (C) (O) (R) (on) (E) (Green) (") (EXECUTE)

(1: File number, CORE: file comment)

Stored programs can be retrieved simply by pressing the [LOAD] and (1) (file number) keys. Furthermore, a catalog of stored file names such as the one shown in Figure 39 can be displayed on the CRT by pressing the [CAT] softkey.

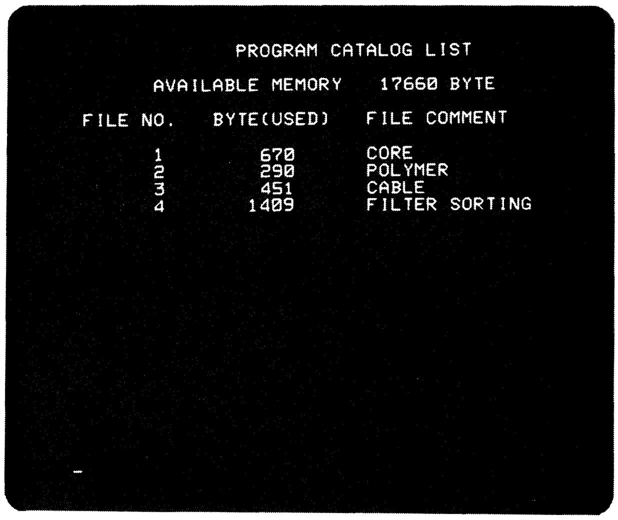


Figure 39. ASP File Catalog Display

6.1 Evaluation of Magnetic Materials (using ASP Function)

Using the 4194A's ASP function, it is possible to automatically calculate, display (on the CRT), and output (to a plotter) magnetic-material frequency characteristics, such as initial AC permeability μ_{iac} and its relative loss coefficient $\tan\delta/\mu_{iac}$, based on impedance measurement data.

The flowchart for this ASP task is shown in Figure 40 and the program table in Figure 41.

Figure 42 shows a CRT display of the initial AC permeability μ_{iac} and relative loss coefficient $\tan\delta/\mu_{iac}$ frequency factors. The initial AC permeability value is found using the following equation.

$$\mu_{iac} = \frac{\ell L}{\mu_0 A N^2}$$

Where,

ℓ : DUT's average magnetic path length (m)

L : DUT's self-inductance (H)

μ_0 : Absolute permeability of a vacuum ($4\pi \times 10^{-7}$)

N : No. of turns

A : DUT's cross-sectional area [m^2]

The relative loss coefficient is found using the equation:

$$\frac{\tan\delta}{\mu_{iac}} = \frac{\dfrac{R_{eff}-R_W}{2\pi f L}}{\mu_{iac}}$$

Where

- R_{eff} : Resistance (Ω) of the coil and the DUT
- R_W : Resistance (Ω) of the coil only
- L : DUT's inductance (indicated value)
- f : Indicated frequency (Hz)
- μ_{iac} : Initial AC permeability

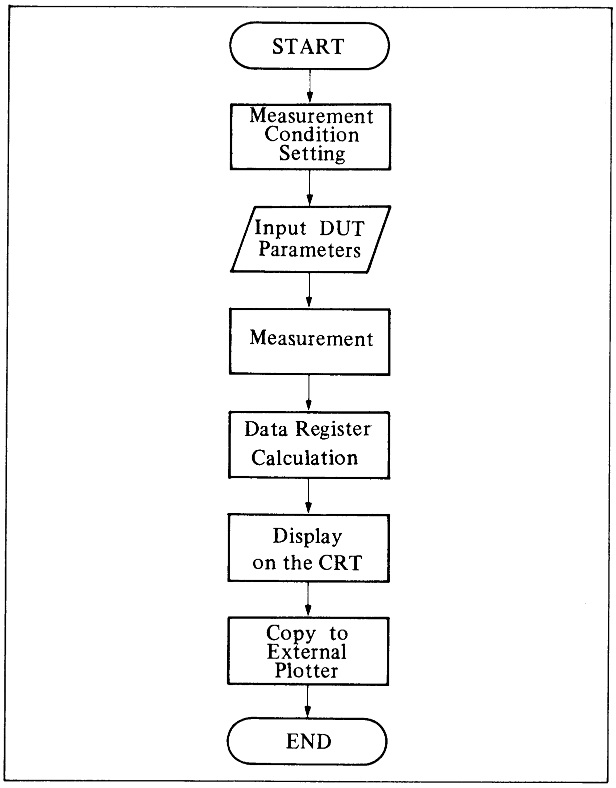


Figure 40. Flow Chart of Magnetic Materials Evaluation Program

```
    10 RST
    20 FNC1;IMP3;SWT2;SWM2
    30 START=10 KHZ;STOP=1 MHZ;OSC=.02
    40 BEEP
    50 CMT"SET HP-IB TO TALK ONLY MODE & PRE
SS (CONT)"
    60 PAUSE
    70 BEEP
    80 CMT"M.PATH LENGTH(mm)=?    ->PRESS (EN
TER),(CONT)"
    90 PAUSE
   100 R1=Z*1E-3
   110 BEEP
   120 CMT"CROSS SEC.AREA(mm2)=? ->PRESS (EN
TER),(CONT)"
   130 PAUSE
   140 R2=Z*1E-6
   150 BEEP
   160 CMT"NUMBER OF TURNS=?      ->PRESS (EN
TER),(CONT)"
   170 PAUSE
   180 R3=Z
   190 BEEP
   200 CMT"WIRE RESISTANCE(Ω)=?  ->PRESS (EN
TER),(CONT)"
   210 PAUSE
   220 R0=Z
   230 SWTRG
   240 E=A;F=B
   250 A=R1*E/(4*PI*1E-7*R2*R3**2)
   260 B=(F-R0)/(2*PI*X*E)/A
   270 ASC2;AUTOA;BSC2;AUTOB;UNIT0
   280 CMT"A;AC I.PERMEABILITY    B;RELATIVE
LOSS FACTOR"
   290 MKR=100 KHZ
   300 COPY
   310 BEEP
   320 DISP "PROGRAM END"
   330 END
```

Figure 41. An Example of Auto Sequence Program for Magnetic Materials Evaluation

6.2 GO/NO–GO Testing of Ceramic Filters (using ASP Function)

The 4194A's ASP function can also be used in production line GO/NO–GO testing. The application described here is autosorting (GO/NO–GO testing) of 10.7MHz ceramic filters. Once the DUT is connected and the ASP program run, the ASP function can control the 4194A's marker/line cursor function to provide automatic calculations.

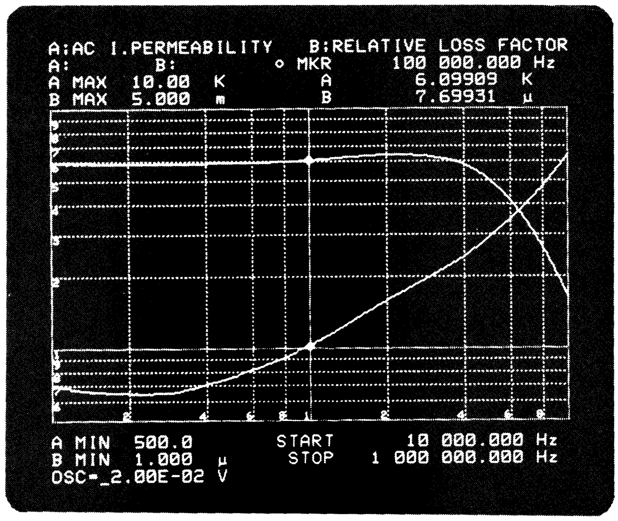


Figure 42. Initial AC Permeability μ_{iac} and Relative Loss Coeffiicient $\tan\delta/\mu_{iac}$ Frequency Characteristics

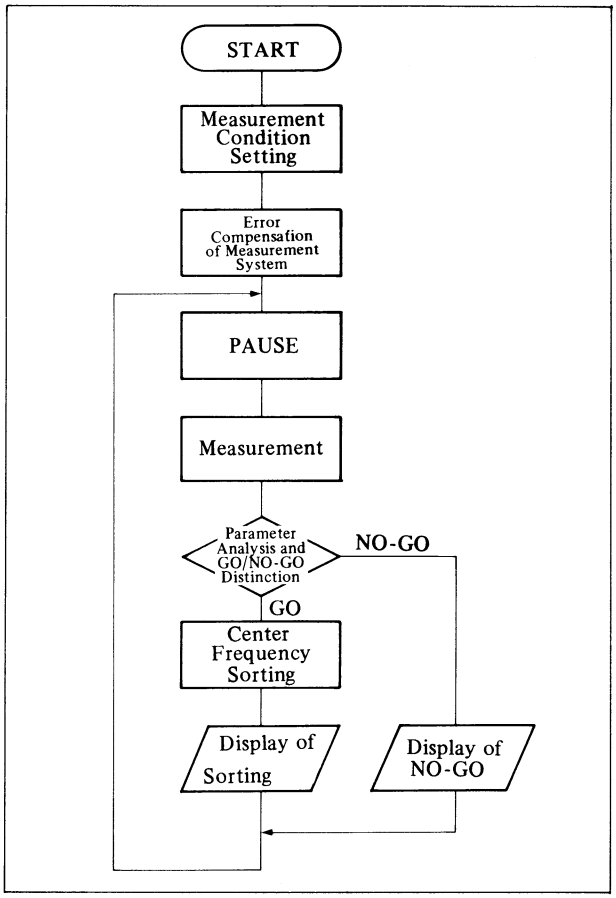


Figure 43. Flow Chart of Ceramic Filter GO/NO–GO Testing Program

Eventually, the various desirable DUT parameters are displayed such as insertion loss, ripple, −3 dB bandwidth, −20 dB bandwidth, spurious attenuation, and group delay deviation. In addition, by calculating the center frequency (f_C) from the −3 dB bandwidth, and using this f_C value in combination with the function (IF ~ THEN), the 4194A can perform GO/NO–GO testing at several levels as a function of the set center frequency.

The program flowchart for this application is shown Figure 43 and the program listing in Figure 44.

The 4194A is equipped with terminals of PROGRAM START for ASP execution and EXTERNAL TRIGGER useful for systemization. An 8-bit I/O interface is also included to facilitate connection with handlers and external equipment for complete system setups.

```
  10 RST
  20 FNC2;GPP3;SWM2;OSC=-5 DBM;ZIT1
  30 CENTER=10.7 MHZ;SPAN=5 MHZ
  40 AMAX=0;AMIN=-80;BMAX=10U;BMIN=0
  50 BEEP
  60 CMT"MAKE THE THROUGH CONNECTION AND P
RESS (CONT)"
  70 PAUSE
  80 SWTRG
  90 OFSTR;AOF1;BOF1
 100 BEEP
 110 CMT"CONNECT THE DUT AND PRESS (CONT)"
 120 PAUSE
 130 SWTRG
 140 ANA0;MCF1;MKMXA
 150 R1=MKRA
 160 IF R1<-7 THEN GOTO 1000
 170 MCF4;DLCURS=-3
 180 R3=LCURSR-LCURSL
 190 IF R3<140K OR R3>220K THEN GOTO 1000
 200 R0=SQR(LCURSR*LCURSL)
 210 DLCURS=-20
 220 R20=LCURSR-LCURSL
 230 IF R20>520K THEN GOTO 1000
 240 MCF5;MKR=11.2M;SMKR=13.2M
 250 ARSTR;ANA1;MKMXA
 260 R2=R1-MKRA
 270 IF R2<40 THEN GOTO 1000
 280 MKR=R0-100K;SMKR=R0+100K
 290 ARSTR;ANA1;MKMXB
 300 SMKR=MKR;MKMNB
 310 MCF2
 320 IF DMKRB>1.5U THEN GOTO 1000
 330 IF R0<10.61M THEN GOTO 1000
 340 IF 10.61M<=R0 AND R0<10.64M THEN R4=1
 350 IF 10.64M<=R0 AND R0<10.67M THEN R4=2
 360 IF 10.67M<=R0 AND R0<10.70M THEN R4=3
 370 IF 10.70M<=R0 AND R0<10.73M THEN R4=4
 380 IF 10.73M<=R0 AND R0<10.76M THEN R4=5
 390 IF 10.76M<=R0 AND R0<10.79M THEN R4=6
 400 IF 10.79M<=R0 THEN GOTO 1000
 410 BEEP
 420 DISP "GO!  SORTING NUMBER=",R4
 430 GOTO 110
1000 BEEP
1010 WAIT 20
1020 BEEP
1030 DISP "NO-GO!"
1040 GOTO 110
1050 END
```

Figure 44. An Example of Auto Sequence Program for Ceramic Filter GO/NO–GO Testing

6.3 GO/NO–GO Testing of Low Pass Filters (using Programmed Points Measurement Function and GO/NO–GO Function)

In testing filters, sometimes the frequency points to be evaluated are already known. In such cases, the 4194A's GO/NO–GO function can be used to automatically sweep those particular points only, and determine whether or not the measured value for each point falls within the present acceptability range.

In this application, the GO/NO–GO function can be used when testing a low pass filters, for conformance with the acceptability range at each measurement point of 16 particular frequencies.

The measurement point and upper and lower limit values are set by first pressing the (MORE MENUS) and [SET PROG TABLE] keys to display the limit setup table. (See Figure 45.) Up to 401 sweep point settings can be made. The [LIMIT on/off] softkey is used to select whether or execute GO/NO–GO testing based on the current limit settings. When this softkey is on, GO/NO–GO testing is executed for each sweep point. (See Figure 46.) If all measured values are within the designated limits, a "1" is entered in the 4194's GONG register.

Any measured values that exceed the preset limit, will cause a "0" to be entered in the GONG register. This GONG register data can be output to an external device via the 4194A's 8-bit I/O interface, or can be read via HP-IB. When the [LIMIT on/off] softkey is off, a programmed point sweep can be executed without performing GO/NO–GO testing, GO/NO–GO testing can be done using the programmed point sweep function in combination with the ASP function. The programmed point sweep and GO/NO–GO testing combination is especially useful for applications where evaluation of certain sweep points is more important than performing a normal sweep test. One example of such an application is the rapid sorting of wideband filters.

PROGRAMMED POINTS TABLE 1

N	SWEEP:FREQUENCY(Hz) SWEEP POINTS	LIMIT FOR DATA A MINIMUM	MAXIMUM
1	100 000.000	-5.00000E+00	9.99999E+37
2	200 000.000	-5.00000E+00	9.99999E+37
3	400 000.000	-5.00000E+00	9.99999E+37
4	500 000.000	-7.00000E+00	9.99999E+37
5	600 000.000	-2.20000E+01	-5.00000E+00
6	800 000.000	-4.50000E+01	-2.80000E+01
7	1 000 000.000	-6.50000E+01	-4.80000E+01
8	1 400 000.000	-9.40000E+01	-7.70000E+01
9	1 500 000.000	-9.99999E+37	-8.20000E+01
10	1 600 000.000	-9.99999E+37	-8.50000E+01
11	2 000 000.000	-9.99999E+37	-8.00000E+01
12	3 000 000.000	-9.99999E+37	-8.50000E+01
13	4 000 000.000	-9.99999E+37	-8.80000E+01
14	6 000 000.000	-9.99999E+37	-8.80000E+01
15	8 000 000.000	-9.99999E+37	-8.80000E+01
16	10 000 000.000	-9.99999E+37	-8.80000E+01
17			

Figure 45. Limit Setup Table

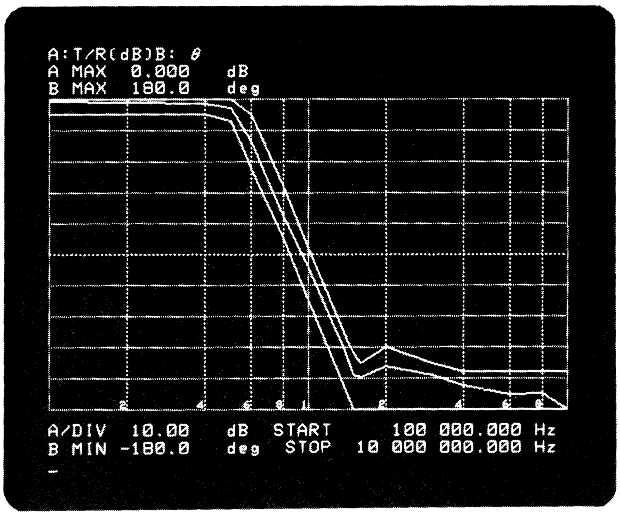


Figure 46. Measurement Display Superimposing the Limit Line

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